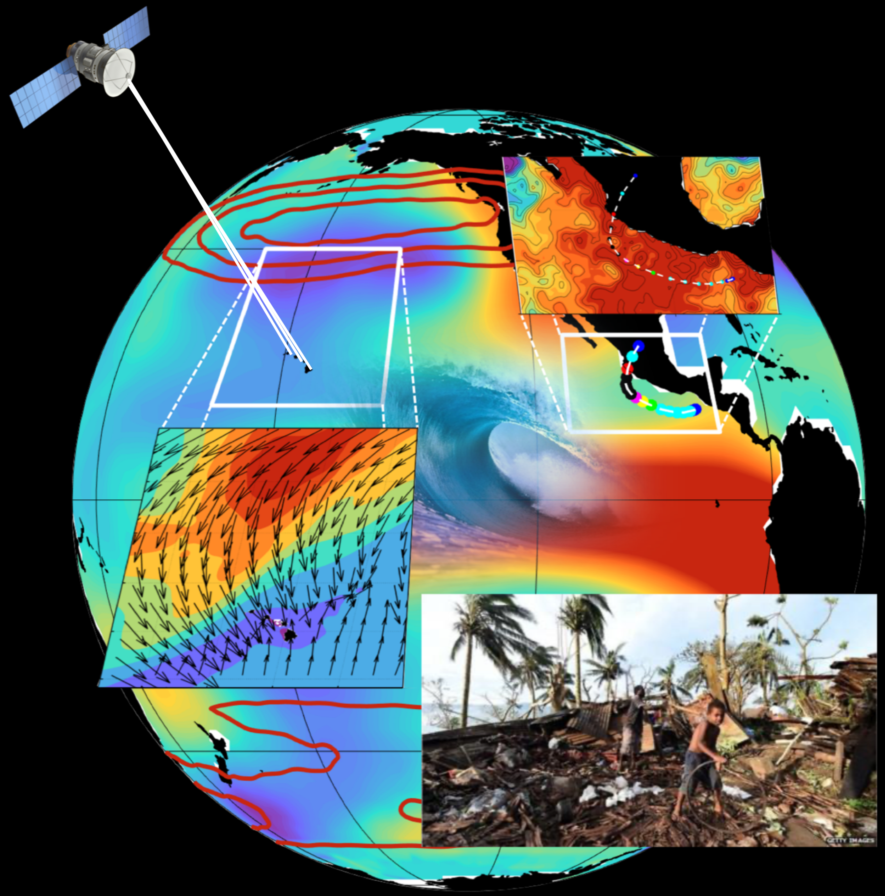


Climate-driven coastal vulnerability – The worldwide influence of El Niño Southern Oscillation

Julien Boucharel

LEGOS

Institut de Recherche pour le Développement
FRANCE

... the susceptibility of a coastal area to be affected by either flooding or erosion processes *Anfuso et al., 2021, JMSE*

New Zealand

Oahu, Hawaii

Maldives

- ➔ **600 million people live at less than 10 meters above sea level.**
- ➔ **Without mitigation = displacement of up to 200 million people in 100 years**

What causes flooding / erosion?

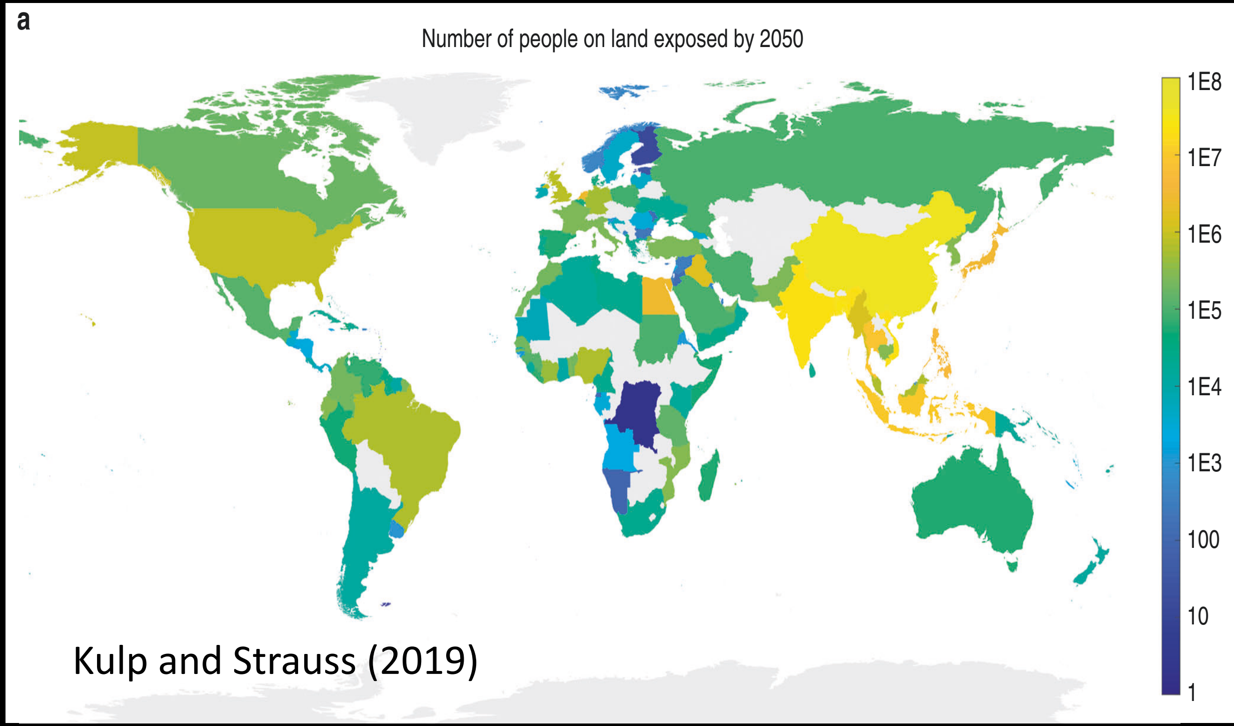
➔Anthropogenic constraint

Agricultural practices:

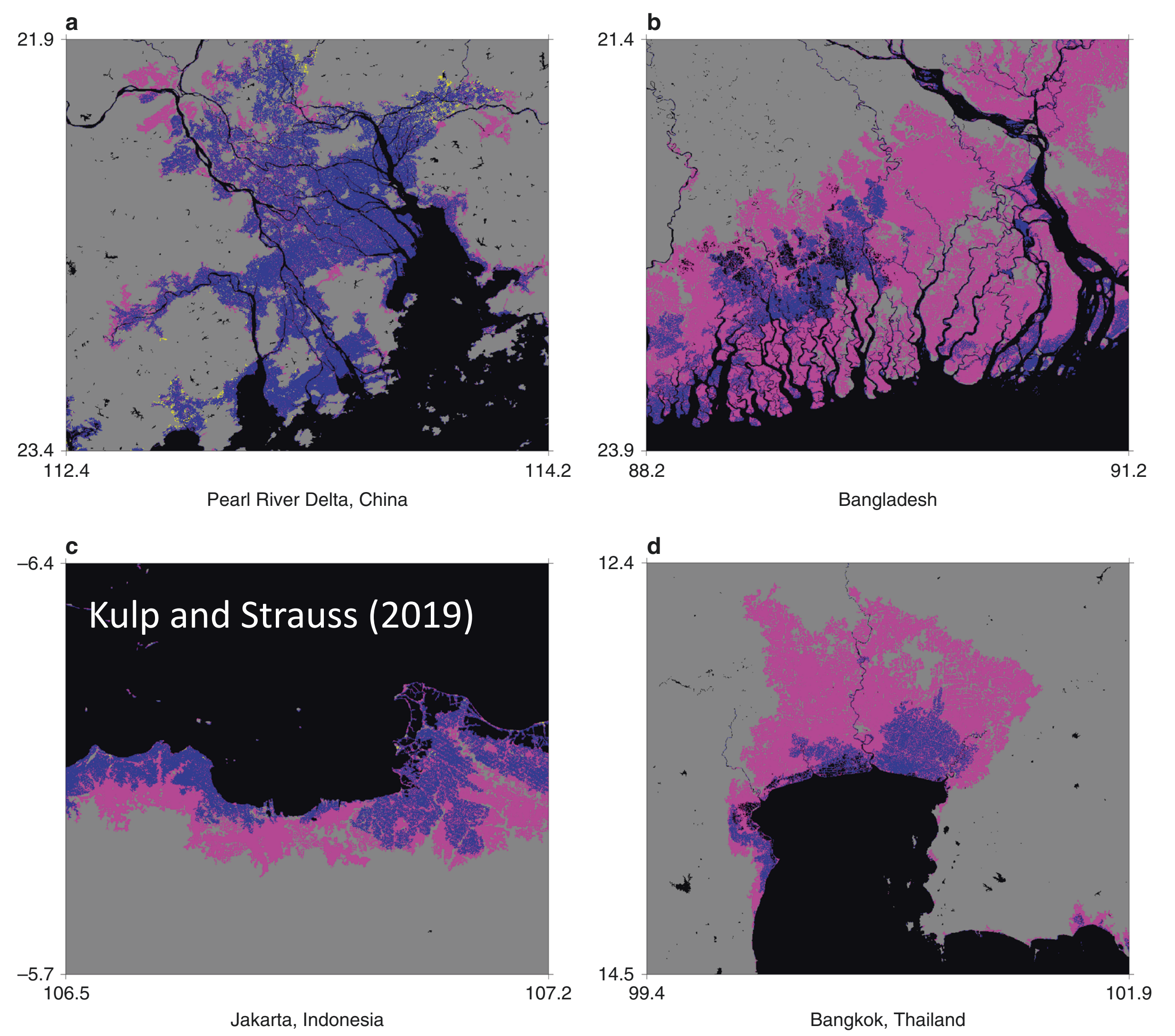
- Deforestation
- Soil tillage
- Damming

What causes flooding / erosion?

➔Anthropogenic constraint

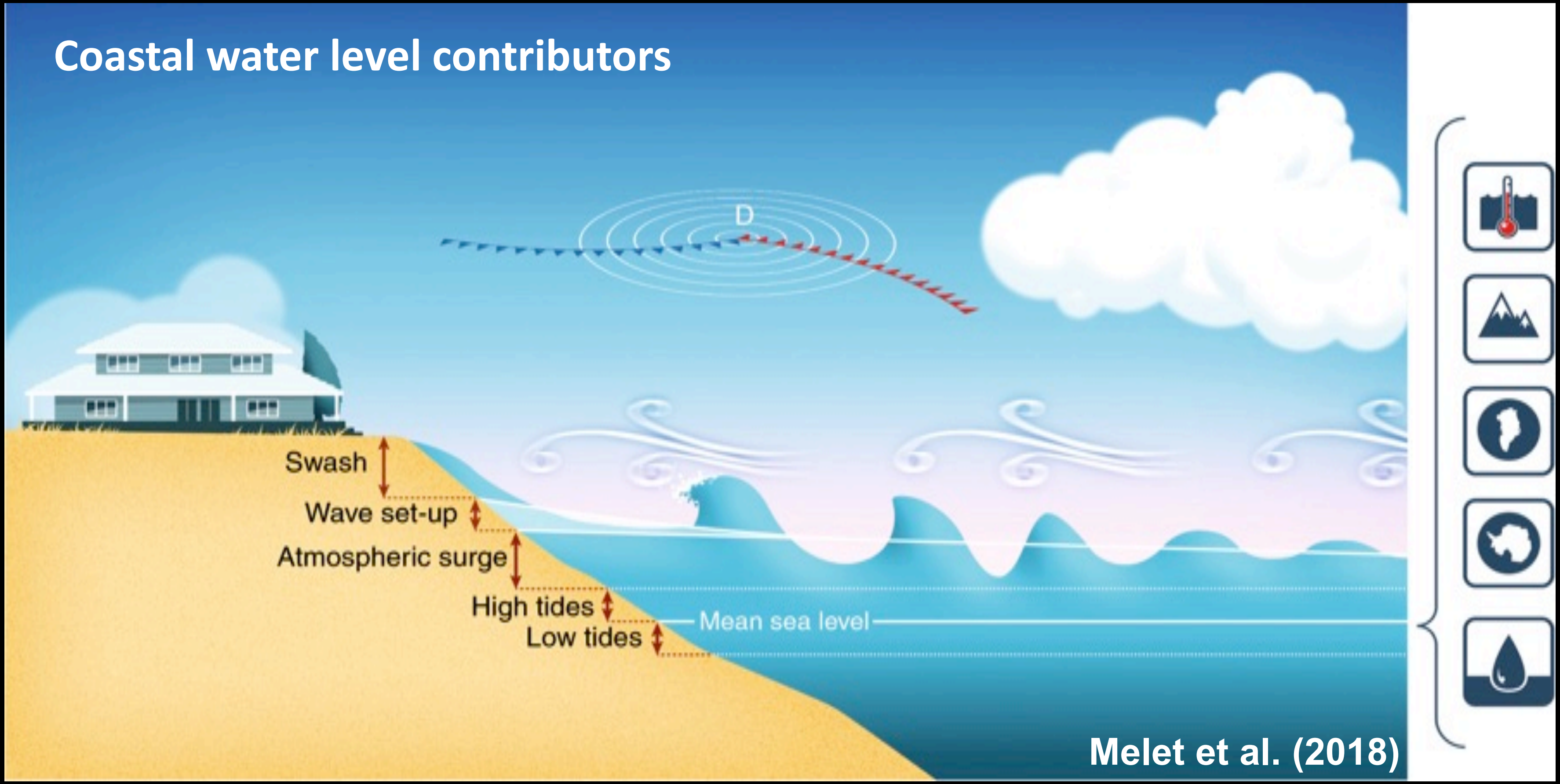


Coastal population increasingly more at risk

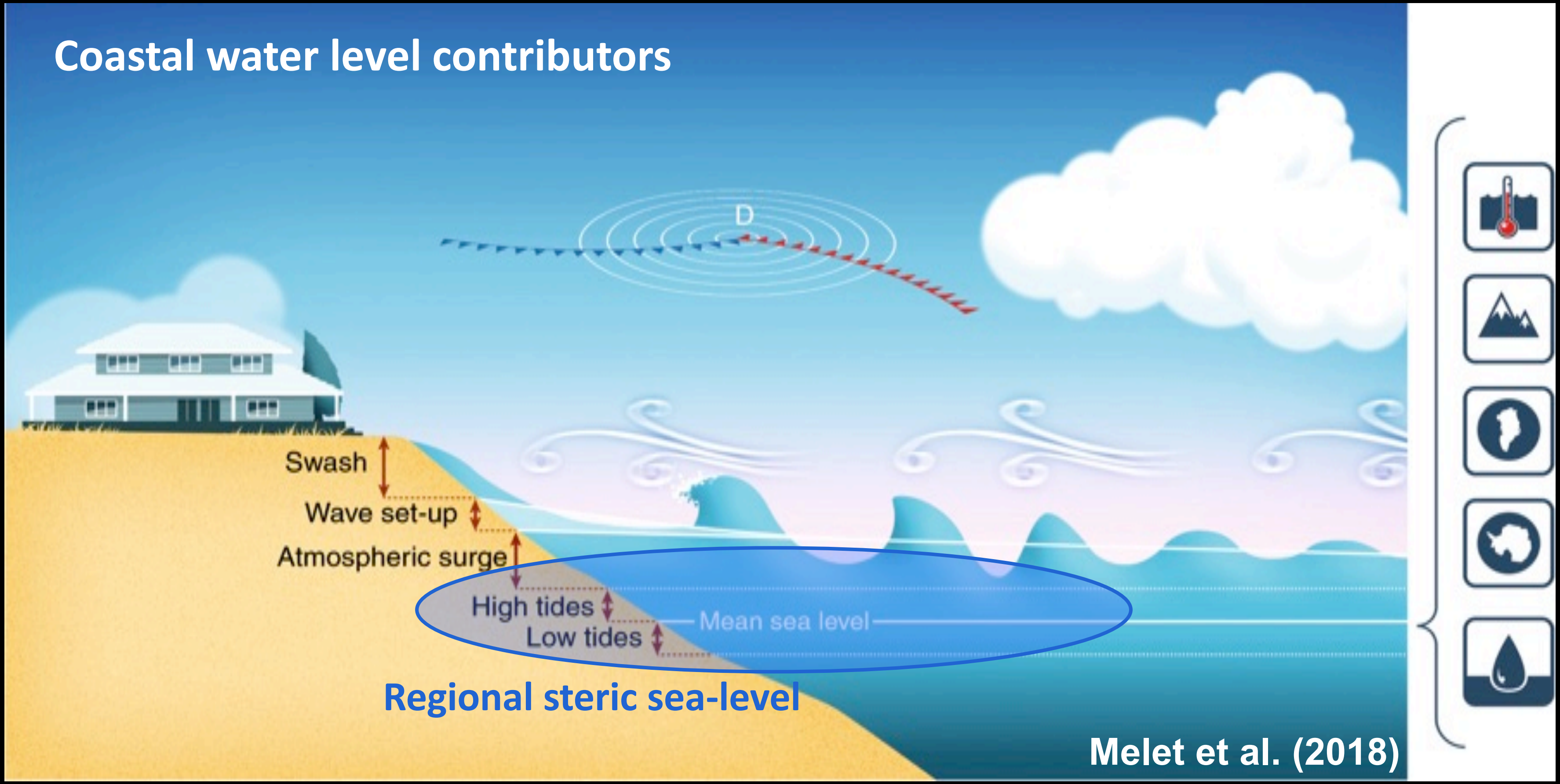


Permanent inundation surfaces predicted by topographic elevation model given the median K17/RCP 8.5/2050 sea-level projection.

