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The driving factors of coastal evolution: toward a systemic approach

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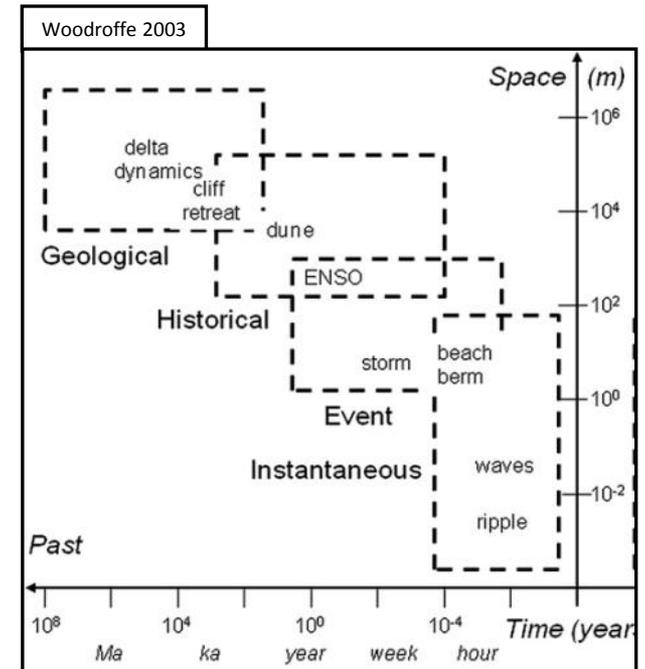


Definitions and context

Bourail, New Caledonia, M.Garcin 2012

- 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...)





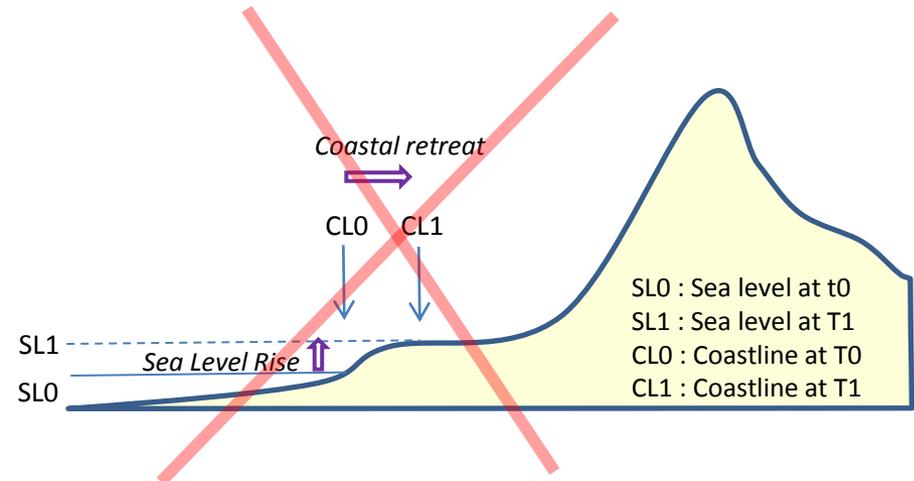
Raiatéa, French Polynesia, M.garcin 2006

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 ?**

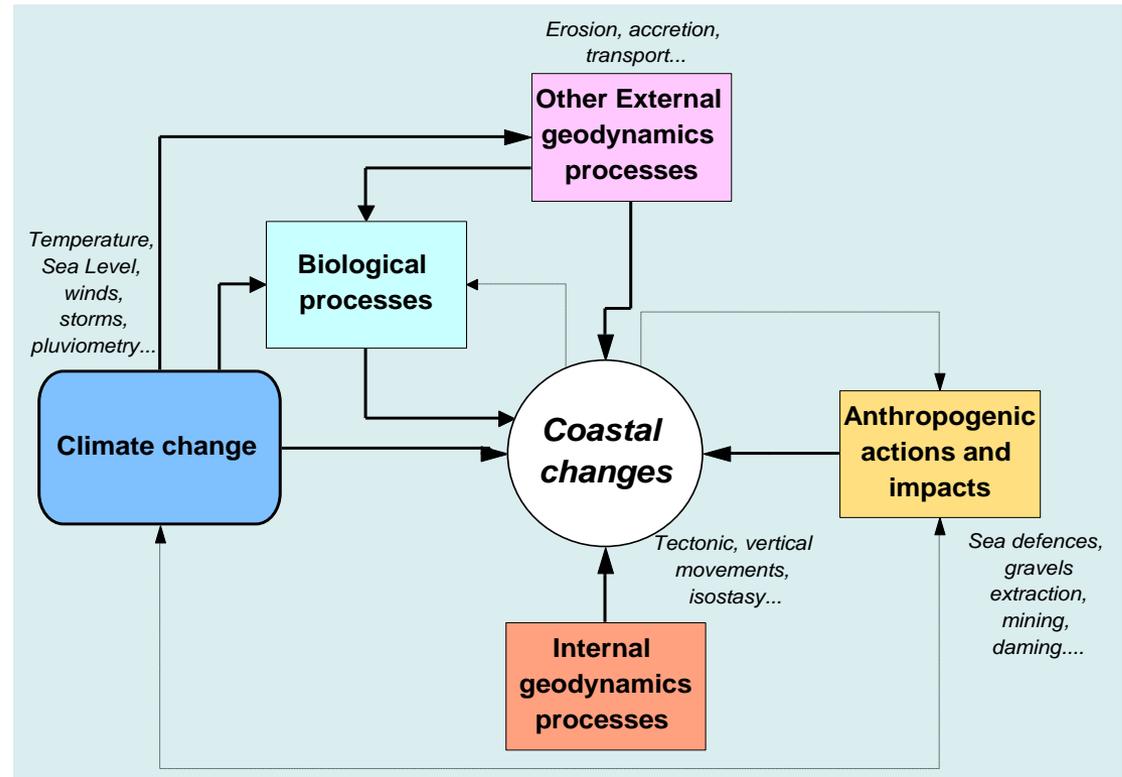
- Climate change does not only affect sea level but others parameters like :
 - air and sea temperatures,
 - atmospheric and oceanic circulations etc.
 - all these parameters affect the ocean, as well as lands and societies...and thus the coasts
- Impact of CC to coastline change can't be reduced to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



