



**CTCN**  
CLIMATE TECHNOLOGY  
CENTRE & NETWORK

**MPA**  
Mauritius Ports Authority

# Climate change vulnerability and adaptation study for the port of Port Louis in Mauritius

CTCN Technical Assistance Project – Ref Nb 2016000013

## D1 – CONTEXT IDENTIFICATION REPORT



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## ACRONYMS

<b>MPA</b>	Mauritius Ports Authority
<b>ICZM</b>	Integrated coastal zone management
<b>CCD</b>	Climate Change Division
<b>MMS</b>	Mauritius Meteorological Services
<b>MOI</b>	Mauritius Oceanography Institute
<b>CC</b>	Climate change
<b>JICA</b>	Japan International Cooperation Agency
<b>UNDP</b>	United Nations Development Programme
<b>UNFCC</b>	United Nations Framework Convention on Climate Change
<b>GEF</b>	Global Environment Facility
<b>MCT</b>	Mauritius Container Terminal
<b>GIS</b>	Geographic Information System
<b>MoESDDBM</b>	Ministry of Environment, Sustainable Development, and Disaster and Beach Management
<b>TEU</b>	Twenty-foot equivalent unit
<b>CD</b>	Chart Datum
<b>UNCTAD</b>	United Nations Conference on Trade and Development
<b>IFC</b>	International Finance Corporation
<b>MEXA</b>	Mauritius Export Association
<b>NOAA</b>	National Oceanic and Atmospheric Administration
<b>IOWAGA</b>	Integrated Ocean Waves for Geophysical and Other Application

## INTRODUCTION

Mauritius, as a small island developing state, is highly vulnerable to the adverse impacts of climate change. Port Louis harbor is exposed to a number of combined risks from sea level rise including storm surge, flooding and more powerful and frequent winds, thereby challenging the resilience of the port infrastructure whilst at the same time disrupting the supply chain.

The objective of the study is to conduct a climate change vulnerability and adaptation study for the port of Port Louis and assist with the identification of adaptation options and their monitoring.

The scope and nature of the technical assistance include:

- Review existing national plans and strategies related to the port sector in the context of climate change, to identify opportunities and options to address gaps and needs ;
- Undertake a climate risk assessment for the port of Port Louis, to identify current vulnerabilities and future risks, evaluate the risks, identify and prioritize adaptation options using a multi-criteria analysis and set a monitoring baseline ;
- Formulate an action plan for the implementation of adaptation options in relation to climate change for the port sector, with specific action targets and time frames ;
- Identify capacity building needs of engineers, marine personnel and other cadres of the port sector, on climate change, vulnerability assessment monitoring and evaluation and adaptation technologies.

This report, as Deliverable 01, is the context identification report, presenting a review of background documentation, mapping of port infrastructure and operations, historical impacts of climatic events and preliminary recommendations for port resilience.

# 1. INCEPTION MISSION

## 1.1. SITE VISIT

A site visit was organized on 14th to 18th of January 2019, including a kickoff meeting, visual inspection, meetings and interviews with stakeholders and data collection.

The table below presents the meetings organized:

**Tabl. 1 - Inception mission agenda**

Date	Meetings details
Tuesday 15 JAN	Inception meeting with MPA followed by site visit of the port area Workshop to identify the vulnerability matrices and operation thresholds
Wednesday 16 JAN	Department of Environment (ICZM, CCD etc) – Mr. Oh Seng
	Ministry of Finance and Economic Development – Mrs Ramsurn
	Mauritius Meteorological Services – Mr Raj Durmeea, Deputy Director MMS
Thursday 17 JAN	Training sessions : <ul style="list-style-type: none"><li>• Scientific and technical aspects of Climate Change (CC);</li><li>• Climate Finance: Ports adaptation project financing possibilities.</li></ul>
Friday 18 JAN	Mauritius Oceanography Institute (MOI) - Mrs Ruby Mootienpillay, Director
	MPA, Management Support Services - Mrs Aruna Devi Bunwaree Ramsaha, the Deputy Director General
	National Disaster Risk Reduction and Management Centre –Mr Servansing
	Debriefing meeting with MPA

Data collection was initiated during the site visit and continued afterwards. The list of collected documents is presented in chapter 1.2.

During the visit, part of the Capacity Building Program was carried out, with two training sessions on the following themes: Scientific and technical aspects of Climate Change (CC); Climate Finance: Ports adaptation project financing possibilities (presentations are included in **Erreur ! Source du renvoi introuvable.**).



**Fig. 1. Training session at MPA premises (17/01/2019)**

## 1.2. DATA COLLECTION

The inception mission aimed at collecting relevant data, documents and information relative to existing national plans and strategies on the port sector with relation to climate change resiliency, and also mapping past impacts of climate change on the operation of the ports.

Data collection continued throughout the project where gaps have been identified. Some specific data has been acquired for the purpose of the study (wind and bathymetry data).

Table 2 presents the data made available for this study, in particular by the Ministry of Environment and Sustainable Development and in the Mauritius Port Authority.

**Tabl. 2 - Available data**

Documents	Status
JICA, 2015, Coastal Conservation Plan (CCP) for the Baie du Tombeau, Pointe aux Sables and Albion regions under the JICA Project for Capacity Development on Coastal Protection and Rehabilitation in the Republic of Mauritius	collected
GIBB, PRDW, June 2017, Consultancy Services for Coastal Protection, Landscaping and Infrastructural Works in Mauritius / Preliminary Design Report Baie du Tombeau site, Ministry of Social Security, National Solidarity, and Environment and Sustainable Development (Environment and Sustainable Division)	collected
Project Document (project currently under implementation): Accelerating the Transformational Shift to a Low-Carbon Economy in the Republic of Mauritius ( <a href="https://www.greencclimate.fund/projects/fp033">https://www.greencclimate.fund/projects/fp033</a> )	collected
2012, National Climate Change Adaptation Policy Framework for Republic of Mauritius, UNDP	collected
April 2017, UNFCCC Third national communication report for the Republic of Mauritius, Ministry of Environment, Sustainable Development, and Disaster and Beach Management	collected
UNDP, Adaptation Fund, 2017, Consultancy Services for the preparation of a National Coastal Zone Adaptation Strategy for the Republic of Mauritius, Ministry of Environment, Sustainable Development, and Disaster and Beach Management	collected
Climsystem, 2014, Assessing the costs of coastal inundation for Baie du Tombeau, Port Louis, Mauritius	collected
Brief Adap'action	collected
Brief GEF Energy Efficiency Project	collected
Draft Climate Change Bill	collected
Factsheet Nationally Appropriate Mitigation Actions for Low Carbon Island Development Strategy for Mauritius (NAMA)	collected
Technology Needs Assessment Projects (TNA) (Adaptation, Energy, Mitigation)	collected
Table summarising the total climate financing that Mauritius has been able to mobilize after the Paris Climate Agreement.	collected
Downtime at the Mauritius Container Terminal (MCT) (due to swell, wind warning, heavy rainfall) for the last 9 years.	collected
High resolution map of the port, with land cover information (identified assets, infrastructures, areas, activities and buildings)	collected
Organigram of the MPA	collected
Former and new masterplan of Port Louis harbor (extracts)	collected
Design study of the flood wall	collected
Cranes specifications	collected
MOI study relative to wave and tide data (records on 5 months in Jan-May 2018)	collected
Rain, wind and pressure data on the following events: cyclone Lola in March 2008, cyclone Carol in 1960, cyclone Dutch, flash floods in March 2013	collected
Bathymetric data around the Container Terminal	collected
Long time series of wind measurements at Fort William	collected

Table 3 presents the additional data requested for this study but not made available. For the purpose of the study, data gaps have been filled with publicly available data wherever possible. Implications are discussed in the methodology section.

**Tabl. 3 - Missing data**

<b>Documents</b>	<b>Status</b>
Former and new masterplan of Port Louis harbor	Partially available
Technical study and design of island terminal and breakwater structure at Port Louis harbor	Confidential
Specific numerical modeling study report for the island terminal and breakwater structure (including wave time series)	Confidential
Specific report of the physical modeling study for the island terminal and breakwater structure	Confidential
Flooding and landslide national risk profile	Public sources
Long term times series of climatic parameters (>15 years): water level, wave, pressure, temperature, for statistical analysis	Public sources
Topography (on the water catchment)	Public sources
Bathymetry (West Coast of Mauritius)	Public sources
GIS of hydrographic network	Public sources
Port Louis Drainage Study (for the landside flood risk)	Not available

## 2. REVIEW OF DOCUMENTATION AND HISTORICAL IMPACTS

### 2.1. REVIEW OF EXISTING PLANS AND STRATEGIES OF ADAPTATION TO CLIMATE CHANGE, IN RELATION TO PORT LOUIS HARBOR

Mauritius has been ranked 16th country with the highest disaster risk and 10th as the most exposed to natural hazards as per the 2018 World Risk Index. The threatening impacts of climate change in Mauritius are already being felt with an accelerated sea level rise, accentuated beach erosion, increase in frequency and intensity of extreme weather events such as flash floods, cyclones and water scarcity.

National, sectoral strategies and plans have been elaborated to implement the recommendations of the international conventions. Key legislative and policy measures have been set in place to strengthen the environmental management and sustainable development frameworks of the country.

The MoESDDBM (Ministry of Environment, Sustainable Development, and Disaster and Beach Management) has the mandate to fulfil the reporting requirement of Mauritius to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol (KP) and now the Paris Climate Change Agreement. Since March 2010, a Climate Change Division has been established at MoESDDBM. It is in charge of the coordination of climate change activities and the mainstreaming of climate change action into key sectors.

#### 2.1.1. Relevant national plans and strategies mentioning Port Louis Harbour

The existing national plans and strategies relevant to the Mauritian Port Sector in general and Port Louis in the context of projected impact for Climate change are presented below. Relevant extracts include:

- **Third national communication report for the Republic of Mauritius, Report to the United Nations Framework Convention on Climate Change:**

*(quote) "The infrastructure sector in Mauritius is already affected by adverse impact of climate change with the recent occurrences of cracks on roads, collapse of bridges, flooding of culverts, and damages due to landslides.*

*The Mauritius Container Terminal (MCT) is particularly vulnerable to the impacts of severe weather systems such as heavy swells, strong winds, gusts and storm surges, which may result in stoppage of operations for several days. For instance, adverse weather conditions in 2013 led to a stoppage of port operations for 21 days resulting in a shortfall in revenue of about MUR 3.9 billion and in 2014, the suspension for 10 days represented a shortfall in revenue amounting to MUR 1.9 billion.*

*Recently, during the period from 10 to 13 March 2015, the Mauritius Ports Authority (MPA) had stopped all operations and closed the port for 79 hours due to storm surges so that the safety and integrity of Port infrastructures and ships in the harbor were maintained."*

- **The Master Plan of Port Louis Harbor:**

*[Only extracts of the current and former Master Plans (2009 and 2016) have been collected by the Consultant, the main part of the reports being considered as confidential by MPA.]*

The MPA has commissioned a new Port Master Plan which caters to the requirements of the port for the next 25 years, taking into consideration new opportunities such as transshipment, bunkering, seafood, cruise and ocean related businesses. It was required to prepare a traffic forecast and make recommendations for port infrastructure required to handle the future traffic and propose a land use plan.

On the basis of the collected document (Executive summary, 05\_Existing port infrastructure and facilities, 06\_7\_Port operations analysis), no specific mention to climate change or even natural risks impacts is mentioned, except one sentence relative to the flood wall:

*(quote) "A flood defense barrier set back from the quay does consume otherwise valuable stacking and operational space but is crucial to protecting against flood waters during cyclones."*

Nevertheless, the port infrastructure to be constructed needs to be designed whilst taking into consideration the impact of climate change.

■ **The National Disaster Scheme (NDS) from the National Risk Reduction and Management Centre:**

The NDS is intended to be a functional document to support agencies and stakeholders in understanding and undertaking their roles, responsibilities and actions in emergencies. This document is organized per risk: cyclone, Heavy Rain/ Torrential Rain/ Flooding, tsunami, high waves, water crisis, earthquake, landslide, Port Louis Flood Response Plan.

*(quote) "Recommendations to Mauritius Ports Authority (MPA) are included in the document, regarding cyclone, tsunami, high waves and within the Port Louis flooding response plan."*

■ **The National Disaster Risk Reduction Strategic Framework and Action Plan, 2013:**

*[This document has been made available to the Consultant with a confidential status]*

It was developed to identify risks and assess the exposure of people, property, critical facilities, infrastructure, and economic activities as well as the potential losses (human, economic and financial) related to flooding, coastal inundation and landslide prone areas.

According to established scenarios, high coastal risk due to storm surges near Port Louis occurs in an area from Baie du Tombeau to Baie de la Grande Rivière, East of the port.

### 2.1.2. Other relevant national plans and strategies

Some relevant national plans and strategies in the framework of climate change adaptation do not mention specifically the port:

■ **National Climate Change Adaptation Policy Framework, 2012:**

It focuses on the following sectors: Water demand and supply, Agriculture and terrestrial ecosystem, Fisheries and marine ecosystem, Tourism and coastal management. Port Louis city and Port Louis harbor are included as coastal areas in Tourism and coastal management.

**Tabl. 4 - Tourism and coastal management plan (National Climate Change Adaptation Policy Framework, 2012)**

**6.4.4 Tourism and coastal management**

Issues	Interventions	Indicator subset 1	Impacts	Indicator subset 2
Water needs competing with needs of local communities	Water efficiency, rainwater harvesting, desalination	Number of desalination plants in operation in hotels	Increased water autonomy from hotels and increased water availability for local communities	Water availability in communities nearing hotels
		Number of rainwater harvesters in operation in hotels		
Coastal erosion affecting infrastructure, beaches and tourist attractions	Protection of critical ecosystems such as coral reefs and mangroves, economic valuation of ecosystem services	Beach erosion rate (meters per year)	Increased quality of tourist product and increased quantity of visitors	Proportion of “repeaters”(% of total visitors)
		Coral cover and coral condition (live, bleached, broken, etc.)		Tourism revenue
	Implement setbacks and protection measures	Infrastructure affected by sea-level rise	Existing and planned infrastructure protected or reviewed	Avoided losses in infrastructure
			All of the above	Job creation

It recommends cross-sectoral and sectoral investments, in particular flooding management plans (including Port Louis basins flood management plan) and coastline management plans for inundation (including Port Louis coastline management plan and Grand Port coastline management plan).

■ **Other documents:**

Many guidelines, programs and studies have been carried out regarding climate change adaptation strategies in coastal areas, such as:

- Guideline for Climate Change Adaptation Strategy (Coastal Setback), JICA;
- The Project for Capacity Development on Coastal Protection and Rehabilitation in the Republic of Mauritius, JICA;
- Consultancy Services for Coastal Protection Landscaping and Infrastructural Works in Mauritius, Preliminary design report, Baie du Tombeau site, GIBB, June 2017;
- The Adaptation Fund Project “Climate Change Adaptation Program in the Coastal Zone of Mauritius”;

The port of Port Louis as coastal infrastructure is not included in these documents.

The port of Port Louis, as a crucial infrastructure for the whole Mauritian economy, is highly vulnerable to the adverse impacts of climate change, as it is exposed to a number of combined risks from sea level rise including storm surge, flooding and more powerful and frequent winds. Nevertheless, the main national plans and strategies documents, as the National Climate Change Adaptation Policy Framework or Guideline for Climate Change Adaptation Strategy (Coastal Setback) do not mentioned specifically the issue of the port. If mentioned, the port is mainly considered as a common coastal asset (like beaches or touristic infrastructures). It is not presented as a crucial asset per se, considering its economic and logistical role within the Mauritian economy.

## 2.2. HISTORICAL IMPACTS

Data concerning historical impacts are scarce. Impacts have been identified based on discussions with MPA and MMS.

The main climate change disruption for the operations of the port of Port Louis is linked to bad weather, especially during the cyclonic season. The main current impacts of natural hazards impacting the port operations are the followings:

- Flooding of the quays by overtopping waves (swell) ;
- Stoppage of crane operations due to excessive wind speeds;
- Insufficient visibility due to heavy rainfall.

The adverse effect of strong swells and winds is mainly limited to the container quay; however heavy rainfalls may cause flash floods at the scale of the whole city of Port Louis. The Port is mainly concerned by the floods of the streams Latanié and Le Pouce. The most striking flash flood was the event of March 2013 which impacted the Caudan waterfront in the city centre but did not reach the port area.

The figure below represents the main components and areas of the port system, highlighting the most vulnerable areas, as indicated by MPA. The numerical modelling in deliverable O2 allows to better estimate the area impacted by operational and extreme climatic events.



**Fig. 2. Overview of the existing vulnerable areas, as identified by MPA**

Three additional information sources are worth mentioning to illustrate the impact of climate events on the port or its surroundings:

- A video of an overtopping event on the Mauritius Container Terminal, made available by MPA (figure below, date and conditions unknown);
- A video on Youtube illustrating slight overtopping at the end of the port basin on the Caudan waterfront (near the Astrolabe Shopping Centre), during a cyclone (outside of port premises, not illustrated above);
- An online press article describing the impact of the flash flood of 2013 in Port Louis city centre and on the Caudan waterfront (outside of port premises, not illustrated above).



**Fig. 3.** Photo extracted from a video of an overtopping event at the western end of the Mauritius Container Terminal, with the oil terminal jetty in the distance (source MPA). Date and conditions are unknown.

### 3. IDENTIFICATION OF VULNERABILITY MATRIX AND THRESHOLDS

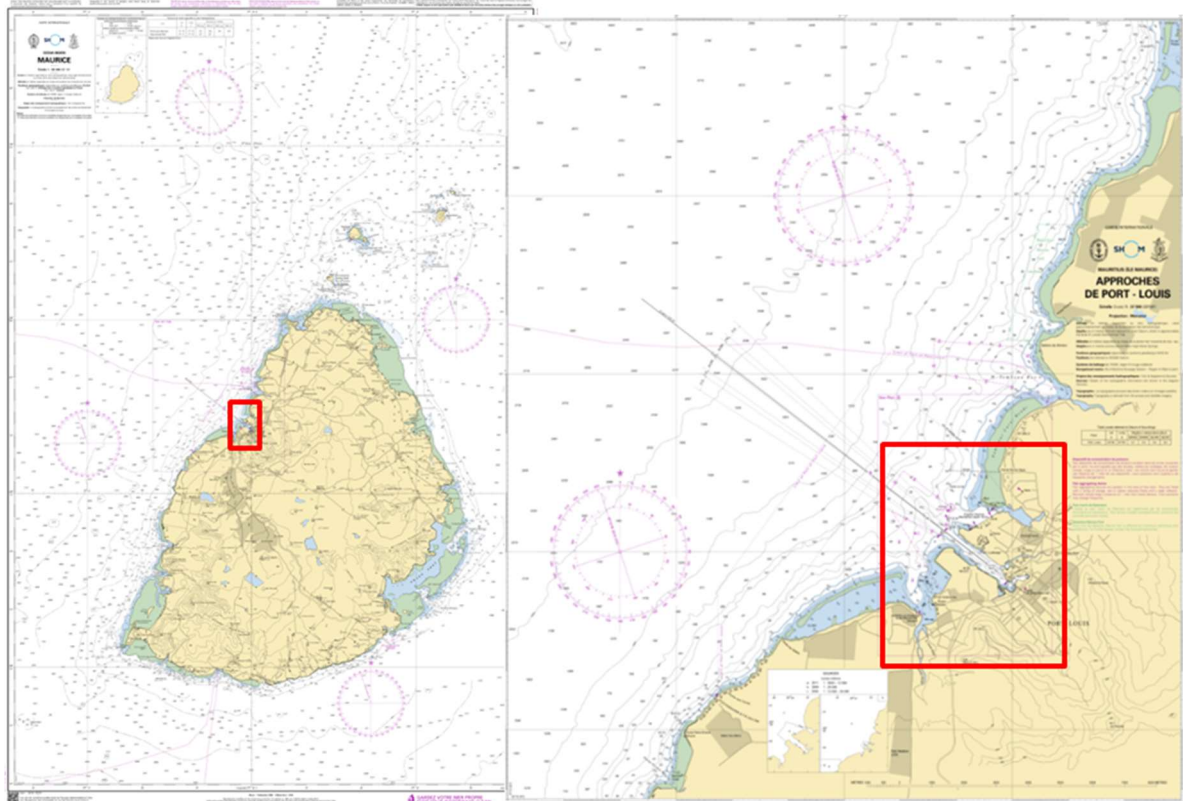
#### 3.1. PORT INFRASTRUCTURE AND OPERATIONS

The Mauritius Ports Authority (MPA) is the sole national port authority set up under the Ports Act 1998, to regulate and control the port sectors in the Republic of Mauritius, including Rodrigues and all outer islands.

The MPA is a landlord port authority, providing the main port infrastructure and superstructure, together with related facilities. It also provides marine services and navigation aids, while it regulates and controls all port activities and environmental issues within the designated port areas.

### 3.1.1. Commercial presentation

The port of Port Louis is located close to the city of Port Louis, the capital city of Mauritius, in the North-Western part of the country.

