Climate Change Impacts to the Southern California Coast

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Pacific Coastal and Marine Science Center, Santa Cruz, CA

Santa Monica Pier, January 1983 (Paul Silhavy)
What is the problem?

- Climate change, including sea level rise, changing wave climates, and storms will place additional stresses on coastal systems worldwide

- Coastal flooding from SLR alone could displace ~200 million people by 2100

- Nationally, $1.4 trillion of coastal property could be at risk at high tide by the end of the century

- 500,000 people, one million jobs, and $100 billion in property are threatened by climate change along the California coast over the next century

- In Los Angeles County: 4,000 people and $4 billion in property at risk per Pacific Institute Report (not inclu. river discharge, waves, coastal change, changes in storms, etc.)

- 1982-83 El Niño storms caused ~$2.2 billion in storm damage to California, $1.1 billion in 1997-98

www.californiacoastline.org/
Projections for Southern California

SLR for Los Angeles (NRC, 2012)
- 28 cm of sea level rise by 2050 (range 13-61 cm)
- 93 cm of sea level rise by 2100 (range 44-167 cm)
- Includes global and regional effects (e.g., wind and circulation patterns, sea level fingerprint, glacial isostatic adjustment, tectonics)

Storms for Southern California (Bromirski et al., 2012; USGS)
- No significant changes in wave height
- Extreme events approach from ~10-15 degrees further south

El Niño for 21st Century (Cai et al., 2015, Barnard et al., 2015)
- More frequent extreme events
- Doubling of winter erosion
- Wave energy increase by 30%
Coastal Vulnerability Considerations

• Global factors:
  • Eustatic sea level

• Regional factors:
  • Ocean circulation patterns
  • Glacial fingerprinting
  • Tectonics (large-scale)
  • Isostasy

• Local factors:
  • Subsidence
  • Local tectonic deformation
  • Fluvial discharge AND sediment supply changes
  • Development and restoration

• Seasonal and storm impacts:
  • Steric effects
  • Waves and storm surge
  • River discharge
Coastal Vulnerability Approaches

**STATIC: NOAA SLR Viewer**
- Passive model, hydrological connectivity
- Tides only (MHHW)
- Excellent elevation data, datum control
- Wetland migration model, socioeconomic impacts
- ‘1st order screening tool’

**DYNAMIC: CoSMoS**
- GCM ensemble forcing
- Includes wind, waves, sediment transport, fluvial discharge, and vertical land movement rates
- Range of SLR and storm scenarios
- Flooding extent explicitly modeled, hydrological connectivity

http://www.coast.noaa.gov/slr/

Our Coast Our Future: [www.prbo.org/ocof](http://www.prbo.org/ocof)
CoSMoS: A Tool for Coastal Resilience

- Physics-based numerical modeling system for assessing coastal hazards due to climate change
- Predicts coastal hazards for the full range of sea level rise (0-2, 5 m) and storm possibilities (up to 100 yr storm) using sophisticated global climate and ocean modeling tools
- Developing coastal vulnerability tools in collaboration with federal, state, and city governments to meet their planning and adaptation needs
- Emphasis on directly supporting federal and state-supported climate change guidance (e.g., Coastal Commission) and vulnerability assessments (e.g., LCP updates, OPC/Coastal Conservancy grants)
Identifying Future Risk with CoSMoS

1. Global forcing using the latest climate models

2. Drives global and regional wind/wave models

3. Scaled down to local hazards projections
CoSMoS Version Summary

CoSMoS 1.0
- So Cal, 470 km coastline (Pt. Conception -> Mexico border)
- Historical storms, 2 SLRs
- Global & regional parts continue to run operationally

CoSMoS 2.0
- North-Central CA coast, 170 km, (Bodega Head to Half Moon Bay)
- 21st century winds & waves
- High resolution grids of lagoons and protected areas
- Annual, 1 yr, 20 yr, 100 yr storm events in combination with SLR 0 m to 5 m at 0.25 m increments +5 m
- Web-based tool

