12th International Workshop on Wave Hindcasting and Forecasting and 3rd Coastal Hazards Symposium

Hawai'i's Big Island, October 30 – November 4, 2011

Present and Future Flooding and Erosion Coastal Risk Assessment in Practically Ungauged Large Areas: Methodology and Results for South America

Sonia Castanedo, Borja G. Reguero, Ana J. Abascal, Inigo J. Losada, Roberto Minguez, Fernando J. Mendez

UC UNIVERSIDAD DE CANTABRIA

IH cantabria INSTITUTO DE HIDRÁULICA AMBIENTAL UNIVERSIDAD DE CANTABRIA

CANTABRIA CAMPUS INTERNACIONAL Agua y Energía

Motivation

Annual report about the Economics of Climate Change

Objectives

To assess climate change impact on:

flooding levels

erosion rates

port reliability and operability

- Sea level rise
- Long-term wave climate changes
- Extreme value wave climate changes

Methodology

$f_x(x)$

Historical Data Bases

$z = g(x)$

$f_Z(z)$

Coastal impacts Hazard - Uncertainty

$E(z)$

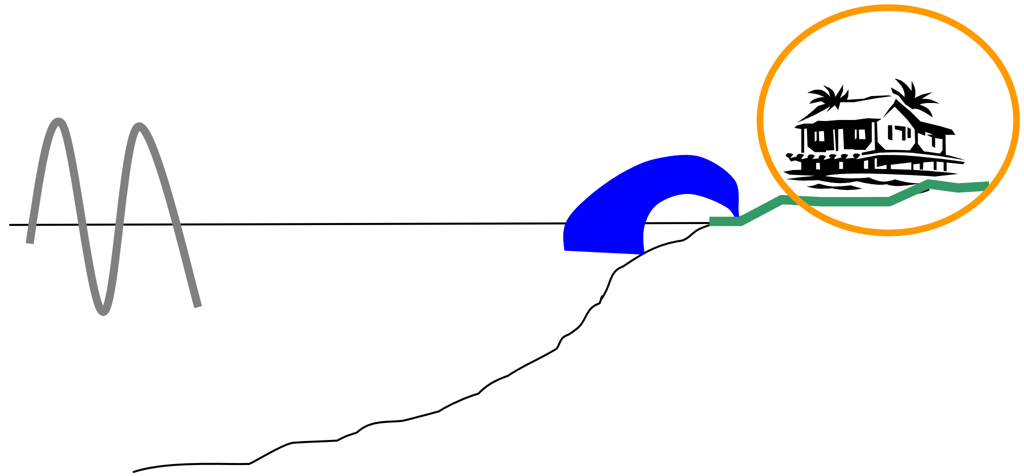
Exposure

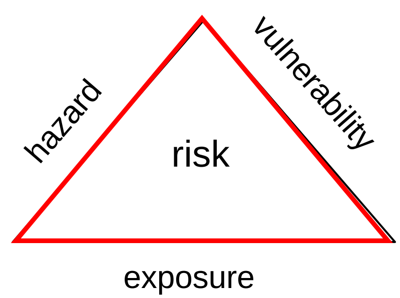
$V(z)$

Vulnerability

R

Risk Assessment

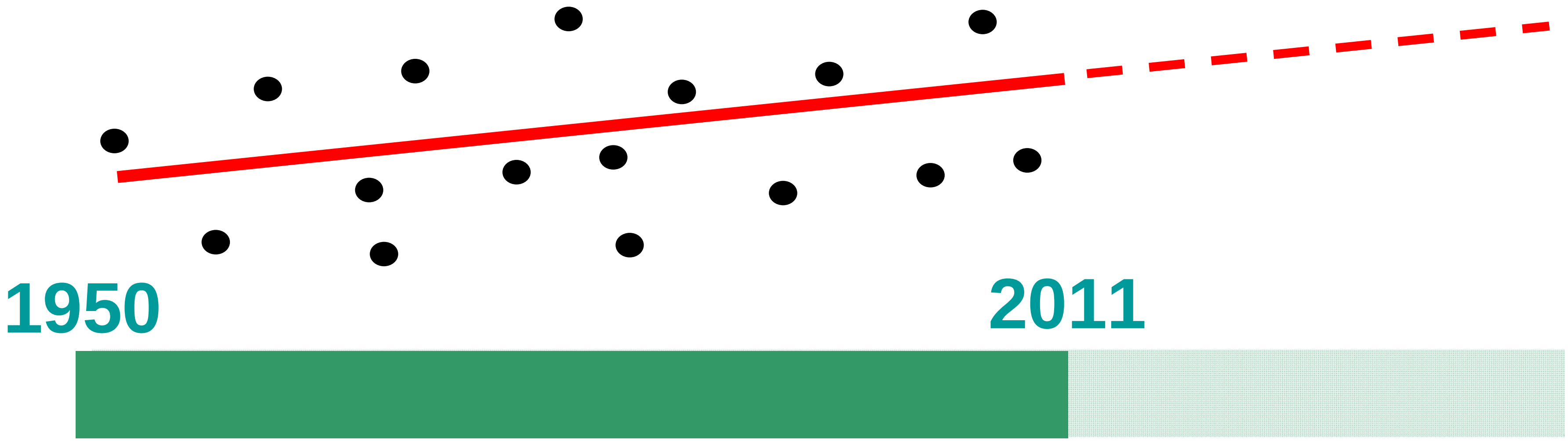




The “risk triangle” after Crichton (1999)

$$R = \int_{-\infty}^{\infty} f_Z(z) E(z) V(z) dz,$$

Methodology

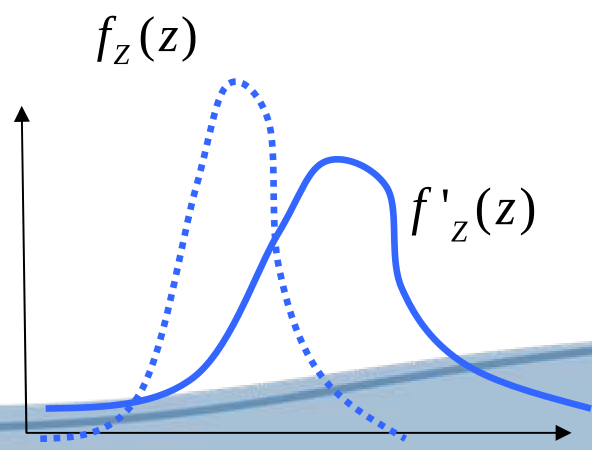


Present, t

Future, t'

$f_Z(z)$

$f'_Z(z)$



Methodology

Present, t

$f_x(x)$

Historical Data Bases

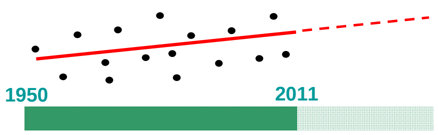
$z = g(x)$

$f_Z(z)$

Coastal impacts
Hazard - Uncertainty

R

Risk Assessment



$E(z)$

Exposure

$V(z)$

Vulnerability

$$\Delta R\,?$$

Future, t'

$f'_x(x)$

Historical Data Bases

Long-term trends
Climatic variability

$f'_Z(z)$

Coastal impacts
Hazard - Uncertainty

R'

Risk Assessment

Details of the study

To assess climate change impact on:

flooding levels

erosion rates

port reliability and operability

Regional scale (50 km)

Present, t

$f_x(x)$

Historical Data Bases

$z = g(x)$

$f_Z(z)$

Coastal impacts
Hazard - Uncertainty

R

Risk Assessment

$E(z)$

Exposure

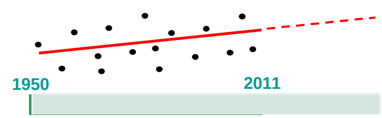
$V(z)$

Vulnerability

Future, t'

$f'_x(x)$

Historical Data Bases



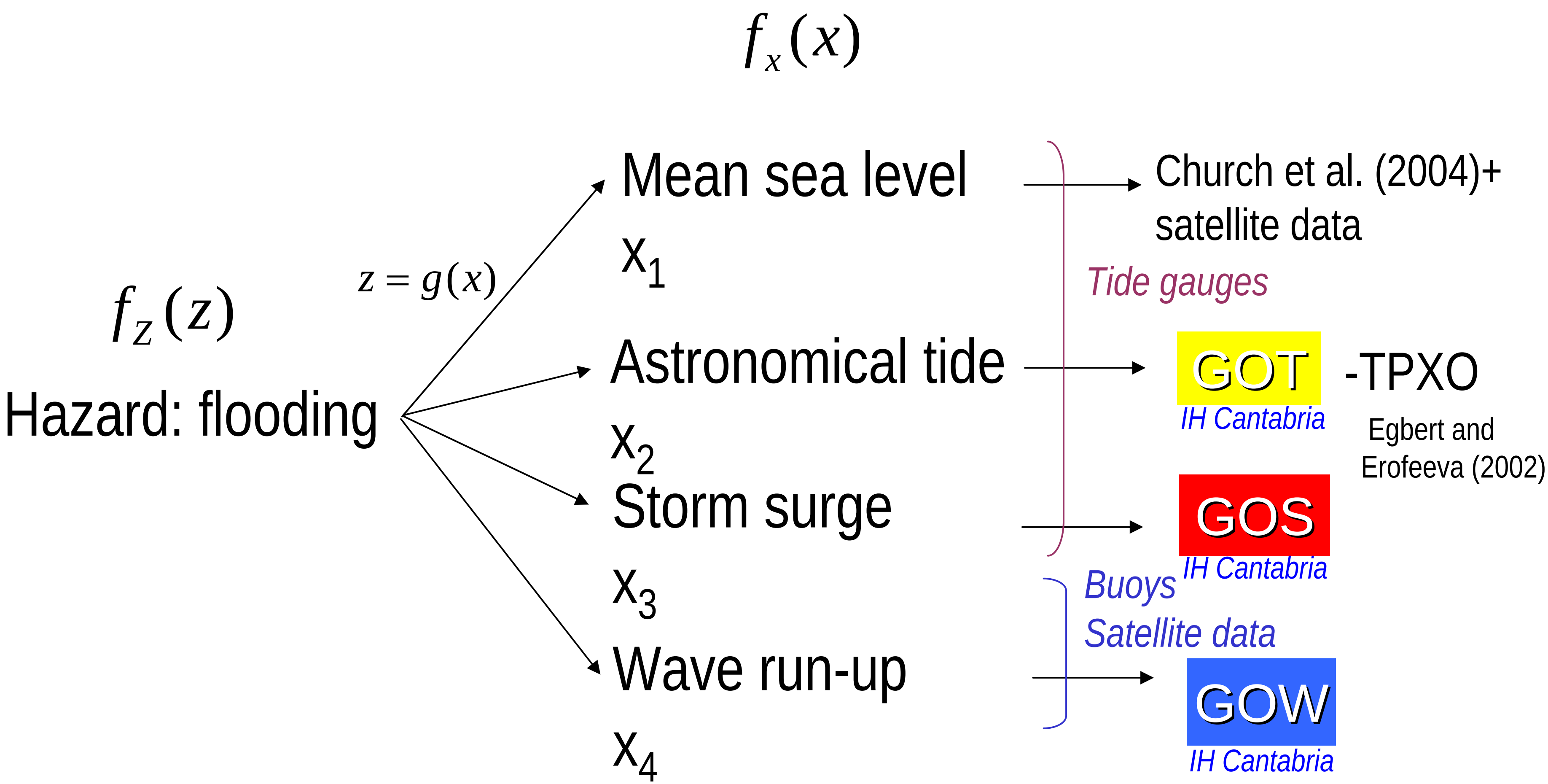
Long-term trends
Climatic variability

$f'_Z(z)$

Coastal impacts
Hazard - Uncertainty

R'

Risk Assessment



GOW: Global Ocean Waves
GOS: Global Ocean Surges
GOT: Global Ocean Tides

GOT

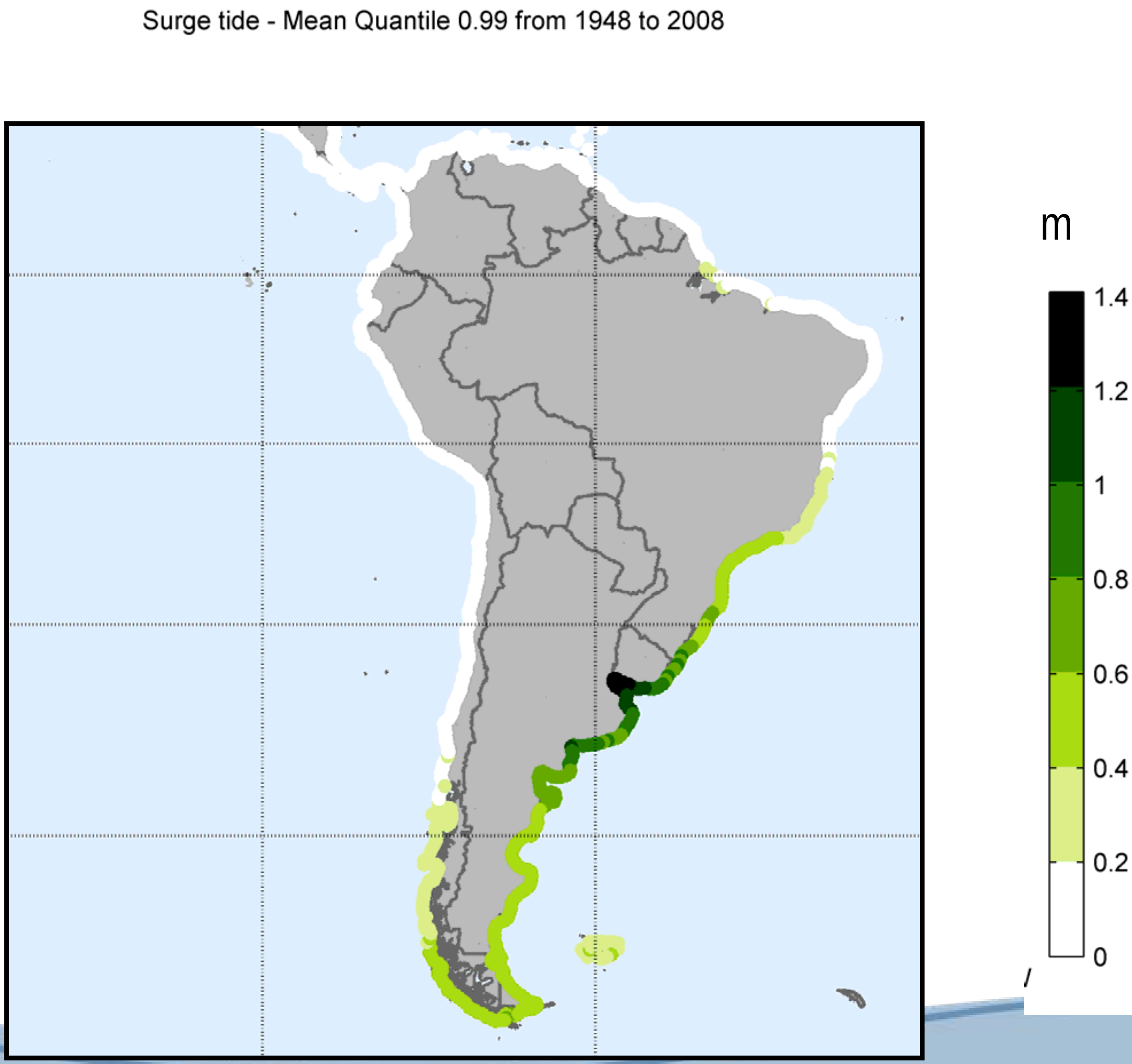
Highest astronomical tide 1948-2008, 0.25º

