The Maldives

The 2014–2016 El Niño in the Maldives: Climate, Impacts, and Response

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Abstract Sitting atop an oceanic ridge running from the Lakshadweep Islands to the north to the Chagos Islands to the south, the Republic of Maldives dots the periphery of 26 atolls in the Indian Ocean. It has a total land area of 298 km^2 (115 mi^2) but the Republic as an archipelago encompasses 90,000 km^2 of ocean surface. The Maldives 1192 islands are low-lying and small and face environmental risks due to geophysical hazards, water availability, disease, and food insecurity. The dispersed population of 350,000, as well as the livelihoods of expatriate workers, are highly vulnerable to climate variability. They are also affected by El Niño impacts, which tend to be modulated by the influences of other air-sea interactions such as the Indian Ocean Dipole (IOD). The impacts of El Niño are also influenced by an ever-warming Indian Ocean as well as by atmospheric waves. In this chapter, the variation of indices for these influences are compared in order to extrapolate the impacts of climate change from mid-2014 to mid-2016. This study concludes that some of these impacts—including coral bleaching, drought (in the northern islands), flooding (in some seasons), infectious disease, and fishery and agriculture loss—are due to the very strong El Niño that formed in 2015.

Keywords El Nino · Climate · Maldives · Arabian Sea · Indian Ocean

The combination of an El Niño event and the ongoing warming of the Indian Ocean made the 2014–2016 period the warmest on record with regard to both sea and land surface temperatures. Bleaching due to this warming led to a large loss of live corals, and rainfall anomalies led to flooding across the country. Along with El Niño, both the oceanic Indian Ocean Dipole (IOD) and the atmospheric Madden Julian Oscillation (MJO) were drivers of flooding. As a result, the incidence of dengue picked up during the El Niño, particularly in the Central and Southern Atolls, though such an increase

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was not typical during other recent El Niño events. During the 2015–16 event, fishery production also declined in the Northern and Central Atolls, though the catch in the Southern Atolls increased, a trend similar to previous El Niño events for which data is available.

1 Political and Economic Setting

"The Maldives faces environmental risks that leave the population highly vulnerable due to its far-flung geography of 1192 small islands, the majority of which are at elevations less than 2 m above mean sea level (MEE 2017, MEEW 2007). The islands are scattered on the periphery of 26 natural atolls on a north–south axis from 0.5 °S below the equator to 800 km above" (Zubair et al. 2017a (Fig. 1).

Population has risen considerably from approximately 100,000 in 1960 to 350,000 in 2016. This precipitous increase has contributed to threats to the sustainable use of finite resources such as water (Fig. 2). Furthermore, an expatriate worker population of 63,637 (2014 census) also puts enormous stress on limited resources, especially since the number of expat workers is believed to be substantially higher than official statistics indicate (MNPI 2018).

The Maldives underwent constitutional reform that led to a multi-party election in 2008. Only two years later, however, a turbulent period began with questions about

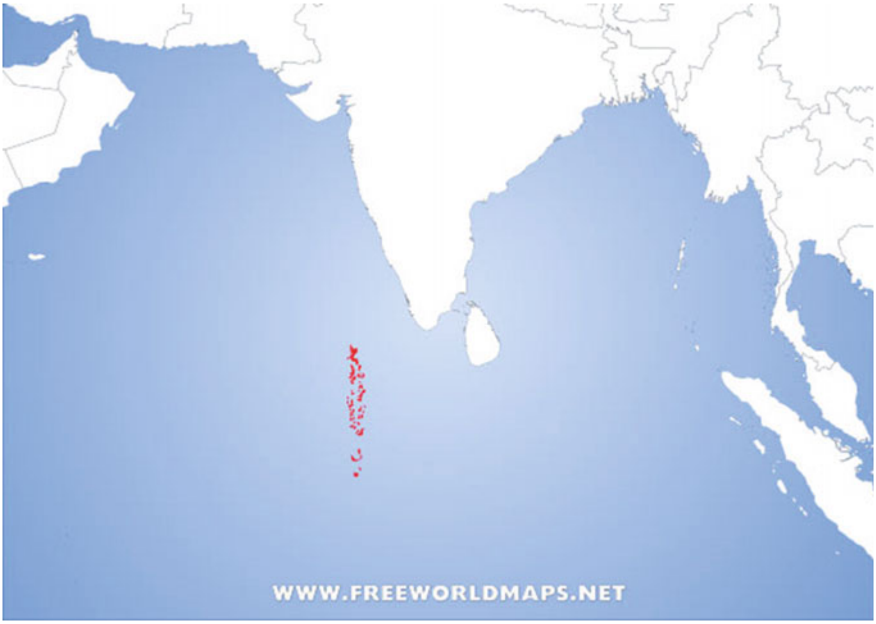

Fig. 1 Regional Map of The Maldives (Free World Maps 2020)

Fig. 2 Dense population of Malé Maldives (Wikipedia 2017)

the legitimacy of the government, resulting in deep societal divisions. More recently, the elections of 2018 brought to power a stable government with a two-thirds majority in parliament and a commitment to addressing sustainability.

