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

Climate Change Projections for the Caribbean and Implications for Air and Sea Ports

By

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Key Climate Risk Factors for Seaports and Airports in SIDS

- Increasing air ^{0}T and SST → (i) thermal expansion of ocean surface (ii) greater *convection potential* over ocean
- Rising sea level and surge → (a) raise H_2O levels (b) *high amplitude waves* and increased potential for damage
- Higher wind speeds→ increased storminess (IPCC AR5)
    - No clear trend in total projected storm numbers BUT *tropical cyclone intensity projected to increase*
    - *Frequency of the most intense storms* likely to increase substantially in some basins
    - Likely increase in both *global mean tropical cyclone maximum wind speed* and *rainfall intensity*

Representative Concentration Pathways Scenarios

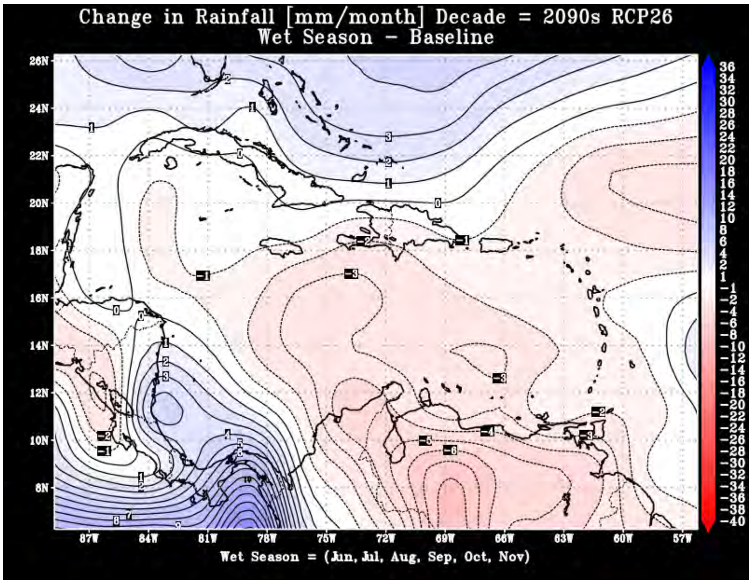
- The 4 RCPs are defined by the IPCC as follows:
- One *high* pathway ⟶ radiative forcing exceeds 8.5 W/m^2 by 2100 and continues to rise for some period thereafter;
- Two intermediate *stabilization* pathways ⟶ radiative forcing is stabilized at around 6.0 W/m^2 and 4.5 W/m^2 after 2100;
- One *low* pathway - where radiative forcing peaks at about 3 W/m^2 before 2100 and declines thereafter.

RCP	**Description**
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2(~1370 ppm CO_2e) by 2100.
RCP6	Stabilization without overshoot pathway to 6 W/m^2(~850 ppm CO_2e) at stabilization after 2100
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2(~650 ppm CO_2e) at stabilization after 2100
RCP2.6	Peak in radiative forcing at ~3 W/m^2 (~490 ppm CO_2e) before 2100 and then decline (the selected pathway declines to 2.6 W/m^2 by 2100).

Projected Wet Season Rainfall

RCP 2.6 CMIP5 Multi-Models

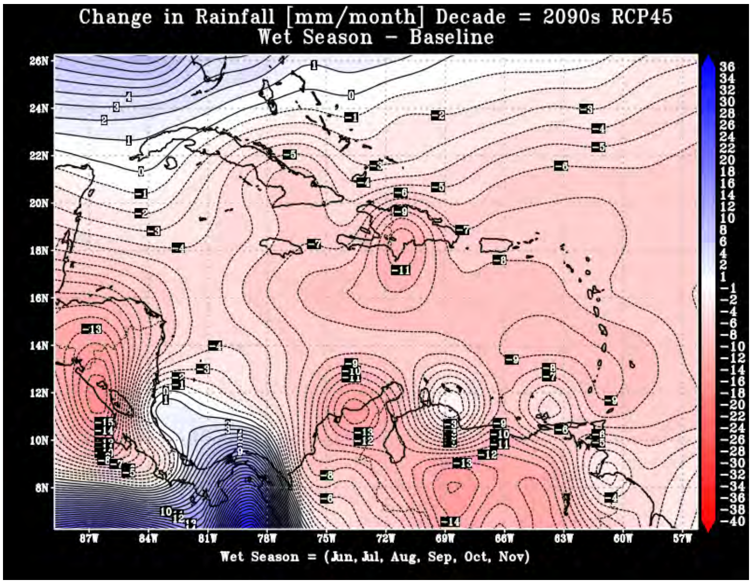
Rainfall difference Relative to Baseline (1985-2005)



