Mercredi 7 mai 2025 | Voilà Hotel Bagatelle Mall

Gestion des risques côtiers

épisode 1

État des lieux et perspectives

European Union

ADAPT ACTION

UN PROGRAMME AFD GROUPE

BUSINESS MAURITIUS

Gestion des risques côtiers

État des lieux et perspectives

> État des connaissances scientifiques et enjeux

Étude opérationnelle sur les risques côtiers (érosion et submersion) à Maurice et à Rodrigues

Aléas, vulnérabilité et enjeux au regard du changement climatique

M. Éric DAVID
Expert international multirisque
BRGM

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Directrice de l'Innovation et des activités Commerciales et Internationales
BRGM

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Professeure de géographie
Université de Limoges - UMR CNRS Géolab

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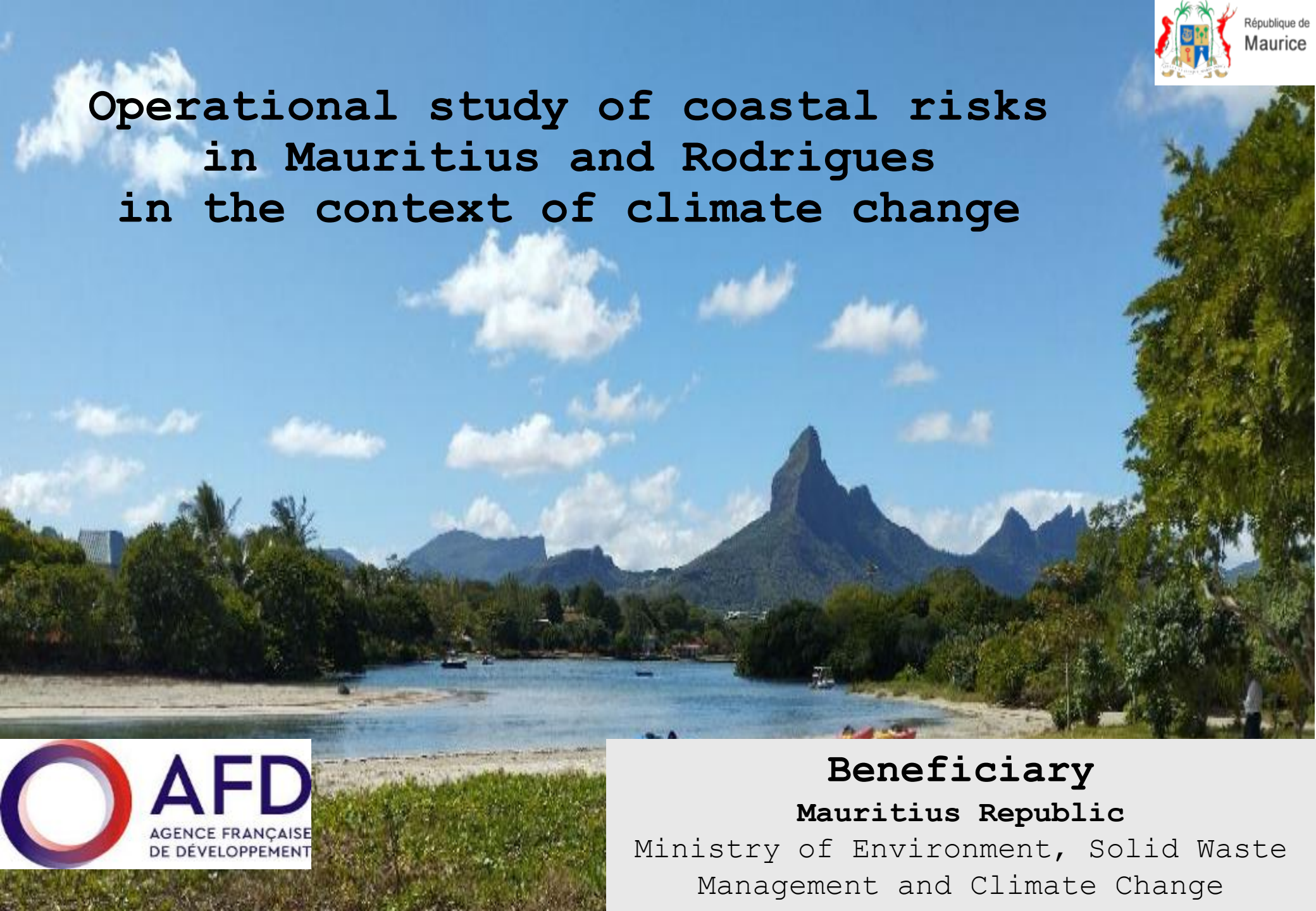
BUSINESS MAURITIUS



Operational study of coastal risks in Mauritius and Rodrigues in the context of climate change

République de Maurice

AFD
AGENCE FRANÇAISE DE DÉVELOPPEMENT

Beneficiary

Mauritius Republic

Ministry of Environment, Solid Waste Management and Climate Change

RÉPUBLIQUE FRANÇAISE
Liberté
Égalité
Fraternité

Géosciences pour une Terre durable
brgm

Géosciences pour une Terre durable

BRGM
SERVICE GÉOLOGIQUE NATIONAL

BRGM
SERVICE GÉOLOGIQUE NATIONAL

Le BRGM est l'établissement public français de référence dans les applications des sciences de la Terre pour gérer les ressources et les risques du sol et du sous-sol.

Créé en 1959,
le BRGM est placé sous la tutelle
du ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation,
du ministère de la Transition écologique, et du ministère de l'Économie, des Finances et de la relance.

SES MISSIONS

1000 salariés
dont plus de 700 chercheurs et ingénieurs

- **Recherche scientifique**
  dont la recherche appliquée pour l'innovation des entreprises
- **Appui aux politiques publiques**
- **Coopération internationale**
- **Sécurité minière**
- **Formation**
  dont la formation supérieure diplômante et la formation professionnelle continue

Géosciences pour une Terre durable

brgm

Le BRGM a pour ambition de répondre à des enjeux majeurs pour notre société, plus particulièrement à ceux liés au changement climatique, à la transition énergétique et au développement de l'économie circulaire.

Autour des géosciences, le BRGM développe une expertise pour contribuer à une gestion harmonisée et un usage maîtrisé du sol et du sous-sol des villes et des territoires.

BRGM — SERVICE GÉOLOGIQUE NATIONAL — **WWW.BRGM.FR**

Géologie et connaissance du sous-sol

Gestion des eaux souterraines

Risques et aménagement du territoire

Ressources minérales et économie circulaire

Transition énergétique et espace souterrain

Données, services et infrastructures numériques

Project Objectives

- The objective of this project is to provide the Mauritian government with **a comprehensive knowledge and assessment of current and future coastal hazards and risks** (tsunami exclude)
- **To reduce the vulnerability** of Mauritius and Rodrigues to coastal hazards
- **Integrating the effects of climate change**

- **BRGM** (Coastal Risks and climate change Unit, Risks Division) France (Orléans, Rennes)
- **Metéo France** /Indian Ocean Direction (La Réunion), in charge of cyclonic prevision for OI.
- **University of Limoges**/GéoLab (France) & **University of Mascareignes** (Mauritius)

Project Objectives

- Coastal risks assessment and mapping of Mauritius and Rodrigues coasts in present (2025) and future (2050, 2100)
  - Coastal risks = coastal hazards x assets
    - coastal hazards = coastal flooding and coastal erosion and shoreline retreat (tsunami exclude)
    - Assets : present day assets (typology)
  - Whole coasts mapping of Mauritius and Rodrigues (scale around 1/20,000)
  - 3 hotpots chosen by the steering Committee (higher resolution mapping and assessment):
    - Mauritius : Flic en Flac, Anse la Raie,
    - Rodrigues : Port Mathurin.
  - Project deliverables include reports, maps and GIS data and training (capacity building of Mauritians)

Hazards

Forcing factors

- *Cyclones and tropical storms*
- *Southern swells*
- *Relative Sea level rise (CC)*

Submersion

Coastal erosion

2025 / 2050 / 2100

Assets

- *Vulnerability*
- *Risk assessment*

N. BERNARDIE-TAHIR

Measures

- *Adaptation strategy*
- *Ecosystemics services (NBS)*

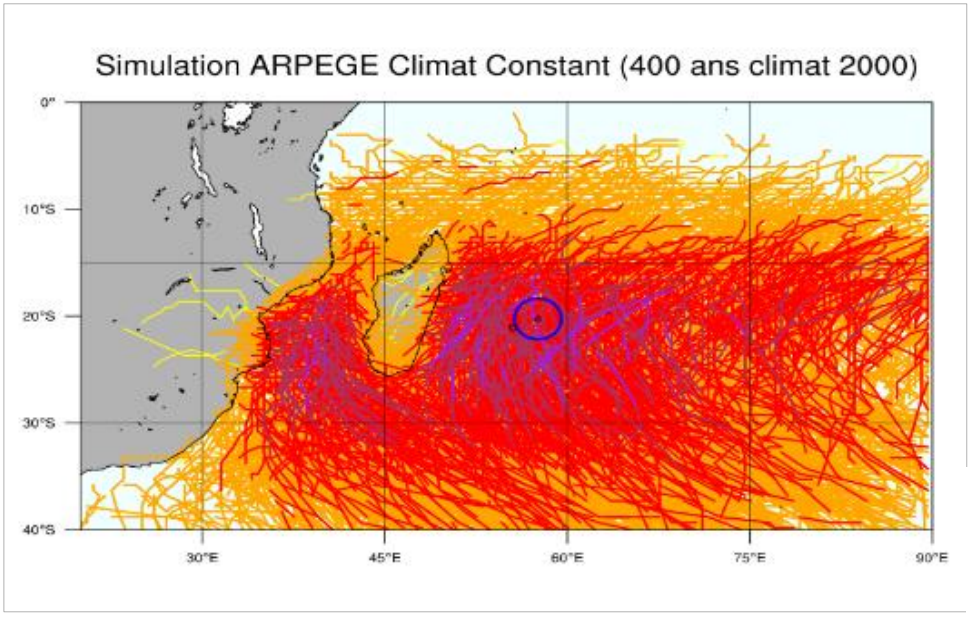
Decision tools (Maps, Guidance) for

- *Prevention planning*
- *Adaptation strategy*
- *Crisis management scenario*

Forcing factors

Cyclones, extreme meteo-oceanic conditions and sea level rise

Cyclonic hazard

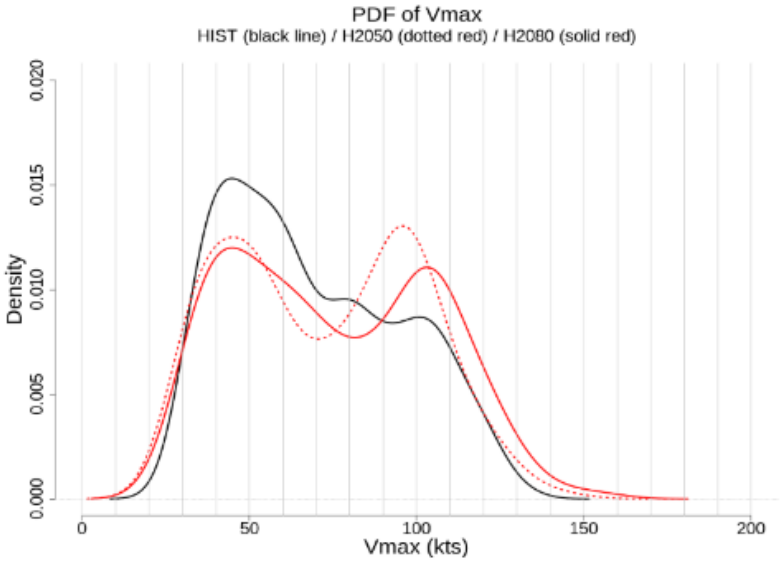


Progress :

Identification of Cyclonic potential evolution for future century (200km around Mauritius and Rodrigues)

Product :

Data base of past – present and future cyclone (220) and tropical storms (164)



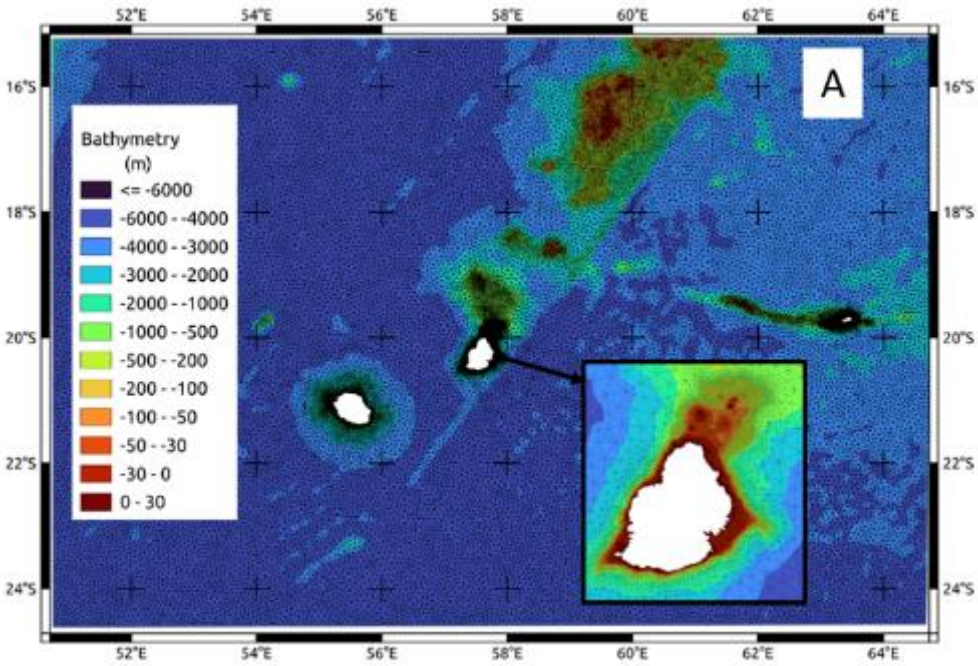
Proposed evolution of the cyclone intensity distribution curve for the two time frames considered (2050, 2080-2100)

