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

**Climate change projections for the
Caribbean and Implications for Air and
Sea Ports**

By

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

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UNCTAD Regional Workshop “Climate Change Impacts & Adaptation for Coastal Transport Infrastructure in Caribbean SIDS”
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Key Climate Risk Factors for Seaports and Airports in SIDS

- Increasing air $^{\circ}$ T and SST → (i) thermal expansion of ocean surface (ii) greater *convection potential* over ocean
- Rising sea level and surge → (a) raise H₂O 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

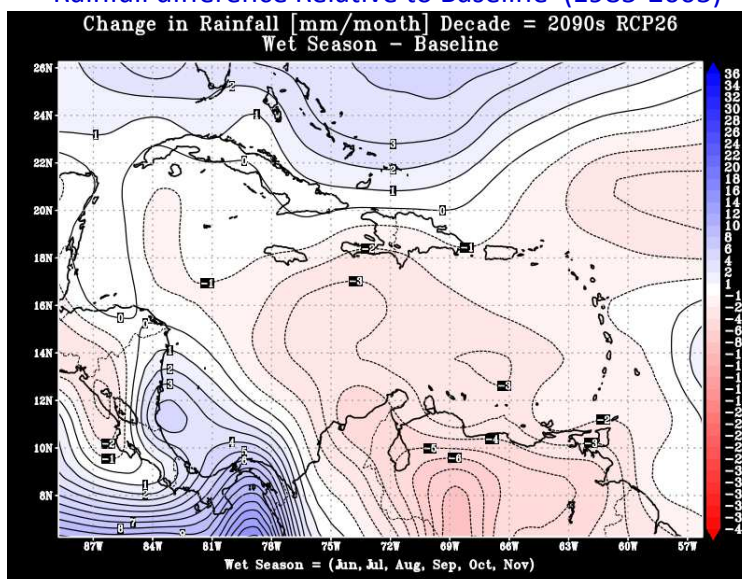
- The 4 RCPs are defined by the IPCC as follows:
 - One *high* pathway → radiative forcing exceeds 8.5 W/m² by 2100 and continues to rise for some period thereafter;
 - Two intermediate *stabilization* pathways → radiative forcing is stabilized at around 6.0 W/m² and 4.5 W/m² after 2100;
 - One *low* pathway - where radiative forcing peaks at about 3 W/m² before 2100 and declines thereafter.

RCP	Description
RCP 2.6	Peak in radiative forcing at ~3 W/m ² (~490 ppm CO ₂ e) before 2100 and then decline (the selected pathway declines to 2.6 W/m ² by 2100).
RCP 4.5	Stabilization without overshoot pathway to 4.5 W/m ² (~650 ppm CO ₂ e) at stabilization after 2100
RCP 6.0	Stabilization without overshoot pathway to 6 W/m ² (~850 ppm CO ₂ e) at stabilization after 2100.
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m ² (~1370 ppm CO ₂ e) by 2100.

Projected Wet Season Rainfall

RCP 2.6 CMIP5 Multi-Models

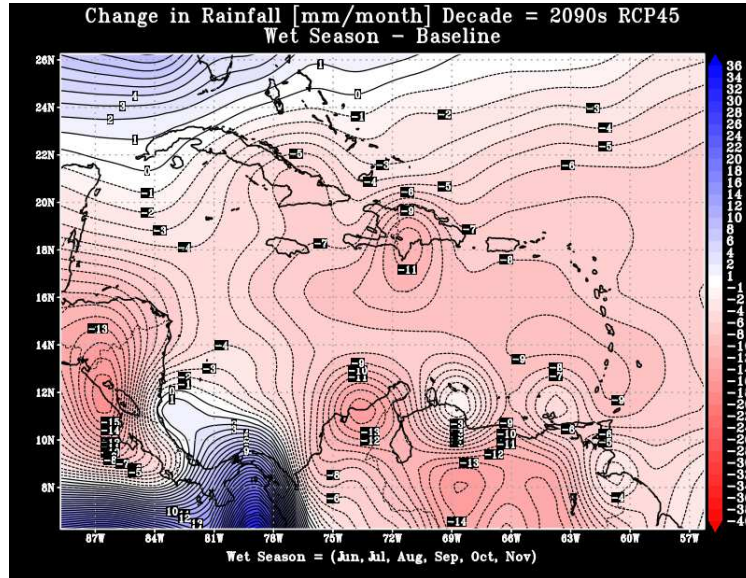
Rainfall difference Relative to Baseline (1985-2005)