➔Natural constraint

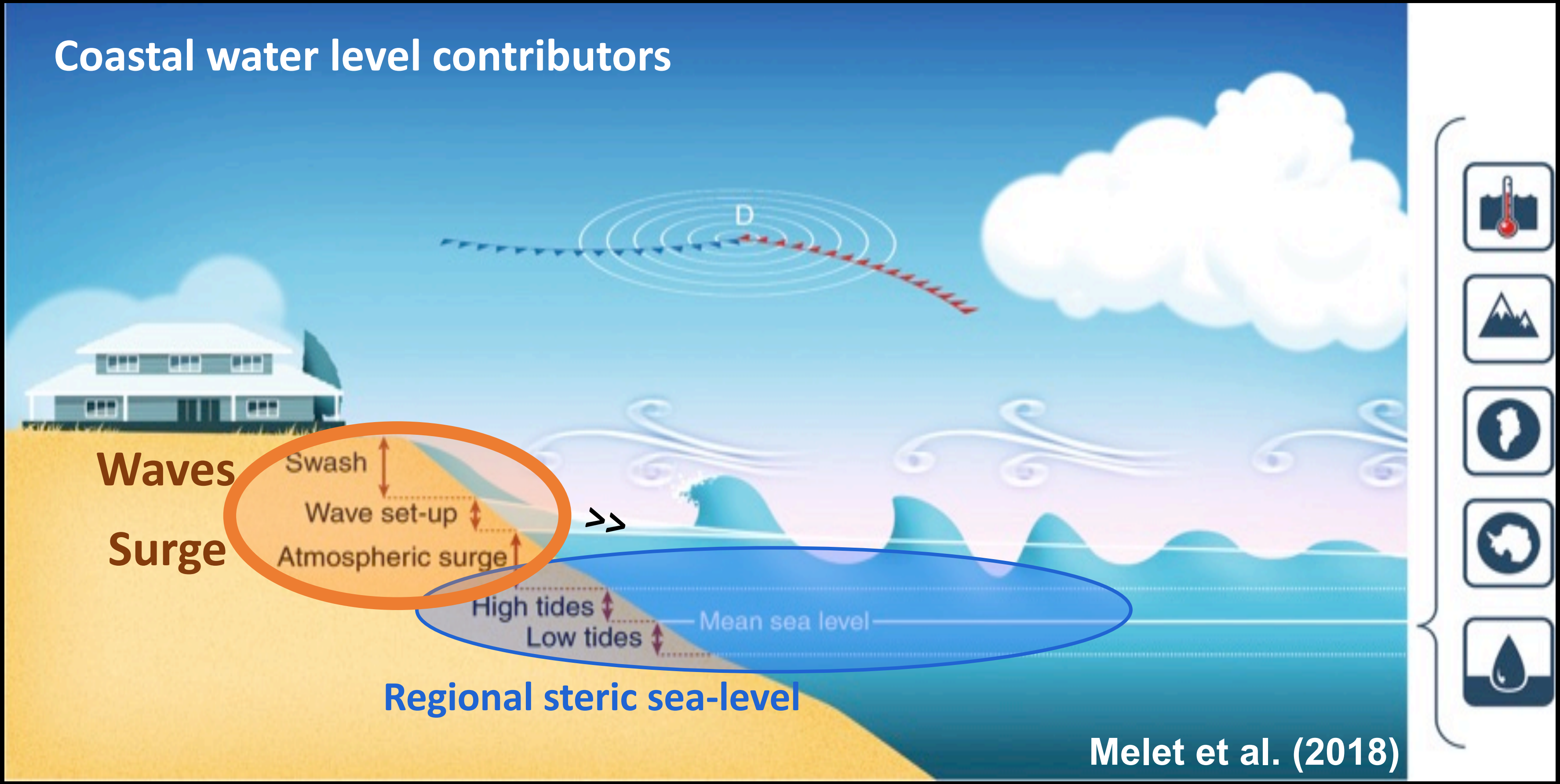


→Natural constraint



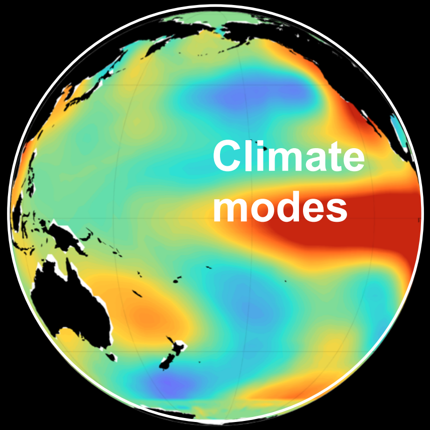
What causes flooding / erosion?

➔Natural constraint

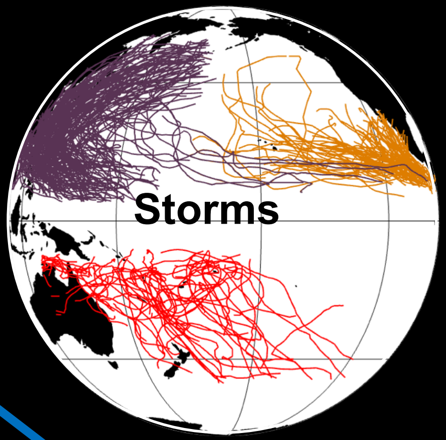


A NEW FRAMEWORK

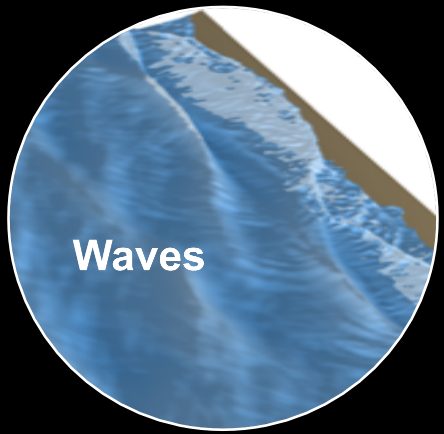
Objectives: Understanding the connections between global climate variability and coastal hazards



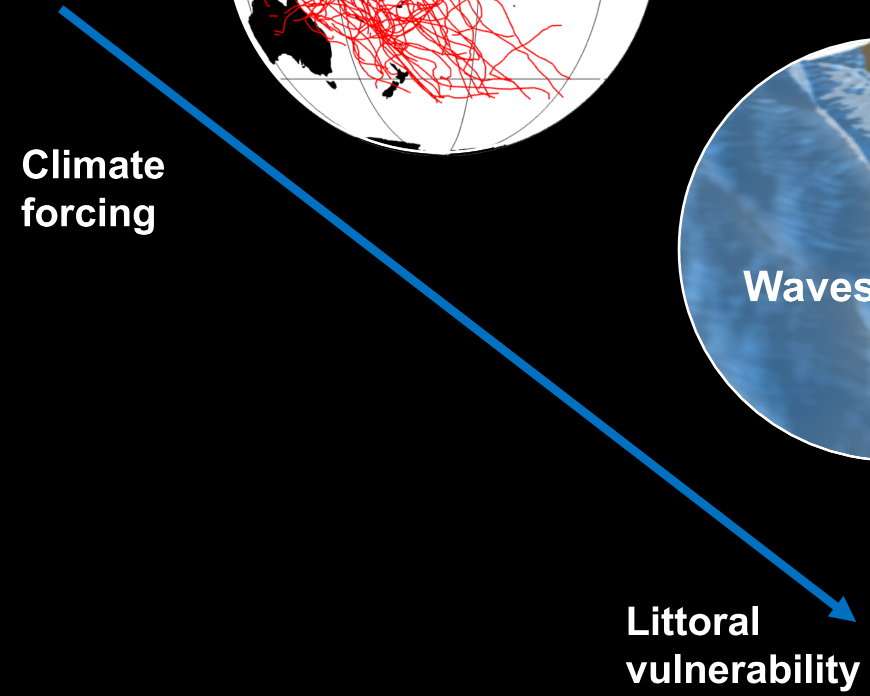
Basin scale



Beach scale



Human scale



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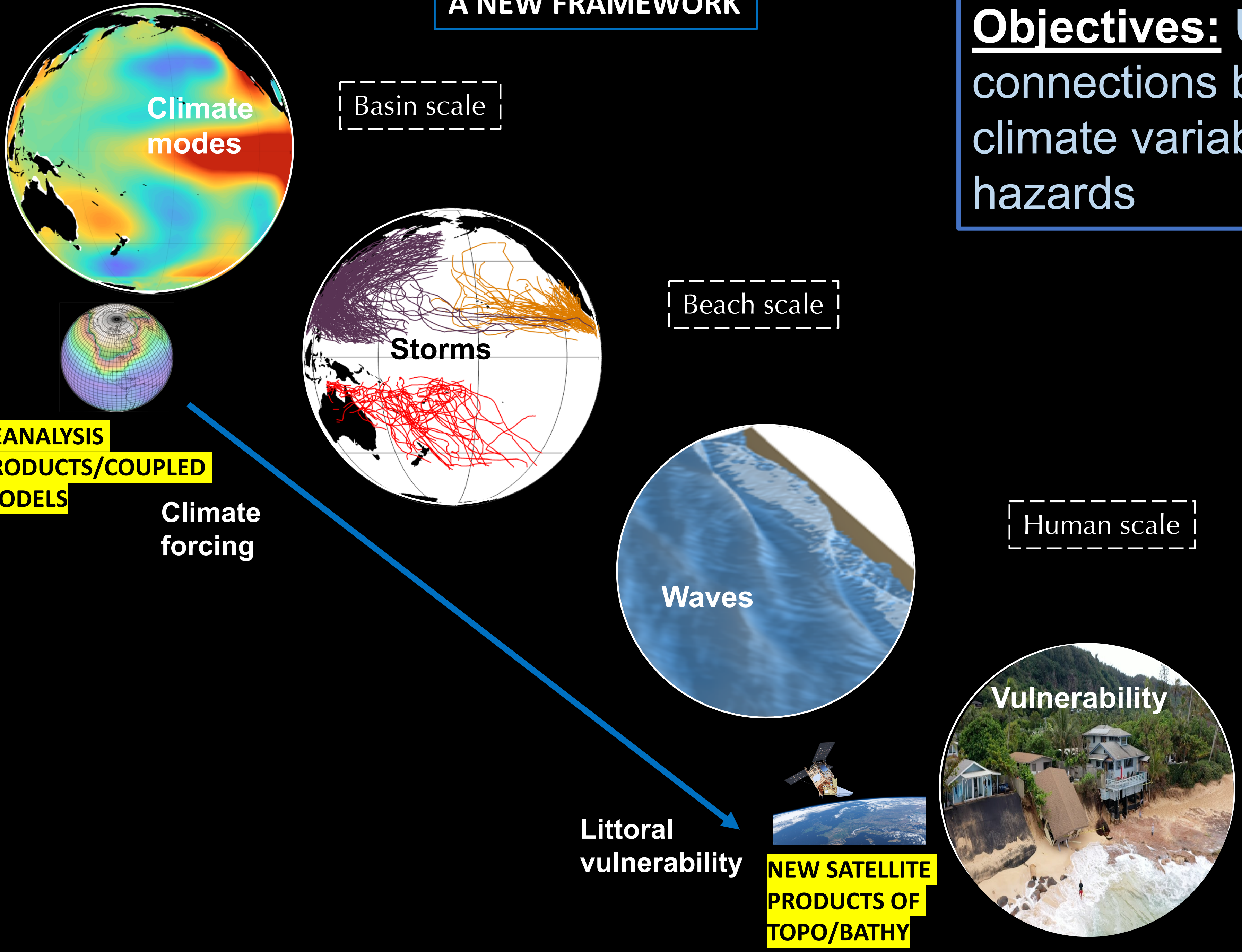

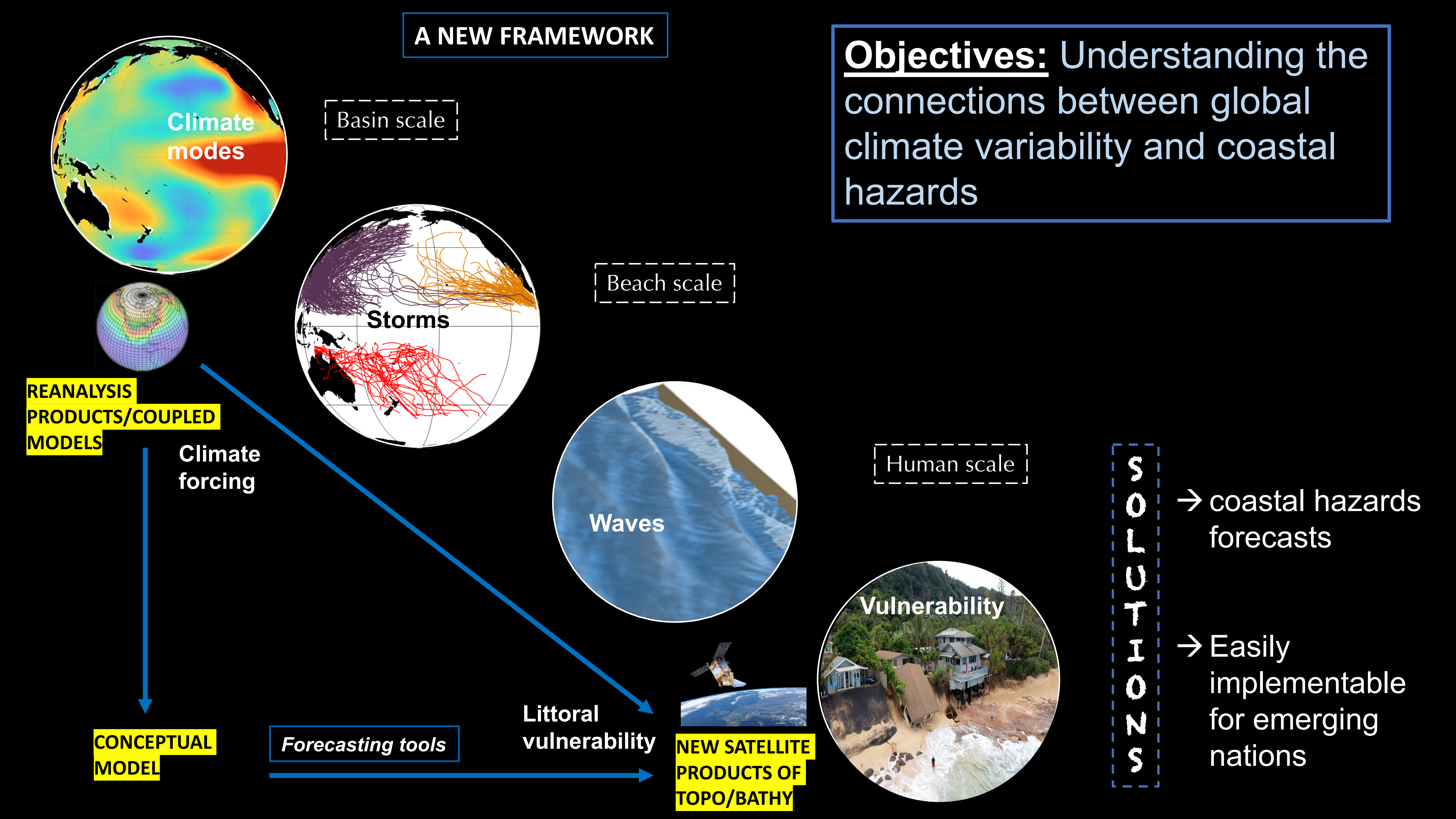

A NEW FRAMEWORK
Objectives: Understanding the connections between global climate variability and coastal hazards
Climate modes
Basin scale
Storms
Beach scale
Waves
Human scale
Vulnerability
REANALYSIS PRODUCTS/COUPLED MODELS
Climate forcing
CONCEPTUAL MODEL
Forecasting tools
Littoral vulnerability
NEW SATELLITE PRODUCTS OF TOPO/BATHY
SOLUTIONS
→ coastal hazards forecasts
→ Easily implementable for emerging nations

OUTLINE:

1) A new paradigm for the influence of El Niño on coastal wave extremes in the Pacific

2) The global influence of El Niño on coastal hazards

1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

nature geoscience | ARTICLES
PUBLISHED ONLINE: 21 SEPTEMBER 2015 | DOI: 10.1038/NGEO2539

Coastal vulnerability across the Pacific dominated by El Niño/Southern Oscillation

Patrick L. Barnard[1]*, Andrew D. Short[2], Mitchell D. Harley[3,4], Kristen D. Splinter[4], Sean Vitousek[1], Ian L. Turner[4], Jonathan Allan[5], Masayuki Banno[6], Karin R. Bryan[7], André Doria[8], Jeff E. Hansen[9], Shigeru Kato[10], Yoshiaki Kuriyama[6], Evan Randall-Goodwin[1,11], Peter Ruggiero[12], Ian J. Walker[13] and Derek K. Heathfield[13]

JGR Oceans

Research Article

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Research Letter | Open Access

