The driving factors of coastal evolution : toward a systemic approach

Manuel Garcin, Gonéri Le Cozannet

COLLÈGE DE FRANCE 1530

The driving factors of coastal evolution

Toward a systemic approach

M. Garcin
With contribution from
G. Le Cozannet

New Caledonia, M.Garcin 2012

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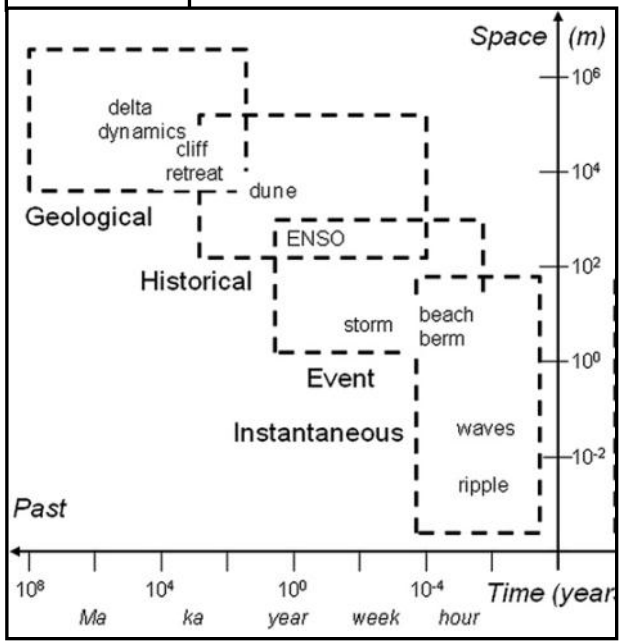
Definitions and context

- The coast is the **interface** between ocean and lands in consequence the coast is under the influences of
  - marine processes
  - continental processes
  - human communities

- The coast evolves at different **nested timescales** : from geological time scale (pluri-millennia), historical time scale (centuries, decadal), event time scale (few hours to few days) to physical process (hours, minutes, seconds…)

Woodroffe 2003

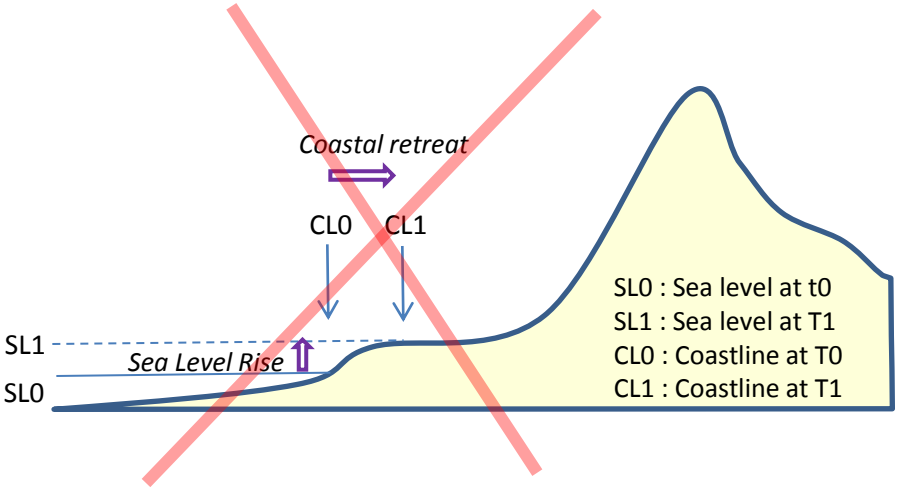


e.g. Woodroffe 2003, Coco & Murray 2007

Coastal mobility
a response to forcing factors

- If, at least a marine or a continental variable evolves, the **coast tempts to adapts to this new condition**
- Characterization of the pluri-decadal coastal mobility is relatively easy, but identifying the cause(s) of this mobility is not trivial
- The present question is: **what is (and will be) the impact of climatic sea level rise on coasts** ?

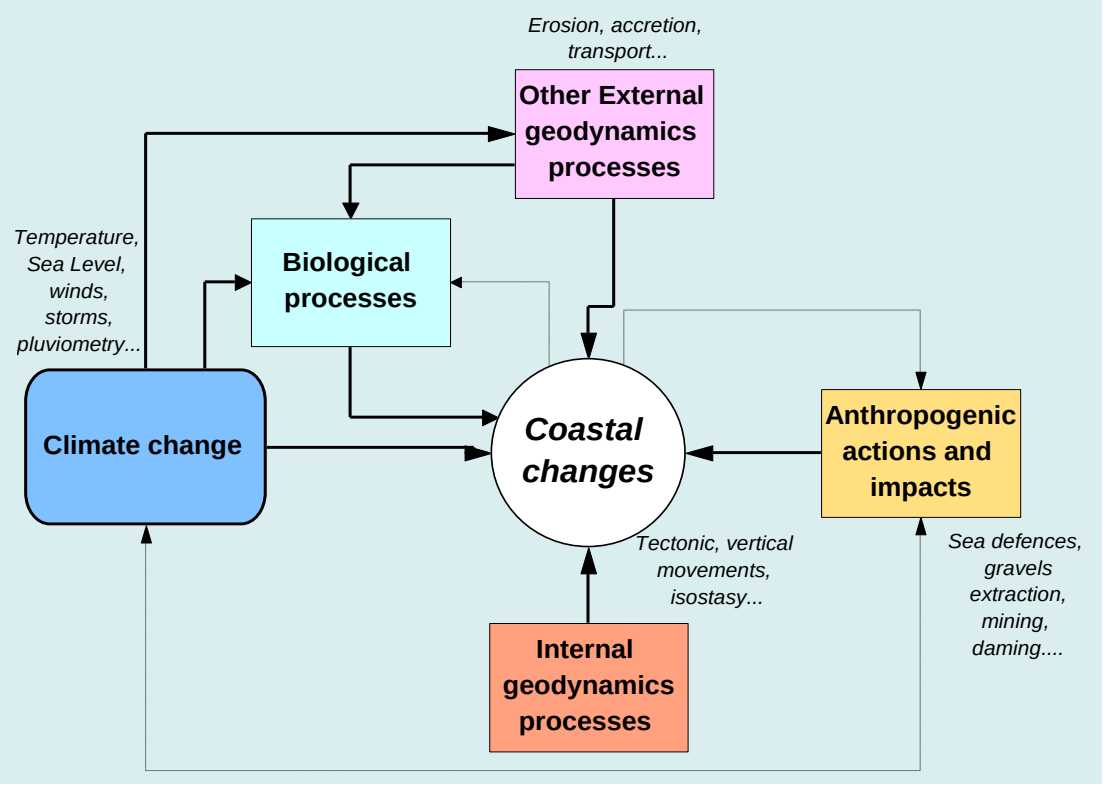
- Climate change does not only affect sea level but others parameters like :
  - air and sea temperatures,
  - atmospheric and oceanic circulations etc.
  - all these parameters affect the ocean, as well as lands and societies…and thus the coasts
- Impact of CC to coastline change can't be reduced to a simple mechanistic projection of sea level landward