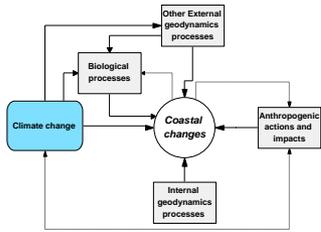
The question is: **Why it's impossible to directly assign a new coastline to a given variation of the sea level?**

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

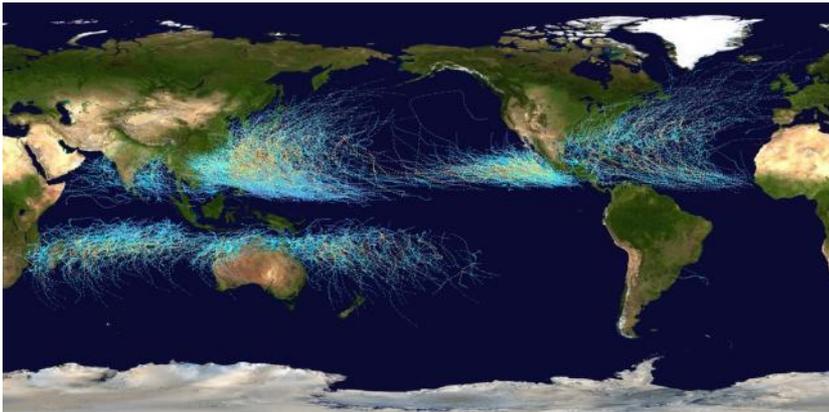
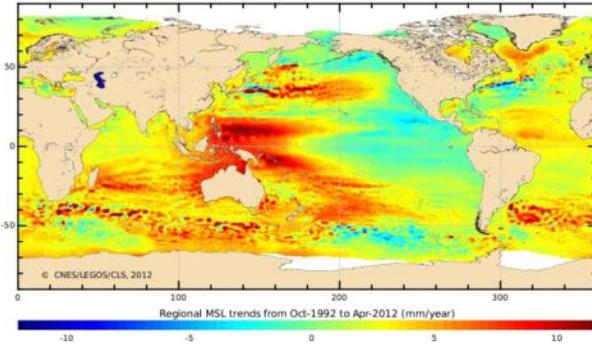


- > => the coast, the **forcing factors and related parameters constitute the “Coastal system”**
- > Numerous interactions and feedbacks are existing between factors & attribution of causes of coastal changes to one or another factor is complex and difficult



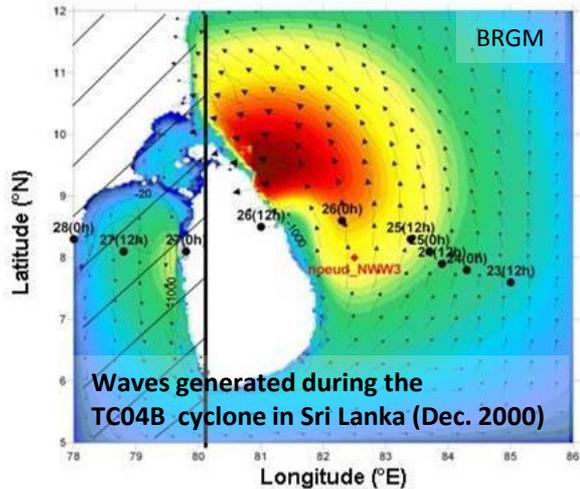
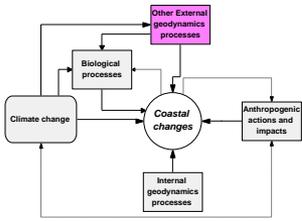
Forcing Factor: The Climate

- 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

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**

High coastal erosion during the Xynthia storm



La Tranche/Mer, France, M.Garcin 2010

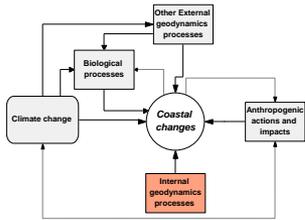
Erosion of lateritic soils



New Caledonia, M. Garcin 2012

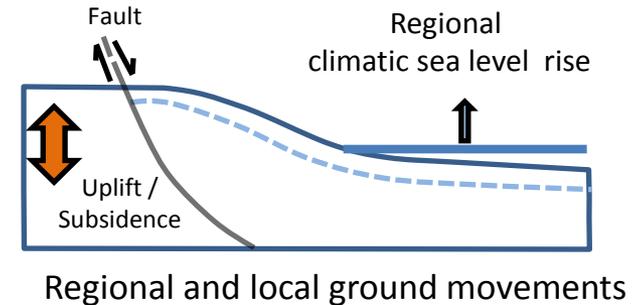
External geodynamics processes

- 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**



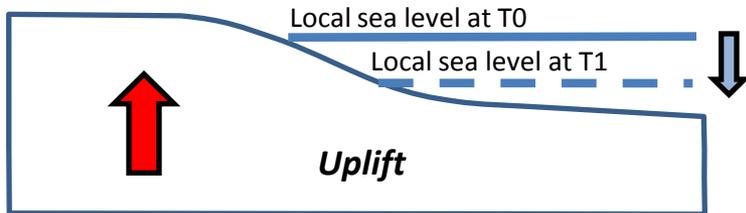
Internal geodynamics processes

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

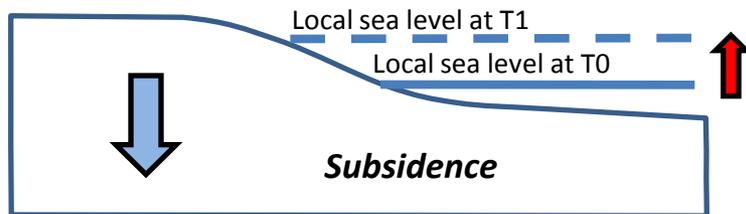




Local sea level regression



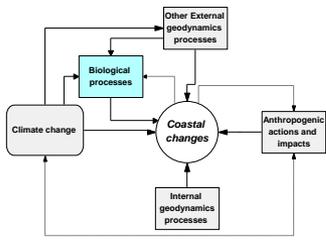
Local sea level transgression



- 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..

