summer school 2015

Sea Level Rise: evidences, scenarios and local consequences

Guillem Chust

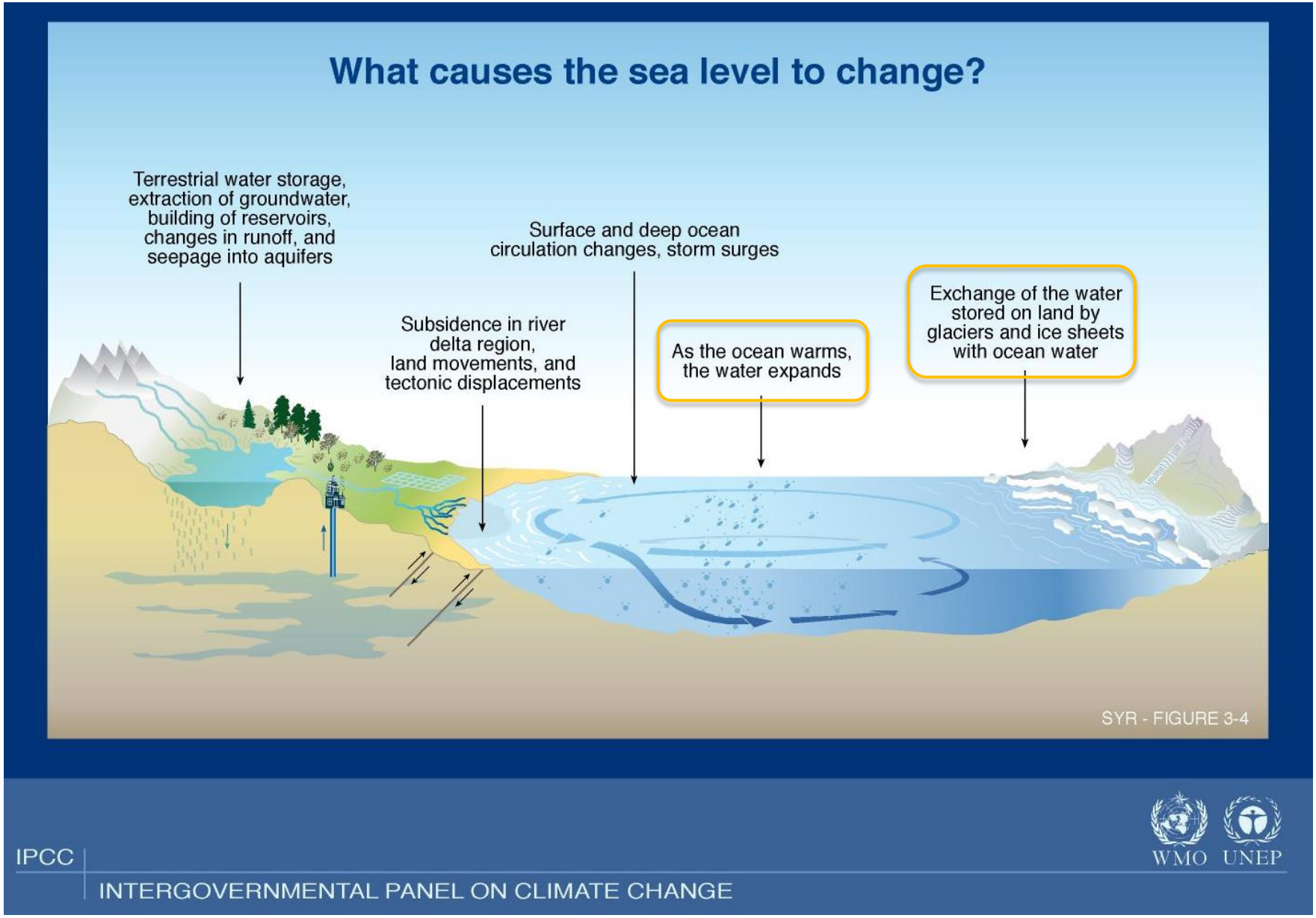
Marine Research Division
AZTI-Tecnalia
Sukarrieta (Spain)

Index

Sea Level Rise

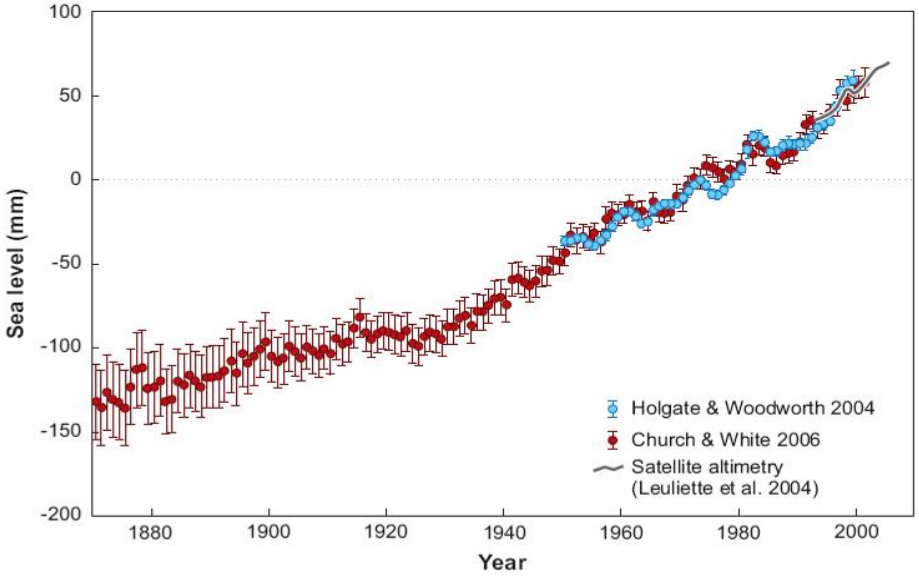
- Measurements and projections for the Bay of Biscay
- Impacts in the Basque coast (urban, beaches, habitats, species)
- Species distribution shifts
- Sea level variability (storm surges)
- Interaction with extreme waves

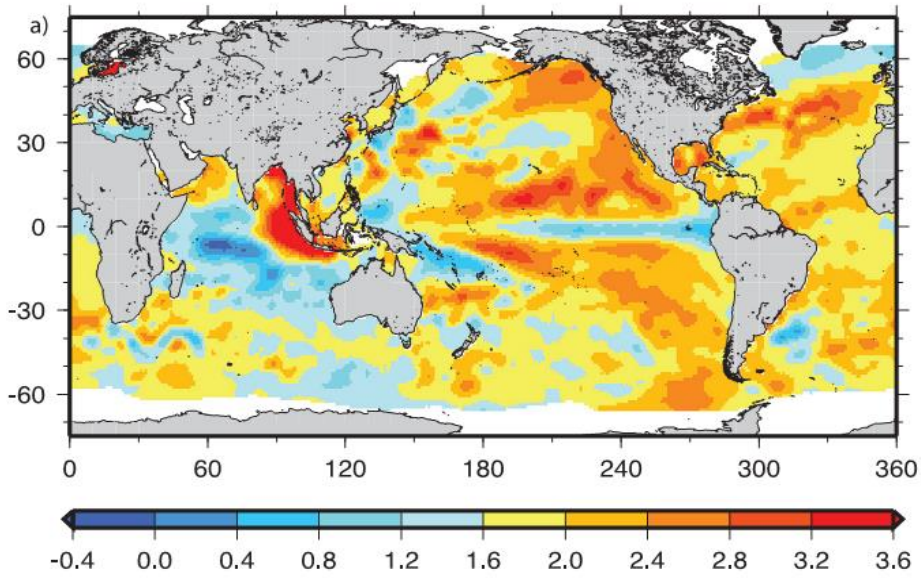
Sea Level Rise



Global sea level trends

- Global mean sea-level rate: 1.8 ± 0.3 mm/yr between 1950 and 2000 (Church *et al.*, 2004), with large spatial variability at regional scales





SLR = Thermal expansion + ice melting

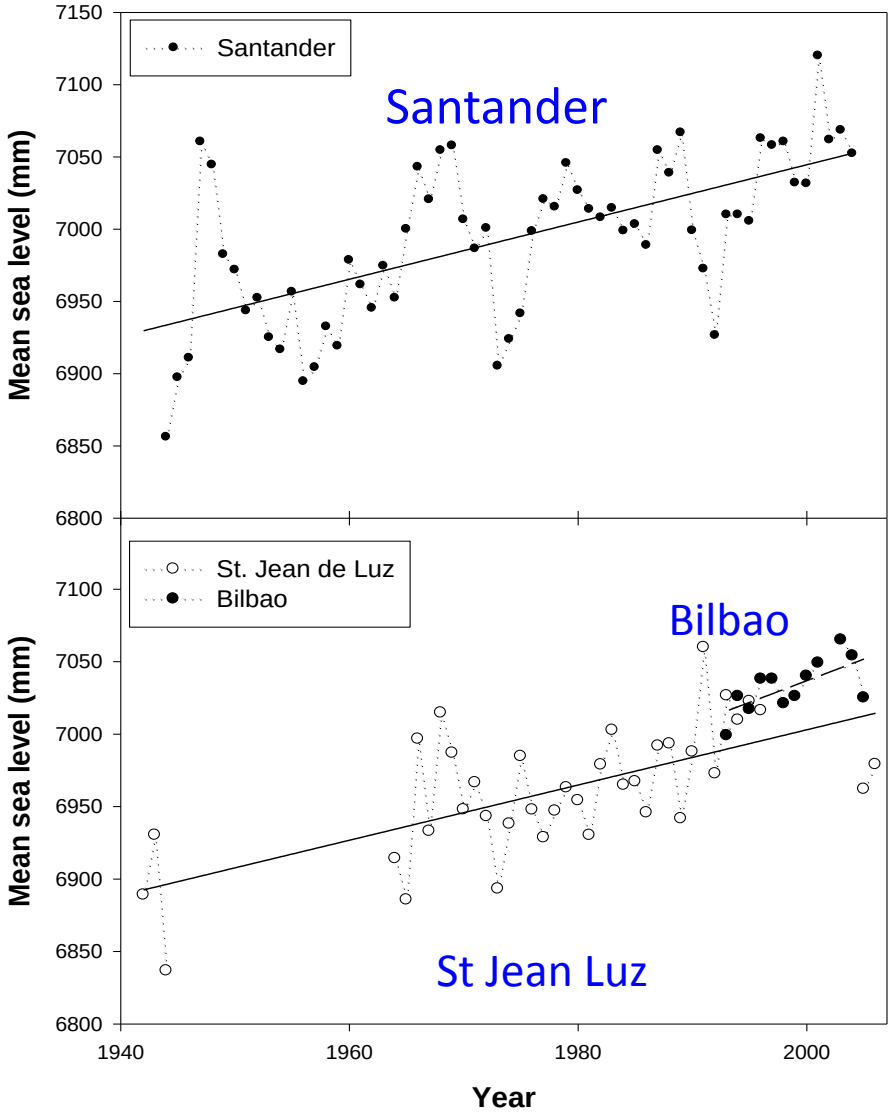
Linear trends in mean sea level (mm yr^{-1}) for 1955 to 2003 based on the past sea level reconstruction with tide gauges and altimetry data (IPCC 4AR, 2007)

Sea level rise within the Bay of Biscay

Location	Method	Time period	Rate and error (mm yr^{-1})	Reference
Vigo	Tide gauge	1943 - 2001	2.91±0.09	Marcos et al. (2005)
La Coruña	Tide gauge	1943 - 2001	2.51±0.09	Marcos et al. (2005)
Santander	Tide gauge	1943 - 2001	2.1	Marcos et al. (2005)
Brest	Tide gauge	1890 - 1980	1.3±0.5	Wöppelmann et al. (2006)
Brest	Tide gauge	1980 - 2004	3.0±0.5	Wöppelmann et al. (2006)
Newlyn	Tide gauge	1915 - 2005	1.77±0.12	Araújo and Pugh (2008)
St. Mary's	Tide gauge	1968 - 2006	1.73±0.52	Haigh (2009)
Open water of Bay of Biscay	Satellite altimeters and Tide gauge	1993 - 2002	3.09±0.21	Marcos et al. (2007)
Open water of Bay of Biscay	Satellite altimeters	1993 - 2005	2.7	Caballero et al. (2008)
Basque coast	Foraminifera-based transfer functions	20th century	2.0	Leorri et al. (2008)
Basque coast	Foraminifera-based transfer functions	20th century	1.9	Leorri and Cearreta (2009)

Regional sea level measurements

Sea-level measurements (tide gauge) along the Basque coast and nearby records



2.08 ± 0.33 mm yr^{-1}

2.99 ± 1.08 mm yr^{-1}

2.09 ± 0.42 mm yr^{-1}

Chust et al. 2009. *Estuarine, Coastal and Shelf Science* 84:453-462

Regional climate scenarios for the 21st century

Sea level variability

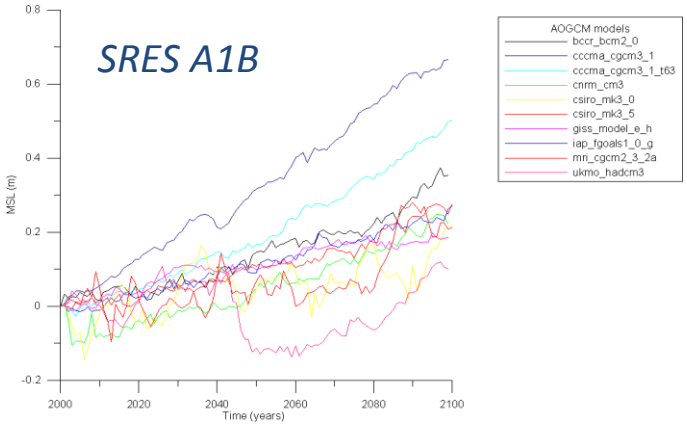
⇒ Mean Sea Level Rise (thermal expansion + ice melting)

⇒ Storm surges (meteorological tides)

