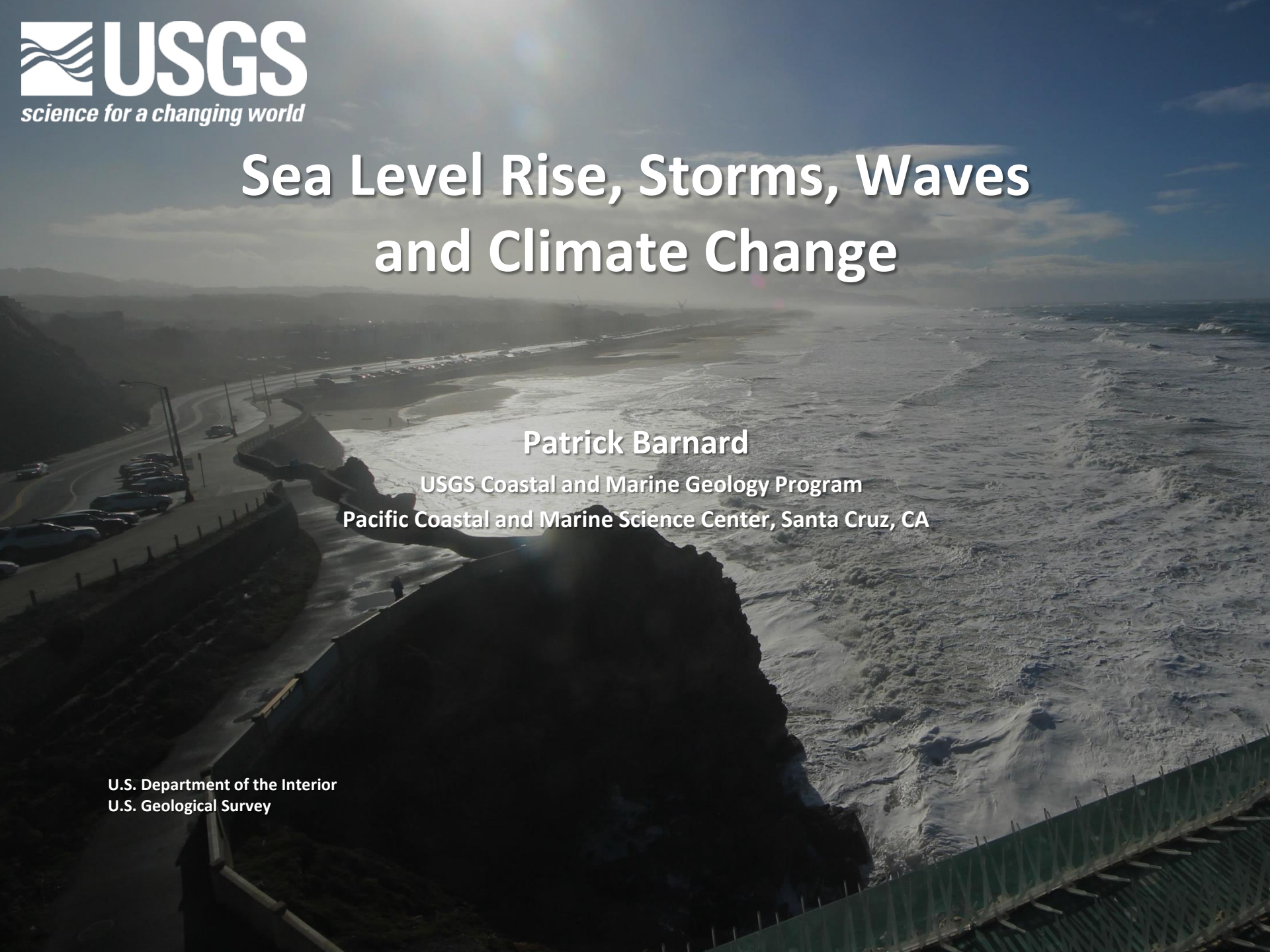

USGS
science for a changing world

Sea Level Rise, Storms, Waves and Climate Change

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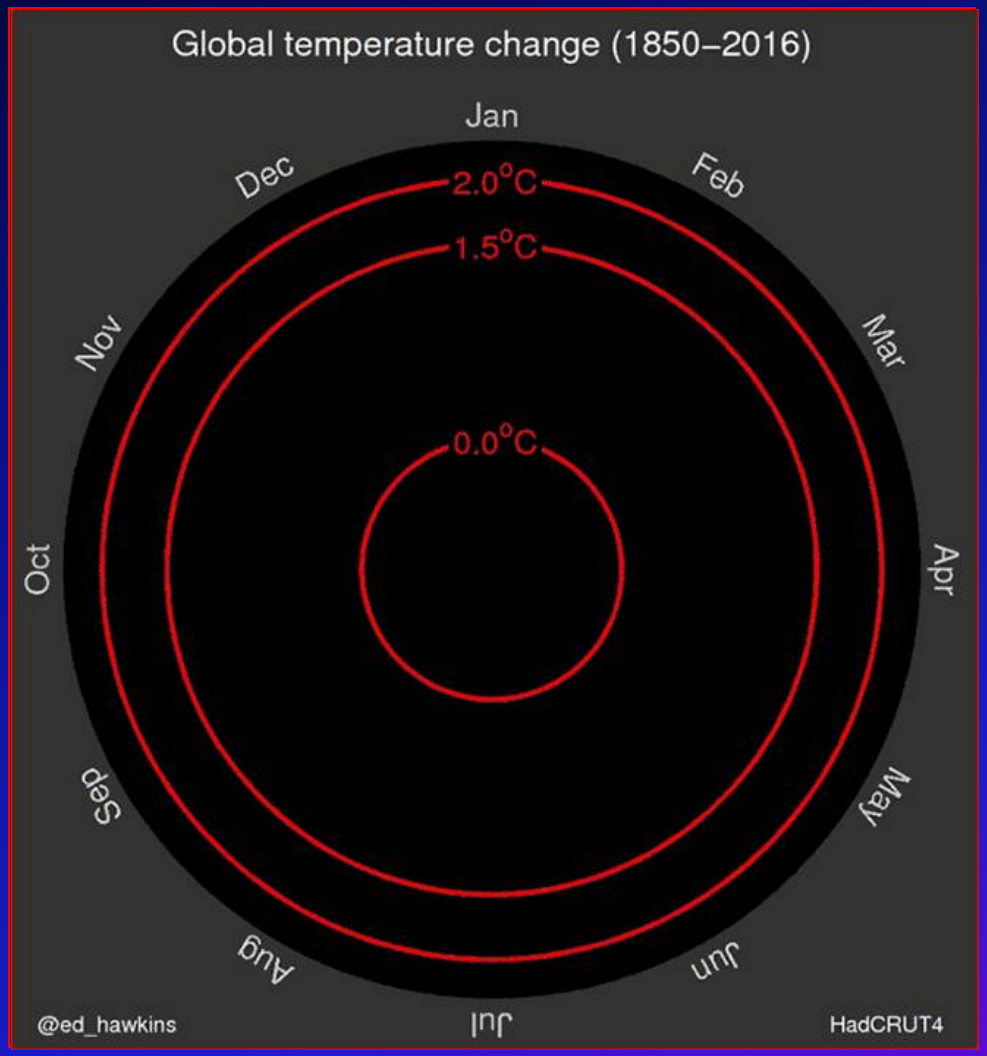
U.S. Department of the Interior
U.S. Geological Survey