$$f_x(x)$$

GOS

Storm surge reanalysis
1948-2008 1h, 0.25º

$$f_x(x)$$

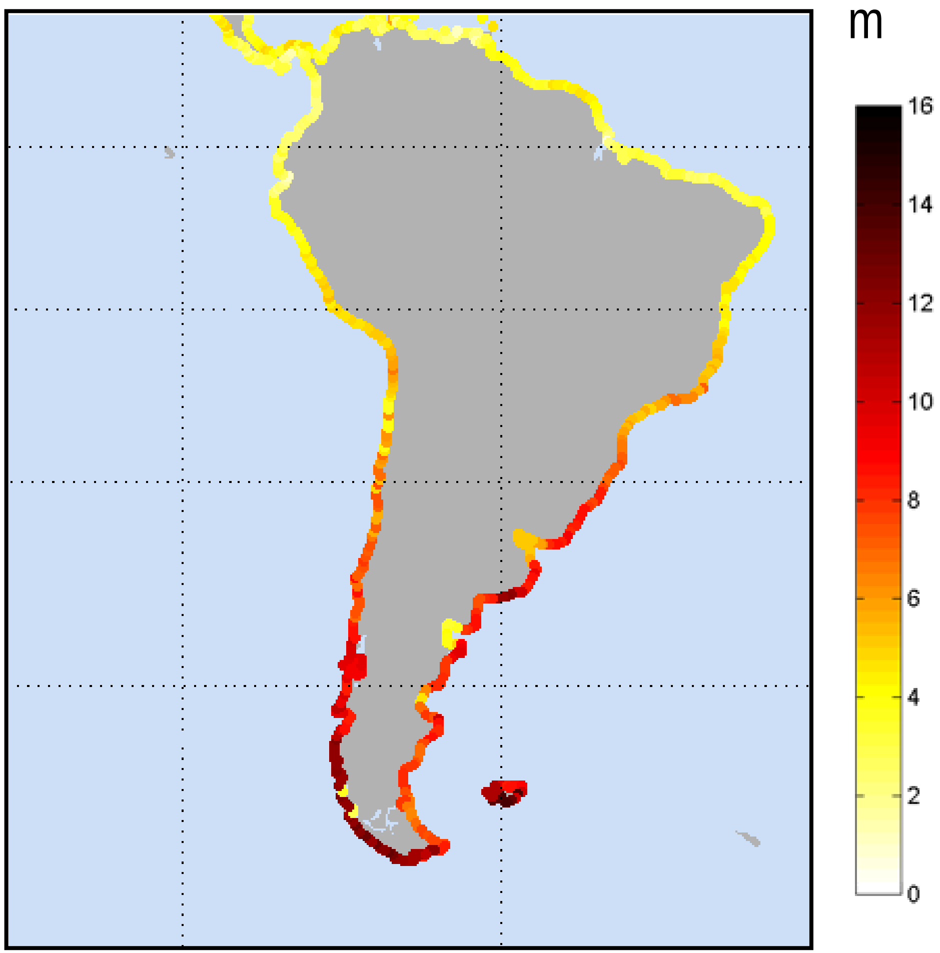


GOW

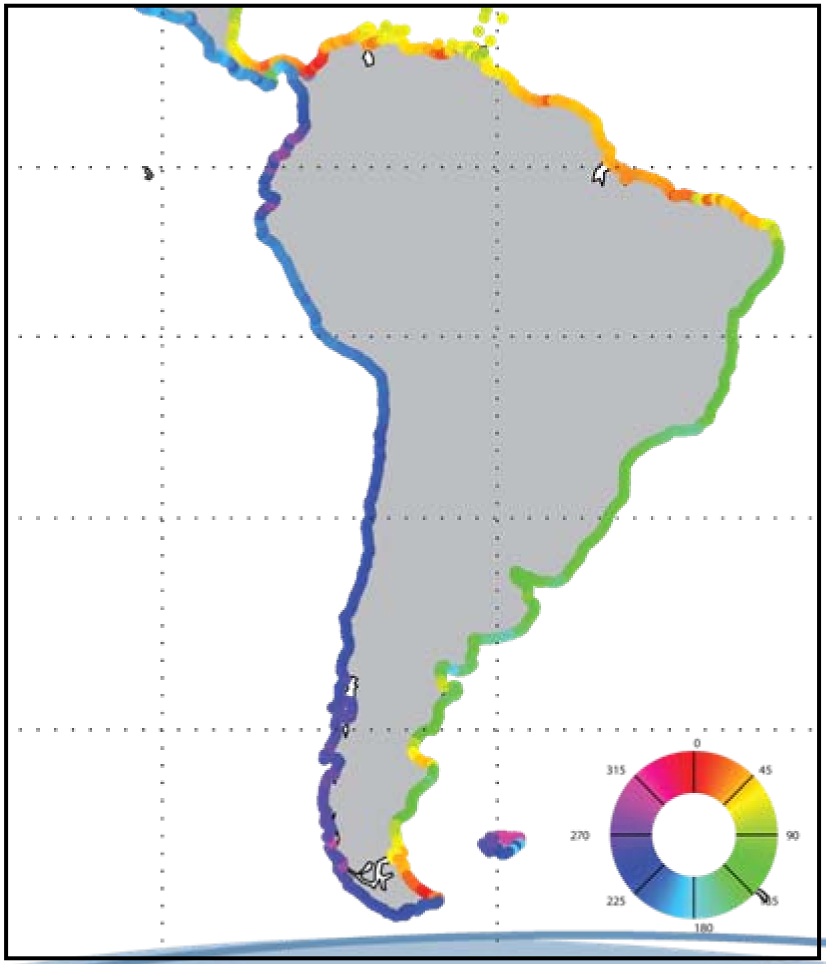
Wave reanalysis 1948-2008 1h, 0.25º

$$f_x(x)$$

Hs Tr=50 years in the year 2010 [m]
DEEP WATER



Annual mean energy flux direction



Present, t

$f_x(x)$

Historical Data Bases

$z = g(x)$

$f_Z(z)$

Coastal impacts
Hazard - Uncertainty

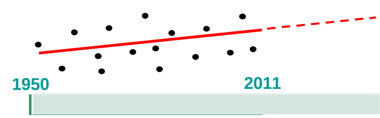
R

Risk Assessment

Future, t’

$f'_x(x)$

Historical Data Bases



Long-term trends
Climatic variability

$f'_Z(z)$

Coastal impacts
Hazard - Uncertainty

R'

Risk Assessment

$E(z)$

Exposure

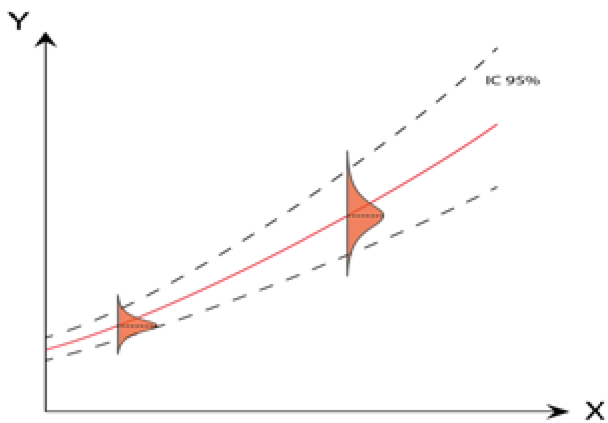
$V(z)$

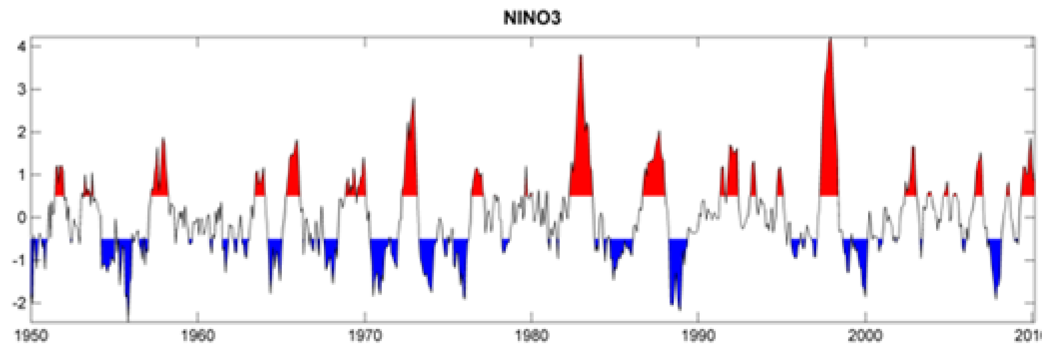
Vulnerability

$$f_x(x) \rightarrow f'_x(x)$$

Long-term trends and climate variability based on historical data bases

- Regression models
-Time dependent POT (Pareto-Poisson) for log-term trends of extreme events (Mendez et al., 2006)





$$H(x;\mu,\psi,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\psi}\right)\right]^{-1/\xi}\right\}$$

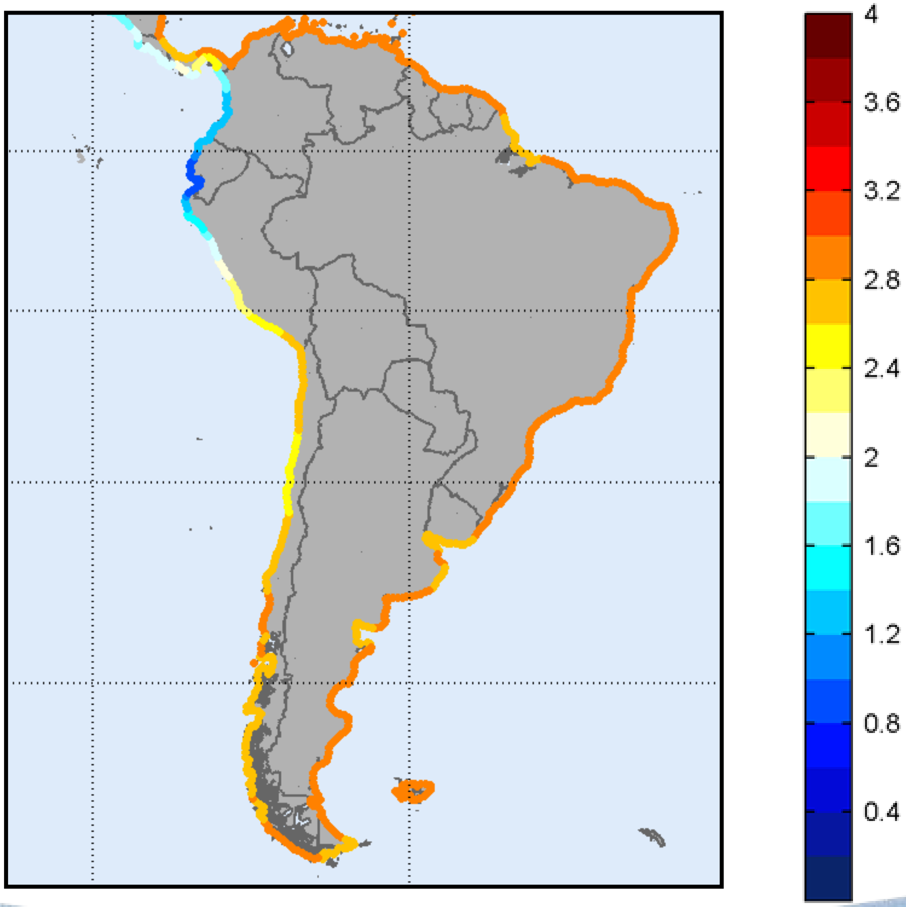
$$\mu(t) = \beta_0 + \beta_{LT}\cdot t$$
$$\psi = \alpha_0$$
$$\xi = \xi_0$$

$$H(x;\mu,\psi,\xi) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\psi}\right)\right]^{-1/\xi}\right\}$$

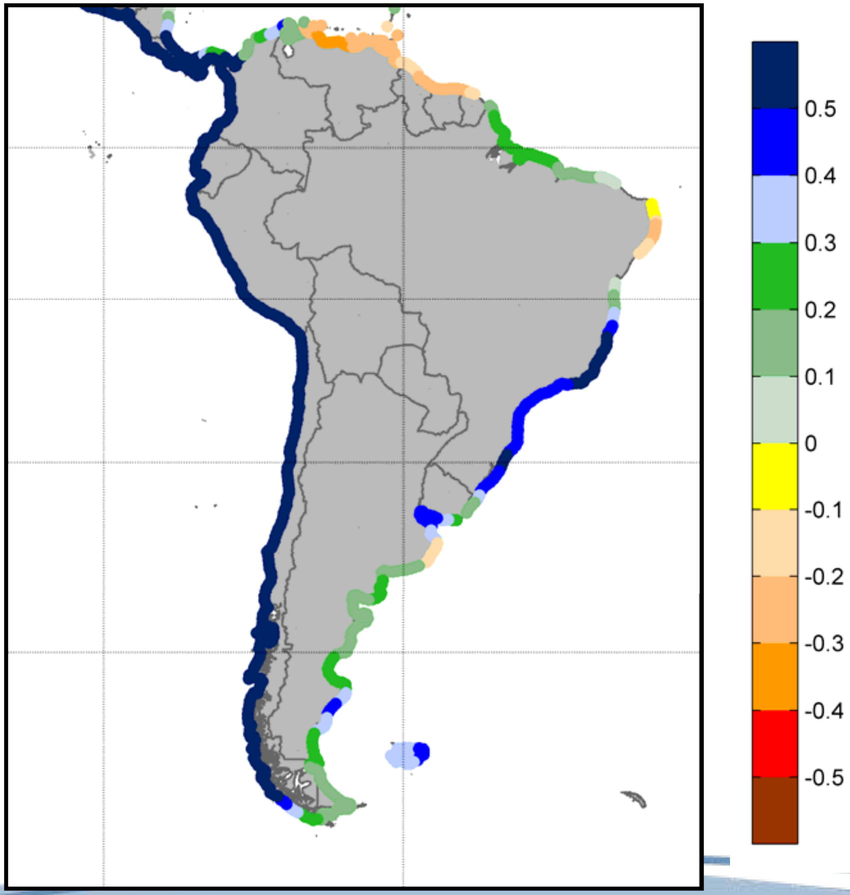
$$\mu(t) = \beta_0 + \beta_{Niño3}\cdot Niño3(t)$$
$$\psi = \alpha_0$$
$$\xi = \xi_0$$

$$f'_x(x)$$

Long-term trend of MSL (1950-2009) (mm/year)

