Sea level rise and coastal morphological changes on tropical islands

*New Caledonia and French Polynesia (South Pacific)*
The Project

- Work completed within the CECILE project (Coastal Environmental Changes: Impact of sea LEvel rise) => See Poster Le Cozannet et al. same session
- Project objectives: to contribute to assessing the physical impact of sea level rise on shorelines during the recent past (last 50 years) and near future (next 100 years).
- Focus on tropical islands: New Caledonia, French Polynesia, La Réunion (Indian Ocean), French Caribbean
- What is the importance of recent sea level rise with respect to other causes of change?
- What will be the consequences of sea level rise for coastal change in the future?
Generic driving factors influencing coastline mobility, dynamics and morphology

- 5 families of driving factors affecting coastline mobility
  - Climate change
  - External geodynamic processes linked to climate change
  - Internal geodynamic processes
  - Biological processes
  - Anthropogenic actions and impacts

- To note: interactions & retroactions

Coastline mobility is an indicator integrating numerous parameters

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Driving factors

Or The data problem
• Spatial variability of sea level rise
  – heterogeneous at the global scale but also at the scale of each ocean basin
• Spatial variability of CC impacts on:
  – winds,
  – storms and cyclones (frequency, intensity, trajectories), high level of uncertainty for future evolution
• Sea surface temperature (SST), salinity and acidity (pH)
  – effects on ecosystems and more particularly on coral reef systems
Surficial geodynamical processes

- Coastal geodynamical processes
  - variability of the impact of CC on wave climates
  - in consequence, variability of the littoral drift, the coastal behavior at a specific shoreline can be modified

- Surficial geodynamical processes on land that can be modified by Climate Change
  - The surficial erosion in the watersheds, the triggering of the landslides, the sedimentary transport in the rivers ...
  - The modifications of processes on land can influence the sedimentary supply at the coast (sedimentary budget at coast), the ongoing processes can change the mobility of the coastline
  - But uncertainties in the evolution of rainfall in the CC context

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The internal geodynamical processes

- The internal geodynamics can be of primary importance for coastline mobility.
  - Vertical movements generated by both tectonics or isostasy or cooling of volcanoes can counteract, compensate or amplify the local sea level change.
- Vertical movements are not necessarily homogeneous for large territories => site dependent

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Anthropogenic actions with direct and indirect impacts on the shoreline mobility

• Actions with direct impacts
  – Sea defense works including (groynes, sea walls, rip rap ...beach nourishments, embankments etc.)

• Actions with indirect impacts
  – Gravel and sand extraction (from the sea floor, from rivers)
  – River hydraulic works like damming (sediment trapping, lack of sediment supply to the coast by rivers)
  – Mining activities in the watersheds (supplementary sediment supply)
  – Modification of the land use (erosion processes)
  – Ground subsidence (exploitation of petroleum or water)
  – Urbanization and pollution

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Remarks about driving factors & coastal geomorphology

• The **variability of the forcing factors** in itself can explain why the coastline mobility is not homogeneous everywhere and why it will not be homogeneous in the next 100 years.

• The same forcing factors applied in various geological & geomorphological contexts:
  – different effects
  – each type of coastal geomorphology has a different **resilience** and **coping capacity**

• Analysis of the **past evolution** of each **type of coast** to **climate changes** can give some keys to understanding the future.

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• The question is what is the Sensitivity of coastlines to SLR?

  – Method
  
  • systemic analysis => identification of active forcing factors for each site
  • Reconstruction of past evolution of the forcing factors
    – sea level rise, vertical movements, anthropogenic actions etc.
  • Classical analysis of coastline evolution
    (Comparison between aerial photos (from the 50’s) with recent HiRes satellite images => evolution of coastline
  • Analysis of the causal effects for the system
  • Numerous Uncertainties => SLR, quantifications of others forcing factors, complex system

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Preliminary results on 2 test sites in South Pacific

- **New Caledonia**
  - (several test sites)
  - Data from SHOM, DITTT, DIMENC and the government of New Caledonia

- **2 atolls in French Polynesia**
  - (Scilly et Manihi)
  - Data from SAU, part of the government of French Polynesia
Recent SLR at the scale of the South Pacific

- Global sea level is rising but shows regional variability (e.g. Lombard et al. 2005)
  => need to perform a regional reanalysis in order to assess the recent trends in the areas of interest
- The climate component of sea level rise can be reconstructed using global ocean modeling and tide gauge records (Becker et al., submitted) over the past 50 years

  - Results obtained show that:
    - French Polynesia is affected by about 2mm/yr of sea level rise for the 52-year period from 1950 to 2002
    - New Caledonia is affected by about 1.3mm/yr sea level rise for the 52-year period from 1950 to 2002
French Polynesia examples

• Work in progress on 2 atolls:
  – Manihi in the Tuamotu archipelago (27x 8 km)
  – Scilly in the Society archipelago (13x 13 km)
• Reef atoll on volcanoes of relatively small size
• Relatively simple geological history
• Relatively homogeneous coastal morphologies
• Direct anthropogenic impacts (embankment, sand extraction)
• No influence of continental processes

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Atoll coastal system

Systemic causal graph

Climate change

- Cyclones / tropical storms
  intensity or frequency
- Wind
- OffshoreWave climate
- SST, acidity, salinity
- Sea level

Lagoonal wave
climate, hydrodynamics

Barrier reef accommodation

- Bioclastic sand from reef erosion
- Sand extraction

Sea defense, dykes, embankments...

