Ivan Metocean Overview

- Focus on deep water for now
- Agenda
  - Ivan Wind/Wave Hindcast
  - Current Hindcast
  - Wave/Wind measurements
  - Historical perspective
  - NWS Wind Forecasting
- Each talk followed by 5-min questions

Ivan Characteristics

- Category 3-4 Hurricane
- Central pressure 939 mb
- Radius=20-30 nm
- Max Wave $H_{\text{max}} \sim 96$ ft
- Wind=92 kt (33 ft, 30 min)

API/RP-2A 100-year...
- $dhw H_{\text{max}} = 71.2$ ft
- Wind=87 kt (33 ft, 30 min)
Hindcast Methodology

- Modeling done by OWI
- Basic Steps
  - Specify storm parameters (time history of pressure, etc.)
  - Run wind model to determine wind field every 30 minutes
  - Use modeled winds to drive wave & surge models
  - Validate against site measurements

Wind & Wave Comparison
NDBC Buoy 42040
Wind & Wave Comparisons at Marlin TLP

Wave & Wind Hindcast Summary

- Methods & models (Gumshoe) same as used for API RP2A.
- Excellent comparisons with Ivan measurements at buoys & platforms
- Gumshoe model works for Ivan
- $H_{\text{max}} \approx 96$ ft; $W_{\text{max}} = 92$ kt (33°, 30 min)
- RP2A 100-yr:
  - $H_{\text{max}} = 71$ ft; $W = 87$ kt (33°, 30 min)
Ivan Current Hindcast

- Review Hurricane Currents
- Hindcast Currents from Ivan
- Design Implications?

Hurricane Current:

- Generated by local wind stress
- Strongest on right side in DW (10’s of km wide)
- Current peaks within 1-3 hours of max wind
- Strong inertial component persists 3-4 days
Hurricane-Loop Interaction

- Varying temperature and salinity profile has strong influence on hurricane current
- Joint hurricane-Loop load cases likely important for southern DW areas

Effect of Different Temperature and Salinity on Hurricane Current profile

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Hindcasting Ability...

- Current hindcast ability not as developed as that for winds, waves
- Little data to compare against, no profile data above 30 m
- Bulk mixed-layer model does good job in 5 of 6 comparisons with ML averages

ML Model Compared to Measurements, Hurricane Frederic (Sept. 1979)
Hindcasting Ability

- Recent data shows substantial shear in mixed layer
- M-Y 1D profile model compares well in DW
- Bathymetry needed around shelf/slope
- Models are very sensitive to inputs

Profiles Near Time of Peak Current Near Genesis

Ivan Hindcasts

- Commercial hindcast available with HYCOM
- Preliminary comparison on slope with Navy data shows reasonable agreement
- Bulk ML, M-Y 1D profile analyses also performed
- No DW current data for validation

Snapshot of Ivan HYCOM Currents
Model Comparisons for Ivan in DW

- Mixed-layer depth and average speed from Bulk ML, M-Y 1D profile models similar
- HYCOM mixed-layer average speed is similar, but profile and ML depth are questionable

Profiles Near Time of Peak Current in DW

Model Comparisons Continued

- Bulk ML, M-Y 1D profile model predict similar currents across storm track
- M-Y 1D predicts higher mean speeds on 100 m
- HYCOM result includes Ulysses eddy currents, so not shown
Summary of Currents

- Ivan model efforts hampered by lack of data for validation
- Bulk ML, M-Y 1D profile models with limited prior validation yield similar results for Ivan in DW
- HYCOM results in DW are questionable – need to investigate
- M-Y 1-D profile model should be used to derive criteria for shallow draft platforms (Bulk ML model suitable for spars)

Industry Site Measurements at Marlin and Medusa

- Marlin TLP
  - Wind at top of crane
  - Wave radars on SE (noisy) & SW sides
  - High sampling rates
- Medusa Spar
  - Wave radars on SE (noisy) & NW sides
  - High sampling rates
Wind Spectrum at Marlin

83.5 kts at 173 ft, 67.5 kts at 33 ft
15:30 - 16:30

102.2 kts at 170 ft, 81.5 kts at 33 ft
17:30 - 18:30

1-sec gust factor 1.36
1-min gust factor = 1.15

- Gust factors agree reasonably well with NPD
- Earlier spectrum agrees with NPD model but later
  spectrum is deficient in very low frequency energy

Wave Time Series at Marlin

Ivan Waves at Marlin

Hmax=86.3
Hs,max=50.6 ft

Time (hours) on 15 Sep
Wave Time Series at Marlin
16:30 - 17:30 on 15 Sep

Wave Height Distribution at Marlin
Wave Height Distribution at Medusa

Platform Damage at Petronius and Pompano
Petronius Platform Damage

Damage at 54.1’ 57.4’ above storm water level (after accounting for 2.6’ storm surge, tide, and setdown)

\[ H_s = 51.1’ \]
\[ T_p = 15.4s \]