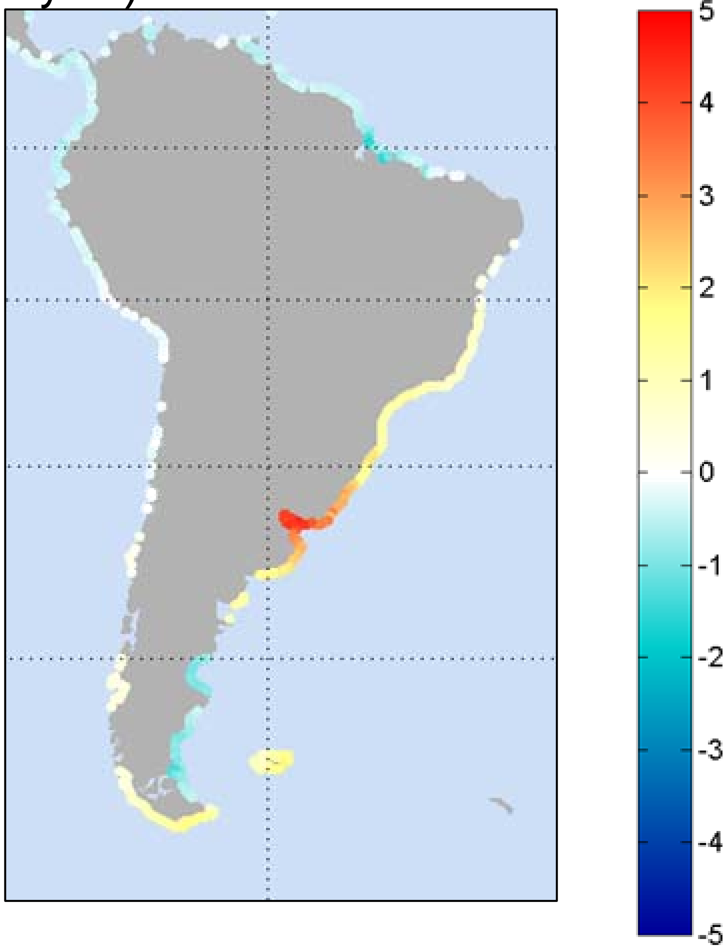


Correlation MSL-Niño3

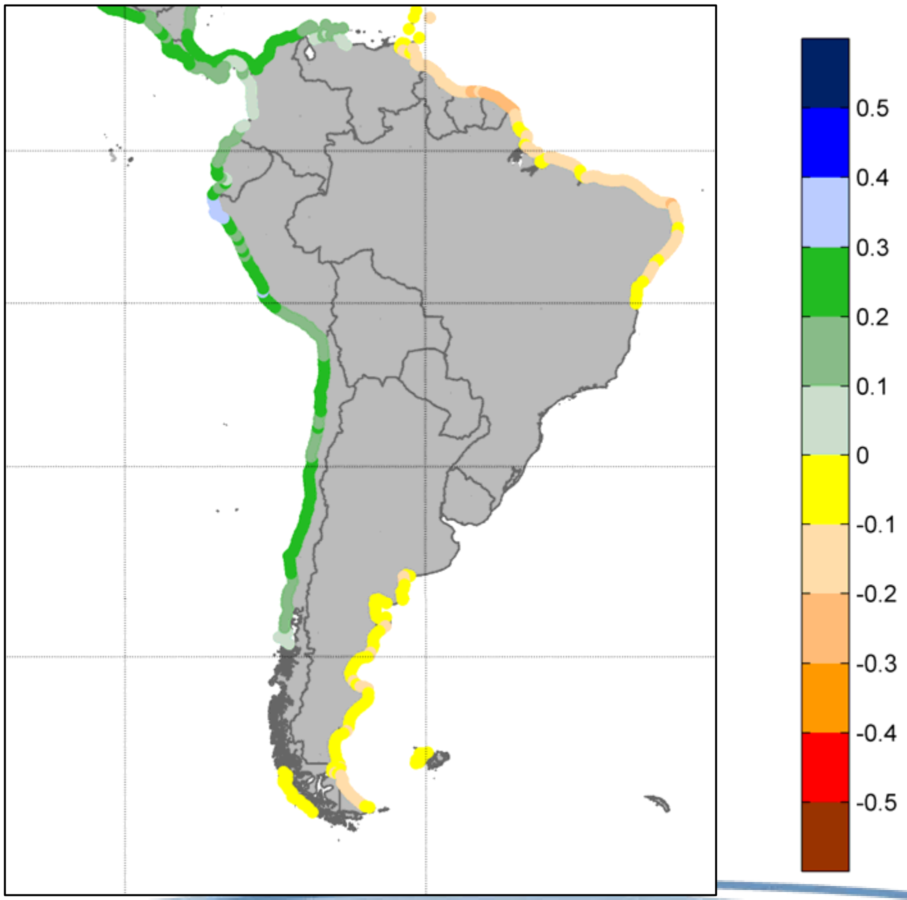


$$f'_x(x)$$

Long-term trend of annual maxima storm surge (mm/year)

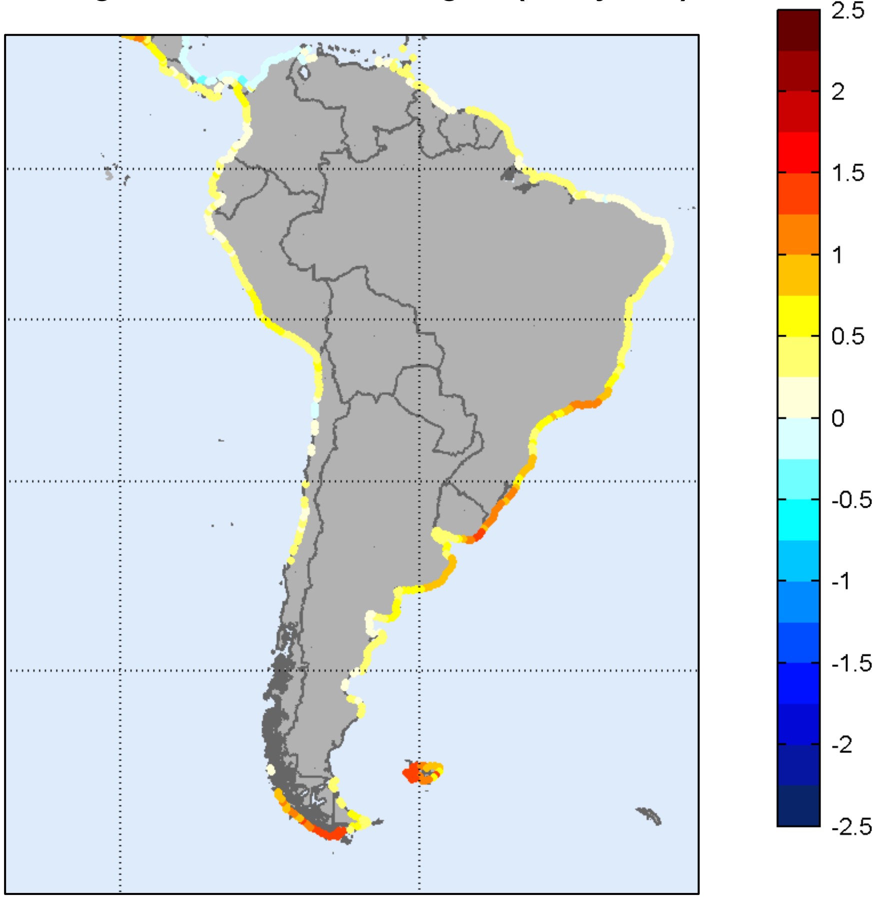


Correlation SS 95% -Niño3

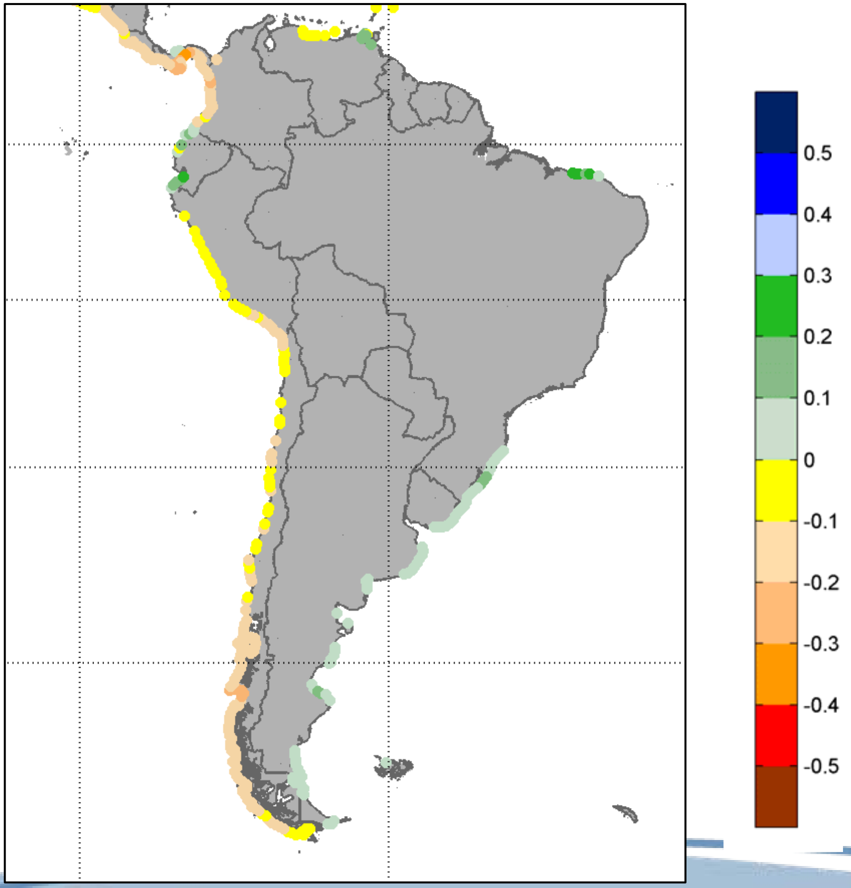


$$f'_x(x)$$

Long-term trend of annual maxima of significant wave height (cm/year)



Correlation SWH 95% -Niño3



Present, t

$f_x(x)$

Historical Data Bases

$z = g(x)$

$f_Z(z)$

Coastal impacts
Hazard - Uncertainty

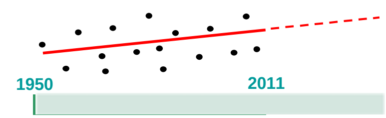
R

Risk Assessment

Future, t'

$f'_x(x)$

Historical Data Bases



Long-term trends
Climatic variability

$f'_Z(z)$

Coastal impacts
Hazard - Uncertainty

R'

Risk Assessment

$E(z)$

Exposure

$V(z)$

Vulnerability

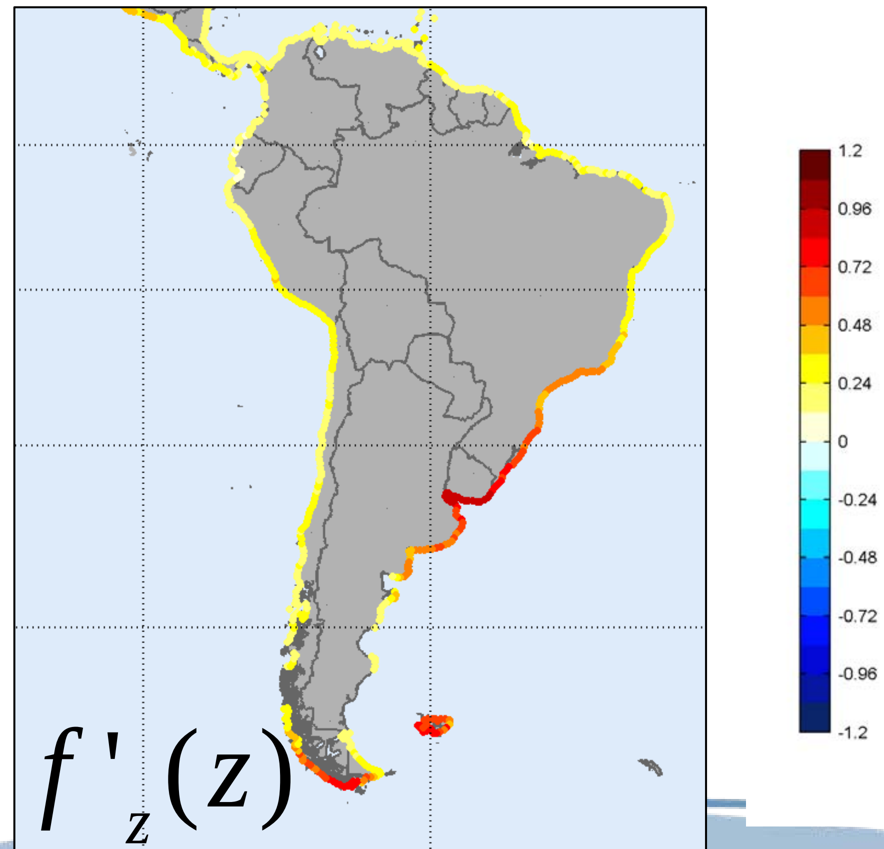
$$z = x_1 + x_2 + x_3 + x_4$$

Flooding level= MSL+ astronomical tide+ storm surge+ wave run-up

parallel isobaths (Snell's law) + Stockdon et al. (2006)

500 years return level (m)

Long-term trend of annual maxima of flooding level (cm/year)



Present, t

$f_x(x)$

Historical Data Bases

$z = g(x)$

$f_Z(z)$

Coastal impacts
Hazard - Uncertainty

R

Risk Assessment

$E(z)$

Exposure

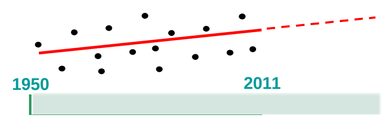
$V(z)$

Vulnerability

Future, t'

$f'_x(x)$

Historical Data Bases



Long-term trends
Climatic variability

$f'_Z(z)$

Coastal impacts
Hazard - Uncertainty

R'

