"Relax. Pot temperatures have been going up and down for centuries."

Heatwave, in the ocean

Claudia Deal, Lucy Courtenay and Sophie McClellan enjoy the amazingly warm water at Bronte Beach. Picture: Sam Ruttyn

ANTON ROSE

the maximum recorded is 25.2°C.

exceptionally high sea water tem-

23.8°C," the website said.

towards New Zealand. But this year

ICTP-CLIVAR Summer School on Marine Heatwaves: Global Phenomena with Regional Impacts

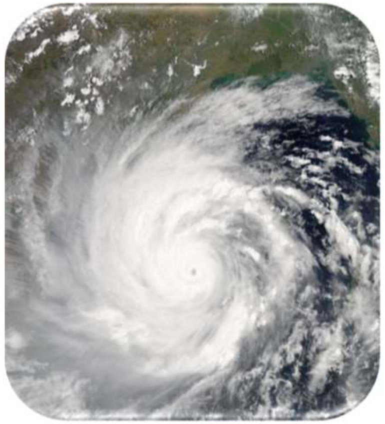
24 - 29 July 2023
An ICTP Hybrid Meeting
Trieste, Italy

Further information:
http://indico.ictp.it/event/10191/
smr3857@ictp.it

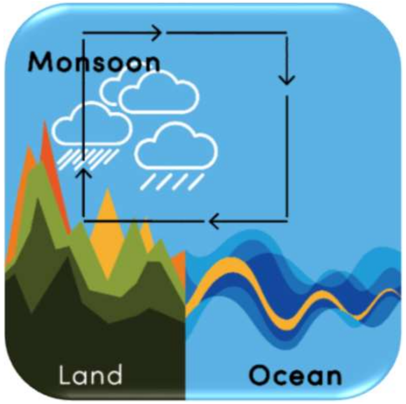
Marine Heatwaves and Impacts on the Atmosphere

Roxy Mathew Koll
Indian Institute of Tropical Meteorology

Tropical Cyclone



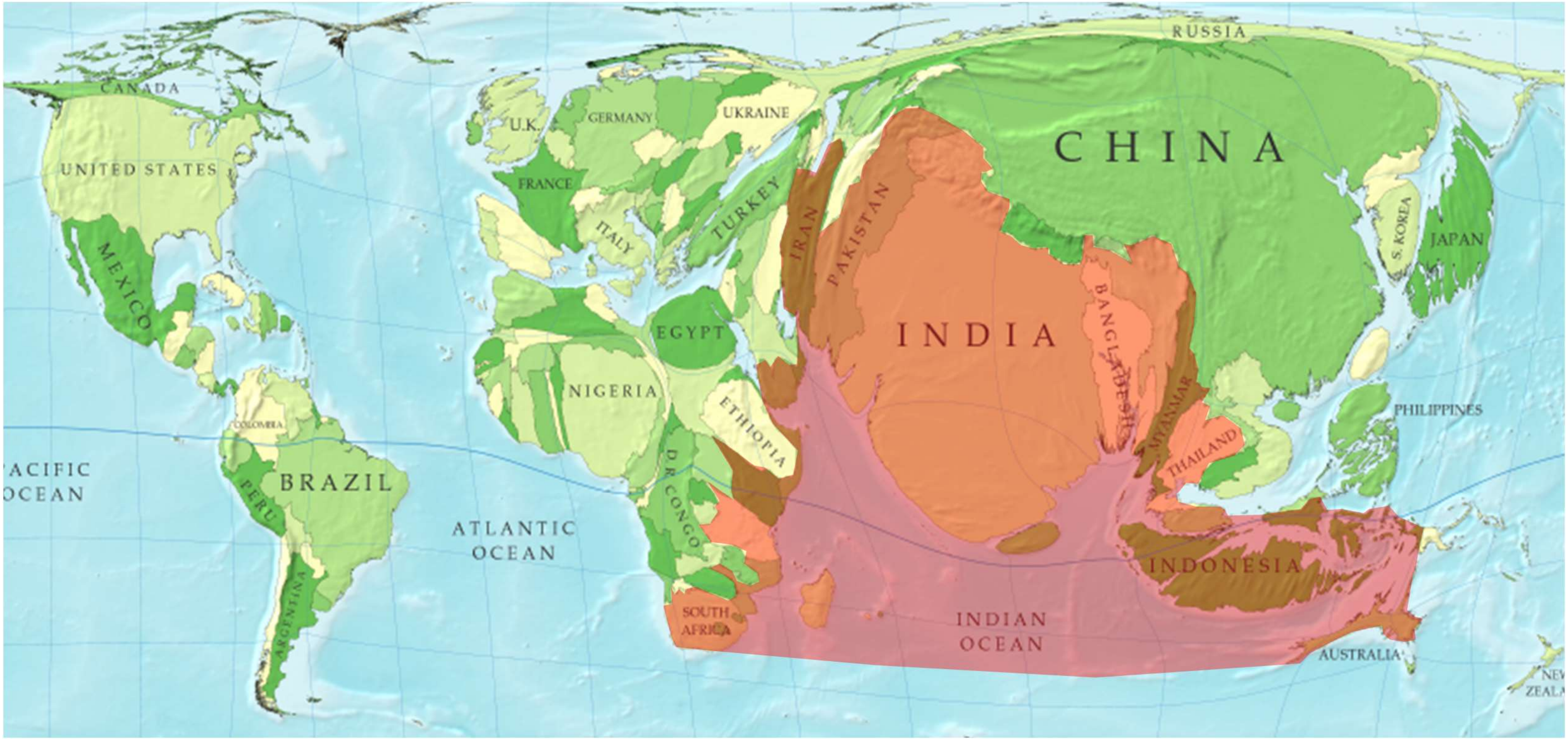
Monsoon



Terrestrial Heatwaves

Why the Indo-Pacific?

