USGS
science for a changing world

Climate Change Impacts to the Southern California Coast

Patrick Barnard, Li Erikson, Amy Foxgrover, Liv Herdman, Patrick Limber, Andy O'Neill and Sean Vitousek

USGS Coastal and Marine Geology Program
Pacific Coastal and Marine Science Center, Santa Cruz, CA

U.S. Department of the Interior
U.S. Geological Survey

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

USGS

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)

L.A. City Lifeguards

Storms for Southern California (Bromirski et al., 2012; USGS)

-No significant changes in wave height

-Extreme events approach from ~10-15 degrees further south

Brad Graverson, January 2010

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%

USGS

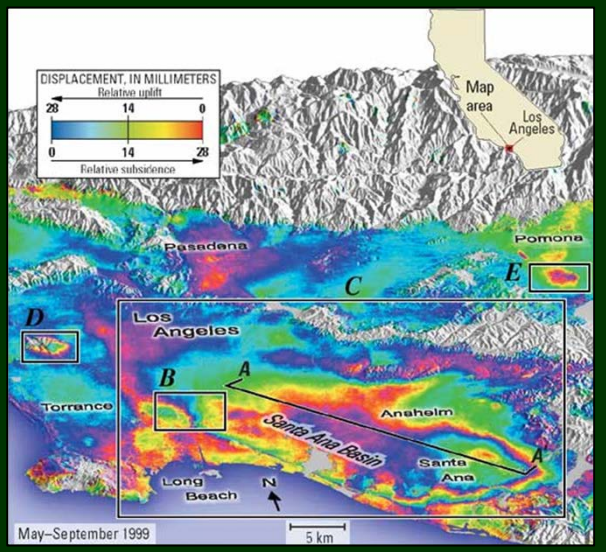
Coastal Vulnerability Considerations

- **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**

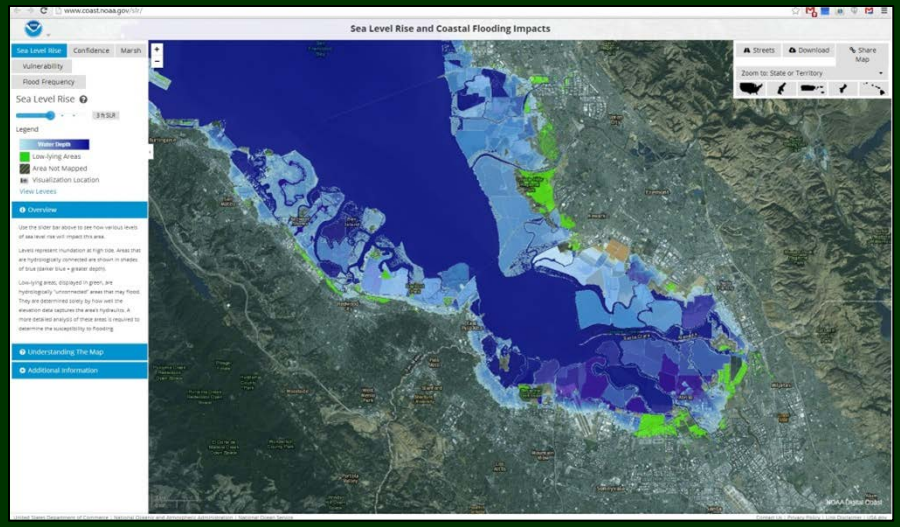
- **Seasonal and storm impacts:**
  - **Steric effects**
  - **Waves and storm surge**
  - **River discharge**



USGS

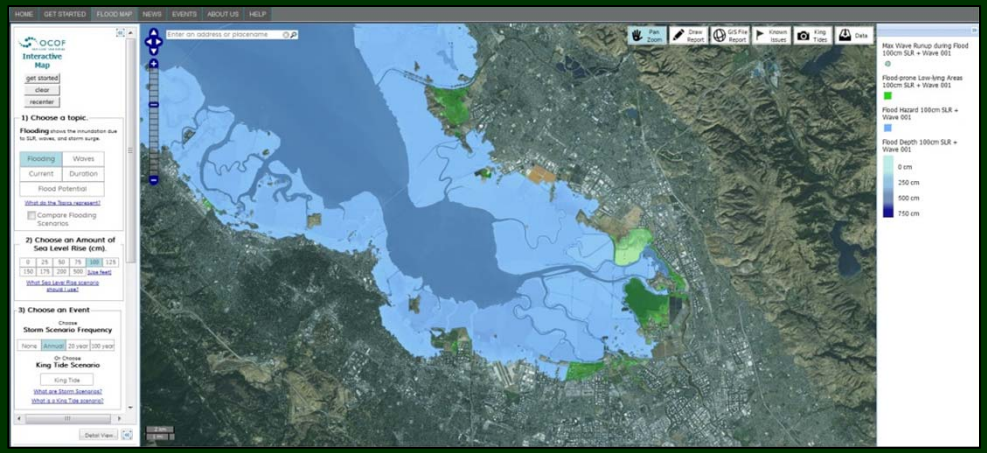
Coastal Vulnerability Approaches

- **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'



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

- **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



Our Coast Our Future: *www.prbo.org/ocof*

USGS

CoSMoS: A Tool for Coastal Resilience

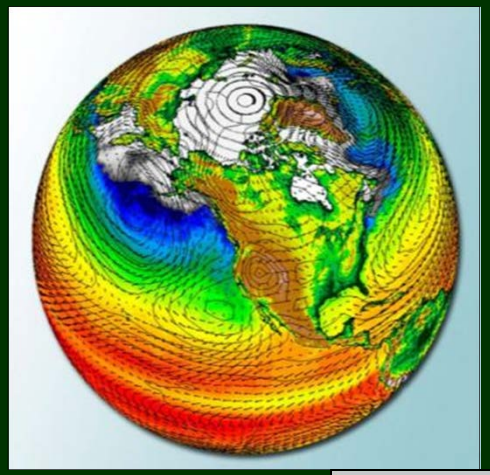
- **Physics-based numerical modeling system for assessing coastal hazards due to climate change**
- **Predicts coastal hazards for the full range of sea level rise (0-2, 5 m) and storm possibilities (up to 100 yr storm) using sophisticated global climate and ocean modeling tools**
- **Developing coastal 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)**

Gary Griggs, UCSC

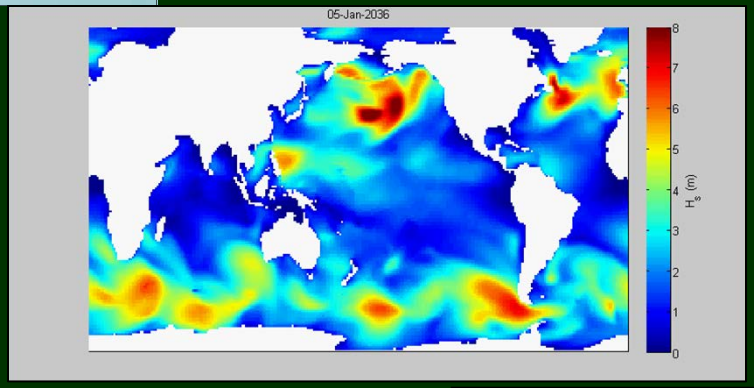
Brad Graverson, January 2010

USGS

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

USGS

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

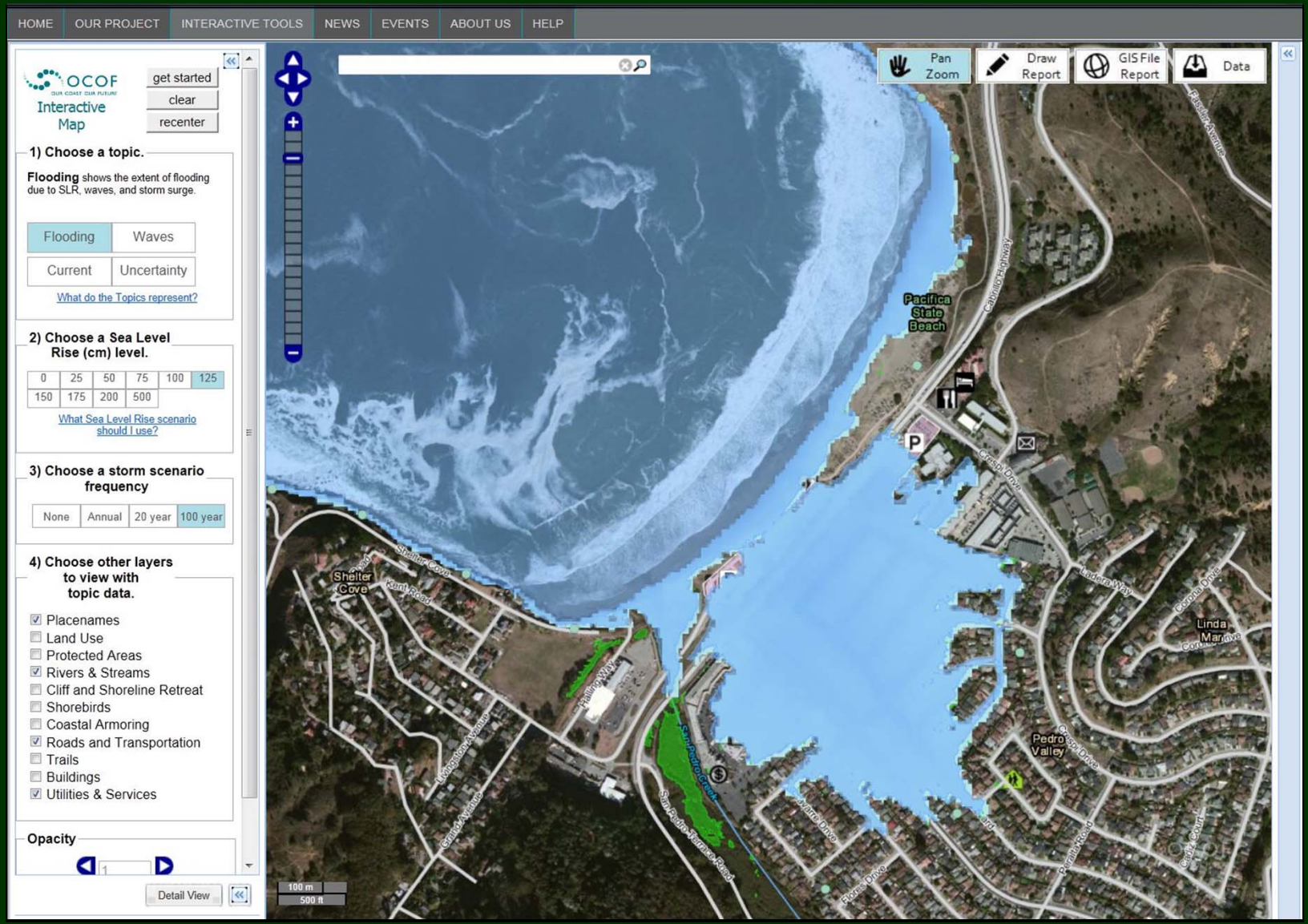
- North-Central CA coast, 170 km, (Bodega Head to Half Moon Bay)
- 21st century winds & waves
- High resolution grids of lagoons and protected areas
- Annual, 1 yr, 20 yr, 100 yr storm events in combination with SLR 0 m to 5 m at 0.25 m increments +5 m
- Web-based tool

CoSMoS 2.1

- San Francisco Bay
- Spatial- & time-downscaled climate scenario winds
- Fluvial discharges
- Vertical land motion
- Marsh accretion

USGS

CoSMoS 2.0- CenCal/NorCal



USGS

www.prbo.org/ocof **(Our Coast - Our Future)**

SoCal CoSMoS Version Differences

CoSMoS 1.0

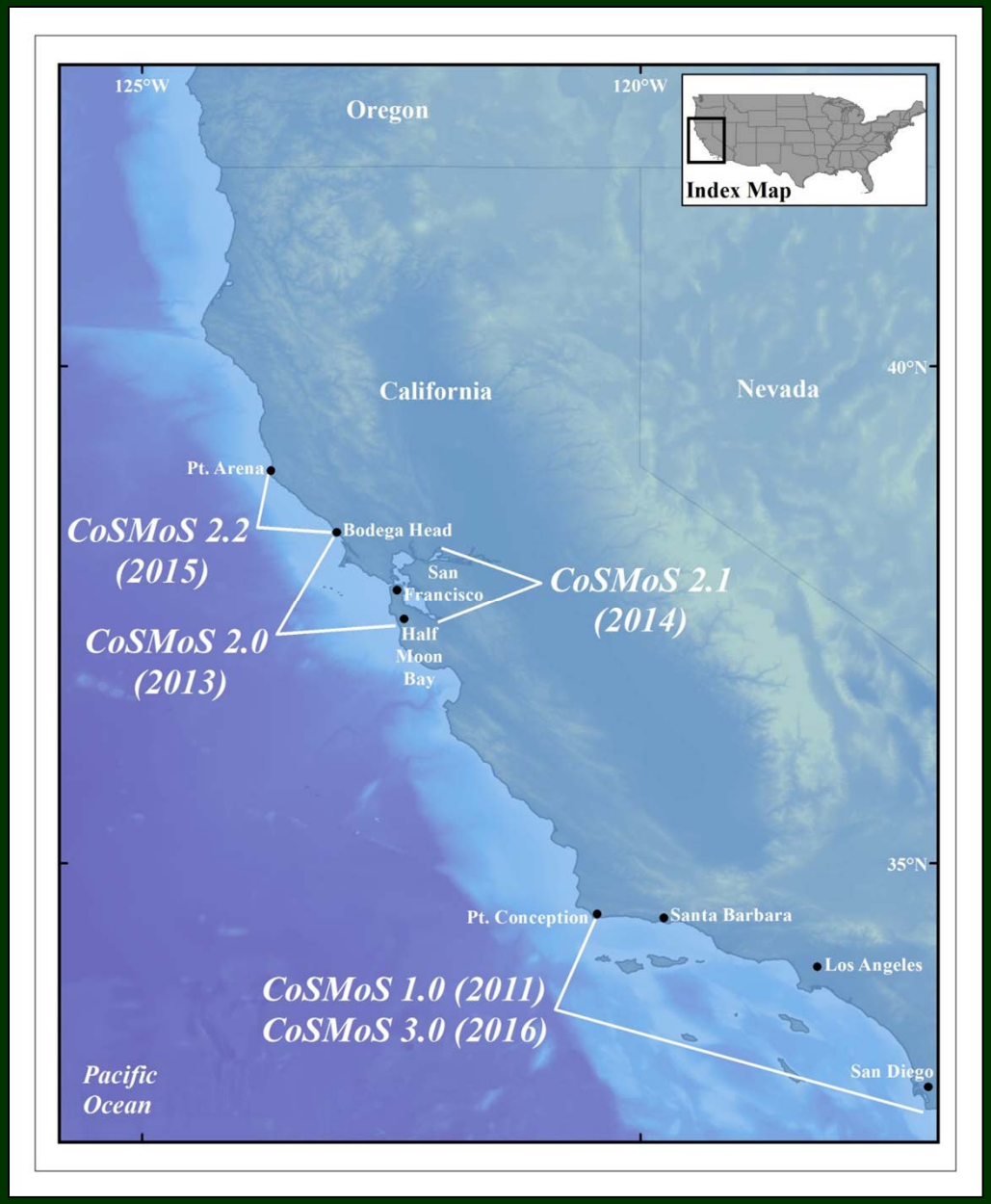
- So Cal, 470 km coastline (Pt. Conception -> Mexico border)
- Historical storms, 2 SLRs
- Global & regional parts continue to run operationally