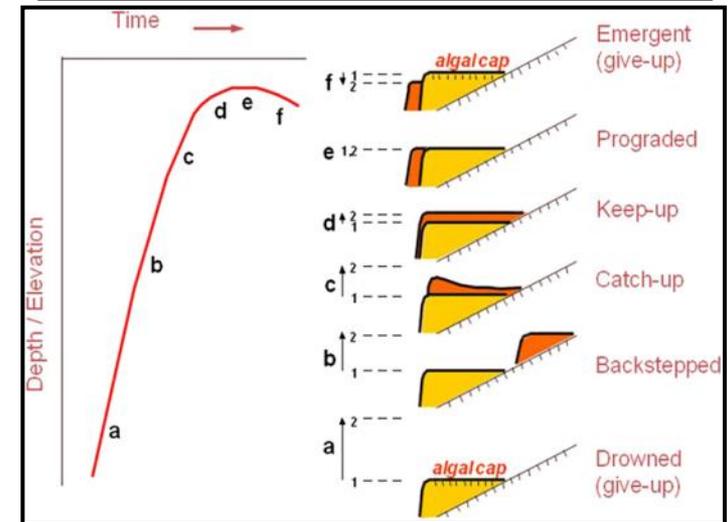
- Vertical ground movements have **consequences for the coastline position** and **coastal hazards** (erosion and flooding)

Example of biological factors: the reefs

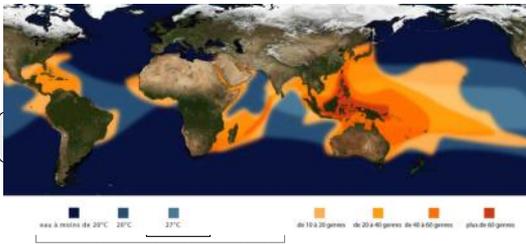


- Reefs play a crucial role in the evolution of tropical islands as a **biological resource**, a **sediment suppliers**, and a **protective barrier** against swells and waves during storms and cyclones
- Climatic parameters like sea level, ocean temperature, salinity and acidity are crucial for coral 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)



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 ?

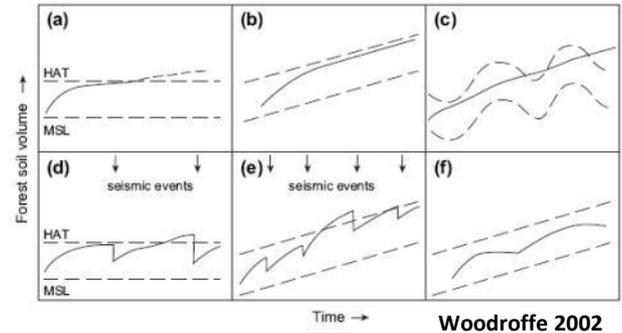


Example of biological factors : the mangroves



mangroves

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

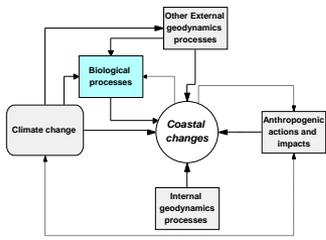


- Important role of the mangroves in the coastline evolution: role in the sedimentation rates and protection against erosion and waves during extreme events
- Mangroves are influenced by rises of sea level, CO₂, air and water temperatures, precipitation: pattern, frequency and intensity
- All these parameters 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**.

Shells ridge (Mt St Michel France)

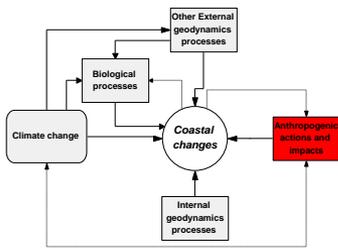


Société Géologique et Minéralogique de Bretagne

Shells ridge detail (Mt St Michel France)



Société Géologique et Minéralogique de Bretagne



Anthropogenic

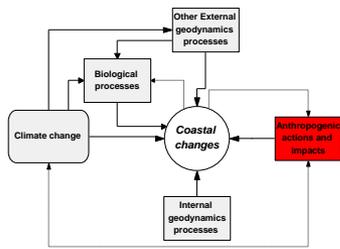
- Two different types :
 - **Direct actions** on the coast
 - **Indirect actions** which didn't affect the coastal system but have an impact on it.
- Direct and indirect actions have impacts on the coastal system, wanted or not...sometime at short time and sometimes at longer timescale
 - Direct anthropogenic 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

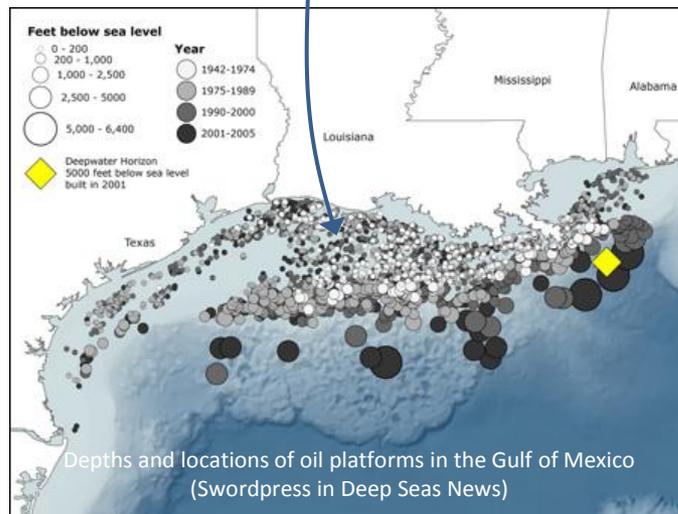
- The indirect anthropogenic actions are various. The feedback effects on coastal zone were generally not wanted or even imagined
 - At the watersheds scale
 - Hydraulic works within the rivers : ex. Dams trapping sediments
 - Extracting sand and gravels in the rivers
 - Changes in the land use and land 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**



Indirect anthropogenic actions



- 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**



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**...