Temperature Change



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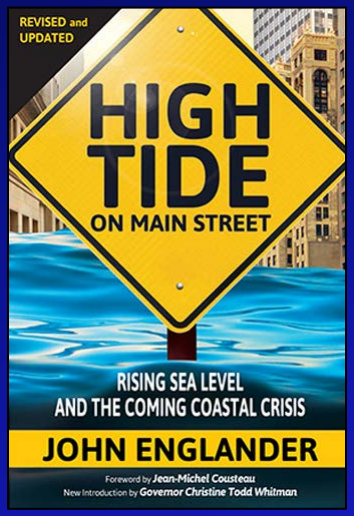
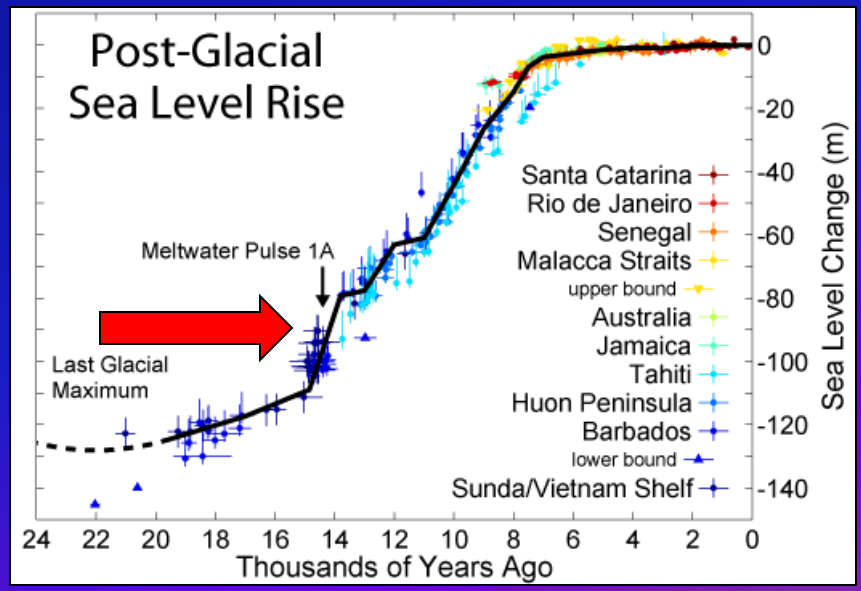
Ed Hawkins, University of Reading

http://www.climate-lab-book.ac.uk/2016/spiralling-global-temperatures/#more-4330

Climate Change Factoids

- Based on the cyclical pattern of earth's orbit around the sun we should actually be experiencing global cooling right now
- The rate of $C0_2$ increase in the atmosphere is 20,000 times faster than any time in the last 500 million years
- 15 million years ago global temperature was ~6° warmer (CO_2 was the same as today), but sea level was 30 m higher
- 125,000 years ago global temperature was ~2° warmer but sea level was 8 m higher
- 14,000 years ago sea level rose 20 m in 4 centuries (Meltwater Pulse 1A)





Fleming et al. (1998), Fleming (2000), Milne et al. (2005)

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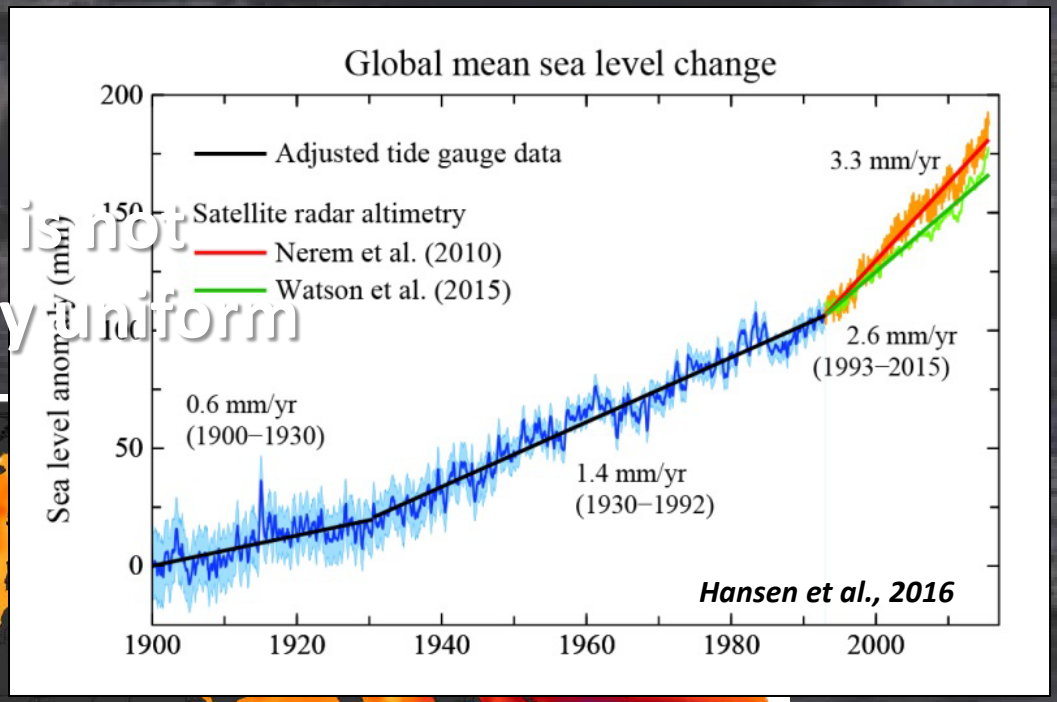
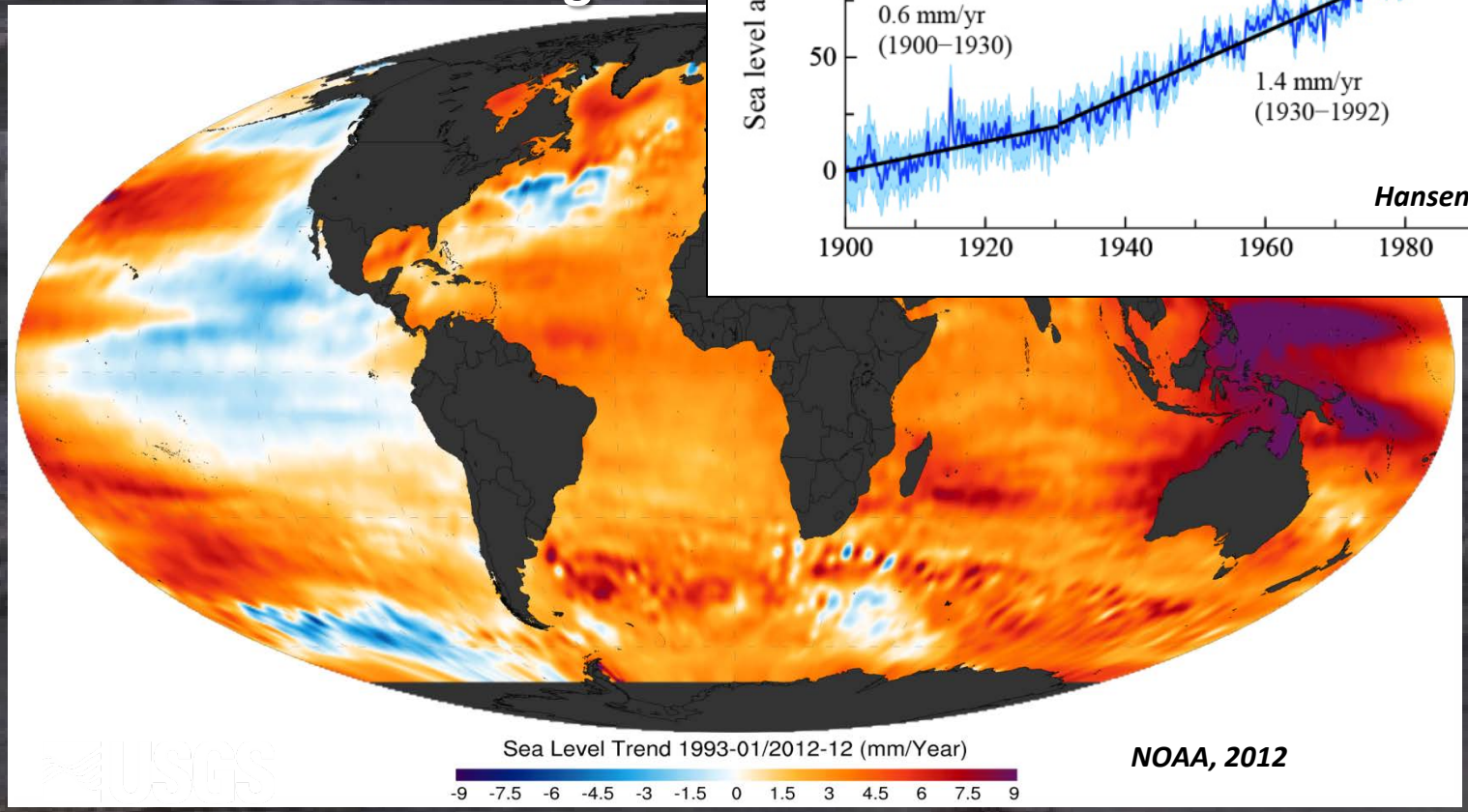
Recent Sea Level Rise