The question is: **Why it's impossible to directly assign a new coastline to a given variation of the sea level?**

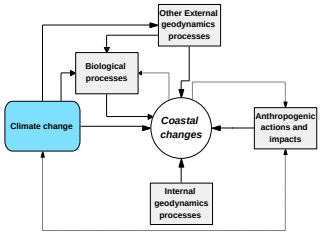
The 5 main families of forcing factors

- Coastal changes is driven by **5 main categories** of factors :
  - Climate
  - Others external geodynamics processes
  - Internal geodynamics processes
  - Biological processes
  - Anthropogenic actions and impacts



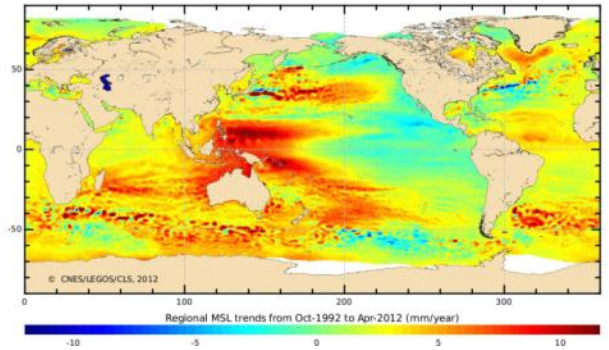
> => the coast, the **forcing factors and related parameters constitute the "Coastal system"**

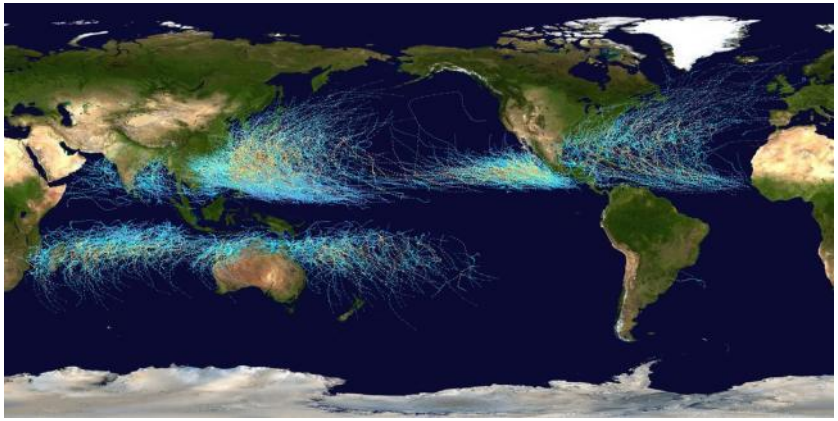
> Numerous interactions and feedbacks are existing between factors & attribution of causes of coastal changes to one or another factor is complex and difficult



Forcing Factor: The Climate

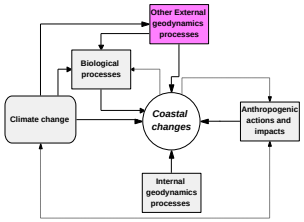
- Evolution of climatic parameters are spatially highly variable
  - Sea level
  - Temperature
  - Salinity and acidity of ocean etc.



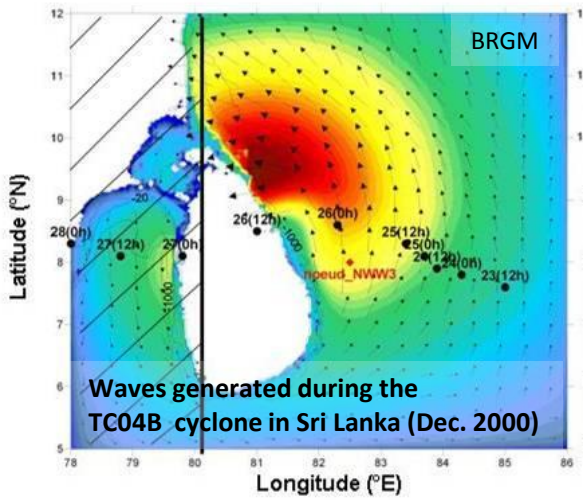


- Others climatic parameters and processes acting on the coastal evolution
  - Dominant winds (trade winds…)
  - Storms and Cyclones Intensity and frequency
    - => even if there remains high uncertainties on the effects of CC on cyclogenesis
  - Atmospheric Pressure

Cazenave and Llovel 2010, Stammer, B.Meyssignac, Becker et al. 2012,



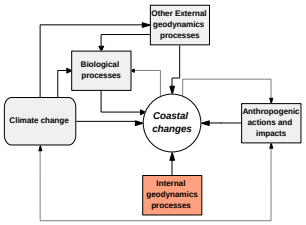
External geodynamics processes



- CC can potentially modify winds climate (trade winds, storms and cyclones) inducing wave climates change (wave height, orientations, frequency…) which modify:
  - the wave energy during “normal” and extremes events at coast
  - The cross-shore currents
  - The long-shore drift currents
  - => can modify the **coastal behaviour** (erosion ⇔ stability ⇔ accretion) and the level of **coastal erosion** and **flooding hazards** at which each coastal segment is exposed
- The wave climate changes have an impact on the **coastline position**

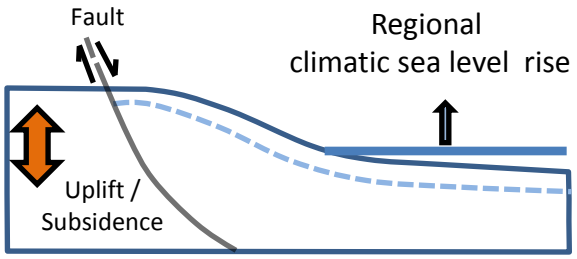
External geodynamics processes

- The CC affects also precipitations (pattern, frequency, intensity) on lands which indirectly modify:
  - At the watersheds scale
    - Runoff and surficial erosion of soils
    - Triggering of landslides (impact on frequency and intensity)
    - => inducing indirectly modification the **supply of sediment to the rivers**
  - Water and sediment discharges of rivers at outlets
    - => modification of the sediment supply at the coast and thus the **coastal sedimentary budget** which can lead to a modification of the coastal behaviour and mobility (accretion⇔stability⇔erosion)
  - likely indirect **incidence** of rainfall changes **on the coastline position**



Internal geodynamics processes

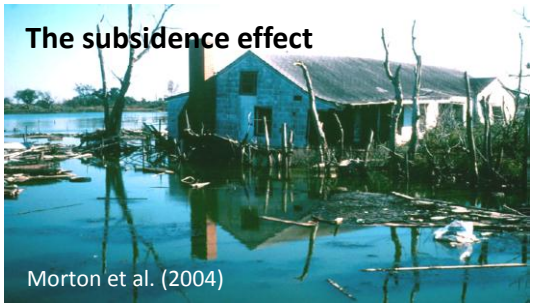
- At coast the relative sea level is composed by:
  - the regional climatic sea level
  - vertical movements of ground