Corresponds to 60th 80th (40th – 70th) percentile estimate of maximum crest from Ivan hindcast

Pompano Platform Damage

Damage at 54.1’ 61.3’ above storm water level (after accounting for 1.6’ storm surge and tide)

\[ H_s = 45.4’ \]
\[ T_p = 16.8s \]
\[ H_s = 29.2’ \]
\[ T_p = 10.2s \]

Corresponds to 95th 99.9th (90th – 99th) percentile estimate of maximum crest from Ivan hindcast

Unlucky? Crossing wave trains? Wave enhancement by platform?
Wave / Platform Interaction

What is the height of the undisturbed wave crest (green water) that might be inferred from local platform damage?

Measurement Summary

- Wind spectra fit standards
- No evidence of “freak” (rogue) waves
- Distributions of measured wave crests fit design standards
- Damage provides no compelling evidence for criteria change
Ivan Characteristics

Ivan...
- Pressure 939 mb (93%)
- Radius=25 nm (25%)
- Forward Spd=10 kt (50%)
- Wind=92 kt (33 ft, 30 min)
- Max Wave $H_{max}$~96 ft

API/RP-2A 100-year...
- $d/w H_{max}$=71.2 ft
- Wind=87 kt (33 ft, 30 min)

Key Questions

- What return interval was Ivan?
- Was Ivan statistically "unexpected"?
- Should criteria be increased & if so in what part of Gulf?

Satellite image of Ivan
Ivan’s Return Interval?  
Site-to-Site Variability

- Model hindcast (GUMSHOE) gives large site-to-site variability
- Causes of variability
  1. Water depth & fetch
  2. Insufficient sample of severe storms
  3. Regional differences

100 yr & max \( H_s \) along the 600 ft isobath based on Gumshoe site hindcast

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Insufficient Sample of Severe Storms

- Parametric model cross section of the \( H_s \) in Hurricane Camille.
- Extremal fit for site near maximum of Camille. W/o Camille, \( H_{100} \) is 4 ft lower.

Given small size of storms & infrequent occurrence, we need several hundred years of data to sufficiently reduce this “noise”
Regional Variations

- Recent work suggests real regional variations
  - Severity
  - Frequency
- Possible physical causes
  - Persistent Loop water
  - Gulf geometry
  - Atmospheric influences

Removing the “Noise”

- $10^4$ JIP is addressing issue
- Solution 1: combine (pool) sites that are similar but not identical sites
- Solution 2: develop a deductive model

<table>
<thead>
<tr>
<th>Uncertainty of n-yr Hs</th>
<th>100-yr</th>
<th>10k-yr</th>
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<tbody>
<tr>
<td>Gumbel Site</td>
<td>±2.5’</td>
<td>±5.0’</td>
</tr>
<tr>
<td>Gumbel Pooled</td>
<td>±1.6’</td>
<td>±2.0’</td>
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</table>

Pooling reduces uncertainty
Choosing the Optimal Pooling Size

- Apply “cross-validation” (Chouinard, 1992, OTC)
- Optimal dist. ~ 100 miles
- 10-4 JIP has found similar results
- Results that follow use pooling at 5–7 sites
- Will also use this 100-mi scale in another key wa-

What Return Interval Was Ivan?

- ~2500 yr $H_s$ at site where peak occurred
- Exceeded $H_{s100}$ over ~150 mile swath
How Does Wind Compare?

- ~700-yr Wind Spd (33 ft, 30 min)
- Exceeded 100-yr over ~60 mile swath

How Current Compare?

- ~700-yr 50-m
- Exceeded 100-yr over ~20 mi swath
- Storm that causes 100-yr Hs does not usually cause 100-yr wind or current
Was Ivan Statistically Unexpected?

- Intuition: expect one, 100-yr storm in 100 yrs in entire Gulf
- Fact: expect $H_{s100}$ exceeded somewhere in Gulf every 4 yrs
- Because:
  - Must treat Gulf as statistically independent regions
  - Assume “regions” in Gulf are 100 mi apart
  - Expect a 2500-yr $H_s$ in 100 yrs
  - That sounds like Ivan!