CoSMoS 2.1
- San Francisco Bay
- Spatial- & time-downscaled climate scenario winds
- Fluvial discharges
- Vertical land motion
- Marsh accretion
CoSMoS 2.0- CenCal/NorCal

www.prbo.org/ocof (Our Coast - Our Future)
SoCal CoSMoS Version Differences

CoSMoS 1.0

- So Cal, 470 km coastline (Pt. Conception -> Mexico border)
- Historical storms, 2 SLRs
- Global & regional parts continue to run operationally

CoSMoS 3.0 (updated SoCal)

- So Cal, 470 km coastline (Pt. Conception -> Mexico border)
- Future waves downscaled within the Pacific Basin using global climate model (GCM) winds
- Space- & time- downscaled local winds and sea level pressures
- High resolution grids of lagoons and protected areas
- Fluvial discharges
- 100 yr storm events in combination with SLR 0 m to 1.5 m in 0.5 m increments
- Shoreline change: both cliffs and sandy coast
CoSMoS Version Summary
Model Overview: Global to Regional to Local

Select storm events based on $TWL_{proxies}$

Regionalized storm response

20-year storm return

Global winds

Regional (Tier I)

Local (Tiers II & III)

Sea level pressures (kPa)

waves

arrows=winds

USGS
A total of 11 Tier II sub-models
Each with varying number of ‘domain decomposition’ grids
3 sub-models for Los Angeles county

<table>
<thead>
<tr>
<th>Tier II sub-models</th>
<th>Geographic extents (north to south)</th>
<th>County</th>
<th>Number of DD grids</th>
<th>Number of Xbeach profiles</th>
<th>Grid resolution (m) Most coarse</th>
<th>Finest</th>
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<tbody>
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<td>gc</td>
<td>Pt. Mugu to Pt. Conception</td>
<td>Santa Barbara</td>
<td>6</td>
<td>1,057</td>
<td>70 x 90</td>
<td>18 x 16</td>
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<tr>
<td>ve</td>
<td>King Harbor to Pt. Mugu</td>
<td>Ventura</td>
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<td>5 x 15</td>
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<td>Ventura</td>
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<td>Los Angeles</td>
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<td>20 x 20</td>
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<td>mk</td>
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<td>4</td>
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<td>130 x 145</td>
<td>30 x 40</td>
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<td>la</td>
<td>Port of L.A. to Newport</td>
<td>Los Angeles</td>
<td>4</td>
<td>413</td>
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<td>7 x 11</td>
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<td>ty</td>
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<td>San Diego</td>
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<td>233</td>
<td>30 x 60</td>
<td>10 x 20</td>
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<td>sd</td>
<td>U.S. Mexico border to Dana Pt.</td>
<td>San Diego</td>
<td>9</td>
<td>466</td>
<td>90 x 140</td>
<td>10 x 13</td>
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</tbody>
</table>

All topobathy grids in the nearshore were populated with 2 m resolution data.
Overview of Processes Included in CoSMoS

Flood level is the combination of:

- rSLR + tides + seasonal effects + storm surge + wave setup + wave runup + fluvial discharge backflow
Fluvial Discharge in CoSMoS

-44 fluvial discharge locations
-future discharge based on historical relationship between SLP and discharge
Sea Level Anomalies in CoSMoS

(A) Use historical data to develop linear model

SLA (m) vs. SSTA (°C)

upper envelope
SLA = 0.0546 \cdot SSTA + 0.0745
r = 0.90

98th percentile extremes

(B) example output of SSTs from GFDL-ESM2M

SLA percent change

Cross-shore transect ID

-80 -60 -40 -20 0 20 40 60 80

0 20 40 60 80

0 20 40 60

-0.1 0.0 0.1 0.2 0.3 0.4 0.5

-2020 2040 2060 2080 2100
CoSMoS validated with January 2010 Storm

Los Angeles tide gauge

Predicted and observed modeled water levels differ by 6 to 52 cm

RMS = 12 cm
$R^2 = 0.97$
- Number of runs completed for the
  - 100 yr storm event +
  - SLRs 0 cm, 50 cm, 100 cm, 150 cm

