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"Climate Change Impacts and Adaptation for Coastal Transport Infrastructure in Caribbean SIDS"

Applying the thresholds method/approach

The Example of SAINT LUCIA

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PROSPERITY FOR ALL

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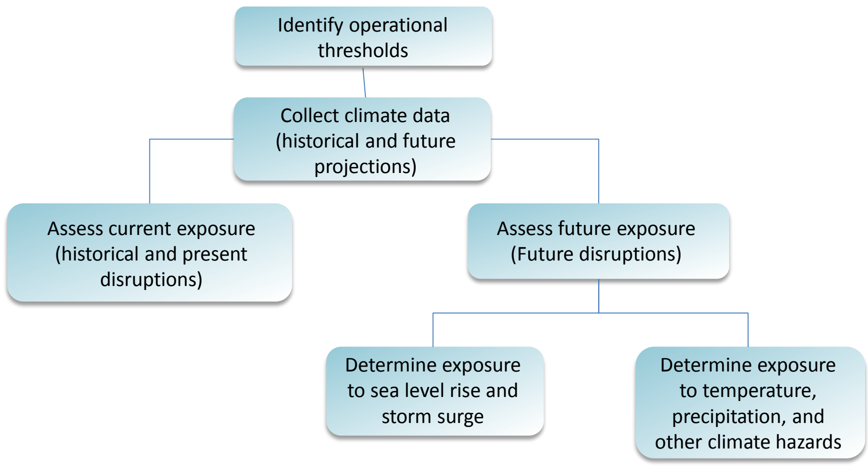
Synopsis

1. The operational thresholds method
2. The Example of Saint Lucia
    - 2.1 Identification of the operational thresholds
    - 2.2 Collection of climate data
    - 2.3 Estimation of historical and future disruptions
3. The Example of Jamaica
4. Some thoughts

The operational thresholds method



The Example of Saint Lucia

Critical assets

The four major transportation assets in Saint Lucia are:

- ***Hewanorra International Airport***
- ***George F. L. Charles Airport***
- ***Port Castries***
- ***Port Vieux Fort***

The Example of Saint Lucia

Identification of the operational thresholds

Employee ability to work safely outdoors and heat index

Heat index is provided at http://www.nws.noaa.gov/om/heat/heat_index.shtml

NOAA's National Weather Service

Heat Index

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution · Extreme Caution · Danger · Extreme Danger

Generic thresholds:

Heat Index over 103 °F is "high" risk

Heat Index over 115 °F is "very high" risk

The Example of Saint Lucia

Identification of the operational thresholds

Employee ability to work safely outdoors and heat index

For example the threshold of heat index equal 115 °F will be exceeded if the temperature is over 92 °F and at the same time humidity is over 75%.

	Combinations of temperature and relative humidity						
Humidity / Heat index thresholds	70%	75%	80%	85%	90%	95%	100%
Heat Index over 39.4 C (103 °F) is "high" risk	32.2 °C (89.9 °F)	31.4 °C (88.5 °F)	30.8 °C (87.5 °F)	30.4 °C (86.8 °F)	29.9 °C (85.8 °F)	29.4 °C (85 °F)	28.9 °C (84 °F)
Heat Index over 46 C (115 °F) is "very high" risk	34 °C (93.2 °F)	33.3 °C (92 °F)	32.6 °C (90.7 °F)	32.1 °C (89.7 °F)	31.5 °C (88.7 °F)	31.1 °C (87.9 °F)	30.4 °C (86.7 °F)

All combinations of Temperature and Humidity were compared with climate data and it was found that most disruptions are likely to be associated with relative humidity of 80 %.

The Example of Saint Lucia

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature

Takeoff length requirements vary by aircraft type, and are available from aircraft manufacturers.

The types of aircrafts that fly into HIA include, inter alia, Airbuses (A300's) Boeings (722 – 738), DC10, DHC 6 -8.

For Boeing aircrafts this information is available at:
Source: Boeing, 2013
(http://www.boeing.com/assets/pdf/commercial/airports/acaps/737.pdf).

This manual (Boeing, 2013) provides Takeoff Runway Length Requirements, in a series of charts.