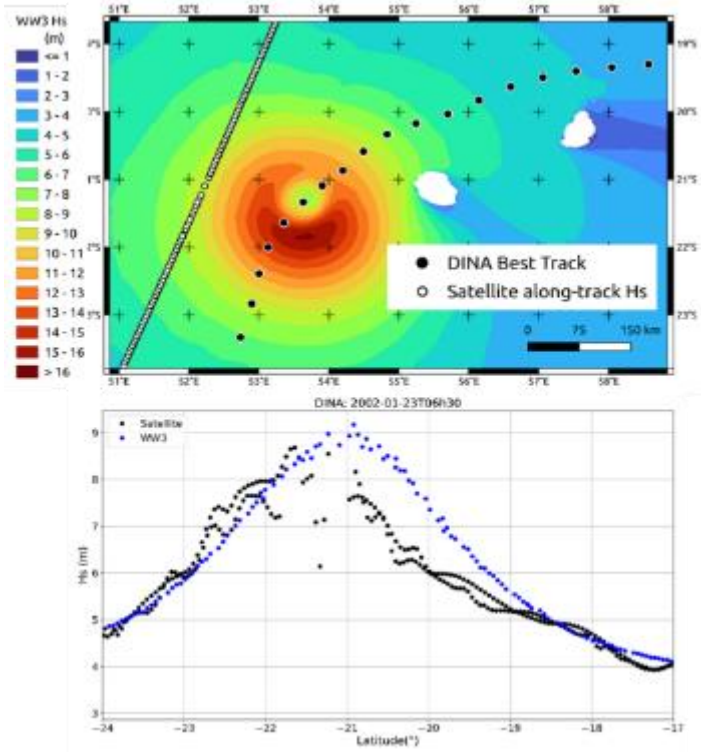
Meteo-France Reunion is the WMO Center in Indian ocean and is in charge of cyclonic prevision for the whole area.

CYCLONE-INDUCED EXTREME METEOCEANIC FORCING CONDITIONS (PRESENT DAY AND FUTURE)

By modelling the extreme meteorological and oceanic conditions induced by cyclones off the coast of Mauritius and Rodrigues for current and future climatic conditions, we are assessing the impact of the cyclones on the regional and local marine environment (offshore conditions that induce flooding and coastal erosion).

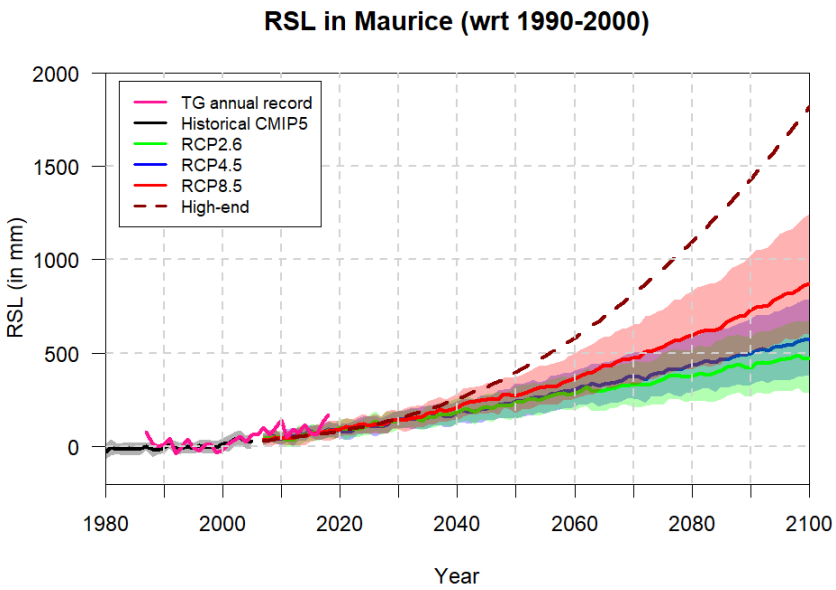
- *Waves*
- *Storm surges*



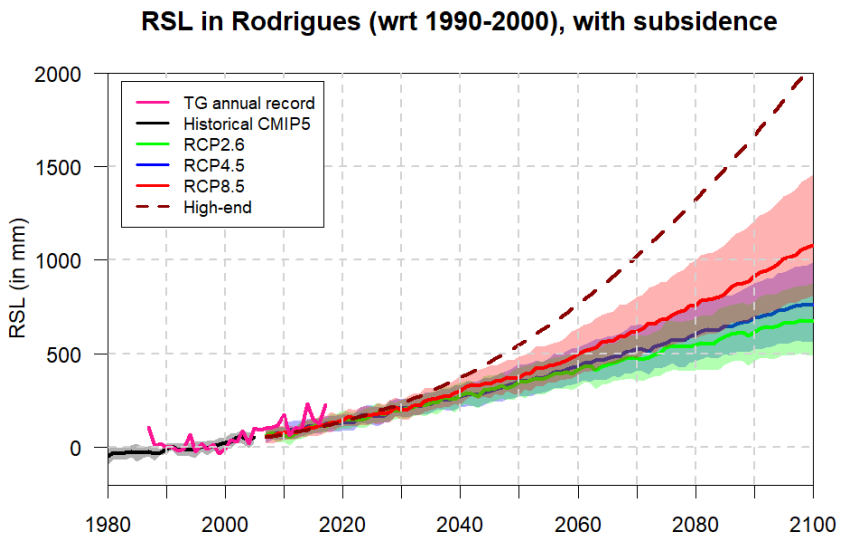


Meshes used to calculate waves on Mauritius (A) and Rodrigues (B).

Sea level projections in Mauritius Rodrigues



	2050	2100
RCP2.6	0.24 (0.16-0.33)	0.48 (0.29-0.67)
RCP4.5	0.24 (0.15-0.34)	0.57 (0.38-0.79)
RCP8.5	0.27 (0.18-0.37)	0.87 (0.61-1.24)
High-end	0.40	1.82



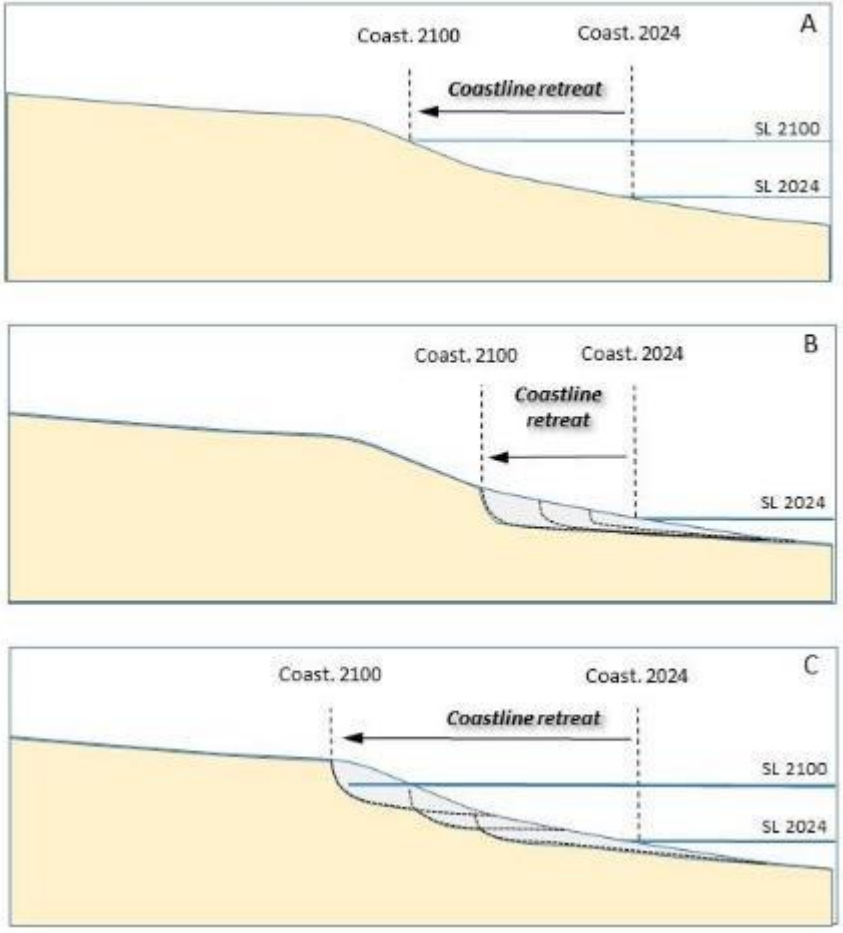
	2050	2100
RCP2.6	0.24 (0.16-0.31)	0.47 (0.28-0.66)
RCP4.5	0.24 (0.16-0.33)	0.56 (0.36-0.77)
RCP8.5	0.26 (0.17-0.37)	0.87 (0.60-1.25)
High-end	0.44	1.84
VLM (subsidence 2mm/yr)	+0.11	+0.21

Coastal erosion and shoreline retreat hazard

Progress :
Quantification of potential coastal erosion on the whole Mauritius and Rodrigues

Products :
Maps for 2025, 2050, 2100
General and detailed hot spots

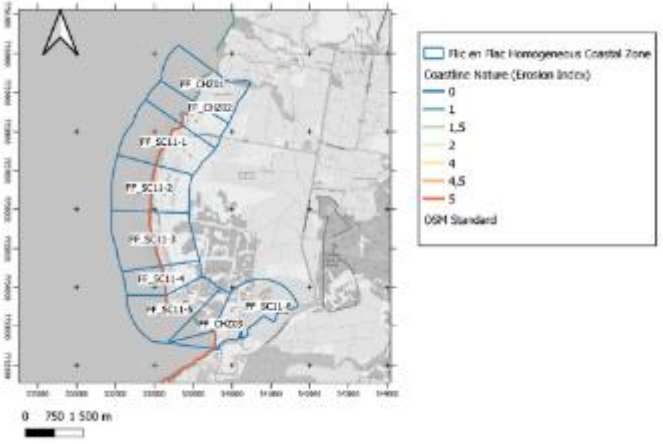
Coastal erosion and shoreline retreat



Effect on the coastal retreat of A) sea level rise, B) coastal erosion, C) both (SL: sea level, Coast : coastline)

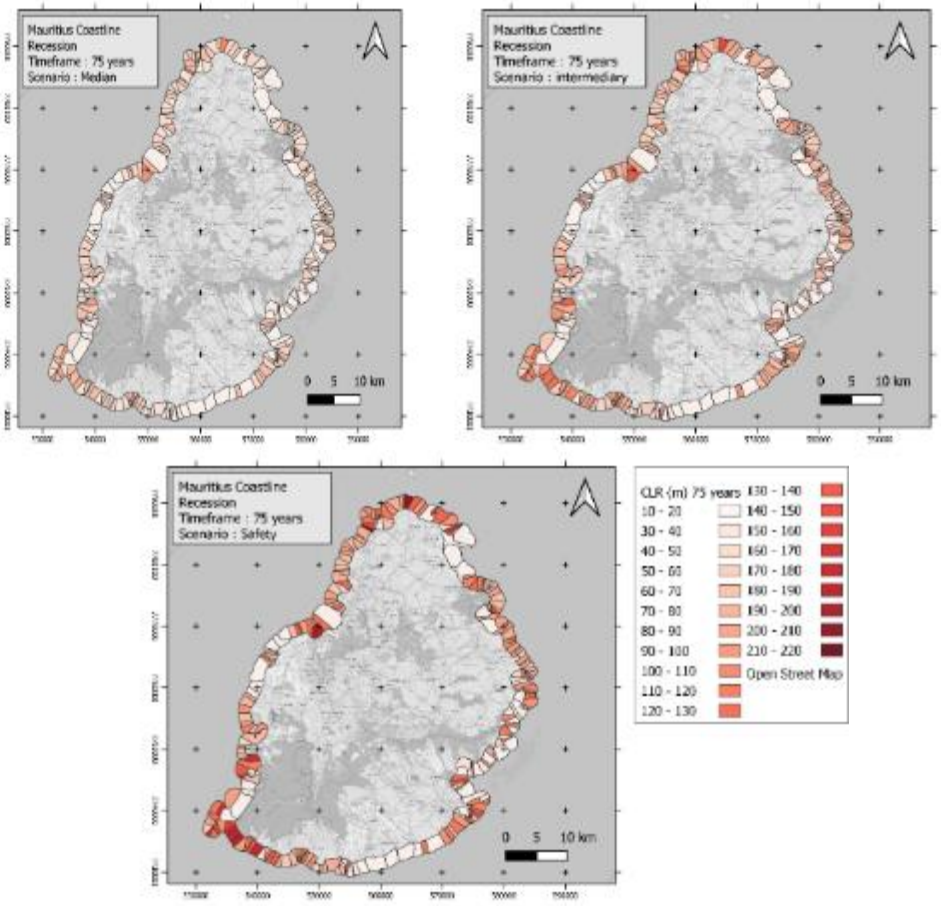
The causes of this retreat are multifaceted, including both natural and anthropogenic factors, as well as natural phenomena exacerbated by anthropogenic activities