<table>
<thead>
<tr>
<th>County</th>
<th>Number of cross-shore transects (CSTs)</th>
<th>Number of TierIII XBeach runs</th>
<th>Number of TierI&amp;II Delft3D runs</th>
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<tr>
<td>Santa Barbara</td>
<td>1,057</td>
<td>25,368</td>
<td>18</td>
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<tr>
<td>Ventura</td>
<td>683</td>
<td>16,392</td>
<td>42</td>
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<tr>
<td>Los Angeles</td>
<td>1,184</td>
<td>28,416</td>
<td>48</td>
</tr>
<tr>
<td>Orange</td>
<td>663</td>
<td>15,912</td>
<td>24</td>
</tr>
<tr>
<td>San Diego</td>
<td>1,215</td>
<td>29,160</td>
<td>36</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4,802</strong></td>
<td><strong>115,248</strong></td>
<td><strong>168</strong></td>
</tr>
</tbody>
</table>
Products- Wave and Currents

- Delft3D model results from all local SWAN and FLOW runs are used to...

To generate maps of maximum wave heights and maximum currents
**Products - Flood Maps**

- Delft3D model results from high resolution grids (inlets, harbors, etc.)
- Combined with open coast XBeach results
- Overlaid and differenced from the 2 m resolution DEM

To generate maps of flood extents, duration, and depth
Malibu – SLR 0 cm
Malibu – SLR 50 cm
Malibu – SLR 100 cm
Malibu – SLR 150 cm
Santa Monica Pier – SLR 0 cm
Santa Monica Pier – SLR 100 cm
Santa Monica Pier – SLR 150 cm
L.A. Harbor / Long Beach
CoSMoS-COAST: Coastal One-line Assimilated Simulation Tool

- A numerical model to simulate long-term shoreline evolution.
  - Coastline is represented by shore-perpendicular transects:

- Numerically solves conservation of sediment mobilized by waves & sea-level rise.

- Modeled processes include:
  - Longshore sediment transport
  - Cross-shore sediment transport
  - Effects of sea-level rise
  - Sediment supply by natural & anthropogenic sources

- Synthesized from models in scientific literature (with several improvements):

- Uses data assimilation (Extended Kalman Filter) to improve model skill.
Model has ~4800 transects with ~100 m grid spacing

Model type:
- longshore + cross-shore + rate
- cross-shore + rate
- historical rate only
- no prediction (sea-wall, harbor, etc.)
Shoreline Data:

- 5 shorelines from USGS National Assessment
- 20 shorelines extracted from LIDAR surveys
  (most are from SCRIPPS 2003 – 2009; most are south of Long Beach)
- 20 shorelines from USGS surveys
  (only in Santa Barbra area 2005 - present)
- **We need MORE!**
Data Assimilation

We use the *extended Kalman filter method* of Long & Plant 2012

- Auto-tunes model parameters for each transect to best fit the historical shoreline data
- We improved the method to handle sparse shoreline data and ensure that parameters are positive or negative.

Simulation output for a single transect at Del Mar Beach:
Shoreline Projections

2100 shoreline w/ sea-level rise:
- 0.0 m
- 0.5 m
- 1.0 m
- 1.5 m
- 2.0 m
- 5.0 m
Factors Driving Sea Cliff Erosion & Retreat

- Rain
- Wave Energy
- Cliff Toe Height
- Coastal Slope
- Rock Strength
Rain, SLR cause more cliff retreat (rain effects are in beta mode)

Walkden & Hall, 2005; 2011
Results: Palos Verdes
Results: examples

Solana Beach

Palos Verdes

Sea level rise (m)

- 0.2
- 0.5
- 1.0
- 1.5
- 2.0

Highway 1

Laguna Beach

Malibu
What’s Coming Summer 2016

- 40 scenarios of SLR + storms
- Long-term coastal evolution integrated into flood mapping
- Socioeconomic impacts
- Groundwater, hurricane impact pilots
- Our Coast Our Future (OCOF) web tool