Despite its remoteness, the Maldives is an important player in Indian Ocean geopolitics for a number of reasons, including territorial water disputes, relations with India, strategic location, the presence of China, US-China geopolitical competition, and sea level rise due to global warming. Perhaps the most immediate geopolitical issue, however, is the Maldives position as a proxy battleground in escalating regional conflicts between China and India. Although India maintains a "Neighborhood First Policy" that encompasses the Maldives in its strategic security considerations, China's current "outgoing" foreign policy agenda, most visibly through its multi-trillion dollar "One Belt, One Road" (OBOR) infrastructure development initiative, increasingly destabilizes regional relations. Kapoor succinctly sums up the situation:

> The Indian Ocean is a key highway for global trade and energy flows (Albert 2016). The Maldives is geographically positioned like a 'toll gate' between the western Indian Ocean chokepoints of the Gulf of Aden and the Strait of Hormuz on the one hand, and the eastern Indian Ocean chokepoint of the Strait of Malacca on the other. Thus, while the ISLs [international shipping lanes] in the vicinity of the Maldives have broad strategic significance for global maritime trade, they are of particular importance to India. Fifty per cent of India's external trade and eighty per cent of its energy imports transit these ISLs (Singh 2019). It is obvious, therefore, that any significant Chinese presence in this region has the potential to impede trade movement that is vital to India's economic interests, and such a possibility must be guarded against. (2020: 1)

Of great concern to India, for example, was the unique layover of Chinese warships in the Maldives in 2017. Later that year, the Maldives joined the Maritime Silk Road, part of China's OBOR initiative (also called the Belt and Road initiative, BRI), in order to receive financing to develop its domestic infrastructure such as the USD$200 million China-Maldives-Friendship Bridge (Gan 2020). Joining, however, eventually rendered the Maldives a debtor to China. This move was also very concerning to India, and rightly so, for not long after the Maldives government found itself falling behind on its OBOR loan payments, which turned out to be a "debt trap" similar to that into which the Sri Lankan government had fallen in 2015. When the Sri Lankan government defaulted on its OBOR loans, China was able to negotiate favorable terms for a 99-year controlling lease of the strategic Sri Lankan Port of Hambantota (Glantz et al. 2019). The Maldives government was close to defaulting in 2018. India, however, could not countenance a similar geopolitical encroachment upon another of its South Asian neighbors, so, moving tactically, it intervened to finance the Maldivian government's shortfall with China. In 2020, India funded a causeway to link Malé with 3 nearby islands for USD$500 million (Gan 2020). This geopolitical proxy drama in India's "neighborhood" continues even now, unabated.

2 Climate of Maldives

Even though the Maldives total land area is quite small, the country as a whole is spread from just south of the equator to 7 °N of the equator, a large swathe of ocean that results in often marked variations in climatic characteristics. The Maldives Meteorological Service (MMS) has five main stations (Fig. 3) positioned along this north–south expanse.

In the descriptions below, Hanimadhoo is taken as representative of the northern atolls, Hulhule as representative of the central atolls, and Gan as representative of the southern atolls. In addition, it is also useful to consider the respective stations in the Lakshadweep islands of India (Minicoy and Amini) and that in the Diego Garcia Islands in the Chagos Archipelago, as these have longer records and can help interpret the climate. The rainfall and wind averages at the main stations are as follows:

Rainfall: The Maldives receives an annual average rainfall ranging from 1700 mm in the northern-most station of Hanimadhoo to 2350 mm in the southern-most Gan station (Fig. 3). The mean annual cycle of rainfall in the Maldives shows a dry season from February to March and a wet season from April to November, with the southernmost islands receiving high rainfall during the December-January period when the Inter-Tropical Convergence Zone (ITCZ) is over the Southern Maldives. The northern stations receive their highest rainfall during the summer monsoon month of June, and the southern-most stations show a rainfall peak in December (FECT ND).

Wind: The Maldives tends to see a seasonal reversal in wind direction, with northeasterlies from December to March and southwesterlies from April to November. For the northernmost islands, the southwesterlies tend to last from May to October. The wind speeds peak in the northern region in June and in the southernmost islands in December. Storms and cyclones tend mainly to affect the northern islands (MEEW 2007).