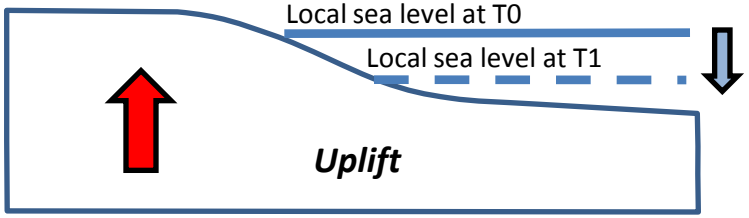
Regional and local ground movements

- The vertical movements can counteract, compensate or amplify the climatic sea level rise giving the local relative sea level
  - Vertical movements can be of different origins :
    - tectonic (Tuvalu, Alexandrie, Loyalty islands …),
    - isostatic (isostatic rebound linked to ice sheets melting : Fennoscandia or Laurentides, hot spot volcanoes…)
    - Thermic and linked to the cooling of volcanoes…

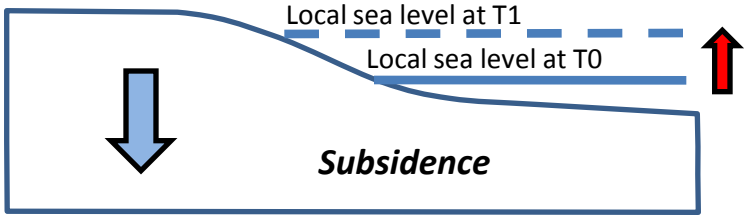
e.g. Mörner 1976, Peltier 2004, Ballu et al. 2011, Wöppelmann et al. 2013



Local sea level regression

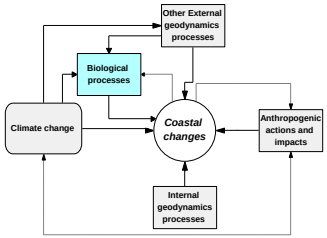


Local sea level transgression



- Vertical movements are not necessarily homogeneous at the regional scale or even at island scales
  - Vertical movements of each site must be characterized
    - Studying the geological and geomorphological context, neotectonic and seismicity
    - Monitoring the ground movements using GPS, InSAR etc..
  - Vertical ground movements have **consequences for the coastline position** and **coastal hazards** (erosion and flooding)

e.g. Wöppelmann et *al*. 2013

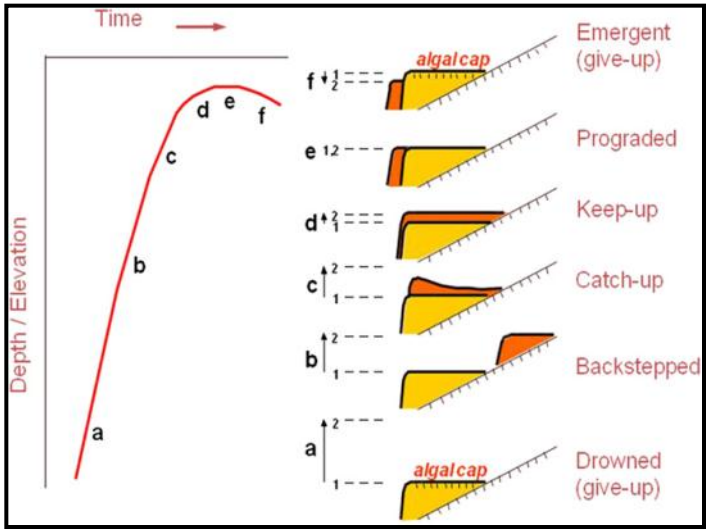


Example of biological factors: the reefs

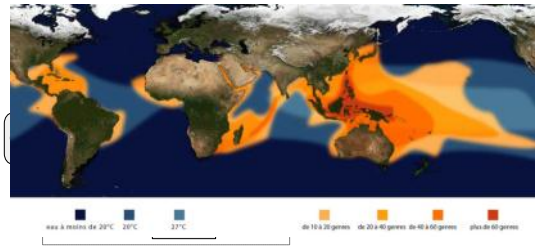
- Reefs play a crucial role in the evolution of tropical islands as a **biological resource**, a **sediment suppliers**, and a **protective barrier** against swells and waves during storms and cyclones

- Climatic parameters like sea level, ocean temperature, salinity and acidity are crucial for coral reef life
  - The reefs have been able to accommodate the sea level changes during the Quaternary as demonstrated by numerous researchers…
  - But the remaining question is: what will be the capacity of coral reefs to accommodate in the context of higher rate of sea level rise as predicted in the future decades ?

illustration of the response of reefs to variations in Holocene sea level (Woodroffe 2003, 2012)

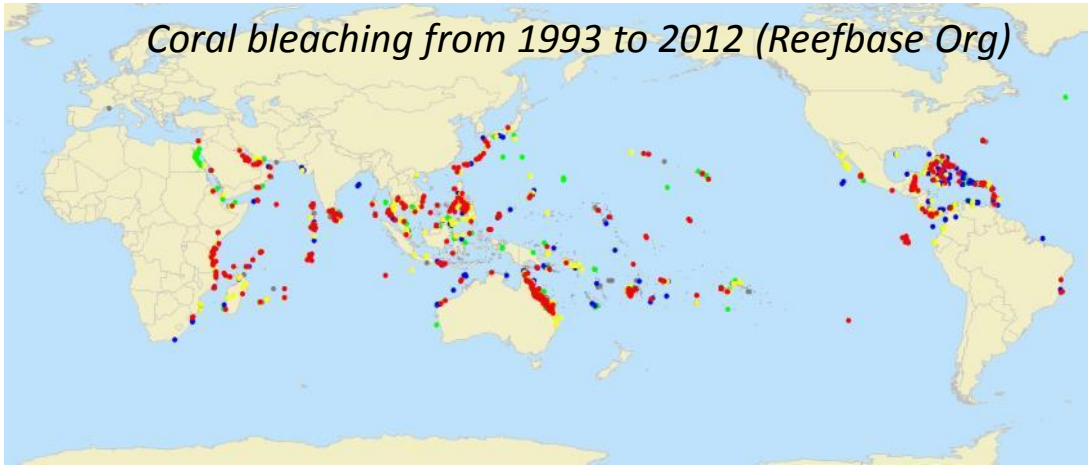


e.g. Pirazolli et al. 1986, 1988; Bard et al.1990, 1996, 210, Woodroffe 2008, Cabioch 2003, Camoin et al. 2013



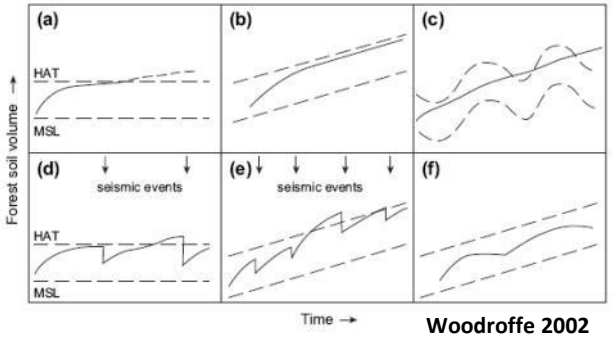
Example of biological factors : the reefs

- CC induced also an increase of SST and of the acidity of ocean
- Reefs are very sensitive to these parameters; exceeding a threshold for one of these parameters leads to a coral bleaching ...and decreases their adaptation capacity to accommodate to the sea level rise.
- => What will be the impact on the reefs (barrier and fringing) of SST, salinity and acidity changes?
- What will be the impact of reefs evolution on the **coastal mobility**, on coastal hazards ?