*For more information, contact Patrick Barnard: pbarnard@usgs.gov


Our Coast- Our Future tool: www.prbo.org/ocof
Socioeconomic Impacts

Number of Residents in the Bay Area Affected by 500cm of SLR and a 100yr storm

Residents in Hazard Zone

- **80,000**
  - 75% - 100%
- **40,000**
  - 50% - 74%
- **20,000**
  - 25% - 49%
- **10,000**
  - 1% - 24%
Socioeconomic Impacts

Population At Risk by Sea Level Rise
No Additional Storm Surge

County/City | Residents
---|---
Marin County | 267
| Sausalito | 340
| Belvedere | 1247
| Tiburon | 2555
| Mill Valley | 1665
| Corte Madera | 15542
| Larkspur | 2623
| San Rafael | 6882
| Ross | 392
| Novato | 158
| Unincorporated Marin County | 59
Sonoma County | 238
| Petaluma | 69
| Unincorporated Sonoma County | 16
Napa County | 2475
| Napa | 116
| Unincorporated Napa County | 774
Solano County | 3279
| American Canyon | 16
| Vallejo | 62
| Benicia | 38
| Fairfield | 34
| Suisun City | 255
| Unincorporated Solano County | 0
Contra Costa County | 712
| Pittsburg | 34
| Concord | 0
| Martinez | 34
| Hercules | 0
| Pinole | 0
| Richmond | 0
| El Cerrito | 0
| Unincorporated Contra Costa County | 0
Alameda County | 0
| Albany | 0

Current Time: 11:00:40 AM
Hurricane Potential

- Hurricanes/tropical storms have the potential to significantly impact Southern California
  - San Diego Hurricane, October 2, 1858, produced hurricane/gale force winds from San Diego to LA
  - Un-named, September 25, 1939 (Long Beach), resulted in 90 deaths
  - Hurricane Nora, September 25–26, 1997, $100s of millions in damage

- Peak potential during El Niño, but overall probability of landfall is very low

- Research planned for SoCal (May 2016)
  - Will hurricane potential increase with climate change in the 21st century?
  - What is the probability of a hurricane making landfall?
  - What are the coastal hazards (e.g., coastal flooding, erosion) associated with such an event?
2015-2016 El Nino

How recent increases in ocean temperatures compare to strongest El Niño on record

Potential rain
California stands to get above normal amounts of rain from January to March 2016 because of El Niño.

Chance of above normal precipitation
- 33% – 39%
- 40% – 49%
- 50% – 59%
- 60% – 69%

Sources: NOAA, Climate Prediction Center
@latimesgraphics
Mean monthly sea level anomalies at the Los Angeles tide gauge

Mean monthly sea level anomalies at Los Angeles

2015-2016 El Nino
CoSMoS 3.0 Southern California

Global
- Global conditions of future climate scenarios
- GCM winds
- WW3 wave model

Regional
- Tides, water levels, and regional forcing
- SWAN wave model
- Regionalized storm response
- 20-year storm return

Local
- High resolution hydrodynamics and waves
- Delft FLOW-WAVE
- XBEACH

Open coast
- Fluvial discharge
- VLM
- Coastal change
- Results projected onto hi-res DEM
Select storm events based on $TWL_{proxies}$

Generate a wave look-up-table (LUT) that correlates offshore wave conditions with nearshore wave results at the 4,802 CSTs.

Select storm events based on $TWL_{proxies}$

- $4 \text{s} < T_p < 25 \text{s}$
- $160^\circ < D_p < 360^\circ$
- $0.25 \text{m} < \text{SWH} < 9 \text{m}$
Select storm events based on $TWL_{proxies}$

1. Derive relationship between observed SLP gradients, winds, and storm surges
2. Develop $TWL_{proxy}$ return period curves at each CST and define coastal segments that respond similarly to coastal storms
3. Select storms (dates) associated with the 1yr, 20yr, 100yr return periods of each coastal segment

SWAN
Numerical model runs of wave propagation from offshore to nearshore.