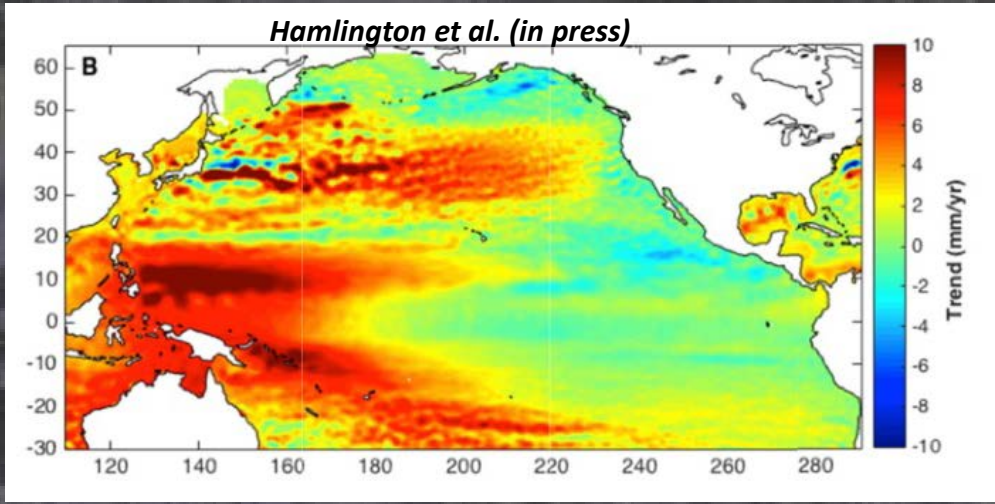
Global SLR is accelerating

SLR is not spatially uniform

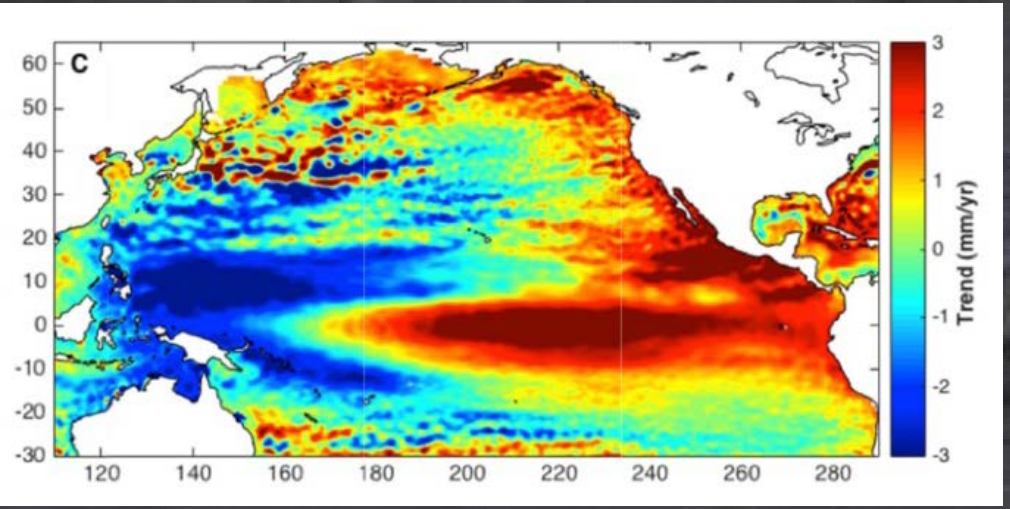




Recent Sea Level Rise



1993-2011



2011-2015

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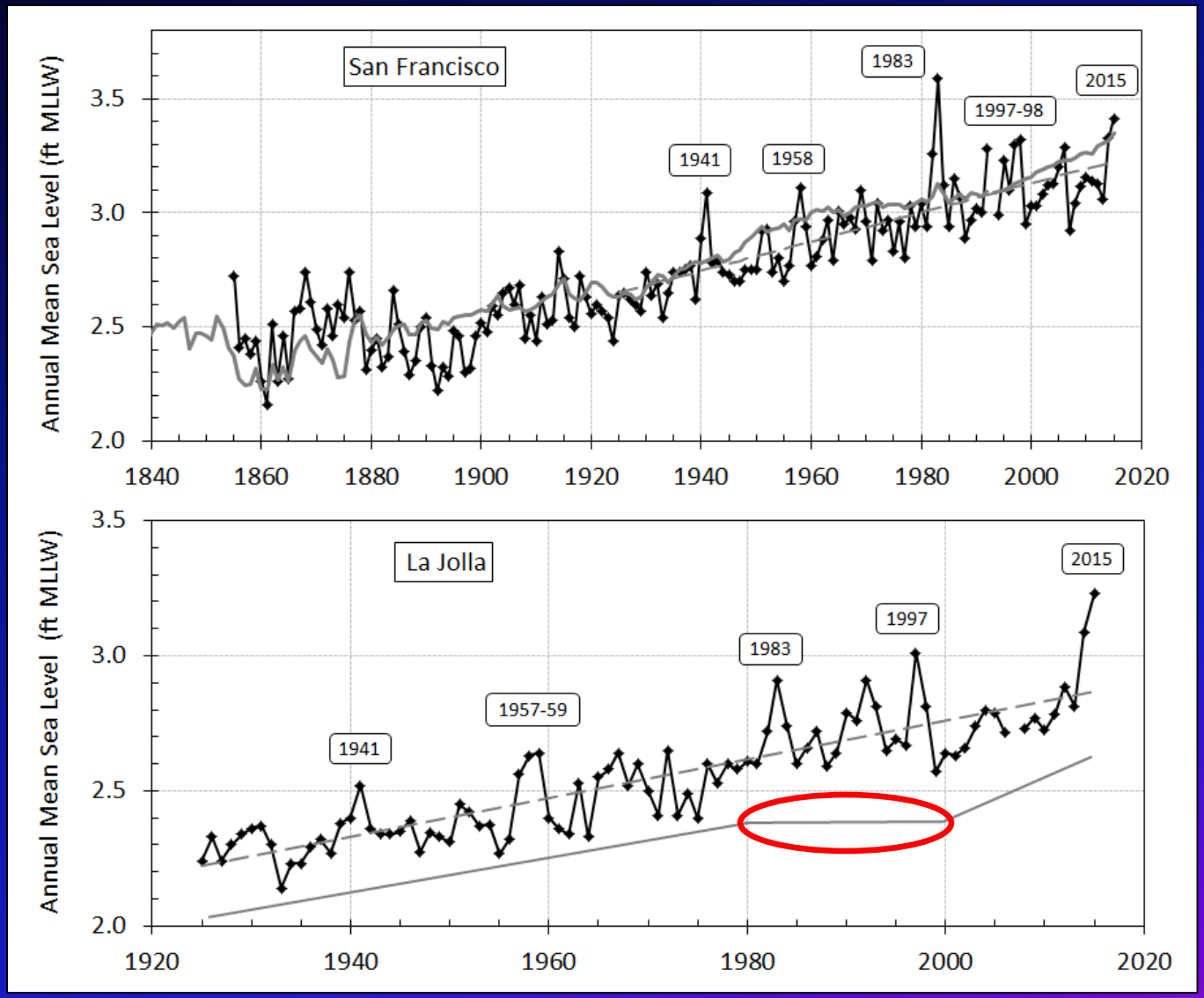
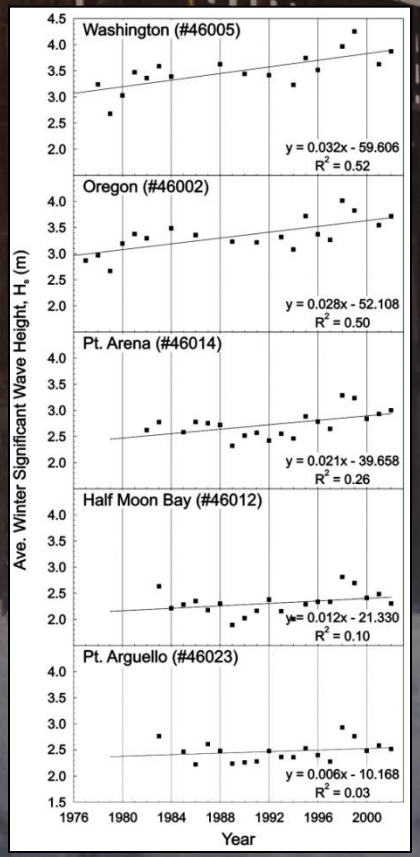
Regional Sea Level Rise