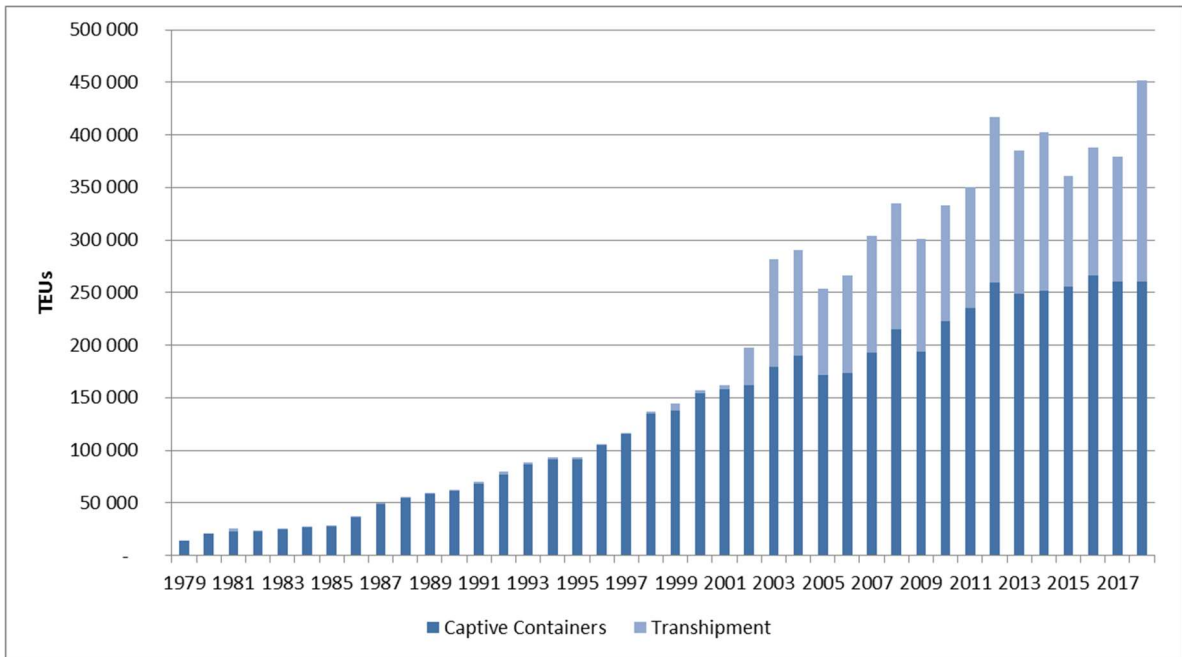


**Fig. 4. Location of MPA in Mauritius (SHOM map)**

As the principal gateway of the country, Port Louis Harbor plays a vital role in the national economy by handling about 99% of the total volume of the external trade. All strategic imports such as food and petroleum products, raw materials for the textile industry, and major exports such as sugar and textile, transit through the harbor. The port sector contributes more than 2% to Mauritius GDP.

General cargo traffic represents half of the total traffic. As in many small islands, import traffic has a predominant weight compared to export traffic (84% of total cargo traffic in 2018, 71% of total container traffic).

At the end of the 1990s, Mauritius opted to develop its transshipment activity. The choice is appropriate since no other regional island port held this position. Today, transshipment represents 30% of Mauritius' port traffic. The port becomes an important hub for the transshipment of containers moving between other countries and plays a role in redistributing to the secondary ports in the area, which are less served by the main transoceanic lines.



**Fig. 5. Container traffic historical data (captive and transshipment) (MPA data)**

Currently Port Louis is mainly served by two ship-owners: MSC and Maersk. They account for 79% of container traffic in Mauritius. Maersk mainly serves Mauritius from its hubs in Salalah (Oman) and Tanjung Pelepas (Malaysia). MSC includes Mauritius on its long-distance lines, such as the Australia Express (which runs from Australia to Europe) or the Africa Express (which links China to West Africa). CMA-CGM, having relocated its activities on Reunion Island, has deserted Port Louis.

The Government plans to develop the Port Louis Harbor into a regional maritime, logistics and business hub. The objective is to provide a port that is well equipped, professionally managed and constantly upgraded to promote higher productivity and performance at competitive rates. In this respect, Mauritius intends to embark on a strategy that would result in a substantial increase in transshipment trade, from 268,820 TEUs in 2013 to about 495,000 TEUs by 2020 and 745,000 TEUs by 2025.

### 3.1.2. Technical presentation

#### 3.1.2.1. Navigation channel and port basins

Fig. 6 below gives an overview of the port.

Port Louis is accessible through two dredged channels: one channel providing access to the Mauritius Container Terminal (MCT) and Oil Jetty, and the other channel allowing access to the other parts of the port (i.e. Terminal I, Terminal II, Bulk Sugar Berth, etc.).

The navigation channel to the MCT has been dredged to -14.5m Chart Datum (CD) and has a channel width of 360m.

The navigation channel to Terminals I and II has a maintained depth of -12.5m CD and a channel width of 180m. The channel has a turning circle with a diameter of 350m, which is located between Terminal II and the cruise jetty.

Basin depths in Trou Fanfaron and the Lataniers basin are much shallower, featuring a basin depth between -5mCD and -6mCD.

#### 3.1.2.2. Terminals

Port Louis Harbor includes a dedicated container terminal, a multi-purpose terminal as well as terminals for handling fish and dry bulk products like coal, sugar, wheat and cement; a petroleum jetty for the discharge of petroleum products and a dedicated cruise jetty to accommodate cruise vessels.

Port Louis features three main Terminals:

- Terminal I comprises multi-purpose quays A to D and the fish berths in Lataniers Basin and Trou Fanfaron;
- Terminal II consists of multi-purpose quays 1 to 4, and
- Terminal III includes the two Mauritius Container Terminal berths, offering a quay length of 560 meters by -14.0 m CD, supported by 24 hectares of terminal area.

Further quay facilities include the bulk sugar terminal and cruise jetty at the southern side of the port and the Oil Jetty just west of Terminal III. Recently a port extension has been completed West of the port basin at Fort William. This area was not in use at the time of writing.



**Fig. 6. Satellite view of the Port (MPA Master Plan, 2016)**

An expansion project of the Mauritius Container Terminal has been carried out in 2016-2017, which added 240 meters of quay at -16.5 meters CD and 7.5 hectares of yard space. The project also requires the extension of the quay apron by 9 meters seaward, deepening of the berth box and approach channel to -16.5 meters CD and new rails.

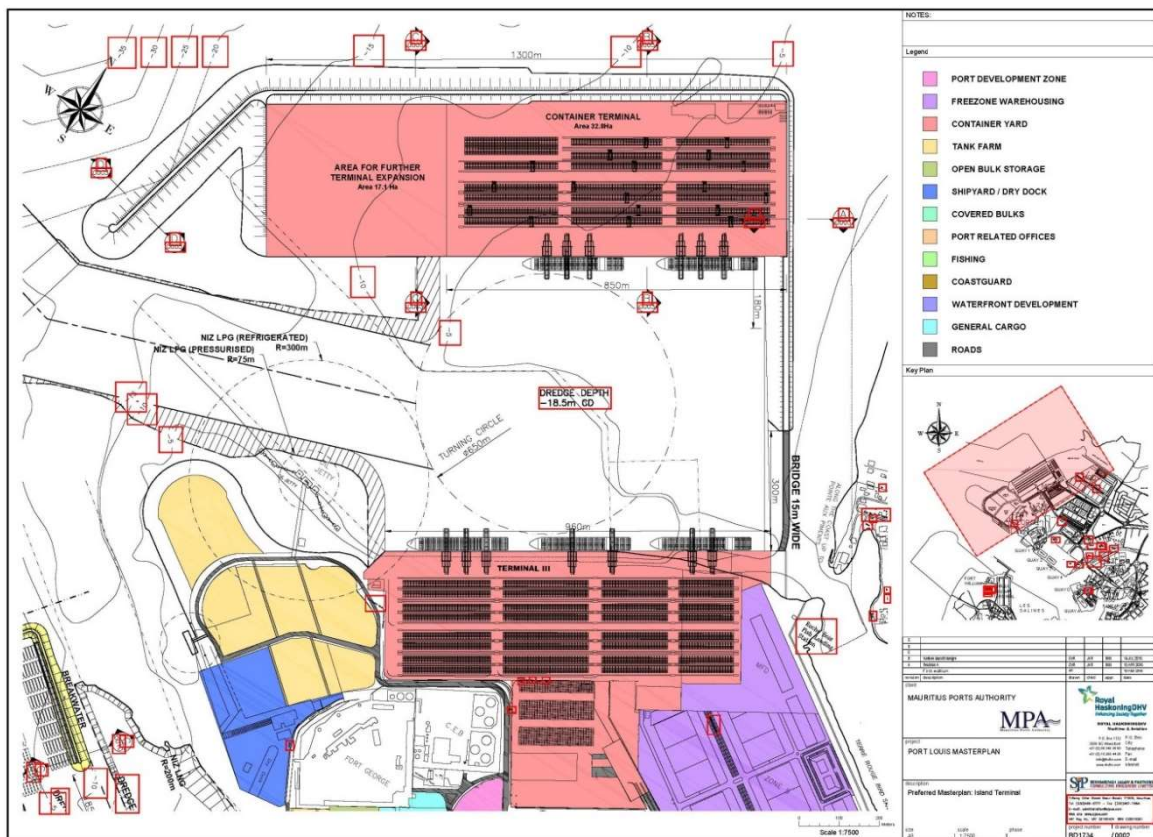
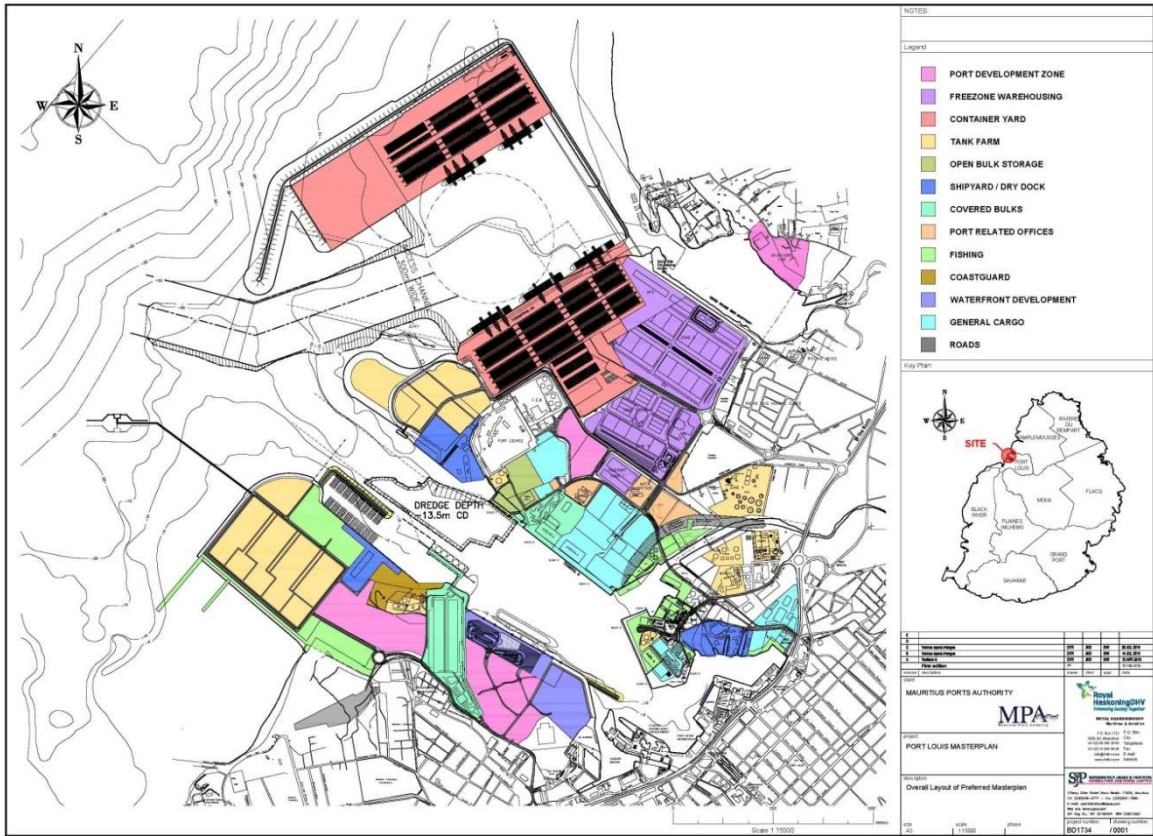


**Fig. 7. Satellite view of the MCT extension (MPA Master Plan, 2016)**

Once the full capacity of the 960m long berth will be reached (variously estimated at 1.1-1.4 million TEU per year), a further expansion will be needed.

The 2009 master plan suggested building a breakwater on the reef and a further terminal (the Island Terminal) on reclaimed land inshore of it. The project is also justified by the protection it will offer to MCT and the oil berth from wave action, reducing downtime. It will optimize the overall operation by allowing the new terminal to operate as a single unit with MCT. The cost of the breakwater is estimated at US\$224 million.

A preliminary technical study & design of island terminal and breakwater structure at Port Louis harbor has been carried out and presented in February 2019 to MPA, government officials, interested stakeholders, donors, port operators, other investors, etc.



**Fig. 8. Plans of the island terminal extension (MPA Master Plan, 2016)**

## 3.2. PORT VULNERABILITY AND OPERATIONAL THRESHOLDS

The analysis has been based on the recent methodological approaches relative to climate change vulnerability of the port system (case studies and generic vulnerability matrices). This documentation is enclosed in Annexes.

The preliminary analysis of the port vulnerability and operational thresholds has been carried out through a workshop with MPA organized during the Inception Mission.

### 3.2.1. Structural vulnerability

When designing infrastructure, climate change typically takes into account sea level rise. It is less common to take into account other parameters such as increased storm frequency, increased wind speed or wave height. Design parameters come in principle with an uncertainty interval, the upper bound being taken to account for such factors. However practices may differ.

According to MPA, the infrastructures have already been designed to take climate change into account. We assume this to be sea level rise. MPA or other stakeholders have mentioned no information relative to the existing structural vulnerability of the assets of the port of Port Louis. The economic impact of climate change will occur in the future, as the added cost of building new infrastructure for stronger loads, compared to building new infrastructure with present state loads. This potential additional cost may be analysed in the next steps of the project, when identifying potential adaptation solutions.

### 3.2.2. Operational vulnerability

The table below proposes a preliminary, high level operational vulnerability matrix based on the initial discussions with MPA. It concerns the present situation. This approach is refined in Deliverable 02 about the cost of climate change, to include a more detailed breakdown of port operations / assets and to include potential climate hazards not identified by MPA in the present situation.

**Tabl. 5 - MPA preliminary operational vulnerability matrix**

	Port operations	Navigation and berthing	Materials and handling	Vehicles and Movement	Goods storage	Transport and supply chains
		Accessibility and mooring	Crane operation	Vehicles' operation	Storage	Access
Climate hazards	Temperature increase	Not sensitive.	Not sensitive.	Not sensitive.	Very hot days can threaten perishable goods	Not sensitive.
	Heavy rainfall	Not sensitive	Heavy rain can reduce visibility, delaying shipping and transport.	Not sensitive	Not sensitive	Not sensitive
	Sea level rise	Higher sea levels can increase the risk of chronic flooding and lead to permanent inundation of dock facilities, making a port inoperable	Not sensitive.	Not sensitive.	Not sensitive.	Not sensitive
	Winds	Accessibility and mooring is not guaranteed above certain (extreme) wind speed.	Cranes cannot be used above defined wind speeds. Inoperable cranes can cause delays in shipping.	Not sensitive	Not sensitive.	Not sensitive
	Increase in extreme events (storms)	Increase in overtopping rates, hence flooding of berth facilities	Not sensitive.	Not sensitive	Not sensitive	Not sensitive

The slow down or closure of the port has the following consequences:

- For the shipping lines : forced stopover in South Africa and feeder service to Mauritius ;
- For the terminal operator : technical unemployment of the labour force ;
- For the private sector (represented by the Mauritius Export Association – MEXA): delays in goods supply and shipping.

As indicated by the Mauritius Export Association (MEXA), in 2013 the port has had to stop operations for a total of 21 days due to bad weather resulting in a shortage of revenue of around 3.9 billion rupees *at national level* (equiv. to 110 M US\$). Similarly in 2014 port operations had to be suspended for 10 days due to adverse weather conditions which financially represented a shortage in revenue amounting to 1.9 billion rupees for the country (equiv. to 54 M US\$). This corresponds to a reported cost *at national level* of about 5.4 M US\$ per day of closure.

For MPA specifically, an estimation of the closure cost has been made on the basis of the annual turnover of MPA during the period 2011-2015 (period of availability of financial data) and the number of operation days in the considered year. The MPA operation revenues per day could be estimated on average at 0.9 M US\$. This corresponds to a reported cost at the port level of about 17% of the cost at national level.

These numbers assume *full closure of the port* during periods of downtime, which may be a conservative assumption. Also the most appropriate financial metric to estimate the cost of climate change may depend on its end purpose. This approach is refined in Deliverable 02 about the cost of climate change.

### 3.2.3. Operational thresholds

The table below presents the operational thresholds identified with MPA for the main climate variables, in the present situation.

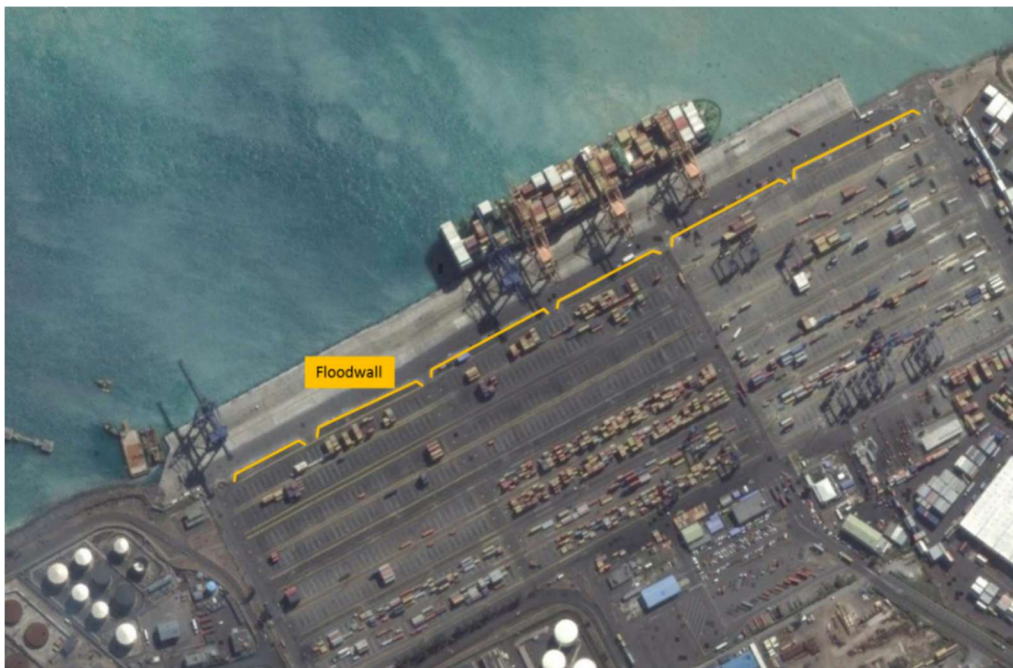
**Tabl. 6 - Operational thresholds of the port of Port Louis for the main climate variables**

	Operational threshold	Impact description	Comments	Quantified Impacts
<b>Heavy rainfall</b>	Decision taken by the TC operator	No visibility for the crane operators	Subjective decision likely based on rainfall intensity	1.7 days per year in average (2010-2018)
<b>Winds</b>	Wind speed > 18 m/s (65 km/h)	Cranes at the port are unable to operate	Season of strong winds : June-Sept	3.4 days per year in average (2010-2018)
<b>Increase in extreme events (storms)</b>	1. Waves > 2m 2. Waves > 1.5m	1. Ships are unable to stay in the basin 2. Ships under 200m length are unable to stay in the basin	Stop-over period of 1-2 days	10 days per year in average (2010-2018)
<b>Temperature increase</b>	<i>Pavement designed to tolerate maximum seven-day temperature of 41.4°C</i>	<i>Threaten perishable goods</i>	<i>Not mentioned by MPA and/or private sector</i>	NA

### 3.3. PRELIMINARY OBSERVATIONS ON THE QUALITATIVE EFFECT OF CLIMATE CHANGE AND ON PORT ADAPTATION

#### 3.3.1. Flooding of the quay

The flooding of the quay at the Mauritius Container Terminal (MCT) (altimetry is 2.6 m above chart datum) occurs during the passage of cyclones and in cases of adverse weather conditions. This concerns primarily overtopping due to wave action (swell). Accordingly, with a view to mitigate the effects of the flooding on the containerized cargo in the stack yard, a flood wall was proposed and has been constructed just in front of the stack yard.