Look-up-table (LUT) linking deep water wave conditions with waves at 20m depth of each cross-shore transect (CST)

GCM winds

WaveWatch3 global & Eastern North Pacific runs (2010 – 2100)

GCM SLPs

observed SLPs

GCM SSTS

observed SSTs

observed SLAs

Deep water waves

Waves at 10m to 15m water depth of each CST

Runup ($R_{2m}$) time-series at each CST (using analytical model) (2013 – 2100)

CST foreshore slopes

$TWL_{proxy} = R + SS + SLA$

(where i represents individual CSTs)

$TWL_{proxy}$:
- Total water level
- CST: cross-shore transect
- GCM: global climate model
- SST: sea surface temperatures

Dashed boxes represent observation or other model data
Select storm events based on $TWL_{proxies}$
Four 100-yr storm events identified for the SoCal Bight. Using the RCP 4.5; GFDL-ESM2M model.

Select storm events based on $TWL_{proxies}$

<table>
<thead>
<tr>
<th>100 yr event storm dates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm 1: February 2074</td>
<td></td>
</tr>
<tr>
<td>Storm 2: February 2044</td>
<td></td>
</tr>
<tr>
<td>Storm 3: January 2070</td>
<td></td>
</tr>
<tr>
<td>Storm 4: March 2059</td>
<td></td>
</tr>
</tbody>
</table>

These four storms are simulated explicitly with all the bells and whistles of the CoSMoS model (tiers I, II, and III)

Space & time-varying wind & pressure fields

- $0 \text{ m/s} \leq \text{winds} \leq 35 \text{ m/s}$
- $98.6 \text{ kPa} \leq \text{SLPs} \leq 102.3 \text{ kPa}$

Deep-water wave conditions

- $6.0 \text{ m} \leq H_s \leq 6.8 \text{ m}$
- $16 \text{ s} \leq T_p \leq 18 \text{ s}$
- $264^\circ \leq D_p \leq 291^\circ$

Steric water levels

- $0.10 \text{ m} \leq w*l \leq 0.12 \text{ m}$
Tier I and Tier II
Delft3D (SWAN + FLOW)

Tier II
SWAN + FLOW
(2D horizontal)

Tier I
SWAN + FLOW
(2D horizontal)

Tier III
XBeach (1D cross shore)

Elevation (m, NAVD88)

Cross-shore distance (km)
Fluvial discharge rates were assigned at Delft3D FLOW grid cells coincident with USGS gauging stations.

- no available 21st century storm specific projected peak discharge rates available at the local level, and
- therefore parameterized hydrographs were constructed
  - Duration and rate of increase and decrease of discharges (i.e., the shape of the hydrograph)
  - Peak discharge rates associated with specific future storm events
Unit hydrograph was developed using available 15 minute time-series at 9 gauging stations within the study area.

![Unit hydrograph](image)

<table>
<thead>
<tr>
<th>USGS gauging station ID</th>
<th>Lat (°N) (NAD27)</th>
<th>Lon (°E) (NAD27)</th>
<th>Mean Q (cm³/s)</th>
<th>Med. Q (cm³/s)</th>
<th>Length of record (years)</th>
<th>99.95th percentile</th>
<th>Events ≥99.95th percentile</th>
<th>Mean duration (days)</th>
<th>µ (days)</th>
<th>S (days)</th>
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<td>0.00</td>
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<td>0.49</td>
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<td>0.74</td>
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<td>92</td>
<td>98</td>
<td>5</td>
<td>1.29</td>
<td>-2.15</td>
<td>1.01</td>
</tr>
</tbody>
</table>

- mean: 0.80  0.38  61.73  80  5  0.53  -2.19  1.17
- min.: 0.05  0.00  13.51  9  3  0.21  -3.66  0.79
- max.: 2.90  1.84  91.89  290  8  1.29  -1.11  1.80
Peak discharge rates associated with specific future storm events:

