An assessment of the combined and independent impacts of ENSO and IOD on rainfall deviation driven *Maha* season paddy cultivation in Sri Lanka

Aruni B. Abeysekera[1], Shiromani Jayawardena[2] Ranjith Punyawardena[1], Buddhi Marambe[3] and Thavananthan Sivananthawerl[3]

[1]*Natural Resources Management Centre, Department of Agriculture, Peradeniya, Sri Lanka*

[2]*South Asian Hydro-met Forum, Regional Integrated Multi-Hazard Early Warning System, Thailand*

[3]*Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka*

Eighth WMO International Workshop on Monsoons (IWM-8)
Indian Institute of Tropical Meteorology (IITM) Pune, India
17-21 March 2025

Outline

Introduction

Objectives

Data and Methodology

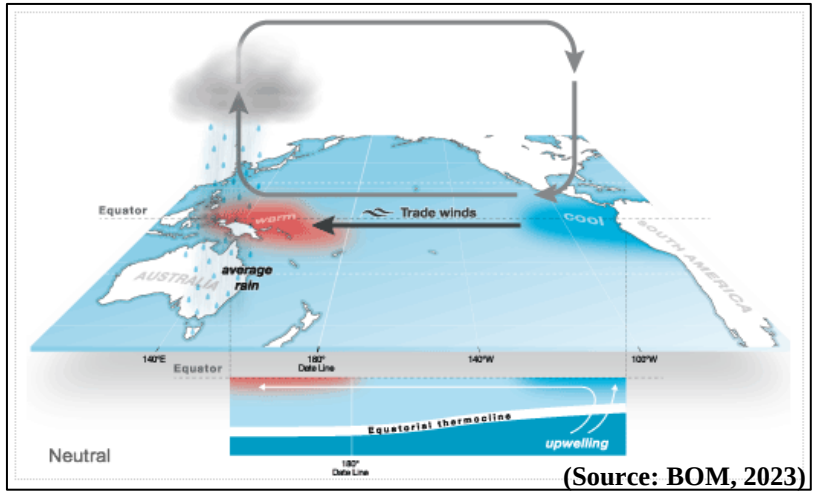
Results and Discussion

- Impact of ENSO and IOD phenomena on the rainfall regime of Sri Lanka
- The influence of ENSO and IOD driven rainfall deviations on the *Maha* seasonal paddy cultivation
- Impact of independent ENSO and IOD events over combined events

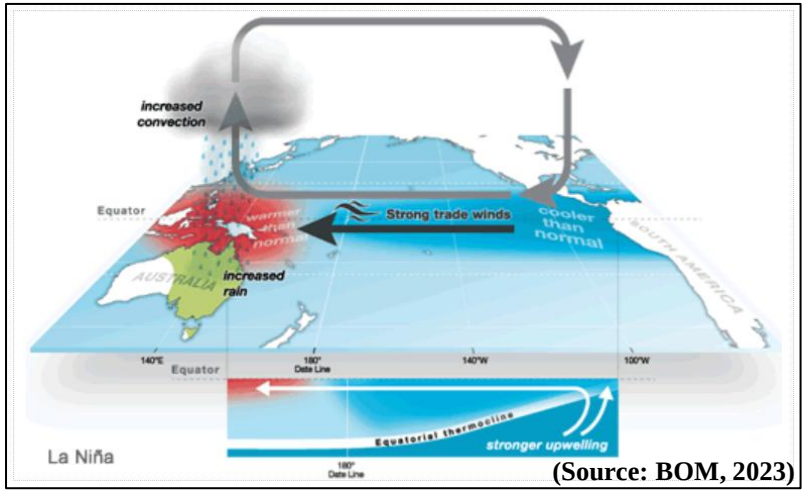
Conclusions

Introduction

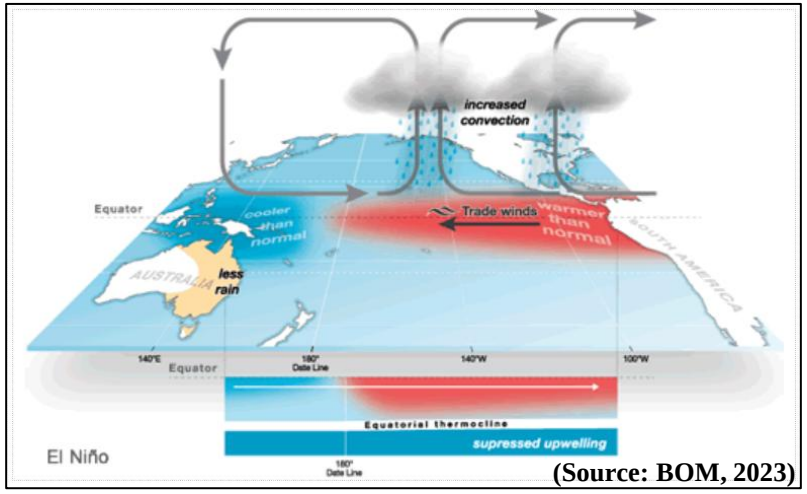
- ENSO and IOD - climatic drivers - disrupt the weather pattern – in their genesis site and distant locations across the globe through the teleconnection
- ENSO occurs in the tropical Pacific Ocean (Philander, 1989; McPhaden *et al.*, 2006)
- ENSO cycle has three distinct phases (McPhaden, 2002)
  - Neutral phase
  - *El Niño* (the warm phase)
  - *La Niña* (the cold phase)



(Source: BOM, 2023)

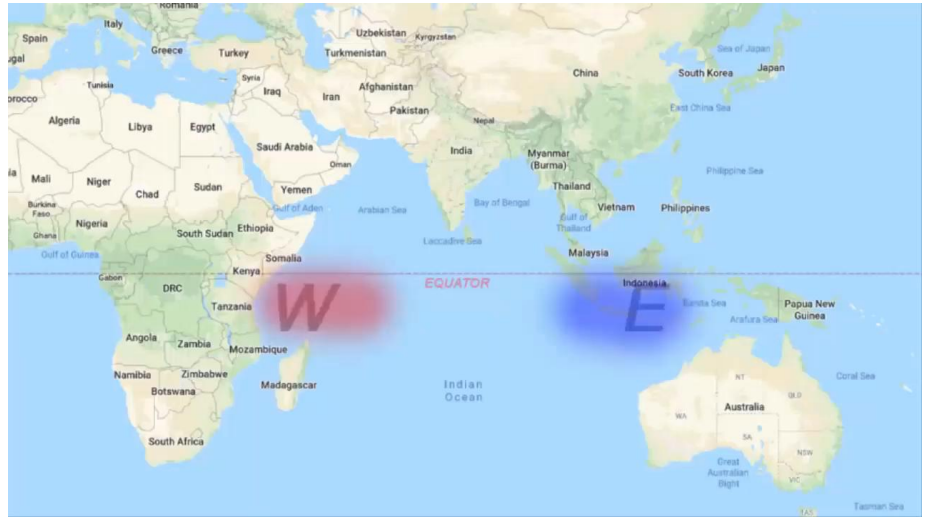


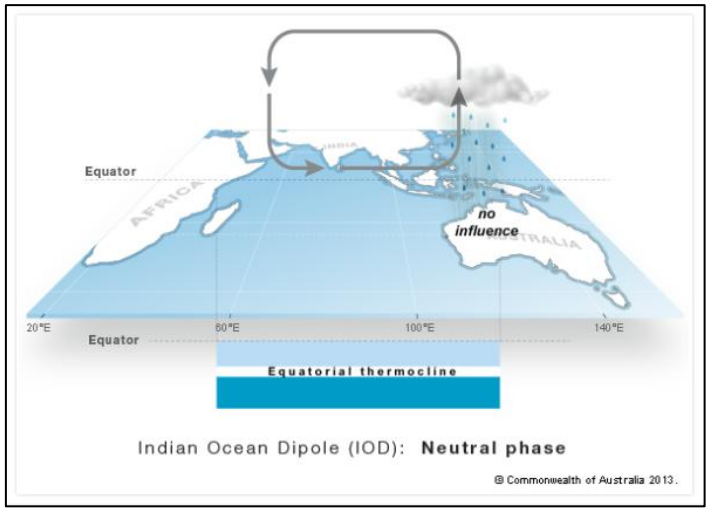
(Source: BOM, 2023)

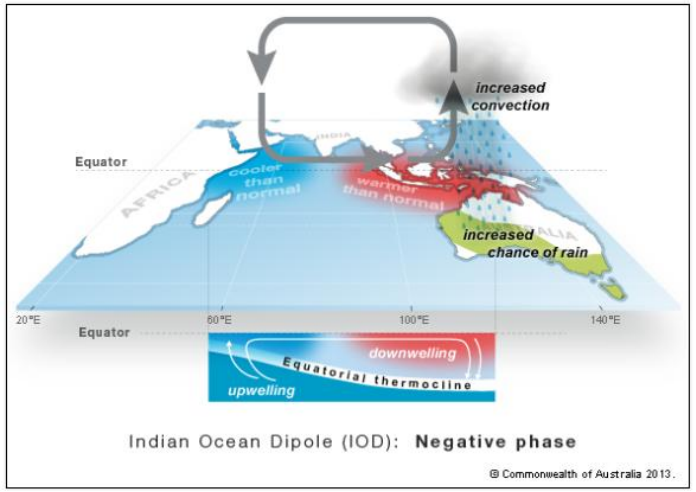


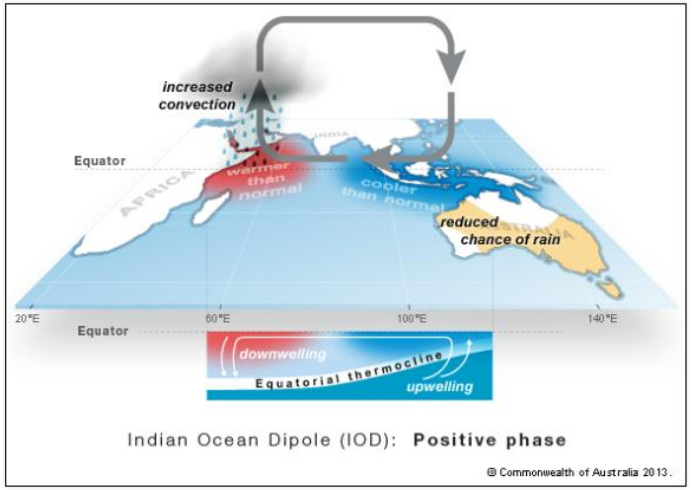
(Source: BOM, 2023)

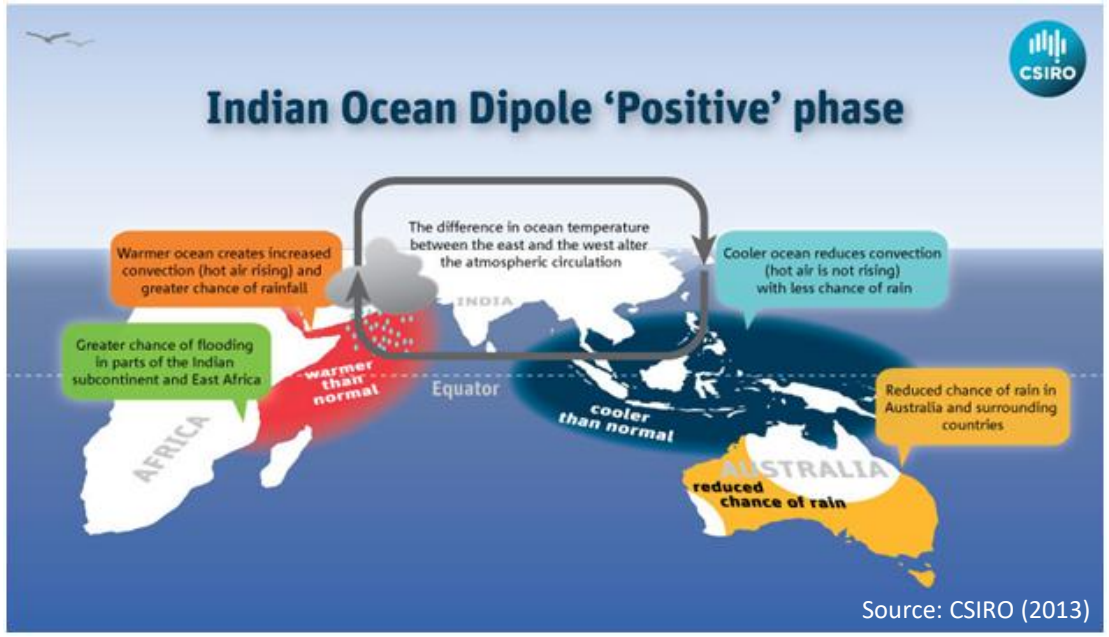
- IOD ocean-atmospheric coupled phenomenon associated with an east-west gradient in the tropical Indian Ocean SST anomalies (Saji *et al*., 1999; Webster *et al*., 1999)
- Also known as Indian Nino
- IOD cycle has phases,
  - Neutral
  - IOD-positive (warm)
  - IOD-negative (cold)



