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Coastal Vulnerability in Ventura County using CoSMoS

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Pacific Coastal and Marine Science Center, Santa Cruz, CA

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

Collaborators and funders:

What is CoSMoS?

- Physics-based numerical modeling system for assessing coastal hazards due to climate change
- Ongoing development for the last decade
- Utilizes models that have been developed over the past several decades
- 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
- 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)
- Designed for community-scale planning

Ventura Pier, December 2015
(Ricky Staub)

What makes CoSMoS unique?

- Explicit, high-resolution, dynamic modeling of waves, currents, storm surge, flooding, and beach change
- Considers the future evolution of storm patterns based on the latest Global Climate Models
- Uses state-of-the-art projections of (dynamically-downscaled) winds and waves to calculate surge and seas
- Extensively tested, calibrated, and validated with local, historic data on waves, water levels and coastal change
- Flood projections are based on dynamic wave set-up, i.e., any area that is wet for at least 1 minute during a storm scenario
- Flooding is determined by the dynamic interaction of the evolving profile and ocean conditions during the storm event, including dune erosion and overtopping, and also the preceding long-term evolution of the coast
- Coastal change projections are based on a series of strenuously tested, peer-reviewed models, and calibrated by the local behavior of the coast
- Predicts the horizontal and vertical evolution of the entire beach profile through time

The CoSMoS Team*- who are we?

Research Director
Patrick Barnard, Ph.D.

Modeling Director
Li Erikson, Ph.D.

CoSMoS Manager
Andy O'Neill, M.S.

Hydrodynamic Modeling
Liv Herdman, Ph.D.
Rose Martyr, Ph.D.
Jessica Lovering, Ph.D.

Global Wave Modeling
Christie Hegermiller, Ph.D. candidate

GIS
Amy Foxgrover, M.S.

Cliff Modeling
Pat Limber, Ph.D.

Shoreline Modeling
Sean Vitousek, Ph.D.

Field Work
Dan Hoover, Ph.D.
Alex Snyder. M.S.

Director of Outreach
Juliette Hart, Ph.D.

***collectively over 150 years of experience in numerical modeling, oceanography, civil engineering, atmospheric science, and coastal geology**

CoSMoS Coastal Storm Modeling System USGS

The CoSMoS Team- who are we?

DEMs
Jeff Danielson, Dean Tyler (USGS EROS Data Center)

Socioeconomics
Nate Wood, Jeanne Jones, Matt Jamieson (USGS Western Geographic Science Center)

Our Coast – Our Future Web Tool
Michael Fitzgibbon, Maya Haden, Sam Veloz, Grant Ballard, Julian Wood (Point Blue)

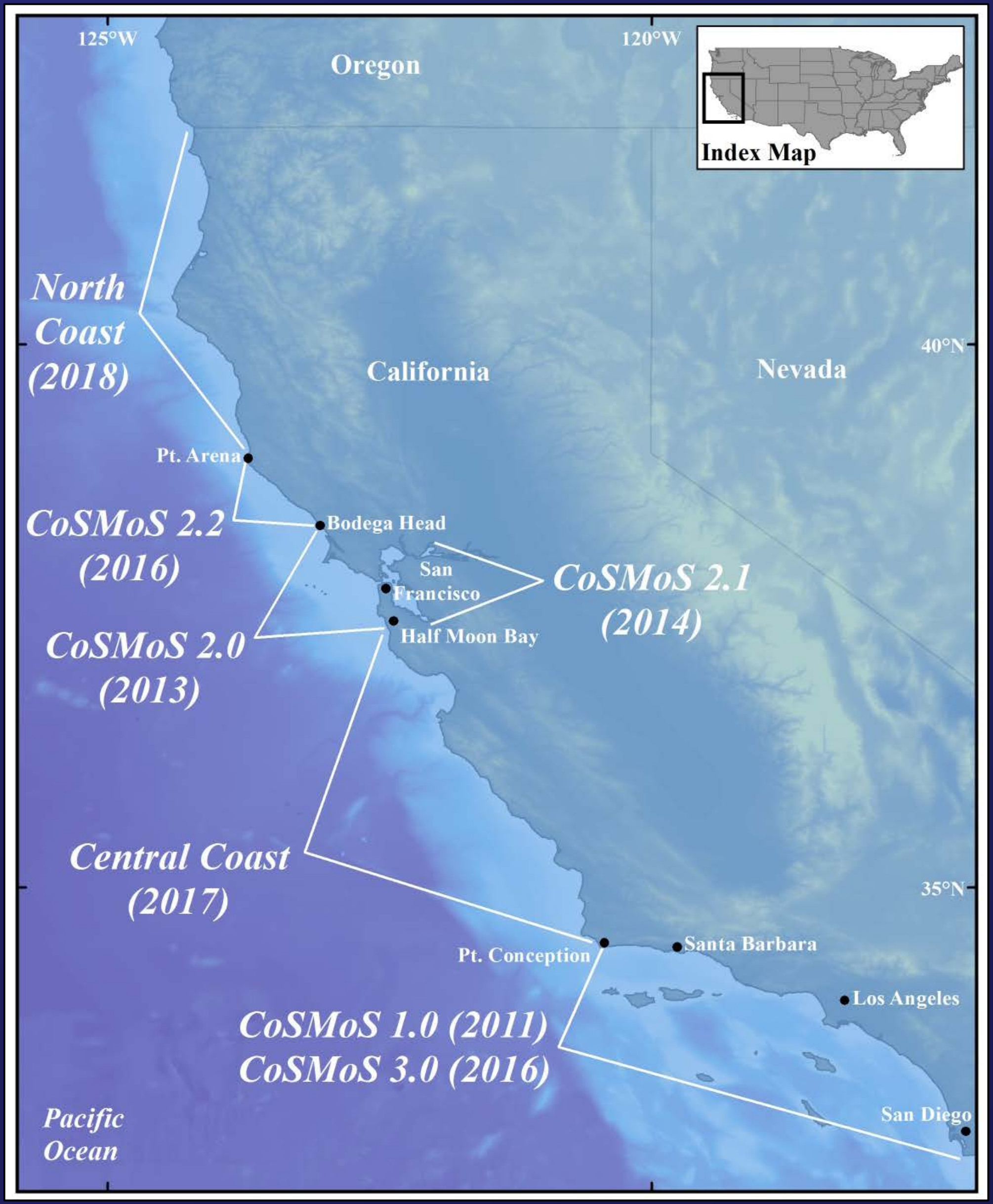
Modeling Support
Maarten van Ormondt, Edwin Elias (Deltares)

Dynamical Downscaling
Dan Cayan, David Pierce (Scripps)

Statistical Downscaling
Fernando Mendez (U. of Cantabria)

Additional Collaborations
Oregon State University (Ruggiero), U. of Hawaii (Fletcher), UC Berkeley (Stacey)

Where has CoSMoS been applied?



Who uses CoSMoS?

County

- Sonoma County
- Marin County
- Santa Mateo County
- Santa Clara County
- Santa Barbara County
- Los Angeles County
    - Office of Emergency Management
    - Department of Beaches and Harbors
- San Diego County

State

- California Coastal Commission
- California Coastal Conservancy
- California Department of Emergency Services (CalOES)
- California Department of Fish & Wildlife
- California Department of Transportation (CalTrans)
- California Energy Commission
- California Natural Resources Agency
- California Ocean Protection Council

Federal

- National Park Service
- NOAA Gulf of Farallones National Marine Sanctuary
- NOAA Office for Coastal Management
- National Estuarine Research Reserve (NOAA)

Who uses CoSMoS?

City

- City of San Francisco
- City of Pacifica
- City of San Jose
- City of Santa Barbara
- City of Los Angeles
- City of Santa Monica
- City of Hermosa Beach
- City of Long Beach
- City of Huntington Beach
- City of Imperial Beach
- City of Oceanside
- City of Encinitas
- City of Carlsbad
- City of San Diego
- City of Imperial Beach

Regional Scale

- AdaptLA: Coastal Impacts Planning for the LA Region
- California Climate Science Alliance
- Coastal Ecosystem Vulnerability Assessment (CEVA, Santa Barbara)
- LA Regional Collaborative on Climate Action and Sustainability (LARC)
- Regional Water Quality Control Board for LA and Ventura Counties
- San Diego Regional Climate Collaborative
- Southern California Coastal Water Research Project (SCCWRP)
- Wetlands Recovery Projects (San Diego - Orange County region & LA - Ventura - Santa Barbara region)

Where can I get more information?

USGS CoSMoS website:

http://walrus.wr.usgs.gov/coastal_processes/cosmos/

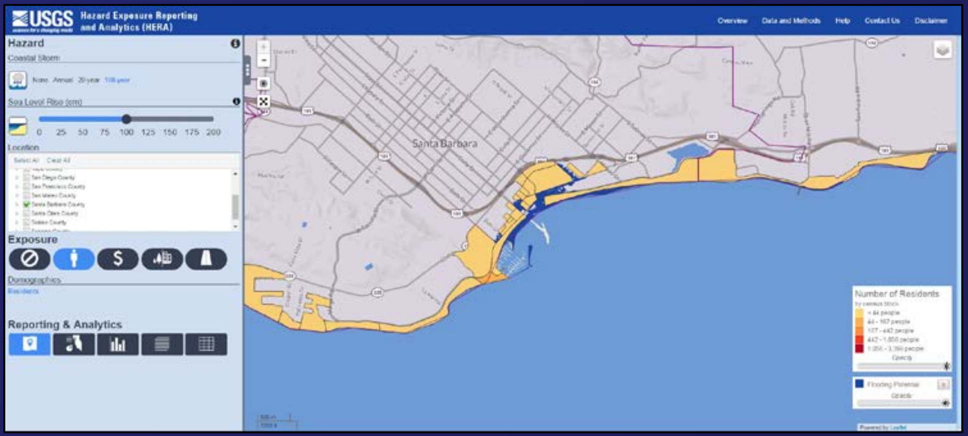
Data and detailed technical report:

https://www.sciencebase.gov/catalog/item/5633fea2e4b048076347f1cf

Our Coast - Our Future tool: www.ourcoastourfuture.org,

http://beta.ourcoastourfuture.org

HERA Tool: www.usgs.gov/apps/hera



Supporting References
(peer-reviewed)

Barnard, P.L., van Ormondt, M., Erikson, L.H., Eshleman, J., Hapke, C., Ruggiero, P., Adams, P.N. and Foxgrover, A.C., 2014. Development of the Coastal Storm Modeling System (CoSMoS) for predicting the impact of storms on high-energy, active-margin coasts. *Natural Hazards*, Volume 74 (2), p. 1095-1125, http://dx.doi.org/10.1007/s11069-014-1236-y

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Palaseanu-Lovejoy, M., Danielson, J., Thatcher, C., Foxgrover, A., Barnard, P.L., Brock, J. and Young, A., 2016. Automatic delineation of seacliff limits using Lidar-derived high-resolution DEMs in Southern California. *Journal of Coastal Research*, Special Issue Volume 76, p. 162-173, http://dx.doi.org/10.2112/SI76-014

Thatcher, C.A., Brock, J.C., Danielson, J.J., Poppenga, S.K., Gesch, D.B., Palaseanu-Lovejoy, M.E., Barras, J.A., Evans, G.A., and Gibbs, A.E., 2016, Creating a Coastal National Elevation Database (CoNED) for science and conservation applications: Journal of Coastal Research, SI no. 76, p. 64–74, at http://dx.doi.org/10.2112/SI76-007

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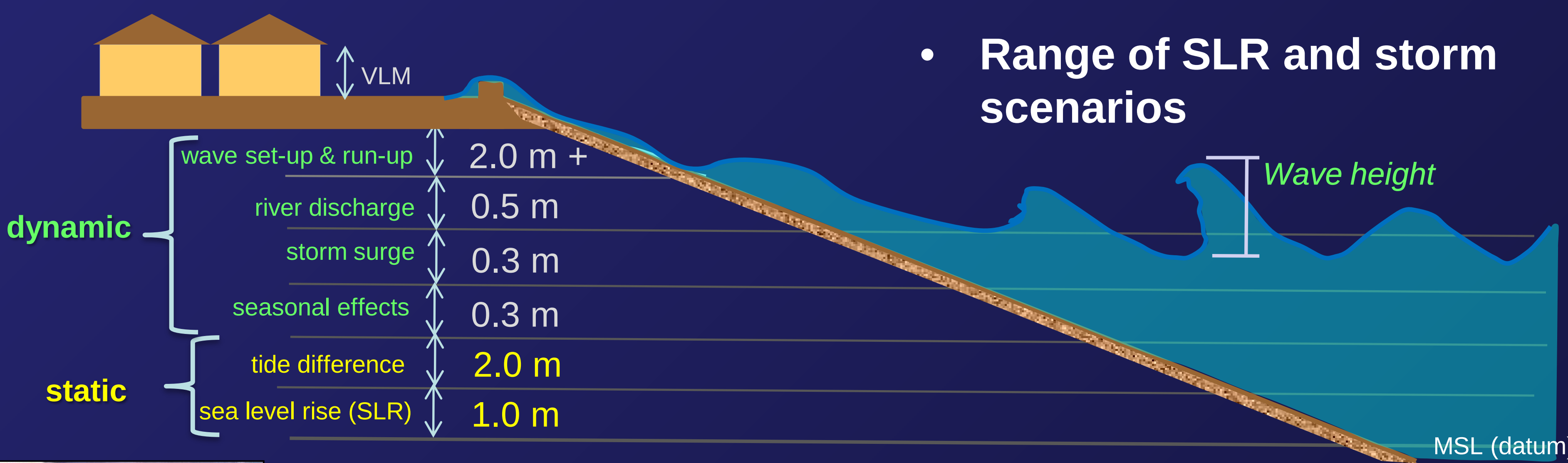
What’s included in CoSMoS approach?

Static: SLR Viewer (“bathtub”)

- Passive model, hydrological connectivity
- Tides only
- ‘1st order screening tool’

Dynamic: USGS CoSMoS

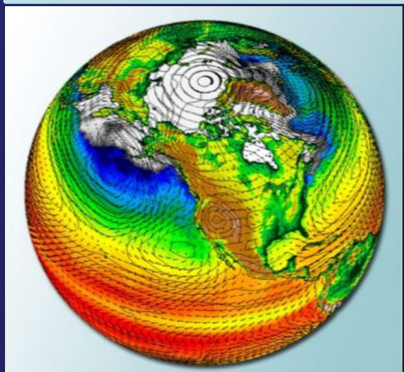
- All physics modeled
- Forced by Global Climate Models
- Includes wind, waves, atmospheric pressure, shoreline change
- Range of SLR and storm scenarios



CoSMoS Method

Global Scale

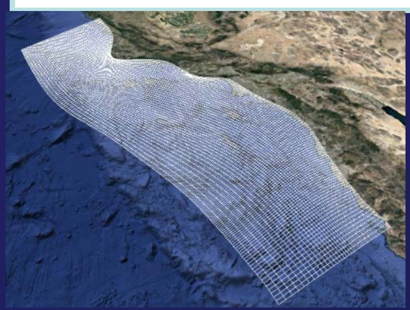
Deep water waves computed with WW3 and GCM winds



Regional Scale

Swell propagation, wave generation, storm surge, astronomic tides, and downscaled SIO winds/SLPs

(Delft3D+SWAN)

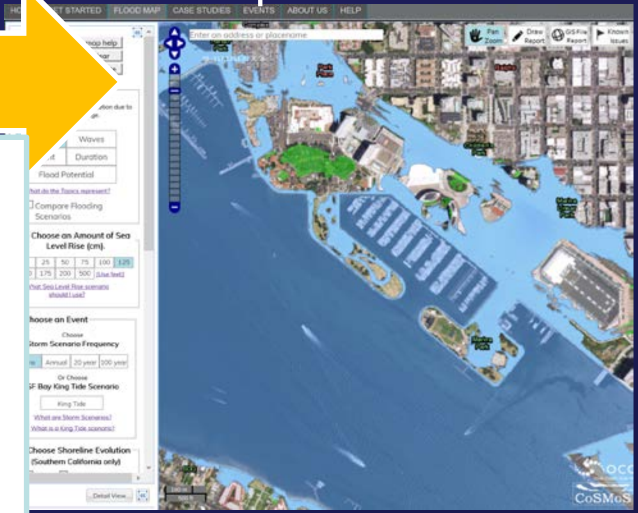


Local Scale

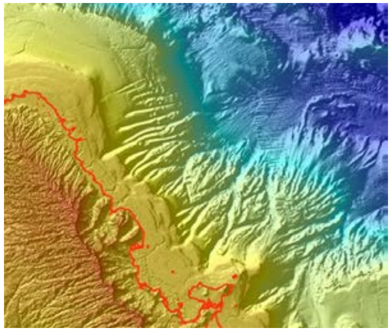
Nearshore waves, wave setup and runup, storm surge, tides, overland flow, fluvial discharge, long-term topo-bathy change

(Delft3D+SWAN + XBEACH)

Maps & webtools



2m resolution DEMs



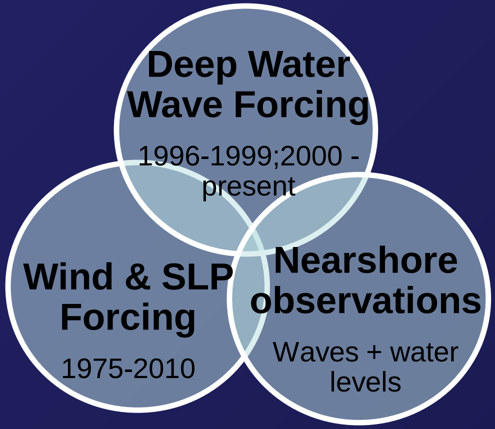
CoSMoS validation

CoSMoS model components and performance validated :

- **Extensive historical data including storms**
  Nov/Dec 1982
  Dec 2005
  Jan 2010

- **Water levels** – across the Bight
- **Waves** – buoys
- Wave runup
- **Storm-driven morphodynamic change** – XBeach
- **Long-term shoreline change** – CoSMoS Coast

Storm events:



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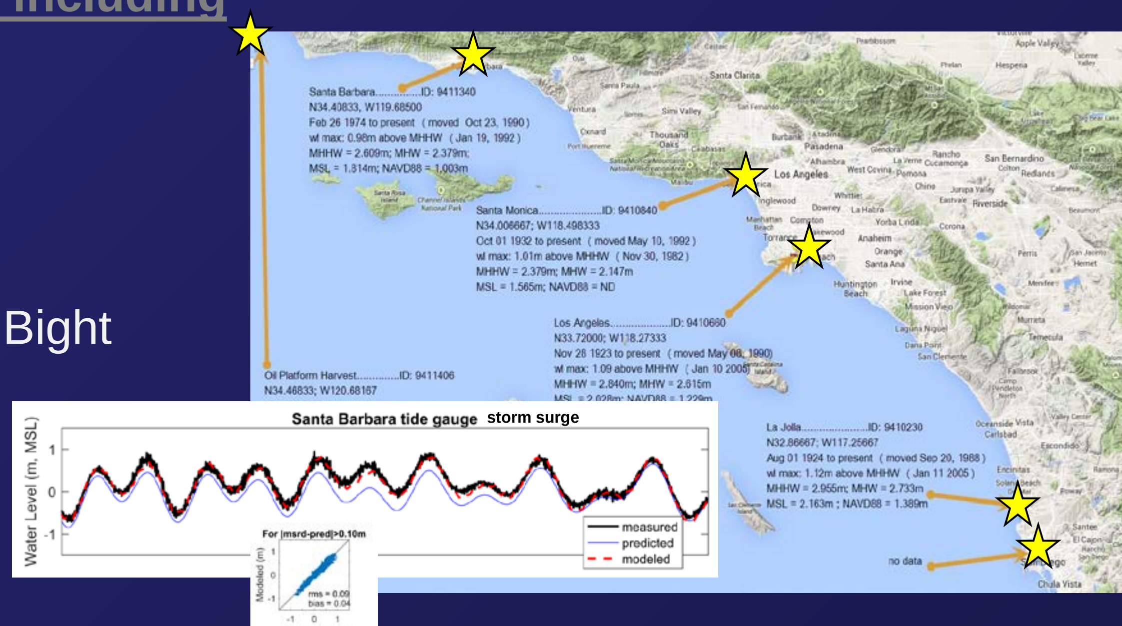