Segmentation of the territory into homogeneous coastal zones (267 for Mauritius, 36 for Rodrigues)

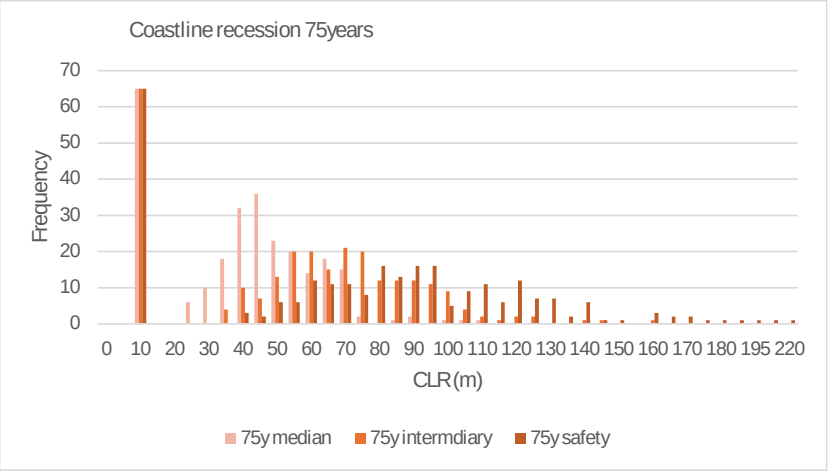


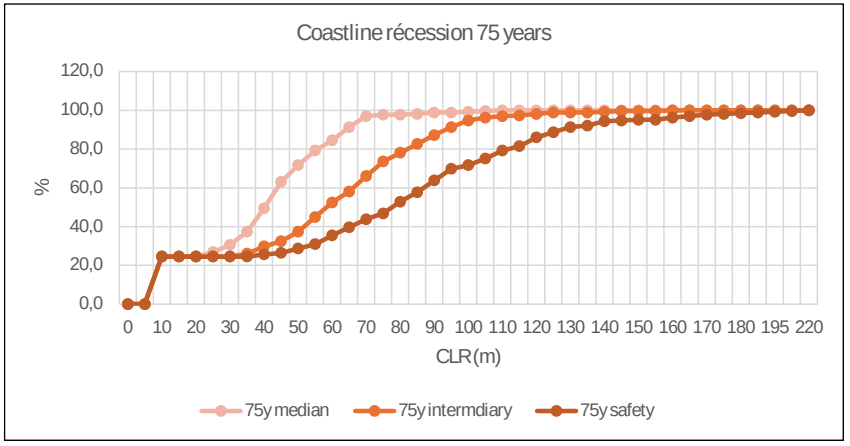
Example on Flic en Flac

Example of shoreline retreat by cells in 2100 for the 3 studied scenarios



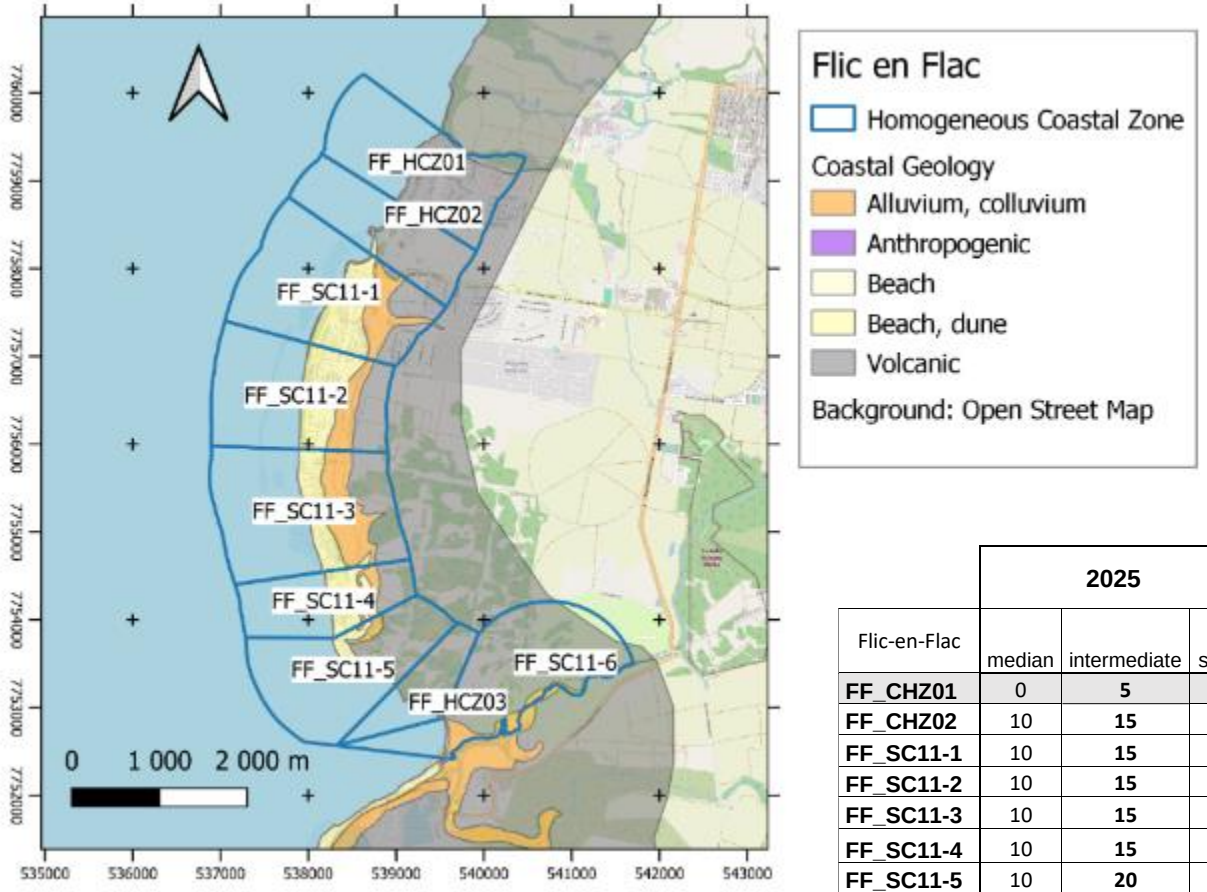
Maps of potential shoreline retreat by sediment cell and homogeneous zones in Mauritius for the 2100 period and the three studied scenarios





several tens of metres to a hundred metres by the year 2100

Shoreline retreat at local scale (sub-cells)

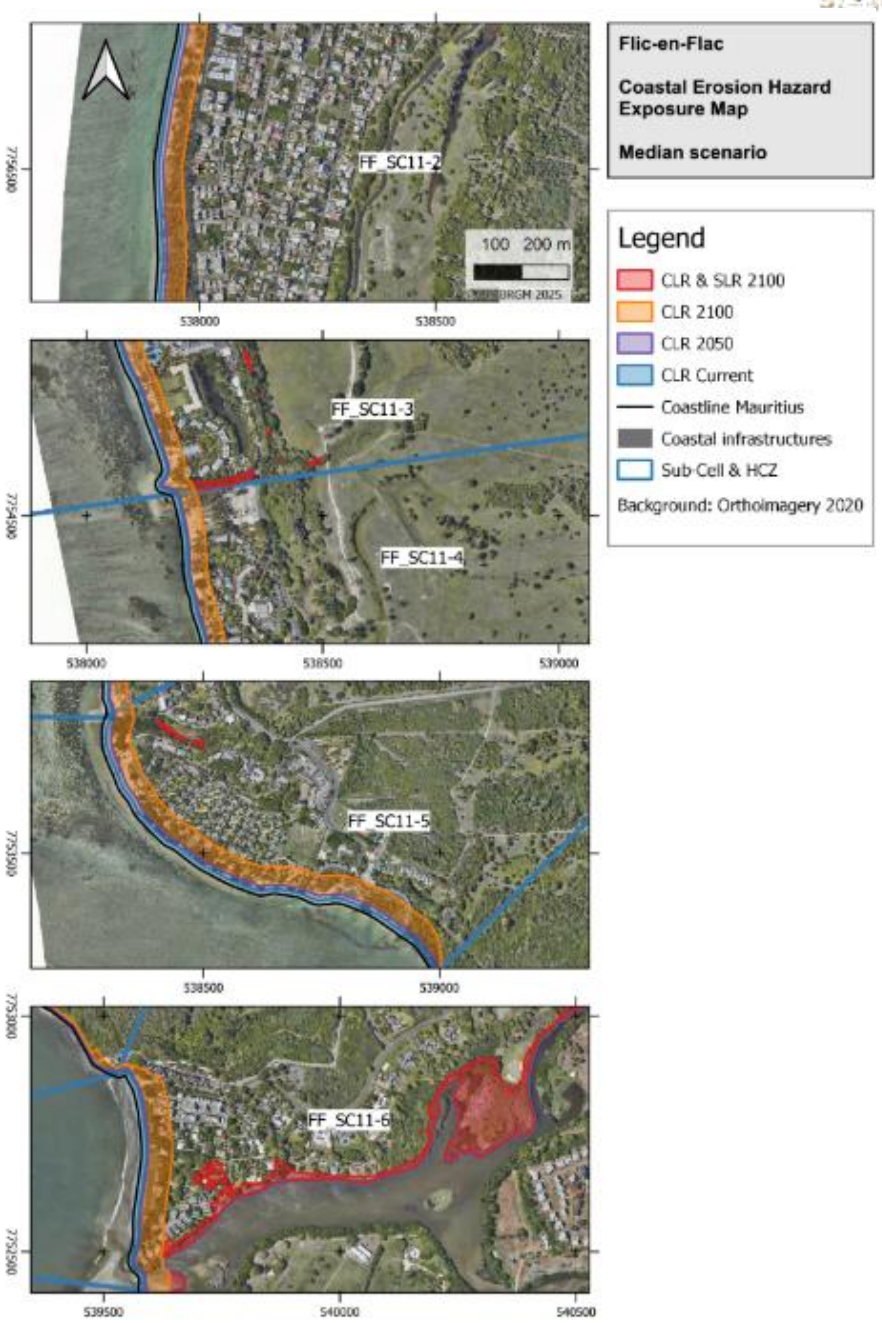


Homogeneous coastal zones, sub-cells and coastal geology of Flic en Flac

	2025			2050			2100		
Flic-en-Flac	median	intermediate	safe	median	intermediate	safe	median	intermediate	safe
FF_CHZ01	0	**5**	5	5	**5**	10	10	**10**	10
FF_CHZ02	10	**15**	20	20	**30**	35	60	**75**	85
FF_SC11-1	10	**15**	20	15	**25**	30	45	**60**	70
FF_SC11-2	10	**15**	20	20	**30**	45	60	**75**	95
FF_SC11-3	10	**15**	15	15	**20**	25	50	**60**	70
FF_SC11-4	10	**15**	20	15	**25**	40	50	**70**	85
FF_SC11-5	10	**20**	25	20	**50**	65	60	**95**	110
FF_CHZ03	0	**5**	5	5	**5**	10	10	**10**	10
FF_SC11-6	10	**15**	15	15	**25**	35	65	**80**	95

Coastline recession estimations for homogeneous zones and sub-cells of Flic-en-Flac, 2025, 2050 and 2100 timeframes

Example of shoreline retreat hazard map at local scale (GIS)



Maps of coastline retreat hazard for 2025, 2050 and 2100 (median scenario)

Zoom of 4 hazard-sensitive areas for Flic-en-Flac

Coastal flooding hazard

Coastal flooding processes

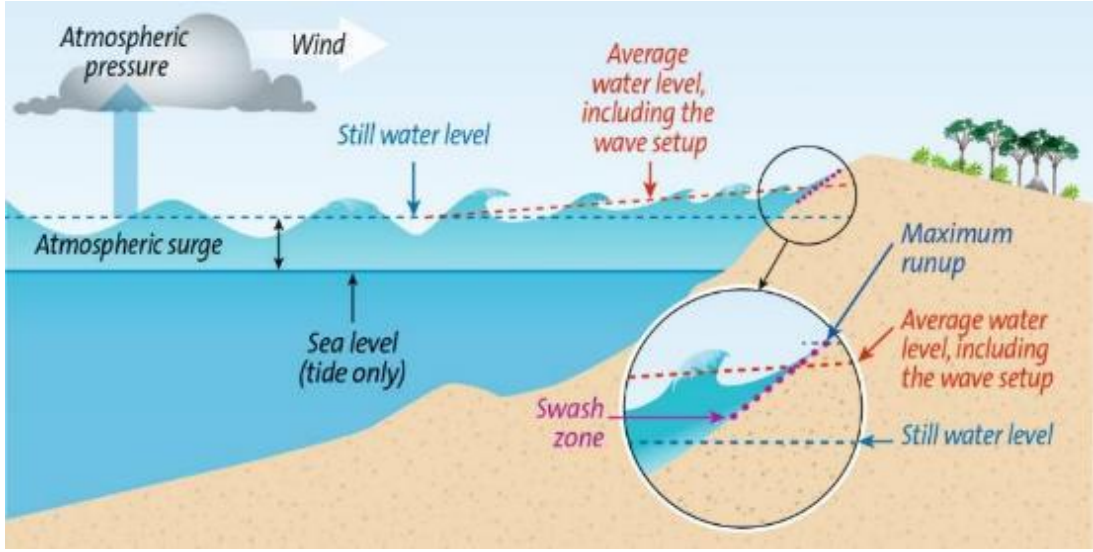
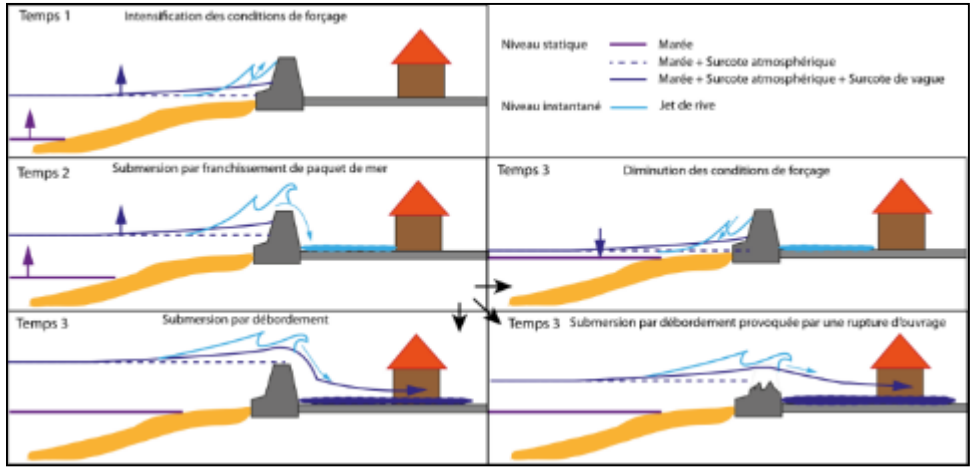