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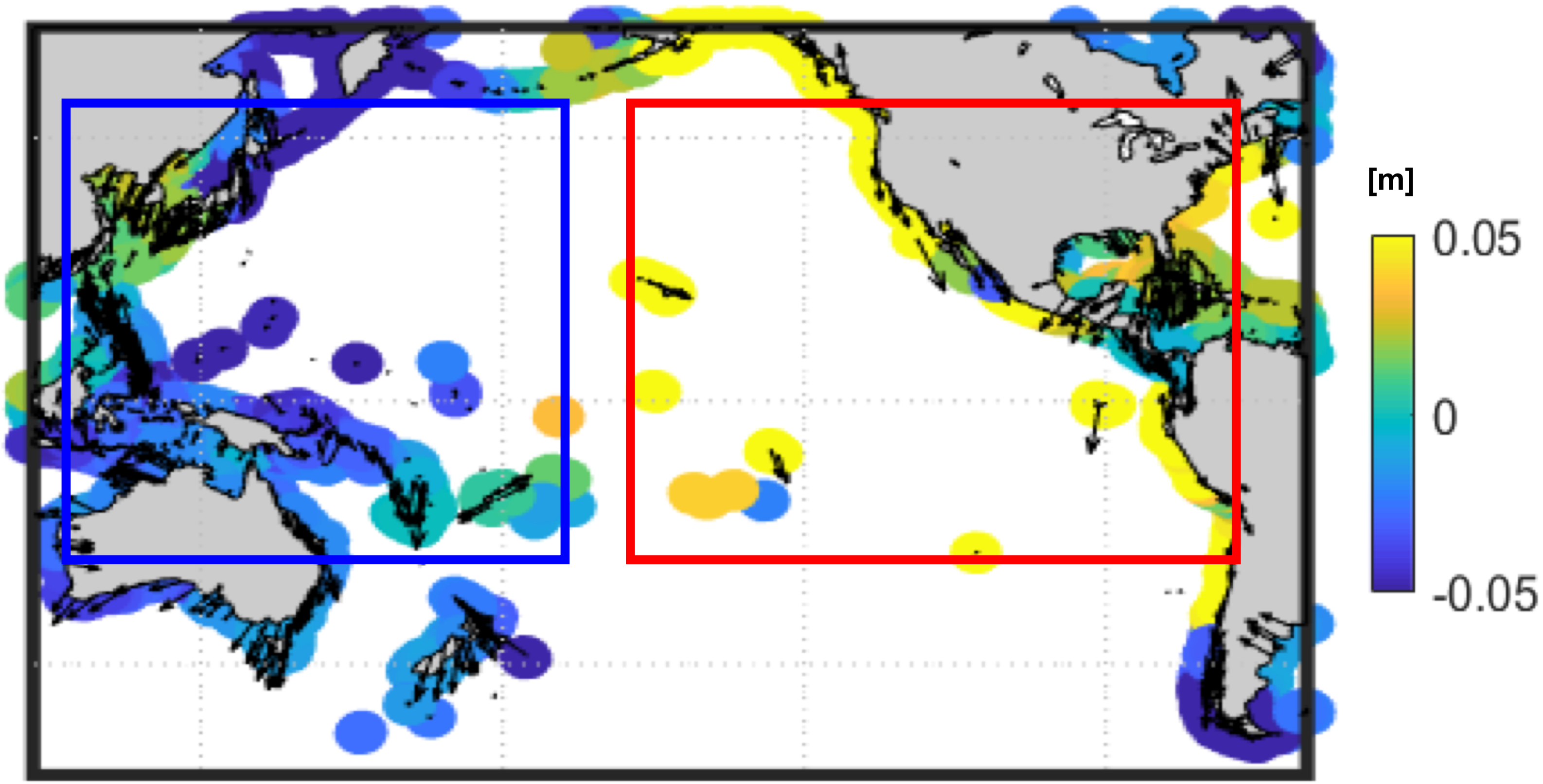
El Niño DJF composites



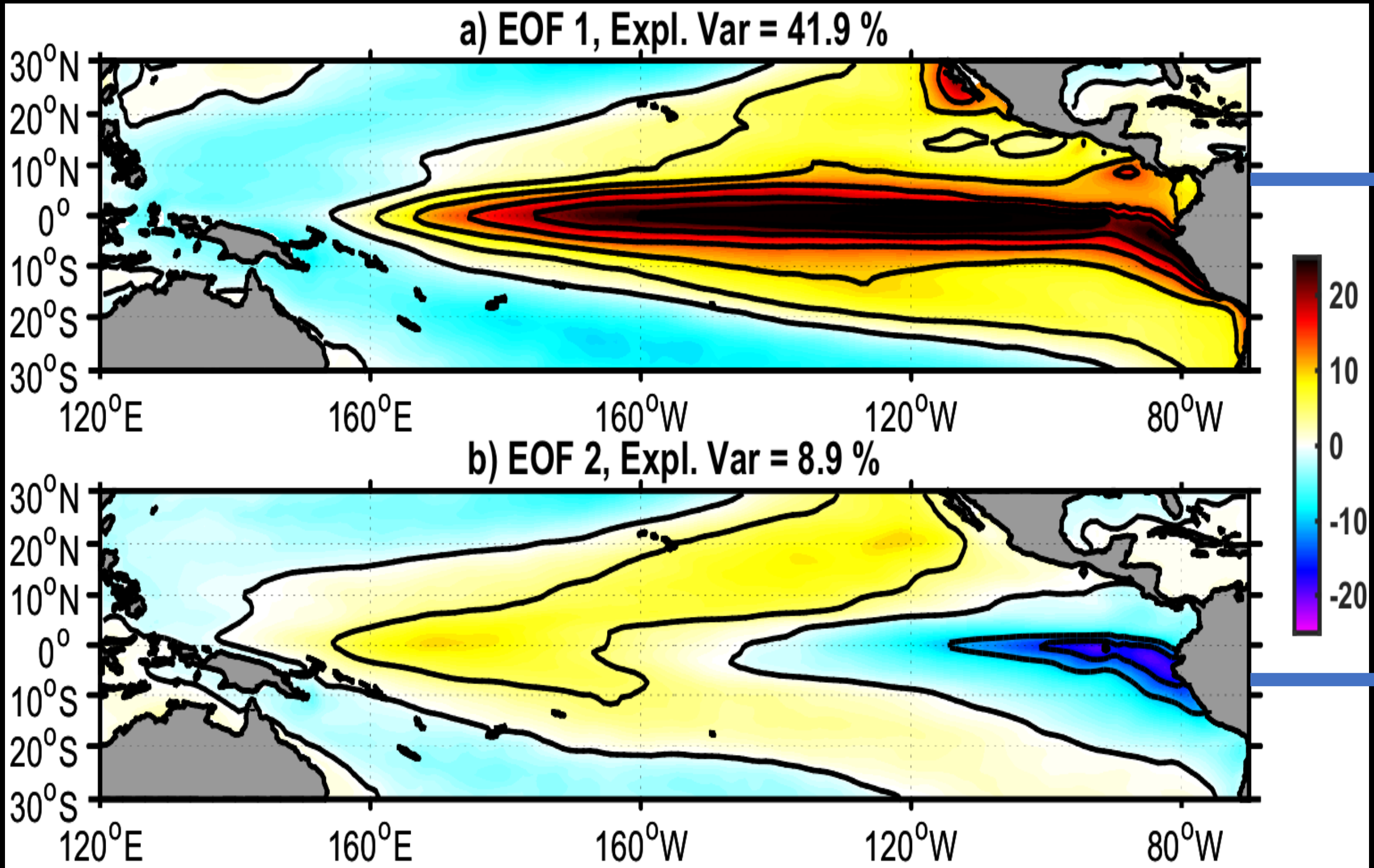
Wave run-up = sea level produced by waves at the shoreline

- At coasts with $\xi < 0.3$, $R = 0.043\sqrt{H_s L_0}$
- At coasts with $\xi > 0.3$, $R = 1.1\left[0.35\beta\sqrt{H_s L_0} + 0.5\left(H_s L_0\left(0.5625\beta^2 + 0.004\right)\right)^{1/2}\right]$

Stockdon et al. (2006)

1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

ENSO spatial complexity



Spatial patterns of interannual SST anomalies decomposition into EOF

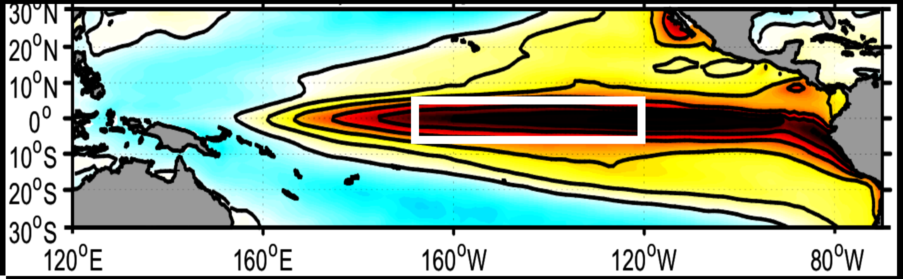
Eastern Pacific (conventional) El Niño

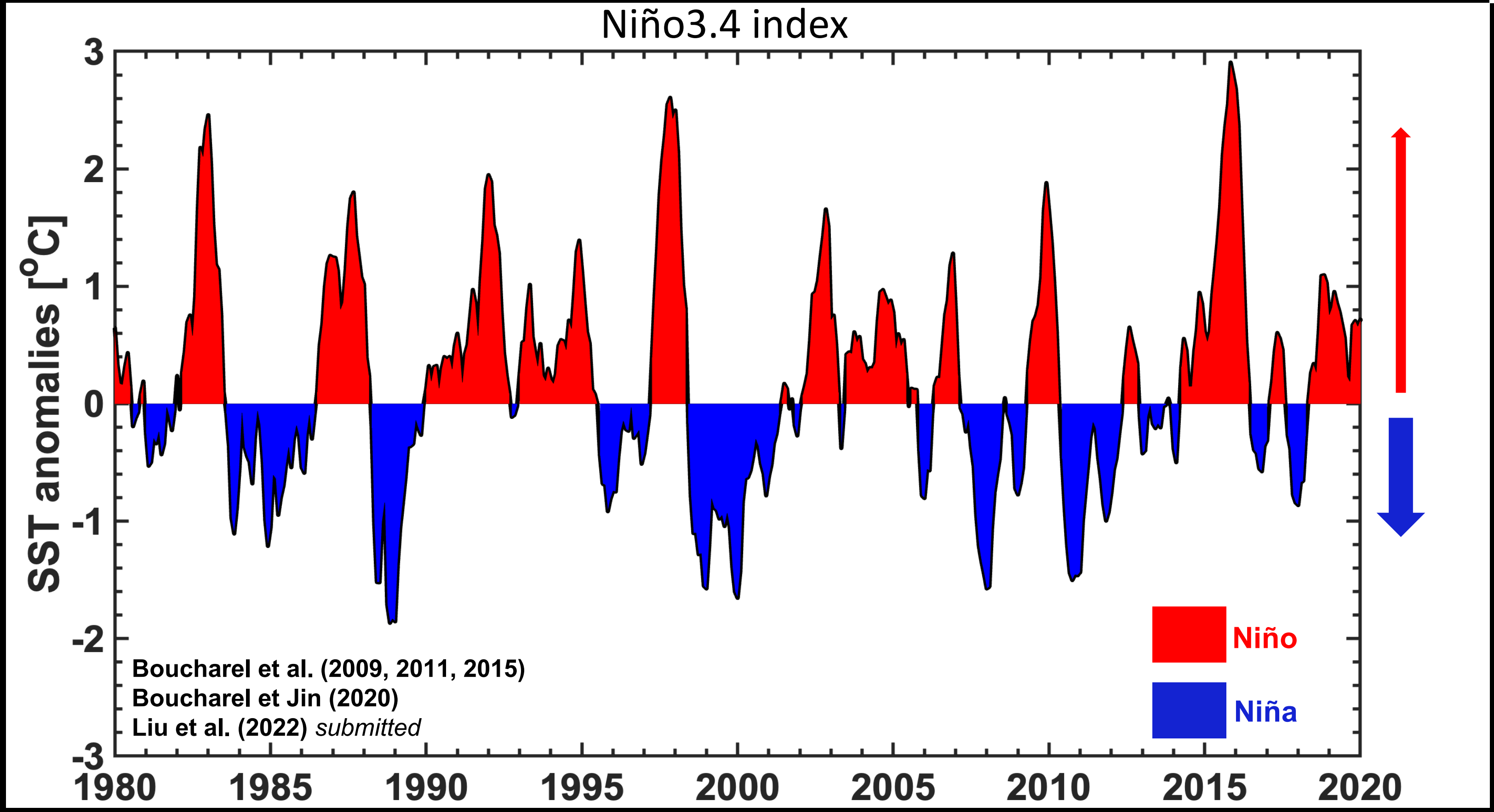
Central Pacific (Modoki) El Niño

Kug et al. (2009)
Kao and Yu (2009)

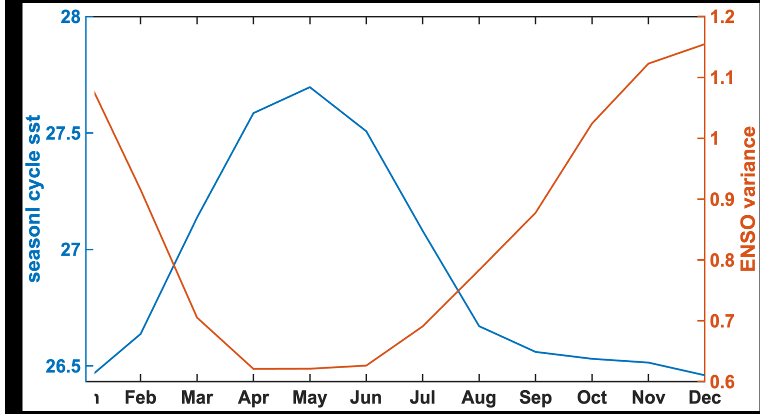
1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

ENSO temporal complexity





El Niño / La Niña asymmetry



Different impacts of ENSO depending on the season

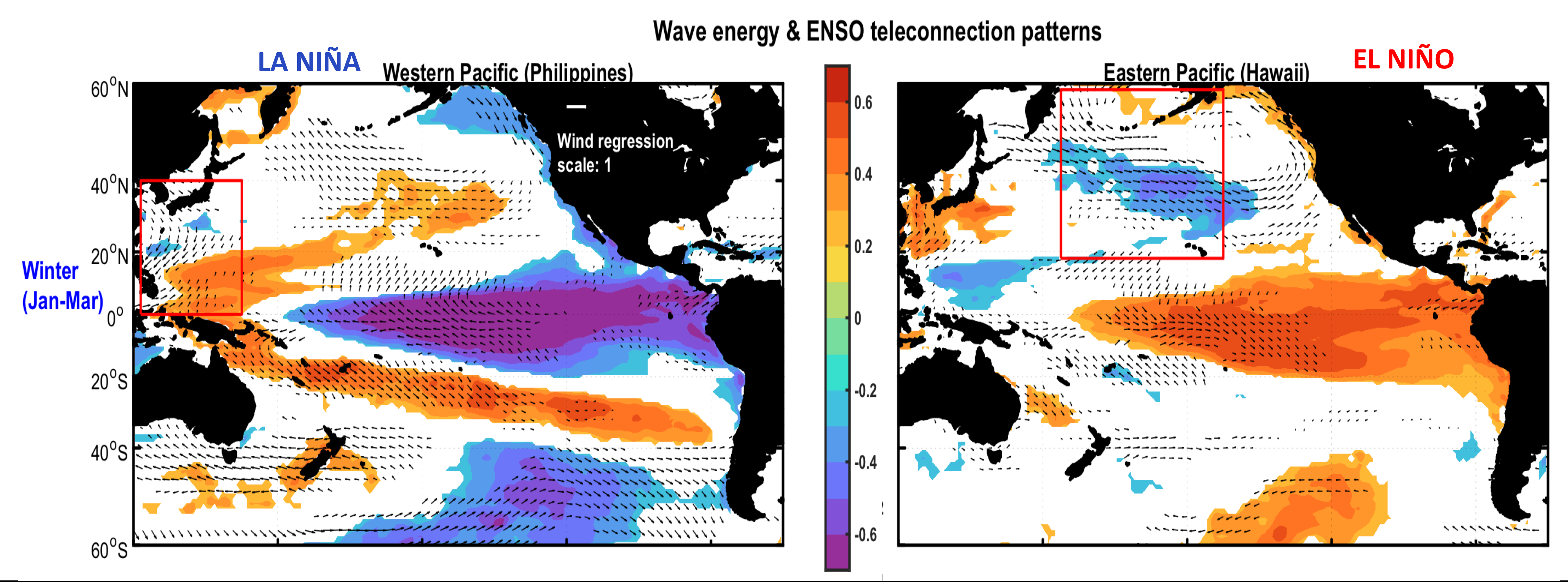
1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

Winter wave activity across the Pacific

Wave Energy = $H_s^2 * T_p$

H_s = Wave height

T_P = Peak period



1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

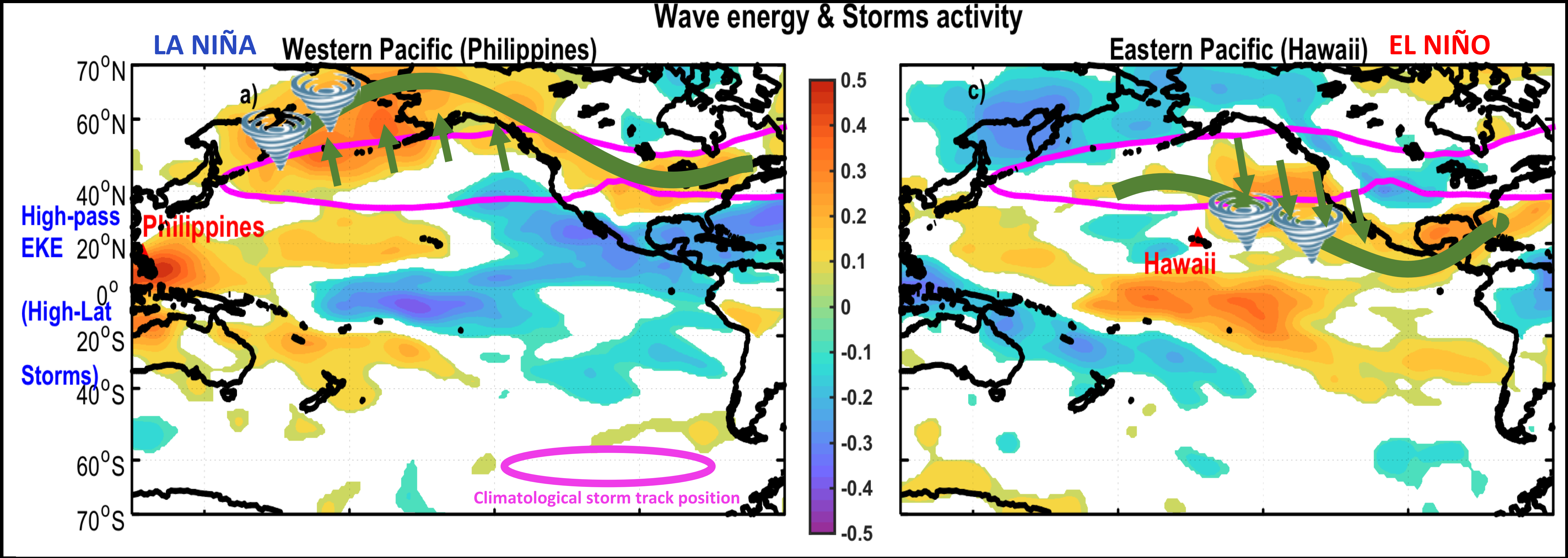
Winter wave activity across the Pacific and extra-tropical storminess