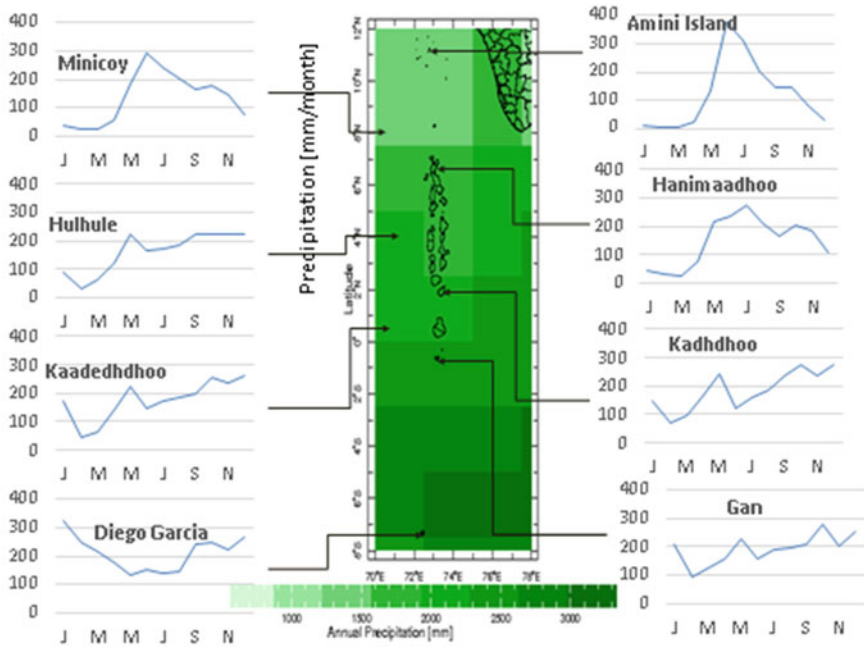

Fig. 3 Annual Rainfall of Lakshadweep-Maldives-Chagos Archipelago along with rainfall climatology of the synoptic (WMO) weather stations (Vose et al. 1992)

3 Strength of El Niño Teleconnections in Maldives

El Niño has significant impacts on rainfall, sea surface and land temperatures, winds, and other associated climate features across the Maldives. Its impacts, however, tend to vary by region, by decade, and by season as well as from event to event (Zubair et al. 2016). El Niño also tends to generate additional contrasts between northern, central, and southern islands.

The temperature warms during El Niño throughout the Maldives, with some modulation by sea conditions due to Indian Ocean dynamics. This interannual warming, in conjunction with the general warming of the regional seas, has resulted in temperature increases (Fig. 3) that exceed the tolerance levels of coral reefs. Significant coral bleaching associated with El Niño occurred, for instance, in the Maldives in both 1997 and 2016. Other discernible impacts have also been observed with regard to water resources, droughts, floods, fisheries, agriculture, health (especially dengue transmission), and coral reefs. The impact on coral reefs is particularly critical, given the islands' coral reef-based geology.

4 Challenges in Communicating El Niño to and Its Impacts on Society

MMS communications on seasonal and regional nuances of teleconnections to sectoral experts has been tricky, particularly in relation to El Niño's influence on rainfall. Communicating temperature influences in the seas and on land has been more straightforward, especially with regard to temperature-based impacts on coral reefs and health.

5 Forecasting El Niño for Maldives

National preparedness for El Niño is under the umbrella of the ministries in charge of Environment and Energy, Defense, Aviation, Fisheries, and Agriculture. The primary responders to climate extremes and disasters are the Maldives Meteorological Service (MMS), the Water Supply division under the Ministry of Environment, and the Disaster Management Centre.

The Maldives Meteorological Service (MMS) is the mandated department for weather and climate prediction and communication of usable information to the public. There have been considerable advancements in prediction capability in the last decades, mainly through the installation of prediction systems and the sustained attention of officials at MMS. Collaboration with organizations such as the World Meteorological Organization (WMO) and the Foundation for Environment, Climate, and Technology for Research (FECT) has also been beneficial. Furthermore, the Maldives Marine Research Centre and other organizations under the Ministry of Fisheries have been proactive in monitoring coral reef bleaching after the damage from the 2014–2016 El Niño.

The MMS relies on WMO and other international forecast centers for global and regional monitoring and prediction information. The officers of the MMS participated in the annual South Asia Climate Outlook Forum (SASCOF). The SASCOF of April 2014 projected a slight dry tendency over the central and northern islands and a slight wet tendency for the southwest (summer) monsoon from June to September. The SASCOF held six months later in October of 2015 predicted a slight wet tendency for October to December across the Maldives.

