Precipitation responses to ENSO and IOD in the Maldives: Implications of large-scale modes of climate variability in weather-related preparedness

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Abstract

This research seeks to address the extent to which indices of large-scale modes of climate variability (El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD)) can be linked to physical differences in the local mean and extreme rainfall conditions experienced in the Maldives in order to suggest implications for disaster risk reduction (DRR). While some significant differences in precipitation metrics do occur at the local level between different phases of the large-scale modes of climate variability studied, they do not occur for all sites studied. While the constrained availability of historical meteorological data in the region is a limiting factor in this analysis, these findings suggest that with respect to decision-making related to extreme precipitation, ENSO/IOD forecasting may be most helpful on local scales, when supplementing an approach of on-going readiness in which communities are prepared to effectively manage hazards in any phase of the large-scale modes of climate variability studied. These conclusions are based on only precipitation; results may vary for other impacts including changing sea levels and sea surface temperatures.

1. Introduction

In the Indian Ocean, where precipitation is characterised by interlinkages between large-scale modes of climate variability and long-term climate trends (Kerns and Chen 2018; Li, Xie, and Du 2015, 2016), projecting future climatic behaviour has important implications for weather preparedness. Two key modes of this region’s large-scale mode of climate variability are the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). Using the Maldives as an example, this research seeks to address the extent to which ENSO and IOD can be linked to physical differences in local mean and extreme rainfall conditions in order to explore implications for disaster risk reduction (DRR).

ENSO is characterized in the El Niño phase by strong anomalous warming in the eastern equatorial Pacific. The El Niño Modoki has been proposed, characterised by warming in the central tropical Pacific and cooling in the eastern and western tropical Pacific (Ashok et al. 2007; Yeh et al. 2009). This phenomenon has been associated with a weakening of the East Asian summer monsoon (Weng et al. 2007). IOD involves irregular oscillation of sea surface temperatures (SSTs) in the Indian Ocean with potential to impact precipitation patterns (Webster et al. 1999). During a positive IOD event, SSTs are cool in the east and warm in the west, and this change in heat distribution leads correspondingly to a reversal in wind direction from westerlies to easterlies. IOD events lead to increases in rainfall in India and east Africa, and decreases in the Maritime Continent and Australia (Vinayachandran, Francis, and Rao 2009).

Multiple interactions among ENSO, IOD, and Madden-Julian Oscillations (MJO) are reported in the literature (Izumo et al. 2014; Le and Bae 2019; Lu et al. 2018; Rao et al. 2009; Sang, Singh, and Xu 2019). In an atmosphere–ocean coupled general circulation model, ENSO is found to impact the development of the IOD in years of co-occurrences (Behera et al. 2006). However, Cai, Sullivan, and Cowan (2011) note that ENSO’s influence on the IOD in CMIP3 models is amplified by model deficiencies giving rise to spurious teleconnections.

Considerable effort has been directed towards predicting the behaviour of ENSO, given its potential for wide-ranging and far-reaching impacts, including implications for floods and droughts (e.g. Kovats et al. 2003; Lyon and Barnston 2005; Tong et al. 2006). In the aftermath of the 1982–83 El Niño, which was the strongest on record at the time, yet neither predicted nor even detected until the event was well underway, attention was given to observing and attempting to forecast fluctuations in the tropical Pacific (McPhaden et al.

2001). Models informed by these new observations from the Tropical Ocean Global Atmosphere (TOGA) programme performed well in predicting ENSO indices, with lead times of 6 to 12 months (Latif et al. 1998).

Modelling suggests that there is also potential to forecast positive IOD events; for example, Luo et al. (2008) find, using a coupled model, that the 2006 and 2007 events can be predicted 3 or 4 seasons ahead, and regional IOD-related climate anomalies predicted 1–2 seasons ahead. Shi et al. (2012) suggest a lead time of one season for IOD event prediction, which could extend to two seasons for large events, although it is noted that the tendency of the forecast system to overestimate the occurrence of large events is a source of uncertainty.

The use of such forecasting in disaster preparedness could help to mitigate negative impacts if actions are taken (e.g. Bouma et al. 1997; Goddard and Dilley 2005; Lemos and Dilling 2007; Roncoli 2006), with such forecasting discussed specifically for ENSO (e.g. Barnston, Glantz, and He 1999; Cabrera, Letson, and Podestá 2007; Landsea and Knaff 2000; McPhaden 1999; Tozier de la Poterie et al. 2018). ENSO forecast data comes in many forms, both deterministic (Barnston et al. 2017) and probabilistic (L'Heureux et al. 2018). The official ENSO forecast has been probabilistic since 2002 (Tippett et al. 2017), reflecting the probability of El Niño, La Niña, or neutral conditions but not their strength. Their probabilistic nature impacts on how forecasts are perceived and used; in theory, users can apply their own needs-based decision-making threshold to such forecasts (Broad, Pfaff, and Glantz 2002; Fundel et al. 2019). In practice, it may be challenging to integrate probabilistic forecasts into existing practices, as noted by Hayman et al. (2007) in the context of seasonal climate forecasts provided to Australian farmers.

If such forecasts are to be useful in building local readiness for climate variability, there is a need to distinguish between forecasting a climate phenomenon's onset versus forecasting impacts (Glantz 2015; Glantz and Ramirez 2020; Lemos and Dilling 2007). Historical records (Kumar, Rajagopalan, and Cane 1999; Yim et al. 2014) and climate models (Wang et al. 2015) both offer insights into the relationships between forecasted phenomena (e.g. ENSO) and climate variables at the regional scale. However, ENSO has been mostly linked to changes in seasonal precipitation anomalies (Indeje, Semazzi, and Ogallo 2000; Lyon et al. 2006; Montecinos and Aceituno 2003; Zubair et al. 2008), leaving the potential impacts on intraseasonal extreme events relatively overlooked (notable exceptions here include Curtis et al. 2007; Gershunov 1998).