Wave Energy = $H_s^2 * T_p$

H_s = Wave height

T_P = Peak period

EKE = Eddy Kinetic Energy at 850 mb (High-pass filtered 14 days^{-1})



Interannual variability of winter wave activity across the Pacific dominated by the EP El Niño/La Niña influence on the NH jet stream

1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

Summer wave activity across the Pacific

Wave Energy = $H_s^2 * T_p$

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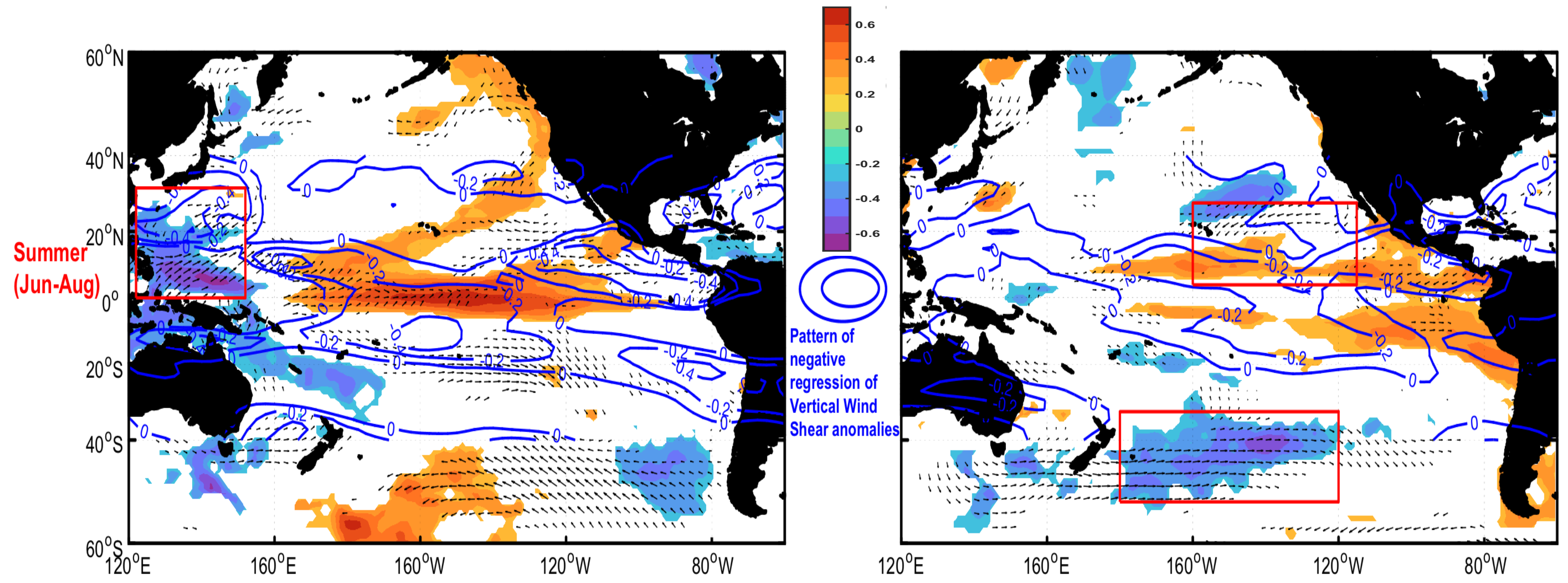
T_P = Peak period



Onset of CP El Niño

Decay of EP El Niño

1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

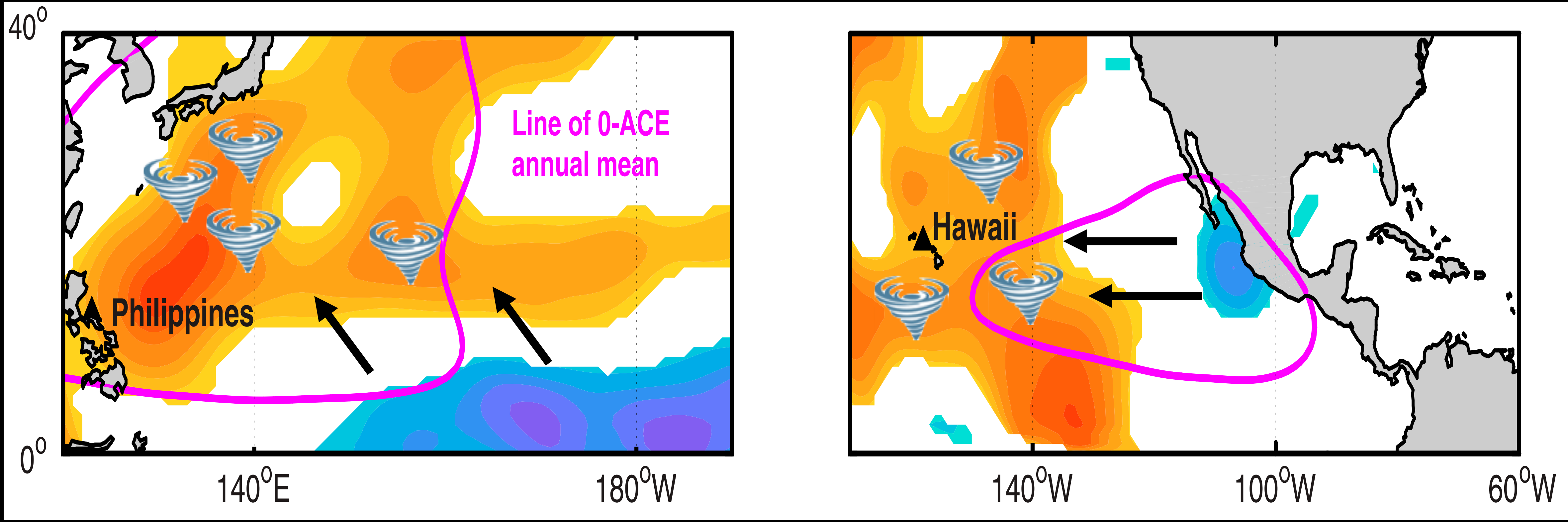
Summer wave activity across the Pacific and Tropical Cyclone activity

Wave Energy = $H_s^2 * T_p$

H_s = Wave height

T_P = Peak period

ACE = Accumulated Cyclone Energy



Onset of CP El Niño

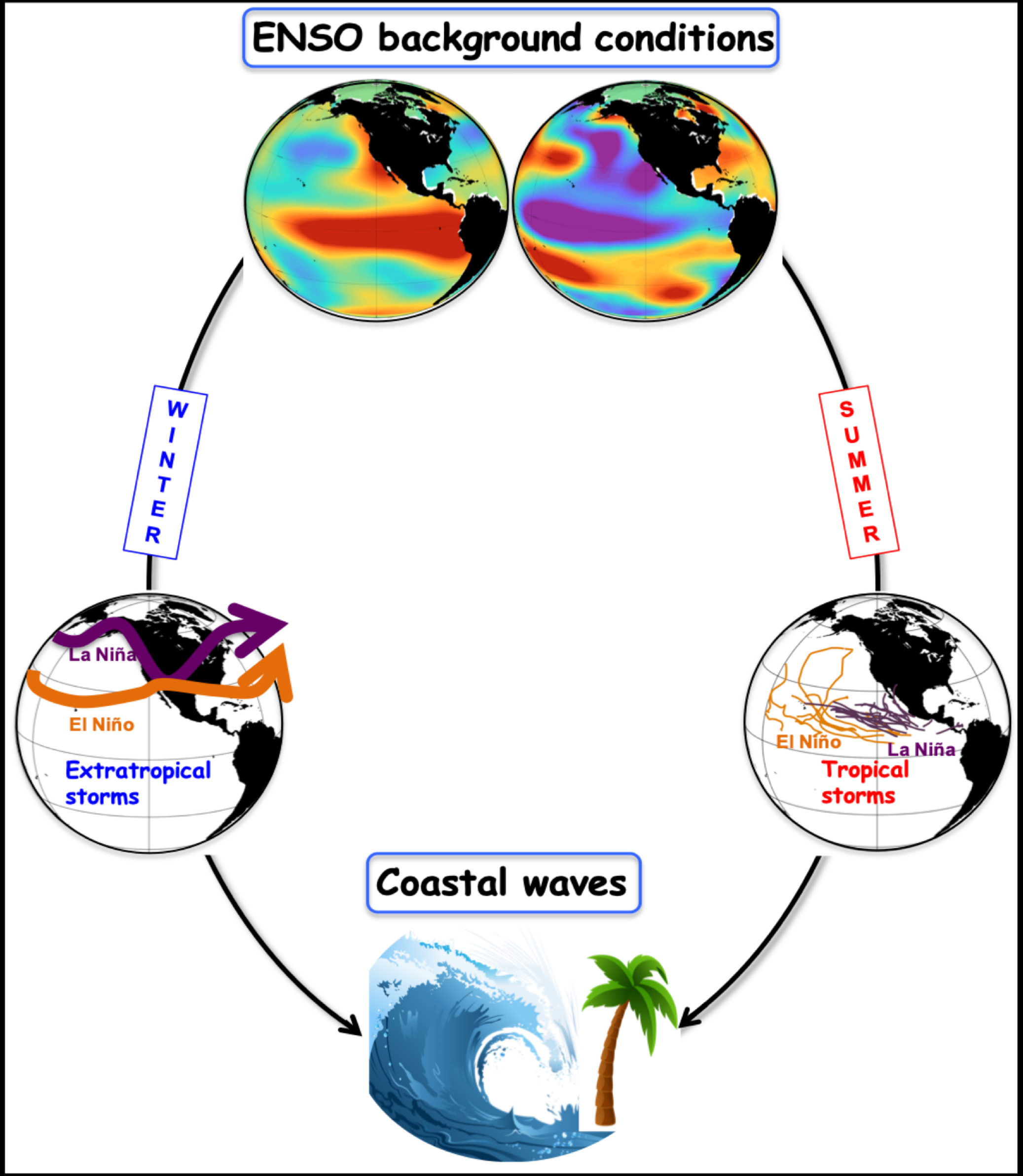
Decay of EP El Niño

Lin et al., 2020

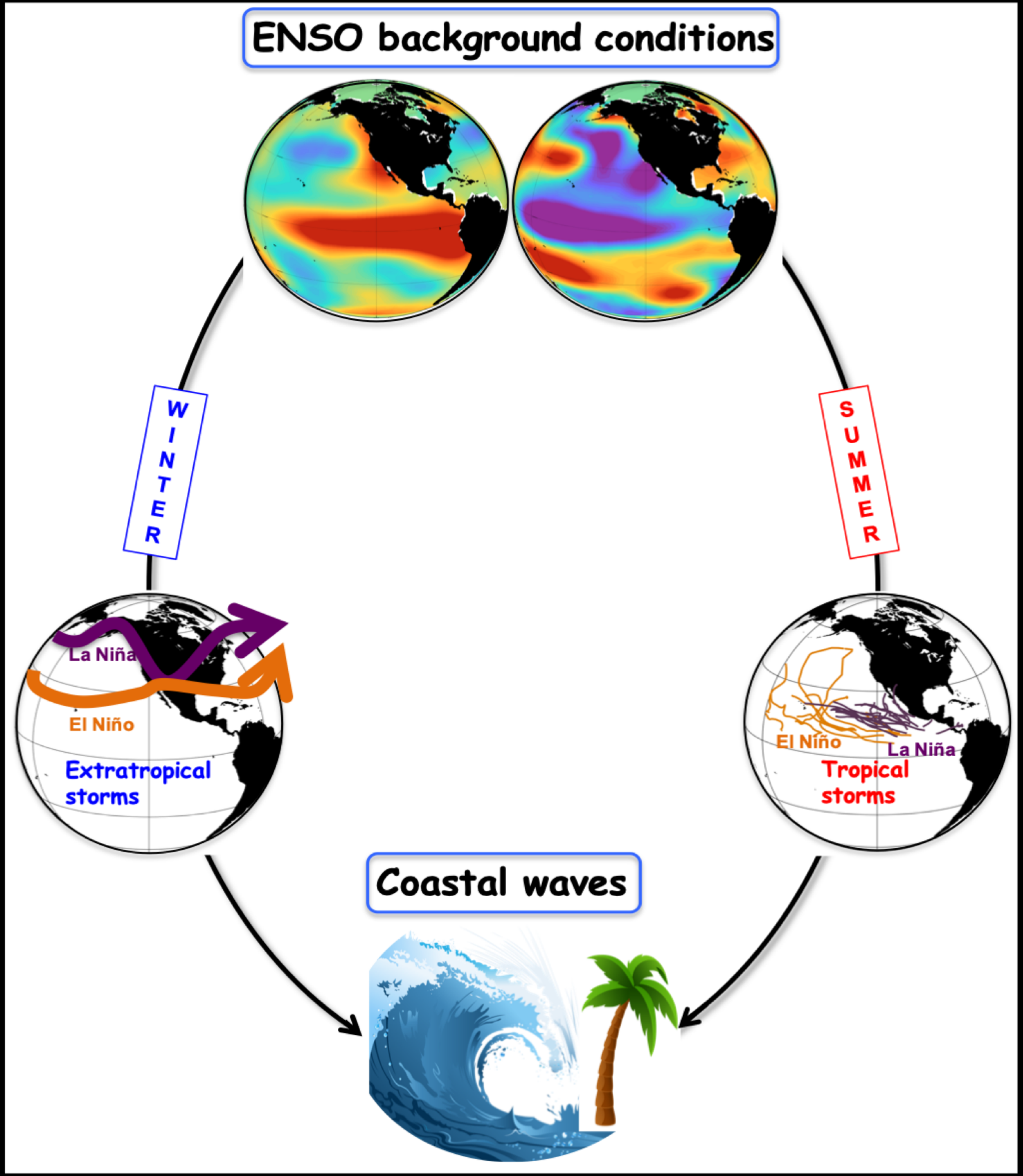
Jin, Boucharel and Lin, 2014, 2015
Boucharel et al., 2016b

1) A new paradigm for the complex influence of El Niño on pan-Pacific coastal wave extremes

The seasonally modulated ENSO influence on Pacific coastal waves



The seasonally modulated ENSO influence on Pacific coastal waves



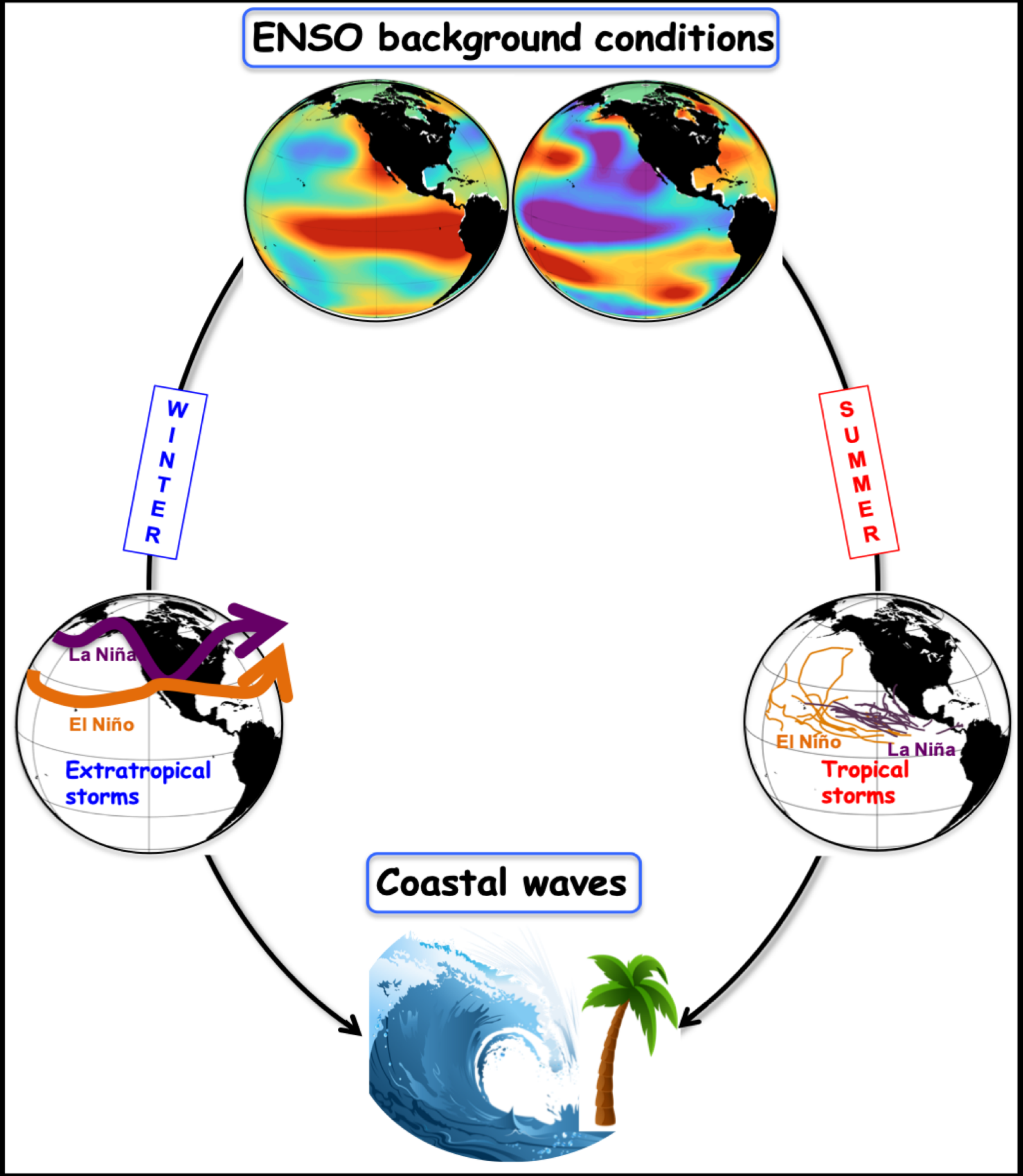
$$\frac{dZ}{dt} = \left[-\left(\gamma_0 + \frac{2i\pi}{T} \right) + m(t) \right] Z(t) + \omega(t),$$

