Sea-Level Measurement, Determination, and Application in the Gulf of Mexico

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SEA LEVEL RISE 2010
CONFERENCE
MARCH 1-3 2010

For more information on the International Conference on Sea Level Rise in the Gulf of Mexico visit our website www.SeaLevelRise2010.org

Corpus Christi, Texas
Sea-Level Measurement, Determination, and Application in the Gulf of Mexico - Outline

• NOAA’s Sea Levels Online Product
• From Tide Station to Sea Level Product – how is that done?
• Gulf of Mexico Sea Level Variations:
  – Seasonal
  – Long-term trends
  – Interannual variations
• Application to Frequency and Duration of Inundation, Now and with Sea Level Rise (SLR)
The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

Sea Level Trends
mm/yr (feet/century)

- 9 to 12 (3 to 4)
- 6 to 9 (2 to 3)
- 3 to 6 (1 to 2)
- 0 to 3 (0 to 1)
- -3 to -6 (-2 to -1)
- -6 to -9 (-4 to -3)
- -9 to -12 (-6 to -5)
- -12 to -15 (-6 to -5)
The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.
From Tide Station to Sea Level Product

Tide Station at Presidio, San Francisco, CA

1854 - 2009

- Data and Reference Datum Continuity
- Vertical Stability of Structures Maintained and Monitored
- Annual Leveling from Sensors to Local Bench Marks
- Annual Preventive Maintenance
- Sensor Calibration Checks and Swap-outs
- Backup Sensors and Alternate Data Collection Modes
- Active Quality Control and Monthly and Yearly Product Generation
- Overlapping Data when New Technology Sensors Installed

The mean sea level trend is 2.01 millimeters/year with a 95% confidence interval of ±0.21 mm/yr based on monthly mean sea level data from 1897 to 2006 which is equivalent to a change of 0.66 feet in 100 years.
NOAA Tide Station Configurations

Calcasieu Pass, LA

Bob Hall Pier, Corpus Christi, TX
NOAA Tide Station at Port Isabel, TX
Referencing Of The Sensor Zero To Station Datum Through Leveling And Bench Marks

Bench Mark “9 USE”

Tide Station
Port Isabel, TX Tide Station Bench Mark
Elevation Relationship to Tidal Datums

BM 9 USE 2.069m

Mean Higher High Water (MHHW) 1.594m

North American Vertical Datum (NAVD88) 1.435m

Mean Sea Level (MSL) 1.423m

Mean Lower Low Water (MLLW) 1.175m

Pt. Isabel Station Datum 0.000m

Tidal Datum Elevations based on 1983-2001 National Tidal Datum Epoch

Note: Bench Mark “9 USE” is approximately 0.18m (6 inches) above the ground
8779770  PORT ISABEL, TX  Observed Hourly Heights and Monthly Mean Sea Level for Calendar Year 2009
Elevation Relative to Station Datum (meters)

8779770 PORT ISABEL, LAGUNA MADRE TX - Monthly Mean Sea Level (MSL) 1944 - 2009
Average Seasonal Cycle
8779770 Port Isabel, Texas

Port Isabel, TX

Source: NOAA

The average seasonal cycle of mean sea level, caused by regular fluctuations in coastal temperatures, salinities, winds, atmospheric pressures, and ocean currents, is shown along with each month's 95% confidence interval.
Drivers of Seasonal Changes in Mean Sea Level

Mean monthly geostrophic zonal currents from satellite altimetry (aviso.oceanobs.com) between 1993-2008 at 28°N, 95°W along 50-m isobath are shown below (diamond).

Seasonal changes in wind field drive a strong signal in the coastal currents and their transport along the Texas coast (Cho et al. 1998, Zavala-Hidalgo et al. 2003). When currents are westward (eastward), coastal SL rises (falls) due to the cross-shelf sea surface height gradient.

See Poster Session – William Sweet et al
Mean Sea Level Trend
8779770 Port Isabel, Texas

Port Isabel, TX  3.64 +/- 0.44 mm/yr

The mean sea level trend is 3.64 millimeters/year with a 95% confidence interval of +/- 0.44 mm/yr based on monthly mean sea level data from 1944 to 2006 which is equivalent to a change of 1.19 feet in 100 years.

