Briefing note

Tropical Cyclones: Impacts, the link to Climate Change and Adaptation

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Following the string of high intensity tropical cyclones in the Atlantic basin in 2017 and the devastating impacts on Small Island Developing States (SIDS), a number of questions have been raised about linkages between these cyclones and climate change. This briefing provides clarity on scientifically-supported connections between existing tropical cyclones and climate change. The briefing also summarises how climate change may affect tropical cyclones at increased global mean temperatures in the future and provides a summary of the observed socio-economic impacts of these extreme events on SIDS.

Key Findings:

- The Atlantic Hurricane season brought horrific destruction over the Caribbean. In Barbuda, over 90% of structures were destroyed, resulting **in the island being completely uninhabited for the first time in 300 years**. **Across the Caribbean the economic costs of tropical cyclones amount to 2% of GDP annually since the 1950.**
- The South Pacific has recently been hit by particularly destructive cyclones like Winston and Pam. **Estimated economic cost of Cyclone Pam in Vanuatu across all sectors was approximately 64% of the country's GDP in 2016. In Fiji, Cyclone Winston displaced over 130,000 people.**
- Attribution of tropical cyclones to climate change is difficult. However, a robust increase of the most devastating storms with climate change is evident. **Under 2.5°C of global warming, the most devastating storms are projected to occur twice as often as today.**
- The climate hazard posed by cyclones is **further intensified by increasing risks of flooding through heavier precipitation and sea level rise as a result of climate change.**
- The capability of many Islands to adapt to tropical cyclones is limited and such events can further erode their capacity to adapt to climate change impacts. **The Loss and Damage inflicted by tropical cyclones, in particular on small island states, needs to be recognised and adequate support needs to be provided by the international community.**
- Post-disaster investment needs to be ambitious in scale and scope, **supporting the transition to resilient, low carbon societies.**

1. Socio-Economic Impacts of Tropical Cyclones on SIDS

Tropical cyclones, also referred to as hurricanes or typhoons, are particularly significant hazards for SIDS. Large cyclones often encompass entire islands, affect significant percentages of the population and have substantial socio-economic impacts at the national scale, making SIDS one of the most exposed groups to these extreme events[i]. Cyclones have long-term negative effects on economic growth, particularly for small states and islands, with countries taking over 15 years on average to fully recover from these shocks[ii]. For Pacific SIDS, tropical cyclones have resulted in an estimated average annual loss of US$180million for the past 50 years[iii]. Across the Caribbean, the economic costs of tropical cyclones have averaged approximately 2% of GDP annually since the 1950s, a conservative estimate given the likelihood of considerable underreporting of damages[iv]. In addition to economic losses, tropical cyclones also have significant environmental implications, including damages to coral reefs which provide critical ecosystem services including coastal protection from storms. More frequent tropical cyclones also result in increased loss and damage since affected areas, particularly in developing countries, have insufficient time and resources to recover between events.

In the Pacific, there have been a number of intense tropical cyclones that have resulted in significant loss and damage for island states in recent years. In February 2016, Cyclone Winston was recorded as one of the largest and most intense tropical cyclones in the Southern Hemisphere and had severe impacts throughout the South Pacific[v]. In Fiji, over 60% of the population was affected with 22% of the nation's housing either destroyed or damaged and over 130,000 people being displaced[vi]. Destruction of approximately 500 schools prompted Fiji to seek an emergency assistance loan of US$50million to assist in reconstruction efforts[vii]. Cyclone Winston's path resulted in two separate interactions with Tonga, where more than half of the island's crops were damaged. Cyclone Pam, in 2015, affected over 70% of the population in Vanuatu, displaced 65,000 people and resulted in 11 deaths and over 17,000 buildings being damaged or destroyed[viii]. The estimated economic cost of Cyclone Pam on Vanuatu across all sectors was approximately 64% of the country's GDP. In 2013, Typhoon Haiyan, another high intensity cyclone, had devastating impacts in the Philippines in particular. The typhoon resulted in over 6,000 casualties and had effects on approximately 16 million people in over 44 provinces[ix]. Over 4 million people were displaced from their homes and approximately 1.1 million houses were either totally or partially damaged.