Projected Wet Season Rainfall

RCP 4.5 CMIP5 Multi-Models

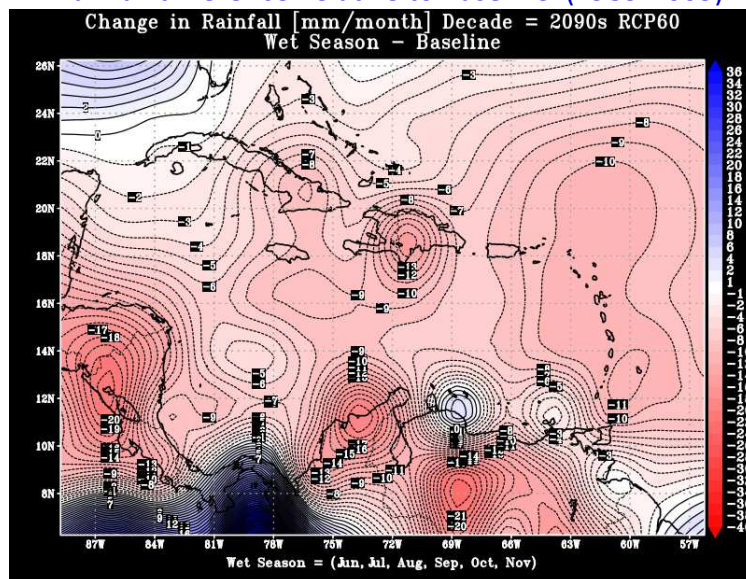
Rainfall difference Relative to Baseline (1985-2005)



Projected Wet Season Rainfall

RCP 6.0 CMIP5 Multi-Models

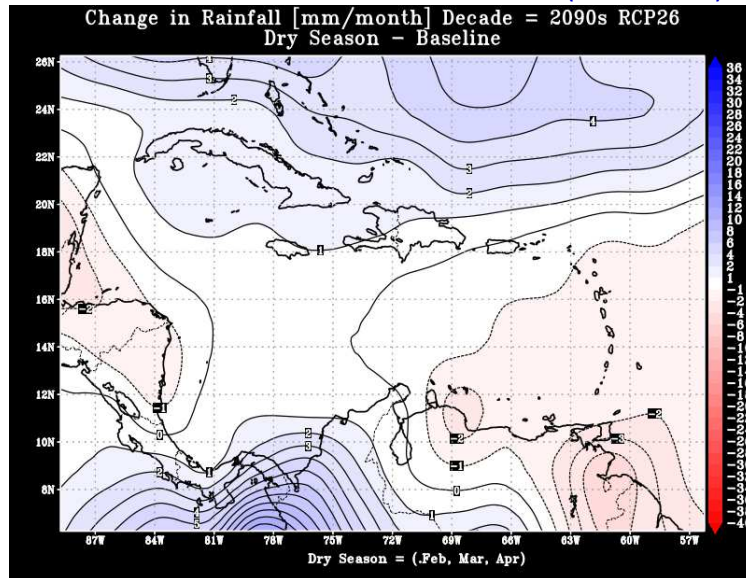
Rainfall difference Relative to Baseline (1985-2005)



Projected Dry Season Rainfall

RCP 2.6 CMIP5 Multi-Models

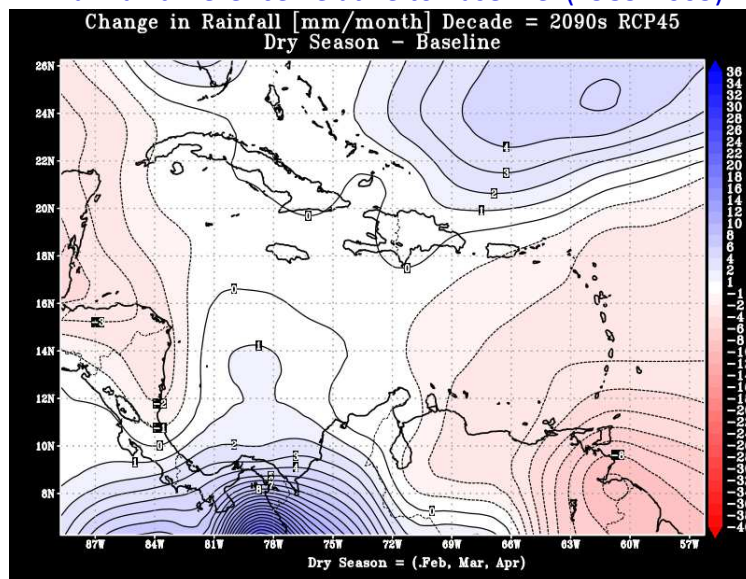
Rainfall difference Relative to Baseline (1985-2005)