⇒ Wave extreme events (tides + run-up)

Projections for the thermosteric sea level rise

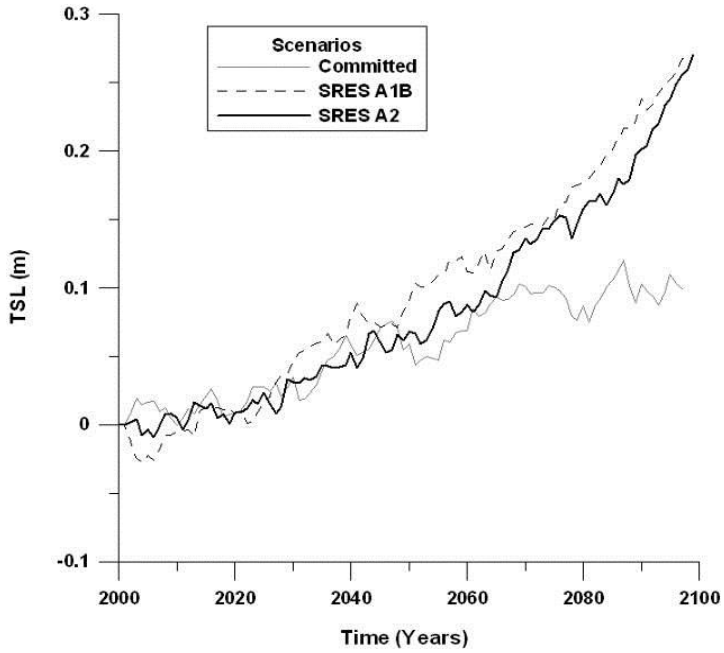
WCRP ⇒ Tª ocean Salinity ⇒ Sea level

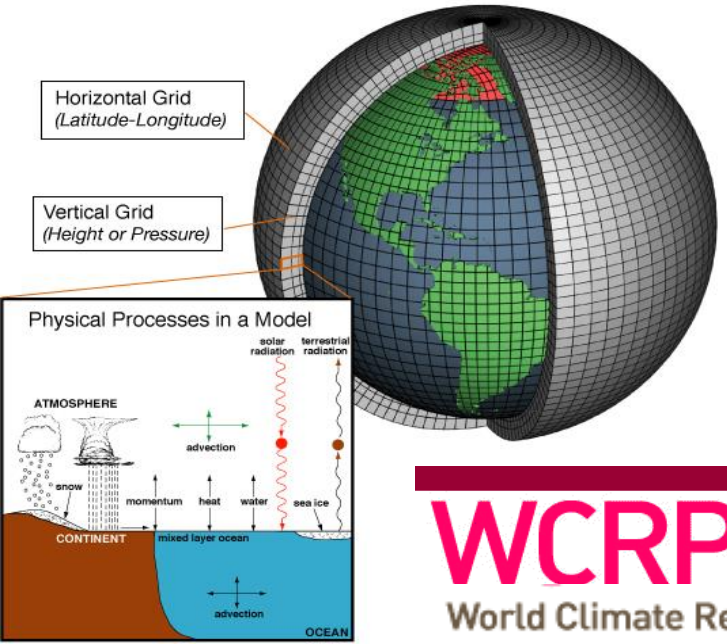


1. **Column water integration**

$$TSL = \frac{1}{g}\int_{-H}^{0} \alpha dp$$

2. **Model selection**



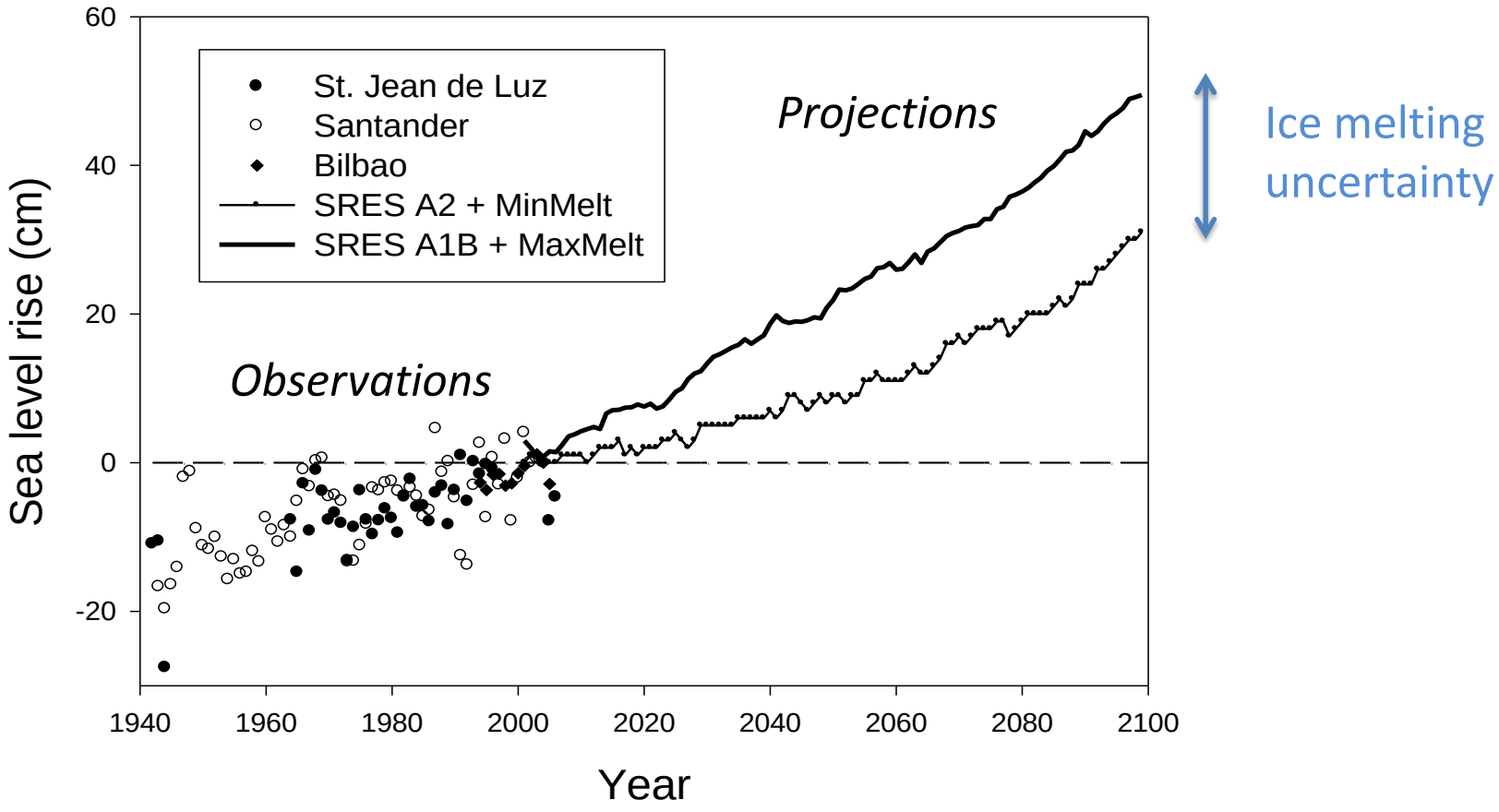


Chust et al. 2010. *Estuarine, Coastal and Shelf Science* 87:113-124

ESSP DIVERSITAS
WCRP
World Climate Research Programme

Mean Sea Level Rise for the bay of Biscay

Thermal expansion + ice melting (4 to 20 cm) => 29 to 49 cm



Chust, G., Borja, Á., Caballero, A., Irigoien, X., Sáenz, J., Moncho, R., Marcos, M., Liria, P., Hidalgo, J., Valle, M. & Valencia, V. (2011) Climate change impacts on coastal and pelagic environments in the southeastern Bay of Biscay. *Climate Research*, **48**, 307–332.

IPCC **4**AR (2007)
SLR: 18 and 59 cm

IPCC **5**AR (Sep. 2013)
SLR: between 26 and 82 cm

Special Report on Emissions Scenarios (SRES)

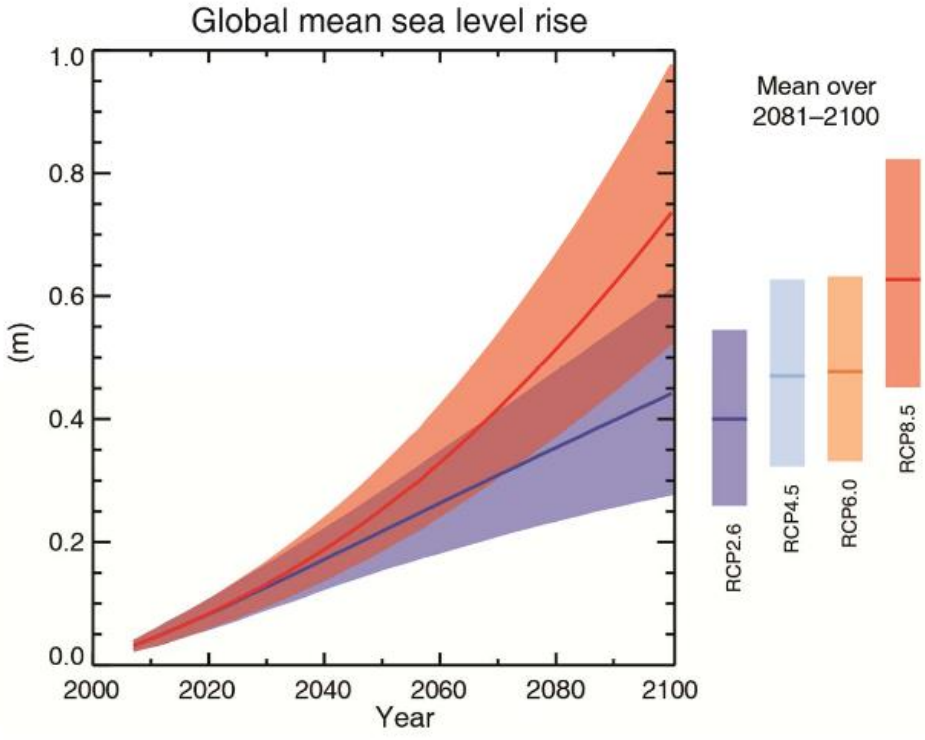
- A1
- A2
- B1
- B2

Representative Concentration Pathway (RCP) scenarios

- RCP2.6
- RCP4.5
- RCP6.0
- RCP8.5

➢ Global: 1 m

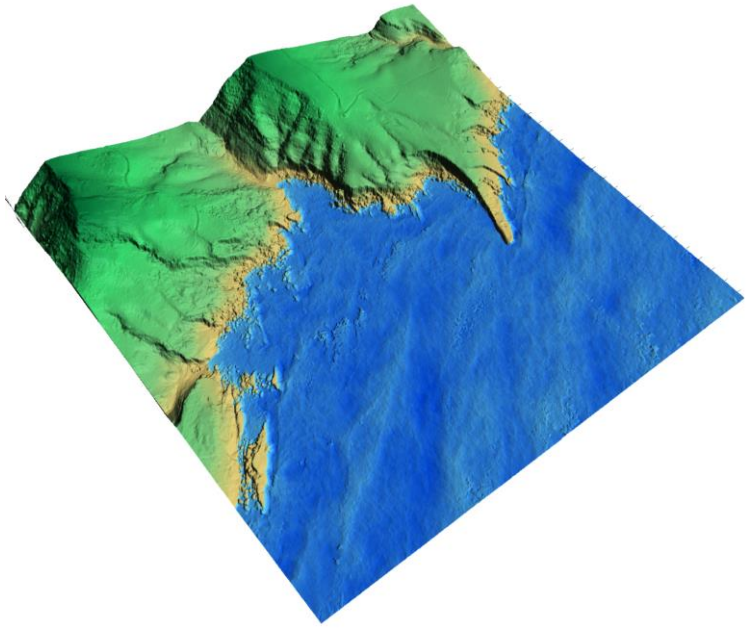
(Rahmstorf et al., 2007. Science 316: 709)



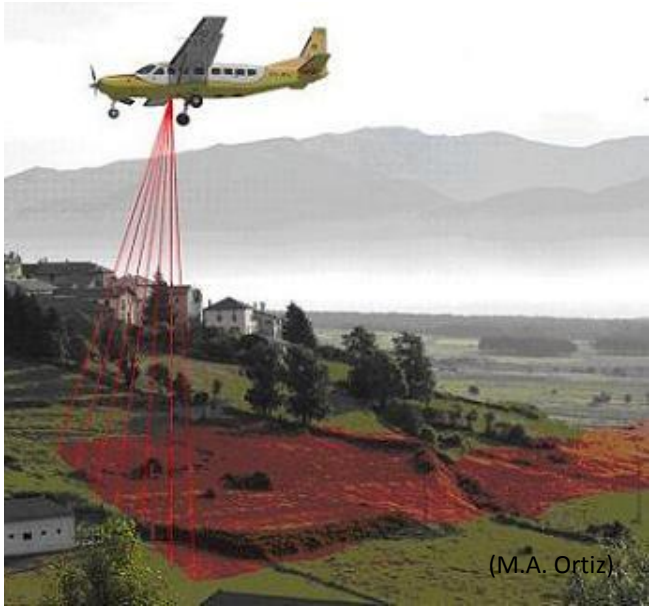
Expected impacts from sea level rise using high-resolution cartographic data

