An Overview of Global and Regional Sea-Level Rise Projections

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Outline

- Global Mean Sea Level
- Regional Sea Levels
- Sea Level Extremes (time permitting!)
Sources of Sea Level Rise (Global)

**What causes the sea level to change?**

- **Terrestrial Water Input**
  - 0.12 mm/yr
  - 0.38 mm/yr

- **Land-based Ice**
  - 0.68 mm/yr
  - 0.86 mm/yr

- **Ice Sheets in**
  - Greenland 0.33 mm/yr
  - Antarctica 0.27 mm/yr

- **Thermal Expansion**
  - 0.8 mm/yr
  - 1.1 mm/yr

**Add water**

**Thermal expansion**

**1971-2010 & 1993-2010**
Global Average Sea Level Rise

- **Trend based on tidal gauges**
- **Satellite measurements:**
  - University of Colorado
  - Commonwealth Scientific and Industrial Research Organisation

**Trends in Global Average Absolute Sea Level, 1870-2008**

- **1.7 mm/year (~7 in./100 yrs)**
- **3.2 mm/year (~13 in./100 yrs)**

**La Nina**

- Increase in the rate to > 3 mm/yr is of significant concern for coastal regions

Data sources:

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climatechange/science/indicators.
More closer to home: Projections for South Florida

Stay tuned for the update!
Recent Global Mean Sea Level Projections

- Update to USACE guidance
- Sea Level Rise projections from IPCC Assessment Report V (AR5)
- NOAA scenario projections (NOAA 2012) developed NCA, 2014
- National Research Council (NRC 2012) projections for West coast of the United States
- Sea Level Rise projections issued for state-level planning. These include the states of Maryland, Massachusetts, and New York
- Probabilistic Projections that have become available recently in the literature (Kopp et. al. 2014; Jevrejeva et al. 2014)
IPCC (AR5) GMSL Projections (m)

<table>
<thead>
<tr>
<th>Year</th>
<th>RCP2.6</th>
<th>RCP8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>0.13 [0.09–0.16]</td>
<td>0.13 [0.10–0.16]</td>
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<tr>
<td>2060</td>
<td>0.26 [0.18–0.34]</td>
<td>0.33 [0.24–0.42]</td>
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<tr>
<td>2100</td>
<td>0.43 [0.28–0.60]</td>
<td>0.73 [0.53–0.97]</td>
</tr>
</tbody>
</table>

“The IPCC’s global mean sea-level scenarios do not necessarily provide the right information for coastal decision-making and risk management”

Hinkel et al., (2015), Nature Climate Change
Sea Level Rise: NOAA (2012) report for NCA

Scenario Planning
Multiple Futures

Uncertainties

What we know today

Global Mean Sea Level Rise (cm above 1992)

- Highest - 2.0 m
- Intermediate-High - 1.2 m
- Intermediate-Low - 0.5 m
- Lowest - 0.2 m

Year

1900 1950 2000 2050 2100

Observed

1992
Past and Projected Changes in Global Sea Level (NCA 2014 report)
Comparison of GMSL Projections

Graph showing the comparison of SLR projections from NOAA, USACE, and NOAA-Int. with different levels of projection (Low, Intermediate, High).

- **NOAA-Low**
- **USACE_Low**
- **NOAA-Int.Low**
- **USACE_Intermediate**
- **NOAA-Int.High**
- **USACE_High**
- **NOAA-High**

Y-axis: SLR (m. relative to 1992)
X-axis: Years (2000 to 2100)
Comparison (cont.)

The graph illustrates the projected sea level rise (SLR) from 2000 to 2100, with SLR measured in meters relative to 1992. Different lines and legends represent various scenarios and models:

- **NOAA-Low**
- **USACE_Low**
- **NOAA-Int.Low**
- **USACE_Intermediate**
- **NOAA-Int.High**
- **USACE_High**
- **NOAA-High**
- **IPCC RCP 8.5**

The shaded area represents the IPCC AR5 projections, indicating the range of possible SLR scenarios.
Sea Level Rise rates in the US

- **Tectonic uplift**
- **Land subsidence**

**Sea Level Trends**
- 15 to 21 (5 to 7) mm/yr
- 12 to 15 (4 to 5) mm/yr
- 9 to 12 (3 to 4) mm/yr
- 6 to 9 (2 to 3) mm/yr
- 3 to 6 (1 to 2) mm/yr
- 0 to 3 (0 to 1) mm/yr
- -3 to 0 (-1 to 0) mm/yr
- -6 to -3 (-2 to -1) mm/yr
- -9 to -6 (-3 to -2) mm/yr

- **2-3 mm/yr** (> global ave.)
Sea Level Rise is not uniform (why?)