Projected Dry Season Rainfall

RCP 4.5 CMIP5 Multi-Models

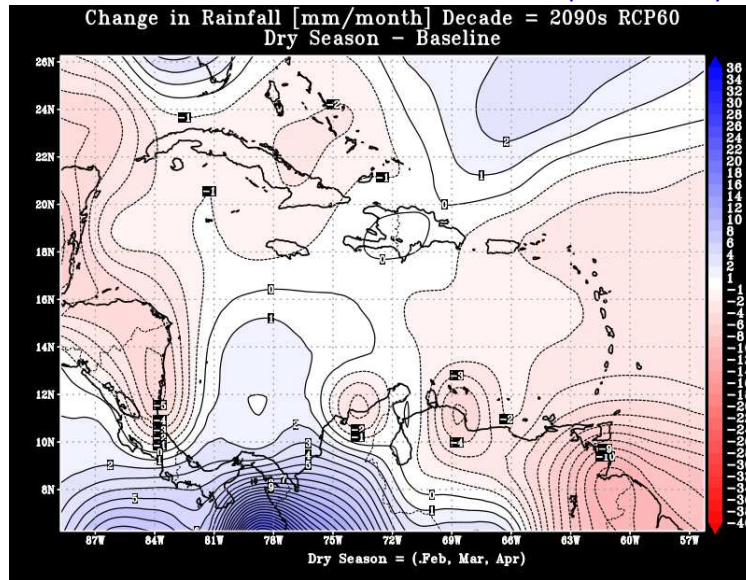
Rainfall difference Relative to Baseline (1985-2005)



Projected Dry Season Rainfall

RCP 6.0 CMIP5 Multi-Models

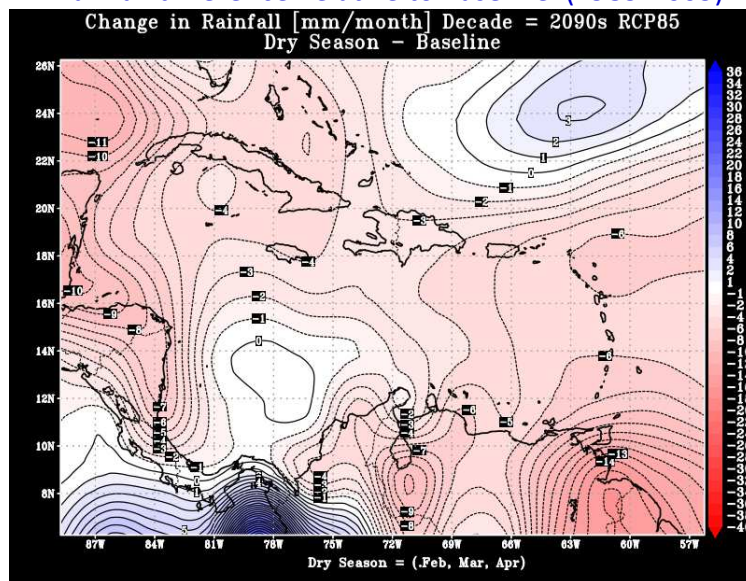
Rainfall difference Relative to Baseline (1985-2005)