Stochastic climate model

Hasselmann, 1976

Boucharel and Jin, 2020

The seasonally modulated ENSO influence on Pacific coastal waves



Coastal wave episodes

Climate forcing

$$\frac{dZ}{dt} = \left[-\left(\gamma_0 + \frac{2i\pi}{T}\right) + m(t)\right] Z(t) + \omega(t),$$

Return period (~ 15 days)

Stochastic forcing

Stochastic climate model

Hasselmann, 1976

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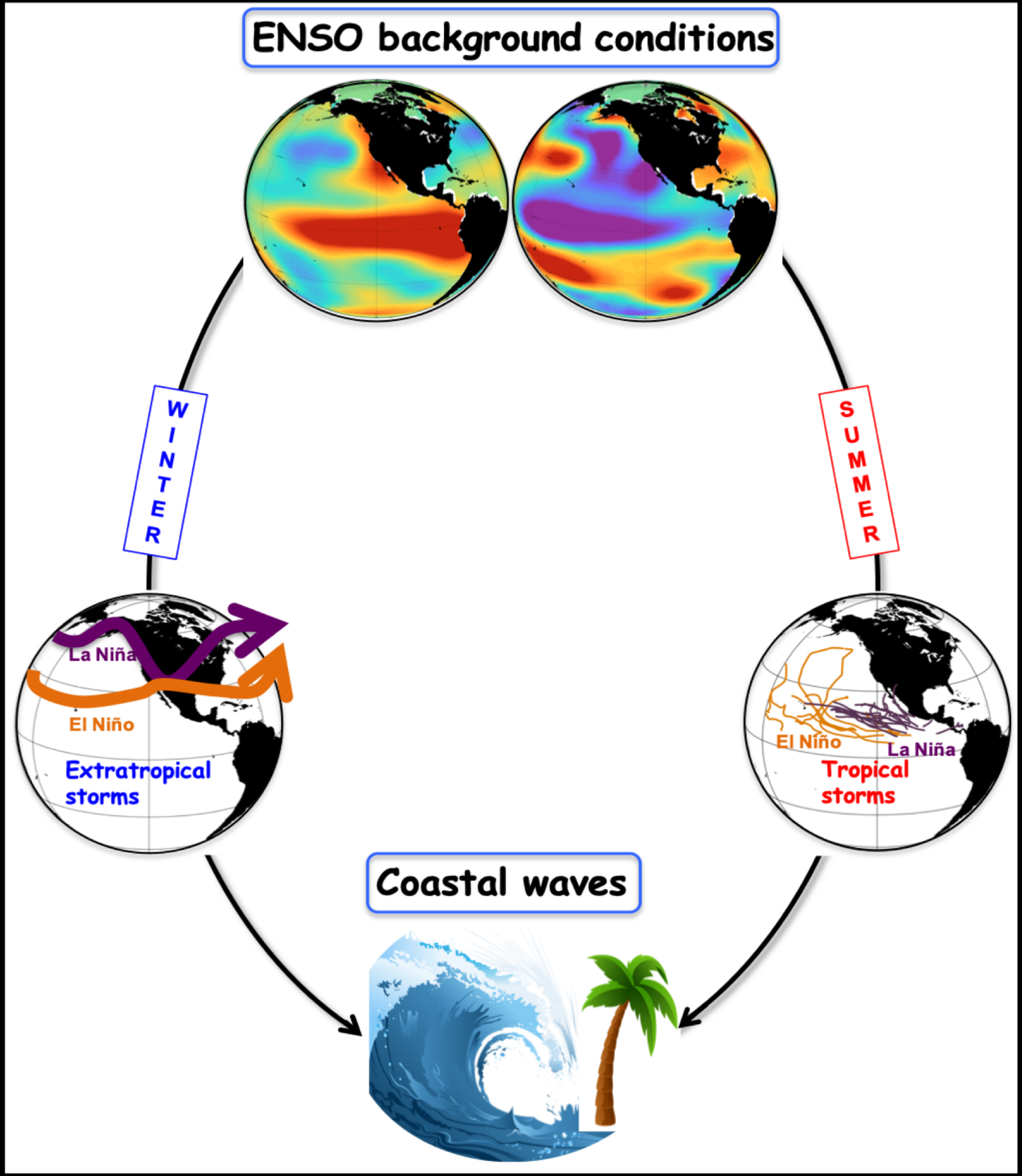

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Stochastic forcing

Stochastic climate model

Hasselmann, 1976

Boucharel and Jin, 2020

$$m(t) = \left[\gamma_A cos \frac{2\pi(t-\phi)}{T_A}\right] + [\gamma_C C_{mode} + \gamma_E E_{mode}]$$

Annual cycle

CP El Niño

EP El Niño

Climate forcing

Boucharel et al, 2021a

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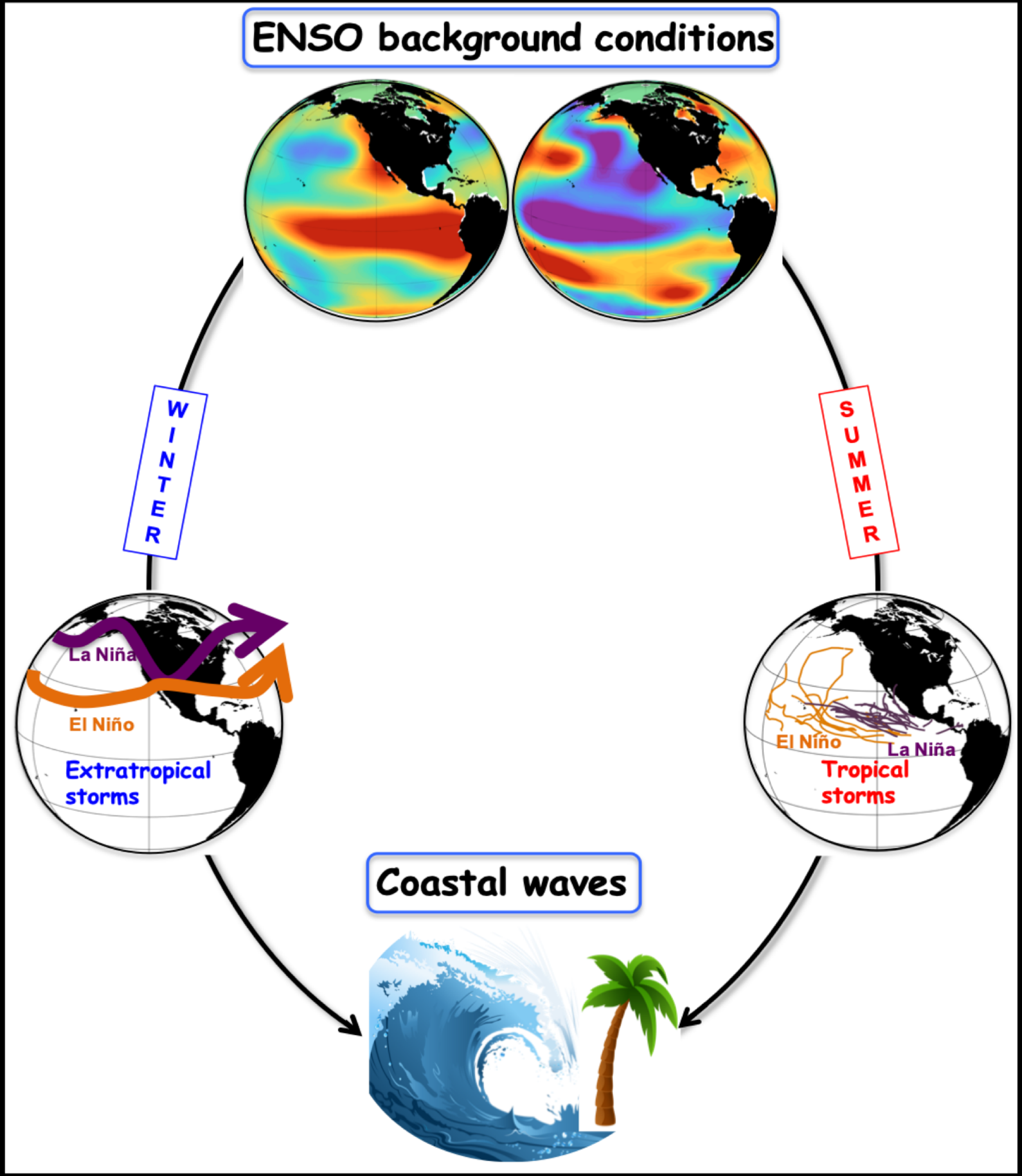
The seasonally modulated ENSO influence on Pacific coastal waves



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Annual cycle

CP El Niño

EP El Niño

Climate forcing

Boucharel et al, 2021a

$$| Z^2 | = Ke^{-\gamma_0}\left[1 + \frac{m(t)}{\gamma_0} + \frac{m^2(t)}{\gamma_0^2}\right]$$

Full analytical solution for coastal wave amplitude

Boucharel and Jin, 2020

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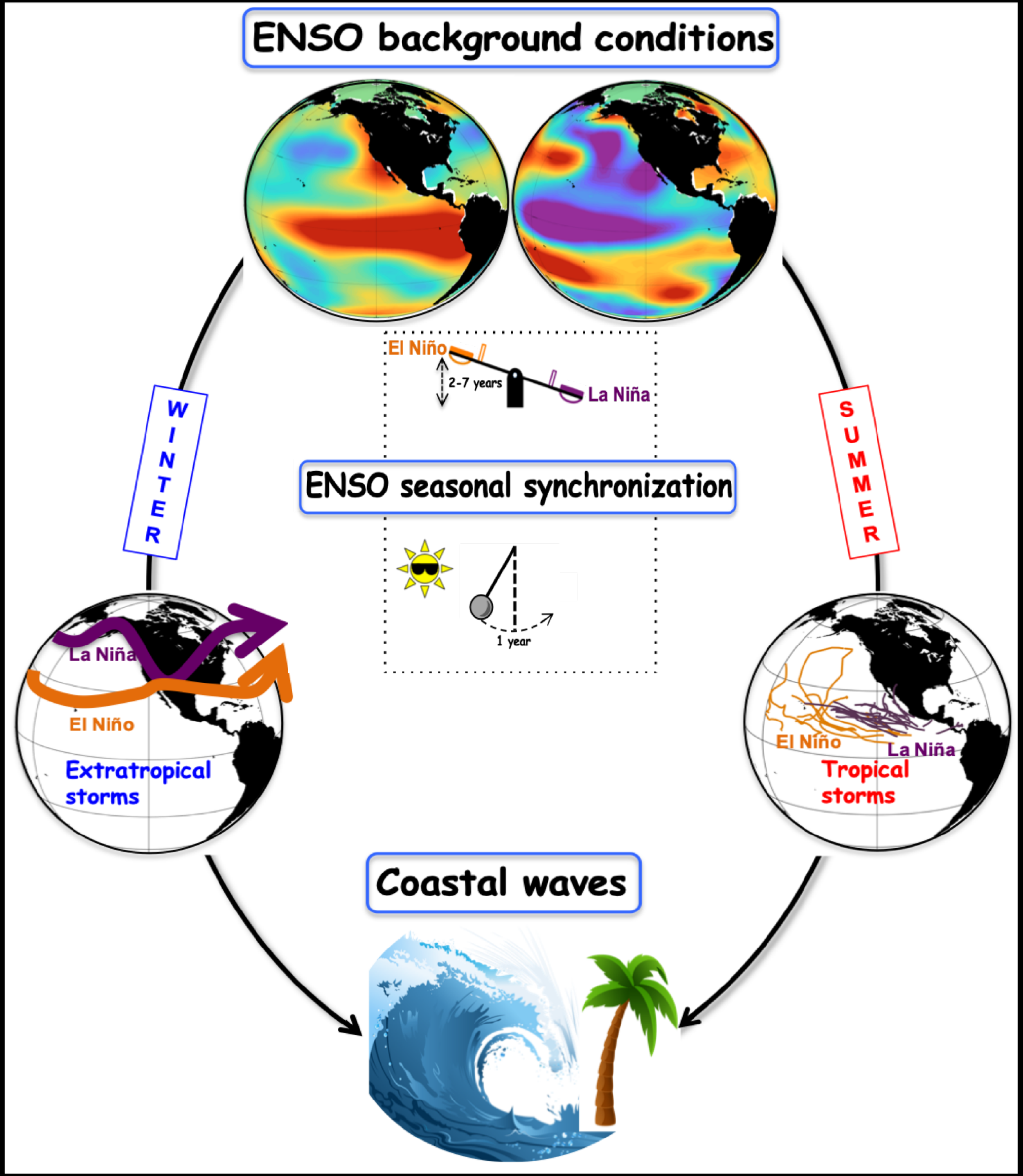
The seasonally modulated ENSO influence on Pacific coastal waves



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Full analytical solution for coastal wave amplitude

Boucharel and Jin, 2020

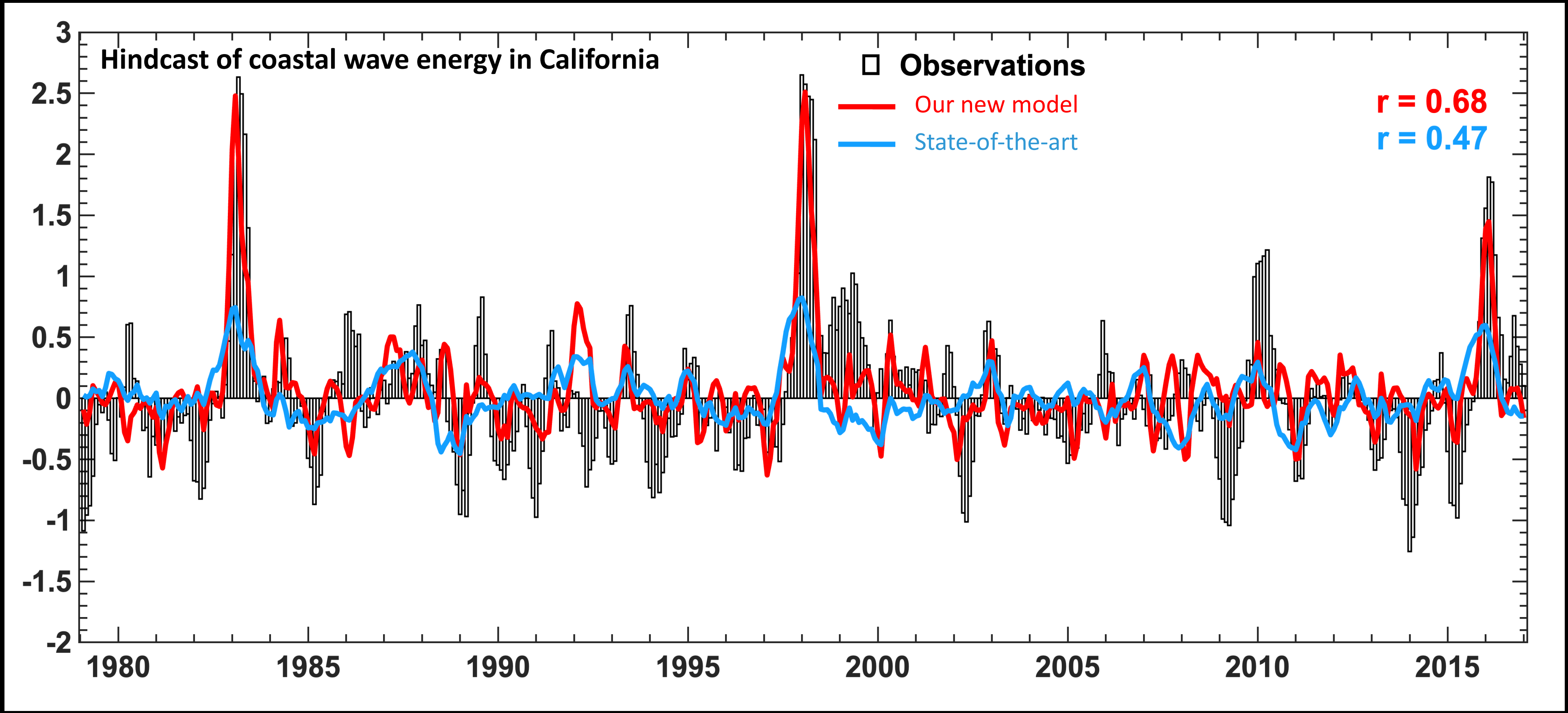
Linear climate effect

Nonlinear climate interactions (ENSO/Annual cycle)

Some results from this new conceptual model

Before (state-of-the-art)
→ Considering the canonical EP El Niño form only

New "complex ENSO" model
→ Considering the full expression of El Niño spatial diversity and temporal irregularity



New theory to understand the **complex ENSO influence** on a key driver of coastal vulnerability: **waves** in the Pacific but…

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AND OCEANOGRAPHY
PUBLISHED BY THE INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

A simple theory for the modulation of tropical instability waves by ENSO and the annual cycle

By JULIEN BOUCHAREL[1,2], and FEI-FEI JIN[1,3]*, [1]*Department of Atmospheric Sciences, SOEST, University of Hawaii at Manoa, Honolulu, Hawaii, USA;* [2]*LEGOS, University of Toulouse, CNRS, IRD, CNES, UPS, Toulouse, France;* [3]*Laboratory for Climate Studies, Beijing Climate Center, Chinese Meteorological Agency, Beijing, China*

PNAS
Proceedings of the National Academy of Sciences of the United States of America

RESEARCH ARTICLE

Check for updates

On the influence of ENSO complexity on Pan-Pacific coastal wave extremes

Julien Boucharel, Rafael Almar, Elodie Kestenare, and Fei-Fei Jin
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PNAS
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Keyword, Author,

