Climate of Maldives and Its Impacts:
Posters from FECT and Partners

Foundation for Environment, Climate and Technology

Websites- www.tropicalclimate.org/maldives/, http://www.climate.lk/peer/

Blog - http://fectmv.blogspot.com, https://peersl.wordpress.com/

Station Average Climatologies

Atolls in Green, Meteorological stations in red

Male,Coastal Erosion, Water Queues

Aerial View of Male, September 2015

Sea Erosion in Maldives

People lining up to collect water in Male in December 2014

Climate and Water Conference

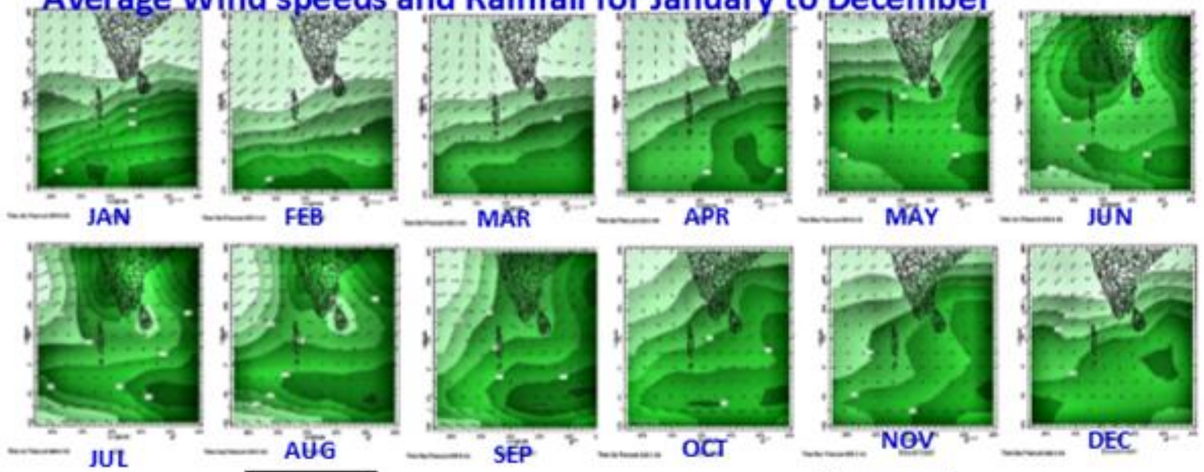
Organizers and some speakers at the Workshop, September 2015

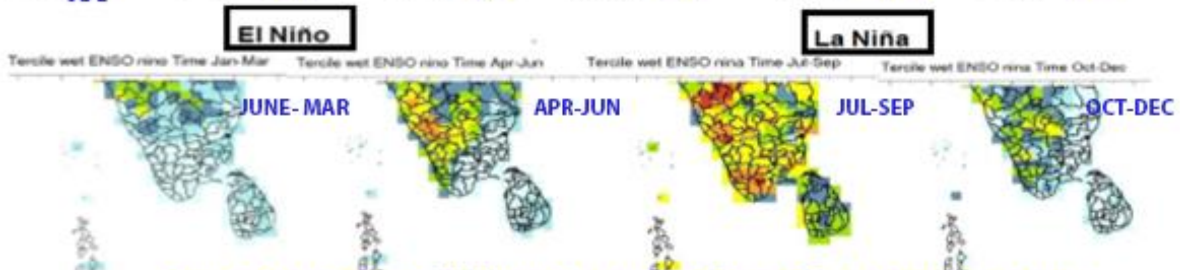
Participants at the workshop in September 2015

Audience members watching a presentation at the workshop in September 2015

Climate Analysis

Average Wind speeds and Rainfall for January to December





Deviations in Rainfall from Average during El Nino and La Nina

Staff and Visitors at Digana Resort Review Meeting

Introduction, Acknowledgement and Contents

Atolls of Maldives

Schematic of Atolls of Maldives
Map credits- High commission of Maldives Malaysia

Introduction

This is a compilation of the posters and other visual material prepared by the Foundation for Environment, Climate and Technology of our work in the Maldives. These projects involve the development of both fundamental and useable climate information for the Maldives, the study of its impacts on water resources, disaster hazards such as droughts, floods and storms and health hazards such as dengue and how communities, organizations and institutions may adapt.

These projects were conducted in collaboration with the Maldives National University, Maldives Meteorological Service, Male Water Supply and Sewerage Company, Ministry of Environment, Health Protection Agency of the Ministry of Health, LaMER and Renewable Energy Maldives in the Maldives. In Sri Lanka, the Department of Geography and the Masters program in Sustainable Development of the University of Peradeniya contributed.

Our international collaborators are primarily at the Columbia University including its Water Center, Applied Physics and Applied Mathematics Program, the Lamont Doherty Earth Observatory and the International Research Institute for Climate and Society. Assistance from NASA Goddard Space Flight Center, the State University of New York - Albany, the University of North Carolina -Chapel Hill are gratefully acknowledged as well.

Acknowledgements

The program was sponsored by the Cycle 1 grant under the PEER program of the US National Academy of Science with sponsorship from USAID. This funding was augmented with funding from the Cycle 3 grant from the PEER program with direct sponsorship from USAID Sri Lanka and Maldives. The work also was funded by the MacArthur Foundation through its grant to support a Masters in Sustainable Development targeted at Sri Lanka and Maldives and also by FECT.

- Much of the work reported here have been done by our staff namely: L. Zubair, P. Agalawatte, J. Viswanathan, Z. Yahiya, U. Ratnayake, A. Kamiss, I. Sandamali, C. Gunaratne, A. Afaaf, & K. Wijeratne. Sarith Mahanama, & Rolf H. Reichle of NASA, and Shaky Sherpa have helped us in several different ways.
- These posters draw on the inputs of our collaborators Michael Bell (IRI), Paul Roundy (SUNY-Albany), Zahid (Maldives Meteorological Services), Adam Sobel (Columbia University), Nishan Ahmed (Health Protection Agency) & Mohamed Rasheed (Male' Water & Sewerage Company) and Majeeda Mohamed (Maldives National University).
- These posters were presented at a workshop at the Maldives National University in Male in September of 2015 and the images from this workshop and poster display are below.
- We thank Dr. Shazla Mohamed, Dr. Mizna Mohamed and the staff of the Maldivian National University for hosting the workshop.

Contents

Contact

In Sri Lanka:

Foundation for Environment Climate & Technology,
Digana Village, Rajawella, 20180, Sri Lanka.
Phone: +94-81-2376746, +94-81-4922992
E-mail: fectmv@gmail.com

In Maldives:

Ms. Hudha Ahmed: Phone: (960)3309882
hudha.ahmed@renewableenergymaldives.com.mv
Dr. Mizna Mohamed: Phone: (960) 3345420
mizna.mohamed@mnu.edu.mv

Wells, Water Cuts and Adaptation

Historic well in Male that served residents during water cuts, credit: Lareef Zubair

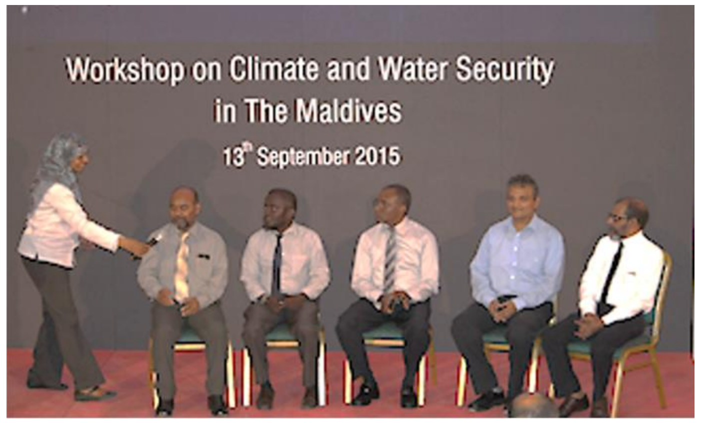
Lining up to collect water in Male, December 2014,

About FECT

FECT is an R&D think-tank which promotes climate and environmental science and technology and its societal use around the Indian Ocean. Our work is oriented towards risk management in water resources, disasters, agriculture, energy, environment and public health sectors. We collaborate with government institutions, research institutes and universities. We are chartered as a non-profit agency to develop capacity widely.

Audience at the Workshop on Climate and Water Security held at the Maldivian National University on the 13th September, 2015 consisted of USAID officials(Paul Richardson- top left in the first panel), Scientists, Researchers, University students and students from schools

Speakers:Mr. Abdul Matheen Mohamed (Minister of State for Environment and Energy) Ms. Nihani Riza (USAID), Ms. Zeenas Yahiya Ms. Shazla Mohamed (MNU), (FECT) & at the Workshop on Climate and Water Security at the Maldivian National University



The Panel at the Workshop on Climate and Water Security comprised of Mr. Zahid (MMS), Mr. M. Mustafa (Ministry of Environment and Energy), Mr. R. Bari, Dr. L. Zubair (FECT) & Mr. M. Rasheed (MWSC), The discussion was moderated by Dr. Mizna Mohamed (MNU)

Some participants at the Poster exhibition held during the Workshop on Climate and Water Security

FECT
Foundation for Environment, Climate & Technology

http://www.tropicalclimate.org/maldives/ http://www.climate.lk and http://www.peersl.wordpress.com

Workshop on Climate and Water Security

In the Maldives

The Principal Organizers at the Workshop on Climate and water security comprised of Dr.Mizna Mohamed (MNU), Dr. Zahid (MMS), Dr. Shazla Mohamed (MNU), Mr.Mohamed Rasheed Bari (Water care, Water safety),), Dr. Lareef Zubair (FECT), Mr. Mohamed Rasheed (MWSC).

Speakers at the Workshop on Climate and Water Security held at the Maldivian National Universiry on the 13th September, 2015, Starting from the top left side Dr. Shazla Mohamed (MNU), Dr. Lareef Zubair (FECT), Mr.Abdul Matheen (Ministry of Environment and Energy), Ms. Nihani Riza, (USAID Sri Lanka & Maldives.), Ms. Zeenas Yahiya, Researcher/Manager (FECT), Mr. Mohamed Rasheed (MWSC),) Dr. Zahid (MMS), Mr.Mohamed Rasheed Bari (Water care, Water safety), Ms. Zameela Ahamed (Maldives GCC Project),Mr. Mustapha (UNOPS),Mr.Prabodha Agalawatte(FECT) ,Dr.Mizna Mohamed (MNU).

Maldives National University staff comprised on the Left side panel photo are Dr. Shazla Mohamed and Dr.Mizna Mohamed, Paul Richards for USAID in the back(Red Shirt). Right side panel starting from the right- Ms.Aimaan Abdulla, Ms.Mariyam Rilvana, Ms. Fathimath Shuxna.

The Foundation for Environment, Climate and Technology staff who prepared the posters and supported to successfully execute the workshop. Left side photo from the left Ms.Udara Ratnayake,Ms.Shobana,Ms.Chamidu Gunaratne,Ms.Aishath Afaaf Abdul Nasir. Right side photo on the top starting from left Mr.vjanan,Mr.Akram kamiss,Mr.Prabodha Agalawatte ,Dr.Lareef Zubair. Right side photo on the bottom starting from left side Mr.Akram kamiss, Ms.Indika sandamali and Mr.Prabodha Agalawatte.

FECT Foundation for Environment, Climate & Technology — Maldives National University — MWSC — Columbia University — USAID From the American People — University at Albany State University of New York — IRI

Websites- www.tropicalclimate.org/maldives/ , http://www.climate.lk/peer/ , http://fectmv.blogspot.com , https://peersl.wordpress.com/
Email contacts at Sri Lanka- climate@sltnet.lk & fectmv@gmail.com Email contacts at Maldives- hudha.ahmed@renewableenergymaldives.com.mv , mizna.mohamed@mnu.edu.mv
Twitter: @fectmv https://twitter.com/fectmv

Monthly Climate Advisories

for the Maldives

Prabodha Agalawatte, Lareef Zubair, Zahid (MMS), Zeenas Yahiya, Janan Visvanathan, Michael Bell (IRI)

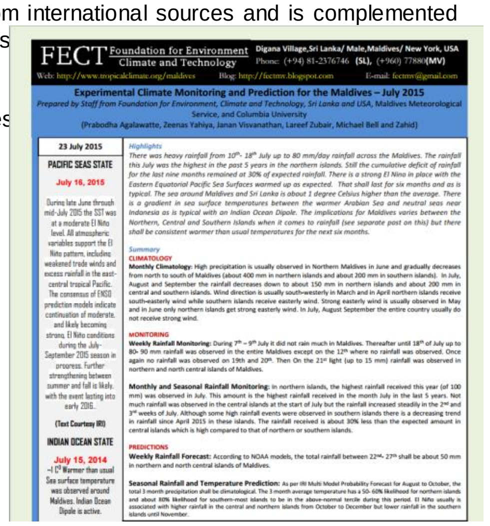
Summary

This monthly Hydro-Meteorological Advisory is prepared and disseminated by the Foundation for Environment, Climate and Technology (FECT) in collaboration with the Maldives Meteorology Services (MMS) and the International Research Institute for Climate and Society (IRI) at the invitation of the Ministry of Housing and Environment in Maldives in 2009. Since 2012, this advisory has been issued in the middle of each month. The advisory is available by email, blog and website and an archive is accessible as well .

The advisory consists of Monitoring and Prediction of ground conditions and climatic drivers. It provides information products available from international sources and is complemented by ground observations. The Advisory consists

1. Monthly Climatology
2. Rainfall Monitoring
   a. Daily satellite derived rainfall estimates
   b. Monthly rainfall derived from satellite rainfall estimates
   c. Monthly and seasonal monitoring
3. Ocean Surface Monitoring
4. Rainfall Predictions
   a. Weekly predictions from IRI
   b. Seasonal predictions from IRI

Each of the above topics are described further in the sections below

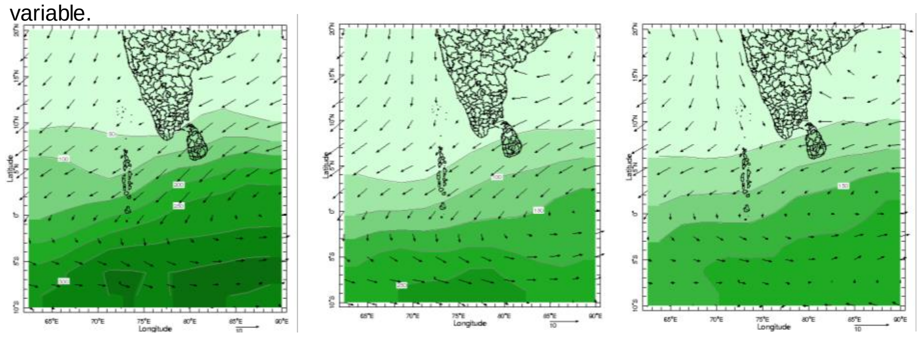

FECT Foundation for Environment Climate and Technology

Experimental Climate Monitoring and Prediction for the Maldives – July 2015

Fig 1: Sample of the monthly advisory

Monthly Climatology

The average rainfall and wind conditions in contemporary months are described in this section. Monthly Climatology is defined as the long-term average for each month of a given variable.



January **February** **March**

Fig 2: monthly rainfall climatologies and wind climatologies are given for 3 months. Regions between contour lines show the average observed rainfall during each month. Darker shades of green show higher average rainfall. Arrows show the wind direction during the month while the size of the arrow shows the magnitude of the wind speed. Source: NOAA

Daily Rainfall Monitoring

Rainfall observed in the previous week is given based on Satellite derived gridded observations with a 0.25^0 resolution from NOAA-CPC and a spatial coverage from Minicoy island in the North to Chagos islands in the South.

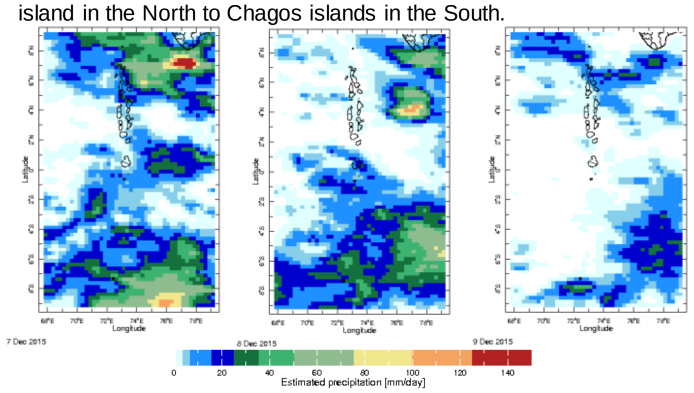


Fig 3: Satellite derived gridded observations with a 0.25^0 resolution from NOAA-CPC

Monthly Rainfall Monitoring

This section describes the average rainfall of the previous month as well as how the monthly average of the previous month deviates from the historical average (monthly anomaly).

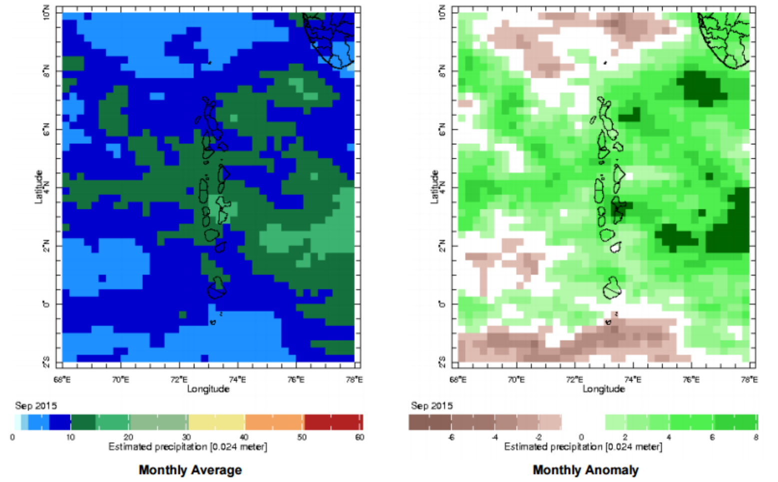
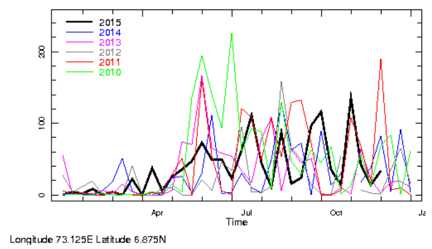


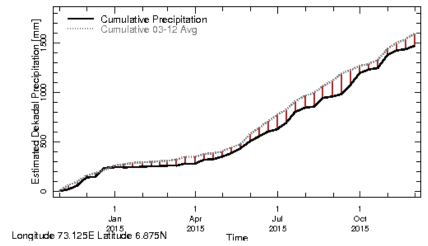
Fig 4: Observed average rainfall (Left) and the rainfall anomaly of the same month (right). In the anomaly figure green color show regions which received above average rainfall and brown color show regions with less than average rainfall. Source: NOAA/CPC and IRI

Monthly and Seasonal Monitoring

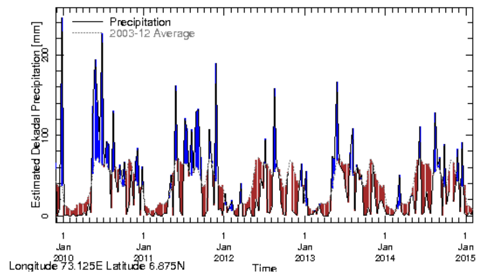
The comparison between rainfall in the past 365 days and rainfall during previous years is given in this section. The comparison is done for 3 regions of the Maldives (Northern islands, Central islands, and Southern islands) separately.