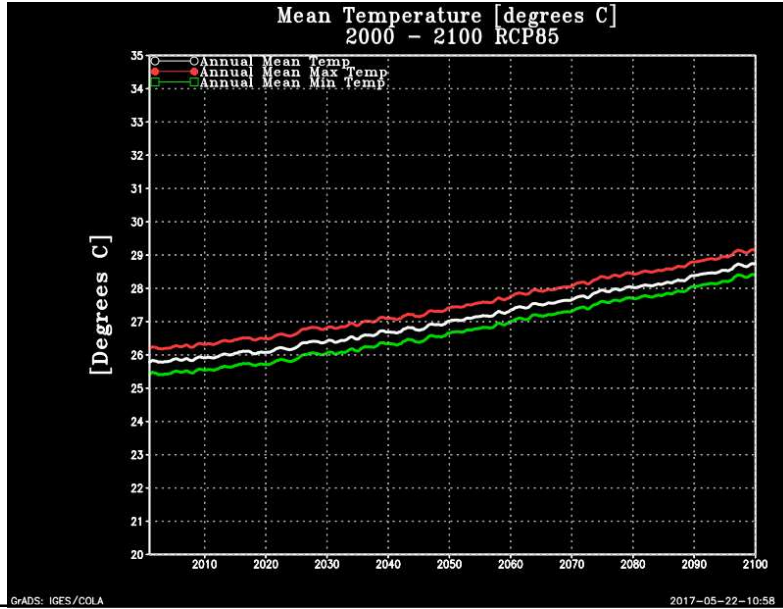
Projected Dry Season Rainfall

RCP 8.5 CMIP5 Multi-Models

Rainfall difference Relative to Baseline (1985-2005)