Ivan not a major surprise based on pre-Ivan distribution

Metocean Summary

1. Ivan generated peak $H_{max} \sim 96$ ft
2. Highest in 100 yrs but not by much
3. Ivan generated ~2500-yr $H_s$ using the pre-Ivan extremal distribution
4. Ivan peak wind & current ~ 700-yr event
5. Could argue Ivan is an “outlier”
6. But new designs in Eastern Gulf should include Ivan
7. Under peak of Ivan, a d/w facility could have seen wave loads ~80% higher than present design but still << then 100% factor of safety
8. Further work:
   a. Look at metocean in shallow sites
   b. Review API metocean guidelines
   c. Obtain more upper water column currents
**2005 Season Forecast**

**Dr Gray Forecast...**
- 15 Named Storms
- 8 Hurricanes
- 4 Intense hurricanes

**NOAA FORECAST**
- 12-15 Named Storms
- 6-9 Hurricanes
- 3-6 Major Hurricanes

Factors supporting an active hurricane season:

- Warmer than normal sea surface temperature
- “La Nada”
- Multi-decadal Atlantic signal
2005 HURRICANE SEASON

- 7 Tropical Storms
- 2 Major Hurricanes (Dennis & Emily)
Standardized 5-yr Running Mean Anomalies

ACE Index (BLUE)
SST in MDR (20W-90W) (10N-21.5N) (RED)

ATLANTIC MAJOR HURRICANES (1944-2004)

MAJOR HURRICANES
5 YEAR AVERAGE
Tropical Prediction Center Performance Measures
yearly-average official track forecast errors and trend lines, Atlantic basin

Errors cut in half in 15 years
**Tropical Prediction Center Performance Measures**

Yearly-average official intensity forecast errors and trend lines, Atlantic basin

**Hurricane Charley Minimum Central Pressure**
9 - 14 August 2004

- Charley deepened
- 104 mb to 941 mb
- 4 h 35 min near landfall
- NIGHTMARE!
FORECAST IMPROVEMENT

- Better Observations
- Improved Computer Models

How Do We Track A Hurricane?

Satellite Imagery
- GOES East and West
- Visual, IR, WV
- Every 15-30 minutes (rapid update for research)
- Used to determine location, motion, and intensity

Aircraft Reconnaissance
- USAF C-130 - Primary Mission Operations
- NOAA P-3 - Primary Mission Research
- NOAA G-IV - High Altitude Operations
- More accurate than satellite

Doppler Radar
- 250 nm range for reflectivity tracking
- 125 nm range for Doppler velocity estimates
- Location, wind, motion, rainfall estimates and tornado detection
High Resolution Vis

RECONNAISSANCE FLIGHT PATH

Aircraft “ALPHA” Pattern

Hispaniola
TRACKING AND FORECASTING HURRICANES IN 2004

2004 Track Guidance (1st Tier)
2004 Track Guidance (1st Tier)

Track Forecast Skill (Early Models)
2004 - Atlantic Basin

Intensity Forecasts

NHC Official Intensity Forecasts
Atlantic Basin
GFS TRACK FORECASTS FOR IVAN FROM 9/7/04 12Z – 9/11/04 12Z HAD A SIGNIFICANT RIGHT BIAS.
GFS TRACK FORECASTS FOR IVAN FROM 9/13/04 12Z – 9/15/04 12Z WERE EXCELLENT IN SPECIFYING IVAN’S LANDFALL LOCATION ON GULF COAST.

IVAN CHARACTERISTICS

- Typical Cape Verde Storm
- Southern Most Major Hurricane
- Reached Category 5 Three Different Times
- Was a Category 5 for over 30 consecutive hours.
- Weakened and made landfall as Cat 3
### IVAN TRACK FORECAST ERRORS

<table>
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<tr>
<th># HOURS</th>
<th>NHC</th>
<th>FSSE</th>
<th>10 YR AV</th>
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<tr>
<td>120</td>
<td>289</td>
<td>199</td>
<td>319</td>
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</tbody>
</table>
WIND PROBABILITY PRODUCT

- Experimental Product in 2005
- Available on NHC Homepage
- Graphical and Text
- Could become Operational in 2006
Gene Hafele

Warning and Coordination Meteorologist

gene.hafele@noaa.gov

281-337-5074 x 223
HURRICANE-INDUCED SEAFLOOR FAILURES IN THE MISSISSIPPI DELTA

by

James R. Hooper, Fugro-McClelland Marine Geosciences &
Joseph N. Suhayda, Consulting Oceanographer

HURRICANE-INDUCED SEAFLOOR FAILURES IN THE MISSISSIPPI DELTA

Presented to the 2005 Offshore Hurricane Readiness and Recovery Conference
American Petroleum Institute
Houston, Texas
July 26-27, 2005

James R. Hooper, P.E.
Senior Consultant
Fugro-McClelland Marine Geosciences, Inc.
THE DELTA FRONT SEAFLOOR HAS A BAD REPUTATION.