Example of biological factors : the mangoves

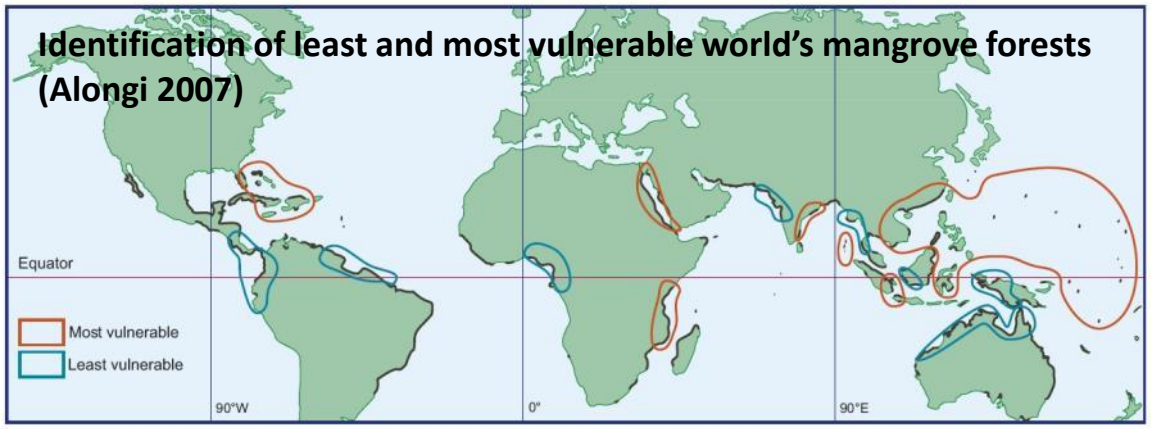
Six patterns of mangrove development in relation to changes in sea-level

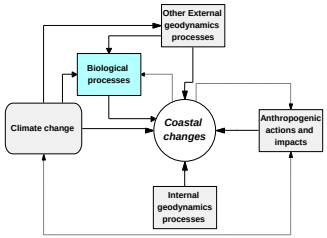


Woodroffe 2002

- Important role of the mangroves in the coastline evolution: role in the sedimentation rates and protection against erosion and waves during extreme events
- Mangroves are influenced by rises of sea level, CO_2, air and water temperatures, precipitation: pattern, frequency and intensity
- All these parameters influence the mangroves evolution, what impact on the **mobility of coastline** ?

e.g. Plaziat 1995, Woodroffe 2002, Gilman et *al.* 2006, Done et al. 2006, Alongi 2007

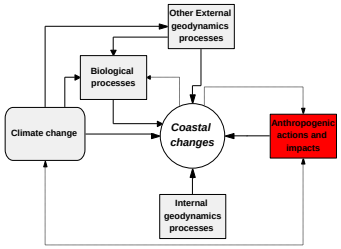




Biological processes

- In more temperate seas, biologic productivity of benthos (bivalves, gastropods…) can be affected by CC with incidences on the production of bioclasts
  - This modification of bioclasts production can modify the sedimentary budget of bioclastic sandy beach and shells ridges
  - Modifications of the beach resilience to erosion and in consequence to **coastline changes**.

e.g. Alongi 2007

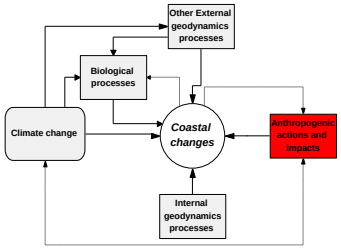


Anthropogenic

- Two different types :
  - **Direct actions** on the coast
  - **Indirect actions** which didn't affect the coastal system but have an impact on it.
- Direct and indirect actions have impacts on the coastal system, wanted or not…sometime at short time and sometimes at longer timescale
  - Direct anthrophogenic actions
    - Coastal defense works (against erosion or submersion)
      - Hard : breakwaters, dykes, groynes, rip rap, levees etc. (strategy "*hold the line*")
      - Soft : revegetation, *ganivelles* etc…
      - Intermediate : beach nourishments (strategy "*advance the line*")

Direct anthropogenic actions

- Coastal facilities
  - Harbours, Wharf,
  - Embankments for roads, railways, airports….
  - Promenades
  - Sea side urban facilities…
- The main objective of direct actions is to “hold the line” =>**direct incidence on the coastal evolution and mobility**



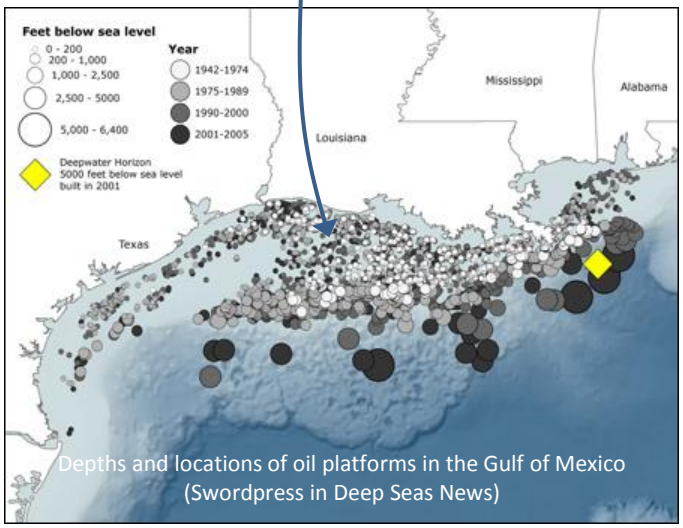
Indirect anthropogenic actions

- The indirect anthropogenic actions are various. The feedback effects on coastal zone were generally not wanted or even imagined
  - At the watersheds scale
    - Hydraulic works within the rivers : ex. Dams trapping sediments
    - Extracting sand and gravels in the rivers
    - Changes in the land use and land cover inducing some modification of erosion processes ex. :
      - » Deforestation, reforestation, crops development, urbanization…
      - » open cast mining etc.
      - » => Modification of the sedimentary fluxes in the rivers outlets modifying the coastal sedimentary budget
  - » modification of coastal sedimentary budget => potential **coastline changes**

e.g. Paskoff & Clus-Auby 2007, Morton et al. 2004, 2007, Garcin et al. 2013

Indirect anthropogenic actions


Devon Energy Corporation, 2006



Depths and locations of oil platforms in the Gulf of Mexico
(Swordpress in Deep Seas News)