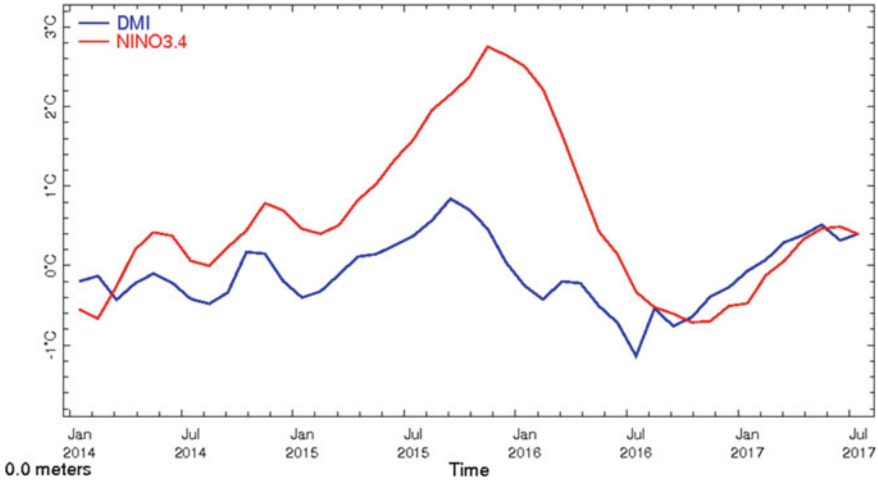

Fig. 4 The monthly variation of Oceanic Niño Index (NIÑO3.4) and Dipole Mode Index (DMI), 2014–2017 (Zubair et al. 2003)

6 Teleconnections During the 2014–16 El Niño and Their Impacts

6.1 2014–2016 El Niño Event

Based on the Niño 3.4 indices (Fig. 4), an El Niño began to form in October 2014 and persisted until April 2016. Transition to the La Niña phase extreme occurred beginning in October 2016. As per the Niño 3.4 record, the 2014–2016 El Niño proved to be among the three strongest events on record (since at least 1950), even challenging the intensity of the 1997–1998 event.

6.2 Indian Ocean Dipole (IOD)

Usually, El Niño is associated with a positive Indian Ocean Dipole (IOD), which is characterized by seasonably warmer central Arabian and Indian Ocean sea surfaces temperatures accompanied by cooler seas adjacent to the Sumatra Islands (Zubair et al. 2003). The air–sea coupling that sustains the IOD picks up around June and dies off by late December. A positive IOD compounds the warming of the ocean due to El Niño. Rainfall has no discernible association with IOD from January to May, a weak dry tendency from June to August, and a significantly wetter tendency from September to December. The IOD index of DMI (Fig. 3) was weak during 2014, positive during 2015, and negative during 2016 in terms of the classification presented in Zubair et al. (2003).

The Dipole Mode Index (DMI) was above the standard deviation of + 0.3 °C from July to November 2015 and below -0.3 °C from May to November 2016 (Fig. 4). DMI was also below the -0.3 °C threshold from July to September 2014, although it was weakly positive for the rest of 2014. The impact of the interplay of the NIÑO and DMI has to be interpreted by region and by season. For example, from September to December, DMI influences on rainfall would typically be found to complement that of the 2015 El Niño across the Maldives central islands.

6.3 Indian Ocean Warming

The Indian Ocean has been warming around the Maldives at a much faster rate than can be explained only by global warming. This rise has been compounded by El Niño, leading to an unprecedently high rise in SSTs close to the Maldives. The oceanic temperature (SST) around the Maldives during the 2014–2016 period was comparable to that recorded during the 1997–1998 El Niño event (Fig. 5).

6.4 Madden–Julian Oscillation (MJO)

The Madden–Julian Oscillation (MJO) has a significant impact on Maldivian rainfall and temperature and can also modulate the impact of El Niño, even though MJO's impact tends to be shorter lived than El Niño's. MJO oscillations are characterized by eight phases (Wheeler and Hendon 2004). In phases one and two, MJO has a significant enhancing influence on Maldivian rainfall, with some influence in the northern islands stretching into phase three. When MJO is in phases five, six, and seven, rainfall tends to be suppressed.

In mid-October of 2014, MJO was in phase one and its impacts strengthened over the Indian Ocean. In 2015, rainfall increased from March to mid-June, and then again in July and October. Rainfall increases were also observed in 2016 (mid-January, June, July, and late November), but significantly decreased in October and December.

7 Climate Over Maldives, 2014–2016

7.1 Rainfall

The rainfall from April 2015 to May 2016 (Fig. 6) followed historical trends for the northern and central islands. These trends are represented for El Niño, near neutral, and La Niña in Fig. 6 as red, green, and blue, respectively, for the three regions. In