Map based on Population

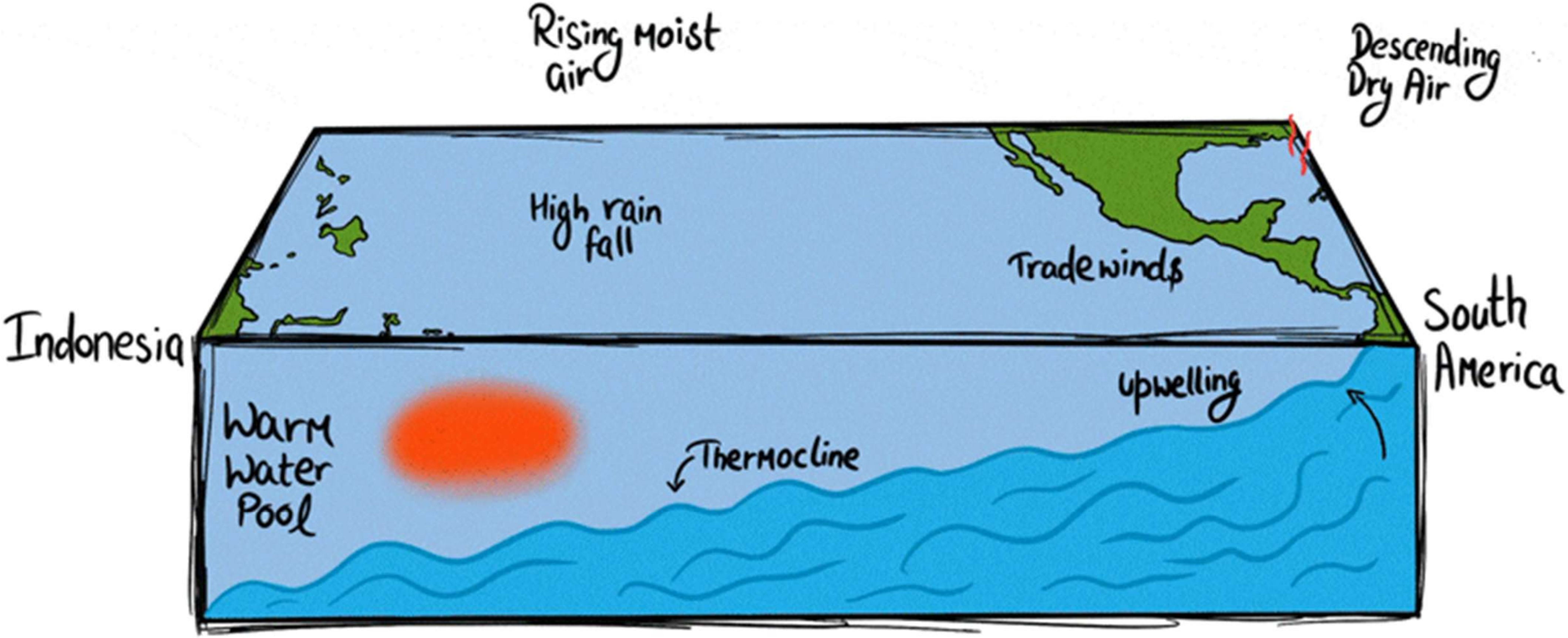


Ocean talking to the Atmosphere

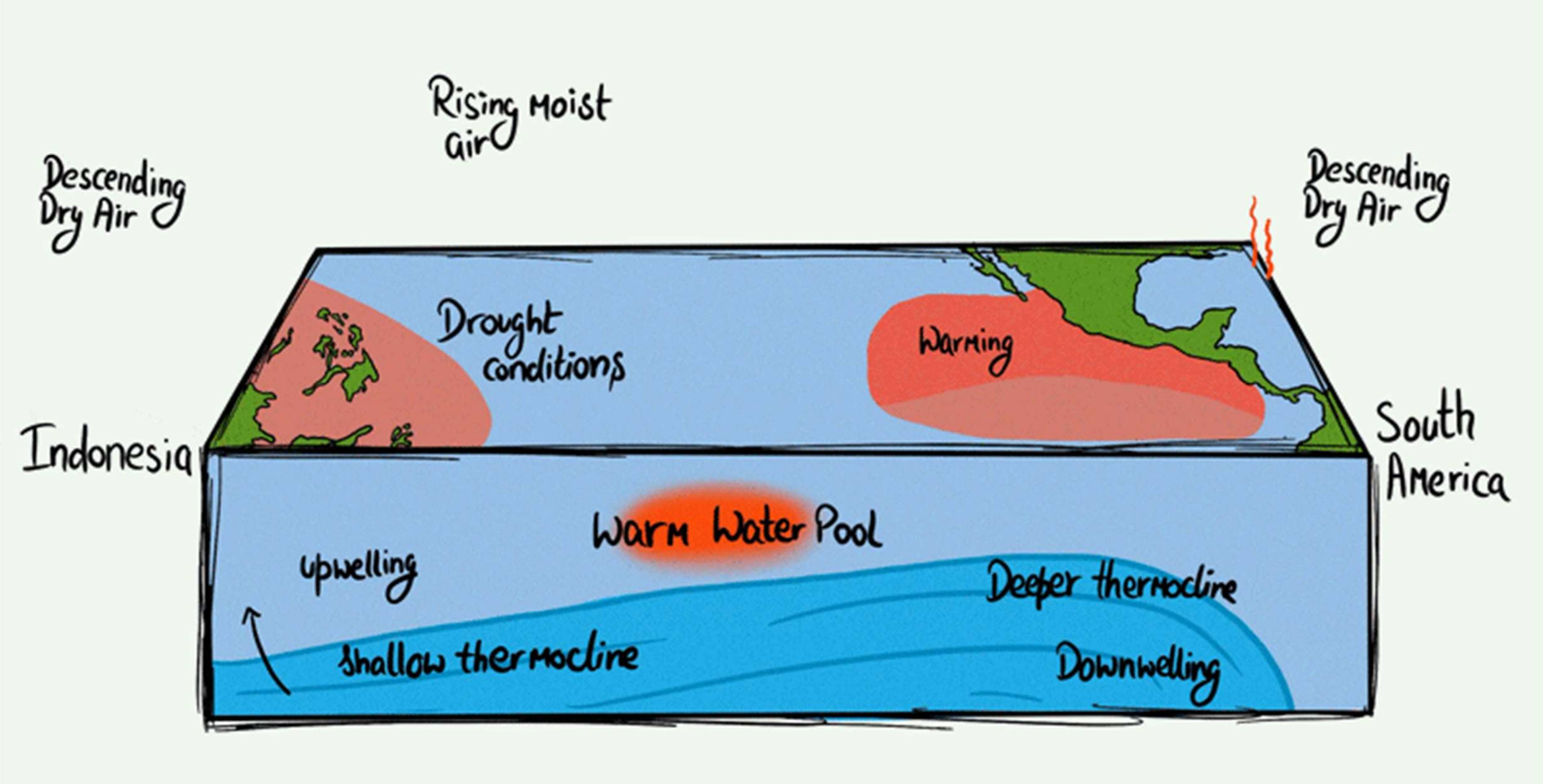
The oceans impact weather and climate by heating (and cooling) the lower atmosphere. In particular, as seawater evaporates, the ocean surface cools; and when the moisture later condenses into cloud droplets, this heat is released, warming the atmosphere. This moistening, and then warming, makes the air buoyant, driving low-level baroclinicity and atmospheric convection, causing wind convergence at the surface and divergence aloft. At the equator, ocean heating of the atmosphere can result in towering convective clouds that reach the top of the troposphere. These disturbances in turn drive teleconnections in the atmosphere, affecting weather and climate remotely.