Furthermore, location makes a difference. For instance, the spatial characteristics of small islands can lead to a mismatch between the scales on which such insights are generated, and the scales on which decision-making must take place. Gridded datasets and global models used in these studies typically possess resolutions ranging from 0.5° × 0.5° (e.g. Cherchi and Navarra 2013; Yim et al. 2014), which corresponds to ~55 km at the equator. In contrast, Malé island in the Maldives is 1.7 km long and 1.0 km wide.

Additionally, Grove and Adamson (2018) argue that El Niño now has an effect on society stemming from how the phenomenon is represented in the media and perceived in the public imagination, which is as important as the physical effects of the phenomenon itself. Particularly when the timescale of variability corresponds to timescales on which people make decisions in their everyday life, as ENSO does, social responses are elicited (Stehr and von Storch 1995). This 'social construction' of climate variability (Pettenger 2016) can have practical impacts on policy. As noted by Bankoff (2004) in relation to the Philippines, a range of environmental hazards (e.g. deterioration in water supply) is increasingly being ‘blamed’ on ENSO, when there are significant local factors that could also be addressed (e.g. deforestation or pollution). This ‘social construction’ of ENSO may lead decision-makers to assume action is required without considering the relevance of the forecasted information for their specific decision-making circumstances.

This necessitates reflection on the extent to which ENSO/IOD’s fingerprint can be identified in local Maldivian weather data, to infer how useful ENSO/IOD forecasts might be for anticipating local Maldivian weather. For example, farmers aiming to harvest watermelon in the MAM season may wish to anticipate heavy rainfall as it can cause the watermelon to swell too quickly and burst. In 2017, heavy rain in May destroyed several fields on the islands of Thoddoo, an intensive producer of watermelons, causing substantial financial losses (Anon 2017). If, in February, a farmer has the forecasted probabilities of what ENSO/IOD indices may be in MAM, and the consensus of ENSO prediction models indicate that El Niño conditions are likely, what can the farmer infer about local rainfall?

To contribute to filling this need, this research seeks to address:

1. To what extent are different phases of ENSO and IOD activity as specified by their indices associated with physical differences in the local precipitation conditions experienced in the Maldives?
2. What are the implications of the presence or absence of such associations for forecasting in weather-related decision-making, most notably for DRR?

Relationships between historical ENSO/IOD indices and local precipitation metrics over overlapping 3-month seasons are assessed using observed data from five meteorological stations in the Maldives. Our approach is similar to that of Lyon et al. (2006) assessing rainfall response to ENSO in the Philippines, but extended to rainfall extremes. Dilley and Heyman (1995) examined the Maldives as part of a study of ENSO connections to flood and drought, based on declared disasters. To the authors' knowledge, the work presented here is the only study exploring links between observed rainfall extremes and ENSO for Indian Ocean island countries.

2. Methods

2.1 Precipitation data

The meteorological data were kindly provided by the Maldives Meteorological Service. Precipitation at five meteorological stations in the Maldives is analysed (Figure 1): Gan (data available for 1978-2012), Hanimaadhoo (1992-2012), Hulhulé (1975-2012), Kaadedhdhoo (1994-2012), and Kadhdhoo (1990-2012). Scarcity of historical meteorological data is a known issue in island contexts (Foley 2018), and the data landscape is especially challenging compared to post-industrial nations (e.g. Hammer, Holzworth, and Stone 1996; Stone and Auliciems 1992), where it is possible to establish probabilistic relationships between broad-scale SST anomalies and local rainfall based on records of 100 years or more at certain locations. The Global Historical Climatology Network (Vose et al. 1992), which underpins the work of Stone, Hammer, and Marcussen (1996) on global relationships between rainfall and the Southern Oscillation Index (SOI), only provides a record longer than 100 years for one site situated in an Indian Ocean island country, Seychelles Aero, and even this is disrupted by an eight-year gap from 1964-1972.

In such circumstances, given that the alternative would be to avoid carrying out any analysis until sufficiently long datasets have been generated, we opt to proceed carefully in the reality of constrained data, a standard approach for decision-making which is necessary irrespective of data quality and quantity. That said, we note that the brevity of records and the variable record length across stations demand caution in interpreting the statistical analysis, particularly the extent to which any relationships identified should be considered a meaningful basis for decision-making.

Figure 1 illustrates the annual cycle in total seasonal precipitation at each station for 12 overlapping, 3-month seasons (e.g., January-March, February-April, etc.), derived from all available years of data, and highlights the heterogeneity of the rainfall climate of the Maldives. The Maldives experiences monsoonal climate. The dry season (northeast monsoon) extends from January to March. The wet season (southwest monsoon) runs from mid-May to November.