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

USGS

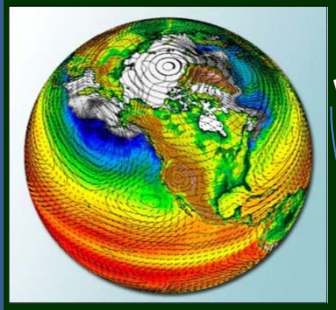
CoSMoS Version Summary



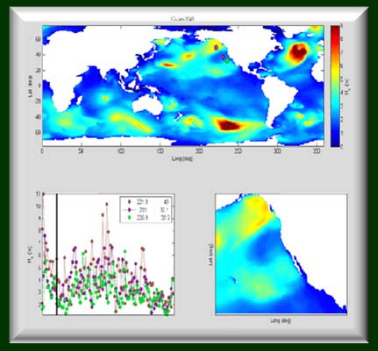
USGS

Model Overview: Global to Regional to Local

Global



winds



waves

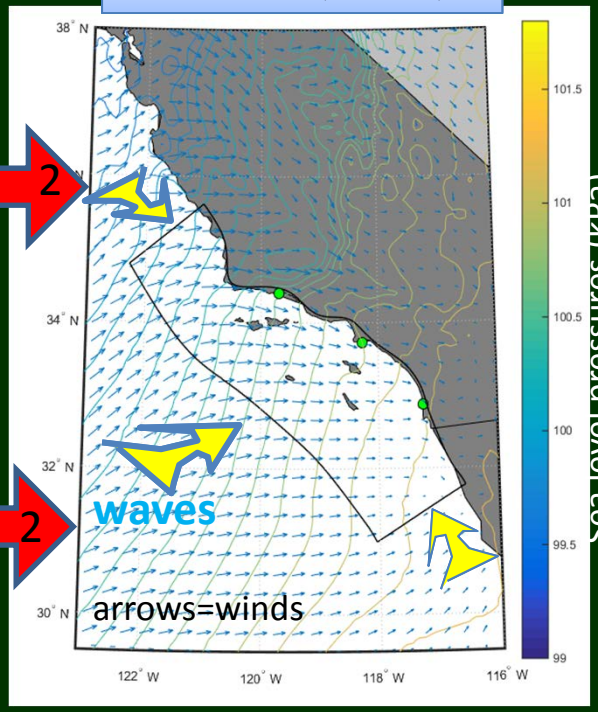
1

Select storm events based on $TWL_{proxies}$

2

2

Regional ***(Tier I)***



3

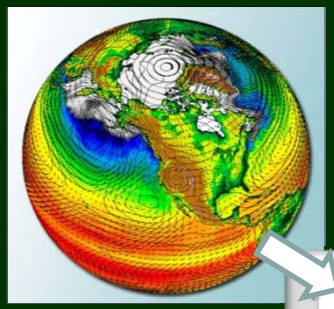
Local ***(Tiers II & III)***

USGS

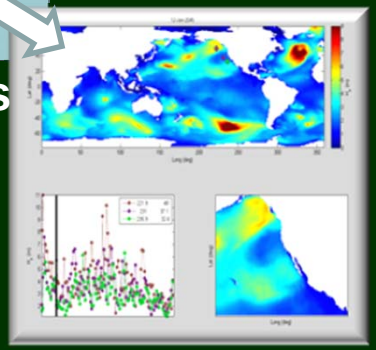
CoSMoS 3.0 Southern California

Global

Global conditions of future climate scenarios



GCM winds



WW3 wave model

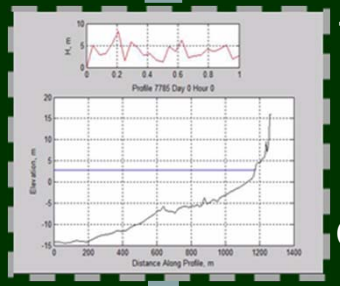
Regional

Tides, water levels, and regional forcing

Local

High resolution hydrodynamics and

XBEACH



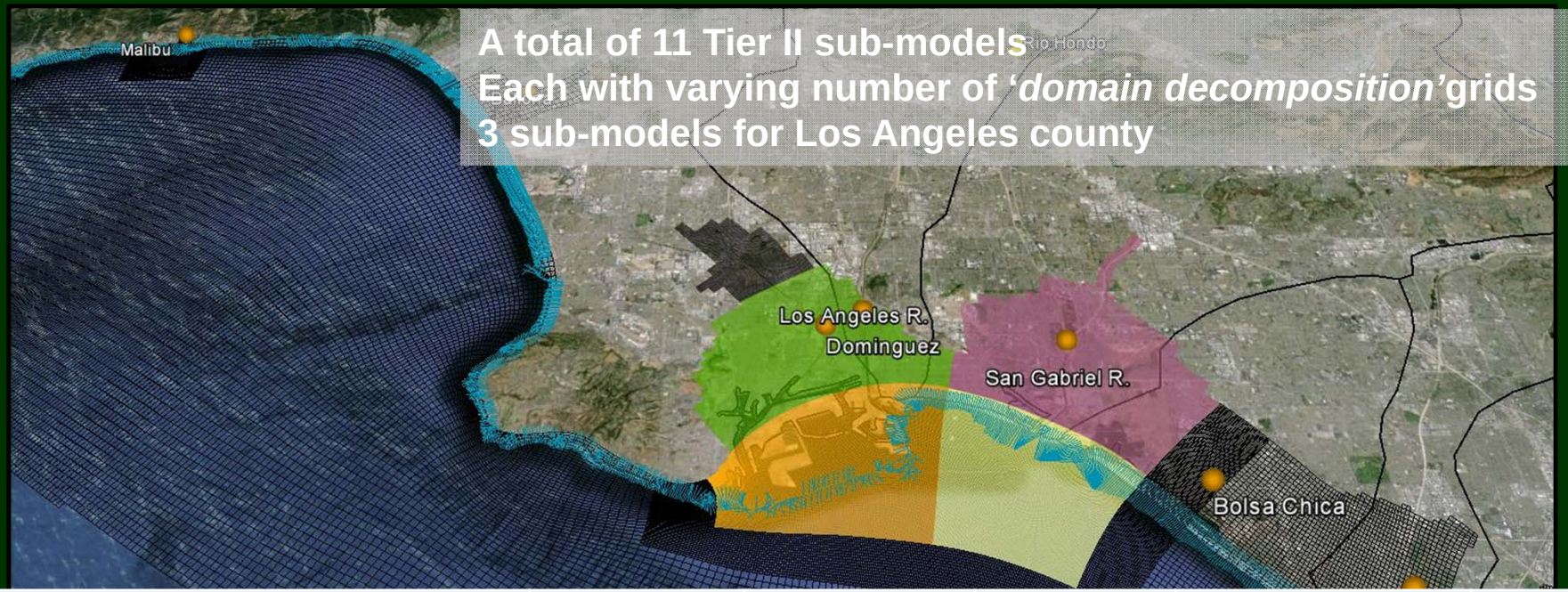
Open coast

Fluvial discharge
VLM
Coastal change

results projected onto hi-res DEM

USGS science for a changing world

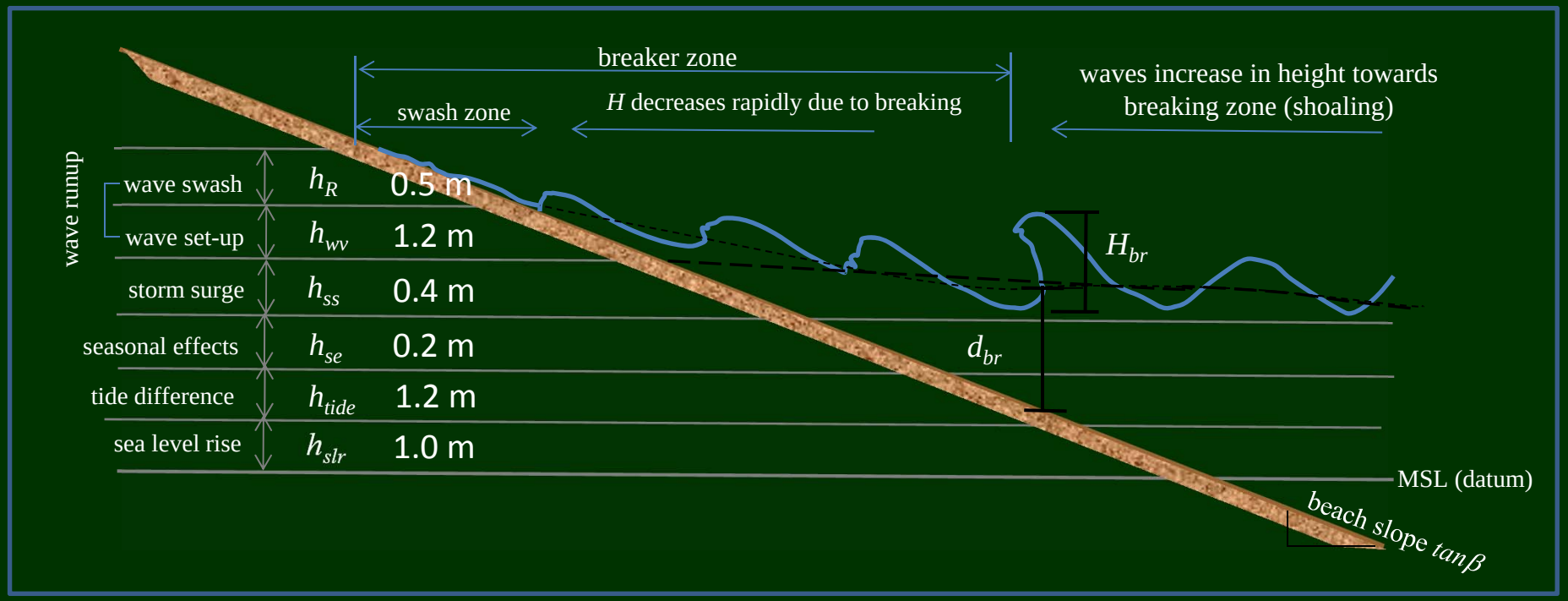
CoSMoS Coastal Storm Modeling System USGS



Tier II sub-models						
Sub-model name	Geographic extents (north to south)	County	Number of DD grids	Number of Xbeach profiles	Grid resolution (m)	
					Most coarse	Finest
gc	Pt. Mugu to Pt. Conception	Santa Barbara	6	1,057	70 x 90	18 x 16
ve	King Harbor to Pt. Mugu	Ventura	13	341	100 x 110	5 x 15
is	Santa Monica to Isla Vista	Ventura	6	217	90 x 90	5 x 15
pm	Torrance to El Capitan	Los Angeles	8	486	100 x 110	20 x 20
mk	King Harbor to Marina Del Rey	Los Angeles	4	410	130 x 145	30 x 40
la	Port of L.A. to Newport	Los Angeles	4	413	90 x 115	25 x 45
oc	Santa Ana to Alamitos Bay	Orange	12	175	35 x 65	7 x 11
np	Dana Pt. to Newport	Orange	9	488	70 x 85	5 x 8
cb	Dana Pt. to Ocean Beach	San Diego	9	516	30 x 60	10 x 15
ty	U.S. Mexico border to Dana Pt.	San Diego	6	233	30 x 60	10 x 20
sd	U.S. Mexico border to Dana Pt.	San Diego	9	466	90 x 140	10 x 13