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RESEARCH ARTICLE

On the influence of ENSO complexity on Pan-Pacific coastal wave extremes

Julien Boucharel, Rafael Almar, Elodie Kestenare, and Fei-Fei Jin
+ See all authors and affiliations

… ENSO influence extends beyond the Pacific and affects coastal vulnerability globally

A new satellite-based global product of shoreline position

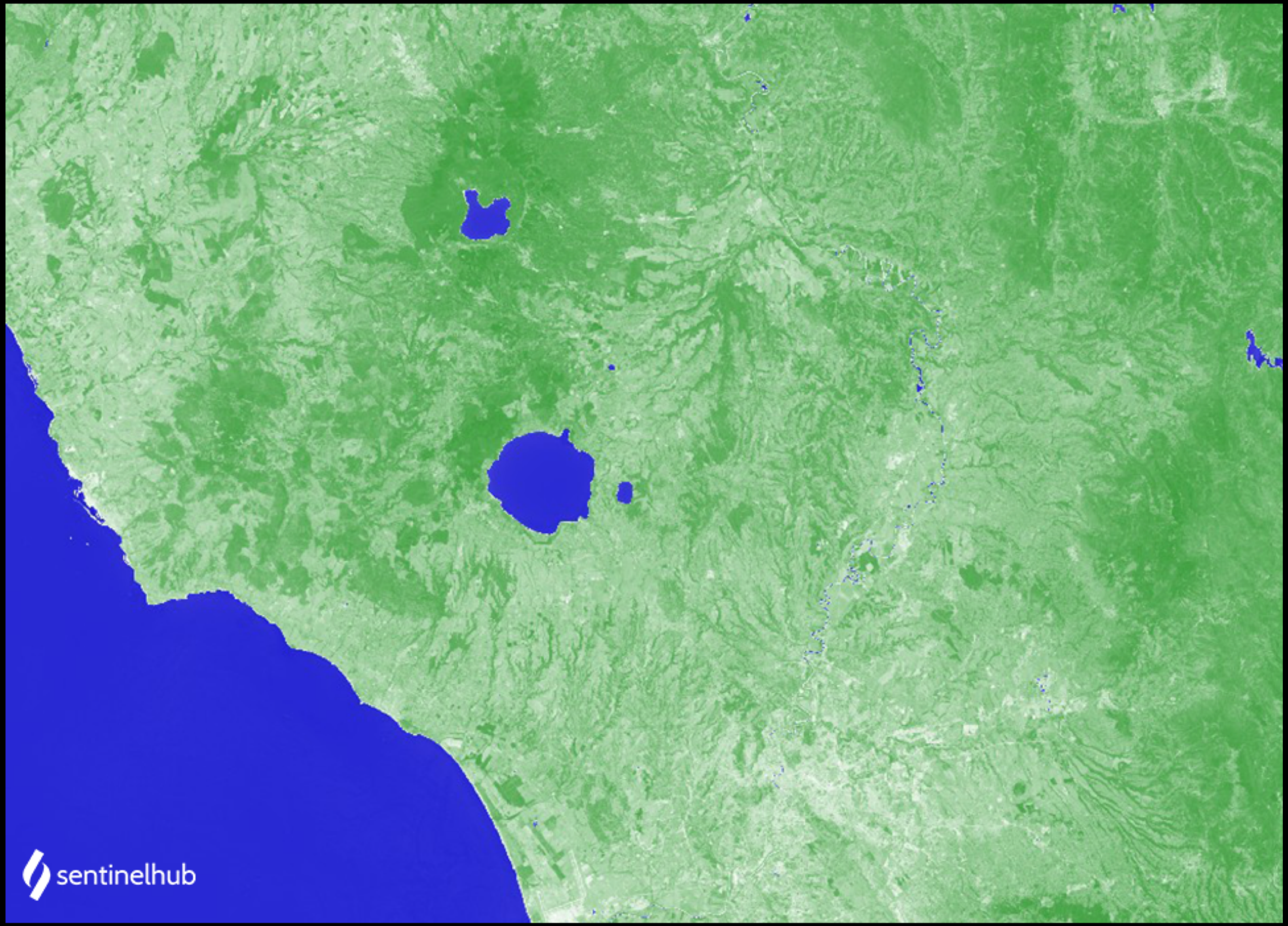
Landsat 5, 7, 8

A new satellite-based global product of shoreline position

Normalized Difference Water Index (NDWI)

The NDWI is an index used to monitor changes related to water content in water bodies. As water bodies strongly absorb light in visible to infrared electromagnetic spectrum, NDWI uses green and near infrared bands to highlight water bodies

Pixels when NDWI > 0 → Sea
Pixels when NDWI < 0 → Land



Example: NDWI in Rome (Italy)

A new satellite-based global product of shoreline position

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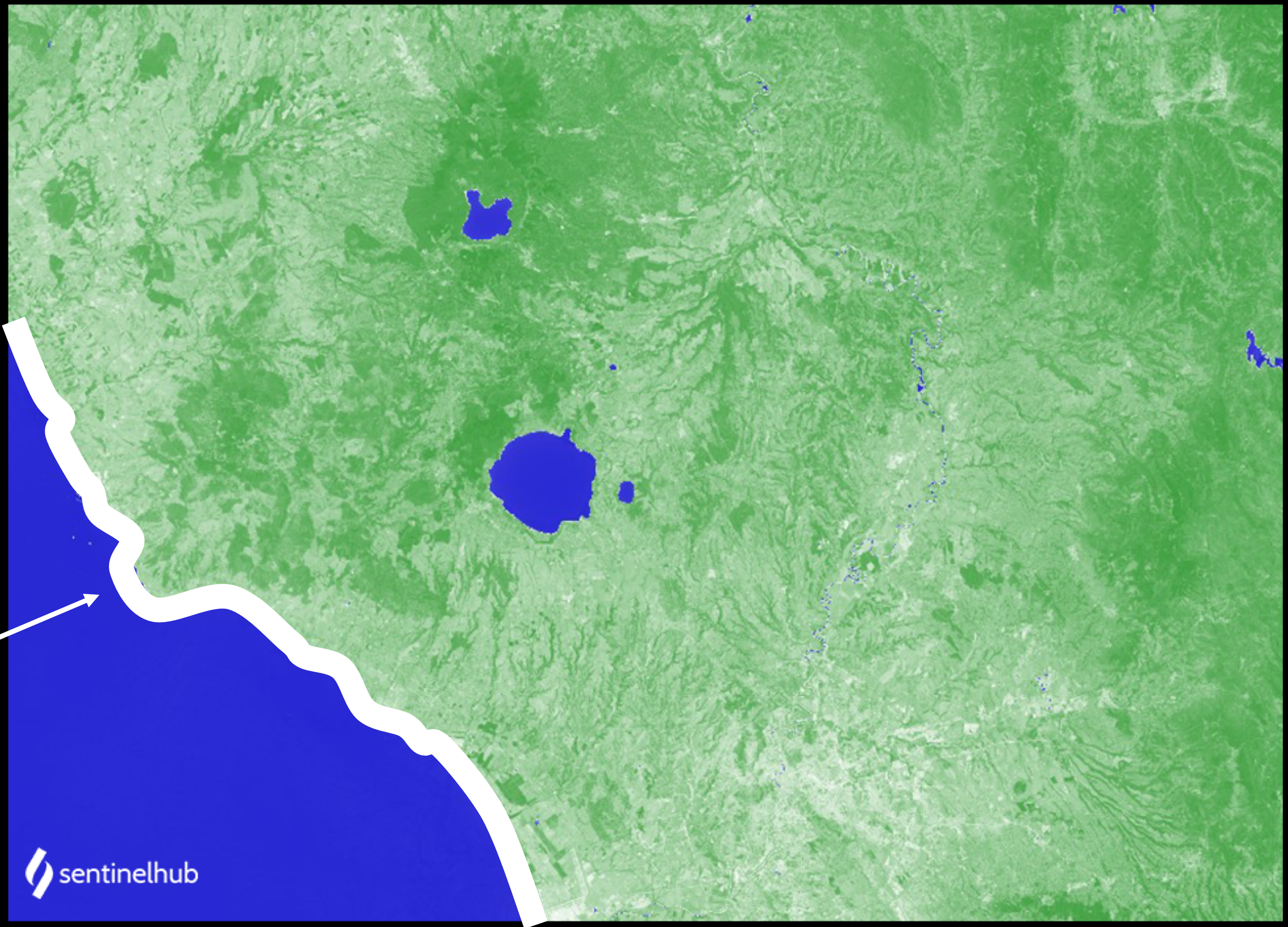
Pixels when NDWI > 0 → Sea
Pixels when NDWI < 0 → Land

SHORELINE position = Interface
McFeeters, 1996



Example: NDWI in Rome (Italy)

2) The global influence of El Niño on coastal hazards – (1) Erosion

A new satellite-based global product of shoreline position

Google Earth Engine

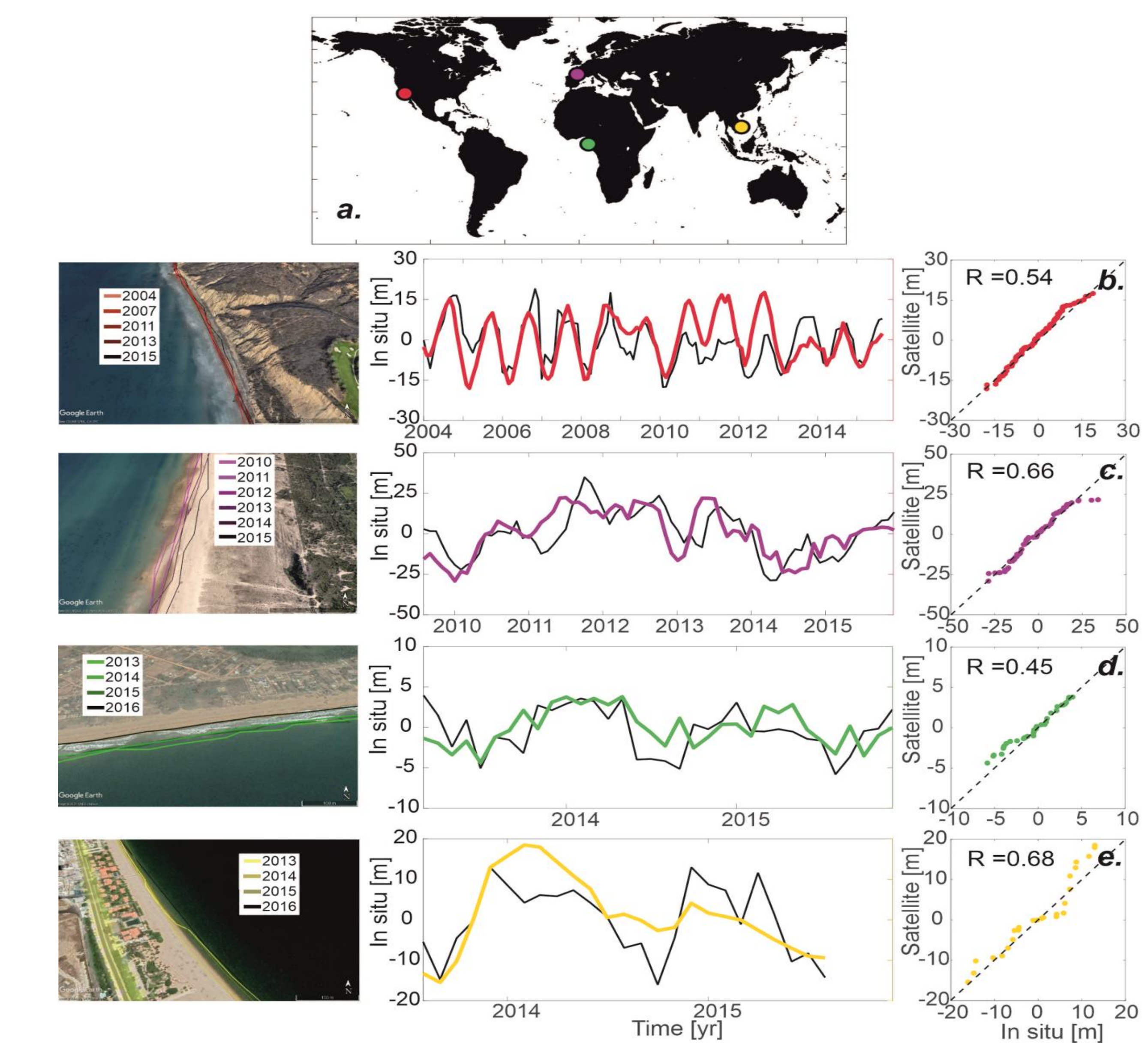

(Google, 2018)

- Extracted at 14,140 coastal points between 60ºN and 60ºS using monthly composites from 238 multiple satellite acquisitions provided by the Landsat missions 5, 7 and 8.

- Calculation on GEE (10,000 hours; 3 PB of data)

➔ Monthly Shoreline data set from 2000 to 2017 at a spatial (along-shore) resolution of ~0.5º

A new satellite-based global product of shoreline position



Good agreement between monthly satellite estimations and *in situ* measurements (both local surveys and camera systems) at sites closest to the extraction point

2) The global influence of El Niño on coastal hazards – (1) Erosion

Drivers of shoreline evolution

SHORELINE DRIVERS

Wave energy flux

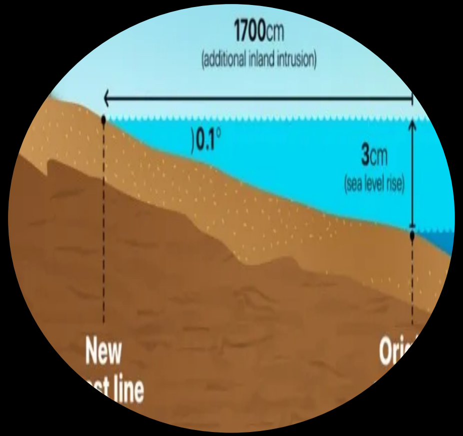
ERA5 (Sig. Wave height, period)

Sea level

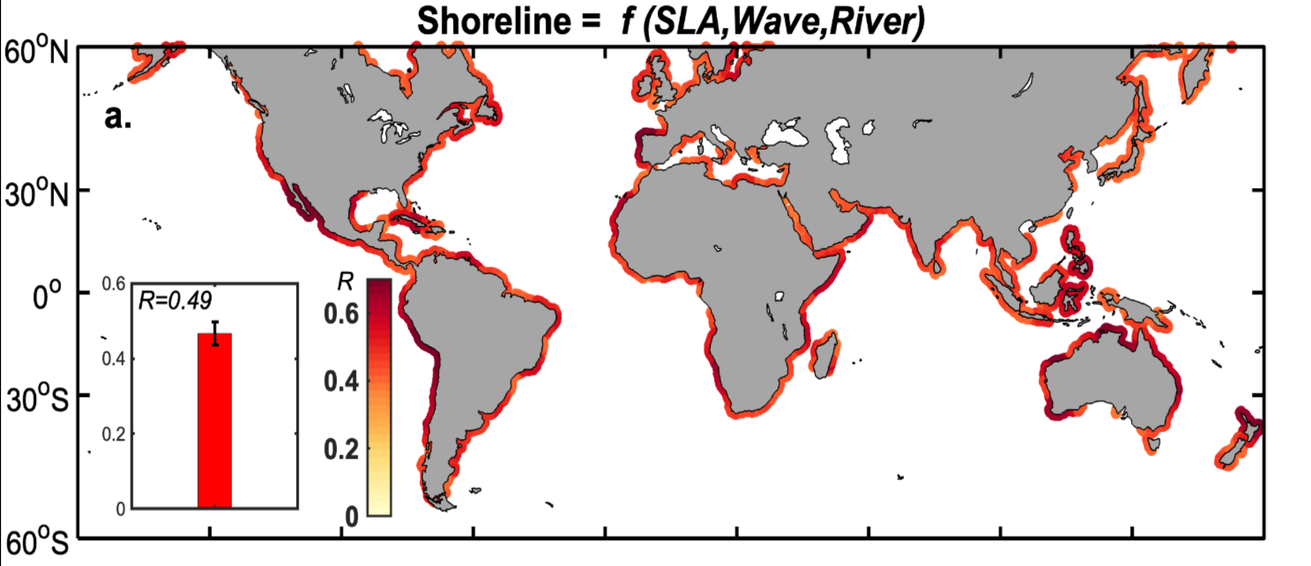
AVISO MOG-2D (mean SLA, DAC, tide corrected)

River flow

ISBA-CTRIP (freshwater discharge from land)