Source: NOAA
The plot shows the interannual variation of monthly mean sea level and the 5-month running average. The average seasonal cycle and linear sea level trend have been removed. Interannual variation is caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The interannual variation for many Pacific stations is closely related to the El Niño Southern Oscillation (ENSO).
Uncertainties in sea level trends derived from tide station records are dependent upon length of series.

Long-term NOAA Tide Stations - Northern Gulf of Mexico

Selected Stations for Analysis
Average Seasonal Cycles in Mean Sea Level, Gulf of Mexico

- Key West, FL
- Naples, FL
- Cedar Key, FL
- Pensacola, FL
Average Seasonal Cycles in Mean Sea Level, Gulf of Mexico

Grand Isle, LA

Port Isabel, TX

Galveston Pier 21, TX
Relative Sea Level Trends – Gulf of Mexico

Key West, FL  2.24 +/- 0.16 mm/yr

Naples, FL    2.02 +/- 0.60 mm/yr

Source: NOAA
Relative Sea Level Trends – Gulf of Mexico

Cedar Key, FL  
1.80 ± 0.19 mm/yr

Pensacola, FL  
2.10 ± 0.26 mm/yr

Source: NOAA
Relative Sea Level Trends – Gulf of Mexico

Grand Isle, LA  9.24 +/- 0.59 mm/yr

Source: NOAA

Galveston Pier 21, TX  6.39 +/- 0.28 mm/yr

Source: NOAA
Relative Sea Level Trends and Vertical Land Motion

Vertical Land Motion near Grand Isle Tide Station ~ 6 mm/yr; Relative Sea Level trend is ~ 9 mm/yr; Residual Trend is ~ 3 mm/yr

Vertical Land Motion near Galveston Tide Stations is ~ 3 mm/yr; Relative Sea Level Trend is ~ 6 mm/yr; Residual Trend is ~ 3 mm/yr
Satellite Altimetry is used to estimate basin scale change in sea level

Once adjusted for local vertical land motion, sea level trends from tide stations roughly agree with nearby altimeter trends
Establishing the Instrumental Record and Land-based Reference System for Global Sea Level

Mean Sea Level Trend
8735180 Dauphin Island, Alabama

The mean sea level trend is 2.53 millimeters/year (0.06 foot/century) with a standard error of 0.50 mm/yr based on monthly mean sea level data from 1966 to 1997.

Local Relative Sea Level Trends
Vertical and Horizontal Land Movement

Co-located CORS and Tide Stations

CORS – NGS Continuously Operating Reference System
Interannual Variation in Monthly Mean Sea Level since 1980 – Gulf of Mexico

Key West, FL

Galveston Pier 21, TX
Frequency and Duration of Inundation and Sea Level Rise

- How often will local land surfaces be inundated and how high will the water levels get?
- How long will these surfaces be inundated, regardless of elevation?
- Is there a relationship between the elevation and the duration of an inundation event?
- How will inundation profiles change with sea level rise?
Port Isabel, TX Tide Station Bench Mark
Elevation Relationship to Tidal Datums

BM  9 USE 2.069m

Mean Higher High Water (MHHW) 1.594m

North American Vertical Datum (NAVD88) 1.435m

Mean Sea Level (MSL) 1.423m

Mean Lower Low Water (MLLW) 1.175m

Pt. Isabel Station Datum 0.000m

Elevation difference 0.475m

Tidal Datum Elevations based on 1983-2001 National Tidal Datum Epoch
### Bench Mark “9 USE” Port Isabel Texas – Frequency and Duration of Inundation Over Last 6 years

8779770 PORT ISABEL, LAGUNA MADRE TX

Jan 01, 2004 To Dec 31, 2009

Reference Datum = 2.069 Meters (User)

12 High Tides Analyzed 80.8 Total Hours Inundated

<table>
<thead>
<tr>
<th>Period Start</th>
<th>Period End</th>
<th>Time of High Tide</th>
<th>Tide Type</th>
<th>Elevation above Datum (Meters)</th>
<th>Duration of Inundation (Hours)</th>
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<td>09/22/04 09:12</td>
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8779770 PORT ISABEL, TX - Inundation above Elevation of BM "9 USE"

For 2010 with RSLR 3.6 mm/yr

Hurricane Ike

BM “9 USE” inundated for 36 hours
8779770 PORT ISABEL, TX - Inundation above Elevation of BM "9 USE"

For 2050 with RSLR of 3.6 mm/yr

Hurricane Ike

BM “9 USE” inundated for 64 hours
8779770 PORT ISABEL, TX - Inundation of Elevation of BM "9 USE"