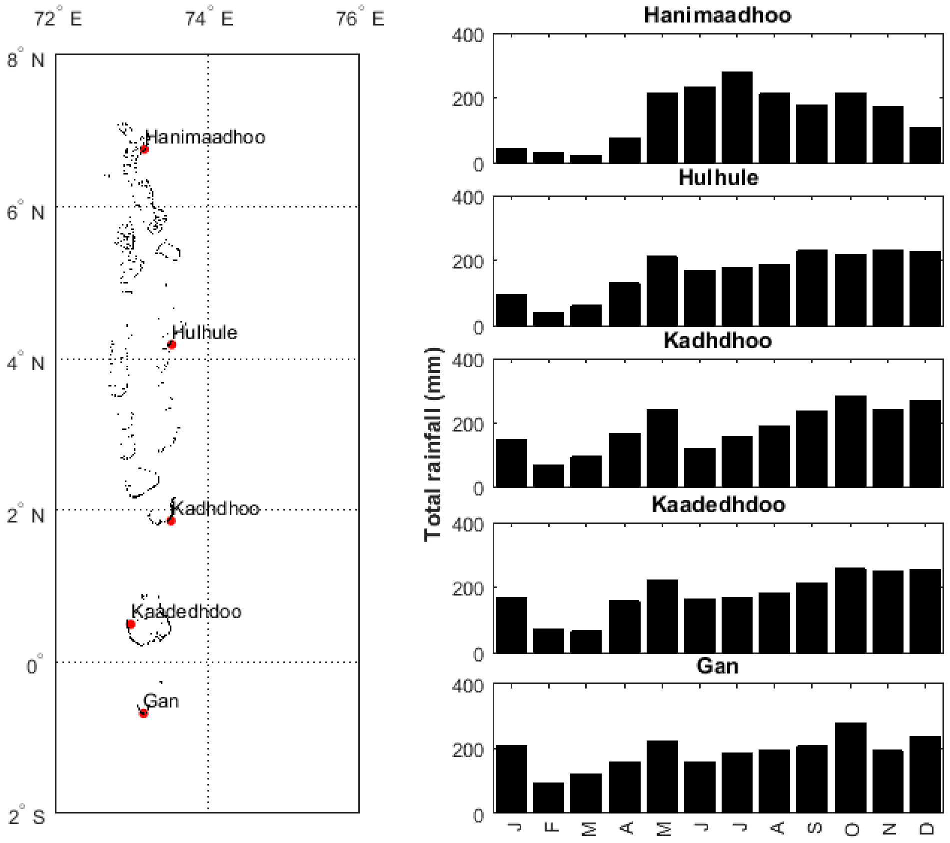

Fig. 1 Map of study area (left) and average precipitation climatology for each station (right).

2.2 Climate variability indices

While several studies have explored links between ENSO and local climate in various regions based on monthly data (Torrence and Webster 1999), the official ENSO probability forecast is delivered at the timescale of these same overlapping 3-month seasons. Therefore, the methodology selected here specifically interrogates links between *the indices of the phenomena* at the timescale on which they are predicted and local conditions, rather than links between the phenomena itself and local conditions. Thus, this research is concerned with the perspective of someone who is receiving an ENSO forecast and needs to decide what to do.

El Niño events are identified using the Oceanic Niño Index (ONI). An El Niño (La Niña) is diagnosed when the 3-month running mean of SST anomalies in the Niño 3.4 region is above (below) the threshold of +0.5°C (-0.5°C) for five consecutive periods. For Gan, the period covered by the dataset contains 14 El Niño events, and for the remaining stations, 8 El Niño events can be examined. As per Lyon et al. (2006) we consider 8 El Niño events a minimum threshold for dataset inclusion.

We also consider El Niño Modoki or central Pacific El Niño using the Trans-Niño Index (TNI), which measures the gradient in SST anomalies between the central and eastern equatorial Pacific. The TNI dataset is derived from the HadISST dataset (Titchner and Rayner 2014). The time series is the standardized Niño 12 minus the Niño 4 with a 5-month running mean applied, which is then standardized using the 1950-1979 period[1].

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[1] Available at https://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/TNI/

The monthly SST Dipole Mode Index (DMI) dataset is derived from the HadISST dataset[2]. Based on the anomalous SST gradient between the western and south eastern equatorial Indian Ocean, the IOD is positive (negative) when the DMI is positive (negative).

2.3 Analysis of extreme precipitation responses

Seasonal precipitation statistics, including extreme statistics, were computed using daily data at each station for 12 overlapping, 3-month seasons (e.g., January–March, February–April, etc.). The statistics are described in Table 1.

ID	Indicator	Unit
R_{sum}	Accumulated precipitation amount	Mm
R_{mean}	Mean daily precipitation amount	Mm
R_{X1day}	Max 1-day precipitation amount	Mm
R_{X5day}	Max 5-day precipitation amount	Mm
SDII	Simple daily intensity (Ratio of total precipitation to number of wet days)	mm/day
R_{10}	Number of heavy precipitation days (≥ 10 mm)	Days
R_{20}	Number of very heavy precipitation days (≥ 20 mm)	Days

Table 1 Overview of precipitation metrics

These 3-month seasonal statistics were cross-referenced against the ONI to identify seasons that correspond to an El Niño/La Niña/neutral ENSO, and averaged to derive the mean annual cycle associated with El Niño/La Niña/neutral ENSO for each statistic. The same

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[2] Available at: http://www.jamstec.go.jp/frcgc/research/d1/iod/DATA/dmi_HadISST_jan1958-dec2012.txt

process was applied using the DMI to derive the annual cycles associated with a positive (negative) IOD for each statistic, and using the TNI for the El Niño Modoki.

The statistical significance of the differences in metrics for each 3-month season during El Niño, La Niña, and the neutral phase of ENSO, during positive and negative TNI and during positive and negative IOD, is evaluated using the Kruskal-Wallis test (Kruskal and Wallis 1952). This is a test of the null hypothesis that two or more sets of data are samples from the same distribution, against the alternative that they are not.

This is a nonparametric equivalent of the one-way ANOVA, and is therefore suitable for use with small sample sizes where the condition of normality required by the one-way ANOVA cannot be assessed. However, the p-value can be inaccurate for samples of less than 5. Table 2 indicates how many 3-month seasons corresponding to each state of the ONI, TMI, and DMI are available for study at each station. Bold values denote station-season-index combinations with 4 or less instances over the observational period.