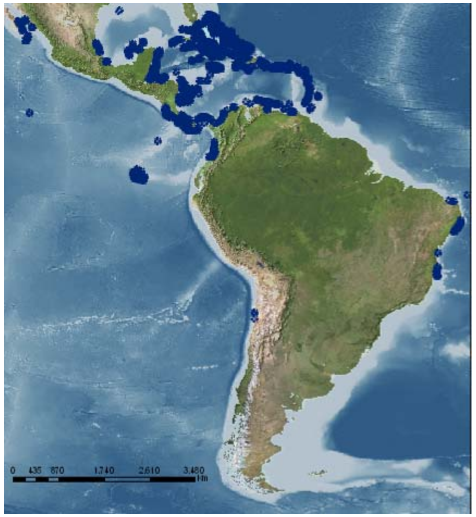
Risk Assessment

Based on available GIS information (CIESIN, GLOBCOVER, LAND COVER, ...)

$$E(z)\ V(z)$$

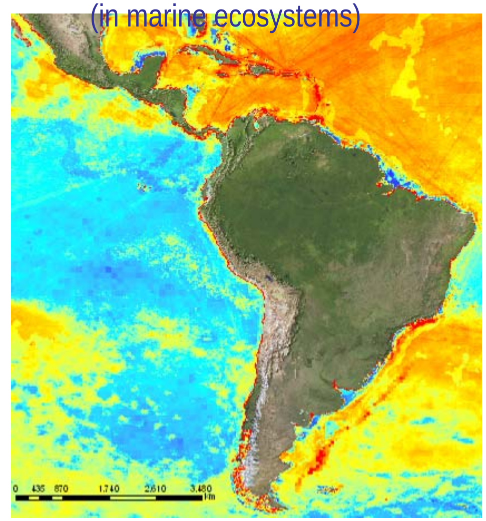
- 0.50º ~ 50 Km = Global Level (Low Resolution, LR)

Reefs

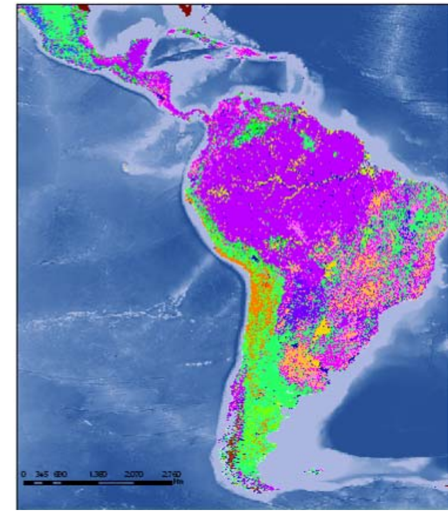


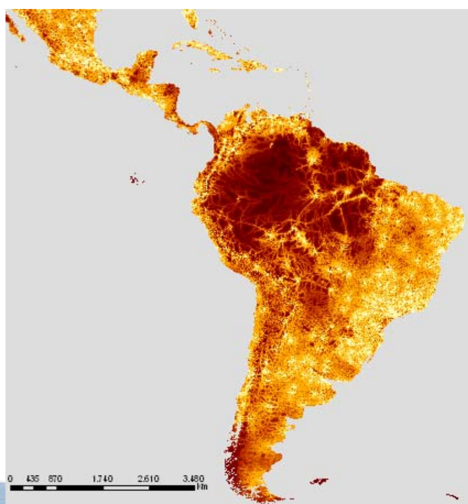
Ecosystems

Human impact
(in marine ecosystems)

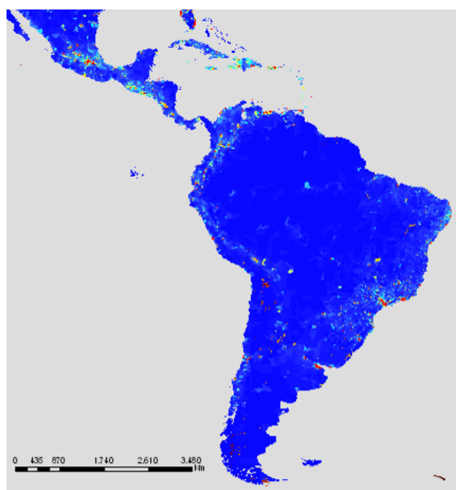


GlobCover, Land cover

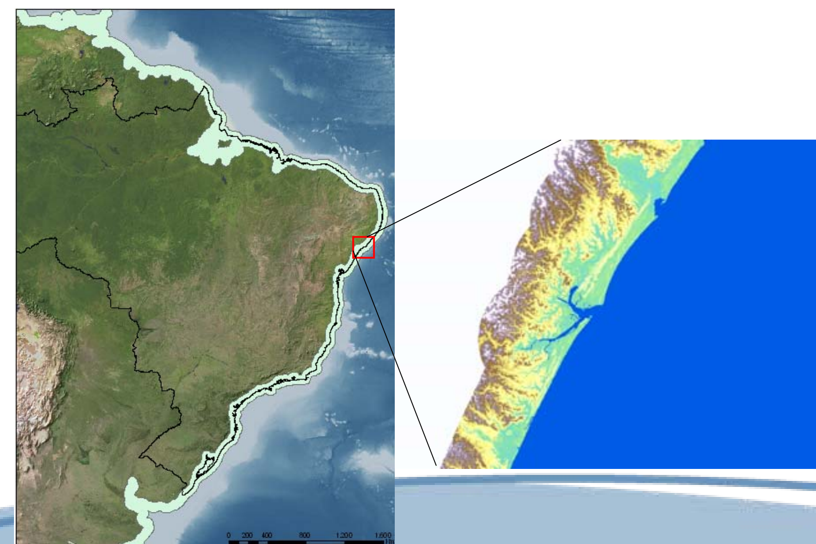




Roads



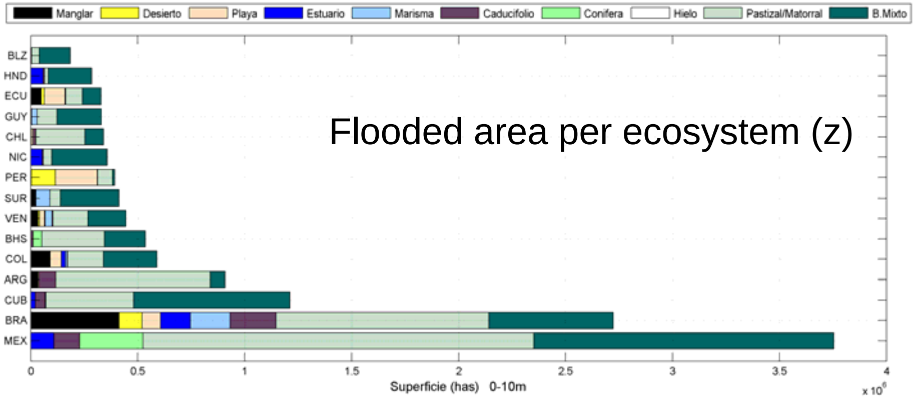
Population density

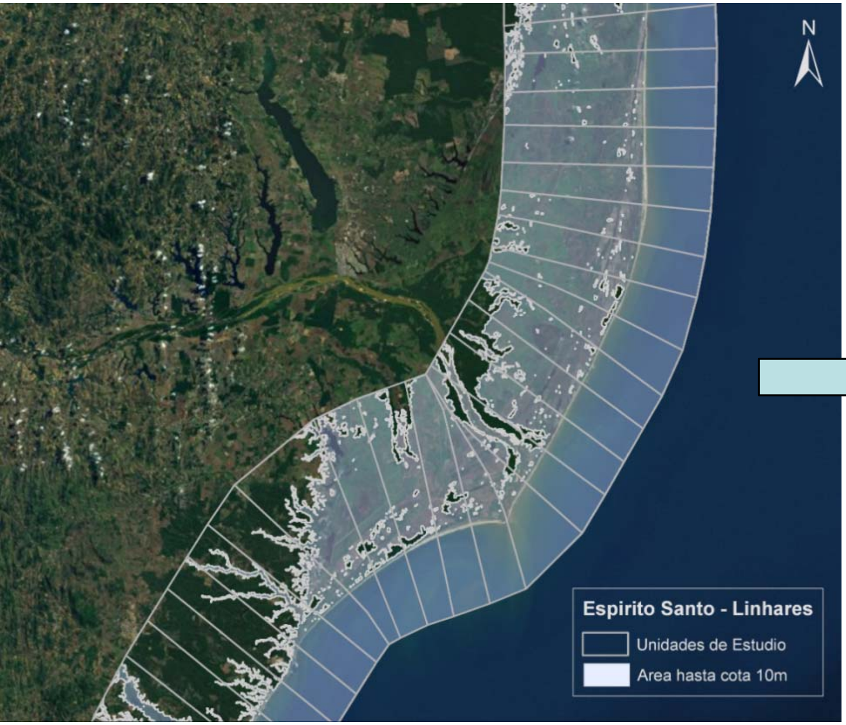


Digital Terrain Model: STRM 90m

$$E(z)\ V(z)$$

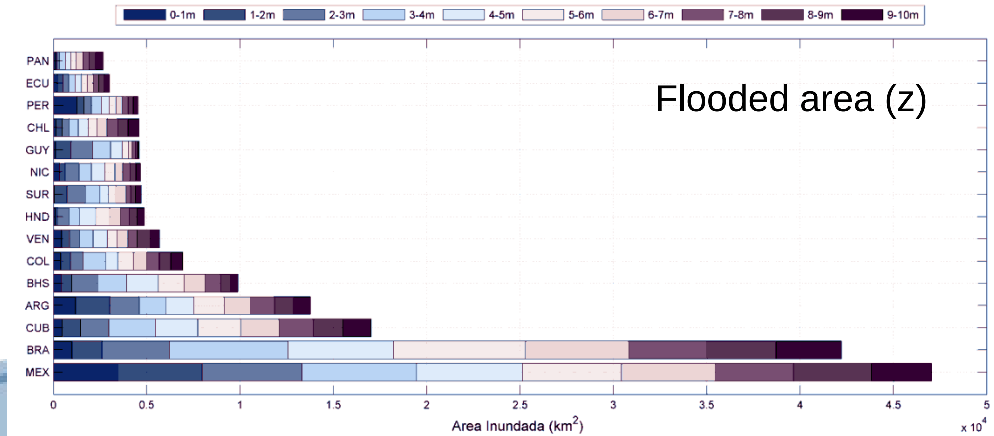
Flooded area per ecosystem (z)





Population (z)

Flooded area (z)



Present, t

$f_x(x)$

Historical Data Bases

$z = g(x)$

$f_Z(z)$

Coastal impacts
Hazard - Uncertainty

R

Risk Assessment

$E(z)$

Exposure

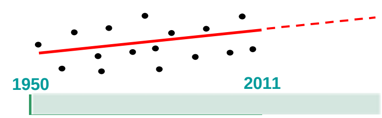
$V(z)$

Vulnerability

Future, t’

$f'_x(x)$

Historical Data Bases



Long-term trends
Climatic variability

$f'_Z(z)$

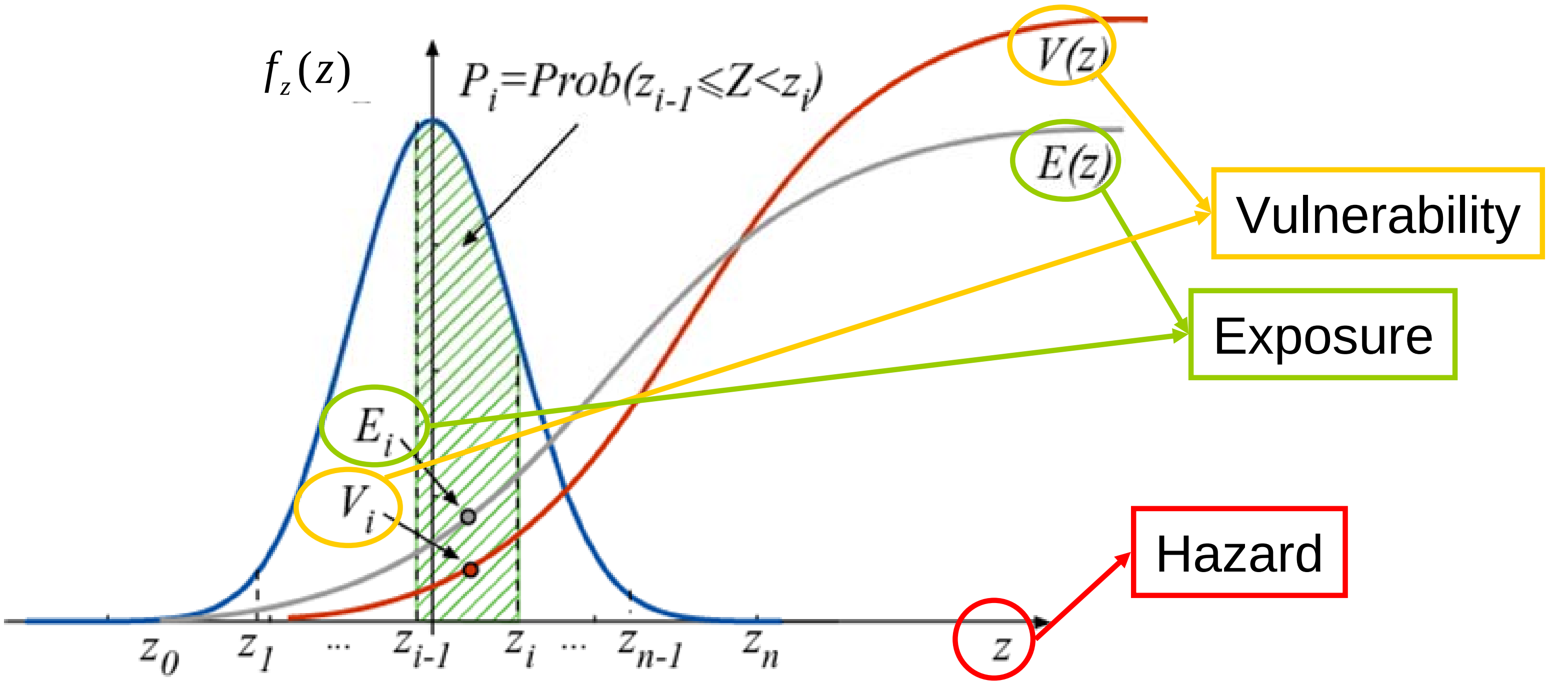
Coastal impacts
Hazard - Uncertainty

R'