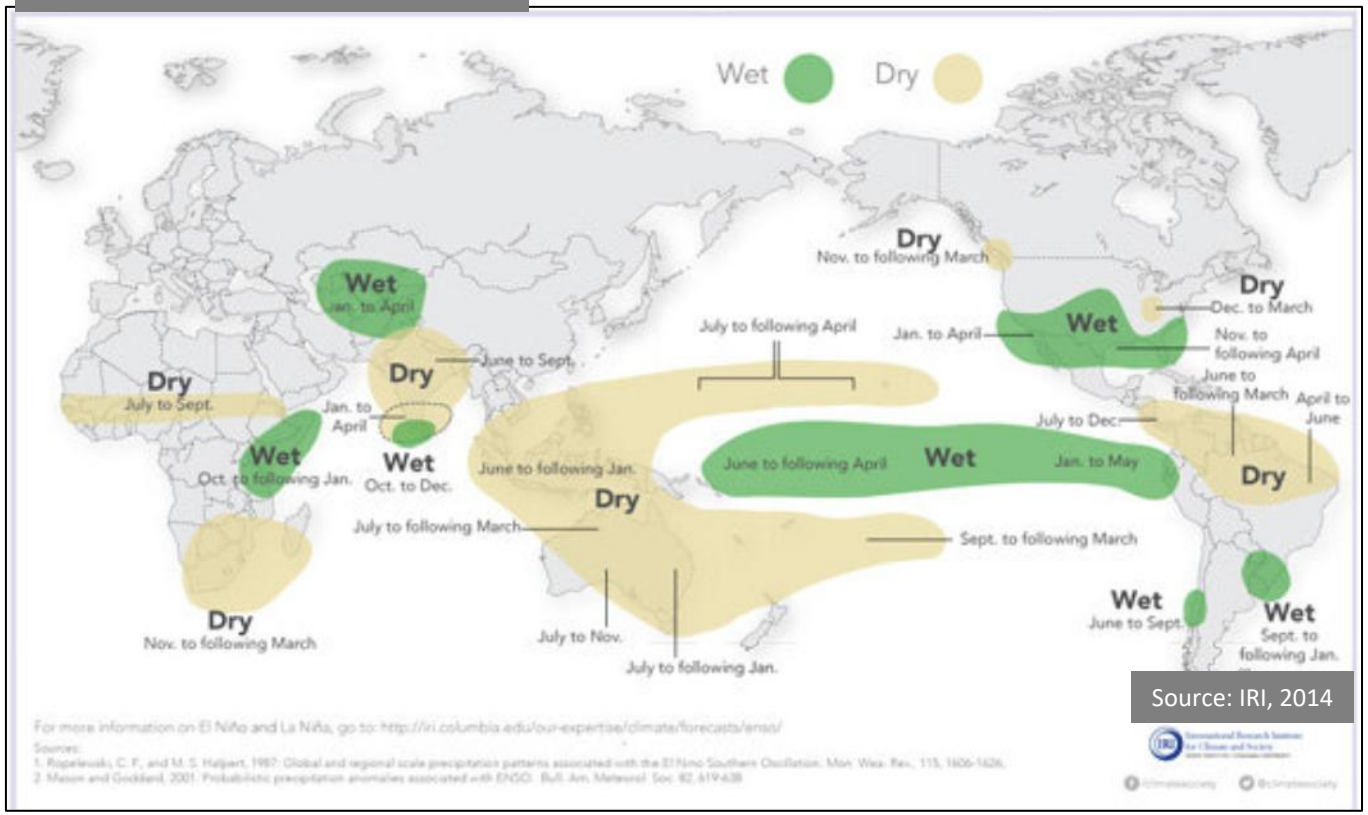






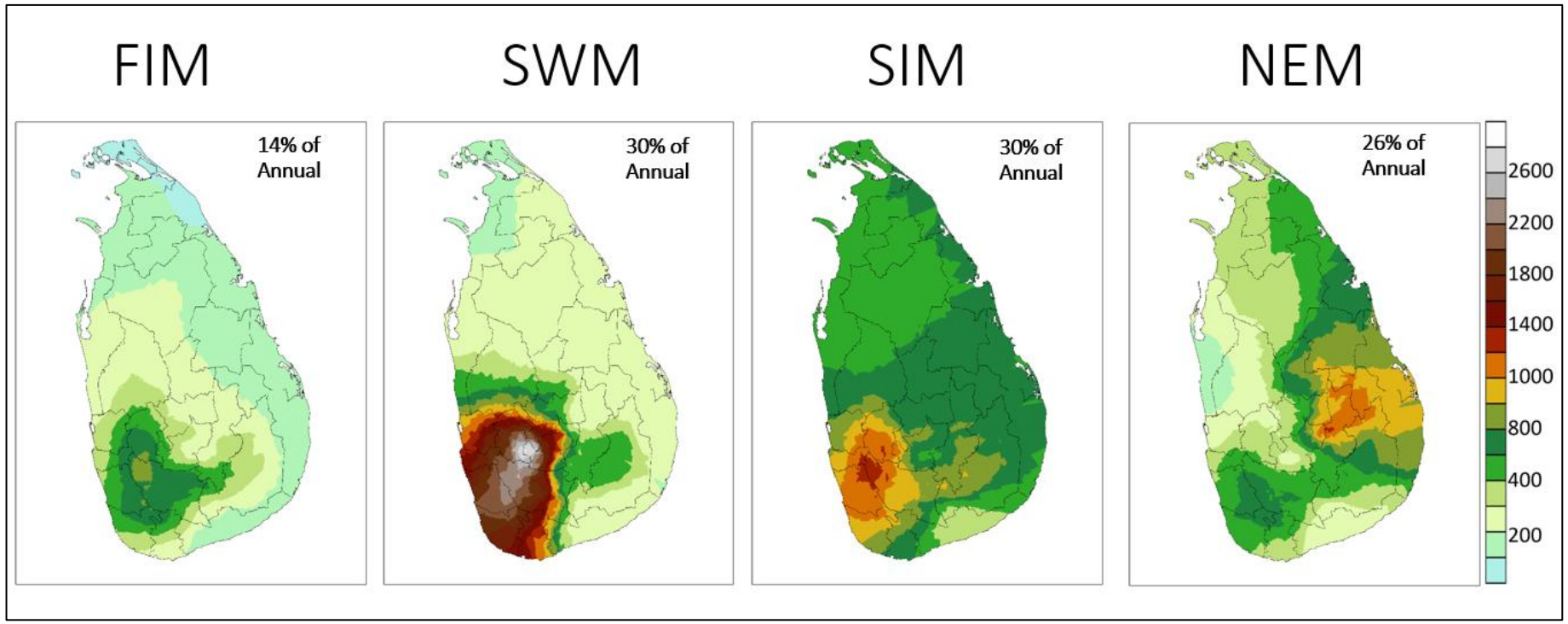


Global impact of *El Niño*



- *El Niño* can trigger IOD-positive events (Saji *et al*., 1999; Webster *et al*., 1999; Allan *et al*., 2001)
- Inter-connection of IOD-negative and *La Niña* events - much weaker (Aparna *et al*., 2012)
- Considerable number of IOD events occur without triggering by ENSO

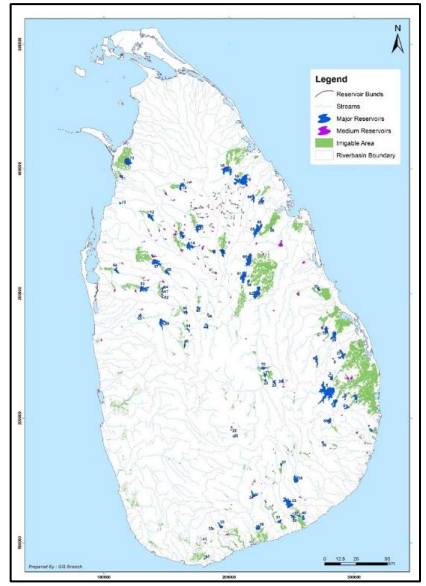
Four rainfall seasons of Sri Lanka



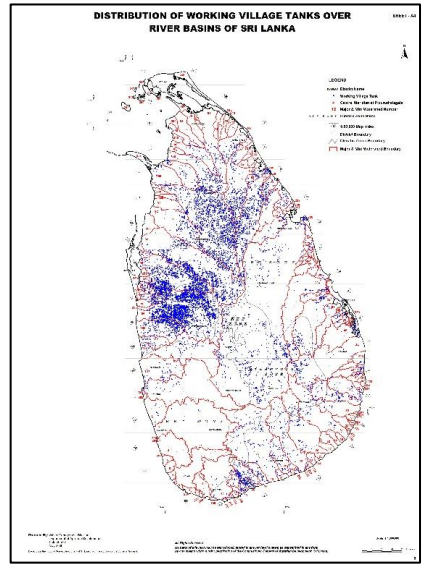
Rainfall Season	First Inter-monsoon	Southwest Monsoon	Second Intermonsoon	Northeast Monsoon
Period	Mar - Apr	May - Sep	Oct - Nov	Dec - Feb
Rainfall (mm)	260	546	548	459
Percentage (%)	14	30	30	26
Cultivation Season	*Yala*		*Maha*	

Seasonal rainfall pattern (1991-2020 average rainfall: Source: DOM)

- Rice - the staple food of Sri Lanka – is a semi-aquatic plant
- The deviation in sown and harvested extent and the average yield of paddy in Sri Lanka - directly correlated with - deviations in the seasonal rainfall (Yoshino and Suppiah, 1983; Suppiah, 1985; Punyawardena, 2002; Marambe *et al*., 2015)
- Rice is grown in the country - under irrigation or rainfed conditions (Dhanapala, 2000)
- Studying the negative or positive effects of ENSO and IOD phenomena on agricultural systems – important - seasonal agro-met advisories on strategic decision-making before the start of each growing season



Spatial distribution of major reservoirs in Sri Lanka (Source: ID, 2020)



Spatial distribution of minor reservoirs in Sri Lanka (Source: DAD, 2011)

Objectives of the study

General objective

To understand the spatial and temporal variations of the rainfall climatology of Sri Lanka under the influence of ENSO and IOD phenomena and their impact on the *Maha* season paddy cultivation in Sri Lanka

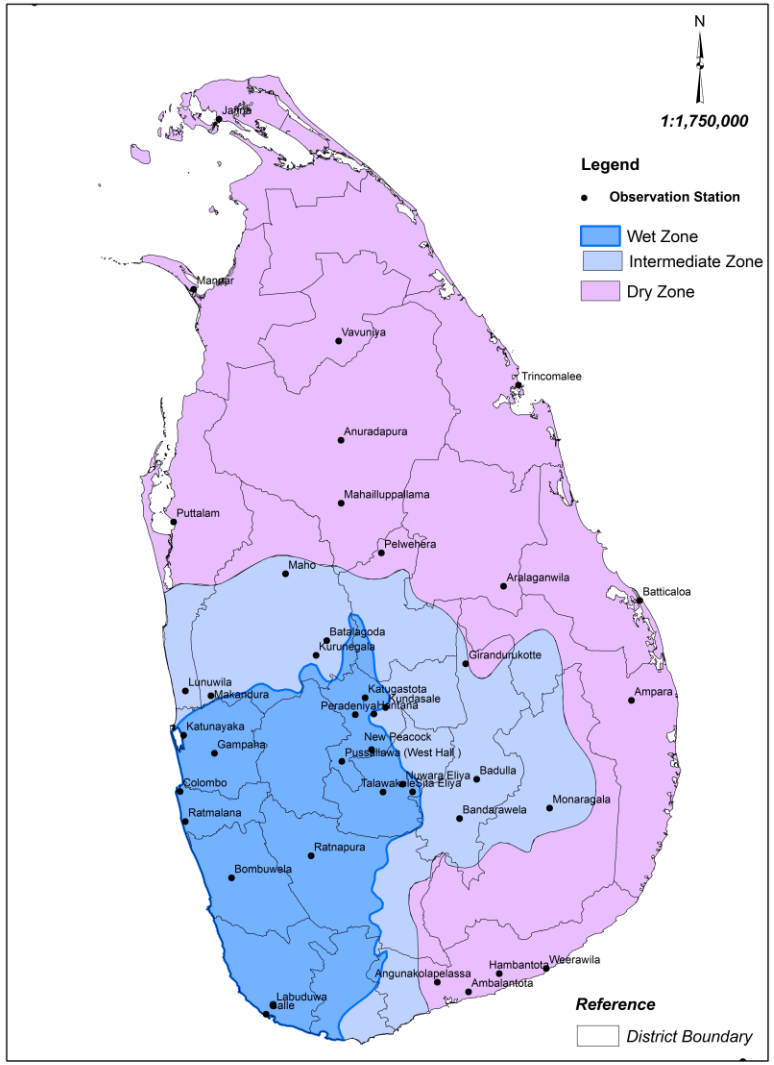
Methodology

Daily Rainfall data

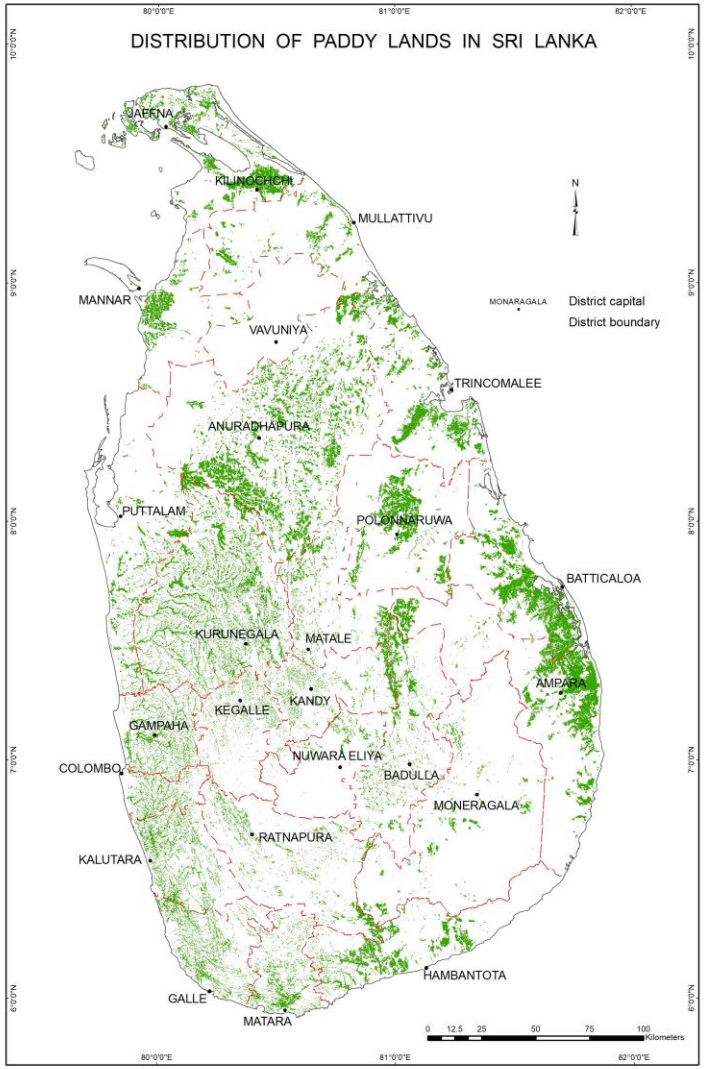
- 41 weather stations across the three major climatic zones (WZ, IZ & DZ)
- from 1976 to 2020