High-resolution airborne data

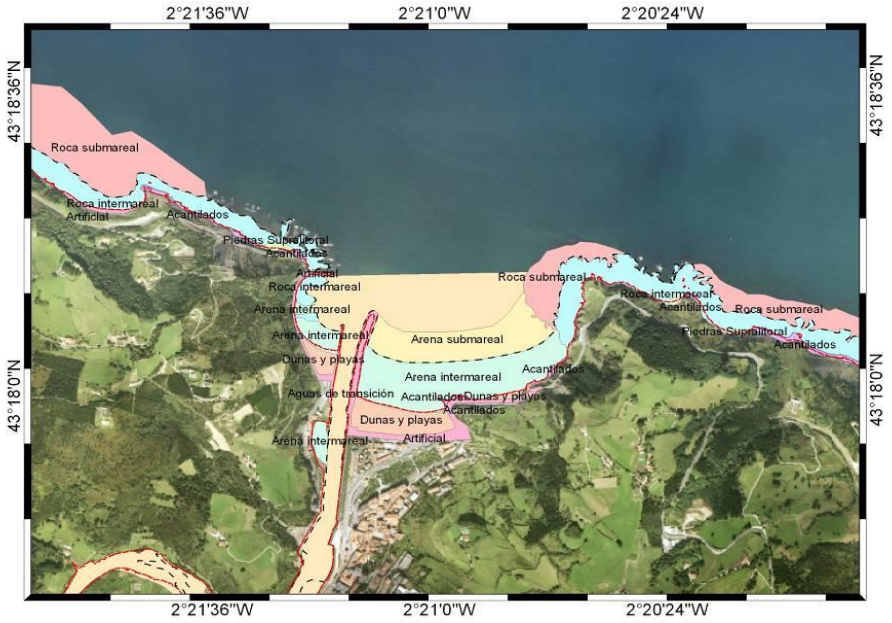
- **LIDAR-based Digital Terrain Model (DTM)**
  - Spatial resolution: 1 x 1 m
  - Vertical accuracy: 15 cm



