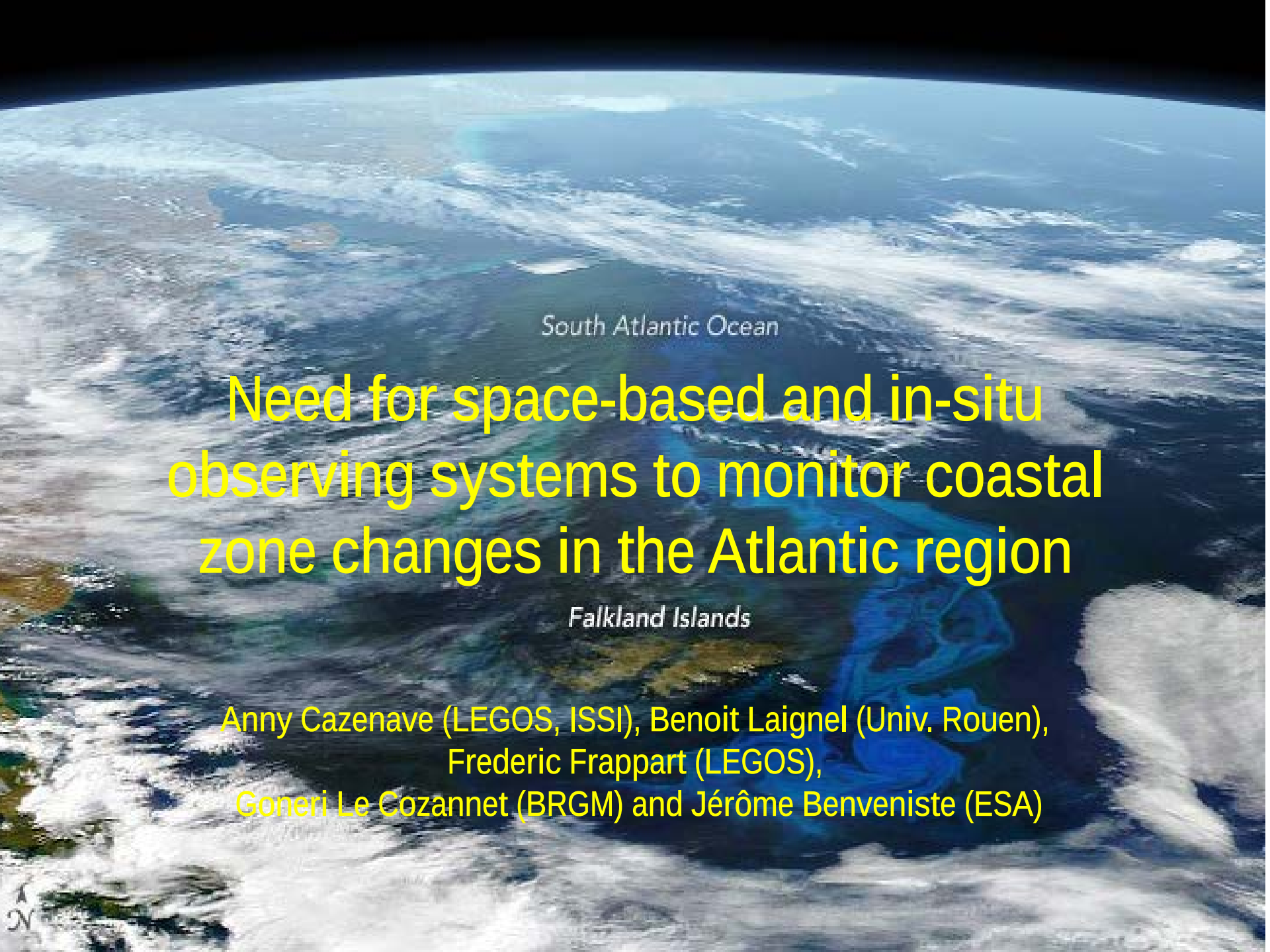


Need for space-based and in-situ observing systems to monitor coastal zone changes in the Atlantic region

Anny Cazenave (LEGOS, ISSI), Benoit Laignel (Univ. Rouen),
Frederic Frappart (LEGOS),
Goneri Le Cozannet (BRGM) and Jérôme Benveniste (ESA)

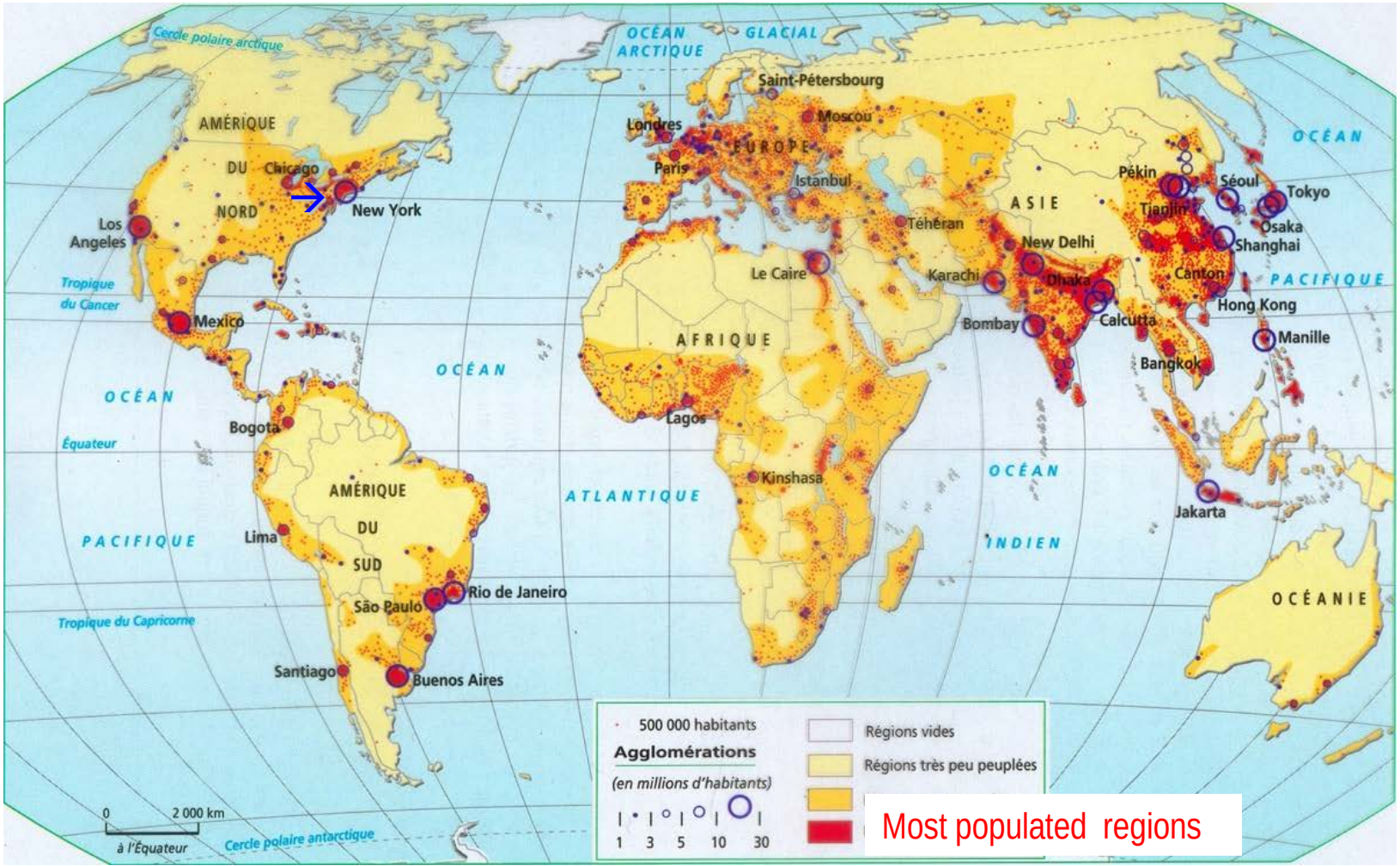
The Atlantic Ocean

Atlantic coastlines length:

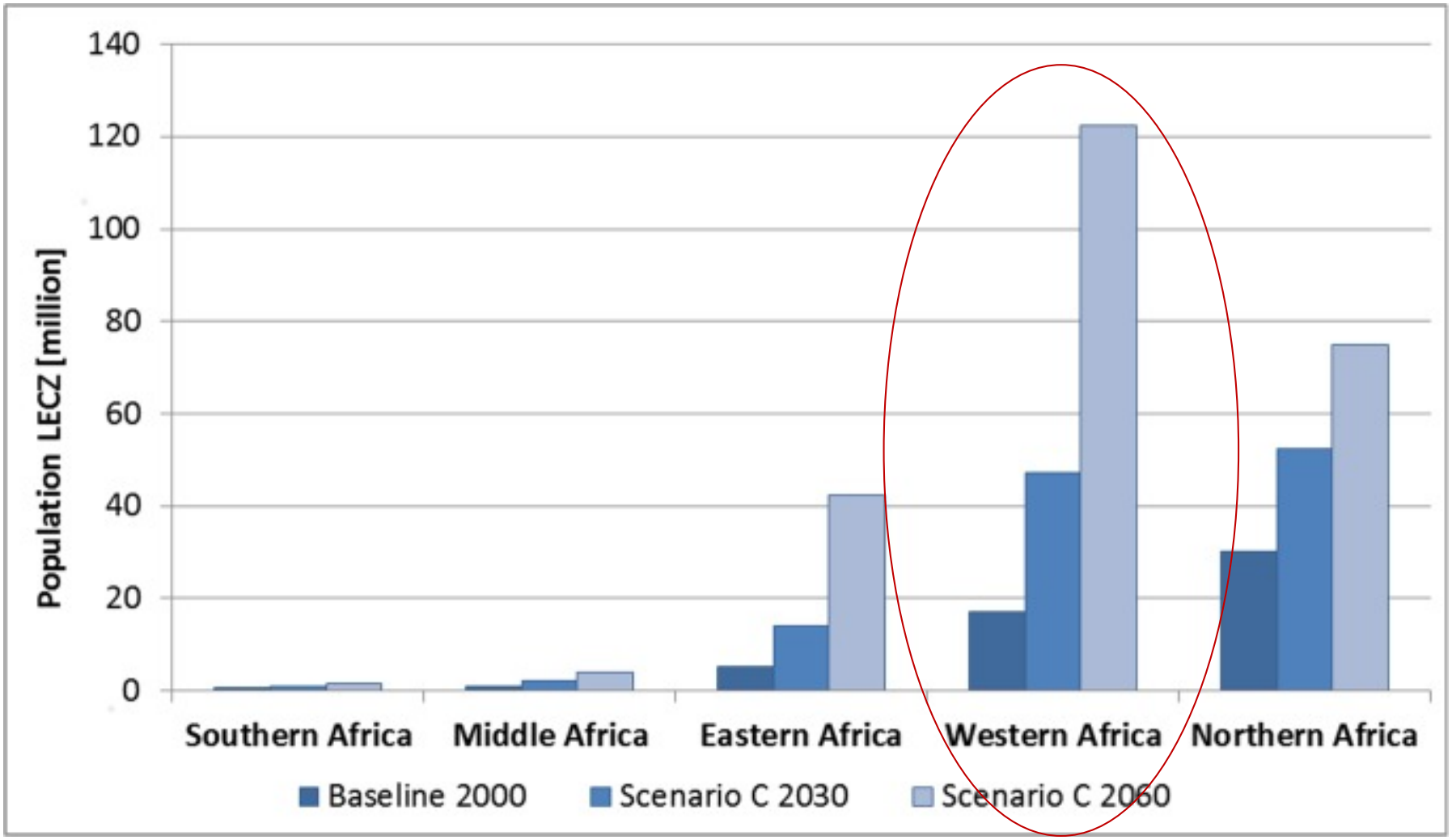
Europe (EU):
>60 000 km (including Med Sea)
Eastern USA:> 10 000 km
West Africa: > 10 000 km
Brazil: ~7500 km
Argentina: ~6000 km
……

Coastal Zones

- Population of low elevation coastal zones (LECZ; <10 m): 10% of the world population; half is urban (11 of the world's 15 largest cities are located near the coast)
- Strong harbour, industrial & tourism activities
- Among the most productive ecosystems on the planet, regulate water flow & mass (i.e., nutrient, carbon, salt), filter pollutants & contaminants



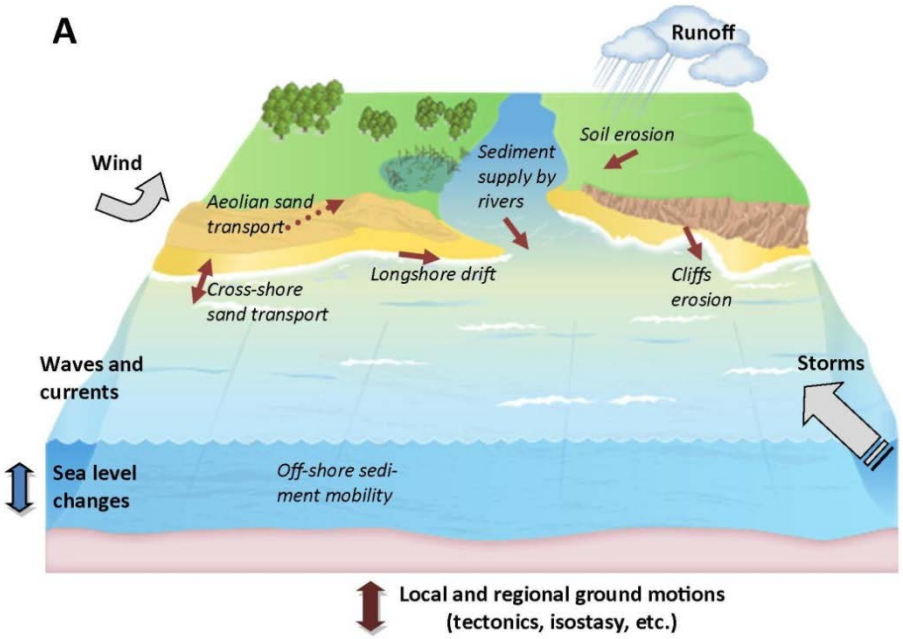
Population estimates in the African Low Elevation Coastal Zone (<10 m above sea level)

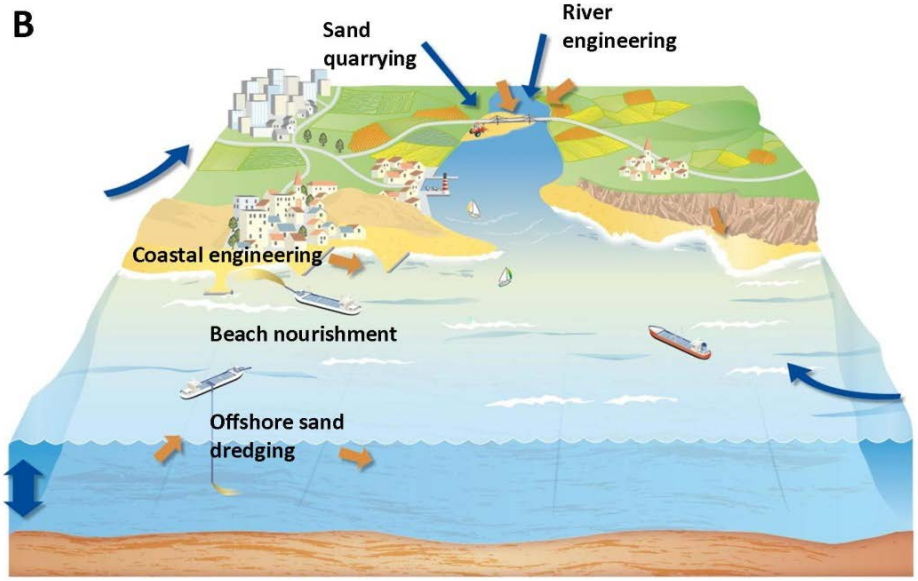


Coastal Zones

- *Coastal regions and populations are exposed to pressures and hazards from both land and sea*