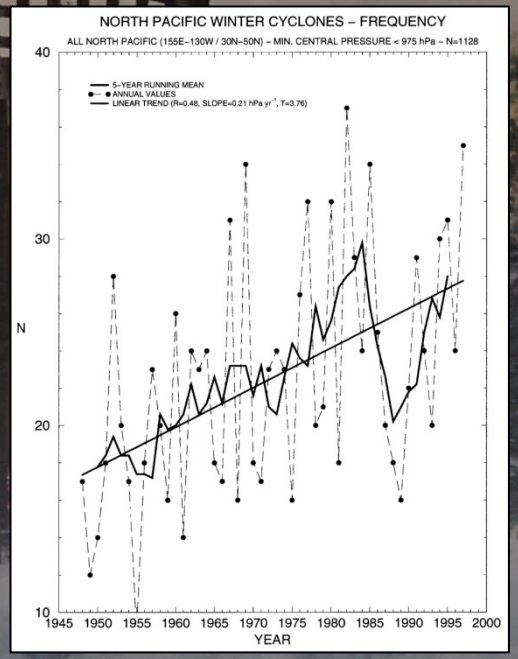
Flick et al. (2016)

Recent Findings- Storms

- Storms and average winter and extreme waves are getting larger and more frequent for much of U.S. West Coast

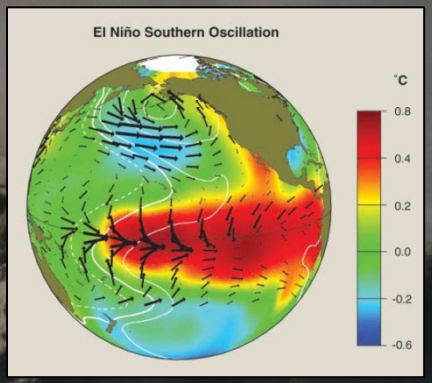


Allan and Komar (2006)

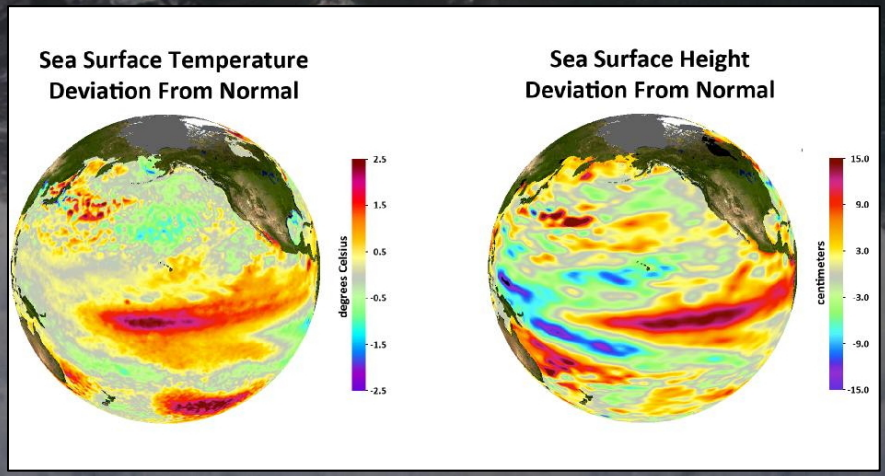


Graham and Diaz (2001)

- No evidence for changes in the strength or frequency of El Niños over last ~150 years (Ray and Giese, 2012) but perhaps a shift in styles



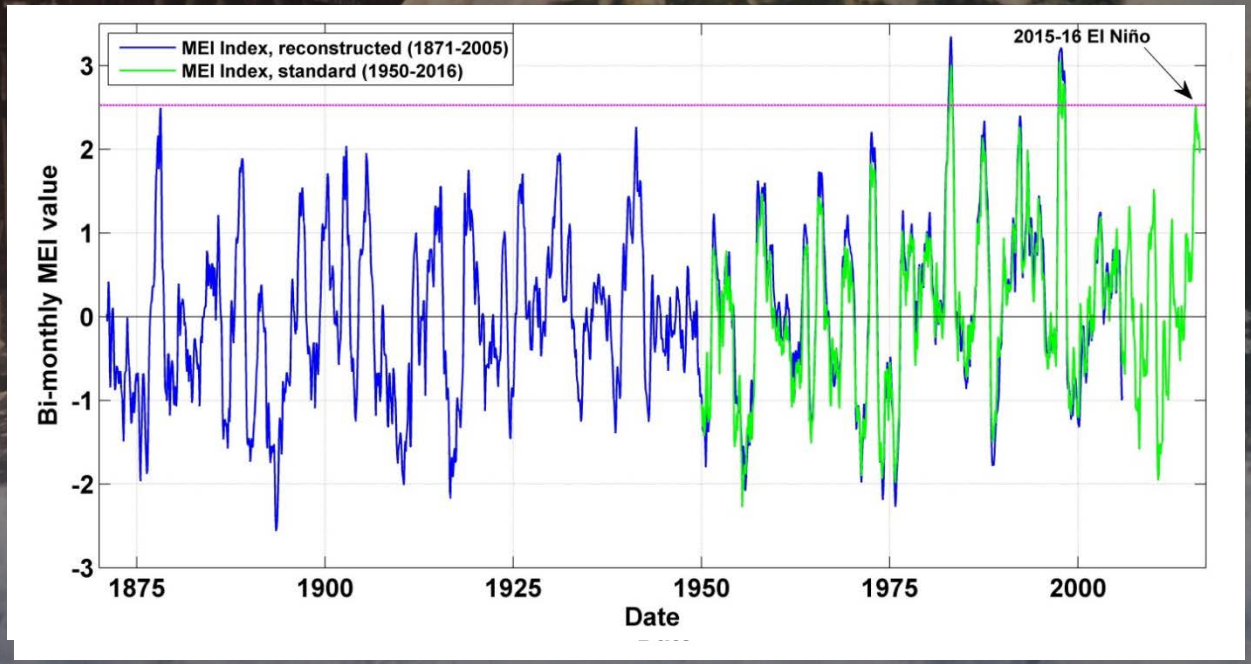
McPhaden et al. (2006)



Lee and McPhaden (2010)

2015-16 El Niño Impacts in California

- SST conditions at or above historical extreme El Niños
- Water level anomalies +15-20 cm across California
- Wave energy > 50% above the average winter
- Top 3 El Niño Events since at least 1870



Ventura Pier, December 2015 (Ricky Staub)

USGS

2015-16 El Niño Impacts in California

USGS

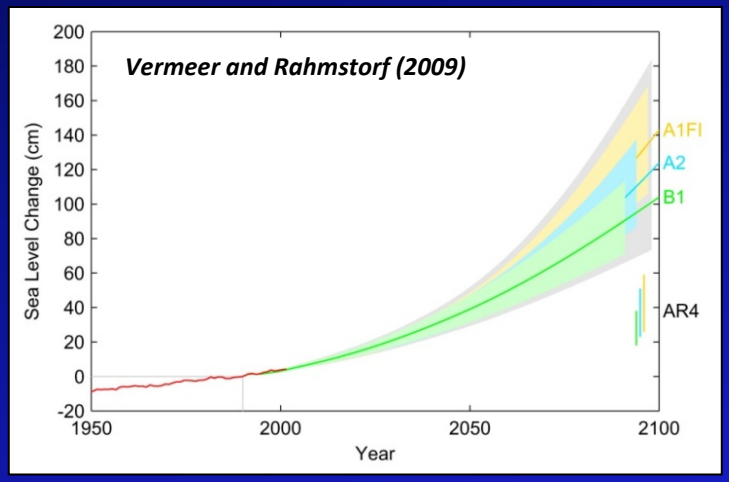
2015-16 El Niño Shoreline Change

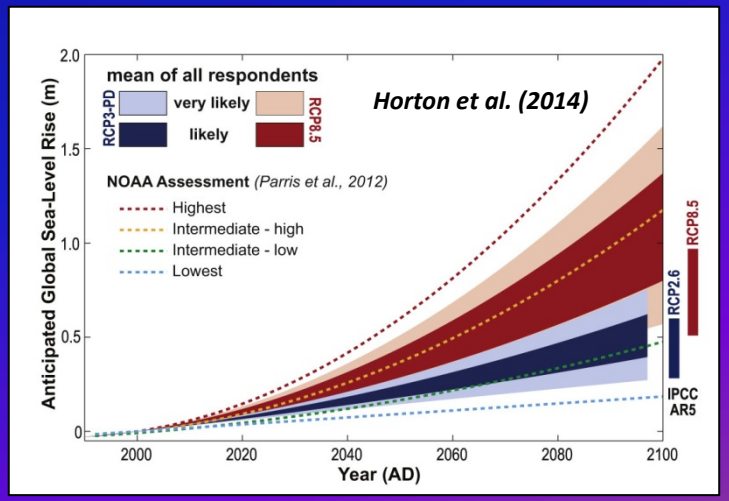
- Most significant winter beach erosion in the historical record across CA
- 80% more erosion than the average winter
- Shoreline retreat 2-5 times the prior winter