Projected Wet Season Rainfall

RCP 4.5 CMIP5 Multi-Models

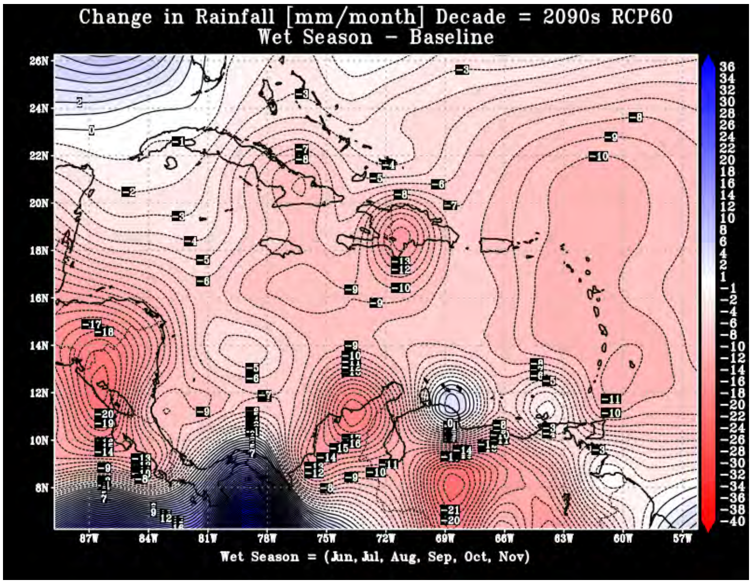
Rainfall difference Relative to Baseline (1985-2005)



Projected Wet Season Rainfall

RCP 6.0 CMIP5 Multi-Models

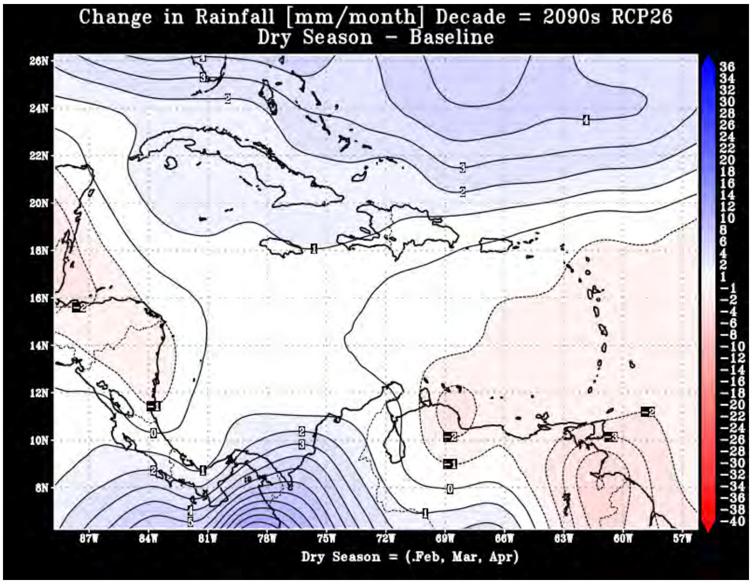
Rainfall difference Relative to Baseline (1985-2005)



Projected Dry Season Rainfall

RCP 2.6 CMIP5 Multi-Models

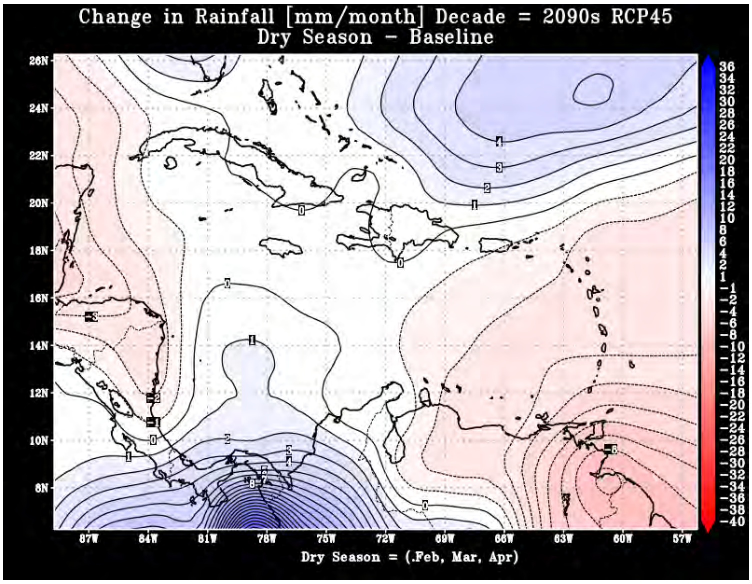
Rainfall difference Relative to Baseline (1985-2005)



Projected Dry Season Rainfall

RCP 4.5 CMIP5 Multi-Models

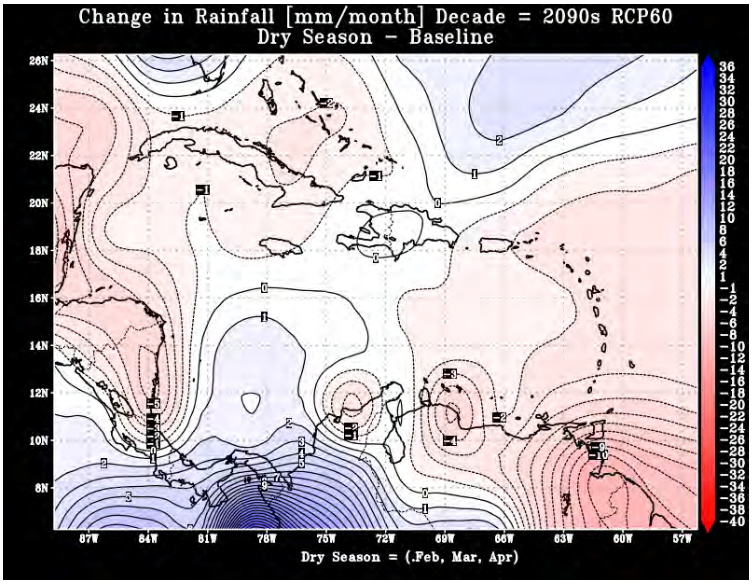
Rainfall difference Relative to Baseline (1985-2005)