- Offshore
  - Dredging of marine sand and gravel decreasing the shoreface sedimentary stock used during the recovery stage of sandy coastline
- Onshore/offshore
  - Pumping water (e.g. Manila…), petrol and gaz induce ground subsidences with impact on the local relative sea level (e.g. Mexico Gulf…)

- The effects of anthropogenic actions can be summarized as follow :
  - Modification of coastal sedimentary dynamics and fluxes
  - Degradation of the functioning of the coastal systems
  - … all these changes lead frequently to :
    - a **loss of coastal resilience** to the extreme events…
    - a **modification of the coastal hazards** …
    - **coastline changes**

Morton et al. 2004, 2007

Concluding remarks on forcing factors

Huahine French Polynesia M.Garcin 2006

- The **number of interacting factors** playing a role on the coastal dynamics and coastline mobility is largely enough to **explain why the coastal change is highly variable**, and why this will remain so...
- Moreover, the forcing factors and parameters act on coasts with **highly variable characteristics**…

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THE COASTAL VARIABILITY

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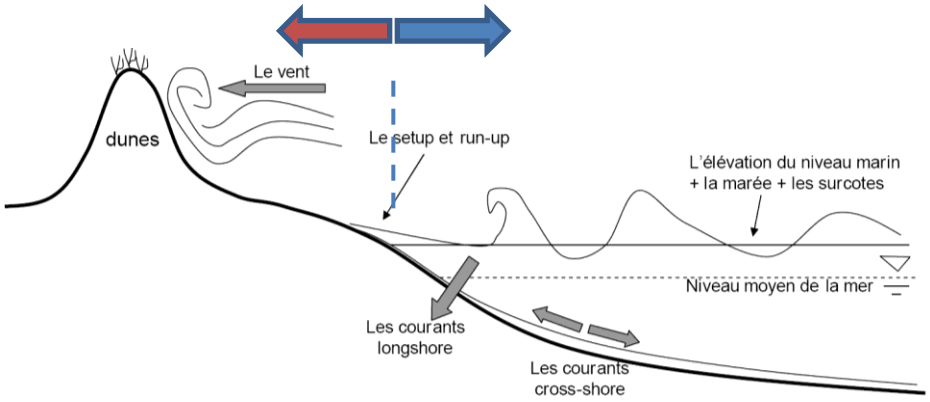
Geomorphological contexts

- 2 main types of coast : **accumulating coasts** or **ablating coasts**
- **Accumulating coasts**
  - Beaches, marshes, estuaries, deltas, reefs…
  - The behavior of a coastal strip can be variable (erosion, stability, accretion) according to season, year or decades
  - Reversibility of coastline behaviour, possibility of a recovery phase after erosional event, resilience
  - Sensitivity to cross shore and drift currents, waves, storm surge and to evolution of the sedimentary budget

Accretion, stability or erosion



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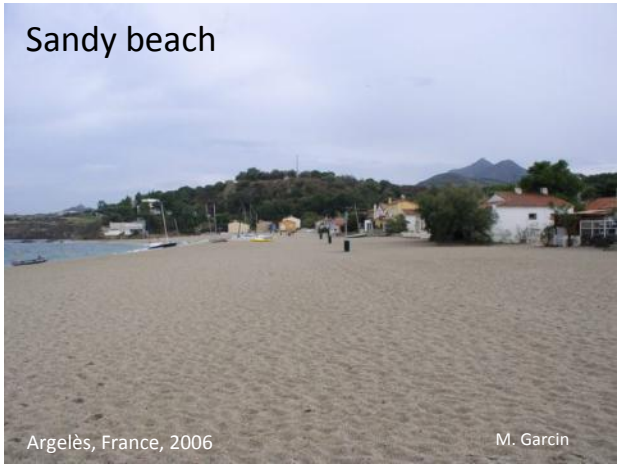
Erosion of dune toe,

Huge sand stock counteracting erosion

Flat Sandy bay & flat hinterland

Sandy beach



Muddy Tidal flat

Urbanized sand spit


Sandy beach, beach rock and coral pinnacles
Hikaduwa, Sri Lanka ,M. Garcin 2007

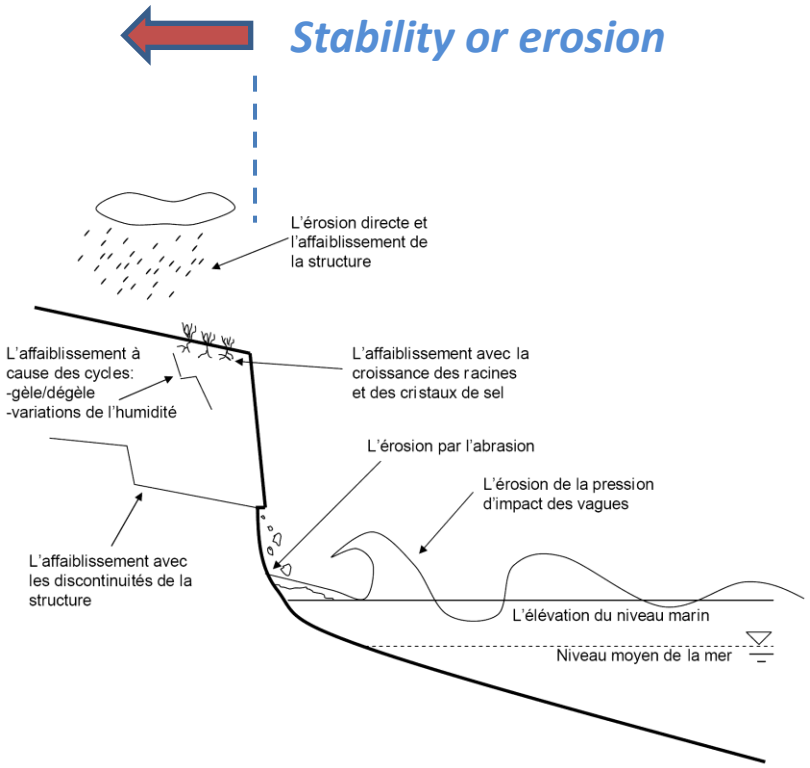

Beaches with montaneous hinterland and estuary
Tautira , French Polynesia M.Garcin 2005


Estuary
Thio, New Caledonia , M.Garcin 2012


Sandy beach and dune erosion
Esposende , Portugal M.Garcin 2010

Geomorphological contexts

- **Ablating coasts : rocky coasts and cliffs**
  - Irreversibility of coastline retreat
  - Importance of the lithology, fracturation, weathering (humidy and frost) in the evolution of rocky coasts
  - Sensibility to wave action and sea level