3. Results

Results indicate that there are some significant differences in extreme precipitation metrics during an El Niño/La Niña, during TNI+/- and IOD+/- phases, but these differences are highly localised, occurring at specific stations and in certain months.

In four out of five stations, there is a significant difference between total rainfall and average daily rainfall in NDJ in El Niño/La Niña phases (Figure 2). The exception is Hanimaadhoo, where precipitation is characterised more strongly by the summertime monsoon. Conversely, in Hulhulé, the difference in total rainfall and average daily rainfall in El Niño/La Niña phases is significant throughout most of autumn/winter, from SON to NDJ. Hulhulé also exhibits significant differences in the 5-day maximum metric in autumn/winter, with higher values in El Niño periods. Several precipitation statistics measured at Kadhdoo (including SDII, R_{10} and R_{20}) are found to exhibit significant differences in winter months during El Niño and La Niña phases.

		DJF	**JFM**	**FMA**	**MAM**	**AMJ**	**MJJ**	**JJA**	**JAS**	**ASO**	**SON**	**OND**	**NDJ**
Hanimaadhoo	ONI+	7	6	5	**3**	**4**	**4**	**4**	**4**	6	6	6	6
	ONI-	9	8	7	**4**	**4**	**4**	6	7	7	7	9	10
	ONIn	**4**	6	8	13	12	12	10	9	7	7	5	**4**
Hulhulé	ONI+	13	11	7	6	9	9	7	7	12	13	13	13
	ONI-	15	14	12	8	9	7	9	10	10	11	13	14
	ONIn	9	12	18	23	19	21	21	20	15	13	11	10
Kadhdhoo	ONI+	7	6	5	**3**	5	5	5	5	7	7	7	7
	ONI-	9	8	7	**4**	**4**	**4**	6	7	7	7	9	10
	ONIn	6	8	10	15	13	13	11	10	8	8	6	5
Kaadedhdoo	ONI+	6	5	**3**	**1**	**2**	**2**	**4**	**4**	6	6	6	6
	ONI-	9	8	7	**4**	**4**	**4**	6	7	7	7	9	10
	ONIn	**3**	5	8	13	12	12	8	7	5	5	**3**	**2**
Gan	ONI+	12	10	7	6	9	9	7	7	10	11	11	11
	ONI-	13	12	10	6	8	6	8	9	9	10	12	13
	ONIn	9	12	17	22	17	19	19	18	15	13	11	10
Hanimaadhoo	TNI+	8	8	9	7	6	6	6	6	6	7	7	8
	TNI-	13	13	12	14	15	15	15	15	15	14	14	13
Hulhulé	TNI+	13	14	15	12	12	12	11	11	13	14	13	14
	TNI-	25	24	23	26	26	26	27	27	25	24	25	24
Kadhdhoo	TNI+	8	8	9	7	6	6	6	6	6	7	7	8
	TNI-	15	15	14	16	17	17	17	17	17	16	16	15
Kaadedhdoo	TNI+	8	8	9	7	6	6	6	6	6	7	7	8
	TNI-	11	11	10	12	13	13	13	13	13	12	12	11
Gan	TNI+	12	12	13	10	10	10	9	9	11	12	11	12
	TNI-	23	23	22	25	25	25	26	26	24	23	24	23
Hanimaadhoo	DMI+	10	16	15	12	13	15	14	14	15	14	12	9
	DMI-	11	5	6	9	8	6	7	7	6	7	9	11
Hulhulé	DMI+	17	24	22	19	20	21	20	19	22	22	18	14
	DMI-	20	14	16	19	18	17	18	19	16	16	20	23
Kadhdhoo	DMI+	11	17	16	13	14	16	15	15	16	16	14	11
	DMI-	12	6	7	10	9	7	8	8	7	7	9	11
Kaadedhdoo	DMI+	10	16	15	12	13	14	14	14	14	13	12	9
	DMI-	9	**3**	**4**	7	6	5	5	5	5	6	7	9
Gan	DMI+	15	22	20	16	18	19	18	18	20	20	16	13
	DMI-	20	13	15	19	17	16	17	17	15	15	19	21

Table 2 Number of 3-month seasons corresponding to each state of the ONI and DMI at each station. Bold values denote station-season-index combinations with 4 or less instances over the observational period.