Projected Dry Season Rainfall

RCP 6.0 CMIP5 Multi-Models

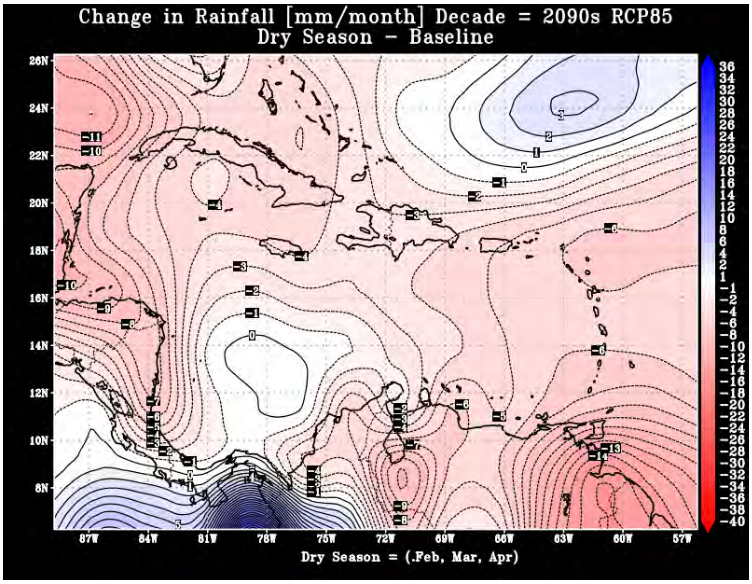
Rainfall difference Relative to Baseline (1985-2005)



Projected Dry Season Rainfall

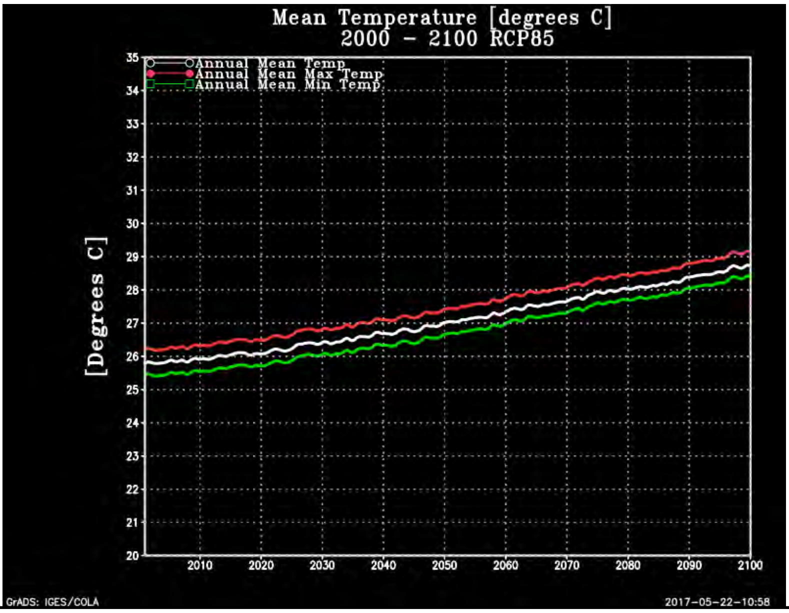
RCP 8.5 CMIP5 Multi-Models

Rainfall difference Relative to Baseline (1985-2005)