- *Earth environments mostly impacted by human activities & climate change*



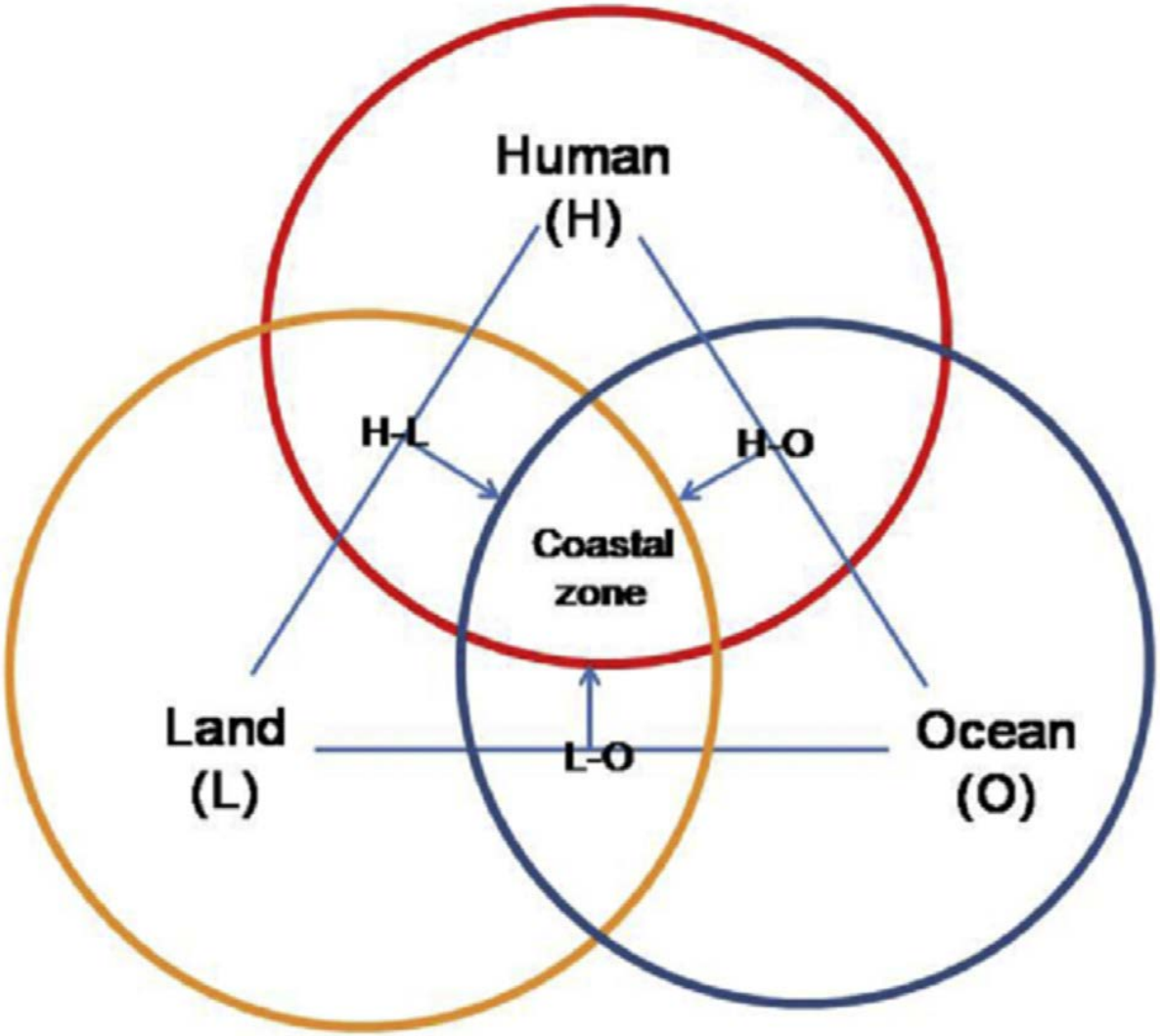


Natural processes

Human activities

Source: Cazenave and Le Cozannet, 2014

Drivers of Coastal Zones Changes



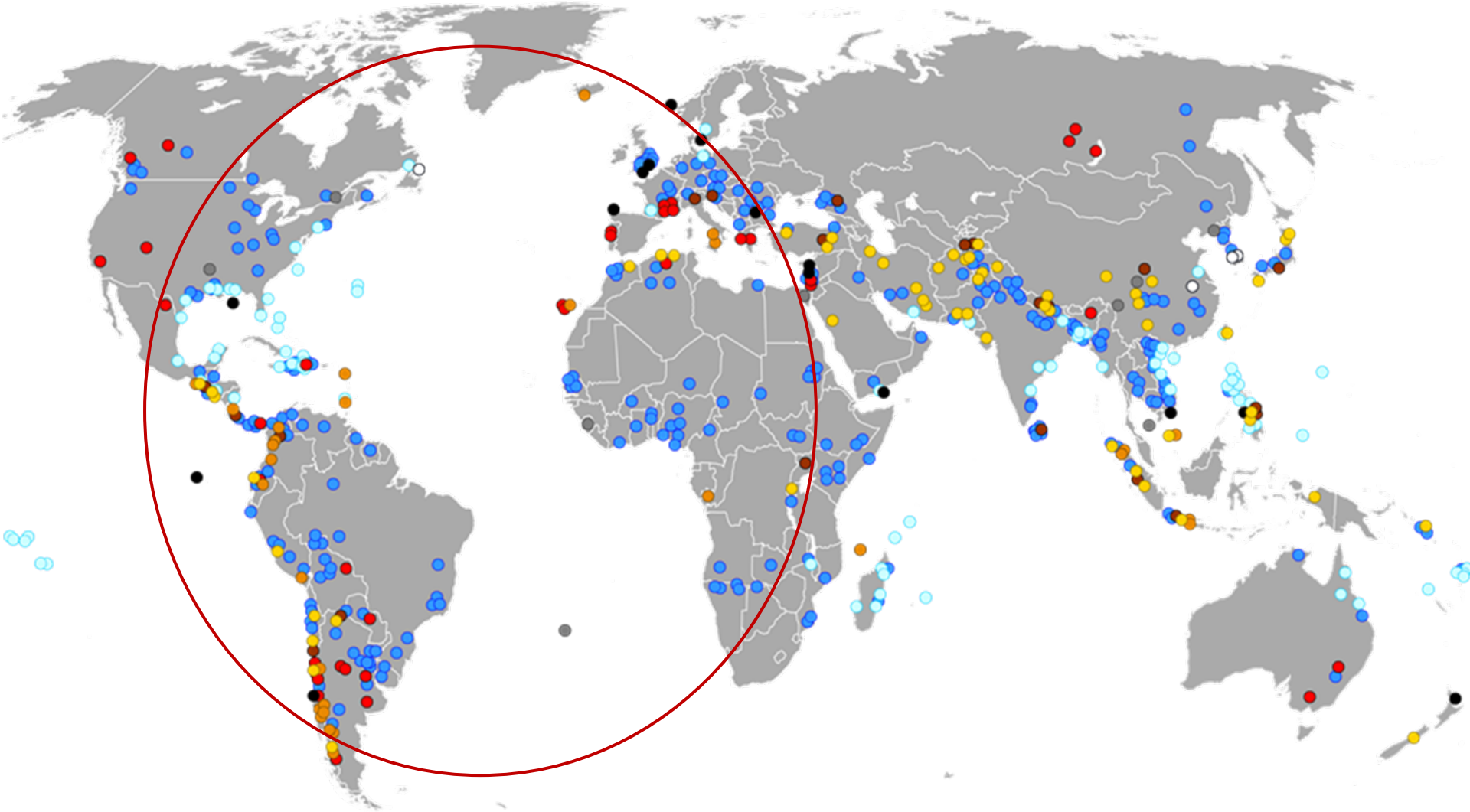
Climate change impacts →

Sea level rise, more intense storm surges & river floods

→Increased disasters:

→inondations & shoreline retreat

Natural disasters between 2000 and 2017

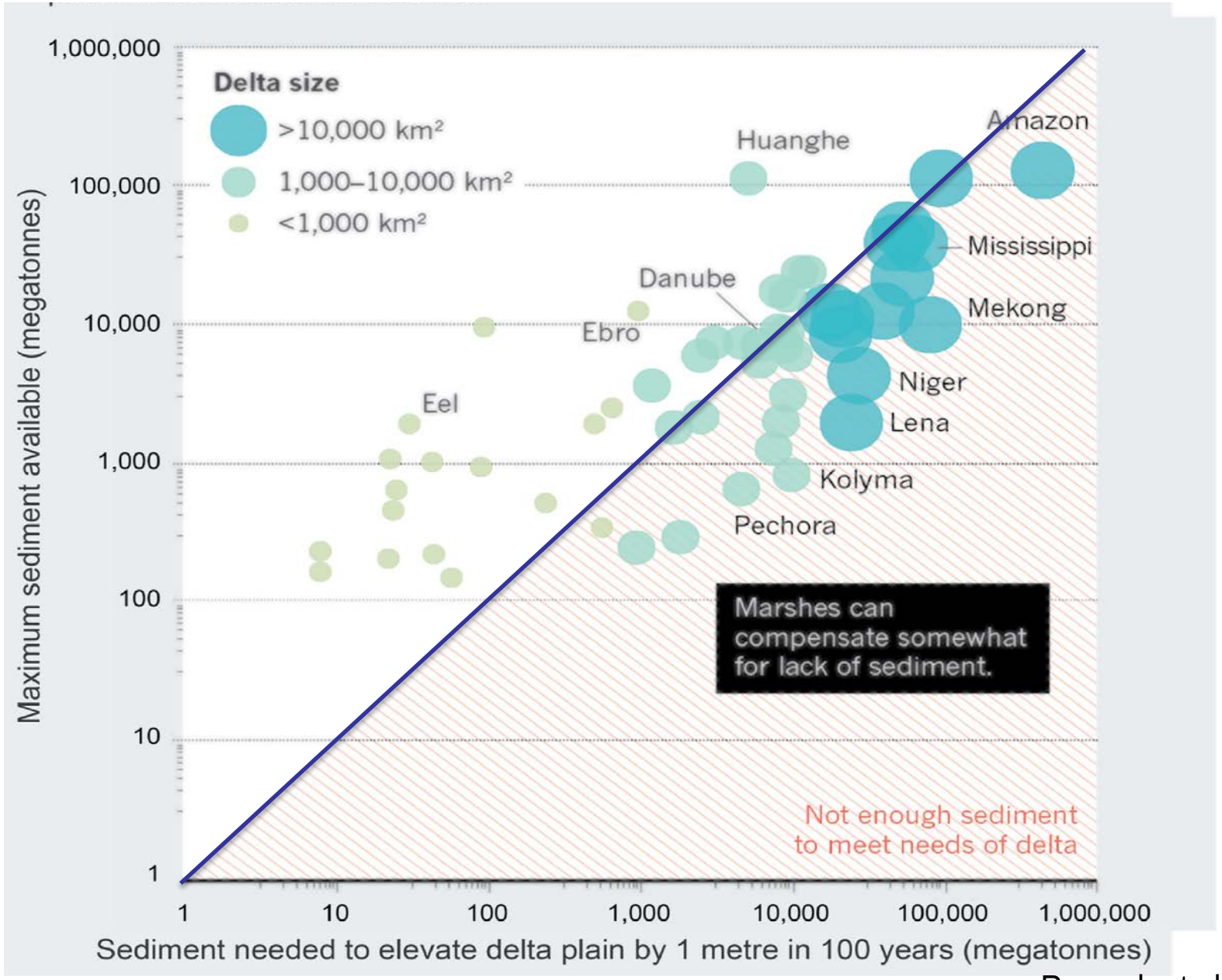


Source :CNES

A few numbers…

- Sea level is today higher by 10 cm on average than in the 1990s (25 cm in some regions)
- Flooding has doubled along parts of the US coast in the past 30 years because of sea level rise
- 25% of sandy beaches are eroding at a rate > 0.5 m/yr
- In Europe, 75% of shorelines are in erosion
- In some river deltas, sediments supply is decreasing because of river dam building, leading to coast disequilibrium

Sediment deficit in large river deltas



Ramesh et al., 2016

Socio-Economic issues in the coastal zones

Reduction of beach surfaces→ impact on tourism

Wetlands changes→ inundation, salinization

Design and building of infrastructures (harbours, dikes ...) as protection against the sea should be reviewed → considerable costs

According to OECD, economic loss on coastal human properties (houses, buildings, business…) affected by hydro-meteo-marine events in 2005 was estimated at 3000 billion $ (5% of annual global GNI). This number may be higher by a factor of 10 in 2070

Oceanic processes affecting coastal zones

Ocean dynamics in the coastal zone is governed by forcing factors, conditions at the boundary (heat, momentum and fresh water fluxes) and internal forces (gravity and tidal potentials).