All topobathy grids in the nearshore were populated with 2 m resolution data

Overview of Processes Included in CoSMoS

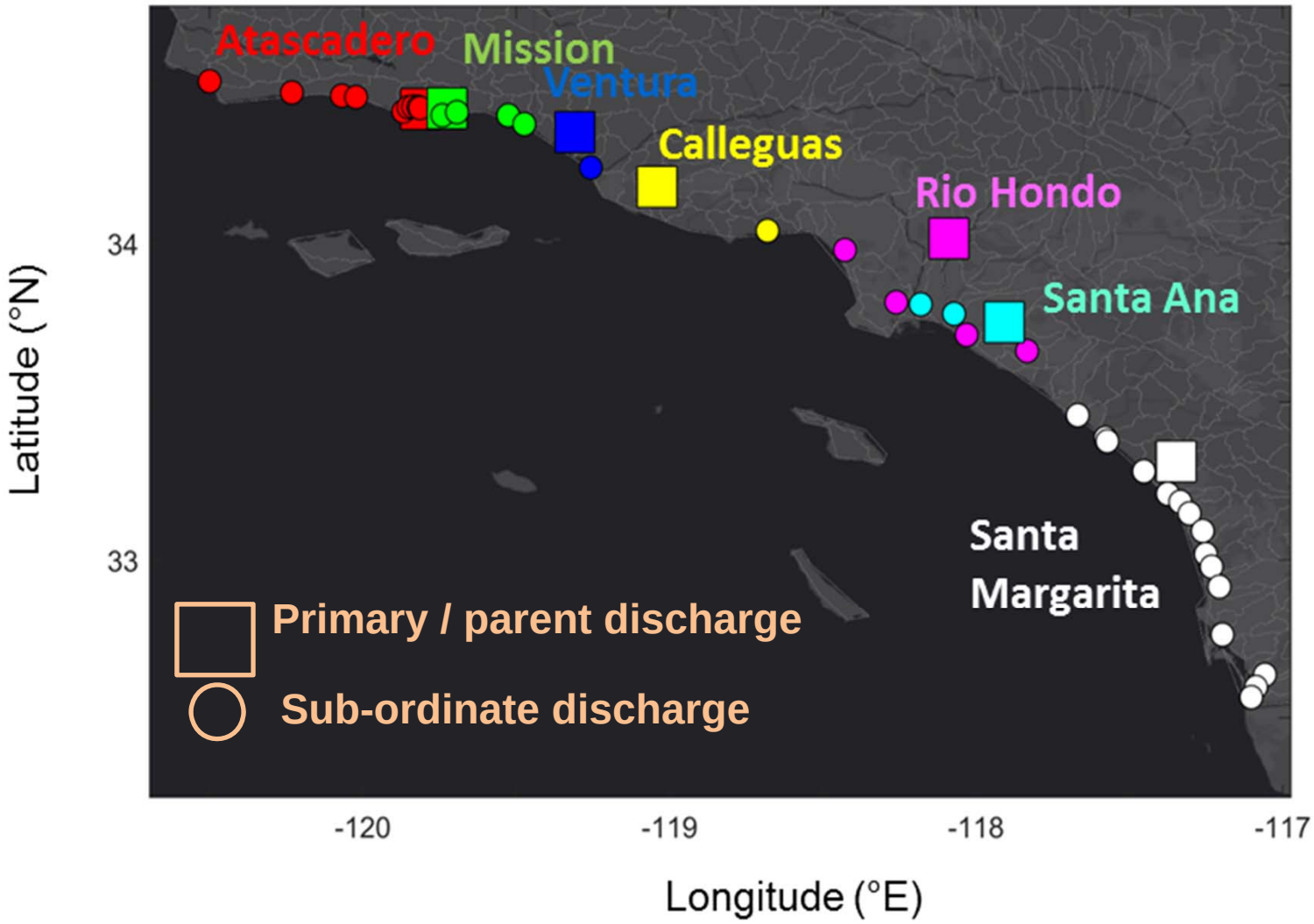


flood level is the combination of

$$rSLR + tides + seasonal\ effects + storm\ surge + wave\ setup + wave\ runup + fluvial\ discharge\ backflow$$

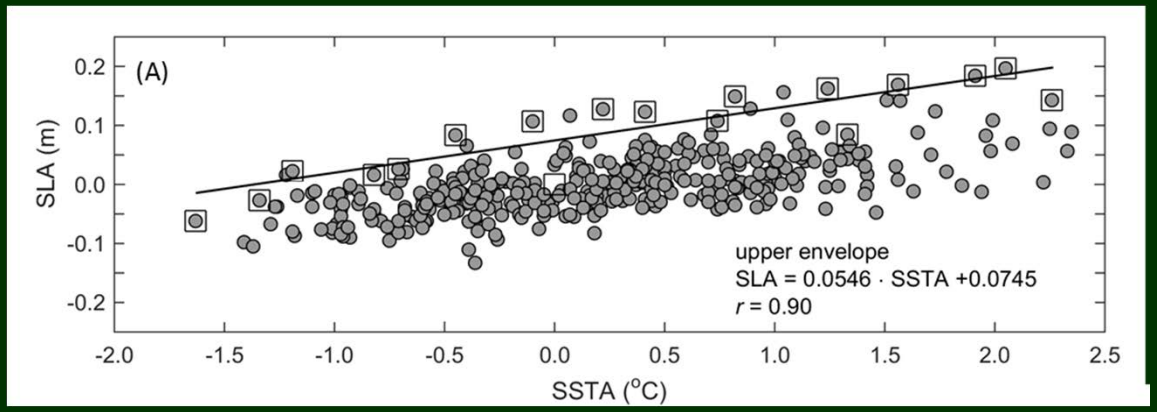
USGS

Fluvial Discharge in CoSMoS

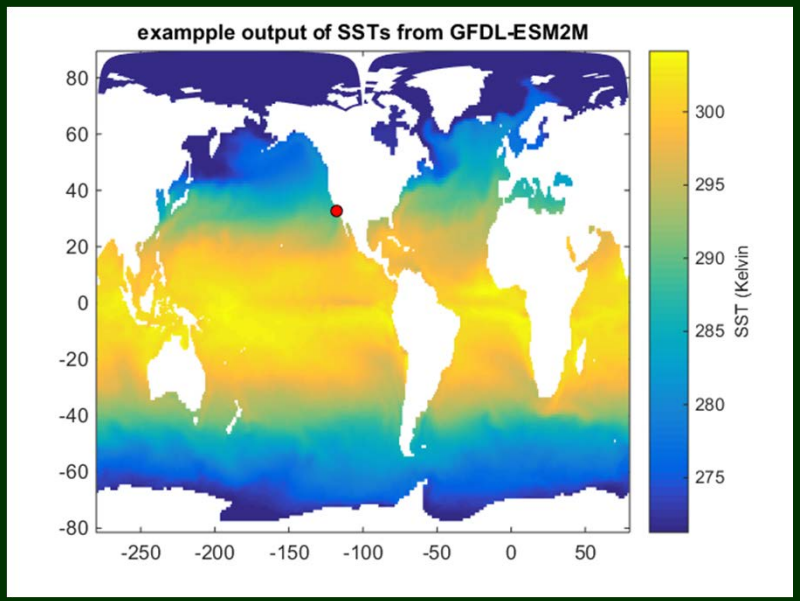


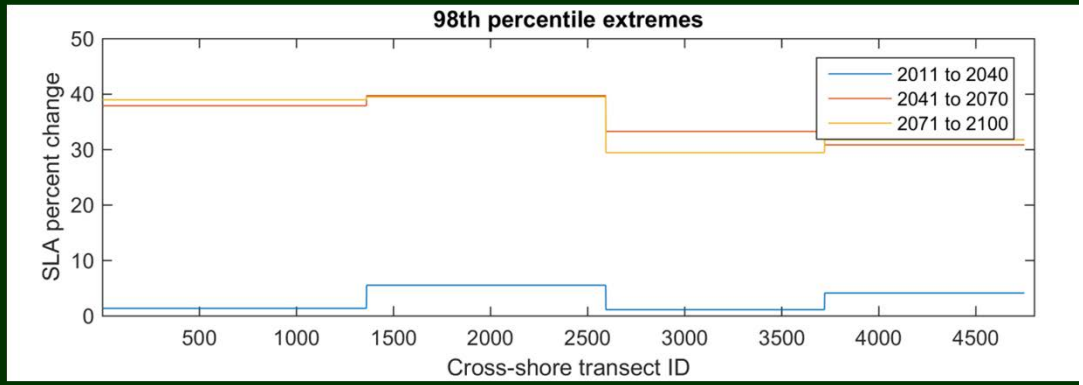
-44 fluvial discharge locations
-future discharge based on historical relationship between SLP and discharge