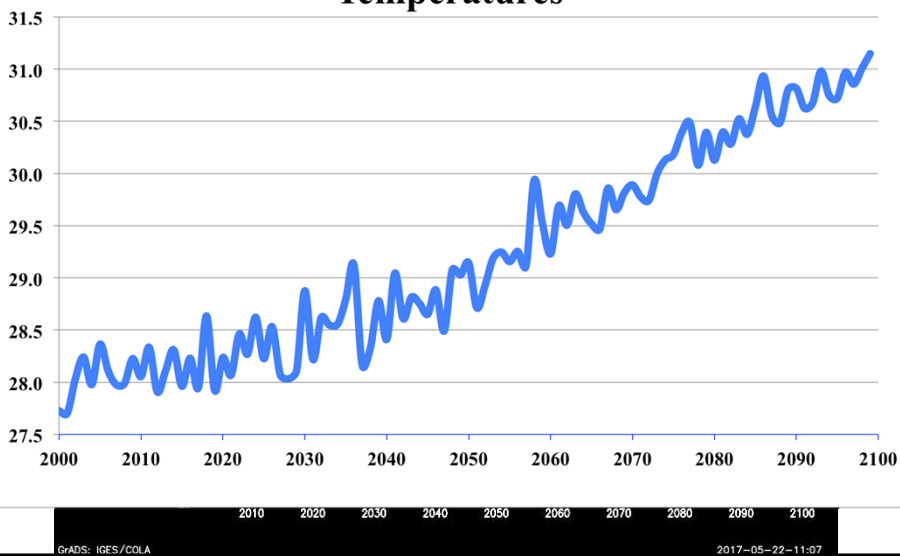


Projected Temperature - St. Lucia
RCP 2.6 - 8.5 CMIP5 Multi-Models

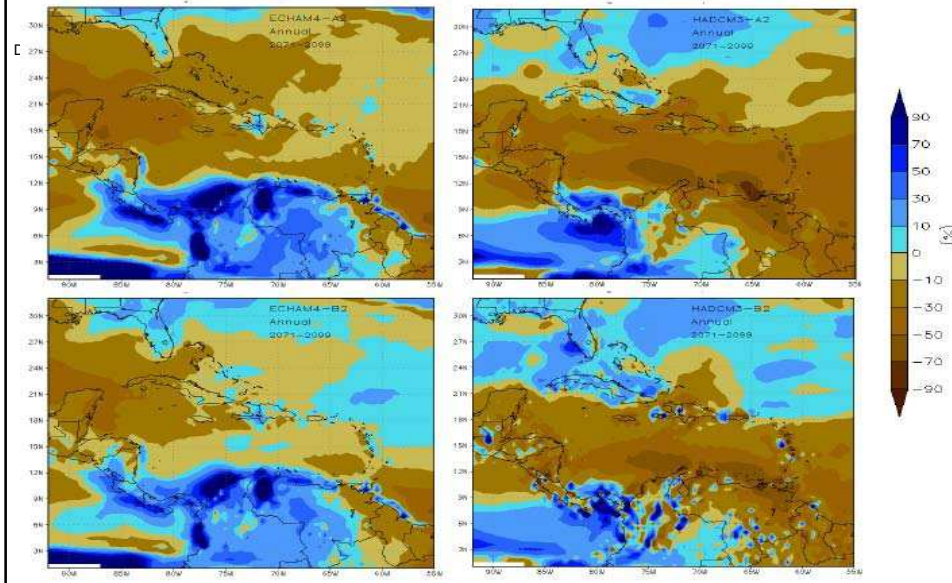


Projected Temperature - Kingston, Jamaica

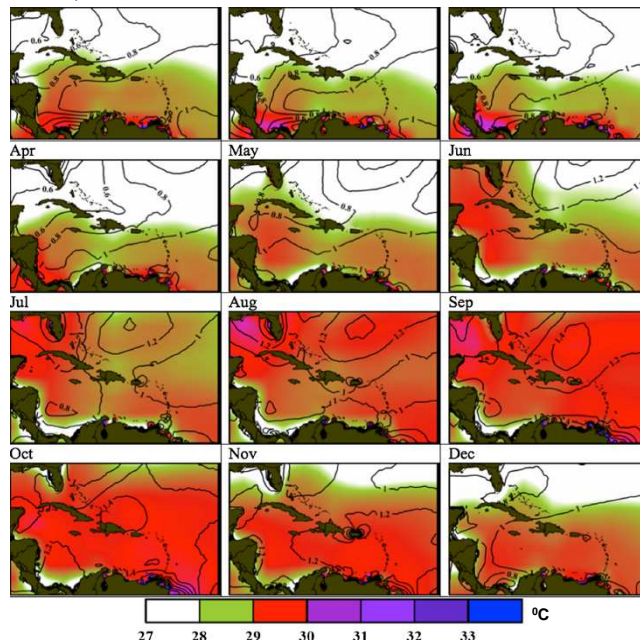
Barbados Mean Annual Maximum Temperatures



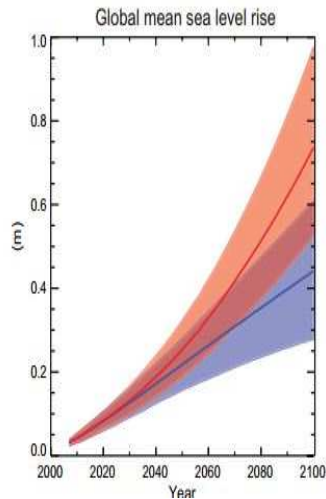
Drying trend between -25% and -30 % by end of Century. Drying far exceeds natural variability. Drier wet season likely (Taylor, 2011)



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

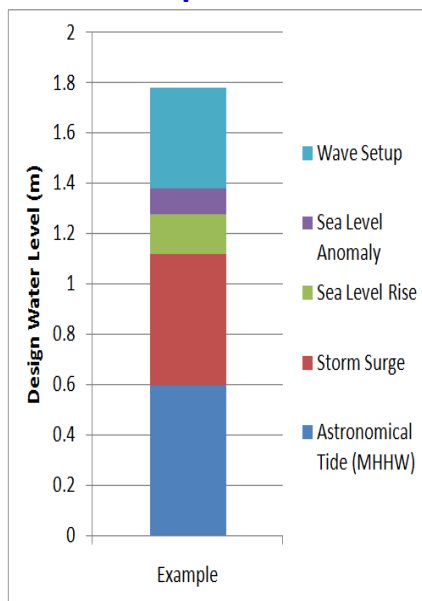


20th Century Observed SLR in SIDS Regions



- 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, $\sim 1.8\text{mm yr}^{-1}$.
- ▶ 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