Paddy cultivation data

- District-wise paddy data
- Cultivation data - sown and harvested extents
  - major irrigation
  - minor irrigation
  - rainfed
- paddy productivity and production data
- from 1979 to 2020



Location map for the selected rainfall observation stations in Sri Lanka



Spatial distribution of paddy lands in Sri Lanka

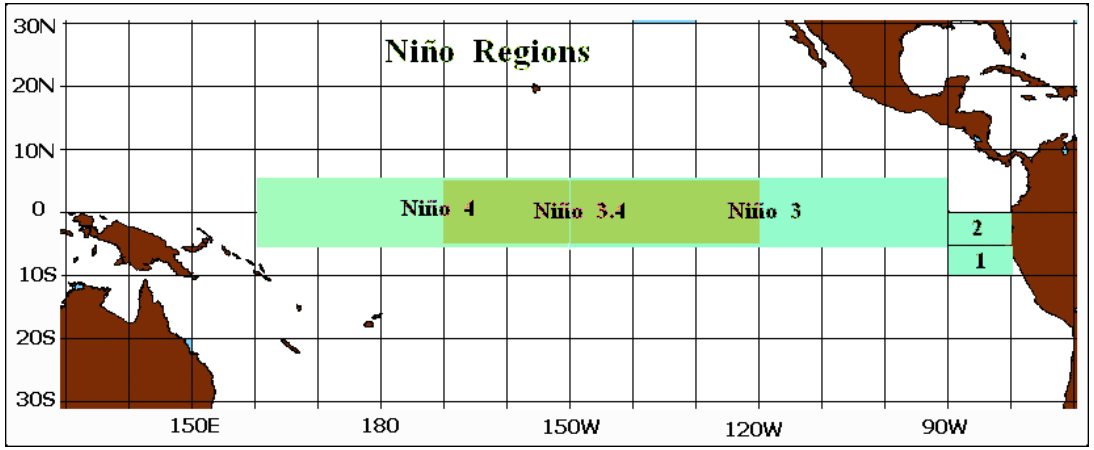
Rainfall indices used in the study

- In the present study, ENSO or IOD events analyzed related to the neutral years

Index	Definition
Cumulative seasonal rainfall (mm)	Total rainfall received during the season or month
Number of wet days	Total number of days that received rainfall >1mm during the season
Number of heavy rainfall events	Total number of days that received rainfall higher than the value of 90th percentile of the standard average period
Maximum consecutive dry days	The largest count of consecutive days that received rainfall <1mm during the season

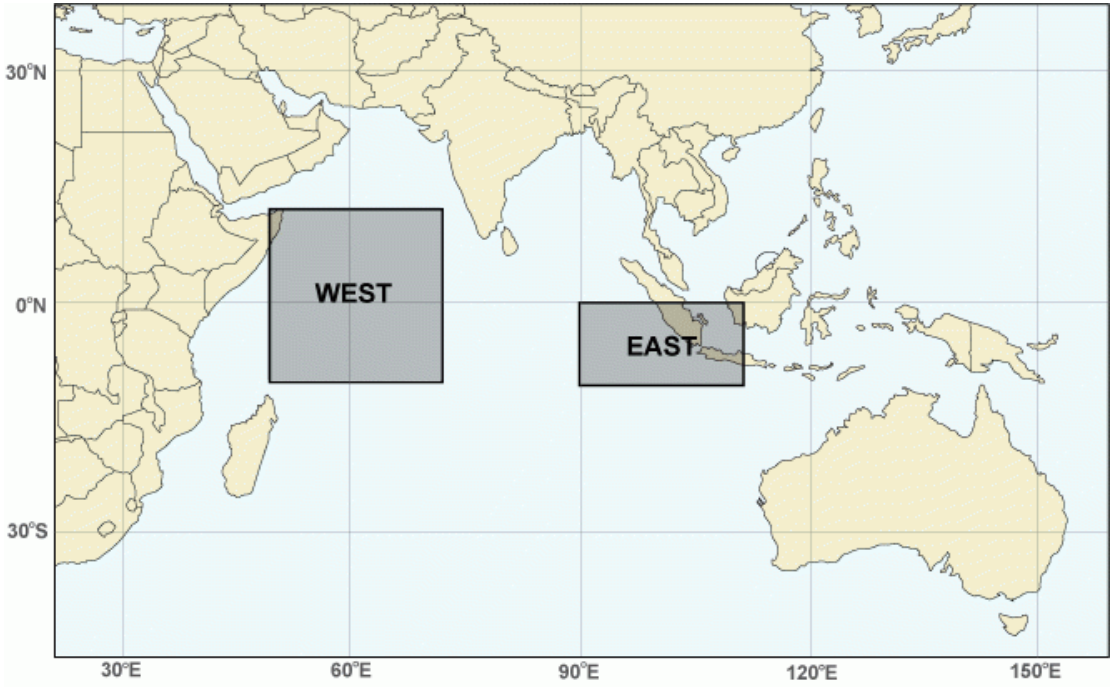
Sea Surface Temperature (SST) data

ENSO - Ocean Nino Index (ONI)



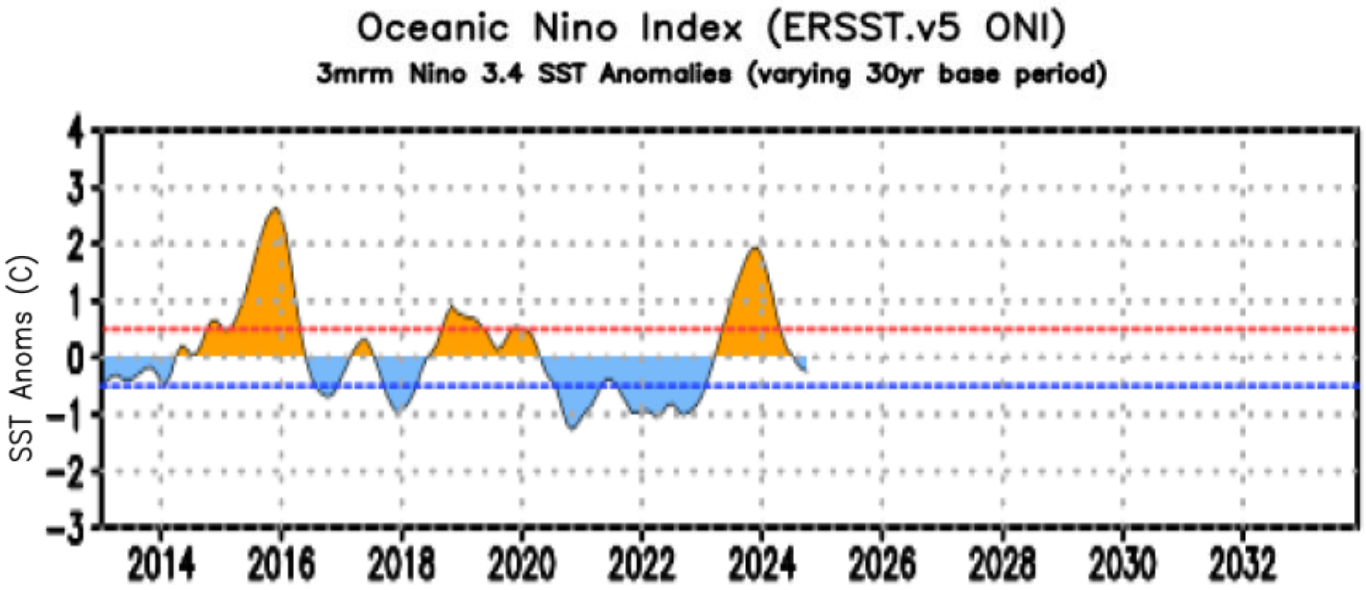
Nino 3.4 region (5ºN-5ºS,120º-170ºW)
(source: http://ggweather.com/enso/glossary.htm)

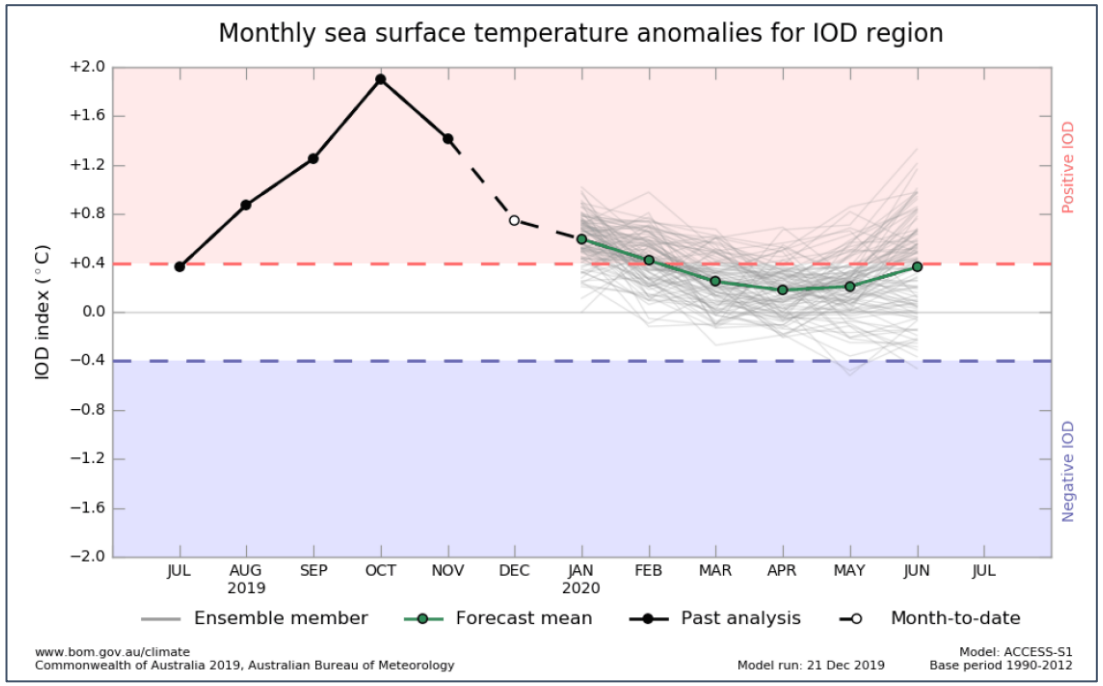
IOD - Dipole Mode Index (DMI)



The two poles in the Indian Ocean (Source: BOM, 2023)

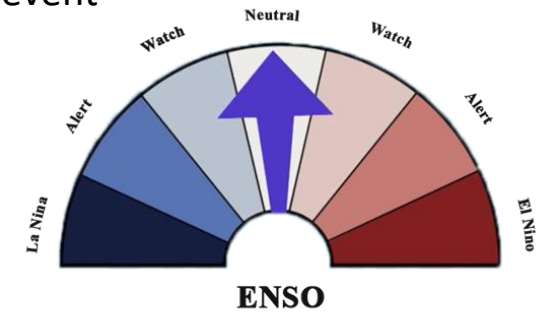
Data source: National Oceanic and Atmospheric Administration (NOAA) of the United States Climate Prediction Centre (CPC)