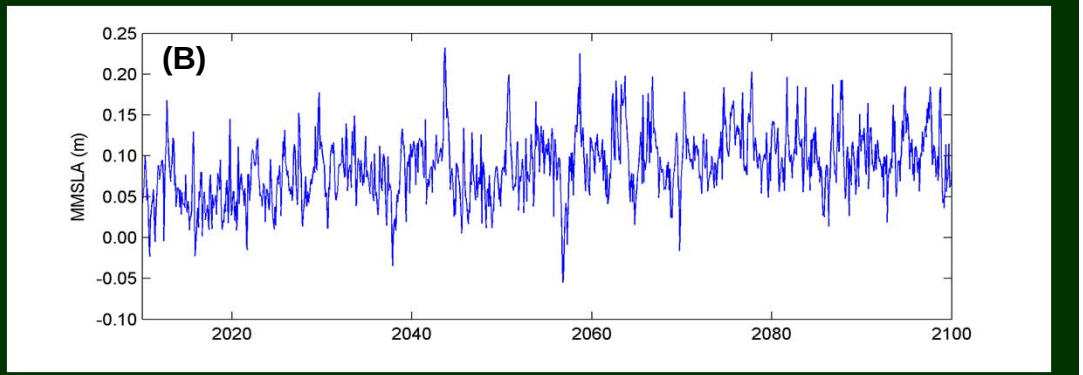
Sea Level Anomalies in CoSMoS



Use historical data to develop linear model

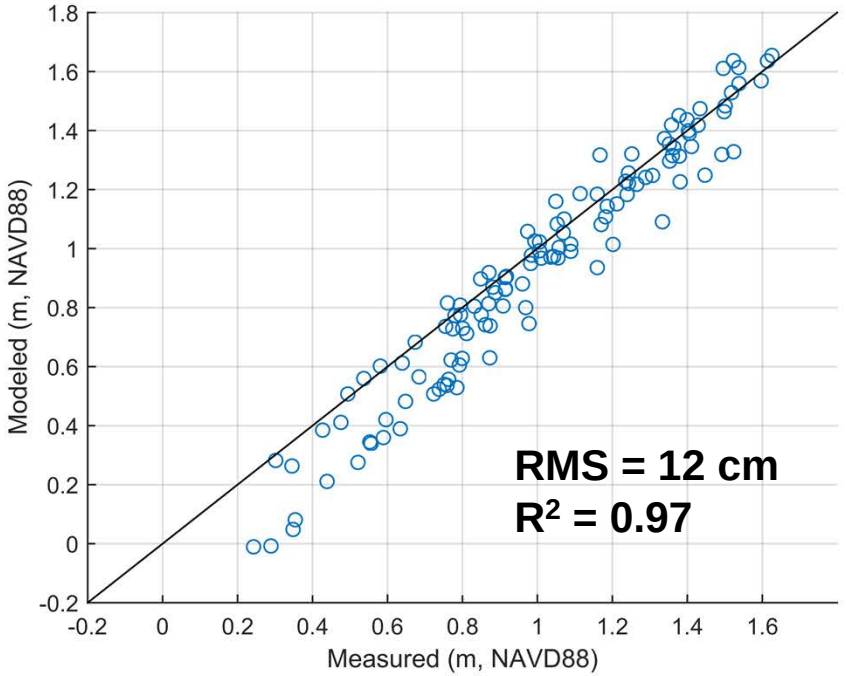


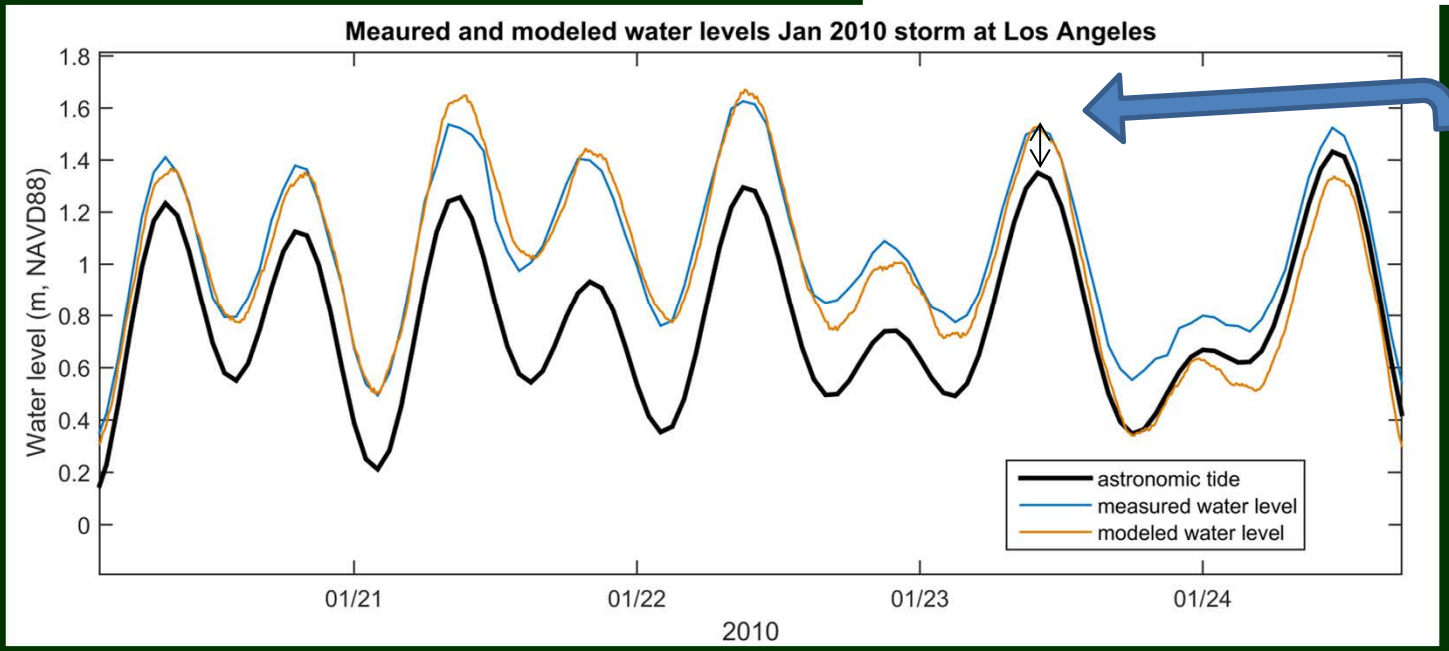




CoSMoS validated with January 2010 Storm

Los Angeles tide gauge



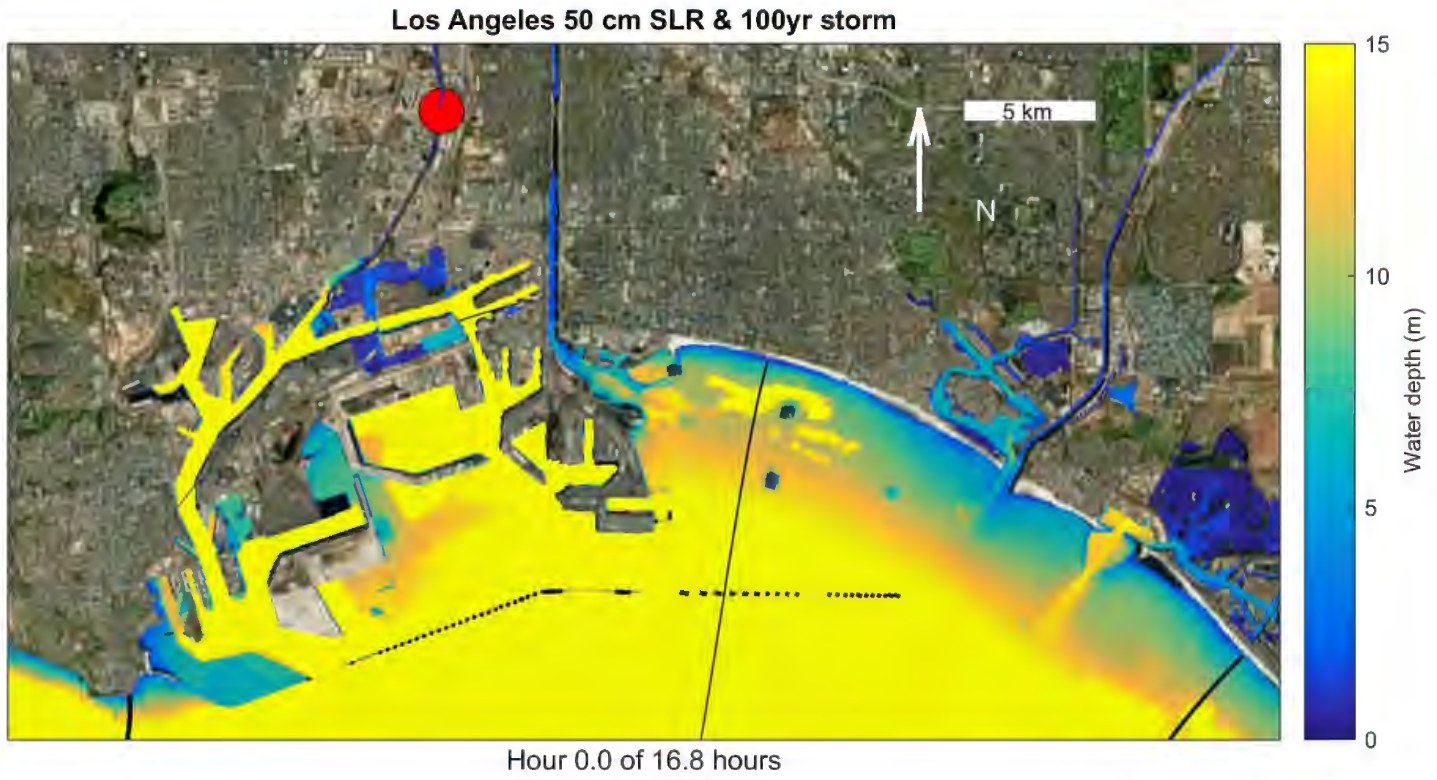


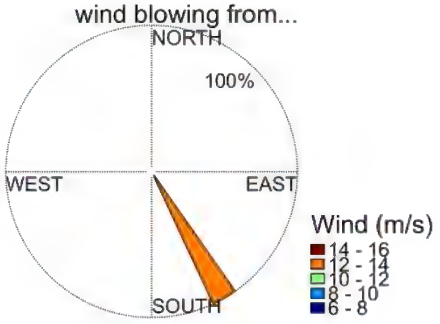
Predicted and observed/modeled water levels differ by 6 to 52 cm

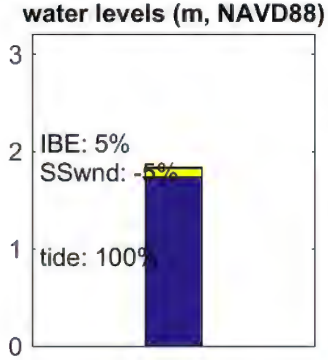
- **Number of runs completed for the**
  - **100 yr storm event +**
  - **SLRs 0 cm, 50 cm, 100 cm, 150 cm**

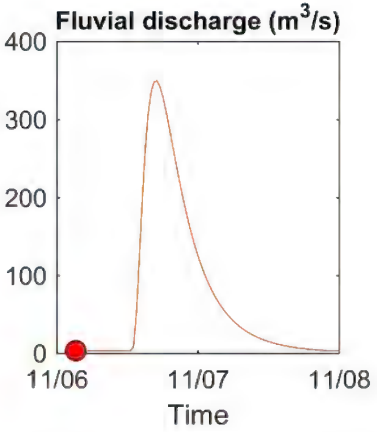
County	Number of cross-shore transects (CSTs)	Number of TierIII XBeach runs	Number of TierI&II Delft3D runs
Santa Barbara	1,057	25,368	18
Ventura	683	16,392	42
Los Angeles	1,184	28,416	48
Orange	663	15,912	24
San Diego	1,215	29,160	36
Total	*4,802*	*115,248*	*168*

USGS


Los Angeles 50 cm SLR & 100yr storm
5 km
N
15
10
5
0
Water depth (m)
Hour 0.0 of 16.8 hours


wind blowing from...
NORTH
100%
WEST
EAST
SOUTH
Wind (m/s)
14 - 16
12 - 14
10 - 12
8 - 10
6 - 8