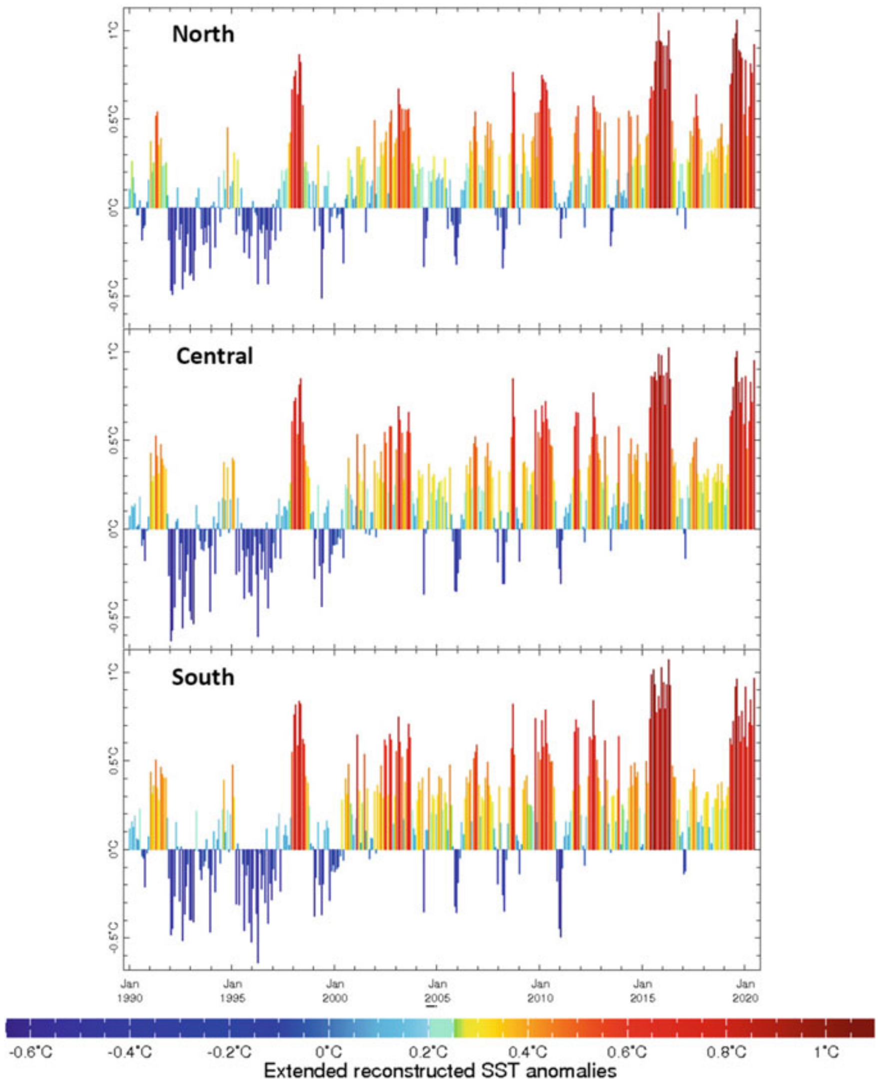

Fig. 5 SST Anomalies for **a** Northern Region, **b** Central Region and **c** Southern Region of Maldives during 1990 to 2020, using the NOAA ERSST data. (Huang et al. 2017)

the northern islands, the high climatological rainfall for June to September (Panel 1) is diminished due to El Niño. In the central islands, El Niño led to increased rainfall in May and from October to December, and deceased rainfall from June to August and again from January to April. In the southern Islands, rainfall is usually lower from June to August and higher from October to November.

During the 2014–2016 period:

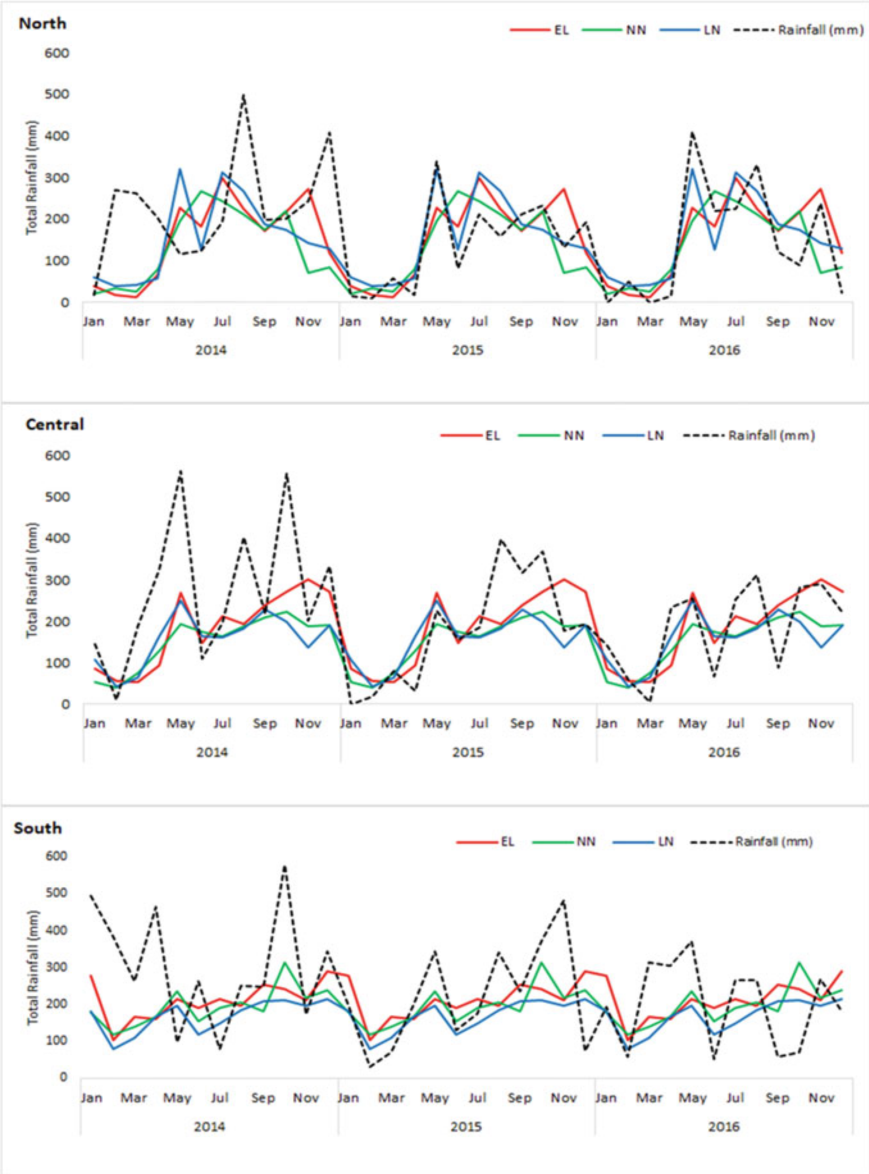

Fig. 6 Average monthly rainfall for different geographical regions of Maldives during El Niño (red line), Neutral (green) and La Niña (blue). Rainfall from Jan 2014 to December 2016 is also shown. Rainfall data is from the Maldives Meteorological Service

From June to October 2015 in the north, rainfall decreased but the impact of this reduction was ameliorated by the high rainfall in May 2015.

In the central islands, rainfall from July to October 2015 was high, an increase El Niño alone does not explain. Rainfall in November and December 2015 was not as high as expected.

In the southern islands, rainfall was highly variable from month to month, with large extremes that did not have a clear relationship trend during past El Niño events.

7.2 Temperature

The temperature during 2014–2016 in Northern, Central, and Southern Maldives were the warmest on record. Warming SSTs and the El Niño/IOD event drove this increase.

8 What Were the Impacts on the Maldives?

The principal El Niño-related impacts were on coral bleaching, flooding, dengue, and fisheries.

8.1 Coral Bleaching

Large areas of coral were bleached in the strong 1997–1998 El Niño event. Most areas recovered up to 40 percent in the following years (Pisapia et al. 2016). As the El Niño event persisted throughout 2015 and worsened in 2016, however, reefs bleached again starting in May of 2015. The 2015–2016 El Niño caused the largest episode of mass bleaching in the Maldives since 1998 (Ibrahim et al. 2017; Muir et al. 2017, Gomez et al. 2016).

The timing of this bleaching event can be interpreted based on "Degree Heating Weeks" (DHWs), a product of NOAA's Coral Reef Watch (Gomez et al. 2016) which shows how much heat stress has accumulated in an area over the previous 12 weeks by adding up sea surface temperatures that exceed the bleaching threshold during that timeframe. When an area reaches four DHWs, significant coral bleaching is likely, especially for more susceptible coral species. In the Maldives, thermal stress peaked at five DHWs during May 2016.

Table 1 Reported flood/landslide disasters and their effects in different provinces and regions (Northern, Central and Southern) in Maldives during 2014–2016

Time		Rainfall Anomaly (mm)	Average Annual (mm)	Affected Provinces	Damages
2015	May June	Southern 59 Central—59 North—42	Southern—194 Central—194 Northern 212	Upper North, North, Upper South, South Central, South	Infrastructural and crop damages
	Aug	76	189	North Central	Sections in Maafannu flooded
	Nov	27	156	South	80 houses were damaged; about 200 households were flooded
2016	Jan	– 29	43	South Central	
	Apr	100	120	North Central	Flooding at the Maldives' main airport and in the capital Malé

Source http://floodlist.com/asia

8.2 Flooding

In the 2014–2016 period, there were floods (Table 1) and droughts (MEE 2016). It is possible that the El Niño event, intensified by MJO, spawned some of these events, though such hydrometeorological extremes do not follow the patterns anticipated with an El Niño.