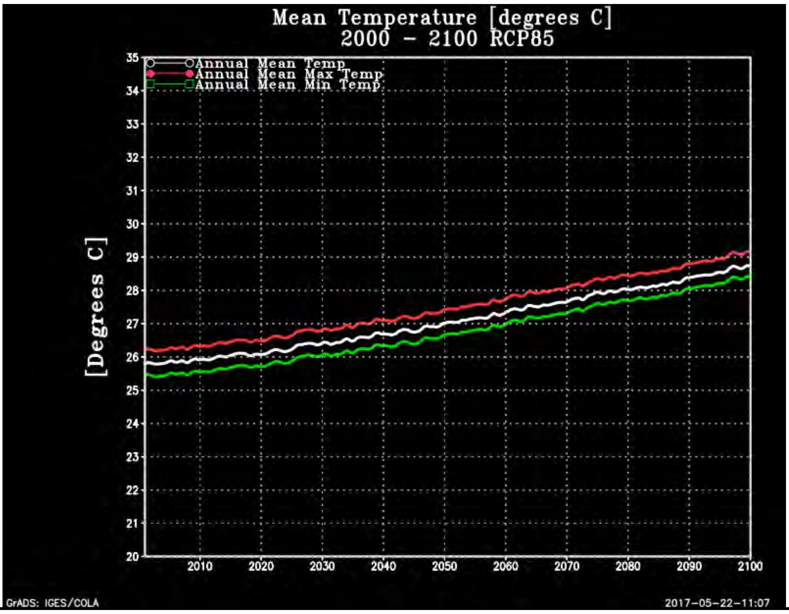
Projected Temperature - St. Lucia

RCP 2.6 - 8.5 CMIP5 Multi-Models

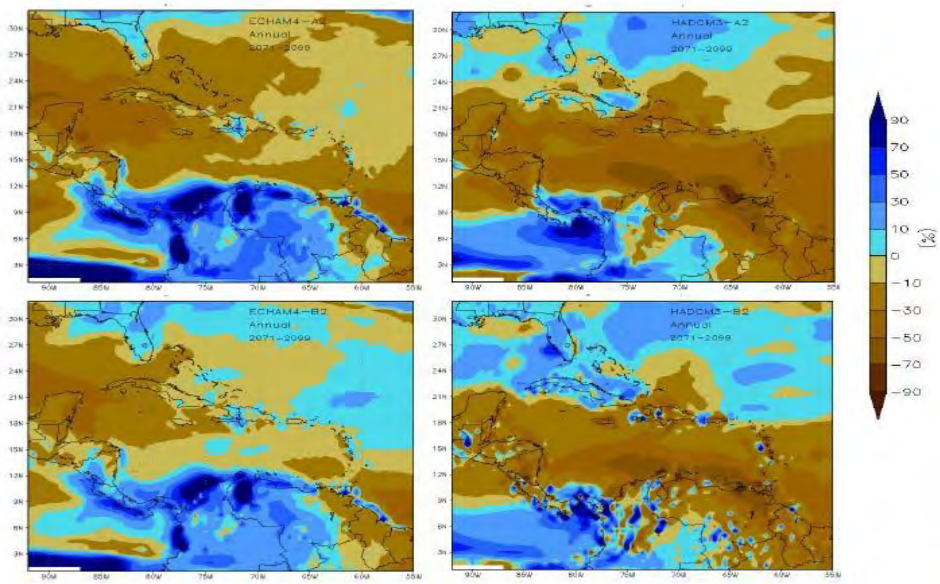


Projected Temperature – Kingston, Jamaica

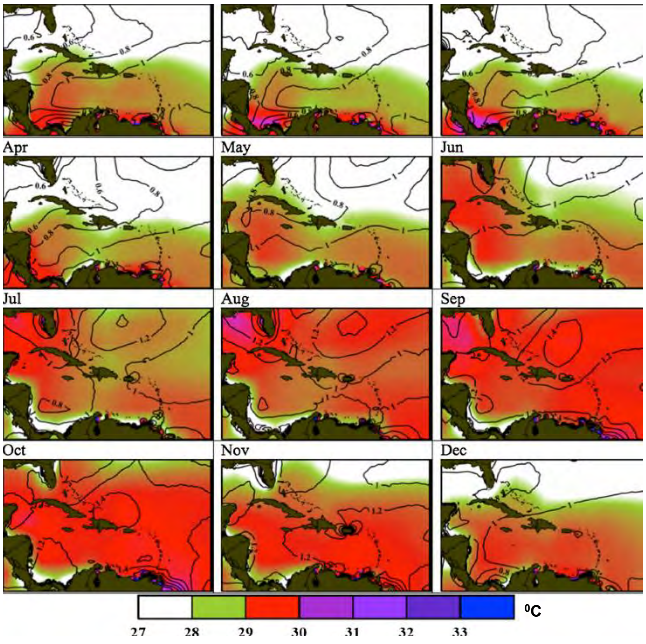
RCP 2.6 - 8.5 CMIP5 Multi-Models



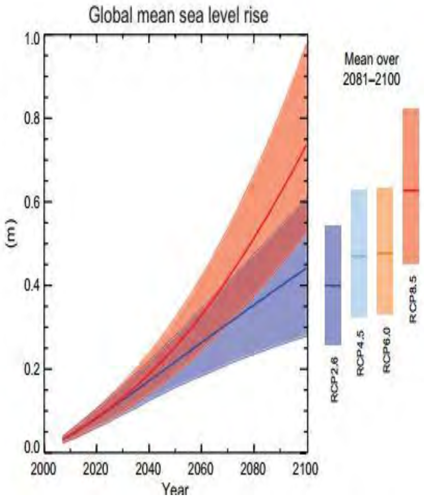
Drying trend between -25% and -30 % by end of Century. Drying far exceeds natural variability. Drier wet season likely (Taylor, 2011)



Source: Nurse and Charlery, 2015. *Theoretical and Applied Climatology*, December 2014, DOI: 10.1007/s00704-014-1346-1