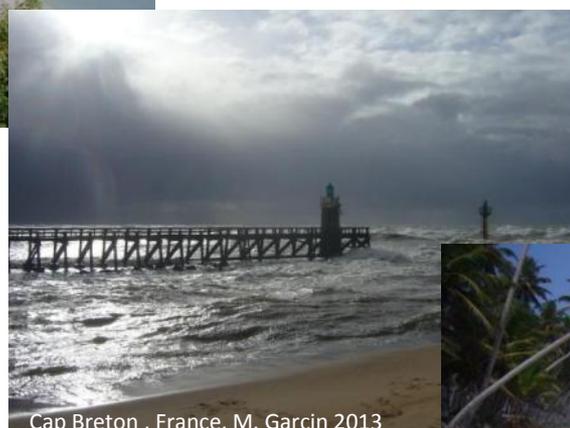


Pte du Roselier M. Garcin 2012



Teignmouth UK M.Garcin 2013

M.



Cap Breton , France, M. Garcin 2013

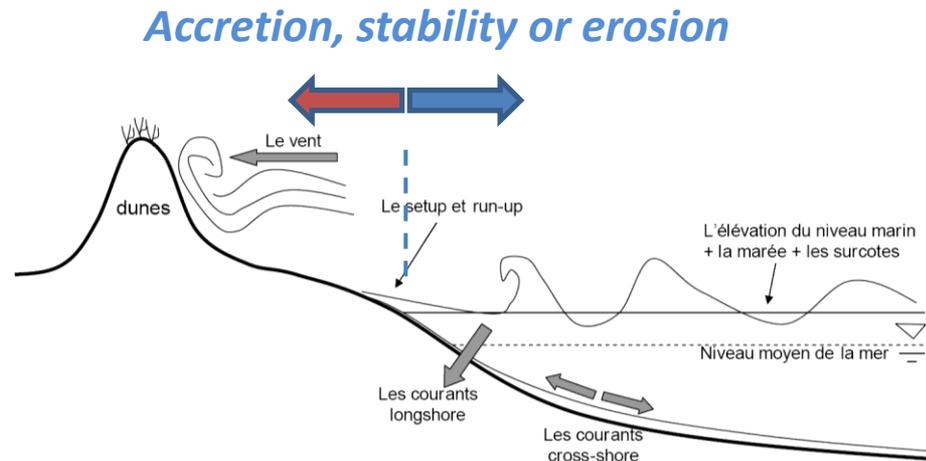


Kogalla beach, Sri Lanka M.Garcin 2009

THE COASTAL VARIABILITY

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



Erosion of dune toe,
Huge sand stock counteracting
erosion



Flat Sandy bay & flat hinterland



Sandy beach

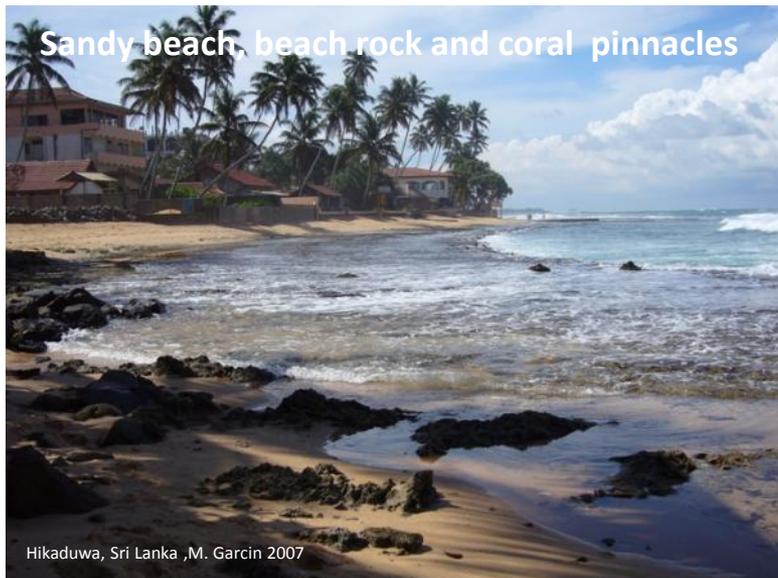


Muddy Tidal flat



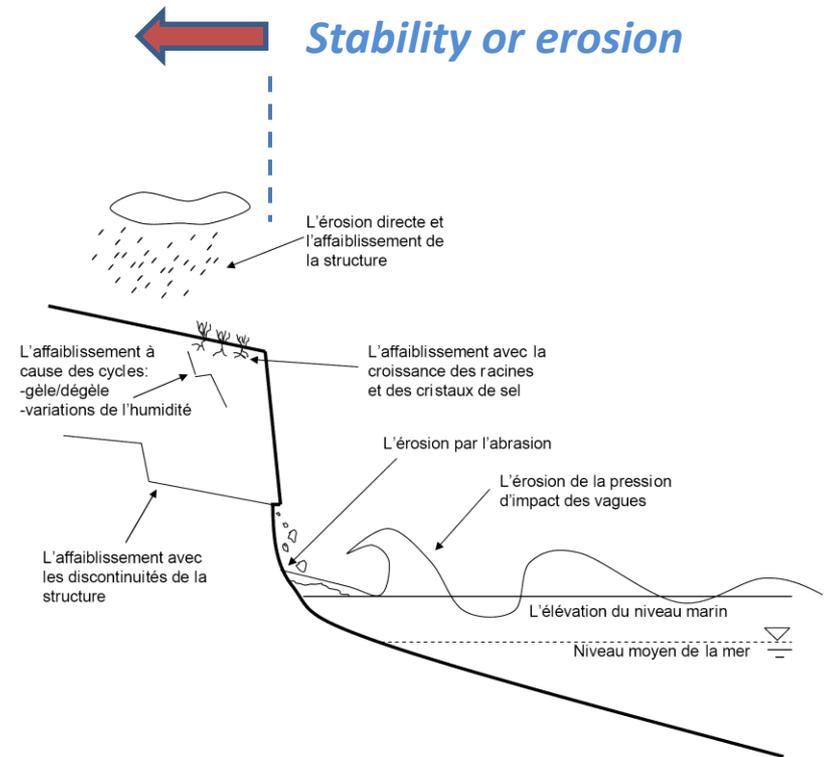
Urbanized sand spit





Geomorphological contexts

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



Rocky coast (fracturation)