Rainfall in the current year (black) compared to rainfall in previous 5 years



Rainfall of past 365 days (black) compared to average rainfall in previous 8 years



Rainfall in the past 5 years with above-average rainfall hatched in blue and below-average hatched in brown

Fig 5: The dekadal (10 day) rainfall of this year as well as in previous 5 years (top left). The total rainfall of past 365 days compared to the average rainfall of the year (top right). A brown color hatch represents below average rainfall while a blue color hatch represents above average rainfall. The bottom figure shows rainfall in the past 5 years and brown and blue hatches represent below and above average rainfall. Source: NOAA/CPC and IRI

Ocean Surface Monitoring and Pacific and Indian Ocean State

The Sea Surface Temperature (SST) anomaly is presented as a figure. This figure provides valuable information on phenomena such as El Nino/ La Nina, the Indian Ocean Dipole etc. In addition to this a summary of the state of the Pacific sea issued by the IRI containing El Nino and La Nina predictions is also included in the advisory.

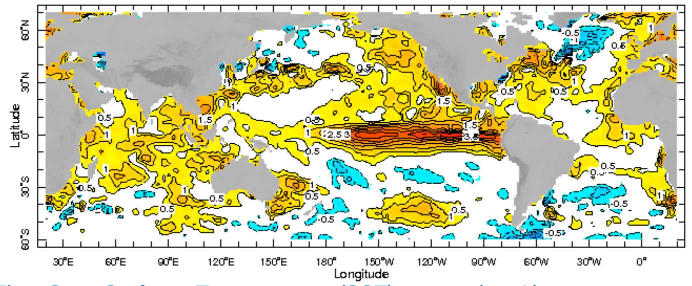
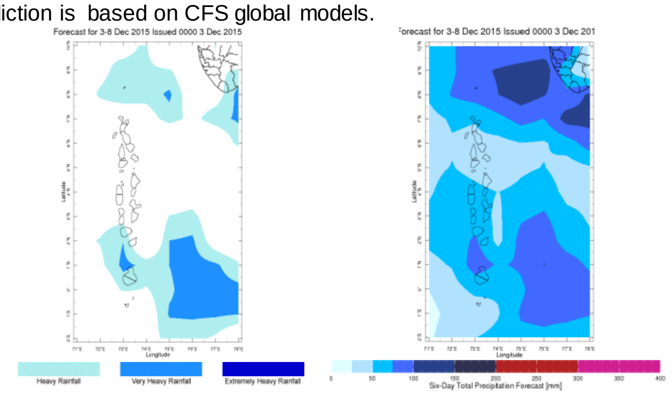


Fig 6: The Sea Surface Temperature (SST) anomaly. Above average sea surface temperature is coloured in shades of yellow while below average rainfall is shaded in blue. Source: NOAA/CPC

Weekly Rainfall Prediction

This section provides the total rainfall forecast for the next six days issued by NOAA/CPC. This prediction is based on CFS global models.



Extreme Rainfall Forecast **Total Six Day Precipitation Forecast**

Fig 7: The expectancy of heavy rainfall events during the following six days (left), and the prediction of total rainfall amount during this period (right).

Seasonal Rainfall and Temperature Prediction

The latest seasonal precipitation and temperature prediction for the next 3 months by the IRI is provided in this section.

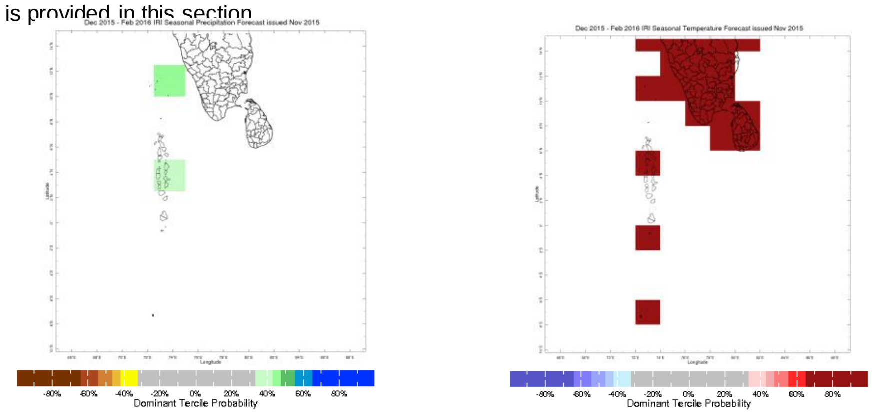


Fig 8: 3 month rainfall (left) and temperature(right) prediction. The color shading indicates the probability of the most dominant tercile -- that is, the tercile having the highest forecast probability. The color bar alongside the map defines these dominant tercile probability levels. The upper side of the color bar shows the colors used for increasingly strong probabilities when the dominant tercile is the above-normal tercile, while the lower side shows likewise for the below-normal tercile. The gray color indicates an enhanced probability for the near-normal tercile (nearly always limited to 40%).

Dissemination

The report can be read at **www.fectmv.blogspot.com & www.tropicalclimate.org/maldives**

Zeenas Yahiya, K. Wijeratne, Udara Ratnayake, Lareef Zubair, Yoosuf Ashraj, Aishath Afaaf,
Zahid (MMS), M. Rasheed (MWSC), Majeeda Mohamed & Mizna Mohamed (MNU)

Availability of Freshwater
in Greater Male

Summary

As in the rest of the Maldives, groundwater and rainwater is available in the Greater Male Islands (Male, Villingili, Hulhumale & Hulhule). The fresh water aquifers are stressed due to increased demand in water, excessive extraction, waste water contamination and sea water intrusion. Greater Male is at the leading edge of water sustainability under urbanization across the 194 inhabited islands and across other coastal systems. We carried out a survey in Greater Male to analyze the availability of water, desalination and mitigation options for freshwater security and environment pollution. We estimate the water budget in the islands, surveyed households with regard to awareness and mitigation options for water scarcity. This poster presents the methodology and preliminary findings. The water demands has far outstripped demand and become dependent of expensive desalination plants. Water contamination has been aggravated due to inadequate awareness, and improper sewage, stormwater, sewage and solid waste disposal system. Now, there is a need to minimize the draw on desalination, renew and enhance rainwater harvesting systems and reduce demand and contamination.

Introduction

Figure 1a : Map of Male,Villingili, Hulhule and Hulhumale islands in Maldives.

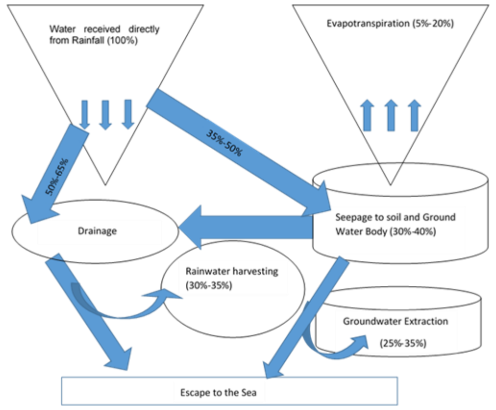


Figure 1b : Schematics of typical water balance for Maldives

The Maldives consists of 1,190, small, low lying and tiny Islands, grouped into 20 Atolls that together form a chain of islands over 820 KM in length, over an area of more than 90,000 km² in the Indian Ocean. Greater Male' in Maldives comprises of four inhabited islands namely Male' Villingili, Hulhumale and Hulhule. While Hulhule is the international airport island, Villingili, Hulhumale and Male are inhabited islands. The population in Male is around 150,000.00 (2013). In 1988, the government of Maldives introduced sewerage network in Male and in 1995 a desalination plant with a water distribution network. 60% of water and waste water in Greater Male is collected and desalinated by the Maldives Water Supply and Sewerage Company. Sea water desalination has been used to some extent as a mitigation option for water scarcity. The whole population of Male has access to desalinated water through piped network, and sewerage systems. Similarly systems are installed in 22 other islands. Between 2004 - 2010, water shortages were experienced by 81 Islands in the Maldives. According to Ministry of Housing & Environment by the year 2020 the demand for energy is supposed to increase by 20% with respect to the present usage.

Water Supply

Rainwater harvesting is the primary source of drinking water in 90% of the outer islands with groundwater being used for washing, agriculture and other domestic uses. Annual water recharge in Maldives is estimated to, range on average, 40%-50% of the rainfall falling above the vegetation lines. Given the low cost of rainwater harvesting, it contribution to future supply should be maximized. ***Groundwater:*** The thickness of fresh water lens available for extraction is influenced by number of factors such as Island width, island geology/geography, rainfall recharge rate, abstraction rate, evapo-transpiration and tidal movement.

Photo credit: Lareef Zubair

An artisanal well in Maldives.

Artisanal Well: In 1970s each household in Male included of a shallow well at a depth of 1.0 -1.5 meters. In recent years, these wells are not being used for drinking although it could be used for flushing toilets and similar uses. ***Water-Reuse***: Waste water, namely Grey water A & B (wastewater from washing hands/face, drinking, bath, heating and cooling; and wastewater from kitchen); and Black water (waste water from toilet) should be reused.

Water Treatment and Desalination

Villingili and Male are the two islands which have freshwater scarcity problem with deficit freshwater availability than the freshwater requirement. The highest freshwater requirement is recorded in Male. 7 Million Cu.Mtrs/year of water are being desalinated. Water desalination is a way of mitigation of freshwater scarcity in Greater Male due to limited space availability.

To estimate the desalination capacities for Greater Male', secondary data on desalinated water capacities, related energy consumption and cost (2005 – 2015) were obtained from Maldives Water & Sewerage Company.

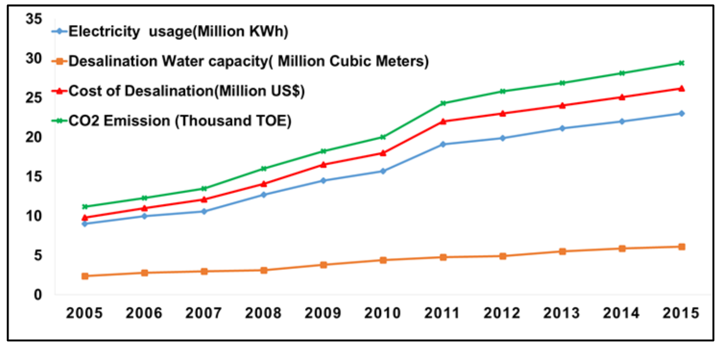


Figure 2: Desalinated water capacities at Maldives Water and Sewerage Company and related energy consumption and cost per year

Water Budgeting

Freshwater lens were calculated according to the methods used in Dr. Zahid's thesis which assumes freshwater lens exist 250 Meters from the coast. Recent rapid changes in land reclamation, population, tourism & industry in Hulhule and Hulhumale are not accounted for yet.

Islands	Population	Annual Rainfall (mm)	ET (mm)	Water usage (Cubic mtrs/day)	Water Demand (Cubic mtrs/day)	Groundwater availability (Cubic mtrs/day)
Male	114643	1660	250	9400	12600	8270
Villingili	7690	1660	215	630	840	180
Hulhule	300	1660	215	30	30	3260
Hulhumale	*3168*	1660	180	260	350	2420
Total				**10320**	**13820**	**14130**

Table 1: Population and estimations for water balance in Greater Male (2012)

The desalination water capacity in Greater Male was recorded in MWSC as 13420 Cu.Mtr/day in 2012 whereas total water demand for four islands can be estimated as 13820 Cu.Mtr/day . The freshwater availability per day in Greater Male is approximately 14130 Cu.Mtrs.

The groundwater availability was estimated as 30% of the calculated freshwater lens volume. The freshwater requirement was calculated using primary data obtained through household surveys (30 housing units in Greater Male' area - Villingili & Hulhumale), meetings with stakeholder agencies and technical personnel's.

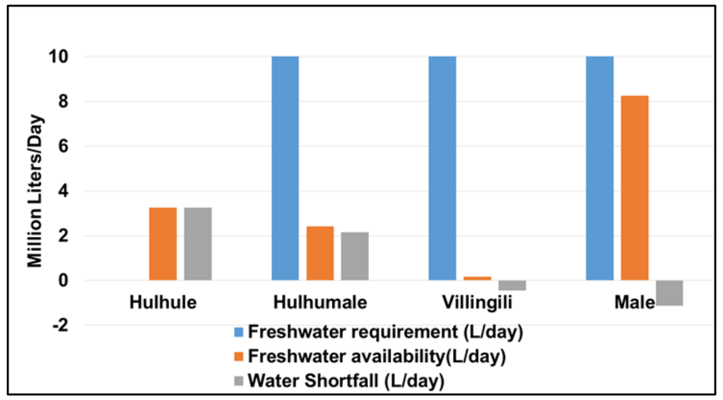


Figure 3: Freshwater requirement for households in Male, Vilingili, Hulhule and Hulhumale in 2012 without toilet flushing usage.

Survey and Findings

K. Wijeratne, and Y. Ashraj carried out this survey in 2013 with guidance from Zubair, Rasheed and Zahid to estimate/ analyze the groundwater capacities in Male, Villingili, Hulhumale & Hulhule and identify the possible mitigation options for freshwater scarcity. Overall survey of water supply, demands and its histories were obtained through interviews with key informants and literature review. In Villingili and Hulhumale 30 housing units were surveyed to calculate the freshwater requirement and energy consumption. The Average and standard deviation of per capita use of water were calculated using research questionnaires.

Findings of the survey:

- Per Capita use of desalinated water/day wass 81 L with a standard deviation of 75 L
- Almost all households did not know about:
  - -The amount of water being used
  - - energy consumption
  - - environmental pollution
  - - water pollution in their island
- The waste water disposal quantity (2013) is 5 Million Cubic meters and being pumped under ground without being treated.
- Solid garbage disposal is approximately 250 MT/day which is dumped and burned and has indirect impacts on water supply. In addition, disposal for plastic water bottles is a major contributor to non-biodegradable waste. Better solid waste management is essential.

People lining up to collect water in Male in 2014

Key recommendations from the Survey are that:

- Awareness among all stake holders in the Maldives is necessary on the use of water, energy and disposal of waste water and solid garbage.
- Some, water can be reused by applying waste water treatment in Greater Male area. Groundwater should be used for toilet flushing and more efficient toilets too can be promoted.

Lessons and Recommendations

Through review of history, water budgets, household surveys and analysis of trends in water supply and demand, we have been able to assess the water use practices, some of the mitigatory steps for meeting demand while reducing the need for costly desalination:

1.Improved awareness on water usage, water pollution, and environmental pollution
2.Refining rainwater harvesting and management in Greater Male
3.Water desalination using fossil fuel at MWSC can be converted to Solar Desalination.
4.Improving waste water treatment techniques
5.Increasing storage capacity of rainwater harvesting.
6.Storm-water and Sewerage disposal within Male has to be better managed.

Water Demand has been increasing exponentially – now with the government proposing to relocate the majority of people to Hulhumale and with recent agreement to set up an additional desalination plant, there could be rapid change in circumstances. Still the lessons from water budgeting, analysis of the economics and environmental costs of mitigation options and household surveys still is relevant.

References

- Zahid, The influence on Asian monsoon variability on precipitation patterns over the Maldives.(2011)
- Wijeratne, K., Internship report on the status of freshwater and the environment in Greater Male. (2013)

FECT Foundation for Environment, Climate & Technology
MWSC Male' Water & Sewerage Company Pvt. Ltd.

Estimation of Water Scarcity

in Maldives

Udara Rathnayake, Lareef Zubair, Prabodha Agalawatte, Zeenas Yahiya, Zahid , K. Wijeratne ,Shaky Sherpa

Summary

We hope to use the monitored and predicted climate information to develop ongoing assessments monitored and predicted water supply for the islands of the Maldives. Towards this end, we shall use a water balance where we estimate precipitation, evaporation, groundwater infiltration and run-off as best as possible with the available data. Described below is our ongoing work with a focus on rainfall and evaporation .

Introduction

Water scarcity is the lack of supply to meet the demand for water within a region. Droughts, floods, water pollution, waste and misuse of water are contribute to water scarcity. Population growth, sea level rise and climate changes can undermine the sustainable use of water in a region. All of these are important in the Maldives.

Estimation of water balance helps in identifying scarcity. These assessments aid decision making in the management of water supply, agriculture, environment and industry. Water balance can be used to assess the current and trends in water resource availability.

Water Balance

The major components of a water balance are evapotranspiration, precipitation, runoff and groundwater storage. Within a specific area over a specific period of time, water inflows can be budgeted against water outflows and change of storage.

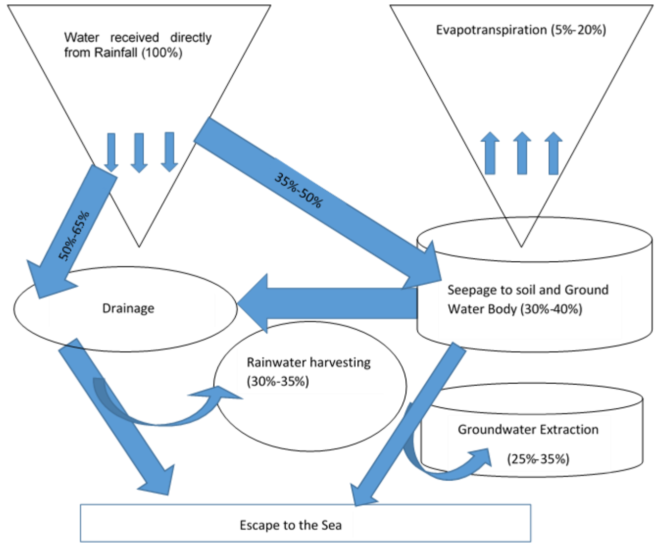
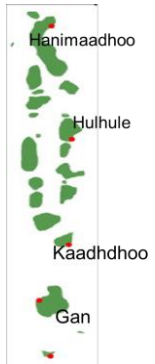


Figure 1: Schematics of a typical Water Balance

Island Water Balance

Estimates for all the components are needed for each island at least at a monthly or preferably shorter time scale to aid decision making.

Precipitation



Islands in Maldives receive all the fresh water from rainfall. Rainfall can be estimated from ground observed station data.

There are long records for five stations distributed from North to South in the Maldives. There is high variability in the climate across the Maldives and this is exemplified by the change in seasonality of rainfall shown below. Hanimadhoo has its peak in July similar to Northern India and Gan which is in the Southern Hemisphere, has its peak rainfall in December and stations inbetween have a bimodal pattern as well. These changes in seasonality from North to Souththat can be largely explained by the seasonal migration of the Tropical Convergence Zone and monsoonal influences.