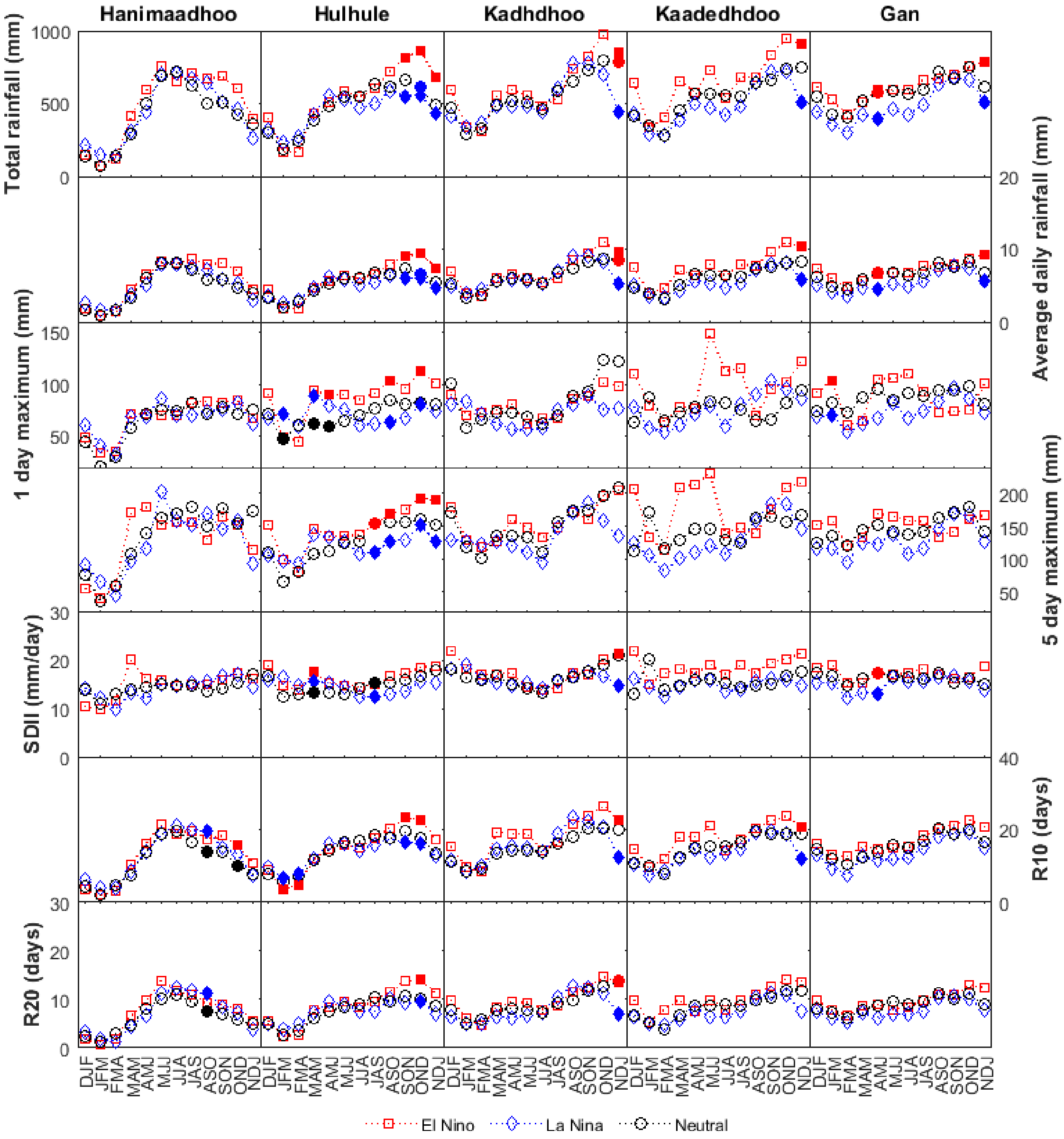

Fig. 2 Annual cycle associated with El Niño (red), La Niña (blue) and neutral ENSO (black) for means of each precipitation statistic described in Table 1. Statistically significant differences as evaluated using the Kruskal-Wallis test are indicated using pairs of filled symbols. If there

is a significant difference between El Niño and La Niña, but no significant difference is found between the neutral ENSO phase and El Niño (La Niña), the neutral ENSO symbol is filled red (blue).