8.3 Dengue

Dengue first emerged in the Maldives in 1979 and now occurs perennially, with seasonal peaks and regular epidemic outbreaks. Dengue dynamics are strongly influenced by human behavior, demographics, and environmental and climate factors that affect mosquito vectors more than they do humans. The incidence of dengue for the northern, central, and southern regions are shown in Fig. 7.

The "seasonality" of dengue experiences a delay of one to two months with rainfall and tends to be consistent in the seven provinces of the Maldives (Zubair et al. 2018).

Dengue epidemics have been identified in 2006, 2007, 2008, and 2011. Epidemics appear to be coincident with a narrow range of temperatures (i.e., minimum temperature of 25–27°C and maximum of 29–32°C) in most of the provinces.

From mid-2014 to mid-2016, there was a major rise in dengue cases in the central region in mid-2015 and a substantial rise across the Maldives from April to August

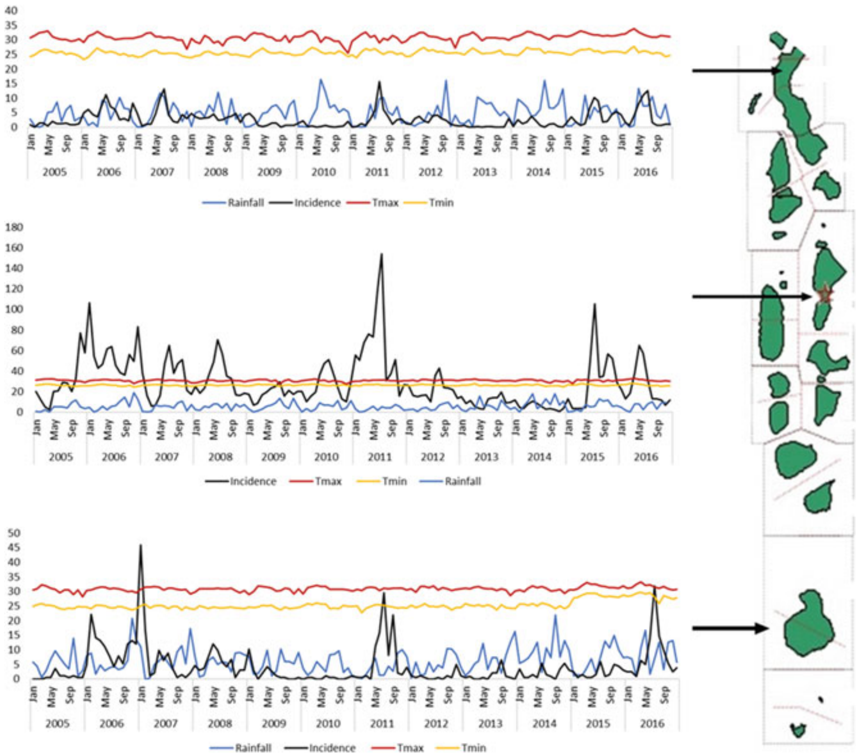

Fig. 7 Dengue incidence, rainfall, temperature climatology in the north, central, and southern regions of the Maldives from 2005 to 2016. Dengue data was provided by the Health Protection Agency of the Maldives Ministry of Health and the rainfall and temperature data are provided by the Maldives Meteorological Service

2016, which was a period of low Niño 3.4 SST values. From 2005 to 2014, dengue incidences coincided three out of four times with low Niño 3.4 SST values.

8.4 Fisheries

The fisheries sector is the second most important economic sector after tourism and the most important source of livelihoods across the Maldives. Tuna, which is the major catch, has become an important commodity for both export and domestic consumption.

Climate has profound effects on oceanic fish habitats. One of the environmental factors that generally affects the biology and migration of many fish species is temperature (Magnuson et al. 1979; Gulland 1980). The geographical distribution of fish populations, particularly pelagic species, is influenced by fluctuating SSTs even small changes to which may lead the fish stock to higher latitudes (Cushing and Dickson 1976; Pörtner and Peck 2010). A dramatic influence of seasonality on the distribution of Mantas has, for example, been documented in the Maldives (Anderson et al. 2011). Overall fishery production shows seasonal peaks in April to May and in October to November (Fig. 8).

During SST warmings from 2014 to 2016, there was a significant drop in fish capture for the North and Central Maldives, while there was an increase in the Southern region. Interannual variation (Fig. 9) shows that the catch in the south does not correlate with that in the north. Further data collection and analysis is called for.