Diagram of the different contributions to the water level during a storm (surges) as far as the shore

Storm database

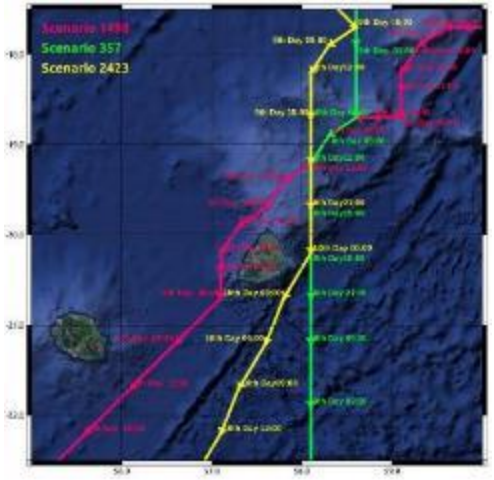
- 2 Storms of 100 year return period (for Hs/Slr combination)
- 2025, 20250, 2100

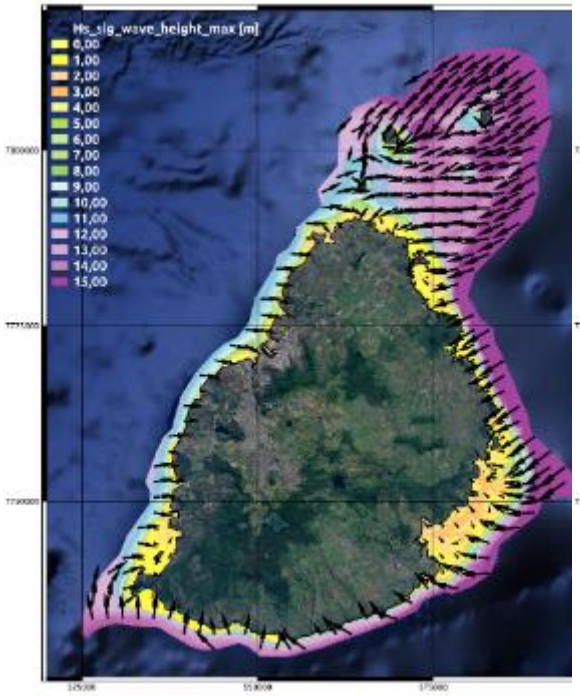
Hazard : maximum of flooding extension

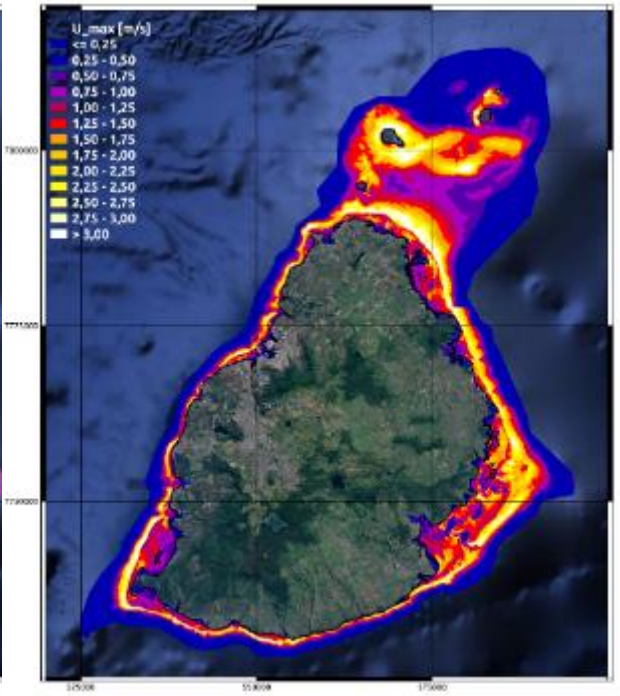


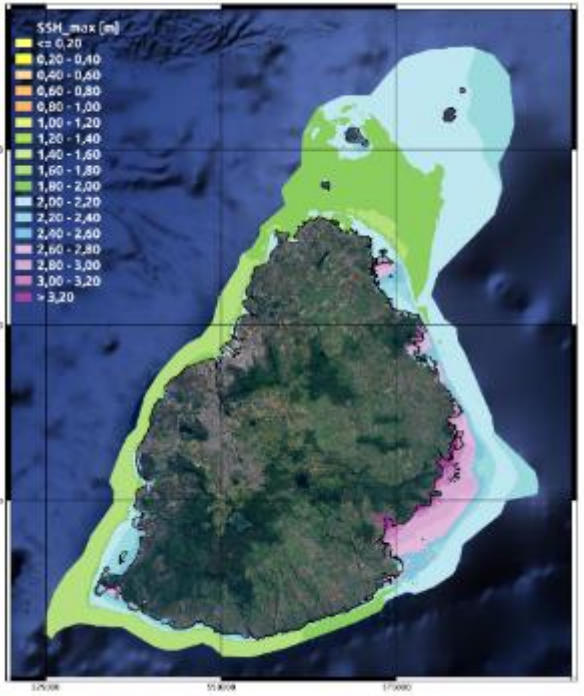
Types of coastal flooding : wave overtopping, overflowing, failure

Examples of Cyclonic scenarios



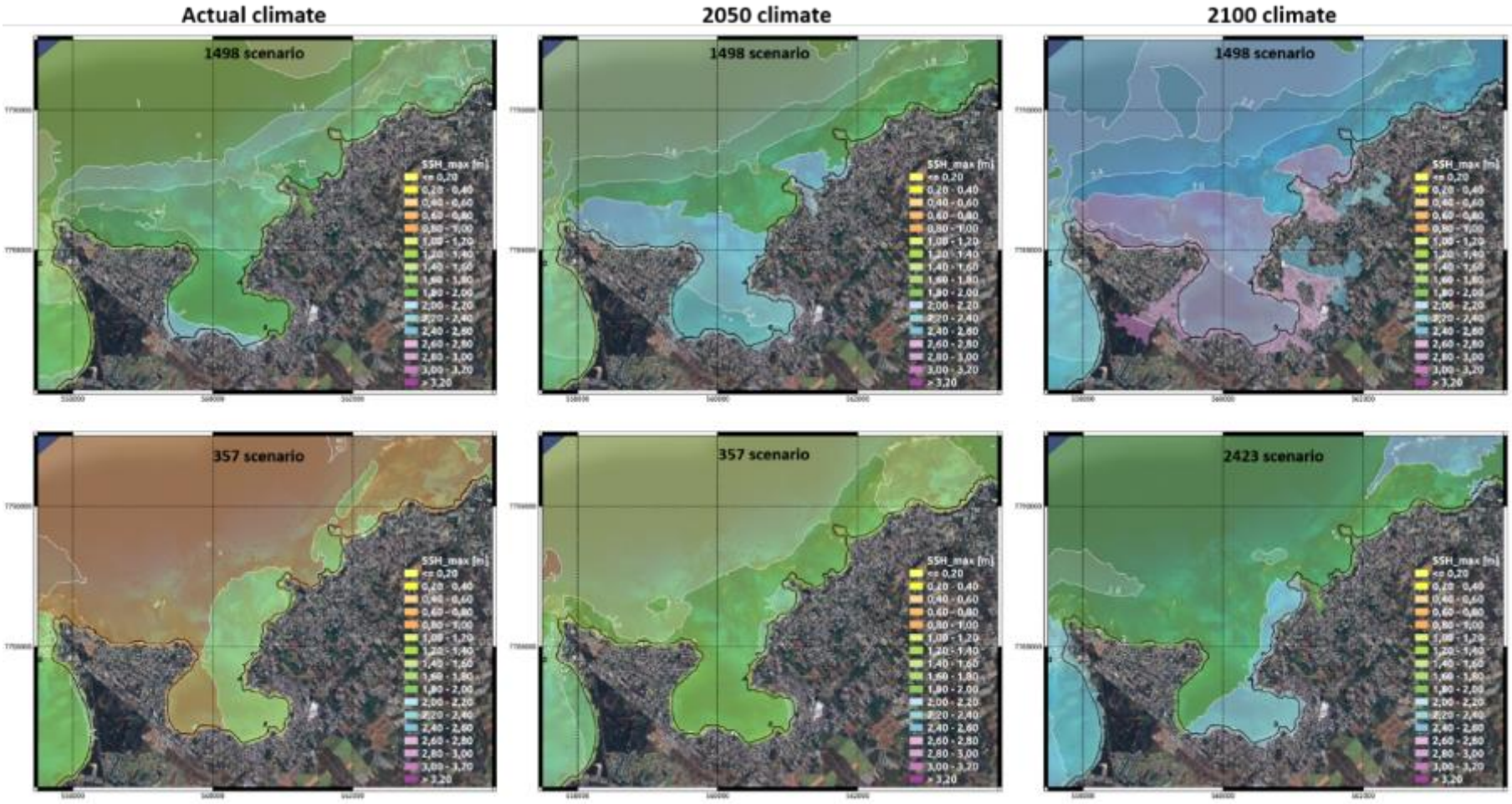






2100 climate , scenario 2423 : Significant wave height, current velocity and maximum sea surface

Flooding hazard assessment by modelling

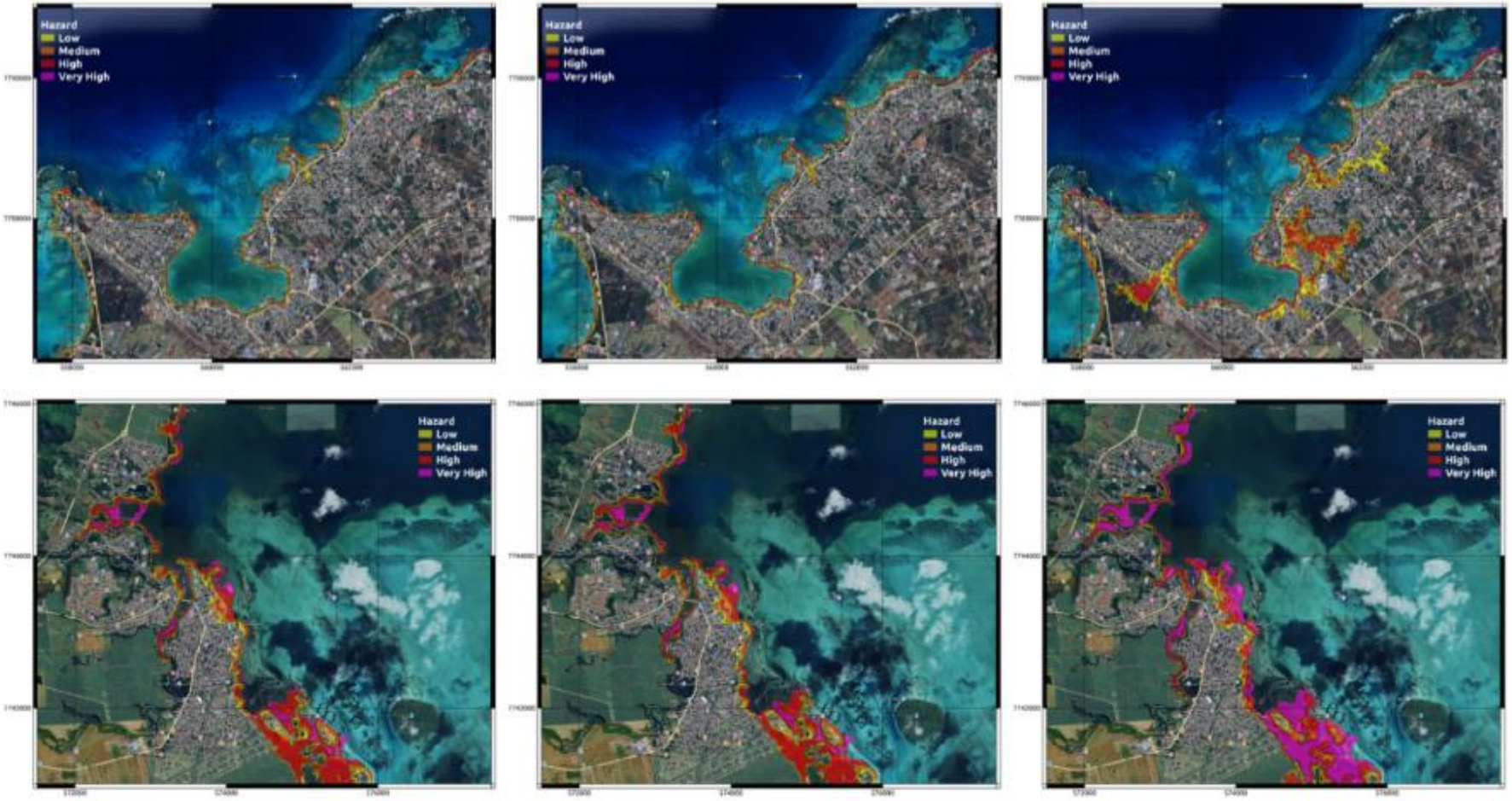


Example of a close up comparison of the **computed maximum sea surface height** on the several simulated scenarios on the Grand Baie area (centennial return period)

