Applying the Coastal Storm Modeling System (CoSMoS) to Assess the Physical and Ecological Impacts of Climate Change

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Motivation

• Sea level rise will place additional stresses on coastal systems worldwide.

• Rate of global SLR has increased by 50% over last two decades (e.g., Merrifield and Merrifield, *Journal of Climate*, 2009).

• West Coast sea level rise has been suppressed for the last thirty years, BUT wind pattern changes may signal return to global or higher rates of SLR (Bromirski et al., *Journal of Geophysical Research*, 2011).

• Trends of increased average winter and extreme wave energy for much of U.S. West Coast (Allan and Komar, 2006; Menendez et al., 2008; Ruggiero et al., 2010).

• Climate models suggest more El Niño like conditions over next century (Cayan et al., 2008) = higher seasonal water levels coupled with extreme wave conditions.
Coastal Impact of Projected Climate Trends

- Accelerated beach erosion rates
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- Greater incidence of cliff failures
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- Landward translation of coastal flooding and inundation
- More dangerous navigation conditions
- Beach/shore safety more often compromised
Etc…
Critical Infrastructure
Global Sea Level Projections (by 2100)

- **0.18 to 0.59 m** Intergovernmental Panel on Climate Change (IPCC, 2007)
  - does not include ice sheet contributions from Greenland (7 m stored) and Antarctica (60 m + stored)
- **0.5 to 1.9 m** Rahmstorf (Science, 2007)/Vermeer and Rahmstorf (PNAS, 2009)
  - relates sea level rise to mean surface temperature
- **0.8 to 2 m** Pfeffer et al. (Science, 2008)
  - constrained by observations of ice sheet dynamics
- **5 m** Hansen (Environ. Res. Lett., 2007)
  - non-linearity, amplifying polar feedbacks- ‘albedo flip’
  - sea level was 75 m higher at ~50 Ma
  - at 5 Ma, sea level was ~25 m higher, but only 2-3°C warmer (A2 emissions scenario is 4.5°C warmer)

**even money = 1 m**
• 1.8 to 5.5 m of SLR by 2500 using latest IPCC Models (2013): Representative Concentration Pathways (RCP) radiative forcing scenarios
• Sea level will rise for several centuries after stabilization (Jevrejeva et al., *Global and Planetary Change*, 2011)
What is an extreme storm?

- Difficult to define
  - Wave height/energy
  - Wind speed/direction
  - Atmospheric pressure
  - Wave direction
  - Storm duration
  - Beach state
  - Water level

- Largest waves = ~10 m
  (highest 1/3, 1 in 100 = ~15 m)

- Elevated water levels
  - Tide level (~2 m variation)
  - Seasonal variations (up to ~30 cm)
  - Surge (up to ~70 cm)
  - Wave set-up (up to ~1.7 m)
  - Worst case = ~4.7 m
Components of Total Water Level Predictions

- **MSL (datum)**
- **$h_{slr}$**
- **$h_{br}$**
- **$d_{br}$**
- **$H_{decreases rapidly due to breaking}$**
- **waves increase in height towards breaking zone (shoaling)**

Wave run-up: $h_{R}$
Wave set-up: $h_{wv}$
Wind set-up: $h_{wn}$
Barometric set-up: $h_{Ap}$
Tide difference: $h_{tide}$
Sea level rise: $h_{slr}$

(adapted from Frisby and Goldberg, 1981)
Modeling System Essentials

- Accurate, high resolution Digital Elevation Model (DEM)
- Physics included
  - Long waves important (infragravity)
  - Wave set-up and run-up
  - Surge (wind/pressure fields)
- Realistic forcing conditions/scenarios
  - Appropriate SLR scenarios
  - Atmospheric forcing from General Circulation Models (GCMs)
- Relevant products
CoSMoS Highlights

- 1st physics-based numerical modeling system for assessing coastal hazards on West Coast
- Predicts coastal inundation/flooding, wave heights, beach erosion, and cliff failures
- Flood hazards based on a 2 m resolution digital elevation model
- For hindcast/nowcast/forecast, uses Pacific Ocean-scale atmospheric forcing to make predictions every 100 m alongshore
- For climate change impacts, uses GCMs as forcing to simulate both typical and extreme events
CoSMoS Version 1.0- SoCal