USGS

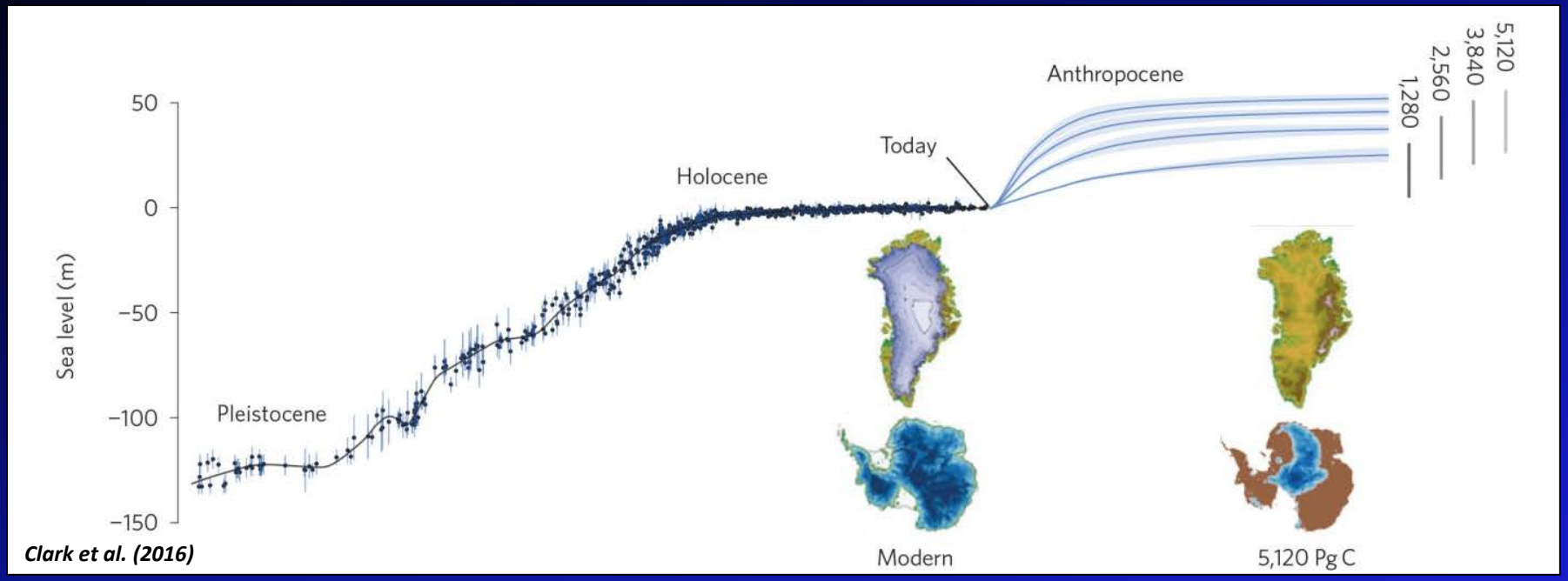
Global Sea Level Projections (by 2100)

- **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'
  - New paper in *Atmospheric Chemistry and Physics*
- **0.26 to 0.82 m** Intergovernmental Panel on Climate Change (*IPCC*, 2014)
  - ice sheet contributions from Greenland (7 m stored) and Antarctica (60 m + stored) conservatively included (excluded in AR4: IPCC, 2007)
- **0.4 to 1.2 m** Horton et al. (*QSR*, 2014)
  - expert assessment of median range





Sea Level (Far) Beyond 2100



Clark et al. (2016)

- **Up to 50 m+ SLR expected over the next 10,000 years depending on emissions scenario**
- **With net zero future emissions we are committed to 1.7 m of SLR**
- **Same carbon emissions in 21st century will commit us to 9 m more of SLR**
- **Lag of sea-level rise behind temperature forcing reflects the long timescale of ice-sheet response to a climate perturbation**
- **Policy decisions made in the next few years to decades will have profound impacts on global climate, ecosystems and human societies for millennia**

Projections for San Francisco Area

SLR for San Francisco (NRC, 2012)

-28 cm of sea level rise by 2050 (range 12-61 cm)
-92 cm of sea level rise by 2100 (range 42-166 cm)

Storms for California

-No significant changes in wave height
-Extreme events approach from ~10-15 degrees further south

El Niño for 21st Century

-More frequent extreme events
-Doubling of winter erosion
-Wave energy increase by 30%

Net effect

-Today's 100-year coastal water level event is projected to occur every 1-5 years by 2050 for much of California
-Greatest impacts on low-lying coastal areas (e.g., Stinson Beach, San Francisco Bay)

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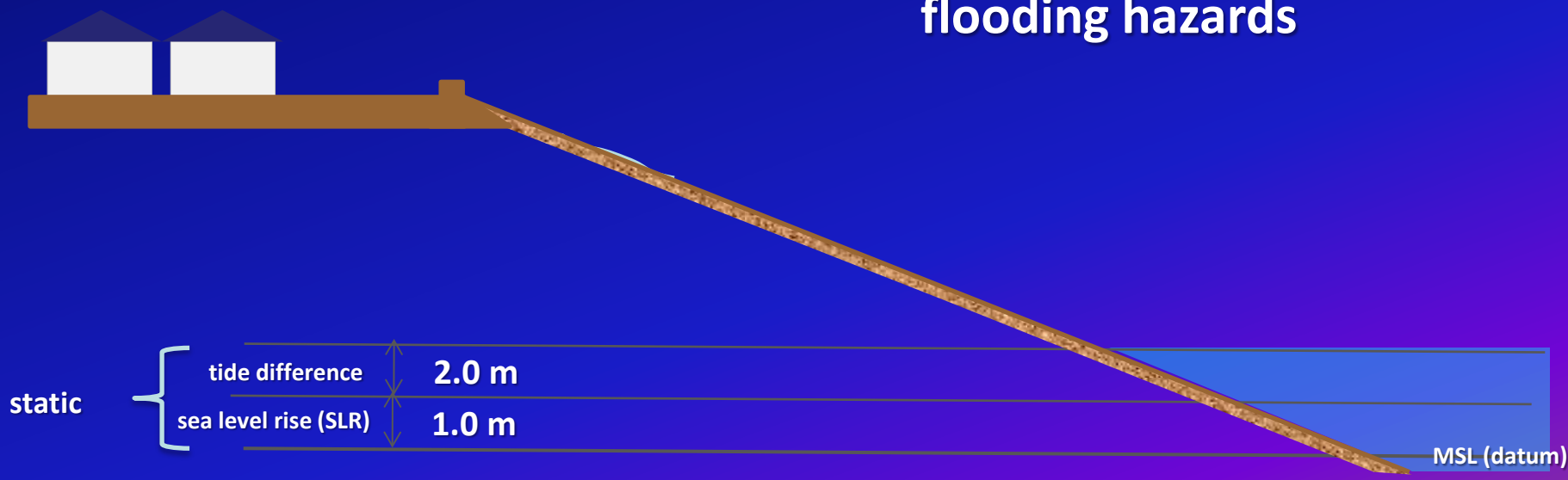
Coastal Vulnerability Approaches