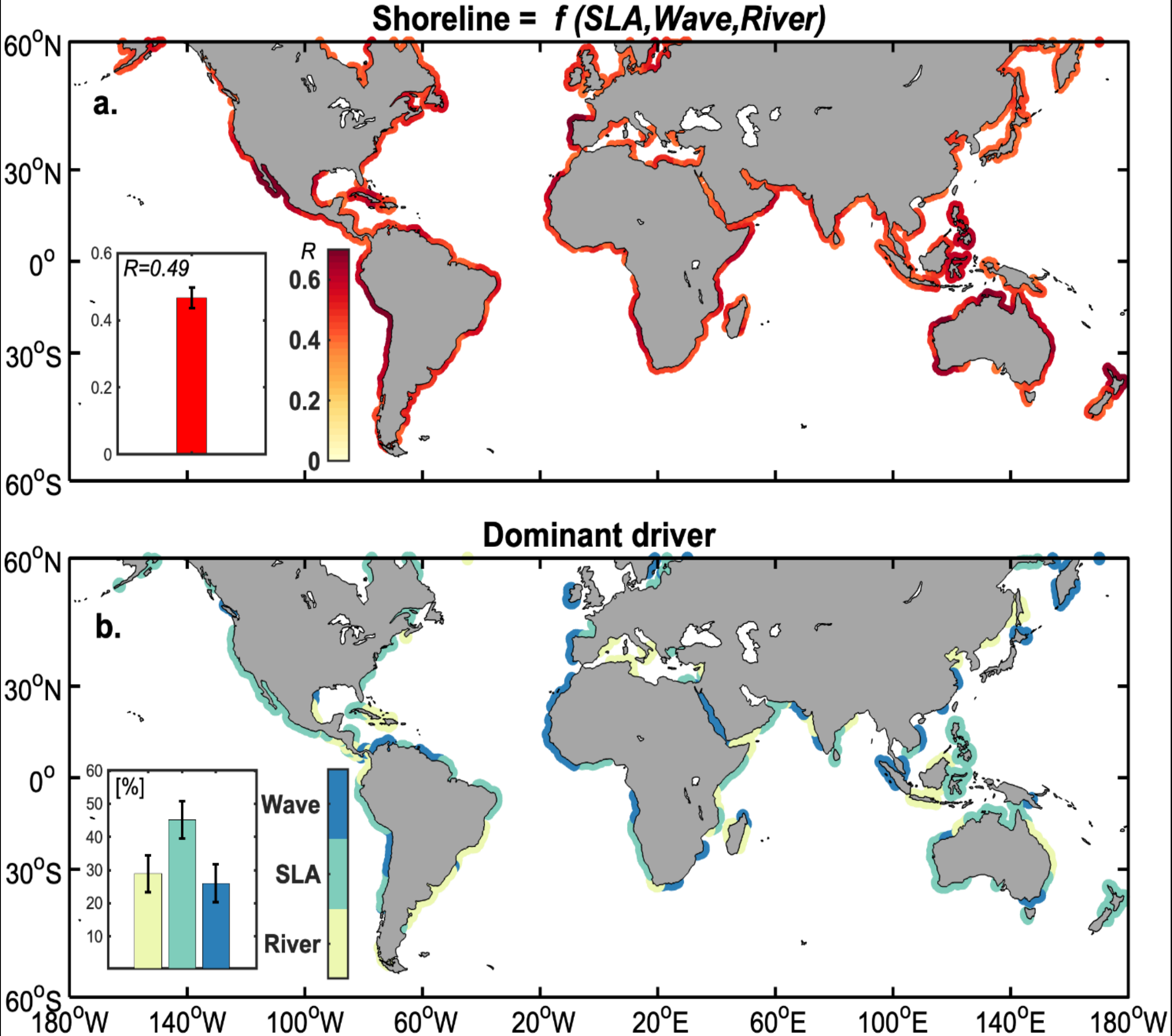


Drivers of shoreline evolution



S(x,t)=α Sea level (x,t)+ β Waves (x,t) + γ Rivers (x,t)

Drivers of shoreline evolution



S(x,t)=α Sea level (x,t)+ β Waves (x,t) + γ Rivers (x,t)

- **SLA dominant driver of shoreline position changes at interannual timescales**
- **Significant contributions from Waves on open west facing shores and under storm tracks**
- **River flow important in enclosed tropical seas and intertropical river basins**

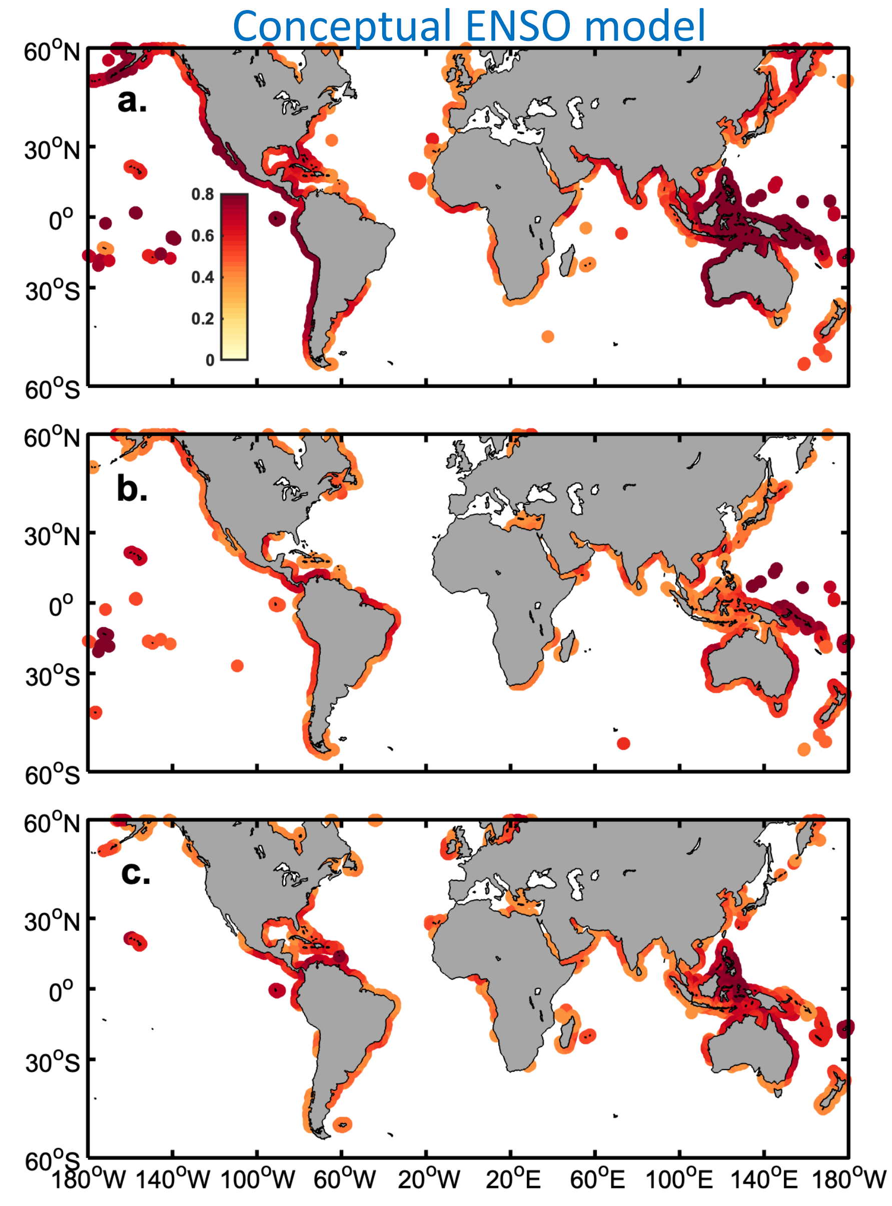
2) The global influence of El Niño on coastal hazards – (1) Erosion

ENSO influence on shoreline drivers

SLA

WAVES

RIVERS



2) The global influence of El Niño on coastal hazards – (1) Erosion

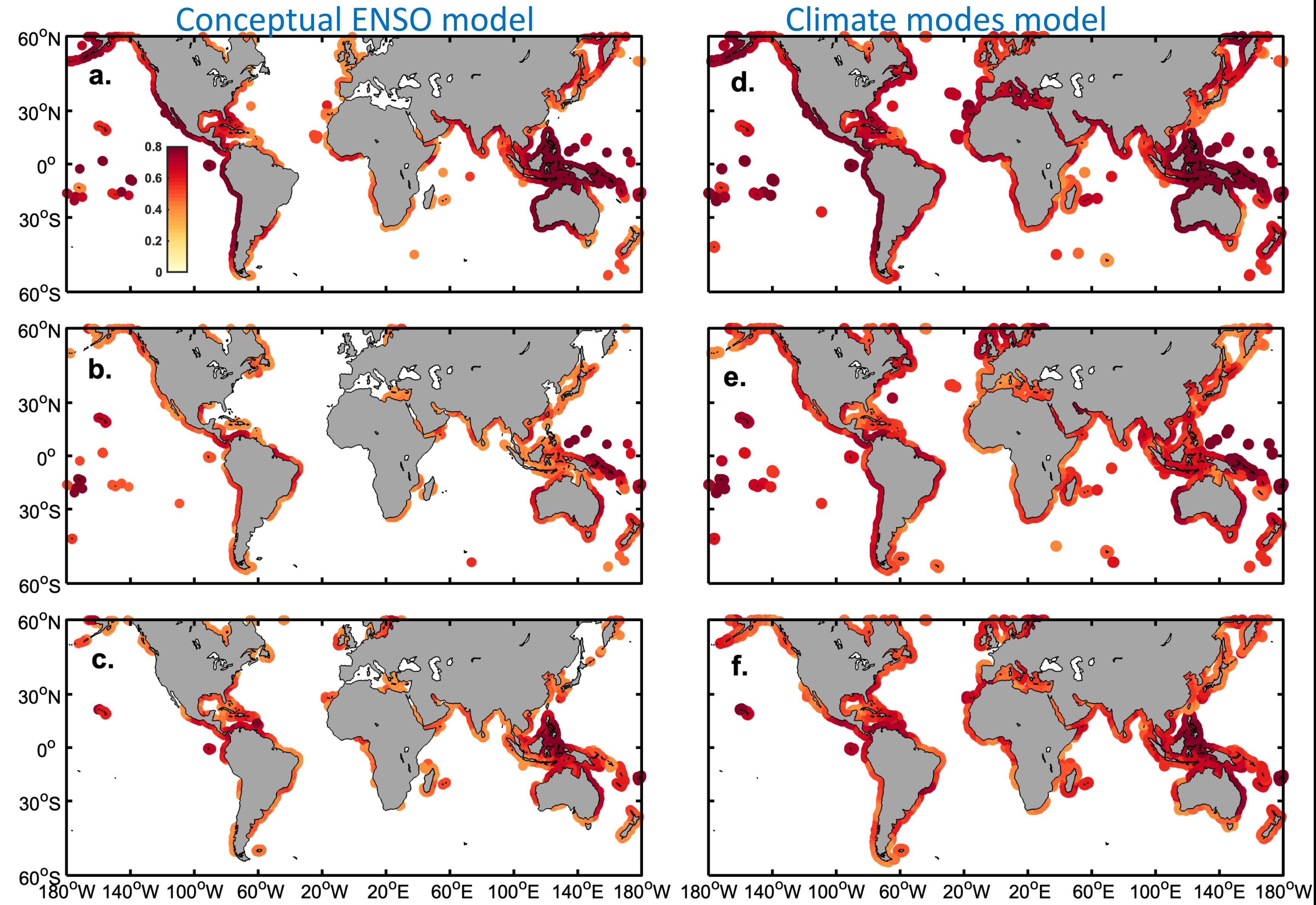
ENSO influence on shoreline drivers

NAO (Northern Hemisphere Extratropical variability)
ENSO (Tropical variability)
SAM (Southern Hemisphere Extratropical variability)

SLA

WAVES

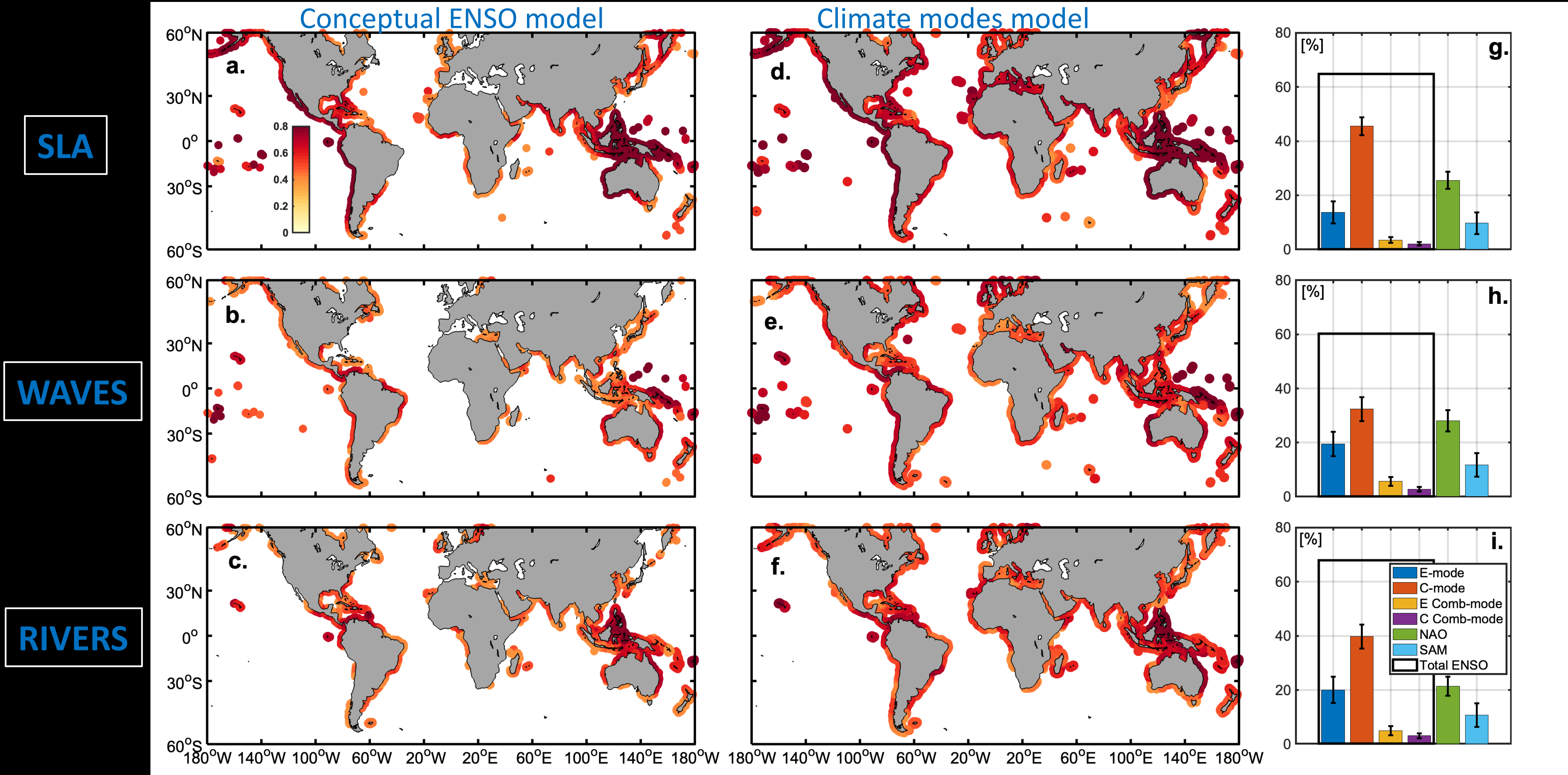
RIVERS



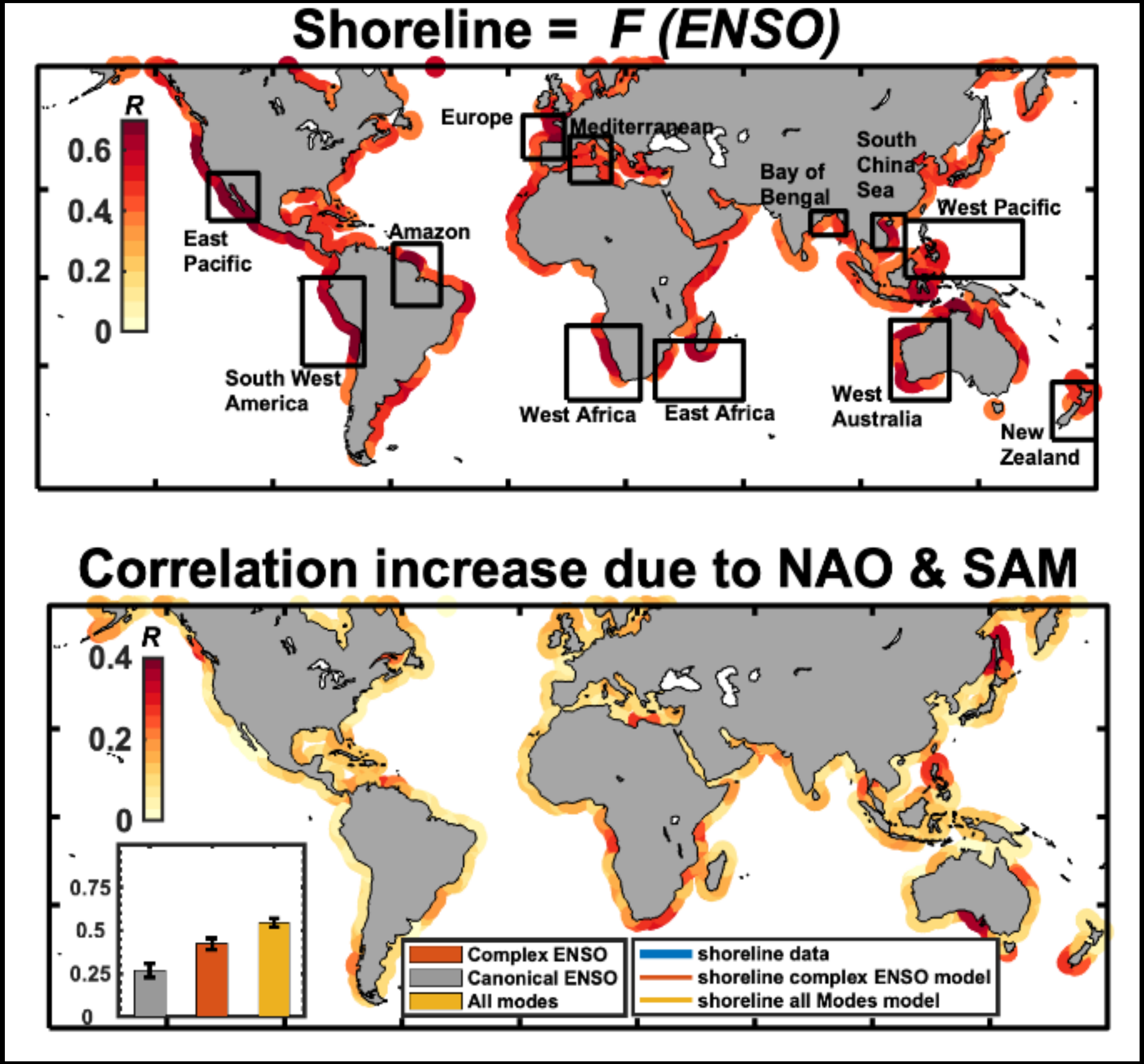
2) The global influence of El Niño on coastal hazards – (1) Erosion