Cliff (landslide)



Chalk Cliff (heterogeneous soft rock, karstic, fractured)



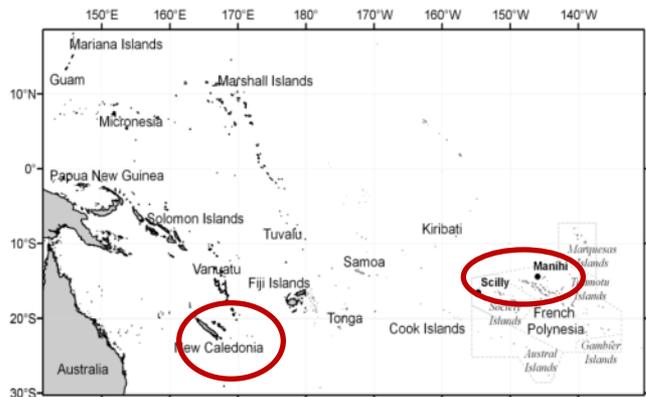
Cliff instabilities and engineering works



Geology and geomorphology conclusion

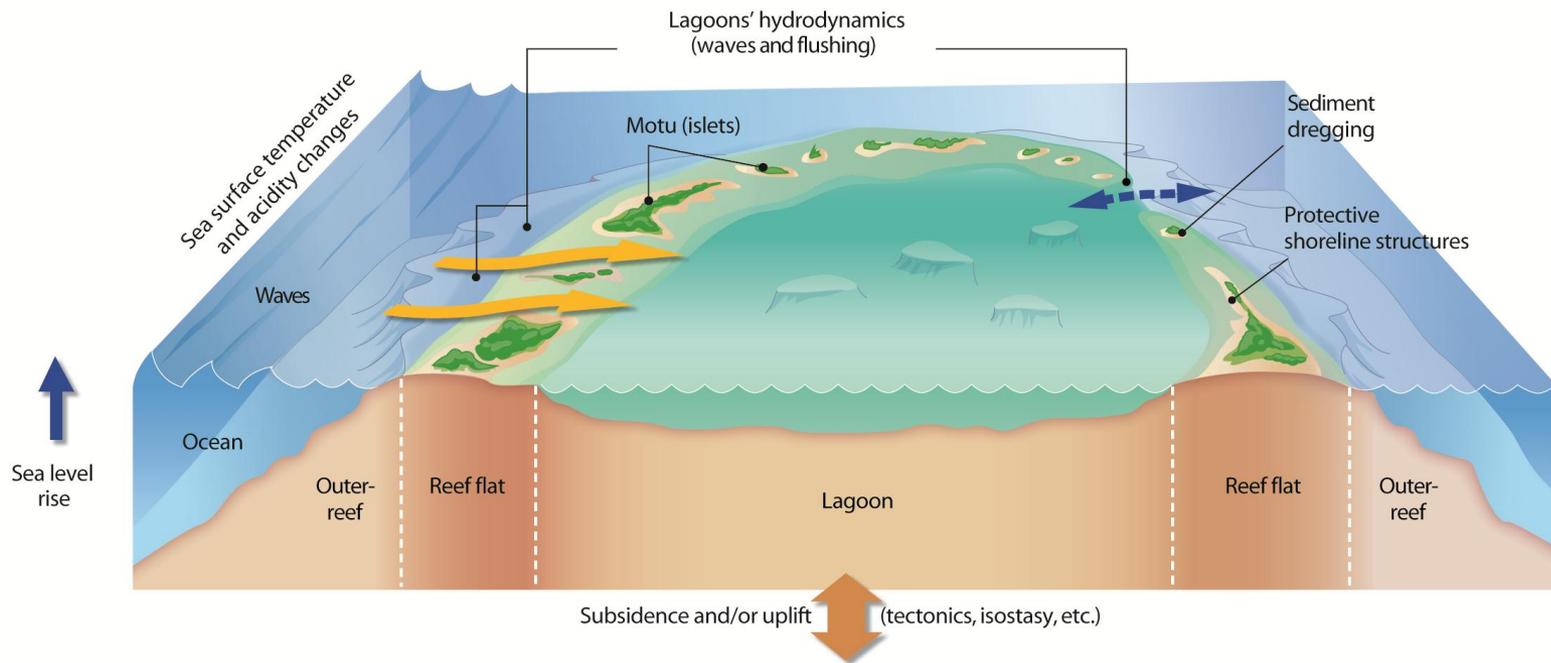
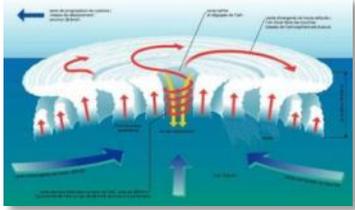


- Same forcing factors applied to different geomorphological and geological contexts:
 - Various and different effects
 - Each coastal type have is own resilience and adaptive capacities to evolution of forcing factors like sea level changes
 - For **evaluating the impact of cc** on coasts it is necessary 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