This results in a wide range of complex phenomena:

- External & internal tides and associated currents
- Storm surges
- Fresh water plumes from rivers
- Trapped coastal waves
- Upwellings/downwellings driven by along-shore wind stress
- Density fronts
- Subsurface counter currents near the shelf break
- Shelf currents generated by deep-ocean currents
- Non-linear interactions of surface waves, winds and currents, producing secondary circulation
- Mesoscale/submesoscale eddies
- ……

- Observations from space and in situ of coastal processes are essential to capture the various phenomena acting on a broad range of spatio-temporal scales

- Numerical modeling and data assimilation are also important for process understanding and providing forecasts of oceanic conditions to help navigation, environmental hazard response, fisheries, etc.

Deltas and estuaries
→ complex hydrodynamical systems

➔ Suffer large water level variations in response to hydro-meteo-marine phenomena: offshore currents, wind-driven shelf circulation & waves, tides, storm surges, sea level rise & inputs from river & groundwater flows

⬇

Their spatio-temporal variations
& their impacts on inundations & coastal morphological evolution
are not well known & difficult to model

because of:

- sparse in situ water level observations
- tide gauges are located in sheltered areas (harbors)
- the phenomena and their interactions differ from one region to another according to the coast morphology, sediment supply, exposure to waves, winds and currents, coastal climate

Key scientific issue/question relevant to coastal zone changes

How better understand the combined effects of the hydro-meteo-marine phenomena (offshore currents, wind-driven shelf circulation & waves, tides, storm surges, sea level rise & inputs from river & groundwater flow) on the spatial and temporal variations of coastal water levels and their impacts on inundations and coastal morphological evolution (→coastal retreat and erosion)?

To answer this question, we need high-quality, integrated and sustained observations of environmental variables to characterize the forcing factors and the response of the coastal zone

Forcing agents

- Sea level rise
- Winds, waves and currents
- Extreme events
- Vertical land motions
- River runoff
- Sediment transport
- Land use change and urbanization

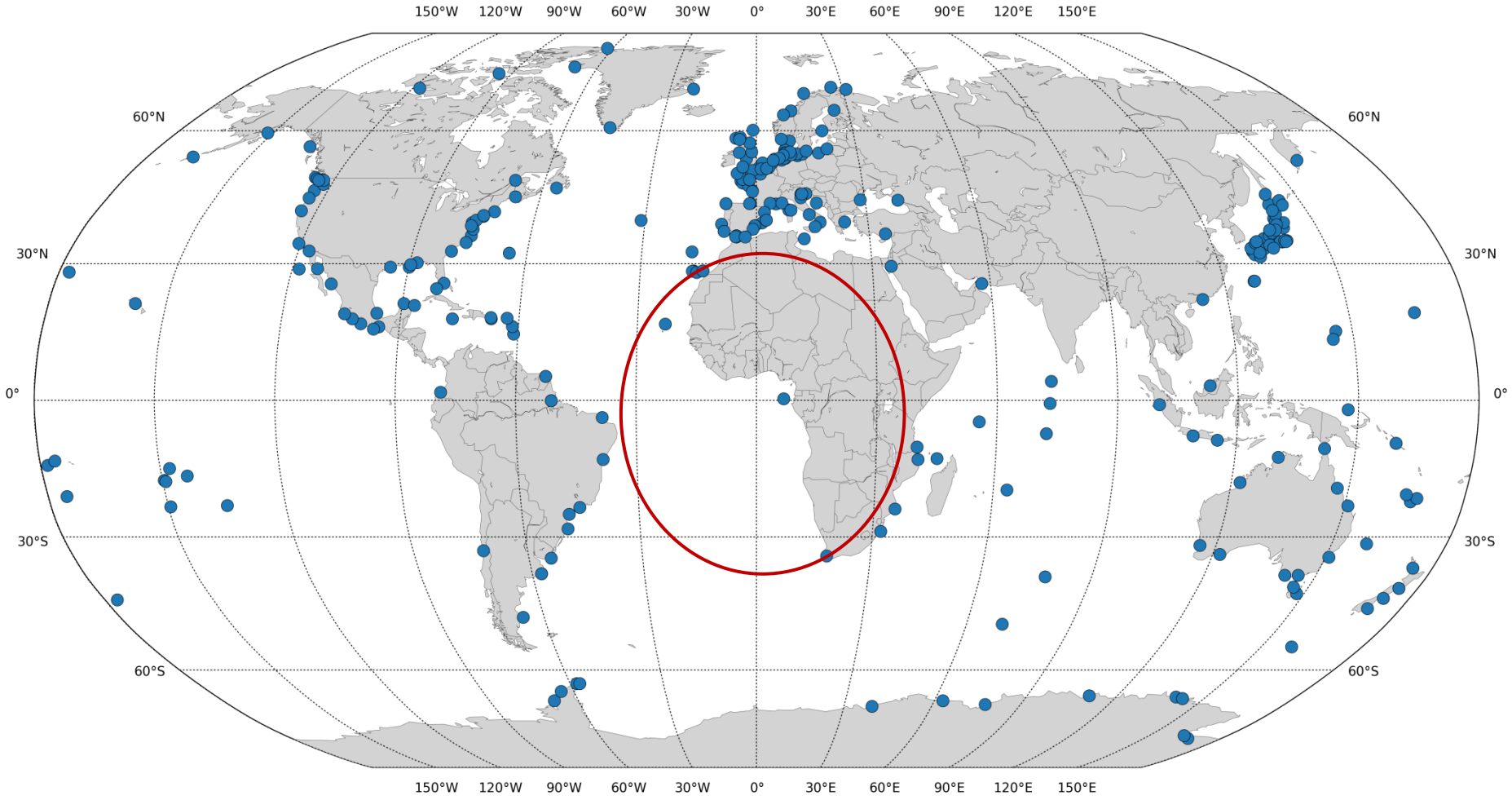
Time scale ranging from hours to centuries

Coastal change parameters

- Shoreline position
- Estuaries morphology
- Land topography
- Coastal bathymetry

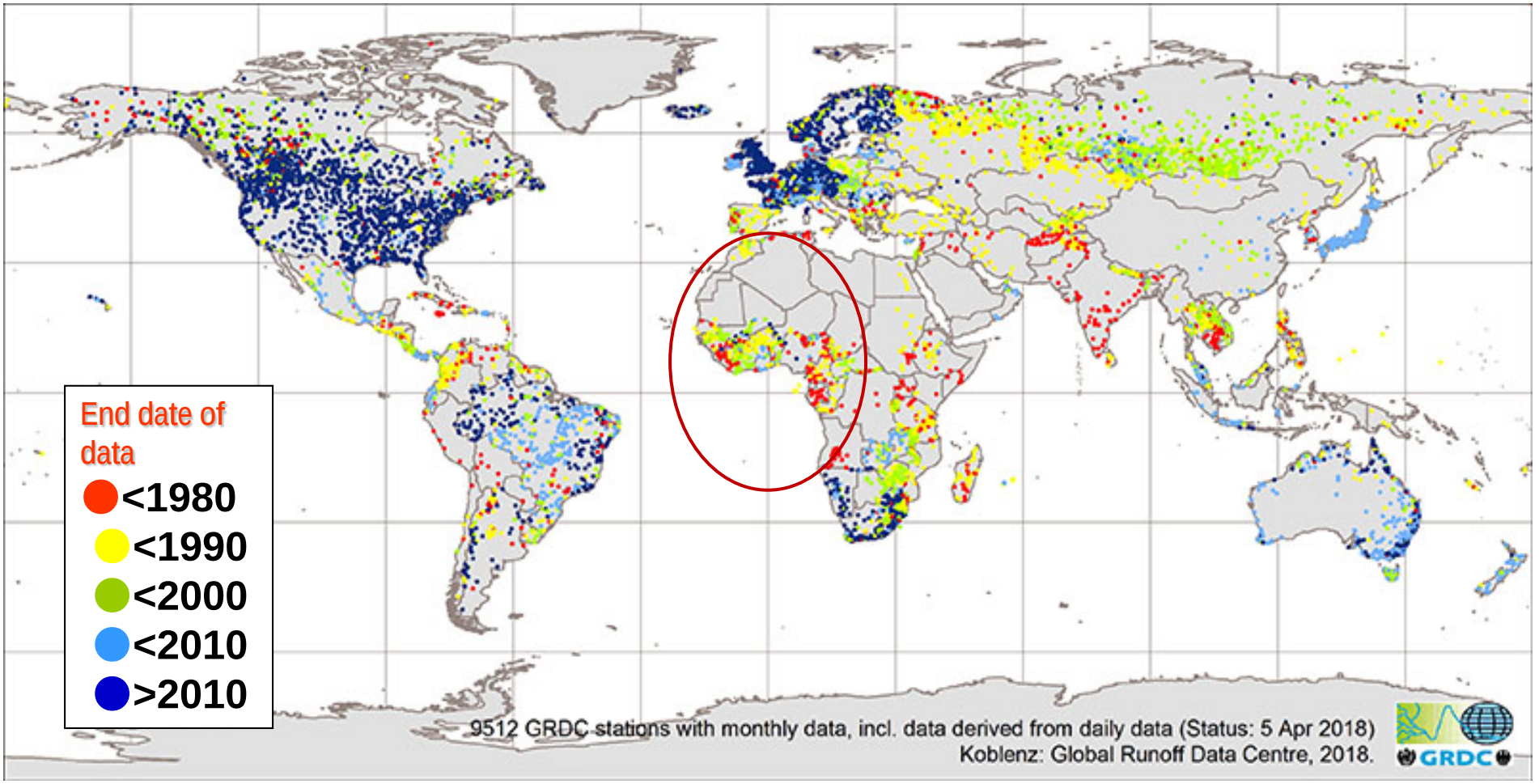
→ Both in situ measurements and remote sensing are needed