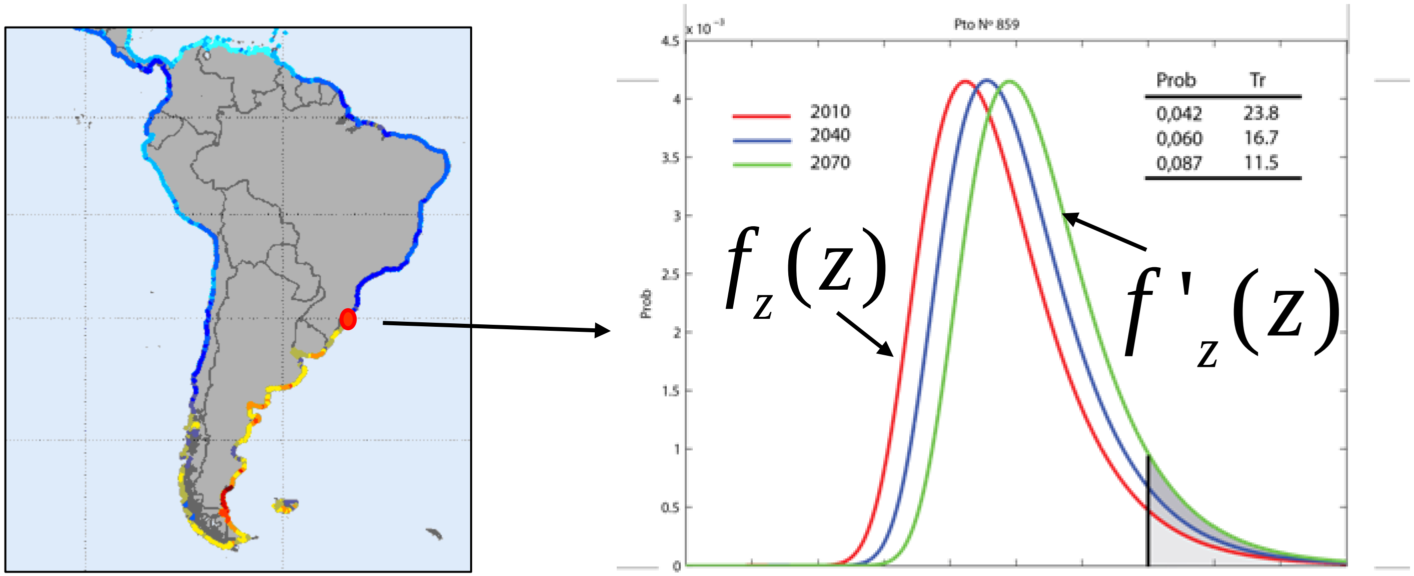
Risk Assessment

Mathematical definition for the expected annual damage

$$R = \int_{-\infty}^{\infty} f_Z(z)E(z)V(z)dz$$



Coastal climate change risk assessment



Present, t

$$R = \int_{-\infty}^{\infty} f_Z(z)E(z)V(z)dz$$

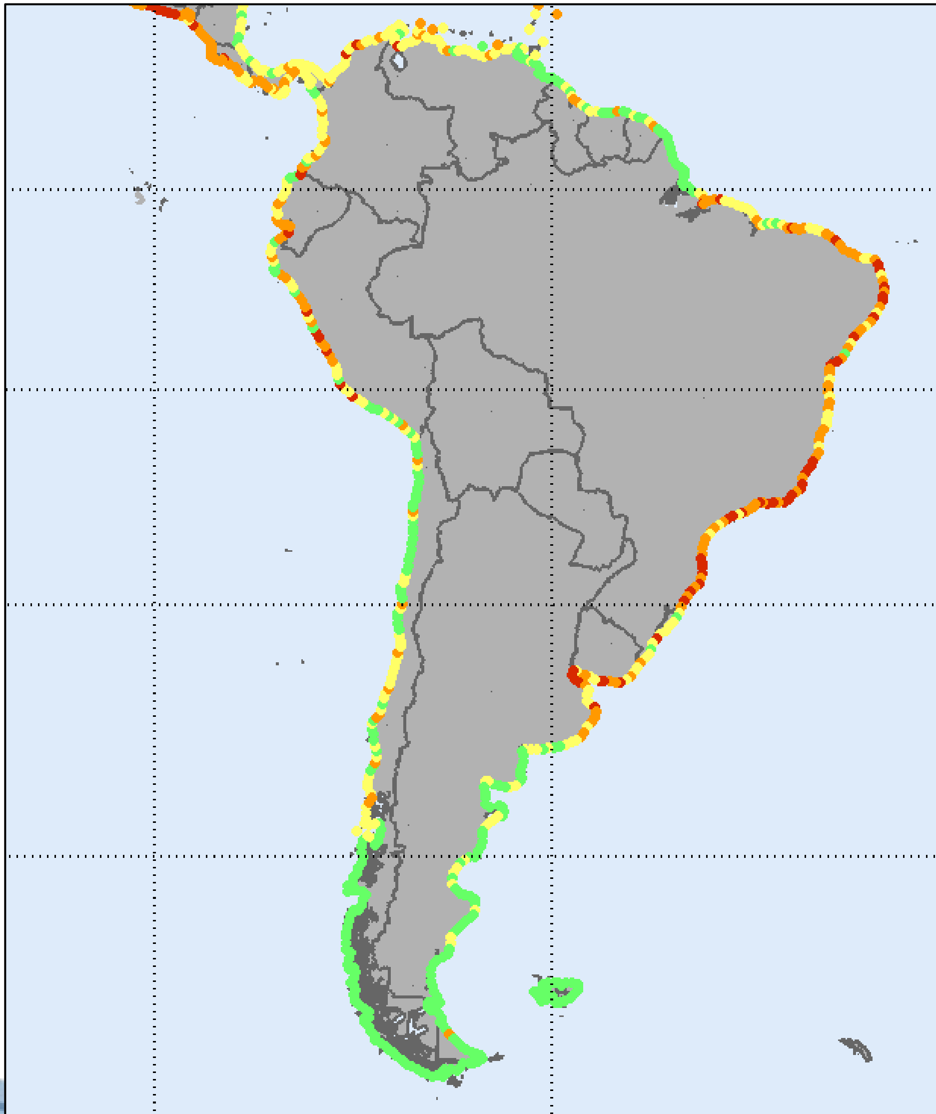
Future, t’

$$R' = \int_{-\infty}^{\infty} f'_Z(z)E(z)V(z)dz$$

$$\Delta R = R' - R$$

Example

Flooding risk levels (in terms of afected population)



$$\Delta R = R_{2040}' - R_{2010}$$

Present, t

$f_x(x)$

Historical Data Bases

$z = g(x)$

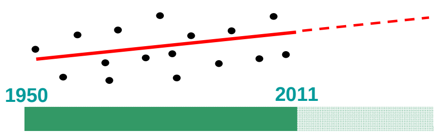
$f_Z(z)$

Coastal impacts
Hazard - Uncertainty

R

Risk Assessment

ΔR



$E(z)$

Exposure

$V(z)$

Vulnerability

Future, t'

$f'_x(x)$

Historical Data Bases

Long-term trends
Climatic variability

$f'_Z(z)$

Coastal impacts
Hazard - Uncertainty

R'

Risk Assessment

12th International Workshop on Wave Hindcasting and Forecasting and 3rd Coastal Hazards Symposium

Hawai'i's Big Island, October 30 – November 4, 2011

Present and Future Flooding and Erosion Coastal Risk Assessment in Practically Ungauged Large Areas: Methodology and Results for South America

Sonia Castanedo, Borja G. Reguero, Ana J. Abascal, Inigo J. Losada, Roberto Minguez, Fernando J. Mendez

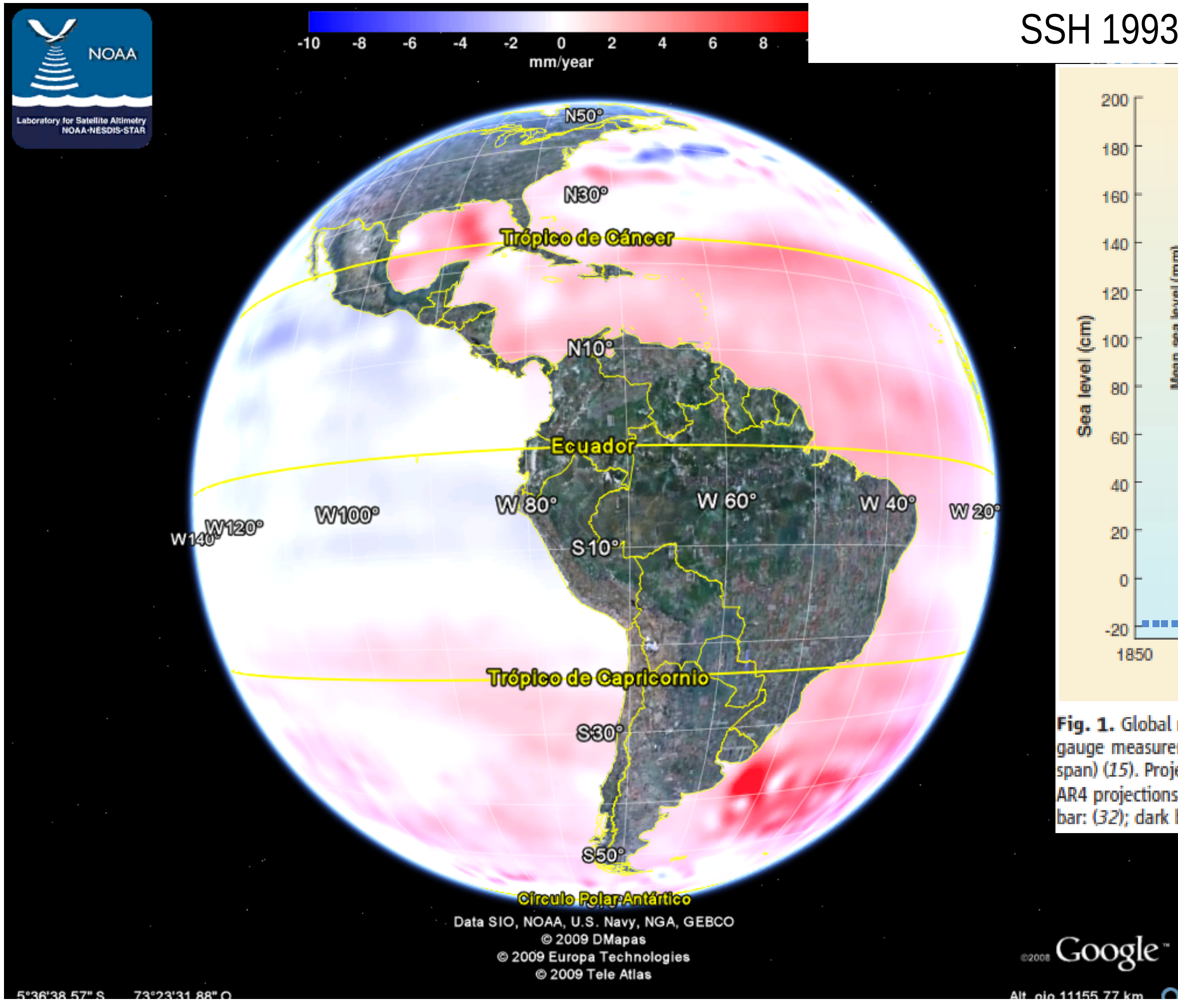
castanedos@unican.es

UC UNIVERSIDAD DE CANTABRIA
IH cantabria INSTITUTO DE HIDRÁULICA AMBIENTAL UNIVERSIDAD DE CANTABRIA
CANTABRIA CAMPUS INTERNACIONAL Agua y Energía

Mean Sea Level:

Regional sea level 1950-2001 Global 1º
Satélite 1993-2009 Monthly Global 1º
UHSLC tide gauges
SSH 1993-2009 (AVISO)

Mean sea level (SSH) - Satellite (1993-2009)



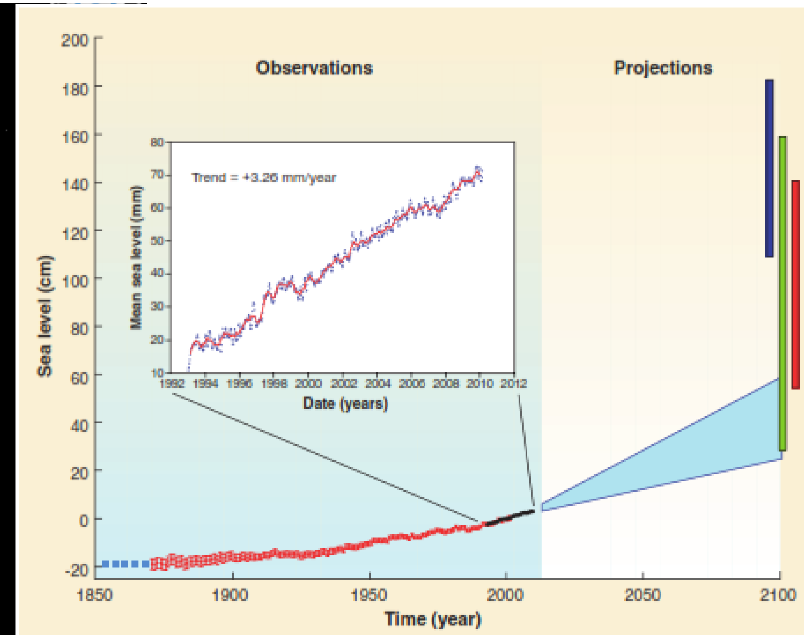


Fig. 1. Global mean sea level evolution over the 20th and 21st centuries. The red curve is based on tide gauge measurements (*10*). The black curve is the altimetry record (zoomed over the 1993–2009 time span) (*15*). Projections for the the 21st century are also shown. The shaded light blue zone represents IPCC AR4 projections for the A1FI greenhouse gas emission scenario. Bars are semi-empirical projections [red bar: (*32*); dark blue bar: (*33*); green bar: (*34*)].

Nicholls et al. 2010. Sea-Level Rise and its Impact on Coastal Zones

Satellite (1993-2009), Satellite+tide gauge (1950-2001)

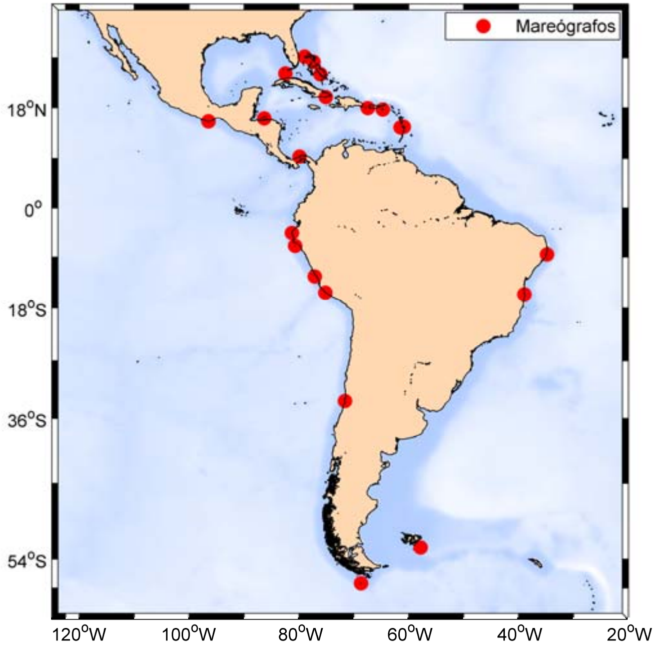
Church, J.A., N.J. White, R. Coleman, K. Lambeck and J.X. Mitrovica (2004), Estimates of the Regional Distribution of sea level Rise over the 1950 to 2000 Period. *Journal of Climate*, 17, 2609-2625.