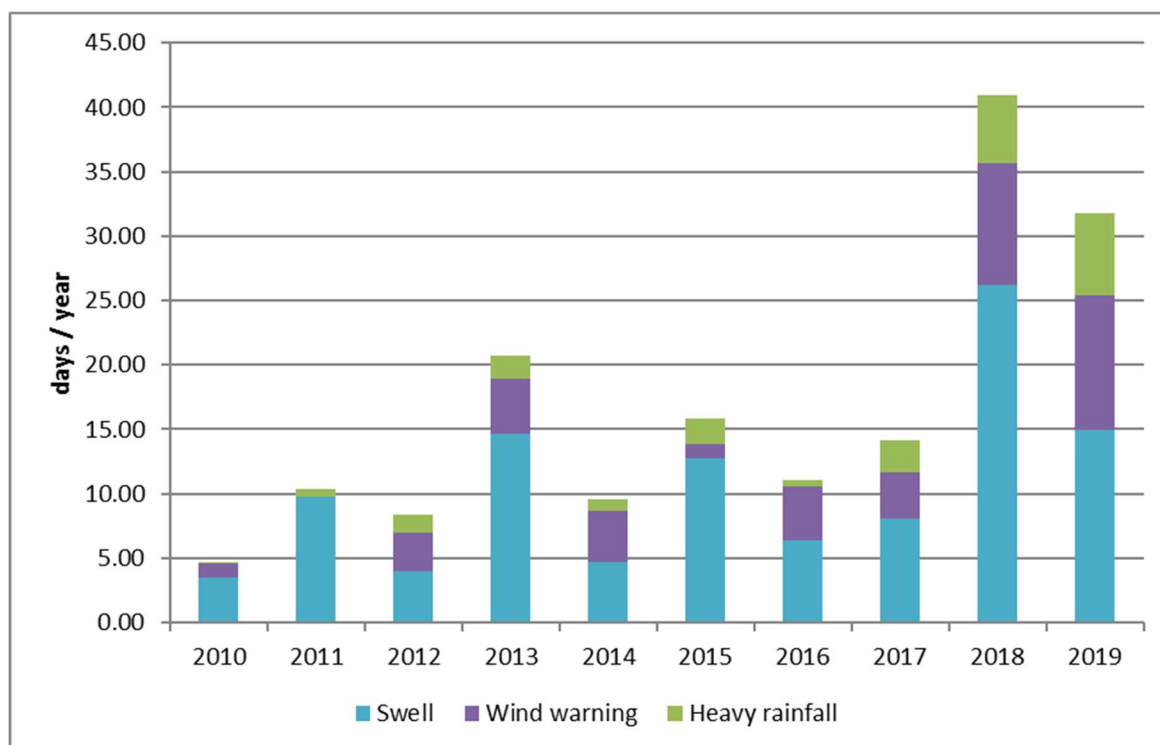
**Fig. 9. View of the flood wall**

### 3.3.2. Closure of the port

In addition to the flooding risk, already addressed by MPA, the main climate disruption for the port of Port Louis is the slow down or closure of the port linked to bad weather, especially in the cyclonic season. Bad weather can be important swell, a wind warning or heavy rainfall.

The figure below presents the closure period per year and per climate variable for the container terminal. It can be observed that swell is an important factor of operational downtime for MCT, followed by wind warning and then by heavy rainfall. As an illustration there were 20 days of closure in 2013 (three cyclones), 10 days in 2014 (two cyclones), and 42 days in 2018 (with 3 cyclonic warnings), the latter being the maximum observed.

No distinction is made to allow separating cyclonic swell events from normal SSW swell events as reported by MPA. This exercise is made below.



**Fig. 10.** Closure period par year and per climate variable for MCT (data MPA)

Above an expected wind of 120 km/h, the port can be preventively closed (administrative closure). Details of the cyclone warning system are shown in the table below.

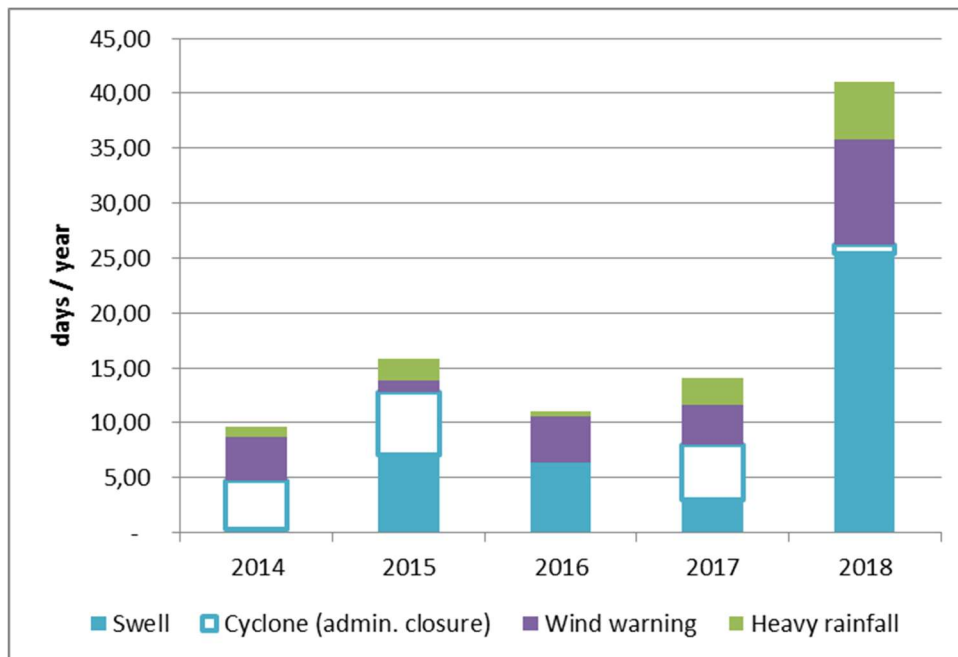
**Tabl. 7 - The cyclone warning system (Mauritius and Rodrigues)**

Cyclone class	General information	Administrative closure of the Port
<b>Class I:</b>	Issued 36 to 48 hours before Mauritius or Rodrigues is likely to be affected by gusts reaching 120 km/h.	No
<b>Class II:</b>	Issued so as to allow, as far as practicable, 12 hours of daylight before the occurrence of gusts of 120 km/h.	Yes

Cyclone class	General information	Administrative closure of the Port
<b>Class III:</b>	Issued so as to allow, as far as practicable, 6 hours of daylight before the occurrence of gusts of 120 km/h.	Yes
<b>Class IV:</b>	Issued when gusts of 120 km/h have been recorded in some places and are expected to continue	Yes
<b>Termination:</b>	Issued when there is no longer any risk of gusts exceeding 120 km/h	

The administrative closures in cyclone warning class 2 are shorter than the overall cyclone-related disruptions. The weather conditions start deteriorating much before the class 2 warning is announced and last much after the warning is terminated.

This second figure splits for the period 2014-2018 the downtime related to administrative closure and to others reasons for the container terminal.



**Fig. 11.** Closure period per year and per climate variable (incl. admin. closure) for MCT (data MPA)

The Terminal I and II are affected by the global administrative closure of the whole port site. They are more sheltered from swell waves but ships would never leave the port during a cyclone.

## 4. NORMAL AND EXTREME CLIMATE CONDITIONS IN THE PRESENT SITUATION

This section characterises the climate in Port Louis based on the data available. Trends and projections are analysed in Delievable 02 on the cost of climate change. Note that the data presented below is not suitable for design purposes.

### 4.1. CYCLONES

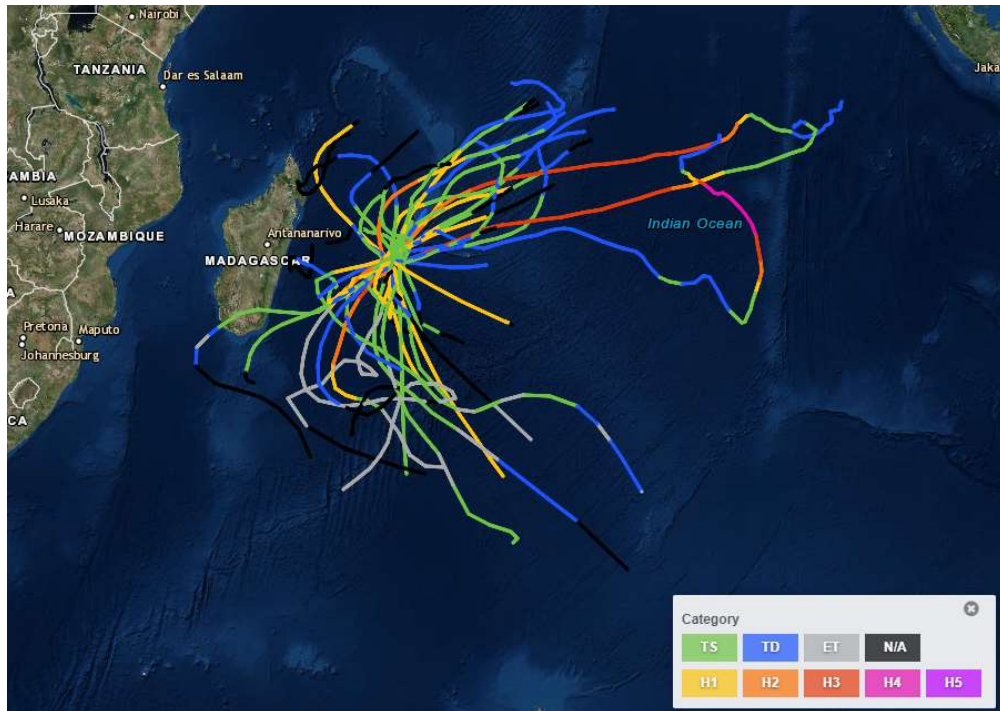
The Mauritius Meteorological Services (MMS) provides a list of historical cyclones having affected the island (<http://metservice.intnet.mu/publications/list-of-historical-cyclones.php>). The cyclones with pressure drops below 990 hPa are presented below.

**Tabl. 8 - List of historical cyclones (MMS)**

Year	Date - month	Name	Classification	Nearest distance from Mauritius	Highest gusts (km/h)	Lowest pressure (hPa)
1892	29 Apr.	-	-	-	216	947
1931	5 - 7 Mar	-	Intense Cyclone	-	137	969
1945	1 - 2 Feb	-	Intense Cyclone	South	150	969
1946	30 Jan - 1 Feb	-	Intense Cyclone	Close West	129	984
1960	16 - 20 Jan	Alix	Intense Cyclone	30 km off Port Louis	200	970
1960	<b>25 - 29 Feb</b>	<b>Carol</b>	<b>Intense Cyclone</b>	<b>Over Mauritius</b>	<b>256</b>	<b>943</b>
1964	17 - 20 Jan	Danielle	Intense Cyclone	40 km South West	219	974
1967	11 - 14 Jan	Gilberte	Severe Depression	Centre over Eastern part	142	978
1970	27 - 30 Mar	Louise	Intense Cyclone	140 km East	140	988
1975	5 - 7 Feb	Gervaise	Intense Cyclone	Over Mauritius	280	951
1978	18 - 21 Jan	Fleur	Intense Cyclone	80 km South East	145	986
1979	21 - 23 Dec	Claudette	Intense Cyclone	Over Mauritius	221	965
1980	12 - 13 Mar	Laure	Intense Cyclone	30 km North East	201	989
1989	4 - 6 Apr	Krissy	Severe Depression	30 km South	150	976
1994	<b>9 - 11 Feb</b>	<b>Hollanda</b>	<b>Intense Cyclone</b>	<b>20 km North West</b>	<b>216</b>	<b>984</b>
1995	24 - 27 Feb	Ingrid	Cyclone	100 km North East	153	989
1998	10 - 11 Feb	Anacelle	Cyclone	50 km East	121	985
1999	8 - 10 Mar	Davina	Intense Cyclone	25 km South East	173	974
2002	<b>20 - 22 Jan</b>	<b>Dina</b>	<b>Very Intense T.C</b>	<b>50 km North</b>	<b>228</b>	<b>988</b>

It is interesting to compare this list to the cyclones spontaneously cited by stakeholders during the site visit: Carol (1960), Hollanda (1994), Daniela (1996), Dina (2002), Lola (2008). Lastly, the cyclone Cilida (December 2018) was mentioned by the MMS as a cyclone that eventually did not strike the island but that could have been a major event if its track had approached Mauritius.

The NOAA database (<https://coast.noaa.gov/hurricanes/>) allows exploring online the characteristics of historical cyclones worldwide. Fig. 12 illustrates recorded cyclones in a 120 km radius around Port Louis. It shows that in general, cyclones form in the upper Indian Ocean where sea surface temperatures are higher, and move counter-clockwise from the North East to the South.



**Fig. 12.** Cyclone tracks impacting Mauritius in a 65 nautical mile radius (120 km) around Port Louis. Source: <https://coast.noaa.gov/hurricanes/>

The NOAA database includes 18 cyclones of category 1 or above in a 120 km radius around Port Louis, between 1932 and 2002. Eight of these are not present in the list provided by MMS, including the notable cyclone Daniella in 1996 (and vice versa, nine cyclones identified by MMA are not in the NOAA database). Pressure and sustained wind speed data from NOAA do not match values reported by MMS, and are missing for older cyclones. For consistency and data quality the NOAA data has not been merged with the MMS data.

## 4.2. RAINFALL

The Mauritius Meteorological Services (MMS) has provided the following records of daily rainfalls in the region of Port Louis for the months of February 1960 (with intense cyclone Carol on 25-29 February), February 1994 (with intense cyclone Hollanda on 9-11 February), March 2008 (with moderate tropical storm Lola on 22-27 March) and March 2013 (with the convective event leading to the flash flood on the 30th of March).

**Tabl. 9 - List of records of daily rainfalls in the region of Port Louis (MMS)**

Date	Amount (mm)			
	February 1960	February 1994	March 2008	March 2013
1	0	4.3	0	0
2	0	0	0	5.0
3	0	0	1.0	0
4	0	0	0	0
5	0	0	0	0
6	4.2	0	0	0
7	0	4.0	0	0
8	1.0	0	0	6.3
9	0.4	11.1	0	0.2
10	4.7	157.0	0	0
11	0	0	0	0
12	0	0	1.0	0
13	0	0	2.0	0
14	28.9	0	55.0	0
15	0	0	2.5	4.5
16	0	3.0	0	7.0
17	1.4	5.0	0	0
18	0	0	4.0	0
19	0	1.5	0	0
20	2.8	0	0	4.0
21	0	0	0	0.8
22	0	0	4.0	0
23	1.1	0	32.0	0
24	0.8	0	16.0	0
25	0.3	0	68.0	0
26	3.8	2.3	37.0	0
27	N/A	3.0	0	0
28	275.0	0	0	0
29	N/A	-	0	0.5
30	-	-	0	140.0
31	-	-	0	14.4

No long term time series of rainfall has been provided.

## 4.3. WAVES

### 4.3.1. Data source

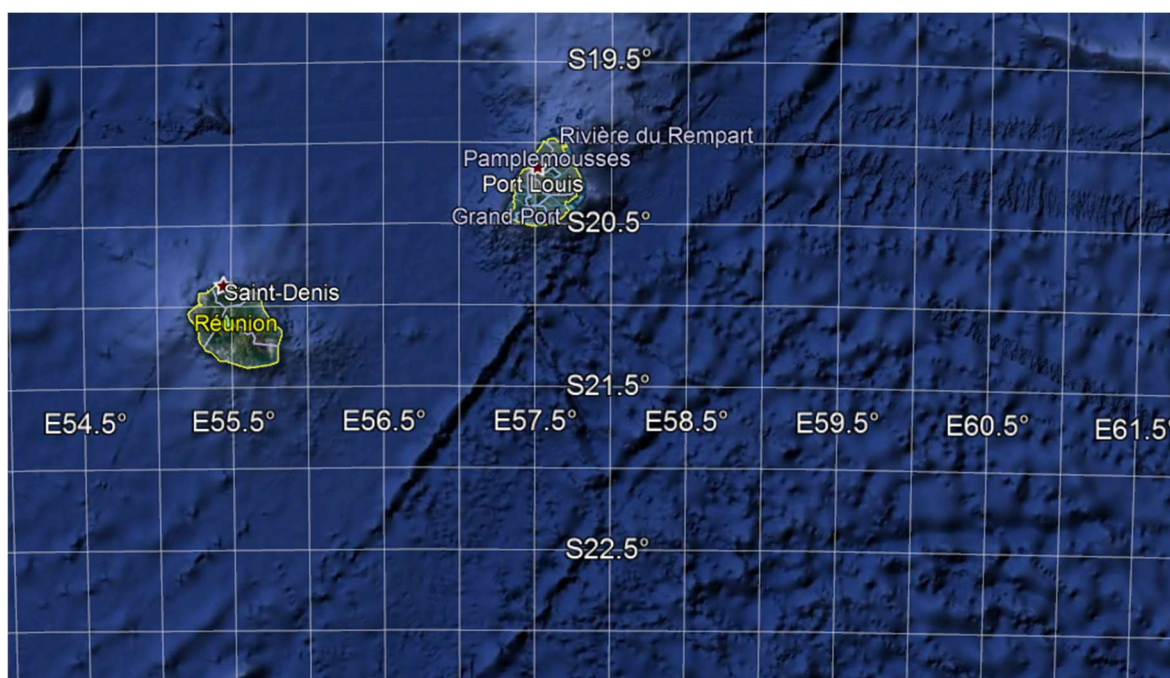
In the absence of long term time series, offshore wave conditions are assessed using wave data coming from the numerical database provided by the GLOBAL model of the IOWAGA project.

IOWAGA (Integrated Ocean Waves for Geophysical and other Applications) is a project funded by the European Union and led by the Ifremer (French Research Institute for Exploitation of the Sea, state-owned oceanographic institution). It proposes a systemic investigation of ocean waves for improving the ocean surface wave compartment of Earth system

models. A task of the project consists of multi-scale wave hindcasts, including research activities for improving the wave generation and propagation models. More information about the project can be found on <http://wwz.ifremer.fr/iowaga>.

The GLOBAL model covers the globe with a regular grid of  $0.5^\circ \times 0.5^\circ$ . At each grid point, the sea state and wind parameters (among others) are provided from January 1990 to January 2019 (29.1 years).

The sea states are modelled using the state-of-the art, 3rd-generation model WaveWatch III, ensuring a high reliability of the data. The wind forcing consists of the CFSR global wind fields.



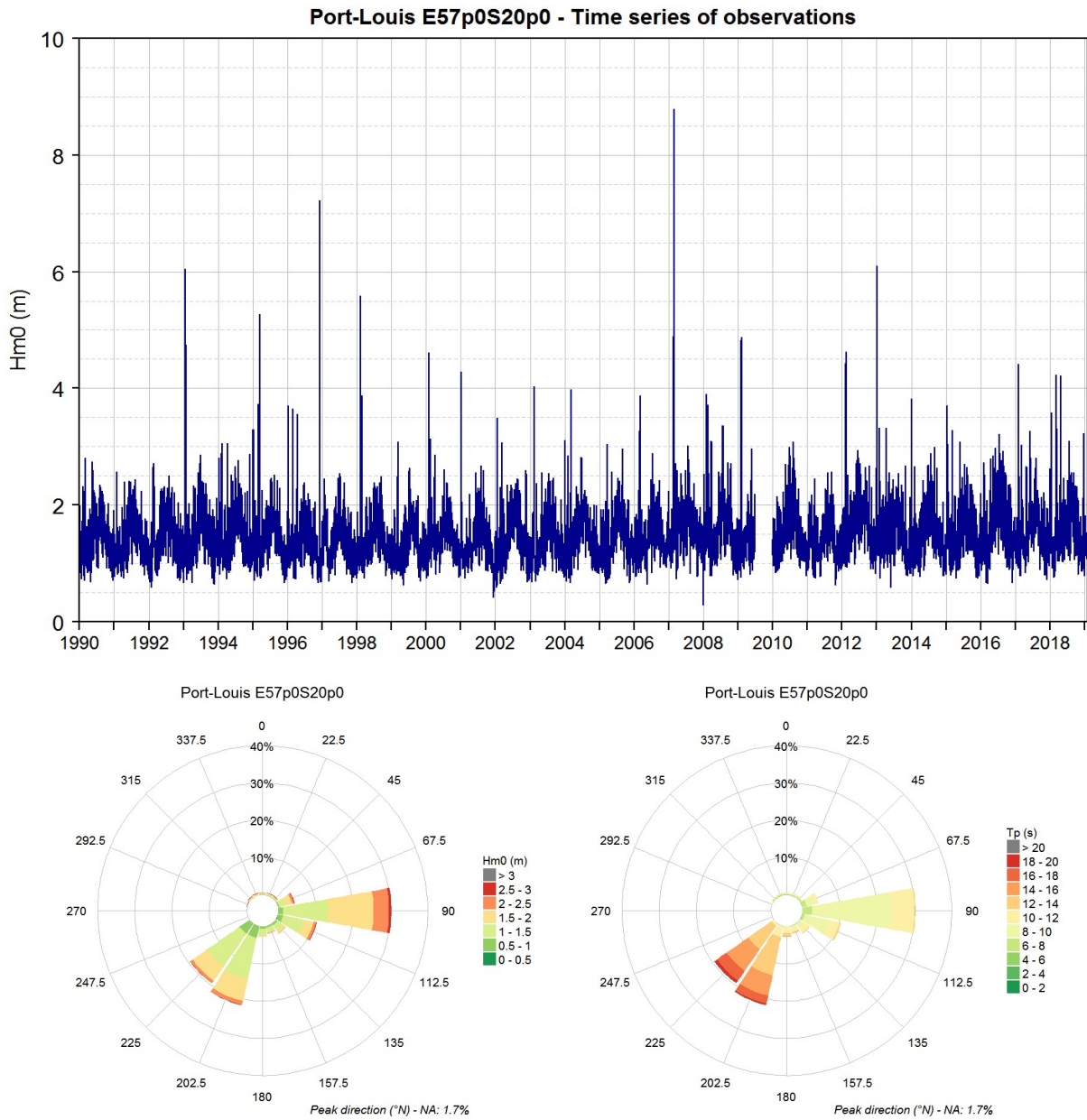
**Fig. 13.** Location of the grid points of the IOWAGA-GLOBAL model

The grid point of coordinates  $20^\circ\text{S}$ ,  $57^\circ\text{E}$  is chosen as analysis point. It is located 50 km north-west of Port Louis.