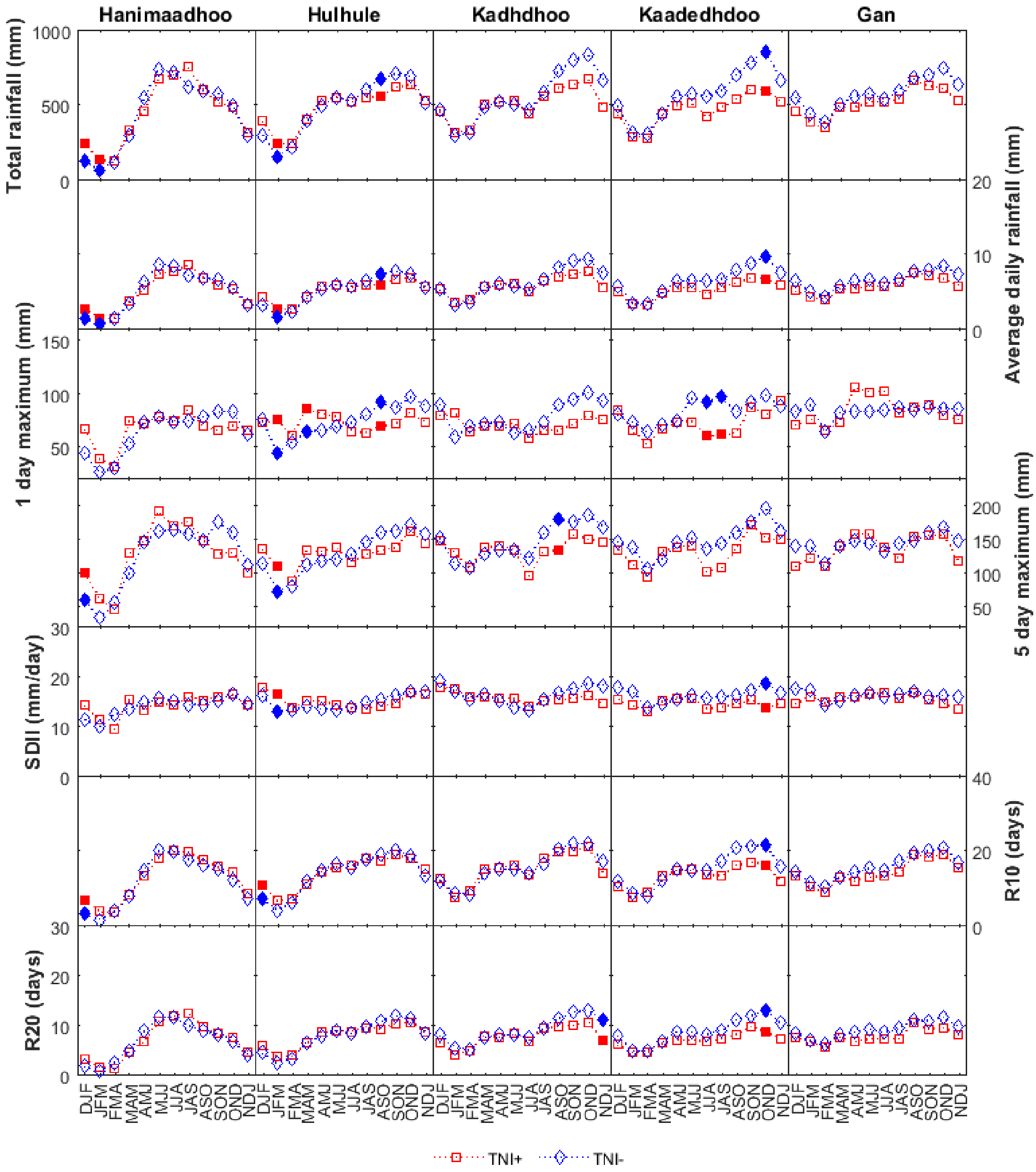

Fig. 3 Annual cycle associated with TNI+ (red) and TNI- (blue) phases for means of each

precipitation statistic described in Table 1. Statistically significant differences as evaluated using the Kruskal-Wallis test are indicated using pairs of filled symbols.

Several precipitation statistics measured at Kaadedhdoo (including SDII, R_{10} and R_{20}) are found to exhibit significant differences in winter months during TNI+/- phases (Figure 3). Here, the TNI+ phase (i.e. El Niño Modoki) is associated with less rainfall, and this is consistent with findings that El Niño Modoki is more effective at supressing precipitation, disrupting the Indian monsoon (Kumar et al. 2006).

However, here, the statistically significant differences in precipitation metrics at Kaadedhdoo occur late in the monsoon season, not throughout. Kaadedhdoo's geography, located to the south-east of the atoll, may render it more sensitive to fluctuations in monsoonal rainfall than other locations studied, which are situated in southerly or westerly locations. At Hulhulé and Hanimaadhoo, too, there are statistically significant differences in some precipitation metrics when El Niño Modoki is compared with La Niña Modoki. The direction of these differences varies, however, with TNI+ (El Niño Modoki) phases associated with more precipitation earlier in the year, and less from May onwards, an inversion of the normal seasonal pattern.

At Hanimaadhoo, Hulhulé and Kadhdhoo, there is a significant difference for five out of seven precipitation statistics in OND between IOD+/- phases, with IOD+ phases associated with greater precipitation (Figure 4). At these locations, some of the metrics of extremeness are also significantly different between IOD+/- in this season, though there is a lack of consistency in terms of what metrics are significant in each location. IOD+ phases are mostly associated with larger values, where these differences exist, but there are isolated exceptions, e.g. DJF 1-day maximum at Hulhulé.

Most of the statistically significant differences identified in this analysis are limited to a single 3-month season at a time, but there are instances where the statistically significant difference in values is sustained for two or even three overlapping, 3-month seasons, representing 4 to 5 months out of the year.