- Outer coast focus - protected bays not modeled
- Flooding based on maximum wave run-up
- Limited set of scenarios
  - ArKStorm
  - January 2010 hindcast
  - January 2010 hindcast + 50 and 100 yr SLR per Rahmstorf (2007)
Dynamic Model Grids

- GFS
- NAM
- NWW III
- ENP
- SoCal
- TPXO 6.2
- meteo models
- tide model
- Santa Barbara Channel
- Los Angeles
- San Diego
-xb xb xb

Map showing regions such as Santa Barbara, Summerland, Carpinteria, Ventura, Los Angeles, San Diego.
Cross-shore Models (XBeach)

- 10 m water depth
- 100 m alongshore spacing

MOP - Backbeach
MOP - Nearshore

Meters
Digital Elevation Model (DEM)

- Coverage from at least +20 m to -20 m for all of Southern California
- Uses most recent high resolution data sets (e.g., multibeam, Lidar)
- 3 m resolution (existing regional DEMs 90 m res)

http://pubs.usgs.gov/ds/487/
Products
Examples from Southern California

Flood Hazard Scenario

- Jan 2010
- Jan 2010 + 50 yr SLR
- Jan 2010 + 100 yr SLR

Del Mar, CA
MOP Profile 120

- H max = 4.31 m
- Maximum Runup Elevation = 3.58 m
- Shoreline Change (mhw) = -59.68 m
- Back Beach Change (mhwh) = -58.32 m
- Profile Accretion = 0.49 m²/m
- Profile Erosion = 0.47 m²/m
- Profile Change (0 to 1.6 m) = -0.74 m²/m
- Flooding = yes
- Inundation = yes
- Flood Duration = 53 hrs
- WL dif (runup-tide) = 2.70 m

Graph showing elevation changes along the profile with distance. Different lines represent initial and final profiles, and symbols indicate key locations such as initial and final shoreline and back beach positions.
Physical Impacts - Other Considerations

• Regional Factors:
  • Ocean circulation patterns
  • Storminess (increase per Cayan et al., Climate Change, 2008)
  • Tectonics (large-scale)

• Local Factors:
  • Subsidence due to sediment compaction (natural and fill) and fluid withdrawal (up to order of magnitude higher than Global SLR)
  • Local tectonic deformation
  • Fluvial discharge AND sediment supply changes (due to both climate and watershed modifications)
  • Development and restoration

G. Griggs, UCSC

Subsidence in San Jose (1933-1969)

Poland and Ireland, 1988
CoSMoS Version 2.0- NorCal

- Collaboration with NOAA, PRBO Conservation Science and NPS- Our Coast-Our Future (OCOF)
- Focus on climate change impacts to SF Bay and outer coast
- Sophisticated product tool with emphasis on ecological impacts
- Storm scenarios developed using latest IPCC (2013) radiative forcing scenarios and GCMs
- Flood flows and bay hydrodynamics modeled, incl. depth of flow and uncertainty
- Fluvial discharge (2013)
- Wind forcing downscaled (2013)
- Relative land movement estimated (2013)
High-resolution (~20 m) parallel computing of San Francisco outer coast
OCOF Highlights

- SLR = 0 to 2 m in 25 cm increments, and 5 m extreme scenario (per Hansen)
- Tide = MHHW for non-storm testing, otherwise joint probability
- Waves and storm conditions = average, annual extreme event, and 100-year return interval extreme event, all based on projected wave conditions derived from ensemble GCM forcing (IPCC 2013 scenarios) and non-stationary statistical projections
- Outer coast completion summer 2012
- SF Bay completion fall 2014
CoSMoS - The Path Forward

• Currently used to assess coastal vulnerability to climate change for Our Coast, Our Future (OCOF) in SF Bay area
• Easily adaptable as more sophisticated climate change models/predictions emerge
• Potential expansion to cover entire U.S. West Coast
• Available as a real-time warning system for emergency managers, lifeline operators, and resource managers

For more information, contact Patrick Barnard: pbarnard@usgs.gov
http://walrus.wr.usgs.gov/coastal_processes/socalhazards
http://cosmos.deltares.nl/SoCalCoastalHazards/index.html