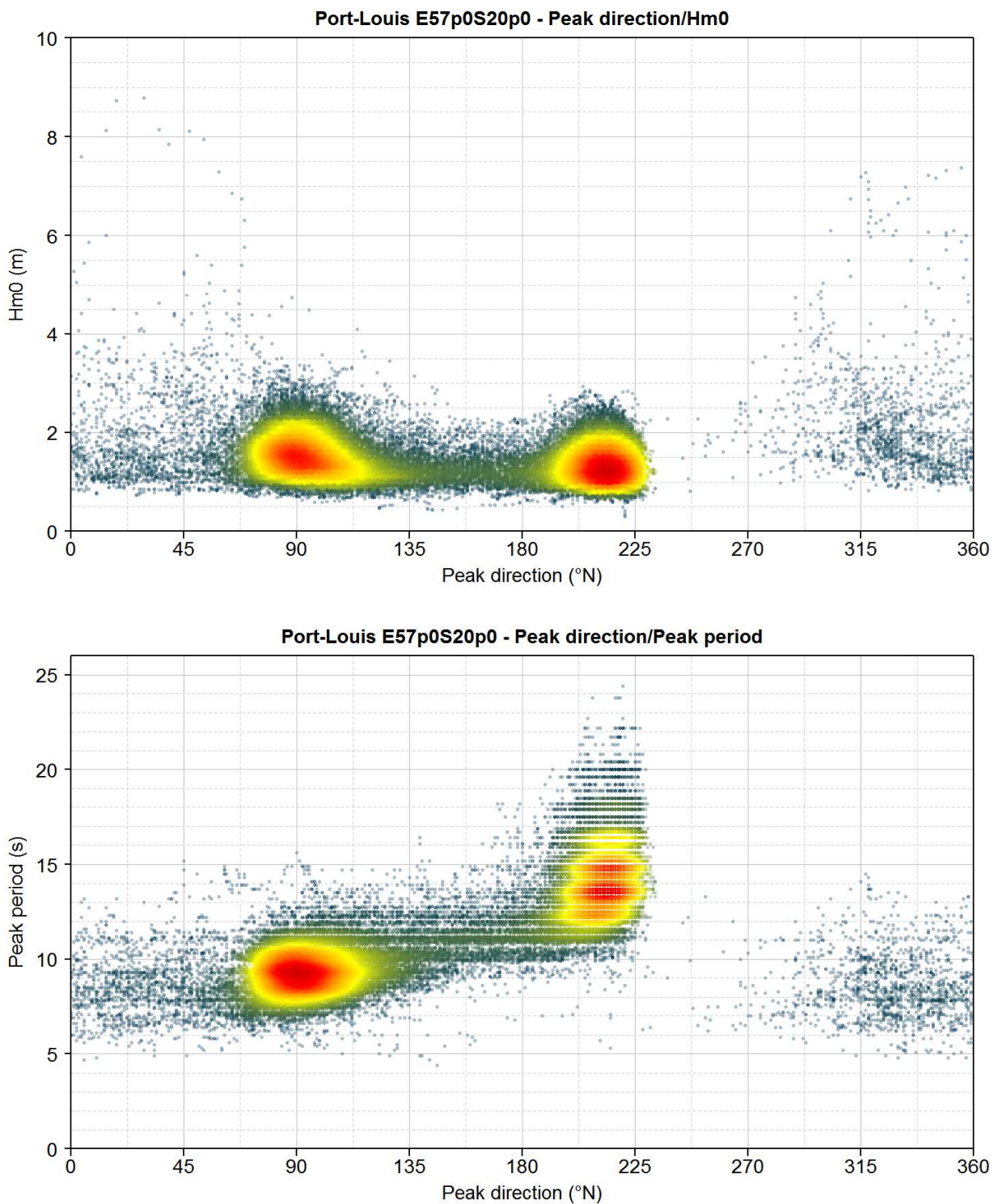
*Important note:* cyclonic events are present in the model but may present inaccuracies. In particular, the temporal and spatial resolution of the wind forcing and of the wave model are not fine enough to represent accurately the maximum conditions in a cyclone. Therefore, all results relative to cyclonic conditions are illustrative only.

### 4.3.2. Wave climate

The wave climate off Port Louis is illustrated in the figures below.



**Fig. 14.** Time series of wave height and wave roses (wave height and period) off Port Louis



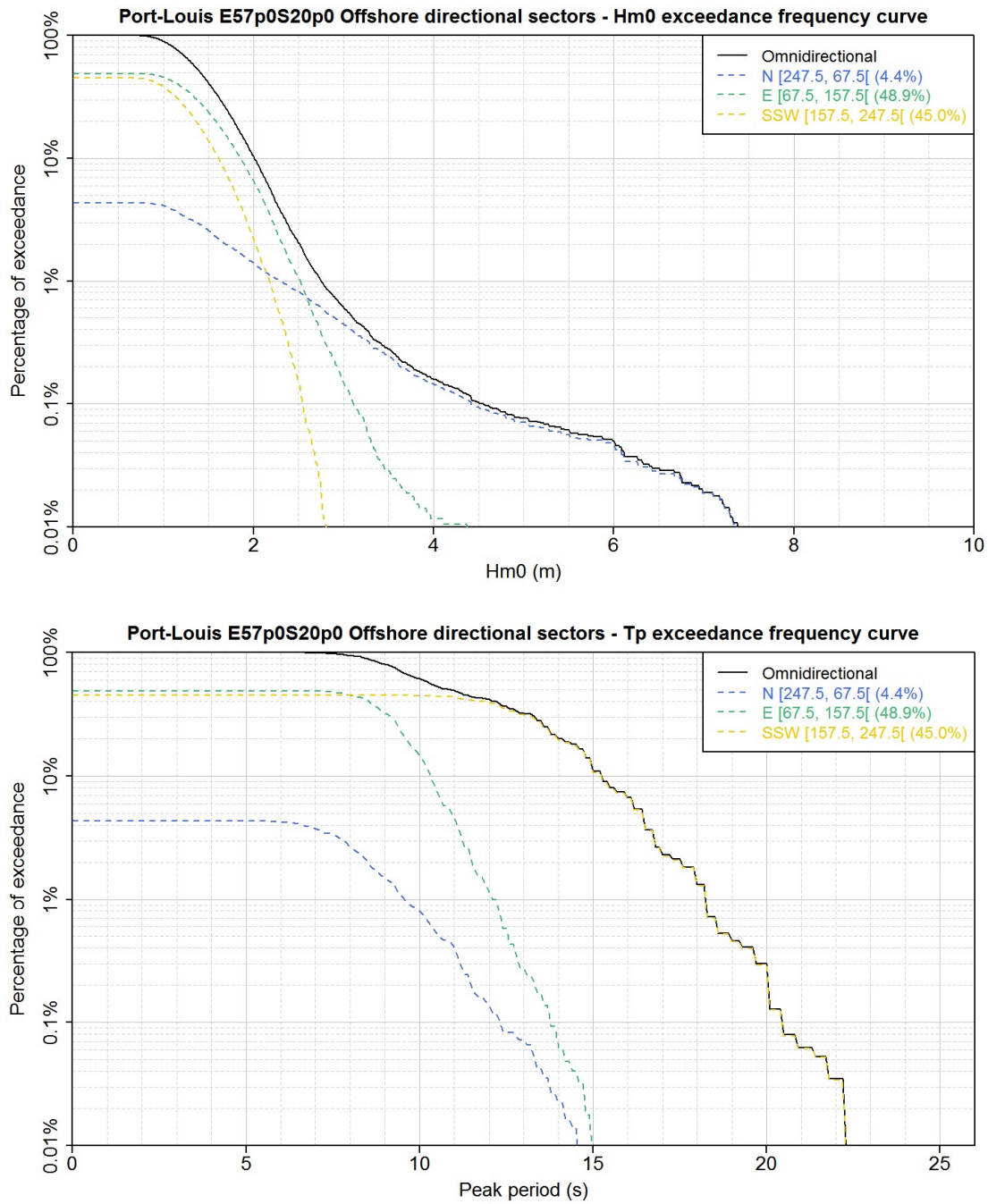
**Fig. 15.** Scatterplot wave height / direction and wave period / direction off Port Louis

The roses and scatterplots show clearly the presence of three distinct directional wave sectors:

- a prevailing East sector (48.9% of data) corresponding to waves generated by trade winds ;

- a South-South-West sector (45% of sea states) with large periods (up to 25 s) but limited wave height (< 3 m) corresponding to southern swells generated in the Southern Ocean having propagated towards the Mascareigne islands (Reunion, Mauritius and Rodrigues);
- a small North sector (4.4% of sea states), infrequent but including the largest wave heights (up to 9 m) corresponding to cyclonic conditions.

They are illustrated in the figure below.

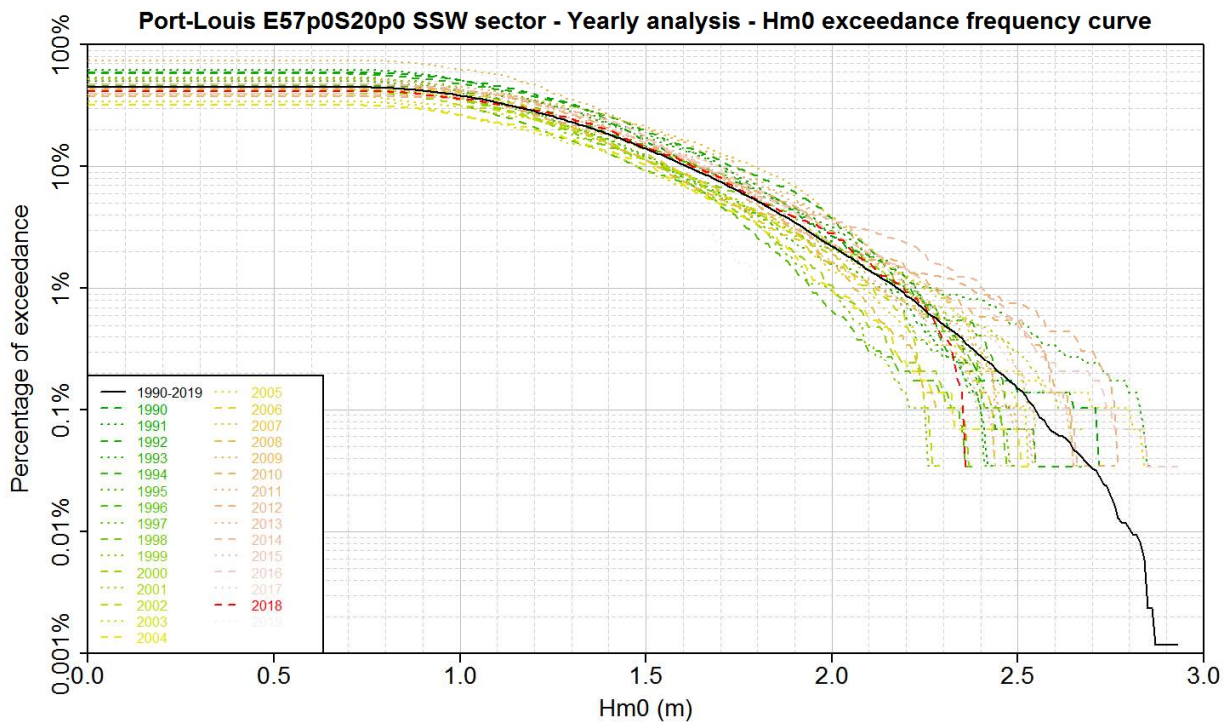


**Fig. 16. Exceedance frequency curve in wave height and period split into directional sectors off Port Louis**

### 4.3.3. Examination of SSW swell conditions in 2018

Following the observation by MPA of increased swell conditions in 2018 leading to a very high downtime (see § 3.2), the yearly SSW swell conditions have been specifically examined.

The figure below shows the exceedance frequency curve in wave height limited to the SSW sector. The black curve corresponds to the full analysis period (it is identical to the yellow curve in the figure above). For each year, the percentage of occurrence is calculated (it corresponds to the value on the y-axis at the left end of the curve). It varies from 31.8% in 2004 to 74.1% in 2009, with the average value of 45%. 2018 appears to be slightly under the 30-year average, both in terms of frequency of occurrence (41.4%) and in maximum wave height (2.36 m).



**Fig. 17.** Yearly exceedance frequency curve in wave height for the SSW sector off Port Louis

Hence, the data from this model does not explain the observed increase in port closure in 2018.

### 4.3.4. Extreme waves

An extrapolation of extreme waves is performed on the sea states of the IOWAGA-GLOBAL model.

The methodology is as follows:

- determination of homogeneous (identically distributed) wave populations, based on directional criteria or others (e.g. wave steepness);
- declustering of the time series (over a  $K$ -year duration) using the Peaks-Over-Threshold (POT) approach:
  - identification and extraction from the time series of storm events exceeding a “physical threshold”  $u_p$  set so as to get  $\lambda_p = 5-10$  storm events per year in average,
  - selection of the wave height peaks of the storm events for setting up a sample of  $N_p$  independent and identically distributed (i.i.d.) data ( $\lambda_p = N_p/K$ ),

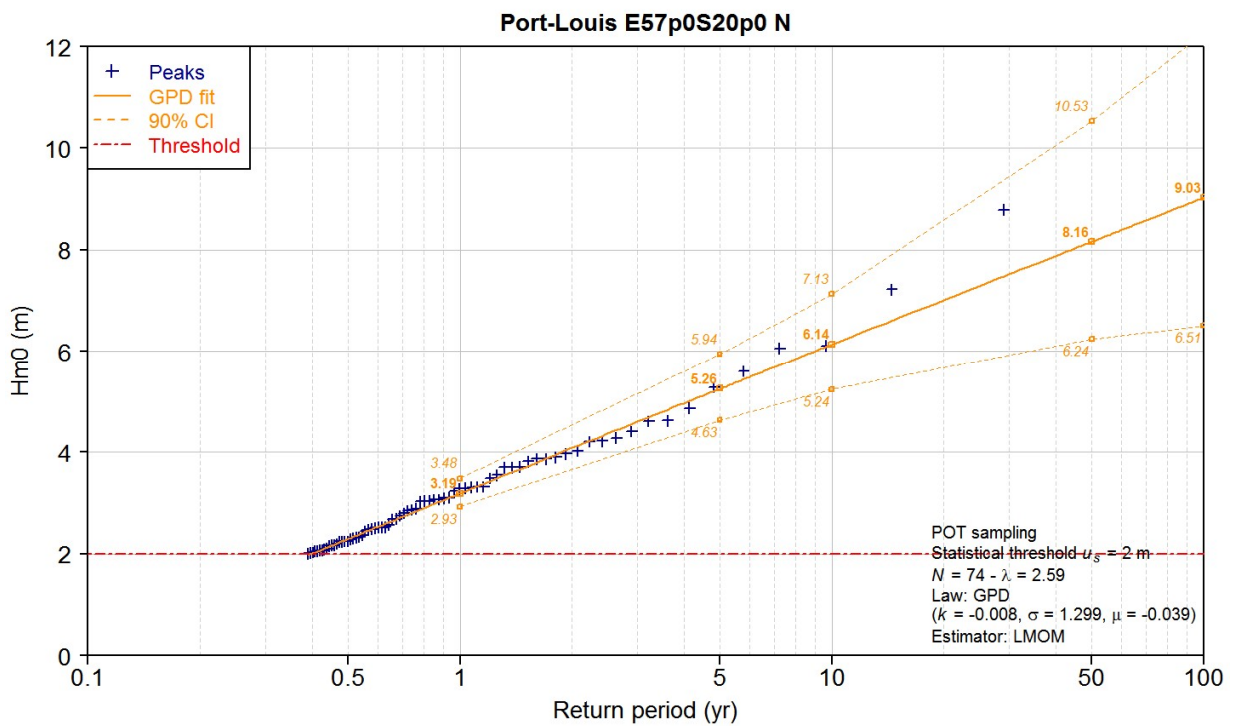
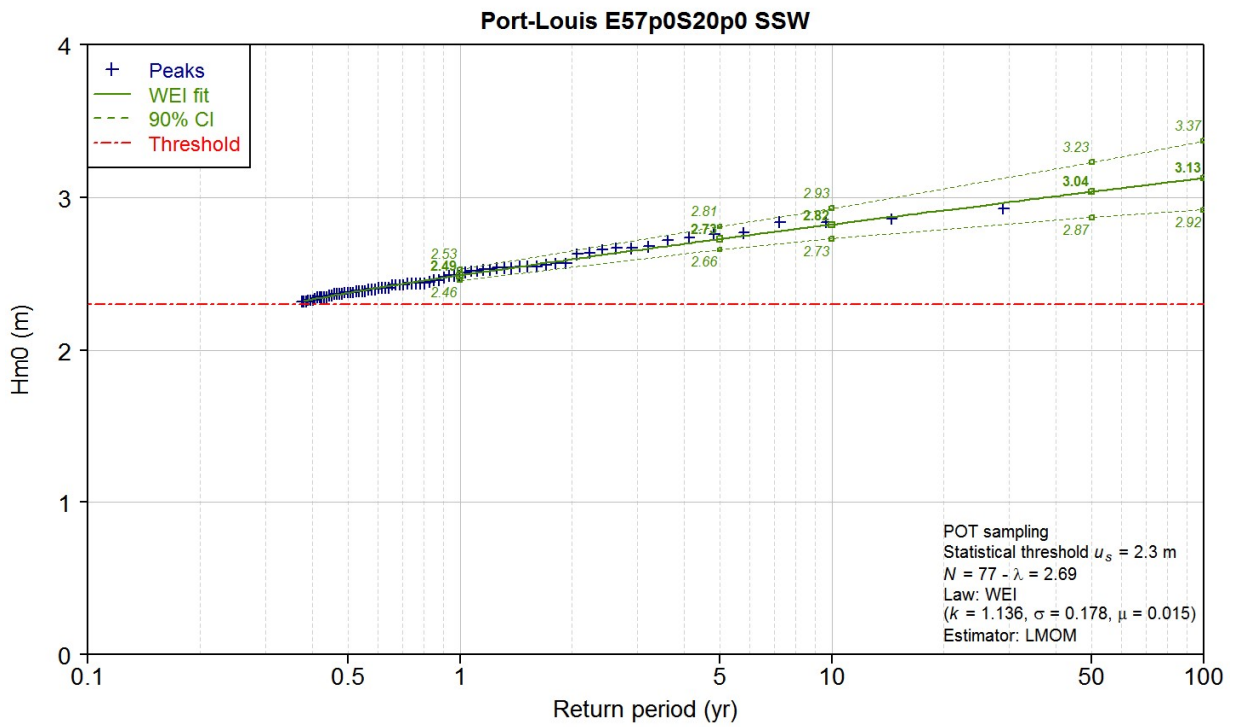
- statistical extreme value analysis applied to the i.i.d. sample:
  - determination of a “statistical threshold”  $u_s$ : the  $N$  peaks exceeding this threshold are considered as extreme values ( $\lambda = N/K$  peaks per year in average),
  - fitting of statistical distributions (GPD, Weibull, Gamma, Exponential) to these extreme peaks,
  - determination of the best-fitting distribution using a statistical test (such as  $\chi^2$  or Kolmogorov-Smirnov),
  - computation of quantiles (return values) for a set of return periods (e.g. 1, 5, 10, 50, 100 years),
  - computation of 90% confidence intervals using the parametric bootstrap method.

*Important note: as explained above, cyclonic conditions are poorly represented in this model. Therefore, the extreme sea states from the N sector (which includes the cyclonic events) are illustrative only and would require to be complemented by a dedicated cyclonic study, out of the scope of this study.*

The results are provided in the table and figures below for the SSW and N sectors (the E sector does not affect the port area).