Rocky coast (fracturation)

Guetary Senix , France, M.Garcin 2006

Cliff (landslide)

Biarritz, France M.Garcin 2006

Chalk Cliff (heterogeneous soft rock, karstic, fracturated)

La Veulette/Mer, France, 2012 G. Le Cozannet

Cliff instabilities and engineering works

Biarritz , France, M.Garcin 2006

M. Garcin 2013

Geology and geomorphology conclusion

- Same forcing factors applied to different geomorphological and geological contexts:
  - Various and different effects
  - Each coastal type have is own resilience and adaptive capacities to evolution of forcing factors like sea level changes
  - For **evaluating the impact of cc** on coasts it is necessary to realize a **typology the coast** taking into account the local **geomorphological** and **geological** context
  - The analysis of **past evolutions** on each type of coast to a **changing sea level** is a key for understanding the future behaviour of the coasts

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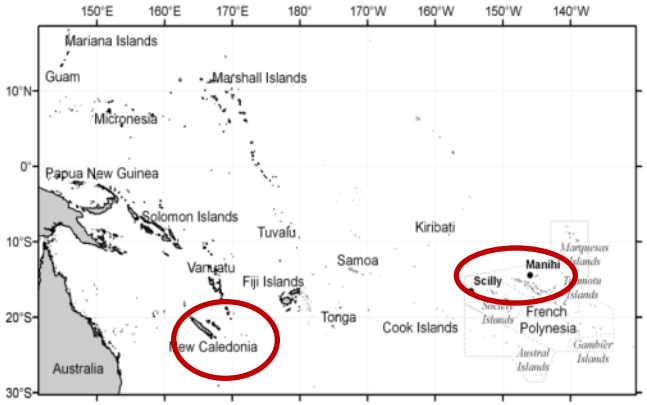
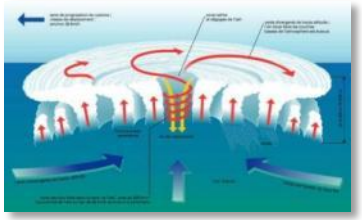
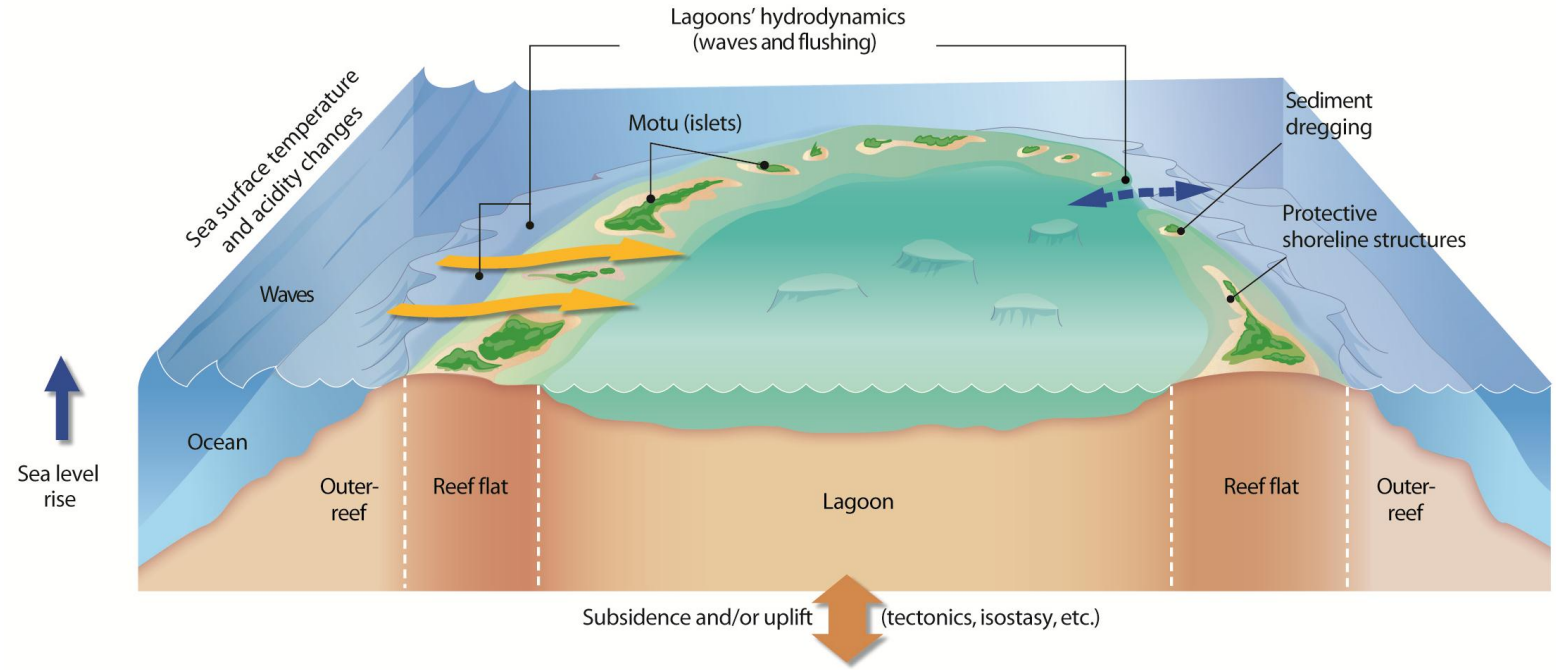


SOME EXAMPLES FROM SOUTH PACIFIC ISLANDS…



Simplified scheme of processes affecting the shoreline in a Polynesian atoll



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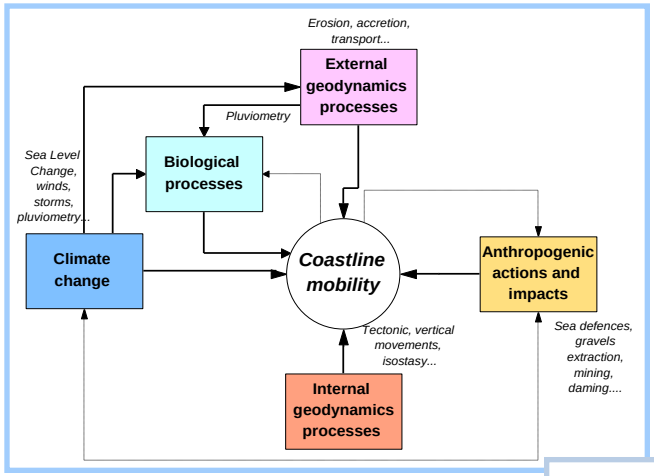
Simplified systemic graph of coastline mobility of an atoll