For 2100 with RSLR of 3.6 mm/yr

Hurricane Ike

BM “9 USE” inundated for 181 hours
Changes in Frequency of Inundation from 2010 – 2100 using statistics from a 6 – year period with 3.6 mm/yr RSLR for BM "9 USE" at Port Isabel
Changes in Duration of Inundation from 2010 to 2100 using statistics from a 6-year period with 3.6 mm/yr RSLR for BM "9 USE" at Port Isabel

- Frequency of Durations 2100
- Frequency of Durations 2050
- Frequency of Durations 2010

Frequency (count) vs. Length of time Bin (hours)
Projected Duration of Inundation vs. Elevation above BM "9 USE" for 2050 using a 5.6 mm/yr RSLR trend

Projected forward using statistics from 6-yr period 2004-2009 (0.23m rise in MSL)

\[ y = 46.067x^{0.7275} \]
\[ R^2 = 0.7693 \]
Figure 1.7 Plot in centimeters (cm) rise over time of past sea-level observations and several future sea-level projections to the year 2100. The blue shaded area is the sea-level rise projection by Meehl et al. (2007) corresponding to the A1B emissions scenario which forms part of the basis for the IPCC (2007) estimates. The higher gray and dash line projections are from Rahmstorf (2007). (Modified from: Rahmstorf, S., 2007: A semi-empirical approach to projecting future sea-level rise. Science. 315(5810), 368-370. Reprinted with permission.)
Extension of Port Isabel Sea Level Record under Varying SLR Scenarios

- **observed annual mean sea level 1944-2009**
- **present trend out to 2100**
- **increased trend to 5.6 mm/yr out to 2100**
- **variable trend with 5.6 mm/yr to 2050 then 10.6 mm/yr out to 2100**
Summary

• Tide Station Records provide information on Relative Sea Level Trends and need to be properly adjusted for vertical land motion to be used for Global (absolute) sea level applications.

• Local relative sea level trends are extremely important to coastal communities because they represent sea level variations at the land-water interface, regardless of cause.

• Local relative sea level trends can be combined with future estimates of global sea level trends to investigate projected changes in frequency and duration of inundation.

• Inundation analyses performed relative to tidal bench mark elevations can provide accurate information on present day conditions; can be used to express impacts of SLR on local land surfaces, and; can provide accurate ground truth points for Digital Elevation Models.
Backup Slides
## Estimated Effects of RSLR on Frequency and Duration of Inundation for Port Isabel, TX

Using various rates of Sea Level Rise

### Using Elevation of Bench Mark "9 USE "

<table>
<thead>
<tr>
<th>6-yr Time Period</th>
<th>RSLR rate mm/yr</th>
<th>Occurrences of Inundation</th>
<th>Duration of Inundation</th>
<th>Elevation Rise Above 2010 MSL</th>
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<tr>
<td>2004-2009</td>
<td>3.6</td>
<td>12 (&lt; 1%)</td>
<td>81 (&lt; 1%)</td>
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<tr>
<td>2045-2050</td>
<td>3.6</td>
<td>99 (4 %)</td>
<td>677 (1%)</td>
<td>0.14</td>
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<tr>
<td>2095-2100</td>
<td>3.6</td>
<td>618 (27%)</td>
<td>4951 (9%)</td>
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<tr>
<td>2004-2009</td>
<td>3.6</td>
<td>12 (&lt; 1%)</td>
<td>81 (&lt; 1%)</td>
<td></td>
</tr>
<tr>
<td>2045-2050</td>
<td>5.6</td>
<td>229 (10%)</td>
<td>1768 (3%)</td>
<td>0.23</td>
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<tr>
<td>2095-2100</td>
<td>5.6</td>
<td>1799 (78%)</td>
<td>20879 (40%)</td>
<td>0.51</td>
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<tr>
<td>2004-2009</td>
<td>3.6</td>
<td>12 (&lt; 1%)</td>
<td>81 (&lt; 1%)</td>
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<tr>
<td>2045-2050</td>
<td>5.6</td>
<td>229 (10%)</td>
<td>1768 (3%)</td>
<td>0.51</td>
</tr>
<tr>
<td>2095-2100</td>
<td>10.6</td>
<td>1449 (63%)*</td>
<td>42991 (81%)</td>
<td>0.77</td>
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