**Tabl. 10 - Extreme sea states off Port Louis**

Sector	Return period (yr.)	Wave height $H_{m0}$ (m)	90% confidence interval (m)	Wave peak period (s)
N	1	3.19	2.93 - 3.48	7.5 - 9.9 - 15.0
	5	5.26	4.63 - 5.94	9.5 - 11.4 - 14.5
	10	6.14	5.24 - 7.13	10.5 - 12.0 - 14.5
	50	8.16	6.24 - 10.53	12.0 - 13.3 - 15.5
	100	9.03	6.51 - 12.27	12.5 - 13.8 - 16.0
SSW	1	2.49	2.46 - 2.53	11.0 - 15.6 - 19.0
	5	2.73	2.66 - 2.81	12.0 - 15.7 - 18.5
	10	2.82	2.73 - 2.93	12.0 - 15.7 - 18.0
	50	3.04	2.87 - 3.23	12.5 - 15.8 - 18.0
	100	3.13	2.92 - 3.37	13.0 - 15.8 - 18.0



**Fig. 18. Extreme wave heights for the SSW and N sectors off Port Louis**

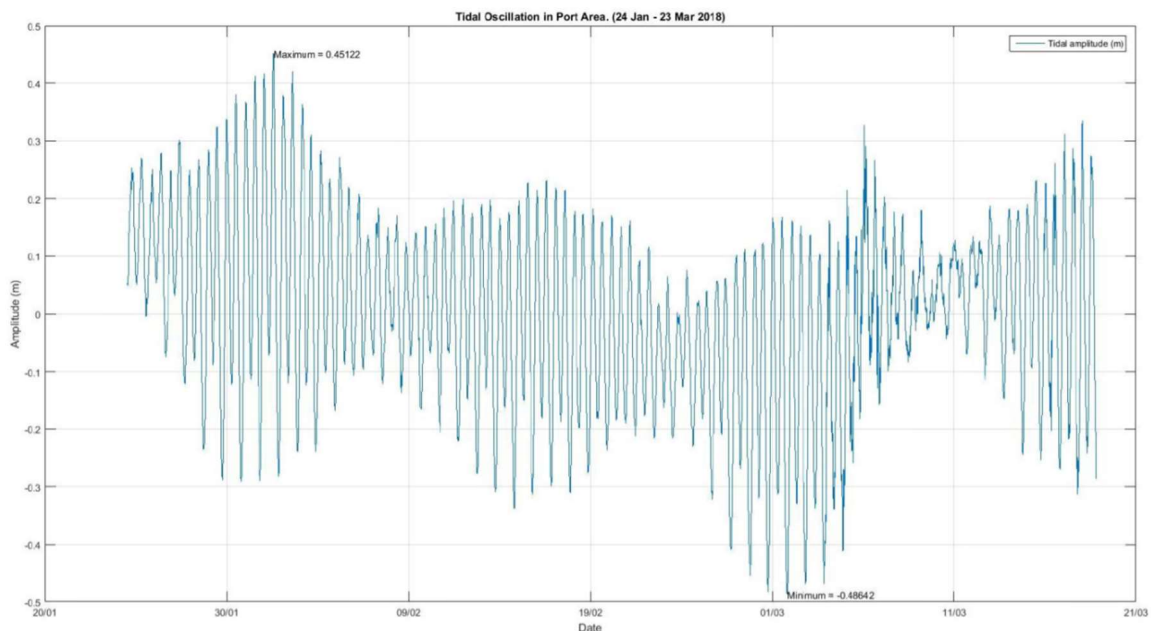
## 4.4. SEA LEVEL

### 4.4.1. Datum

According to the website of the Mauritius Meteorological Services (<http://metervice.intnet.mu/sun-moon-and-tides-tides-mauritius.php>): “the Admiralty Chart Datum (ACD) is the mean of the monthly lowest tides recorded at Port Louis Harbor. These are recorded over a fairly long period of time and the average of all the recorded data gives us the value of ACD which is 132 cm above the zero mark of the tide staff at Port Louis. To convert the ACD values to the zero mark of the tide staff, 132 cm should be added to the heights given in the tide table.”

### 4.4.2. Short term observations

A tidal survey has been performed by the Mauritius Oceanography Institute (MOI) from January 24<sup>th</sup> to March 23<sup>rd</sup> 2018 (see figure below).

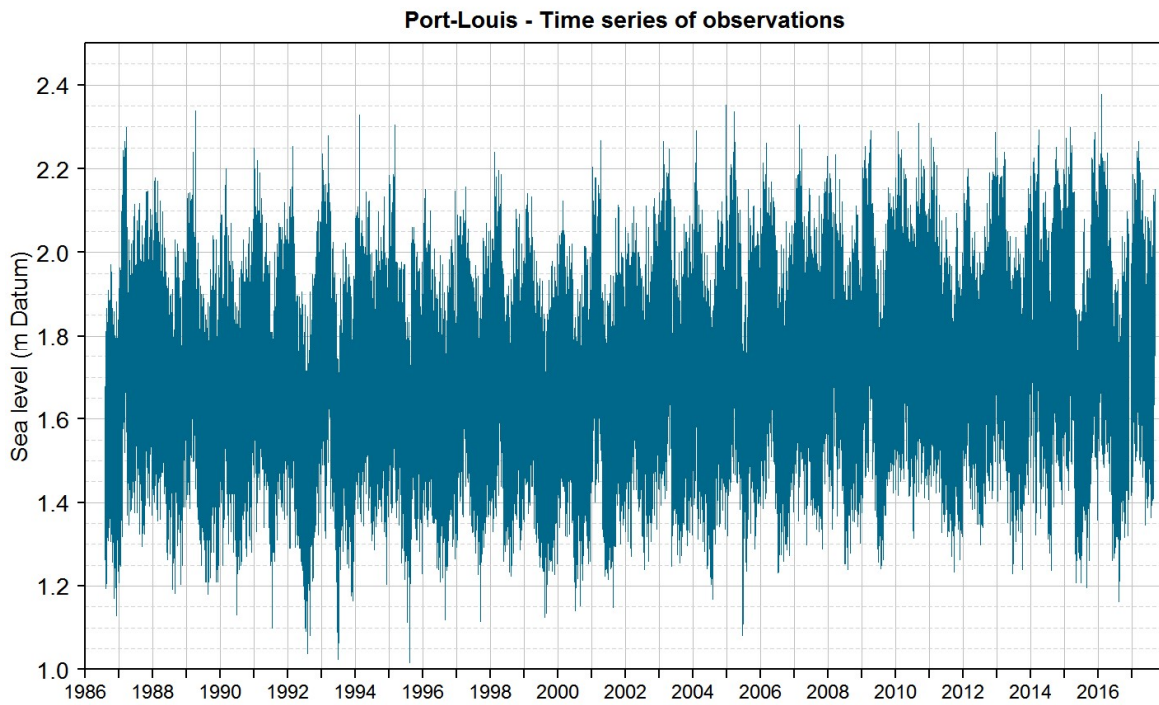


**Fig. 19.** *Tidal observation at Port Louis, 24 January to 23 March 2018*

It shows that the tide at Port Louis is semi-diurnal with diurnal inequalities. The tidal range is rather low at about 0.8 m.

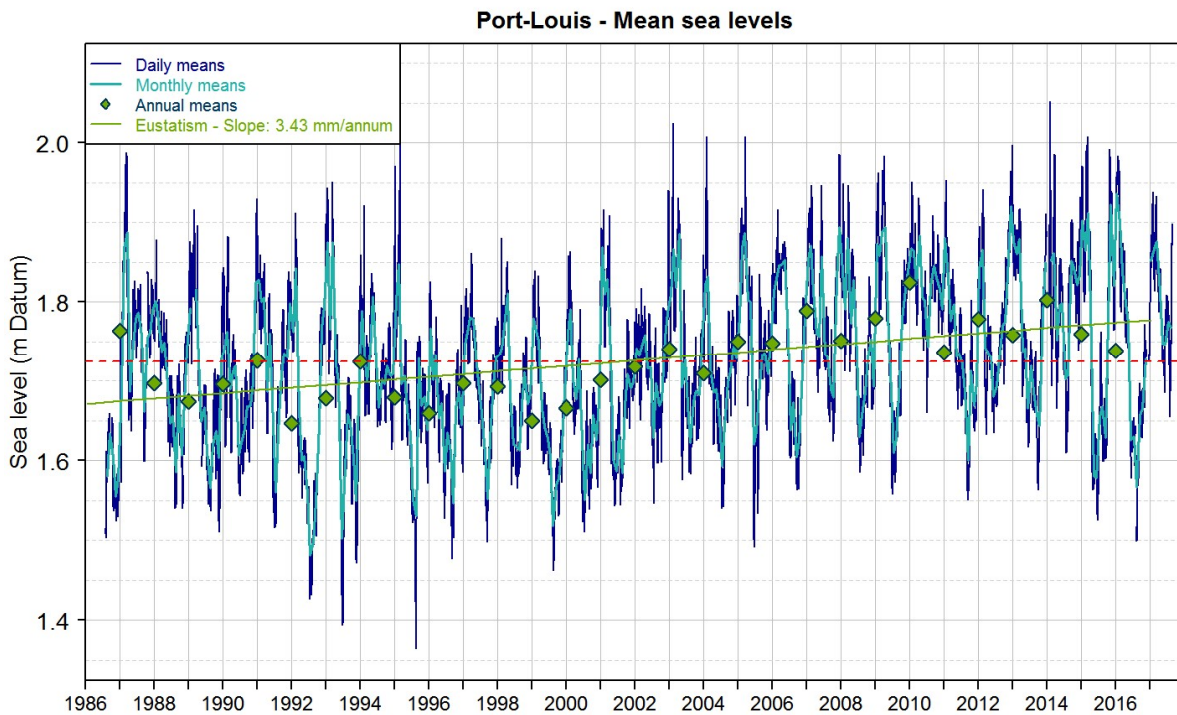
### 4.4.3. Long term observations

Sea level observations at Port Louis are available through the Sea Level Centre of the University of Hawaii (<https://uhslc.soest.hawaii.edu/datainfo/>). The research quality data have been used. Datum information may be found at <http://www.ioc-sealevelmonitoring.org/ssc/stationdetails.php?id=SSC-ptlu>. According to it, the benchmark is the 3m mark on tide staff, which is located 1.6788 m above Admiralty Chart Datum.



**Fig. 20.** Time series of sea level at Port Louis

The daily, monthly and annual mean sea levels may be derived from this long time series. The eustatic trend (sea level rise induced by climate change) is estimated at 3.43 mm/annum, which is slightly above the global average (3.3 mm/annum).



**Fig. 21.** Daily, monthly and annual mean sea level at Port Louis

## 4.5. WIND

### 4.5.1. Wind measurements at Fort-William

#### A. Data source

Daily measurements at Fort William were provided by the Mauritius Meteorological Service (MMS) for the present study, with the following additional information:

*"[...] the co-ordinates of Fort William are: 20°09.1'S 57°28.7'E and it is a Dines Pressure tube anemometer at 15 metres height above mean sea level. The data is recorded through continuous mechanical recording. Wind is measured from the North bearing. For the mean wind, the 6 hourly wind data at main synoptic hours is used. For the gust, it is the instantaneous maximum gust over the 6-hour period. The maximum gust for the day will be the instantaneous maximum gust over the 24-hour period."*

From this information, it is understood and assumed that:

- daily mean wind values are the average of the four mean values averaged over 10 minutes (standard convention) and recorded every 6 hours;
- daily gust wind values are the maximum values of the maximum gust speed averaged over 3 s (standard convention) over the day.

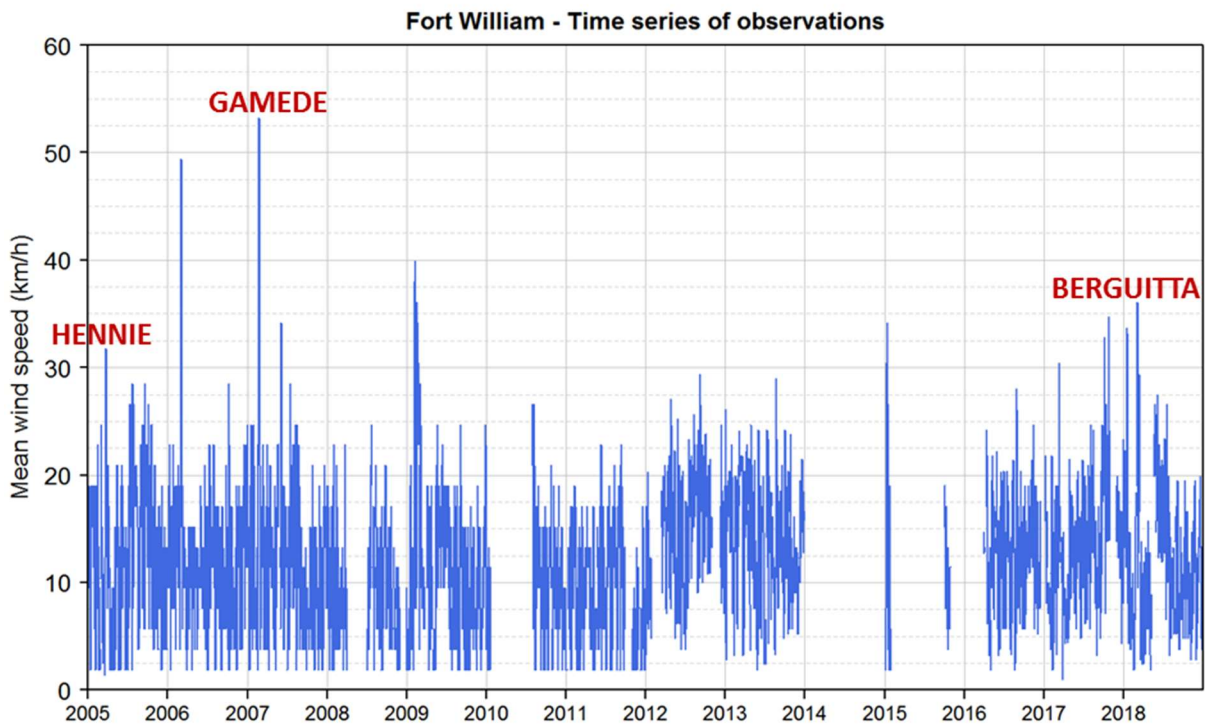
The location of the coordinates provided in this email is illustrated in the figure below. However, note that it is located on a reclaimed area that did not exist before 2013.



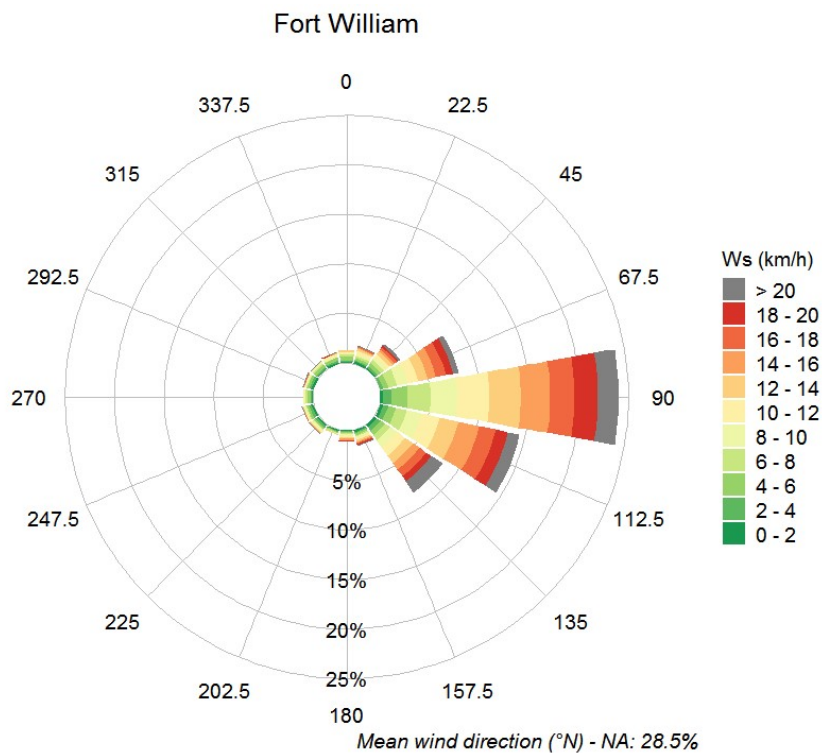
**Fig. 22.** Global mean sea level rise (IPCC, 2013)

#### B. Wind climate at Fort William

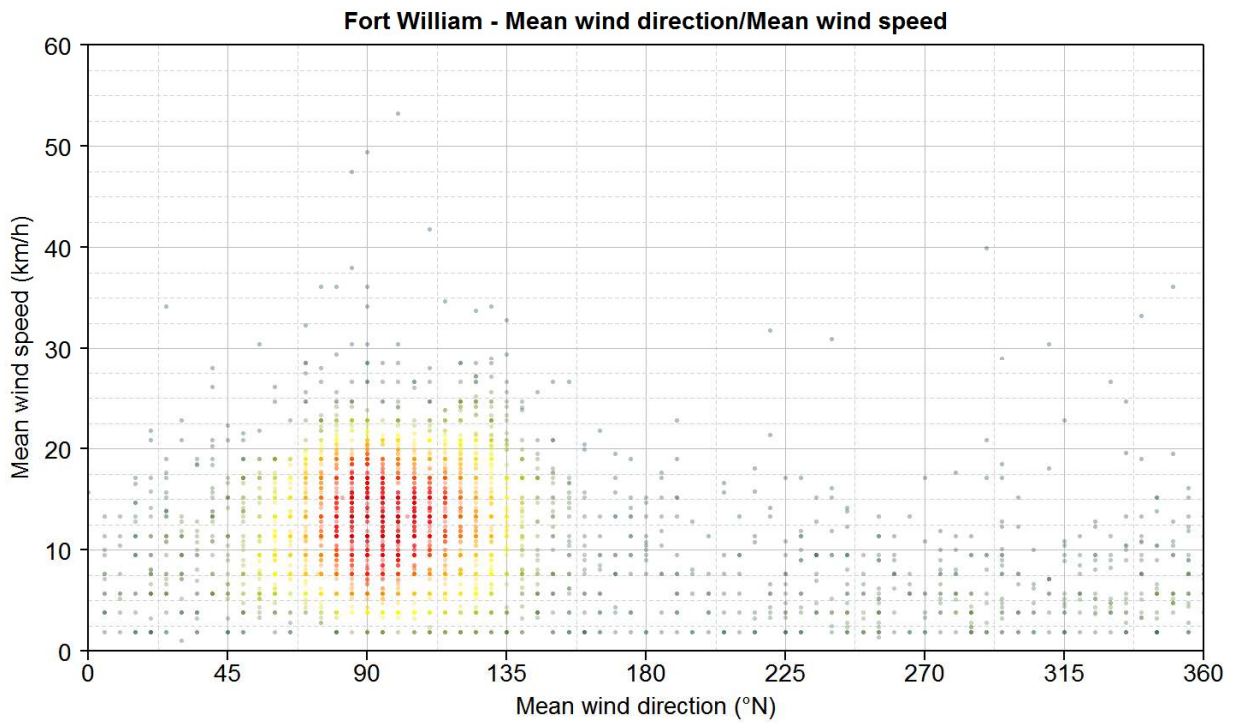
The wind climate relative to mean wind is illustrated in the figures below.