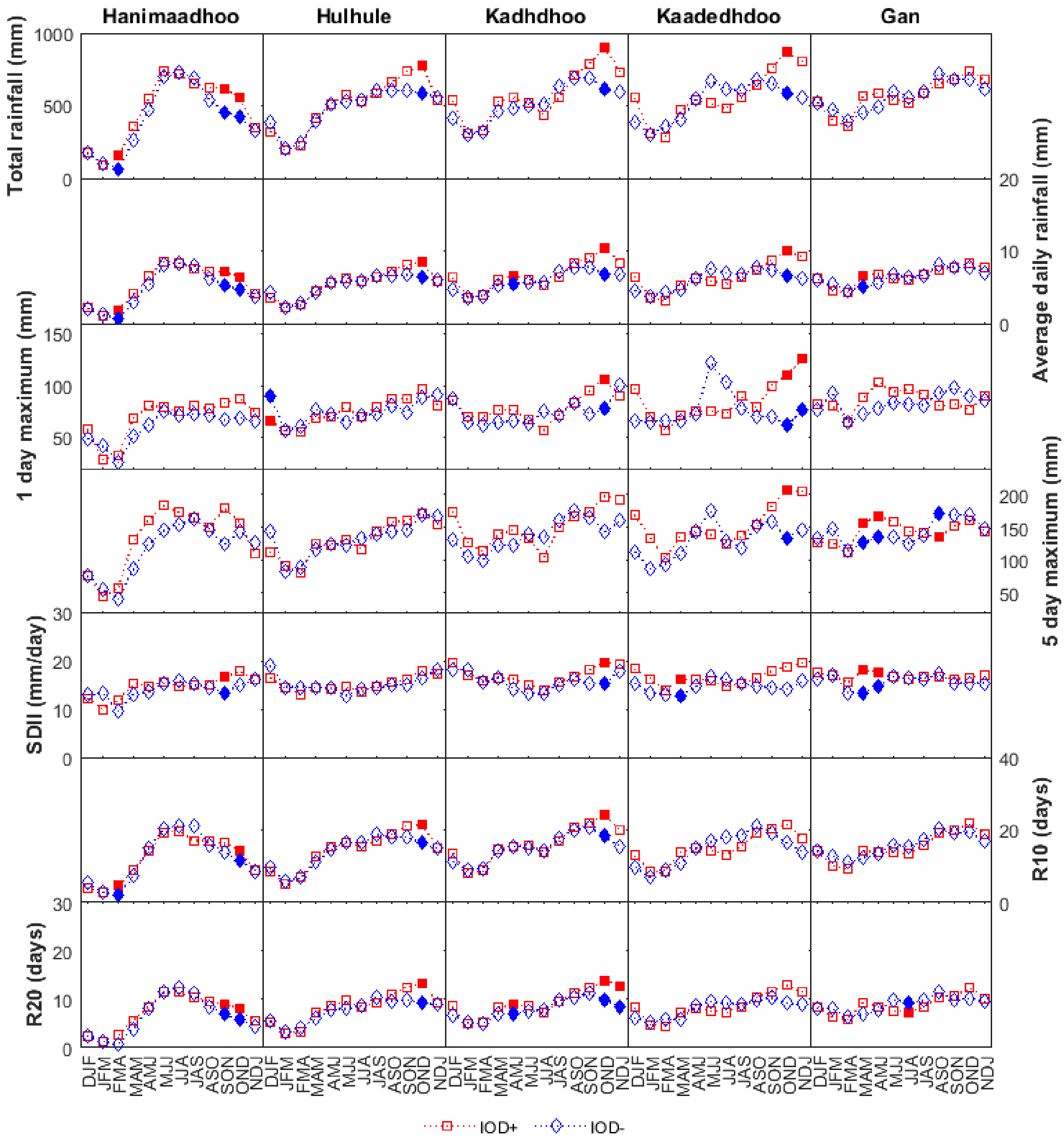

Fig. 4 Annual cycle associated with IOD+ (red) and IOD- (blue) phases for means of each precipitation statistic described in Table 1. Statistically significant differences as evaluated using the Kruskal-Wallis test are indicated using pairs of filled symbols.

4. Discussion

The first research question covered assessing the extent to which large-scale modes of climate variability can be associated with physical differences in the local precipitation conditions experienced in the Maldives. The methodology here specifically examines links between indices on the timescales that are/may be predicted and local conditions, rather than links between the phenomena itself and local conditions. This focus is important to determine how useful and useable ENSO/IOD forecasts might be for weather-related preparedness and readiness (e.g. Glantz 2004; Guimarães Nobre et al. 2019), to prevent disasters before weather manifests rather than dealing with situations when the weather appears or afterwards (e.g. Hewitt 1983; Lewis 1999; Wisner et al. 2004).

Some significant differences in precipitation metrics do occur around the Maldives, but they do not happen at the same times and for the same metrics, for all locations. This may limit the usefulness of ENSO/IOD forecasting with respect to decision-making relating to precipitation extremes. However, these results come with a caveat that the relatively short meteorological records analysed may limit the power of the analysis and its ability to detect an effect of ENSO/IOD on precipitation. It is also worth stressing that the limited usefulness identified here for the Maldives is due to there being only localised connections between the large-scale modes of climate variability and the local rainfall, rather than a lack of predictability of ENSO/IOD.

The second research question covered assessing the implications of highly localised associations between ENSO/IOD and local precipitation conditions in the Maldives for the use of forecasting in weather-related decision-making and DRR. Much has been written about ENSO's links with disasters (e.g. Bouma et al. 1997; Dilley and Heyman 1995; Iqbal and Hassan 2018; Rodríguez-Morata et al. 2018) and resulting impacts on policy (Broad, Pfaff, and Glantz 2002; Glantz 2000, 2001, 2015; Tozier de la Poterie et al. 2018). At the international level, for example, UNESCAP (2016) discussed the need to invest in ENSO early warning systems, emphasising the role that seasonal forecasts could play in decision-making. Cash, Borck, and Patt (2006) describe the increasing use of ENSO forecasting systems amongst diverse decision-makers in the Pacific and southern Africa, including in emergency management and civil preparedness, while Troccoli (2010) notes that seasonal forecast systems are becoming a vital part of decision-making frameworks, especially for climate change adaptation.

Yet, while many small islands are identifying needs for climate and earth observation services, there is also an historical precedent in many island settings of external knowledge superseding traditional knowledge (Rölfer et al. 2020). Following the May 1991 wind storm in Maldives, Cuny and Hill (1992, p. 13) made a specific call to “preserve traditional preparedness mechanisms”. Webber (2017) notes the commercialised nature of climate services, with different providers seeking to differentiate their product and enhance uptake by island decision-makers; The paper explains how this gives rise to trade-offs in the Pacific context between catering to island decision-makers’ ideal information needs and maintaining scientific integrity around what information can feasibly be provided on small island scales. These examples illustrate the specific challenges of using seasonal forecasts and other kinds of climate services in small island contexts.

The highly localised nature of the meaningful associations between ENSO/IOD and precipitation identified here for the Maldives suggests that the role of forecasts of ENSO, IOD, and other climate variability phases in medium- and long-term decision-making for extreme precipitation in the Maldives must be contextually considered. However, as previously noted, there is currently limited data from which to assess these associations, and so such forecasts should not be discarded as a potentially useful tool, as more data with which to assess links to local climate conditions becomes available. Additionally, results may vary for other impacts including changing sea levels and SSTs, impacting fishing, corals, coastal flooding, and saltwater intrusion, all of which have long been of high concern for the Maldives (Alexander and Mercer 2012; Ghina 2003; McGranahan, Balk, and Anderson 2007; Sovacool 2012).