Climate dependant

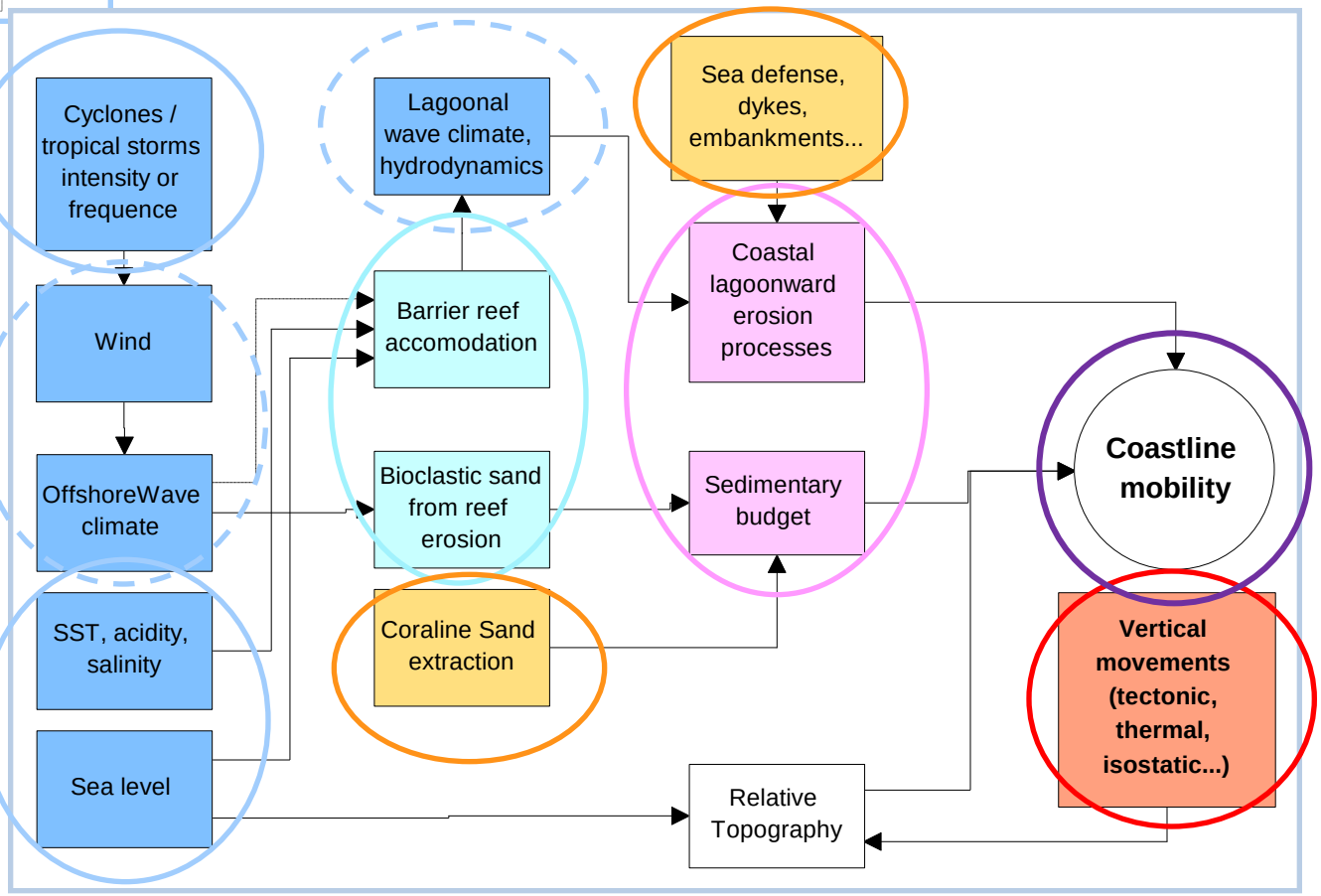
External geodynamics

Biological

Internal geodynamics

Anthropogenic

Coastal Changes



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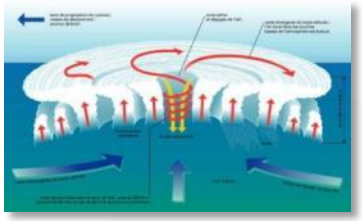
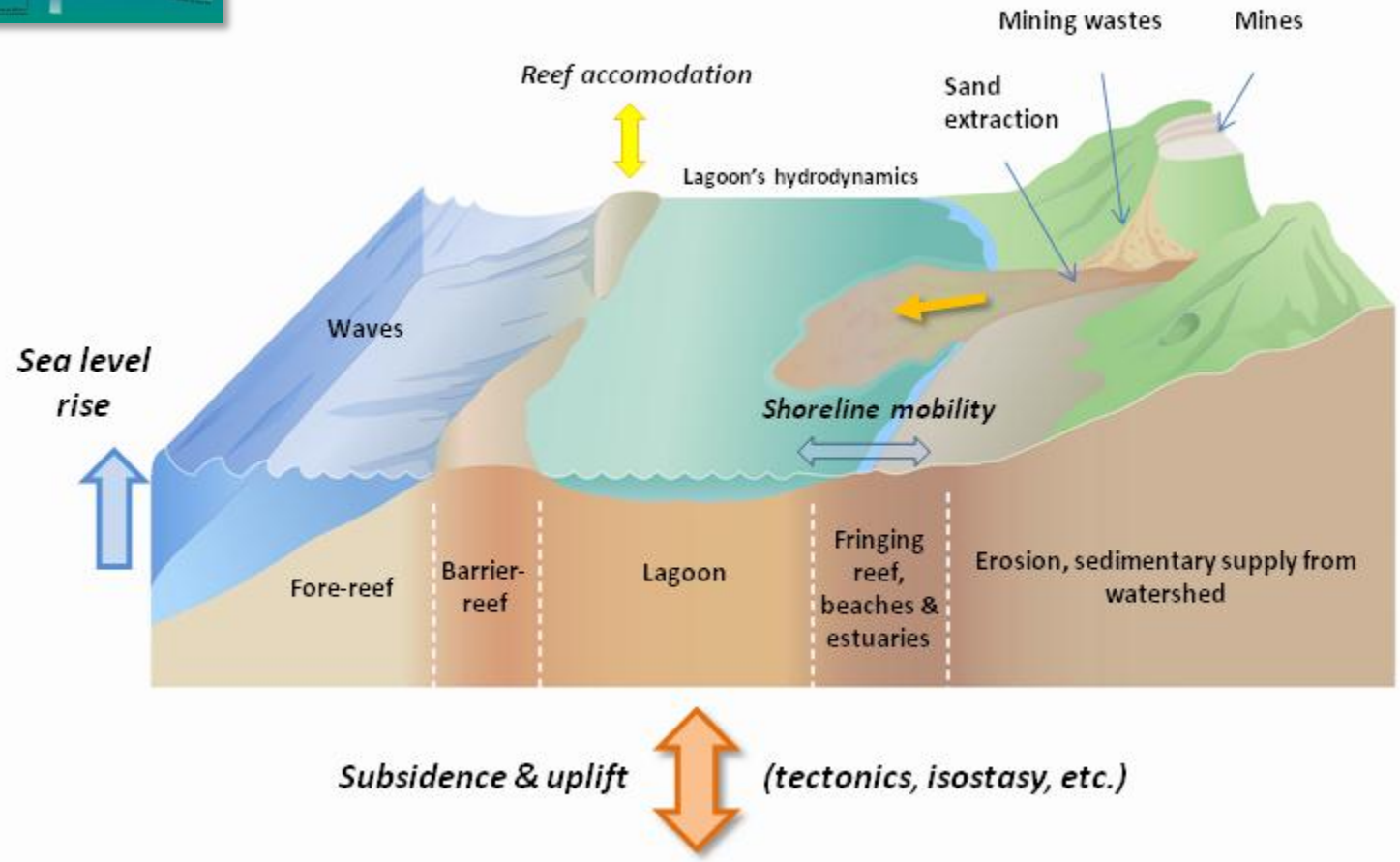
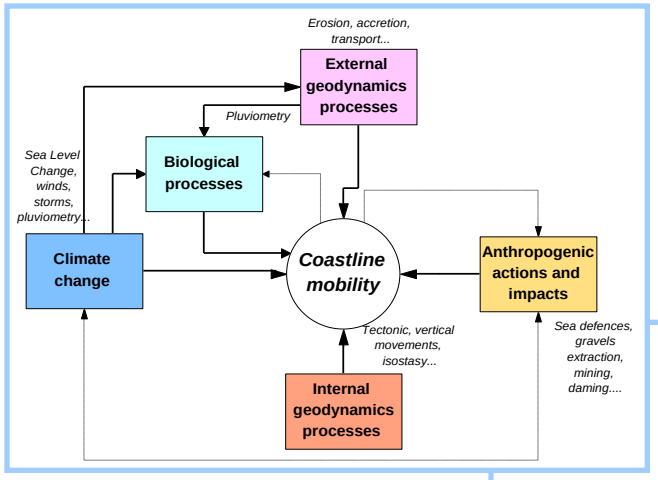
Schematic of a high island