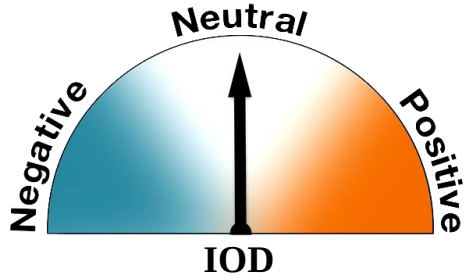
ONI index based ranges,

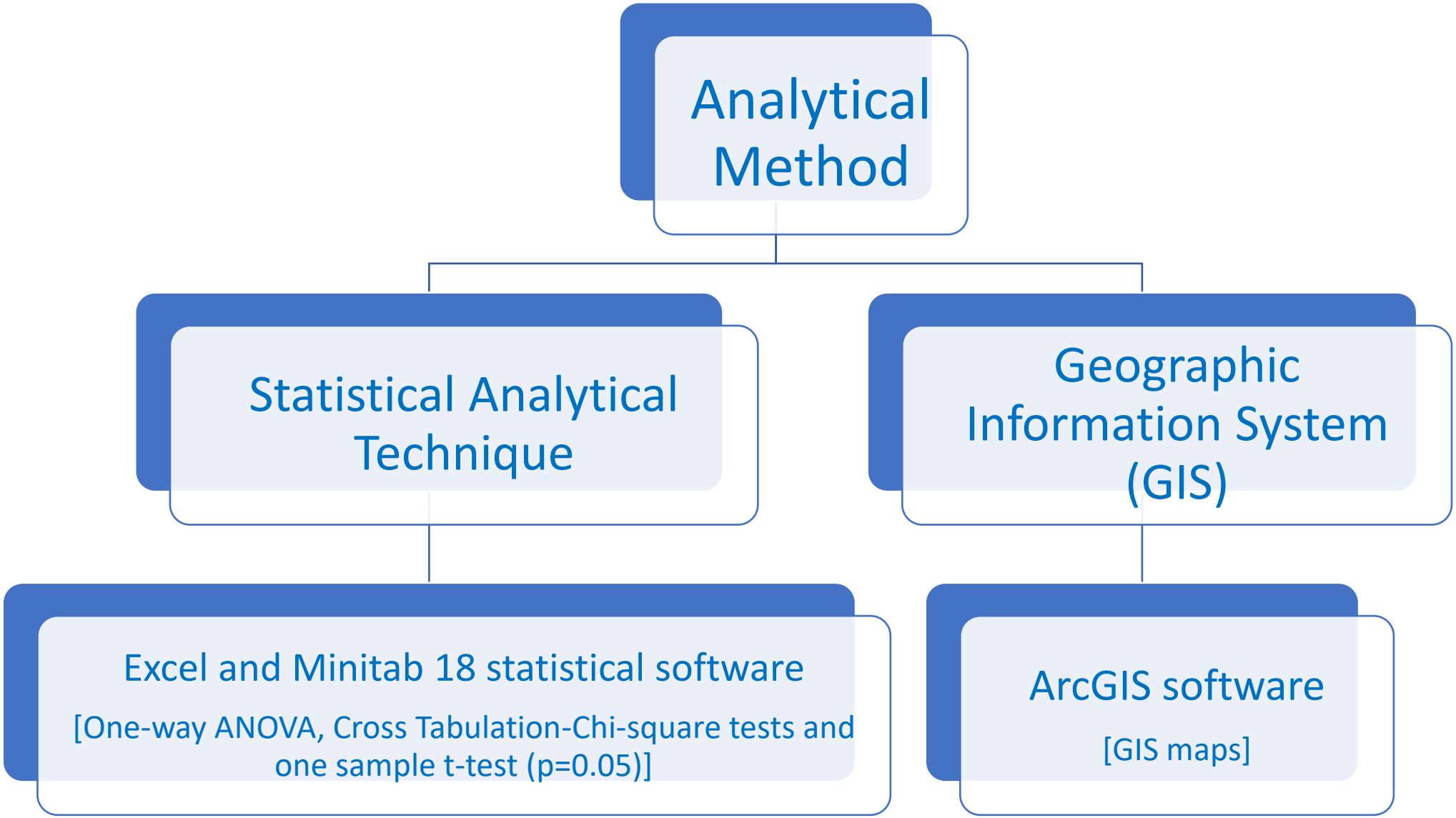
- -0.5 °C to +0.5 °C = ENSO-neutral period
- above +0.5 °C = *El Niño* events
- below −0.5 °C = *La Niña* event



DMI index based ranges,

- -0.4 °C to +0.4 °C = IOD-neutral period
- above +0.4 °C = IOD-Positive events
- below −0.4 °C = IOD-Negative event




Analytical Method
Statistical Analytical Technique
Geographic Information System (GIS)
Excel and Minitab 18 statistical software
[One-way ANOVA, Cross Tabulation-Chi-square tests and one sample t-test (p=0.05)]
ArcGIS software
[GIS maps]

ENSO and IOD events across four rainfall seasons over the study period

***El Niño* and *La Niña* years based on the ONI**

El Niño years		*La Niña years*	
SIM	NEM	SIM	NEM
1976	1976/77	1983	1983/84
1977	1977/78	1984	1984/85
1979	1979/80	1988	1988/89
1982	1982/83	1995	1995/96
1986	1986/87	1998	1998/99
1987	1987/88	1999	1999/00
1991	1991/92	2000	2000/01
1994	1994/95	2007	2005/06
1997	1997/98	2010	2007/08
2002	2002/03	2011	2008/09
2004	2004/05	2016	2010/11
2006	2006/07	2017	2011/12
2009	2009/10		2017/18
2014	2014/15		
2015	2015/16		
2018	2018/19		

IOD-positive and IOD-negative events based on the DMI

IOD-Positive Years		IOD-Negative Years	
SIM	NEM	SIM	NEM
1982	1998/99	1980	1978/79
1994	2019/20	1984	1983/84
1997		1996	1985/86
2006		1998	
2011		2010	
2015			
2018			
2019			

Results and Discussion

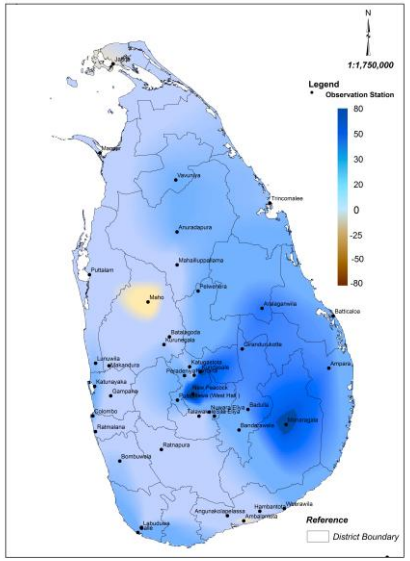
Impact of *El Niño* and IOD-positive phenomena on the rainfall regime of SIM and NEM rains and their influence on the *Maha* seasonal paddy production

Rainfall deviations as influenced by *El Niño* events during the SIM period over neutral years

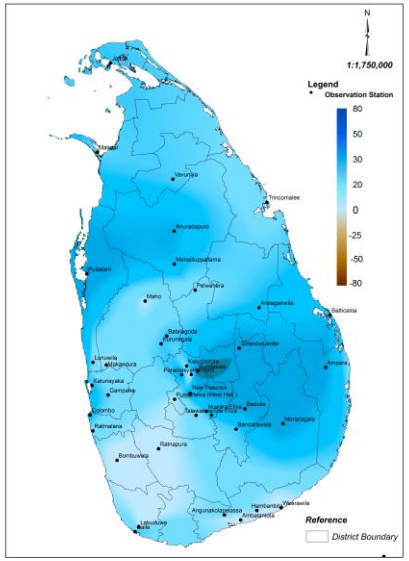
Significant events (p<0.05)

Rainfall Index (*El Niño* years)	Number of stations (out of 41)	Range of rainfall variation (%)
Mean cumulative rainfall	6	30 to 63
Number of wet days	34	4 to 33
Number of heavy rainfall events	13	27 to 70
Maximum consecutive dry days	6	(-30) to (-57)

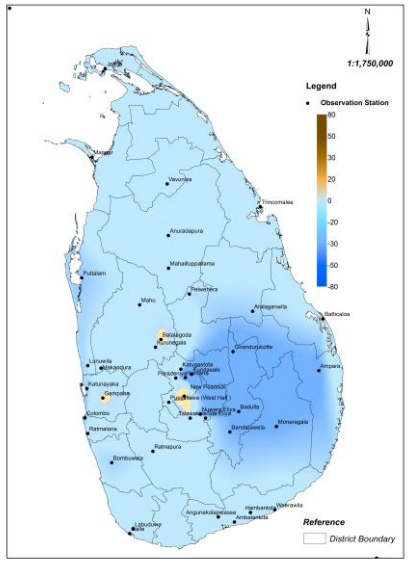
El Niño



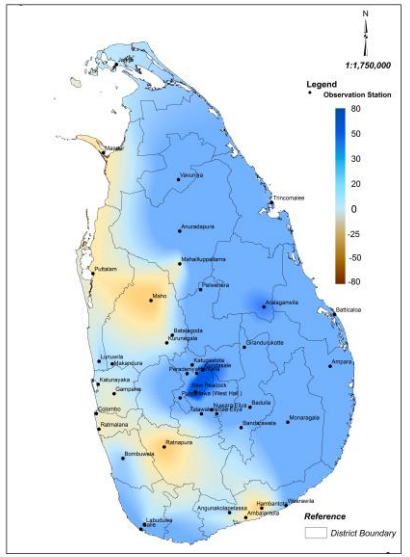
Mean cumulative rainfall



Number of wet days



Number of heavy rainfall events



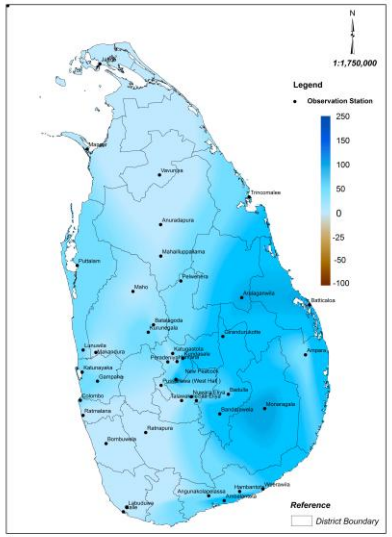
Maximum consecutive dry days

Rainfall deviations as influenced by IOD-positive events during the SIM period over neutral years

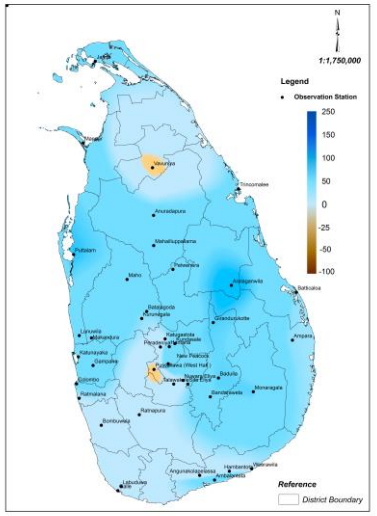
Significant events ($p<0.05$)

Rainfall Index (IOD-positive years)	Number of stations (out of 41)	Range of rainfall variation (%)
Mean cumulative rainfall	15	34 to 72
Number of wet days	33	30 to 84
Number of heavy rainfall events	30	17 to 44
Maximum consecutive dry days	9	(-40) to (-55)

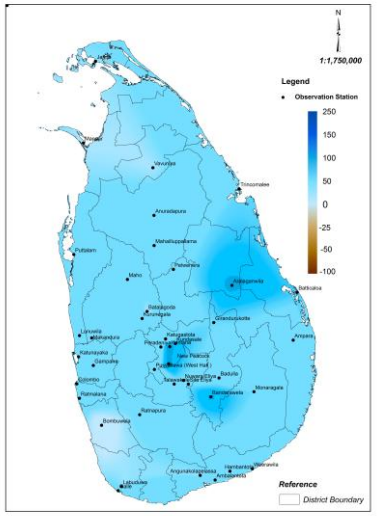
IOD-positive



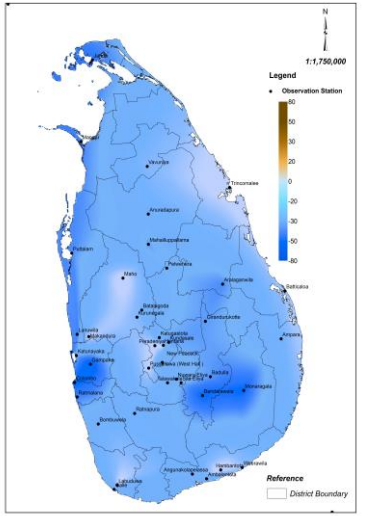
Mean cumulative rainfall



Number of wet days



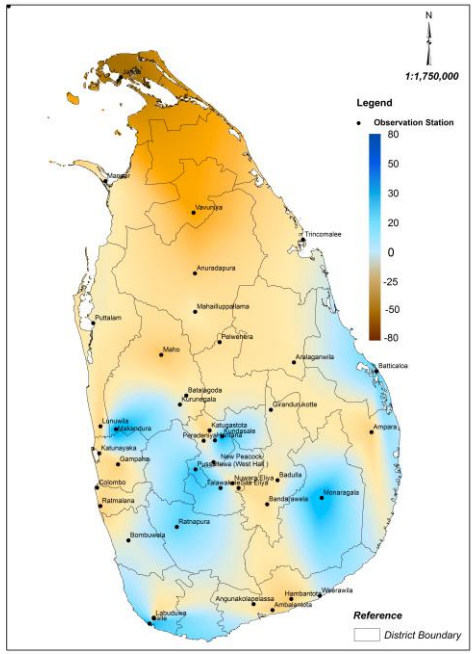
Number of heavy rainfall events



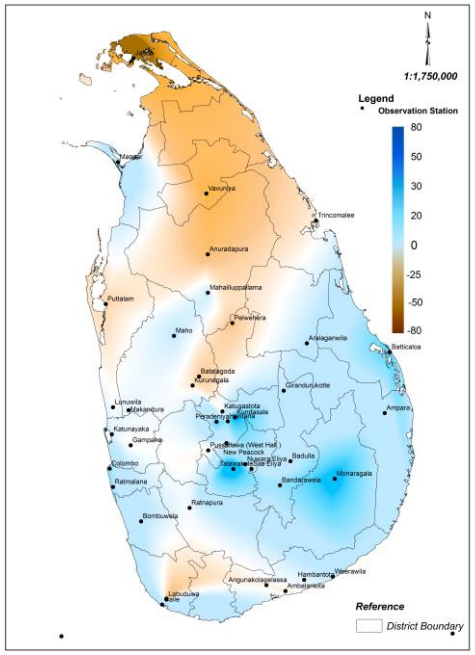
Maximum consecutive dry days

Rainfall deviations as influenced by *El Niño* events in NEM period over neutral years