Analyzed historical discharge rates for 18 these sites with long records (> 30 yrs). Found strong correlations between discharge rates and SLP gradients at 7 sites using a search radius of 0.67 ° to 1° and within 3 days preceding peak discharge rates (those that exceeded the 99.95th percentile)

| USGS gauging station ID | station name              | Drainage area (km²) | r    | p-val | best fits Q=mx+b
<table>
<thead>
<tr>
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<td>m</td>
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<tr>
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<td>Mission Ck</td>
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<td>0.022</td>
<td>1.577E-07, 2.234E-07</td>
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<td>0.003</td>
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</tr>
<tr>
<td>11106550</td>
<td>Calleguas Creek</td>
<td>642</td>
<td>0.74</td>
<td>0.058</td>
<td>6.303E-08, -1.909E-08</td>
</tr>
<tr>
<td>11102300</td>
<td>Rio Hondo (L.A. trib.)</td>
<td>321</td>
<td>0.78</td>
<td>0.040</td>
<td>7.094E-08, 1.376E-06</td>
</tr>
<tr>
<td>11078000</td>
<td>Santa Ana</td>
<td>4403</td>
<td>0.66</td>
<td>0.103</td>
<td>1.662E-08, -2.358E-08</td>
</tr>
<tr>
<td>11046000</td>
<td>Santa Margarita</td>
<td>1873</td>
<td>0.42</td>
<td>0.731</td>
<td>2.702E-08, -1.208E-08</td>
</tr>
</tbody>
</table>
Summary of method for estimation of peak fluvial discharge rates associated with future storm events.

1. Extract sea level pressure (SLP) patterns associated with peak discharge events.
2. Derive conditional relationships between ‘primary’ river $Q_p$ and SLP gradients.
3. Calculate peak discharge rates ($Q_p$) of each river associated with that coastal storm.
4. Calculate watershed areas ($A$) and runoff rates ($R = Q_p/A$).
5. Calculate watershed drainage areas ($A_{sub}$) for each subordinate river/tributary.
6. Define gaged watersheds that are representative of discharges in subordinate rivers/tributaries.
7. Apply $R$ values from representative watersheds to each subordinate river/tributary and estimate $Q_{psub} = R*A_{sub}$. 

CoSMoS model
Each future storm event is dynamically modeled assuming a ‘spring tide’ event. [Nov 2010]  
- But, what should the timing of the forcing agents be with respect to the tide? -

<table>
<thead>
<tr>
<th>Forcing / boundary</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>tides</td>
<td>varies spatially and temporally and is identical for each scenario</td>
</tr>
<tr>
<td>SLR</td>
<td>constant for duration of scenario (but differs between scenarios)</td>
</tr>
<tr>
<td>SLA</td>
<td>constant for duration of scenario (but differs between scenarios)</td>
</tr>
<tr>
<td>deep water waves</td>
<td>constant for duration of scenario (but differs between scenarios)</td>
</tr>
<tr>
<td>SLPs</td>
<td>varies spatially and temporally, timing assigned such that the lowest SLP anywhere within the SoCal Bight aligns with high tide</td>
</tr>
<tr>
<td>winds</td>
<td>varies spatially and temporally linked to the timing of SLPs</td>
</tr>
<tr>
<td>river discharge</td>
<td>varies temporally at each established USGS gauging site via a idealized hydrograph and derived peak discharge rate based on SLP gradients; timing is hardwired to occur with peak 1hr after high tide</td>
</tr>
</tbody>
</table>
Framework for implementation of scenario runs for Tiers I and II

Tier I FLOW
- DW waves
- Winds & SLPS
- Water level & Neumann time-series extracted at Tier II boundaries
- Uniform low wind speed & median fluvial discharges

Tier II FLOW
- Warm-start ‘map’ files (1 set for each SLR & Tier II)
- IT: Nov 01, 2010
- Sim start*: Nov 06, 2010 at 20:00
- Sim end*: Nov 07, 2010 at 20:00
- dt: 0.05 to 0.1 minutes

Tier II WAVE
- Flow & wave-current fields updated every 20 minutes
- IT: Nov 01, 2010
- Sim start: Nov 06, 2010 at 03:00
- Sim end**: Nov 07, 2010 at 03:00
- dt: 0.05 to 0.1 minutes