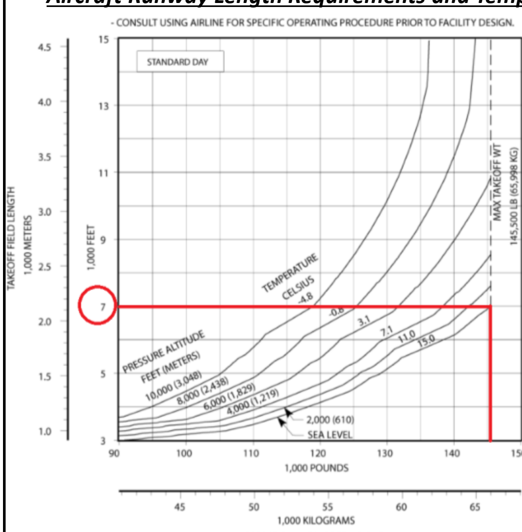
Each chart shows the runway length requirements for a different air temperature starting from the "Standard Day" (STD) temperature of 15 °C.

The temperatures that Boeing aircrafts will require a runway longer than the existing runway of HIA were estimated and used as thresholds.

The Example of Saint Lucia

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature



Takeoff Runway Length Requirements
737-600 (CFM56-7B18/-7B20)

Assuming the following conditions:

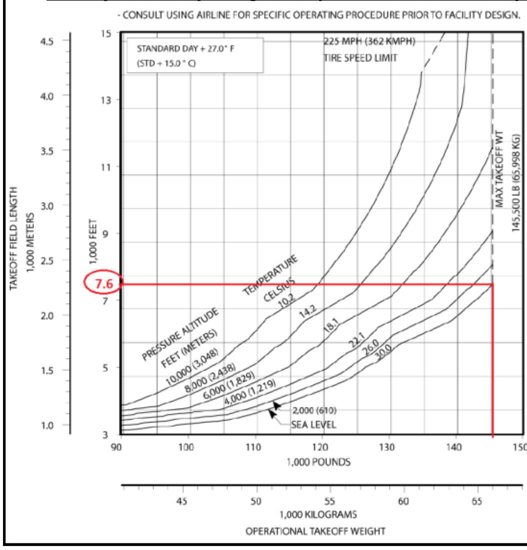
- maximum aircraft takeoff weight
- sea level
- dry runway
- zero wind
- zero runway gradient
- air conditioning off
- and optimum flap setting

The Takeoff length requirement for STD temperature (15 °C) is 7000 ft.

The Example of Saint Lucia

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature



Takeoff Runway Length Requirements
737-600 (CFM56-7B18/-7B20)

Assuming the following conditions:

- maximum aircraft takeoff weight
- sea level
- dry runway
- zero wind
- zero runway gradient
- air conditioning off
- and optimum flap setting

The Takeoff length requirement for STD + 15 °C temperature (30 °C) is 7600 ft.

The Example of Saint Lucia

Identification of the operational thresholds

Aircraft Runway Length Requirements and Temperature

Using the charts, takeoff runway length requirements for 4 models of Boeing 737 aircraft under multiple temperature conditions were estimated.

Hewanorra International Airport (HIA) has a runway length of 2,744 m (9,003 ft)

Takeoff length requirements by aircraft type and temperature.

	Maximum daily temperature			
	STD*	STD + 15 °C	STD + 22.2 °C	**Threshold temperature for**
	15 °C (59 °F)	30 °C (86 °F)	37.2 °C (99 °F)	**2,744 runway length of HIA**
Boeing 737-600	2,134 m (7,000 ft)	2,316 m (7,600 ft)	**3,048 m (10,000 ft)**	**34.2 °C**
Boeing 737-800/-800W/BBJ2	2,377 m (7,800 ft)	2,469 m (8,100 ft)	**3,078 m (10,100 ft)**	**33 °C**
Boeing 737-500	2,469 m (8,100 ft)	2,652 m (8,700 ft)	n/a	**31.2 °C**
Boeing 737-400	2,530 m (8,300 ft)	2,682 m (8,800 ft)	n/a	**31 °C**

The Example of Saint Lucia

Identification of the operational thresholds

Increase of Energy cost and Temperature

Extreme heat can raise energy costs for cooling. According to generic standard 1°C warming will result to 5% increase in energy costs.

Using historical observed data of monthly scale from the Met office service, mean temperature for the period 1986-2005 was estimated to be 26.8 °C.

If temperature exceeds 27.8°C, 29.8°C and 32.8°C the energy cost will raise by 5%, 15% and 30% respectively.