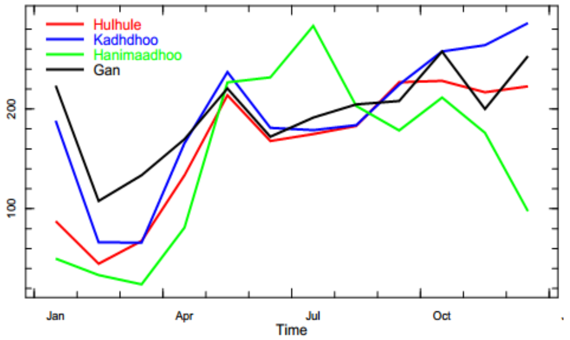


Figure 2: Monthly variation of precipitation in each station

Evapotranspiration

Evaporation from soil or open water surfaces together with transpiration from vegetation referred as evapotranspiration. Evapotranspiration may be estimated using various methods such as Penman-Montieth or those recommended by FAO. We use the Hargreaves equation at this early stage for showing the variations as it uses just mean daily maximum temperature (Tmax) and mean daily minimum temperature(Tmin) as

$$ET = 0.0023 * 118.08 * (T_{mean} + 17.8)\sqrt{(T_{max} - T_{min})}$$ where

Tmean - mean temperatures in degrees Celsius

In the future, we shall compare these estimates with other n

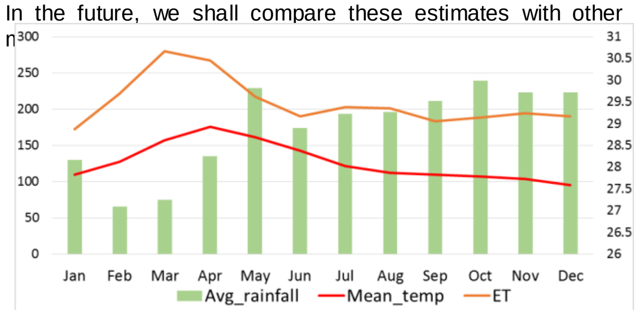
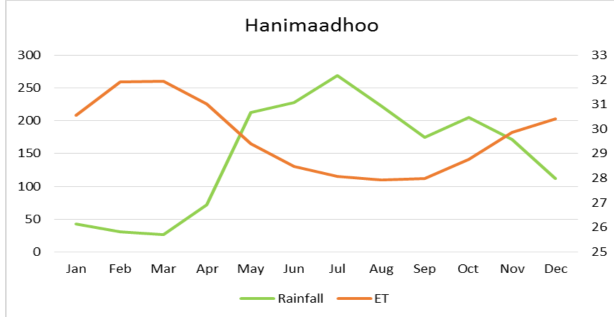
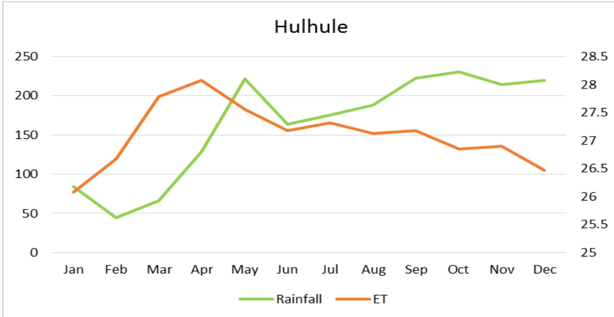
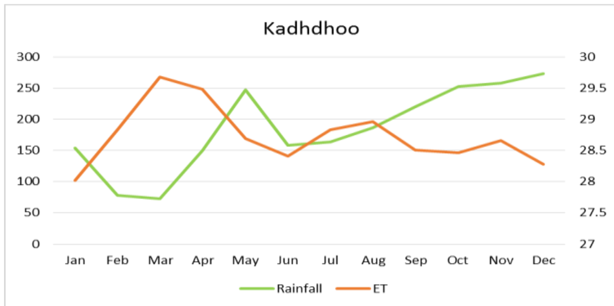


Figure 3: Monthly seasonality of mean temperature, mean precipitation and evapotranspiration for Maldives (based on the average of all the stations). Rainfall is shown in green bars and Temperature in Redline and ET as the orange line.







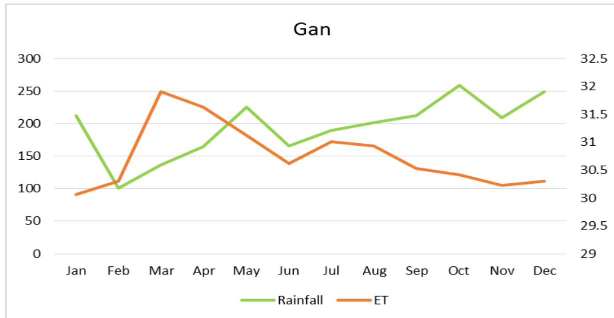


Figure 4: Monthly seasonality of rainfall and evapotranspiration for each station shown in the map from North at top to South at Bottom

Groundwater Storage

Freshwater lens of groundwater is the only natural storage of freshwater in Maldives. If the groundwater is not potable, it is useful for the secondary purposes including bathing, washing and toilet flushing. The thickness of the freshwater lens controls the available volume of extractable fresh groundwater. The available groundwater storage is estimated using freshwater lens thickness, freshwater lens area and the width of the island as estimated by Bailey et al. This relationship along with island geometries can be used to estimate ground water infiltration and reservoir storage. We have to develop estimates for ground water infiltration at short

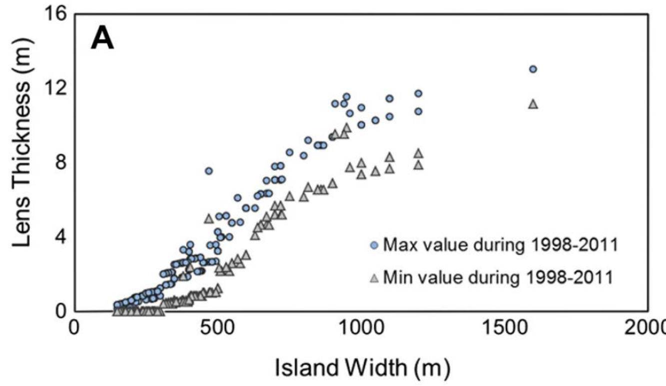


Figure 5 : Freshwater lens thickness variation with island width - Bailey et al 2008

Runoff

Runoff is the residual item that remains from rainfall after evapotranspiration and infiltration to the soil. Very few surface water resources exist due to the geographic nature of the islands of Maldives. Hydrological calculations are used to quantify precipitation losses to determine the volume of runoff from precipitation. The total runoff can be determine by using precipitation losses and total drainage area.

Discussion

This poster shows our initial attempts at developing models and data for water budgeting by island. Through this work a Framework for water budgeting has been developed. In the initial stages, we are focusing on the annual and seasonal time steps. The evaporation and rainfall components of the seasonal water budgets for islands near the main meteorological stations are estimated.

In the near future, the ongoing ground based climate observations shall be combined with high resolution satellite data to estimate ongoing water supply by island. Similar temperature estimates combining ground and satellite data shall be used to estimate evaporation into the future. Other methods of ET estimates shall be compared and we shall conduct field trials to calibrate these models. The ground water estimates are now available annually and are catered towards estimating ground water in the long-term. We need to develop methods to estimate groundwater weekly and monthly Run off.

We shall explore working on water demands fluctuation in the future.

FECT
Foundation for Environment, Climate & Technology

Indika Sandamali, Prabodha Agalawatte, Zeenas Yahiya, Lareef Zubair (FECT)
Majeeda Mohamed(MNU), Nishan Ahmed(HPA),Zahid(MMS), Chamidu Gunaratne

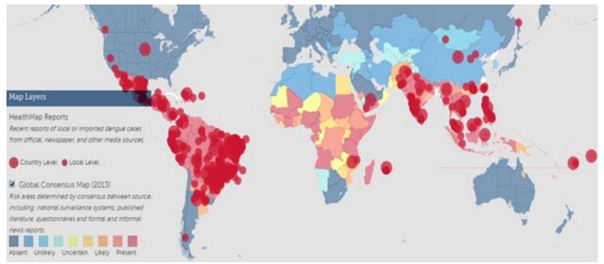
Annual, Seasonal, Regional and Inter-annual Dengue in Maldives

Introduction

Dengue fever is a mosquito-borne disease that occurs in tropical and subtropical areas of the world. Millions of cases of dengue infection occur worldwide each year. Dengue fever is most common in Southeast Asia and the western Pacific islands, but the disease has been increasing rapidly in Latin America and the Caribbean. Maldives has experienced with a high incidence of dengue rate, the disease has been reported from every region of the country. Dengue vector dynamics is strongly influenced by environmental factors, population dynamics and climate. Dengue transmission involves the dengue virus, humans and mosquitos.

Global Consensus Map(2013)

Source recent reports of local or imported dengue cases from official newspaper, and other media sources has been used by Health Map to produce a consensus map.



This figure shows dengue presence and recent alerts not dengue incidents. Light Blue represents the unlikeliness of dengue alerts and darkening of the color shows the level of absence. From Yellow to Red represents the rise of dengue alerts.

Monthly Dengue Cases from 2000 to 2014 in Maldives

The dengue cases has been obtained through the recording system of the Maldivian Ministry of Health (MMOH) from reports across Maldives and the compile data was obtained obtained from the Health Protection Agency (HPA). The monthly dengue cases for all of Maldives from January 2000 onwards is shown below.

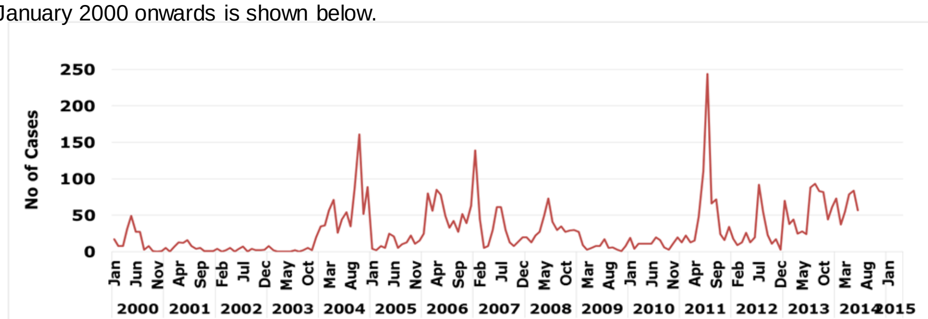


Fig.1. Time Series of Dengue Cases from 2000 to 2014 in Maldives

Time series in Fig.2 shows that the end of the year and the mid-year peak has become more dominant in last 4 years while decrease of incidence is observed in 2009-2010.

Annual Incidence of Dengue in Maldives

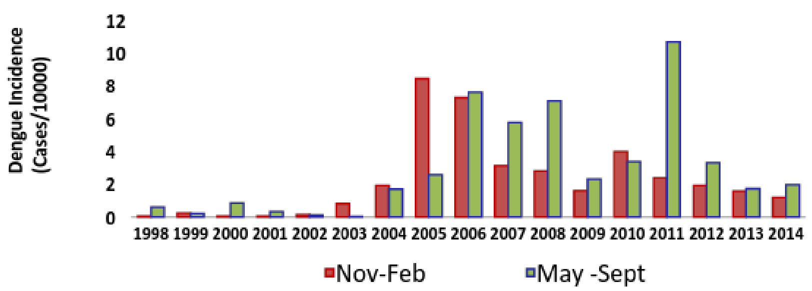


Fig.2 Inter-Annual Variation of Seasonal Dengue Incidence in Maldives

Maldives has two peaks of annual incidence. One occurring between June -July and the other occurring between December and January .Seasonality can be approximately captured by considering the total national case load for the period of November-February and May-September.to 2014.

Regional Variation of Dengue Incidence Seasonality

Dengue incidence was computed by dividing the monthly aggregate of cases for a Province by the population of the province and mulitplying by 10000. The data for cases is from HPA and the population is from Department of Census

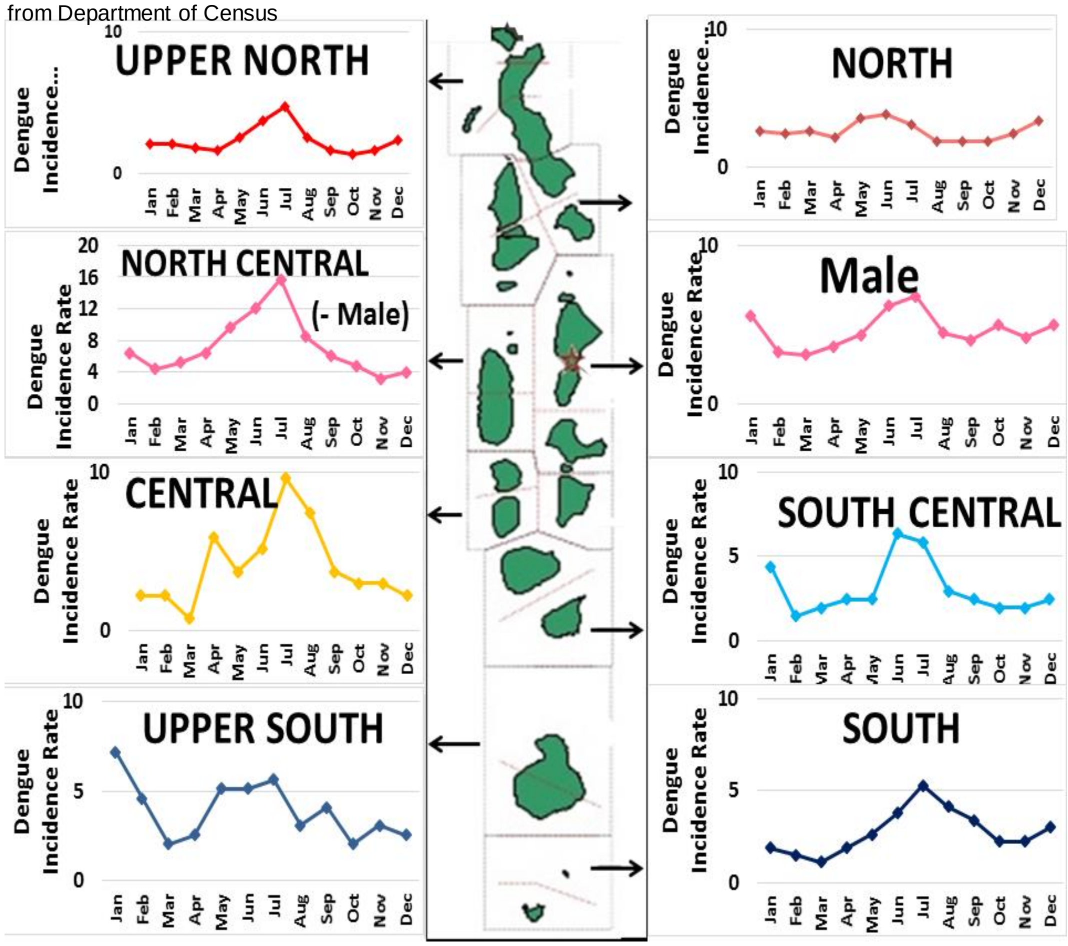


Fig.3.Seasonality of Dengue Incidence for different provinces in Maldives

To obtain normalized incidence by dividing Dengue cases by 10,000. The incidence start take count of population favor. The figure shows variation of Dengue incidence by region.

Comparative Seasonality of Dengue Incidence by Province

The seasonality of dengue in the different provinces is shown in the same graph for easier comparison

In most provinces, the highest peaks is in June and July. The Southern provinces have peaks in December and January. This variation may be explained in relation to the regional climate.

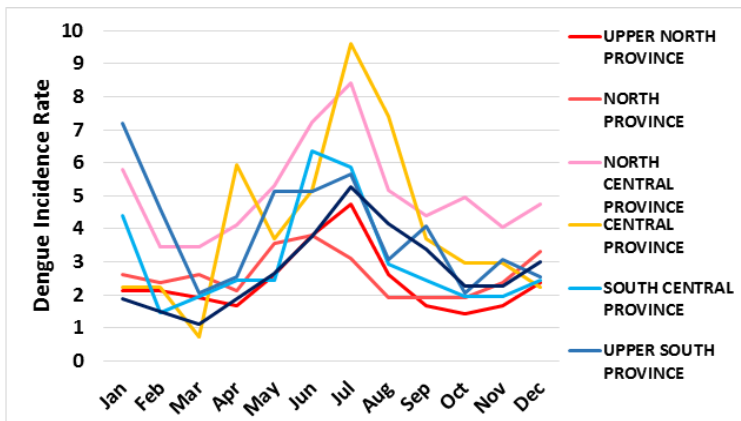


Fig.2. Seasonality of Dengue Incidence from 2000 to 2014 in Maldives

Monthly Incidence of Dengue from North to South

The monthly dengue incidence for the seven provinces and Male. Source: MMOH / HPA is shown. Frequent peaks in Dengue incidence can be observed throughout 2005 to 2008 in each province In the Time Series of Incidence of Dengue in Different provinces from North to South from 2005 to 2014 (Fig.1) but the most significant peak is shown in 2011. The rise of Dengue incidence are very low in years 2009 and 2010..

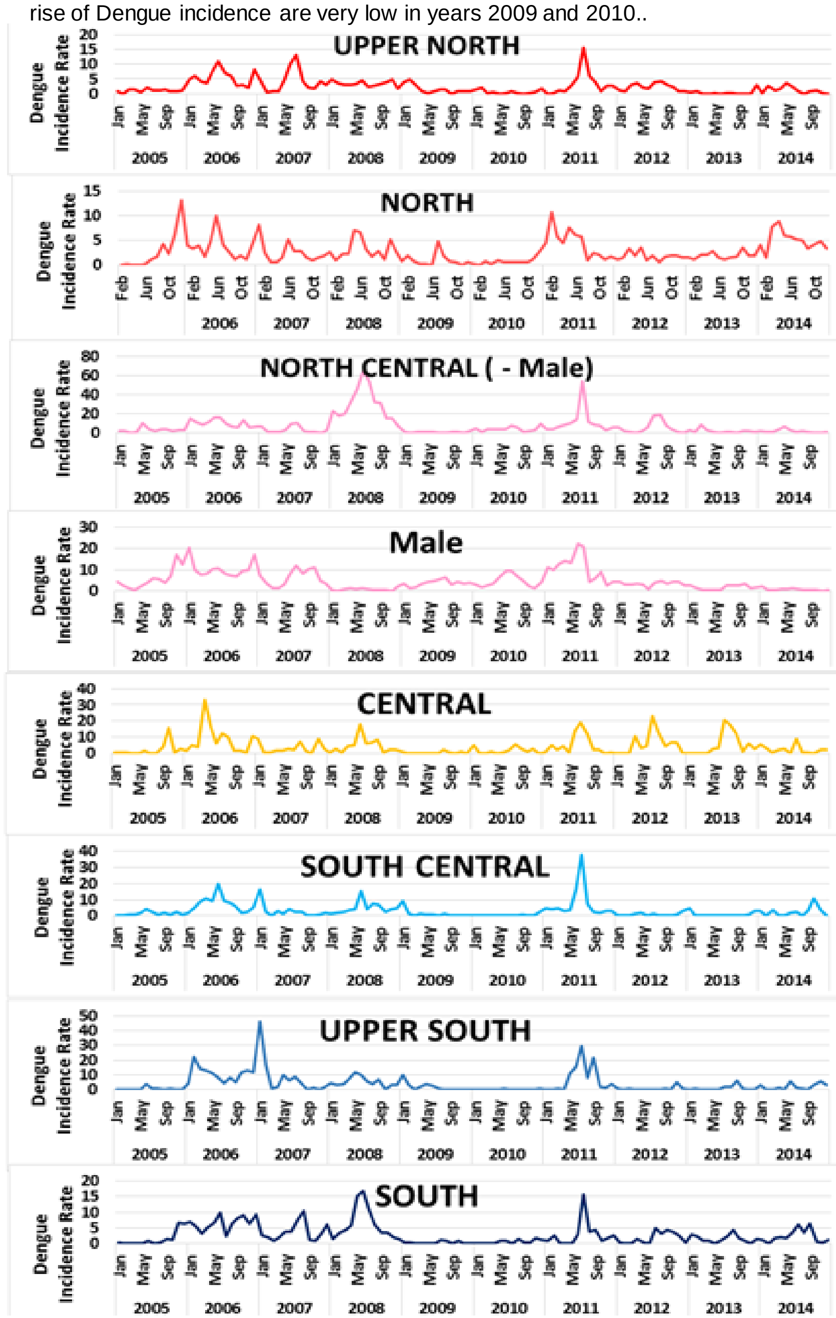


Fig.3 Time Series of Incidence of Dengue in Different provinces from North to South from 2005 to 2014

MALDIVES NATIONAL UNIVERSITY

Foundation for Environment, Climate & Technology

Relationship of Dengue Incidence with Climate in Maldives

Indika Sandamali, Prabodha Agalawatte, Zeenas Yahiya, Lareef Zubair, Majeeda Mohamed(MMU), Nishan Ahmed(HPA), Chamidu Gunaratne

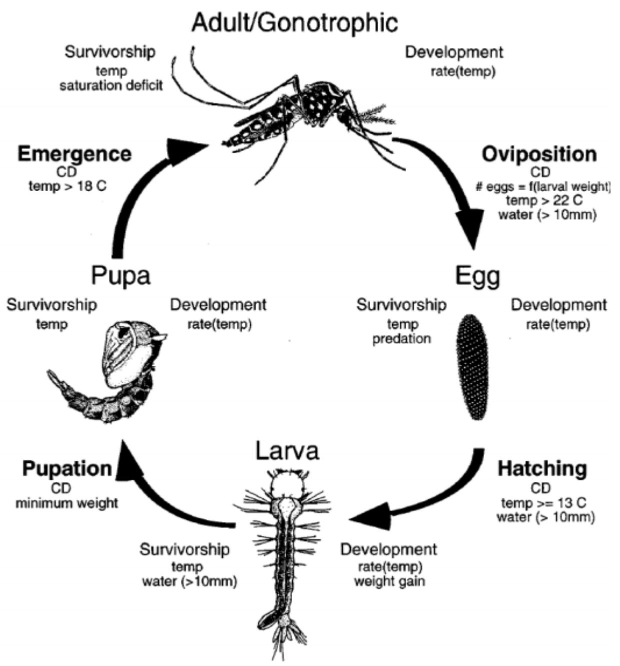
Summary

We quantify the historical relationship of dengue incidence with Minimum Temperature, Maximum Temperature, Rainfall and Water Availability based on observations of the Health Protection Authority of the Maldives Ministry of Health by region and season. Climate observations from the Maldivian Metrological Service and Satellite based data sources. The seasonal variation, regional variation, monthly variation are shown here.