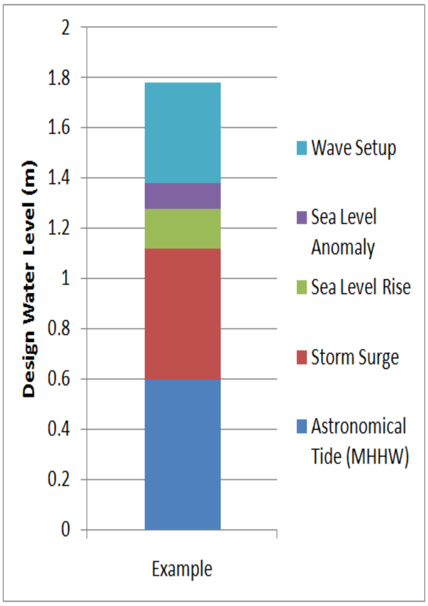
20th Century Observed SLR in SIDS Regions



- Tropical Western Pacific → rate of rise is almost 4 times the global average.
- Indian Ocean → rate of SLR as much as twice global average
- In **Caribbean** → rate of SLR generally higher than global average, ~ 1.8mm $^{yr-1}$.

► Guyana → is a special case - rate of SLR > twice the regional average. Why?

Key Components of Water level Change: Implications for Coastal Air & Sea Ports



i. Astronomical Tide

ii Wave set up → increase in mean water level landward of breaker zone due to *flux of H_2O* at coast

iii Sea level anomaly → measure of the difference between short- and long-term MSL → *negative* and *positive* anomalies

iv Sea level rise

v Storm Surge

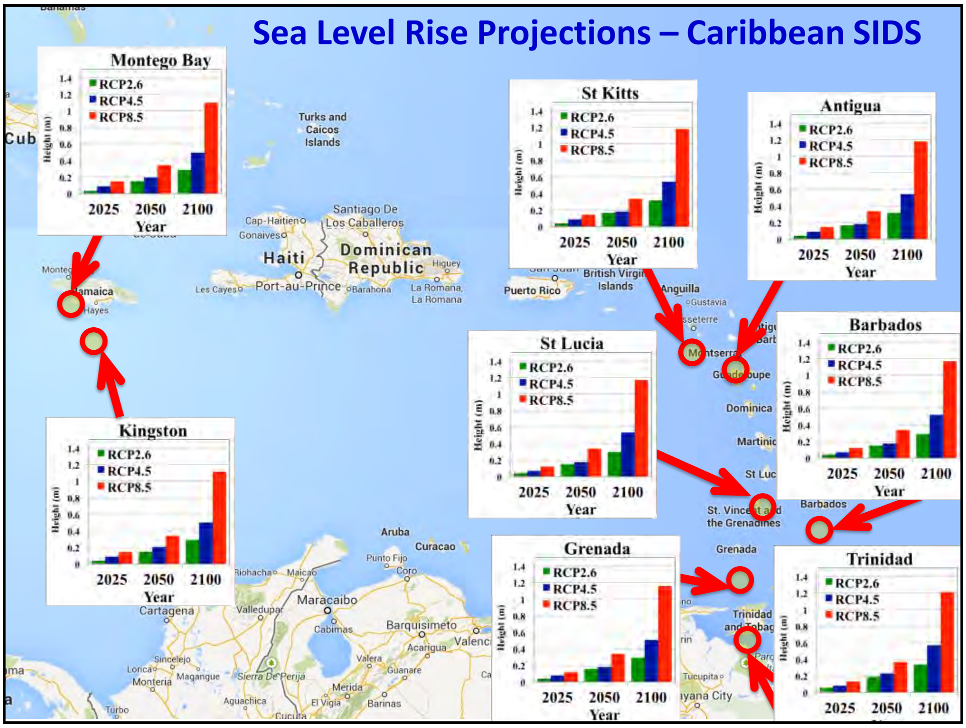
Note:

ii., iii. iv. and v. are *climate-sensitive phenomena*

In coastal areas, quantitatively small changes have disproportionately large effects, e.g. storm surge

- Storm surge is associated with a rapid fall in barometric pressure, accompanied by strong *onshore* winds, as hurricane passes → '*Inverse barometer*' triggers a rapid elevation of H_2O level.
- Surge generates large surface waves, leading to the 'piling up' of H_2O at the coast.
- Relationship between reduction in pressure and H_2O level is <u>not</u> linear:
  - Small drop in pressure can induce a significant rise in H_2O level. For example, a 25.4 mm (1.0 in.) fall in the barometric pressure could produce a sea surface rise of approx. 33 cm (13.0 in.).