Current tide gauge network with colocated GPS/GNSS receivers (distance <1 km)



Courtesy: Guy Woppelmann

In situ river discharge network: The Global Runoff Data center (GRDC)

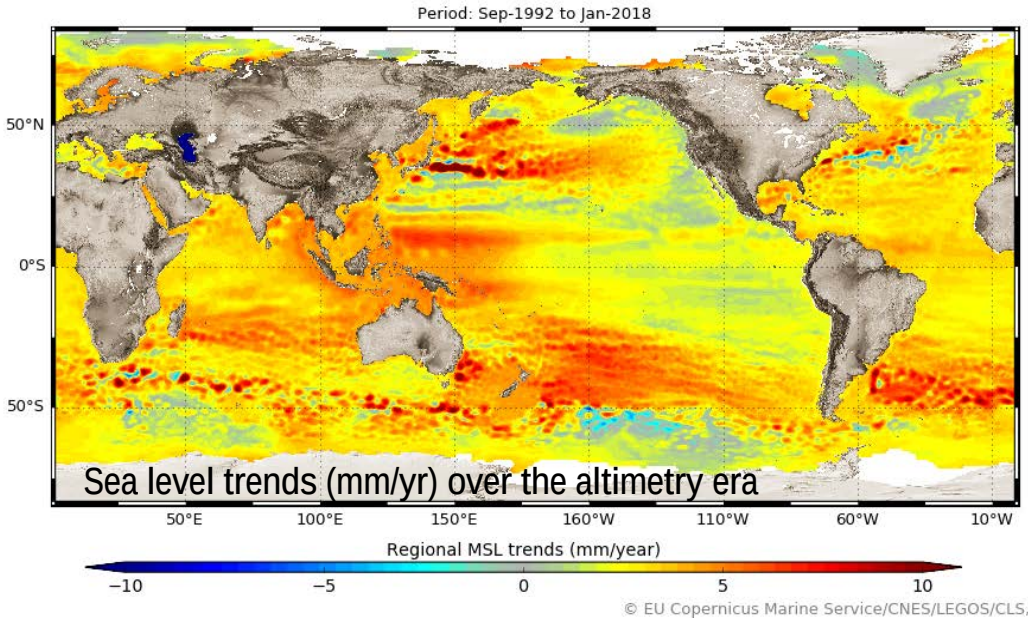


Coastal sea level rise: still very poorly known

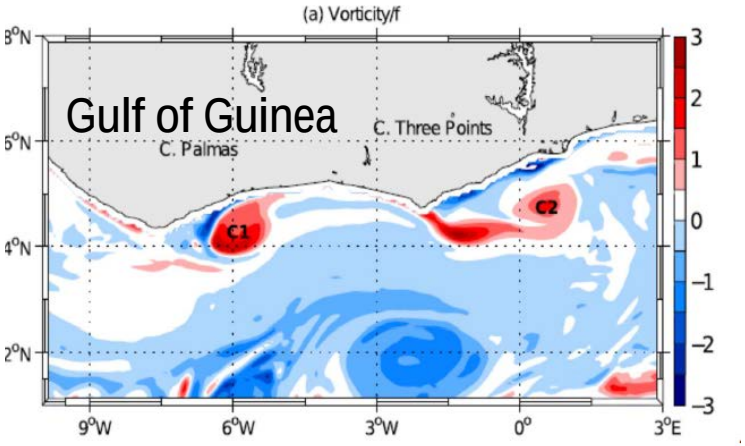
There are reasons to suspect that coastal sea level change is not just an extension of open ocean sea level change but may differ at the coast →

- *High-resolution ocean circulation models show that sea level is different in the coastal zone compared to the open ocean (consequence of trapped Kelvin waves, shelf currents, baroclinic instabilities, etc.)*

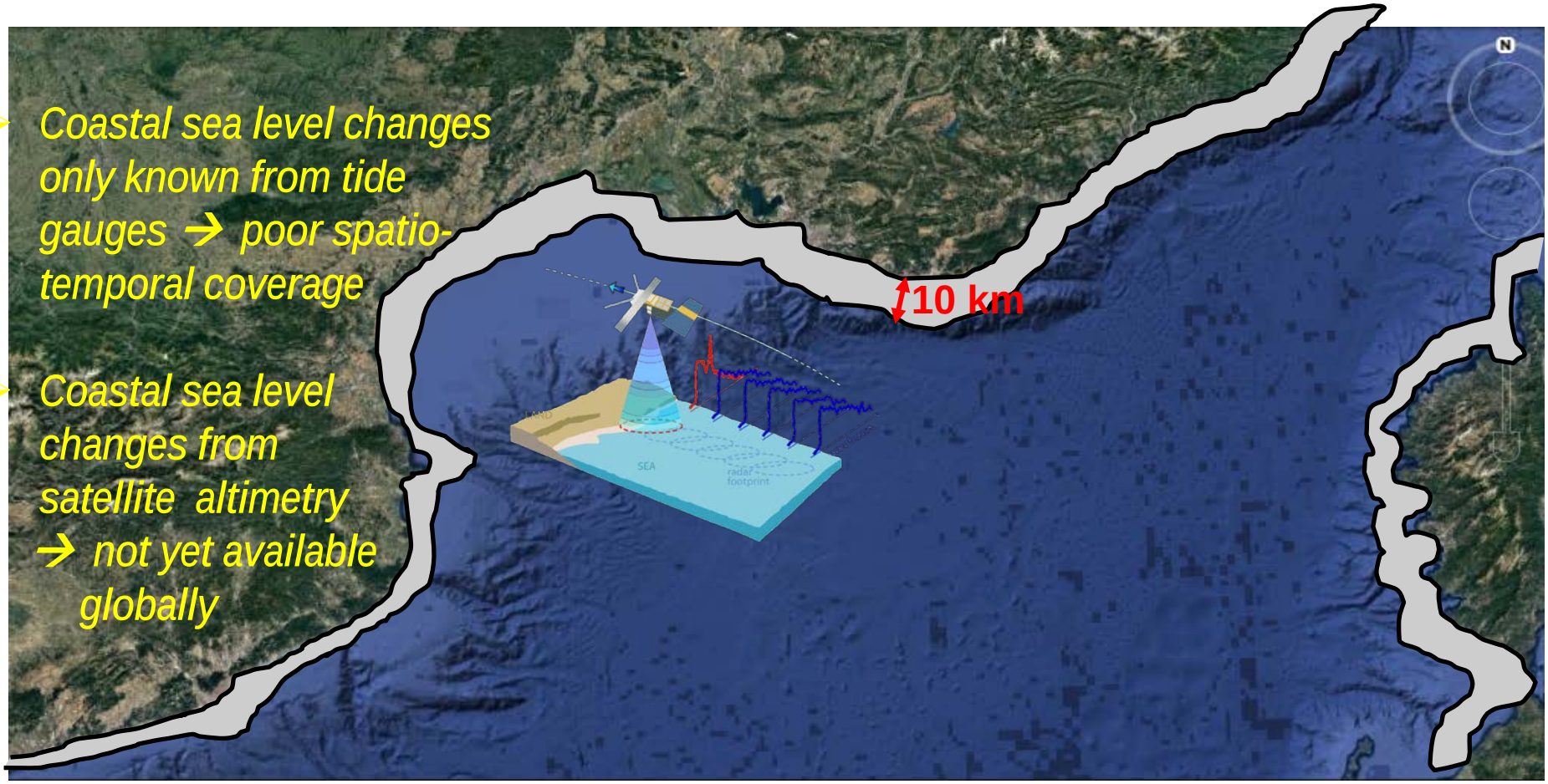
- *Some processes (e.g., waves, river runoff in deltas and estuaries) only occur at the coast, and can also impact coastal sea level*



Sea level trends (mm/yr) over the altimetry era



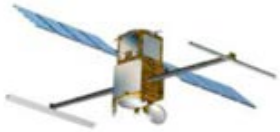
Coastal Altimetry

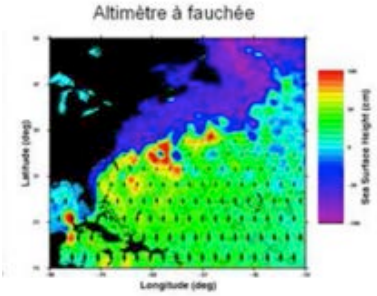


Satellite monitoring of coastal sea level

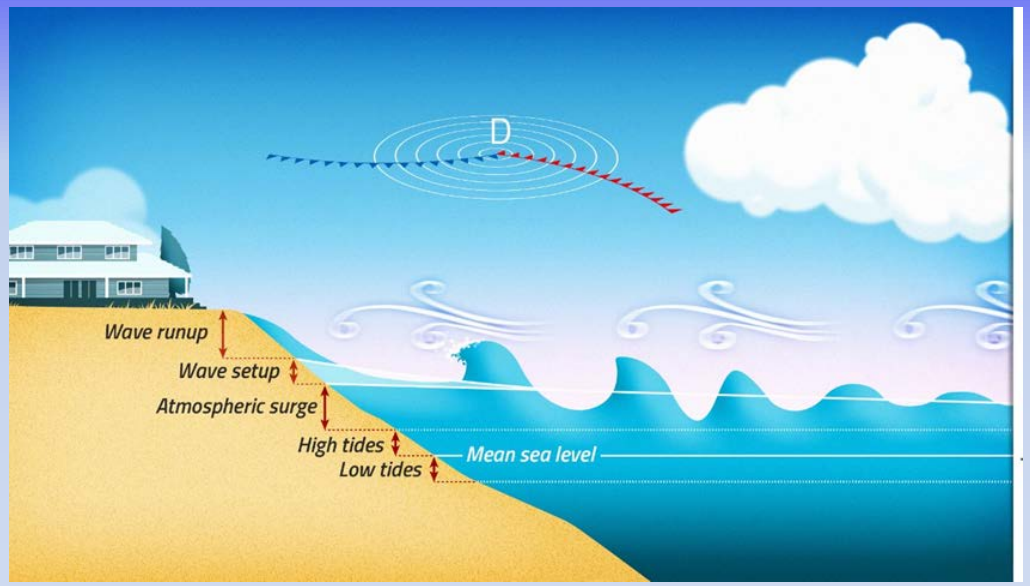
New generation of SAR & interferometric altimeters (Sentinel 3, SWOT…) ➔ resolve the problem & provide fundamental coastal sea level data, allowing:

Mapping of the spatial variability of surface water elevations in different hydrodynamic environments & at different spatial scales (regional and local)





Wind & Wave Measurements in the Coastal Zone



- Wave models available but direct observations in the coastal zones are very limited
- Multi-sensor approach (altimetry, SAR, scatterometry) needed to measure winds & waves in selected coastal regions

→ Constraints on coastal hydrodynamic and flooding models

DEMs and bathymetry at the land-sea interface

- Knowledge of shallow waters bathymetry is mandatory to understand the processes that control the evolution of coastal environments, for decision-making and coastal management; and also for tidal and hydrodynamic modeling

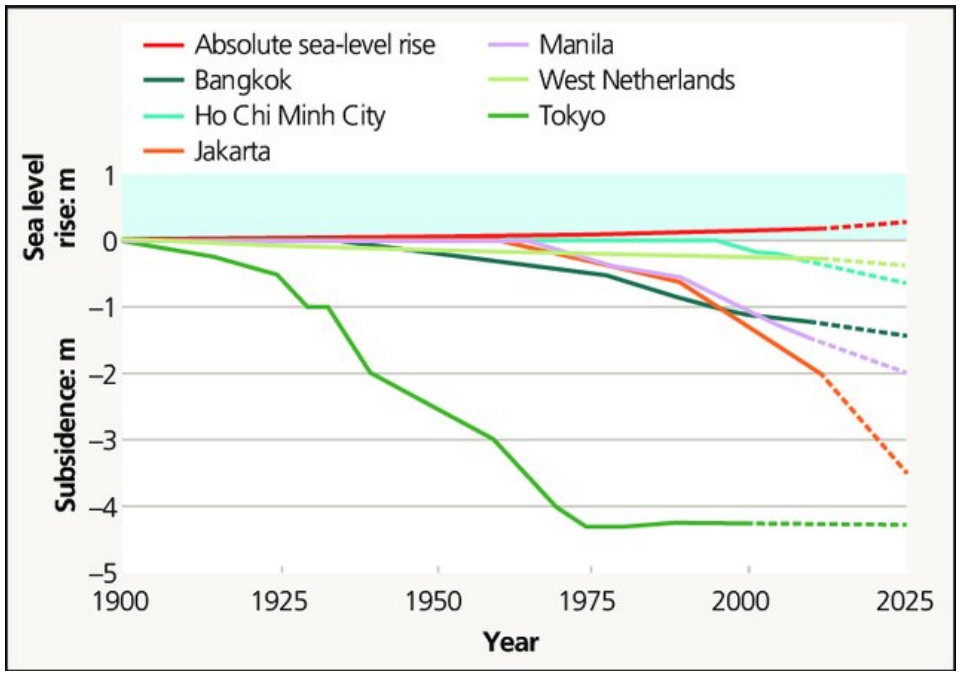
- **Typical requirements for remote sensing observations**
  - Sub tidal zone DEM: few acquisitions/season, 1 to 10 m resolution
  - Shallow water bathymetry: once/season - decade, 1 to 10 m resolution
  - 50~80m depth bathymetry: once/season - decade, 1 to 10 m resolution

- **Current technologies**
  - Operational: Lidar
  - Operational and in development: Stereo High-Resolution and Multispectral Imagery
  - In development: SAR, Optical Imagery

DEM: Digital Elevation Model

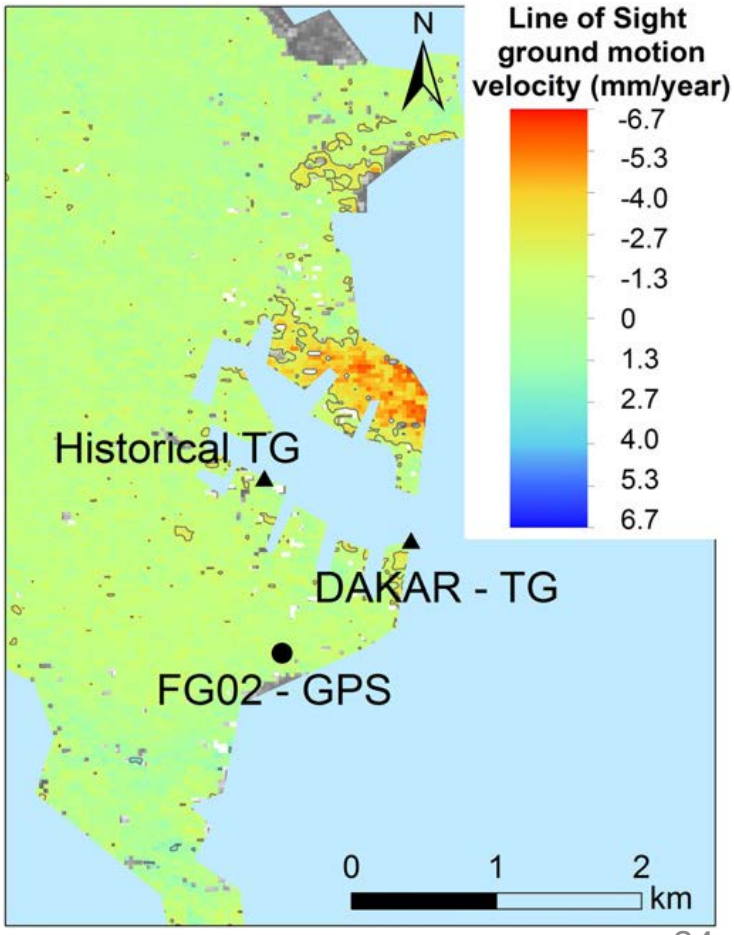
Another important process at the coast….vertical land motions

Ground subsidence in Asian megacities and Netherlands



Source: Deltares

Ground subsidence over 2003-2010 at DAKAR from InSAR (Envisat)



Le Cozannet et al., 2015

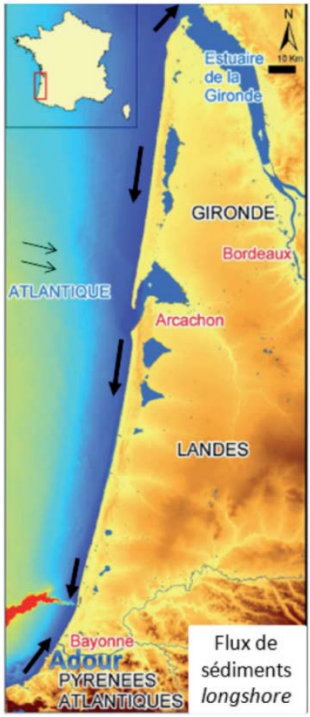
Shoreline change monitoring using satellite imagery

- Shoreline position varies in response to processes acting on different time scales (extreme events, sediment supply, small-scale oceanic processes, sea level rise, etc.). At seasonal to decadal time scale, typical shoreline changes are on the order of +/- 1 m/yr

- Need for:

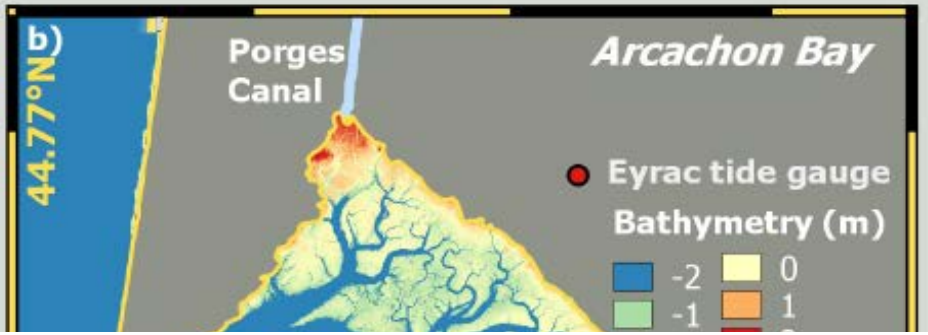
– High-resolution (0.5-1m) optical & SAR images with short repeat cycles (weeks to month depending on the region)

– Automatic post-processing for precise georectification and identification of shoreline indicators