Introduction

Transmission of dengue involves the dengue parasite, vector (mosquito) and humans. The two types of dengue transmitting mosquito are Ae. aegypti and Ae. Albopictus. The dynamics of mosquito life-cycle is the most sensitive to climate. This cycle represented in four stages is captured below. Laboratory studies are used to obtain the sensitivity in each stage.

Climate Influence on Gonotrophic Cycle



Studies to understand mosquito development and survivorship are captured in the gonotropic cycle shown. Environment factor includes temperature, water availability, and relative humidity. These influences vary in the four major stations of mosquito development. Temperature influences vector development rates, mortality, and behavior and controls viral replication within the mosquito. Variability in precipitation influences habitat availability for Ae. aegypti and Ae. albopictus larvae and pupae

Figure1: Cycle of Mosquito Development and Survivorship. Source: Hopp and Foley (2001)

Dengue Incidence and Climate

The dengue incidence in the different provinces were estimated along with the rainfall, minimum and maximum temperature. The monthly climate is plotted against Dengue incidence below.

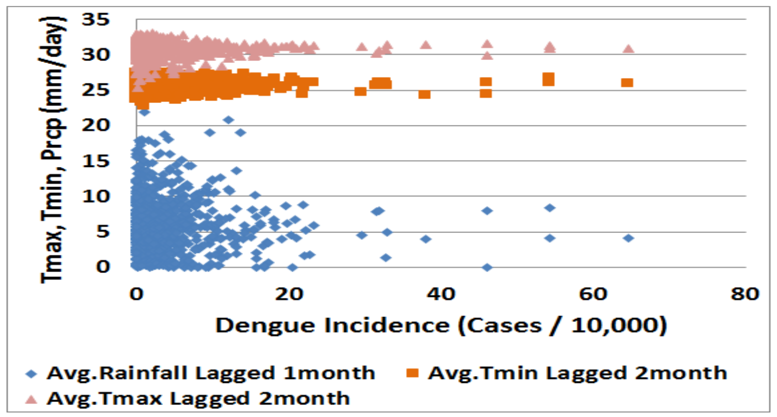
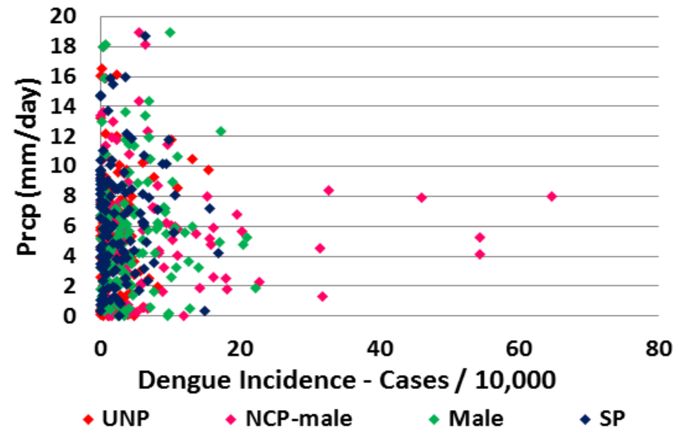


Figure2: Dengue Incidence Against Precipitation Lagged 1month and Tmin, Tmax Lagged 2month by Province. Source: Census Department, Maldivian Ministry of Health (MMOH) and Health Protection Agency(HPA), Maldivian Metrological Service (MMS)

The lag between the climate and incidence is chosen based on the gonotrophic cycle. The graph shows that the months with the highest dengue incidence are closely clustered in temperature of 30-31 degrees C for maximum and 25-26 degrees for the minimum. There is a wider range of monthly rainfall averaging up to 9 mm/day. An analysis of climate sensitivity at daily or weekly time step may provide further insights on the rainfall.

Dengue Incidence and Rainfall by Province

The rainfall in different regions are shown in different colors below.



High incidence of dengue is found regionally after a month between 2mm and 9mm. There is high incidence even for precipitation, rainfall up to 12mm per day. General rise in Incidence can be observed in precipitation up to 0-10. More significantly in North Central Province (Excluding Male).

Figure 3: Precipitation Against Dengue Incidence by Provinces. Source: MMOH, HPA, MMS

Dengue Incidence and Min/Max Temperature by Province

The range of temperature in which there shall be high survivorship in the four phases (different colors for the different phases of the gonotrophic cycle) as identified by laboratory studies is captured by the envelope of Tmin and Tmax shown below. We have superposed the observed rainfall and temperature below as seen in the first chart but here we identify the different regions by color of the data points.

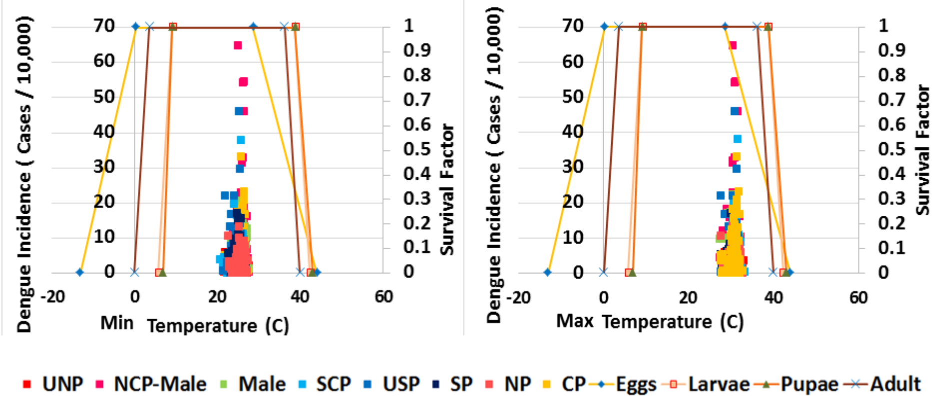


Figure 6: Minimum and Maximum Temperature Dependent Survivorship against Dengue Incidence Source: MMOH, HPA, MMS

What we see is that the temperature is more highly constrained in the Maldives and the sensitivity to climate is much more sensitive than may be understood from the laboratory studies.

Seasonality of Dengue and Climate

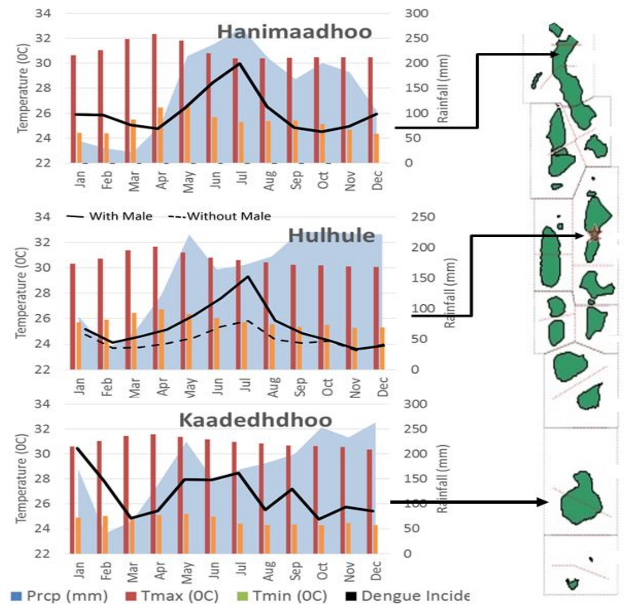


Figure 5:Seasonality of Dengue Incidence with Rainfall, Minimum and Maaximum Temperature. Source: MMOH, HPA, MMS

The monthly average dengue incidence for three of the seven provinces is shown in the graph to the left as a black line. The graph on the top is for the Upper North Province where the Hanimaadhoo station is located. The monthly average for rainfall is shown as blue shading and minimum and maximum temperature is shown as bar graphs in red and yellow. Similar charts for North-Central Province with the Hulhule stations is shown in the middle panel. It is interesting to compare the NCP with and without Male.

The lower graph is for the Upper South Province and the Kaadedhdhoo meteorological station.

The dengue peaks are 1-2 months after the May rains. The lower dengue incidence in December/January are likely due to lower temperatures.

Time Series of Dengue Incidence and Water Availability

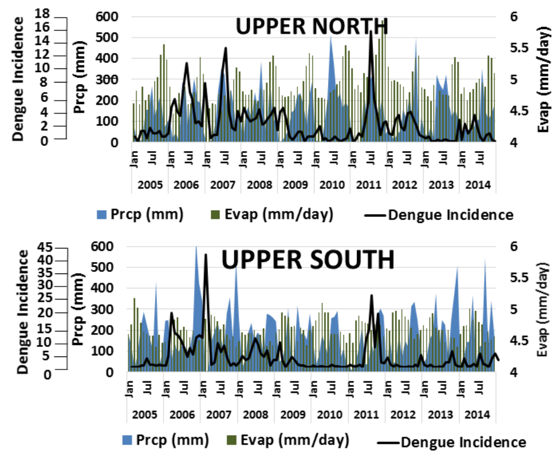


Figure4: Time Series of Dengue Incidence with the Precipitation and Evaporation from 2005 to 2014. Source: MMOH, HPA, MMS

The dengue incidence for the seven provinces as a time series along with daily rainfall, and evaporation were analyzed. The water availability is estimated as the difference between monthly rainfall and evaporation for dengue as breeding takes place in artificial receptacles.

The data for two provinces are shown on the left shows the time lag between the rainfall and dengue peaks. There is very clear relationship.

Future work shall provide the difference between rainfall and evaporation at different time steps.

Conclusions

There is clear evidences of climate drivers of dengue seasonality and epidemic events based on analysis of the climate and incidence data. Rainfall and temperature relationships with dengue remain in different regions even while the seasonality changes. Epidemics have ocured when the minimum and maximum temperatures is between 25-26C and 30-31 C. These relationships are much more sensitive than may be understood from laboratory studies. The relationships are consistent across regions and seasons. We need further analysis at shorter time steps to nail down relationships with rainfall which we are following up now.

FECT Foundation for Environment, Climate & Technology

Maldives Meteorological Service
Republic of Maldives

Seasonality of Climate

In Maldives

Zeenas Yahiya, Lareef Zubair, Prabodha Agalawatte, Indika Sandamali, Udara Rathnayake, Zahid (MMS)

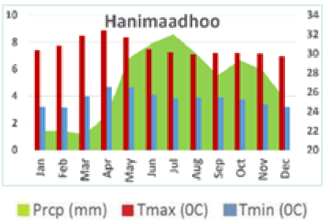
SUMMARY

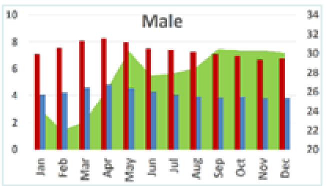
This poster shows the seasonality of Rainfall, Temperature (Minimum and Maximum) based on observations in 5 stations of the Maldives Meteorological Service (MMS) as shown in the map. The data were provided by MMS starting from 1977 for Gan and staring later for the newer stations until 2014. Male' (1974-2014), Hanimaadhoo (1991-2014), Kadhdhoo (1994-2014), Gan (1977-2014)and Kaadedhdhoo (1994-2014). All stations have at least 20 years of data.

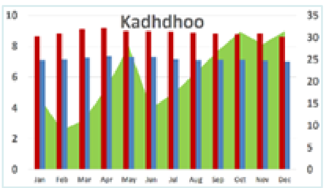
CLIMATOLOGY OF TEMPERATURE AND PRECIPITATION

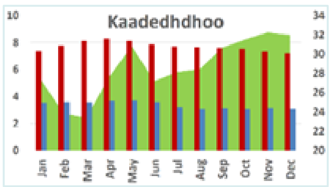
The graphs below show average annual rainfall, mean, minimum and mean maximum temperature observed at five meteorological stations in Maldives shown in the map. The bar charts show the monthly means from January to December. The temperature ranges between 24 °C and 33 °C.

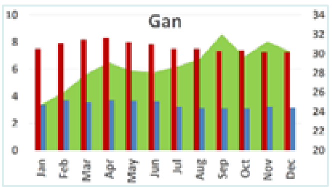
Monthly Average Rainfall, Minimum and Maximum Temperatures in the Maldives







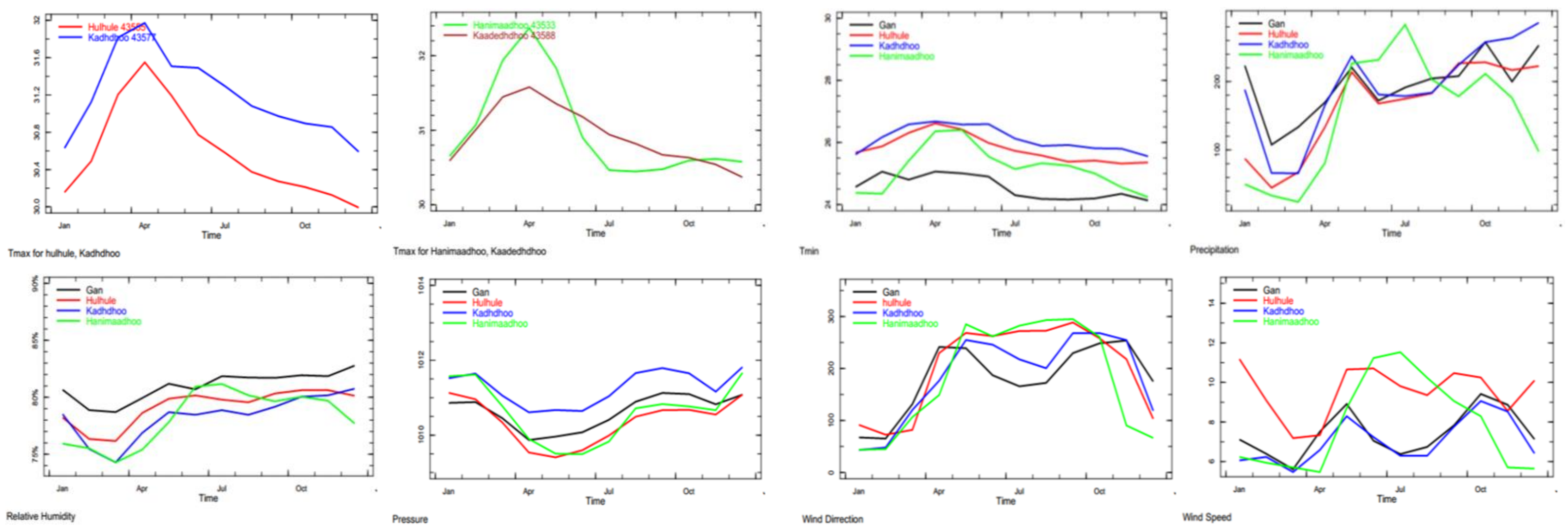


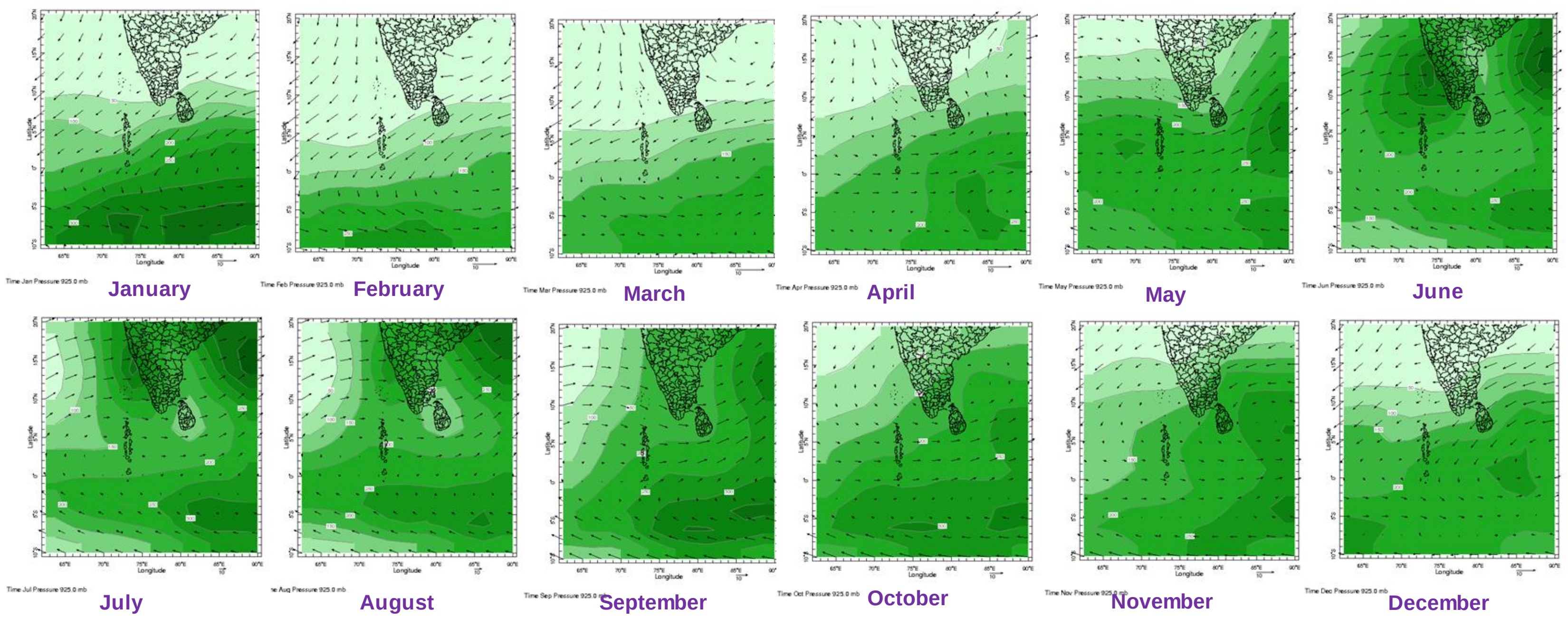


INTRODUCTION

The Maldives extends from 1° South of the Equator to 7° North, aligned North-South along the 73° East longitude. It comprises 26 coral atolls made up of about 1193 islands. The Maldives covers an area of 298 km² and hosts a population of 393,988 in 2014. Although it has a small land area, the climate mechanisms change drastically form the north to the south. In general, the wind directions over the Maldives changes from Westerlies (from mid-May to November) to Easterlies (from January to March). The wind speeds are highest in July and in February. The bimodality of the seasonality from North to South is a contrast: rainfall varies from 1700 to 2200 mm from north to south, with annual lowest rainfall of about 1333mm and highest of 3200 mm. The temperature ranges from 24°C to 33°C and the seasonality is modest with warmer months in April-May. The rainfall is mainly determined by the Northeast monsoon which usually extends from January to March, and the Southwest monsoon from May to November in which Maldives experiences torrential rain, strong winds and storms.