Cronin et al. *Front. Mar. Sci.*, 2019

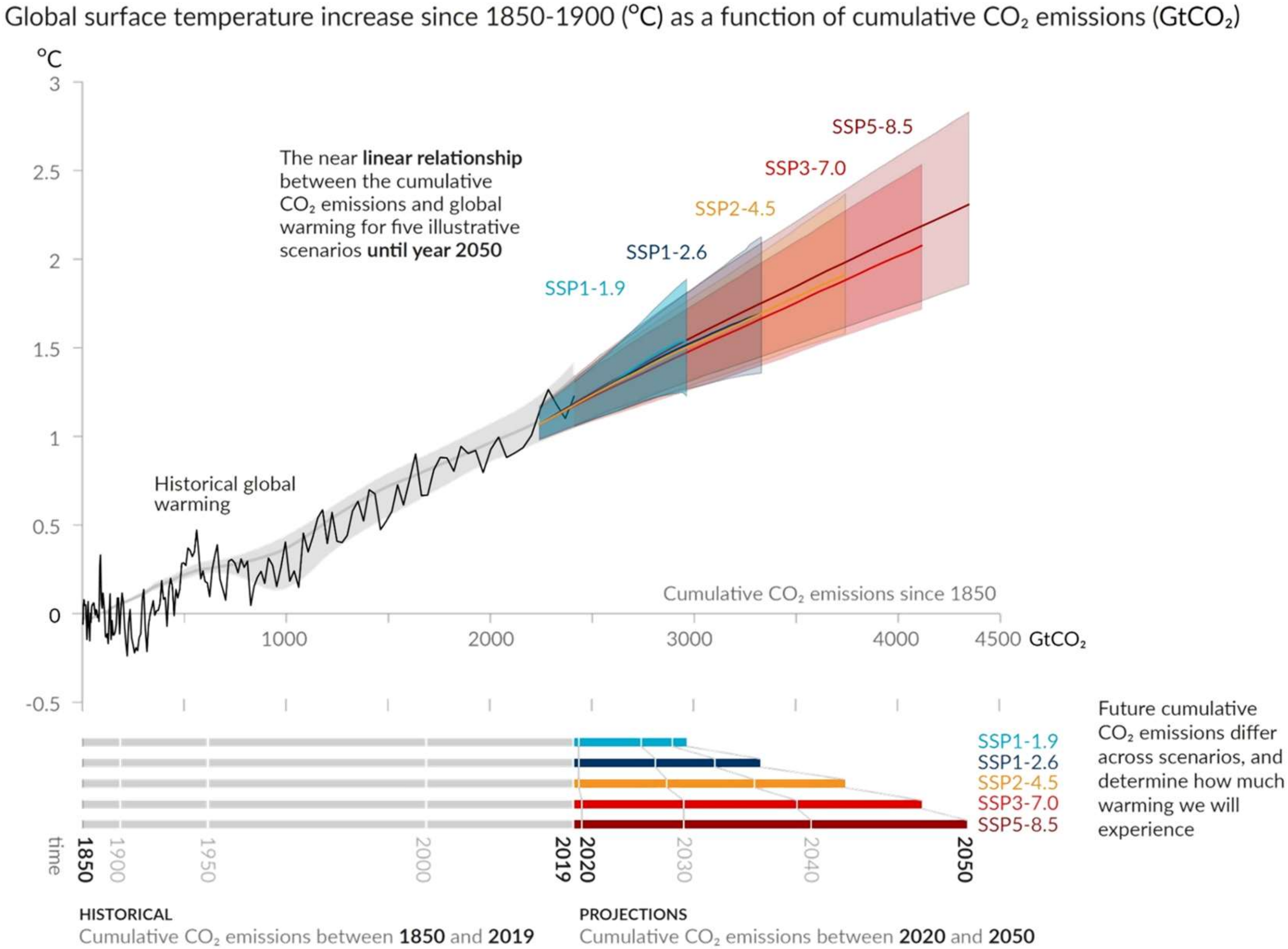
El Niño Southern Oscillation — ENSO neutral



The El Niño


Rising moist air
Descending Dry Air
Descending Dry Air
Drought conditions
Warming
Indonesia
South America
Warm Water Pool
upwelling
Deeper thermocline
Shallow thermocline
Downwelling

Global Warming



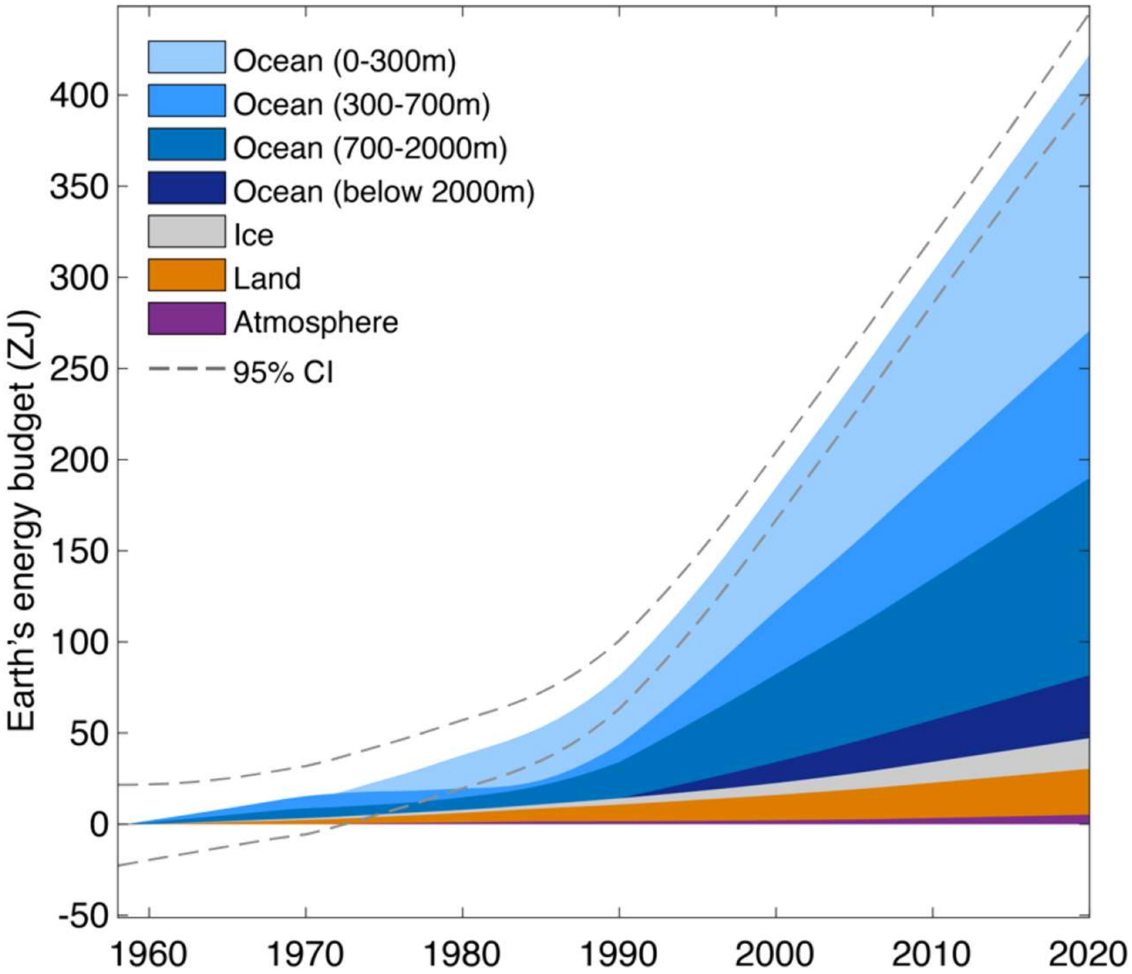
The global mean temperature has reached 1.1 °C as of now.