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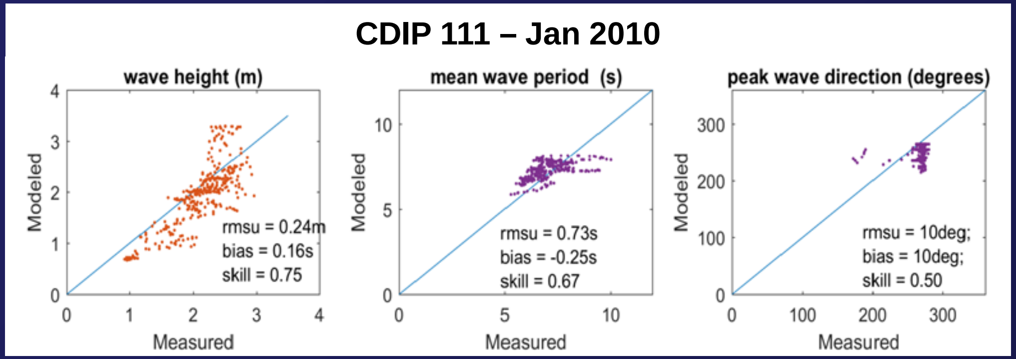

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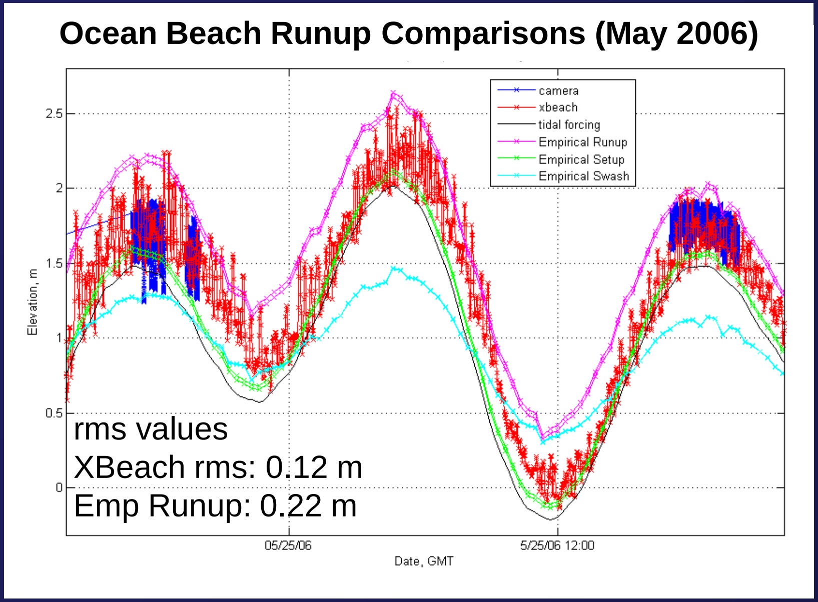

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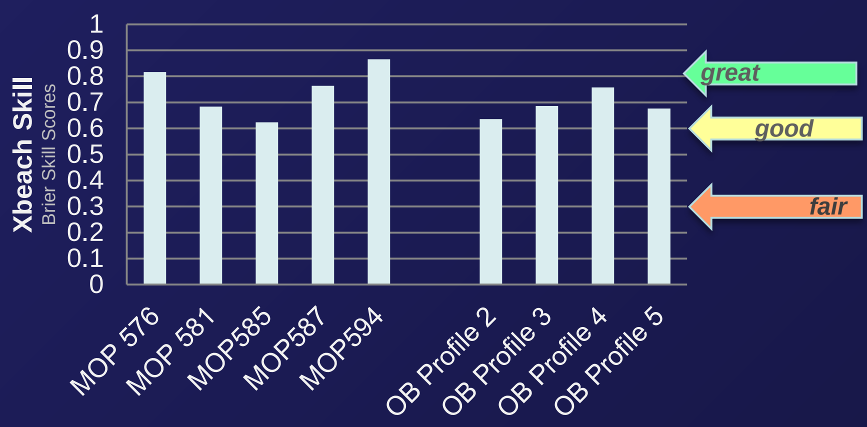

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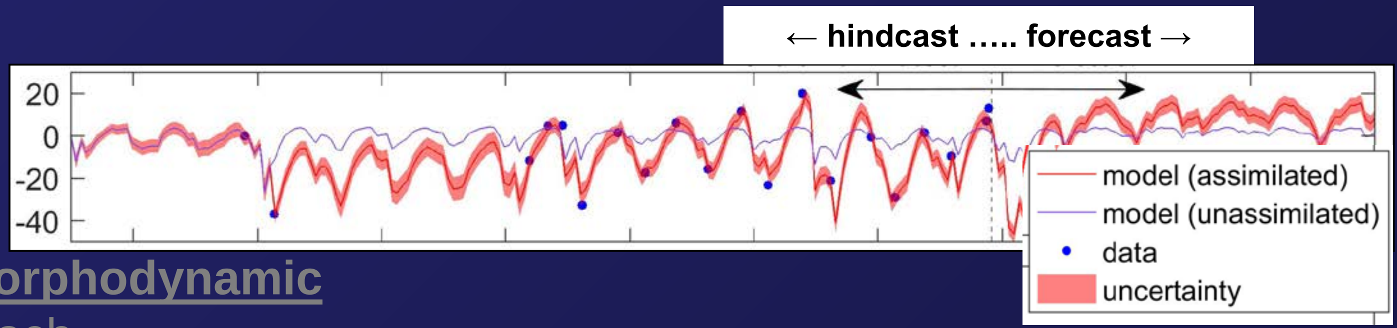


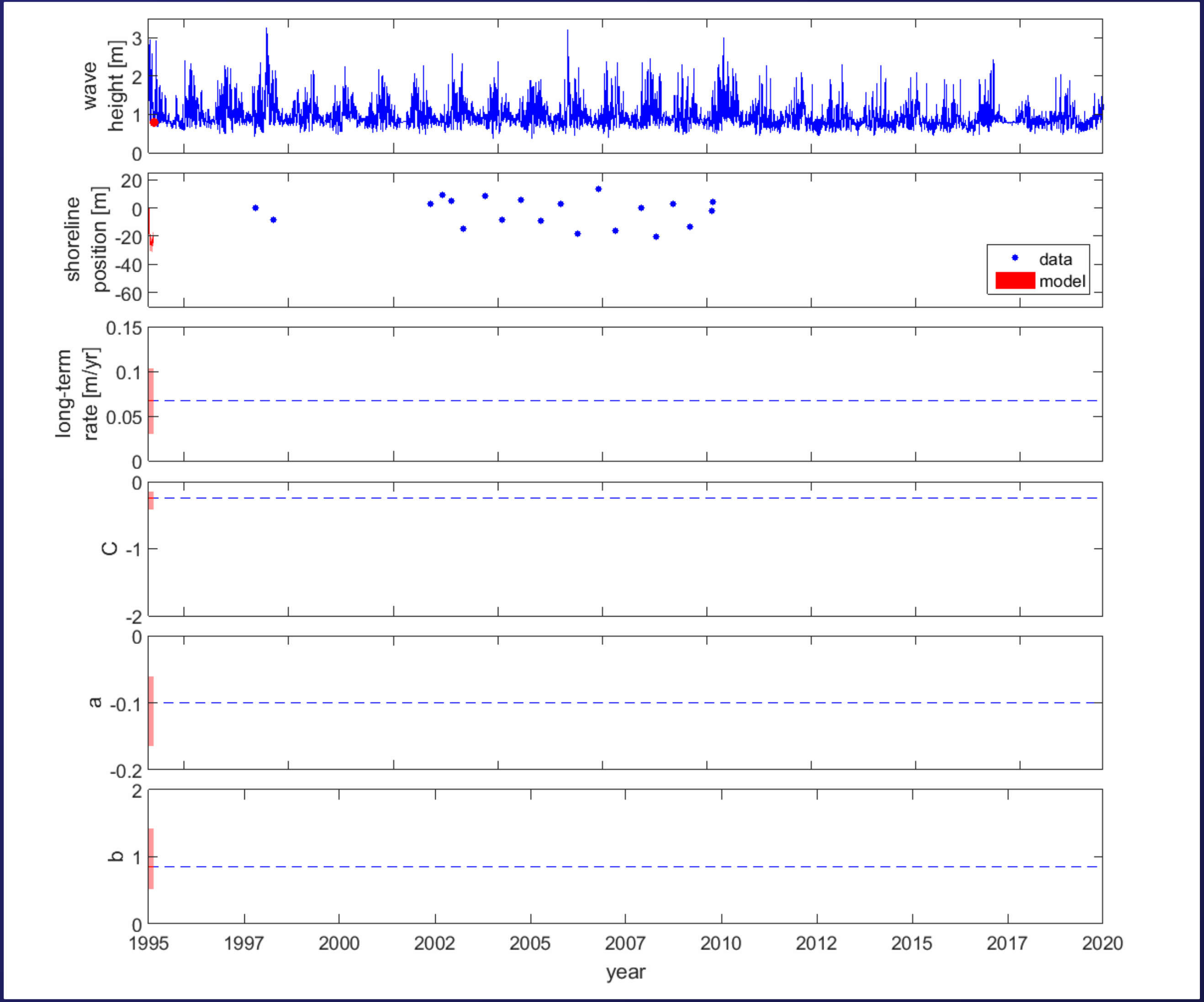
Data Assimilation

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

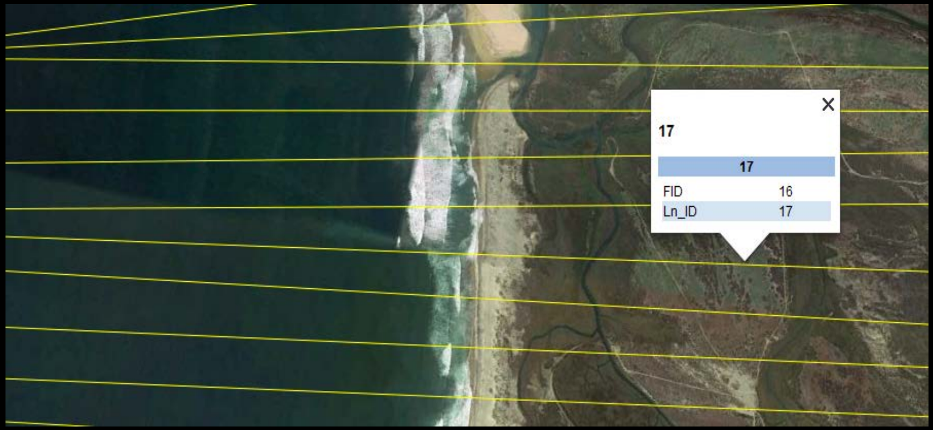
- Auto-tunes model parameters for each transect to best fit the historical shoreline data

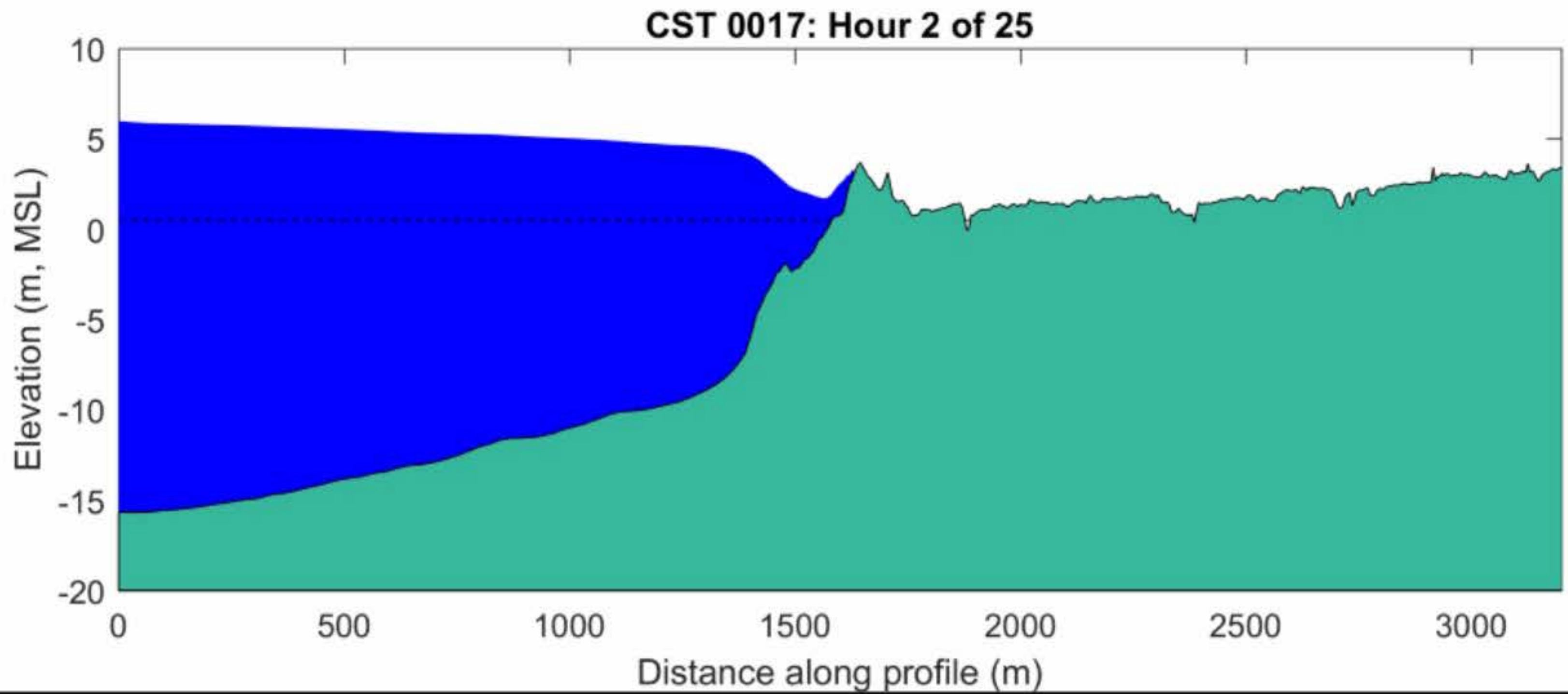
- We improved the method to handle sparse shoreline data and ensure that parameters are positive or negative.

Simulation output for a single transect at Del Mar Beach:

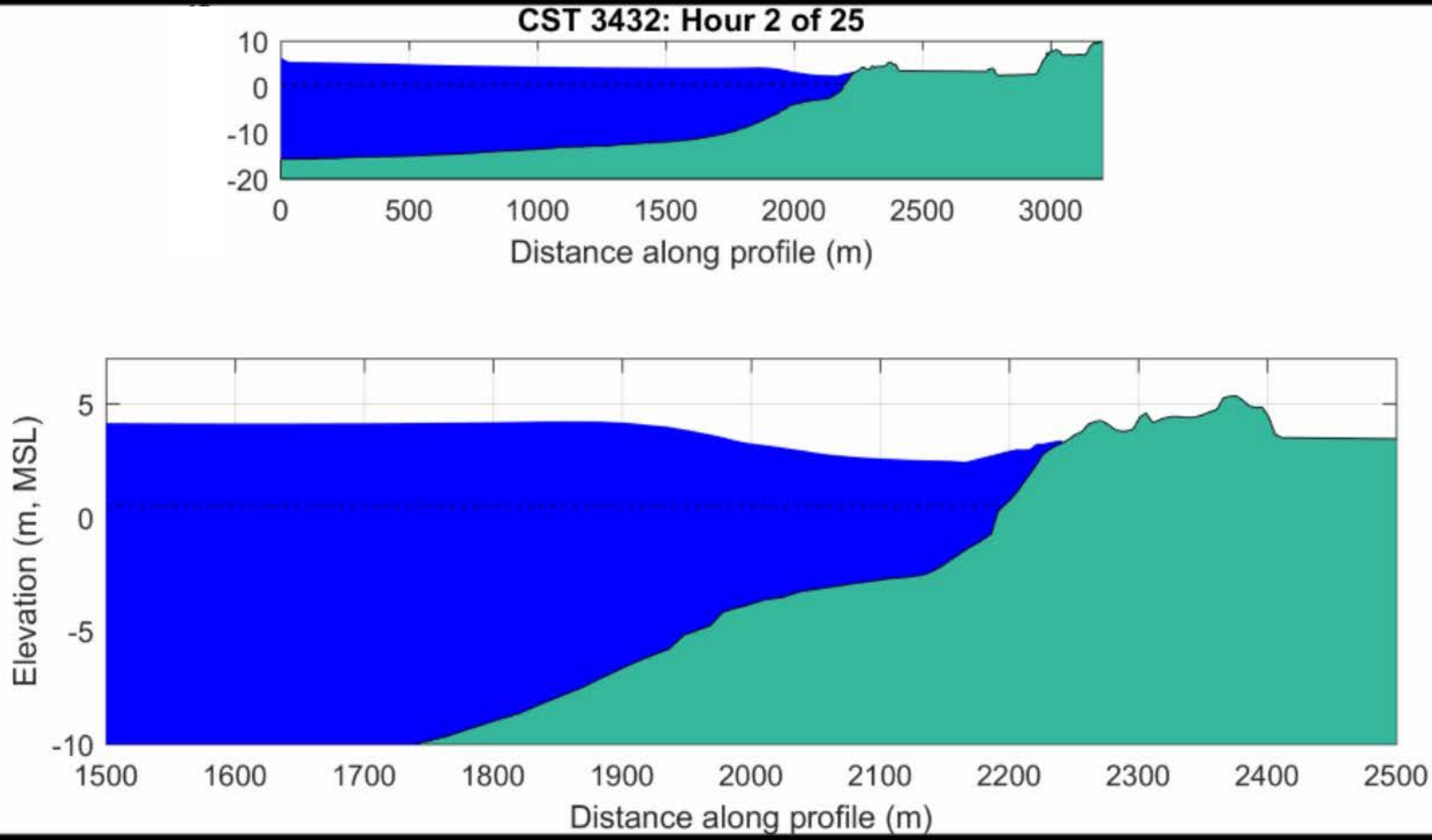


Dune field near Tijuana Estuary - XBeach simulation

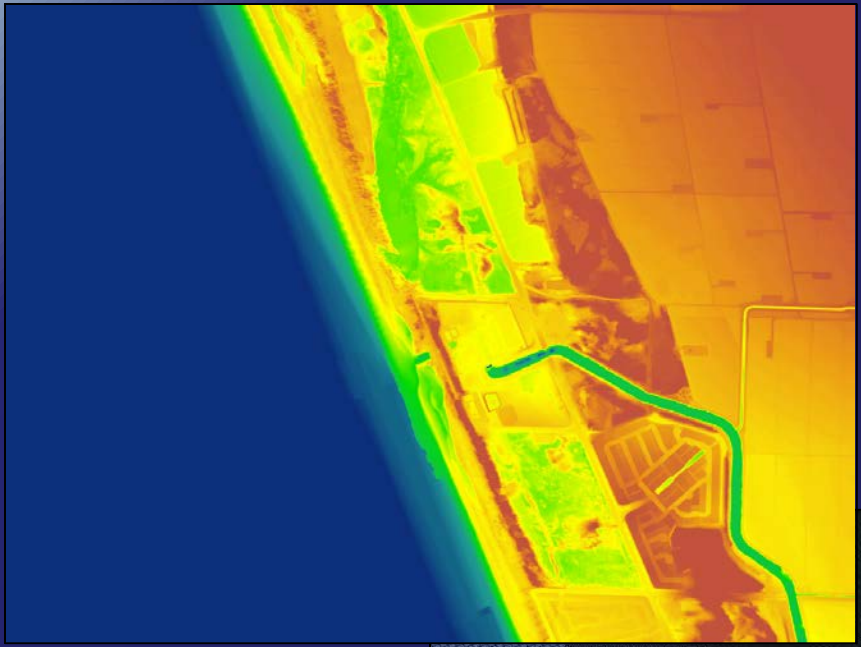





McGrath Lake
3433
3433
FID 3411
Ln_ID 3433


CST 3432: Hour 2 of 25
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
Distance along profile (m)
Elevation (m, MSL)
5
0
-5
-10
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
Distance along profile (m)