Seasonality of Maximum & Minimum Temperature, Rainfall, Relative Humidity, Pressure, Wind Direction and Speed

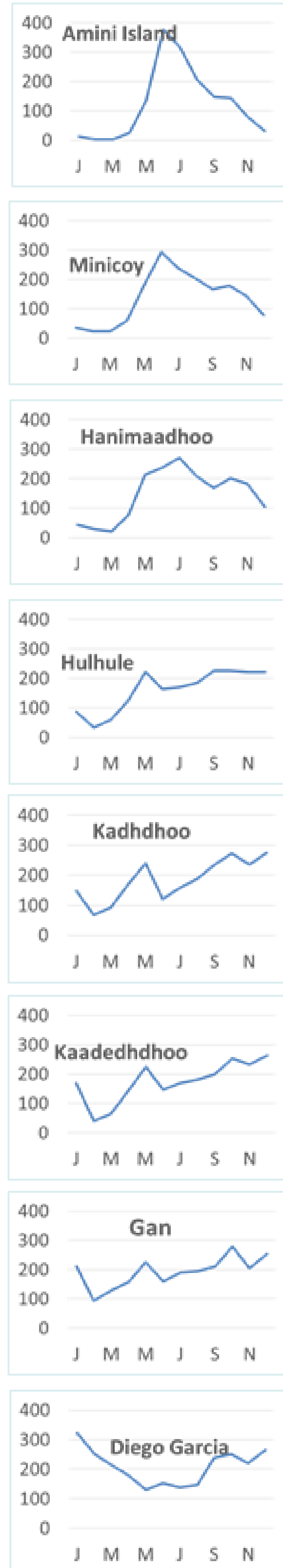


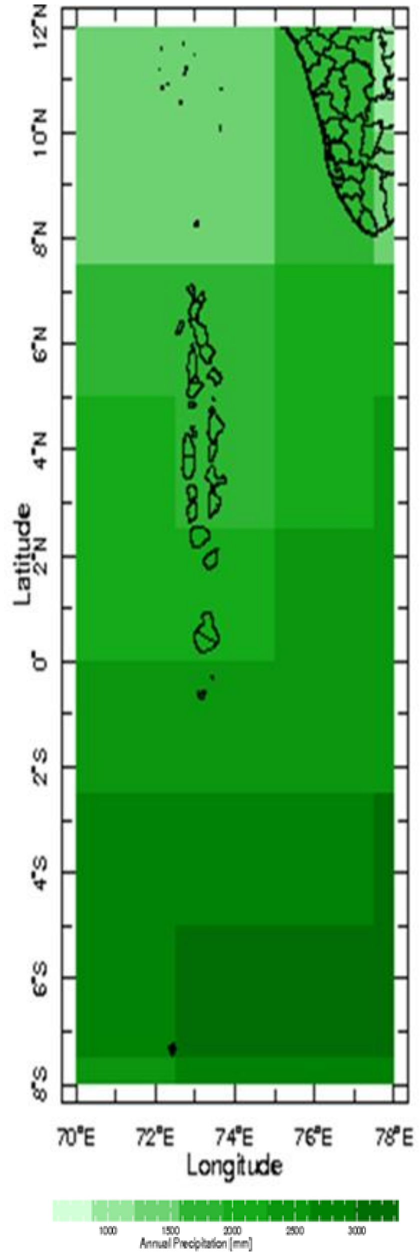


About FECT: Our work is oriented towards risk management in water resources, disasters, agriculture, energy, environment and public health sectors. We collaborate with government institutions, research institutes and universities. We are chartered as a non-profit agency to develop capacity widely. We work in the tropical Indian Ocean.

Chagos, Maldives, and Lakshadweep Rainfall Seasonality

The rainfall of Diego Garica in Chagos and Amini Island and Minicoy in Lakshadweep in India shown a natural progression with that with the Maldives and aid studies of mechanisms because of the longer length of the observations in these locations.





Afterword

The seasonality of Maldives climate is fascinating as it traverses a section across the equator and illuminates many mechanisms of climate such as the Trade Winds, the Monsoon System, El Nino phenomenon, Indian Ocean Dipole, the Madden Julian Oscillation, Storm and Cyclone Formation. This poster provides basic information drawn from Maldives and neigbouring islands that is a foundation for understanding and shall be useful to a range of readers.

Prabodha Agalawatte, Akram Kamiss, Michael Bell, John Del Corral, Benno Blumenthal,
Shaky Sherpa, Zeenas Yahiya, Lareef Zubair

Satellite Based Rainfall Monitoring
for Maldives

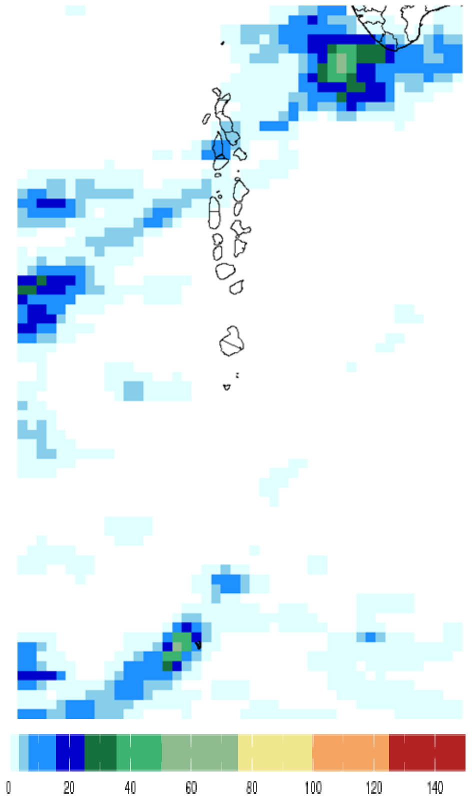
Summary

This poster introduces the satellite based rainfall estimates that is available daily from the CMORPH (Climate Merged Observed and Remotely sensed Precipitation) system. These data are available at a grid of 10 km from 2002 onwards. We have developed a web-based tool to develop interpretive products for the Maldives. Some examples of what this tool and others can produce are shown for one day (to the left) an one location (shown with a red pin to further to the left) and in aggregate by month for one year (below) . These estimates are skillful unless one requires high resolution estimated in space and time. Here, examples of the data, its representation in dekads (3 per month), comparison of current years dekadal rainfall with previous years, dekadal rainfall anomalies and cumulative rainfall deficits and excess over the last 365 days, are presented. The month by month deficits for the last 12 months are also shown.

Data Sources

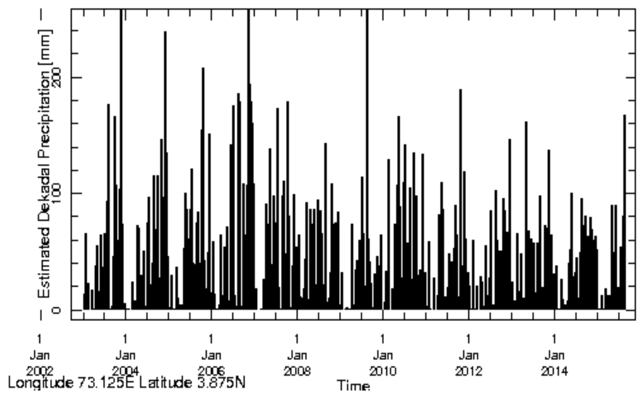
Rainfall data from CMORPH algorithm (NOAA CPC Morphing) which combines satellite based gridded data with available ground observation is used along with bias corrections. The data is available on a 0.1 degree grid (~10 km) at a diurnal, daily time steps. The dekadal and monthly precipitation on a 0.1 x 0.1 degree grid, is obtained by aggregated from daily estimates While the higher resolution RFE rainfall data is available as well for the Maldives North of 5ºN, we have to rely on CMORPH for coverage of Central and Southern Maldives.

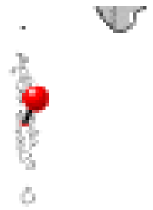
The dekadal precipitation estimates have been aggregated from the daily data. Every month has three dekads, such that the first two dekads have 10 days (i.e., 1-10, 11-20), and the third is comprised of the remaining days of the month and varies from 8-11 days.



Example of CMORPH precipitation estimates over the Maldives for 8th September 2015.

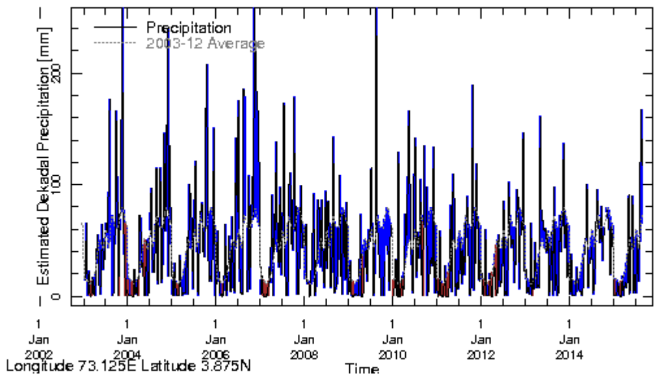
Dekadal Anomalies





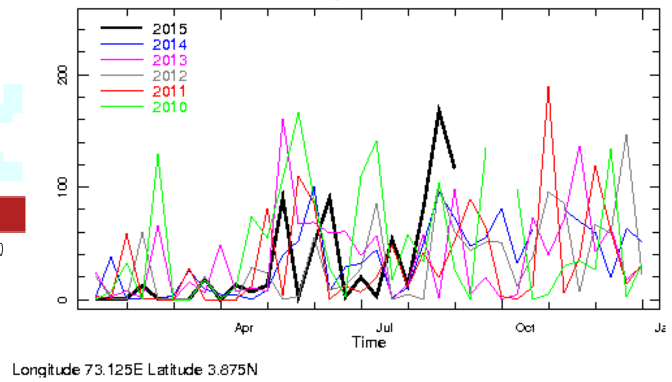
Dekadal precipitation estimates for the selected location from Jan 2002 to the present.*

Time Series



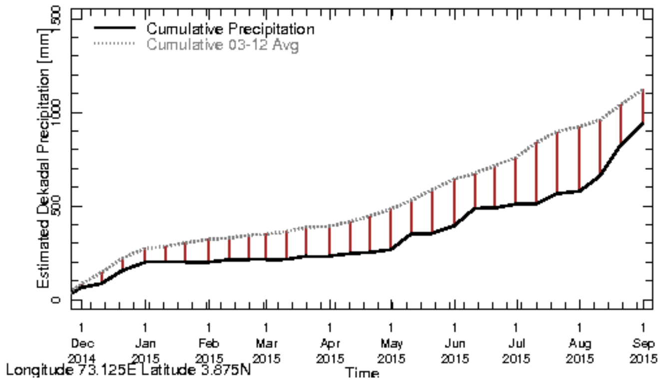
Same as (left) (solid black line) with the addition of the recent short-term average precipitation for the same region (grey dotted line). The blue (red) bars are indicative of estimates that are above (below) the short-term average. Note that the short-term average precipitation data has been smoothed.

Year to Year Comparison



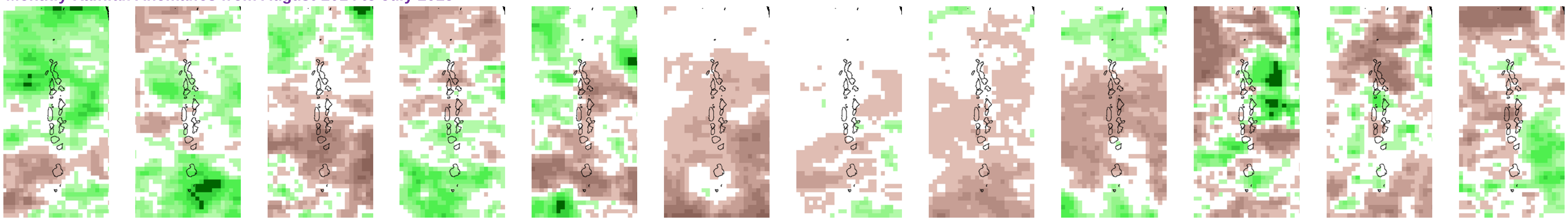
Same as (a) for the current calendar year (thick black line), as indicated by the axis labels. Precipitation estimates from previous years are also shown. (blue- 1 year from present; magenta- 2 years from present; grey- 3 years from present; red- 4 years from present; green- 5 years from present).

Cumulative Rainfall



Cumulative dekadal satellite-derived precipitation estimates (solid black line) and the cumulative recent short-term average precipitation (grey dotted line) for the most recent 12-month period in the selected region. The blue (red) bars are indicative of estimates that are above (below) the short-term average.

Monthly Rainfall Anomalies from August 2014 to July 2015



Monthly rainfall anomalies for Maldives and surrounding seas from August 2014 to July 2015. The anomalies are estimated from the current month's rainfall and the long term average from 2002 to 2012.

IRI

FECT
Foundation for Environment, Climate & Technology

Meteorology and Predictability of Tropical Storm ARB-04in the Indian Ocean during November 2011

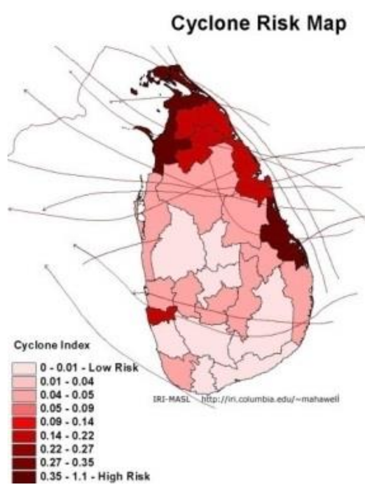
Lareef Zubair (FECT), Adam Sobel (Columbia Univ.), Prabodha Agalawatte (FECT), Zeenas Yahiya (FECT), Zahid (Maldives Met. Service), and Paul Roundy (SUNY-Albany)

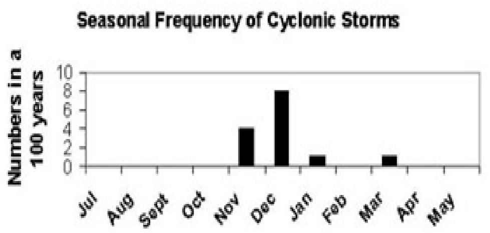
Summary

Tropical Storm ARB-04 (as designated by the Indian Meteorological Department - IMD) or Tropical Cyclone 05 (TC5 as designated by the Joint Typhoon Warning Center (JTWC) had severe impacts in Sri Lanka (with over 20 fishermen losing their lives and a 1000 homes being damaged). There has been debate over whether this storm/cyclone was predictable with enough of a lead time. We address the meteorology and predictability by drawing on the contemporaneous meteorological conditions, ground observations and regional climate model simulations. We draw on global reanalysis archives, ground observations from the Maldives and Sri Lanka and routine global prediction systems. We find that a) that US and Indian operational agencies were able to predict the intensity of the storm and track b) openly available real-time products from weather prediction agencies did predict cyclone risk several days in advance and c) there needs to be a better way of estimating risk for people and the environment.

Storm Tracks over Sri Lanka in 20th Century and Risk

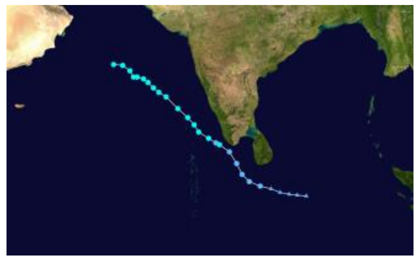
Cyclone tracks for the past 100 years were used to create cyclone hazard risk map. Cyclone Risk was estimated by normalizing a districts frequency of cyclonic or storm landfall by the area of the district. Apart from a single storm in 1967, all other storms and cyclones made landfall in the Eastern Coast. Only one storm has tracked to the South of Sri Lanka after starting in the Bay of Bengal. There is a clear seasonality to the cyclone risk as shown in the graph. 80% of all the cyclones and storms occurred in November and December.



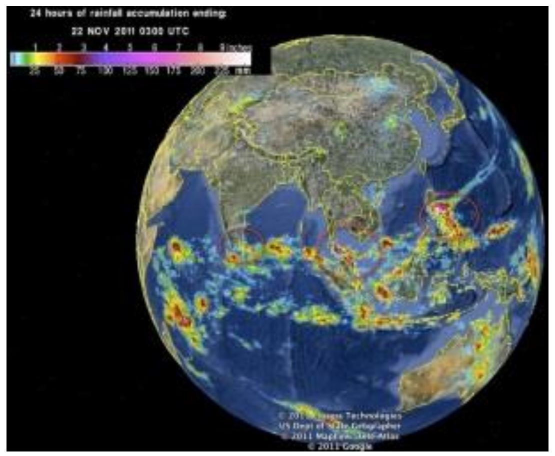


Track of Storm ARB-04 / TC-05

The cyclone Track passes in-between Sri Lanka, India and Maldives. The cyclone initiated formed about 500 km to the South-East of Sri Lanka in the Bay of Bengal around November 22, 2012. This storm then tracked in a North-Westerly direction passing about 200-300 km to the South-East, South, South-West and West of Sri Lanka before heading in-between the Southern Indian Peninsula and Maldives before finally dissipating around December 3rd at the Northern Arabian sea west of Oman.

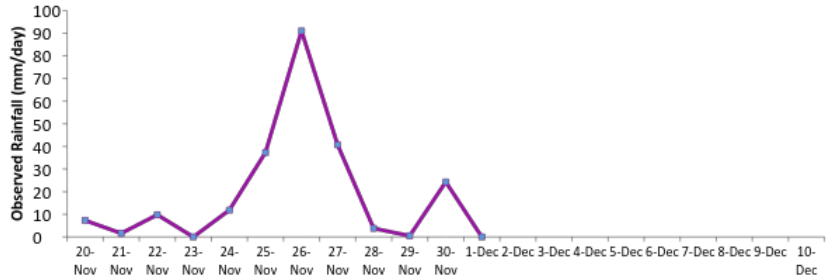


The heaviest rainfall over Sri Lanka was on the 22nd of November (left) and the cyclonic structure was fully formed by the 28th of November (right).

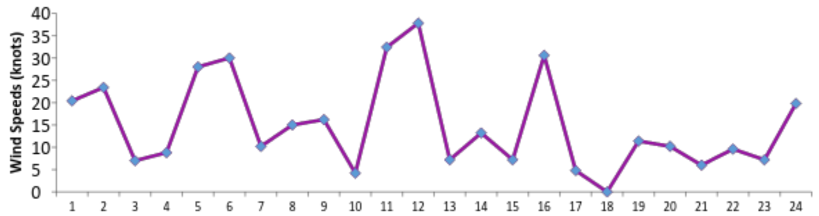


Wind and Rainfall in Southern Sri Lanka

Wind gusts were strong particularly over the oean where fisher s had gone out as there had been no storm warning. The observations for rainfall and wind a two stations on the Southern Coast of Sri Lanka are below.