It will cross 1.5°C in the current decade or next, and 2°C during 2040–2060.

This is because the nationally determined contributions (NDCs) submitted by nations via Paris Agreement are insufficient to flatten the curve.

IPCC Sixth Assessment Report

Where does the Heat from Global Warming go?



Oceans take up 93% of the additional heat from global warming.

Atmosphere + Land + Ice accounts for less than 7% of the heat gain.

Extra heat intake rate by Oceans is
= 6 Hiroshima atomic bomb detonations per second

IPCC Sixth Assessment Report; Nuccitelli et al. *Bulletin of the Atomic Scientists*, 2020

Heat Capacity of Ocean is higher than Land or Atmosphere

Top 2 ½ meters of ocean can store the same heat as the entire troposphere

Heat capacity of soil/rocks and water,

$C_{p(\mathbf{water})} = 4000\ J\ kg^{-1}\ °C^{-1}$ $C_{p(\mathbf{rock/land})} = 800\ J\ kg^{-1}\ °C^{-1}$

The volume of water which exchanges heat with the atmosphere per sq.meter of surface (depth of 100m) is 100 m^3. The density of water is 1000 kg/m^3.
mass = density × volume = $m_{water} = 10^5$ kg.

Seasonal heat storage for ocean

$\Delta E_{oceans} = C_{p(water)}\, m_{water}\, \Delta T$ (ΔT = 10°C, is the typical change in temperature from winter to summer)

= **(X)(X)(X) Joules = X Joules**

The volume of land which exchanges heat with the atmosphere 1 m^3. Suppose the density of rock is 3,000 kg/m^3, the mass of the soil and rock in contact with the atmosphere is 3,000 kg.

$\Delta E_{land} = C_{p(rock)}\, m_{rock}\, \Delta T$ (ΔT = 20°C)

= **(X)(X)(X) Joules = X Joules**

$$\boldsymbol{\Delta E_{oceans} / \Delta E_{land} = X}$$

Heat Capacity of Ocean is higher than Land or Atmosphere

Top 2 ½ meters of ocean can store the same heat as the entire troposphere

Heat capacity of soil/rocks and water,

$C_{p(\mathbf{water})} = 4000\ J\ kg^{-1}\ °C^{-1}$ $C_{p(\mathbf{rock/land})} = 800\ J\ kg^{-1}\ °C^{-1}$

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mass = density × volume = $m_{water} = 10^5$ kg.

Seasonal heat storage for ocean

$\Delta E_{oceans} = C_{p(water)}\ m_{water}\ \Delta T$ (ΔT = 10°C, is the typical change in temperature from winter to summer)

$= \mathbf{(4000)(10^5)(10°)\ Joules = 4.0 \times 10^9\ Joules}$

The volume of land which exchanges heat with the atmosphere 1 m^3. Suppose the density of rock is 3,000 kg/m^3, the mass of the soil and rock in contact with the atmosphere is 3,000 kg.

$\Delta E_{land} = C_{p(rock)}\ m_{rock}\ \Delta T$ (ΔT = 20°C)

$= \mathbf{(800)(3000)(20°)\ Joules = 4.8 \times 10^7\ Joules}$

$$\mathbf{\Delta E_{oceans} / \Delta E_{land} = 100}$$

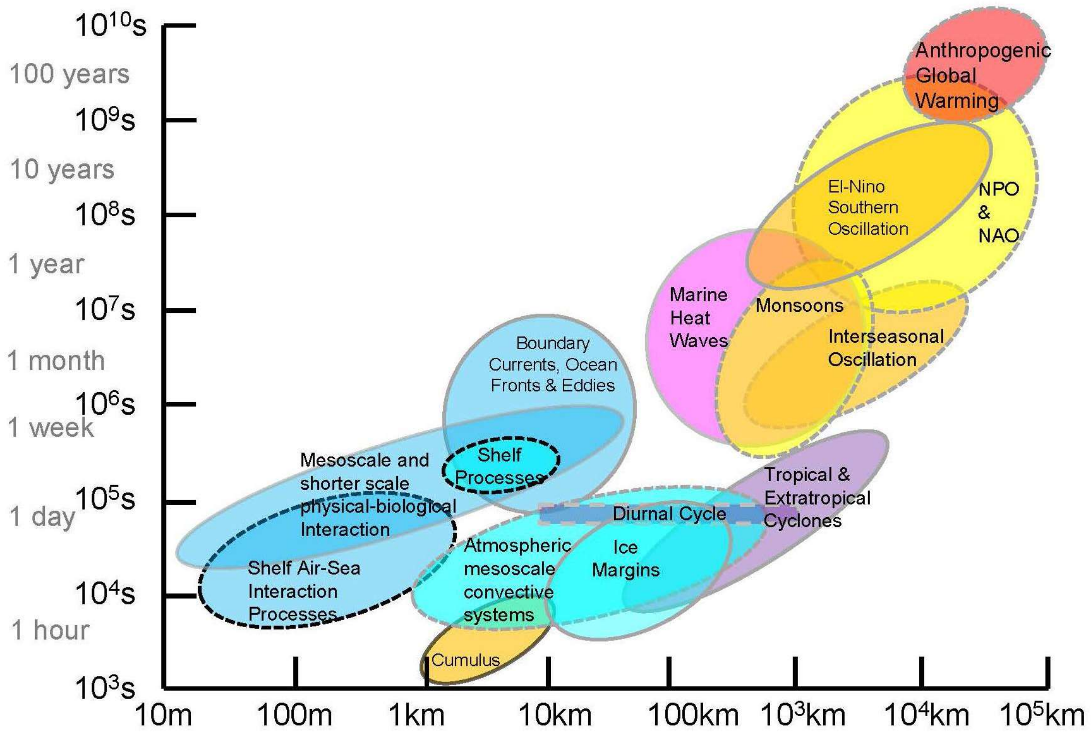
Affects Weather and Climate System

Because the ocean's capacity to store heat is about 1000 times greater than that of the atmosphere, long-term weather and climate predictability has its origins in the oceans.