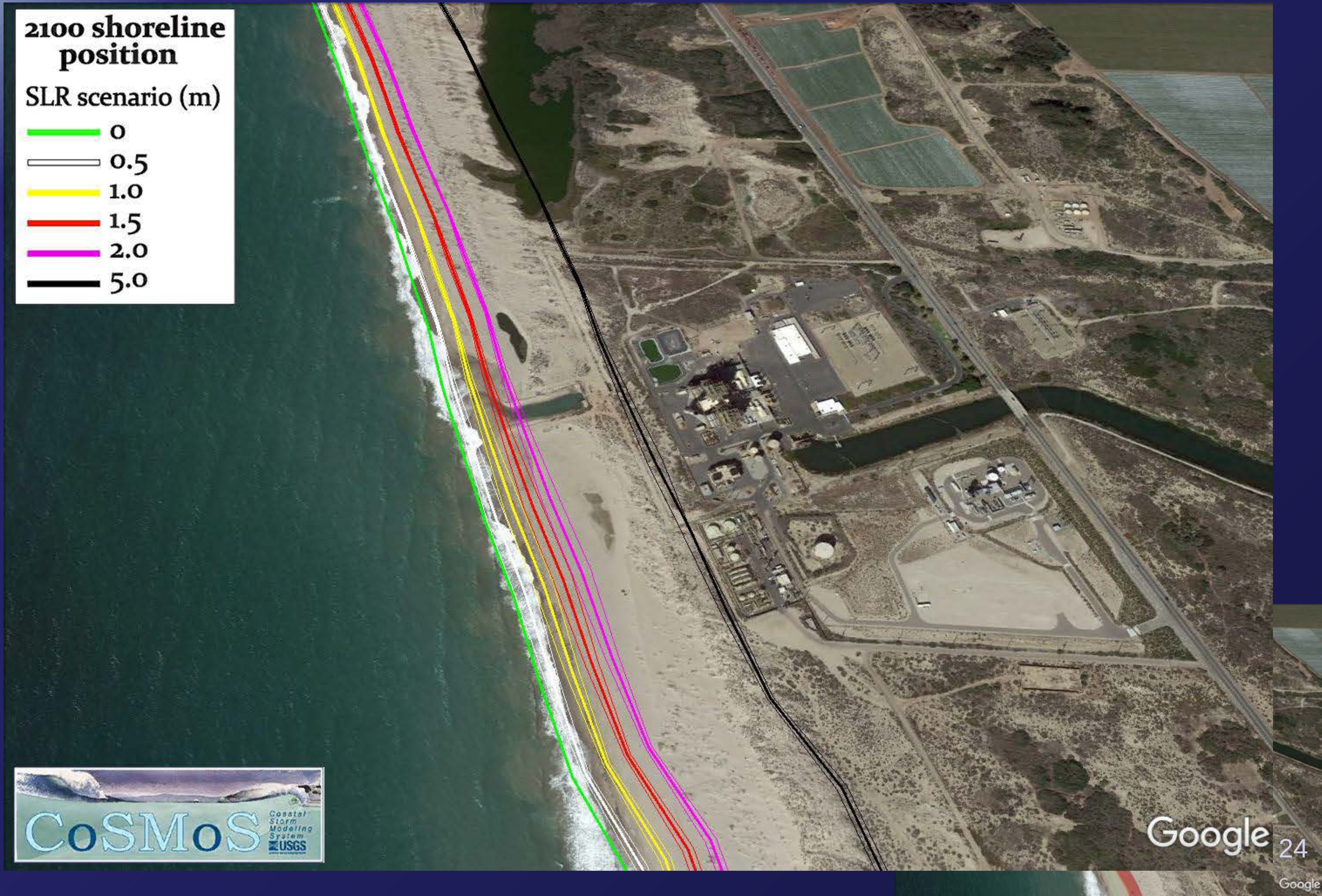
DEM and Computational Grids



DEM: 2 m horizontal resolution

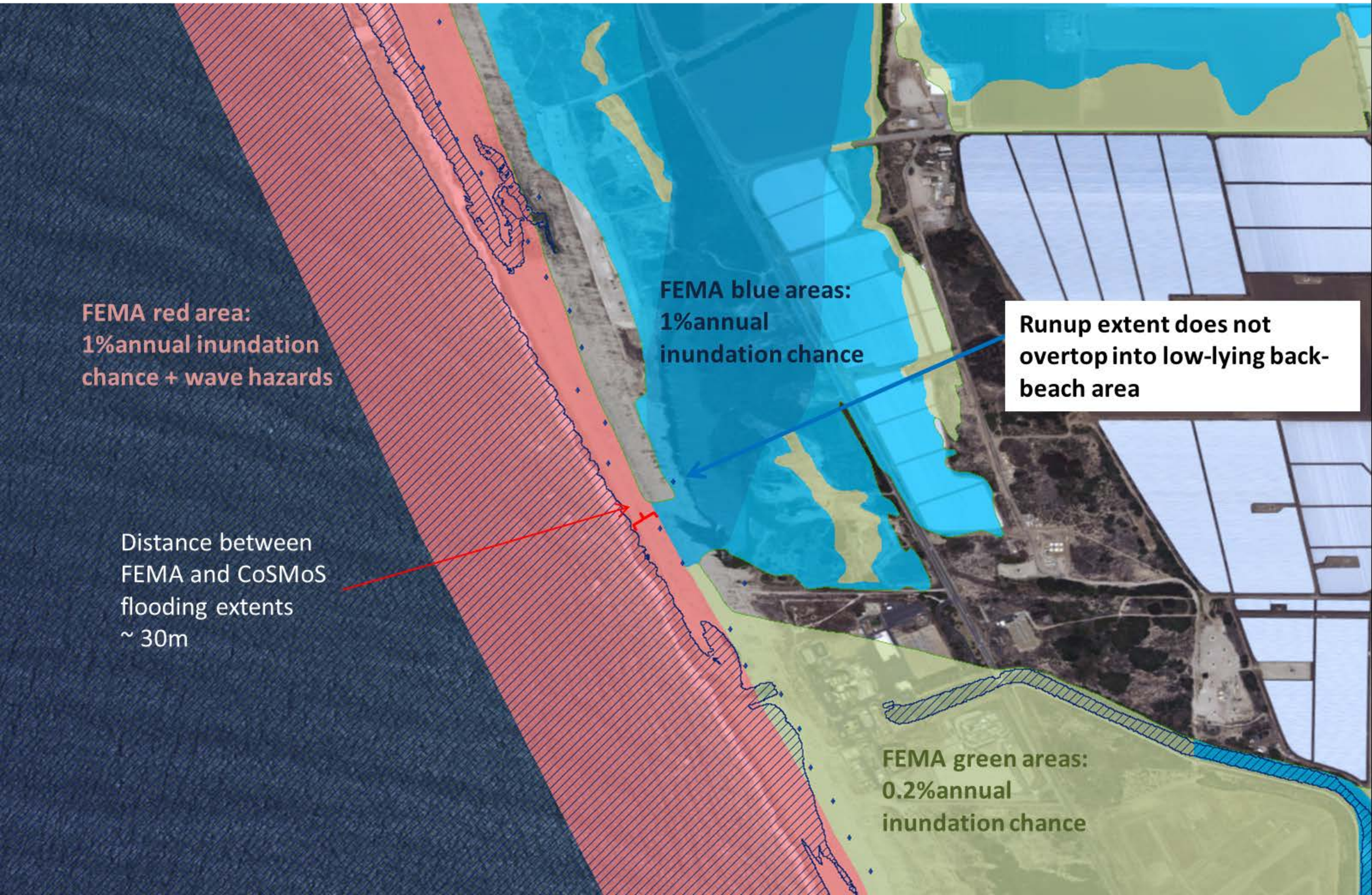
Hydrodynamic grids: 20 x 40 m

Shoreline Projections for 2050 + 100 year storm

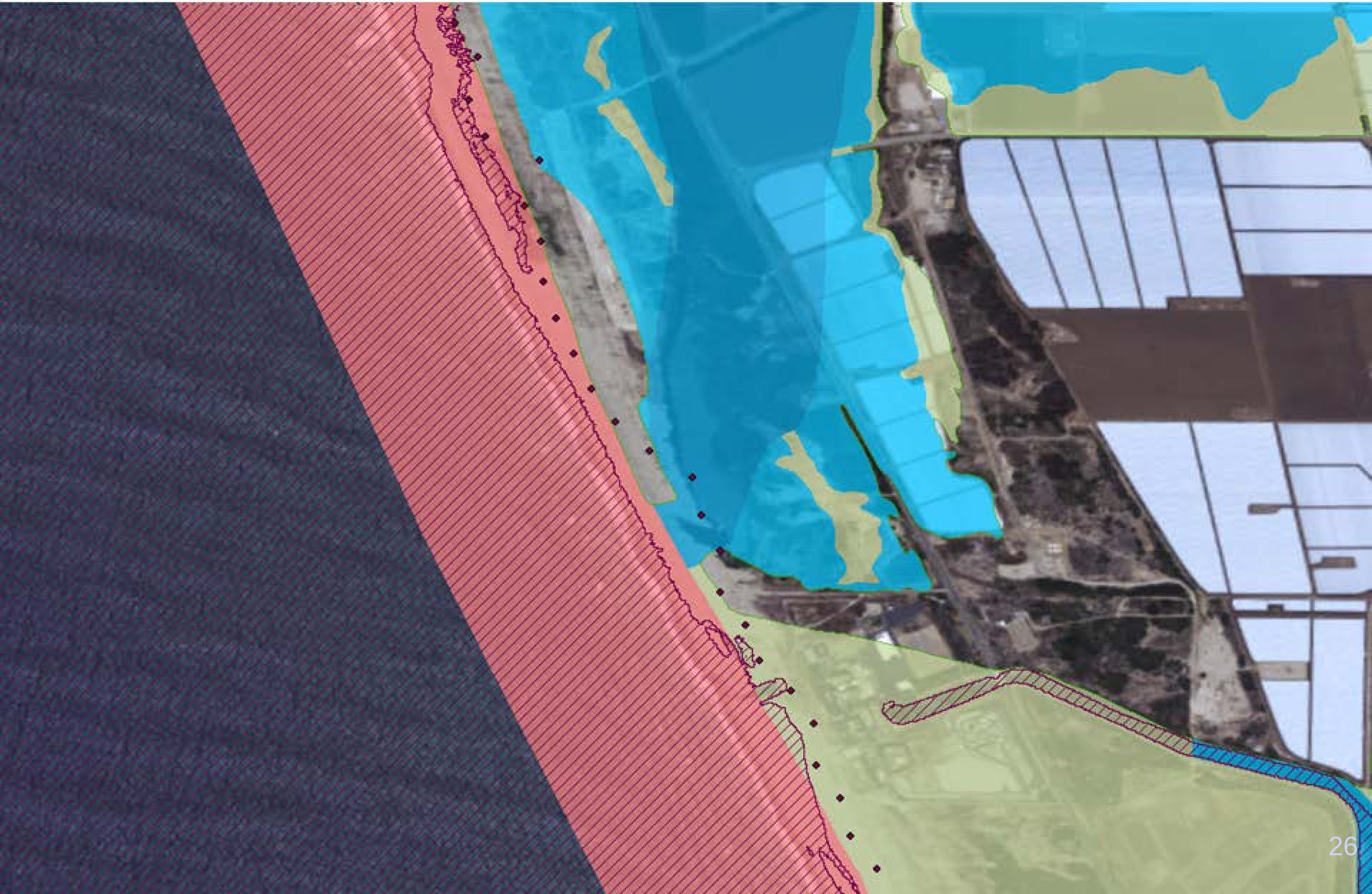


FEMA FIRM +

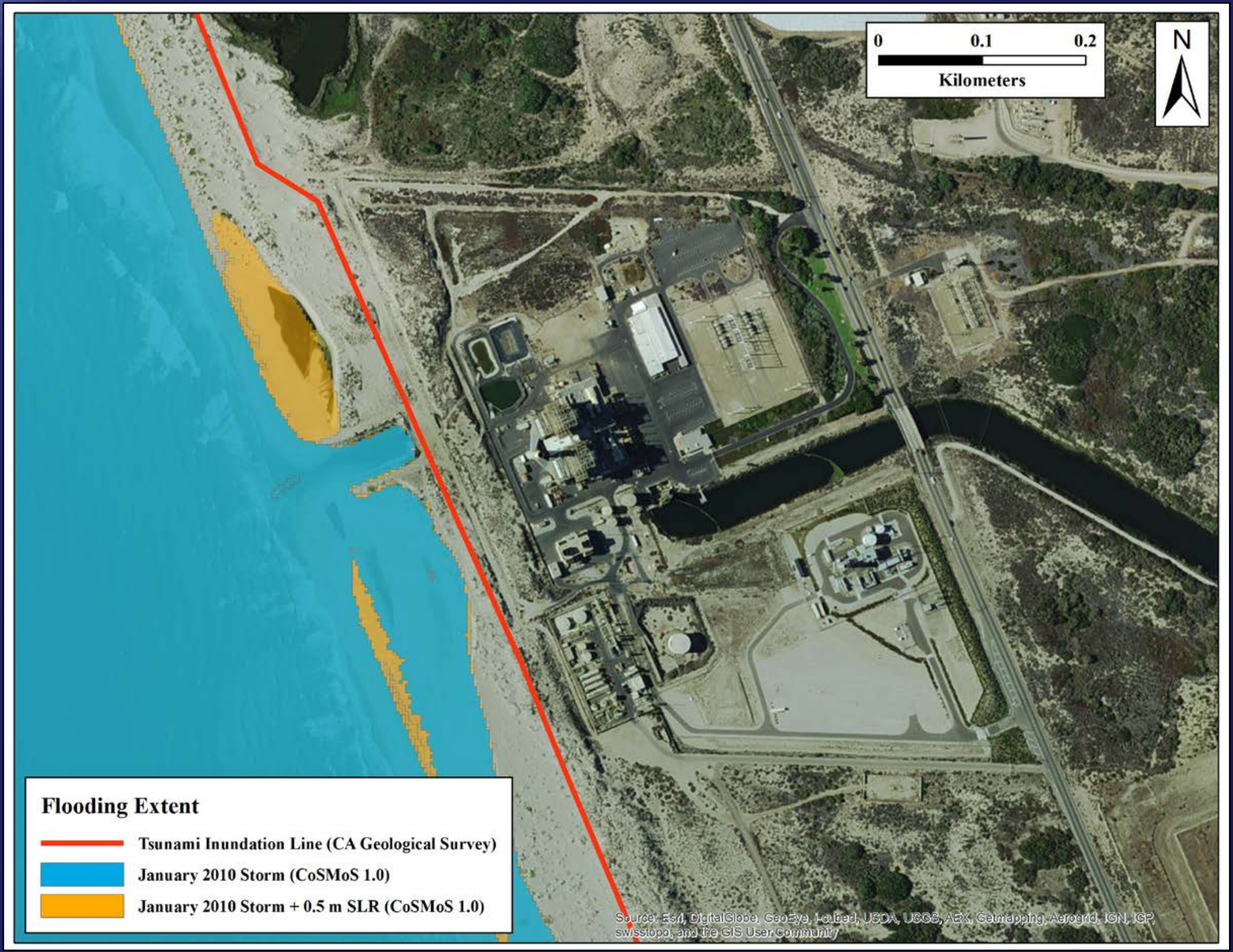
CoSMoS: SLR 0cm 100 yr (flood extent + runup)



FEMA FIRM +
CoSMoS: SLR 50 cm 100 yr (flood extent + runup)



Tsunami Risk



Future Conditions

SLR for Los Angeles (National Research Council)
-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

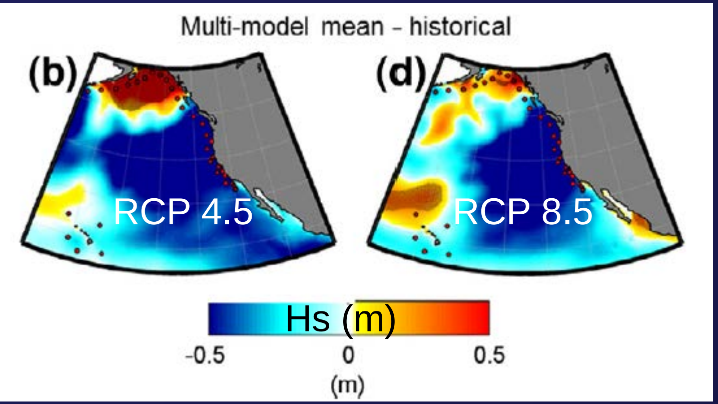
Pending State SLR Guidance for 2100
-20 cm to 52 cm of sea level rise by 2050
-74 cm to 287 cm of sea level rise by 2100

Waves
-No significant changes in wave height, possible decrease
-More south swell influence

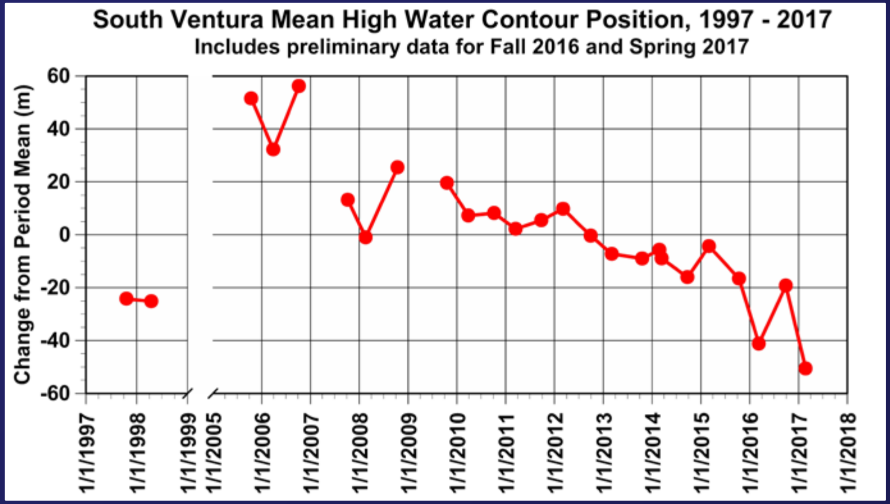
Atmospheric Patterns
-Potential for more extreme El Niño events
-Storm tracks possibly moving north

Sediment Inputs
-Episodic (normal)
-Longer droughts but higher intensity rainfall events

Projected change in wave heights



Erikson et al. 2015



CoSMoS Highlights

- **Extensively tested and validated** for waves, extreme water levels and coastal change, including with local historic storm events
- **40 plausible future scenarios**
- **Downscaled winds** from Global Climate Models (GCMs) (SIO)
- **Downscaled waves** from GCMs (dynamically, not statistically downscaled)
- **High resolution grids** of lagoons, protected areas, and high-interest areas
- **Long-term coastal evolution** (CoSMoS-COAST)
- **Short-term beach and dune response** (XBeach)
- **Long- and short-term coastal change** (i.e., beaches, dunes and cliffs) **integrated into coastal flooding projections**
- **Discharge from rivers** for event response
- **Vertical land motion** factored into flood potential layer
- **Web-based tool** that includes data visualization and download and socio-economic summaries

Conclusions

- **All phases of CoSMoS results show no significant risk of flooding to project site for 100 yr storm event at ~2050 (50 cm SLR) or for decades after**
- **Models developed are state-of-the-art**
- **Dune fields are dynamic**
- **Multiple lines of evidence from models and observations should be used to assess risk**

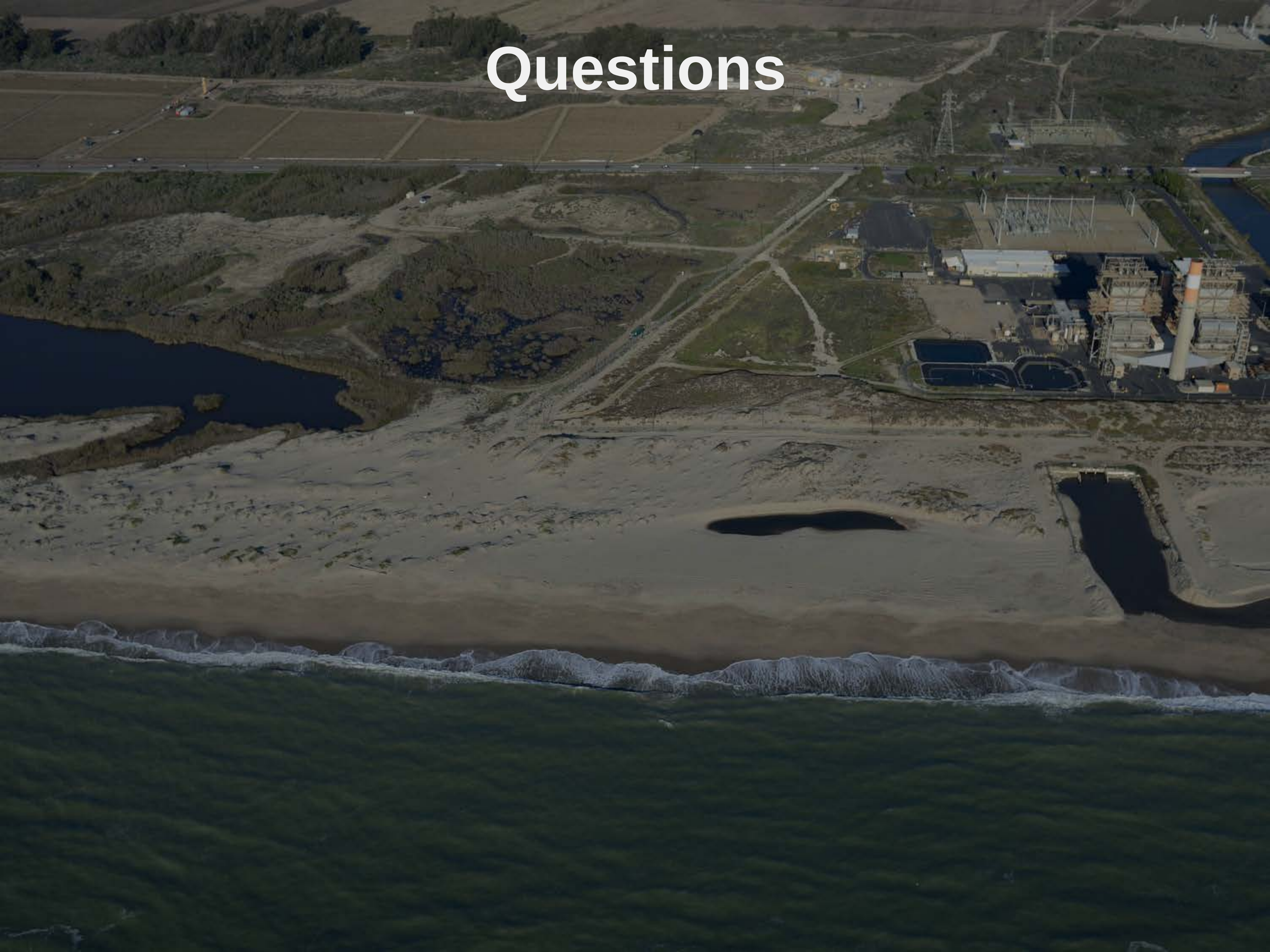
For more information, contact Patrick Barnard:** ***pbarnard@usgs.gov