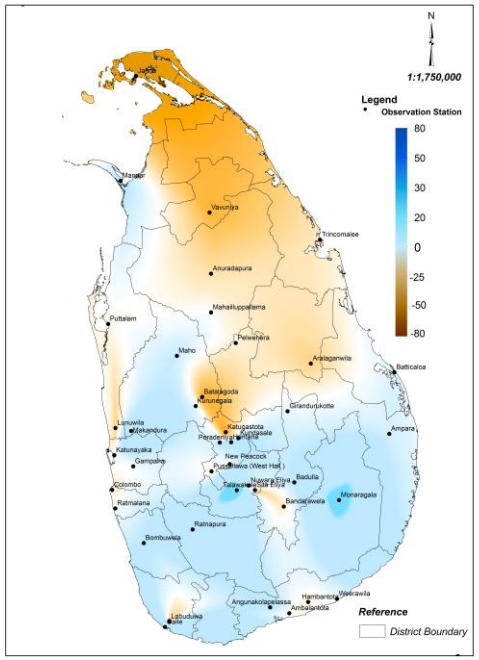
El Niño



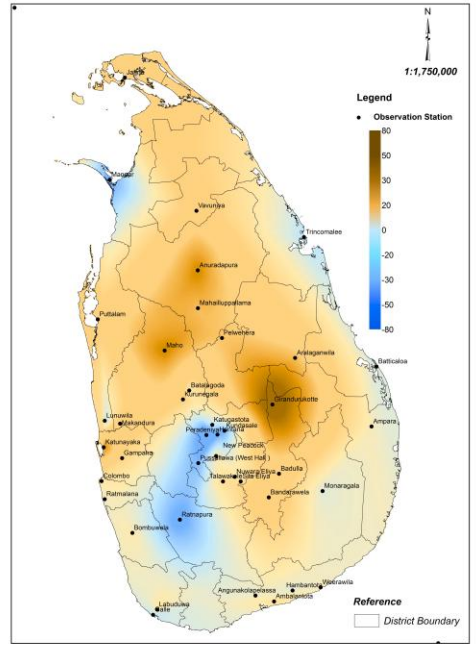
Mean cumulative rainfall



Number of wet days



Number of heavy rainfall events



Maximum consecutive dry days

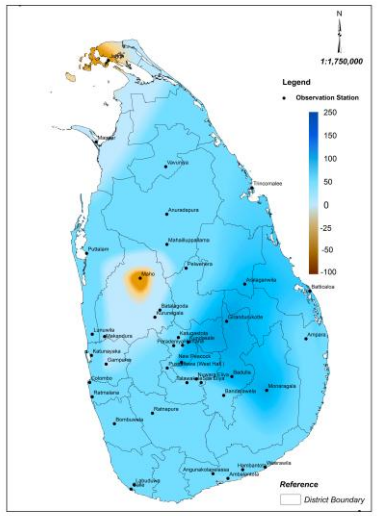
- Previous studies observed a weak, negative correlation of SOI and NEM rainfall during *El Niño* years (Suppiah (1989); Punyawardena and Cherry (1999), Malmgren *et al*. (2003) and Punyawardena *et al*. (2004)
- All three major climatic zones did not exhibit a consistent positive or negative relationship
- Seven significant increasing events ($p<0.05$) observed in wet days

Deviations in mean monthly cumulative rainfall as influenced by *El Niño* events during *Maha* seasons over neutral years

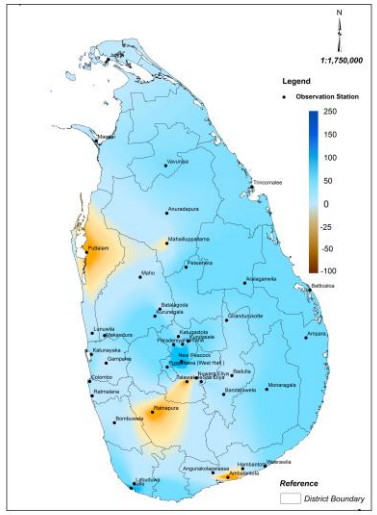
SIM period

NEM period

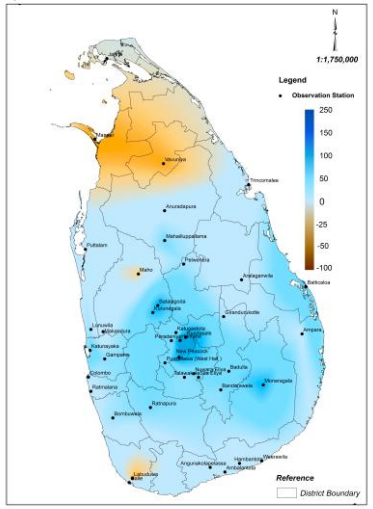
El Niño



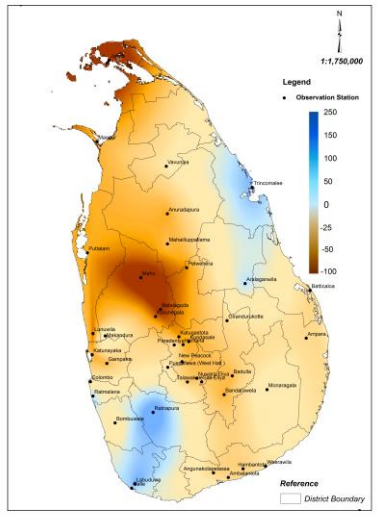
October



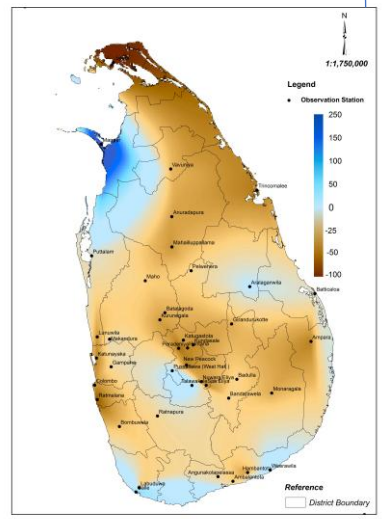
November



December

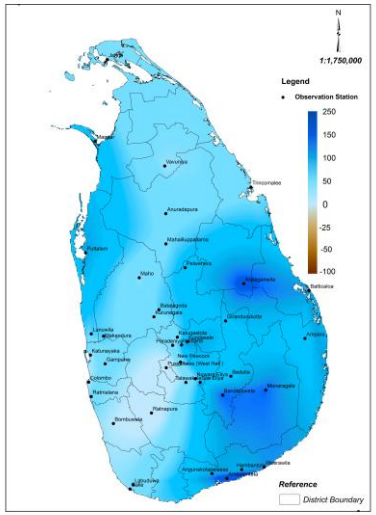


January

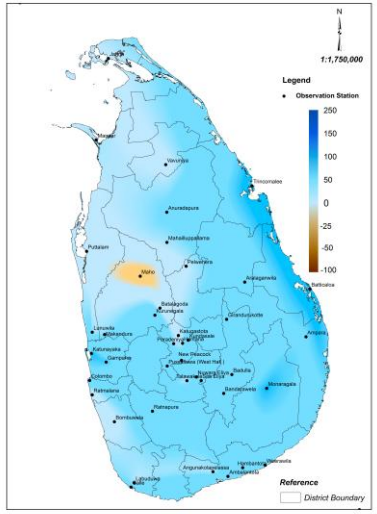


February

IOD-positive



October

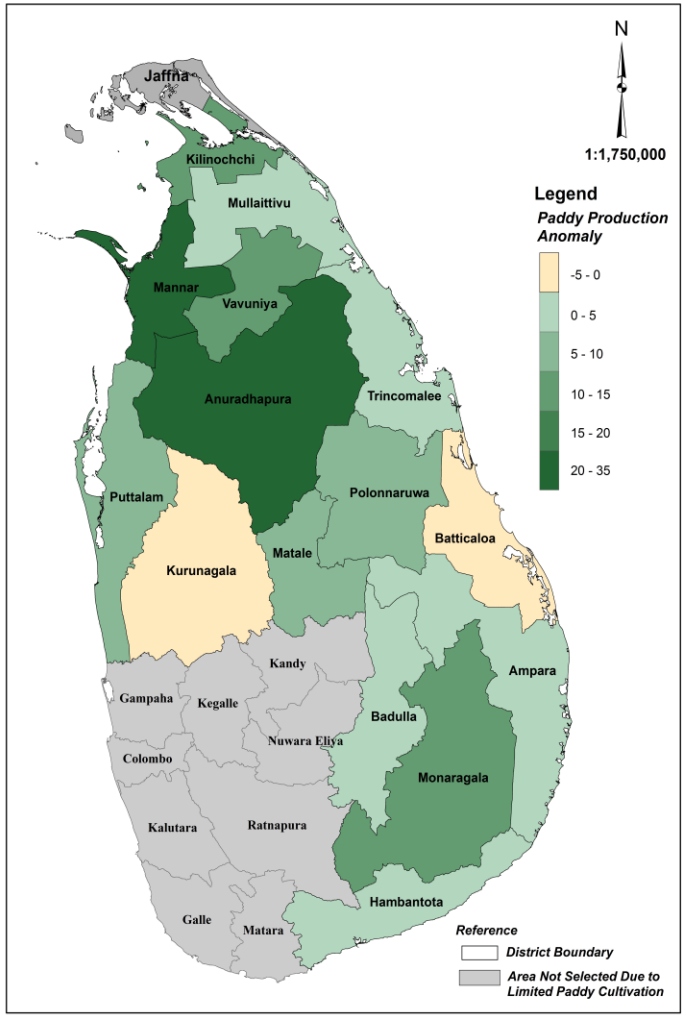


November

- Most frequent occurrences of ENSO peaks observed in December (Tziperman *et al*., 1998)
- The weather systems - leads to positive anomaly of rainfall during December - masked the impact of the *El Niño* effect
- The positive impact in December and negative impact of January and February – resulted insignificant *El Niño* impact – during NEM period

The mean paddy production anomalies in *Maha* seasons during *El Niño* years compared to neutral years

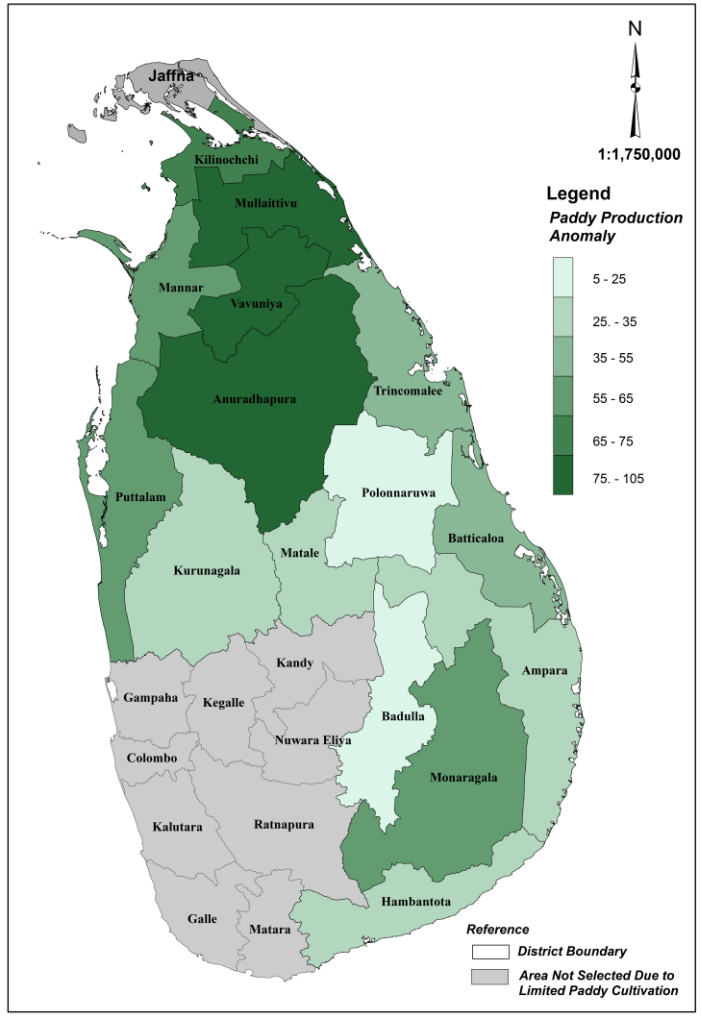
- Among 15 selected major paddy-growing districts, 13 showed an increase in paddy production
  - During the first half of the season – heavy rains – lead to an increase in sown extent
- The events were not statistically significant
  - Flood conditions – lead to resowing, crop damages, and abandoning the season
  - During *El Niño* years, the effect of the NEM rains can cause water scarcity conditions
  - Major/ minor irrigation – higher carry-over storage – tolerate the situation during flowering and PI stages – leads to the increased harvested extent and productivity
  - However, rainfed systems – negatively impacted



Mean paddy production anomalies during *El Niño* years

The mean paddy production anomalies in *Maha* seasons during IOD-positive years compared to neutral years

- All 15 selected major paddy growing districts - showed an increase in paddy production
  - Heavy rains – lead to an increase in the production (productivity and extent)
- Nine statistically significant positive events were observed
  - According to the normal climatology of the country (since the IOD-neutral period), the second half of the season – weather conditions – suitable for normal agronomic activities



Mean paddy production anomalies during IOD-positive years

The expected *El Niño* and IOD-positive impact on the paddy production in *Maha* seasons compared to neutral years