Flooding Hazard mapping

		Speed of currents (m/s)		
		V <= 0.2	0.2 < V <= 0.5	V >= 0.5
Water Heights (m)	H <= 0.5	Low	Medium	High
	0.5 < H <= 1	Medium	Medium	High
	1 < H <= 2	High	High	Very High
	H > 2	Very High	Very High	Very High

Matrix for determining coastal flooding hazard



Flooding hazard maps on the Grand-Baie (top) and **Mahébourg** (bottom) areas for present-day climate conditions (left), 2050 climate (center) and 2100 climate (right)

Flooding Hazard mapping

		Speed of currents (m/s)		
		V <= 0.2	0.2 < V <= 0.5	V >= 0.5
Water Heights (m)	H <= 0.5	Low	Medium	High
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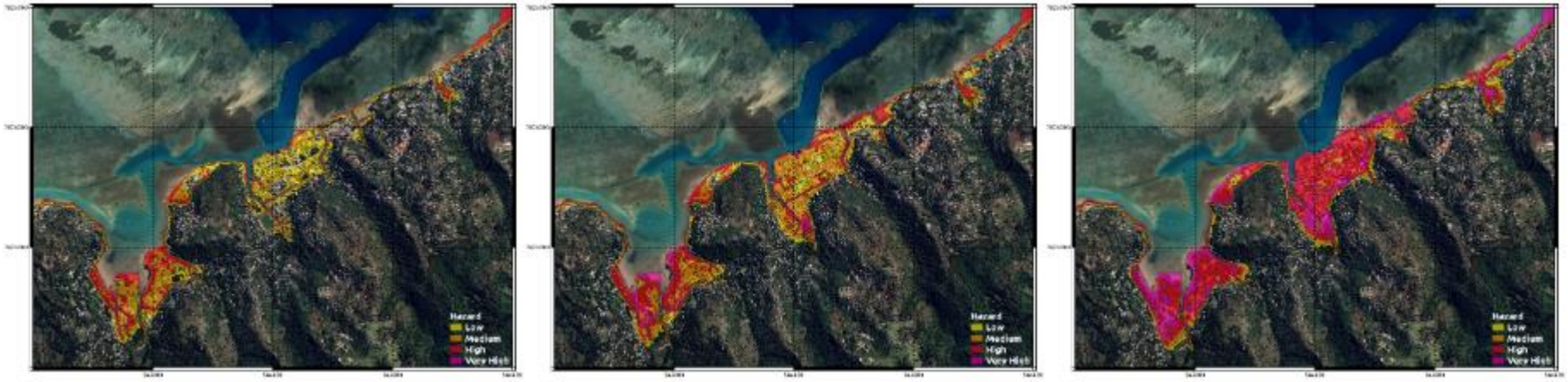
Matrix for determining coastal flooding hazard



Flooding hazard maps on the **Port Mathurin** (Rodrigues) for present-day climate conditions (left), 2050 climate (center) and 2100 climate (right)

Progress :
Quantification of potential coastal marine flooding on the whole Mauritius and Rodrigues

Products :
Maps for 2025, 2050, 2100
General and detailed hot spots

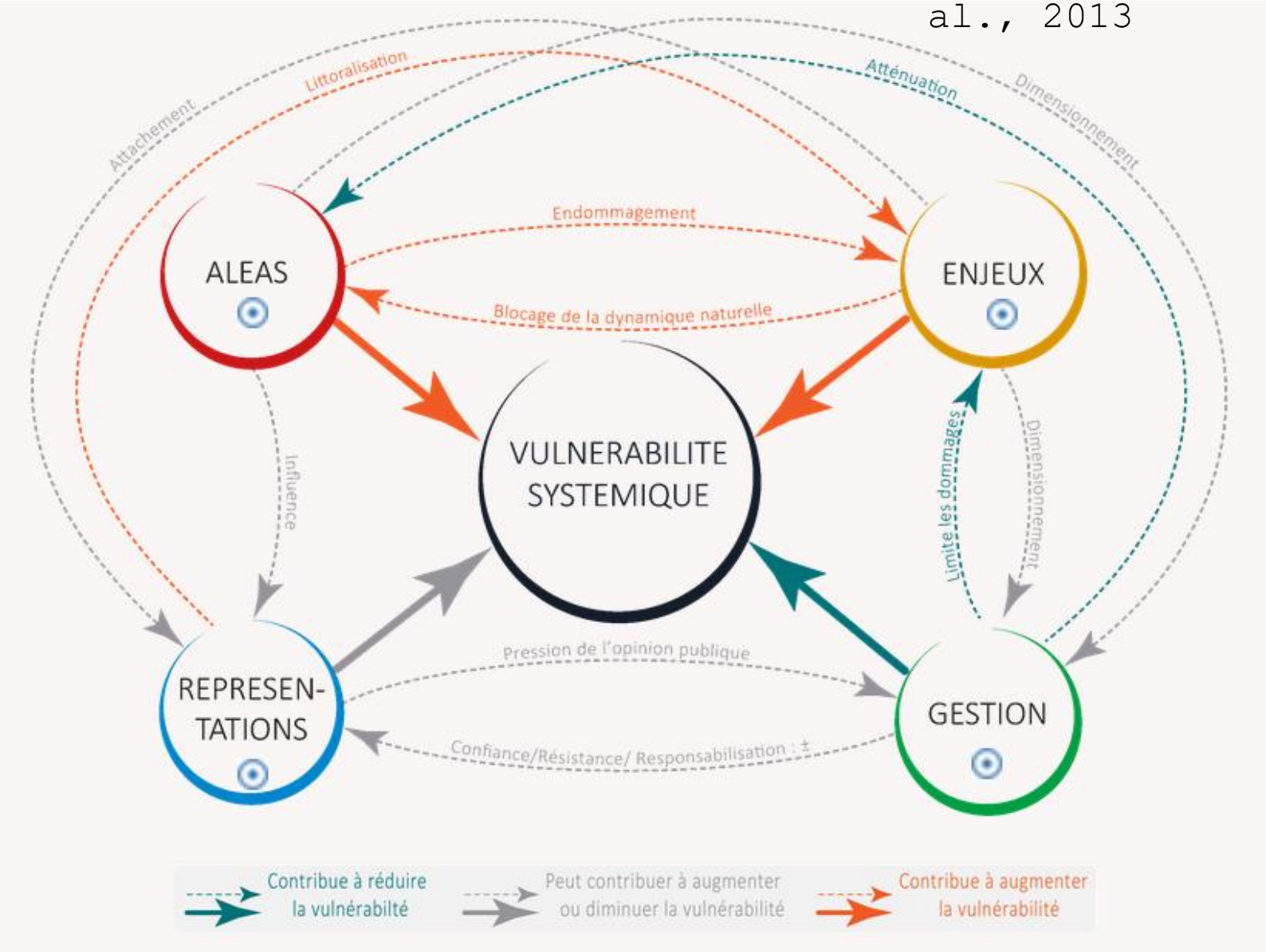
Enjeux, Vulnérabilités et risques

N. BERNARDIE-TAHIR
Professor of Geography

Université de Limoges - UMR CNRS 6042 GEOLAB, France
Former President of the Université des Mascareignes, Mauritius

Enjeux, vulnérabilités et risques

Meur-Ferec et al., 2013



Méthodologie : 3 étapes principales

1. Etablir une typologie des enjeux impactés par les aléas côtiers. Les cartographier

Données statistiques
+
Base de données, rapports, études

2. Evaluer les différentes formes et degrés de vulnérabilités de la société mauricienne (inégalités sociales, perception, gestion publique du risque) et leurs évolutions

Observations paysagères
+
Questionnaires et entretiens
+
Rapports, études

3. Croiser les cartographies des aléas, des enjeux et des vulnérabilités

Cartographie et analyse actuelle et prospective

Une équipe de 4 chercheurs : Prof Nathalie Bernardie-Tahir, Fabien Cerbelaud, Dr Marie Cherchelay (GEOLAB/Limoges), Dr Zyaad Boodoo (Univ des Mascareignes)

Le contexte mauricien

- Un territoire densément peuplé (1,3 M d'hab pour 2040 km^2)

  20 % des habitants du pays résident sur les côtes

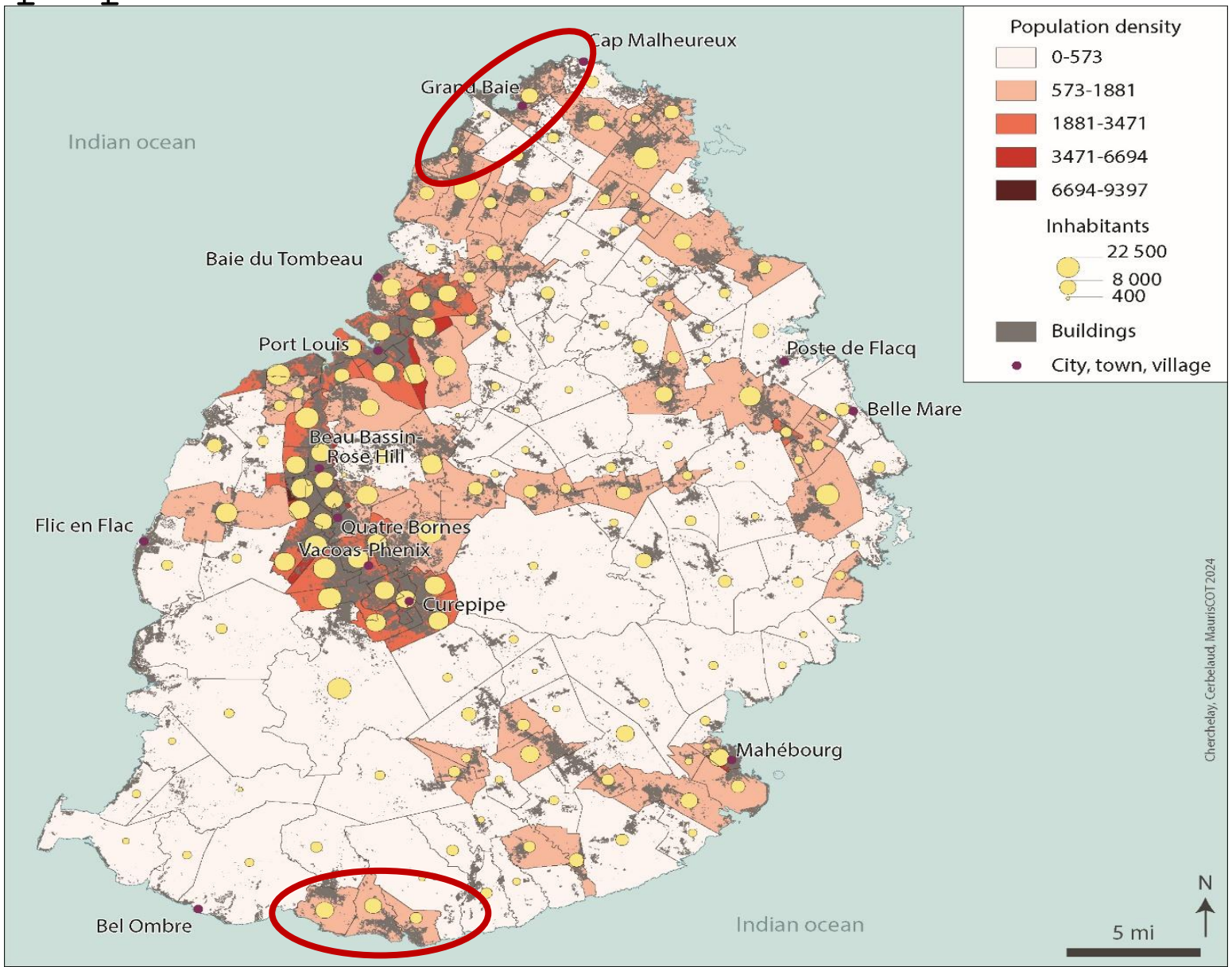
- Les trois piliers du « miracle mauricien » : la sous-traitance industrielle, le tourisme balnéaire, les services financiers off-shore. Pays à revenus intermédiaires.