USGS CoSMoS data: ***http://walrus.wr.usgs.gov/coastal_processes/cosmos/socal3.0/index.html***

Our Coast - Our Future tool: ***www.ourcoastourfuture.org, http://beta.ourcoastourfuture.org***

HERA Tool: www.usgs.gov/apps/hera

Questions



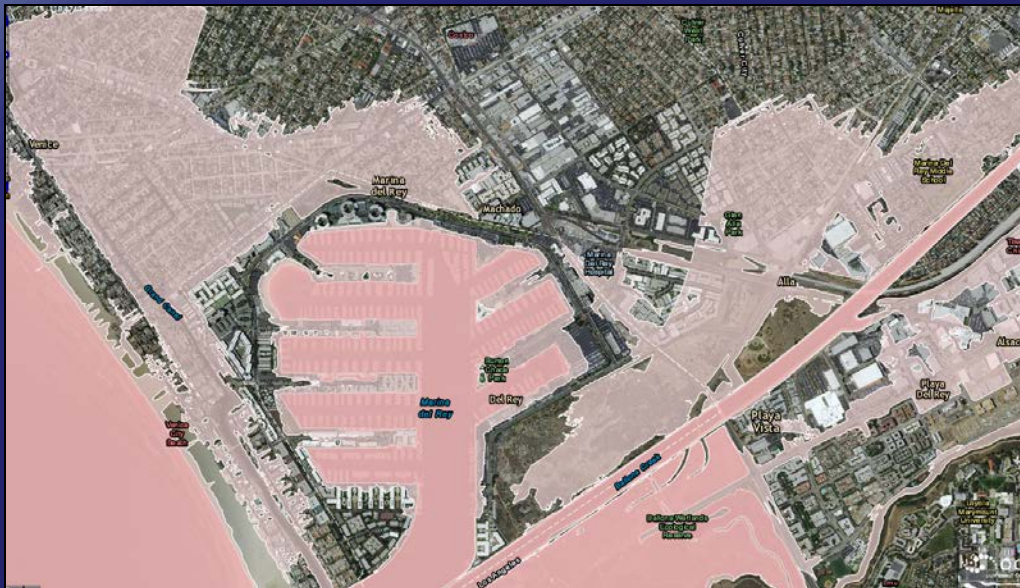
Extra slides

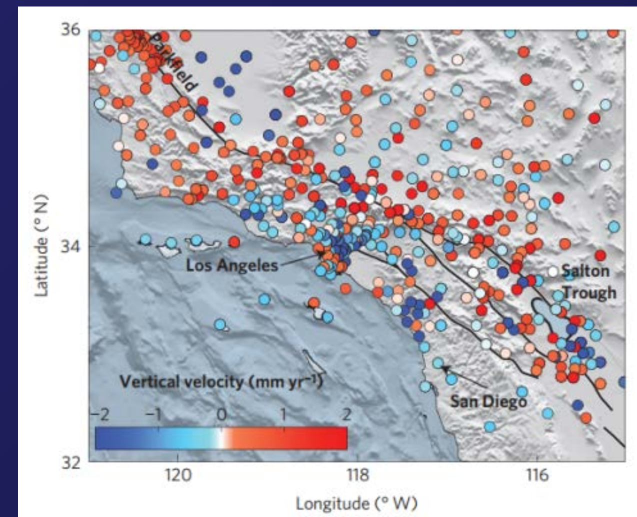
Assumptions for Coastal Change and Flooding

- Long-term projected shoreline position prior to the storm scenario is derived from well-validated dynamical model
- Pre-storm beach profile consistent with present-day beach morphology, but evolved according to the long-term shoreline change rate and sea level
- XBeach model accounts for dune erosion during the 24 hour storm simulation (assumes net longshore sediment transport is negligible during the storm)
- Beach features (e.g., dunes) evolve in concert with the predicted MHW shoreline

Flood potential – mapped uncertainty

Generated by raising and lowering flood elevation data by ε





$$\varepsilon = \pm 0.50\ m \quad \pm 0.18\ m + \ (0.4\ mm/yr | -0.6\ mm/yr)$$

Model uncertainty

(*rms* = 0.12 m, at tide stations)
Area and number of storms validated against are small compared to the geographic extent of the study area and thus model uncertainty is increased

Vertical accuracy of DEM

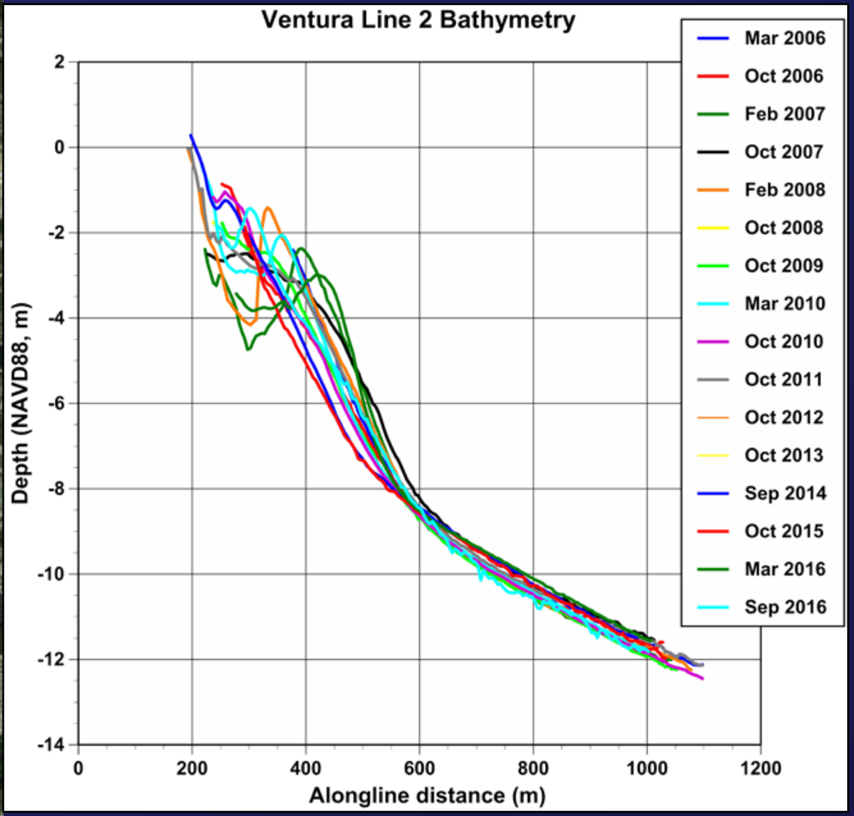
(*rms* = 0.18 m in open terrain) (Dewberry 2012)

Vertical land motion

Spatially variable based on GPS data and statistical and physical tectonic models (Howell et al., 2016)

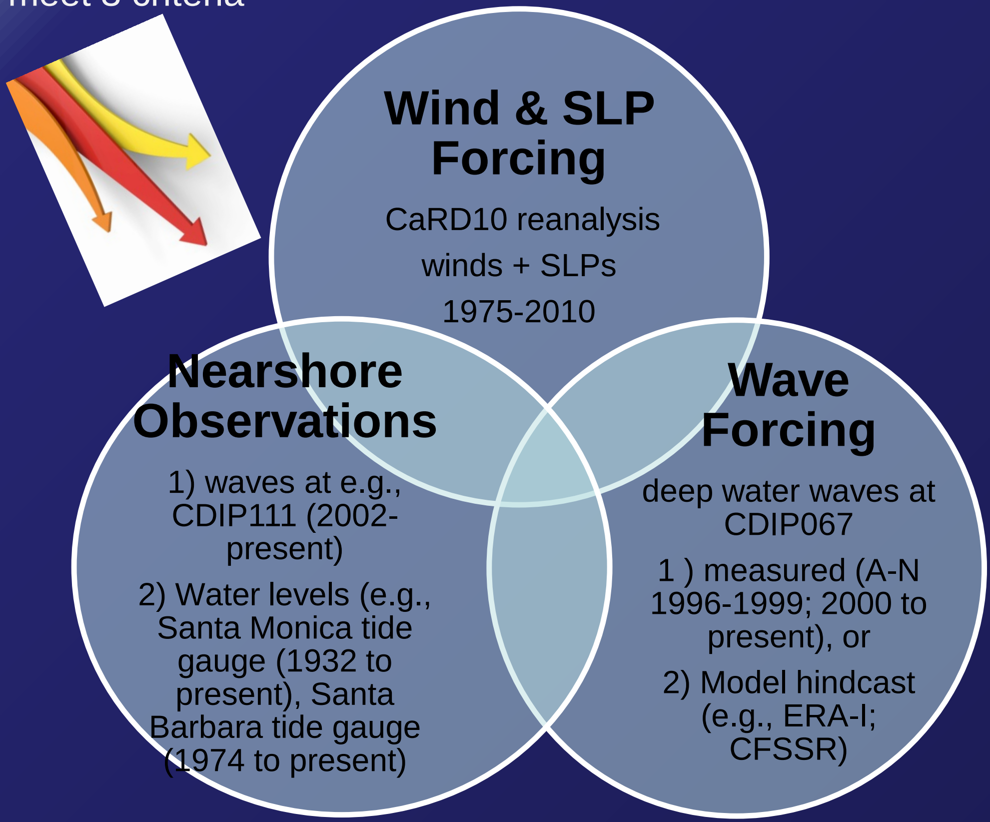
Local Data Collection

- Santa Barbara Littoral Cell Study initiated in 2005
- USGS has collected 24 topo and 16 bathy surveys (semi-annual) at study site
- Included in CoSMoS DEM and coastal change projections



Validation- Storms

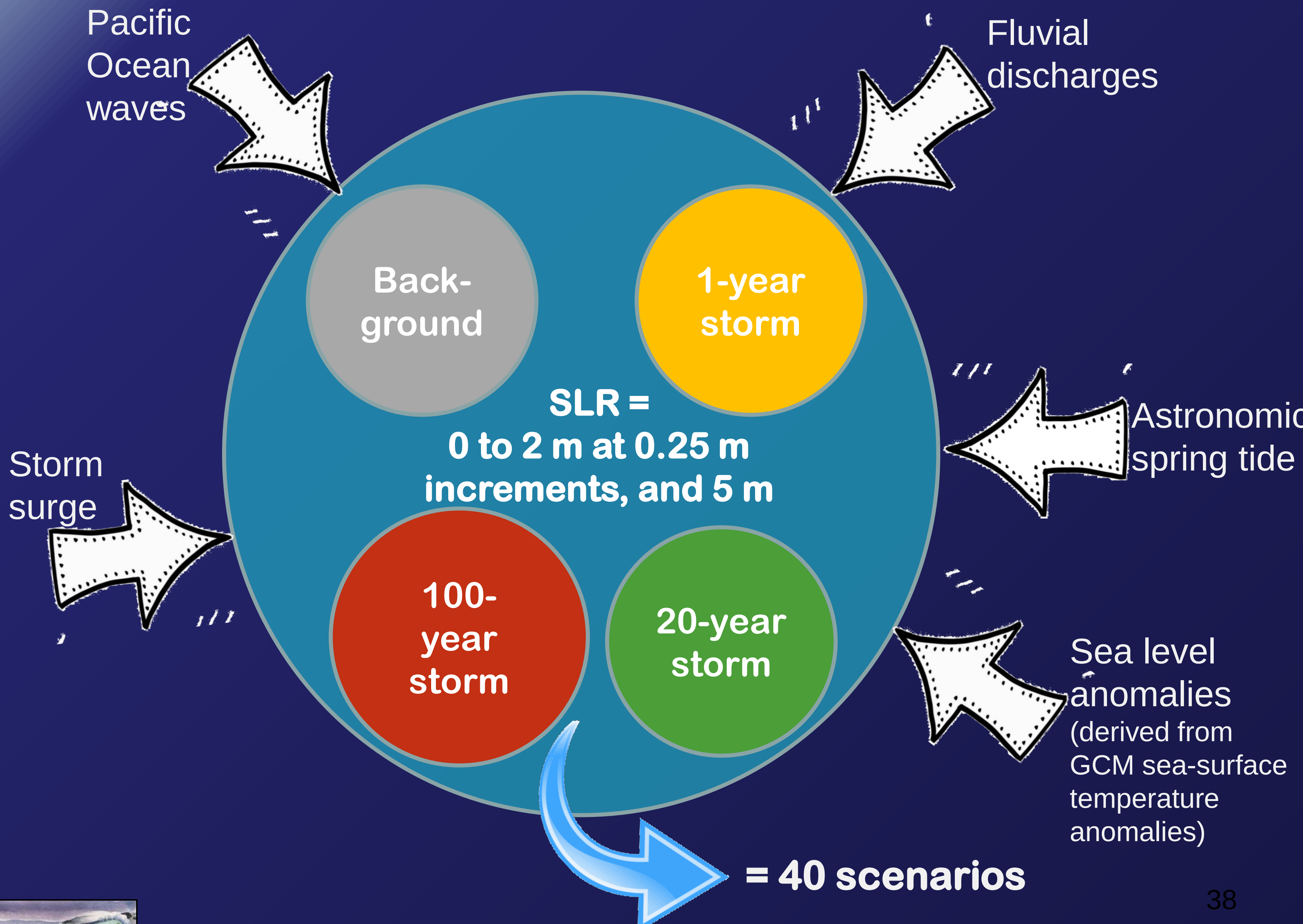
Selection of storm events for validation need to meet 3 criteria



We selected the following storms for validation of ….

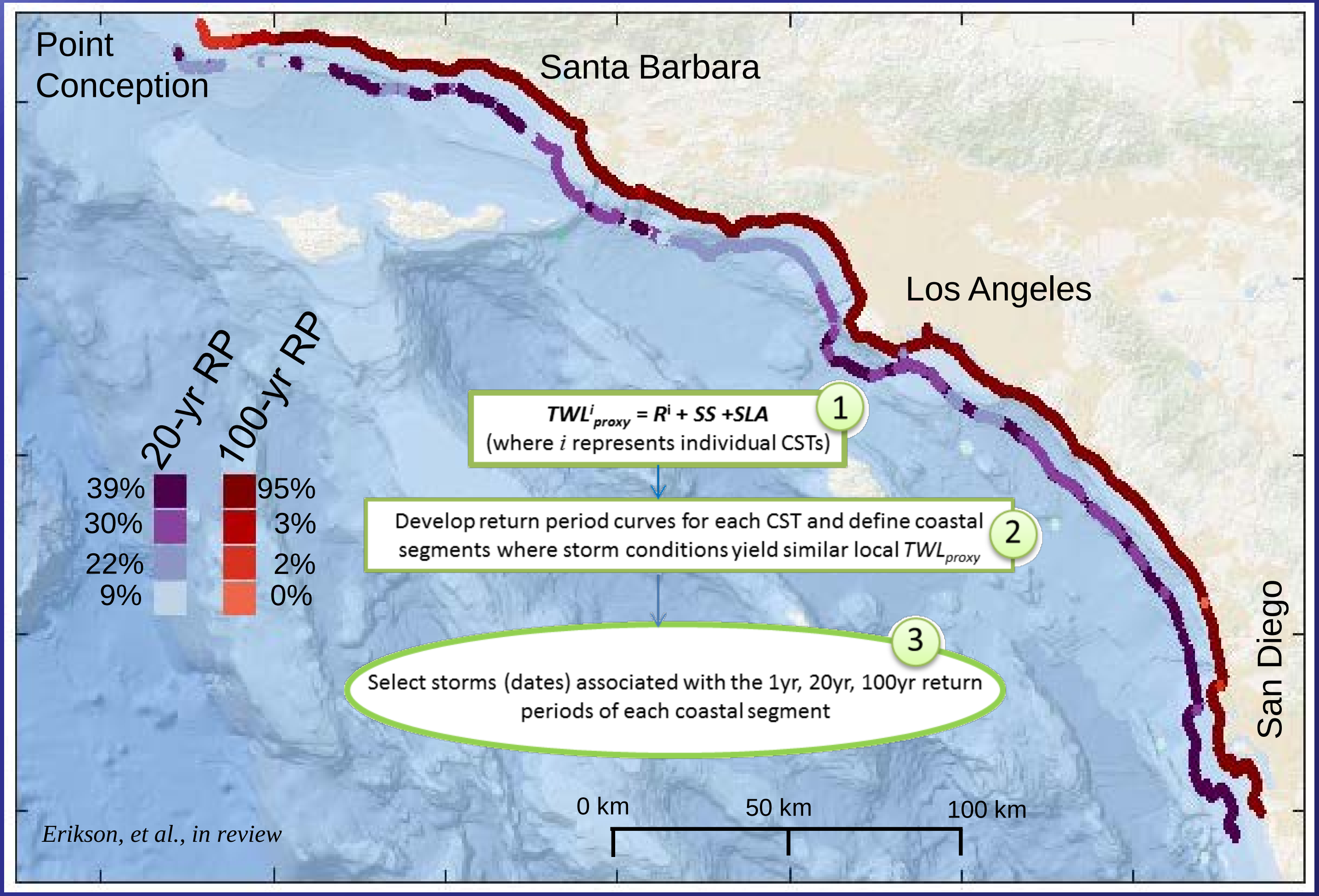
Water levels: Nov/Dec 1982
Dec 2005
Jan 2010

Waves: Dec 2005
Jan 2010



CoSMoS Coastal Storm Modeling System USGS

Selection of Storm Events



- 21st century time series generated for all non-tidal water level components
- Output every 100 m at 10 m contour to determine local return periods

What outputs are available?