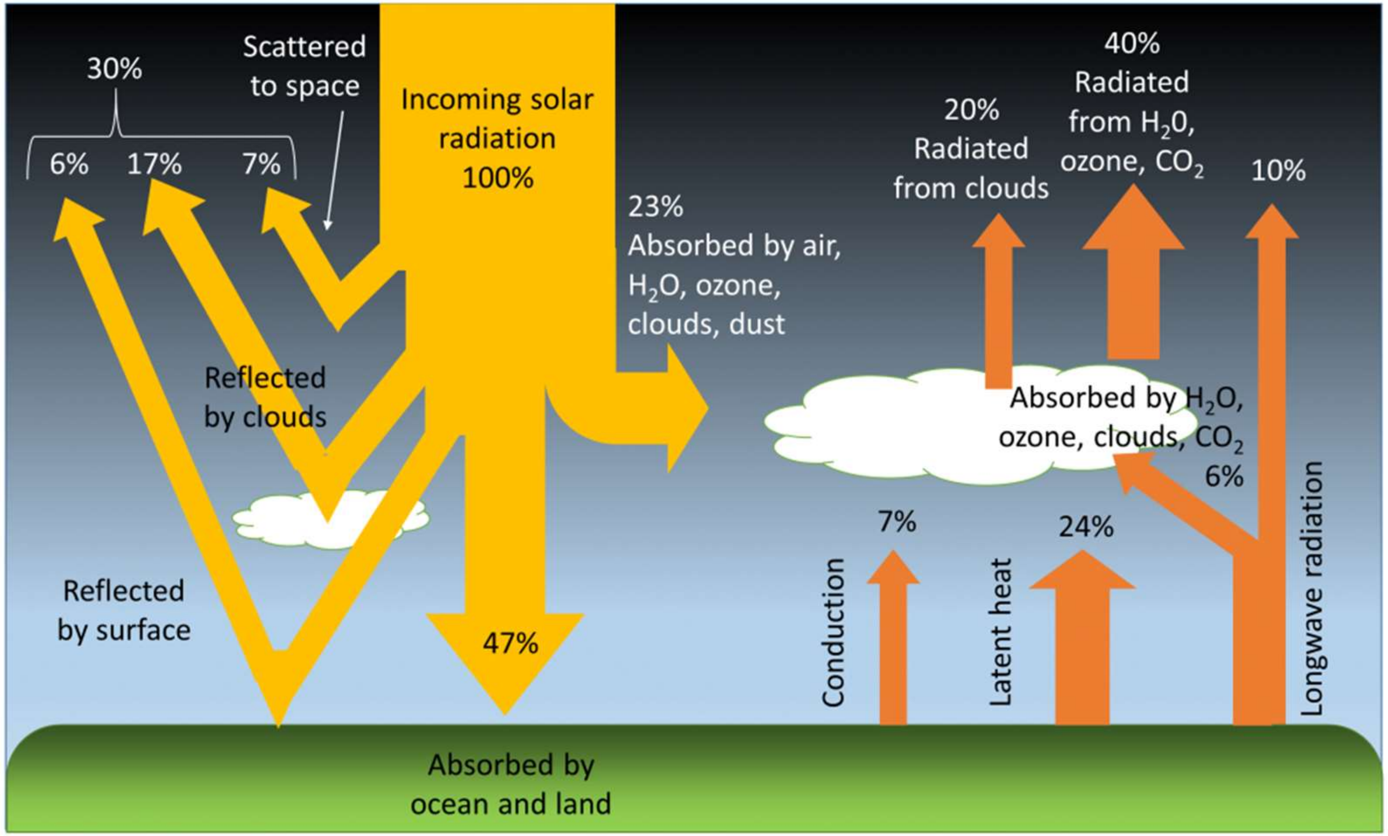
Heat storage and release occurs on a range of time scales and can provide predictability at 10–100 days (e.g., MJO, Monsoon), seasonal-interannual time scales (e.g., ENSO), and decades (e.g., PDO, AMO).

Predictions of weather and climate on these time scales have great economic benefits for agriculture, water resource management, energy management, human and ecosystem health among others.

To achieve useful predictions we must be able to **quantify** where, when and how much heat is released to the atmosphere.



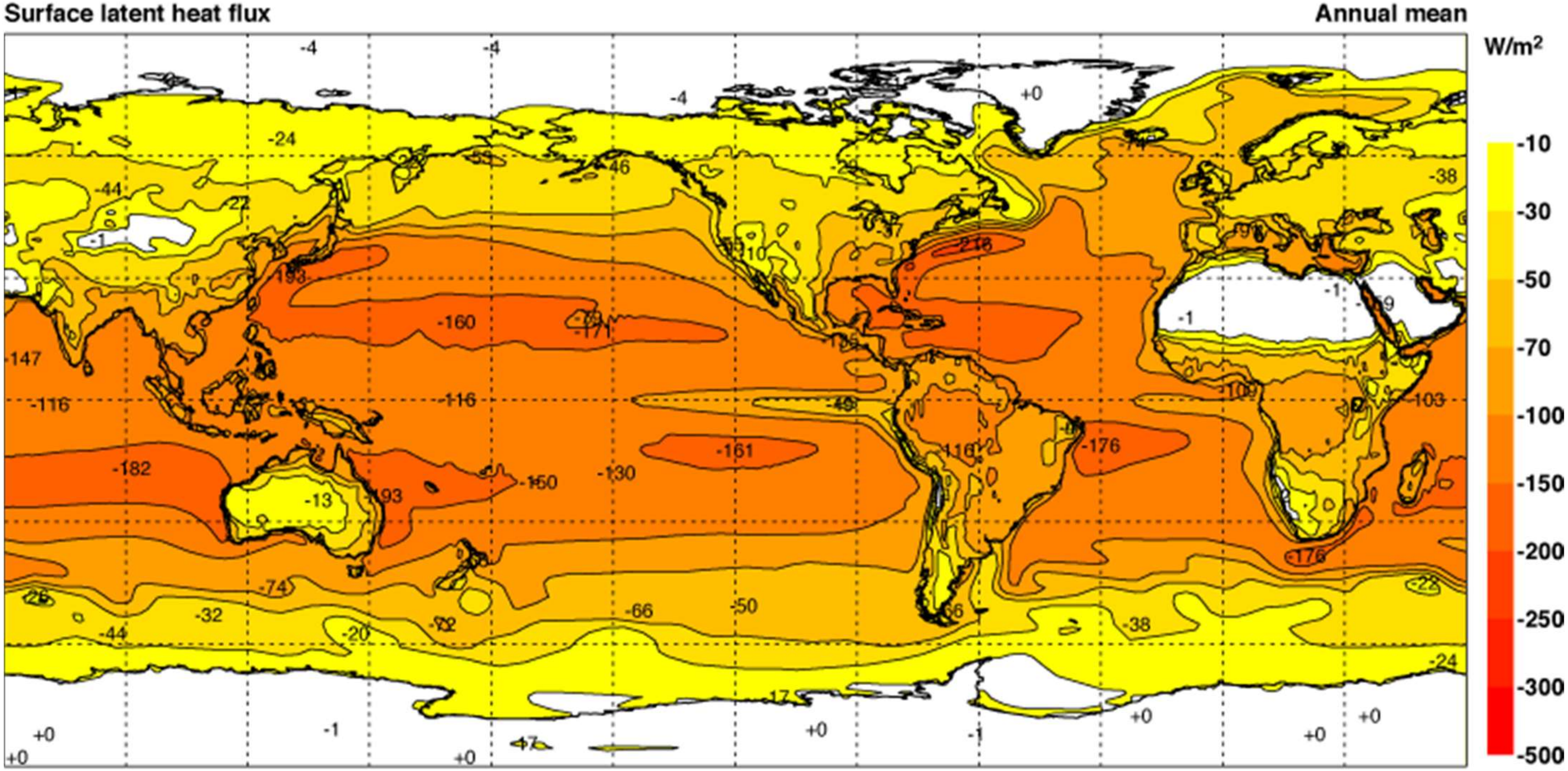
Heat Exchange between Ocean and Atmosphere