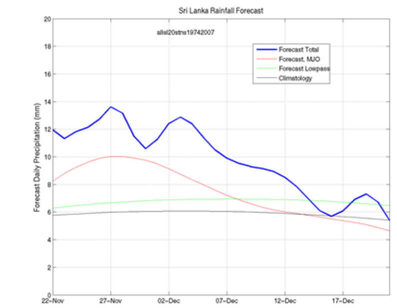
Very high rainfall (90mm) and wind speeds were recorded in the Southern station of Galle on the 26th. The second synoptic station of Hambantota in the South-East was not been able to maintain records after the 24th.



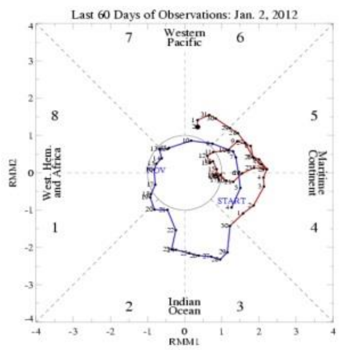
Wind speeds of up to 37.8 knots were recorded at the Southern station of Hambantota on the 25th at 17.30. High wind speeds were recorded on the 22nd and 27th as well.

Roundy's Rainfall Predictions

Rainfall predicted on 21st of November based on Roundy (2011). The component based on MJO is shown to peak around 26-28th of November and while there is an under-prediction, the algorithm given as indication of the extreme weather ahead.



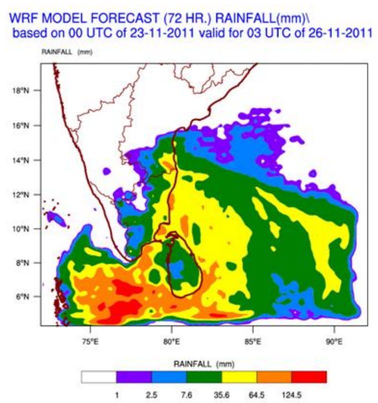
MJO phase space



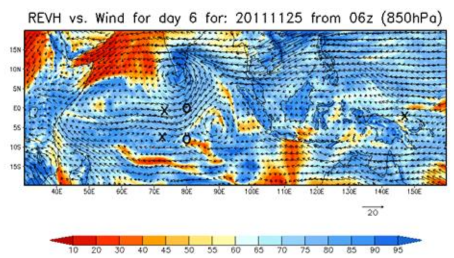
The phase diagram for MJO (Wheeler and Hendon, 2004) (left) shows that the MJO became strongly active over the Indian Ocean from the 22nd to 30th of November 2011.

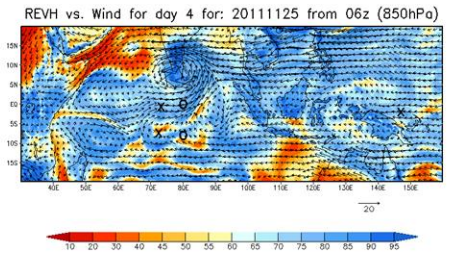
NCMRWF Predictions

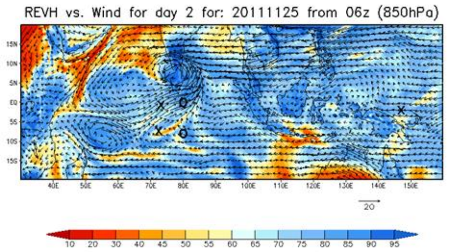
Rainfall predicted 72 hours in advance of the 26th of November by IMD (right) and 10 days in advance. Although these predictions do not identify a cyclone they do identify extreme weather in the coastal areas .



NOAA/GFS Predictions



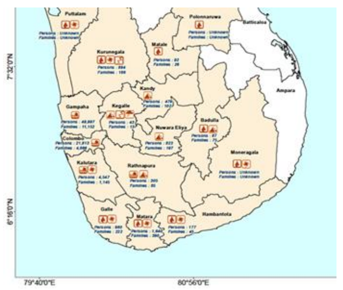




The forecast of relative humidity and wind at 850 hPa for 06 UTC on November 25th is shown on top. This is the GFS model, run by the US National Oceanic and Atmospheric Administration. The plot shown is a six-day forecast. Notice the swirling arrows right on the southern tip of India. That's the predicted TC 5. Sri Lanka well within the forecast storm.

Below it are a set of two more predictions, all valid at the same time (06 UTC on the 25th), but performed four days and two days prior getting closer and closer to the 25th. If you focus on Sri Lanka - around 5-10N, 75-80E. You can see the consistency in these forecasts. The predicted strength of the storm increased a bit in the later forecasts compared to the six-day one, but its position and timing did not change much.

Damage Reports



- Heavy rains and wind caused 19 deaths in Sri Lanka.
- 40 were injured and 43 were reported missing.
- 54844 persons belonging to 13663 families were affected
- 1723 persons belonging to 427 families were displaced.
- 630 houses were fully damaged.
- 5491 houses were partially damaged

Source: Disaster Management Centre- Sri Lanka

Conclusions

1. TC5 was unusual in that it formed to the South of Sri Lanka and proceeded to the Arabian Sea. Such a storm track has only been recorded once before in the last 120 years.
2. TC5 formed and grew during a highly active phase of the Madden-Julian Oscillation. MJO is implicated in the heavy rainfall.
3. US and Indian operational agencies were able to predict the intensity of the storm and track
4. Real-time products from NOAA/CPC and IMD/NCMRWF could have been used to anticipate the risk of heavy rainfall 3-6 days in advance.
5. An algorithm owing to Paul Roundy based on MJO, Kelvin wave and other atmospheric phenomena was able to anticipate heavy rainfall.
6. Advance warning on heavy rainfall was provided by FECT on November 24, 2012 in our weekly hydro-met advisory (http://fectsl.blogspot.com/).
7. Cyclone track forecasting and better use of numerical weather prediction models are needed in Sri Lanka and Maldives.
8. There needs to be a better way of estimating risk for people and the environment rather than based on the storm/severe storm/cyclone classification based on wind speeds alone.

FECT Foundation for Environment, Climate & Technology

COLUMBIA UNIVERSITY

UNIVERSITY AT ALBANY State University of New York

El Niño & La Niña influences on the Climate of the Maldives

Prabodha Agalawatte, Lareef Zubair, Zahid (MMS), Zeenas Yahiya, Akram Kamiss, Chamidu Gunaratne

Summary

This poster introduces the El Nino and La Nina phenomenon, its influences on the regional climate and its influences on rainfall and temperature in the Maldivian region. We find a consistent influence of El Nino which is differentiated by seasons and by regions.

El Niño, La Niña and the Southern Oscillation

The El Niño and La Niña are naturally occurring phenomena where the interaction between the equatorial Pacific ocean and the atmosphere results in a coupled variation of sea surface temperatures (SST) over the eastern tropical Pacific ocean and the east- west atmospheric oscillation. The SST over the eastern equatorial Pacific ocean is an index for the intensity of this phenomena. Based on this index 3 ENSO phases are defined. They are El Niño, La Niña and Neutral. The atmospheric circulation is referred to as Walker Circulation or Southern Oscillation and are illustrated by the Walker Circulation Schematics (left).

The area from the 120^0 W to 150^0 W longitude and 5^0 either side of the equator in the Pacific is defined as the Niño 3.4 area. During an El Niño the running average of SST in the Niño 3.4 area has to be more than 0.4^0C for 3 months. This happens when the Walker Circulation Weakens or reverses. La Niña is the opposite phase of SST where the NINO3.4 is below 0.4^0C. La Niña weakens Walker circulation as seen in the middle schematic.. If neither El Niño and a La Niña is operative the resulting neutral phase can be exemplified by the bottom schematic.

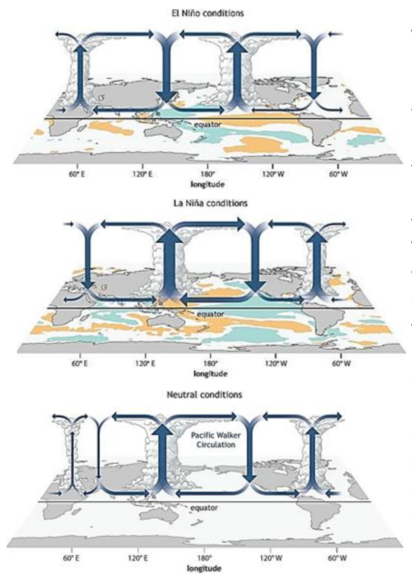


Fig 1: Walker Circulation Schematics of El Niño condition (Top), La Niña (Middle) and ENSO Neutral (Bottom). Image Source NOAA

Rainfall Climatology in El Niño and La Niña phases

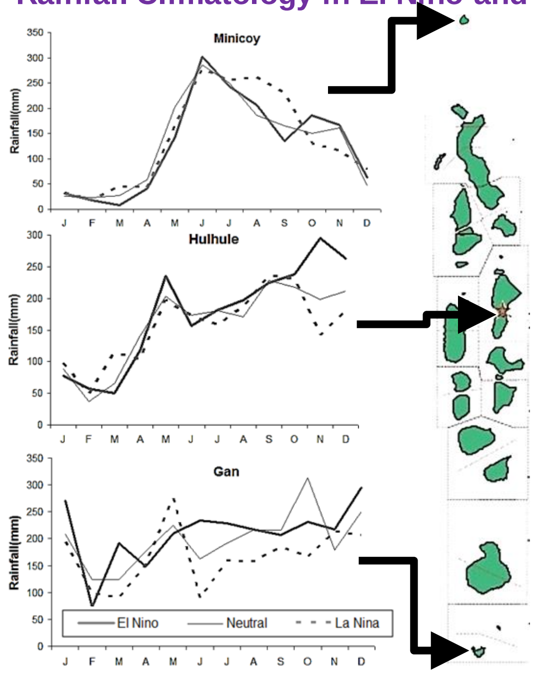


Fig 2: The composite rainfall climatology for Maldives during El Niño, La Niña and Neutral phases in Minicoy, Hulhule and Gan from 1967 to 2008.

Constructing composite climatologies in periods when only El Nino, Neutral or La Nina phases prevailed is a quick way to visualize the influence of these phases.

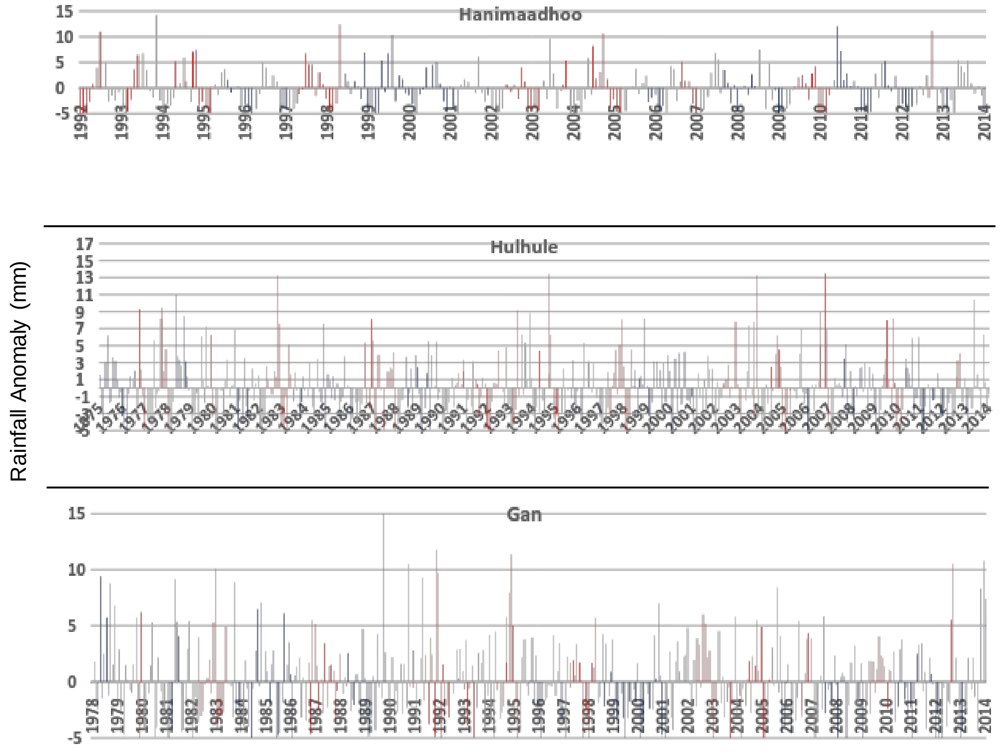
The composite rainfall climatology for Minicoy, India, just north of Maldives, shows weak divergence in Feb, March and Apr, stronger divergence in July to September and in October and November. The enhancement of rainfall in July to September period is similar to that in the wider region.

In Hulhule, an El Nino enhances rainfall in May and October to December while a La Niña enhances rainfall in March and suppresses rainfall in October to December.

El Niño and La Niña affects Gan in southern Maldives in a more complicated way. A La Niña suppresses rainfall in Gan in March as well as May to November and enhances rainfall in April. An El Niño enhances rainfall in March. There is an unusual peak in the rainfall in October when the phase is neutral.

Rainfall and Temperature in El Niño, La Niña and Neutral Phases.

The following time series plot with El Niño and La Niña phases colored in Red and blue show positive rainfall anomalies are mostly in the El Niño phase.



During La Niña Mostly below average temperature is evident.

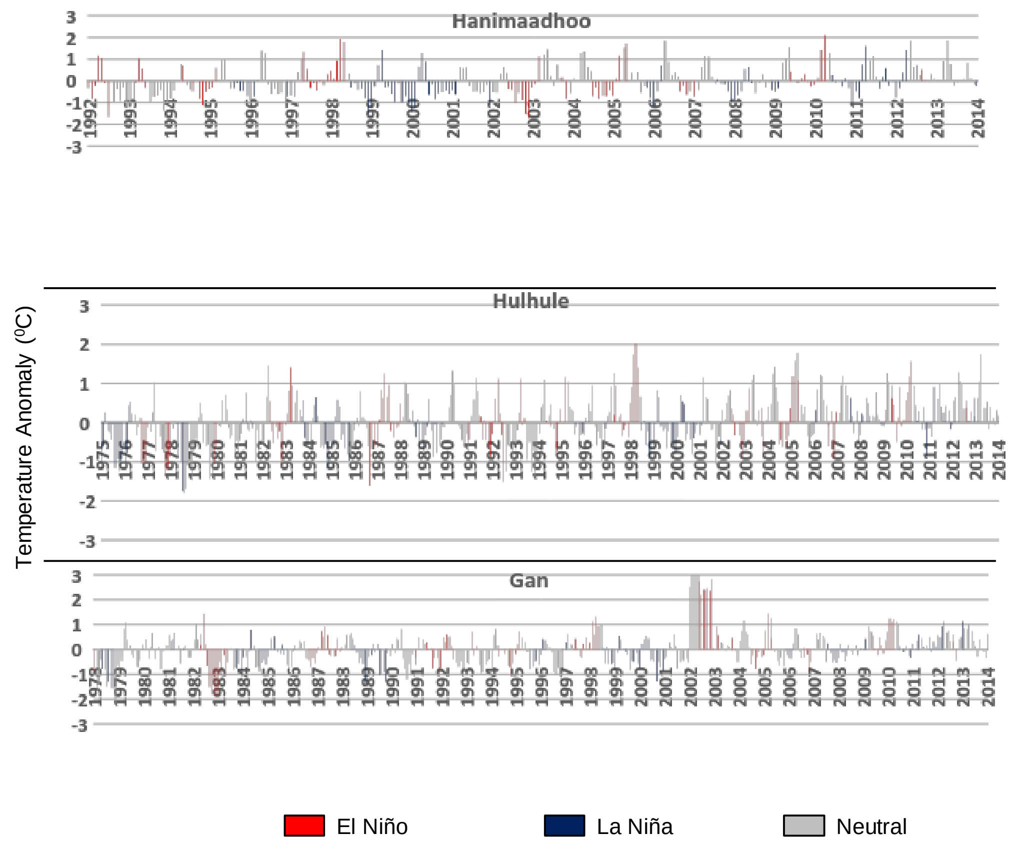


Fig 3: Rainfall Anomaly (Top 3) and Temperature anomaly (Bottom 3) of Hanimaadhoo, Hulhule and Gan colored by the ENSO Phase

El Niño and La Niña Impact on Asian Rainfall and Temperature Climate

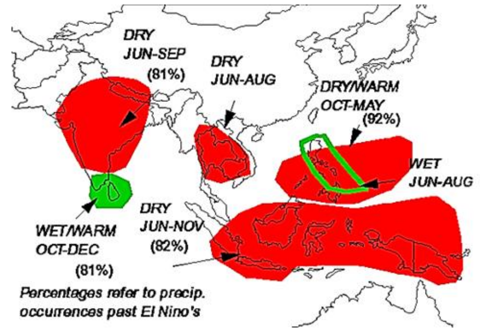


Fig 4: El Niño impact on rainfall map by Ropelewski and Halpert (1987)

Ropelewski and Halpert (1986, 1987) identified the global influence of El Nino on rainfall and temperature. The schematic to the left summarizes the influence in the Asian region. Zubair and Ropelewski (2006) further investigated the impact on Southern Indian and Sri Lanka climate and showed that the effect of El Niño and La Niña on the rainfall shows a strong relationship between El Niño and the rainfall. In Southern India and Sri Lanka during October to December, an El Niño generally leads to wetter than average conditions while the converse holds for La Nina.

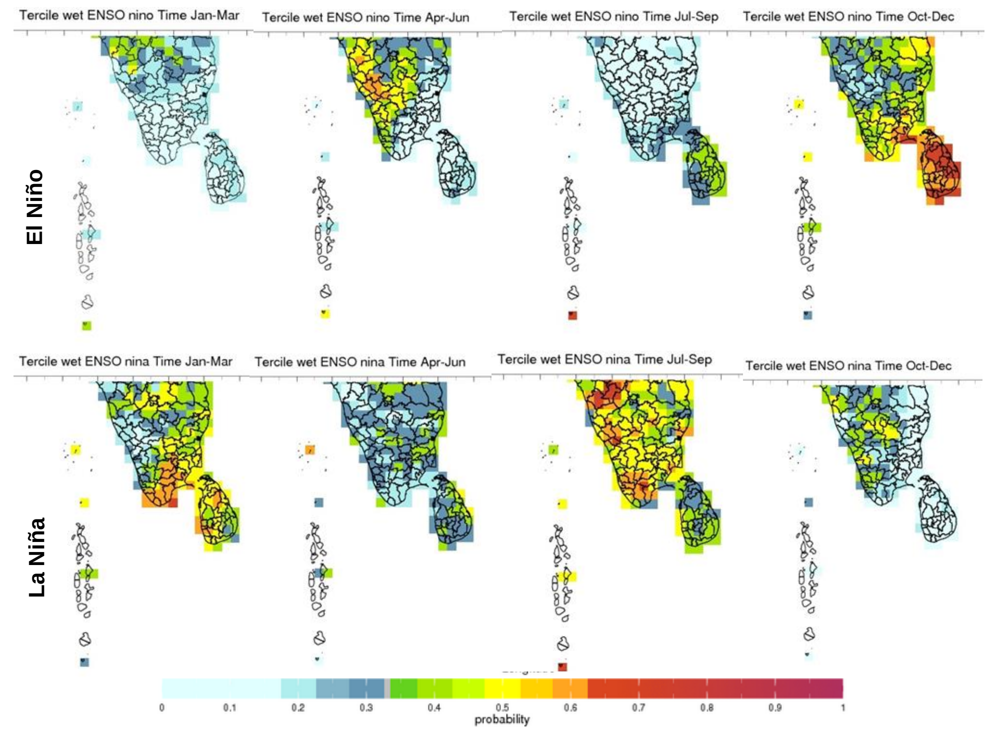


Fig 5: Probability of Above average rainfall under El Niño and La Niña Phases in (L-R) Jan-Mar, Apr- Jun, Jul- Sep, Oct- Dec in the Maldives. Source- IRI and FECT

In central islands during an El Niño there is above average rainfall in Oct – Dec period while it is below average during a La Niña. The impact of an El Niño on northern islands is low while a La Niña brings above average rainfall in Jul- Sep period. Rainfall is mostly suppressed throughout the year in southern islands during a La Niña.