- Long term (LT) cliff recession and sandy beach shoreline change

4 coastal management scenarios + SLR

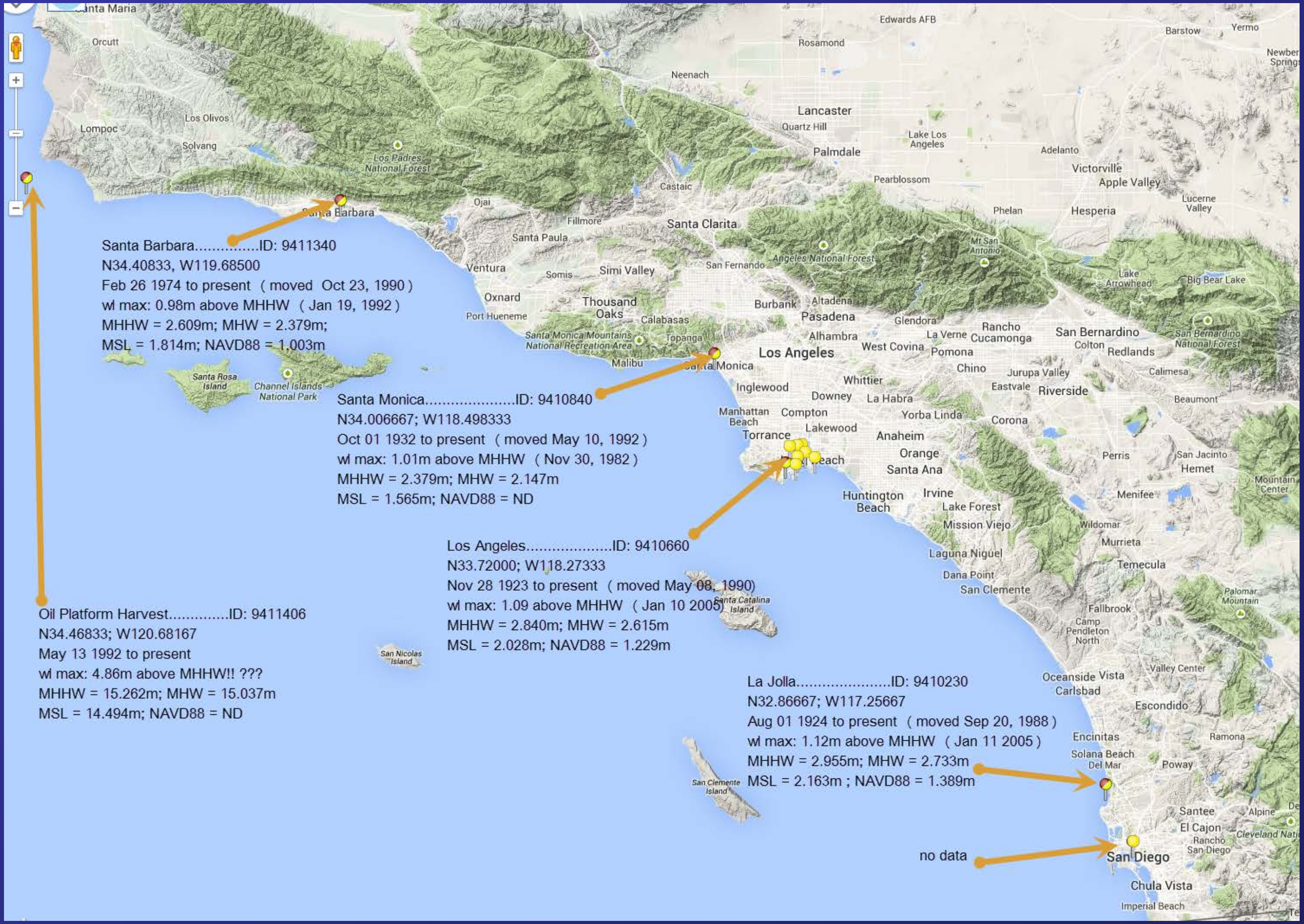
- Flood depths, extents, and low-lying vulnerable areas (including integration of LT morphodynamic change)
- Maximum water levels
- Flood duration
- Maximum wave heights
- Maximum velocities
- Maximum wave runup
- Flood extent uncertainties (model + DEM uncertainties, & vertical land motion)

40 scenarios of SLR + storms

CoSMoS Coastal Storm Modeling System USGS

Water Levels

LOCATIONS FOR WATER LEVEL VALIDATIONS

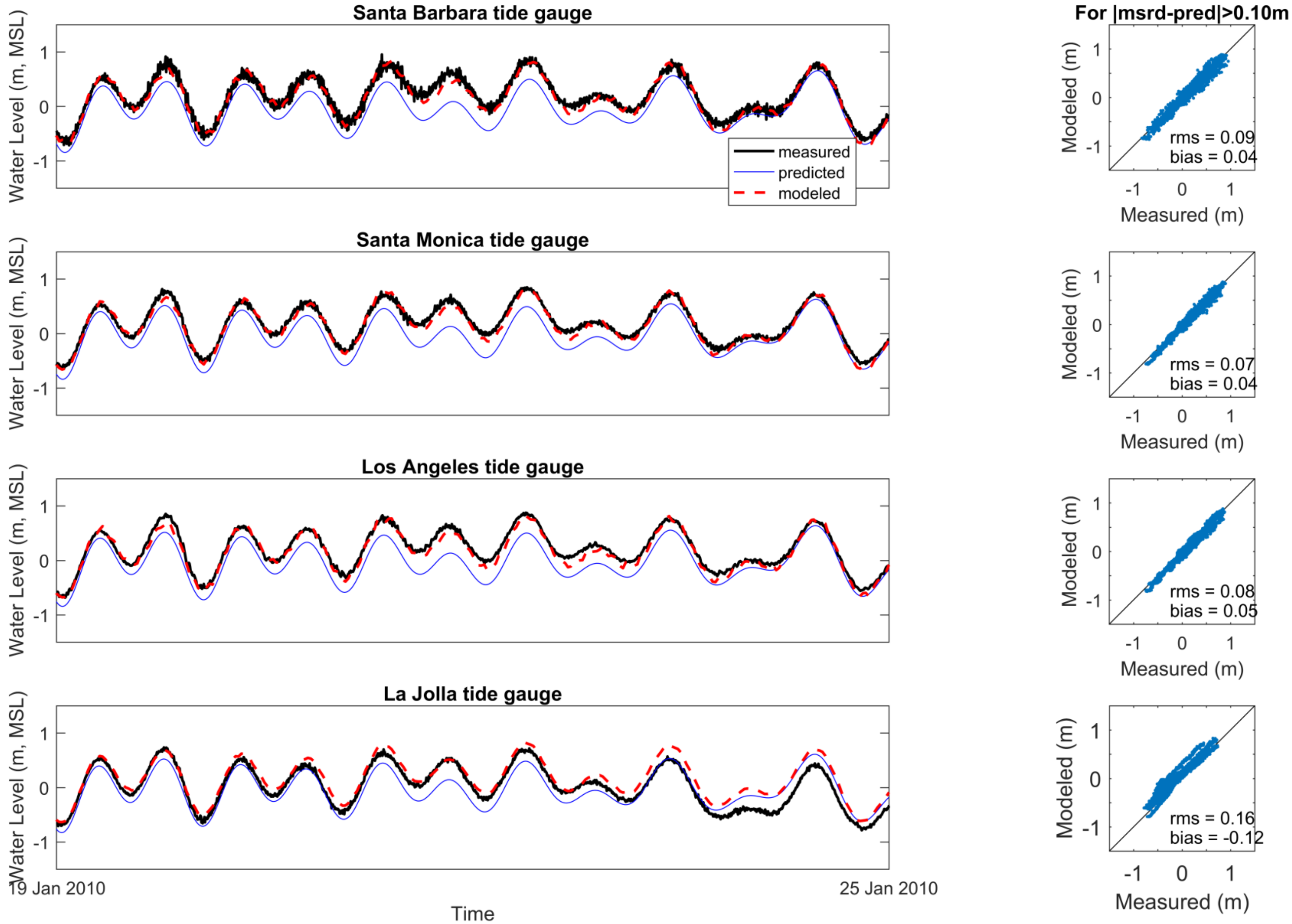


CoSMoS

NON-TIDAL WATER LEVEL VALIDATION
(e.g. storm surge)

Water Levels

Storm of Jan 2010

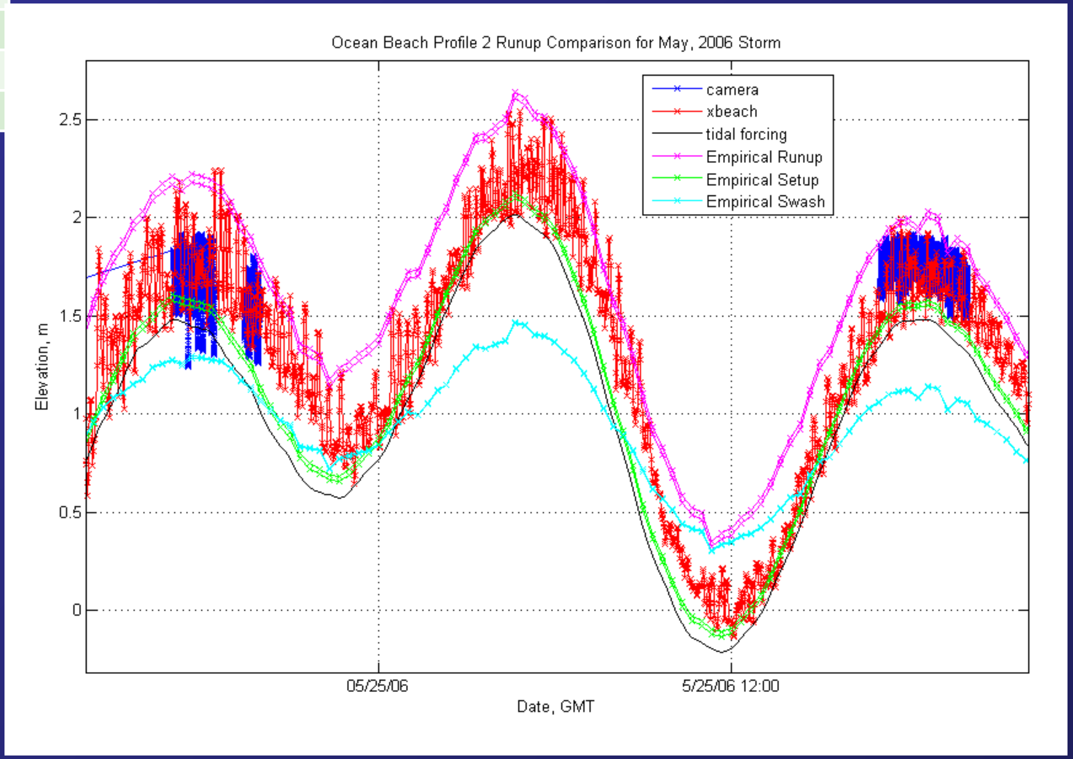


Waves

WAVE RUNUP AND EVENT-DRIVEN SHORELINE CHANGE
(calibrated and validated against profile measurements at Torrey Pines)

Comparisons to remotely measured runup elevations at Ocean Beach

	RMSE	
Date	Xbeach Base	Empirical Runup
22-May-06	0.16	0.30
23-May-06	0.10	0.13
24-May-06	0.14	0.31
25-May-06	0.10	0.12



Waves

WAVE RUNUP AND EVENT-DRIVEN SHORELINE CHANGE
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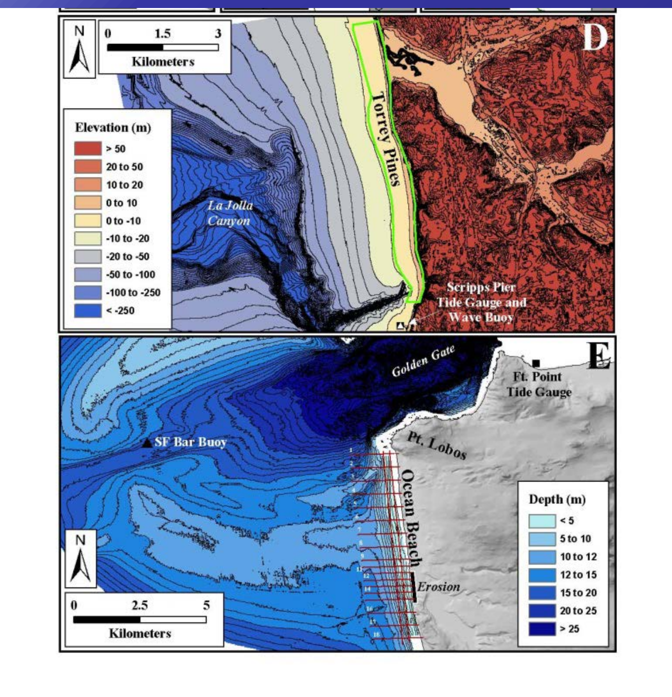
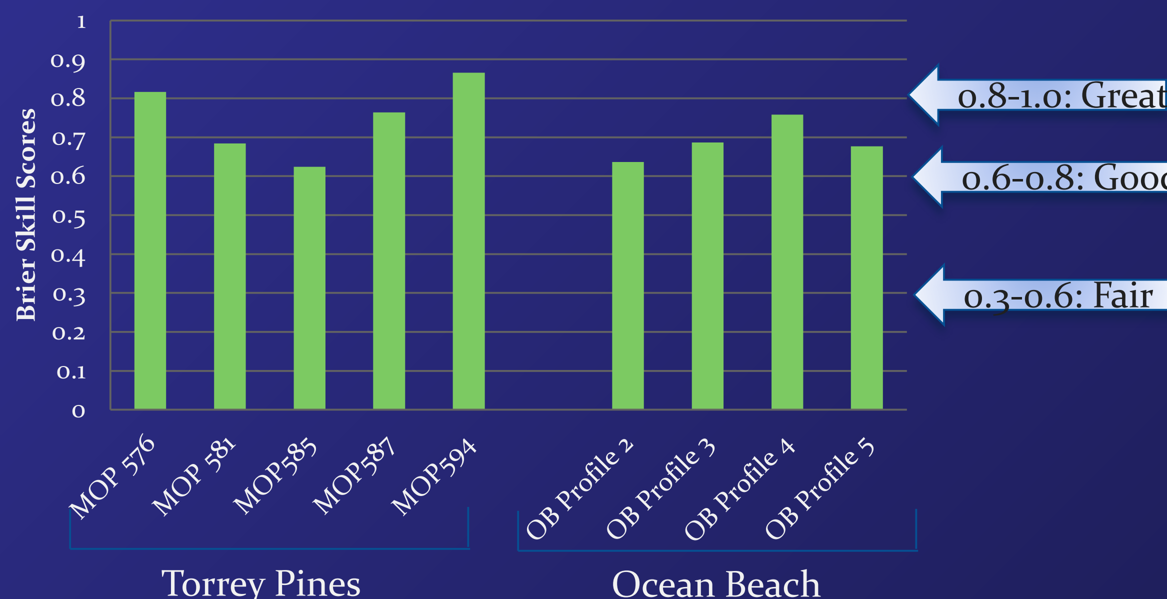
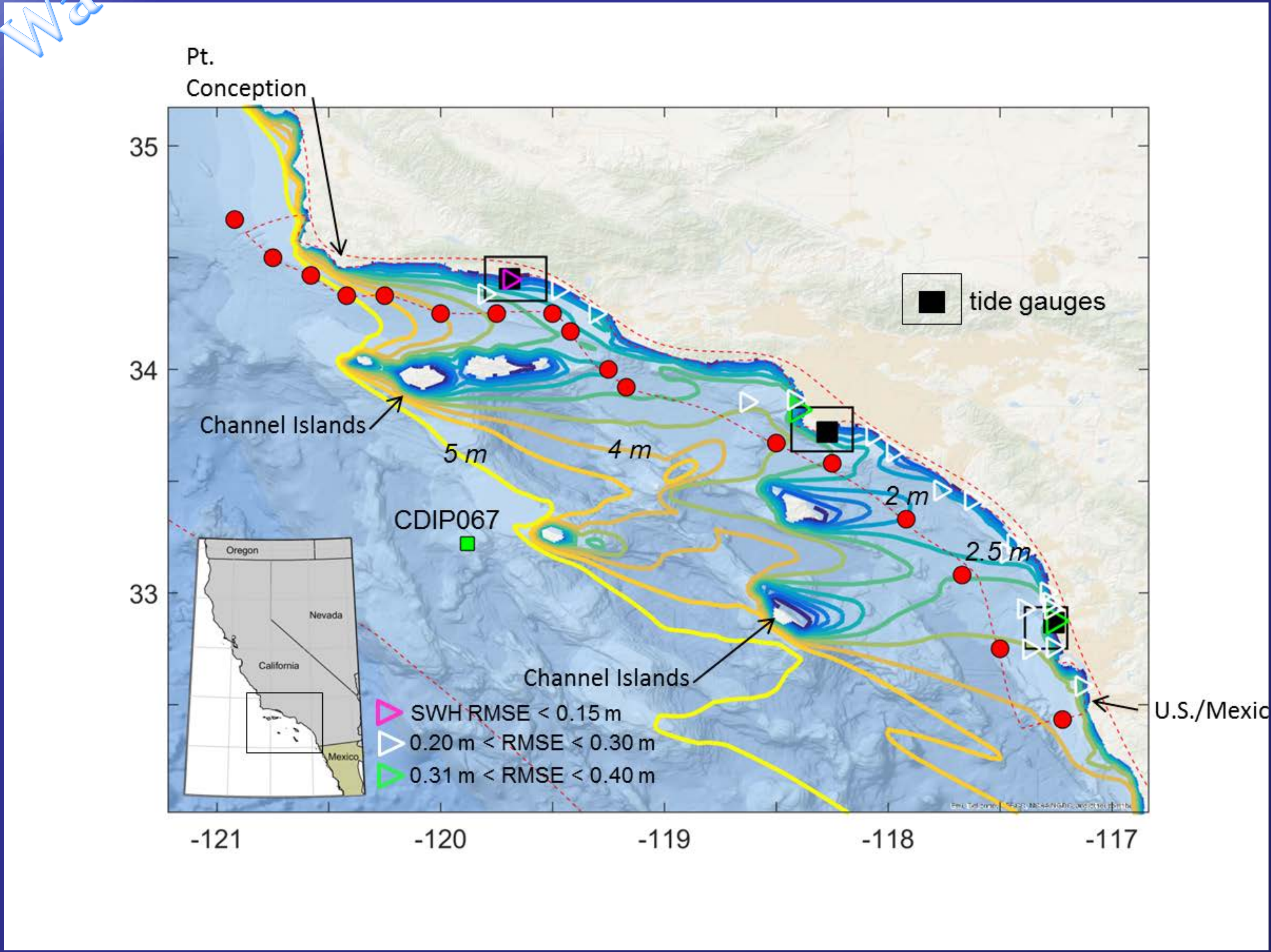


Calibration results of measured morphodynamic change measured over 3 days and simulated with XBeach



30-YEAR WAVE HINDCAST VALIDATION
(basis for generating 100-year projected wave time-series)

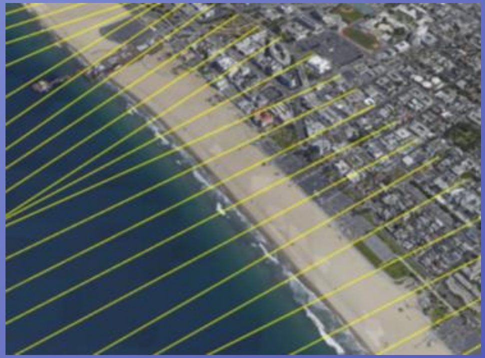
Waves



Hegermiller et al. 2016

CoSMoS-COAST: Coastal One-line Assimilated Simulation Tool

- **A (hybrid) numerical model to simulate long-term shoreline evolution**
  - coastline is represented by shore-perpendicular transects:



- **Two key assumptions: “hold the line” at the urban interface and no nourishment**

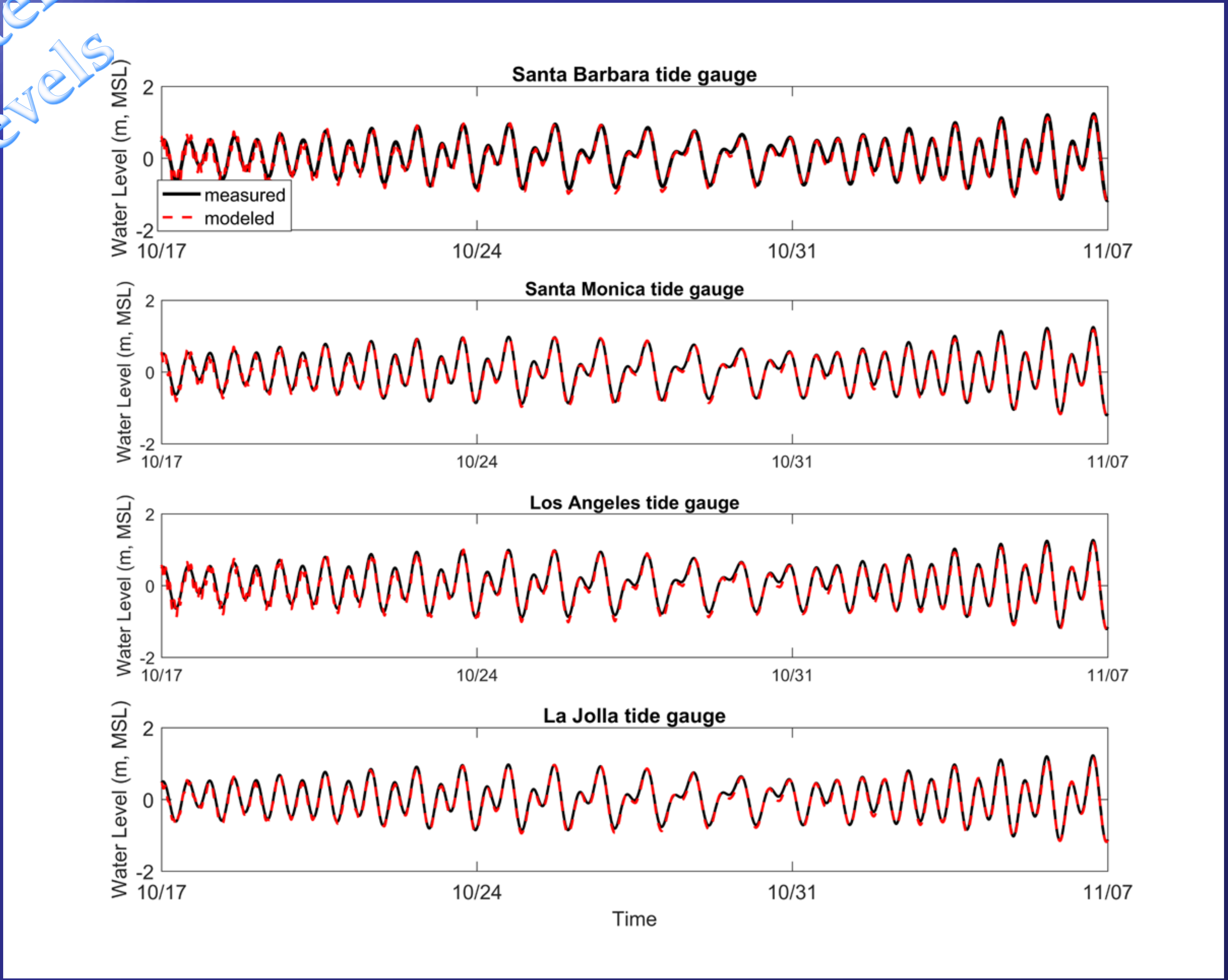
- **Modeled processes include:**
  - **Longshore sediment transport**
  - **Cross-shore sediment transport**
  - Effects of sea-level rise
  - Sediment supply by natural & anthropogenic sources