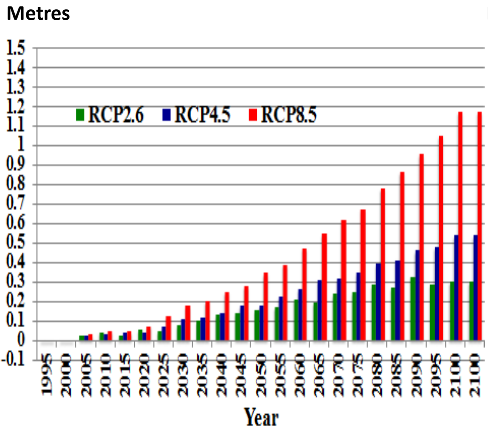
Sea Level Rise Projections – Caribbean SIDS

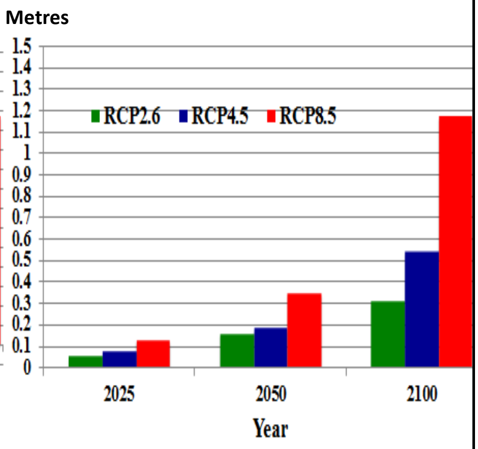


St. Lucia Sea Level Rise Projections

Data extracted for Grid Cells

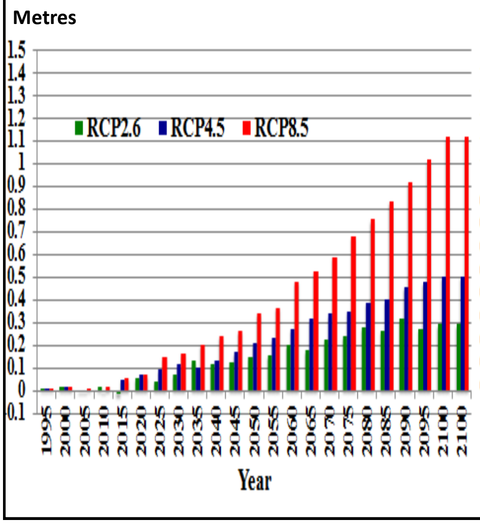
- **13.5° N, 60.5°W (Hewanorra Airport & Port Vieux Fort)**
- **14.5° N, 60.5° W (George F.L. Charles Airport & Port Castries)**

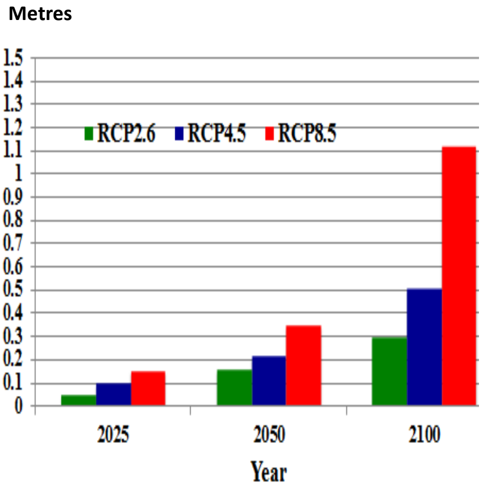




Kingston, Jamaica, Sea Level Rise Projections

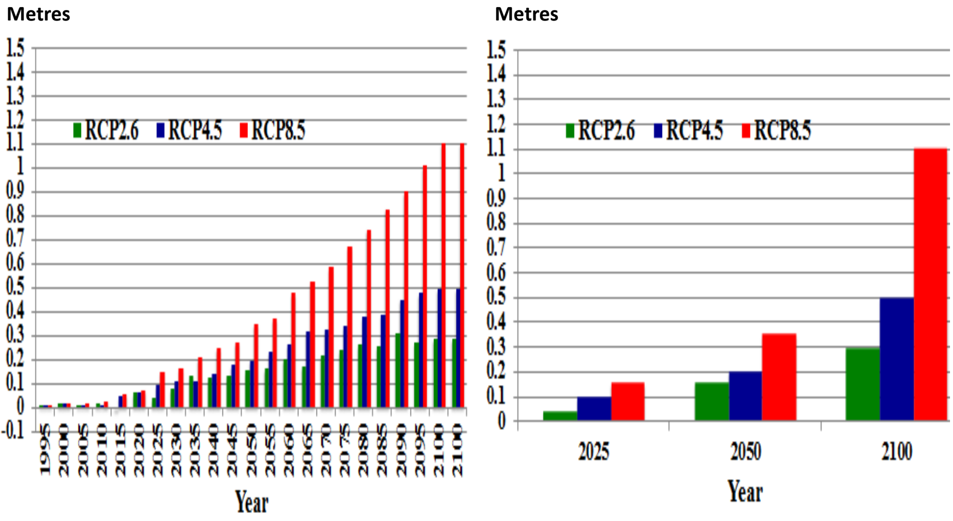
Data extracted for Grid Cell 17.5° N, 76.5°W
(Norman Manley Airport & Kingston Container Terminal)