CONSIDER SHELL’S NEW SP-70B PLATFORM SHORTLY AFTER INSTALLATION IN 1969.
SP-70 PLATFORM 1969

16 Piles Driven to ~400 ft

Water Depth ~300 ft

Seafloor

Seafloor

Hurricane Camille Waves

Fa

SP-70 SEAFLOOR FAILURE
SP-7OB

Hurricane Camille Waves

Soil Force Against 16 Piles & 24 Well Conductors

SP-70 SOIL FORCES

SP-70 SOIL FORCES

Piles Fail at Base of Jacket

Soil Motion
MAJOR HURRICANE HISTORY

- 9 major hurricanes (Category 3 or greater) passed near the delta 1900 - 2004.
- *Camille* passed over the delta with a central pressure of \(~909\) mb.
- *Ivan* passed east of the delta with a central pressure of \(~935\) mb.
HURRICANE CAMILLE

- South Pass 70 landslides caused the seafloor to move downslope by more than 3000 ft in some areas.
- One new 24-well platform toppled and two others were badly damaged by seafloor landslide failures.
- Pipelines were also damaged and destroyed by landslides.
HURRICANE IVAN 2004

- Delta-front landslides during Ivan were similar in size & character to those experienced during Camille.
- One platform in ~480 ft water depth toppled by landslides (MC-20).
- Pipelines were also damaged and destroyed by landslides.

STUDY REGION PLATFORMS AND PIPELINES
WHY IS THE DELTA FRONT PRONE TO SEAFLOOR FAILURES SO DESTRUCTIVE TO PLATFORMS AND PIPELINES?
Consider this Profile line across the seafloor.
Mudlobe Advance = 2.7 mi

SEAWARD ADVANCE OF THE DELTA

MUDFLOWS MOVE THE DELTA FRONT SEAWARD
DEPOSITION IN THE DELTA

- Deposition rates 1-2 ft/yr in front of the major passes.
- Sediments primarily low permeability clay with silt.
- Results in weak strength profiles more than 300-ft thick, and numerous landslides that create a unique seafloor.

SEAFLOOR GEOMORPHOLOGY

From Coleman et al, 1980

Region of Mudflow Gullies

Region of Mudflow Lobes
MUDFLOW GULLIES

- Mobile sediment typically 40 to 80 feet thick.
- Gully lengths up to 6 miles.
- Major mudflow activity occurs several times a year in some gullies, and every few years in others.

STACKED MUDFLOW ORIGIN
MUDFLOW LOBES

- Individual flow thickness ranges from a few feet to ~50 feet.
- Stacked mudflows are more than 100-ft thick in some areas.
- Mudflow lobes tend to remain stable until triggered by large storm waves.

STUDY REGION
SEAFLOOR PROFILE IN SOUTH PASS AREA

STACKED MUDFLOW EXAMPLE

Single flow units

~70 ft Stacked Mudflows

Pre-Delta Parallel Layers
THE FATE OF MUDFLOW SEDIMENTS

WAVE-TRIGGERED SEAFLOOR FAILURES
Of course, the wave is moving
Pressure increase
So the seafloor pressure is also moving
Pressure Decrease

WAVE-INDUCED PRESSURE ON SEAFLOOR

SEAFLOOR MOTION

Wave Crest
Wave Trough
Upward Motion
Downward Motion
Lateral Motion
CYCLIC WAVE-BOTTOM PRESSURES

• Cyclic pressure & sediment motion beneath the waves gradually weakens the sediment.
• Weak sediment in the gullies slowly moves downslope during a storm.
• Cyclic pressures may cause slope failure of some mudflow lobes.

SEDIMENT STRENGTH
THIS STRENGTH VARIABILITY IS TYPICAL OF MUDFLOW LOBES

STRENGTH PROFILES FOR SLOPE STABILITY
STABILITY ANALYSES

TYPICAL SEAFLOOR PROFILE
RESULTS OF STABILITY ANALYSES

• Moderate-size waves can fail the sediments in mudflow gullies.
• Mudflow Lobes with Upper-Bound strength profiles appear to be stable during intense hurricanes.
• Mudflow Lobes with Lower-Bound strength profiles appear to fail during intense hurricanes.

SUMMARY

1. Sediments accumulate in shallow water and, over time, move downslope in gullies as mudflows.
2. These gully mudflows are triggered by waves typical of small to large hurricanes.
3. Intense hurricanes (e.g., Ivan and Camille) create large waves causing large pressures on the seafloor.

4. During Ivan/Camille-size storms, existing mudflow lobes may fail, and mudflows from gullies may overrun previously deposited mudflow lobes.

5. Large-scale seafloor failures are the primary geologic process for seaward growth of the delta.

6. Past rates of seaward growth of the delta front will likely be maintained, and seafloor failures will continue to occur.