- **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**

Water Levels

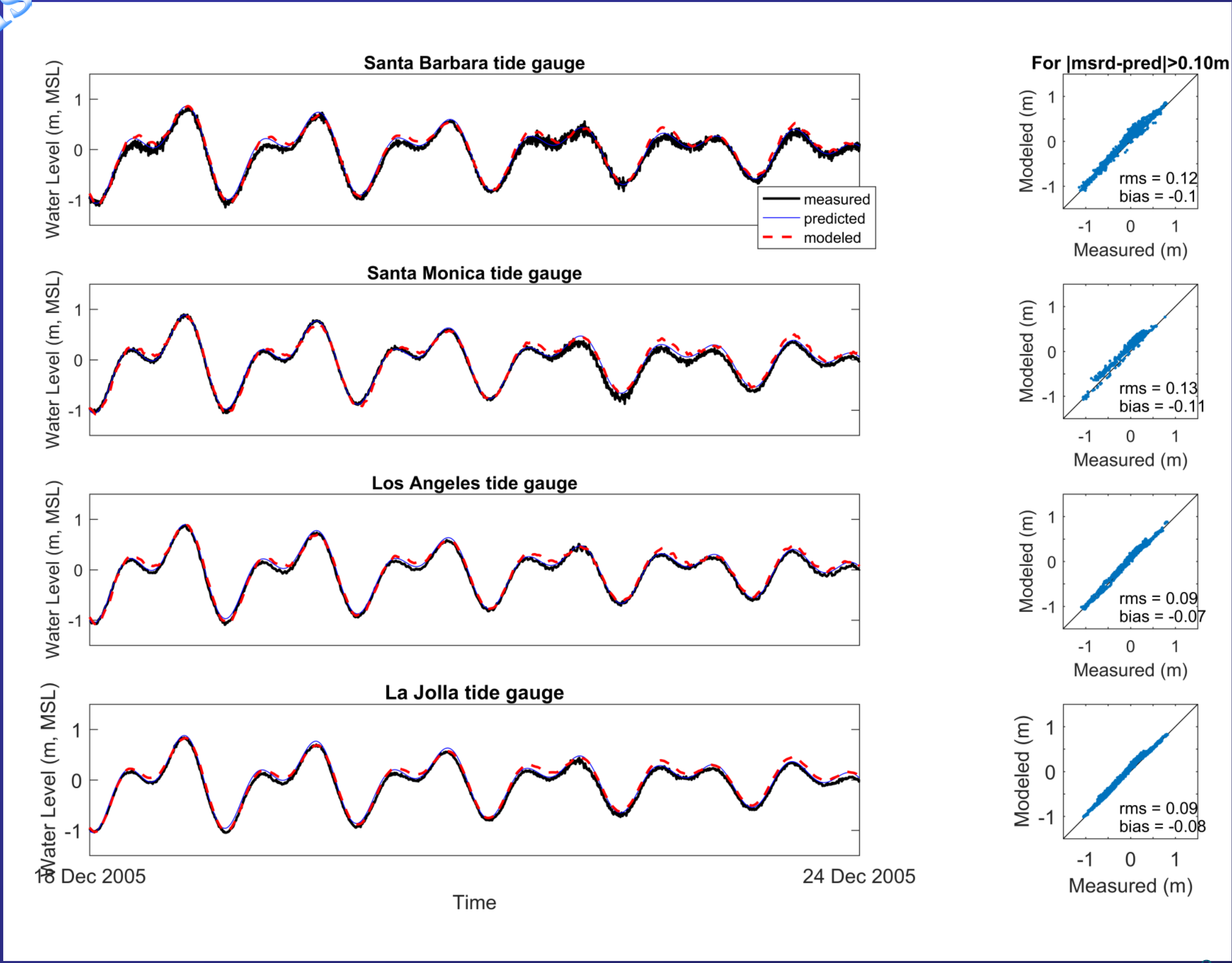
ASTRONOMIC TIDE VALIDATION



NON-TIDAL WATER LEVEL VALIDATION
(e.g. storm surge)

Water Levels

Storm of Dec 2005

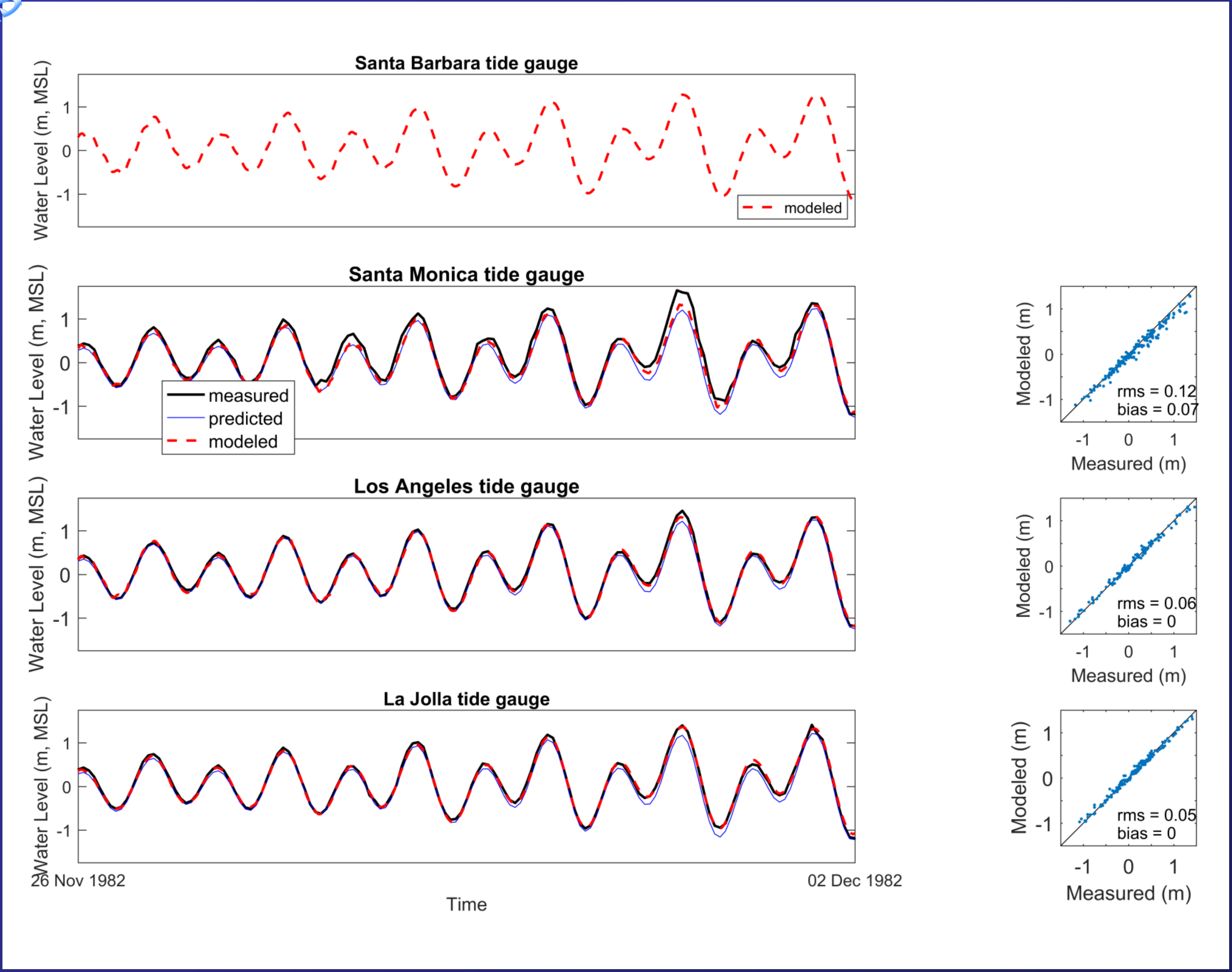


CoSMoS

NON-TIDAL WATER LEVEL VALIDATION
(e.g. storm surge)

Water Levels

Storm of Nov 1982



Waves

30-YEAR HISTORICAL DEEP WATER WAVE CLIMATE VALIDATION
(basis for generating 100-year projected wave time-series)

CoSMoS uses this one (best fit in the extremes)

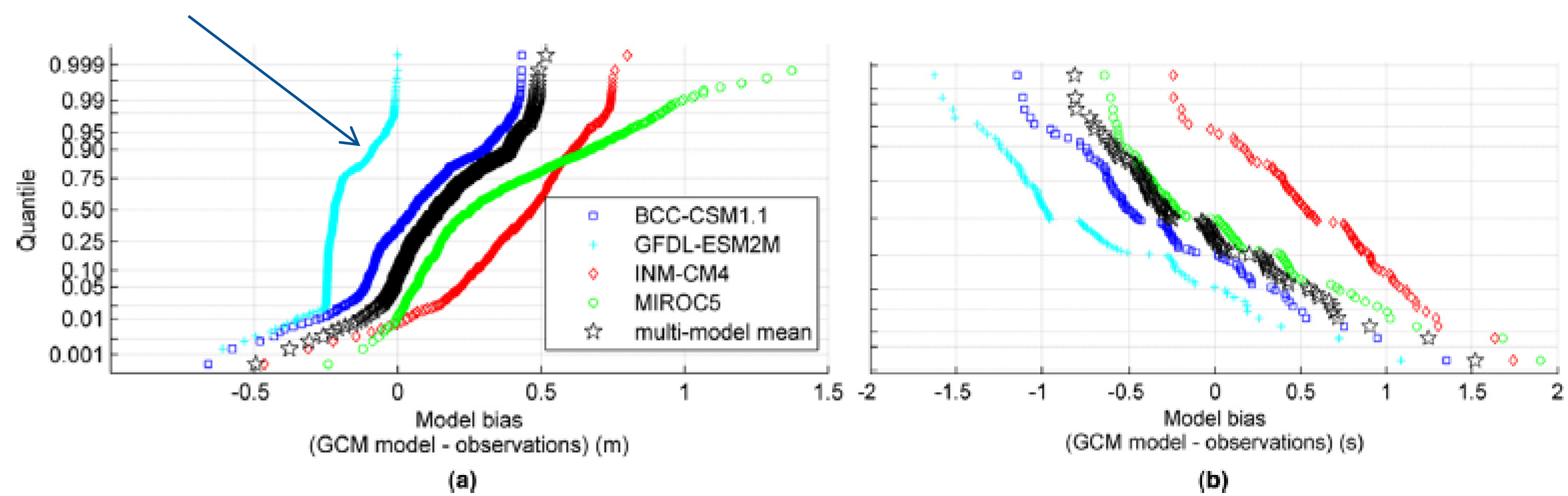
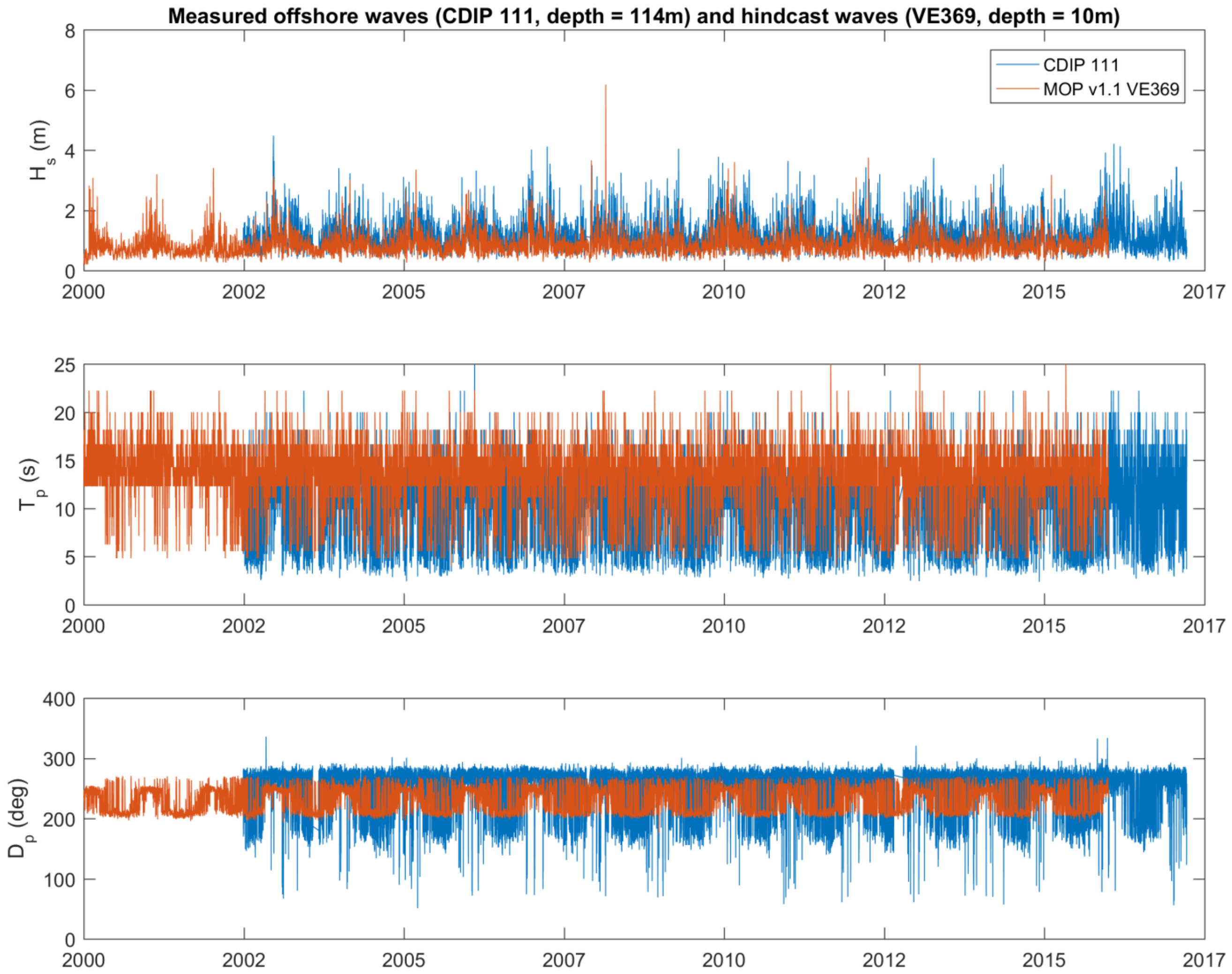
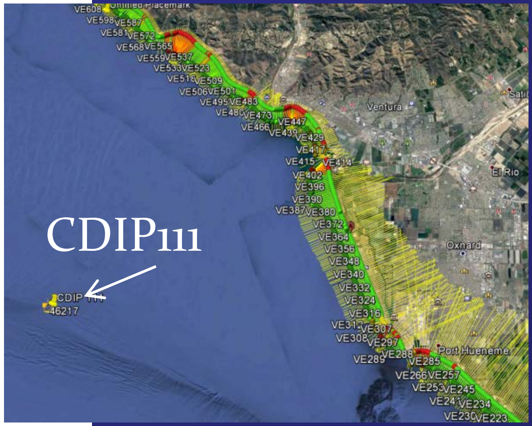
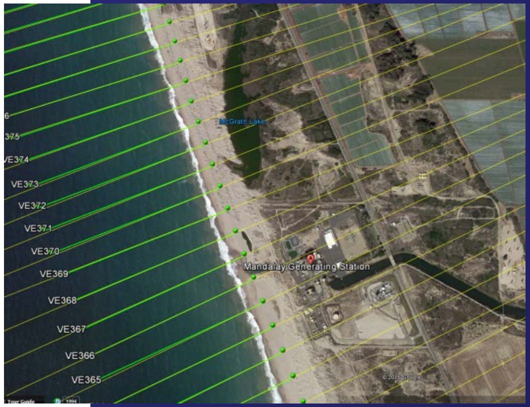


Fig. 4. Model bias with respect to wave buoy observations (model – reference) in the coastal region as a function of quantiles for winter months of November through March. Biases represent the average of 15 buoys for (a) H_s and (b) T_p. See Table 2 and Fig. 1 for buoy locations. Data are plotted on a log-normal probability scale for better visualization of the extremes.