Coastal lagoonward erosion processes

Sedimentary budget

Relative Topography

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

Coastline mobility

External geodynamics processes

Anthropogenic actions and impacts

Biological processes

Internal geodynamics processes

Climate change

Sea Level Change

Cyclones / tropical storms

Relative Topography

Sea defense, dykes, embankments...

Coastline mobility

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Changes in surface area of islands (1961-2001, Manihi)

<table>
<thead>
<tr>
<th>Motu</th>
<th>Net change</th>
<th>Eroded areas</th>
<th>New surfaces</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>+32 910 m²</td>
<td>-19 220 m²</td>
<td>+52 120 m²</td>
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<tr>
<td>2</td>
<td>+265 420 m²</td>
<td>-70 280 m²</td>
<td>+335 700 m²</td>
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<tr>
<td>3</td>
<td>+50 140 m²</td>
<td>-17 920 m²</td>
<td>+68 060 m²</td>
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Erosion & accretion rates
Coastline evolution (1961-2001, Manihi)

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<tr>
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<td>Erosion %</td>
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<tr>
<td>1</td>
<td>48%</td>
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<td>18%</td>
<td>+0.44 m/y</td>
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<tr>
<td>3</td>
<td>2%</td>
<td>+0.72 m/y</td>
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### Surface areas changes are linked to anthropogenic impacts (airport, harbour structures…)

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Coastline evolution

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Preliminary results

• For the 3 motu
  – The 40 yr evolution shows an increase in the surface area of the islands
  – But “Aggradation” is mainly linked to anthropogenic actions that alter the perception of the general evolution of each island
  – Currently, we have no evidence of the impact of past (recent) sea level rise, which seems to be hidden by anthropogenic effects.
  – Future work will focus on islands and atolls without anthropogenic actions in order to analyze the “natural” response
  – Then the results of the coastline evolution will be discussed taking into account the forcing factors (slr, both seasonal and cyclonic wave climates, and tectonics)
New Caledonia

- Mountainous island (400x50km)
- Complex geological history
- Various coastal morphologies
- Large lagoon with distant barrier reef
- Influence of continental processes
- Anthropogenic impact due to mining activities
- Minimal local urbanization

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coastal system of New Caledonia

Systemic causal graph

Climate change

Cyclones / tropical storms intensity or frequency

Rainfall

Wind

Offshore Wave climate

Lagoonal wave climate

SST, acidity, salinity

Barrier reef accommodation

Sea level

Erosion, landslides

Rivers discharge

Sea defense, dykes...

Coastal erosion processes

Relative Topography

Rivers solid discharge

Sedimentary budget at the coast

Mining activities

Gravel extraction

Coastline mobility

External geodynamics processes

Internal geodynamics processes

Biological processes

Anthropogenic actions and impacts

Coastline mobility

Climate change

Sea Level change, storms, cyclones...

Tectonic, vertical movements, isostatic...

Topography

Rivers solid discharge

Coastline mobility

Relative Topography

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

Mining activities

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The Tontouta example

- Mountainous watershed of 500 km²
- Homogeneous lithology: Peridotite
- Huge mining activities since the 60’s (Nickel) => surficial erosion of mining areas
- Mining trash in the slopes until the mid 70’s => supply of “sediment” in the watersheds
- Gravel and sand extraction in the downstream river mainly since the 90’s => extraction of sediment of specific granulometry
- Vertical movement negligible
- Sea level rise around 2mm/ years
Indirect anthropogenic impacts on coastal areas: modifications of river solid discharges

Upstream Material production (Mining trash in watershed)

Downstream Material extraction (Sand and gravels)

Modification of the sedimentary budget at the coastline

impact on the coastline?

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Provisional results

- Major morphological changes between 1954 and 2003, main streams pattern changes.
- Progradation of the front of the delta from 1954 to 2009 of around 200m (progradation of fine lateritic deposits)
- Apparition of silty deposit in the lower estuary of the Tontouta river
- Increasing of tidal surfaces from 1954 to 2003 and from 2003 to 2009. Progradation seaward up to 250 m but generally between 50 and 100m
- Indirect impact of human activities seems to be the major forcing factor of recent evolution
Preliminary results

- Indirect impacts of human activities seem to be the major forcing factor of recent evolution near the Tontouta outlet.
- Currently, we have no evidence of the impact of past (recent) sea level rise which seems to be hidden by anthropogenic effects.
- Other sites with and without mining activities and in different New Caledonian environments and contexts will be studied in order to analyze the potential impacts of SLR.

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Conclusion

• Sea Level Rise
  • Non homogeneous response of the coastline
    • Function of numerous forcing factors
  • Need to assess the SLR impact on various sites in order to analyse the coastal sensitivity
  • Coastal sensitivity to SLR analysis will provide keys for the assessment of potential future effects of SLR with respect to others forcing factors

• Work in progress !
Thanks !

This communication is supported by the French National Agency for Research (ANR) within its Planetary Environmental Changes (CEP) framework. We thank the French Polynesia Government (SAU) and the New Caledonia Government (DIMENC, DITTT) for providing data.