- Les littoraux mauriciens : « espaces moteurs » du développement insulaire

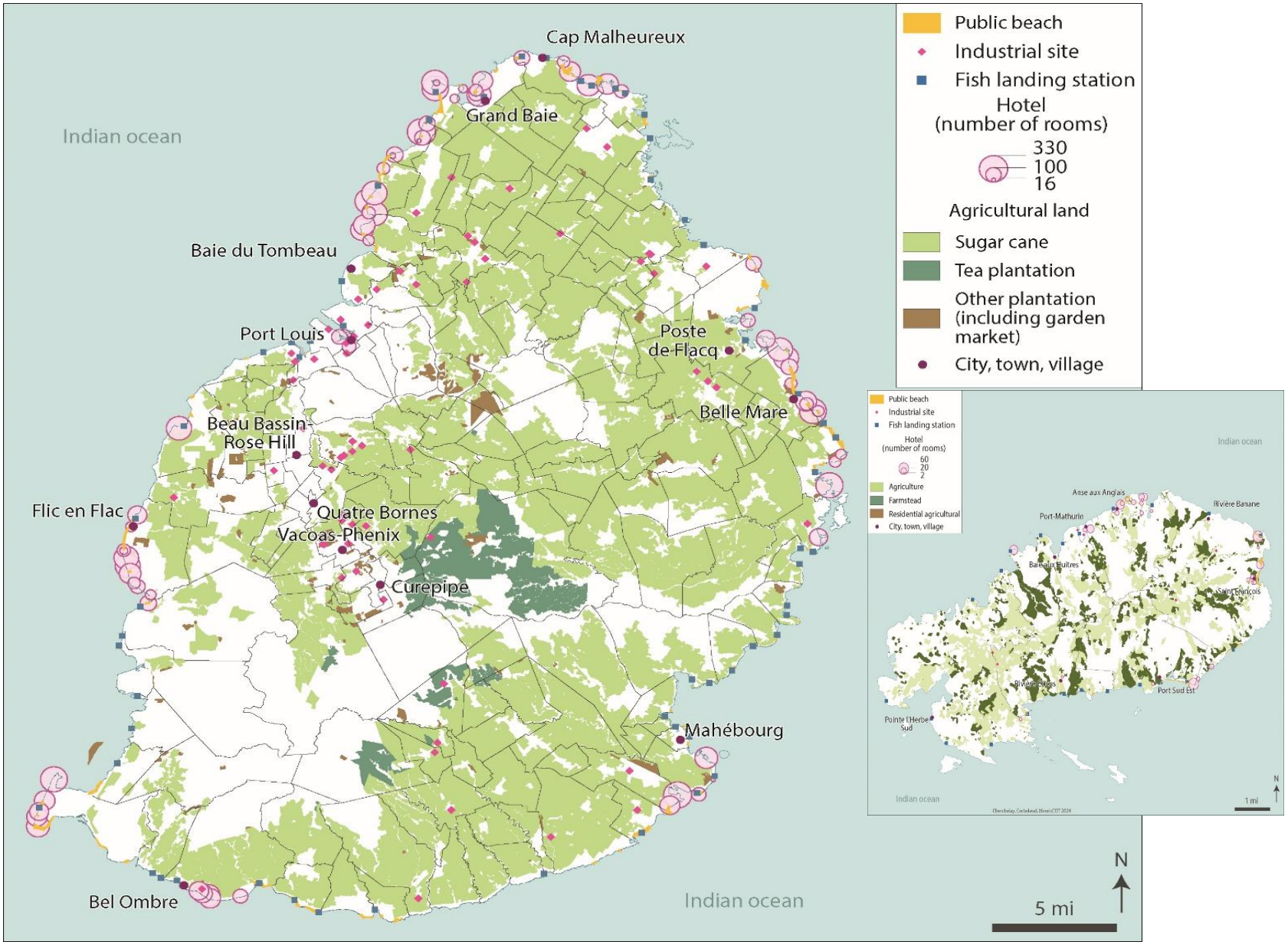
- Le poids du tourisme (très majoritairement balnéaire) : 1,5 millions de touristes en 2024, ¼ du PIB, 20% de la PA

- Des défis (démographiques, économiques, environnementaux) et une sensibilité accrue aux chocs extérieurs

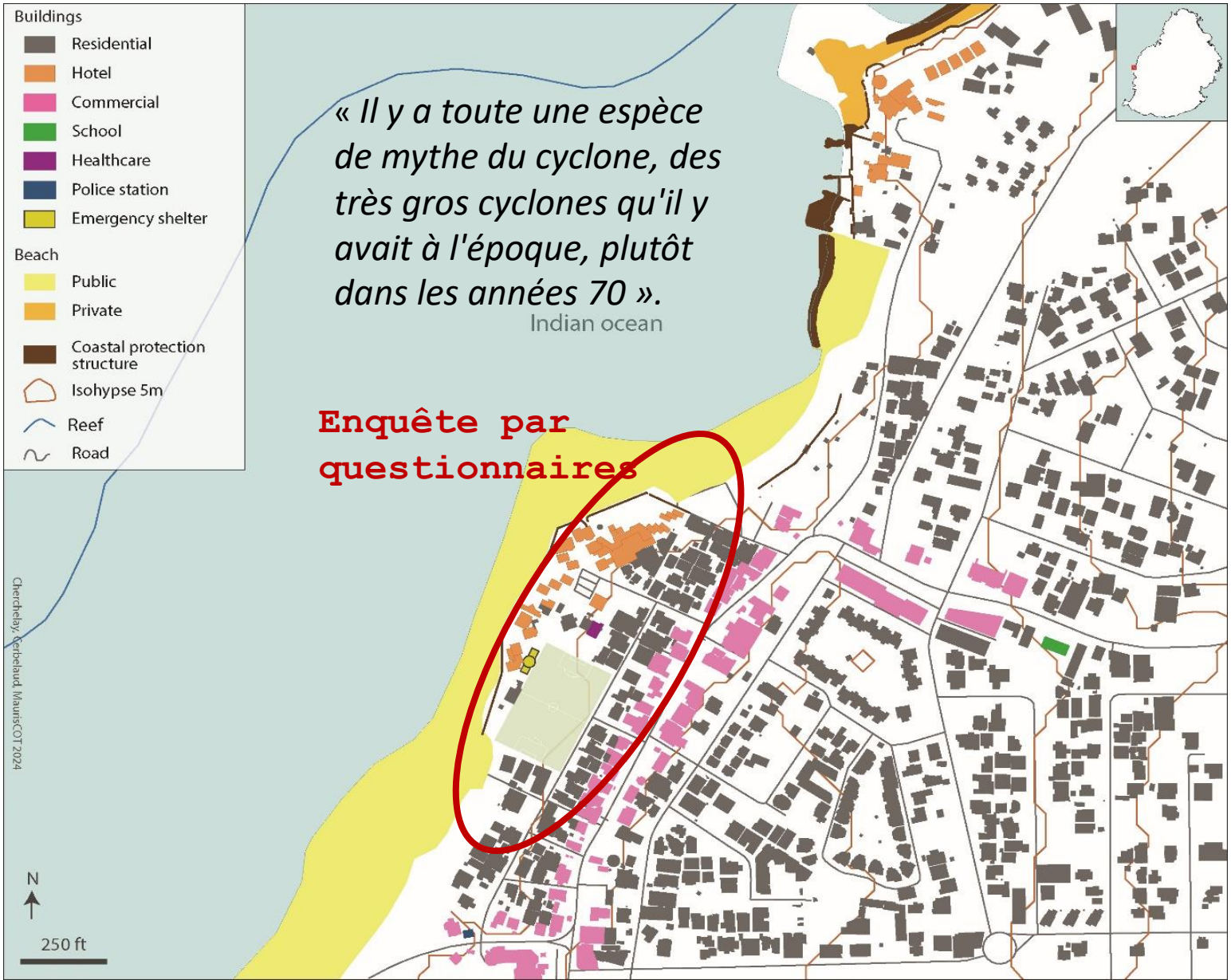
Enjeux /vulnérabilités des populations



Enjeux /vulnérabilités des économies littorales

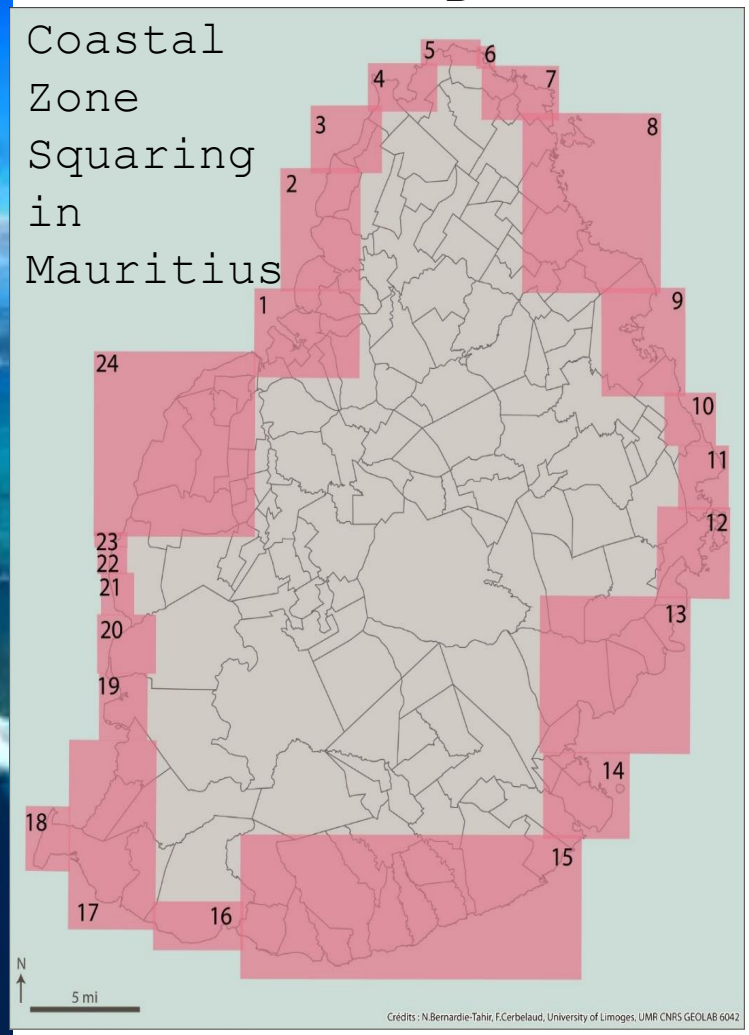


Enjeux/vulnérabilités à Flic-en-Flac



« Il y a toute une espèce de mythe du cyclone, des très gros cyclones qu'il y avait à l'époque, plutôt dans les années 70 ».

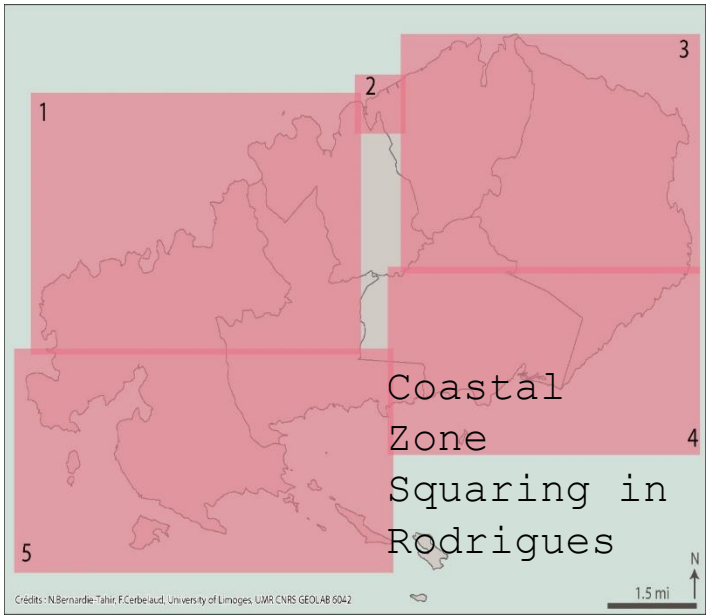
Croisement des aléas/enjeux/vulnérabilités



1 Port-Louis
2 Baie du Tombeau
3 Trou aux Biches
4 Grand-Baie
5 Cap-Malheureux
6 Anse-La-Raie
7 Grand Gaube
8 Poudre d'Or
9 Poste de Flacq
10 Belle Mare
11 Trou d'Eau Douce
12 Ile aux Cerfs
13 Rivière des Créoles
14 Mahébourg
15 Souillac
16 Bel Ombre
17 Baie du Cap
18 Le Morne
19 Grande Rivière Noire
20 Tamarin
21 Flic-en-Flac 3
22 Flic-en-Flac 2
23 Flic-en-Flac 1
24 Albion

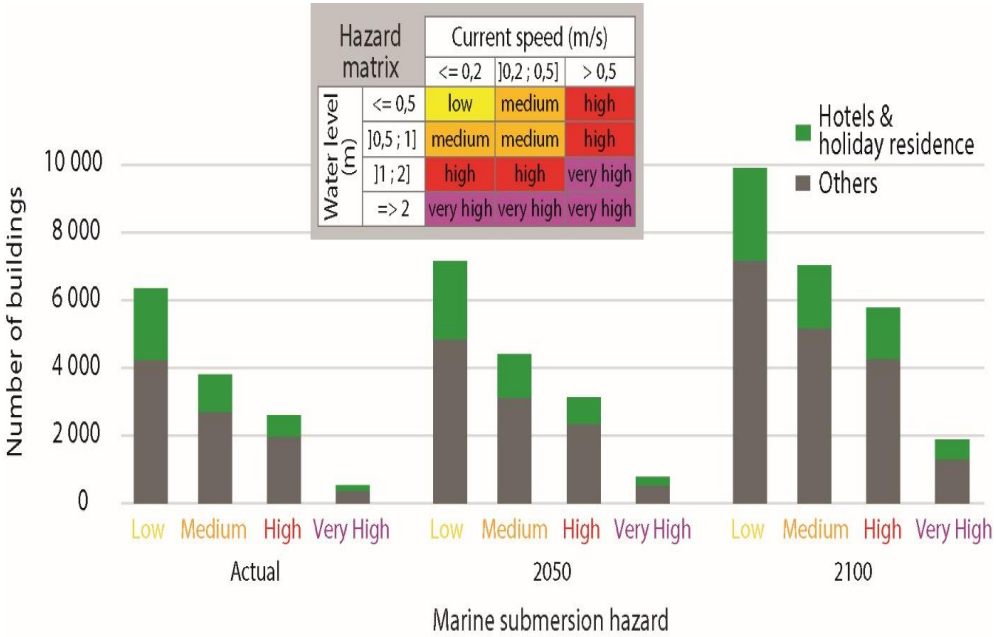
Réalisation d'un atlas de 145 cartes

- Maurice : 48 (aléa Erosion) + 72 (aléa Submersion)
- Rodrigues : 10 (aléa Erosion) + 15 (aléa Submersion)