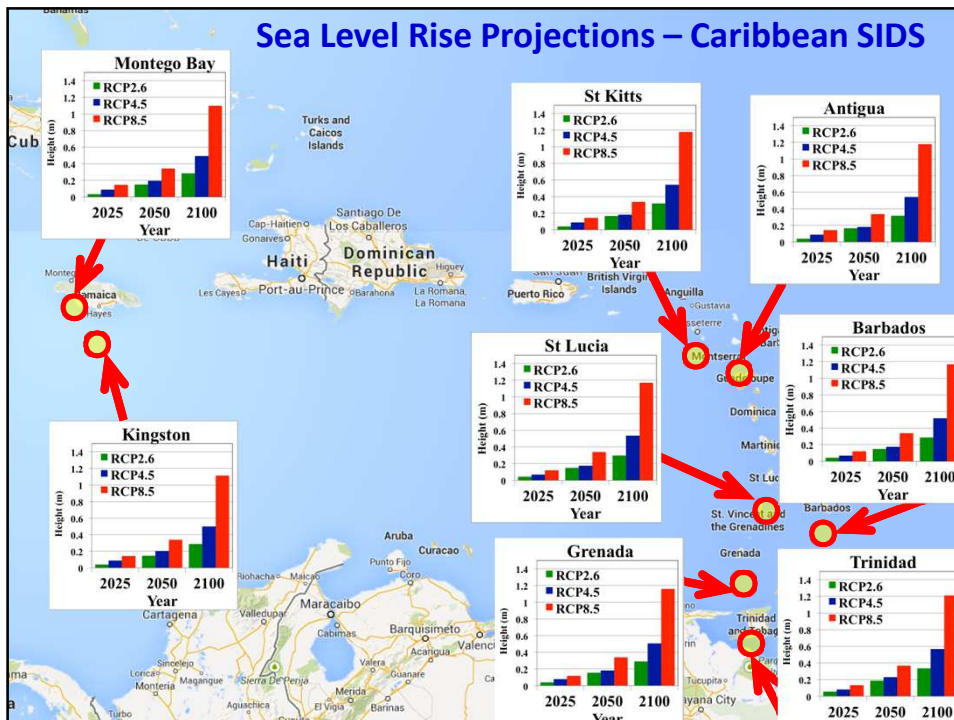
- i. Astronomical Tide
- ii. Wave set up → increase in mean water level landward of breaker zone due to *flux of H₂O* at coast
- iii. Sea level anomaly → measure of the difference between short- and long-term MSL → *negative and positive anomalies*
- iv. Sea level rise
- v. Storm Surge

Note:

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

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

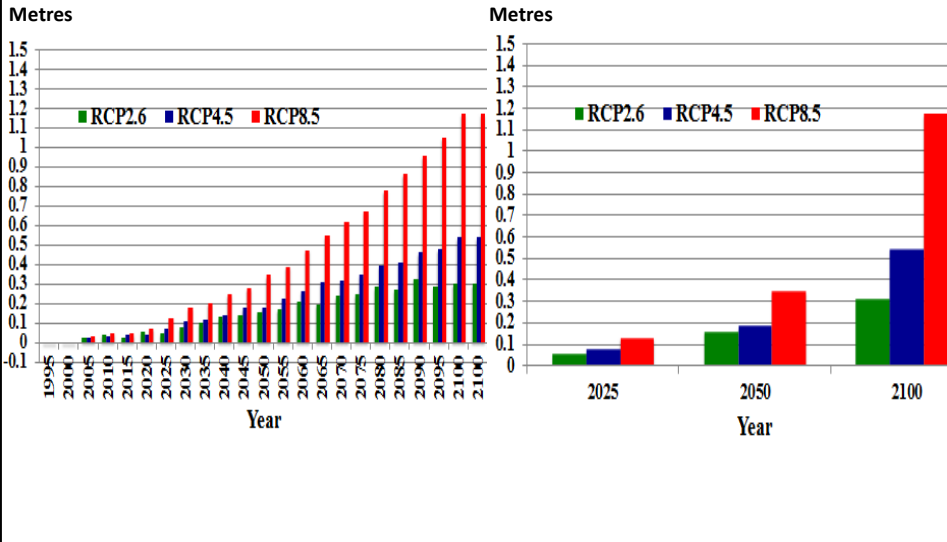
- Storm surge is associated with a rapid fall in barometric pressure, accompanied by strong *onshore* winds, as hurricane passes → ‘*Inverse barometer*’ triggers a rapid elevation of H₂O level.
- Surge generates large surface waves, leading to the ‘piling up’ of H₂O at the coast.
- Relationship between reduction in pressure and H₂O level is not linear:
 - Small drop in pressure can induce a significant rise in H₂O 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.).