Static: NOAA SLR Viewer

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

"Bathtub" models under predict flooding hazards



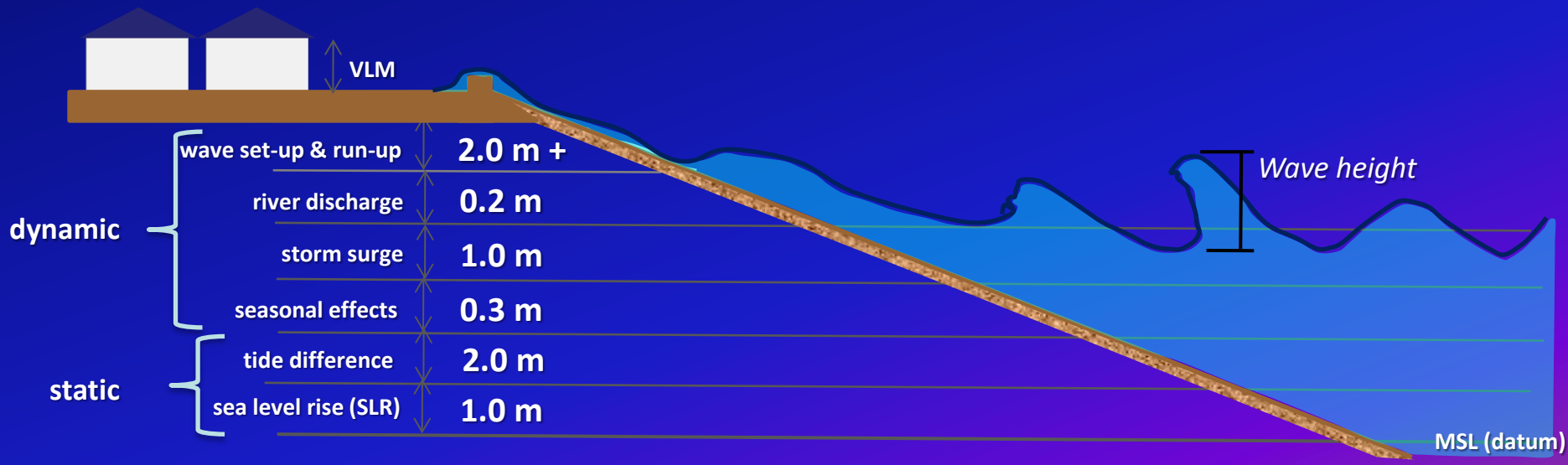
Coastal Vulnerability Approaches

Static: NOAA SLR Viewer

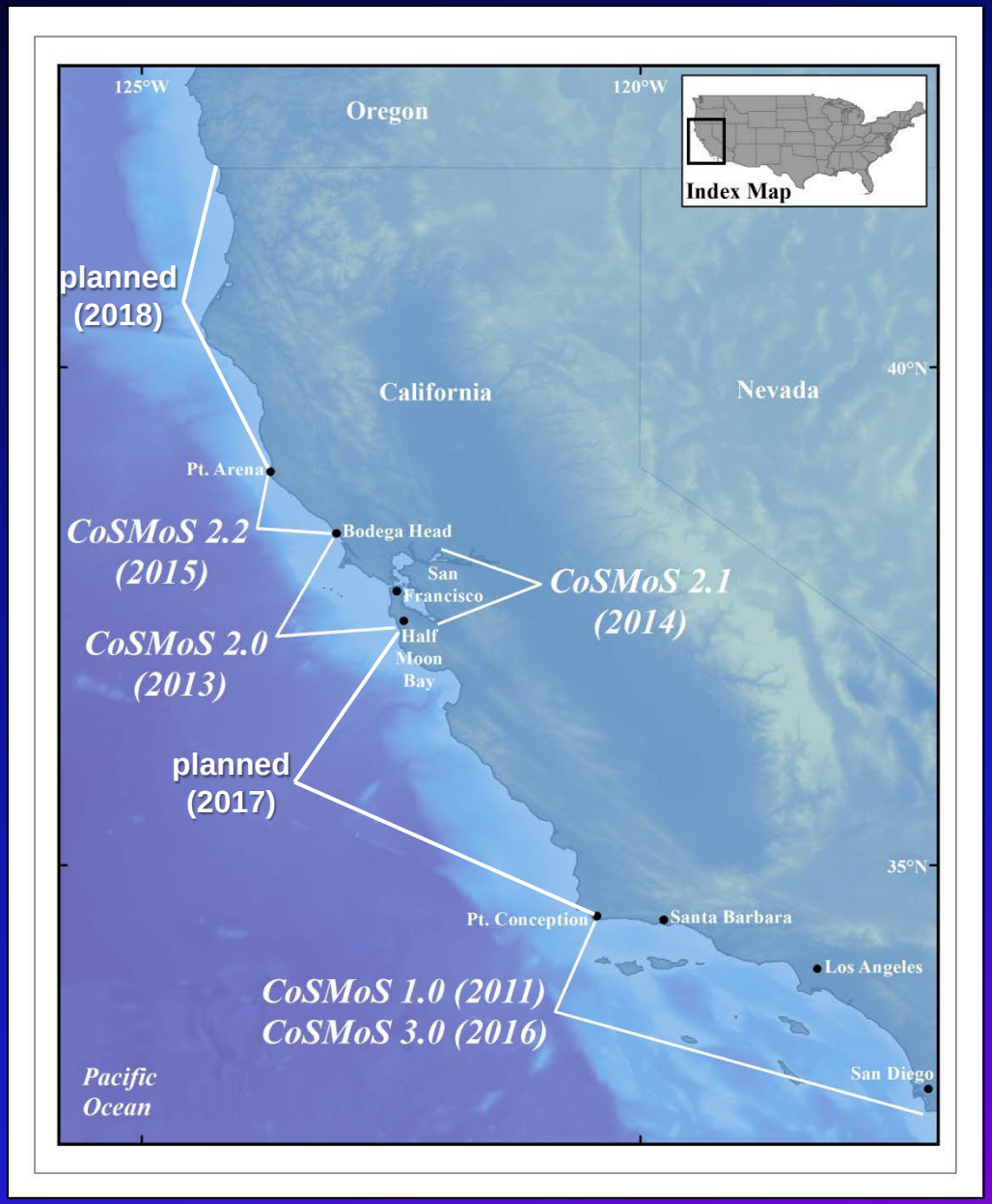
- Passive model, hydrological connectivity
- Tides only
- '1st order screening tool'

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 Coverage



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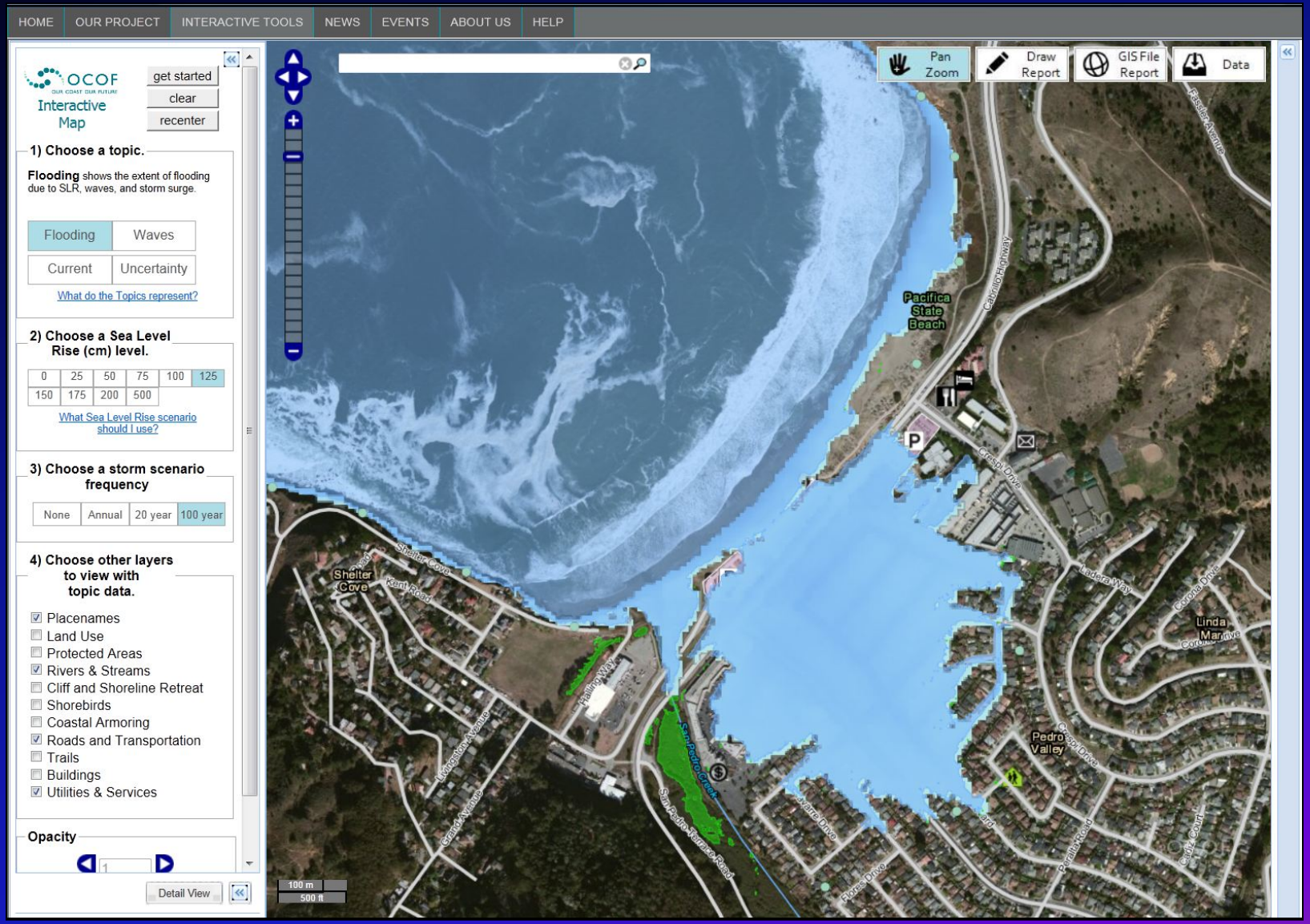
SLR + Storms (Pacifica)