Sensible heat flux depends on SST, air temperature, winds

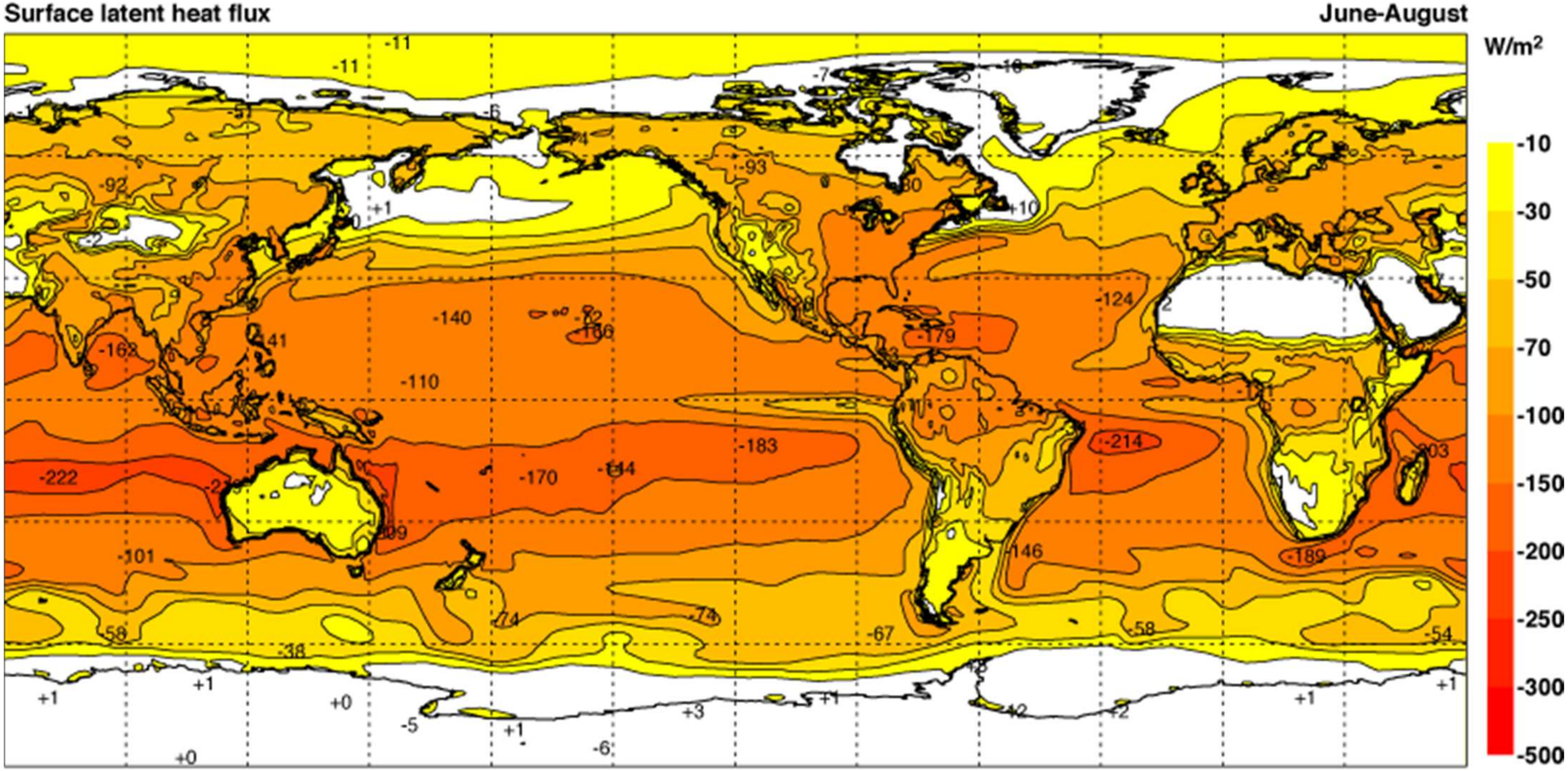
Latent heat flux depends on SST, humidity, winds