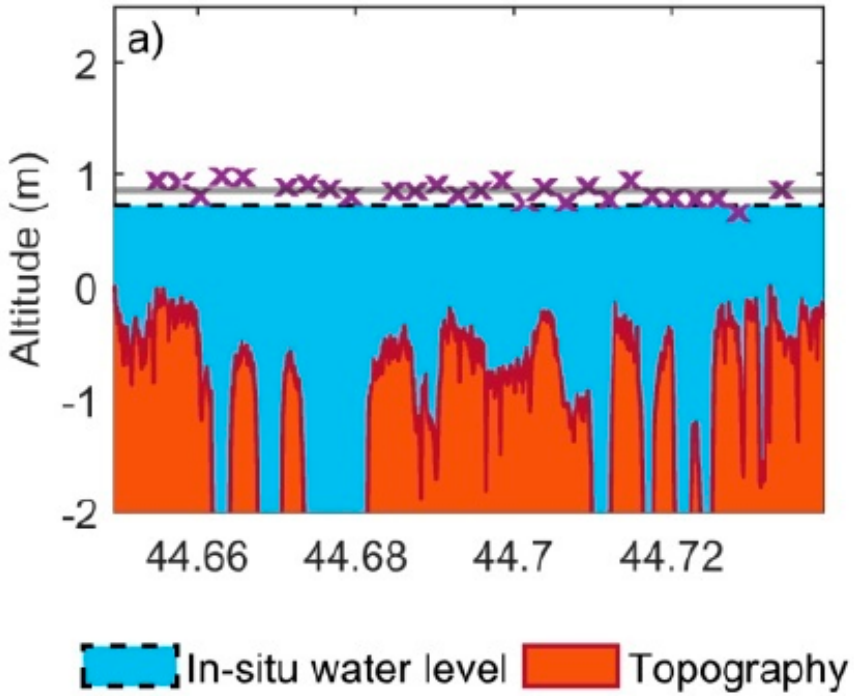


A few recent results based on space & in situ observations in Atlantic coastal zones

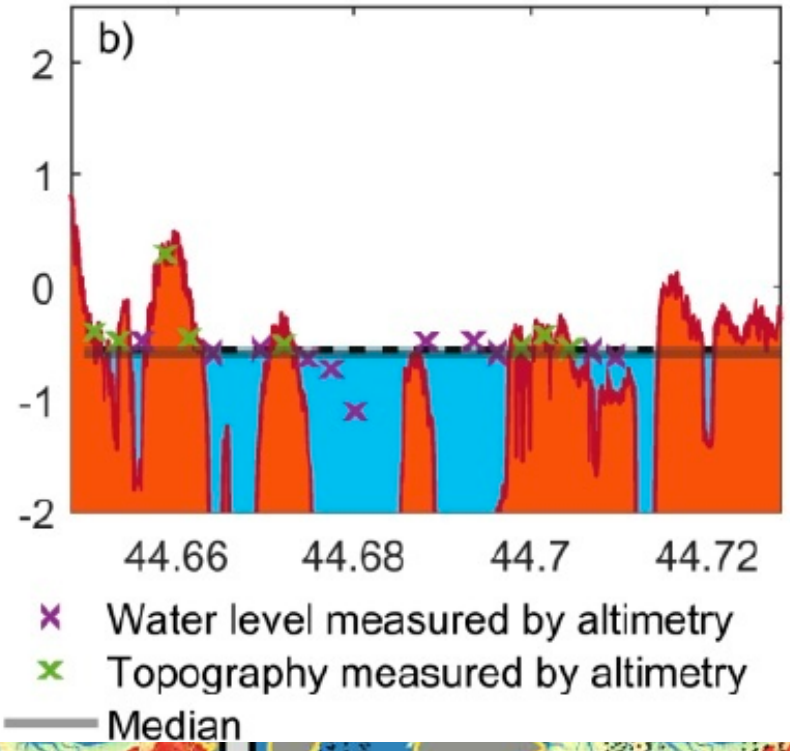
Mesuring sea level and topography of coastal lagoons



CRYOSAT2; High tide
Cycle 7, Track 3015; [17-May-2016 15:20:27]



CRYOSAT2; Low tide
Cycle 3, Track 6564; [04-Sep-2012 22:34:32]