St. Lucia Sea Level Rise Projections

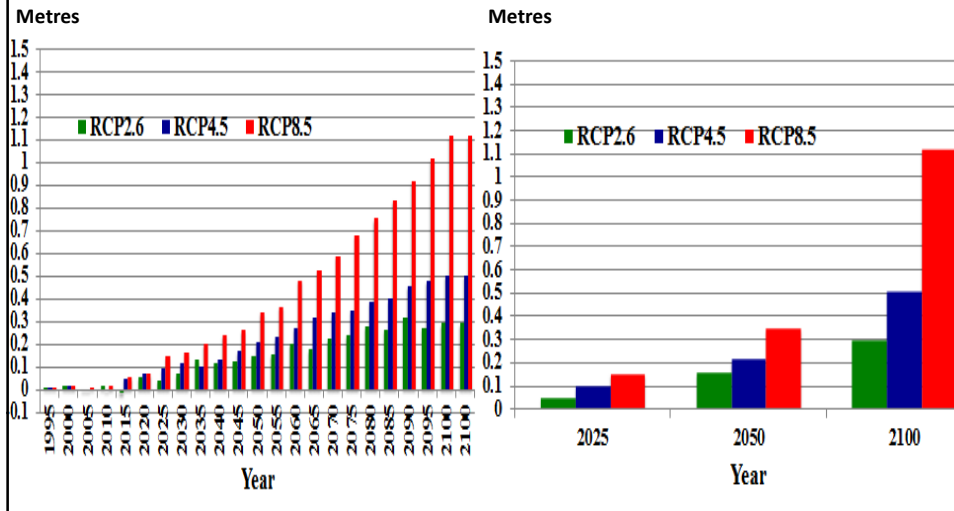
Data extracted for Grid Cells

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



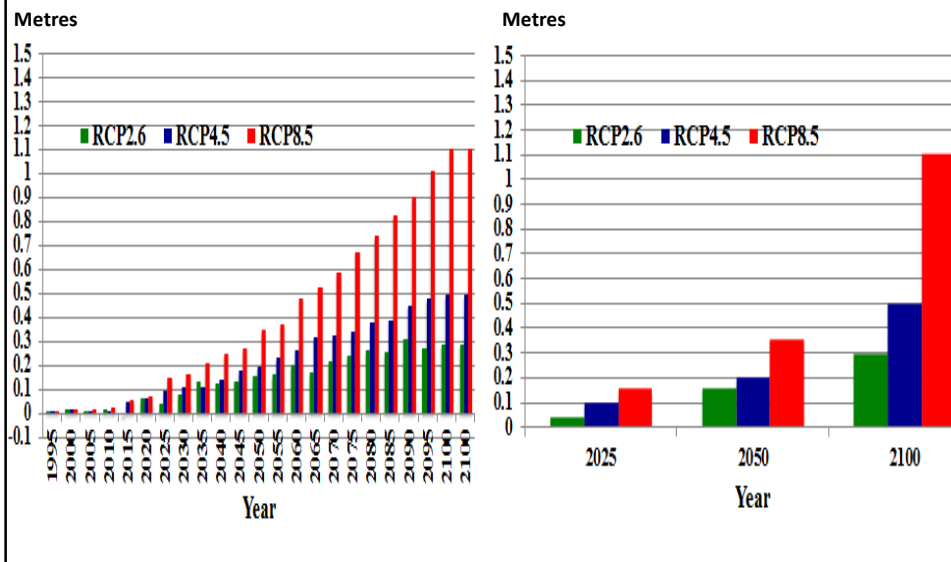
Kingston, Jamaica, Sea Level Rise Projections