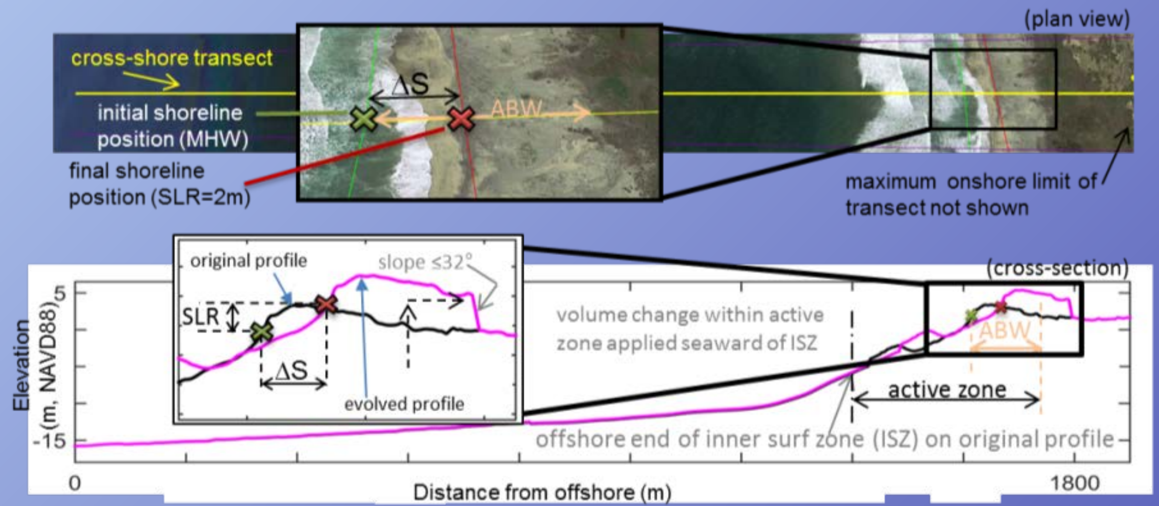
Erikson et al. 2015


Measured offshore waves (CDIP 111, depth = 114m) and hindcast waves (VE369, depth = 10m)
CDIP 111
MOP v1.1 VE369
H_s (m)
T_p (s)
D_p (deg)
2000
2002
2005
2007
2010
2012
2015
2017

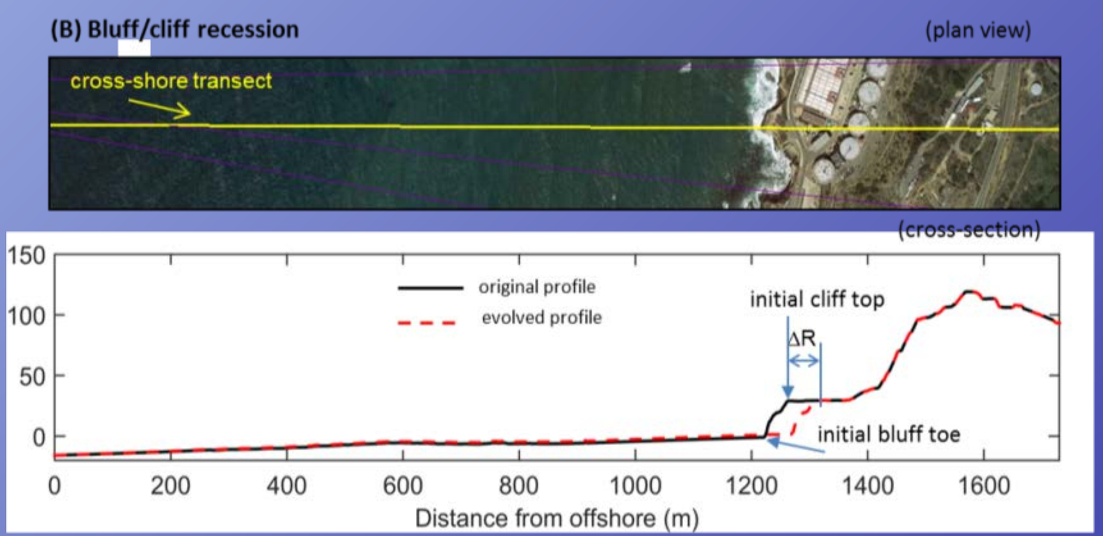

CDIP111
Ventura
Oxnard
Port Hueneme


Mandalay Generating Station

Long-term Morphodynamic Change: Profile Evolution



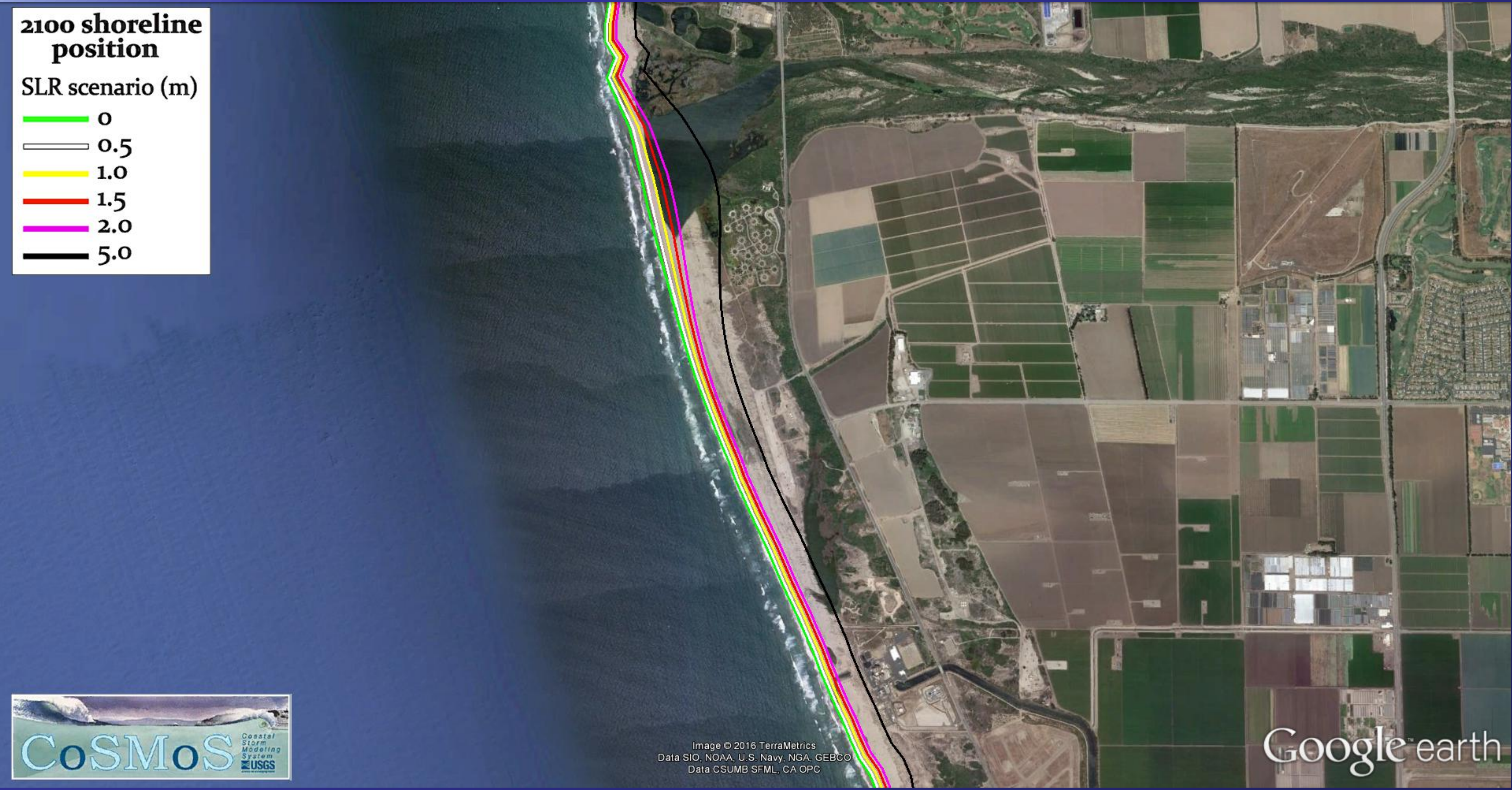
Sandy beaches



Cliffs

Erikson, et al., submitted. Coastal Dynamics.

Shoreline Projections – Santa Clara River



$$\mathrm{DHZ} = (\mathrm{R_h})^{*}\Delta t + \Delta\mathrm{TWL}/\tan\varphi + (100 - \mathrm{yr\ TWL})/\tan\beta$$

where

R_h	historic rate of shoreline change
Δt	time step (10 years)
ΔTWL	change in total water level
$\tan\varphi$	shoreface beach slope
$\tan\beta$	foreshore beach slope

Revell et al. 2011
Climatic Change

$$\underbrace{\mathrm{DHZ}}_{\text{Dune Hazard Zone}} = v_{\mathrm{lt}}\Delta t + \frac{\mathrm{SLR}}{\tan\phi} + \frac{\mathrm{TWL}}{\tan\beta}$$

v_{lt} = long-term erosion rate

Δt = time step = 10 years

SLR = sea-level rise

$\tan\phi$ = shoreface beach slope

(to closure depth?)

$\tan\beta$ = foreshore beach slope

TWL = Total water level

(empirical equation for runup $R = 0.5H_s - 0.22$ from Komar 1999?)

CoSMoS - COAST

$$\text{Hazard zone} = \begin{cases} \underbrace{\dfrac{\partial y}{\partial t}}_{\substack{\text{shoreline}\\ \text{change}}} = \underbrace{-\dfrac{1}{d_c}\dfrac{\partial Q}{\partial x}}_{\substack{\text{longshore}\\ \text{transport}}} + \underbrace{CE^{1/2}\Delta E}_{\text{cross-shore transport}} + \dfrac{1}{\tan\beta}\dfrac{\partial(\text{SLR})}{\partial t} + v_{\text{lt}} + \text{data assimilation} \\ \text{TWL} = \text{dynamically modeled with XBeach} \\ \qquad \text{(includes infragravity wave runup} \\ \qquad \text{and storm induced dune erosion)} \end{cases}$$

Vitousek et al. 2017
JGR – Earth Surface

Q = longshore transport rate

d_c = closure depth

$CE^{1/2}\Delta E$ = cross-shore transport due to waves

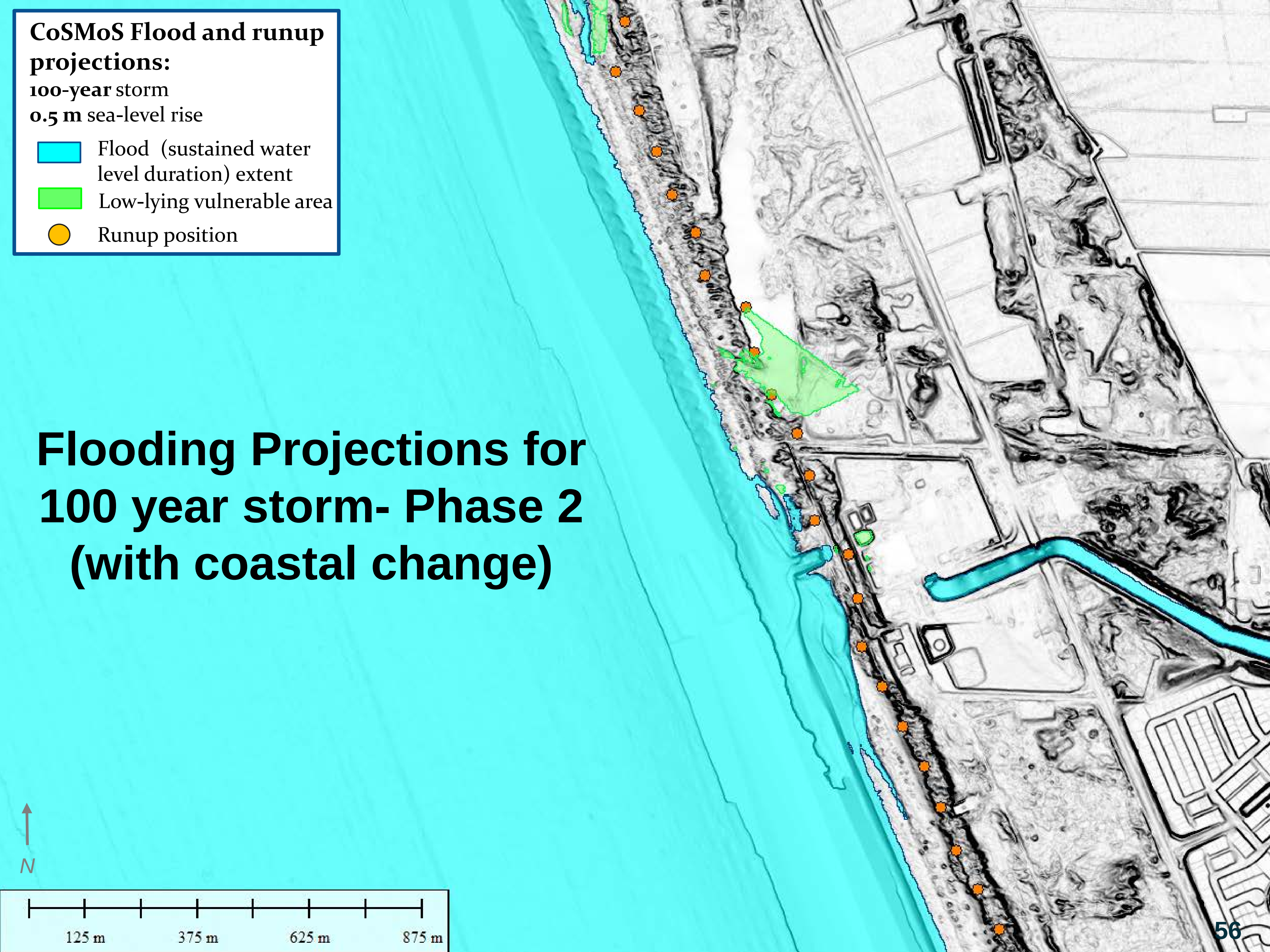
SLR = sea-level rise

$\tan\beta$ = foreshore beach slope

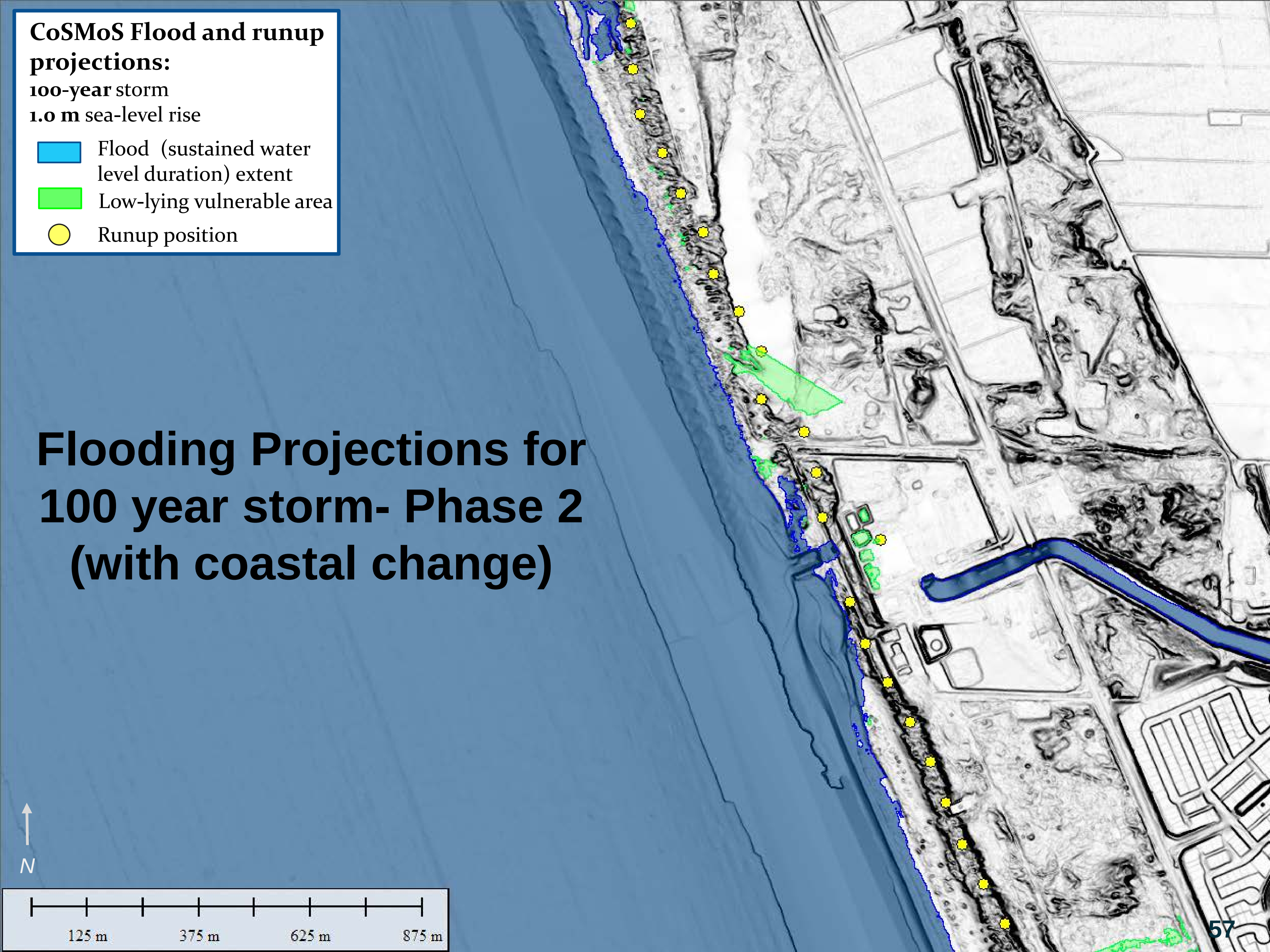
v_{lt} = long-term erosion rate derived from data assimilation

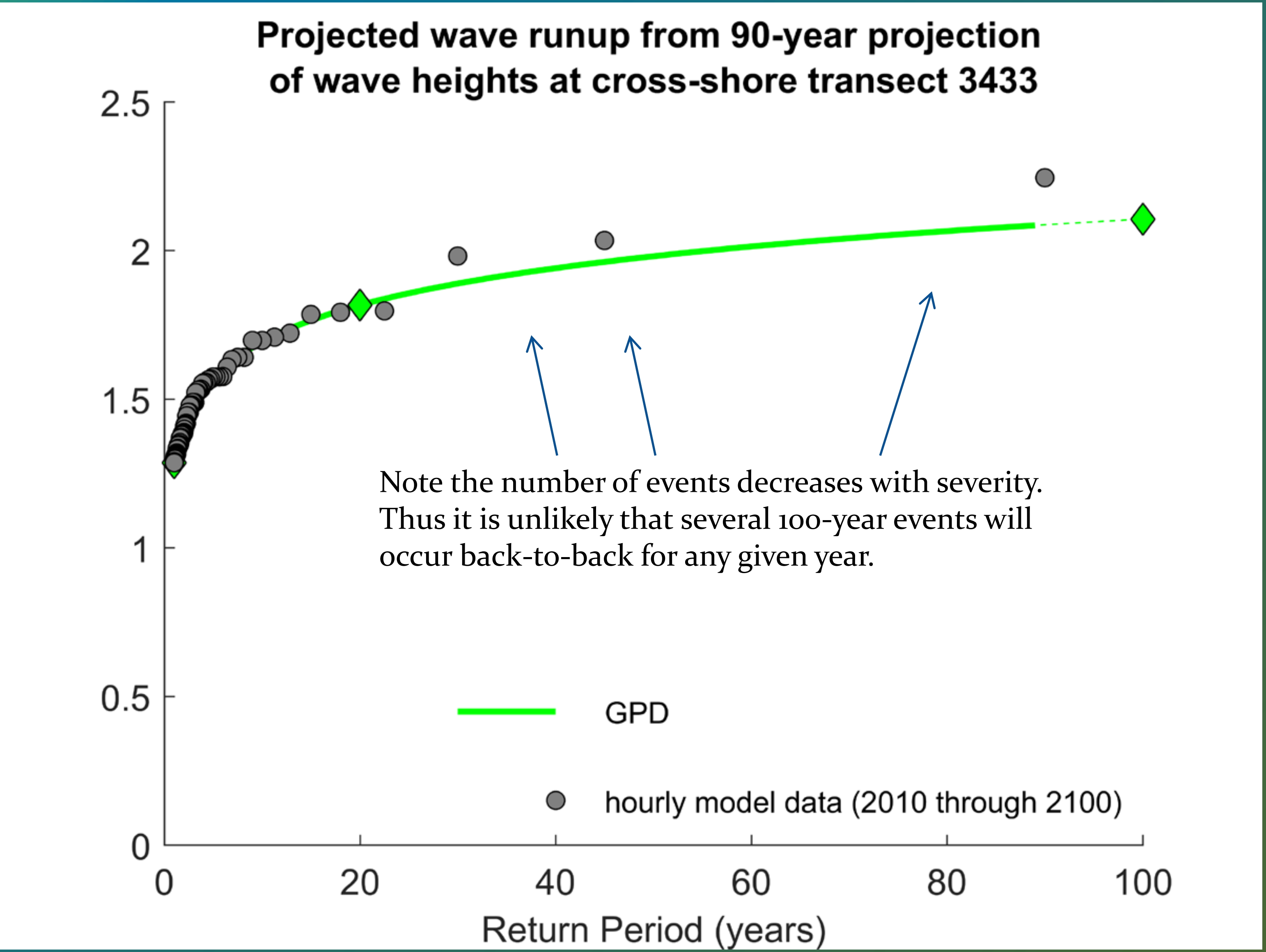
Δt = time step = 1 day for shoreline change; ~5 sec for flooding model

Flooding Projections for 100 year storm- Phase 2 (with coastal change)



Flooding Projections for 100 year storm- Phase 2 (with coastal change)




Projected wave runup from 90-year projection
of wave heights at cross-shore transect 3433
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
Return Period (years)
Note the number of events decreases with severity.
Thus it is unlikely that several 100-year events will
occur back-to-back for any given year.
GPD
hourly model data (2010 through 2100)

- The relationship between fluvial discharges and coastal storm events is site specific and dependent upon the relationship between atmospheric pressure patterns and the primary river within the region of interest