LIDAR: laser altimeter

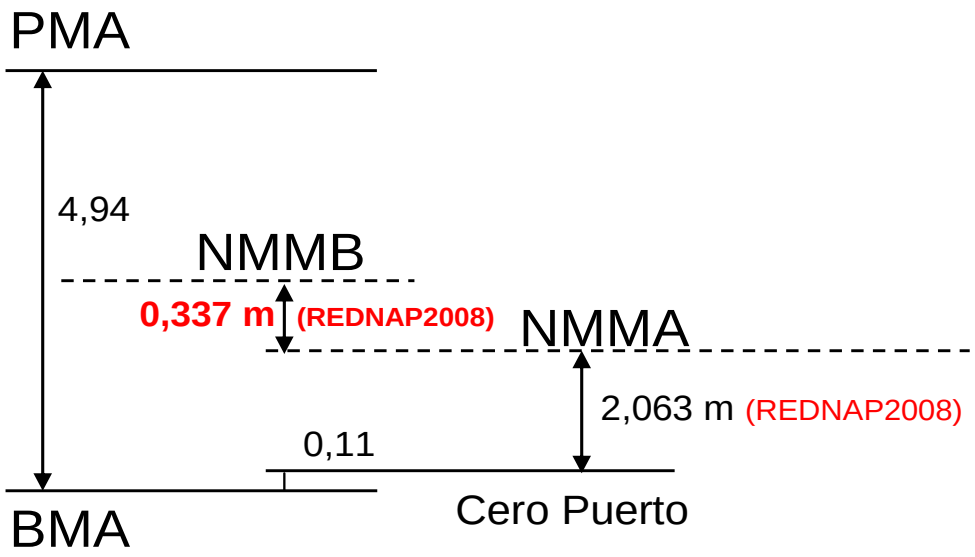


- **Habitat maps from ortophotography:**
  - Spatial res.: 25 x 25 cm



LiDAR validation with GPS and MSL references

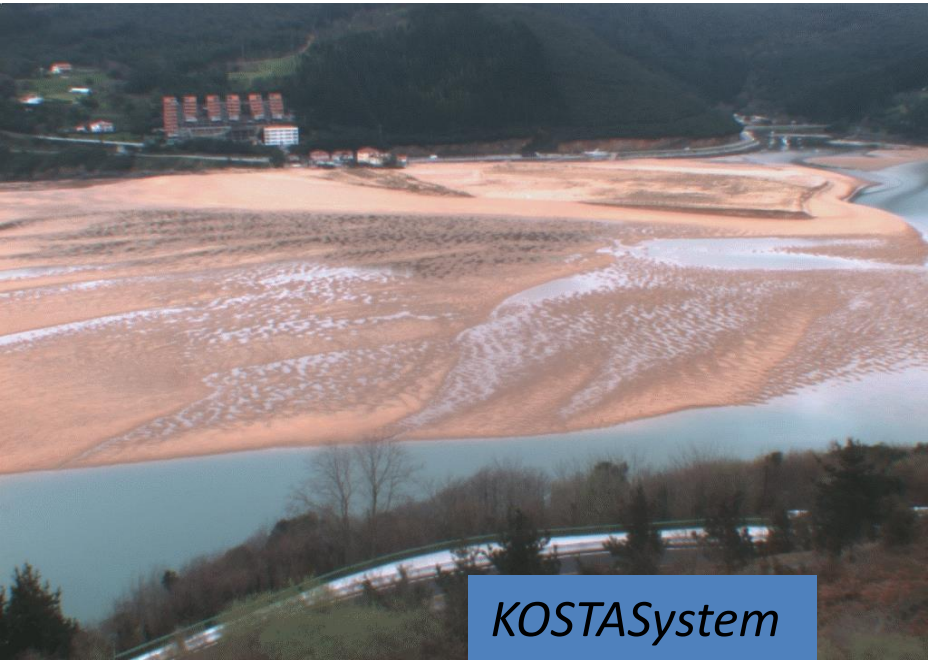
Bilbao I

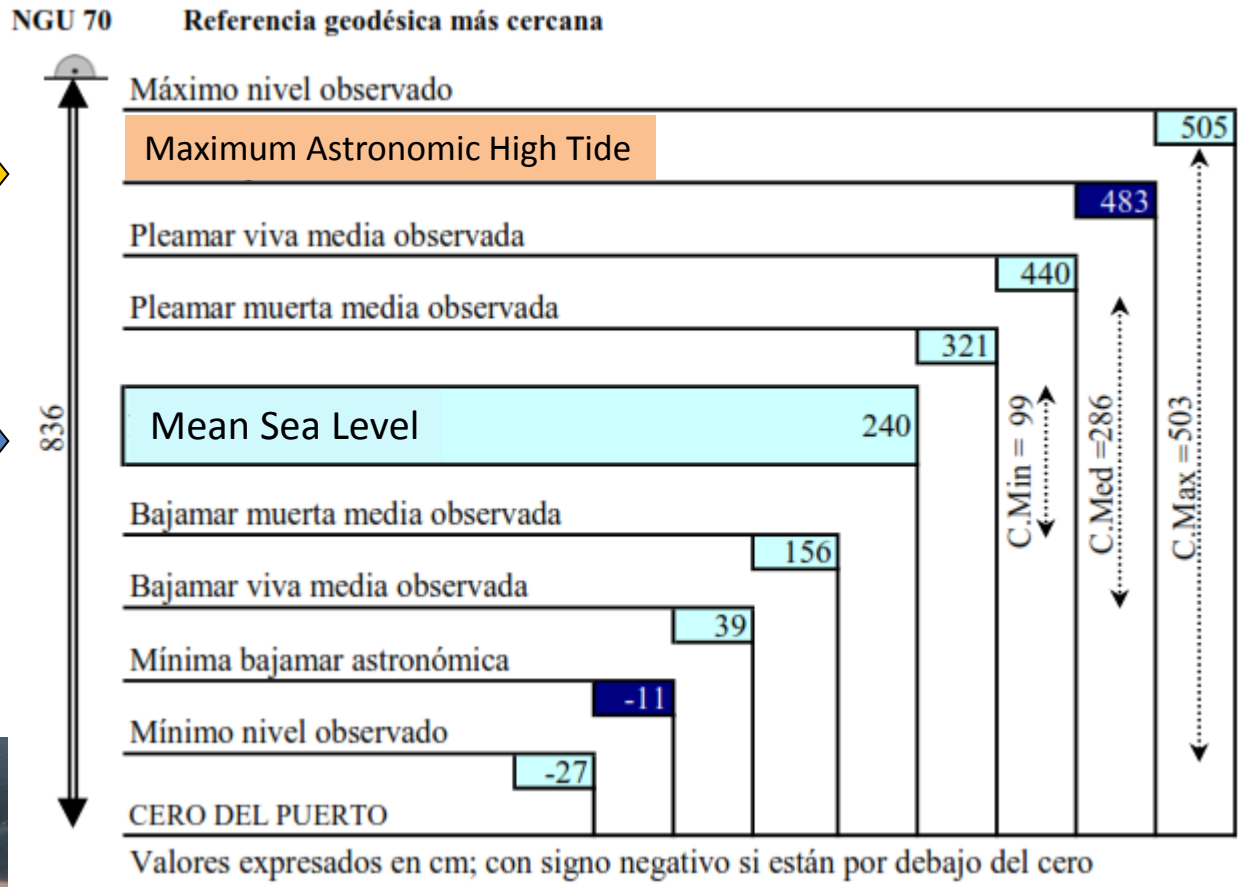


Tides in Bilbao I

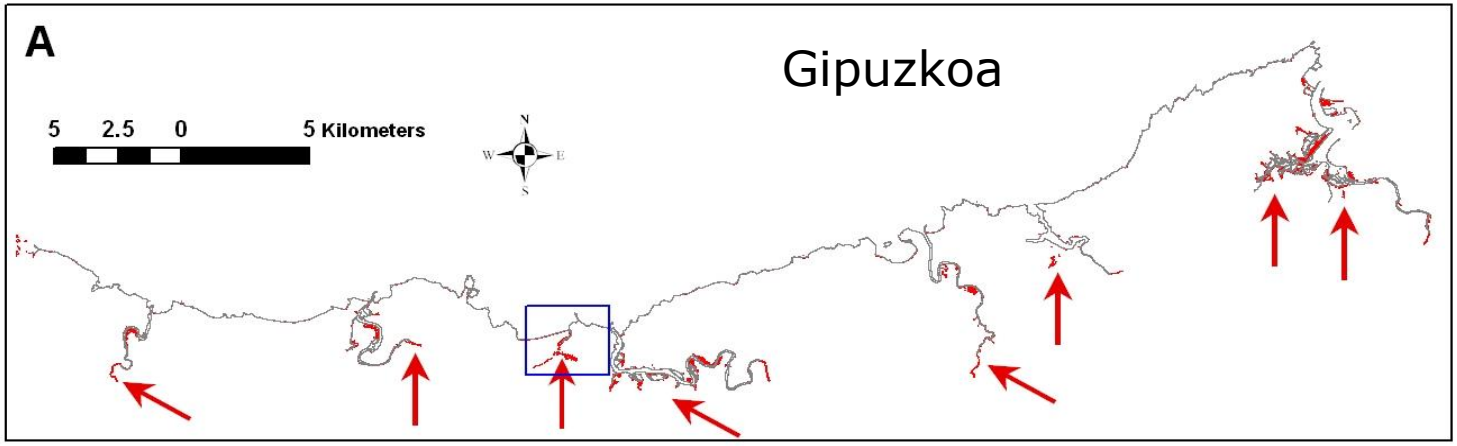
SLR: +0.49 m

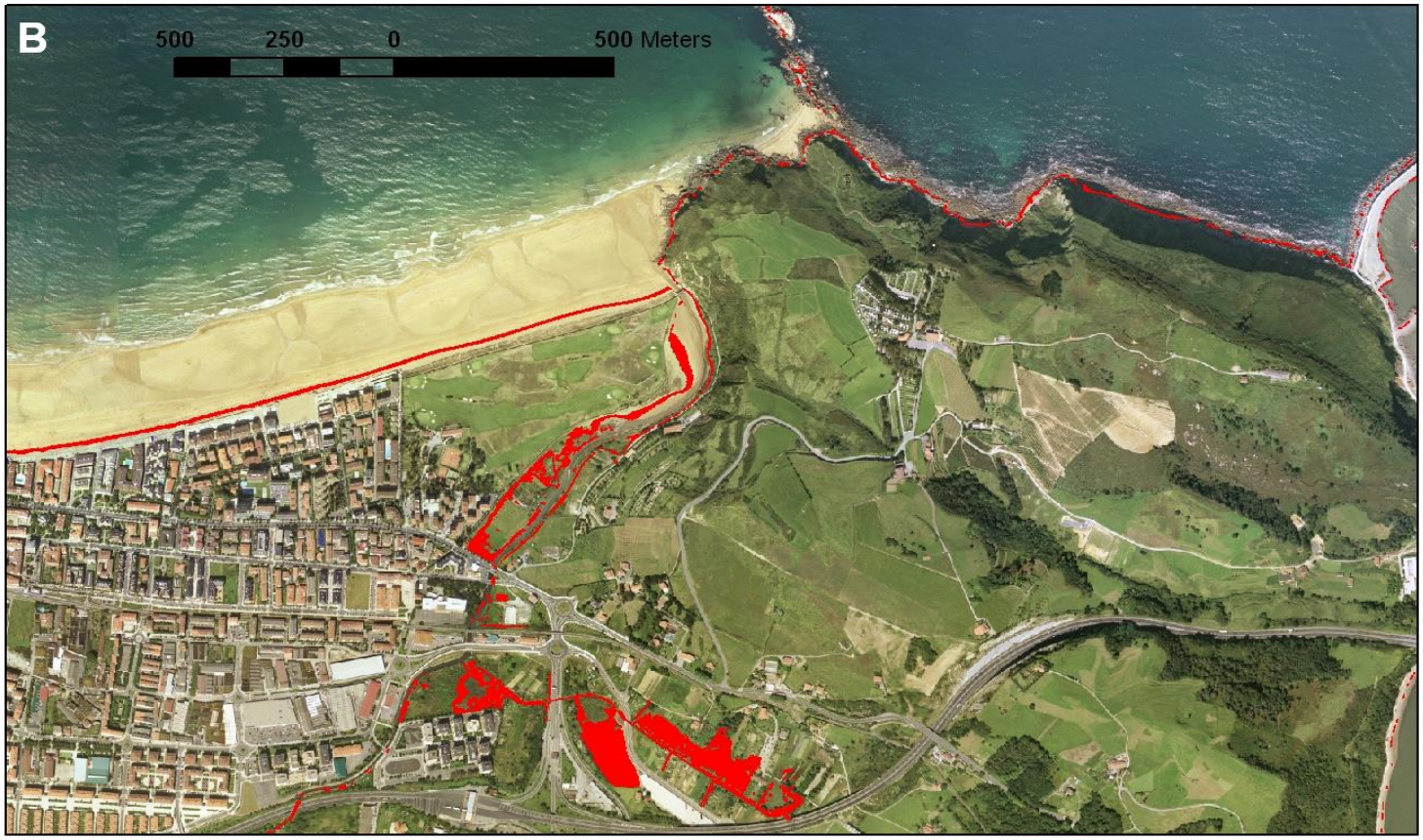
Tide range: 4.94 m





Flood risk map: Sea level rise of 49 cm



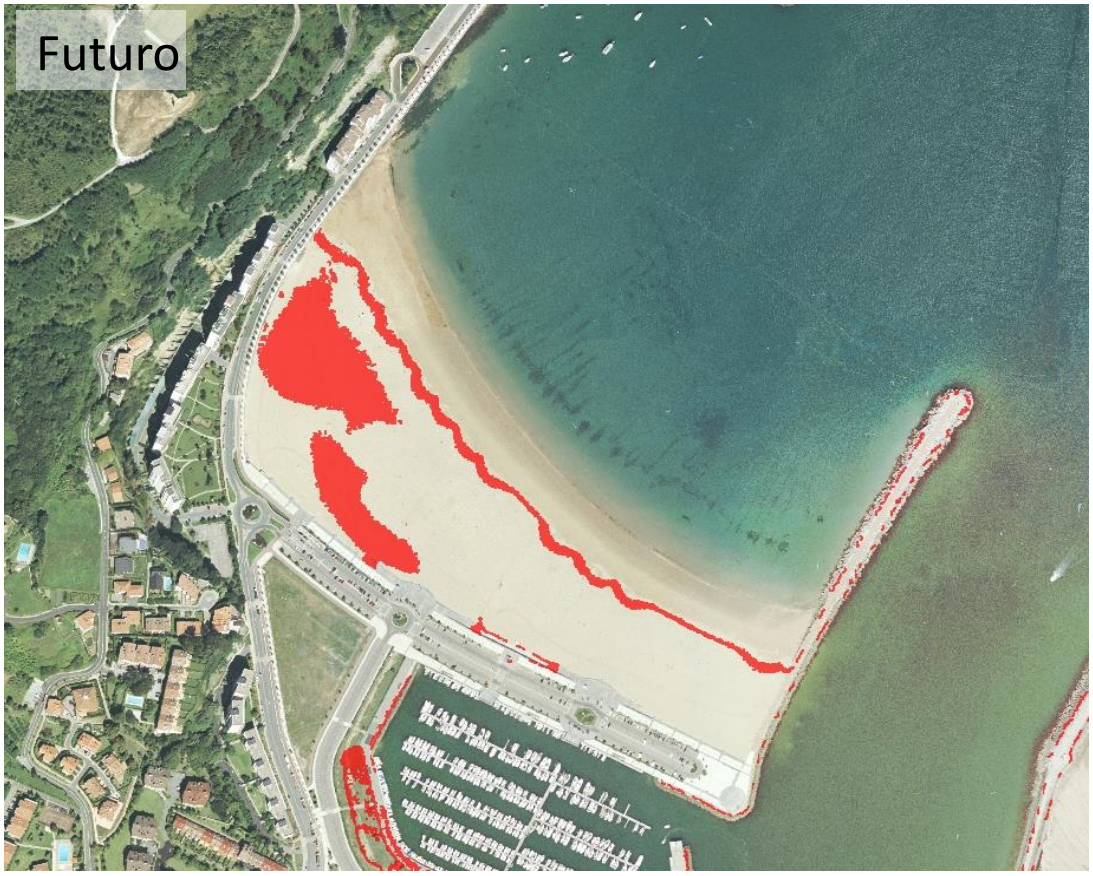


Area affected:

- 110 hectares
- 50% in estuaries

Flood risk map for urban areas

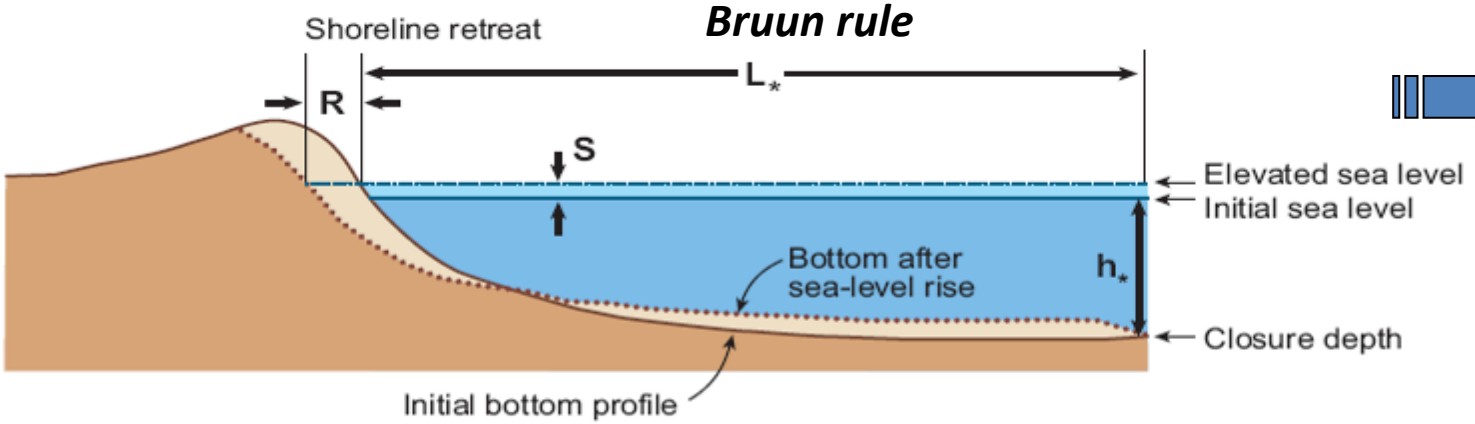
Flood risk map for sandy beaches



Retreat in beach width

25%

Bruun rule



40%

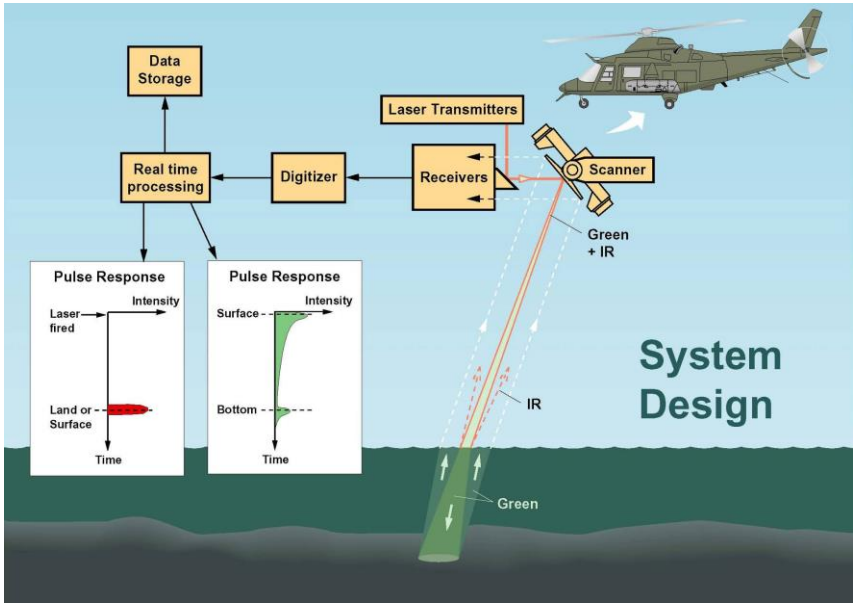
Bathymetric LiDAR (Hawk Eye MK II)

Topographic LiDAR

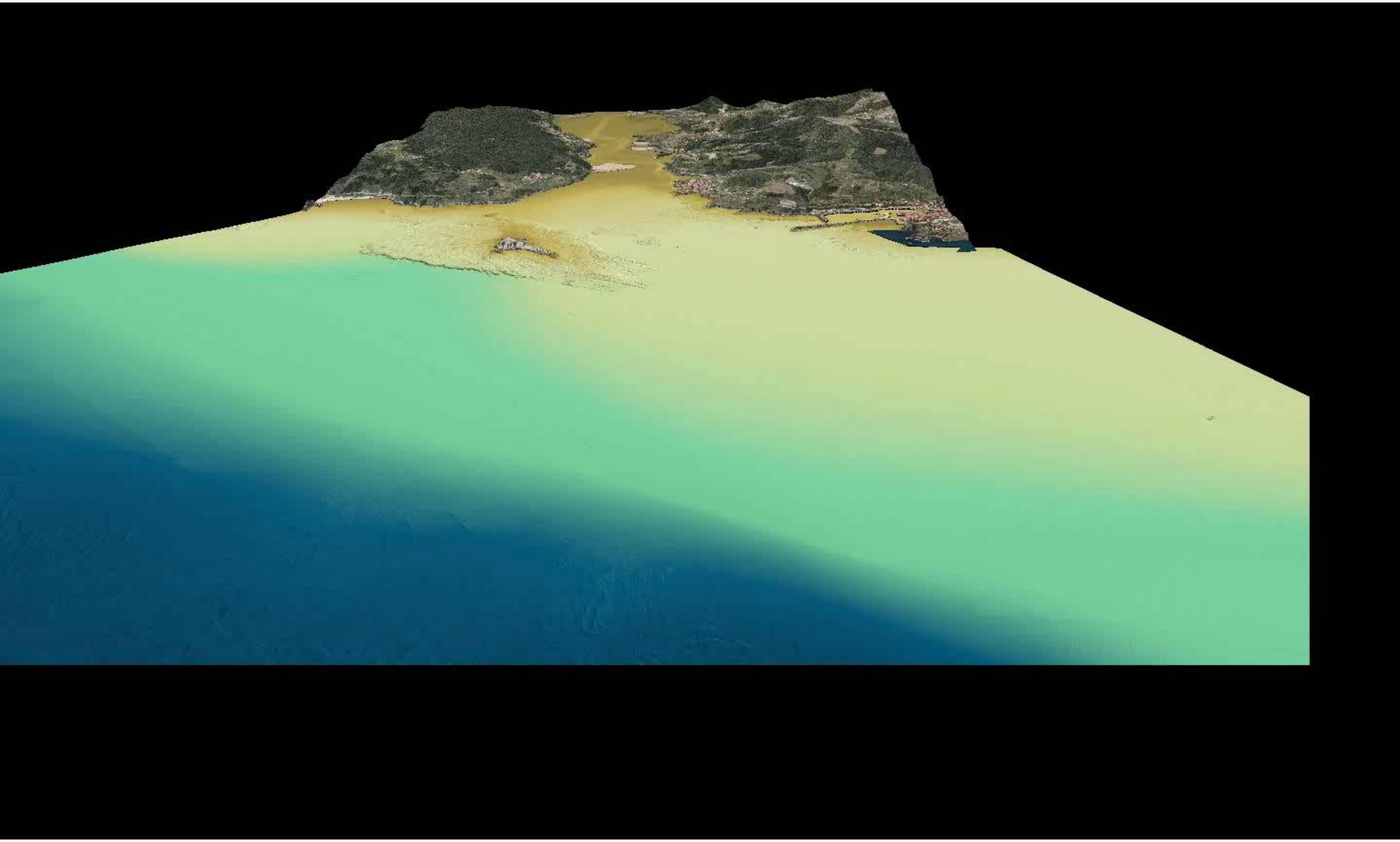
(NIR: 1064 nm)

Bathymetric LiDAR

(Green: 532 nm)

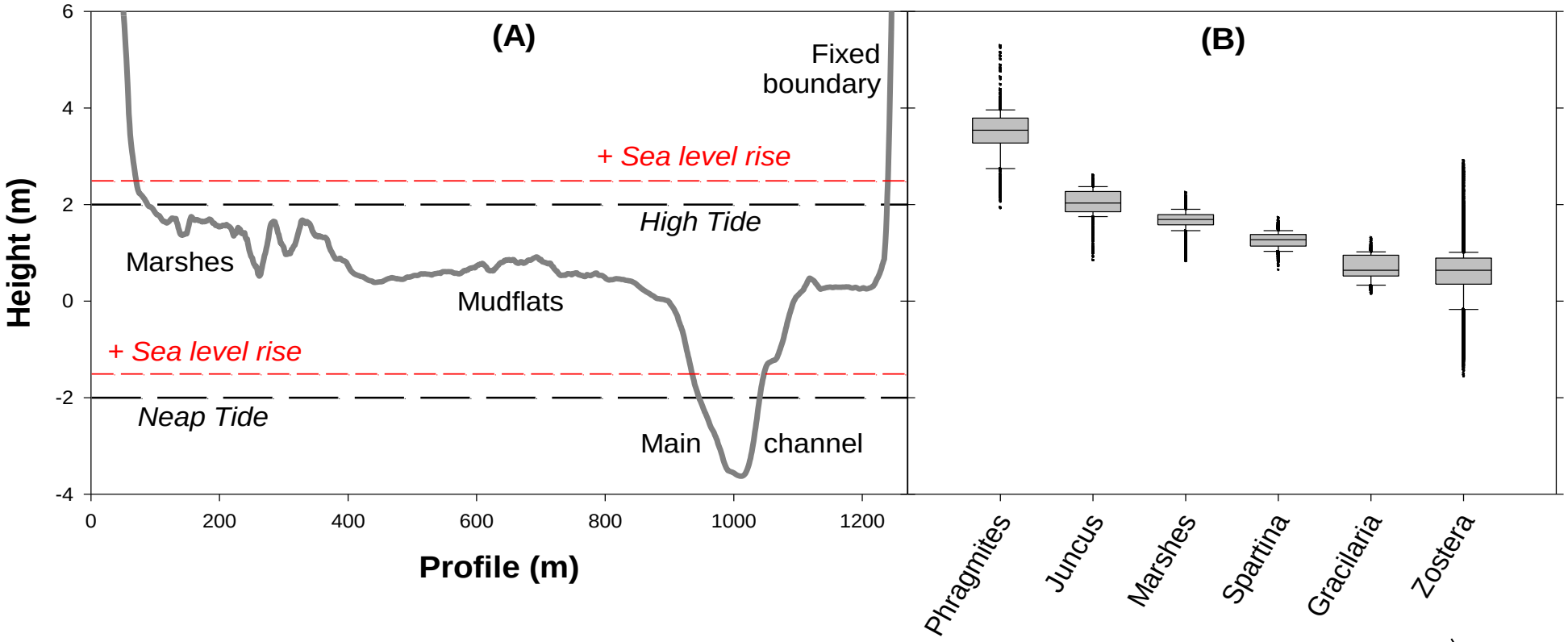


Digital Elevation Model of the Oka estuary



Intertidal area
Subtidal area

Tide zonation of intertidal species communities



Chust et al. 2010 *Estuarine, Coastal and Shelf Science* 89: 200-213

Coupling hydromorphologic and species distribution models

Hydromorphologic model

Simulations under 2 scenarios:

- S1: Scenario with an average SLR of 0.49 m
- S2: Scenario with an average SLR of 1 m

Species Distribution Models

1. Maximum Entropy model (MaxEnt)
   (Phillips et al. 2006)
2. Generalized Additive model (GAM)
   (Hastie & Tibshirani, 1990)
3. Ecological Niche Factor Analysis (ENFA)
   (Hirzel et al. 2002)

Evaluation → Best model selection

Coupling

Projection of the SDM to the future scenarios

Threshold

Habitat suitability changes' assessment comparing the current availability with that from the future

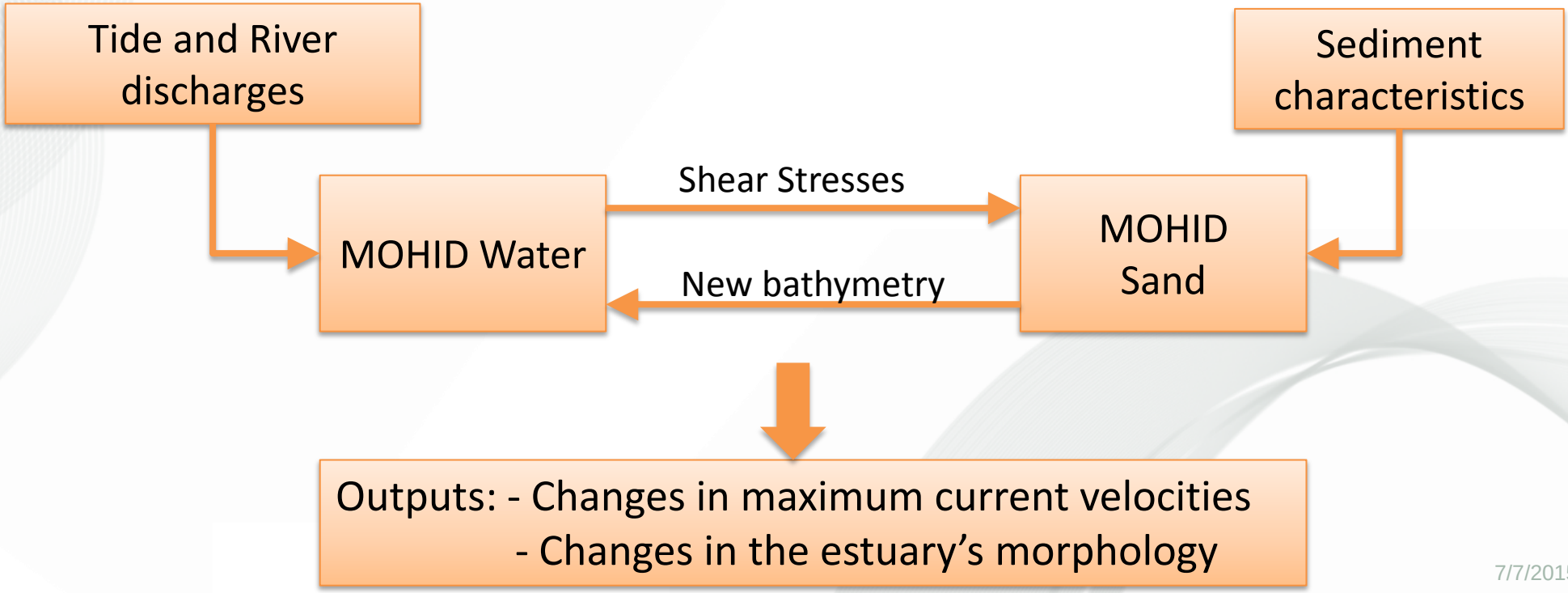
Hydromorphologic modelling

MOHID modelling system:

- Fully non-linear, 3D baroclinic water model
- Integrates hydrodynamic (Neves et al., 2000; Martins et al. 2011) and sand transport (Silva et al. 2004) modules
- Able to simulate non-cohesive sediment dynamics in estuaries driven by tide and river flows