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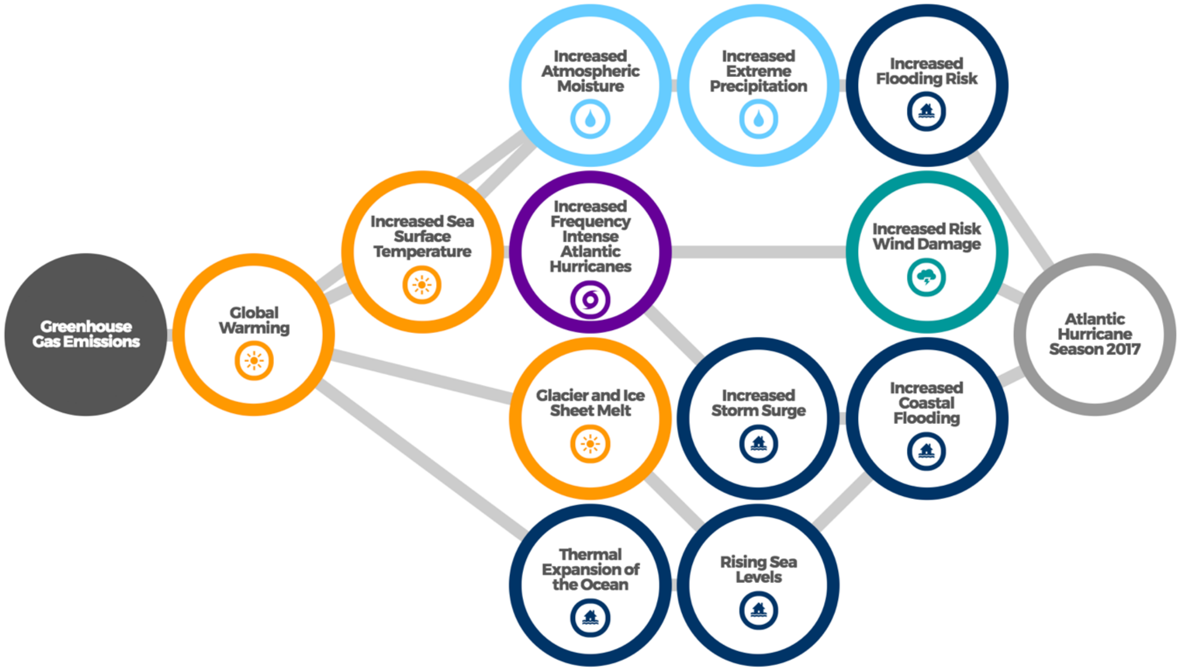

Figure 1: Schematic representation of linkages between anthropogenic climate change and tropical cyclone impacts as experienced in the 2017 Atlantic Hurricane Season. The diagram does not quantify the relative strength of each factor, nor does it illustrate the natural factors that also shape extreme events, including natural variability and regular circulation changes. From Climatesignals.org

Severe and widespread destruction was seen in the aftermath of the successive intense cyclones in the Caribbean during the 2017 hurricane season. Hurricane Irma sustained high intensity winds for a record-breaking period of time and resulted in substantial loss and damage throughout the Caribbean. Extensive damages to critical infrastructure in Anguilla included impairments to over 90% of electricity and communication services with almost all roads being impassible[x]. In Barbuda, over 90% of structures were destroyed, resulting in mandatory evacuations and the island being completely uninhabited for the first time in 300 years[xi]. Mandatory evacuations in Ragged Island in The Bahamas were also ordered after the complete destruction of infrastructure. Over 150,000 homes were affected in Cuba along with extensive damages to the national electricity grid, communications services and agricultural industry[xii]. Hurricane Maria, following just two weeks after Irma, was another high intensity Category 5 storm and affected islands that had recently been impacted. In Dominica, 80% of the country's population sustained damages or destruction to homes while telecommunications and electricity were lost for the entire island[xiii]. The entire island of Puerto Rico was left without electricity or communications and damages are estimated at US$30billion[xiv].

On a global scale, the impacts of climate change are projected to significantly increase damages from tropical cyclones and result in costs of between US$28-68billion per year by 2100 depending on global warming of between 2.7-4.5°C[xv]. In the Caribbean, with 4°C of global warming, the region is projected to face losses of US$350-$550 million per year by 2100[xvi].

2. Tropical cyclone hazards and Climate Change

Global temperatures have increased by approximately 1°C compared to the 1860-1880 average[xvii]. This rise in temperature is associated with a number of changes in the climatic system that increase the risk of extreme weather events. 'Attribution' -the linkage between frequency or severity of events and anthropogenic climate change- is multi-faceted, particularly for tropical cyclones, and is linked to the question of 'attribution of what'. From a purely meteorological perspective, attribution is linked to the event itself. From an impact perspective, however, the climate hazard posed by a tropical cyclone is constituted not just by winds, but also by both coastal and freshwater flooding due to heavy rain linked to tropical cyclones. Therefore, attribution of the climate hazards posed by tropical cyclones and climate change needs to go beyond the meteorological event itself. The schematic in Figure 1 depicts the different channels through which climate change will influence the climate hazard posed by tropical cyclones.