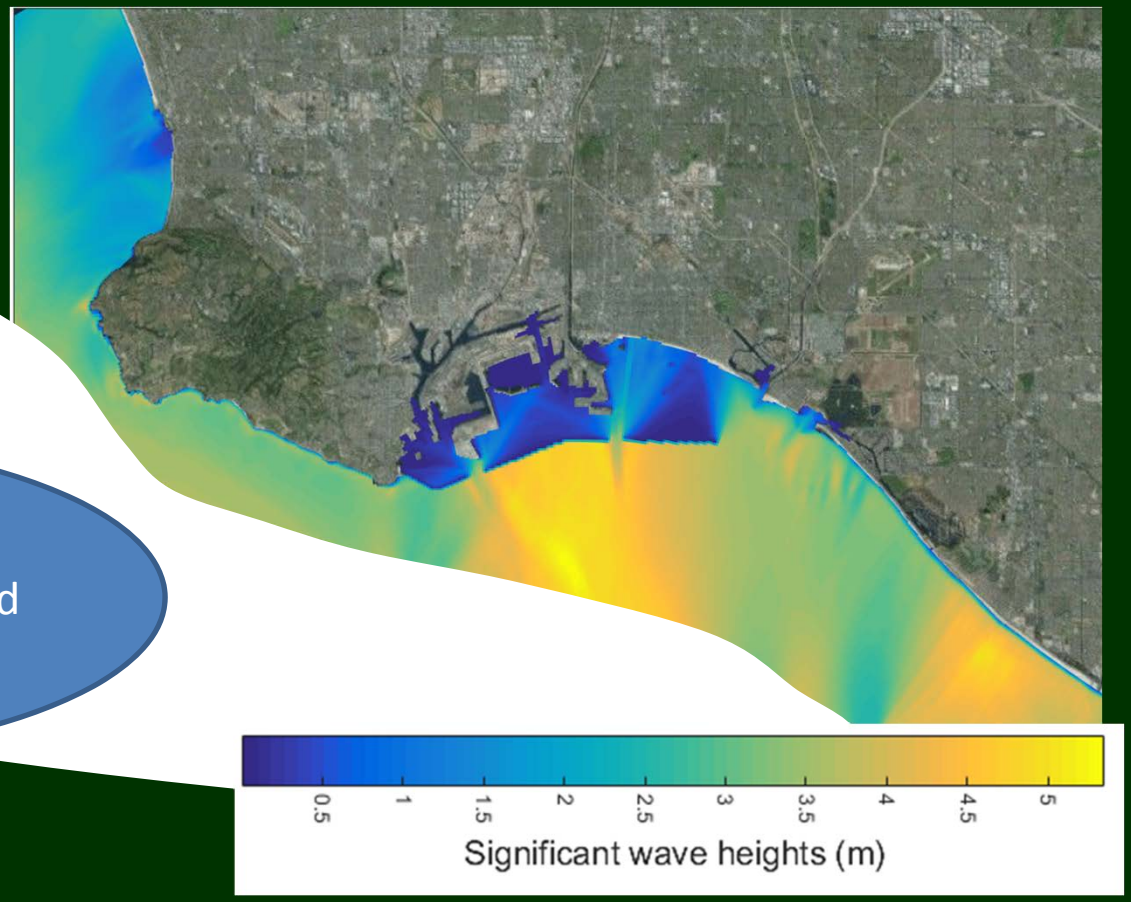

water levels (m, NAVD88)
3
2
1
0
IBE: 5%
SSwnd: -5%
tide: 100%


Fluvial discharge (m3/s)
400
300
200
100
0
11/06
11/07
11/08
Time

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



USGS

Products- Flood Maps

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

To generate maps of flood extents, duration, and depth

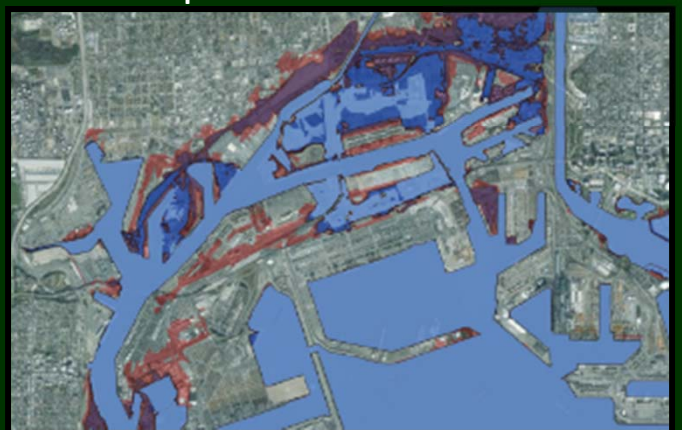
High resolution model results

+

XBeach results along open coast

=

Flood map



USGS

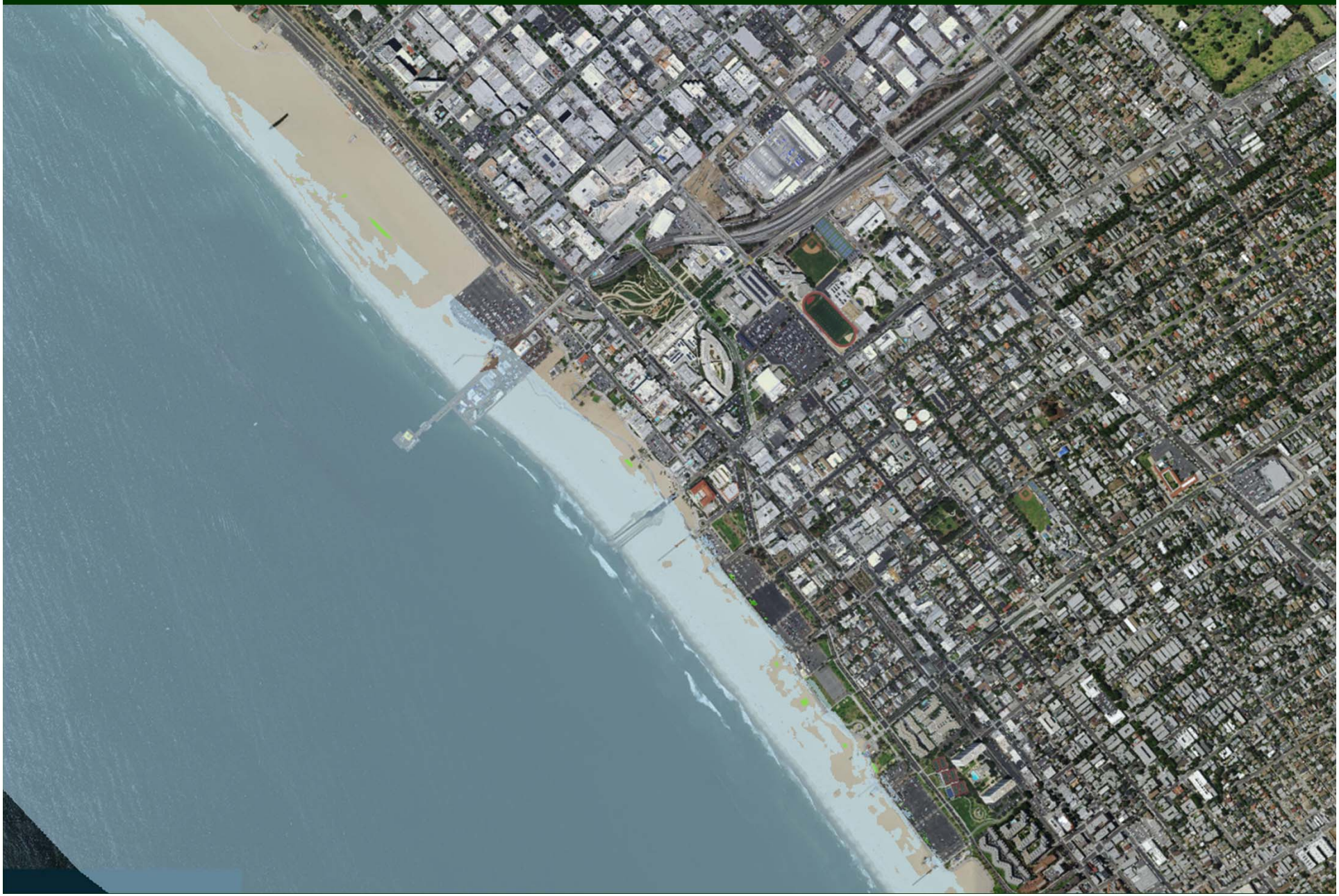
Malibu – SLR 0 cm

Malibu – SLR 50 cm

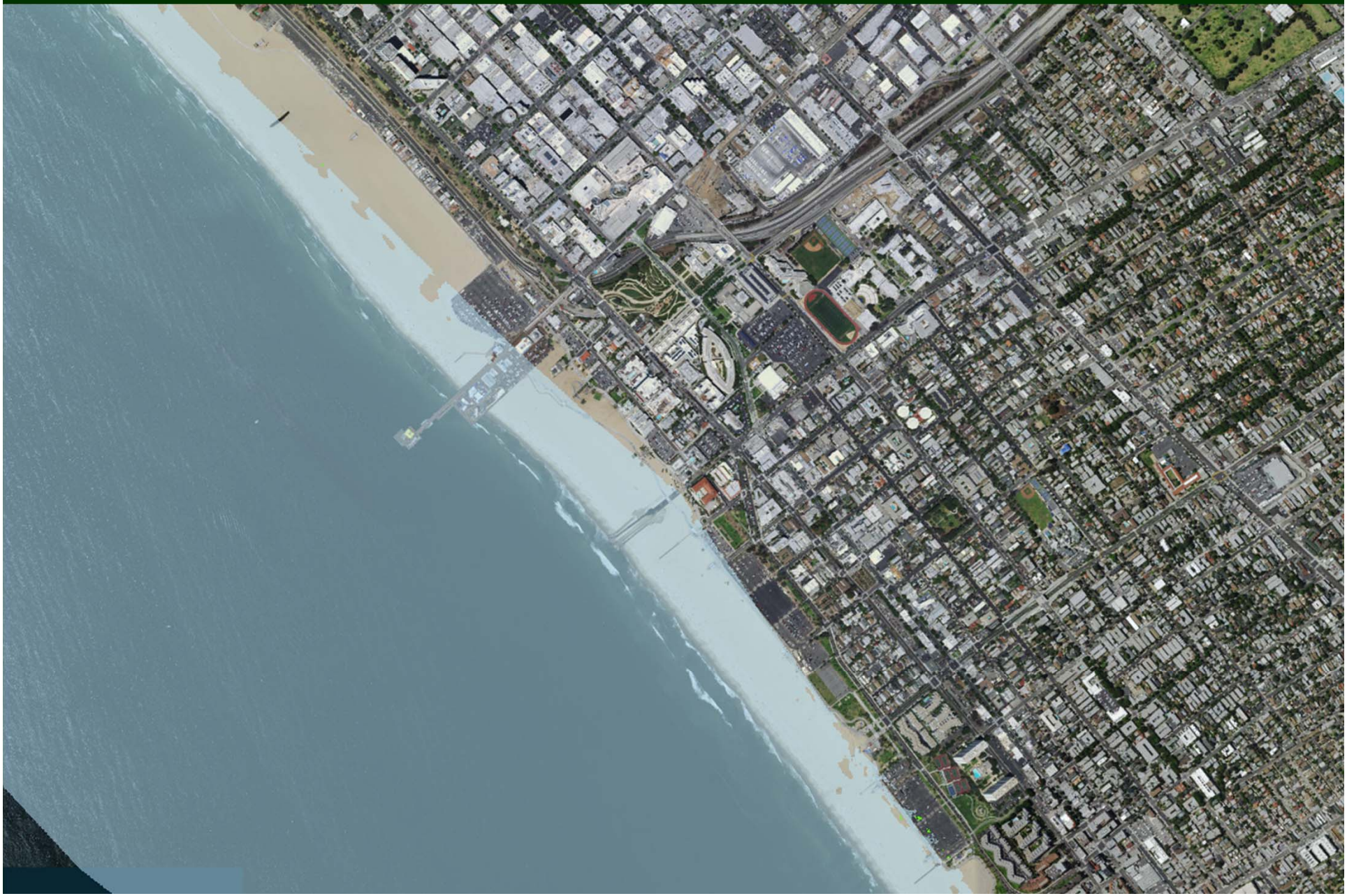
Malibu – SLR 100 cm

Malibu – SLR 150 cm

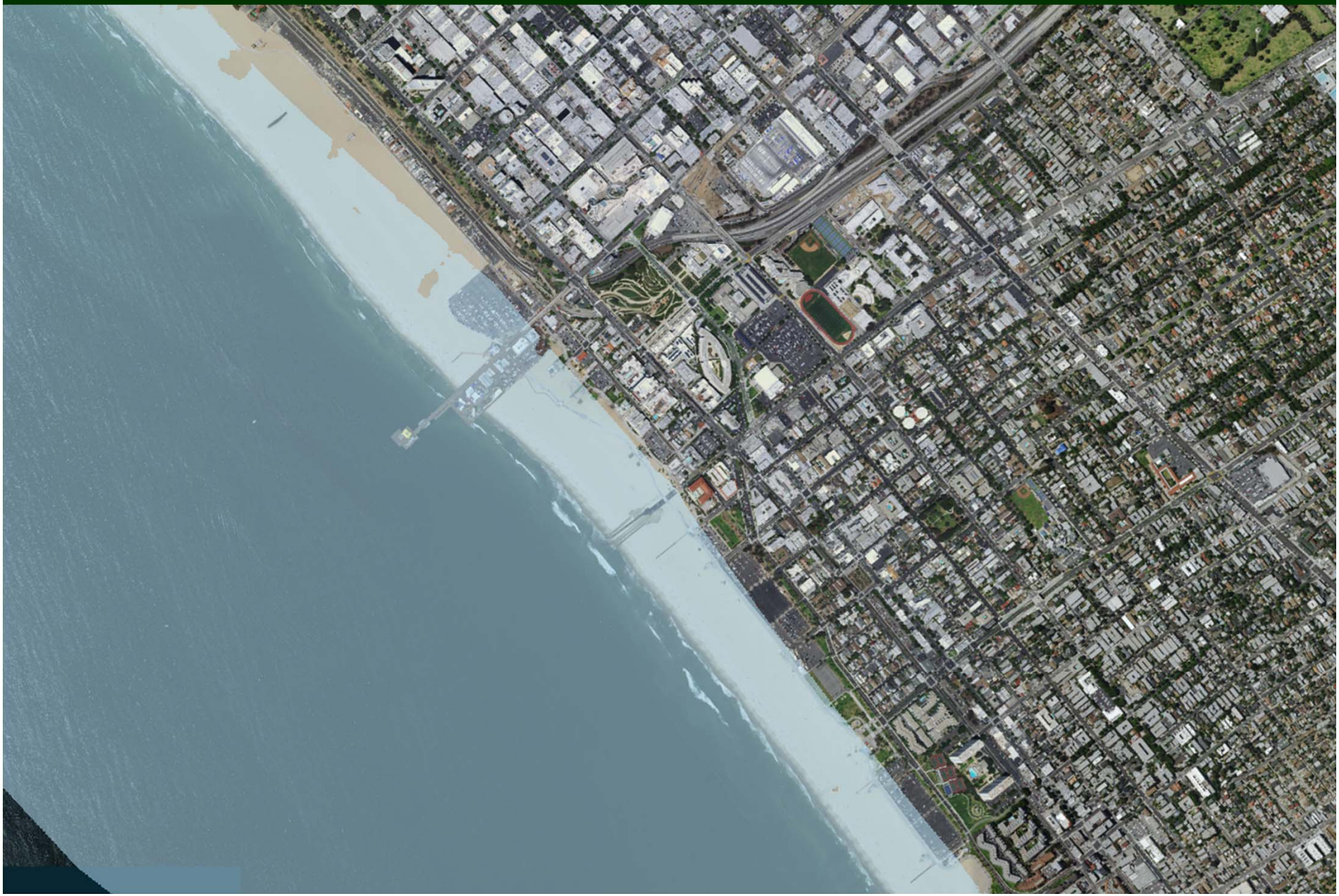
Santa Monica Pier – SLR 0 cm



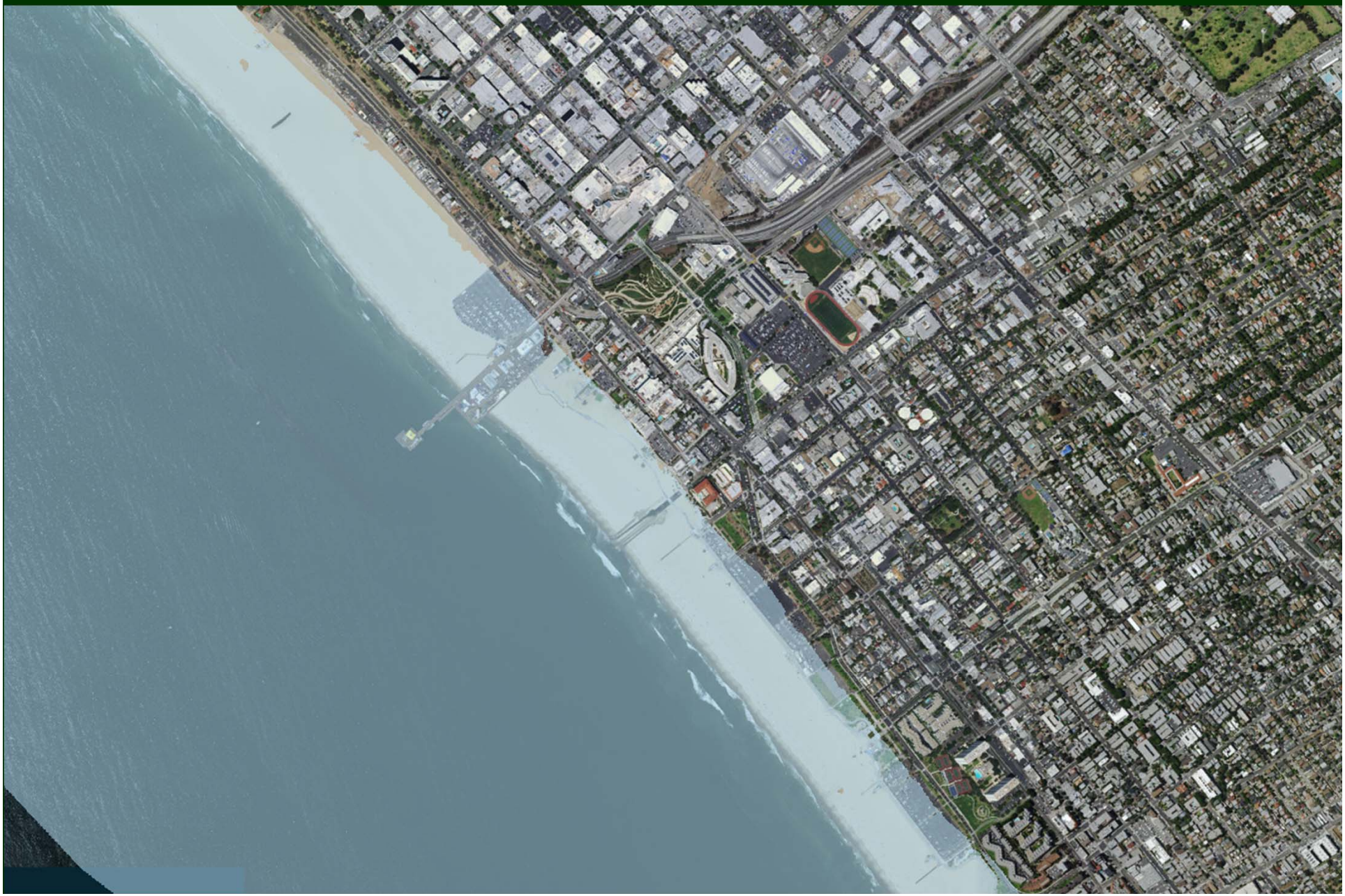
Santa Monica Pier – SLR 50 cm



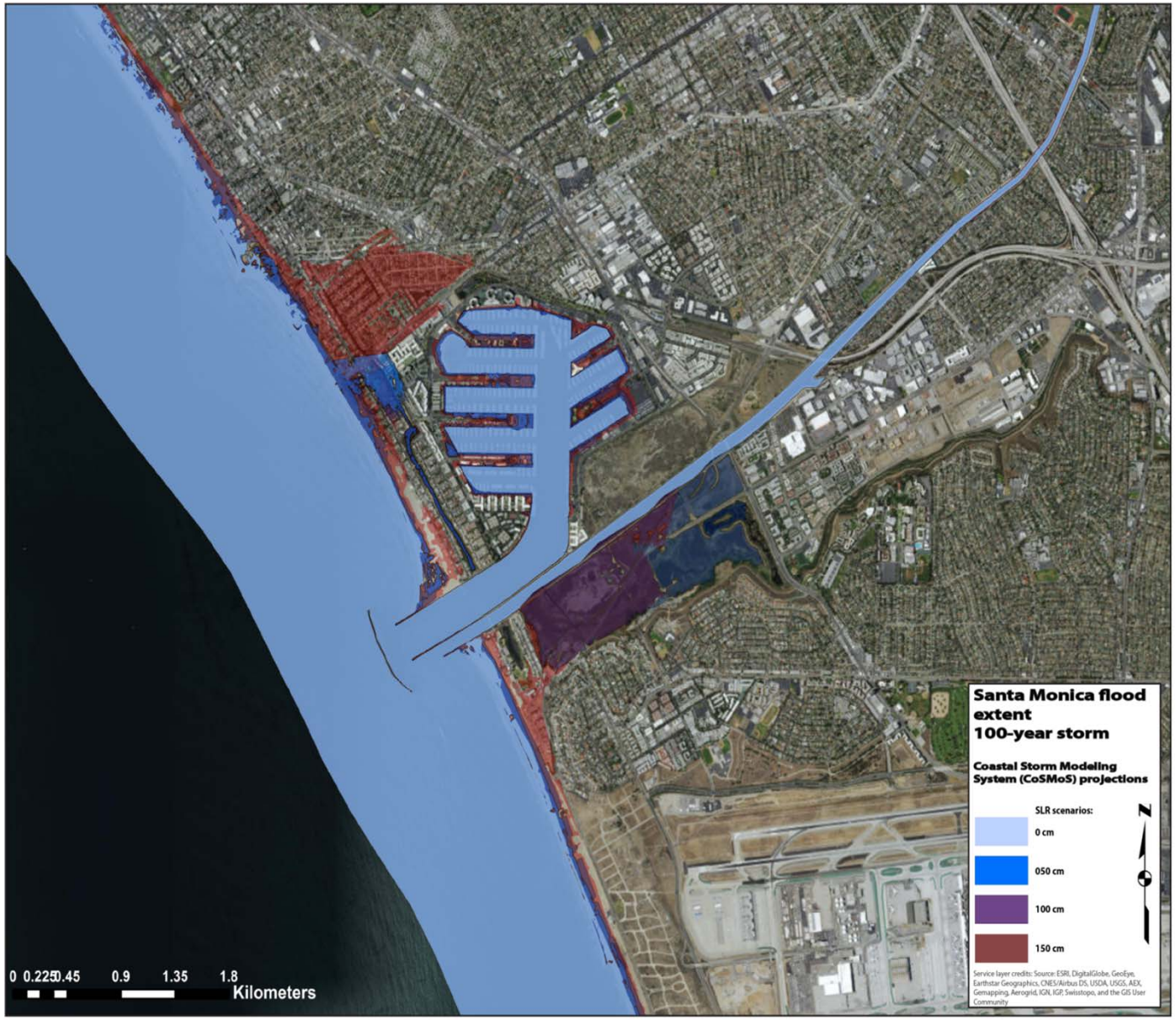
Santa Monica Pier – SLR 100 cm



Santa Monica Pier – SLR 150 cm