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

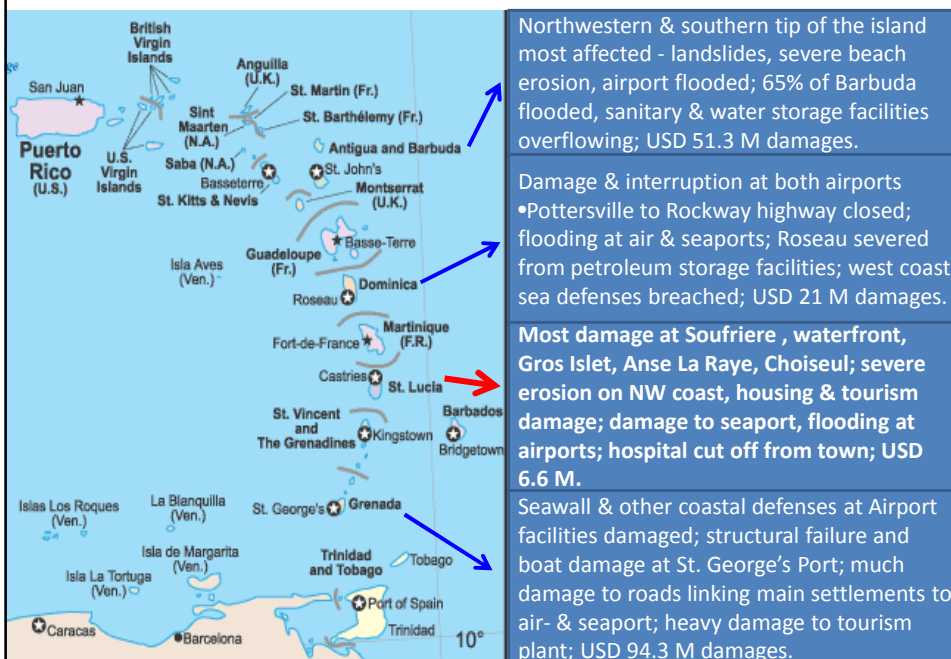


Montego Bay (Jamaica), Sea Level Rise Projections

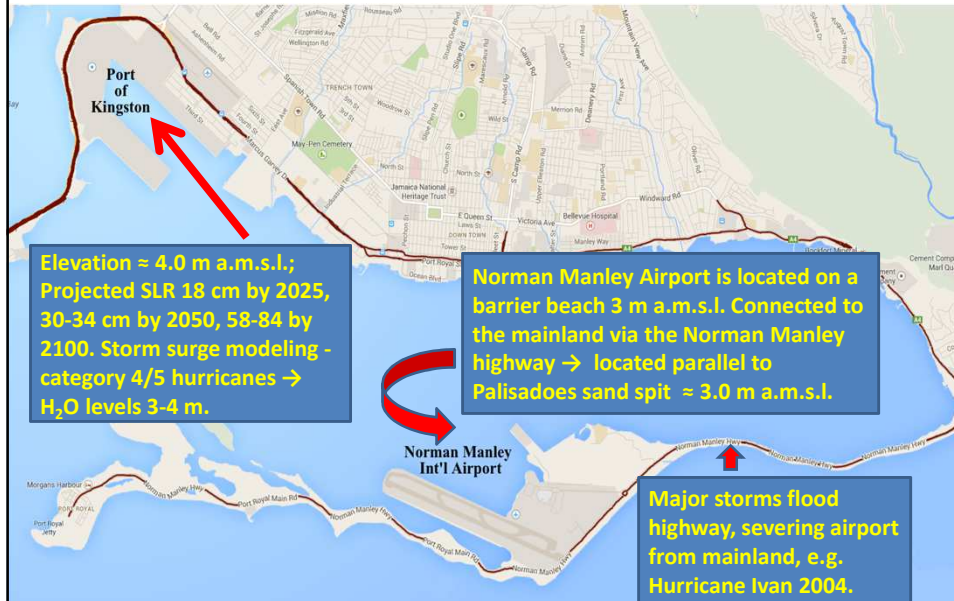
Data extracted for Grid Cell 18.5° N, 77.5°W (Sangster Airport & Falmouth Cruise Port)



Transport & Infrastructure Damage - Hurricane Lenny, Nov. 1999



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



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



Repeated damage from the passage of storms over many decades. In 2004 Hurricane Ivan caused $>$ 300 m of shoreline erosion \rightarrow 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 100 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 → H₂O, 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: <ul style="list-style-type: none"> • Lower air density • Reduced lift generated by aircraft wings; slower climbs • Effect on performance & efficiency 	<ul style="list-style-type: none"> • Lower take-off weights/loads • Longer runways
More frequent Intense rainfall events	Terminals, warehouses & related facilities	<ul style="list-style-type: none"> • Greater incidence of flooding • Sewerage & drainage capacities exceeded, etc. • Disruptions and down-time • Business losses; possible loss of market share • Higher maintenance & operation costs 	<ul style="list-style-type: none"> • 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 ms⁻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 <i>redundancy</i> into critical operations, wherever feasible; off-site warehousing and storage in less vulnerable areas, etc.
Management Systems	Various operational systems need to ‘ <i>mainstream</i> ’ climate change considerations into their procedures, e.g. ‘ <i>shut down</i> ’ and ‘ <i>start up</i> ’ 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 <i>exposure</i> and <i>risks</i> that must be covered.

Thank You

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