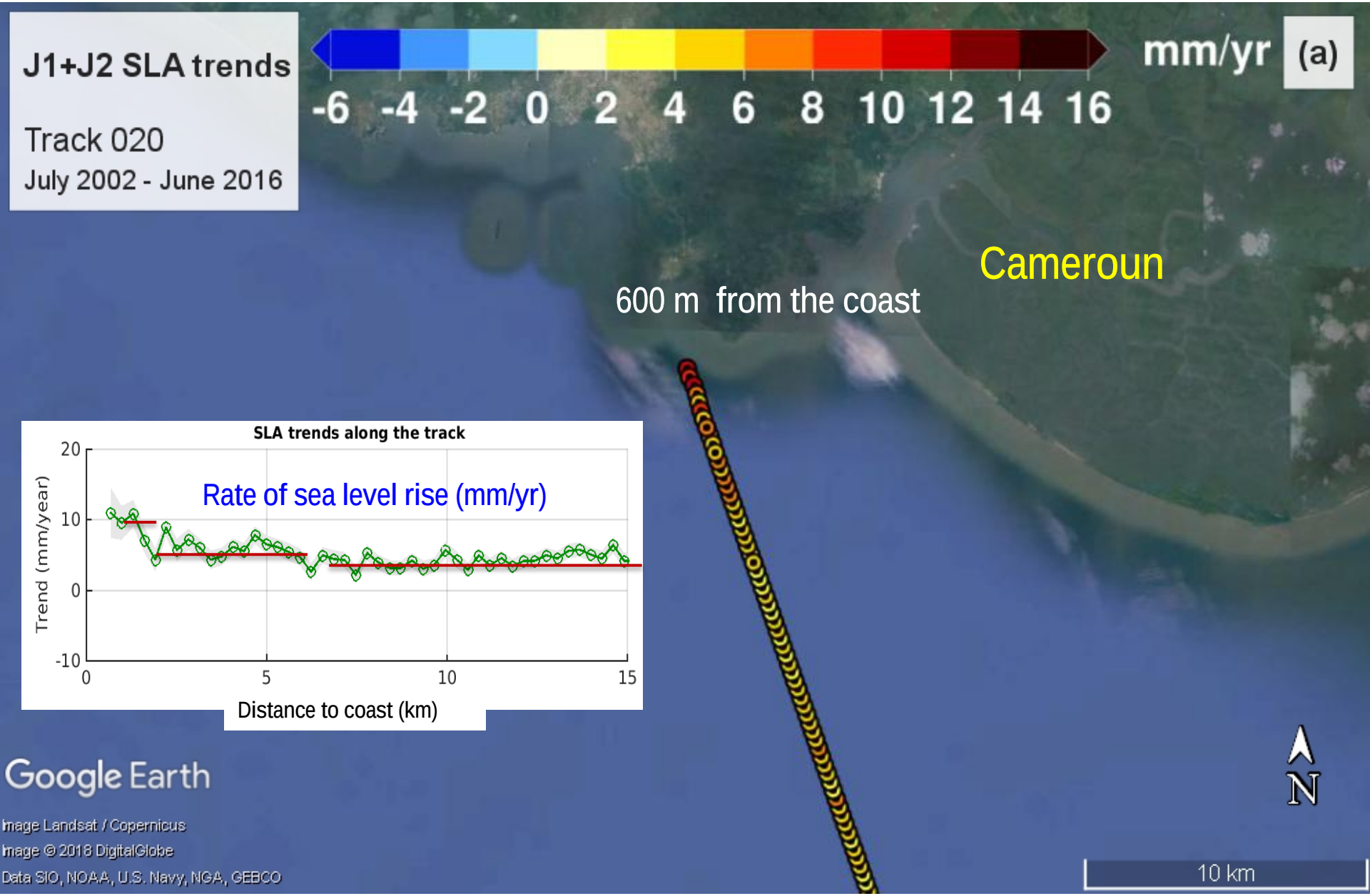


Salameh, Frappart et al., 2018

Satellite Ground Tracks

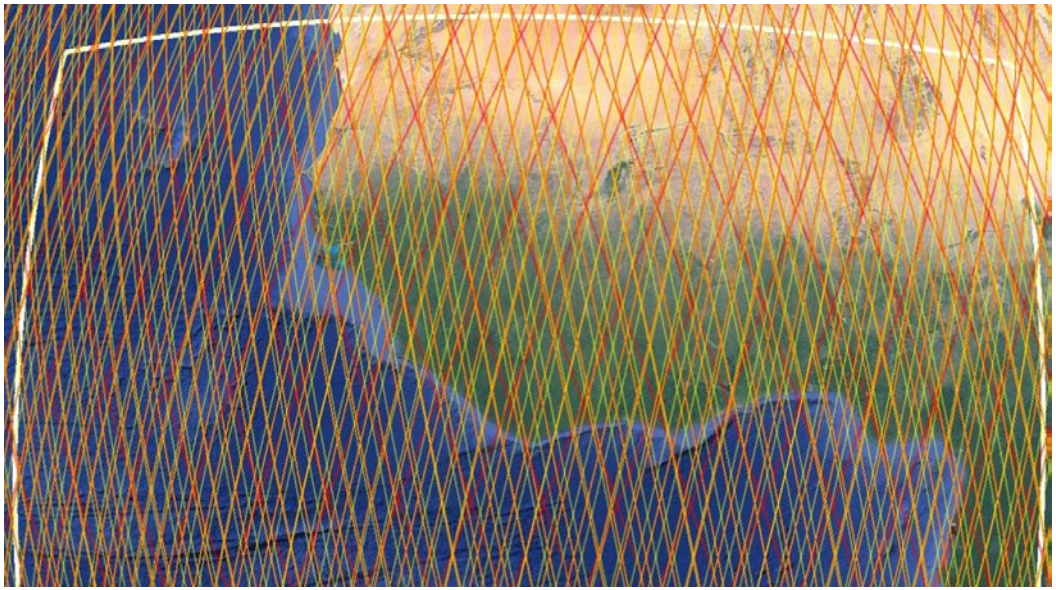
0 3 6 km

Coastal sea level rise in Western Africa from classical altimetry retracking



ESA CCI Sea level Project

Western Africa

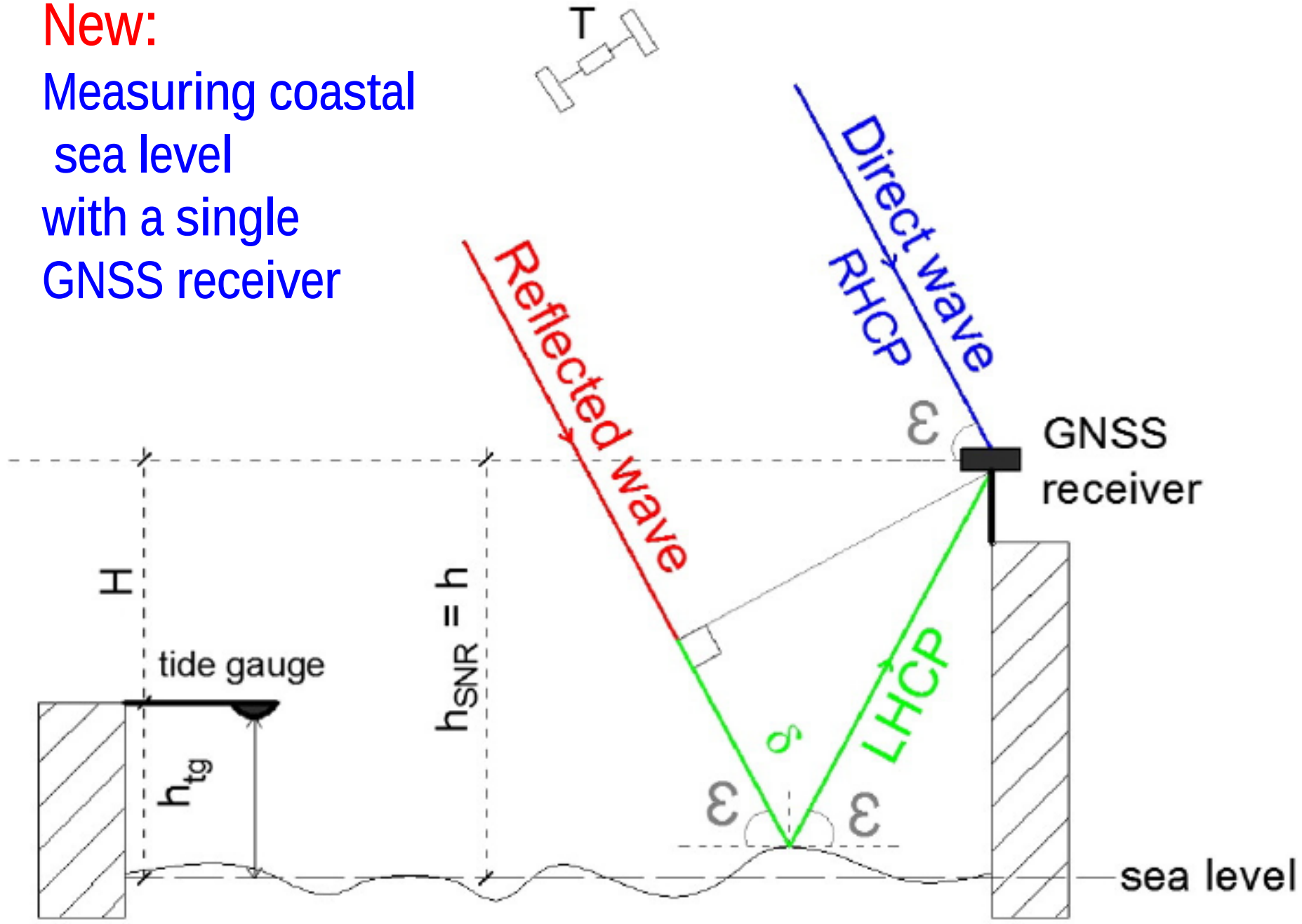


Coverage of altimetry missions

←

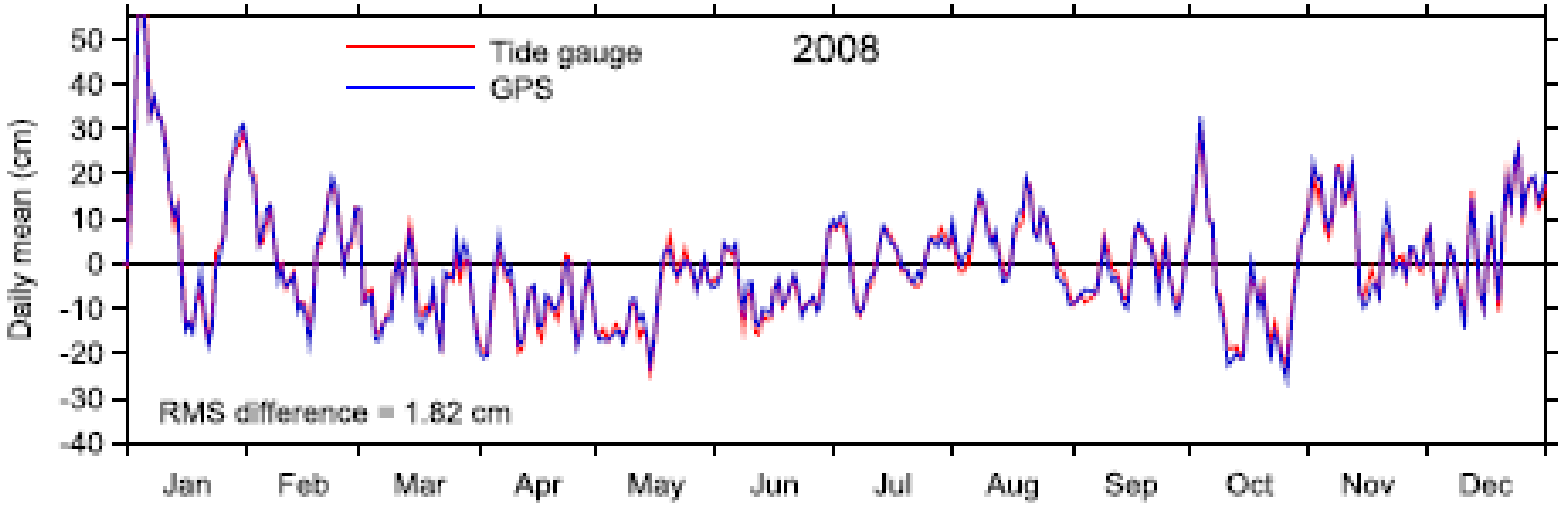
New:

Measuring coastal sea level with a single GNSS receiver



Roussel, Ramillien, Frappart et al., 2015

FIG. 1. Friday Harbor GPS station SC02. (state of Washington,USA)



Larson et al., 2017

Recommendations 1.

To answer the question raised above, precise and sustained monitoring of selected coastal regions from space and in situ is crucial

Observational needs →

- Coastal altimetry data base with global coverage → absolute coastal sea level
- Tide gauges colocated with GPS/GNSS → relative coastal sea level
- Systematic InSAR & GNSS surveys in selected coastal zones → vertical land motions
- Coastal winds, waves and currents (multi-sensor approach)
- River discharge in estuaries and deltas from current and future altimetry techniques
- Sediment concentration from ocean color and optical sensors
- Shoreline change monitoring → high-resolution imagery (SAR and optical)
- High-resolution DEM / Bathymetry using lidar, altimetry & other techniques
- Experimental use of GNSS reflectometry for measuring sea level at the coast
- Temperature and salinity measurements over shallow shelves

Recommendations 2.

Modeling needs →

- High-resolution numerical modeling of coastal hydrodynamic processes
- Assimilation of space data (altimetry) into the models

Other IMPORTANT needs →

- Develop coordination and common strategy among existing coastal climate services
- Transform the space data into easily usable Environmental Information
- Develop Capacity Building in some parts of the Atlantic region (e.g., Africa)

Examples of research projects to be implemented

(1) Multi sensor monitoring of hydro-meteo-marine phenomena in River Deltas (e.g., Seine estuary, Arcachon Bay, Mississippi Delta…)

→ synergetic space-based observations of tides, waves, sea level, storm surges, river runoff, shelf temperature and salinity, bathymetry, shoreline position, etc.

→ objective: improved knowledge of coastal flooding processes during storm events and extreme river discharge, and more generaly of coastal hydrodynamic processes

→ Sentinel 1, 2, 3; CryoSat; Retracked LRM altimetry
SWOT; IceSat-2
Tide gauges, pressure gauges
GNSS receivers
Lidar
Autonomous Underwater Vehicles (T&S)
Aerial photography (drones)
……

Examples of research projects to be implemented

(2) Multi-sensor monitoring of coastal sea level rise, river runoff change & shoreline evolution along the coasts of Western Africa

→ synergetic observations of coastal sea level change, coastal currents, storm surges, shelf temperature and salinity, river runoff, sediment supply & transport, topography & bathymetry, shoreline retreat, ground subsidence

→ Sentinel 1, 2, 3; CryoSat
Retracked LRM altimetry missions
IceSat-2
SWOT
Tide gauges
GNSS receivers
Automatic Underwater Vehicles (T &S)
.....


Thanks for your attention