The Example of Saint Lucia

Identification of the operational thresholds

Other Generic thresholds

Climate Hazard	Sensitivity	Example Threshold	Source
Ports			
Precipitation	Low visibility inhibits crane operation	In Manzanillo, intense rainfall > 20 mm within 24 hours reduces visibility enough to impair operations	IDB, 2015b
		Very heavy rainfall (e.g. >50 mm/day)	IDB, 2015b
Wind Speeds	Ability to berth ships (due to waves)	Varies by facility. For example, at Kingston Container Terminals (KCT) in Jamaica: • Winds ≥ 18 m/s (40.3 mph, 35 knots) force operational shutdown • With winds of 12.8-18 m/s (28.8-40.3 mph, 25-35 knots), discretion is applied	Smith Warner, 2017
Airports			
Wind Speeds	Inability of aircraft to land or take off	Commercial airports: sustained winds of 20 m/s (45 mph, 39 knots) or frequent gusts of 26 m/s (58 mph, 50.4 knots) General Aviation airports: 11.2 m/s (25 mph, 21.7 knots)	ACRP Report 160

The Example of Saint Lucia

Collection of climate data

The database of the Caribbean Community Climate Change Centre (CCCCC) was used as a source, since it provides daily-scale climate data.

Daily-scale climate data for the period 1970 -2099 from the Regional Climate Model (PRECIS) were obtained.

The available projections were based on the A1B scenario which is compatible with the RCP 6.0.

The Example of Saint Lucia

Assess current exposure

Historical data in a daily scale, from the CCCCC database were used.

The data were compared with thresholds and the number of days that the operational thresholds have been exceeded historically, was estimated.

The Example of Saint Lucia

Assess future exposure

(temperature, precipitation, and other climate hazards)

- Compare the projected climate data with the operational thresholds.
- Estimate the number of times the operational thresholds will be exceeded in the future

The Example of Saint Lucia

Assess future exposure

Determine exposure to temperature, precipitation, and other climate hazards

Days of disruptions for the airports.

Airports					
			Disruptions (average days/year)		
Climate Stressor	**Sensitivity**	**Threshold**	**2000-2019**	**2040- 2059**	**2080 - 2099**
Extreme Heat	Employee ability to work safely outdoors	Heat Index* over 30.8 °C (87.5 °F) with relative humidity 80% is “high” risk	2.05 (41 days)	13.2 (264 days)	53.7 (1073 days)
		Heat Index* over 32.9 °C (90.7 °F) with relative humidity 80% is “very high” risk	0	1.05 (21 days)	11.8 (236 days)
	Aircraft take-off length requirements	Boeing 737-600 aircraft would not be able to take off from HIA if the temperature exceeds 34.2°C without reducing aircraft loads	0	0	2.2 (44 days)
		Boeing 737-800/-800W/BBJ2 aircraft would not be able to take off from HIA if the temperature exceeds 33°C without reducing aircraft loads	0	0.7 (14 days)	12.2 (244 days)
		Boeing 737-500 aircraft would not be able to take off from HIA if the temperature exceeds 31.2°C without reducing aircraft loads	1.1 (22 days)	12.1 (242 days)	67.5 (1350 days)
		Boeing 737-400 aircraft would not be able to take off from HIA if the temperature exceeds 31°C without reducing aircraft loads	1.7 (34 days)	12.25 (245 days)	67.9 (1357 days)
Wind Speeds	Inability of aircraft to land or take off	Commercial airports: sustained winds of 20 m/s	0	0	0
		General Aviation airports: 11.2 m/s	0.2 (4 days)	0.1 (2 days)	0.05 (1 days)

The Example of Saint Lucia

Assess future exposure

Determine exposure to temperature, precipitation, and other climate hazards

Days of disruptions for the sea ports.

Ports					
			Disruptions (average days/year)		
Climate Stressor	**Sensitivity**	**Threshold**	**2000-2019**	**2040- 2059**	**2080 - 2099**
Extreme Heat	Energy costs	1°C warming = 5% increase in energy costs if temperature exceeds 27.8°C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	221 (4419 days)	351.5 (7029 days)
		3°C warming = 15% increase in energy costs if temperature exceeds 29.8°C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	47.6 (951 days)	179 (3581 days)
		6°C warming = 30% increase in energy costs if temperature exceeds 32.8°C (mean temperature for the period 1986-2005: 26.8 °C)	N/A	1 (20 days)	15.4 (308 days)
Precipitation	Low visibility inhibits crane operation	Intense rainfall (e.g., > 20 mm/day)	43.5 (870 days)	45.5 (910 days)	46.7 (934 days)
		Very heavy rainfall (e.g. >50 mm/day)	0.9 (18 days)	0.8 (16 days)	0.8 (16 days)
Wind Speed	Ability to berth ships (due to waves)	Winds ≥18 m/s (40.3 mph, 35 knots) force operational shutdown	0	0	0
		With winds of 12.8-18 m/s (28.8-40.3 mph, 25-35 knots), discretion is applied	0	0.05 (1 days)	0

