“Sea Level Acceleration Characteristics in the 20th Century and Extrapolation to 2100”

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February 9, 2011

FSBPA Spring Conference
Two Related Papers


• Houston, J. R. and R. G. Dean “Sea-Level Acceleration Based on U. S. Tide Gages and extensions of Previous Global-Gauge Analyses”, Accepted for Publication in Journal of Coastal Research
Outline

• Significance of Sea Level Acceleration
• Description of Tide Gage Records
• Analysis Issues
• Analysis of High-Quality U. S. Tide Gages
• Results Based on Florida Tide Gages
• US and Florida Rates of Increase Over 20th Century
• Extrapolation to 2100

New
Corps of Engineers Guidance for Global (Eustatic) Sea Level Rise (2009)

Note: All Positive Accelerations

Acceleration = 0.2 mm/yr²

Trend = 1.7 mm/yr
Tide Gage

GPS Receiver

Ground Motion

Crust

Sea Surface

Tide Gauge Station
Sea Level Rise Components as Measured by a Tide Gage

\[
\text{Sea Level} = \text{World-wide Sea Level} + \text{GIA} + \text{Local Effects} + \text{Noise}
\]

- **Eustatic Sea Level**
- Glacial Isostatic Adjustment
- Can Be Natural or Anthropogenic
Sea Level Rise Components as Measured by a Tide Gage

Sea Level = World Wide Sea Level + GIA + Local Effects + Noise

Eustatic Sea Level

Earth

Last Ice Age 20,000 Years Ago

Ice Caps

Presently

Glacial Isostatic Adjustment

Can Be Natural or Anthropogenic
Examples of Local Effects

Natural
• Compaction of Underlying Sediments
• Earthquakes

Anthropogenically Induced
• Withdrawal of Ground Fluids (Gas, Oil, Water)
• Building Heavy Structures on Weak Sediments
Model Results for Glacial Isostatic Adjustment
The Algebraic Relationship

\[ y = a_0 + a_1 t + \frac{1}{2} a_2 t^2 \]

- **Sea Level**
- **Constant**
- **Initial Trend** (mm/yr)
- **Time** (Years)
- **Acceleration** (mm/yr²)

The accepted value of \( a_1 \) over the last century for the eustatic trend is approximately 1.7 mm/yr (6.7 inches per century)
Acceleration Definition

\[ y(t) = a_0 + a_1 t + \frac{a_2}{2} t^2 \]
Tide Gage Data Are Not Always Consistent With the Model
Ideal Tide Gage Record

• Long Record (At least 50 to 60 years)
• Continuous (Minimal gaps)
• Location geologically stable
• Lots of gages of the above type
Example of Tide Gage Record
(San Francisco: The Longest U.S. Gage)

From PSMSL Web Site

1855 - 2009
GIA = 0.68 (0.05) mm/yr
Slope of 1.7 mm/yr

1 Foot

155 Years
Locations of Seven Florida Tide Gages and Two GIA Model Results (mm/yr)

Note: Positive GIA Means Local Sea Level is Rising Faster Than Eustatic
Fernandina Beach, FL Tide Gage

From PSMSL Web Site
Mayport, FL Tide Gage

1 Foot

Slope of 1.7 mm/yr

1928 - 2000
GIA = 0.63 (0.28) mm/yr

From PSMSL Web Site
Miami Beach, FL Tide Gage

Slope of 1.7 mm/yr

1931 - 1980
GIA = 0.36 (0.11) mm/yr

From PSMSL Web Site

Note: GPS located 4.8 km from this tide gage records 0.70 mm/yr.
Key West, FL Tide Gage

1913 - 2009
GIA = 0.36 (0.16) mm/yr
Slope of 1.7 mm/yr

From PSMSL Web Site

Note: GPS located 16 km from this tide gage records 0.30 mm/yr.
St. Petersburg Tide Gage