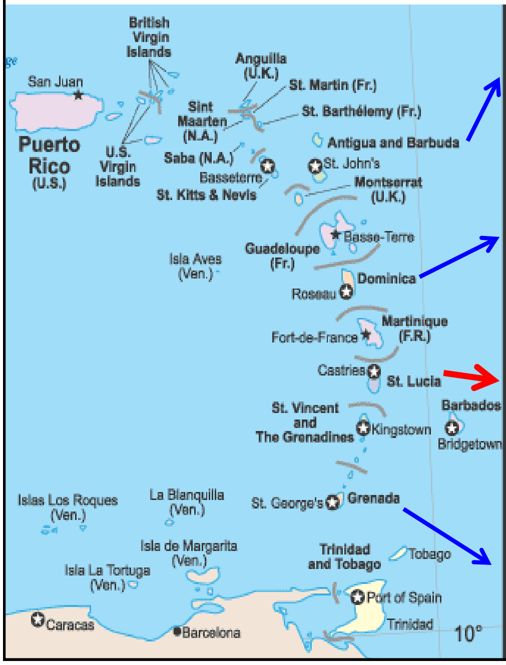


Montego Bay (Jamaica), Sea Level Rise Projections

Data extracted for Grid Cell 18.5° N, 77.5°W (Sangster Airport & Falmouth Cruise Port



Transport & Infrastructure Damage - Hurricane Lenny, Nov. 1999



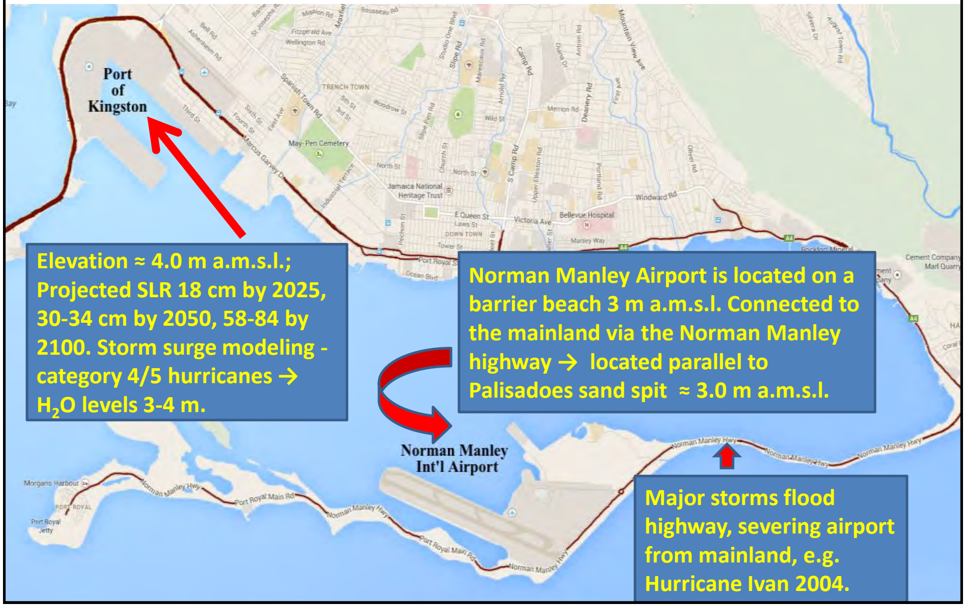
Northwestern & southern tip of the island most affected - landslides, severe beach erosion, airport flooded; 65% of Barbuda flooded, sanitary & water storage facilities overflowing; USD 51.3 M damages.

Damage & interruption at both airports
•Pottersville to Rockway highway closed; flooding at air & seaports; Roseau severed from petroleum storage facilities; west coast sea defenses breached; USD 21 M damages.

Most damage at Soufriere , waterfront, Gros Islet, Anse La Raye, Choiseul; severe erosion on NW coast, housing & tourism damage; damage to seaport, flooding at airports; hospital cut off from town; USD 6.6 M.

Seawall & other coastal defenses at Airport facilities damaged; structural failure and boat damage at St. George's Port; much damage to roads linking main settlements to air- & seaport; heavy damage to tourism plant; USD 94.3 M damages.

Key Risk Factors for Port of Kingston and Norman Manley International Airport



Elevation ≈ 4.0 m a.m.s.l.; Projected SLR 18 cm by 2025, 30-34 cm by 2050, 58-84 by 2100. Storm surge modeling - category 4/5 hurricanes → H_2O levels 3-4 m.

Norman Manley Airport is located on a barrier beach 3 m a.m.s.l. Connected to the mainland via the Norman Manley highway → located parallel to Palisadoes sand spit ≈ 3.0 m a.m.s.l.

Major storms flood highway, severing airport from mainland, e.g. Hurricane Ivan 2004.

Palisadoes Highway Protection - The Main Access to Norman Manley International Airport, Jamaica


Construction Phase


Post-Construction

Repeated damage from the passage of storms over many decades. In 2004 Hurricane Ivan caused > 300 m of shoreline erosion → complete shutdown of airport and isolation of adjacent communities. A decision was taken to raise road to 3.2 m amsl (formerly 0.6 -1.0 m amsl) and build a coastal revetment, at cost > USD 65.3 M.

Sample of Assets and operations At Risk: Air- and Seaports

- Climate-induced changes can cause serious damage to port infrastructure → major business interruption across entire supply chain:

◙ Tarmacs/runways & aircraft, fuel storage tanks

◙ Terminal facilities & associated throughput of passengers, goods and related services

◙ Utilities → H_2O, power supply, telecommunications

◙ Berths, bulkheads, seawalls, breakwaters

◙ Emergency response → e.g. fire and ambulance services

◙ Projected impacts could overwhelm existing capacities, e.g. storm and wastewater management systems

- Caribbean countries, like other SIDS, will be confronted by *increased exposure* and *related cumulative risks* at air & seaports

◊ Implications for *insurance, legal liability* & *operating costs*?