ENSO influence on shoreline drivers

Dominant ENSO influence on global shoreline drivers



ENSO influence on interannual shoreline changes

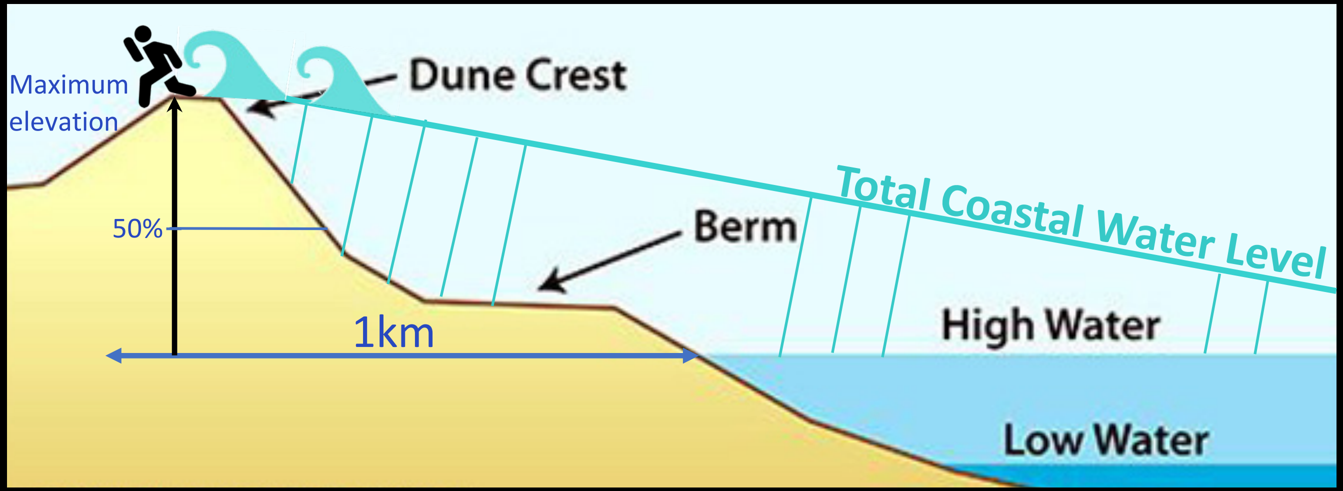


The complex ENSO state, (as compared to its linear expression only)

- integrates the main environmental factors affecting shoreline position even outside the Pacific basin and the tropics
- is a reasonable predictor of shoreline year-to-year changes

2) The global influence of El Niño on coastal hazards – (2) Flooding

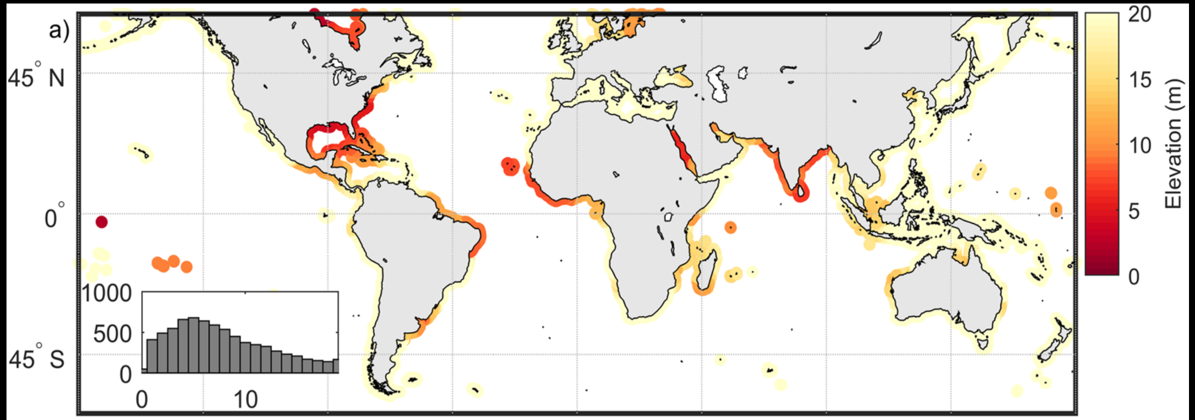
ENSO influence on overtopping events



Overtopping = when total coastal water level reaches 50% of max coastal elevation within 1km of the waterline

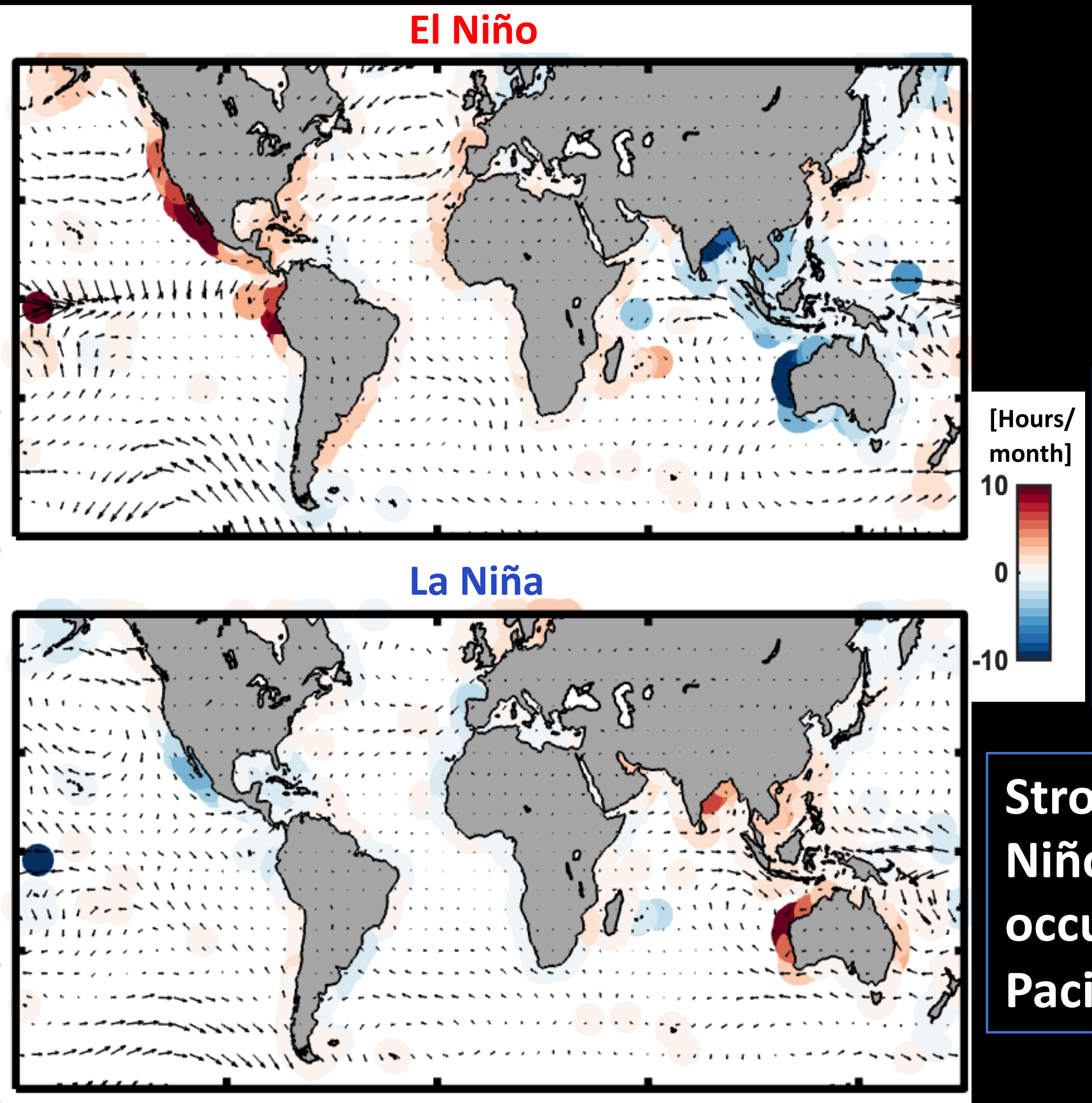
Total coastal water level = Steric + Dynamic + Surge + Tide + Runup

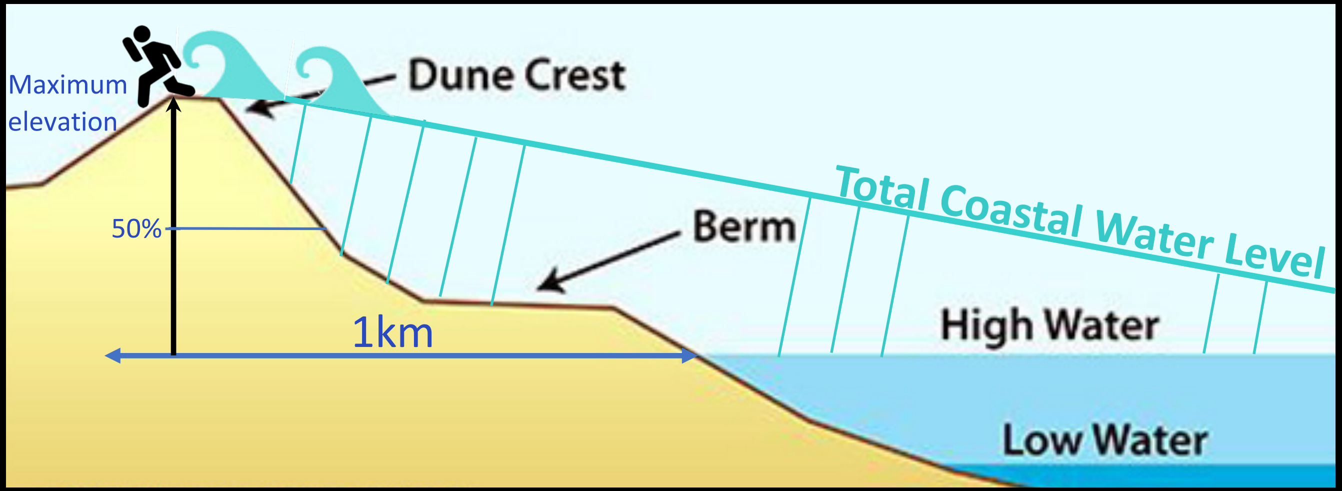
Coastal Elevation = from Digital Elevation Model



2) The global influence of El Niño on coastal hazards – (2) Flooding

ENSO influence on overtopping events





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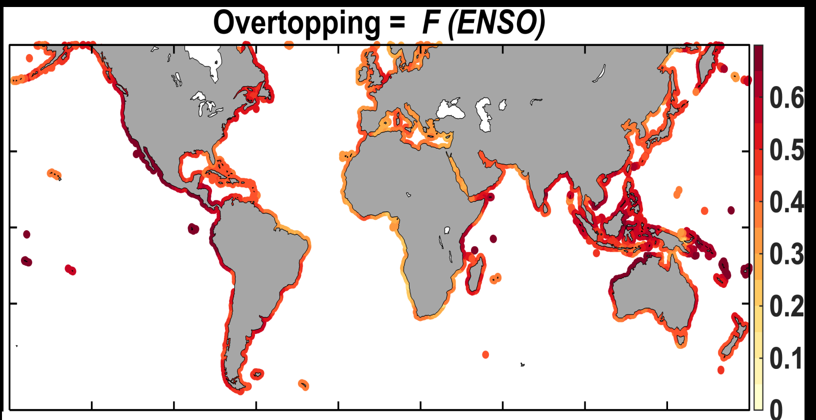
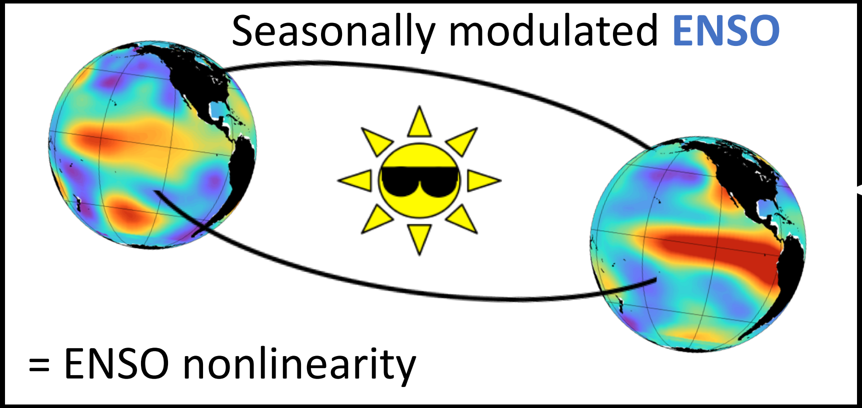
Strong Influence of El Niño on flooding occurrences in the Indo-Pacific basin

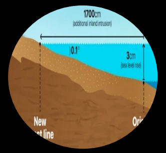


New theory to understand the complex ENSO influence on different key drivers of coastal vulnerability (and possibly more):



Wave energy

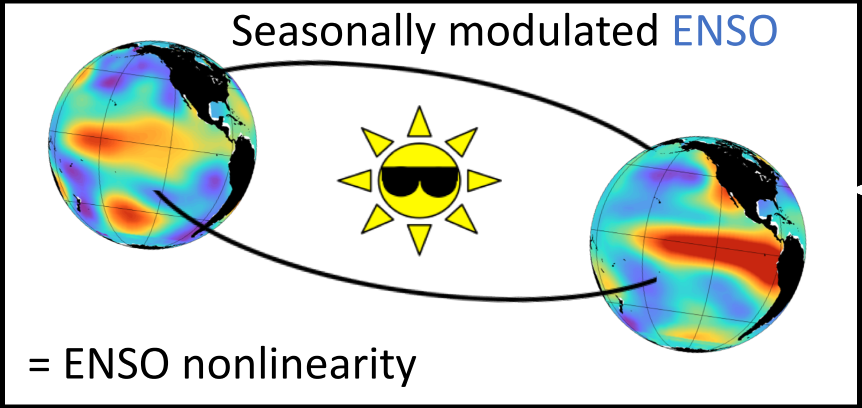
Sea level



River liquid discharge

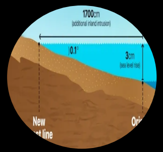
3) CONCLUSIONS & TAKE HOME MESSAGES

New theory to understand the complex ENSO influence on different key drivers of coastal vulnerability (and possibly more):

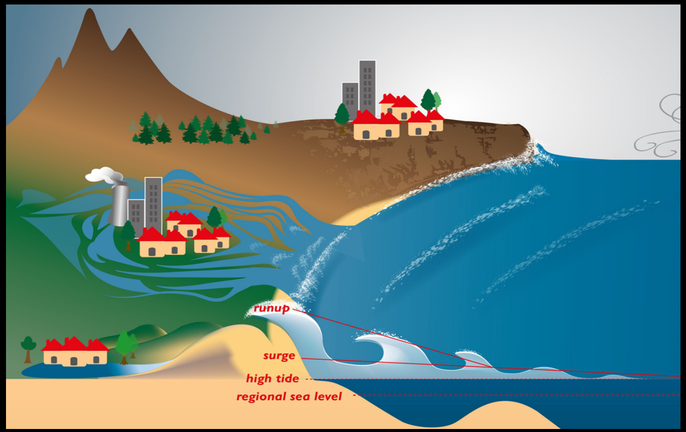


Wave energy

Sea level



River liquid discharge



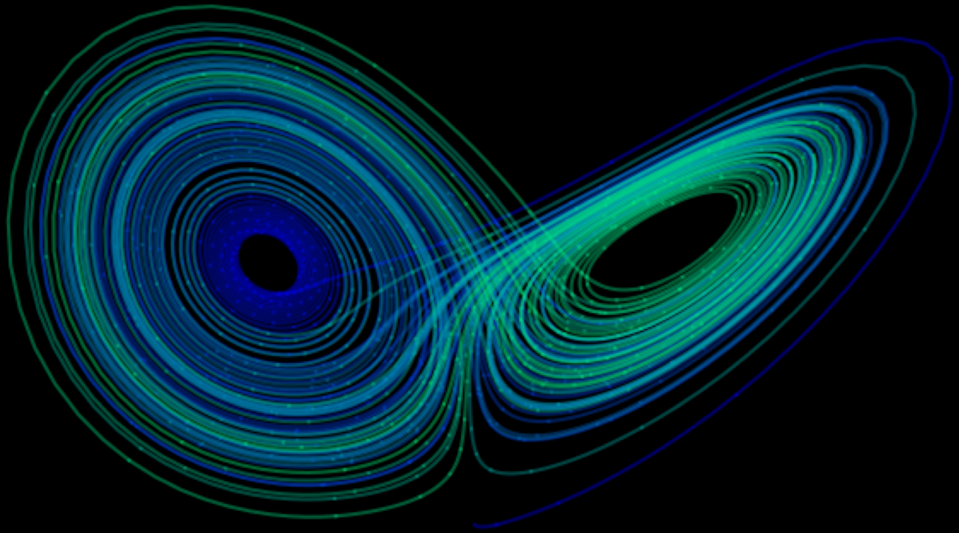
Overtopping occurrence ➔ **FLOODING**

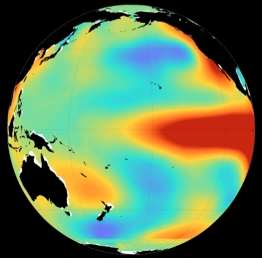
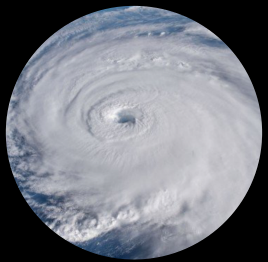
Shoreline evolution ➔ **EROSION**

A BETTER UNDERSTANDING OF ENSO CONTROL ON COASTAL VULNERABILITY

➔ IMPROVING PREDICTABILITY

Mahalo



bouch@hawaii.edu
julien.boucharel@legos.obs-mip.fr