Conclusions

The impact of El Niño and La Niña on rainfall depends on the season and the region. The Maldives has nearly 1200 islands spread in a vast area (from the equator to 8^0 N . In northern islands a La Niña has a higher impact on rainfall than an El Niño. In central islands El Niño/ La Niña impact is highest during October to December. Rainfall is mostly suppressed during a La Niña in southern islands. Generally most of the time an El Nino is associated with the enhancement of rainfall throughout the Maldives.

FECT
Foundation for Environment, Climate & Technology

Impact of the Madden Julian Oscillation

On The Maldives

Prabodha Agalawatte, Lareef Zubair, Zahid (MMS), Zeenas Yahiya, Akram Kamiss

Summary

This poster describes a wave phenomenon that propagates from the Eastern African Coast towards Maldives and further - in some phases the wave augments rainfall and in other phases it suppresses rainfall. This wave takes 30-60 day to play out and it is broken down into 8 phases with phases 1, 2 and 3 being periods when it is over the Maldives and it enhances rainfall. In phases 4, 5, and 6 the rainfall over Maldives tends to be suppressed. This phenomenon can now be skillfully predicted up to 6 days in advance from satellite imagery. This poster describes our work on its impact on the different regions of the Maldives and the potential for prediction.

Madden Julian Oscillation

The Madden Julian Oscillation (MJO) is an eastward moving wave-like large pressure disturbance near the equator that recurs typically in 30 to 60 day intervals that initiates west of Maldives. This phenomenon was first discovered by Roland Madden and Paul Julian in 1971. The wave traverses the planet in tropics at a approximate speed of 4- 8 m/s in the atmosphere. Due to this progression, rainfall is enhanced and suppressed in various parts of the tropics based on the location of the wave.

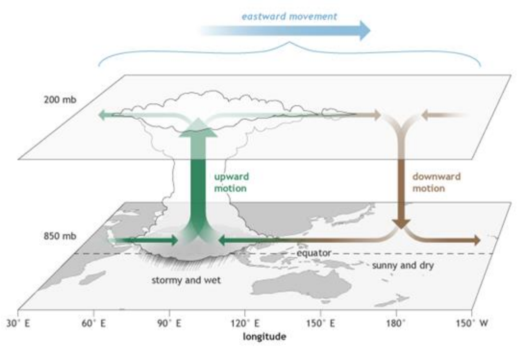


Fig 1: The surface and upper-atmosphere structure of the MJO for a period when the enhanced convective phase (thunderstorm cloud) is centered across the Indian Ocean and the suppressed convective phase is centered over the west-central Pacific Ocean. Horizontal arrows pointing left represent wind departures from average that are easterly, and arrows pointing right represent wind departures from average that are westerly. The entire dipole shifts eastward over time, eventually circling the globe and returning to its point of origin. Image and text Source NOAA

RMM Phase of the MJO

Wheeler and Hendon (2004) split the MJO Cycle into 8 phases based on the "Real-time Multivariate MJO Index" (RMM). Each phase corresponds to 1/8th of the full cycle. An MJO cycle starts in Phase 1 in the western Indian Ocean near Africa and propagates eastwards. The MJO Phase diagram (Fig 2) illustrated the progression of the MJO through different phases.

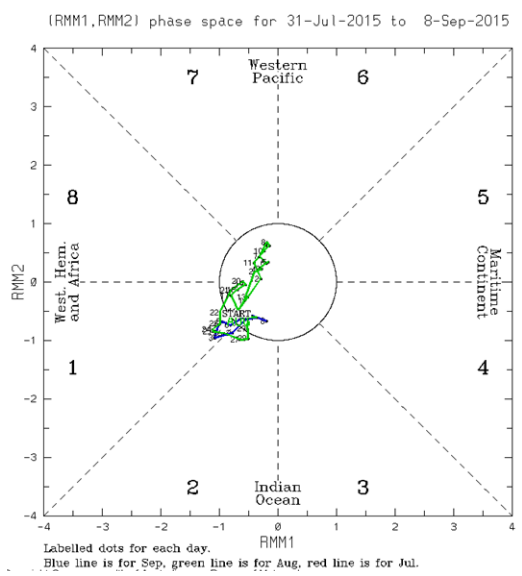


Fig 2: MJO Phase Diagram for 31 Jul 2015 – 8 Sep 2015. Labelled dots are for each observed day. The green line represents the progression in August and the blue line is for September. Image Source Bureau of Meteorology- Australia

A measure of strength and locations of the Madden Julian Oscillation is provided by RMM1 and RMM2. RMM1 and RMM2 are indices that combine cloud amount measured by the Outward Longwave Radiation (OLR) and winds at 850 hPa and 200 hPa levels The amplitude of MJO is defined as $RMM1^2 + RMM2^2$, When the index is within the centre circle of the MJO Phase diagram the amplitude is less than 1 and the MJO is considered weak. When the MJO is weak it does not have a significant impact on the rainfall.

MJO Impact on the Rainfall of The Maldives

As the MJO propagates anomalous rainfall is observed in various parts of the world. Even if the wave is in another region the MJO might still has an influence on the rainfall of a particular region. In order to find out the impact of the MJO on the rainfall of the Maldives the relationship between wind, rainfall anomaly and MJO Phase was studied for different seasons (Jan-Mar, Apr-Jun, Jul-Sep, Oct-Dec). The anomaly is the departure from the long-term average when the MJO phase is in a given phase. The maps below show the anomaly at tropical Indian Ocean region.

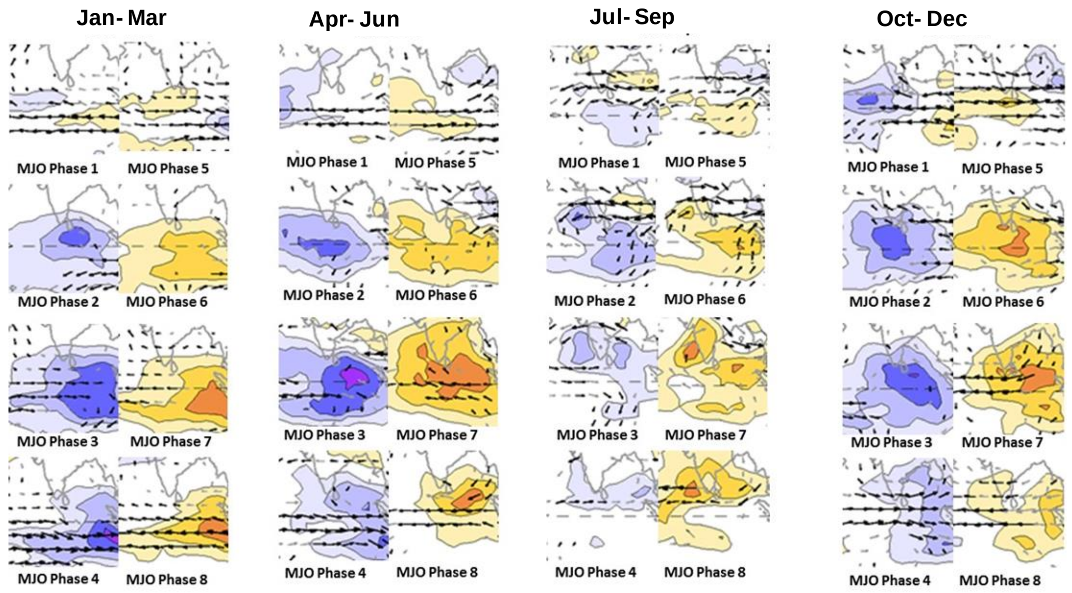


Fig 4: Average Outgoing Longwave Radiation (OLR) used to identify convective rain clouds based on the MJO Phase in the tropical Indian Ocean region. Violet and Blue shading indicated enhanced tropical weather and Orange shading indicates suppressed conditions. The strength and the direction of 850 hPa wind anomalies are given by the length and direction of arrows. Data for the period 1974- 2009 used. Source Bureau of Meteorology- Australia and FECT

Regional MJO Impact

The impact of the MJO phase on the rainfall in different regions can be quantified based on the historical meteorological records as done below. Figure shows the strongest amplification in phase 2 and suppression in phases 5 and 6.

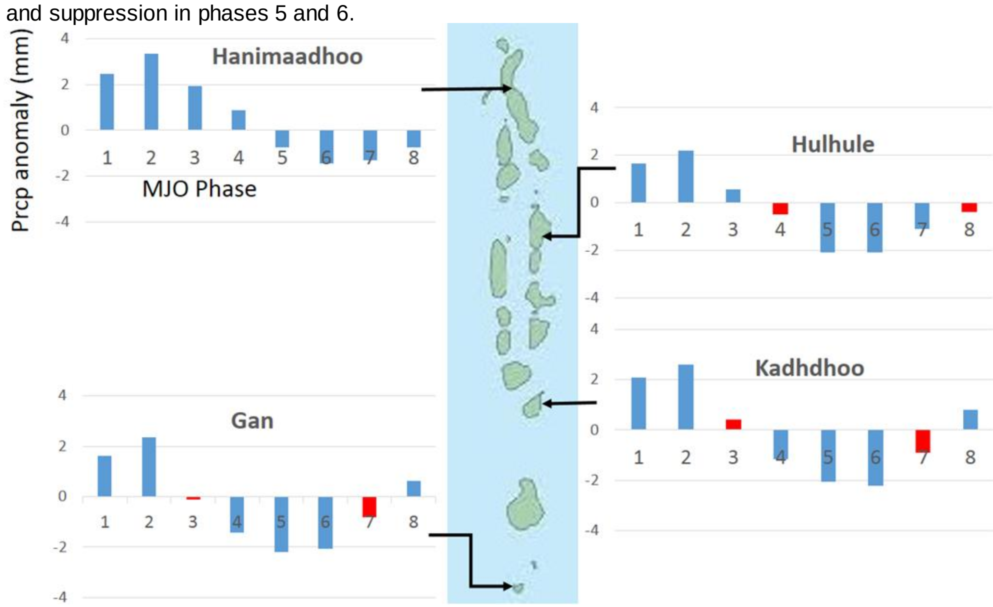
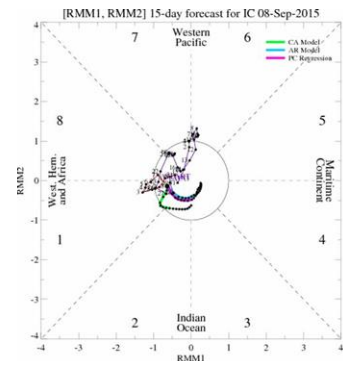


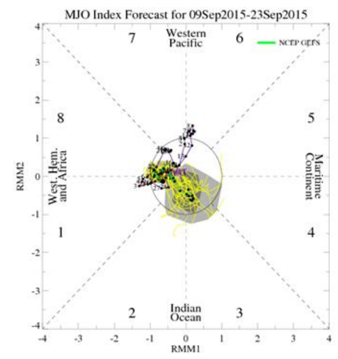
Fig 5: Rainfall Anomalies plotted by phase for 4 locations of the Maldives. Non significant deviations from the average is colored in red. Rainfall data corresponding to days with non weak MJO amplitudes were used.

There is an enhancement in the rainfall when the MJO is in phases 1and 2 across the Maldives. When the MJO is in phase 3 in the eastern Indian Ocean only Hanimaadhoo in the northern Maldives show a significant above average rainfall. When phases 5, 6 and 7 prevail rainfall is suppressed across the Maldives. However there are regional variations in the amplitude of influence. This influence chart and the predictions of MJO phase that are routinely available from forecast centers can help predict rainfall anomalies.

MJO Prediction

Several institutes and individuals provide near-time projections of the MJO phase and amplitude and examples are shown below.





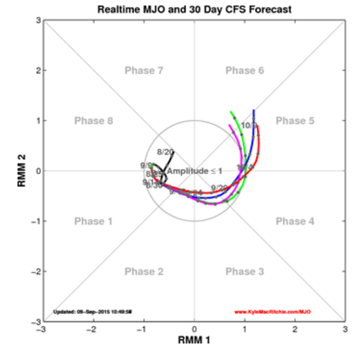


Fig 6: MJO index forecast products of NOAA Climate Prediction Center (Top Left), Paul Roundy of SUNY-Albany, NY (Top Right), and Kyle MacRitchie of SUNY Albany, NY (Left). NOAA CPC projection has Constructive Analogue (CA) model, Autoregressive Model (AR) and Principal Component (PC) Regression Model projections of the MJO index. Paul Roundy's projection use GFS model forecasts while Kyle MacRitchie's projection uses CFS model to project the MJO index.

Rainfall Prediction Based on the MJO

After establishing the relationship between MJO and the rainfall, predictions for the rainfall can be done. Based on the projected MJO phase enhancement and the suppression of rainfall over Maldives can be estimated. Since the impact of MJO on the rainfall changes seasonally, estimation of the rainfall anomaly based on the MJO phase has to be done seasonally as well.

Conclusions

A significant relationship between the MJO and the rainfall of the Maldives was found. In Hanimadhoo in the north, there is a significant relationship between the rainfall and the MJO throughout the entire MJO cycle. In Hulhule the relationship is statistically significant except in phases 4 and 8. The rainfall- MJO relationship is statistically non significant in phases 3 and 8 in southern islands Gan and Kadhdhoo. The highest enhancement in rainfall throughout the Maldives is when the MJO is in Phase 2 and the highest suppression is when the MJO is in phases 5 and 6.

Further studies show that there is a seasonal impact of the MJO on the rainfall in the Maldives. During July to September the impact of the MJO on the rainfall is relatively low compared to the other months of the year. There are methods to project the phase of the MJO which can be used to estimate the enhancement or the suppression of rainfall due to the MJO.

FECT
Foundation for Environment Climate & Technology

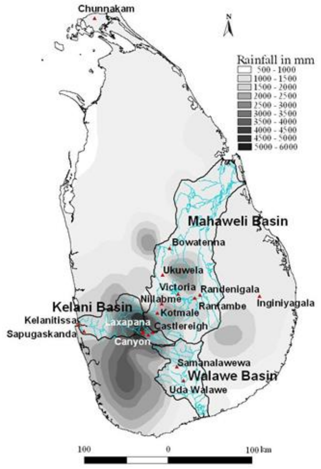
Intra Seasonal Climate Predictions for Sri Lanka

for Water Resources Management

Lareef Zubair, Prabodha Agalawatte, Zeenas Yahiya, (FECT), Paul Roundy (SUNY-Albany) and Adam Sobel (Columbia Univ.)

Summary

Intra-seasonal predictions can help water resources management as it frequently over-rides seasonal predictions. Here a relatively simple methodology based on observations of cloud cover over the Indian Ocean and its relationship with ground-observed data is presented. Through the projection of current cloudiness images on to historical dominant propagation modes, future cloudiness may be predicted and rainfall inferred. This poster describes the implementation and skill analysis of this algorithm for Sri Lanka.



Introduction

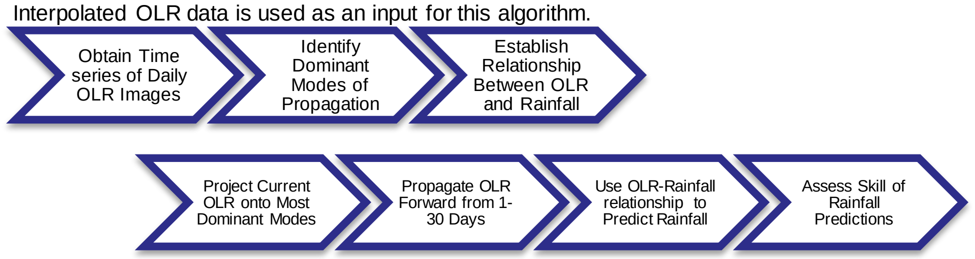
Climate fluctuations at intra-seasonal time have profound influences on management of water resources in Sri Lanka and in the Maldives. Any ability to anticipate these fluctuations is valuable. Recent, improvements in understanding of intra-seasonal (IS) climate variability and the availability of real-time satellite based observations have led to the emergence of methodologies for IS climate predictions from a few days up to a month (Madden and Julian, 1972, Zhang 2005). In particular, there is predictability for rainfall over Sri Lanka and Maldives from the Madden-Julian Oscillation.

The MJO originates in the western tropical Indian Ocean and propagates eastwards across the Indian and Pacific Oceans with a time scale of 30-60 days. Wave phenomenon such as the MJO may be tracked based on satellite observations (Wheeler and Hendon, 2004) and predicted (e.g. Waliser et al., 2005, Roundy and Shreck, 2009). We have:

a) implemented an IS rainfall prediction scheme for Sri Lanka and provided contextualized information to water and environmental managers in an experimental mode
b) found through skill analysis that these predictions are useful but bear improvement,
c) Provided these predictions for water managers.

OLR Based Rainfall Prediction Algorithm

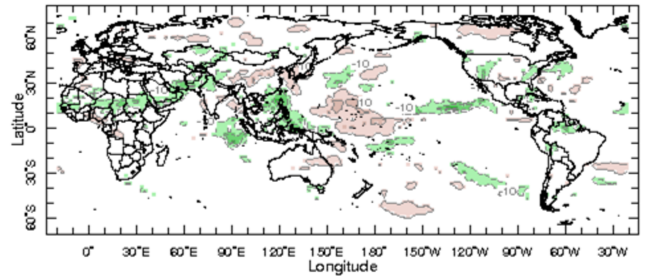
The following 7 step algorithm is used to generate rainfall forecasts in the Paul Roundy method. Interpolated OLR data is used as an input for this algorithm.



These steps can be further explained as follows.

- The Daily Outgoing Long-wave Radiation (OLR) is a proxy for cloudiness and thus rainfall. OLR data from NOAA/ NASA is available from 1974 at a resolution of 250 km which is the input for this algorithm. A part of this historical record (e.g. 1974-2009) is used initially.
- The historical dominant patterns of propagation in the OLR are found using a statistical technique known as Empirical Orthogonal Functions (EOF). The most dominant patterns is found empirically to correspond to the 30-60 day West to East propagation. Only about 4-5 EOF's are needed to capture the critical dynamics.
- A statistical relationship between OLR and contemporaneous rainfall is then established known as Model Output Statistics (MOS).
- Estimate the magnitude and phase of each of the modes in the recent sequences of OLR and identify its projection on to the dominant EOF patterns.
- Given the magnitude and phase of these modes in the recent state of the atmosphere, the OLR is propagated forward in time for 1-30 days.
- The forward propagated OLR and the MOS relationship between OLR and rainfall are used to estimate future rainfall for each of the next 30 days on the ground.
- For a period, that does not include the historical period, the skill of the predictions at different lead times are quantified . The skill of the algorithm is provided along with the predictions.

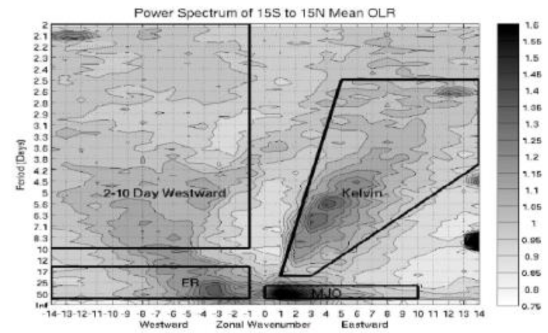
Outgoing Longwave Radiation



Daily estimates of satellite derived outgoing-long-wave (OLR) radiation from NOAA (a proxy for cloudiness) is used. An example for August 2013 is shown at the left. This data is used as an input for the algorithm. Only high values are coloured.

