Importance of Hurricane Impacts in a Shallow Lake

by KANG-REN JIN and R. TOM JAMES
Wind

- Diurnal wind pattern in summer
- Local afternoon thunderstorms
- Ocean breeze as land surface heats up
Wind - Winter Cold Fronts

- Move through in 1 to 3 days
- Produce consistent winds in excess of 7-8 m/s
- Create large waves
- Resuspend sediment
Hurricane Irene
15-16 October 1999
Hurricanes

Hit by hurricane force winds
- Once
- Twice
- Three times

I SURVIVED THE TRIPLE WHAMMY 2004

Source: National Weather Service/National Hurricane Center
Hurricane Wilma October 15-25 2005
Hurricane Frances September 4-5 2004
Hurricane Jeanne September 25-26, 2004
Hurricane Wilma October 24-25 2005
<table>
<thead>
<tr>
<th>Hurricane Name</th>
<th>Peak Date</th>
<th>Max Wind Speed (mi/h)</th>
<th>Persistent Time (Days) ≥ (18 mi/h) (8 m/s)</th>
<th>Max. B. Current (m/s)</th>
<th>Max. B Shear Stress (N/m²)</th>
<th>Max Orbital Velocity (m/s)</th>
<th>Typical Orbital Velocity (m/s)</th>
<th>Typical B Shear Stress (N/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irene</td>
<td>10/15/99 9PM</td>
<td>50 (52)</td>
<td>2.3</td>
<td>0.10</td>
<td>8.2</td>
<td>0.48</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Frances</td>
<td>9/5/04 2AM</td>
<td>66 (67)</td>
<td>4.7</td>
<td>0.18</td>
<td>16.0</td>
<td>0.82</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Jeanne</td>
<td>9/26/04 1AM</td>
<td>70.0 (74)</td>
<td>2.5</td>
<td>0.11</td>
<td>13.2</td>
<td>0.70</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Wilma</td>
<td>10/24/05 11AM</td>
<td>78 (91)</td>
<td>1.5</td>
<td>0.12</td>
<td>13.4</td>
<td>0.71</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
</tbody>
</table>

At Station LZ40
Sediment Concentration in mg/l
1/1/04–12/30/05
Day 267.5
Hurricane Frances
9/2-9/8 (245-252)

Hurricane Jeanne
9/24-9/27 (266-270)
<table>
<thead>
<tr>
<th>Hurricane Name</th>
<th>Peak Date</th>
<th>Max Wind Speed (mi/h)</th>
<th>Persistent Time (Days) $\geq$ (18 mi/h) (8 m/s)</th>
<th>Max. B. Current (m/s)</th>
<th>Max. B. Shear Stress (N/m²)</th>
<th>Max Orbital Velocity (m/s)</th>
<th>Typical Orbital Velocity (m/s)</th>
<th>Typical B Shear Stress (N/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irene</td>
<td>10/15/99 9PM</td>
<td>50 (52)</td>
<td>2.3</td>
<td>0.10</td>
<td>8.2</td>
<td>0.48</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Frances</td>
<td>9/5/04 2AM</td>
<td>66 (67)</td>
<td>4.7</td>
<td>0.18</td>
<td>16.0</td>
<td>0.82</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Jeanne</td>
<td>9/26/04 1AM</td>
<td>70.0 (74)</td>
<td>2.5</td>
<td>0.11</td>
<td>13.2</td>
<td>0.70</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Wilma</td>
<td>10/24/05 11AM</td>
<td>78 (91)</td>
<td>1.5</td>
<td>0.12</td>
<td>13.4</td>
<td>0.71</td>
<td>0.01 – 0.1</td>
<td>0.02 – 0.1</td>
</tr>
</tbody>
</table>

At Station LZ40
P laden mud sediments cover over 40% of lake bed.
Available Sediment
1cm – before 2004
12cm – after 2004 Hurricanes
15-20cm – after Wilma
Available Sediment
1cm – before 2004
7cm – after 2004 Hurricanes
15-20cm – after Wilma
Hurricanes