The question then emerges of how relevant climate services and environmental forecasting are for the Maldives with respect to ENSO, IOD, and indeed, other indices of climate variability. Calls for more climate services and developing global frameworks (e.g. Hewitt, Mason, and Walland 2012) could be challenged on the basis that uncertainties and pre-existing inequalities limit the extent to which those who are most vulnerable can benefit from climate forecasts (Lemos and Dilling 2007). Furthermore, long-range forecasts can also have negative impacts if the information is incorrect (e.g. Changnon 2002).

As has long been known with respect to “useable science” (e.g. Glantz 2004), forecasts do not have to be ‘perfect’ to be useful, but must be transparent in relation to what information and what level of confidence they do or do not provide. Little has been published on useable science for and in the Maldives, suggesting a gap to be filled. Experience could be adapted for the Maldives from programmes such as the Regional Integrated Sciences and Assessments (Parris and Garfin 2016); environmental “report cards” which have been used for other island states (Townhill et al. 2020); and using models to bridge gaps between users such as farmers and researchers for climate impacts on agriculture (Hansen 2005). Mechanisms such as the Climate Outlook Forums (Patt, Ogallo, and Hellmuth 2007) can help ensure that decision-makers are better connected to the information coming from physical sciences, including an improved understanding of unknowns, uncertainties, and usefulness. Applying vulnerability-related knowledge from island experiences (e.g. Lewis 2009) would further assist decision-makers in better connecting hazard-related material to wider DRR policies and actions, as illustrated for Caribbean islands (Dookie, Enenkel, and Spence 2019).

Ideally, there should not be trade-offs or competition between hazards and vulnerabilities or between local and non-local, but a collaboration bringing together all these aspects. Then, irrespective of seasonal or regional forecasts, the local level will be ready for any weather. Mercer (2010) highlights the need to link DRR initiatives at the community, national and international levels. Vulnerability-focused approaches at the local level, but drawing on international expertise, have been shown to support Maldivians in dealing with a wide variety of possible hazards and disasters (Alexander and Mercer 2012). Short-term weather forecasts, such as hours or days of warnings of localised, extreme precipitation, could continue to be useful, particularly for triggering mechanisms such as forecast-based financing (Bischiniotis et al. 2019; Coughlan de Perez et al. 2015), alongside post-weather mechanisms such as insurance for damage (Yore and Faure Walker 2019). Such action may be more effective at avoiding problems stemming from variabilities and extremes, particularly under various uncertainties. It also responds to the call from Mall et al. (2019) for better acceptance of DRR as the framework for climate change related (and other) projects in South Asia including the Maldives.

5. Conclusions

As forecasting improves for the large-scale modes of climate variability explored here, the push for hazard-related preparedness (e.g. forecast-based financing, Bischiniotis et al. 2019) might increase. Since ENSO/IOD onset forecasts might have little predictive capability for local precipitation hazards, these hazard-related approaches need to be implemented with caution, yet again emphasising the importance of dealing with vulnerabilities as well as hazards in order to avoid adverse weather-related impacts.

ENSO has been linked to precipitation extremes in a range of other locations (Zebiak et al. 2015). However, examples exist of ENSO-related forecasts being incorrect, which has the potential to lead to costly errors, although uncertainty information can help to attenuate this risk (Joslyn and LeClerc 2012). The 2014 El Niño was predicted by several forecast systems to be a strong event, when ultimately, only moderate warming occurred (Ineson et al. 2018). Conversely, in Peru, the unexpected development of a “coastal El Niño” in 2017 led to extreme precipitation and severe floods (French and Mechler 2017). Linking the onset of, for example, an El Niño to sector-specific impacts and interventions is a further set of inferences, and it may not be possible to provide information with the level of specificity required to match expectations for localised decisions (Broad et al. 2002).

Instead, rather than a reliance on forecasting followed by ‘getting ready’ (Glantz et al. 2018), the results of this analysis suggest that an approach of on-going readiness may be more effective for managing hazards in any phase of the large-scale climate modes studied, including ENSO. Readiness and preparedness based on seasonal climate forecasts have long been implemented for a variety of sectors such as agriculture (DaSilva et al. 2004) and infectious disease (Meinke and Stone 2005). Meanwhile, the field of DRR developed around understandings of hazard-vulnerability interactions, especially reducing disaster risk by tackling vulnerabilities irrespective of uncertainties and unknowns in hazards and hazard influences (Hewitt 1983; Lewis 1999; Wisner et al. 2004). From other perspectives, such as public health, authors continually stress the importance of and wide-ranging opportunities inherent in reducing vulnerability while supporting widespread readiness and preparedness (Shannon 2015; Stewart et al. 2017; Vallance and Carlton 2015). Notions such as zero-order responders (Briones, Vachon, and Glantz 2019) are taking hold, emphasising how much could and should be done at the local level irrespective of larger-scale environmental changes.

These approaches nonetheless accept that local action is not a panacea, which is the purpose of procedures permitting scaling up to national and international responses (e.g. Hollis 2015). Similarly, on-going readiness and continual DRR is not always politically viable, with such investment not necessarily being deemed to be priority or worthwhile (Forino, Bonati, and Calandra 2018).

This paper supports these opportunities and challenges by noting that robust and useable local and national projections might not always be possible for a local weather-related parameter such as rainfall in the context of climate variability such as ENSO. The research questions here can thus be answered as:

1. Large-scale modes of climate variability are not necessarily associated with physical differences in the local precipitation conditions experienced in the Maldives.

2. The implications are that weather-related decision-making and DRR in small island contexts need to consider the local relevance of climate-related forecasts and draw on an

appropriate blend of vulnerability reduction and climate or weather-related forecasting techniques for that specific setting.

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