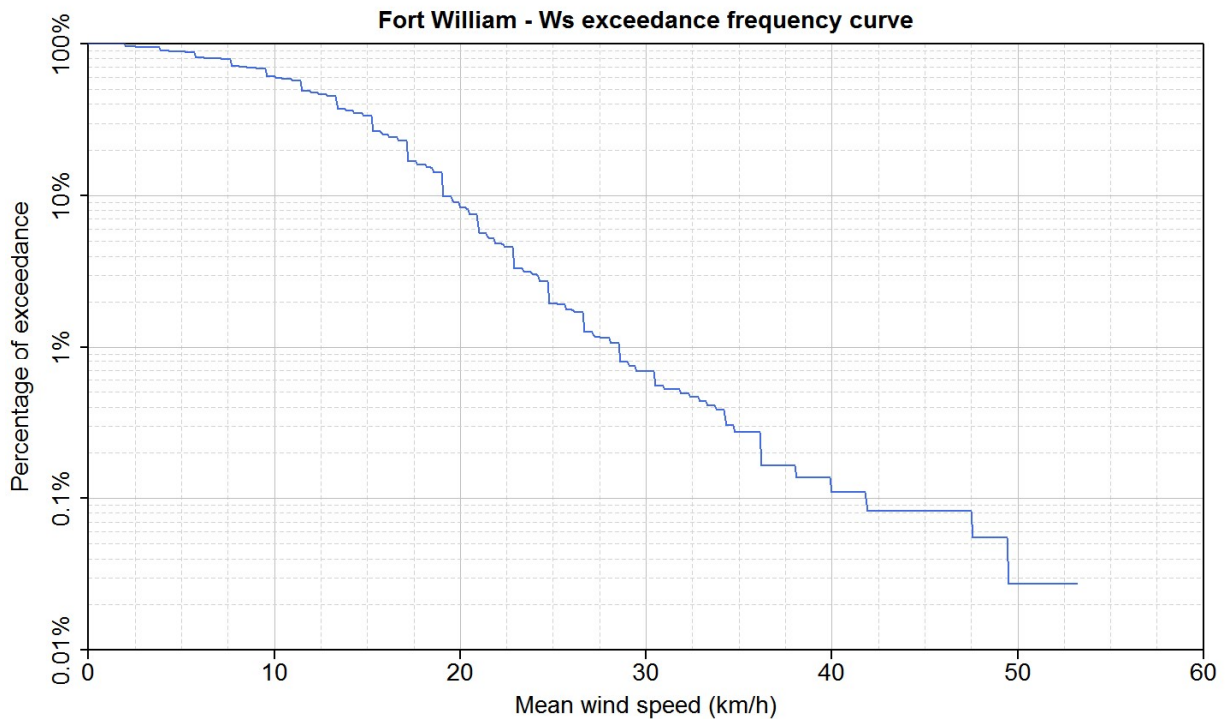
**Fig. 23.** Time series of wind speed at Fort William measurement station



**Fig. 24.** Wind rose at Fort William measurement station



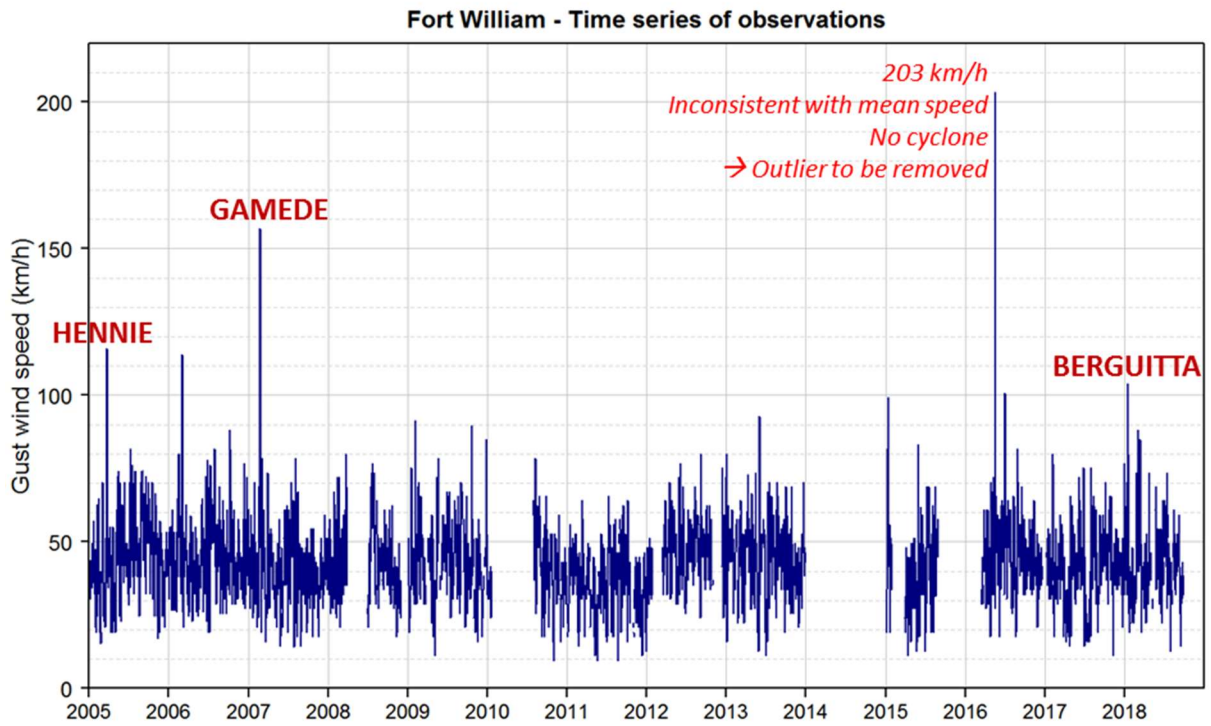
**Fig. 25.** Scatterplot wind speed / direction at Fort-William measurement station



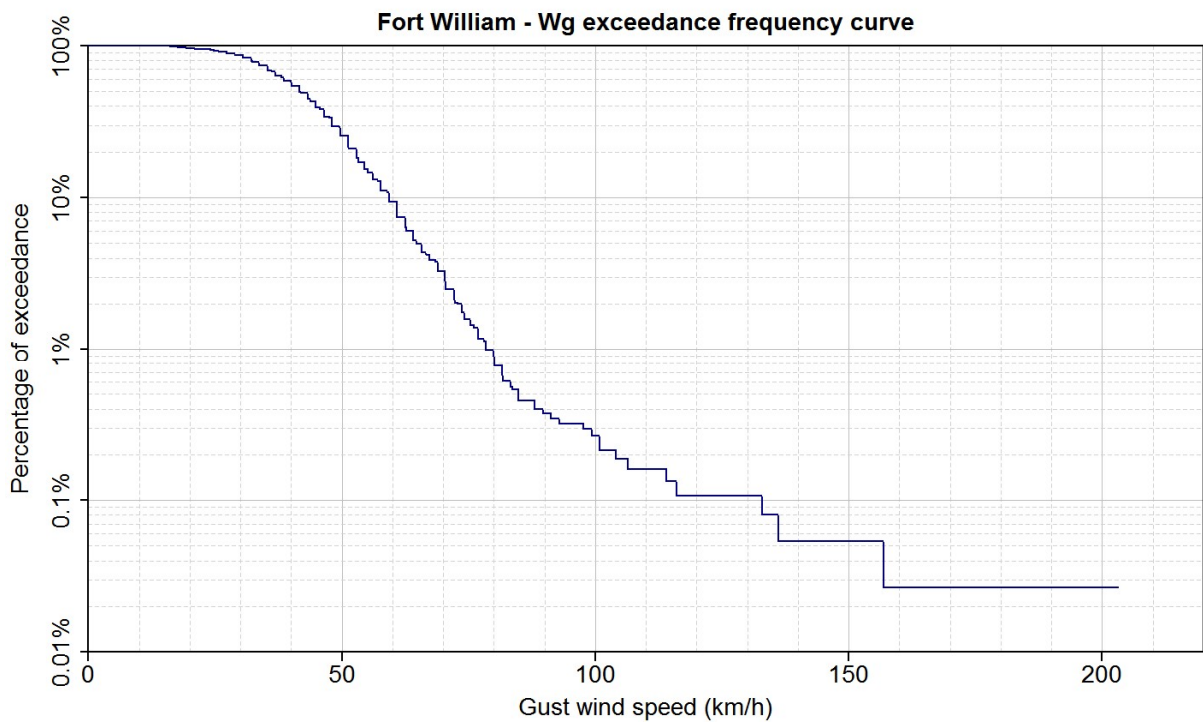
**Fig. 26.** Exceedance frequency curve of mean wind speed at Fort-William measurement station

Trade winds from the east are largely prevailing, but mean wind speeds above 25 km/h may be observed from other directions. In particular, strong winds caused by the cyclones Hennie (24 March 2005), Gamede (24 February 2007) and Berguitta (16 January 2018) are visible.

Figures related to the gust speed (the associated direction is not provided) are given below.



**Fig. 27.** Time series of gust wind speed at Fort William measurement station

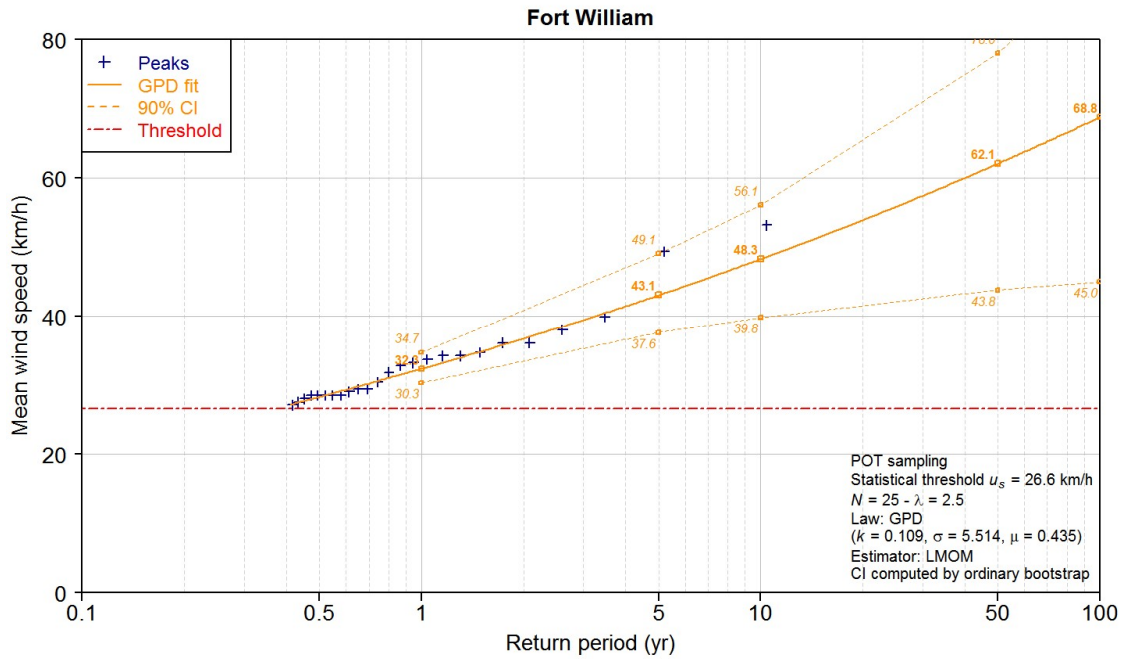


**Fig. 28.** Exceedance frequency curve of gust wind speed at Fort-William measurement station

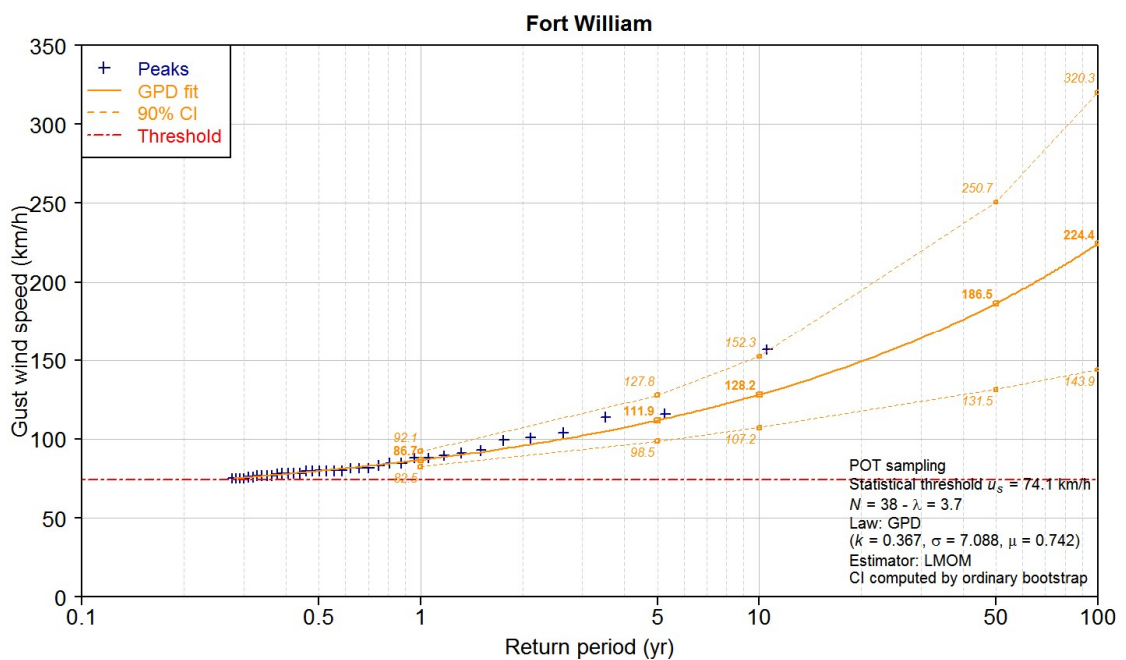
There again, gust winds exceeding 100 m/h may be associated to cyclones Hennie, Gamede (maximum gust speed of 156.8 km/h) and Berguitta. However, the extreme value of 203 km/h recorded on 18 May 2016 could not be associated to any particular weather event and seems to be an inconsistent outlier to be removed from the analysis.

**C. Extreme winds at Fort William**

Extreme mean and gust wind speed at Fort William have been estimated by fitting extreme value distributions. However, the short duration of the time series (about 10 years) causes large uncertainties for high return periods.



**Fig. 29. Extreme mean wind speed at Fort William measurement station**



**Fig. 30. Extreme gust wind speed at Fort William measurement station**

## 4.5.2. Wind measurements at Vacoas

### D. Data source

Measurements at the weather station of Vacoas have been downloaded through the NCEI GIS map portal of the US NOAA (<https://gis.ncdc.noaa.gov/maps/ncei/cdo/hourly>).

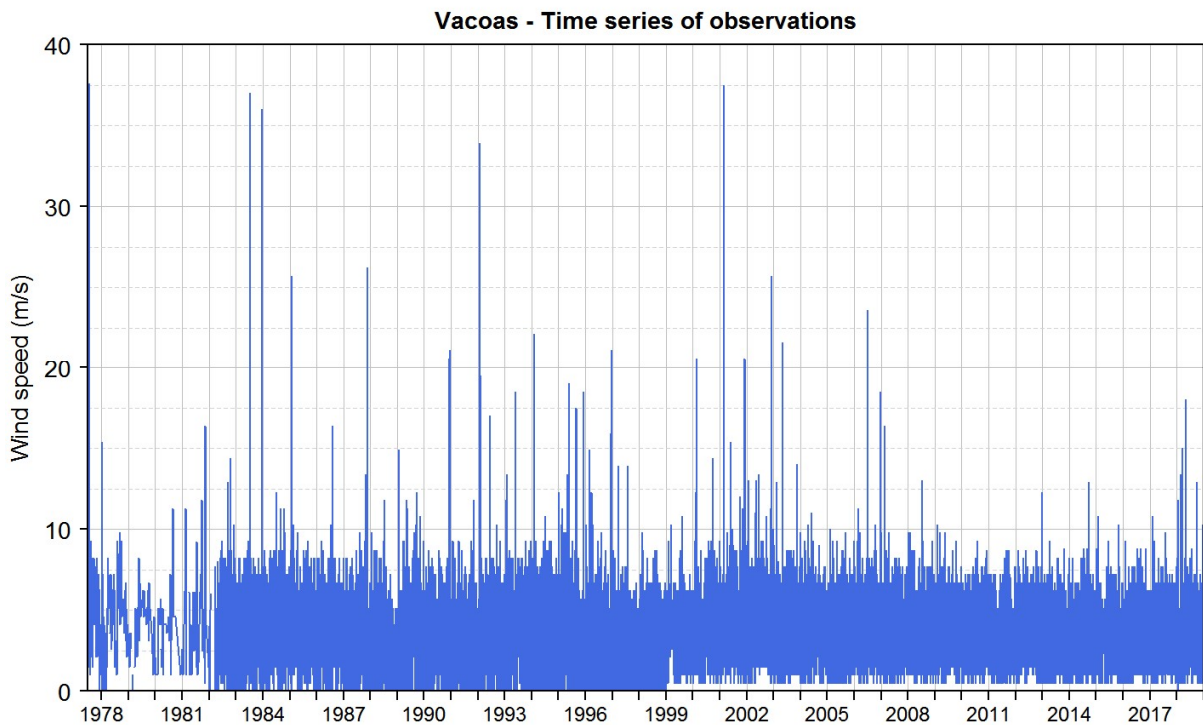
Measurements of various meteorological parameters (wind, pressure, temperature...) are available from July 1977 to December 2018.

The exact definition of the wind speed and direction provided in the measurement files is unclear. It is here assumed to be the wind vector at 10 m above surface averaged over 10 min (standard convention).

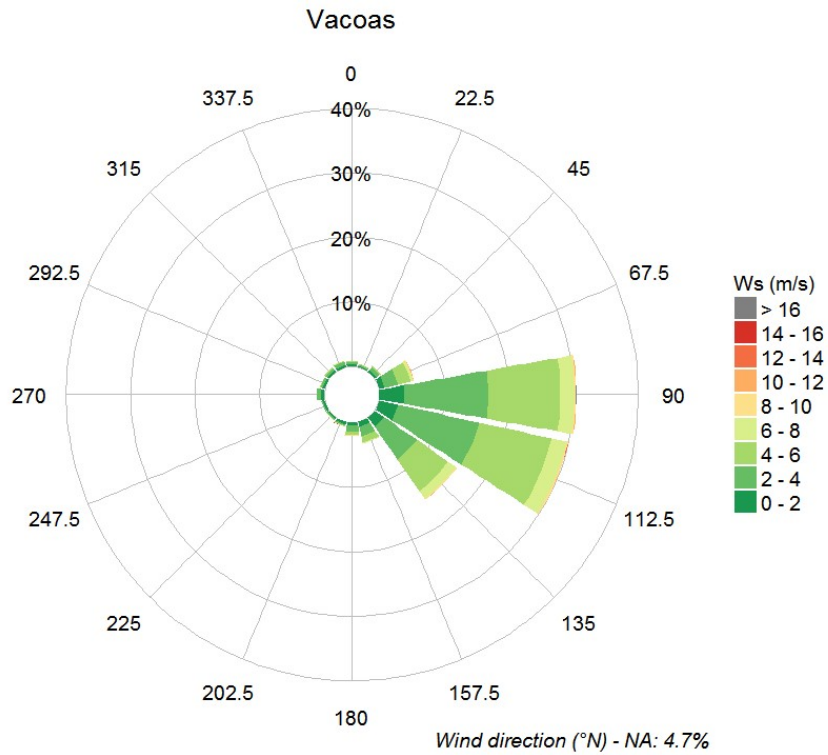
*Important note:* local winds at Port Louis may be expected to be significantly different to those at Vacoas because of the peculiar topographic configuration of the city inside a steep mountain cirque.

### E. Wind climate at Vacoas

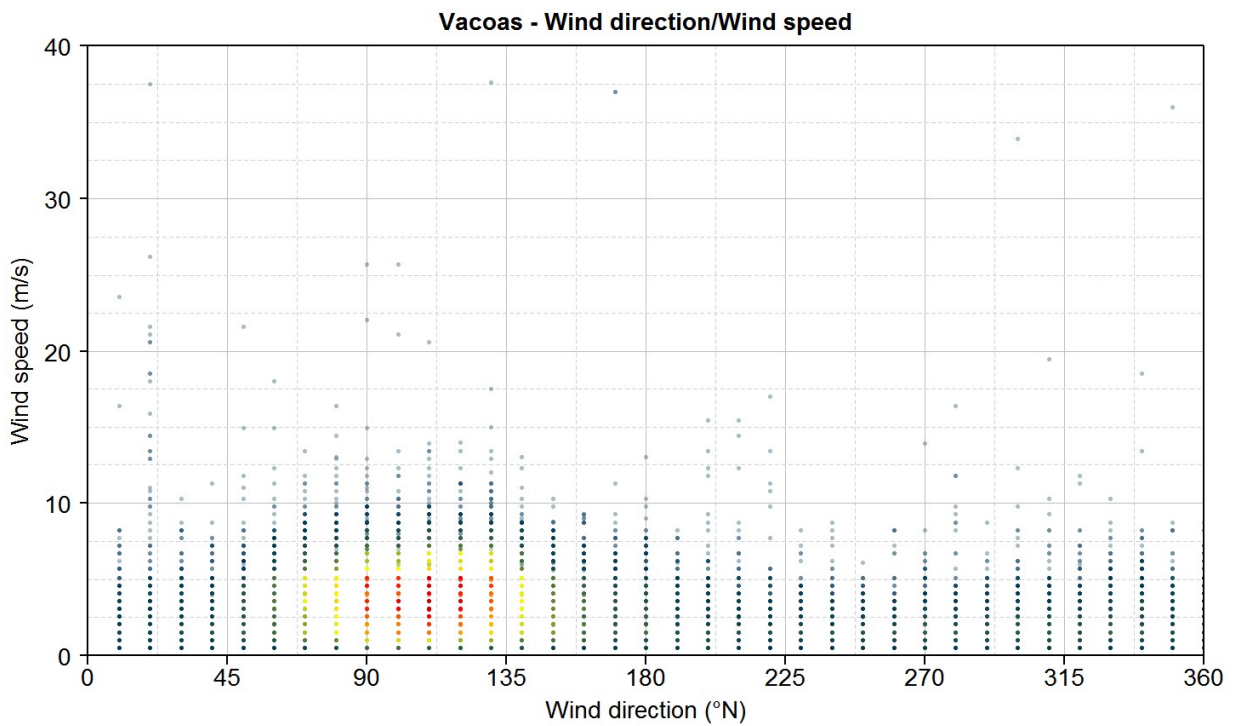
The wind climate is illustrated in the figures below.