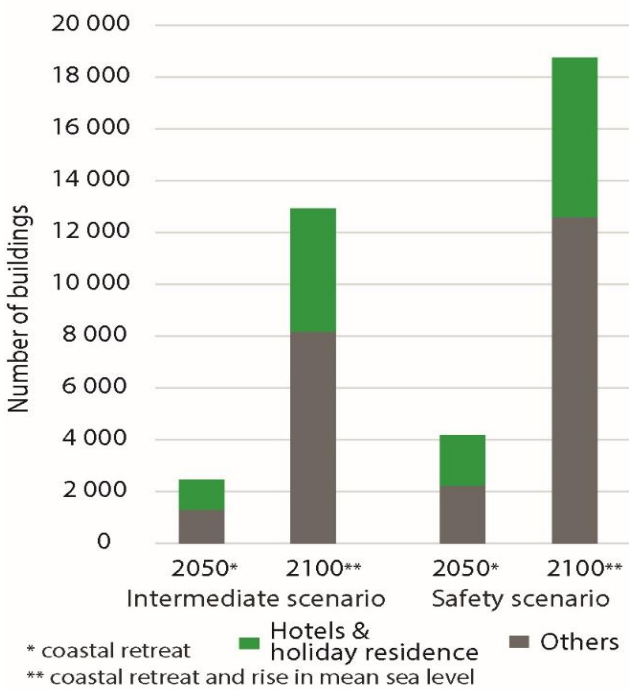


1 Baie du Nord
2 Port-Mathurin
3 Pointe Coton
4 Port Sud-Est
5 Rivière Cocos

Evaluation des dommages sur le bâti littoral

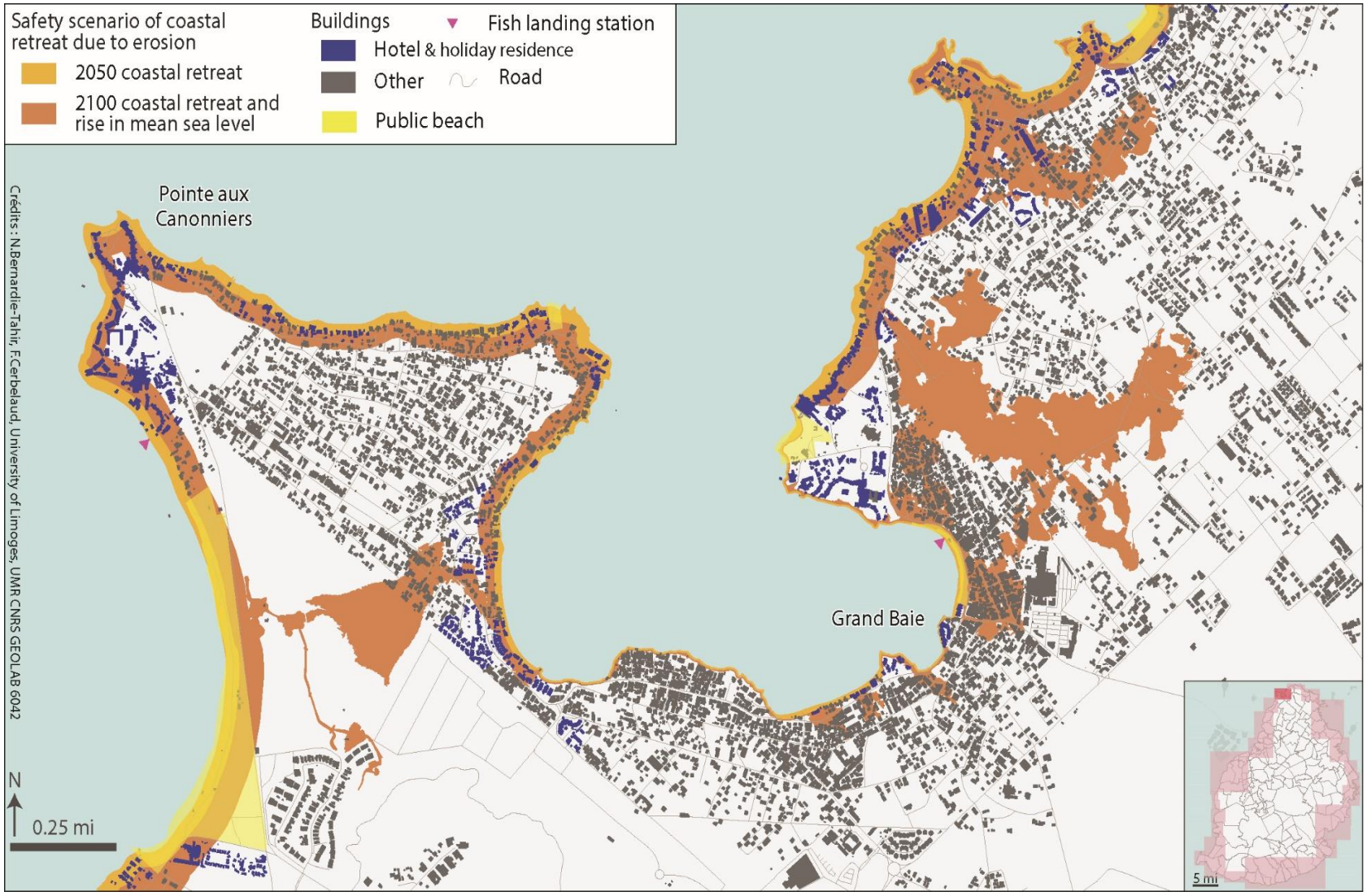


Nombre de bâtiments endommagés par la submersion marine en 2025, 2050 et 2100 à Maurice

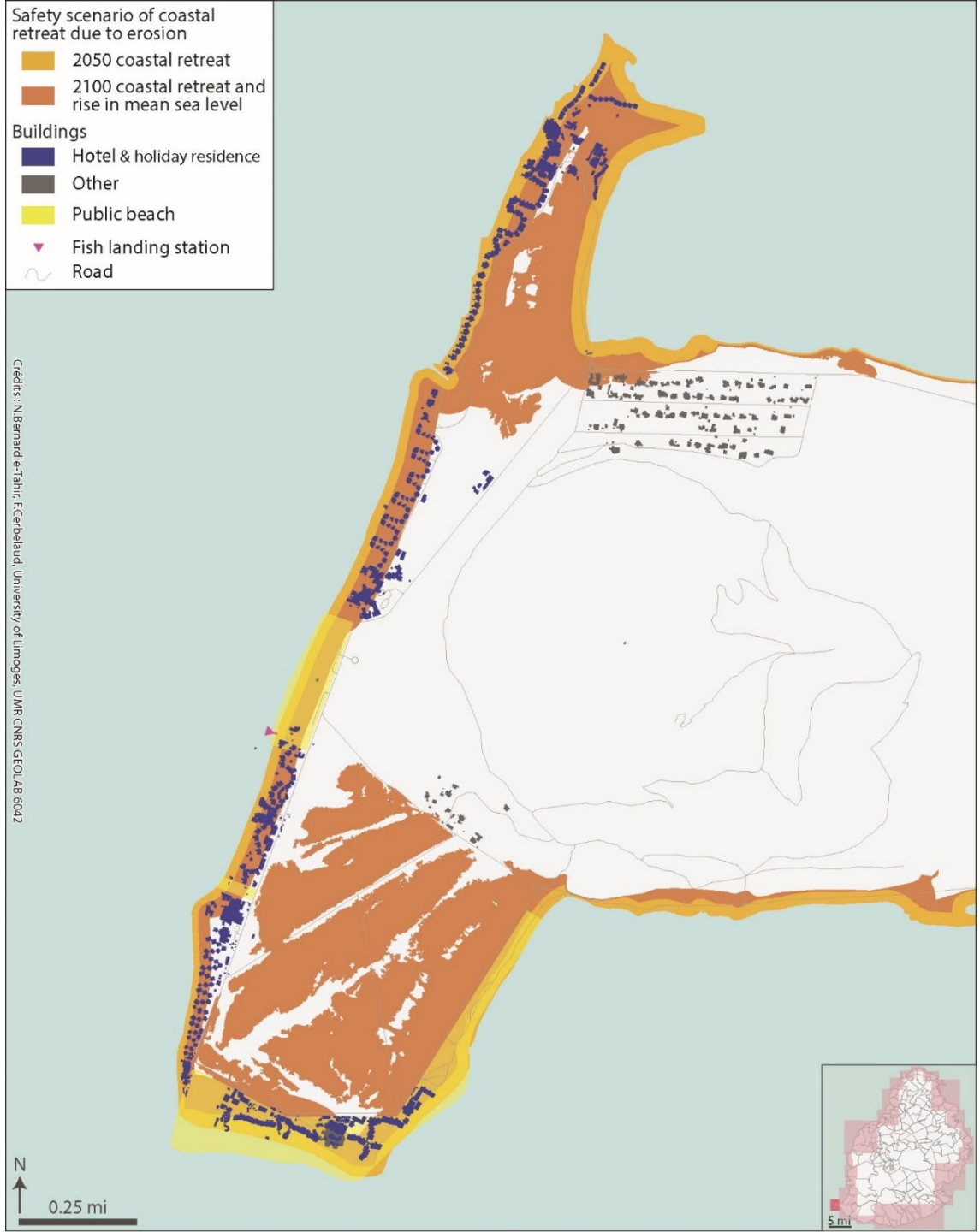


Perte de bâtiments liée au recul du trait de côte (2050) et à l'élévation du niveau marin (2100) selon différents scenarios