The Example of Saint Lucia

Assess future exposure

Determine exposure to sea level rise and storm surge

In Saint Lucia, coastal flooding is primarily caused by tropical storms and hurricanes.

- ESLs were estimated for Saint Lucia (and Jamaica). In order to assess the impacts of a Caribbean hurricane, the effect of a hurricane with the characteristics of Thomas were superimposed on the ESL projections.
- Flood/inundation was assessed (This work is made by the collaborating institute Joint Research Centre (JRC-EC), using dynamic inundation modeling (LISFLOOD-ACC)

The Example of Saint Lucia

Assess future exposure

Determine exposure to sea level rise and storm surge

Extreme Sea levels from JRC:

ESL are driven by the combined effect of MSL, tides (η_{tide}) and water level fluctuations due to waves and storm surges (η_{w-ss}). As a result, ESL can be defined as (Vousdoukas et al., 2017):

$$ESL = MSL + \eta_{tide} + \eta_{w-ss}$$

The climate extremes contribution η_{w-ss} from waves and storm surge can be estimated according to the following equation:

$$\eta_{w-ss} = SSL + 0.2 \times H_s$$

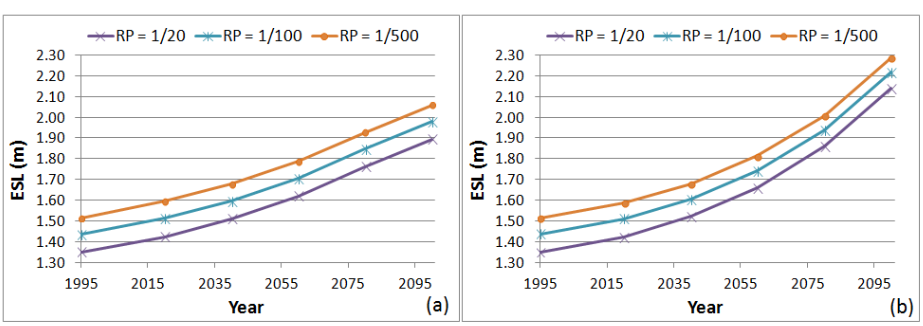
where SSL is the storm surge level, H_s is the significant wave height and $0.2 \times H_s$ is the wave set-up.

The Example of Saint Lucia

Assess future exposure

Determine exposure to sea level rise and storm surge

Extreme Sea levels for Saint Lucia (MSL + tide + storm surge + wave set up + hurricane) from JRC:



Time evolution of ESLs for 3 return periods (RP) and according with the RCP scenarios (a) 4.5 and (b) 8.5.

The Example of Saint Lucia

Assess future exposure

Determine exposure to sea level rise and storm surge
and hurricane

Inundation maps for a Caribbean hurricane (Thomas) superimposed on a 100-year ESL (RCP 4.5, 2050) (ESL = 1.66 m)

The Example of Saint Lucia

Assess future exposure

Determine exposure to sea level rise and storm surge
and hurricane

Inundation maps for a Caribbean hurricane (Thomas) superimposed on a 100-year ESL (RCP 8.5, 2100) (ESL = 2.23 m)

The Example of Saint Lucia

Assess future exposure

Determine exposure to sea level rise and storm surge and hurricane

Table summarizing the impacts to major transportation assets due to coastal flooding. 0: no impacts, 1: Low impact, 2: medium impact, 3: high impact.