1.1.Coastal flooding and sea-level rise

The linkage between climate change and rising sea-levels is unequivocal[xviii] thereby strongly amplifying the risk of coastal flooding due to extreme high sea-levels. Tropical cyclones are of particular relevance for extreme high sea-levels and in parts of some cyclone-prone basins, more than 75% of annual sea-level maxima are found to be linked to tropical cyclones[xix]. In an attribution study targeted on New York City, the return period of Hurricane Sandy's flood height was found to have decreased by a factor of three from the years 1800 to 2000 as a result of sea-level rise[xx]. Rising sea-levels are also projected to contribute strongly to increasing risks in coastal flooding related to tropical cyclones[xxi].

1.2.Extreme precipitation

The devastations caused by flooding due to torrential rain brought by Hurricane Harvey have been a forceful reminder of the destructive potential of heavy rainfall and tropical cyclones. In fact, rainfall extremes related to tropical cyclones account for a large proportion of the very largest extreme precipitation events on record[xxii]. The link between increases in extreme precipitation and climate change is robustly established[xxiii]. As the atmosphere warms, it can carry more moisture. Extreme precipitation events have been found to scale with the moisture carrying capacity and are projected to intensify by about 6% per °C of warming[xxiv].

1.3.Changes in tropical cyclone intensity and frequency

Assessments of trends in tropical cyclone occurrence are hampered by the single event nature of these storms, influences of natural variability such as the Atlantic Multi-Decadal Oscillation (AMO) or the El Nino Southern Oscillation and comparably short time observational records for most basins. For the Atlantic, the only basin with a consistent long-term record, an increasing trend in tropical cyclone activity and intensity is evident over the recent decades[xxv].

Projections for future tropical cyclone activity in a warmer climate indicate on the one hand a decrease in overall activity, but at the same time, a dramatic increase in the occurrence of the most devastating cyclones. For a warming of about 2.5°C by the end of the century, occurrence probabilities of Category 4 or 5 cyclones are found to nearly double across all major basins relative to the recent past[xxvi]. For the South Pacific, an increase by a factor of 4 is reported.

Tropical cyclone formation is influenced by many factors, but the role of warm sea-surface temperatures as the primary source of energy for cyclones is paramount[xxvii]. Following work by Zeke Hausfather[xxviii], we have analysed the probability density of tropical cyclone formation by category against sea-surface temperature. As displayed in Figure 2, warmer sea-surface temperatures will increase the probability of stronger cyclones forming. It is important to highlight that these are probability density functions *not* absolute numbers. Category 5 cyclones would still be less common than lower category cyclones in future warming scenarios (see Methods section for further detail on the analysis).

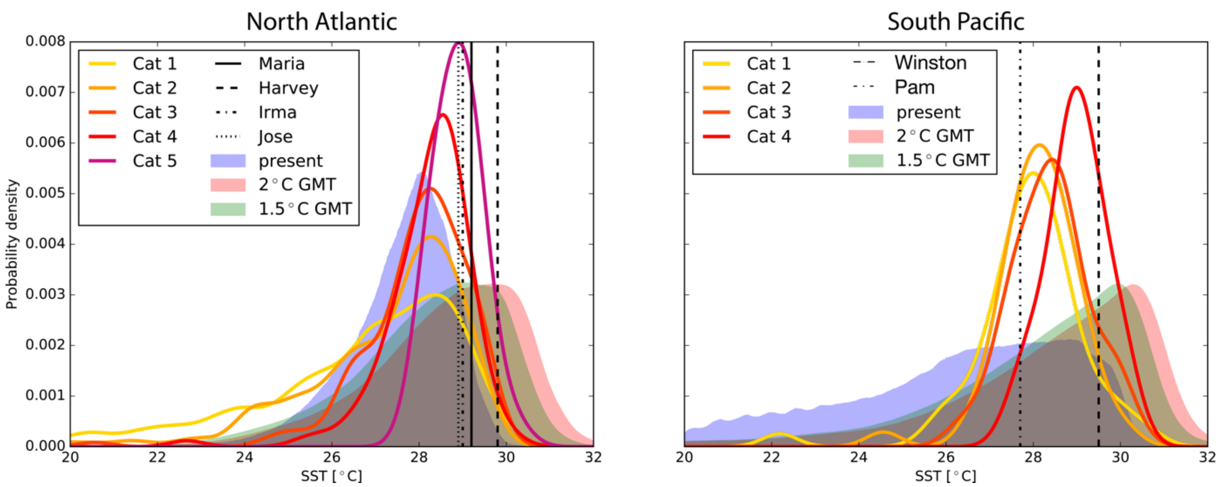

Figure 2: Probability density of tropical cyclone formation against sea surface temperatures (SST) in the formation region by cyclone category for the North Atlantic (left) and the South Pacific basin (right). Black lines show recent tropical cyclones. The shaded areas show monthly sea-surface temperature (SST) distributions for the months of the main cyclone season including all grid cells of the main development region. Present (blue) for the period 1986-2005. Projections for 2°C global warming (red) and 1.5°C global warming (green) are presented for a multi-model mean of CMIP5 models (see Methods).