Tier II FLOW WAVES
- Wave triplets extracted at Tier II boundaries
- Flow & wave-current fields updated every 20 minutes

SLR
- MMSLA
- Astronomic constituents

Tier I time periods:
- IT: Oct 01, 2010
- Sim start: Oct 10, 2010 at 00:00
- Sim end: Nov 07, 2010 at 00:00
- dt: 0.5 minutes

"Restart map files must have same IT as actual run (i.e. as the Tier II scenario run).
"Start times differ based on time needed for specific model to stabilize.
"To attain maximum flooding extents we can end the simulation around Nov 06 2010 20:00 (4 hrs after peak at L.A.). However, to be consistent with previous CoSMoS runs that have been run for a full 25 hr time period and where we have evaluated Xbeach profile changes as well as duration of flooding, we need to run these simulations for a full tide cycle.
50 cm SLR + 100 year storm
Flood extents from open coast Xbeach runs are based on inundation, **not** maximum runup.

Cross-shore transect (CST) 2437

- **Maximum ‘sustained’** (2-min duration) water level reached at the MHHW gauge. This is the inundation elevation.
- Inundation position found by translating the maximum water level onto the eroded profile (eroded profile at time of ‘sustained’ water level – not necessarily the final profile).

Schematic of method used to determine inundation level and position.
Storm 1

Storm 2

Storm 3

Combine storm results of each scenario to find maximum values

[technical term = ‘smooshing’]

Resulting maps of maximum
• Flood extents, depths, and durations
• Velocities
• Wave heights
Group 1: CST 1 to 1360
Group 2: CST 1361 to 2593
Group 3: CST 2594 to 3720
Group 4: CST 3721 to 4802

GCM atmospheric grid

GCM ocean grid

Latitude (°N)

Longitude (°W)

Longitude (°W)
High fluvial discharge events always coincide with high waves, but the converse is not so (i.e., can have high Hs but low Q).

Of note, is that the peak of storm SWHs consistently precede the peak of Q, a plot of the cross correlation (not shown) indicates a shift of ~6hrs.

For simplicity, I suggest we assume high Q with our ocean storm events and constant flows.
CoSMoS-COAST: Coastal One-line Assimilated Simulation Tool

- Intended to be a hybrid between physics-based models and empirical models
- A process-based, one-line (1-D) shoreline model on shore-normal transects:
- Numerically solves a coupled set of differential equations on a series of transects:

\[
\frac{\partial Y}{\partial t} = -\frac{1}{14D_2} \frac{\partial Q}{\partial Y} + \frac{C_2^{1/3}}{4} \frac{\partial E}{\partial b} - \frac{\Delta S_{rel}}{\tan \beta} + \frac{Y_{lt}}{t} \]

- Model is synthesized from process-based models in the literature:
- Uses data assimilation (Long & Plant 2012) to auto-tune the model & improve performance.
- Implemented in Matlab
  - The main script has ~1000+ lines of code
cliff profile models

Waves + SLR + tides + rock strength

SCAPE
(Walkden & Hall, 2005, 2011; Walkden & Dickson, 2009; Carpenter et al., 2014; iCOASST)

\[ E = \frac{H_b^{13/4} T^{3/2} \tan \alpha}{R} \]

Trenhaile Model

@ sea level

\[ E_{bf} = N_o K_{bf} (S_F - S_{Fcr}) \]

\[ S_F = \left[ 0.5 \gamma (H_b/0.78)e^{-\chi_{sw}} \right] \sin^2 \varphi \]

< sea level

\[ E_{ss} = N_o K_{ss} (\tau - \tau_c)^p \]

\[ \tau = 0.5 F_w \rho u_0^2 \]
cliff profile models

Working modules: undercutting, talus, dynamic beach, wave run-up, subaerial erosion (*hillslope diffusion & rain intensity/duration thresholds*)
Los Angeles – SLR 0 cm
Los Angeles – SLR 100 cm
Los Angeles – SLR 150 cm