**Fig. 31.** Time series of wind speed at Vacoas weather station



**Fig. 32.** Wind rose at Vacoas weather station

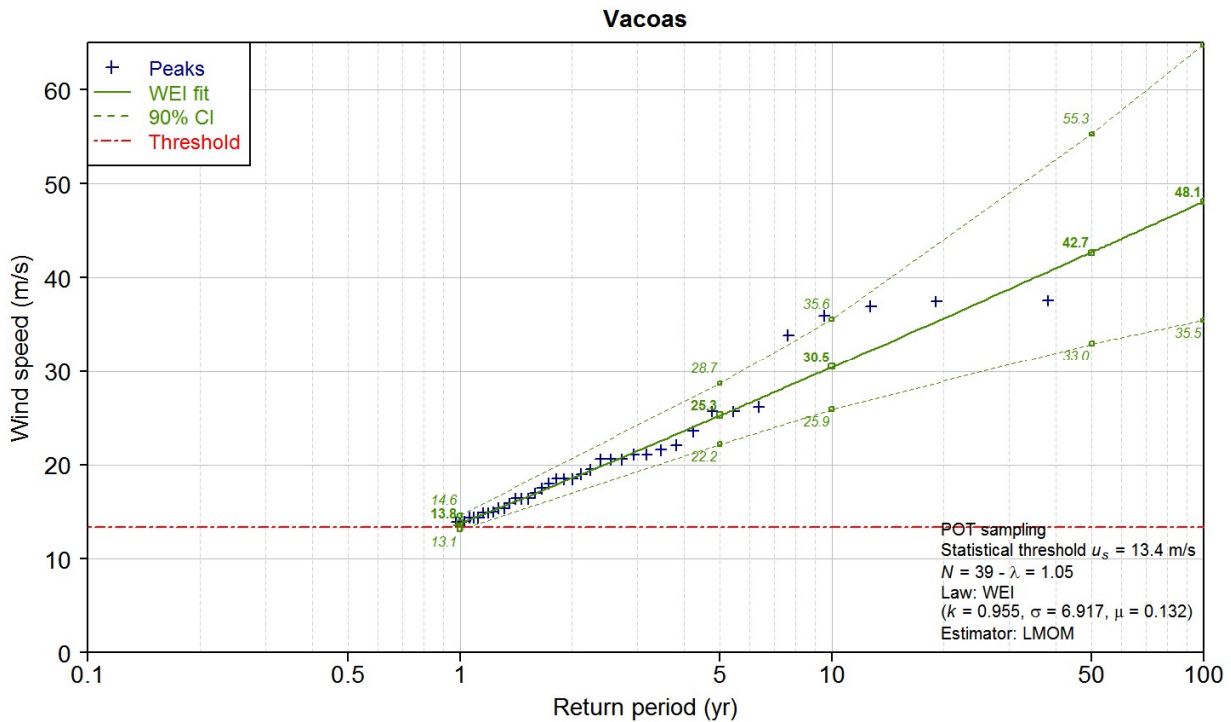


**Fig. 33.** Scatterplot wind speed / direction at Vacoas weather station

## F. Extreme winds at Vacoas

The extreme wind speeds at Vacoas are illustrated in the figure below.

The 100 year return period wind speed is expected to be close to 50 m/s, but the uncertainty is very high. This is typical of extreme winds caused by cyclonic conditions.



**Fig. 34. Extreme wind speed at Vacoas weather station**

### 4.5.3. Additional analysis

The following additional observations can be made when comparing the wind data at Fort William, Vacoas and the wind related downtime at the port:

- Wind directions are comparable at Fort William and Vacoas;
- Mean wind speeds are significantly stronger at Vacoas. This is due to the different definitions of the wind speed. Daily mean values at Fort William are necessarily lower than instantaneous values;
- Extreme gust speeds at Fort William are in line with the estimated return periods of cyclones Cilida and Carol, when accounting for the proper conversion factor:
  - Carol recorded a 256 km/h gust speed;
  - Cilida recorded a sustained 1min wind speed of 112 knots or 202 km/h at 943 hPa (NOAA). This is equivalent to a 248 km/h 3s gust speed when applying said conversion factor from literature (factor of 1.23 according to Table 1.1 of Ref. [29]);
  - The T100 extreme mean wind speed at Vacoas, in spite of large uncertainties, is estimated at 48.1 m/s (173.2 km/h). Table 1.1 of Ref. [29] suggests a conversion factor of 1.66 to derive the corresponding gust speed, which yields 287 km/h;
  - The T100 gust speed in Fort William has been estimated above at 224 km/h;

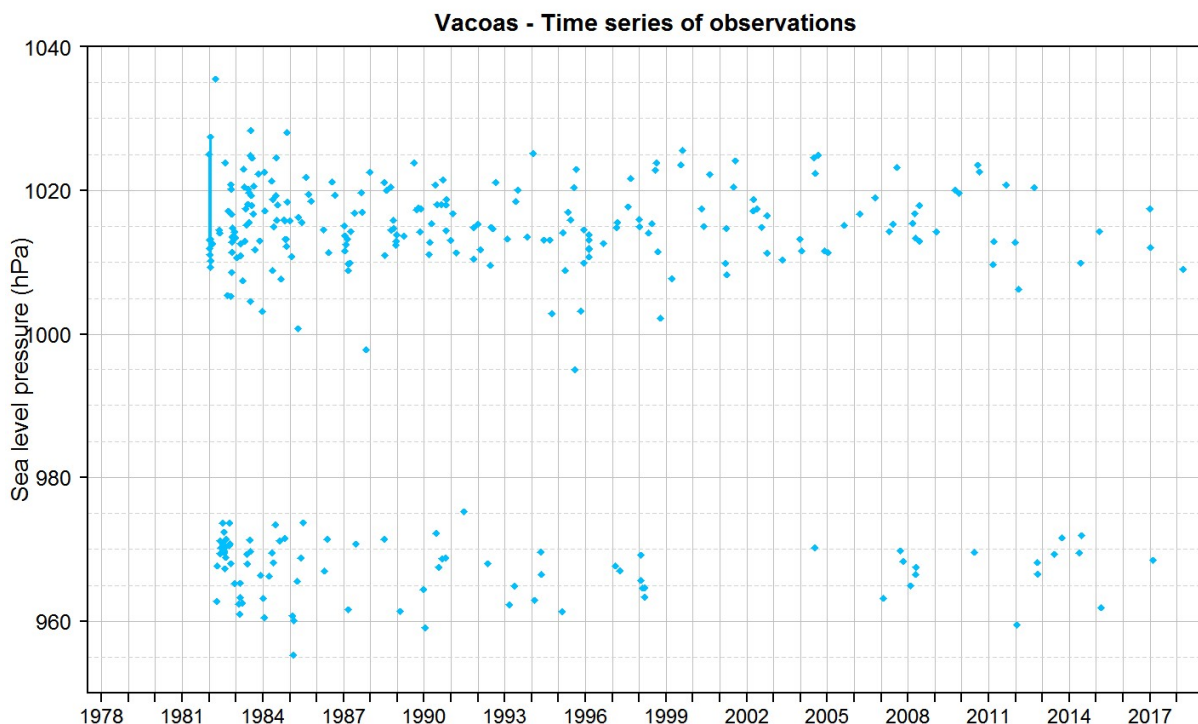
- Globally and in spite of the large uncertainties surrounding the data, this analysis confirms the return period of about 100 years of Cilida and Carol;
- The reported port downtime shows a fair match with the occurrence of gust speeds above the crane operation threshold, given the uncertainty of what is measured and how downtime is applied in practice:
  - A gust speed of 65 km/h occurs about 18 days/year (5% per year)
  - A gust speed of 70 km/h occurs about 11 days/year
  - A gust speed of 75 km/h occurs about 3.4 days/year
  - Port downtime due to excessive wind only (excluding other factors such as cyclones) is about 5-10 days/year for a threshold wind speed (assumed to be the gust speed) of 65 km/h.

These extreme value distributions can hence be used to estimate the cost of climate change under future climate scenarios.

## 4.6. ATMOSPHERIC PRESSURE

### 4.6.1. Observations

Measurements at Vacoas weather station only contain a very small number of sea level pressure observations, as shown in the figure below.



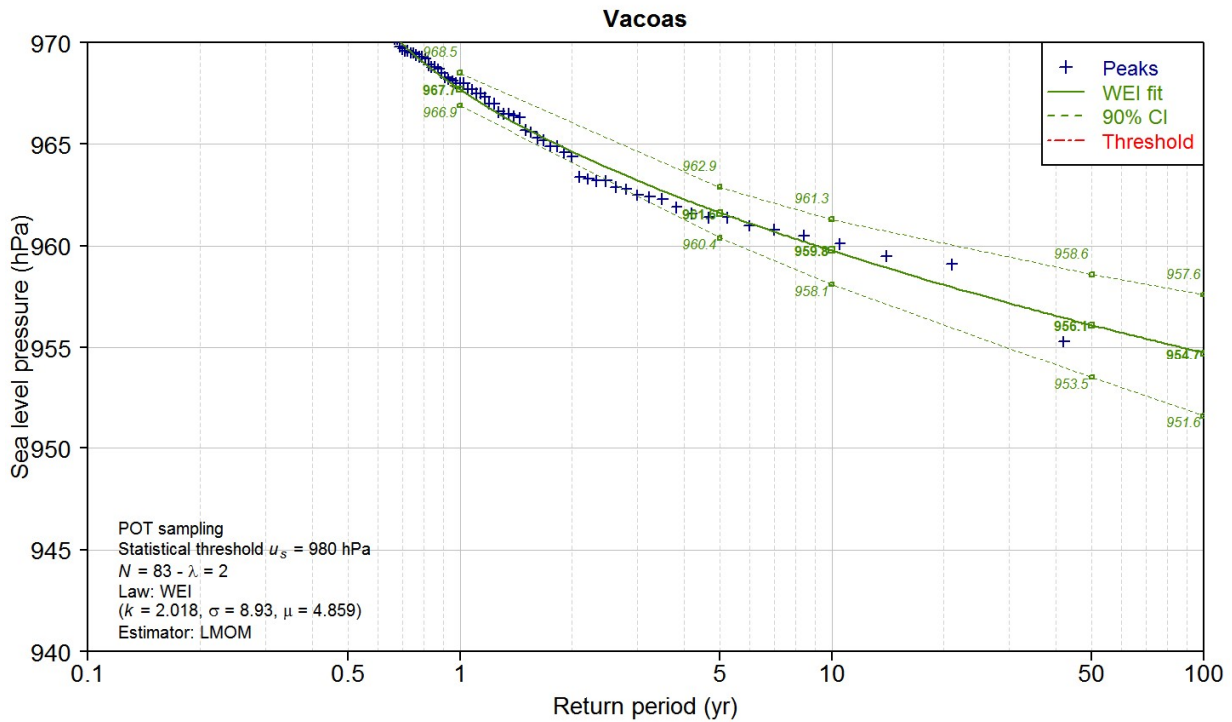
**Fig. 35.** Time series of sea level pressure at Vacoas weather station

However, several remarkable values may be noted such as:

- 955.3 hPa on 17 February 1985 ;

- 959.1 hPa on 14 January 1990 ;
- 959.5 hPa on 20 January 2012 ;
- 960.1 hPa on 26 February 1985 ;

Therefore, it can be seen that many cyclonic low values are available, which allows us to perform a tentative extrapolation of extreme low sea level pressure values. The correlation with the list of cyclones is not evident due to the large number of low pressure points.



**Fig. 36.** *Extreme low sea level pressure at Vacoas weather station*

The values obtained seem consistent with the list of historical cyclones (see § 4.1). It should be noted that Carol (February 1960) is not in the measurement period.

## 5. GENDER AND CAPACITY BUILDING CONTEXT

### 5.1. GENDER ISSUES RELATED TO CLIMATE CHANGE

In 2000, Mauritius together with 188 other UN member states, signed the Millennium Declaration setting out the eight Millennium Development Goals (MDGs). One of the goals was to promote gender equity and empower women, with the target date set at 2015.

It is noteworthy that over the years, Governments in Mauritius have introduced several legislations and measures with a view to moving away from a patriarchal society dating from pre-independence days, to a fairer and unbiased democratic society, where gender discrimination no longer exist, as is the case with modern societies around the world. In that context, a specific Ministry in the Government of Mauritius, namely the Ministry of Gender Equality, Child Development and Family Welfare, for promoting gender equality in Mauritius, exists. Among the main objectives of the Ministry are:

- Promotion and defence of women's rights as human rights, working for the elimination of all forms of discrimination against women and ensuring that legal measures are taken to promote equality between men and women;
- Implementation of gender-sensitive macroeconomic policies and strategies, including those related to poverty alleviation;
- Promotion of the welfare and empowerment of citizens through community-based programmes for an inclusive society.

Numerous initiatives have been taken for ensuring that gender-based discrimination are eliminated in the Mauritian society. In that context, Mauritius has ratified several important international human rights instruments, by:

- Acceding in July 1984 to the Convention on the Elimination of all forms of Discrimination against Women (CEDAW)
- Being a party to the 1995 Platform of Action adopted at the Fourth World Conference on Women in Beijing regarding the advancement of women
- Signing in 1997 the SADC Declaration on Gender and Development
- Signing in 1998 of the Addendum to the Declaration on the Prevention and Eradication of Violence against Women
- Signing in November 2001 the Optional Protocol to the CEDAW, which was ratified in October 2008.

Several legislations to Safeguard Women's Rights have also been introduced by Governments, notably:

1. Sex Discrimination Act (SDA 2002), passed in 2002 which gives effect to provisions of the Convention on the Elimination of All Forms of Discrimination Against Women. It provides for the protection of individuals against discrimination based on sex, marital status and pregnancy in employment, education, provision of goods, services and facilities, accommodation, disposal of property, sports associations and clubs. The Act also provides for the elimination, as far as possible, of all forms of sexual harassment in the workplace, in educational institutions and in other areas of public activity. The Act also provides for the setting up of a Sex Discrimination Division under the National Human Rights Commission.
2. Equal Right to Employment-The right to the same employment opportunities between men and women is ensured by Section 5 (1) of the Sex Discrimination Act (2002), which stipulates that: *"No employer shall, in relation to recruitment, selection or employment of any other person for purposes of training, apprenticeship or employment, discriminate against that other person on the grounds of sex, marital status, pregnancy or family responsibility in –*

- a. *The advertisement of the job;*
  - b. *The arrangements made for the purpose of determining who should be offered that employment;*
  - c. *Determining who should be offered employment;*
  - d. *The terms and conditions on which employment is offered; and*
  - e. *The creation, classification or abolition of jobs.”*
3. Sexual Offences Act 2003 reinforces the sanctions associated with sexual offences.
  4. Protection from Domestic Violence Act, enacted in 1997 and proclaimed in 1998, provides for the issue of Protection Orders, Occupation Orders and Tenancy Orders and widens the definition of domestic violence to include physical, emotional, sexual violence and even threatened violence. The objective is to protect spouses and children from violence at home. Mauritius is one of the few countries in the region to have introduced a comprehensive law to combat domestic violence.
  5. Employment Rights Act 2008, which protects the right of women to maternity benefits by providing for:
    - a. payment of maternity allowance;
    - b. situations of miscarriage and still birth ;
    - c. guaranteeing for a daily break of up to 1 hr with pay to female workers for breast feeding purposes;
    - d. pregnant women not being required to perform overtime or night work two months before confinement;
    - e. high restrictions regarding notice of termination of employment to an employee on maternity leave, to prevent abuse on the part of employers.

Moreover, with a view to transforming Mauritius in a modern democratic society, ensuring equal rights and opportunities for all its citizens, an equal opportunities act was introduced in year 2008. This legislation provides for the implementation of a policy for equal opportunity in employment and education. The Equal Opportunities Commission, a body corporate, established under the Equal Opportunities Act, became operational in April 2012. Its main objective is to eradicate all forms of discriminatory practices in employment and ensuring fair and equal treatment for everyone, tackling discrimination wherever it exists and in whatever form and which may be grounded on race, colour, ethnic origin, sex and sexual orientations, religious beliefs, political opinion, social or economic status, disability etc. The work of the commission involves, among others, elimination of discriminatory barriers, biased policies and prejudicial practices from all spheres of social and economic life in the country.

In line with Government’s policy regarding equitable treatment and opportunities for all of its citizens, the Mauritius Ports Authority (MPA) has publicly communicated that it adheres with the provisions of the Equal Opportunities Act 2008 and endeavours to follow the recommendations of the Equal Opportunities Commission regarding employment policies, procedures and practices. It is thus an equal opportunity employer, who ensures, through the implementation of policies and practices, that its employees feel respected and valued, and can achieve their potential regardless of their status, namely:

- age
- caste
- colour
- creed
- ethnic origin

- impairment
- marital status
- place of origin
- political opinion
- race
- sex
- sexual orientation.

Based on the foregoing, it is obvious that socio-economic impacts ensuing from climate change, will affect all genders equally, regardless whether these concern:

- risks of accidents, including loss of life, as witnessed after the sudden torrential rains of year 2013;
- disruption of supplies of foodstuffs and other imported goods, as well as export of manufactured goods, foodstuffs due to temporary stoppage of work at the port;
- temporary closures of roads, schools, places of work, businesses etc. in the affected areas, particularly Port Louis and its conurbations, liable of resulting in loss of revenue or jobs.

Nonetheless, one exception to the above pertains to seafarers, particularly fishermen, which is at present an exclusively male field of activity. Climate change will not only affect their families as their meagre salaries may decrease, thus affecting the family budget, but also conversely increase risks of loss of life. Most of the workers in these categories, have no safety net to safeguard their families' well-being in case of a tragic occurrence. In most cases, when they are away at sea, the family's welfare rest solely on women who in most cases, have no economic activities. This is a matter of concern that needs to be dealt with appropriately so as to ensure that seafarers' families are amply protected and insured against increasing risks climate change will create. The MPA may, with the assistance of Government agencies operating within the ambit of existing legal frameworks for promoting gender equality, ensure that this issue be given adequate attention.

## 5.2. CAPACITY BUILDING NEEDS RELATED TO CLIMATE CHANGE

The capacity building needs of the different stakeholders are addressed in the capacity building action plan which is part of Deliverable 04.

Nevertheless the difficulties encountered throughout the early phases of the project, in clearly identifying climate hazards in the present situation, illustrate the importance of addressing the full spectrum of climate change adaptation, starting with knowing the issues which have to be addressed.

## CONCLUSION

A major asset in Mauritius, the port of Port Louis is exposed to a number of combined climatic risks including storm surge, flooding and more powerful and frequent winds, thereby challenging the resilience of port infrastructure whilst at the same time disrupting the supply chain.

For many years, the port experienced regular closure periods, representing from 5 to 40 days per year, due to a combination of excessive wind, swell, rainfall and cyclones. Terrestrial flooding is not reported to be an issue at the port, in fact it was not affected during the 2013 flash floods on the Caudan waterfront in the city centre.

The downtime has been particularly pronounced in 2018 and 2019, without clear reasons identified at this stage. A distinction should be made between downtime due to cyclones (administrative closure of the entire port), and downtime of the Mauritius Container Terminal due to swell leading to excessive agitation and to overtopping. The latter is believed by MPA to stem from strong SSW swell events. The numerical model analyses this assumption further in Deliverable 02.

We can assume that climate change will exacerbate these impacts. Deliverable 02 analyses past climate trends and future projections, defines climate scenarios and meteorological events to be modelled, and estimates the cost of climate change based on a more detailed vulnerability matrix.

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# ANNEXES

# ANNEX 1 - CAPACITY TRAINING SUPPORT

# ANNEX 2 - CLIMATE CHANGE VULNERABILITY OF THE PORT SYSTEM: CASE STUDIES

## Ports of New-York and New Jersey

A number of ports have already developed adaptation plans at local and regional scales: an example is the ports of New York – New Jersey (Mills-Knapp et al., 2011).

This project was based on the following guidelines:

- define adaptation to climate change and increased resilience in relation to infrastructure and buildings;
- emphasise the rise in sea level, the set-up due to storm waves and the increase in precipitation as being the most significant climate change impacts for port infrastructure;
- investigate and summarise climate change adaptation measures taken in comparable cities with comparable infrastructure;
- recommend adaptation strategies that are most applicable to the ports' functions and objectives;
- identify synergies and areas of conflict between port development guidelines and recommended climate change adaptation strategies.
- The main conclusions of the study were as follows:
  - New York City faces a significant risk connected with the rise in sea level and adaptation strategies are needed to ensure the resilience of its infrastructure.
  - Generally speaking, adaptation strategies in comparable ports are only just starting to be implemented (the study dates from 2011).
  - The adaptation plans and strategies reviewed worldwide are based mainly on the principles of coastal zone management drawn from the first IPCC evaluation report in 1990, which identified three approaches to adaptation:
    - protection,
    - accommodation,
    - retreat.
  - Strategies to adapt to the impacts of climate change and build resilience can be implemented in harmony with pre-existing directives concerning the sustainable development of infrastructure and buildings, but may also conflict with them.