GOT

Astronomical tide

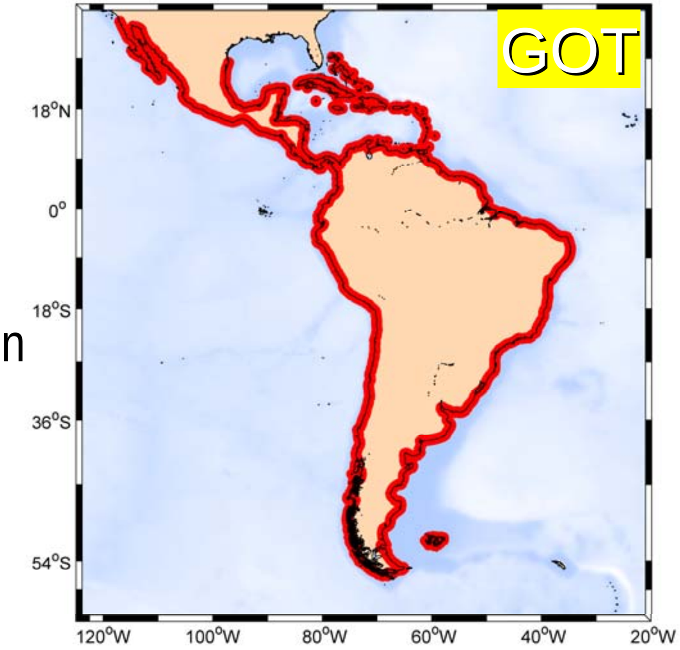
Reconstruction for the period 1948-2100, 0.25º

TPXO+ t_tide



UHSLC tide gauges

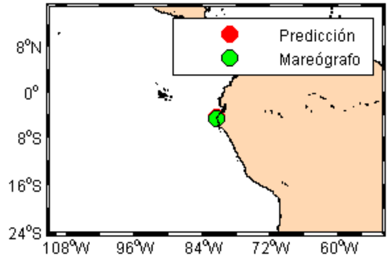
validation

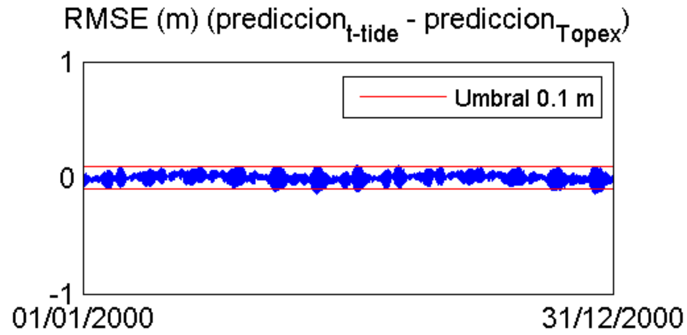


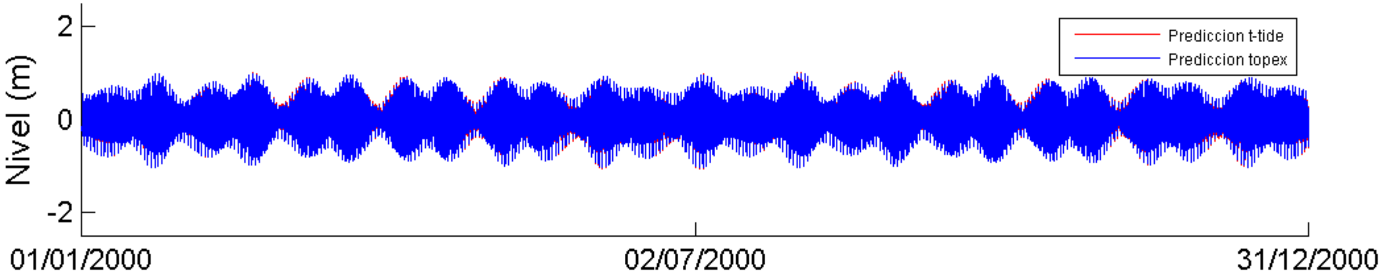
GOT

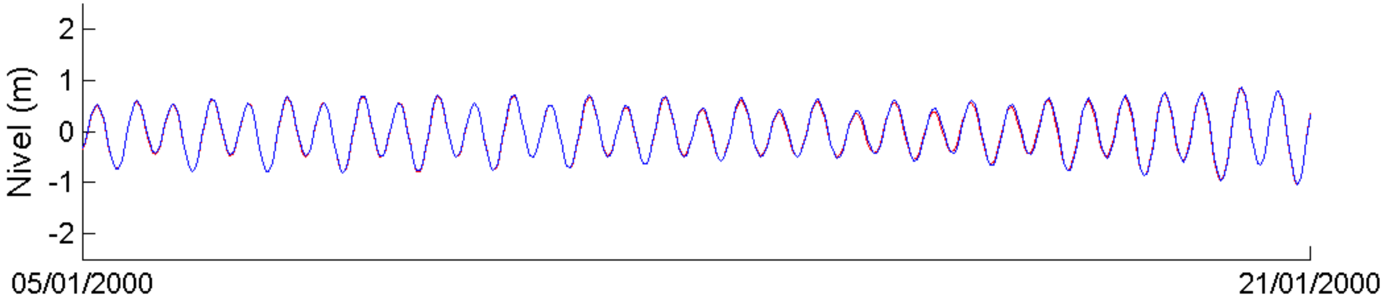
Astronomical tide

Reconstruction for the period 1948-2100, 0.25º





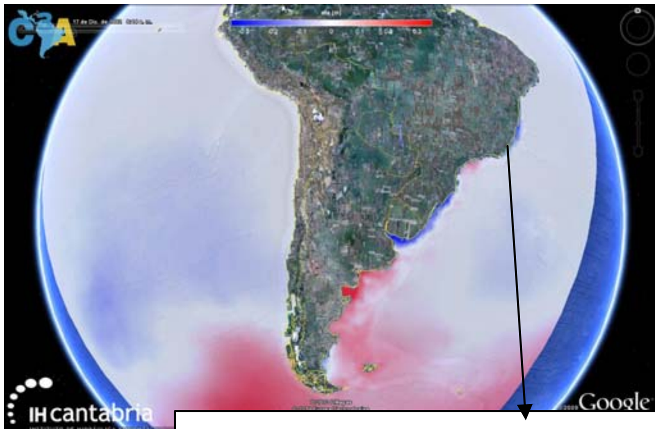


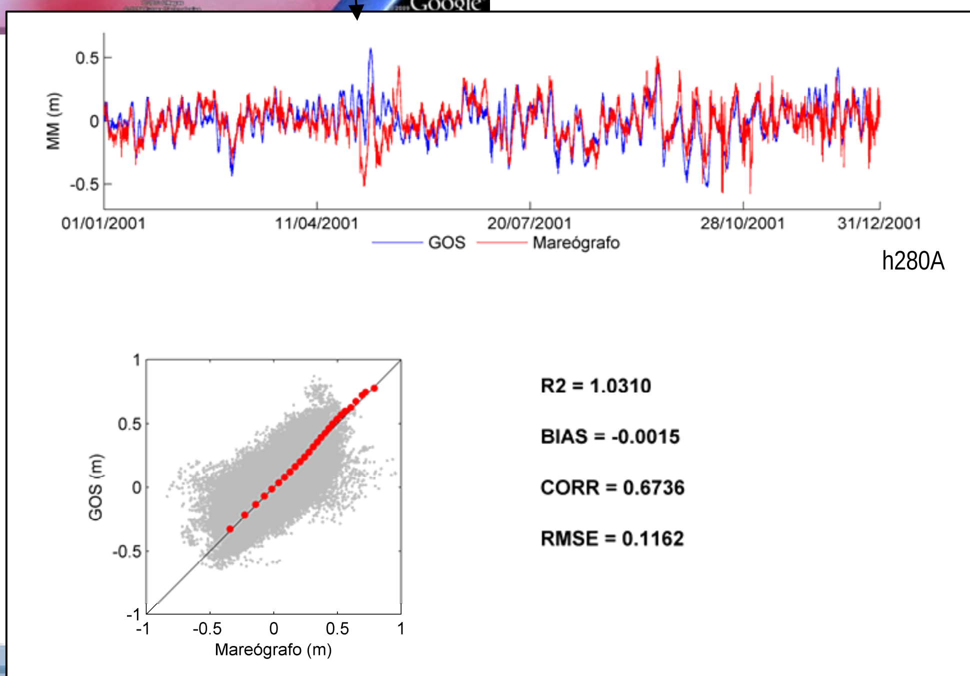


GOS

Storm surge

GOS 1948-2008 1h ALyC 0.25º





Regional Ocean Modeling System (ROMS) (Warner et al., 2008)

-ETOPO2 bathymetry
-NCEP/NCAR atm. forcing (6h)
- OBC: inverted barometer effect

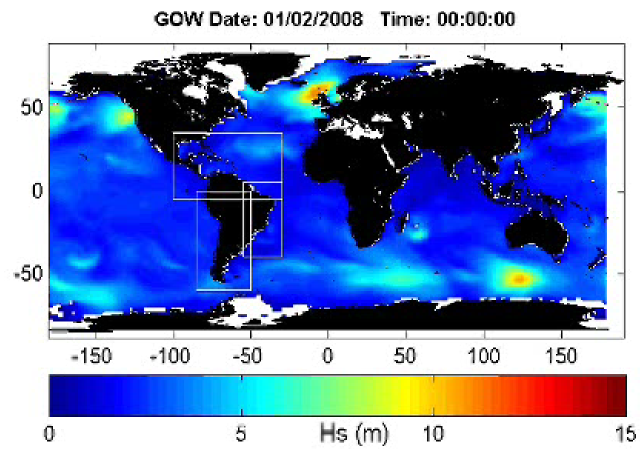
GOW

Waves:

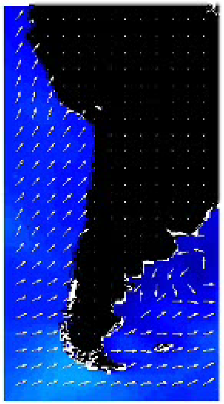
GOW 1948-2008 1h Global 1.5º
GOW 1948-2008 1h SouthPacific 0.5º
GOW1948-2008 1h SouthAtlantic 0.5º
GOW1948-2008 1h The Caribbean 0.25º

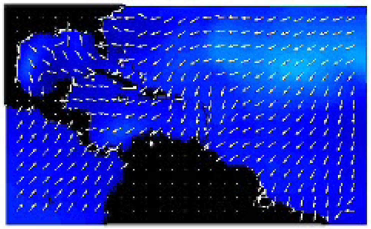
Wavewatch III

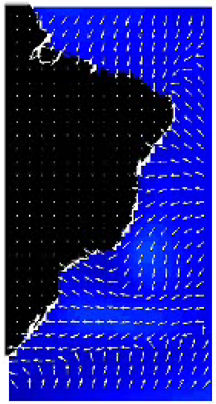
-ETOPO2 bathymetry
-NCEP/NCAR atm. forcing (6h)



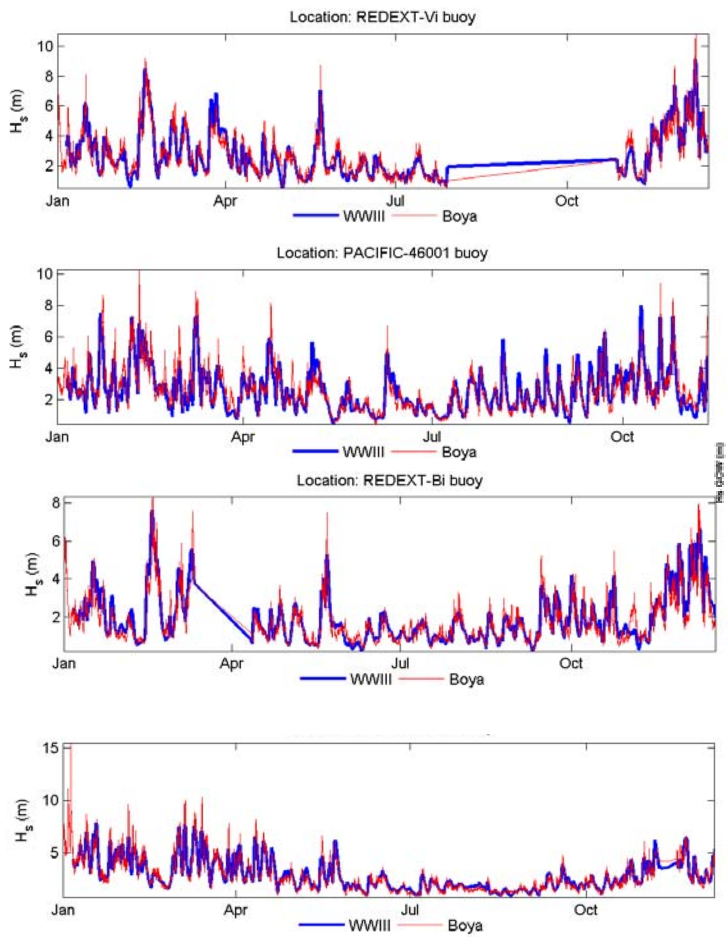
Poster P21 (Reguero et al., 2011)