Fluvial Discharges

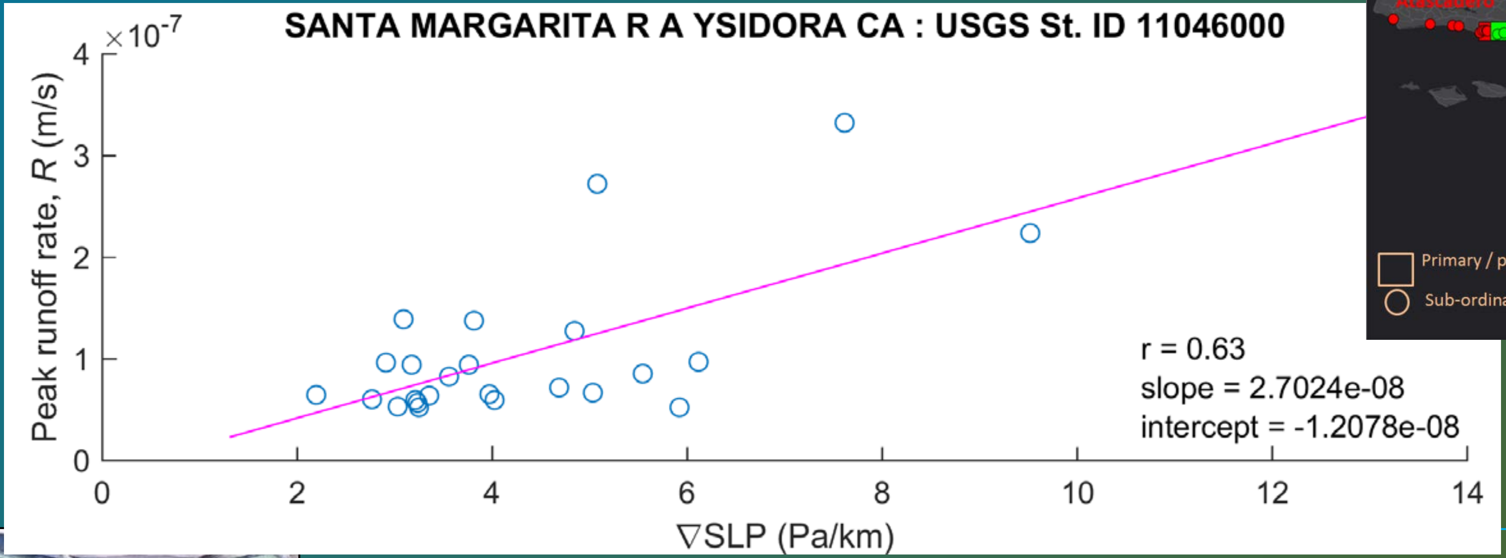
CoSMoS focuses on <u>coastal storms</u>
(not explicitly on fluvial extremes)

>30 fluvial discharge locations used in CoSMoS ver. 3.0, Southern California

Fluvial Discharges: **Peak discharge rates associated with future storm events**

- Analyzed historical discharge rates for 18 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 (defined as those that exceeded the 99.95th percentile)



7 'primary' rivers

Fluvial Discharges: **Peak discharge rates associated with future storm events**

Select coastal storm event based on *TWLproxies*

Extract SLP pattern associated with that particular storm

Conditional relationship between $\nabla SLPs$ and Q_p at each 'primary' river (derived from historical data)

Estimate Q_p of each 'primary' river associated with that coastal storm

Point discharges to CoSMoS Tier 2 models

Calculate primary river runoff rates ($R = Q_p/A$), where A=watershed area

Calculate subordinate river drainage areas (A_{sub})

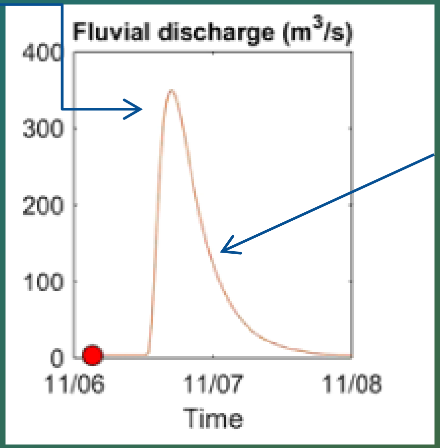
Estimate Q_p of each subordinate river, $Q_{psub} = R*A_{sub}$

Fluvial Discharges

Fluvial discharge rates were assigned at Delft3D FLOW grid cells coincident with USGS gauging stations.

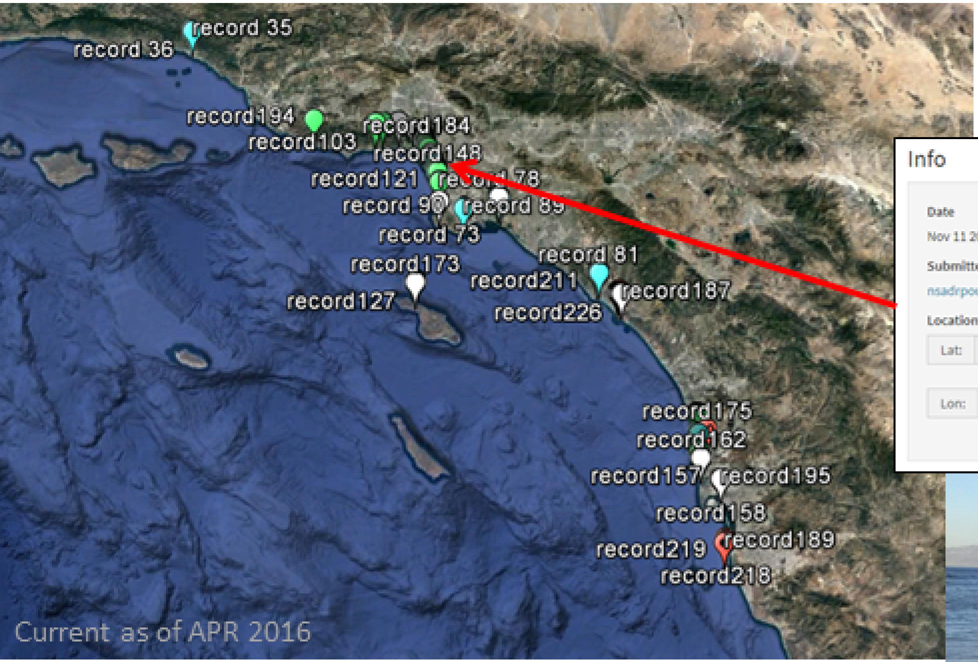
- 21st century storm specific projected peak discharge rates were not available for Southern California at the time of the study
- therefore parameterized hydrographs were constructed
    - Duration and rate of increase and decrease of discharges (i.e., the shape of the hydrograph)
    - Peak discharge rates associated with specific future storm events

magnitude?



shape?

Urban Tides – citizen science initiative to document current tidal lines, beach erosion, and coastal flooding:



Strict guidance on submission: location, orientation, use of structures

Info

Date

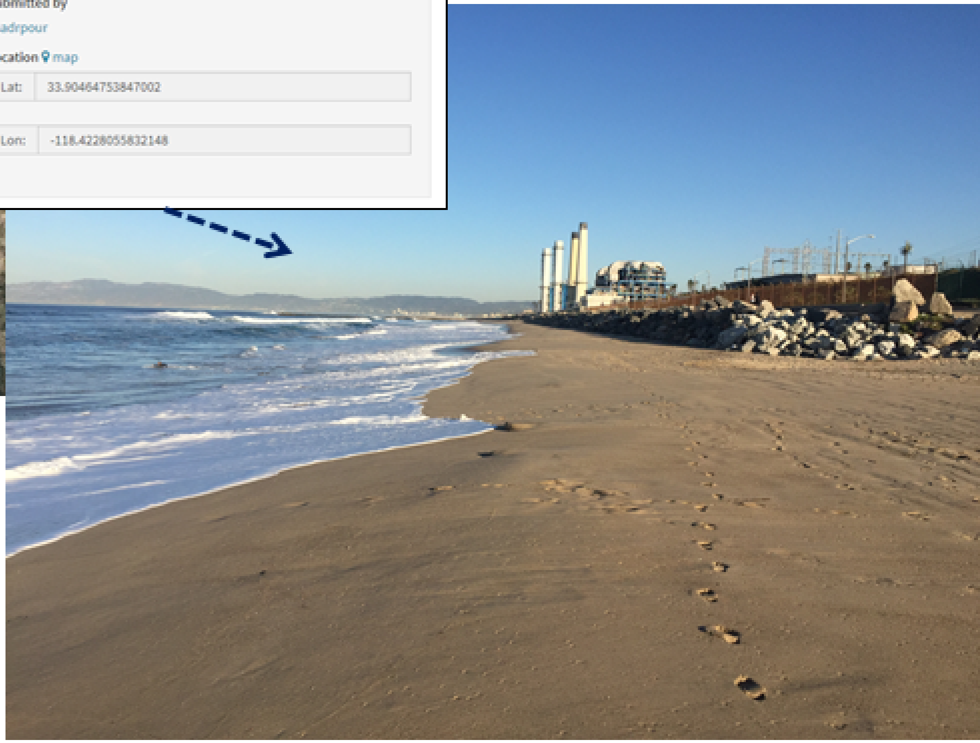
Nov 11 2016 07:40:47 AM

Submitted by

nsadrpour

Location map

Lat:	33.90464753847002
Lon:	-118.4228055832148



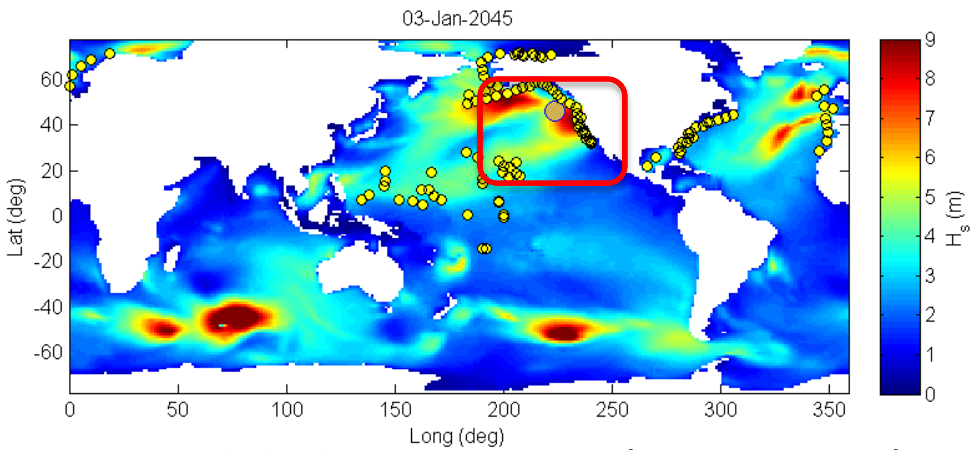
< 30% of sufficient quality for basic scientific comparison

Primary challenges: location, source of flooding, reference to structures, framing flood interest in foreground…

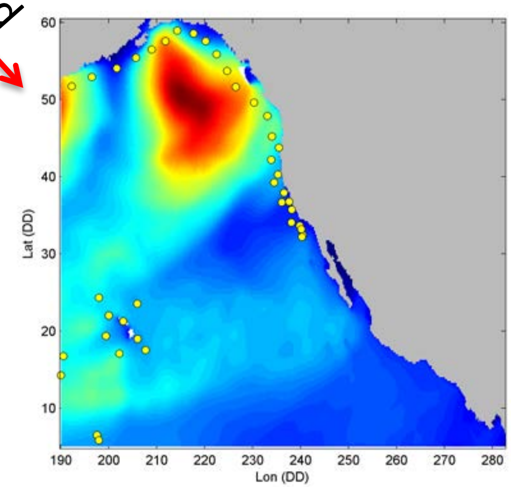
A record shows flooding, is it directly comparable to a projection? … not really

Pool of records further refined for comparisons to specific simulated conditions: Atmospheric pressure, wave conditions, wind speed and direction, river discharge, etc…

Identification of storm events



Near global grid, NWW3 (80°S – 80°N)
1° x 1.25° spatial resolution



WavewatchIII version 3.14 (Tolman 1999)

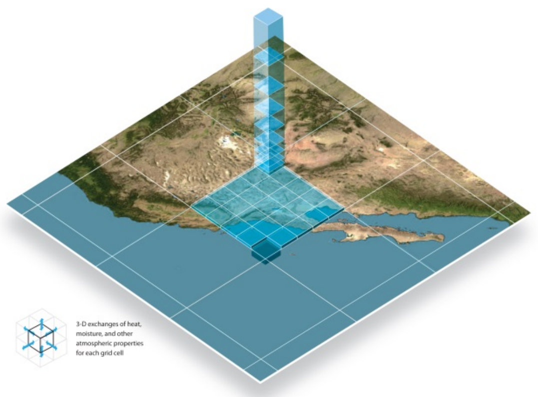
Eastern North Pacific grid (ENP)
180°W to 130°W
0.25° spatial resolution (~27 km at latitude 37°N).

Identification of storm events

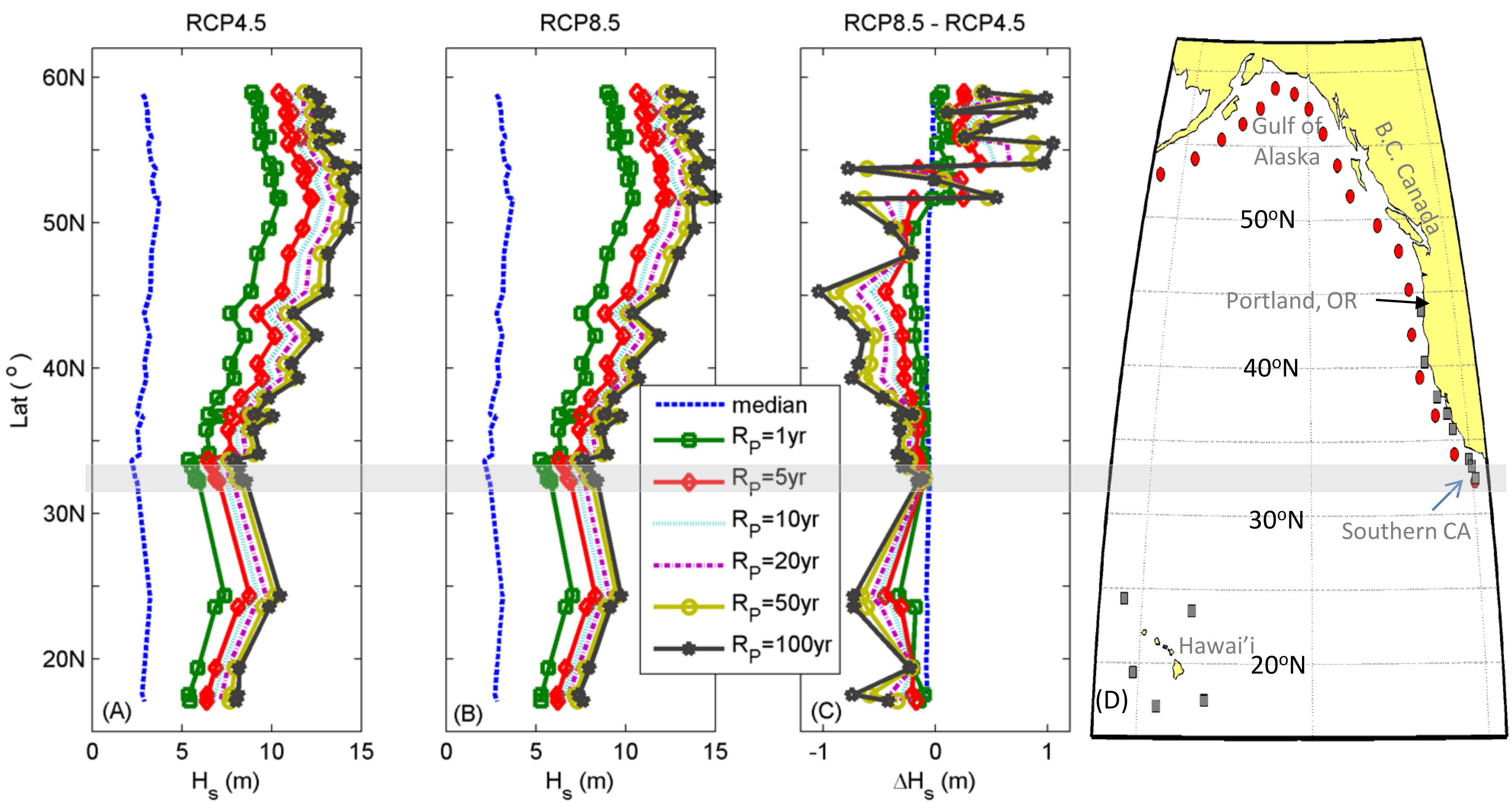
IPCC-AR5 Climate Change Scenarios

Modeling Center	model	GCM model resolution
Beijing Climate Center, Meteorological Administration, China (BCC)	BCC-CSM1.1	2.8^o x 2.8^o
Institute for Numerical Mathematics, Russia (INM)	INM-CM4	2^o x 1.5^o
Model for Interdisciplinary Research on Climate - AOEI, NIES, JAMSTEC, Japan (MIROC)	MIROC5	1.4^o x 1.4^o
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	2.5^o x 1.5^o

- 3 hourly winds converted to 10 m height
- Historical runs 1996-2006
- Projections
  - 2026-2045 & 2081-2100
  - RCP4.5 & RCP8.5



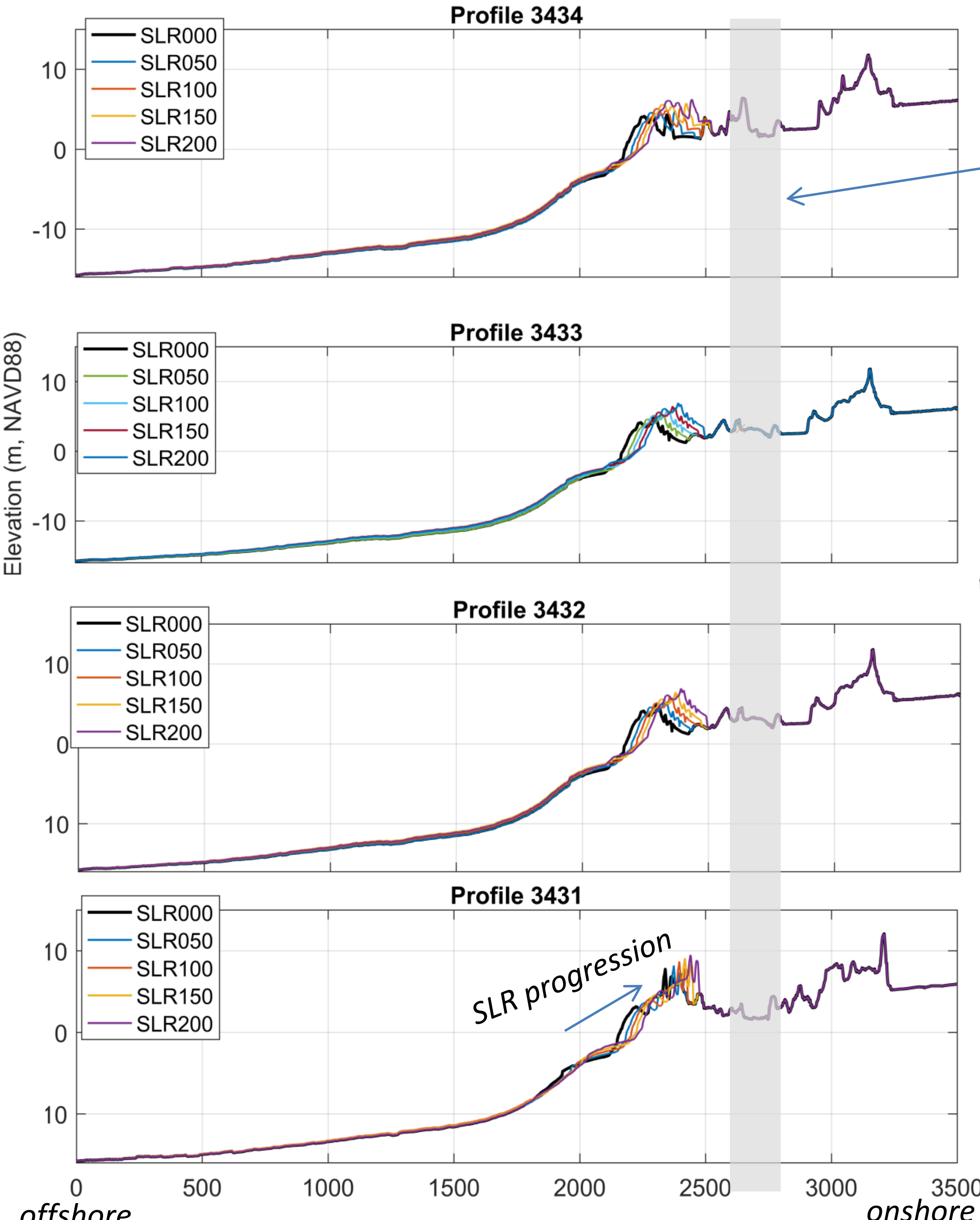
Identification of storm events



2 emissions scenarios, 4 Global Climate Models

- selected climate scenario RCP4.5 (slightly higher waves compared to RCP8.5) [Erikson et al., 2015. Ocean Modeling]
- All data available for download at: http://cmgwindwave.usgsportals.net/

Profile evolution



approx. location of project site