The framework proposed by the IPCC for adaptation in coastal zones was also recalled:

- development of a system for monitoring, detecting and predicting the impacts of climate change;
- identification of the most vulnerable areas and infrastructure;
- definition of adaptation strategies using two approaches:
  - emergency management planning for extreme events (flooding, storm surges)

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<sup>1</sup> Mills-Knapp, S., E. Bourdeau, G. Falco, C. Resler, H. Tovar et S. Zoegall, 2011; *Climate change adaptation and sustainable design at the port authority of New York & New Jersey. Research report, Columbia University, 75 p.* ([http://www.earth.columbia.edu/sitefiles/file/education/capstone/Capstone\\_final\\_5\\_11\\_11\\_reduced.pdf](http://www.earth.columbia.edu/sitefiles/file/education/capstone/Capstone_final_5_11_11_reduced.pdf))

- coastal management planning (longer-term, incremental adaptation strategies),
- education and information of residents and decision-makers on adaptation plans and their progress;
- creation of a flexible and easily adjustable plan including the establishment of precise indicators for measuring the success of adaptation strategies.

### Port of London

The port of London is being adapted in the framework of a comprehensive approach to adapt the capital to climate change (Greater London Authority, 2010<sup>2</sup>).

London has adopted a risk-based approach in order to identify and prioritise major climate risks, estimate their future development and identify the players involved in order to implement response strategies. Consequently, each risk (flooding, drought, etc.) is described in terms of its probability (risk), consequence and vulnerability.

A large section is devoted to understanding the impacts of three natural risks (flooding, drought, heat wave). These impacts are then grouped and discussed in terms of health, the economy, the environment and infrastructure. Lastly, some 30 actions are identified with a view to improving the capital's resilience. A leading player is designated for each one, along with partner organisations and a final completion date.

Great importance is attached to collecting good-quality environmental data covering a long period in order to evaluate climate risks precisely.

### Port of Rotterdam

The city of Rotterdam is particularly affected by climate change, mainly on account of its exposure to the risk of marine flooding (on account of rising sea levels), and river floods. Rotterdam city council has therefore launched a vast adaptation initiative based on a philosophy whereby future changes are seen as an opportunity rather than a threat or fatality<sup>3</sup>. The adaptation measures taken by the port of Rotterdam are thus included in this wide-ranging plan, which aims to make the great port city climate-proof by 2025.

The adaptation strategy concentrates on the risk of flooding, ship accessibility, adapted buildings (for example built on floating structures) and on the urban water system, amongst other things.

### Port of Cartagena

The IFC (International Finance Corporation, the global development aid institution and member of the World Bank group) carried out a case study concerning the port of Cartagena, Colombia, in 2011 (IFC, 2011<sup>4</sup>). This case study was presented at the JRC/IPTS workshop in 2013 (Stenek, 2013).

The study focuses on the Muelles el Bosque maritime terminal and the summary report is written in such a way that general solutions applicable to all ports are discussed at the same time as specific applications for the port concerned.

The study begins in the usual way with a description of the port and its environment (geographical, climatic, economic, social). The port's extremely protected situation means that climate risks change relatively little according to the estimations, being restricted mainly to a rise in sea level.

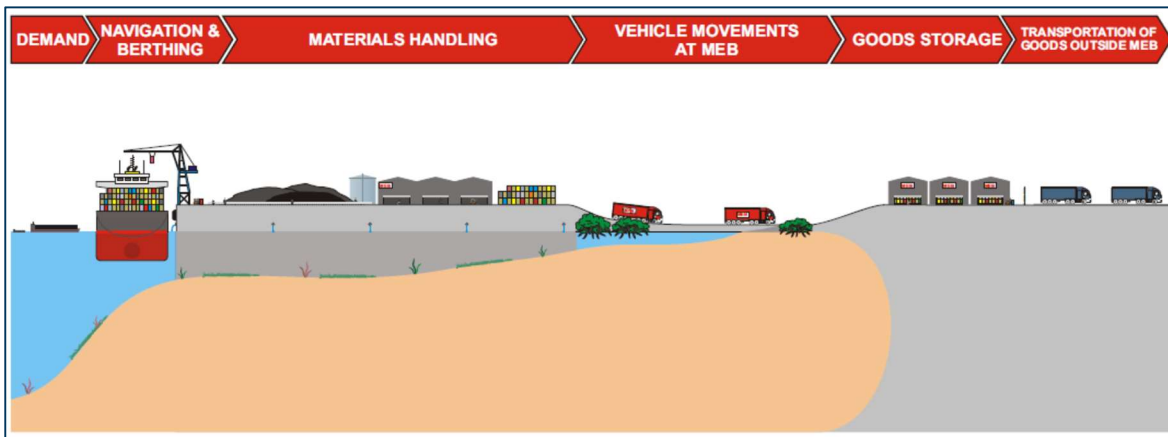
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<sup>2</sup> Greater London Authority, 2010. *The draft climate change adaptation strategy for London – Public Consultation Draft*. ISBN 978 1 84781 337 4

<sup>3</sup> <http://www.rotterdamclimateinitiative.nl>

<sup>4</sup> International Finance Corporation (IFC), 2011. *Climate risk and business ports. Terminal Marítimo Muelles el Bosque, Cartagena, Colombia, IFC/ World Bank group report, 2011*

The main originality of the remainder of the study lies in its analysis of the port's vulnerability and exposure to risk by considering its performance as depending on a system consisting of successive stages within a general environment. This vision of the port is schematised in Figure below.



**Fig. 1. Description of the port of Cartagena as a system of success criteria (IFC / World Bank, 2011)**

The successive stages are as follows:

- levels of trade and the resultant demand for port services;
- navigation outside the port and berthing of ships;
- handling of goods inside the port;
- circulation of goods, vehicles and people inside the port;
- storage of goods inside the port;
- onshore transport outside the limits of the port.

This overall vision, when compared with climate risks, means that critical areas of vulnerability can be quickly identified: in this case the low-lying road connecting the terminal situated on an island to the mainland, which will be threatened by more frequent flooding as a result of the rise in sea level.

This vulnerability seems to be capable of breaking the port's chain of operation, by cutting it off from its external environment.

### **Australian ports**

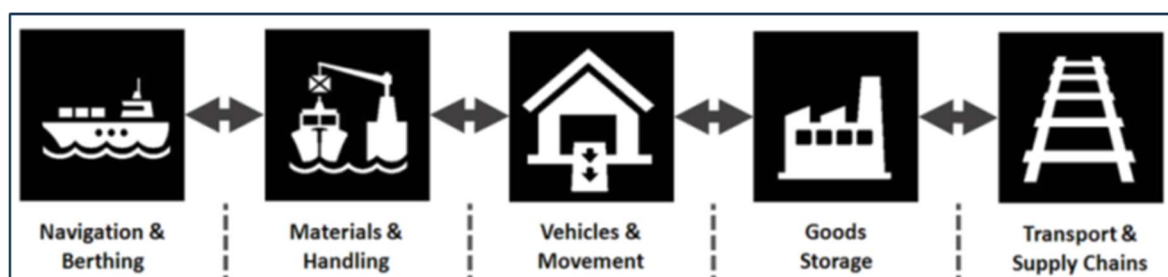
The report on "Enhancing the resilience of seaports to a changing climate" was ordered by the "National Climate Change Adaptation Research Facility" (NCCARF) in 2011. The analysis was performed over a period of 21 months (2011-12) by a multidisciplinary team from two universities.

Three ports served as case studies: Sydney, Gladstone and Port Kembla. The results were published in the form of four reports:

- Report 1: Understanding future risks to ports in Australia (McEvoy *et al.*, 2013<sup>5</sup>)
- Report 2: Functional resilience of the port environs in a changing climate
- Report 3: Structural resilience of core port infrastructure in a changing climate
- Report 4: Synthesis of the entire research project, including policy and related recommendations for adaptation.

Group 1 devoted a large part of its work to assessing present and future climate risks, but it is interesting to note that the ports are analysed as systems, in a similar way to the analysis of Cartagena.

The role of non-climatic factors (economics, demographics, institutions, technologies, logistics) in the process of adapting a port is stressed, thereby recalling that the climate is just one of the reasons why ports must be adapted.



**Fig. 2. Components of a port system (McEvoy *et al.*, 2013)**

Group 2's work is based on functional resilience, which here is understood as being resistance to extreme climatic events. This may be the resistance of a breakwater, or of a type of infrastructure: it is not a question therefore of studying the impact of climate change on the components of the port system identified by 1.

Group 3 focused on structural resilience. This is defined as being the long-term resistance (or deterioration) of the materials forming the infrastructure under the effect of a changing climate.

This work, which was summarised by Group 4, led to the definition of guidelines for adapting the ports to climate change (Scot *et al.*, 2013).

<sup>5</sup> McEvoy D, Mullett J, Millin S, Scott H and Trundle A, 2013. *Understanding future risks to ports in Australia, Enhancing the resilience of seaports to a changing climate report Series, National Climate Change, Adaptation Research Facility, Gold Coast. ISBN: 978-1-921609-84-8 NCCARF.* [https://www.nccarf.edu.au/sites/default/files/attached\\_files\\_publications/McEvoy\\_2013\\_Understanding\\_future\\_risks\\_to\\_ports\\_in\\_Australia\\_WP1.pdf](https://www.nccarf.edu.au/sites/default/files/attached_files_publications/McEvoy_2013_Understanding_future_risks_to_ports_in_Australia_WP1.pdf)

# ANNEX 3 - CLIMATE CHANGE VULNERABILITY OF THE PORT SYSTEM

## Background

### Pioneering works

At the international level, it is only very recently that there has been an awareness of the possible consequences of climate change on port infrastructure (Nicholls, 2008), in spite of repeated warnings from the scientific community on climate change (“CC”) and its effects on rising sea levels, and the signing of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992.

The first international manual on the subject was published by the PIANC in 2008. More recently, the international survey carried out in 2010 by the American Association of Port Authorities (AAPA) and the International Association of Ports and Harbours (IAPH) in collaboration with Stanford University, was the starting signal for urgent action on the subject (Becker et al., 2011) (<http://wpci.iaphworldports.org>).

### The time of discussions and case studies

The UNCTAD and UNECE began to hold meetings on the impact of climate change on international maritime transport in 2009 (UNCTAD, 2011 a) and an “ad hoc” meeting of experts on the adaptation of port infrastructure to climate change was organised in 2011, with 16 experts in different fields attending. The main results and discussions were published online (UNCTAD, 2011 b) and in greater detail in a journal article (Becker et al., 2013<sup>6</sup>).

The first case studies concerned the port of Cartagena in Colombia, with a recent study by the IFC/World Bank (IFC, 2011). Then, in 2013, in the framework of the European Commission’s “Joint Research Centre” (JRC/IPTS), the European Union organised a workshop on the subject and made 17 detailed documents available online. These documents contain an overall analysis of the impacts of CC (see for example Nemry, 2013) and detailed technical reports and case studies.

### Publication of guides

On conclusion of the works and discussions referred to above, a number of guides were published to help ports evaluate their own situation and the measures that could possibly be taken. They are generally drawn up by international or national institutions or organisations.

### Generic port potential vulnerabilities

Ports are critical infrastructure assets that serve as catalysts of economic growth and development. In addition to playing a key role in international trade, they create jobs, generate wealth and value, contribute to national gross domestic product and promote the expansion of related and near-by industries and cities.

While ports are at the heart of international trade and globalization, they are also exposed to the risk of climate change impacts, particularly in view of their location in coastal zones, low-lying areas and deltas. They can be particularly affected by rising sea levels, floods, storm surges and strong winds. Given the concentration of populations, assets and services associated with ports and the crucial role of ports as part of international supply-chains, climate change impacts on ports and their land-based access points, linking the maritime interface with the hinterland, may have serious broader implications; developing effective adaptation response measures is therefore of strategic economic importance.

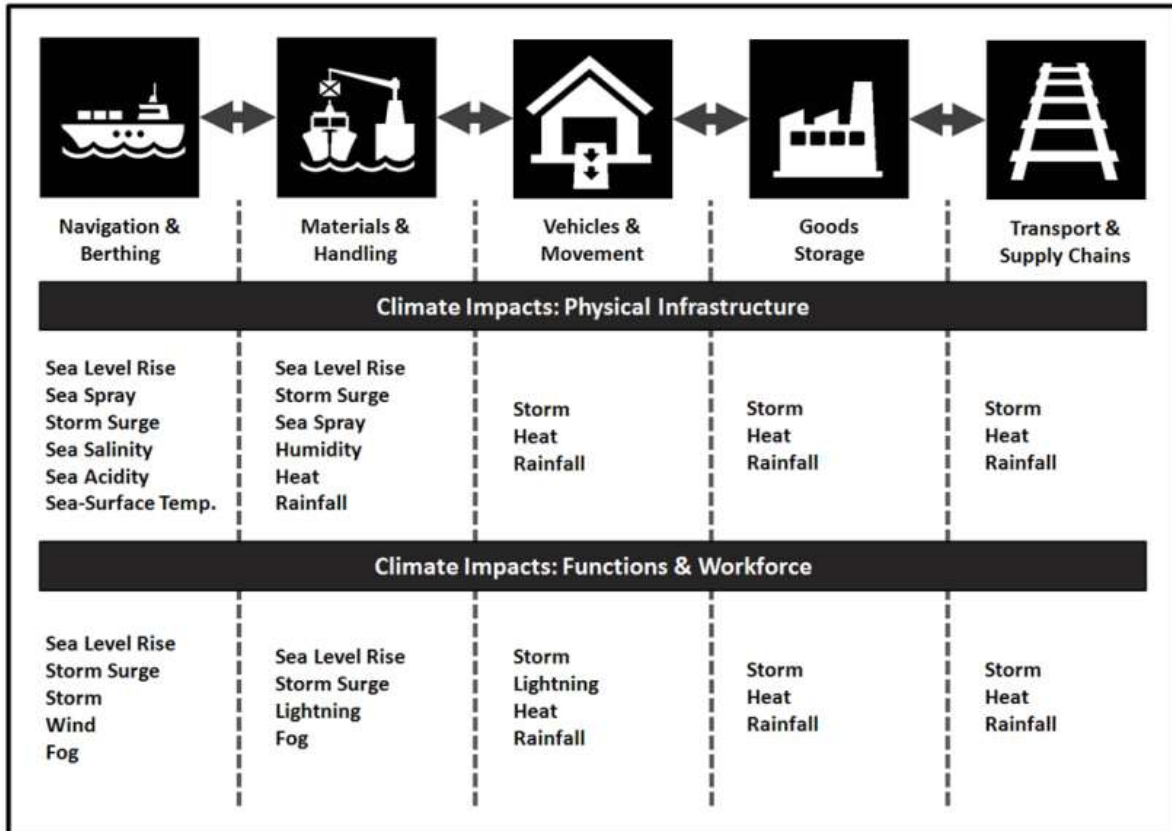
While the type, range and the magnitude of climate change impacts will vary depending on local conditions, ports are expected to be affected by climatic changes, through their infrastructure, operations and services. Associated risks, vulnerabilities and costs may be considerable, in particular for ports in developing regions with low adaptive capacity, and those in Small Island Developing States (SIDS). With SIDS being sea-locked, climatic factors that may severely impact

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<sup>6</sup> Becker, A.H. et. al, 2013. A note on climate change adaptation for seaports: a challenge for global ports, a challenge for global society, *Climatic Change*, October 2013, Volume 120, Issue 4, pp 683-695.

coastal transport infrastructure and services pose particularly serious threats to national economic development prospects.

Modern-day seaports are complex systems; represented by multiple functions and assets. The schematic diagram shown in Figure below is not only useful for highlighting the different sub-components of the system under investigation but also reinforces the importance of considering a range of different variables, beyond just sea-level rise, when identifying future climate risks.



**Fig. 3. Potential climate impacts of different sub-components of the port system (McEvoy, D & Mullett, J, 2013)**

## Port structural vulnerability

The analysis presented here aimed to identify key port infrastructure elements affected by climate change, to understand the deterioration mechanisms relevant to these structural components.

Climate variability has little impact on infrastructure because the systems are built with large design safety factors in place to accommodate sudden impacts of loading (climate-related or not). These designs however consider relatively short term events. Long term changes in weather and increased climate extremes may have an impact, especially if environmental conditions are pushed outside the range for which the system was designed. These changes may have both negative and positive effects on the infrastructure system.

**Tabl. 1 - Port system structural vulnerability matrix**

	Structural port assets	<i>Navigation and berthing</i> Breakwaters and berths	<i>Materials and handling</i> Handling equipment	<i>Vehicules and Movement</i> Internal roads and vehicles	<i>Goods storage</i> Storage areas and buildings	<i>Transport and supply chains</i> Access roads
Climate hazards	Temperature increase	Embrittlement and cracking of bitumen	Degradation of superstructure materials	Embrittlement and cracking of bitumen Damage to road foundations as a result of prolonged drought and low rainfall	Degradation of superstructure materials	Higher deterioration rates of pavement and roadways.
	Heavy rainfall	Heavy rain can overwhelm existing draining systems and cause flooding, creating pavement and embankment failure, erosion, debris movement, etc.	Flooding can cause damage to crane equipment, making it inoperable and halting or slowing	Loss of water seal	Heavy rain can overwhelm existing draining systems and cause flooding, creating pavement and embankment failure, erosion, debris movement, etc.	Heavy rain can overwhelm existing draining systems and cause flooding, creating pavement and embankment failure, erosion, debris movement, etc.
	Sea level rise	Change in water depth and flow. A - positive - impact on the necessary depths of dredging. Increased/decreased sedimentation. Corrosive impact of materials used for maritime structures.	Not sensitive.	Not sensitive.	Not sensitive.	Not sensitive.
	Winds	Not sensitive.	Not sensitive.	Not sensitive.	Failure of roof and cladding	Not sensitive.
	Increase in extreme events (storms)	Increased wave action on waterfront structures	Not sensitive.	Not sensitive.	Not sensitive.	Tropical storms can cause roadway damages

## Port operational vulnerability

The growing importance of logistics in increasingly globalised production and consumption systems strengthens the case for explicit consideration of the climate risks that may impact on the operation of ports in the future, as well as the formulation of adaptation responses that act to enhance their resilience.

Within a logistics chain, seaports are functional nodes of significant strategic importance, and are considered as critical gateways linking local and national supply chains to global markets. However, they are more likely to be exposed to vagaries of climate-related extreme events due to their coastal locations. As such, they need to be adaptive and respond to the projected impacts of climate change, in particular extreme weather events. These impacts are especially important in the logistics context as they could result in varying degrees of business interruption; including business closure in the worst case scenario.

The analysis presented here aims to identify the vulnerability of port logistics operations to climate-related events.

**Tabl. 2 - Port system operational vulnerability matrix**

	Port operations	Navigation and berthing	Materials and handling	Vehicles and Movement	Goods storage	Transport and supply chains
		Accessibility and mooring	Crane operation	Vehicles' operation	Storage	Access
Climate hazards	Temperature increase	Not sensitive.	Not sensitive.	Not sensitive.	Very hot days can threaten perishable goods	Not sensitive.
	Heavy rainfall	Heavy rain can reduce visibility, and delaying shipping and transport.	Heavy rain can reduce visibility, delaying shipping and transport.	Heavy rain can reduce visibility, delaying shipping and transport.	Heavy rain can create flooding, damaging stored goods and storage areas	Heavy rain can overwhelm existing draining systems and cause flooding, delaying transport and supply operations.
	Sea level rise	Higher sea levels can increase the risk of chronic flooding and lead to permanent inundation of dock facilities, making a port inoperable	Not sensitive.	Not sensitive.	Not sensitive.	Sea level rise could increase the risk of flooding of coastal roads to access the port.
	Winds	Accessibility and mooring is not guaranteed above certain (extreme) wind speed.	Cranes cannot be used above defined wind speeds. Inoperable cranes can cause delays in shipping.	Wind can blow over road signs and stir up dust from roads, creating dangerous travel conditions.	Not sensitive.	Wind can blow over road signs and stir up dust from roads, creating dangerous travel conditions.
	Increase in extreme events (storms)	Increase in overtopping rates, hence flooding of berth facilities	Not sensitive.	Tropical storms can cause roadway damages and debris movement, blocking access	Toppling of container in stacking areas	Tropical storms can cause roadway damages and debris movement, blocking access to the port for

		<i>Navigation and berthing</i>	<i>Materials and handling</i>	<i>Vehicles and Movement</i>	<i>Goods storage</i>	<i>Transport and supply chains</i>
	<b>Port operations</b>	<b>Accessibility and mooring</b>	<b>Crane operation</b>	<b>Vehicles' operation</b>	<b>Storage</b>	<b>Access</b>
				to the port for staff and goods.		staff and goods. Closure of linked modes of transport, affecting supply and distribution of goods to and from the port

The operational vulnerability of the port system also includes the manpower vulnerability, as many port workers work outside and are therefore more sensitive to climate variables, in particular extreme heat and high wind speeds which could create hazardous working conditions for port staff.