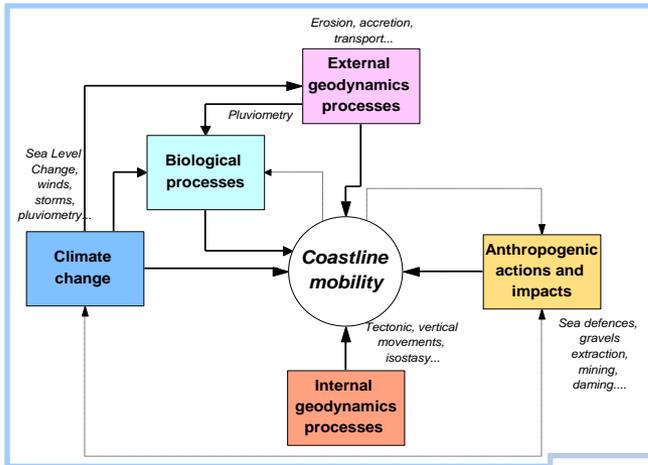


SOME EXAMPLES FROM SOUTH PACIFIC ISLANDS...

Simplified scheme of processes affecting the shoreline in a Polynesian atoll



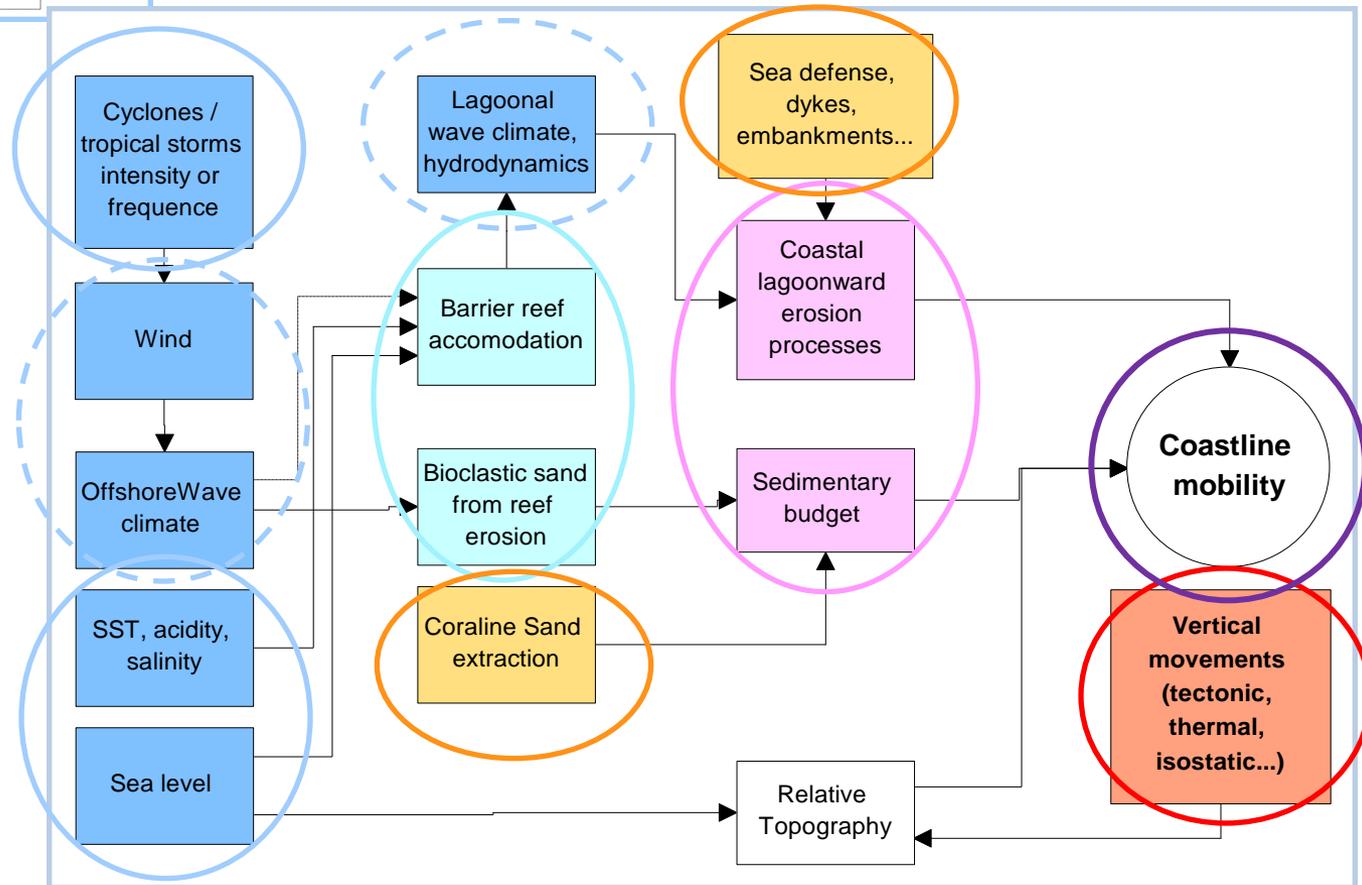
Simplified systemic graph of coastline mobility of an atoll