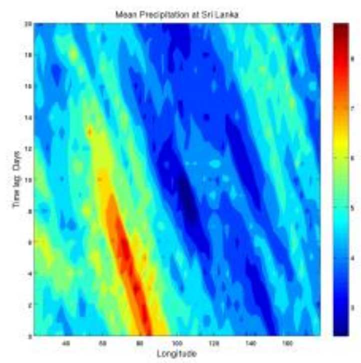
Spectra OF OLR and Dominant Modes

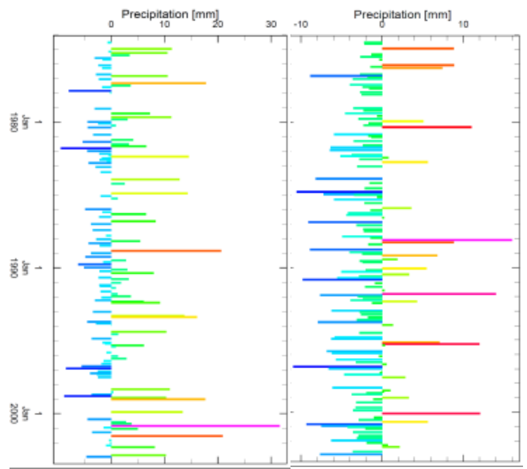
The principal modes of propagation of OLR (of averages between 15^{o}S and 15^{o}N) were identified based on spectral analysis of the daily OLR since 1979. The power spectrum (on right) shows dominant propagation from West to East (MJO – 30-60 days and Kelvin waves (2-20 days), and East to West (2-10 day low pass and Easterly waves). An algorithm has been developed by P. Roundy (2011) for forward prediction by filtering out features other than these modes in the most recent OLR and projecting forward.



OLR – SLR Relation

The correlation between Sri Lankan rainfall (SLR) and OLR (averaged between 15S and 15N) across the Indian Ocean (30E to 160E) for different lags between SLR and OLR. The x-axis shows the longitude, the y-axis the lag and the color the correlation. There is a correlation with OLR to the east of Sri Lanka for up to 12 days ahead.

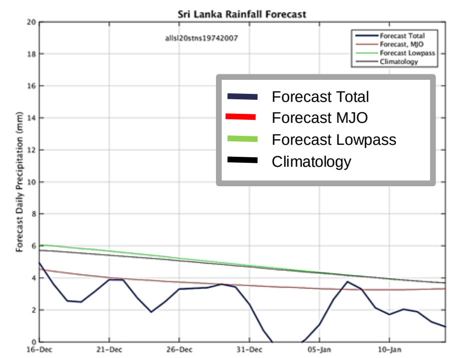




The daily SL rainfall anomaly from 1979 to 2004 is shown when MJO was its minima (above left) and at maxima (above right). The rainfall shows much stronger anomalies at MJO maxima providing evidence for a significant role in rainfall extremes.

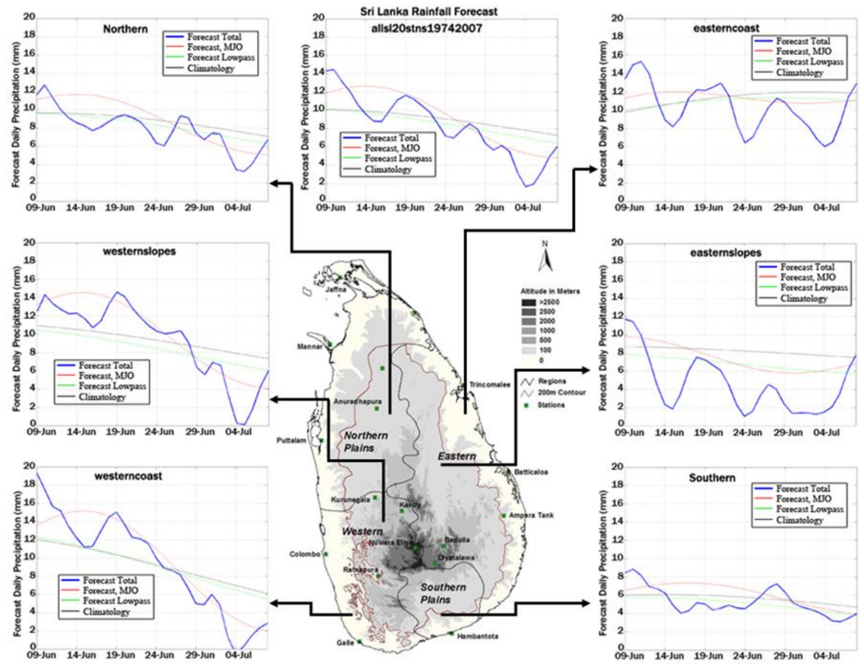
Sample Prediction

Predictions provided for All Sri Lanka by Paul Roundy (SUNY) on December 15, 2015 includes rainfall predictions for the next 30 days, includes estimates for components due to climatology, MJO, and low-pass spectra waves. The blue line is the predicted rainfall. It shows a decreasing trend in rainfall over the following 30 days.

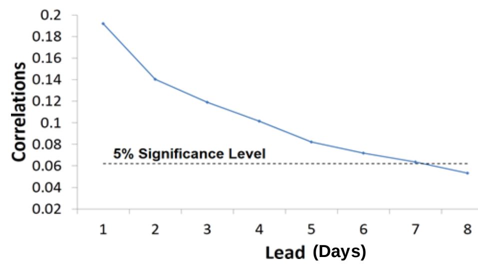


Regional Predictions

Prediction are being generated for Sri Lanka and 6 climatic regions following Puvaneswaran and Smithson, 1999 & Zubair et al., 2008. Sample predictions are laid out below.



Skill of Predictions



The skill of the prediction against the actual observation was estimated statistically as a correlation between observed and predicted rainfall for the period from 2001- 2012. The predictions was found to have a significant amount of skill (null relationship under 95% significance level) up to a lead time of of 7 days.

Conclusions

The ability to correctly predict the weather 2 to 3 weeks in advance is useful for water and environmental managers. The rainfall in tropical countries like Sri Lanka and the Maldives has already been found to have a significant relationship with the MJO. Higher rainfall anomalies can be seen during MJO maximas. There is high correlation between the rainfall in Sri Lanka and the OLR field up to 12 days in advance. A new tool has been developed to achieve precise prediction of long range weather by P. Roundy and applied along with L Zubair in an operational mode for All of Sri Lanka and six climatic regions. The algorithm uses OLR information to predict rainfall by propagating the OLR forward in time for 1- 30 days after establishing the relationship between OLR and the rainfall. There is a statistically significant relationship between predicted and observed rainfall up to 7 days ahead. While these skill levels are modest, these predictions fill a critical gap in the suite of predictions from weather to near-term climate change which is critically important for water management. The National Water managers who are provided with these predictions along with other predictions are receiving these favourably. Skill shall continue to improve with time.

FECT Foundation for Environment, Climate & Technology
Columbia University
University at Albany State University of New York

About Foundation for Environment, Climate and Technology

in the Maldives

Atolls of Maldives

Introduction

As stated by a one-time Minister of Environment in the Maldives, the capacity to undertake climate, climate change and climate adaptation related work needs to be urgently enhanced in the Maldives. The Ministry for Environment and Columbia University initiated discussions in 2009. The Foundation for Environment, Climate and Technology in Sri Lanka and New York grew out of the decade-long collaboration between Sri Lanka institutions grew out of the decade-long collaboration between Sri Lanka institutions and Columbia University. FECT Maldives (http://www.tropicalclimate.org/maldives/) was established in June 2012 to ensure a platform for continued research and scientific knowledge management.
This flyer summarizes the projects conducted FECT in Maldives in collaboration of Maldivian and International institutions and individual scientists.

FECT-Vision

To sustain a network of excellence in climate, environmental and information technologies and related areas where quality research supports sustainable development and advance of technological capacity for societal welfare.

FECT-Contribution

We have undertaken Climate & Environmental research, implemented climate adaptation projects, developed infrastructure for research and trained a hundred personnel since 1997 in Sri Lanka, United States, Botswana, Maldives, East Africa and Comoros. To sustain these advances, we instituted the Foundation for Environment, Climate and Technology (FECT) as a non-profit company in 2003 in Sri Lanka, in 2009 in USA, in 2014 in Comoros and are in process of registering in the Maldives.

FECT contributes to climate, hydrology, adaptation, information technology, social sciences and engineering for sustainable development. Our charter requires us to work towards societal welfare and environmental sustainability without private profit.

Collaborations and Consultations

Maldivian Institutions

Maldivian National University (MNU)
Maldivian Meteorological Service (MMS)
Ministry of Environment (MEE)
Ministry of Fisheries and Agriculture
Disaster Management Centre
Renewable Energy Maldives (REM)
LaMer Pvt Ltd (LaMER)
UNDP Maldives
Marine Resources Center (MRC)

International Institutions

University of Peradeniya, Sri Lanka.
Columbia University Engineering
Columbia University Water Center
Lamont Doherty Earth Observatory

Contributors at Columbia University

Michael Bell, Shaky Sherpas, Upmanu Lall, Jian-Hu Qian, John Del Corral, Kevin Coffey, Michael Tippet, Tony Barnston, Joaquim Goes, Adam Sobel, Bradfield Lyon, Lareef Z,ubair

Contributors in Maldives

Renewable Energy Maldives : (REM)
- Hudha Ahmed
Maldives Meteorological Service : (MMS)
- Zahid, Ali Shareef, Ahamed Muslim, Shimana
Maldives National University : (MNU)
- Mizna Mohamed, Majeeda Mohamed
LaMer (Pvt) Ltd.
- Z Abid, S. Sattar, M. Aslam
Marine Research Centre (MRC)
- Shiham Adam
Health Protection Authority (HPA)
- Nishan Ahmed
Male' Water & Sewerage Company (Pvt) Ltd. (MWSC)
- M. Rasheed

International Contributors

Paul Roundy, State University of New York - Albany
Aravinda De Silva, University of North Carolina – Chapeel Hill
Tristan Graham

Contributors at FECT-Sri Lanka

Lareef Zubair, Zeenas Yahiya, Prabodha Agalawatte, Y. Ahmed, I. Sandamali, C. Gunaratne, N. Shobana, J.Visvanathan, K. Wijeratne, A. Kamiss, R. Zacky, U.Ratnayake

Contact

In Maldives:

Ms. Hudha Ahmed: Phone: (960)3309882
hudha.ahmed@renewableenergymaldives.com.mv
Dr. Mizna Mohamed: Phone: (960) 3345420
mizna.mohamed@mnu.edu.mv

In Sri Lanka:

Foundation for Environment Climate & Technology,
Digana Village, Rajawella, 20180, Sri Lanka.
Phone: +94-81-2376746, +94-81-4922992
E-mail: climate@sltnet.lk & fectmv@gmail.com

Historic well in Male, Served residents during water cuts of November 2014, pix Lareef Zubair

People lining up to collect water in Male November 2013,

People lining up to collect water in Male November 2013

Further Information

http://www.tropicalclimate.org/maldives
http://fectmv.blogspot.com
Email : fectmv@gmail.com
Twitter: @fectmv https://twitter.com/fectmv

FECT
Foundation for Environment, Climate & Technology

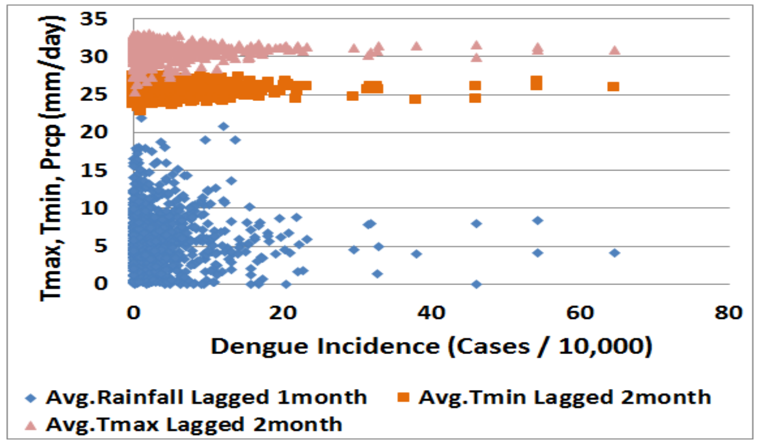
FECT Projects

In Maldives

Planning for Capacity Development in Climate (2009-2011)

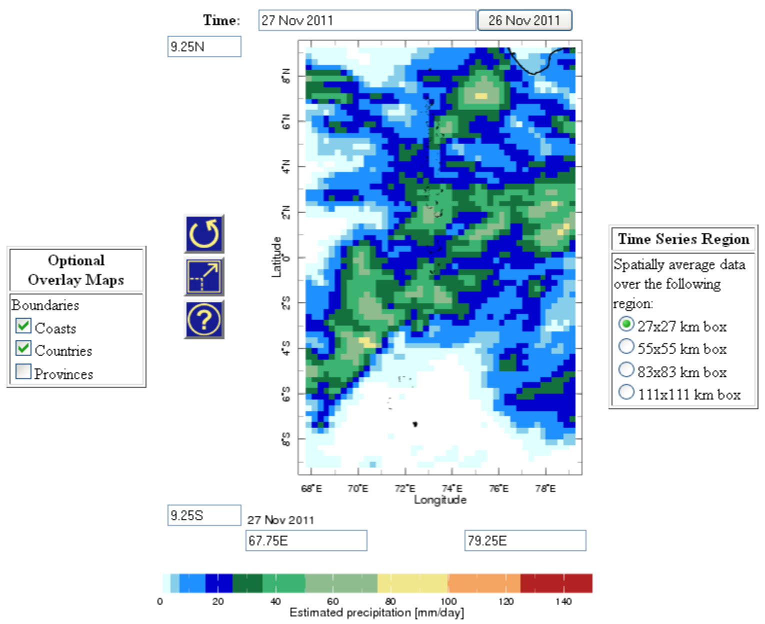
This collaboration with the Ministry of Environment produced a 3 phase roadmap for Climate related research for Maldives

Relationship of Dengue Incidence with Climate in Maldives



The relationship of dengue incidence with Minimum Temperature, Maximum Temperature, Rainfall and Water Availability is analyzed based on observations of the Self Protection Authority of the Ministry of Health, Climate observations from the Maldivian Metrological Services, and Satellite based data sources.

IRI- FECT Rainfall Monitoring Tool



Michael Bell, John De Corral, Shaky Sherpa and Lareef Zubair at Columbia University and FECT have developed a tool to estimate rainfall every 10/25 km regions. These compare well with ground observations from MMS

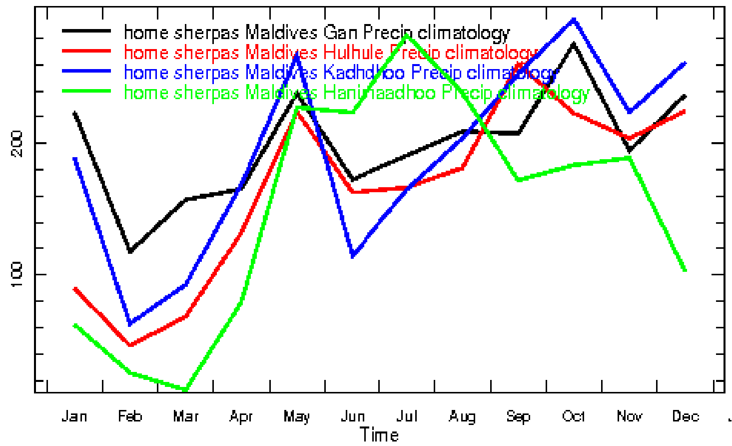
Masters in Sustainable Development Practice at University of Peradeniya (2010) onwards)

This program focuses on Sri Lanka and Maldives. FECT supports collaboration with Maldives through curriculum development. Research support and placements for Maldivian students at the University of Peradeniya. The program is supported by MacArthur Foundation after a global proposal competition for which Maldives Ministry of Environment supported the University of Peradeniya's and FECT's Proposal.

Four cohorts have enrolled in this program. A Maldivian Aisath Afaaf has enrolled for MDP.

Climatological Analysis(2009-2011)

FECT, Columbia University and the Maldivian Met Service undertook climate analysis from ground and satellite observations. Differences in climate across the Maldives were quantified. A research paper on El Nino impacts on Maldives has been drafted

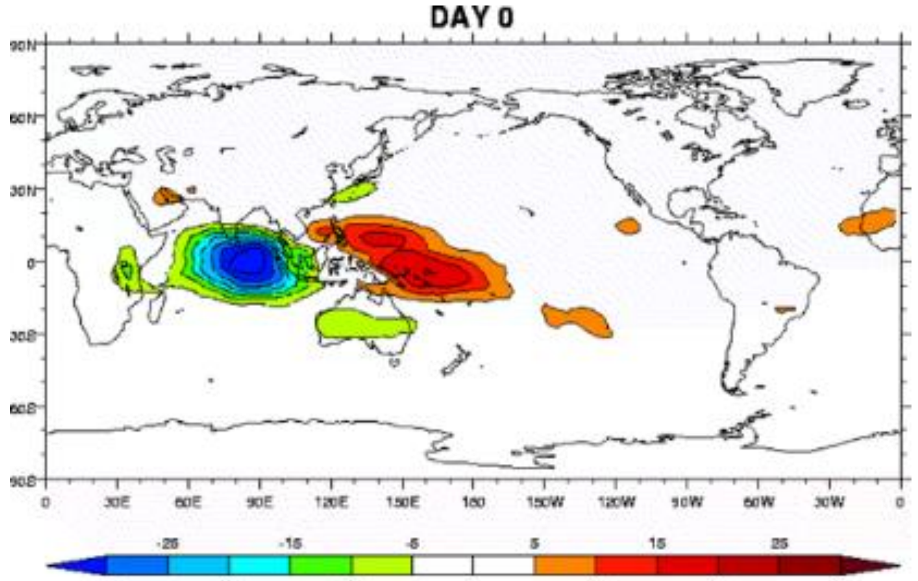


Climate Predictions for Maldives (2011 Onwards)

IRI produces climate predictions 3-6 months ahead – we are now trying to improve the coverage for the Maldives, improve downscaling and to undertake skill analysis.
This and other findings are reported monthly via our Climate report of which a thumbnail is at top

Intra Seasonal Climate Predictions for Maldives (2012-2015)

Intra Seasonal rainfall prediction system is being developed in collaboration with SUNY, Columbia University, MMS supported by the US National Academy of Sciences. Resources from the DYNAMO project are being made available by DR.Adam Sobel of the Columbia University



Drought Monitoring and Climate Change Impacts for Sri Lanka and Maldives (2014-2017)

This project is supported by MNU, MWSC and by the US National Academy of Sciences and is getting underway.

Sustainable Development interns undertook water scarcity analysis and energy and water studies with the support of MWSC and REM.

Photo: A. Yoosuf & K. Wijeratne - Meeting with Eng. M. Rashid (Manager – Engineering, Male Water & Sewerage Company (Pvt) Ltd (MWSC)

Disaster Hazards assessment for Sri Lanka and Maldives with multiple streams of limited data

The project involves expanding, testing, and implementing a hazard analysis framework using data from satellite estimates for soil moisture and prediction products from NASA and NOAA, for combining multiple terrestrial indicators to estimate the probability of drought and floods in Sri Lanka and Maldives. The project is funded by USAID – Peer program.