Blue – Sea level Falling

Red- Sea Level Rising
Source of Regional Variation in Sea Level Relative to Land

- Land subsidence or uplift, Post Glacial Rebound
- Variations in Ocean Currents (e.g. Gulf stream)
- Gravitational and rotational effects of land ice redistribution (more complex)

Ice melt effect
- Greenland
- Antarctica
Combining Components of Sea Level Rise

**Change in Relative Sea Level (RSL):**

\[ \Delta RSL = \Delta SL_G + \Delta SL_{VLM} + \Delta SL_{RM} + \Delta SL_{RG} \]

- Global Mean
- Local: \( f(\text{Uplift/Subsidence, GIA}) \)
- Dynamic Sea Level: \( f(\text{meteo-oceanographic Factors}) \)
- Ice sheet fingerprint: \( f(\text{Changes in Earth’s gravitational Field}) \)

*As suggested in Nicholls et al., 2011*
Dynamic Sea Level Adjustment

Percentage Deviation from Global Mean: Figure 3.21 of Ch.13, AR5

Liu et al. (2015)  

MOM4: Surface Current

(a) Surface current in late 20C  
(b) Difference (Late 21C - Late 20C)
Gravitational and earth rotational effect of ice mass losses
Predicting future extreme sea levels

Extreme value modeling at a single site

Regional Frequency Analysis (use data at multiple locations)
For South Florida Sea Level Rise is a bigger concern in the near future.
Extra slides
Potential options for scenarios

Using Key West rate

- Low (0.2m)
- Low (alternate)(0.8m)
- High (1.5m)
- Highest (2m)

SLR relative to 2000 (m)

Year

2000 2020 2040 2060 2080 2100
Concept of Return Period in Extremes: Paradigm Shift (“Nonstationarity”)

Key West

- Annual Mean
- Annual Maximum
- Trend-Mean
- Trend-Location Parameter

Mean, Annual Max. Sea Level

- 1600: 1800
- 2000: 2200
- 2400: 2600
- 2800: 3000

Year

1920 1940 1960 1980 2000

Time

Construction → Project Operation
Return Period Change – A new paradigm for floods and sea level rise

\[ T = E[X] = 1 + \sum_{k=1}^{\infty} \prod_{t=1}^{k} (1 - p_t) \]
Why should Arctic and Antarctic Regions Matter to us?

(~ 2 million sq.km.)

(~5.4 million sq. km.)
Glaciers retreating

Muir Glacier, SE Alaska

August, 1941 (photo by William Field)  August, 2004 (photo by Bruce Molnia)
AR5: Representative Concentration Pathways

New IPCC (AR5) Approach for Greenhouse Gas Scenarios*

Meinshausen et al. 2011
Rising Seas – Around Florida

- Relative Sea Level (height above a local datum) depends on:
  - Global Mean Sea Level
  - Vertical Land Movement (uplift/subsidence)
  - Regional Variability
Global SLR Projections for 2100—Considerably spread

Source of Estimate

- NCA High
- NCA High Intermediate
- NCA Low Intermediate
- NCA Low

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<thead>
<tr>
<th>Source of Estimate</th>
<th>End of Century (2090-2100) Sea Level Rise (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesnil et al (B1)</td>
<td>0.25</td>
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<tr>
<td>NRC 1967</td>
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<tr>
<td>NRC 2011</td>
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<tr>
<td>Kopp et al</td>
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<td>Vermeer and Rahmstorf (A2)*</td>
<td>1.00</td>
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<td>Horton et al. (A2)*</td>
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<tr>
<td>Jevrejeva et al. (A2)*</td>
<td>0.50</td>
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<tr>
<td>Grinsted et al. (A2)*</td>
<td>0.25</td>
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<tr>
<td>Pfeffer et al. (Phys)</td>
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<tr>
<td>Rohling et al.</td>
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</tr>
<tr>
<td>Katsman et al (2011)</td>
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