El Niño

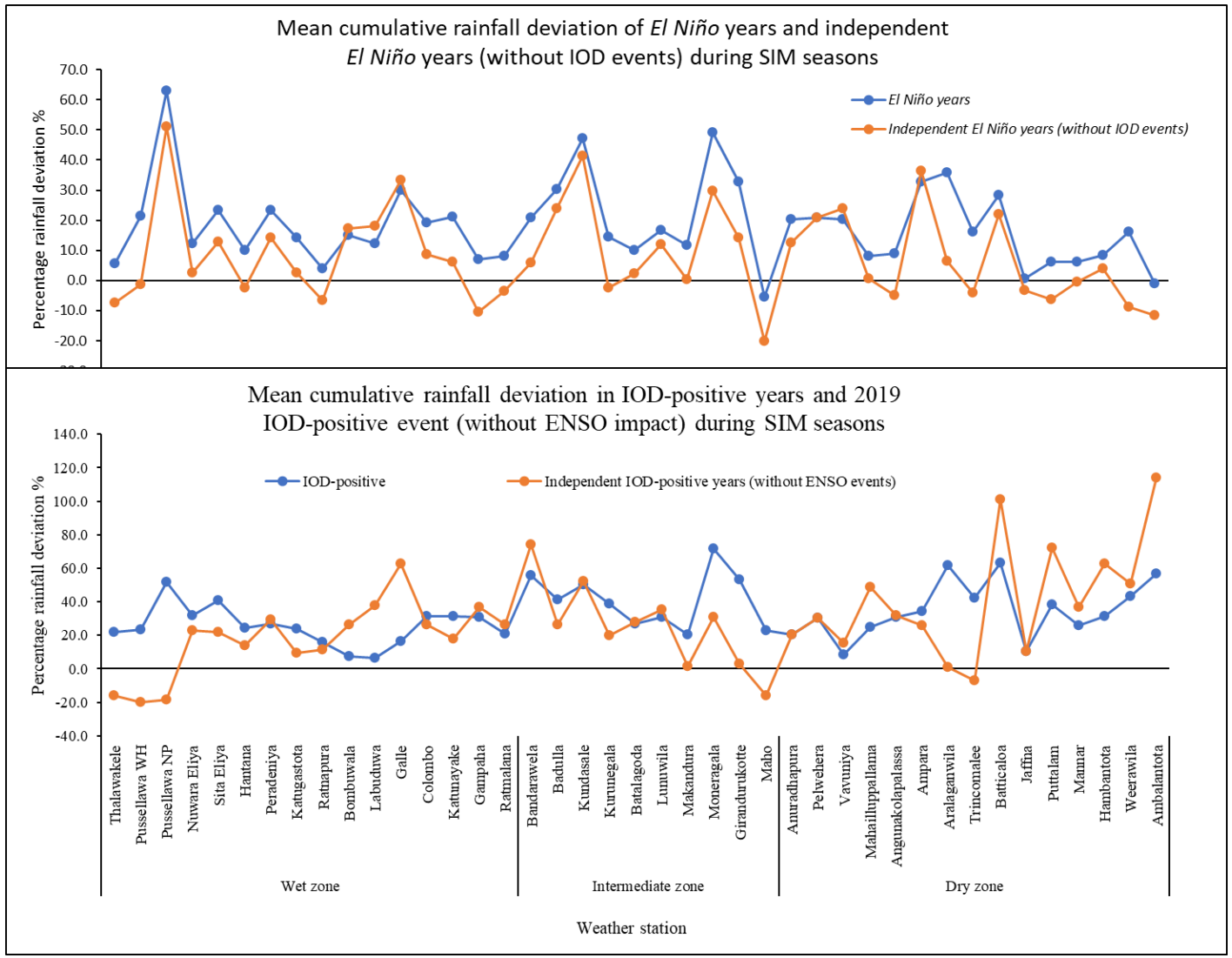
Maha season	Mean paddy production (%)		
***El Niño* impacts (95% CI)**	6.2	to	17.1

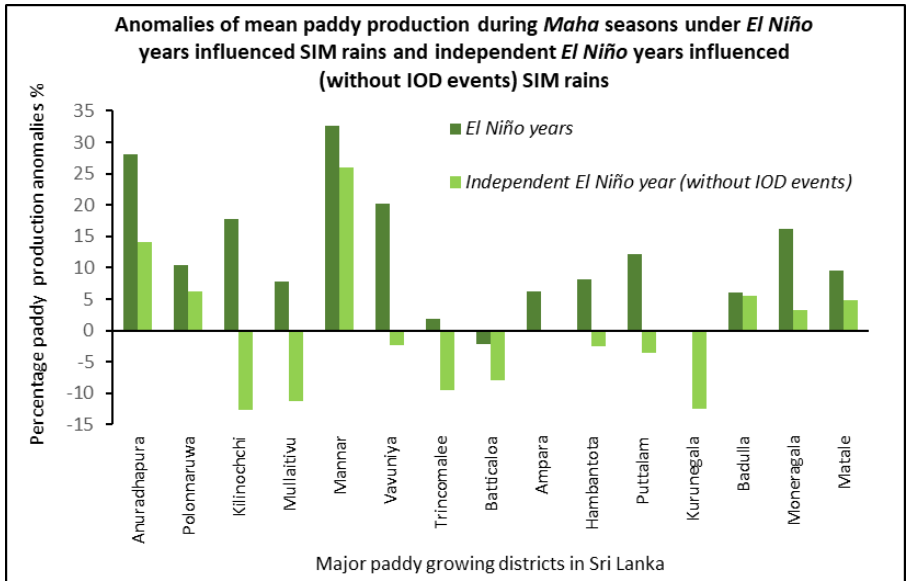
IOD-positive

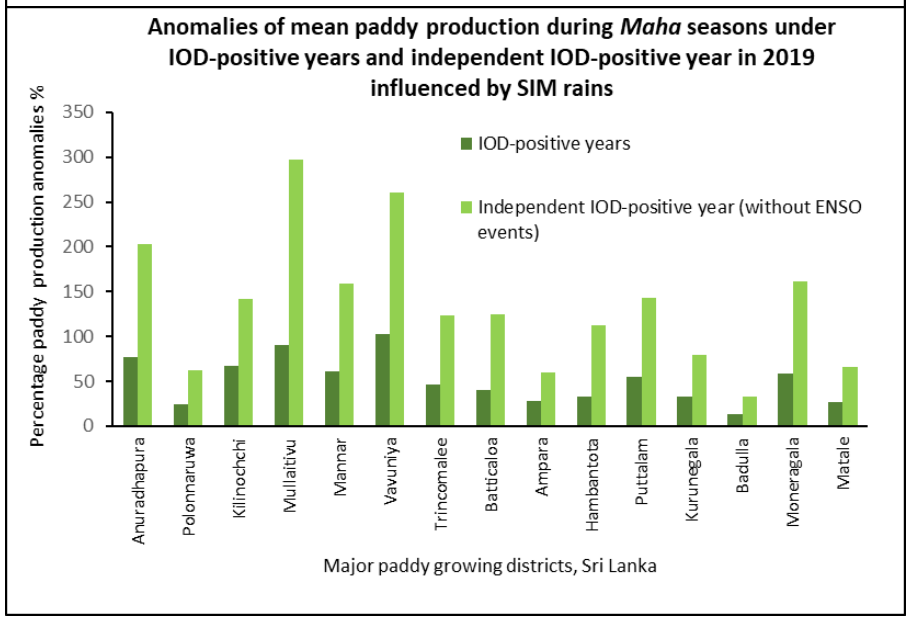
Maha season	Mean paddy production (%)		
Impact of IOD-positive phase (95% CI)	36.3	to	65.0

*Values presented as the 95% Confidence Interval (CI)

Rainfall deviations in SIM rains as influenced by independent *El Niño* and IOD positive events compared to combined events







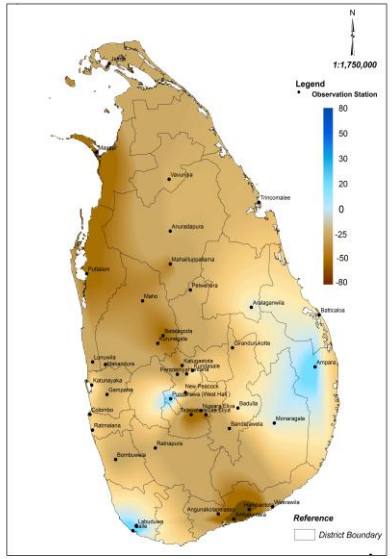
Impact of *La Niña* and IOD-negative phenomena on the rainfall regime of SIM and NEM rains and their influence on the *Maha* seasonal paddy cultivation

Rainfall deviations as influenced by *La Niña* events during the SIM period over neutral years

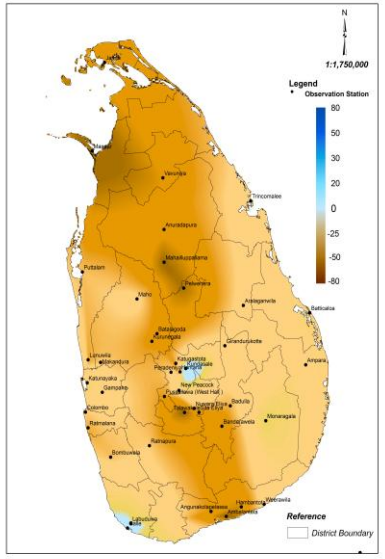
Significant events (p<0.05),

Rainfall Index (*La Niña* years)	Number of stations (out of 41)	Range of rainfall variation (%)
Mean cumulative rainfall	9	(-25) to (-41)
Number of wet days	27	(-8) to (-28)
Number of heavy rainfall events	16	(-26) to (-44)
Maximum consecutive dry days	1	43

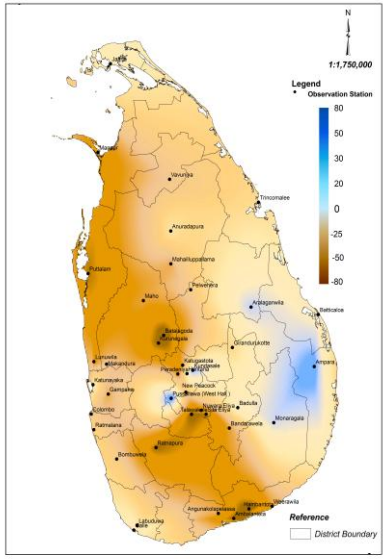
La Niña



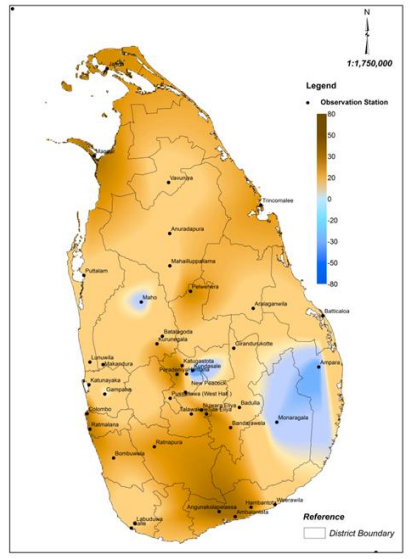
Mean cumulative rainfall



Number of wet days



Number of heavy rainfall events



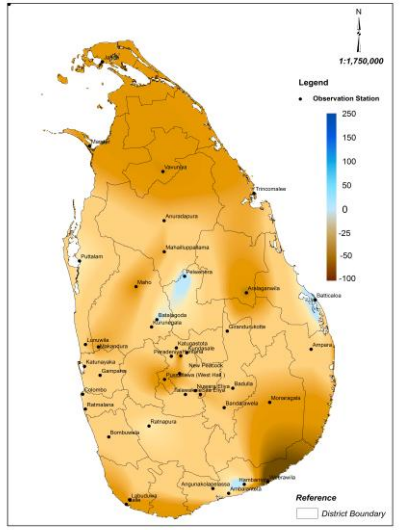
Maximum consecutive dry days

Rainfall deviations as influenced by IOD-negative events during the SIM period over neutral years

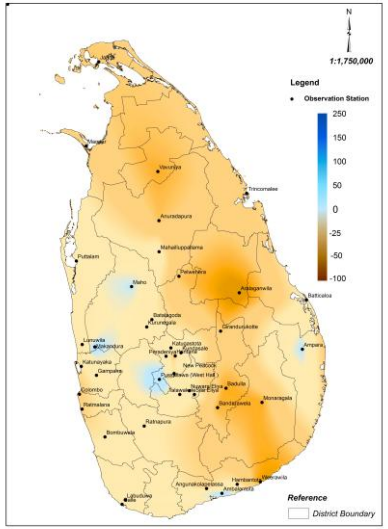
Significant events ($p<0.05$),

Rainfall Index (IOD-negative years)	Number of stations (out of 41)	Range of rainfall variation (%)
Mean cumulative rainfall	1	(-33)
Number of wet days	17	(-13) to (-27)
Number of heavy rainfall events	4	(-38) to (-58)
Maximum consecutive dry days	7	50 to 80