MOHID Water Modelling System
Copyright by Maretec

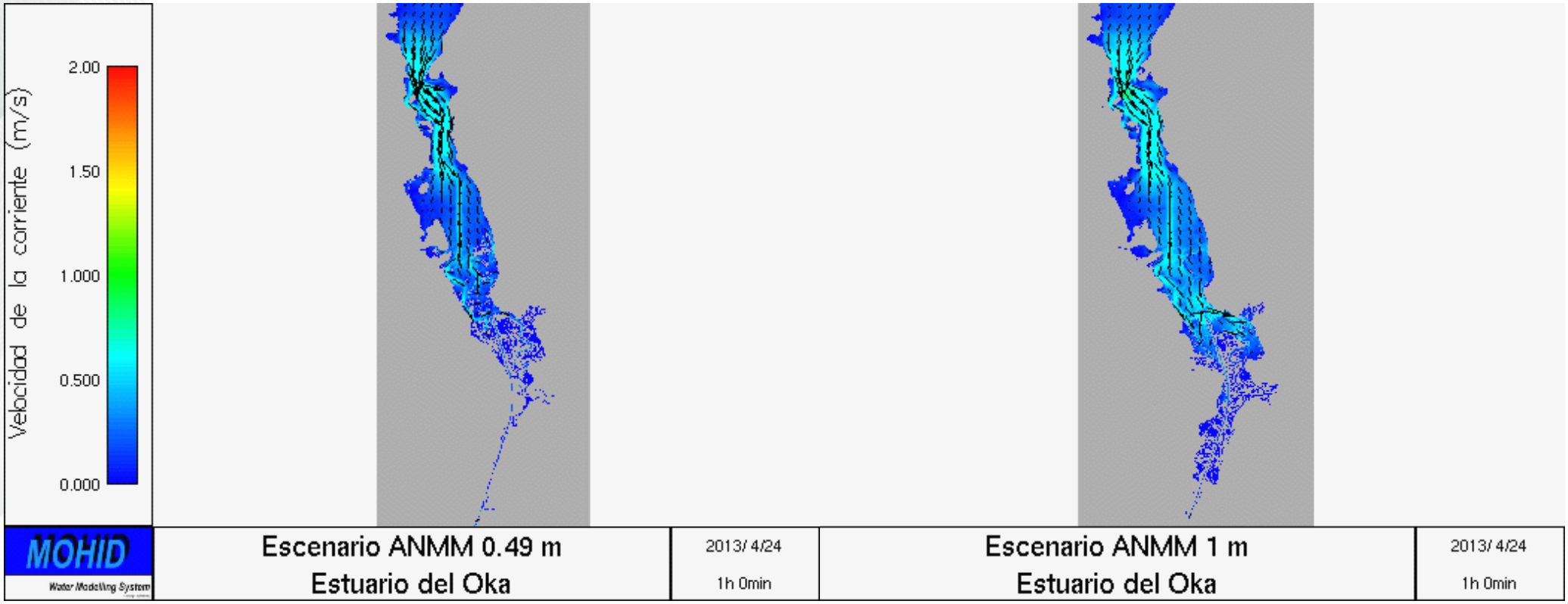
Open source software:
www.mohid.com



Future hidrodynamic

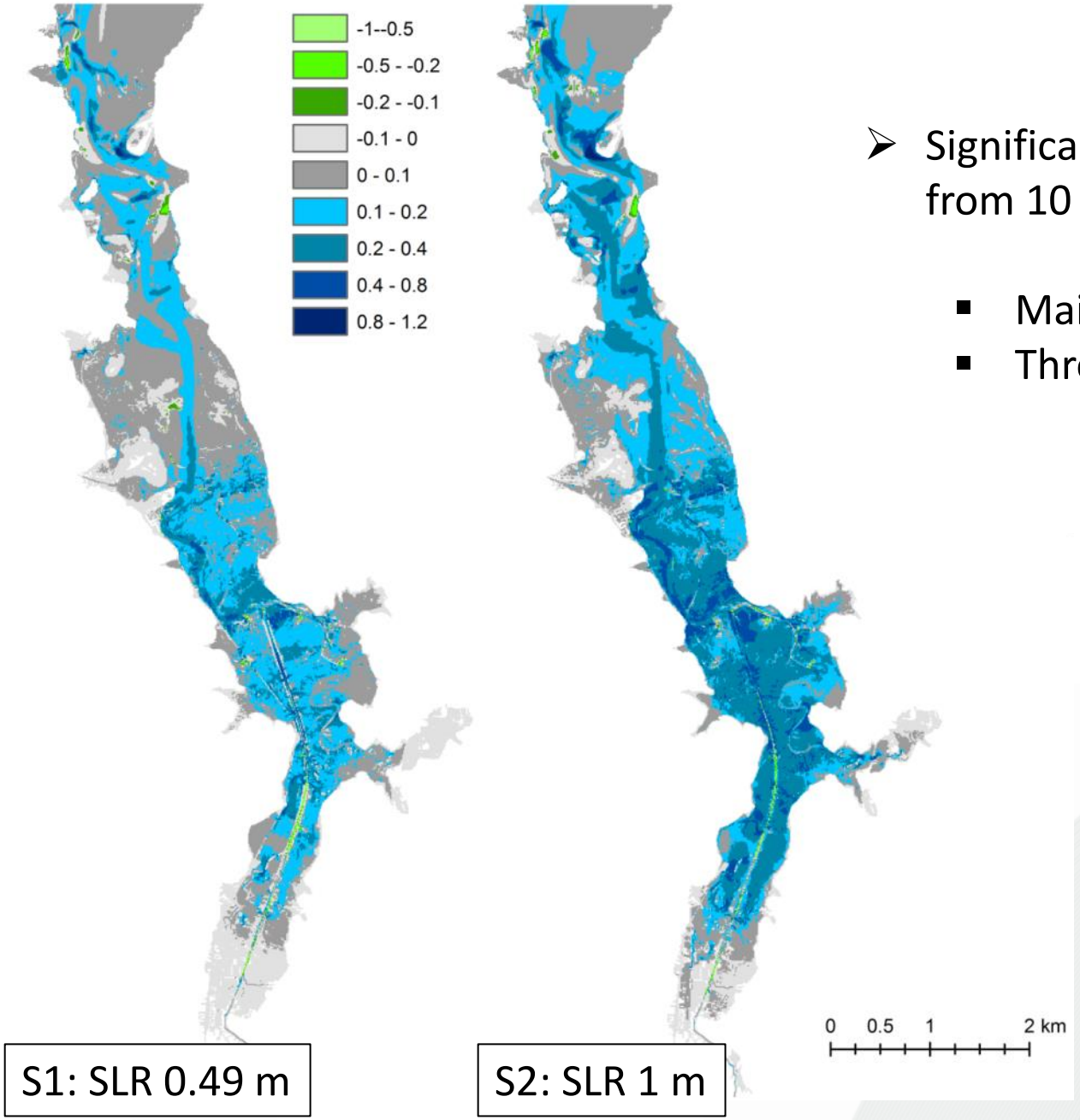
SLR: 0.49 m

SLR: 1 m



Hydromorphologic modelling

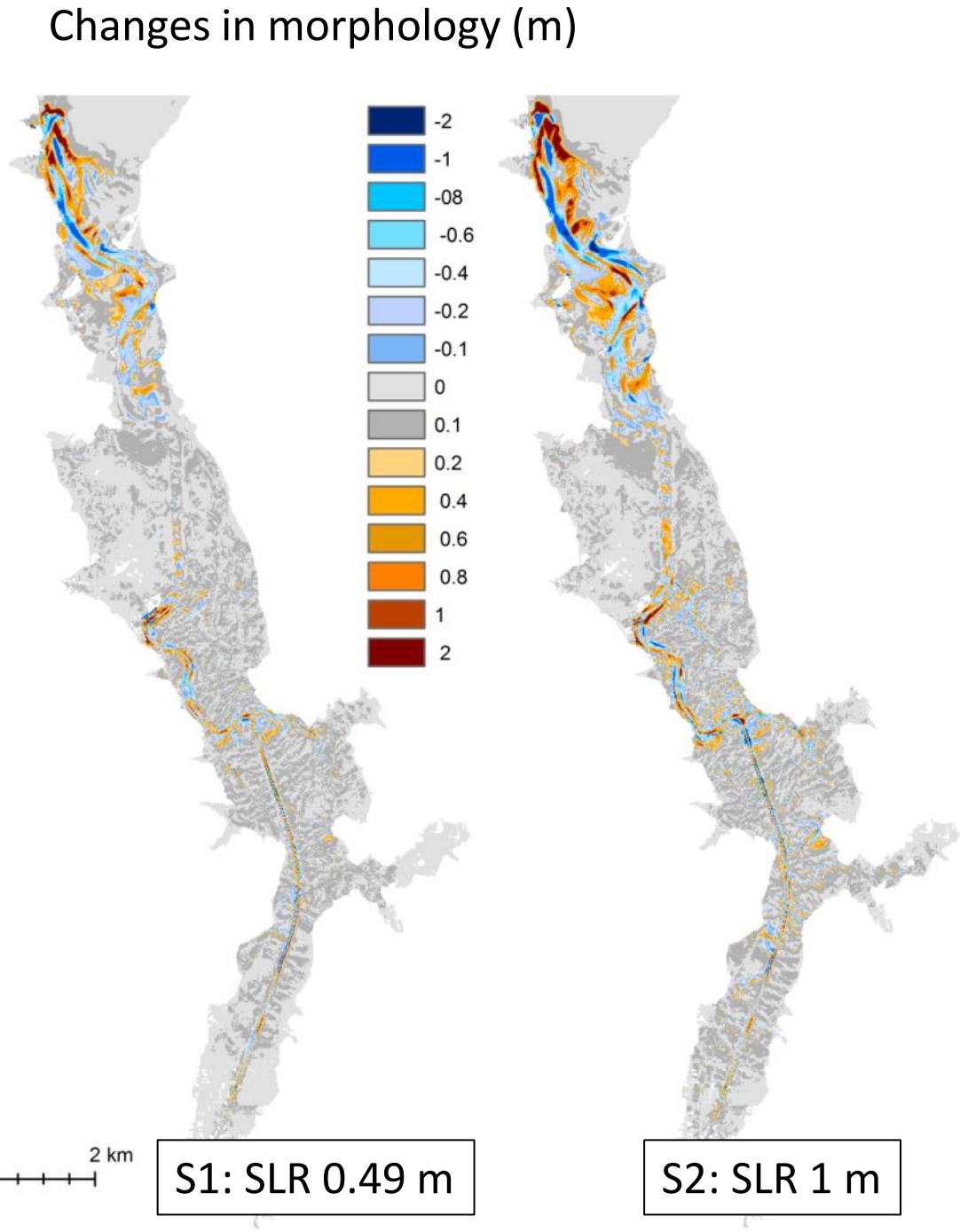
Changes in maximum current velocity (m·s $^{-1}$)



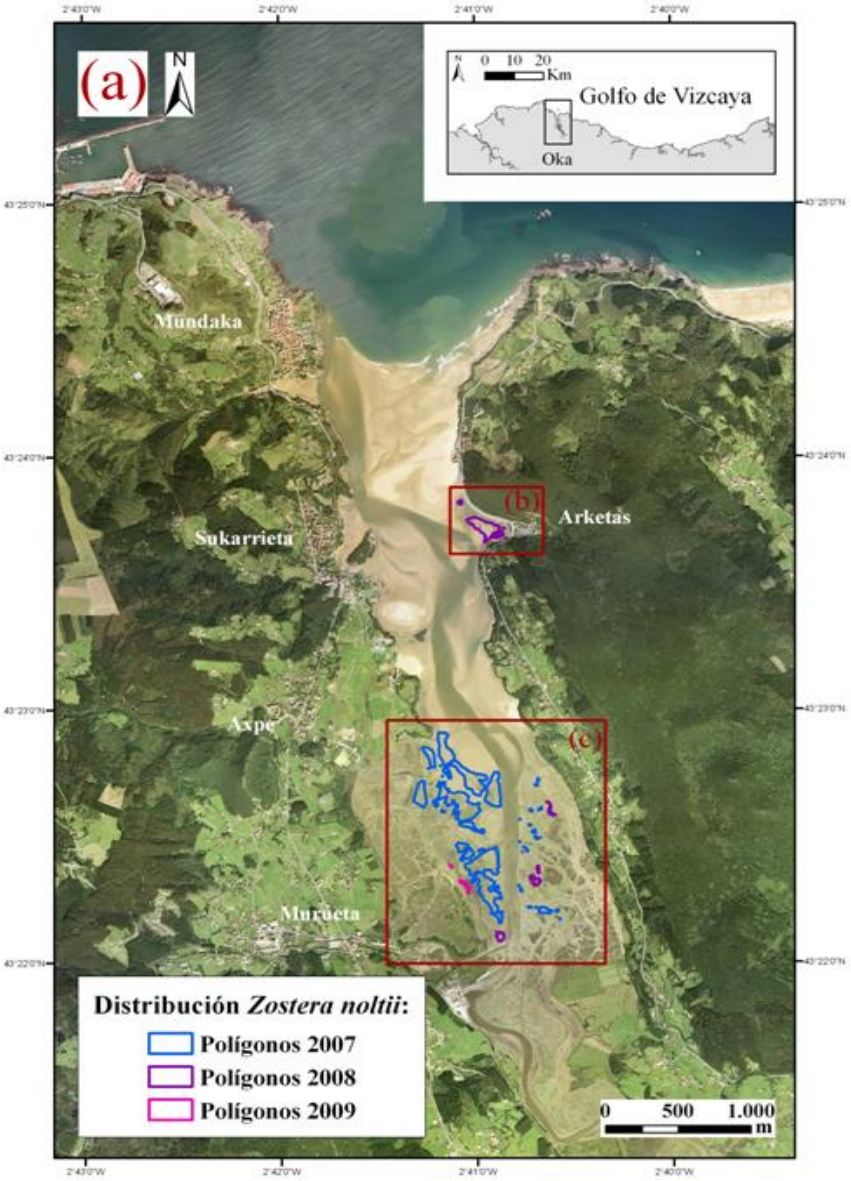
- Significant changes under both scenarios, from 10 cm·s $^{-1}$ up to 40 cm·s $^{-1}$:
  - Mainly along the channel in S1
  - Through the entire estuary in S2

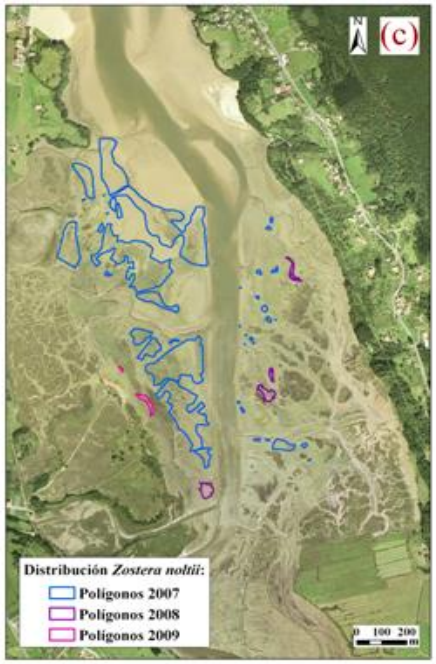
Hydromorphologic modelling

- Morphologic changes not very significant:
  - Accretion <10 cm in the entire estuary
  - Erosion in the borders of the main channel and accretion in the centre



Field work: *Zostera noltii* distribution





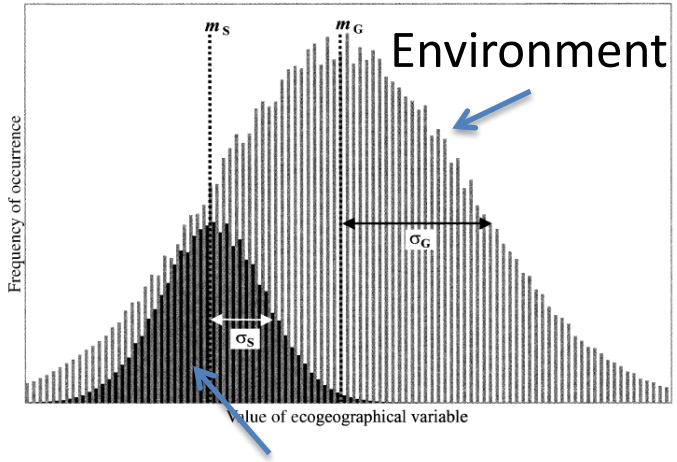
© AZTI-Tecnalia

Species Distribution Modelling

Sediment characteristics

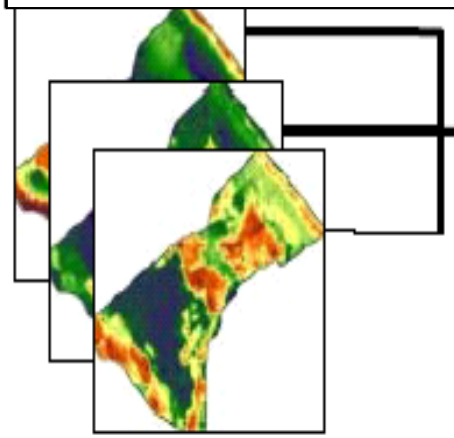
Ocean currents

LiDAR derived topographic height



Species ecological niche

Ecogeographical variables



Presence data

Habitat models:
- GAM
- MaxEnt
- ENFA

Habitat
Suitability
Map

Shift of the seagrass hab

Biological Conservation 170 (2014) 74–85

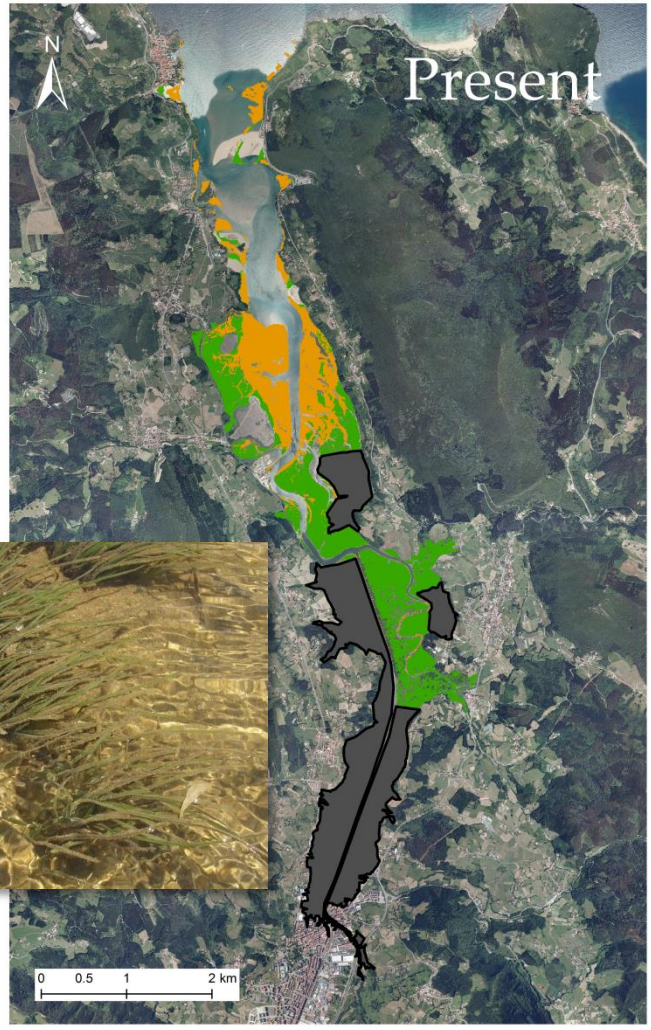
Contents lists available at ScienceDirect

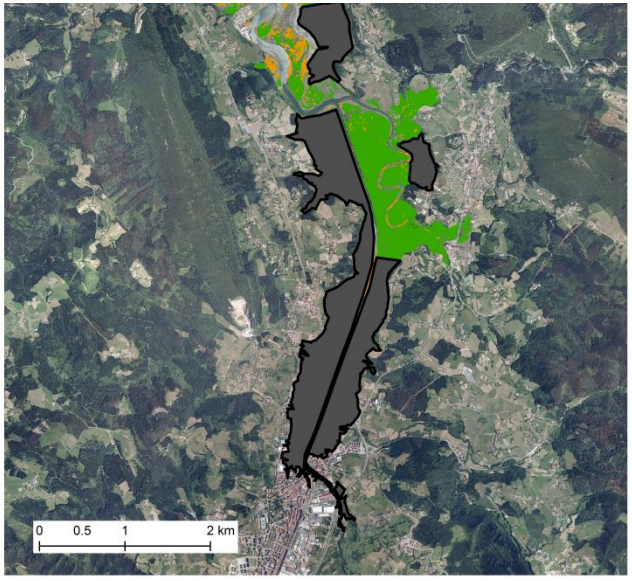
Biological Conservation

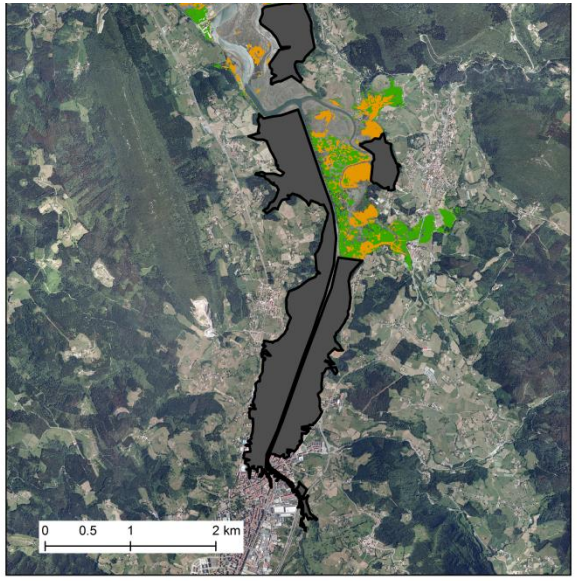
journal homepage: www.elsevier.com/locate/biocon

Projecting future distribution of the seagrass *Zostera noltii* under global warming and sea level rise

Mireia Valle [a,*], Guillem Chust [a], Andrea del Campo [b], Mary S. Wisz [c], Steffen M. Olsen [d], Joxe Mikel Garmendia [b], Ángel Borja [b]