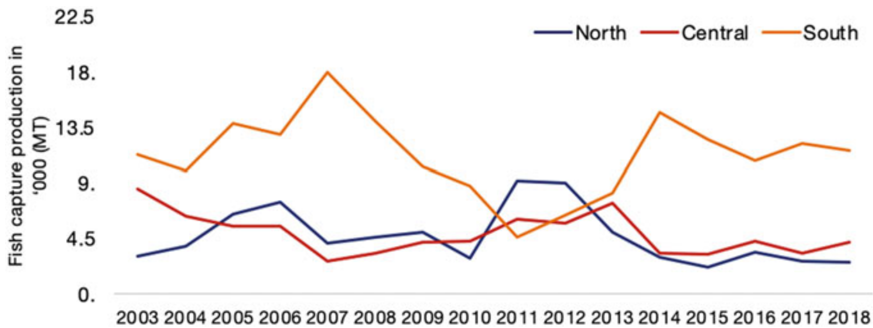

Fig. 8 Annual fish capture production in '000 metric tons (Statistical Yearbook of the Maldives 2017)

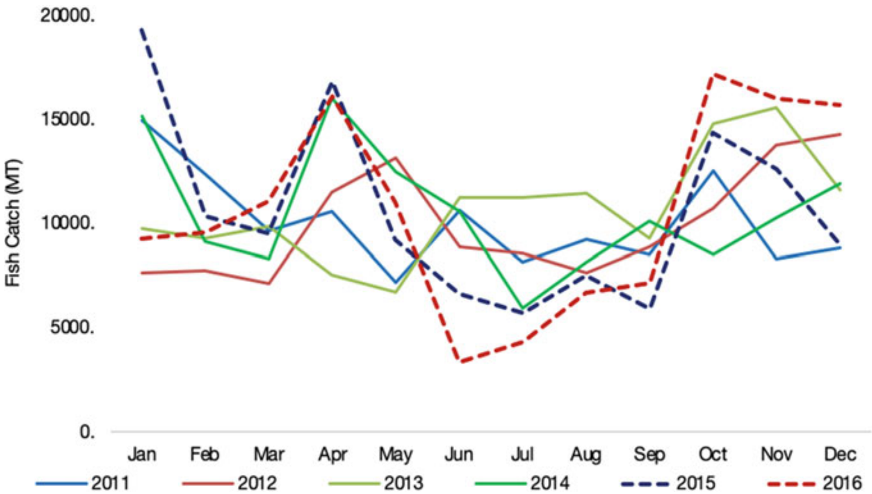

Fig. 9 Monthly fish capture in the Maldives (Statistical yearbook of Maldives 2017)

9 Hurdles and Obstacles

The Maldives Meteorological Service provided extended-range weather forecasts. The Foundation for Environment, Climate, and Technology (FECT) provided a monthly climate bulletin to sectoral experts. The information from both services was provided via social media and email (Agalawatte et al. 2016, Zubair et al. 2017a, b). While El Niño is a clear concern, the regional and seasonal nuances, and communication of those nuances, have confounded several agencies. The only exception was the study of coral bleaching during the 2015–2016 El Niño, as a USAID-sponsored effort led by the IUCN monitored bleaching. Other sectors were not as proactive.

The identification, prediction, and communication of El Niño impacts is particularly challenging in the Maldives. Given all the nuances and the regional complexity of climate variability, studies on impacts have to be deepened and extended to new areas. El Niño education has to be extended to the community level and to schools. In this regard, the pilot project on STEM education by FECT, with support from the PEER program of the US National Academy of Sciences, could be expanded from its pilot program in just three schools.

During the 2015–2016 event, there was occasional news coverage in the English press, but it was mainly focused on coral bleaching. Overall, if media coverage is taken as a whole, while the average person could rely on these reports for an alert, the reports were not adequate for people to be able to make informed, educated responses.

The Maldives has had success in bringing together scientists to work on monitoring bleaching. Building on these successes, analysis of the historical evidence for El Niño impacts on key sectors such as fisheries and tourism must still to be carried out. Our own work on dengue transmission, which is the primary disease of current concern, shows direct relationships with climate variability. The evolution of this 2014–2016 El Niño has lessons for future preparedness and merits study.

10 Lessons

During the 2014–2016 period there was awareness of coral bleaching hazards and water shortages, particularly in the Northern Islands. There was also interest in the media seeking explanations for the climatic anomalies.

The provision of seasonal climate information has been led by the Maldives Meteorological Services working with various international institutions. The predictions from international forecast centers, however, often do not well-represent Indian Ocean dynamics and the influence on El Niño's teleconnections in the region. As a result, the MMS uses caution with these forecasts. El Niño's influence is modulated by other factors such as cyclonic events, MJO, and other Indian Ocean characteristics, which need to be better understood. Prediction models also need to be better assessed through historical validation.

Impact studies should be expanded and deepened, particularly with regard to fisheries, water resources, agriculture, and disasters. Sea level influences of El Niño need to be better understood. The combined influence of El Niño and Indian Ocean warming needs to be better addressed to improve future impact predictions. What is known about the El Niño, including its nuances and its impacts, should be made accessible to the general public. Educational programs with sectoral experts and STEM programs for students will help inform the public (Zubair et al. 2020).

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