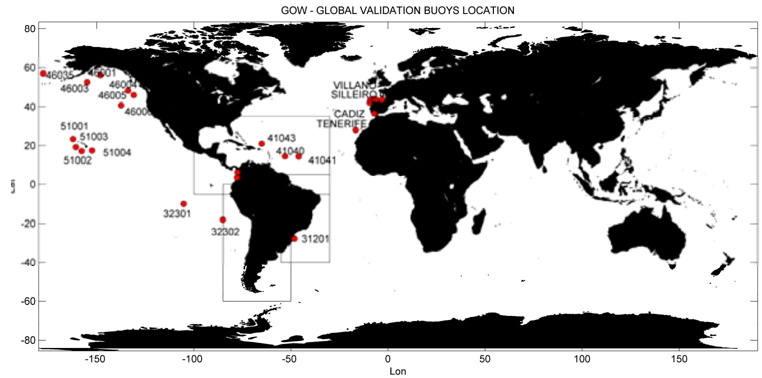


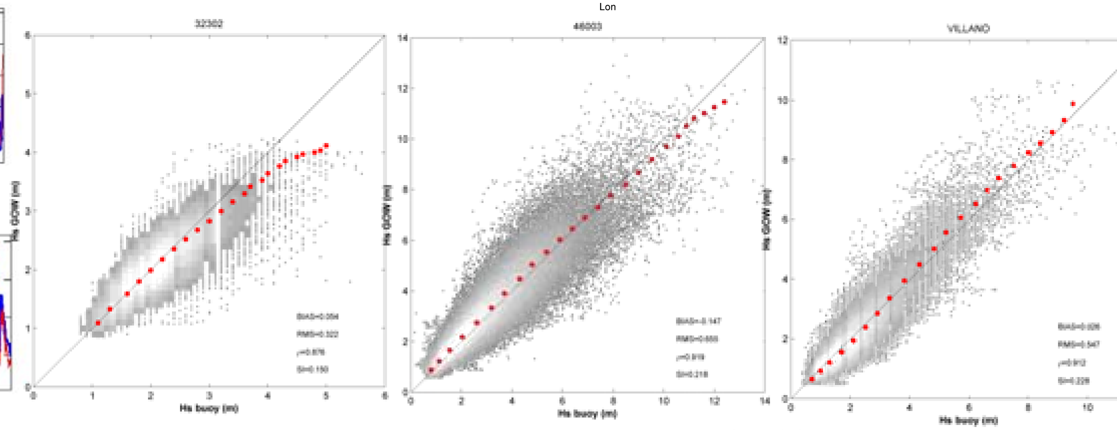


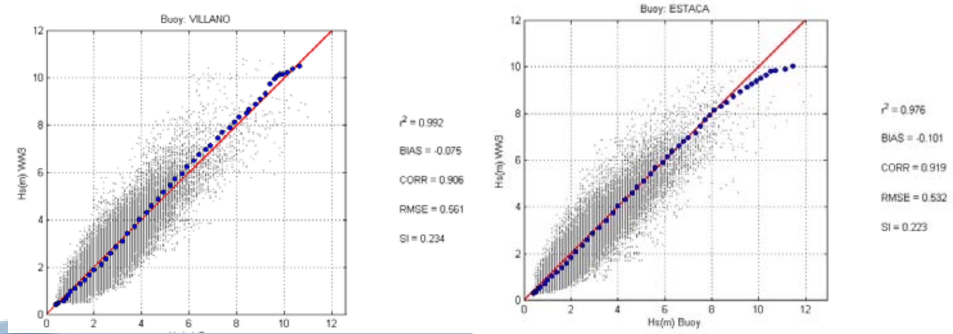


GOW


Location: REDEXT-Vi buoy
Location: PACIFIC-46001 buoy
Location: REDEXT-Bi buoy
Jan
Apr
Jul
Oct
WWIII
Boya

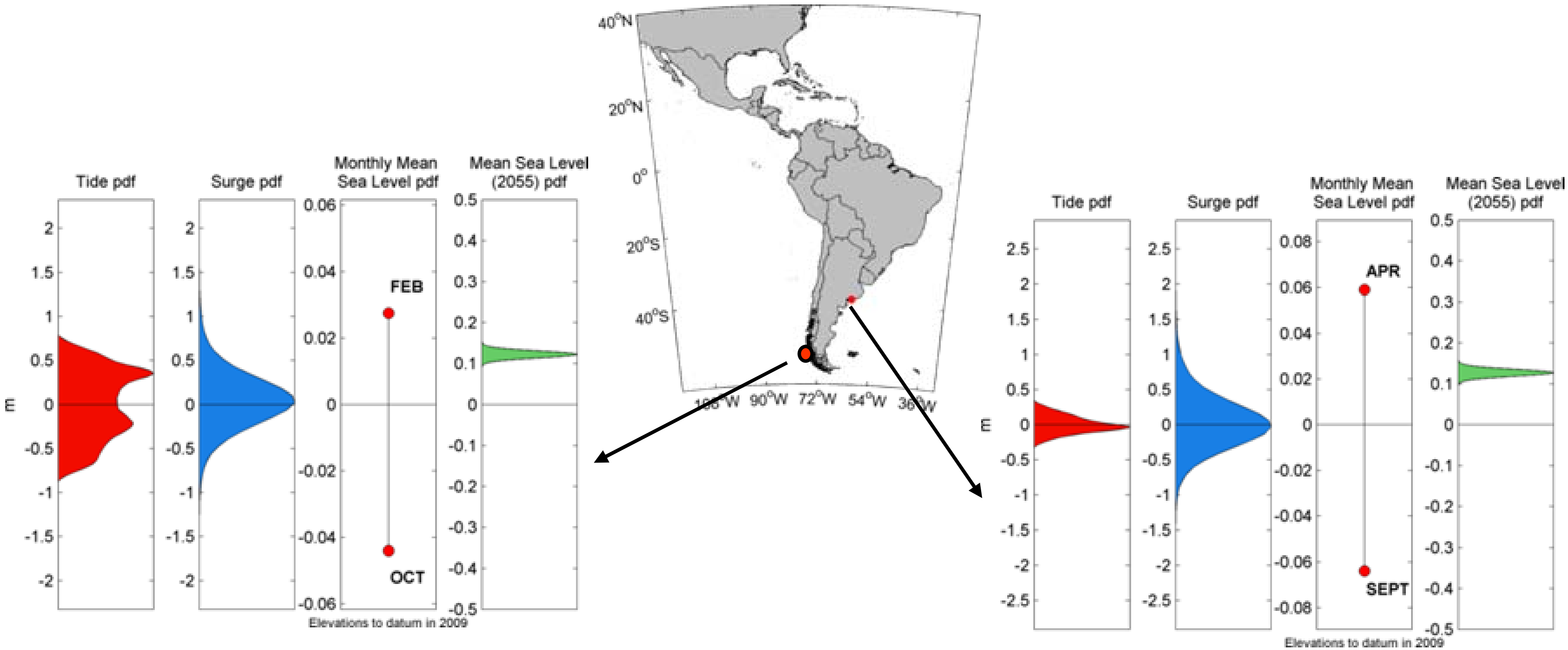

GOW - GLOBAL VALIDATION BUOYS LOCATION
Lon
VILLANO
SILLEIRO
CADIZ
TENERIFE
51001
51003
51002
51004
41043
41040
41041
32301
32302
31201


32302
46003
VILLANO
Hs GOW (m)
Hs buoy (m)


Buoy: VILLANO
Hs(m) WW3
r^2 = 0.992
BIAS = -0.075
CORR = 0.906
RMSE = 0.561
SI = 0.234
Buoy: ESTACA
Hs(m) Buoy
r^2 = 0.976
BIAS = -0.101
CORR = 0.919
RMSE = 0.532
SI = 0.223

Flooding

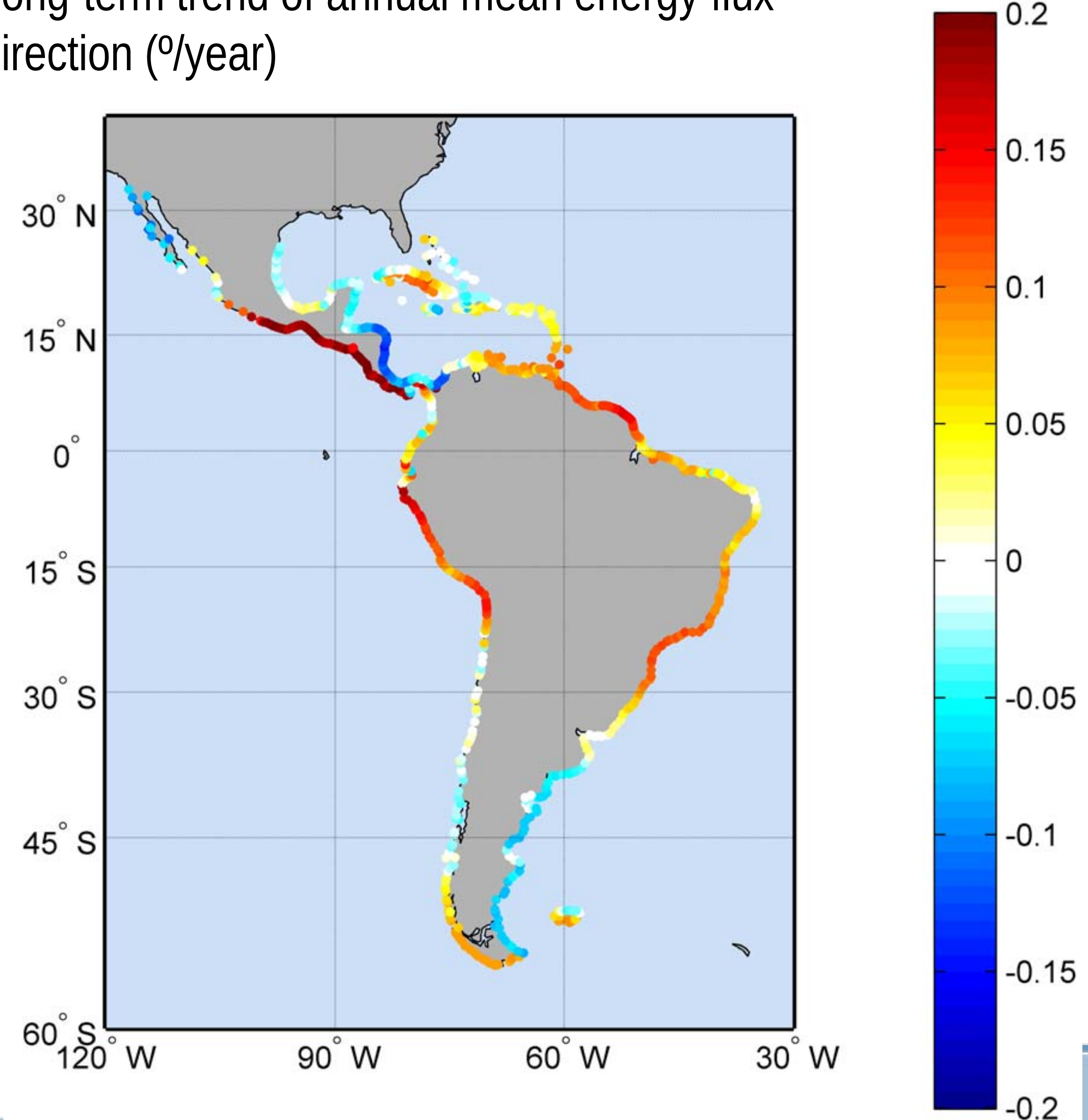
Spatial variability of the different factors



$$f_z(z)$$

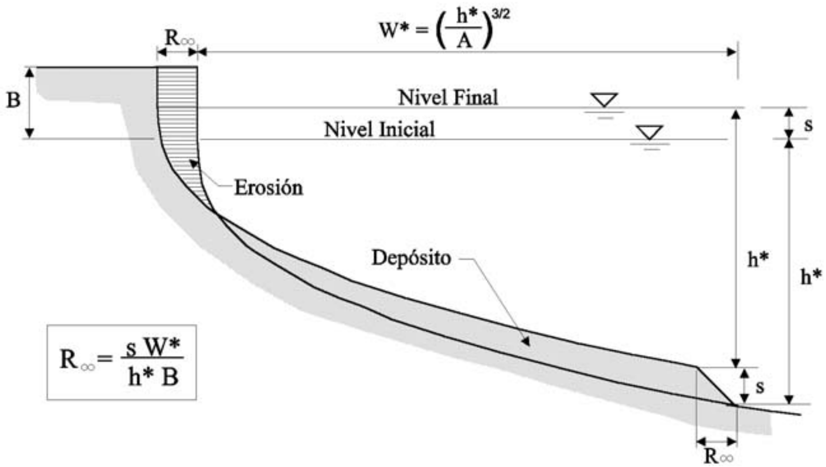
$$f'_x(x)$$

Long-term trend of annual mean energy flux direction (º/year)



Erosion

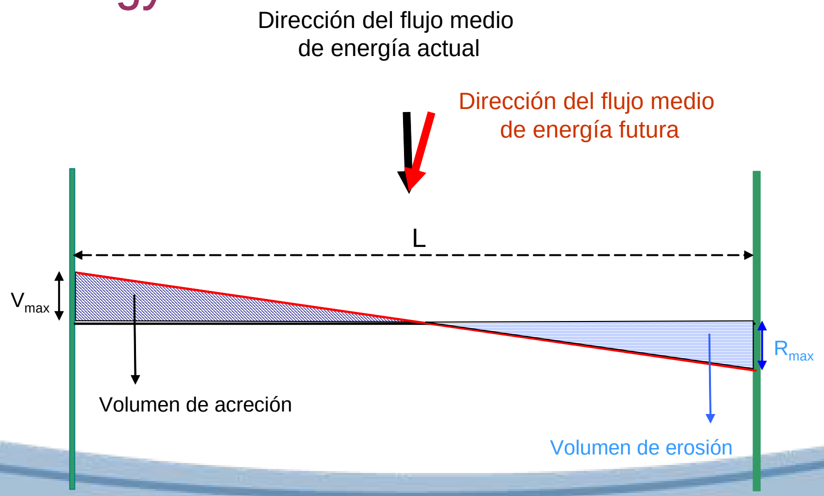
- Cross-shore shoreline retreat



$$z = g(x)$$
$$x = \Delta\eta$$
$$z = RE$$

$$RE = \frac{\Delta\eta \cdot W_*}{h_* + B} = \Delta\eta \frac{(1.57H_{s12})^{1.5}}{\left(0.51w^{0.44}\right)^{1.5}(1.57H_{s12} + B)}$$