Latent Heat Flux at the Surface — Annual



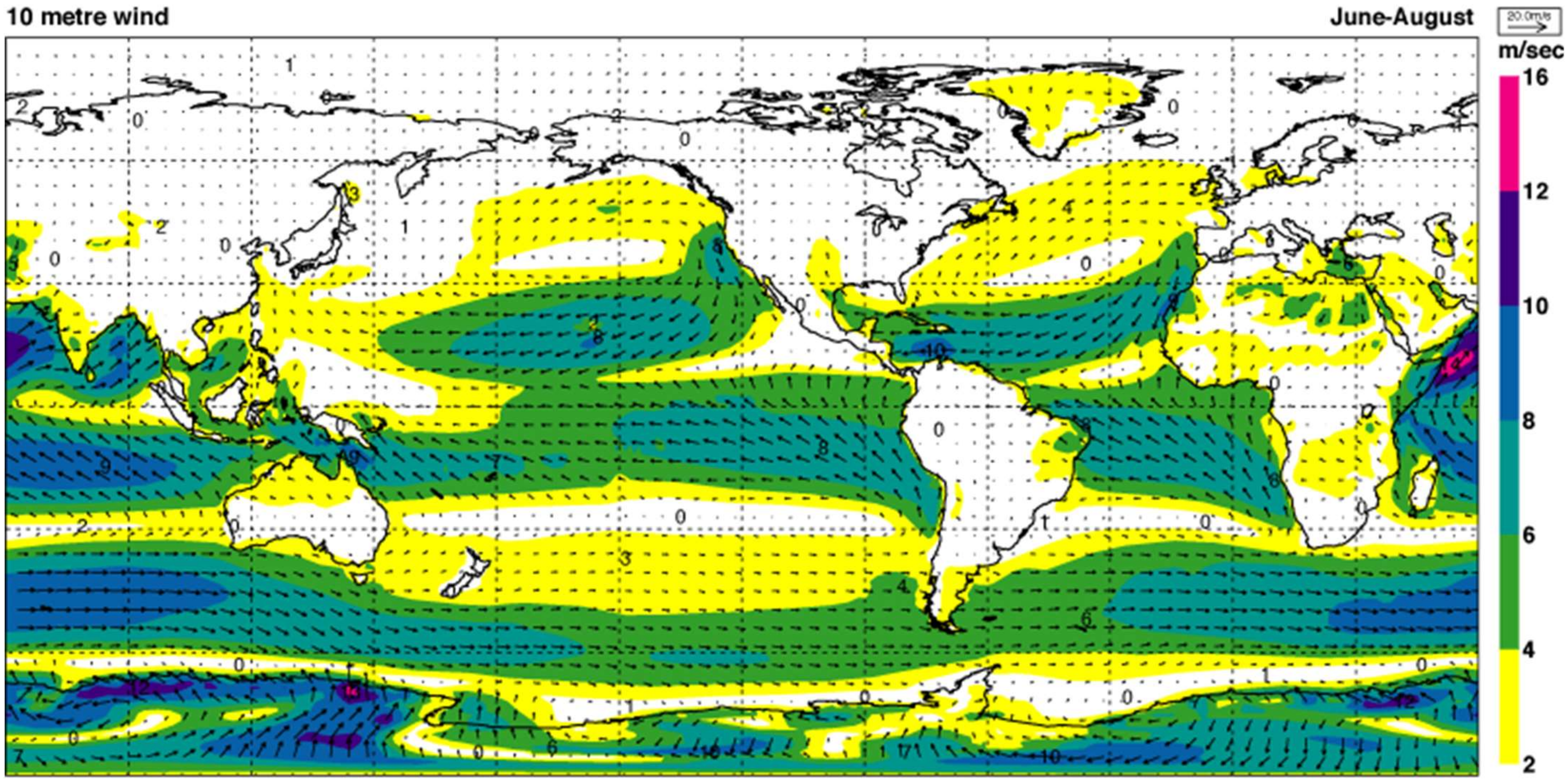
Latent heat flux depends on SST, humidity, winds

Latent Heat Flux at the Surface — northern Summer



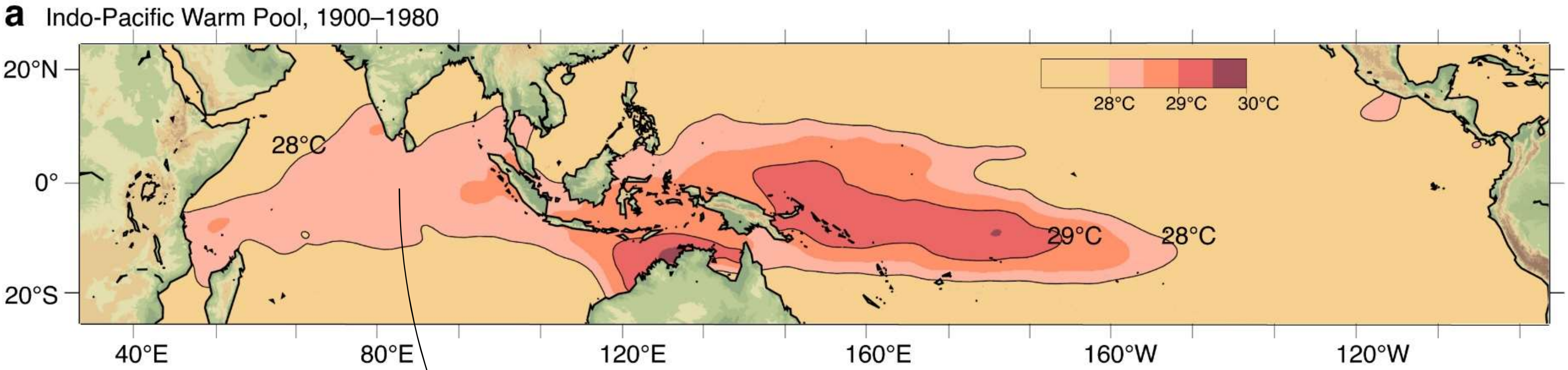
Latent heat flux depends on SST, humidity, winds