(New Caledonian example)





M. Garcin 2013



Simplified systemic graph of coastline mobility of a high island

Climate dependant

External geodynamics

Biological

Internal geodynamics

Anthropogenic

Coastal Changes

Land use

Mining activities

Sand and gravel extractions

Erosion, landslides

Rivers solid discharge at outlets

Sedimentary budget at the coast

Cyclones / tropical storms intensity or frequence

Rainfall

Rivers discharge

Wind

Sea defense, dykes...

Coastline mobility

OffshoreWave climate

Lagoonal wave climate

Coastal erosion processes

SST, salinity, acidity

Barrier and fringing reefs adaptation

Vertical movements (tectonic, thermal, isostatic...)

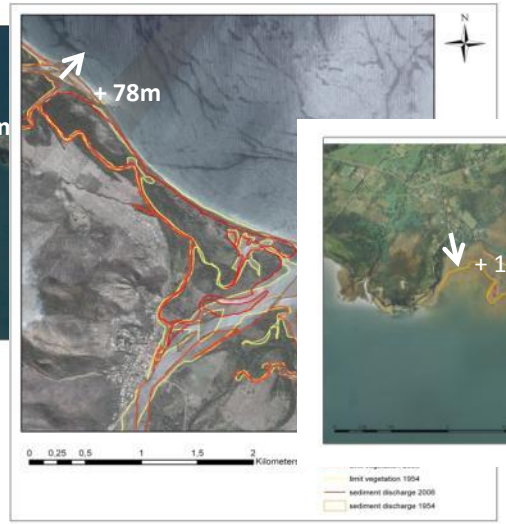
Sea level

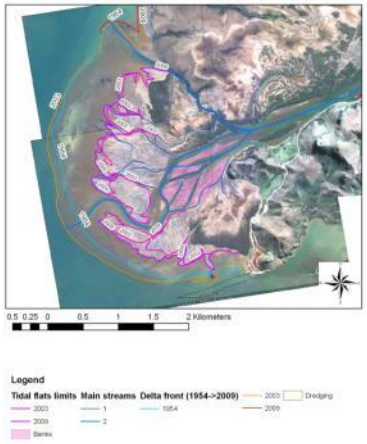
Relative Topography

Mangroves adaptation

COLLÈGE DE FRANCE 1530

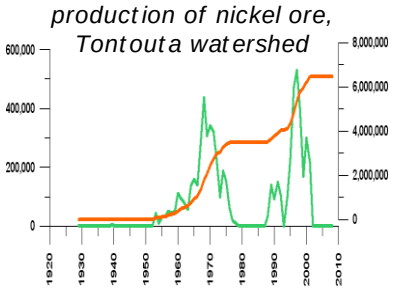
The caledonian estuaries example





- In New Caledonia, analysis of 12 peri-estuarine coastal sites were done
- Analysis of the coastline evolution during the 50 years have been realized
- The **evolutions of coastline are highly variable** from high rate of erosion to high rate of accretion
- Analysis of forcing factors and parameters (marine, continental and human) were done

CeCile



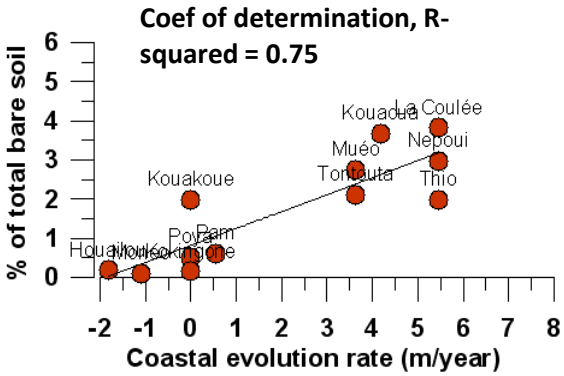
- Results show that the coastal evolution the last 5 decades is highly related to the % of bare soils generated by open cast Ni mining on the watershed (Garcin et al. 2013)
- **An indirect anthropogenic action is the main contributing factor of coastline mobility**, during the last 5 decades, **while the sea level rise** and others parameters **seem to be of a secondary importance**

Erosion of Bare soils and mining Trashs in the watersheds

Transport of thin lateritic Sediment by rivers

Modification of Coastal Sediment budget

Others factors



Conclusion

- **Sea level is « only » one of the forcing factors** of coastal evolution
- **Interactions** (and feedbacks) **between processes are numerous**
- Studies about impact of CC on coastal areas must take into account:
  - global, regional and local parameters, each one influencing the coastal behaviour => **a multi-scale approach** is a necessity
  - **Multi temporal approach** : the present and future evolution is linked to the past history and the evolution trend (residual effect of some changes in the parameters and processes affecting the coast)
  - **Multi disciplinary** works are necessary in order to take into account the complexity of determining the impact of the CC on coastal systems

- Understanding what could be the future of the coasts in a changing climate imply to take into account all processes acting on their evolutions, **a systemic analysis** of the problem seems to be a possible approach.


Thanks