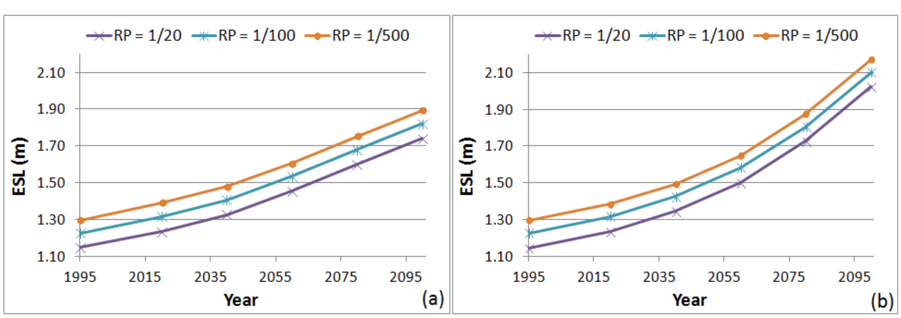
Scenarios	ESL plus Hurricane (m)	Graded impacts to the Major Assets			
		HIA	GFL IA	Port Vieux Fort	Port Castries
RCP 4.5 – 2050 (RP=1/10)	1.53	1	0	3	3
RCP 4.5 – 2050 (RP=1/50)	1.62	1	0	3	3
RCP 4.5 – 2050 (RP=1/100)	1.66	1	1	3	3
RCP 8.5 – 2050 (RP=1/10)	1.56	1	0	3	3
RCP 8.5 – 2050 (RP=1/50)	1.65	1	1	3	3
RCP 8.5 – 2050 (RP=1/100)	1.68	1	1	3	3
RCP 4.5 – 2100 (RP=1/10)	1.87	1	1	3	3
RCP 4.5 – 2100 (RP=1/50)	1.96	2	2	3	3
RCP 4.5 – 2100 (RP=1/100)	1.99	2	2	3	3
RCP 8.5 – 2100 (RP=1/10)	2.12	2	2	3	3
RCP 8.5 – 2100 (RP=1/50)	2.20	3	2	3	3
RCP 8.5 – 2100 (RP=1/100)	2.23	3	2	3	3

The Example of Jamaica

Assess future exposure

Determine exposure to sea level rise and storm surge

Extreme Sea levels for Jamaica (MSL + tide + storm surge + wave set up + hurricane) from JRC:



Time evolution of ESLs for 3 return periods (RP) and according with the RCP scenarios (a) 4.5 and (b) 8.5.

The Example of Jamaica

Assess future exposure

Determine exposure to sea level rise and storm surge
and hurricane

Donald Sangster International Airport
(Runway elevation = 1.37 m)

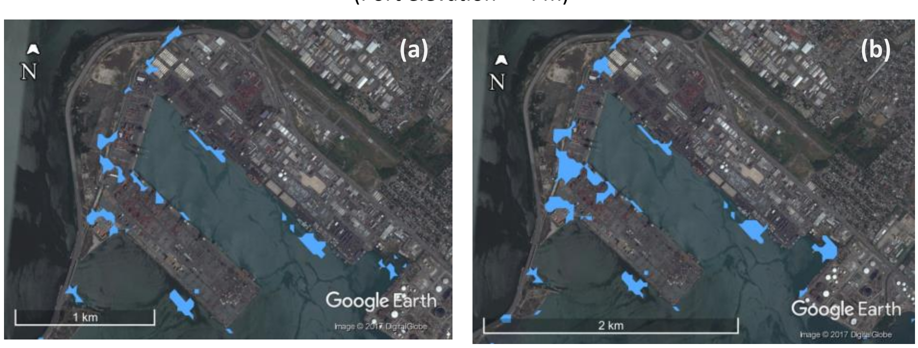
Inundation maps for a Caribbean hurricane (Thomas) superimposed on a 100-year ESL
(a) RCP 4.5, 2050 (ESL = 1.47 m) and (b) RCP 8.5, 2100 (ESL = 2.10 m)

The Example of Jamaica

Assess future exposure

Determine exposure to sea level rise and storm surge
and hurricane

Kingston Freeport Terminal
(Port elevation = 4 m)



Inundation maps for a Caribbean hurricane (Thomas) superimposed on a 100-year ESL
(a) RCP 4.5, 2050 (ESL = 1.47 m) and (b) RCP 8.5, 2100 (ESL = 2.10 m)

Some thoughts

Using the operational threshold method the historical and future disruptions can be determined

Through the inundation mapping the locations which are most likely to be inundated can be determined

The results of the application in Saint Lucia can be improved if the following information is available:

- Specific operational thresholds for the specific facilities
- Historical (observed) data in daily scale
- DEM or LIDAR data of high resolution