Examples of Effects of Two Climate Variables on Air and Sea Port Operations

Variable	Exposure Unit	Effects	Adaptation/Adjustment
Air Temperature	**Aircraft**	**Higher temperatures cause:** • Lower air density • Reduced lift generated by aircraft wings; slower climbs • Effect on performance & efficiency	• Lower take-off weights/loads • Longer runways
More frequent Intense rainfall events	**Terminals, warehouses & related facilities**	• Greater incidence of flooding • Sewerage & drainage capacities exceeded, etc. • Disruptions and down-time • Business losses; possible loss of market share • Higher maintenance & operation costs	• Redesign/retrofitting of infrastructure (e.g. drainage, sewerage) for greater capacity & efficiency • Increased insurance/re-insurance to cover liabilities, demurrage, etc. • Redesign of logistics, business plans, operations manuals, etc.

Kingston Container Terminal: Delivery of 4 Super Post-Panamax Ship-to-Shore Gantry Cranes, 2005 (Photo: Gleaner Newspaper)

Design Criteria for Port Cranes:
(ASCE-7 Standard: Minimum Design Loads….)

● *Wind pressure* is a *critical determinant of tie-down uplift forces* acting on cranes during operation.

◙ Hurricane wind pressure based on 50-yr Mean Recurrence Interval (MRI)

◙ 3.0 s^{-1} gust wind speeds, 10 m above ground

Limitations:

● Criteria based on historical data ⟶ may not reflect present conditions & not representative of future.

● Wind pressure varies as the square of the wind speed; errors increase when speed is converted to *wind pressure* ⟶ reliable wind data critical, e.g.

◙ 10% error in wind speed results in a 21% error in wind pressure calculation; and

◙ Error of *100% (or more) in tie-down uplift force*

[See i. McCarthy et al, 2009. Wind damage to dockside cranes: recent failures and recommendations. In *Lifeline earthquake engineering in a multi-hazard environment*, 1-12;

ii. Frendo, F., 2016. Gantry crane derailment and collapse induced by wind load. *Engineering Failure Analysis* 66, 479-488].

Building Resilience at Ports – The Necessity for Adaptation in SIDS

- Past global GHG emissions & current trajectory guarantee that warming of atmosphere & oceans, and SLR will continue for decades (‘*climate inertia*’ → volume of GHGs already emitted).
- Notwithstanding proposed INDCs ⟶ no evidence that a binding post-Kyoto agreement will eventuate in Paris in December 2015.
  - ◘ Air- and seaport operations face heightened risks. For SIDS, risks are greater ⟶ almost total dependence on these facilities for imports and exports.
  - ◘ Air- and seaport infrastructure represent major investment → amortized over medium-to-long periods, e.g. minimum of 25-30 years, in some cases as many as 50+ years → fall within the timeframe of current climate change projections.

Planning Adaptation at Air and Seaports – Constraints for SIDS

With few exceptions, ‘*protection’* of existing infrastructure and ‘*accommodation’* are the only practical responses available to most SIDS for the following reasons:

- Limited opportunities for relocation away from vulnerable areas → constraint of sheer physical size
- Central role of air and sea ports in these small, highly open economies
- Scarce/insufficient resources to replicate such high cost facilities ⟶ useful life of terminals, runways, taxiways, parking aprons etc. is on average minimum of 30 years.
- As in other jurisdictions , protection and accommodation strategies will therefore have to contemplate a suite of actions involving *infrastructure*, *technological*, *regulatory* and *change management* components.

Examples of Potential Response Strategies for Air & Seaports in SIDS

Infrastructural /Engineering	**Enhance the structural integrity of critical facilities including sea defenses, berths, mooring facilities, runways, parking aprons etc, based on design criteria that reflect changing wind, sea level and wave conditions; recalculation of return periods for major events such as hurricanes and floods, so that more resilient structures can be engineered → Caribbean**
Technological	**Invest in more climate-resilient technologies and equipment in expansion & upgrade programmes, e.g. solar photovoltaics to generate electricity more efficiently for both operations and administration, e.g. Airport at Oranjestad, Aruba; 451-kW PV system at St. Thomas Airport, USVI**
Planning & Development	**Internal capacity building and re-training that recognizes the magnitude and implications of the threat; building of *redundancy* into critical operations, wherever feasible; off-site warehousing and storage in less vulnerable areas, etc.**
Management Systems	**Various operational systems need to ‘*mainstream*’ climate change considerations into their procedures, e.g. ‘*shut down*’ and ‘*start up*’ operations; emergency protocols and evacuation; environmental management systems; occupational safety and health protocols, etc.**
Insurance	**Some risks cannot be avoided ⟶ must be insured by third parties; In many Caribbean SIDS ⟶ collaboration among port management, climate scientists and insurance providers will provide a basis for more reliable quantification of *exposure* and *risks* that must be covered.**

Thank You

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