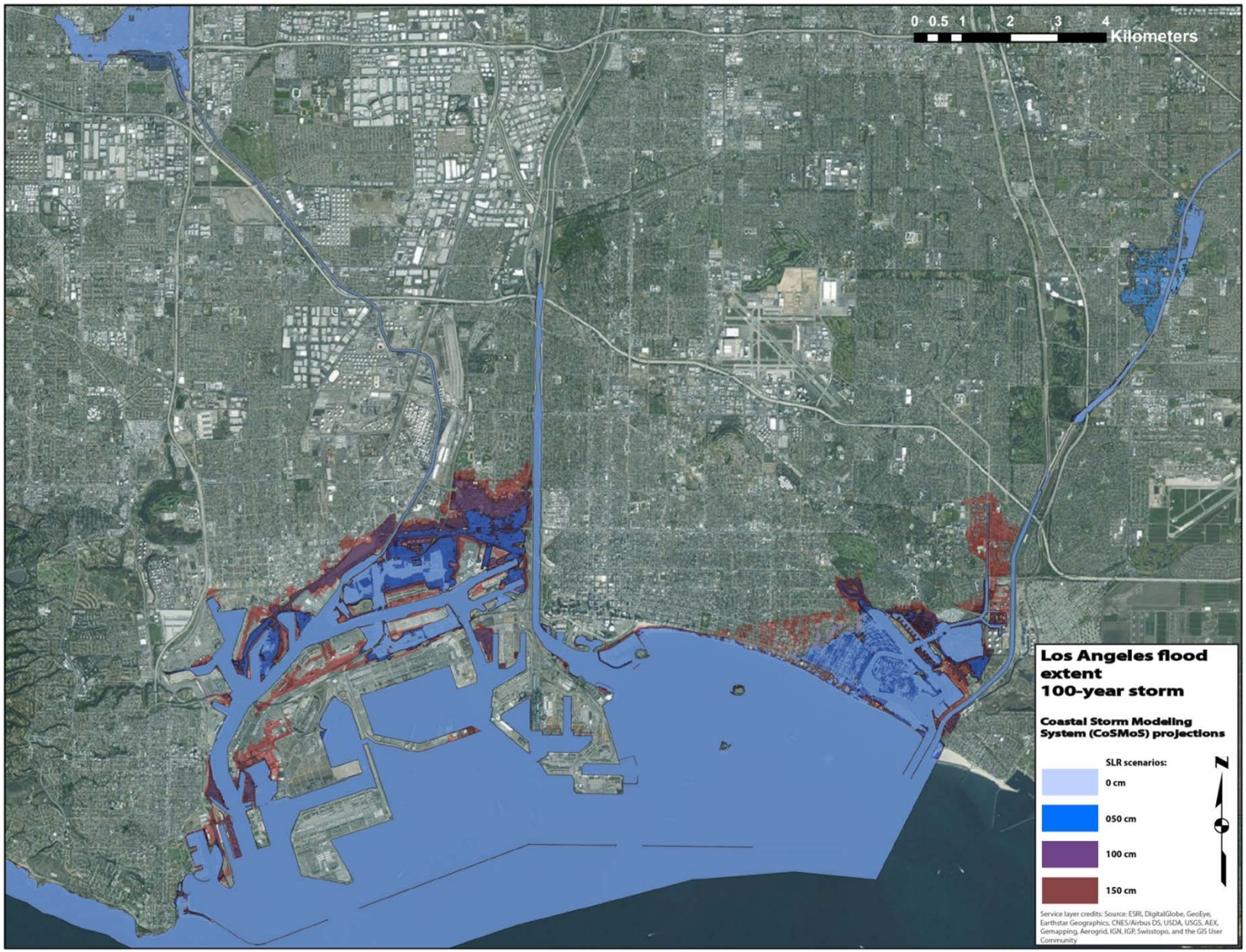


Venice / Marina Del Rey

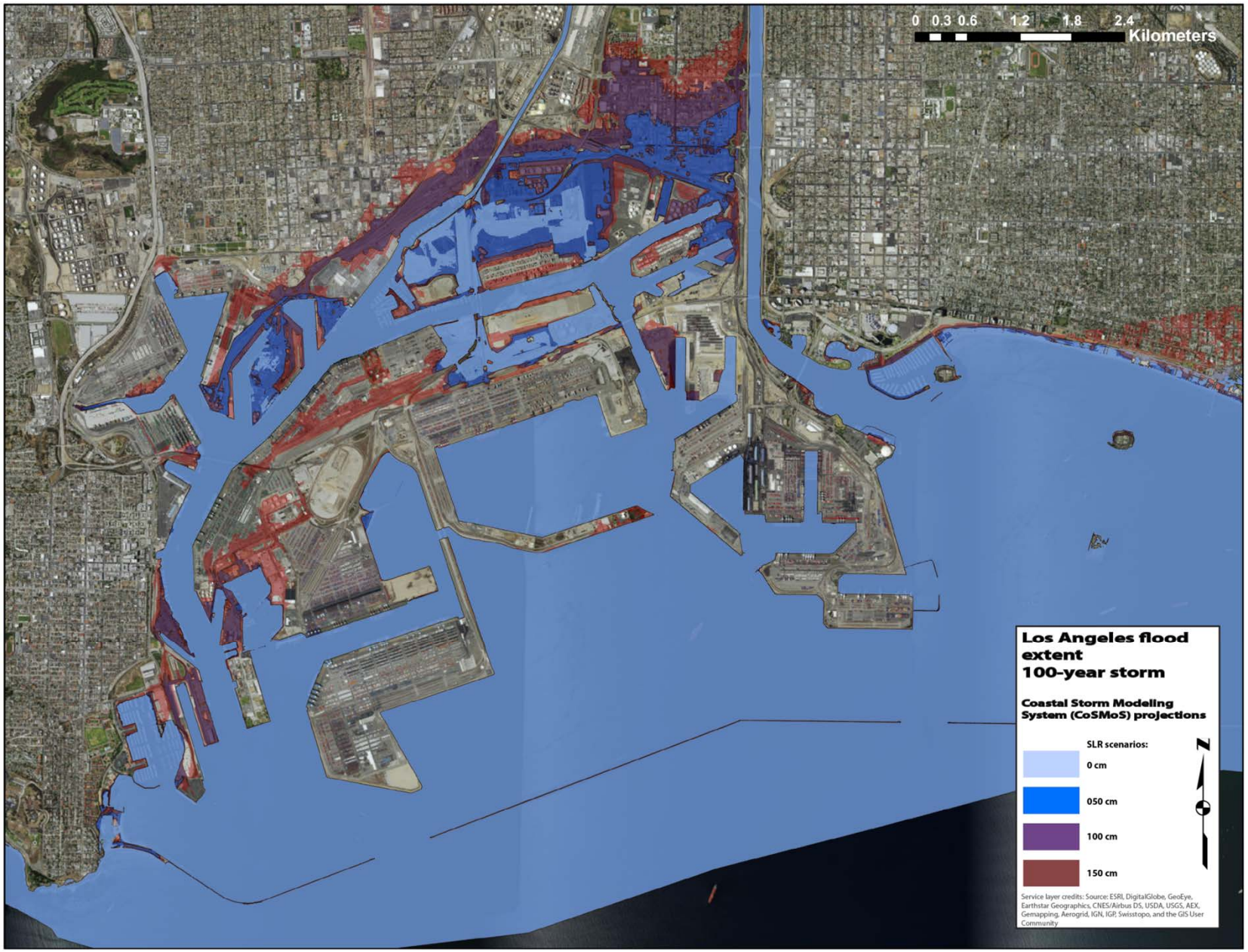


USGS

L.A. Harbor / Long Beach

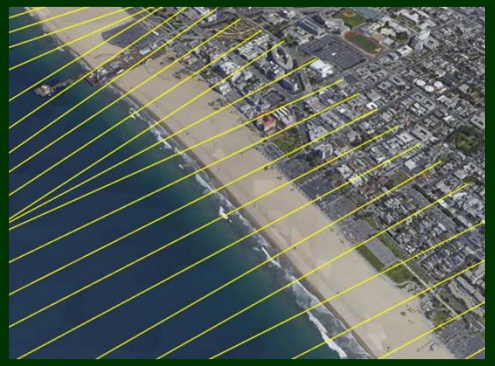


L.A. Harbor


0 0.3 0.6 1.2 1.8 2.4
Kilometers
Los Angeles flood extent
100-year storm
Coastal Storm Modeling System (CoSMoS) projections
SLR scenarios:
0 cm
050 cm
100 cm
150 cm
N
Service layer credits: Source: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Gemapping, Aerogrid, IGN, IGP, Swisstopo, and the GIS User Community

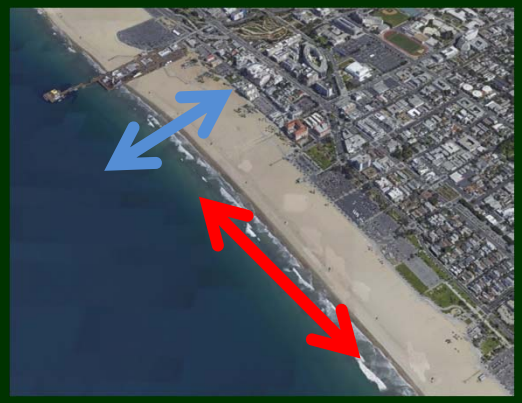
CoSMoS-COAST: Coastal One-line Assimilated Simulation Tool

- **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**

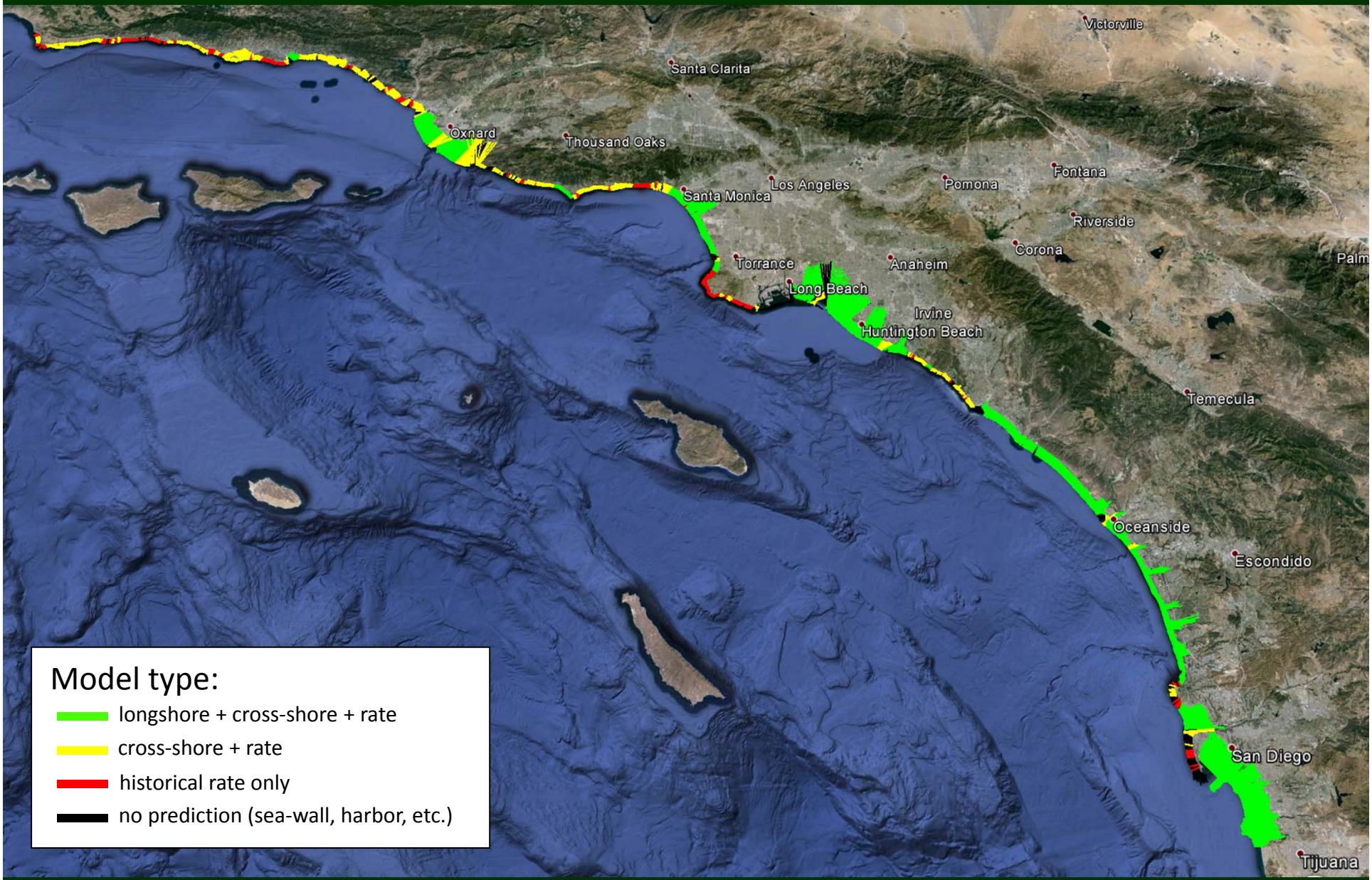
- **Modeled processes include:**
  - **Longshore sediment transport**
  - **Cross-shore sediment transport**
  - Effects of sea-level rise
  - Sediment supply by natural & anthropogenic sources