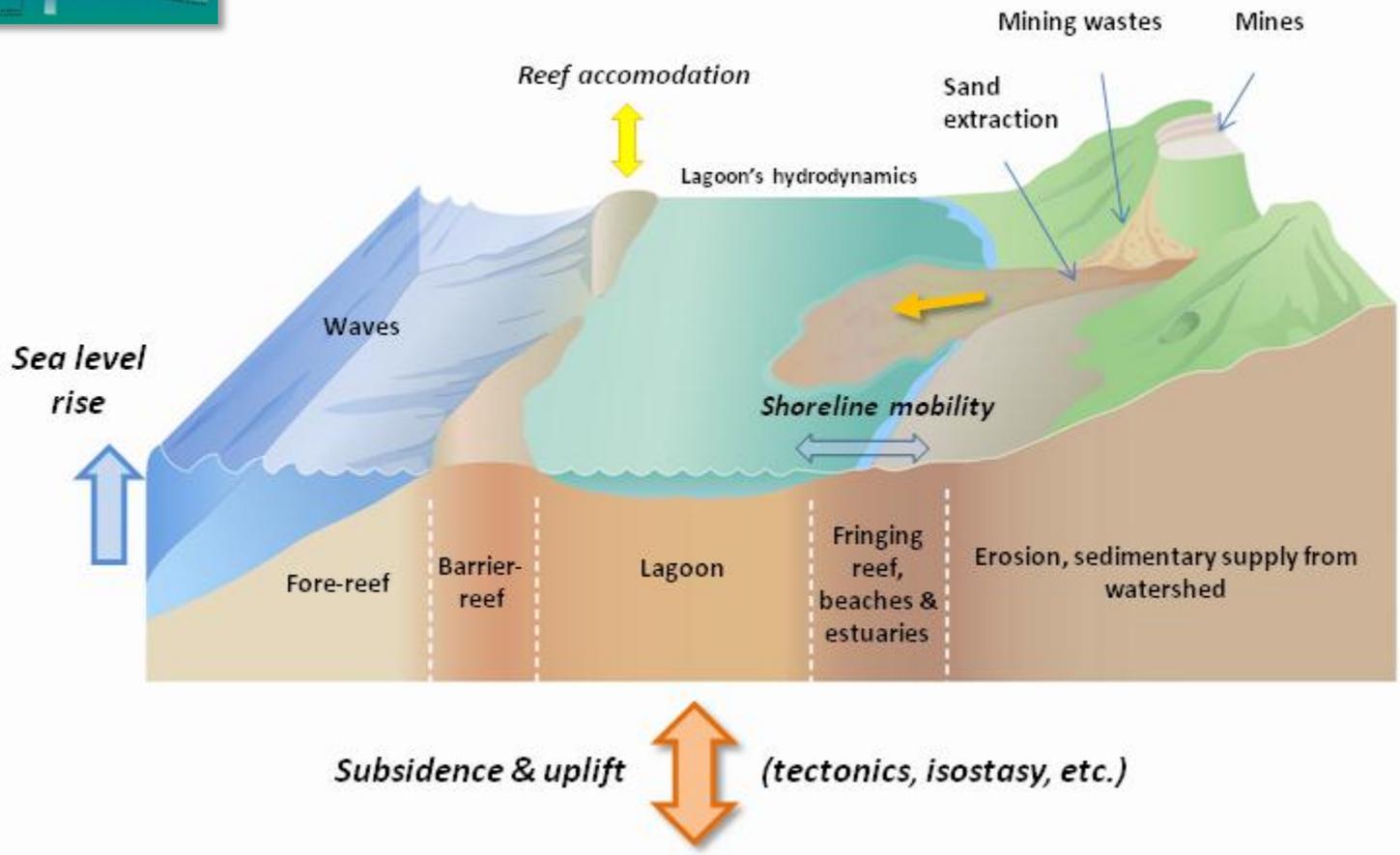
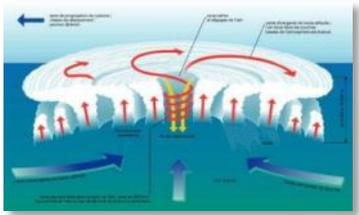
Climate dependant
 External geodynamics
 Biological
 Internal geodynamics
 Anthropogenic

↓

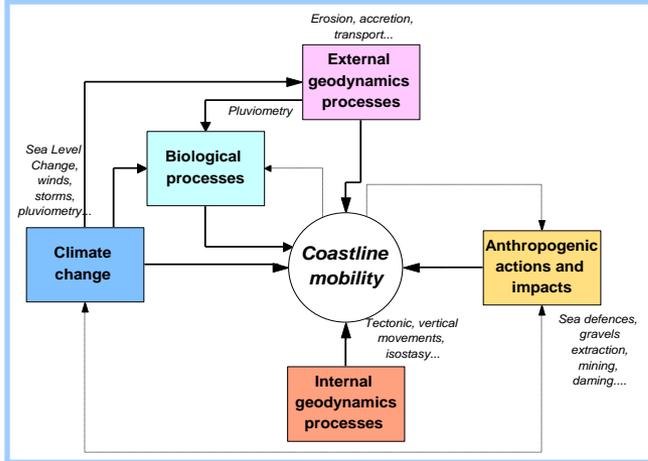
Coastal Changes



Schematic of a high island (New Caledonian example)