We have overlaid recent most devastating tropical cyclones in both basins (black lines). Indicated by shades are the monthly sea-surface temperature distributions for the main cyclone season including all grid cells of the main development region for the present as well as at 1.5°C and 2°C of global warming. It is important to highlight that this is not an analysis of future cyclone formation, but in line with other findings in the literature our analysis indicates a substantial increase in the most devastating tropical cyclones at 1.5°C of global warming and even more so at 2°C of global warming.

3. Implications for adaptation in Small Island Development States

As low frequency high impact events, tropical cyclones already present a challenge for adaptation planning in many SIDs. Not only do adaptation and disaster management plans need to respond to the immediate risks created by cyclones but they must also contend with negative impacts on the adaptive capacity of a country or society. Communities affected by cyclones are often left more vulnerable to other climate change impacts and have fewer resources to respond to future impacts, while low-income countries are also less able to deal with such events because they lack the institutional, financial or technological capacity to adapt effectively[xxix,xxx,xxxi]. Post-disaster priorities may understandably focus on short-term needs thus leaving fewer resources for the implementation of strategically important adaptation projects. The impact of a cyclone event can also change the social acceptability of particular adaptation solutions, for example leading to a preference for 'hard' coastal protection measures.

The potential increases in sea level rise and tropical cyclone intensity outlined above have significant implications for adaptation planning in SIDS. Increased intensity of cyclones can push countries beyond the limits of their adaptation and coping capacities. The impact of Hurricane Irma on Barbuda presents a sobering example of this, where the Government ordered a total evacuation of its population. It is also likely that slow onset impacts such as loss of land and infrastructure due to sea level rise and saline intrusion will be pushed beyond critical tipping points by single weather events. The consequence may be that livelihoods that are already marginal in terms of their viability may be unable to recover.

Climate change presents a risk multiplier in cyclone-prone SIDS, yet there are actions that can help enhance resilience of these countries. The improved integration of climate adaptation and disaster risk reduction at national and community levels can help to ensure that countries are better prepared for cyclones but are also considering the implications of climate change. For example, reforestation in upland areas can reduce flood risk from intense storms and may also reduce the risks of coastal inundation, while resilient community infrastructure such as schools and churches can be used as cyclone shelters. In the Pacific region, the Framework for Resilient Development in the Pacific (FRDP) provides a structure for strengthening the interface between disaster risk reduction and climate change adaptation, while at national levels, countries such as Tonga and the Cook Islands have developed Joint National Action Plans for climate change and disaster risk management within which transformative ambitions could planned. Coordination is also needed at Ministry levels, and there are examples of SIDS bringing together critical functions. For example, Vanuatu has a single Ministry dealing with climate adaptation, meteorology, geo-hazards, environment, energy and critical disaster management.

While devastating in their impacts, crises, including cyclones, can present 'windows of opportunity' to trigger transformational change[xxxii,xxxiii] potentially leading to more resilient societies. However, to do so will require countries to have prepared, and consulted upon ambitious, locally appropriate plans for low carbon and resilient futures. It will also require donors and insurers to move from a 'replace and rebuild' approach to a genuine commitment to 'building back better'. While there has been much rhetoric regarding the need for such approaches, it is less clear whether such an approach is possible on the scale which would be truly transformational. It is therefore critical for SIDS to highlight the implications of climate related extreme events on their ability to adapt to climate change both within the context of international negotiations and in discussions with donors.

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Methods

Tropical cyclone best track data was obtained from https://www.ncdc.noaa.gov/ibtracs. Monthly SST are taken from NOAA[xxxiv]. For each recorded tropical storm, the monthly SST at the location where the storm became strongest is taken. The probability density of cyclones with respect to SST is shown as kernel density estimates. SST distributions for present are based on NOAA observations. They are obtained by aggregating monthly SST for the months of the main cyclone season over all grid cells in the main cyclone development region for the years 1986-2005. For SST projections, monthly SST anomalies are computed for model specific time periods corresponding to 2°C (1.5°C) global warming above preindustrial. We obtain absolute SST projections by adding these anomalies to the absolute SST climatology (obtained from NOAA). Monthly SST projections are aggregated for the months of the cyclone season and the same grid cells as for the observations for a large set of models from the CMIP5 ensemble.

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