Number of Stations Sampled: 27
Data Range: 1.5 - 25 mg/L
Median Value: 6 mg/L
Mean Value: 8.1 mg/L

Sediment Concentration in mg/l
1/1/04 - 12/30/05
Day 209.5

Pre storm conditions

August 2004
Hurricanes

Number of Stations Sampled: 26
Data Range: 4 - 147 mg/L
Median Value: 27.5 mg/L
Mean Value: 35.8 mg/L

Sediment Concentration in mg/l
1/1/04 – 12/30/05
Day 294.5

Four to six fold increase after hurricanes
Total Suspended Solids

November 2004

Number of Stations Sampled: 29
Data Range: 12 - 179 mg/L
Median Value: 66 mg/L
Mean Value: 72.3 mg/L
Hurricanes

Two to four fold increase after a cold front

Number of Stations Sampled: 29
Data Range: 6 - 397 mg/L
Median Value: 77 mg/L
Mean Value: 108.8 mg/L

Sediment Concentration in mg/L
1/1/04–12/30/05
Day 360.5

Total Suspended Solids

December 2004
Number of Stations Sampled: 29
Data Range: 6 - 112 mg/L
Median Value: 47 mg/L
Mean Value: 49.4 mg/L

Total Suspended Solids
January 2005
Sediment Concentration in mg/l
1/1/04–12/30/05
Day 402.5

Number of Stations Sampled: 29
Data Range: 17 - 278 mg/L
Median Value: 125 mg/L
Mean Value: 135.1 mg/L
Number of Stations Sampled: 29
Data Range: 9.5 - 260 mg/L
Median Value: 101 mg/L
Mean Value: 112.2 mg/L

Total Suspended Solids
March 2005
Number of Stations Sampled: 27
Data Range: 6 - 119 mg/L
Median Value: 65 mg/L
Mean Value: 60.6 mg/L
Number of Stations Sampled: 26
Data Range: 5 - 89 mg/L
Median Value: 14.5 mg/L
Mean Value: 18.8 mg/L
Sediment Concentration in mg/l
1/1/04 - 12/30/05
Day 708.5

Total Suspended Solids

December 2005

Number of Stations
Sampled: 28
Data Range: 10 - 141 mg/L
Median Value: 80.5 mg/L
Mean Value: 70.8 mg/L
Number of Stations Sampled: 29
Data Range: 14 - 284 mg/L
Median Value: 109 mg/L
Mean Value: 123.5 mg/L
Number of Stations Sampled: 27
Data Range: 24.3 - 252.4 mg/L
Median Value: 96 mg/L
Mean Value: 110.6 mg/L

Total Suspended Solids
February 2006
Biomass (g dw/m²)

- **Hurricanes Frances and Jeanne**
- **Hurricane Wilma**

<table>
<thead>
<tr>
<th>Date</th>
<th>Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan 04</td>
<td>NS</td>
</tr>
<tr>
<td>Mar 04</td>
<td>NS</td>
</tr>
<tr>
<td>May 04</td>
<td>NS</td>
</tr>
<tr>
<td>Jul 04</td>
<td>&gt; 35</td>
</tr>
<tr>
<td>Sep 04</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>Nov 04</td>
<td>NS</td>
</tr>
<tr>
<td>Jan 05</td>
<td>NS</td>
</tr>
<tr>
<td>Mar 05</td>
<td>NS</td>
</tr>
<tr>
<td>May 05</td>
<td>NS</td>
</tr>
<tr>
<td>Jul 05</td>
<td>NS</td>
</tr>
<tr>
<td>Sep 05</td>
<td>NS</td>
</tr>
<tr>
<td>Nov 05</td>
<td>NS</td>
</tr>
<tr>
<td>Jan 06</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>Mar 06</td>
<td>NS</td>
</tr>
<tr>
<td>May 06</td>
<td>NS</td>
</tr>
<tr>
<td>Jul 06</td>
<td>NS</td>
</tr>
<tr>
<td>Sep 06</td>
<td>NS</td>
</tr>
<tr>
<td>Nov 06</td>
<td>NS</td>
</tr>
<tr>
<td>Jan 07</td>
<td>NS</td>
</tr>
<tr>
<td>Mar 07</td>
<td>NS</td>
</tr>
</tbody>
</table>
Hurricanes