Zostera noltii

Saltamarshes

Wall-enclosed areas

+ 14%

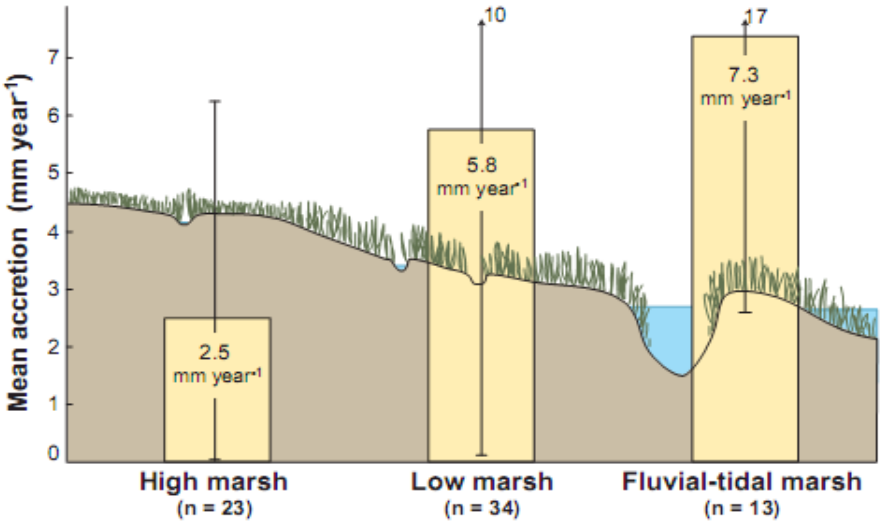
- 22%

+ 18%

- 63%

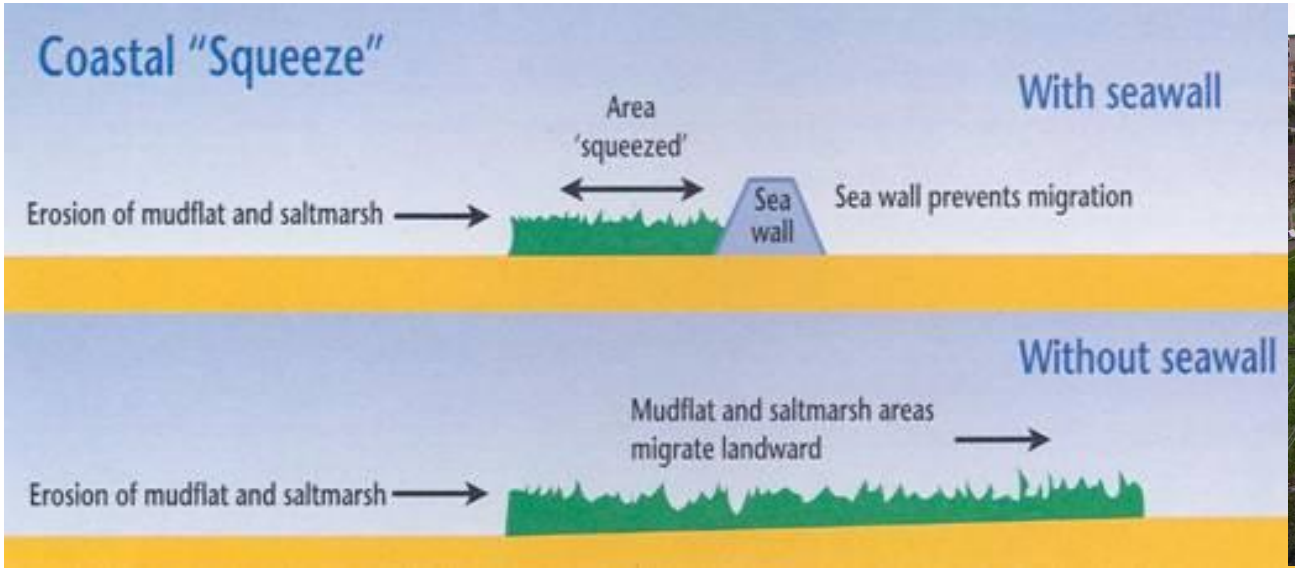
- SLR and derived changes in current velocities are expected to induce the landward migration of the species, increasing the available suitable intertidal areas (14–18%) to limits imposed by anthropogenic barriers.

Saltmarsh accretion

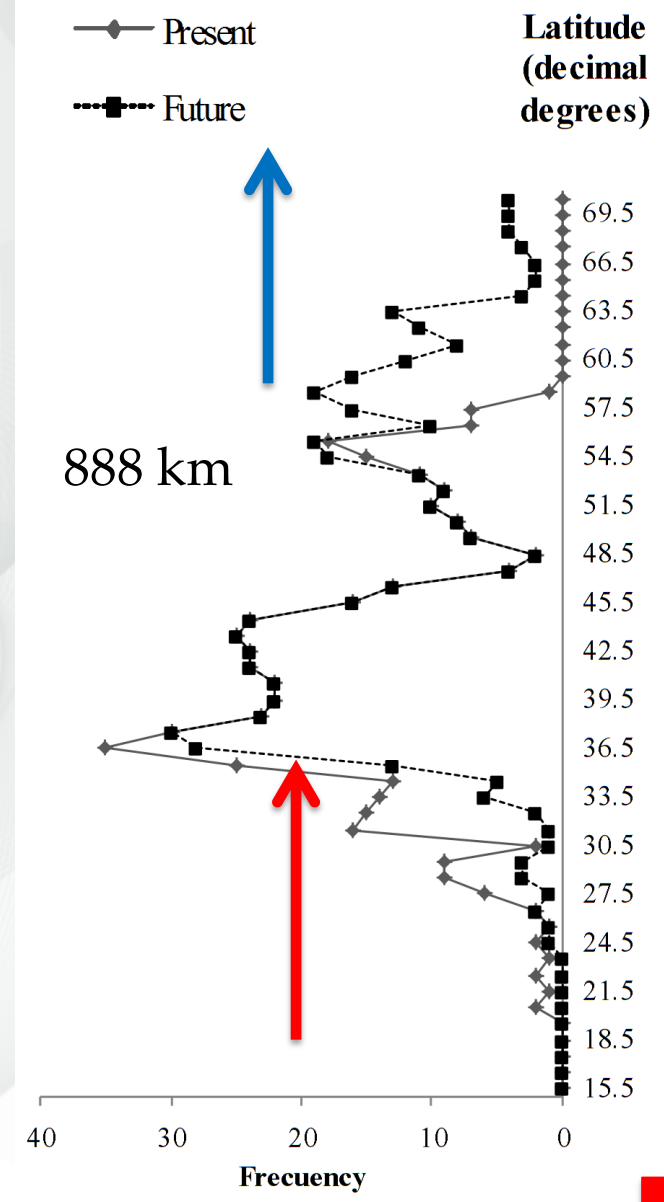


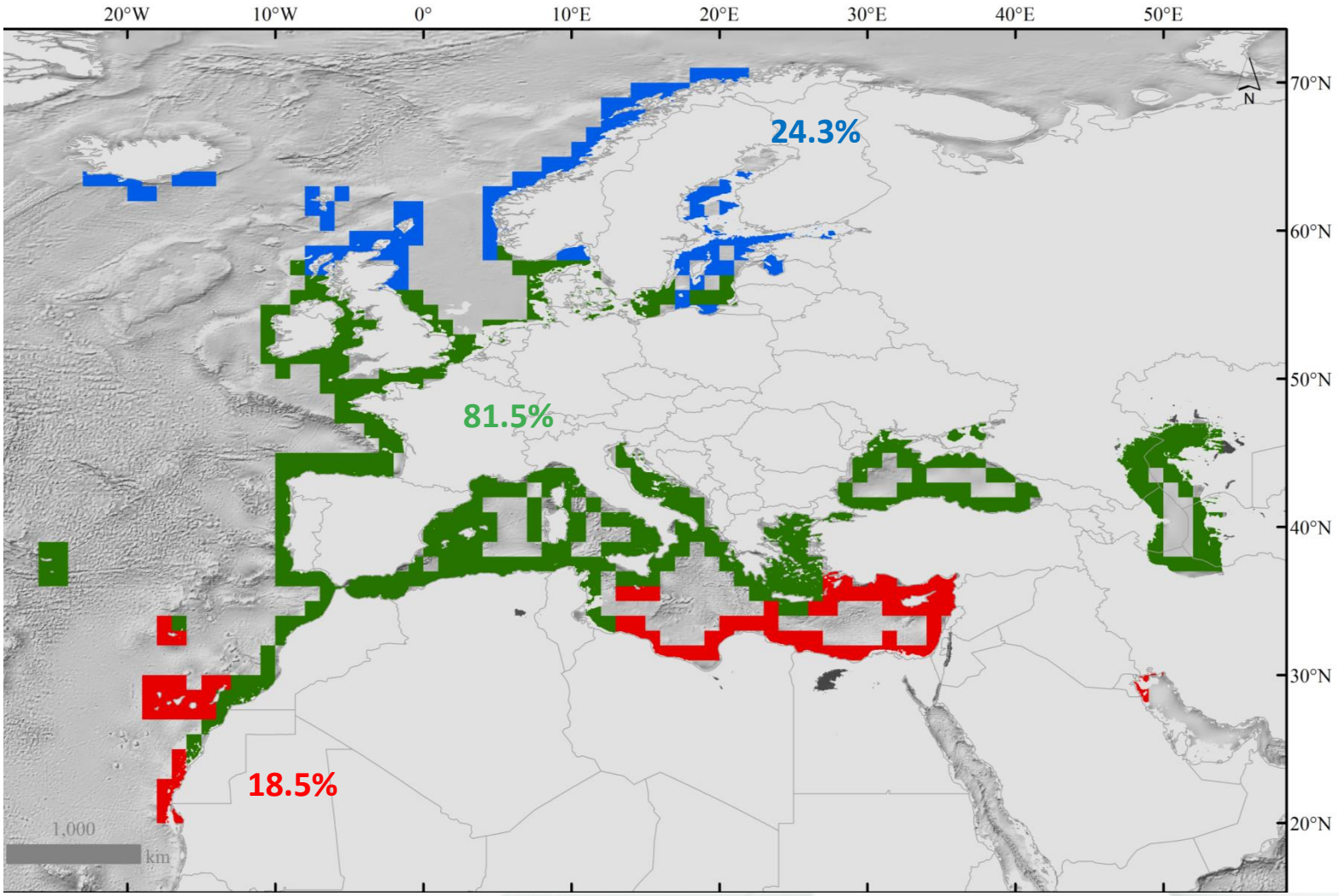
FitzGerald, 2008

Within the Basque estuaries, an accretion rate of 3.7 mm yr^{-1} during the 20th c. (Leorri et al., 2008) suggests that marshes are potentially able to adjust to the projected SLR rates …



Seagrass (*Zostera noltii*) habitat poleward shift under sea warming



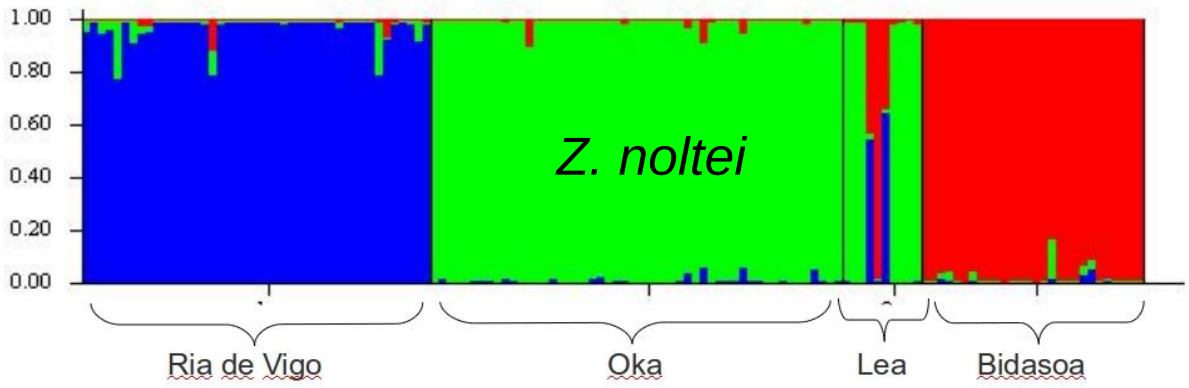


Unsuitable **-18.5%** Stable **81.5%** Colonisable **24.3%**

Valle et al. 2014 Biological Conservation

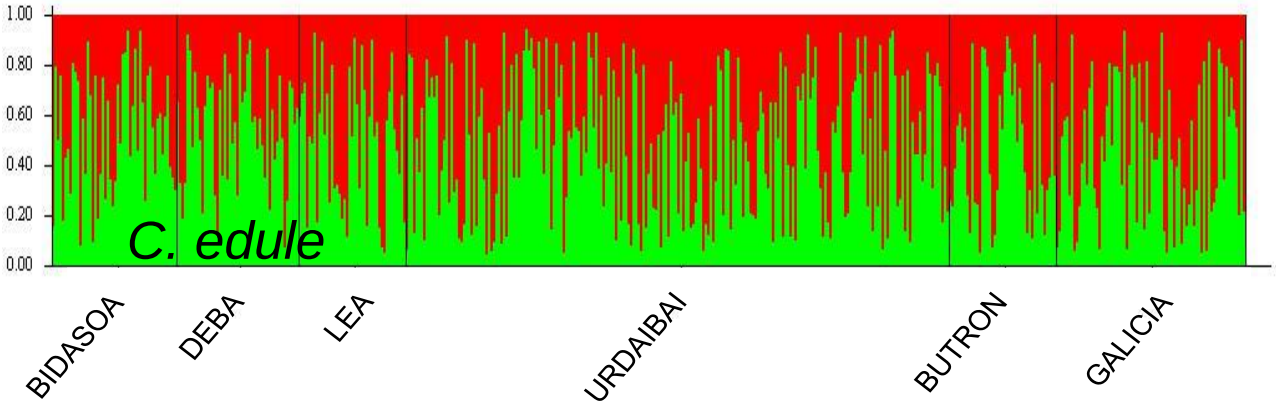
Population genetic analysis

STRUCTURE analysis:



⇒

- 3 clusters; 4 estuaries
- Populations genetically fragmented



⇒

Genetically undifferentiated, indicating they own to a unique panmictic population

Seagrass populations are genetically fragmented ⇒ Dispersal limited ⇒ Limited Capacity for recolonizing new estuaries and ecological adaptation to new conditions ⇒ Vulnerable to CC

Chust, G., et al. (2013) Connectivity, neutral theories and the assessment of species vulnerability to global change in temperate estuaries. *Estuarine, Coastal and Shelf Science*, 131, 52-63.