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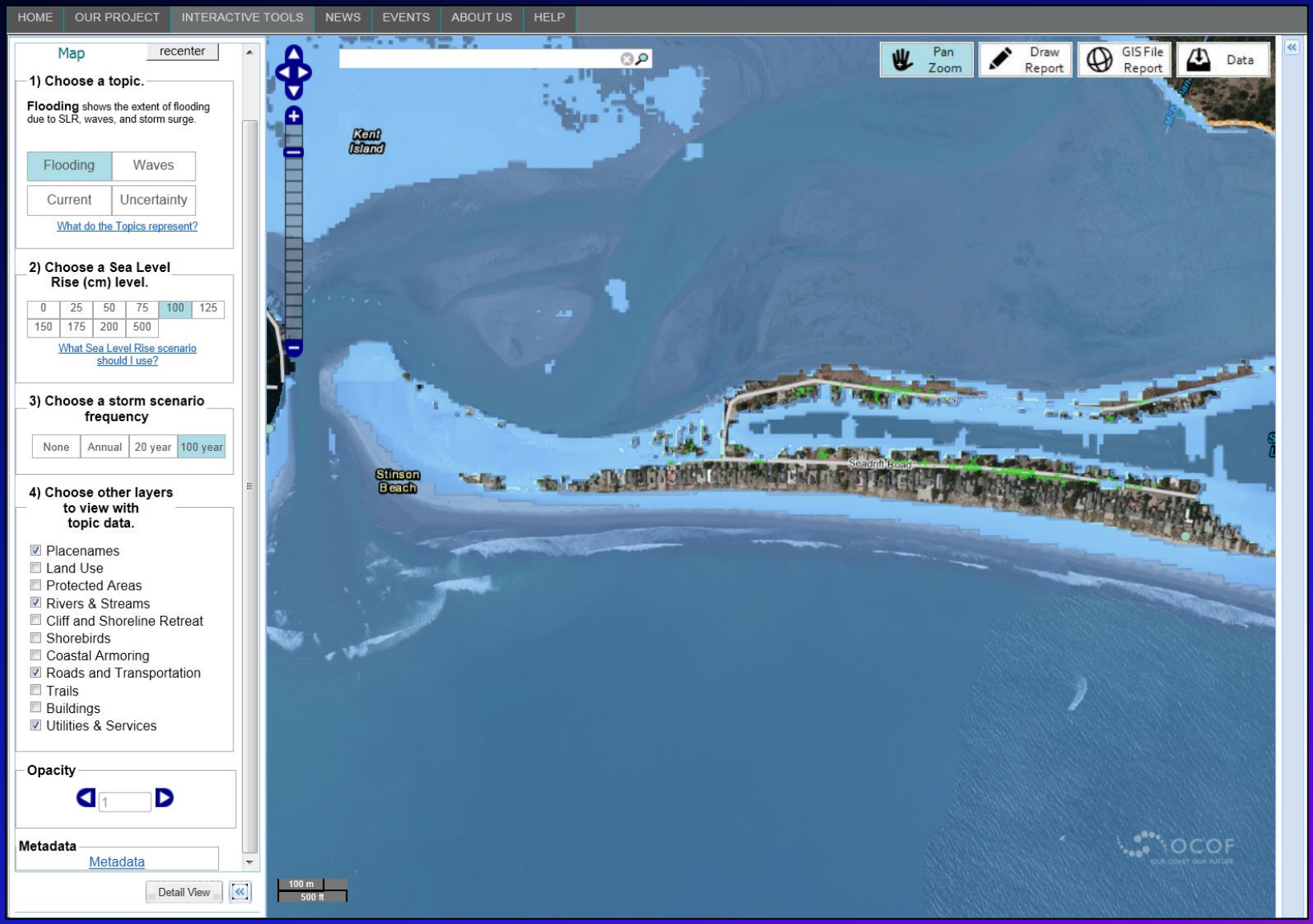
www.ourcoastourfuture.org **(Our Coast, Our Future)**

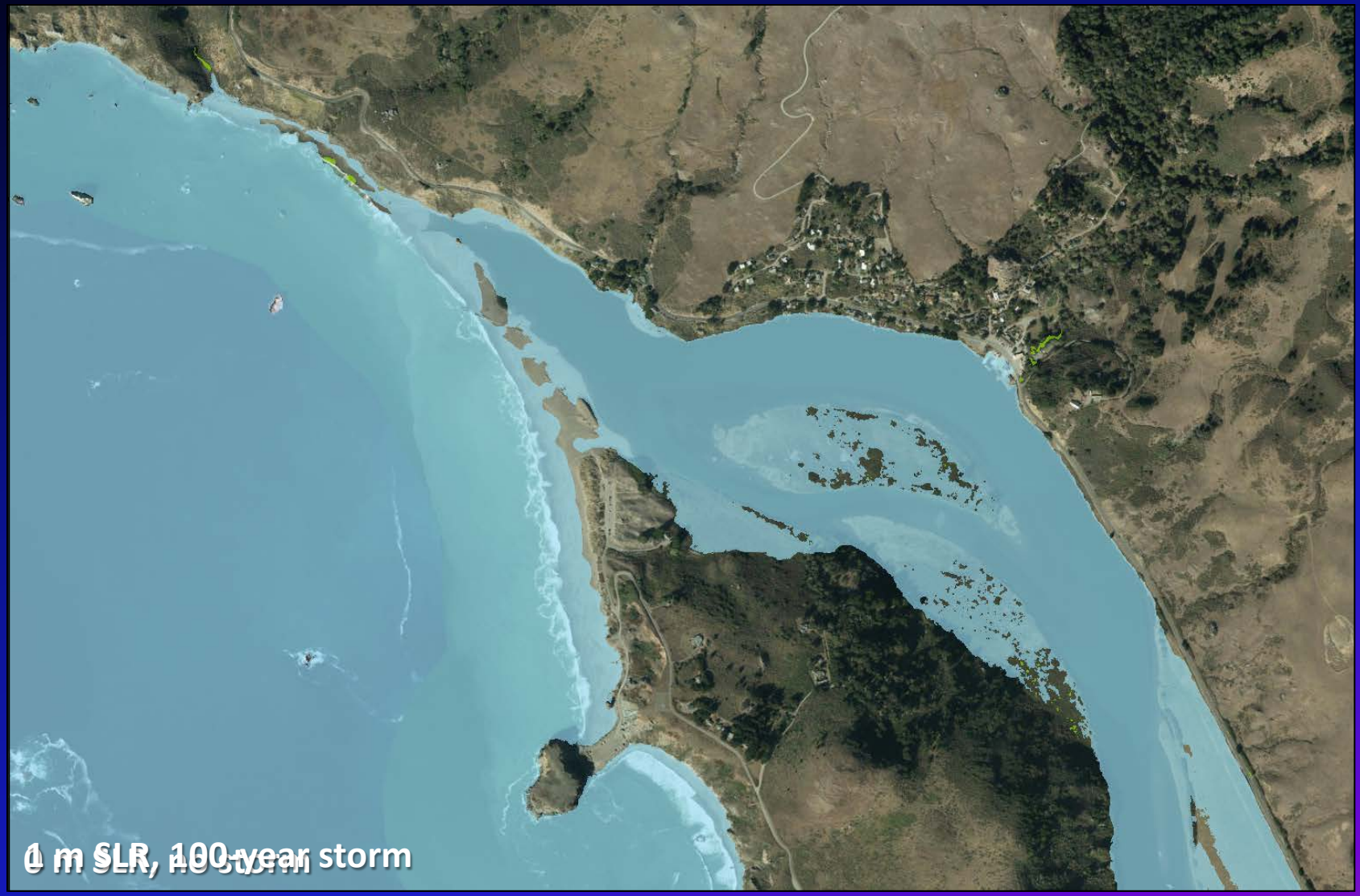
SLR + Storms (Stinson Beach)