- Beach erosion due to changes in annual mean energy flux direction



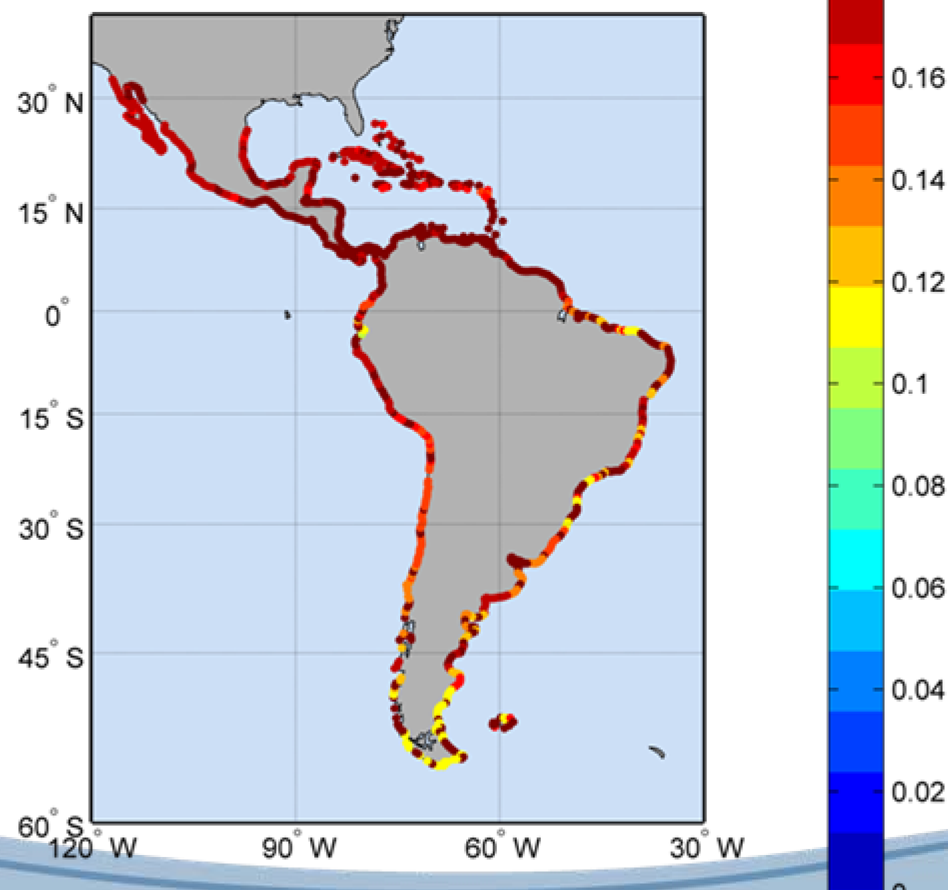
$$z = g(x)$$
$$x = \Delta\beta$$
$$z = RE$$

$$RE_{\max} = \frac{L}{2} tg(\Delta\beta)$$

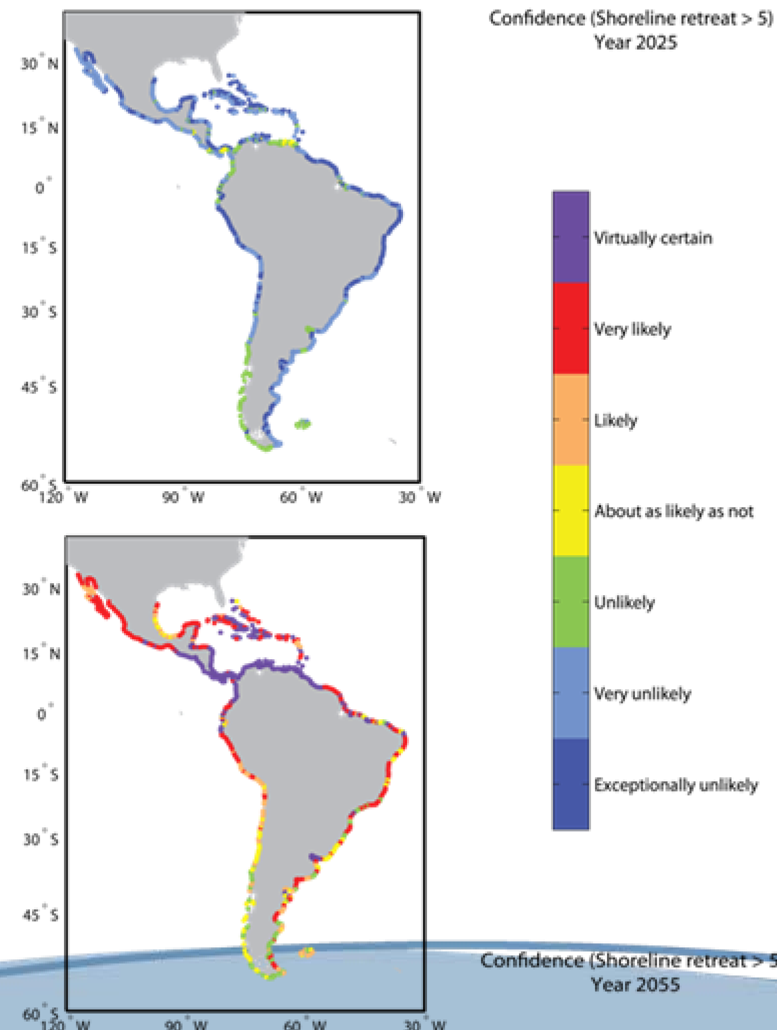
Erosion

$$f'_z(z)$$

Trend in shoreline erosion (m/year)
Erosion in beach profile



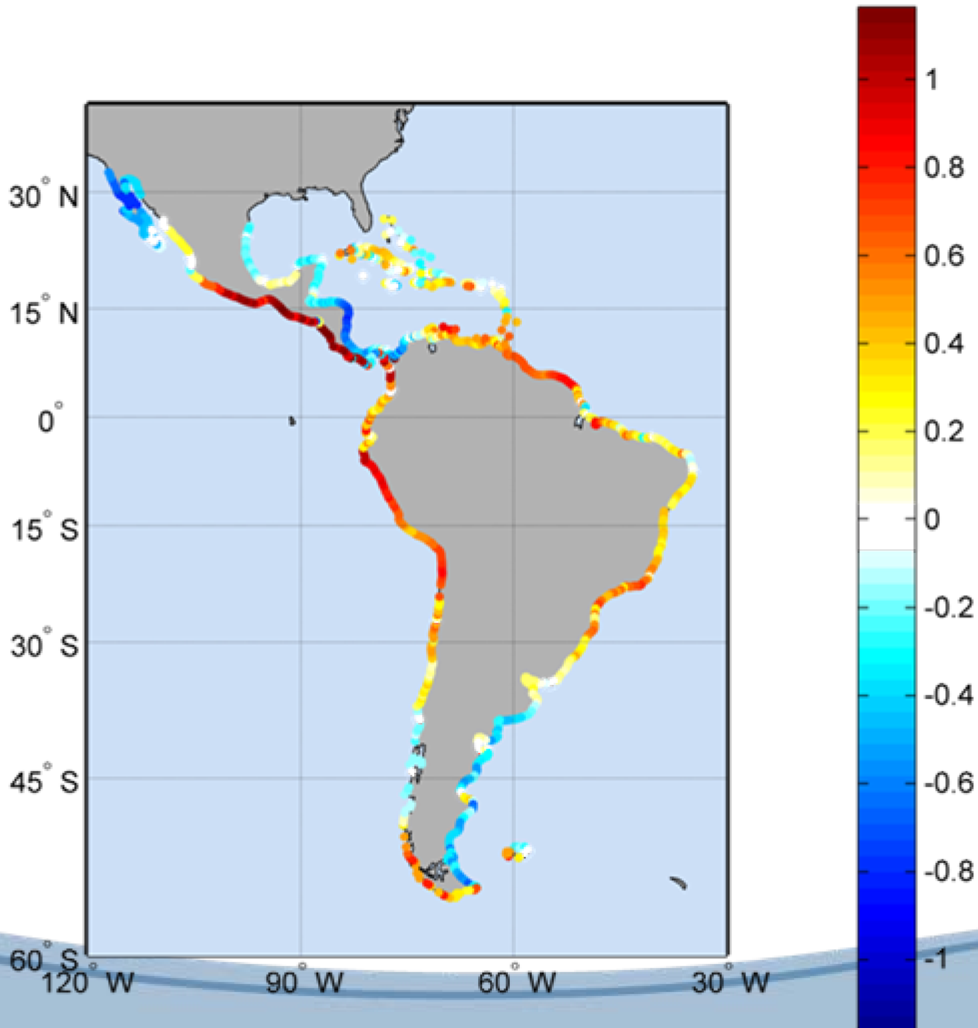
Erosion in beach profile



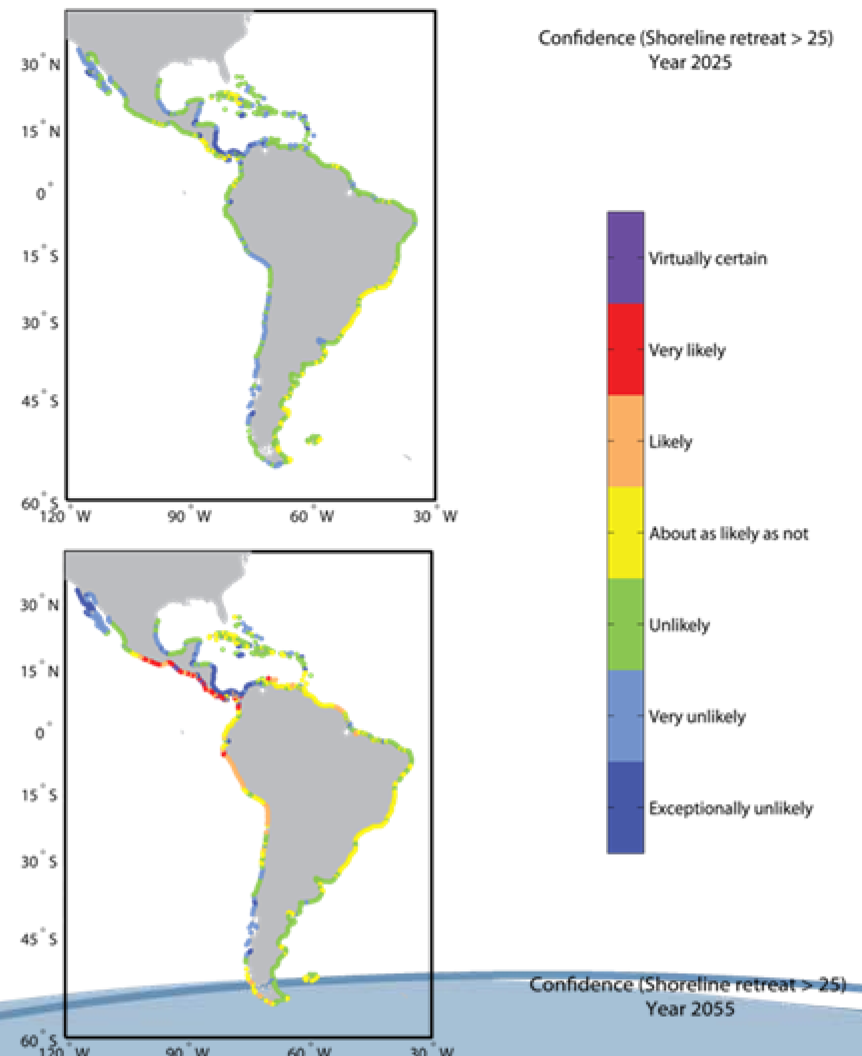
Erosion

$$f'_z(z)$$

Trend in shoreline erosion (m/year)
Potential planform gyre shoreline retreat for a 1000m beach

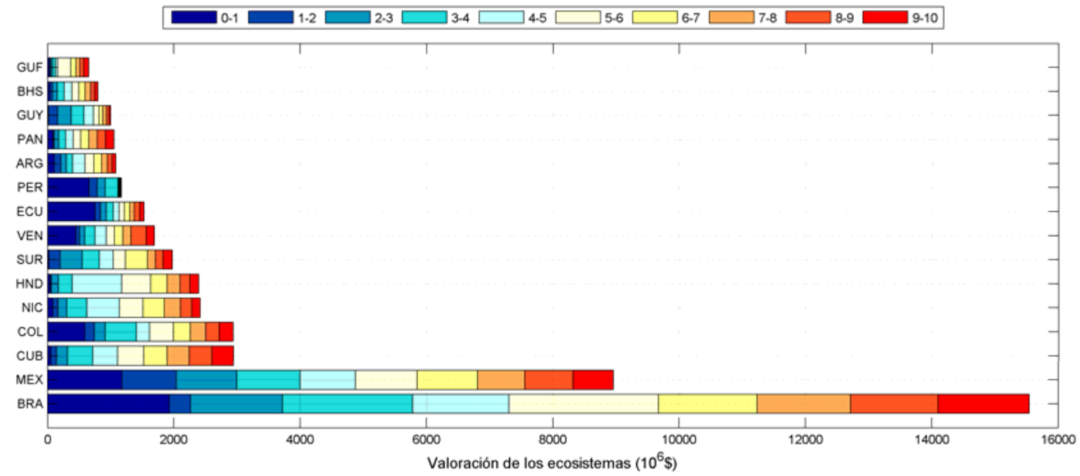


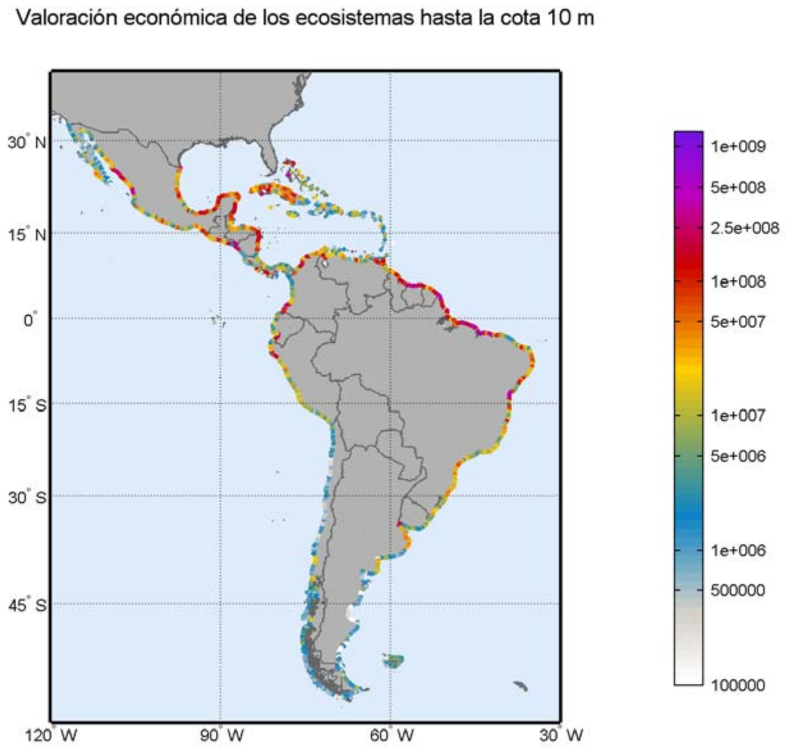
Potential planform gyre shoreline retreat for a 1000m beach



$$V(z)$$

Ecological vulnerability based on Constanza et al. (1997)(1)





(1) ROBERT COSTANZA, RALPH D'ARGE, RUDOLF DE GROOT, STEPHEN FARBER, MONICA GRASSO, BRUCE HANNON, KARIN LIMBURG, SHAHID NAEEM, ROBERT V. O'NEILL, JOSE PARUELO, ROBERT G. RASKIN, PAUL SUTTON & MARJAN VAN DEN BEL (1997) The value of world's ecosystem services and natural capital. Nature 387, 253 - 260

Integration of Risk

Impact of Hazard “h” in ECON_Sector “j” (or ECOL_Sector “k”) in segment “m”