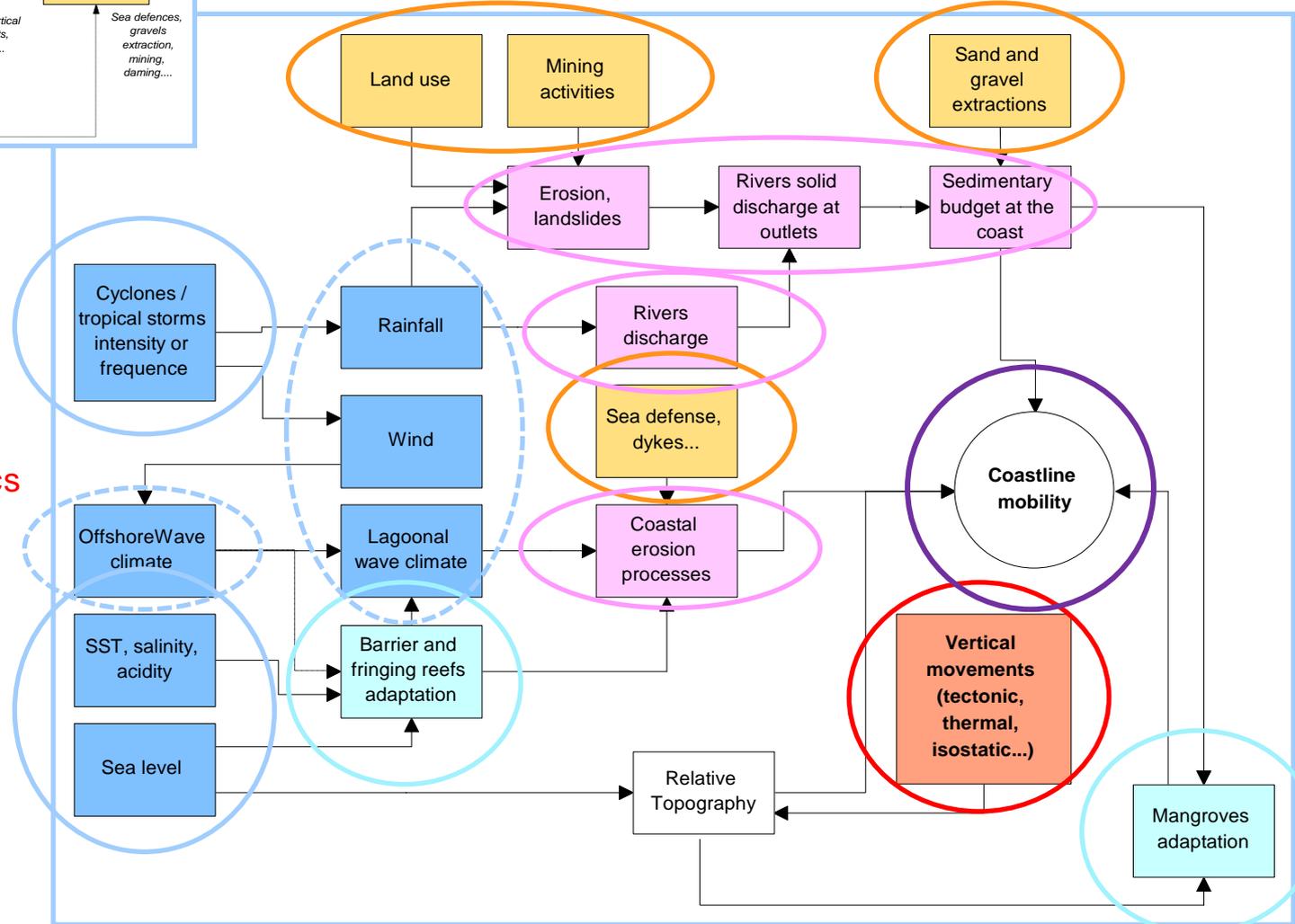
Simplified systemic graph of coastline mobility of a high island



Climate dependant
 External geodynamics
 Biological
 Internal geodynamics
 Anthropogenic

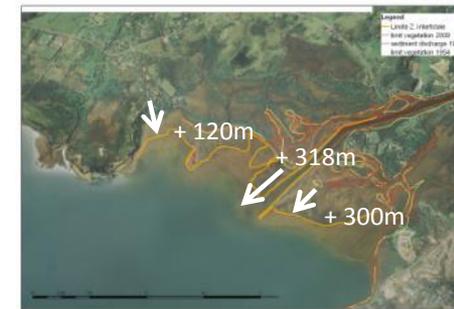
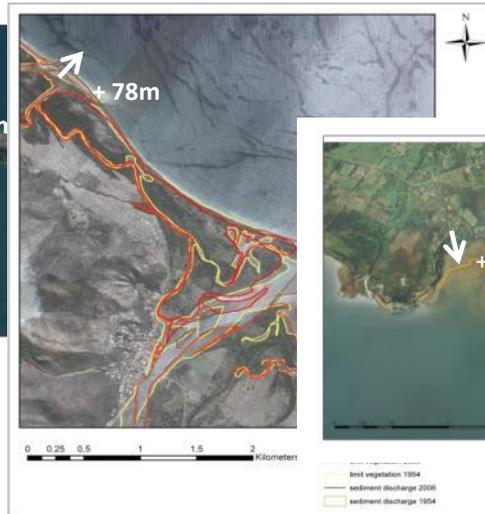
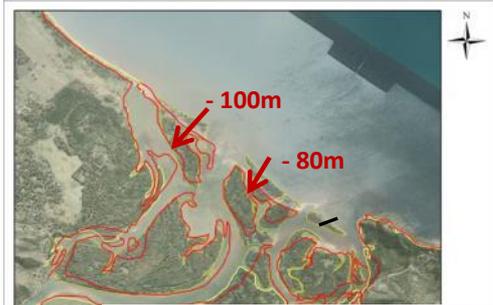
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Coastal Changes



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



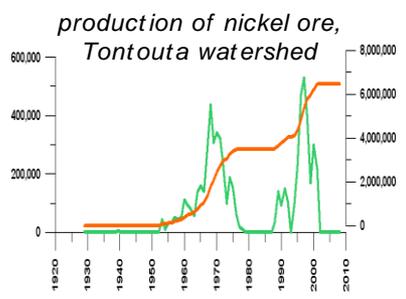
Legend

Tidal flats limits: 2002, 2009, 2000

Main streams: 1, 2, 1954, 2009

Delta front (1954-2009): 2009

Banks: 2009



Erosion of Bare soils and mining Trashes in the watersheds

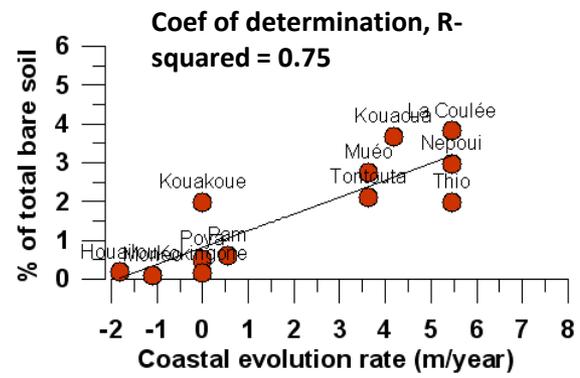


Transport of thin lateritic Sediment by rivers



Modification of Coastal Sediment budget

- 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**



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.