Seagrass restoration experiments

Garmendia et al., 2012

Flood risk from storm surges

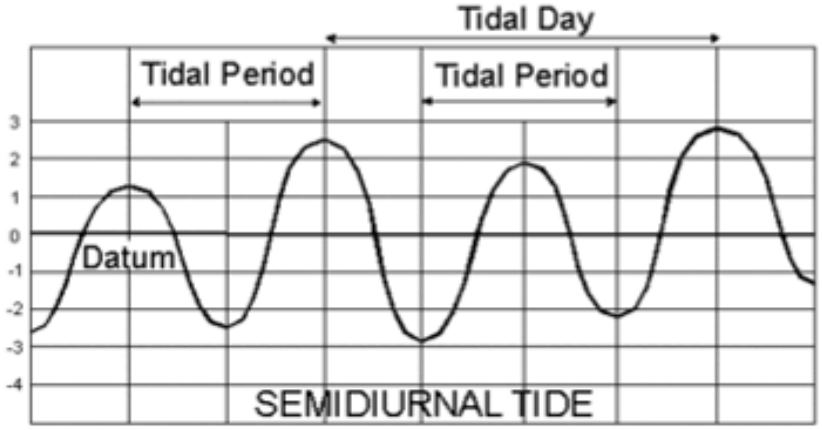
Sea level = Astronomic Tide + Meteorological Tide

Meteorological Tide depends on wind and pressure

Sea level expected by 2050-2100 as a consequence of 50-yr return level

Sea level rise + Storm surge (*marejada ciclónica*) ⇒ 62 cm above Maximum Astron. High tide

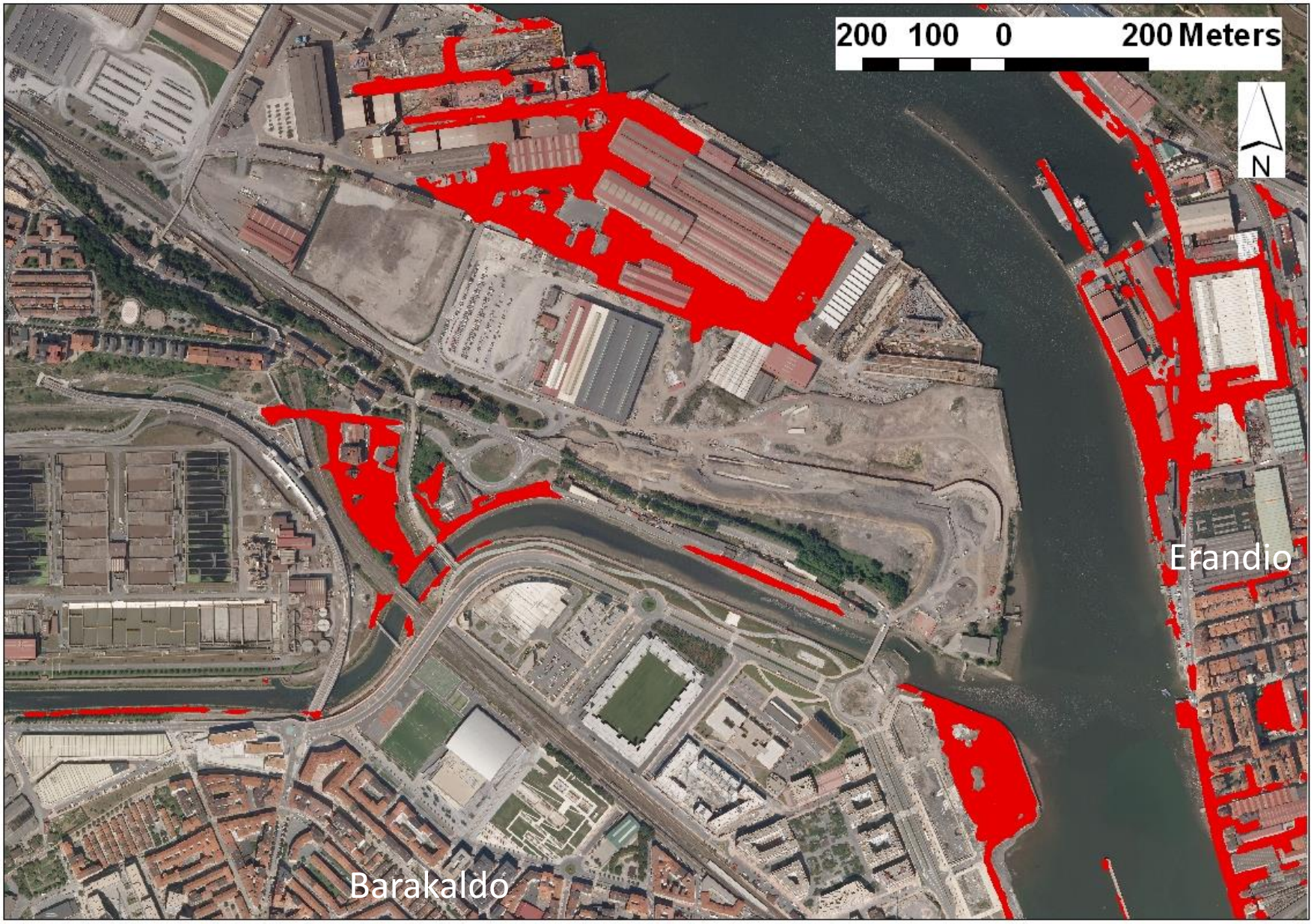
(at present is at 22 cm above MAHT)



Sea level ~ Maximum Astronomic high tide

Marcos et al. (2012) Clim Res

Flood risk from storm surges



Marcos, M., Chust, G., Jordà, G., Caballero, A., 2012. Effect of sea level extremes on the western Basque coast during the 21st century. Climate Research, 51, 237-248

Flood risk from wave extreme events

diariovasco.com

Iniciar sesión con | Regístrate

Portada | Gipuzkoa | Deportes | Economía | Más Actualidad | Gente y TV | Ocio y Cultura | Participa | Blogs | Servicios | Hemeroteca | IR

Alto Urola | Alto Deba | Bajo Deba | Bidasoa | Comarca | Costa Urola | Pasaia -Errenteria | San Sebastián | Tolosa-Goierri | diariovasco.tv

Estás en: diariovasco.com > Noticias Gipuzkoa > **Fallece un hombre arrastrado por una ola en Ondarroa**

kristau·eskola Zatoz gure ikastetxeak ezagutzera 2014-2015 IKASTURTERAKO AURREMATRIKULA

TEMPORAL

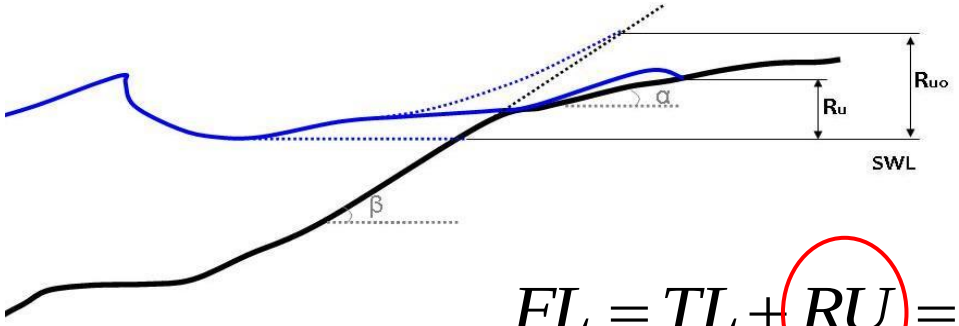
Fallece un hombre arrastrado por una ola en Ondarroa

La víctima es un hombre de 43 años de origen senegalés que se encontraba pescando en el puerto. Tras caer al agua pudo ser rescatado, pero nada pudo hacerse por salvar su vida

28.01.14 - 12:54 - DIARIOVASCO.COM | ONDARROA

Flood risk from wave extreme events

Extreme wave events: methodology



$$FL = TL + RU = AT + MT + RU$$

FL: Flood level

TL: Tide level

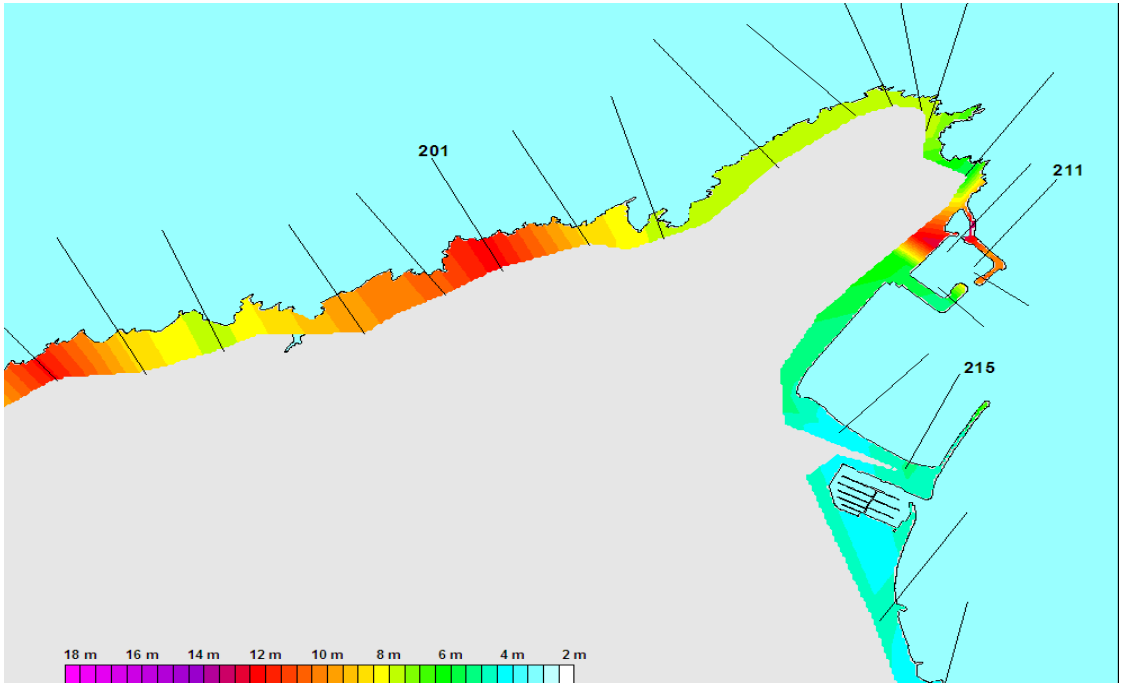
RU: wave run-up (sum of the wave set-up and the wave swash)

AT: Astronomic tide

MT: meteorological tide

RU_0: theoretical run-up

Extreme wave (wave height) flood level expected for a 50-yr return period



Liria et al. 2011 *Journal of Coastal Research*

Flood risk areas

Extreme wave events

Sea-level rise

Liria et al. 2011 *Journal of Coastal Research*

Conclusions and Adaptation strategies

Scenarios | **Impacts** | **Adaptations**

Floods and impacts due to:

- Sea level rise (29-49 cm)
- Storm surges (+62 cm)
- Extreme wave events

⇒ **250 ha of the Basque coast is at risk of flood, concentrated within the estuaries (~50%)**

⇒ **Retreat of beaches on 25-40% of width**

⇒ **The habitat of intertidal species and salt-marshes can be reduced**

- **Maintenance and rebuilding of coastal infrastructures**
- **Revision of drainage systems**
- **To promote coastal resilience such as protection, regeneration of dune plants and intertidal species and wetlands, sand stabilization, establish buffer zones**

Climate Change Documentary:

www.vimeo.com/13292409

References

- Chust et al. (2009). Human impacts overwhelm the effects of sea-level rise on Basque coastal habitats (N Spain) between 1954 and 2004. *Estuarine, Coastal and Shelf Science* 84:453-462.
- Chust et al. . 2010. Regional scenarios of sea level rise and impacts on Basque (Bay of Biscay) coastal habitats, throughout the 21st century. *Estuarine, Coastal and Shelf Science* 87:113-124.
- Chust et al. 2010. Capabilities of the bathymetric Hawk Eye LiDAR for coastal habitat mapping: a case study within a Basque estuary. *Estuarine, Coastal and Shelf Science* 89: 200-213.
- Chust et al. (2011) Climate Change impacts on the coastal and pelagic environments in the southeastern Bay of Biscay. Climate Research 48:307–332.
- Liria et al. 2011. Extreme Wave Flood-Risk Mapping Within the Basque Coast. Journal of Coastal Research, SI 64.
- Valle et al., 2014. Projecting future distribution of the seagrass Zostera noltii under global warming and sea level rise. *Biological Conservation* 170.

Acknowledgements

- Gobierno Vasco (ETORTEK, proyecto K-Egokitzen I & II)
- Ministerio de Medio Ambiente y Medio Rural y Marino, Gobierno de España (Proyecto Ref.: 0.39/SGTB/2007/4.1)
- Agencia vasca del Agua (URA), Gobierno Vasco, proyecto « Inundabilidad de los estuarios vascos »
- Ministerio de Ciencia y Tecnología: ZOSTERMODEL

Thank you for your attention!