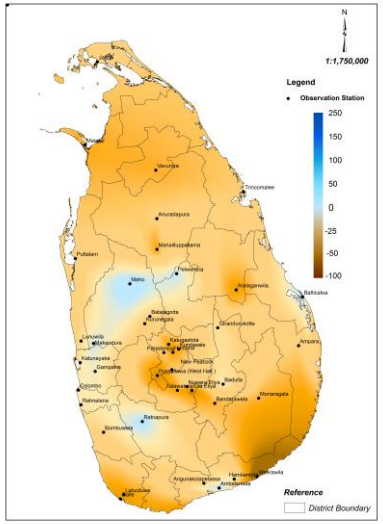
IOD-negative



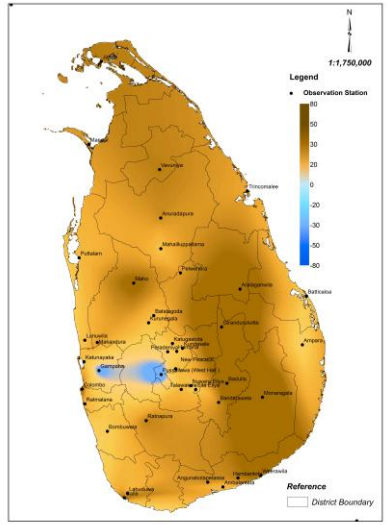
Mean cumulative rainfall



Number of wet days



Number of heavy rainfall events

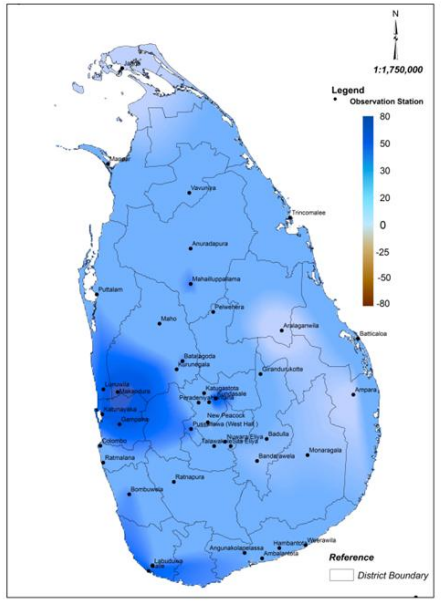


Maximum consecutive dry days

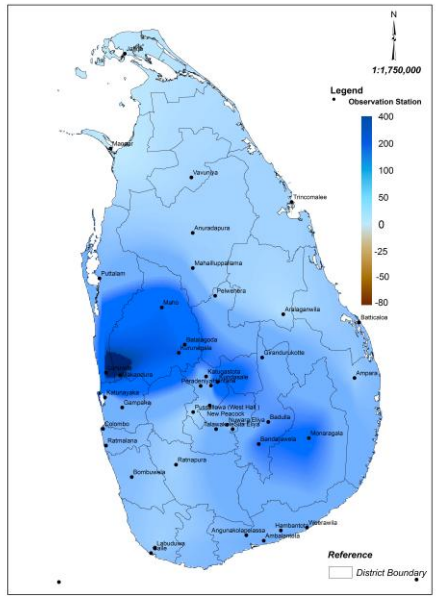
Rainfall deviations as influenced by *La Niña* events in NEM period over neutral years

Significant events (p<0.05),

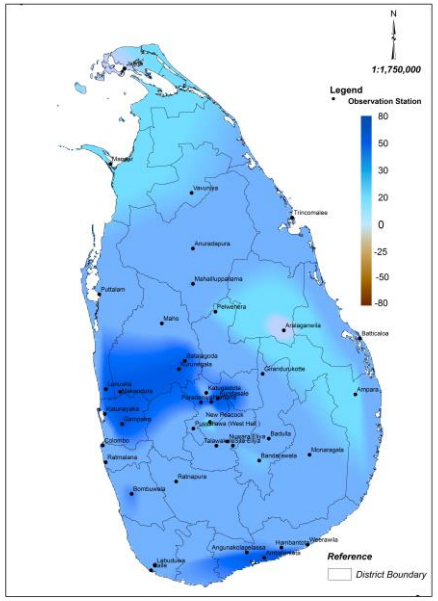
Rainfall Index (*La Niña* years during NEM)	Number of stations (out of 41)	Range of rainfall variation (%)
Mean cumulative rainfall	5	58-82
Number of wet days	39	12-100
Number of heavy rainfall events	36	23-73
Maximum consecutive dry days	8	40-74



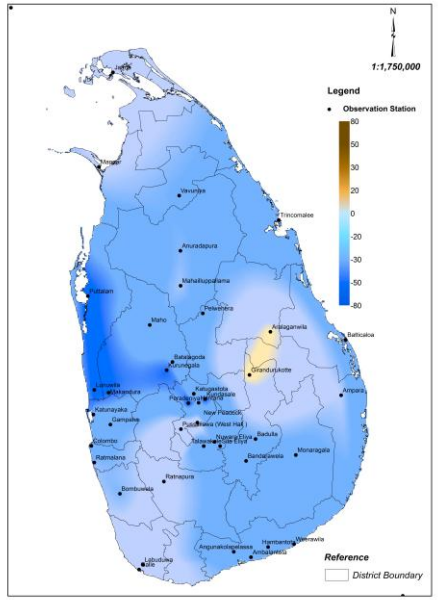
Mean cumulative rainfall



Number of wet days



Number of heavy rainfall events



Maximum consecutive dry days

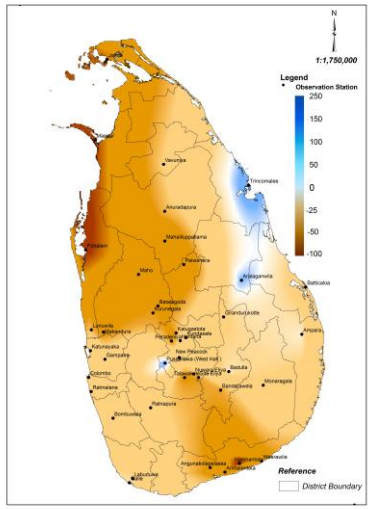
- Previous studies also observed - stronger increasing impact in NEM rainfall during *La Niña* years (Hapuarachchi and Jayawardena, 2015; Jayakody, 2015)

Deviations in mean monthly cumulative rainfall as influenced by *La Niña* events during *Maha* seasons over neutral years

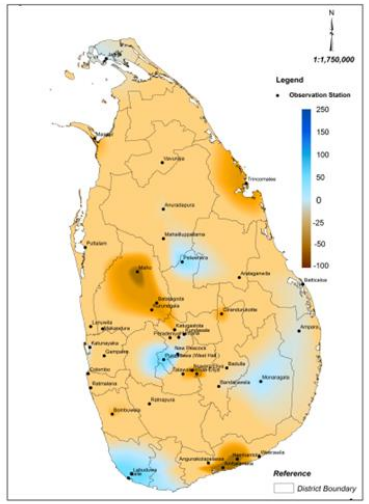
SIM period

NEM period

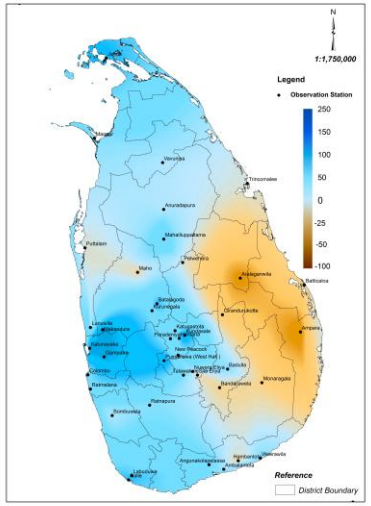
La Niña



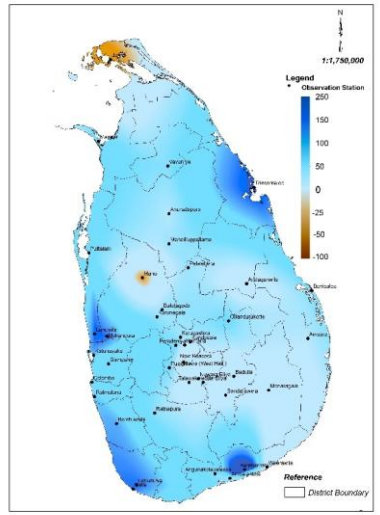
October



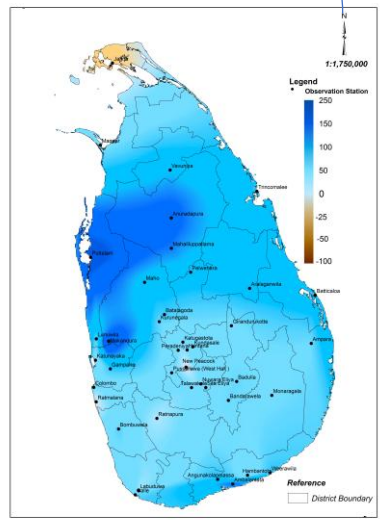
November



December

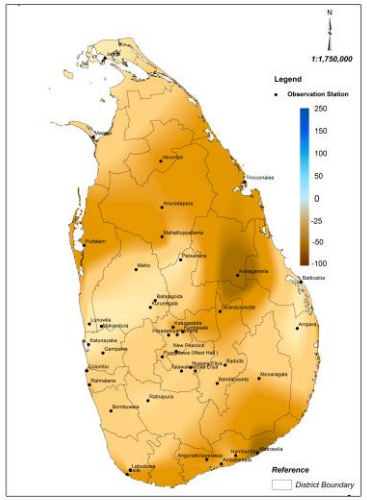


January

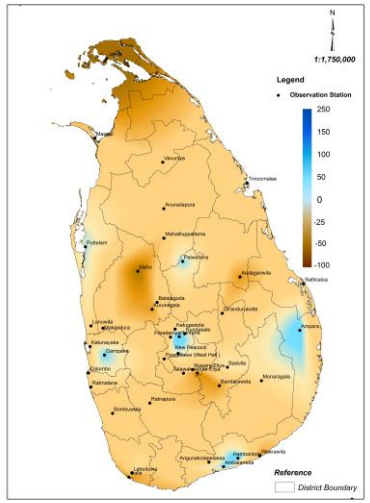


February

IOD-negative



October

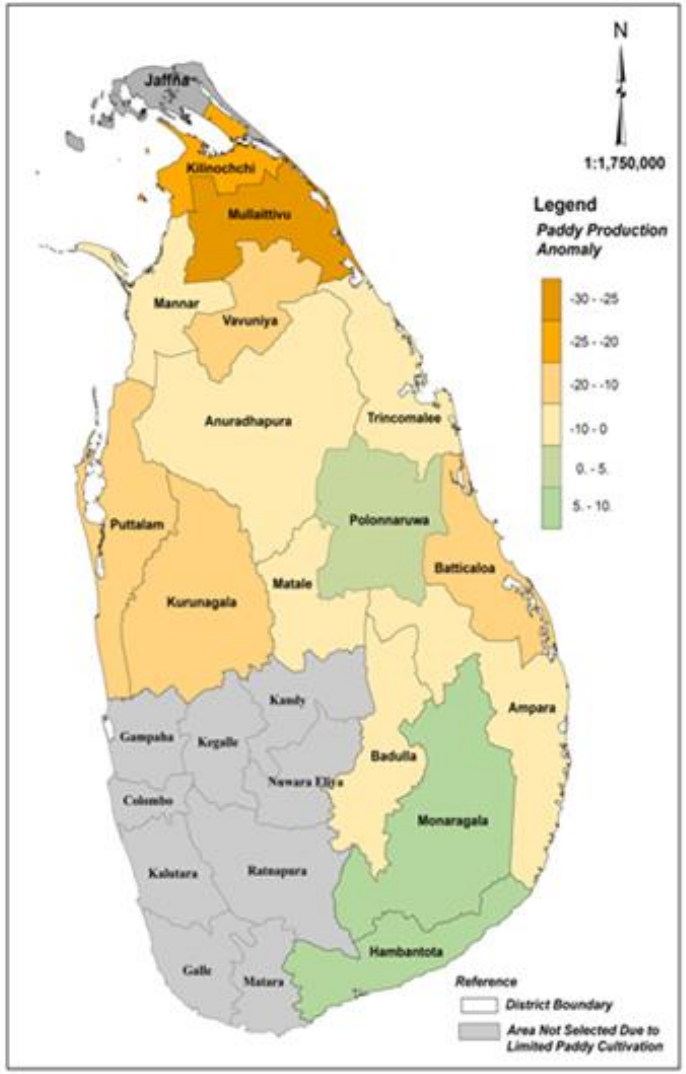


November

- December – the transitional month from below-normal rain under the *La Niña* effect to above-normal
- The weather systems – lead to an increase - short, intense rains during December - masked the *La Niña* impact
- Out of 41 stations four significant decreasing events ($p<0.05$) were observed in January under the *La Niña* impact

The mean paddy production anomalies in *Maha* seasons during *La Niña* years compared to neutral years

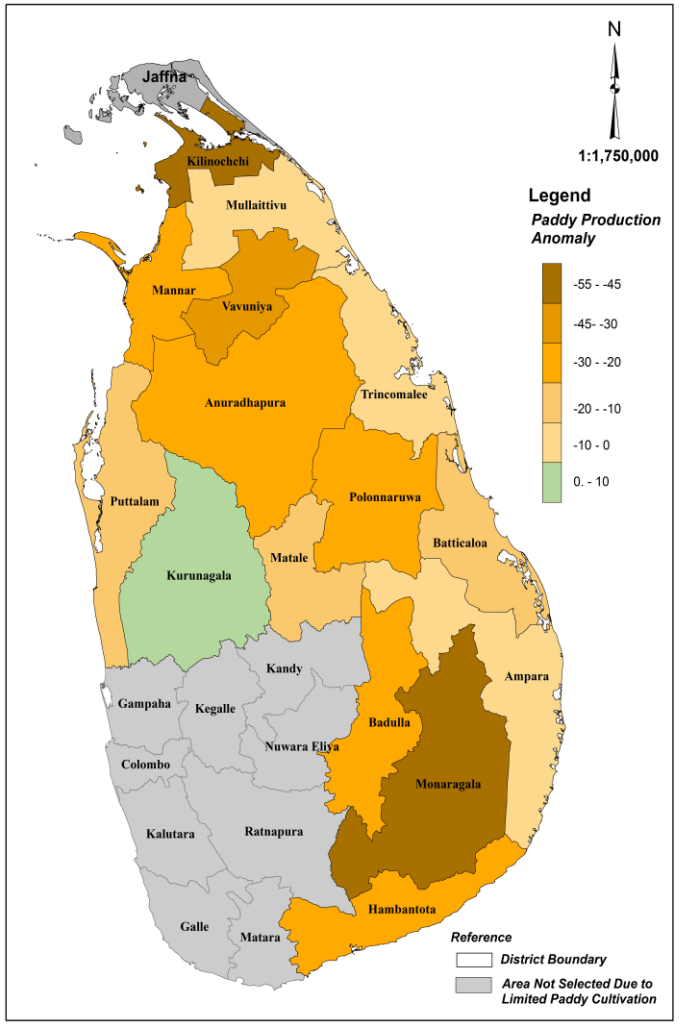
- Among 15 selected major paddy growing districts 12 showed a reduction in paddy production
  - Below normal SIM rains lead to a reduction of the sown extent
- These events were not statistically significant
  - Enhanced rainfall during the NEM period- resulted
    - late cultivations
    - rains during flowering and PI stages
  - This inconsistency – affects the significance of the results