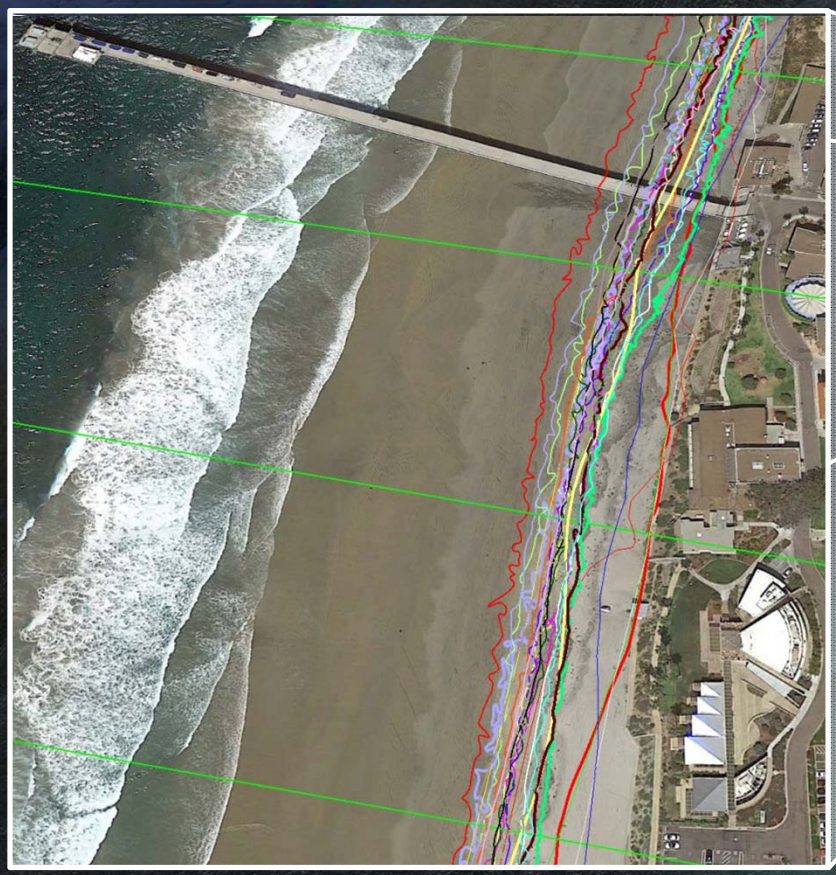
- **Synthesized from models in scientific literature (with several improvements):**
  - Longshore transport: Pelnard-Considere 1956, Larson et al. 1997, Vitousek & Barnard 2015
  - Equilibrium shoreline change models: Miller & Dean 2004, Yates et al. 2009, Long & Plant 2012
  - Cross-shore transport due to sea-level rise: Bruun 1954, Davidson-Arnot 2005, Anderson et al. 2015

- **Uses data assimilation (Extended Kalman Filter) to improve model skill**

Model has ~4800 transects with ~100 m grid spacing



Shoreline Data:



La Jolla Shores

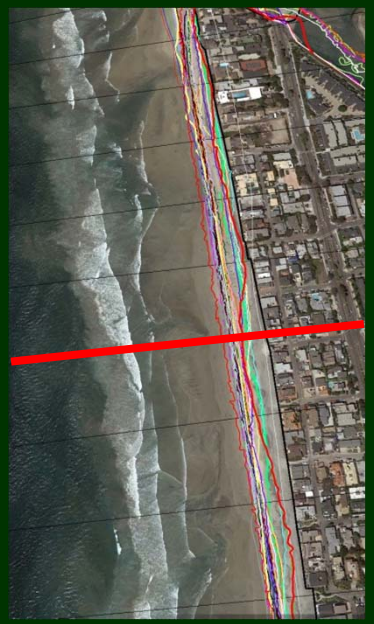
- **5 shorelines** from **USGS National Assessment**
- **20 shorelines** extracted from **LIDAR surveys**
  (most are from SCRIPPS 2003 – 2009; most are south of Long Beach)
- **20 shorelines** from **USGS surveys**
  (only in Santa Barbra area 2005 - present)
- ***We need MORE!***

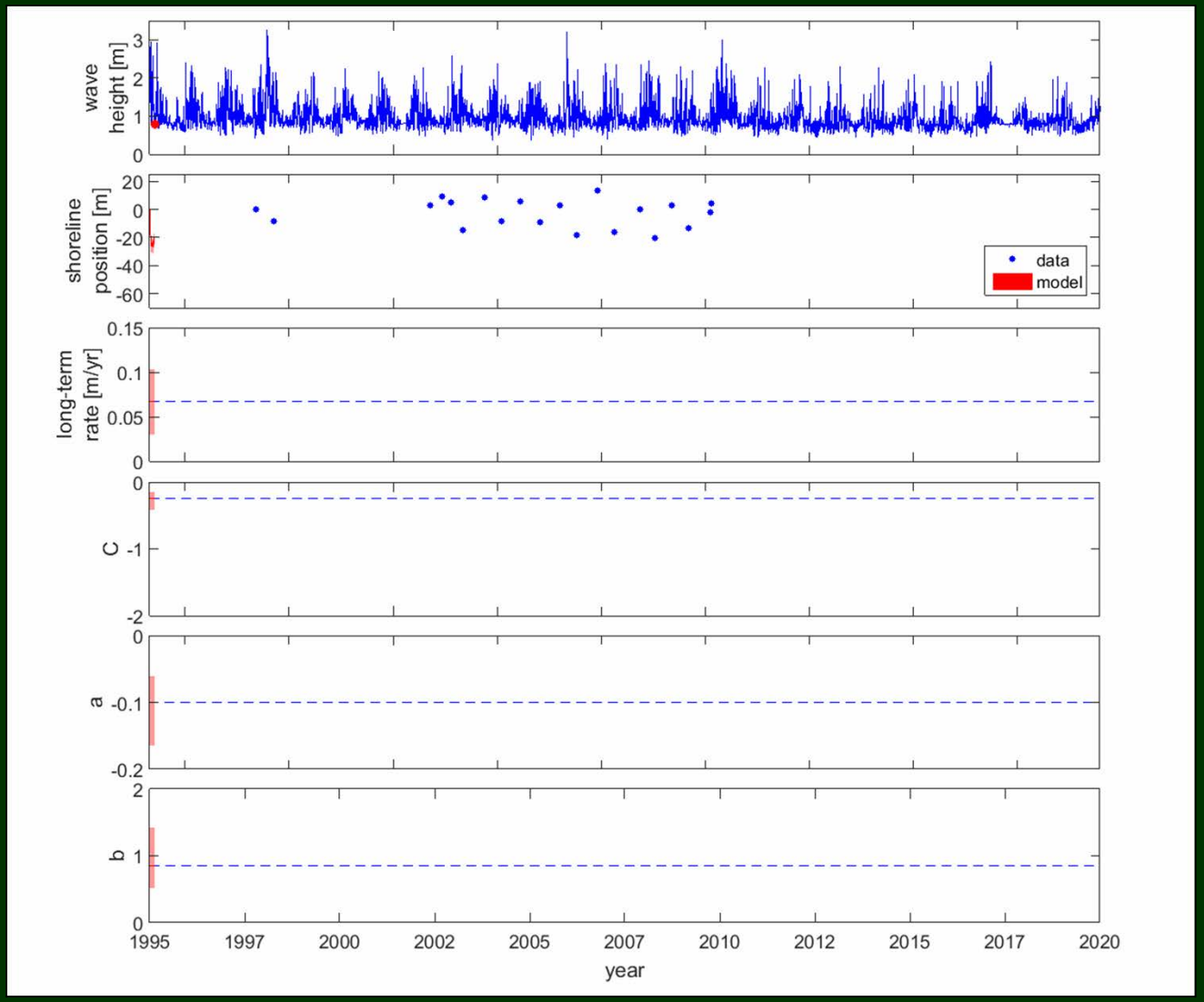
Data Assimilation

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.

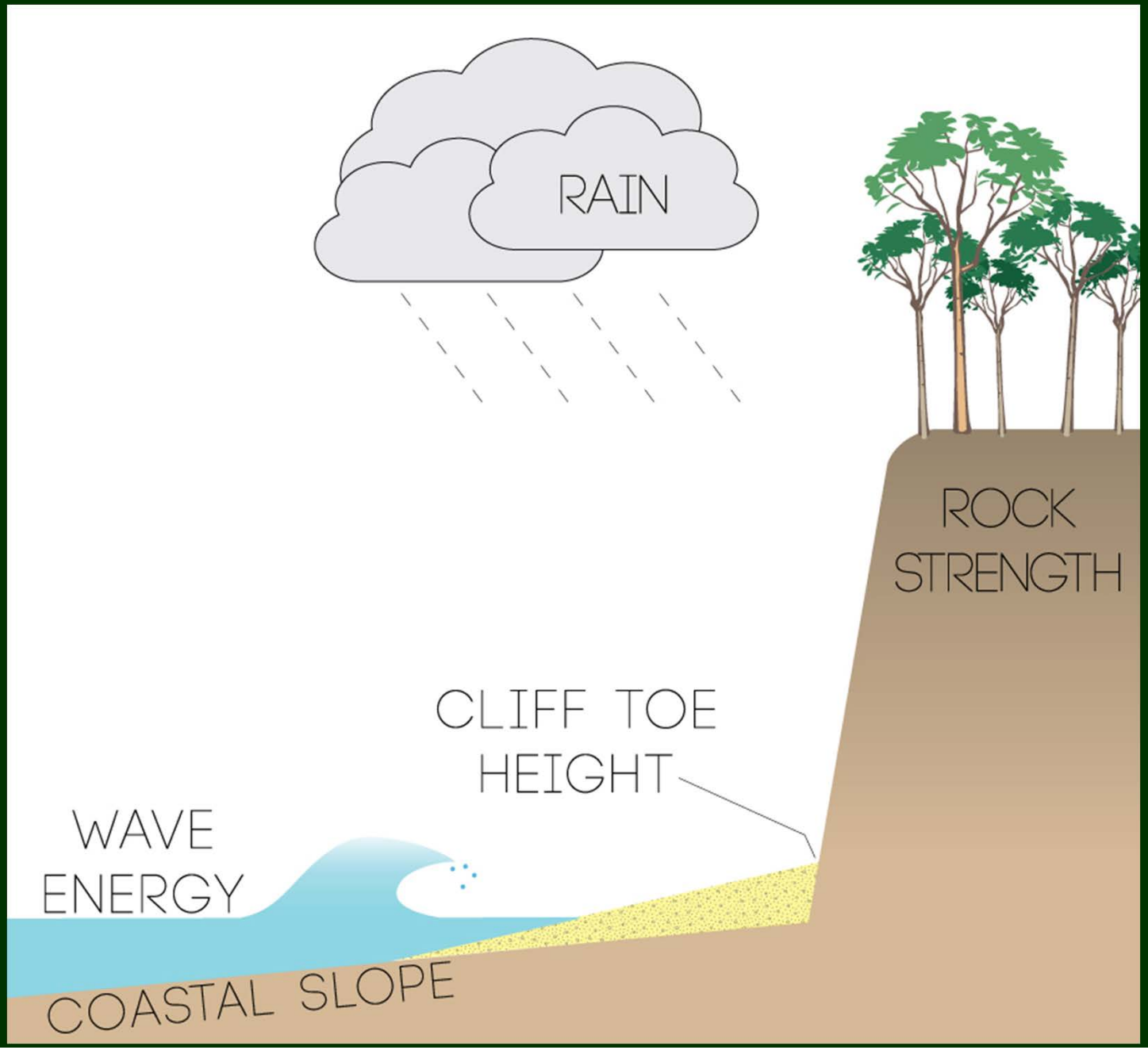
Simulation output for a single transect at Del Mar Beach:



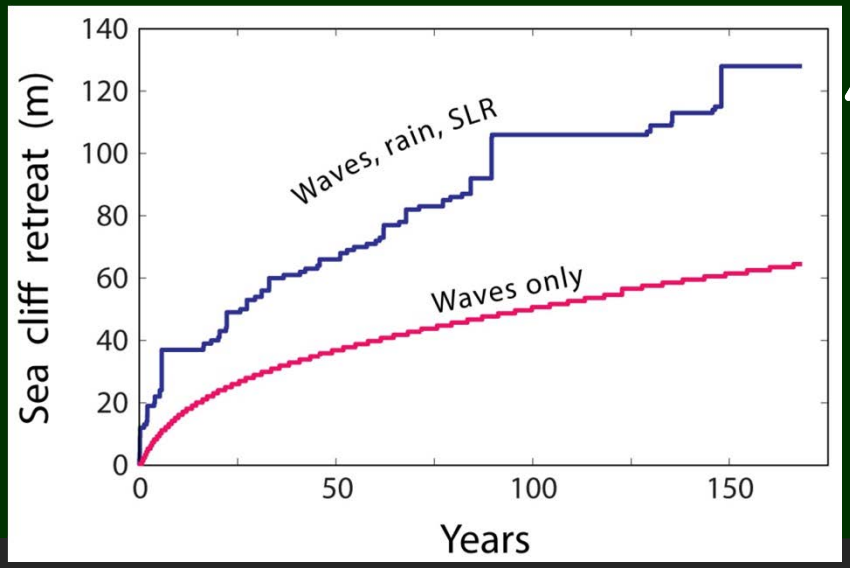


Shoreline Projections

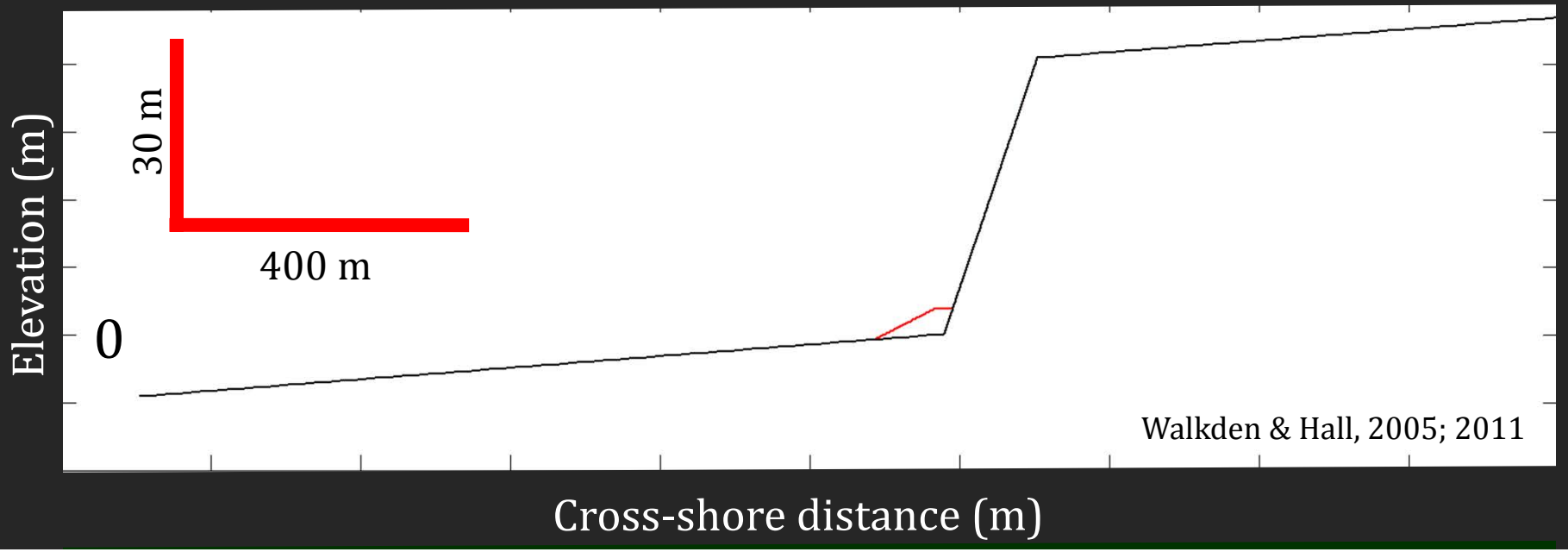
Factors Driving Sea Cliff Erosion & Retreat



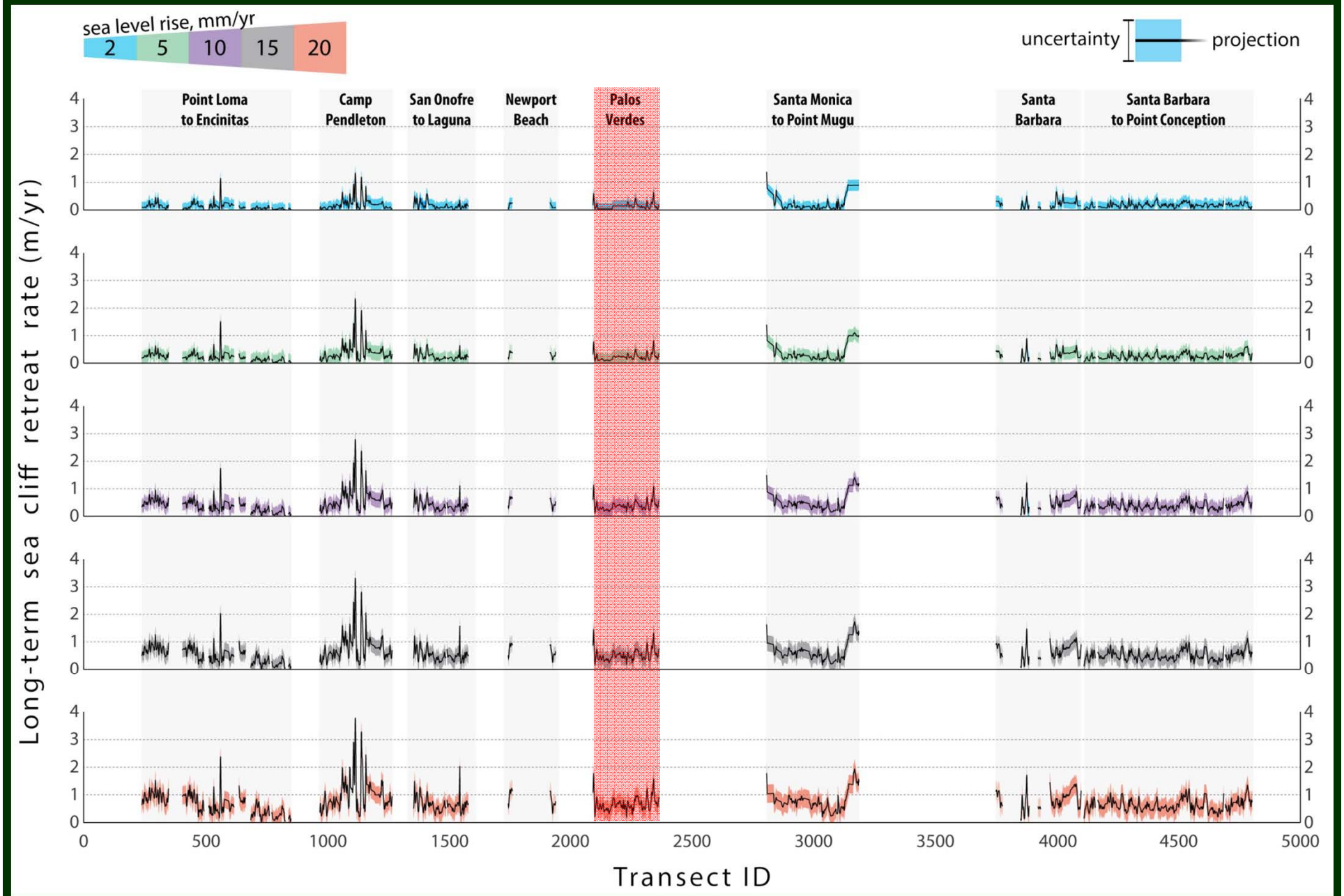
Multi-decadal Models of Sea Cliff Erosion & Retreat



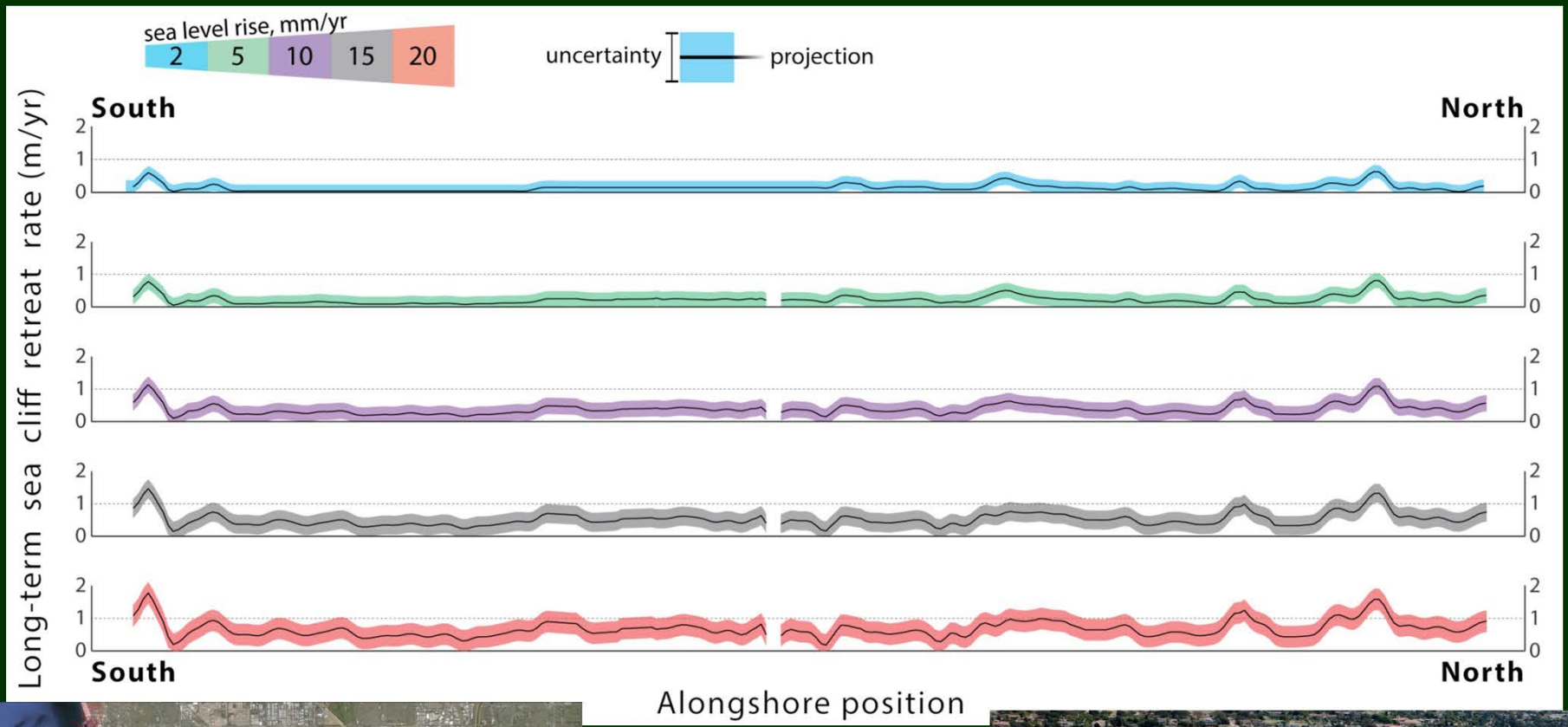
Rain, SLR cause more cliff retreat
(rain effects are in beta mode)



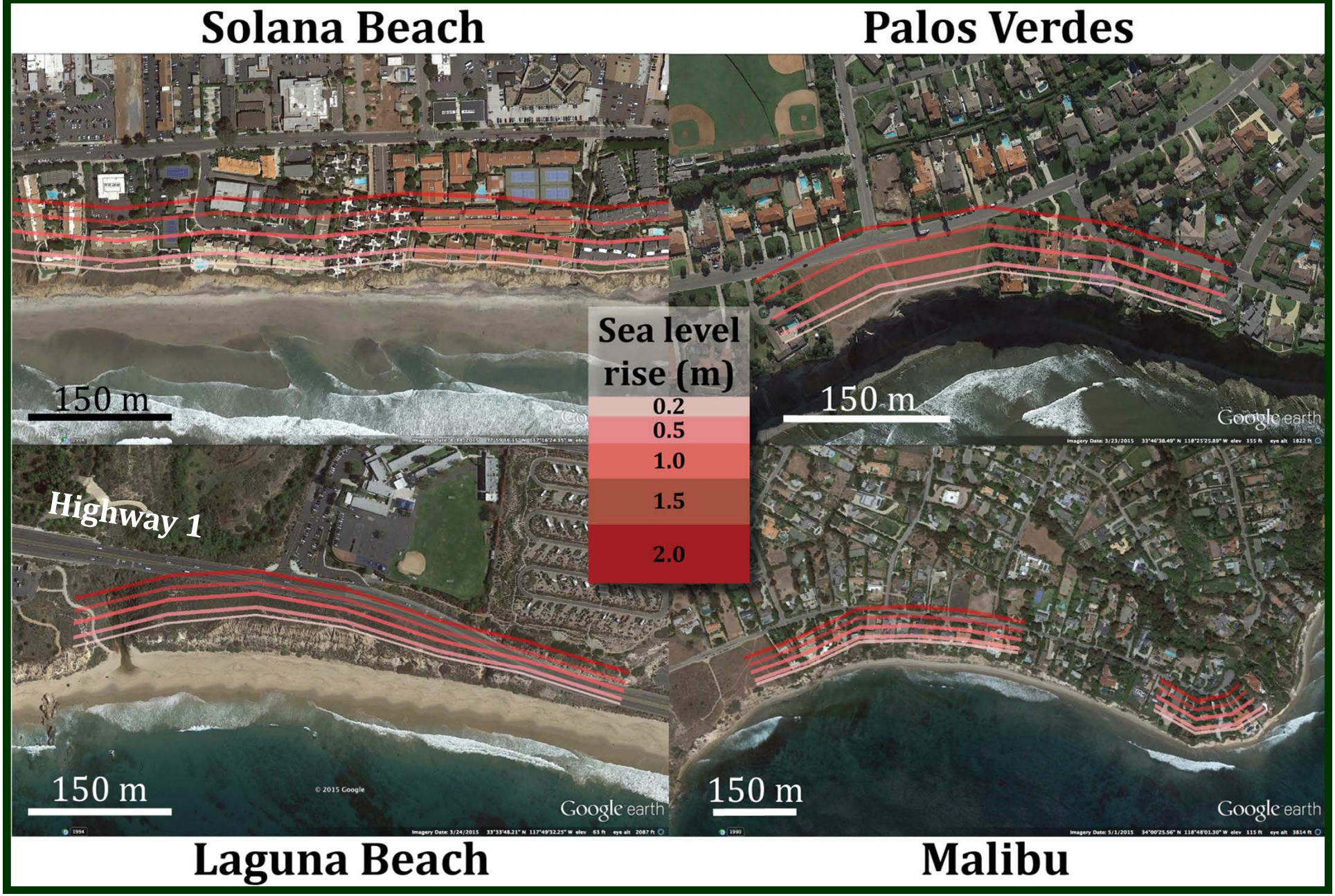
Results


sea level rise, mm/yr
2
5
10
15
20
uncertainty
projection
Point Loma to Encinitas
Camp Pendleton
San Onofre to Laguna
Newport Beach
Palos Verdes
Santa Monica to Point Mugu
Santa Barbara
Santa Barbara to Point Conception
Long-term sea cliff retreat rate (m/yr)
Transect ID
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

Results: *Palos Verdes*



Results: *examples*



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

USGS CoSMoS website: http://walrus.wr.usgs.gov/coastal_processes/cosmos/index.html

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

USGS

SamGozalePhotography