Aléa **érosion** / enjeux / vulnérabilités

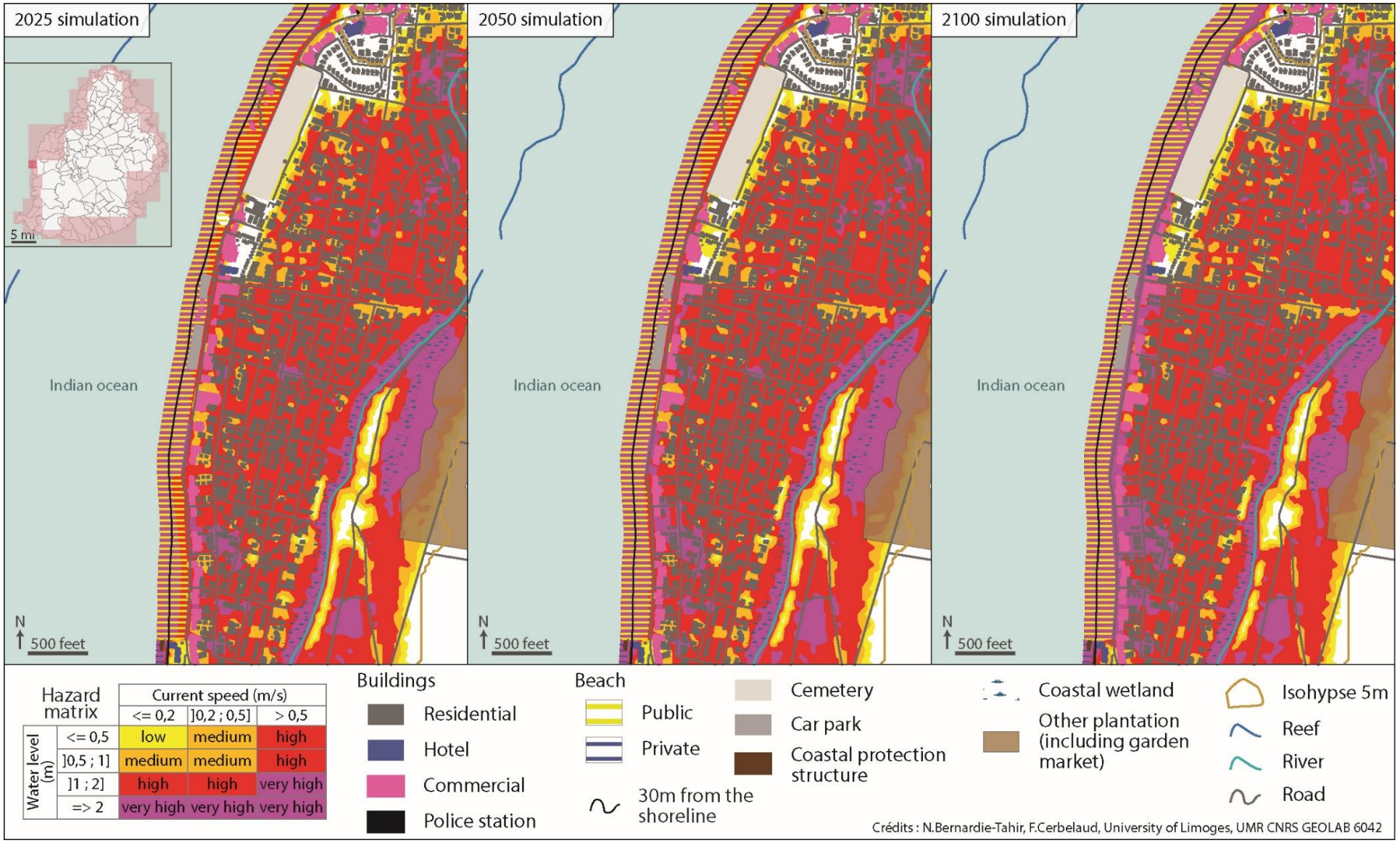


Human assets and safety scenario of coastal retreat due to erosion in Grand-Baie

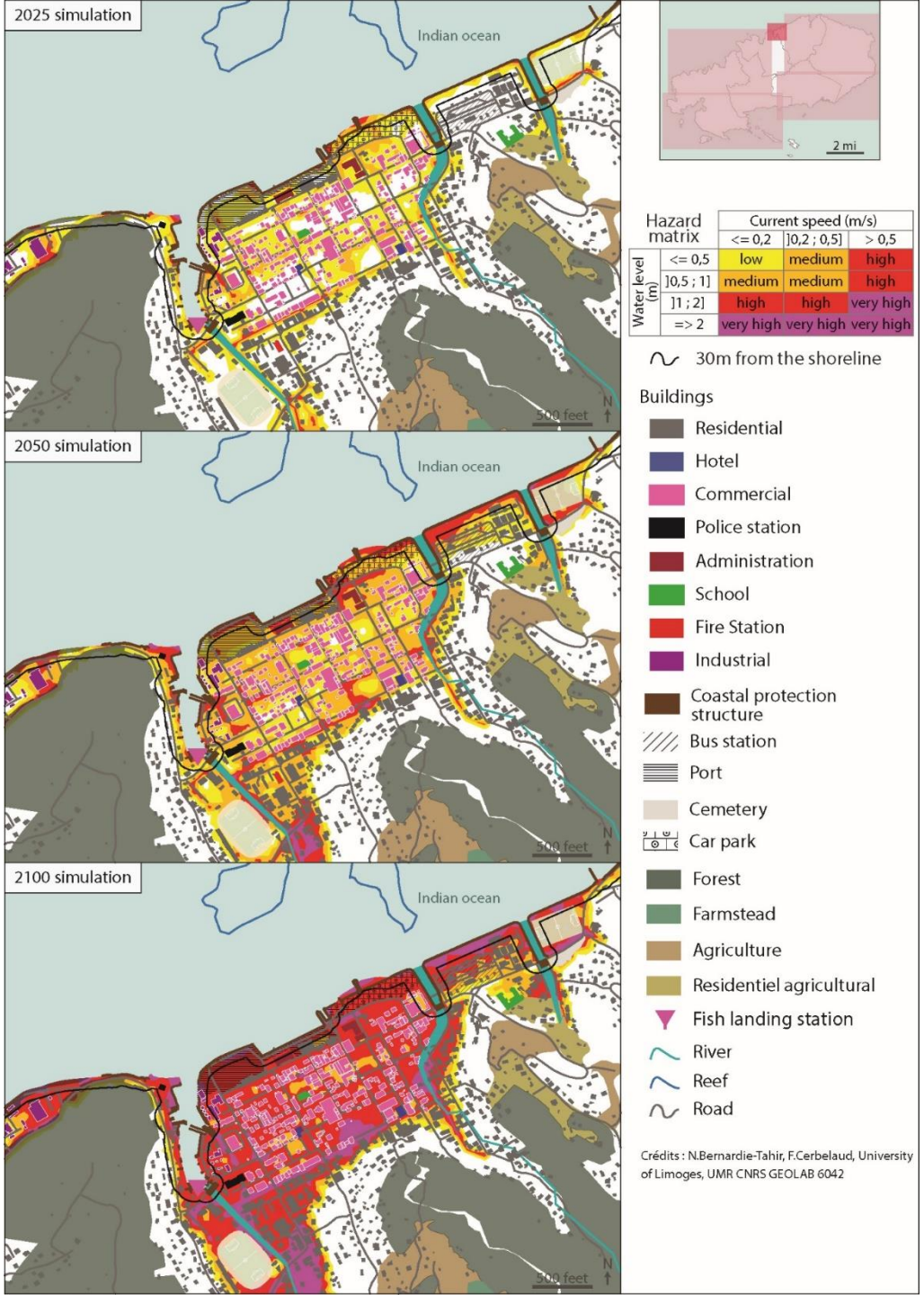


Human assets and safety scenario of coastal retreat due to erosion in Le Morne

Aléa **submersion** / enjeux / vulnérabilités



Human assets and coastal flooding in 2025, 2050, 2100 in Flic-en-Flac



Human assets and coastal flooding in 2025, 2050, 2100 in Port-Mathurin

Adaptation measures and NBS

Adaptation measures

There are many different adaptation measures which can be applied to Maurician context. But which ones are adapted to the Mauritian context, and which ones are effective?
44 actions were subjected to a qualitative evaluation based on 13 general evaluation criteria as to :

⇒ Give an **initial assessment** of adaptation measures to coastal risks, whatever the study site.

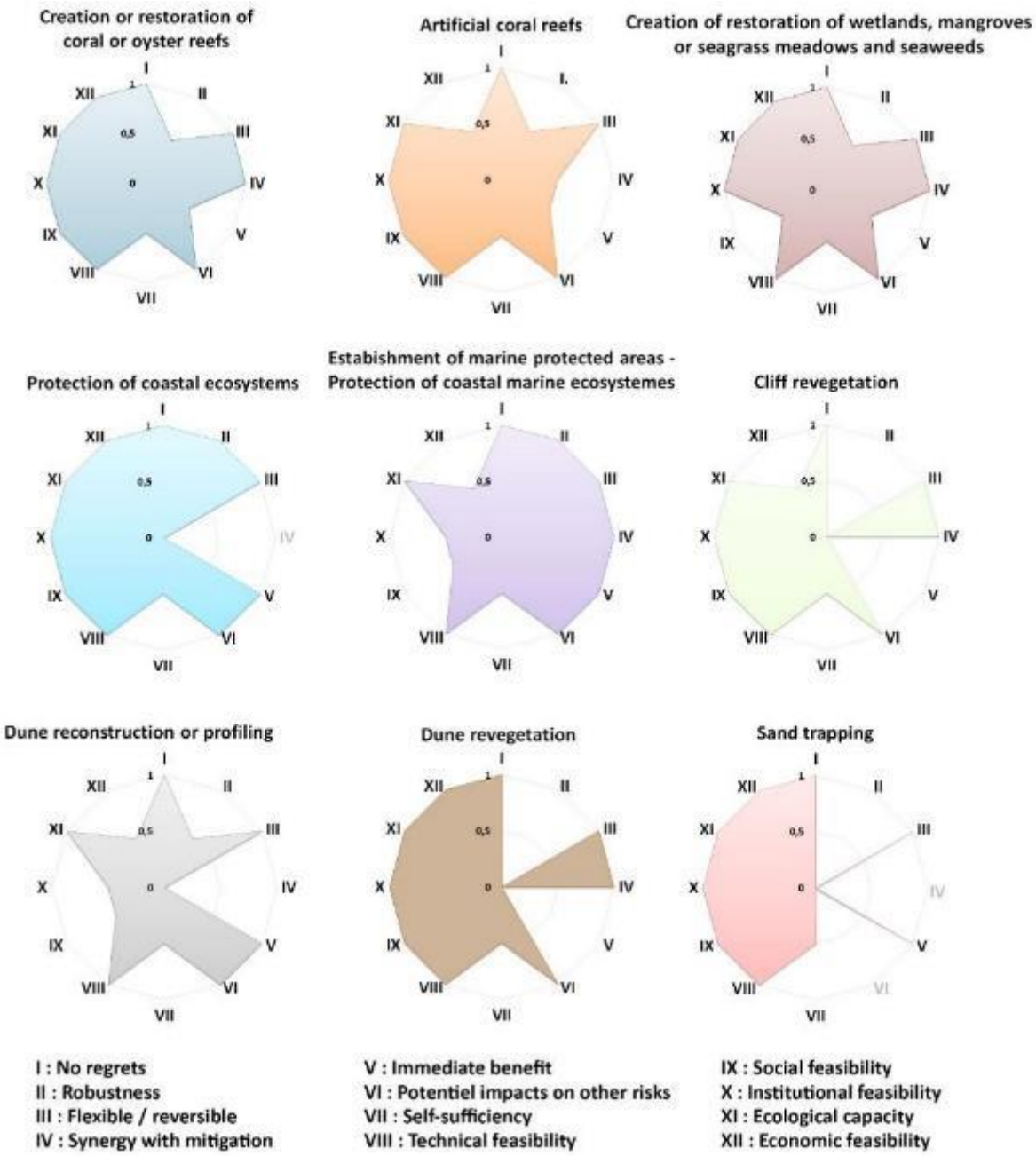
⇒ to identify the **main advantages and disadvantages** of **each meaasure** in relation to the evolution of risks

Categories	Sub-categories
Marine and coastal Nature-Based Solutions (NBS) - 12 actions	Actions on reefs
	Actions on vegetation
	Management
	Actions on dunes
	Actions on cliff
Built infrastructure and technology - 17 actions	Technology
	Actions on beach
	Actions on cliff
	Coastal structures
Socio-institutional adaptation - 15 actions	Management and legislation
	Crisis management
	Increasing knowledge and communication
	Urban planning and related measures
	Strategic retreat

Criteria

- No Regret,
- Robustness,
- Flexibility and reversibility,
- Synergy with mitigation,
- Immediate benefice,
- Potential impact on other risks,
- Life expectancy,
- Self-sufficiency,
- Technical feasibility,
- Social feasibility,
- Institutional feasibility,
- Ecological capacity,
- Economic feasibiliy

Example of analysis of NBS adaptation measure



Comparison of the radar diagrams obtained against 12 criteria for measures in the Nature-based Solutions category

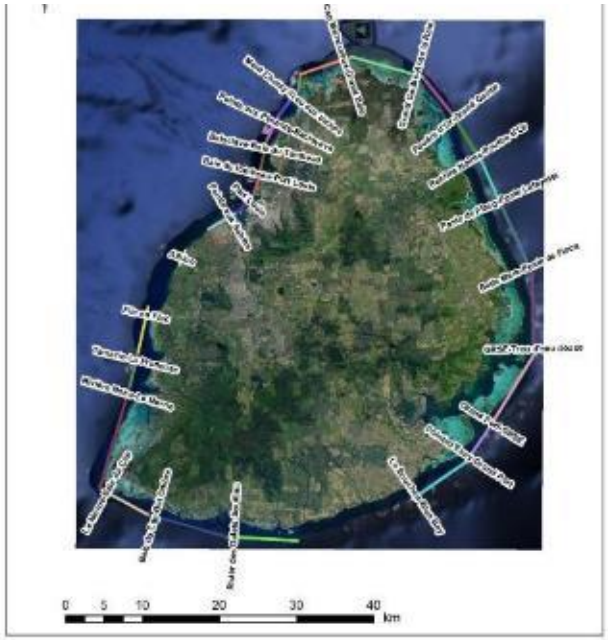
Analysis of the potential of NBS by homogeneous segment

- What is the potential for using NBS for mitigation of coastal hazard in Mauritius and Rodrigues ?
- 6 main ecosystems are considered : récifs coralliens, mangroves, herbiers marins, marais côtiers, vasières, plages de sable et dunes
- 5 criteria (Anthropogenic pressure, Manageability, Reef dependency, hazard, Historical context)

The coast is **analysed by homogeneous sectors** using criteria.

⇒ each sector is assessed in terms of its potential for using NBS for hazard mitigation

⇒ Categorizing the potential of each sector as: Strong/medium/weak



Coastal segments used in the analysis of ecosystems and NBS for Mauritius

Synthetic table of potential NBS application for hazard reduction (realized for each coastal segment)

Albion

Pressures and ecosystems			
Ecosystems (ESA - type)	Exposure to pressure (High - Medium - Low)	Confidence level (Good, Medium, Low)	Ecosystem state (both structural and functional) (Good - Vulnerable - Poor)
Sand beaches / dunes	High (artificialization, tourism)	Low	na
Seagrass	High (artificialization, tourism)	Good	Poor (threatened seagrass beds)
Reefs	High (artificialization, tourism)	Good	Poor (reef mortality)
Coastal vegetation	na	na	na

Pressure and pressure management (technical, social, and institutional feasibility)		
Main pressures and pressure-generating activities	Confidence level (Good, Medium, Low)	Management potential
High artificialization (urbanization, tourism)	Good	Difficult without major changes (political, economic)
Visitor pressure (tourism)	Good	Feasible
Physico-chemical pressures (urbanization)	Good	Challenging but possible (documented initiatives and intentions)
Anchoring	Medium	Feasible
Biological pressure (Acanthaster)	Good	Challenging but possible (documented initiatives and intentions)

Reef dependency level (High - Medium - Low)
High >50%

Hazard	
Erosion (High - Medium - Low)	Flooding (High - Medium - Low)
High	High

History of the sector and protections in place (actions on ecosystems)
Current actions identified : Awareness Monitored site (water quality)

NBS potential for hazard mitigation	
Key points	The sector benefits of strong awareness. Several ecosystems are present. Water quality is monitored. No irreversible impact from physico-chemical pressures. Vulnerable coral (threats to manage, water quality). Threats to seagrass to be managed (anchoring, human activity)
Conclusion	**To be considered and analyzed according to sector margins**

Conclusion :

In Mauritius, NBS solutions can be effective in 18 sectors (75%), while 6 sectors are unsuitable or marginally suitable.

On Rodrigues, NBS solutions can be effective throughout the island (100%) because anthropological pressures are still limited.

Products :

Decision support tools for adaptation strategy and NBS implementation strategy

Thank you
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