1947 - 2009
GIA = 0.49 (0.12) mm/yr

Slope of 1.7 mm/yr

From PSMSL Web Site
Cedar Key II, FL Tide Gage

GIA = 0.36 (0.08) mm/yr

1938 - 2009

Slope of 1.7 mm/yr

From PSMSL Web Site
Pensacola, FL Tide Gage

Slope of 1.7 mm/yr

1 Foot

1923 - 2009
GIA = 0.72 (0.18) mm/yr

From PSMSL Web Site

Note: GPS located 7.5 km from this tide gage records 0.20 mm/yr.
The 44 Continental US Gages Analyzed Here
Analysis for Each of 44 US Gages and Each of 7 Longer-Term Florida Gages

- Determine $a_0$, $a_1$ and $a_2$
- Calculate sea level rise from earliest record date to 2010
- Calculate sea level rise from earliest date to 2100
- Subtract results to determine additional rise from 2010 to 2100
Procedure

Extract $a_0$, $a_1$ and $a_2$ from the record.
Procedure

Extract $a_0$, $a_1$ and $a_2$ from the record

Extrapolate to 2100 using $a_0$, $a_1$ and $a_2$

Report this value
Extrapolated Sea Level Change: 44 US Gages, 2010 to 2100

44 U. S. Gages
Average = 17.0 cm (6.7 Inches)

Sea Level Change (cm)
Number of Tide Gages
Sea Level Change (cm)
Extrapolated Sea Level Change: Florida Gages, 2010 to 2100

Six Florida Gages (Without Miami Gage)
Average = 22.1 cm (8.7 Inches)
Summary of Extrapolations (Note: These Results Include GIA)

Averages of Extrapolated Sea Level Rise 2010 to 2100

- 44 U. S. Gages
  - 17 cm (6.7 Inches)
- 7 Florida Gages
  - All 7 Gages: 11.1 cm (4.4 Inches)
  - Without Miami Beach (Six Gages): 22.1 cm (8.7 Inches)
Summary of Determination of Eustatic Sea Level Rise From 1910 to 2010. (GIA Accounted For)

- 44 U. S. Gages
  - 1.25 mm/yr to 1.90 mm/yr, Depending on GIA Model
- 7 Florida Gages
  - All 7 Gages: 1.51 mm/yr to 1.87 mm/yr, Depending on GIA Model
  - Without Miami Beach (6 Gages): 1.50 mm/yr to 1.88 mm/yr, Depending on GIA Model
Summary

1. Over the last year, we have conducted extensive analyses of quality tide gage data including world-wide and U.S. gages.

2. Tide gage data are “noisy” requiring analysis of many long-term records from areas of geological stability.

3. The results of all of our analyses are consistent - There is no indication of an overall world-wide sea level acceleration in the 20th Century data. Rather, it appears that a weak deceleration is present.

4. Florida tide gage data are limited but appear to be quite consistent with U.S. and world-wide data.

5. While issues exist with extrapolating analysis results forward over the next century, it is one approach (based on data) in the attempt to establish bounds of future sea level rise.

6. Extrapolated 2100 sea levels are considerably less than Corps and other agency guidance, but are in reasonable accord with IPCC of 18 to 59 cm by 2100.
Recommendations

1. Continue collecting tide gage data in Florida. In particular, reactivate the Miami Beach gage.

2. In view of the significant differences in the model-produced GIA values, install GPS units adjacent to longer term tide gages.
Questions?
Our Study of 18 U. S. Gages With Record Lengths > 80 Years and Less Than 5% Missing Data
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Average of 18 Long-Term U. S. Gages

El Nino Events

Dark Line: 11 Month Running Average
Results of Analyzing 5 Long-Term Florida Tide Gages

![Graph showing trend and acceleration of Five Florida Gages](image-url)
Results of Analyzing 44 Long-Term U. S. Tide Gages
Correlation of $a_1$ and $a_2$ For San Francisco Gage Data

San Francisco Gage

Measurements

Best Fit

$a_1$ Increased by 0.5 mm/yr

$a_1$ Decreased by 0.5 mm/yr

$a_1$ Decreased: $a_1 = -0.714$ mm/yr, $a_2 = 0.0190$ mm/yr^2

$a_1$ Increased: $a_1 = 0.191$ mm/yr, $a_2 = 0.0076$ mm/yr^2

Best Fit: $a_1 = -0.3225$ mm/yr, $a_2 = 0.0138$ mm/yr^2