USGS

www.ourcoastourfuture.org **(Our Coast, Our Future)**

SLR + Storms (Russian River)



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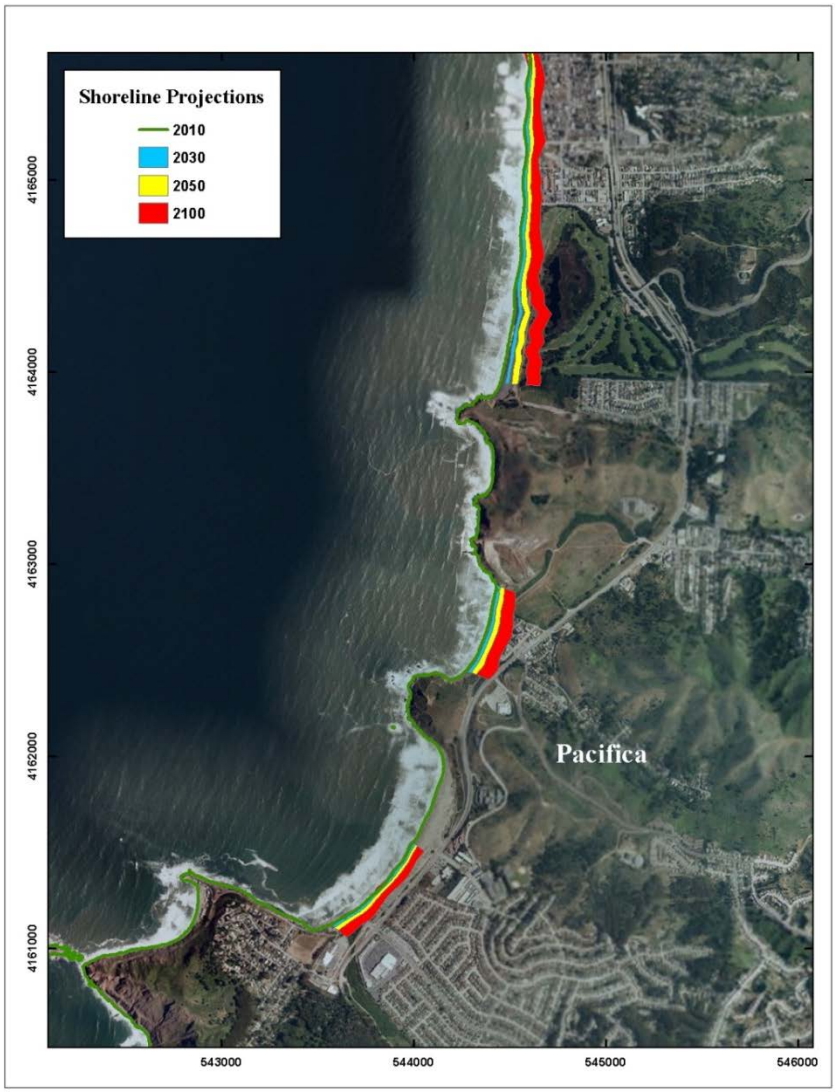
Coming soon to: *www.ourcoastourfuture.org* (Our Coast, Our Future)

Future Shoreline Change

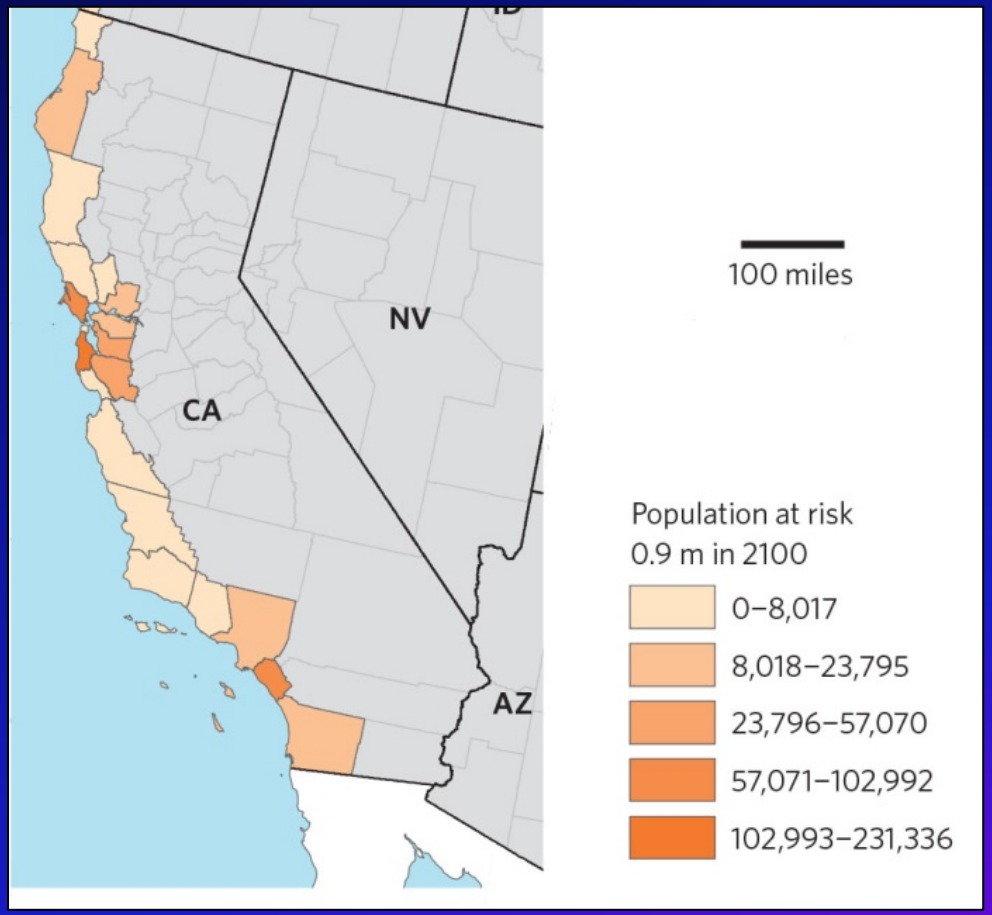


- Shoreline south of San Francisco is the most rapidly eroding section of coast in the state
- Rising sea level will drive shorelines further inland
- Reduced sediment supply from dams, dredging, aggregate mining

USGS

Societal Impacts

- 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 and $100 billion in property are threatened by climate change along the California coast over the next century (Pacific Institute Report)
- For CA the population at risk is 5 times greater when comparing future population growth vs. current population
  - Population at risk by 2100 for 1.8 m of SLR = 1,046,057
- 1982-83 El Niño storms caused ~$2.2 billion in storm damage to California, $1.1 billion in 1997-98



Hauer et al., Nature Climate Change, 2016

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Questions for the 21st Century

- What will the 21st century SLR curve actually look like?
- How will storm patterns change (esp. El Niño)?
- How will the shoreline evolve?
- How will coastal management decisions (e.g., beach nourishment, hard structures, levees, tidal marsh restoration) affect the dynamics of flooding and coastal change?

*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.ourcoastourfuture.org*

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Image courtesy of A. Louie