- Increased available suspended sediments throughout lake
- TSS Increased
- Reduced light availability
- Aquatic vegetation, SAV stressed
- Increased nutrient concentrations
- Impacts extended by cold fronts
Mud thickness-1988

Total mud volume = 0.20 km$^3$

Total mud weight = 2.44*10$^8$ tonnes
= 244,000,000 tonnes
Mud thickness-1998

Total mud volume = 0.17 km$^3$

Total mud weight = $2.15 \times 10^8$ tonnes
= 215,000,000 tonnes
Mud thickness-2006

Total mud volume = 0.13 km$^3$

Total mud weight = $1.58 \times 10^8$ tonnes

= 158,000,000 tonnes
Hurricanes

- Fine particles
  - Resuspended
  - Circulated throughout lake
  - Long settling time
  - Consolidation
- Resuspended under calm wind
Orbital Velocity (cm/s)
1/1/04–12/30/05
Day 247.5
Bottom Shear Stress in dynes/cm²
1/1/04–12/30/05
Day 682.5

Wilma

Bottom Shear Stress in dynes/cm²
1/1/04–12/30/05
Day 247.5

Frances
Significant Wave Height in cm

9/5/2004
Activity profile for $^{210}$Pb for Core M8

Findings of the 2005 investigation:
# Sediment layer from 3 to 12 cm in depth shows that 2004 hurricanes (Frances & Jeanne) makes them up side down by vertical vortex.

Findings of the 2008 investigation:
# Sediment layer from 10 to 11 cm in depth shows that there was a horizontal force in Wilma hurricane that mix the sediment with a strong forcing.
# Sediment layers from 3 to 5 cm and 13 to 17 cm show that Wilma hurricane makes them up side down by vertical vortex.
Activity profile for $^{210}$Pb for Core L9

Findings (2005):
# Sediment layer from 2.5 to 9 cm in depth shows that 2004 hurricanes (Frances & Jeanne) makes them up side down by vertical vortex.

Findings (2008):
# Sediment layers from 6 to 12 cm and from 12 to 17 cm in depth show that Wilma hurricane makes them up side down by vertical vortex.
# Sediment layer from 2 to 6 cm in depth shows that this layer was moved from other place with aging mud than it would be.
Sediment Mixed Depth (CM)

- 7(1)
- 14(2)
- 22(3)
- 6(3)
- 12(4)
- 12(3)
- 11(2)
- 14(2)
- 20(1)
- 12(1)
- 11(2)
- 6(3)
- 

Legend:
- M4
- N6
- K8
- M8
- M11
- N10
- L9
- P10
- "Mud Zone"

地理区域:
- Florida
- Lake Okeechobee
- Kissimmee River
- Fisheating Creek
- West Palm Beach Canal
- Hillsboro Canal
- Miami Canal

比例尺:
- 0 km
- 5 km
- 10 km
Core L9

Total $^{210}$Pb (pCi g$^{-1}$)

Core M8

2004 Hurricane Mixed Depth

2005

2003

1988
submerged aquatic vegetation

- Dominant species
  - Chara, a branched macro algae
  - Vallisneria (eelgrass)
  - hydrilla

- Distributions
Hurricane Irene BS Stress 4-5 N/m^2
Number of Stations Sampled: 27
Data Range: 151 - 472 ppb
Median Value: 278 ppb
Mean Value: 291 ppb
Core L9

Core M8

Total $^{210}\text{Pb}$ (pCi g$^{-1}$)