Mean paddy production anomalies during *La Niña* years

The mean paddy production anomalies in *Maha* seasons during IOD-negative years compared to neutral years

- Among 15 selected major paddy growing districts 14 showed a reduction in production However, these events were not statistically significant
  - Below normal SIM rains lead to a reduction of cultivation extent as same as the productivity thereby production



Mean paddy production anomalies during IOD-negative years

The expected *La Niña* and IOD-negative impact on the paddy production in *Maha* seasons compared to neutral years

La Niña

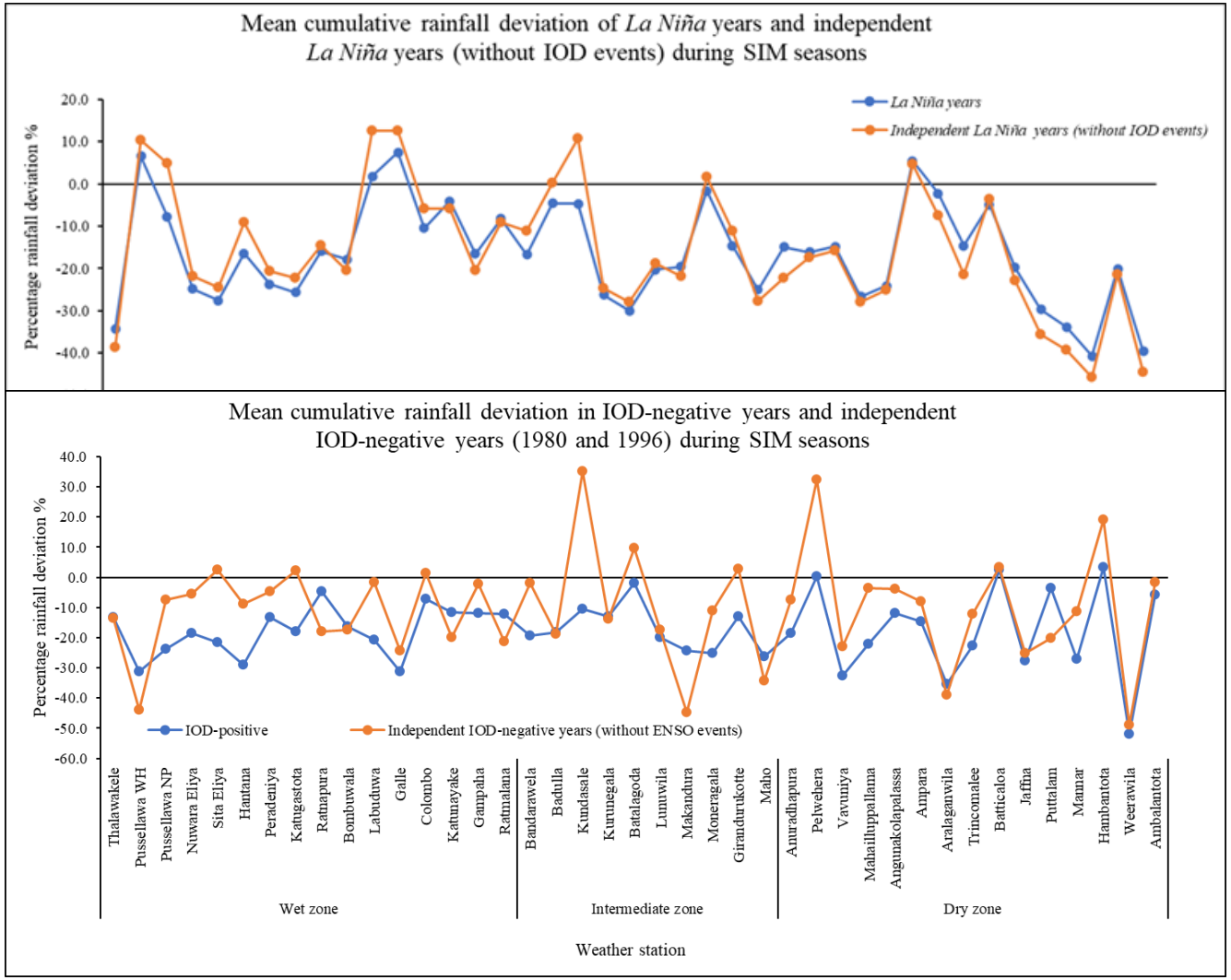
***Maha* season**	**Mean paddy production (%)**
***La Niña* impacts (95% CI)**	-12.8 to -0.6

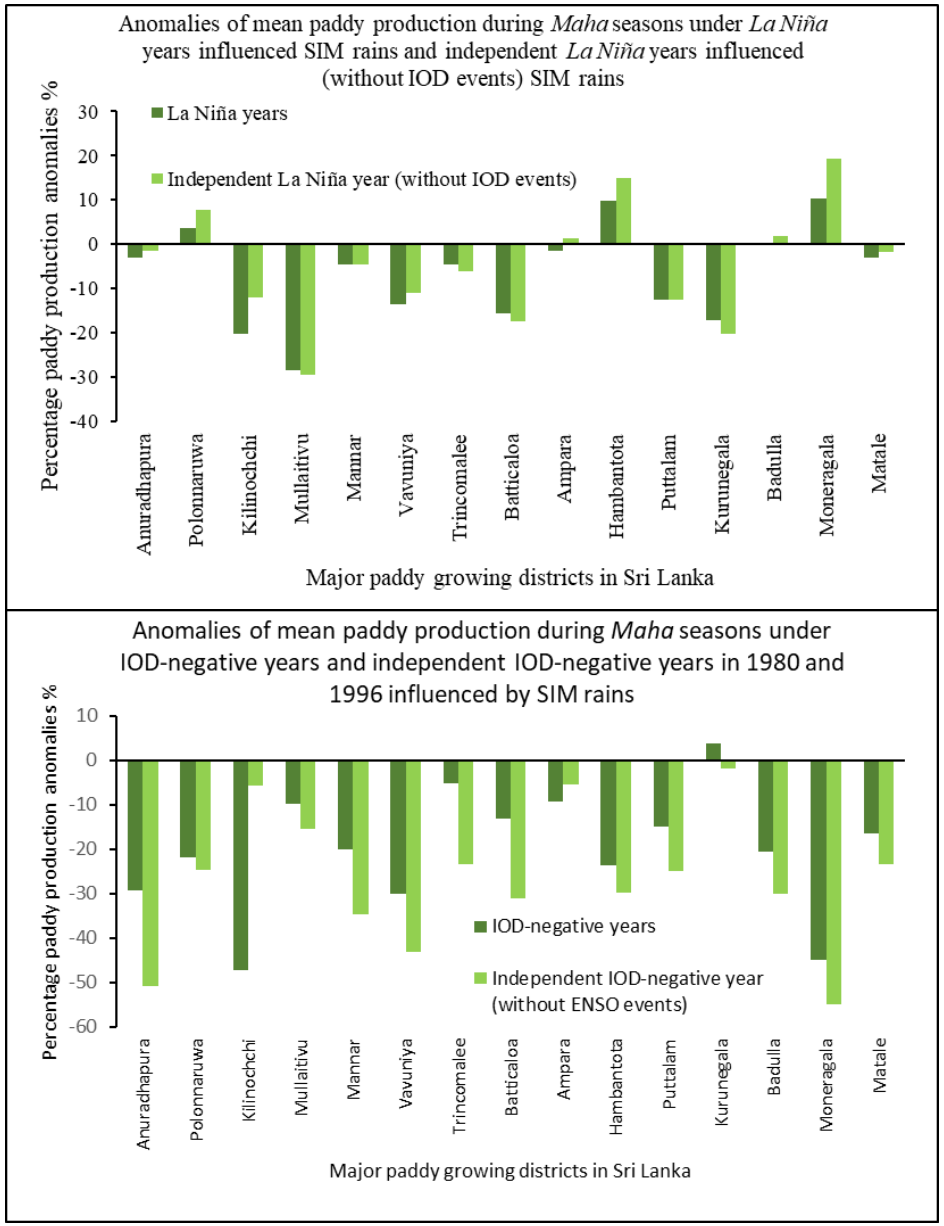
IOD-negative

***Maha* season**	**Mean paddy production (%)**
Impact of IOD-negative phase (95% CI)	-14.6 to -29.1

*Values presented as the 95% Confidence Interval (CI)

Rainfall deviations in SIM rains as influenced by independent *La Niña* and IOD-negative events compared to combined events





Conclusions

El Niño and IOD-positive phases

- Despite these opposing trends of SIM and NEM rains - the national paddy production expected - an increase of 6.2-17.1% in *El Niño* years
- With the above normal SIM rains paddy production showed 36.3 to 65.0% increase during IOD-positive years ($p<0.05$)

La Niña and IOD-negative phases

- Expected impact - reduction of SIM rains and above normal NEM rains - reduction in national paddy production by 0.6-12.8% under *La Niña* impact and 14.6-29.1% under IOD-negative impact ($p<0.05$)

Combined impact over independent impact

- Combined occurrence ENSO and IOD years synergizes positive or negative impact on SIM rainfall
- Independent ENSO events – weak or moderate thus the effect – not significant
- Independent IOD events – rare – difficult to undertake robust statistical testing during the study period [the highest paddy production recorded in 2019/2020 *Maha* season (3.19 million Mt) - independent IOD-positive event - persisted]

Limitations of the study

ENSO and IOD impact on paddy cultivation affect - both climatic and non-climatic factors

Climatic factors

- Contradictory effects of ENSO on SIM and NEM rainfall seasons within the same cultivation season (*Maha*)
- Influence of synoptic weather changes
- weather aberrations due to climate change
- Diverse micro-climate in the country

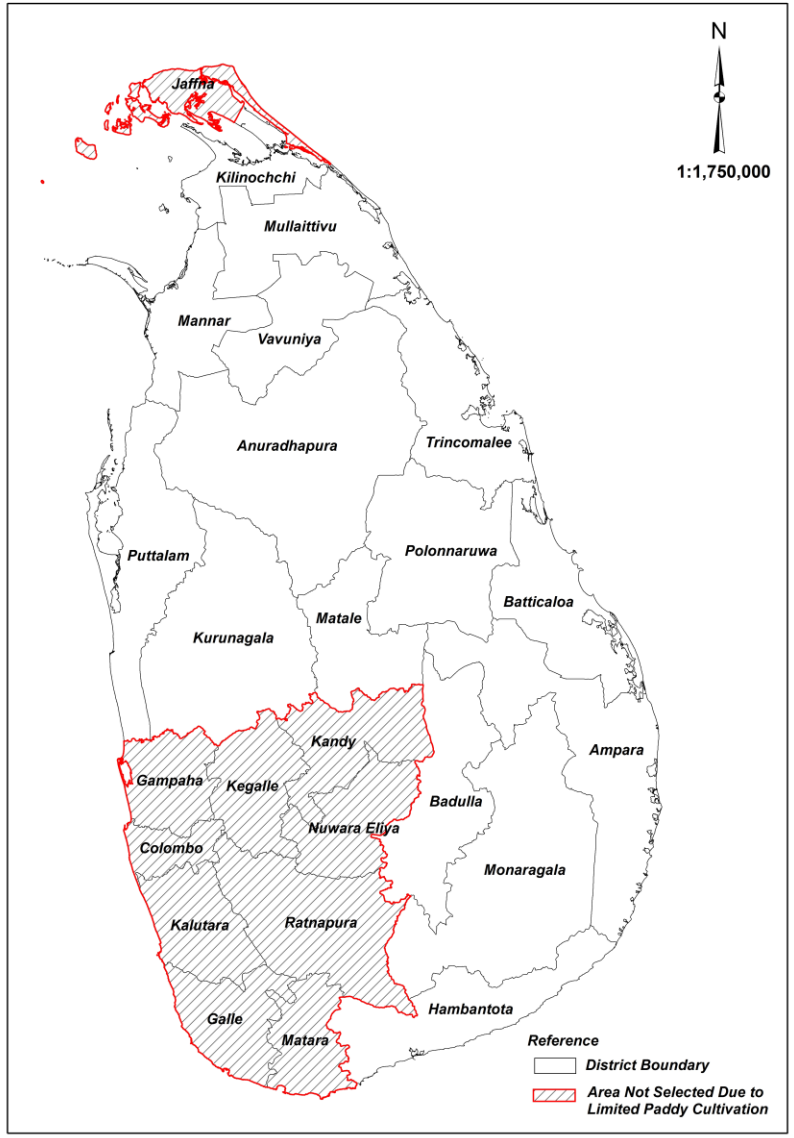
Non-climatic factors

- Availability and price fluctuations of inputs such as agrochemicals and seeds
- management practices
- pest, disease and weed management
- fuel prices affecting machinery usage
- changing policy environment and political decisions

Thank you

Identification of the major paddy-growing districts in Sri Lanka

- Percentage paddy lands out of the total arable lands (> 30 %)
- Average paddy yield in each district (> 4.3 t/ha)
- Districts located in the Dry and Intermediated zones (if it is spread in more than one climatic zone, the zone with higher extent was considered) and
- Contribution to the national paddy production (> 2 %)



The selected major paddy-growing districts for this study