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

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Key Climate Risk Factors for Seaports and Airports in SIDS

- Increasing air $^0$T and SST $\rightarrow$ (i) thermal expansion of ocean surface (ii) greater convection potential over ocean
- Rising sea level and surge $\rightarrow$ (a) raise H$_2$O levels (b) high amplitude waves and increased potential for damage
- Higher wind speeds $\rightarrow$ 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.

<table>
<thead>
<tr>
<th>RCP</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP8.5</td>
<td>Rising radiative forcing pathway leading to 8.5 W/m² (~1370 ppm CO₂e) by 2100.</td>
</tr>
<tr>
<td>RCP6</td>
<td>Stabilization without overshoot pathway to 6 W/m² (~850 ppm CO₂e) at stabilization after 2100</td>
</tr>
<tr>
<td>RCP4.5</td>
<td>Stabilization without overshoot pathway to 4.5 W/m² (~650 ppm CO₂e) at stabilization after 2100</td>
</tr>
<tr>
<td>RCP2.6</td>
<td>Peak in radiative forcing at ~3 W/m² (~490 ppm CO₂e) before 2100 and then decline (the selected pathway declines to 2.6 W/m² by 2100).</td>
</tr>
</tbody>
</table>

**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 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)

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 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

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 → H₂O 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

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 → 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

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

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**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

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructural/Engineering</td>
<td>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</td>
</tr>
<tr>
<td>Technological</td>
<td>Invest in more climate-resilient technologies and equipment in expansion &amp; 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</td>
</tr>
<tr>
<td>Planning &amp; Development</td>
<td>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.</td>
</tr>
<tr>
<td>Management Systems</td>
<td>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.</td>
</tr>
<tr>
<td>Insurance</td>
<td>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.</td>
</tr>
</tbody>
</table>
Thank You

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