Winds — northern Summer



Indo-Pacific Warm Pool, Heat Engine of the Globe

Indo-Pacific warm pool – Sea Surface Temperatures (SST) above 28°C

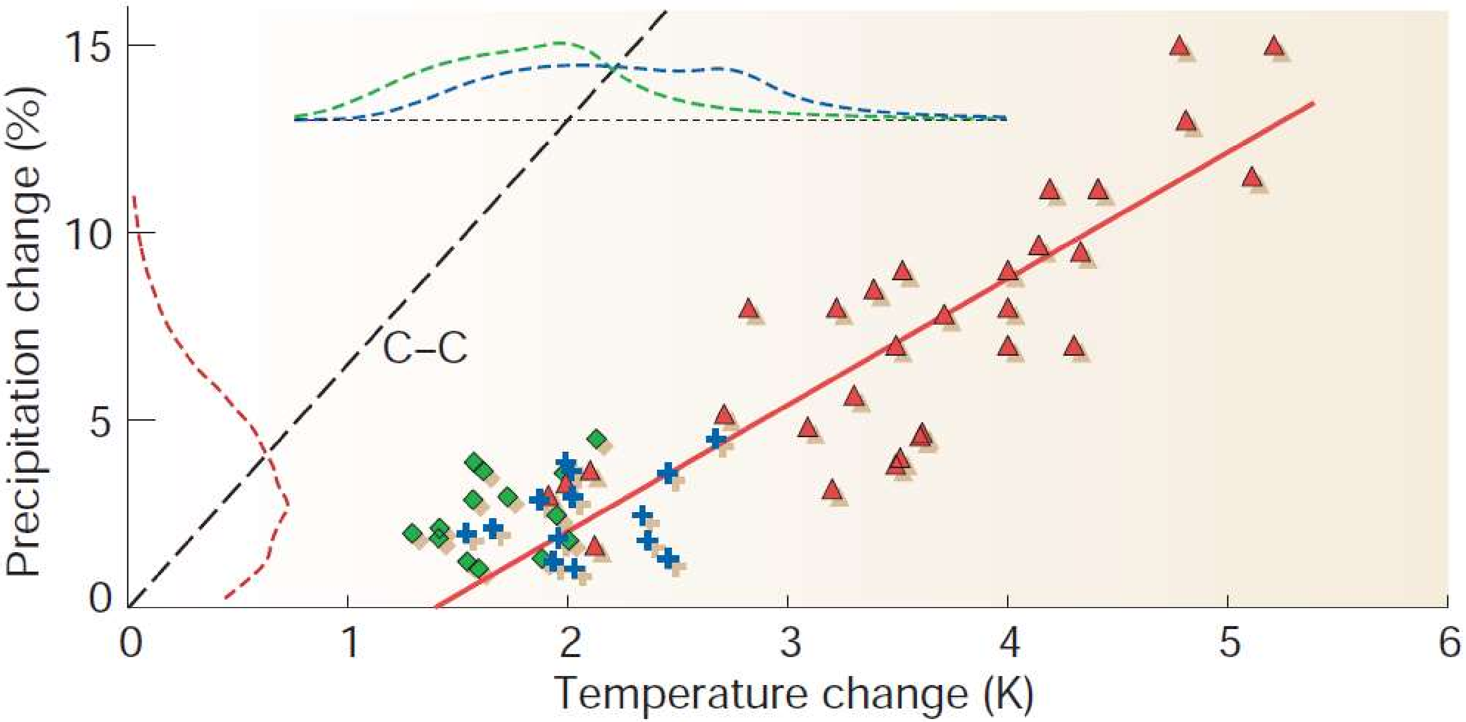


red colors indicate warm pool — above 28°C

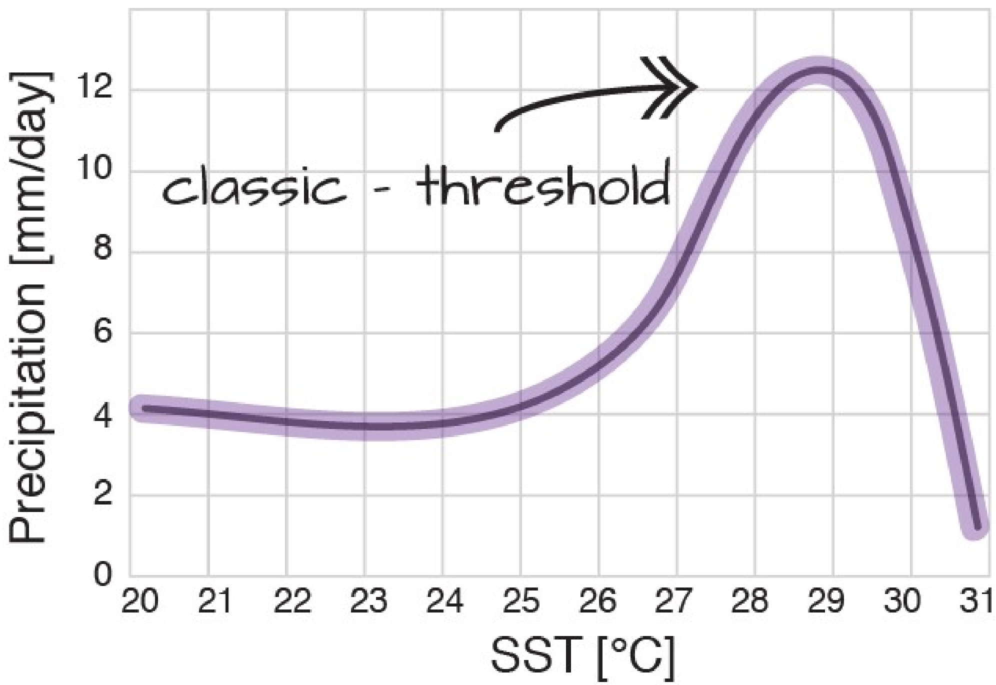
Thermodynamic Response to Temperature Change

The Clausius–Clapeyron relation implies that specific humidity and hence atmospheric moisture would increase roughly exponentially with temperature

7%/℃ – substantially smaller than the sensitivity change documented.



Classical SST-Precipitation relationship



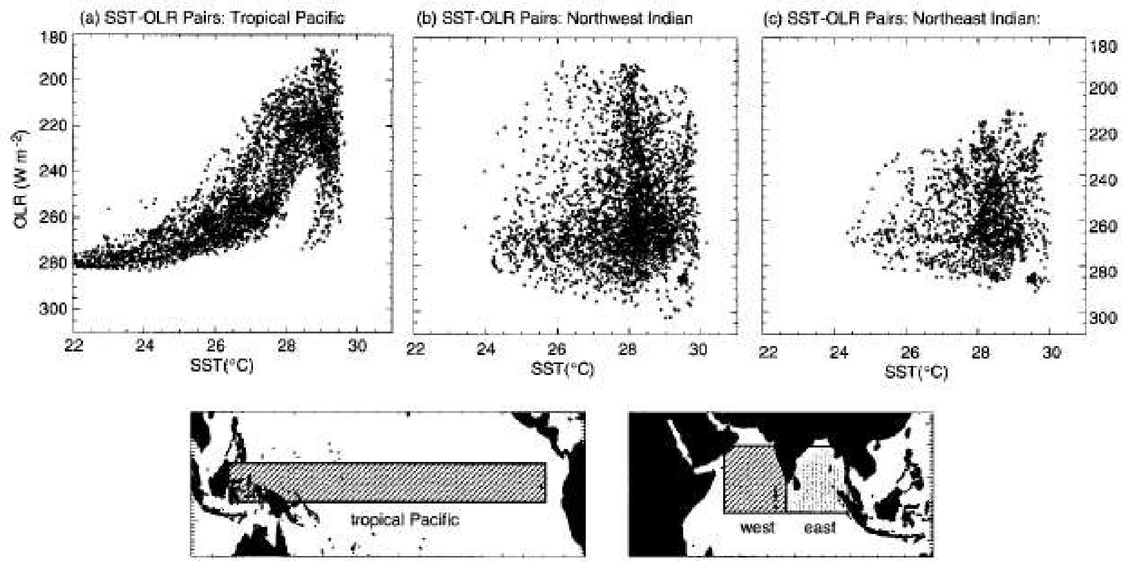


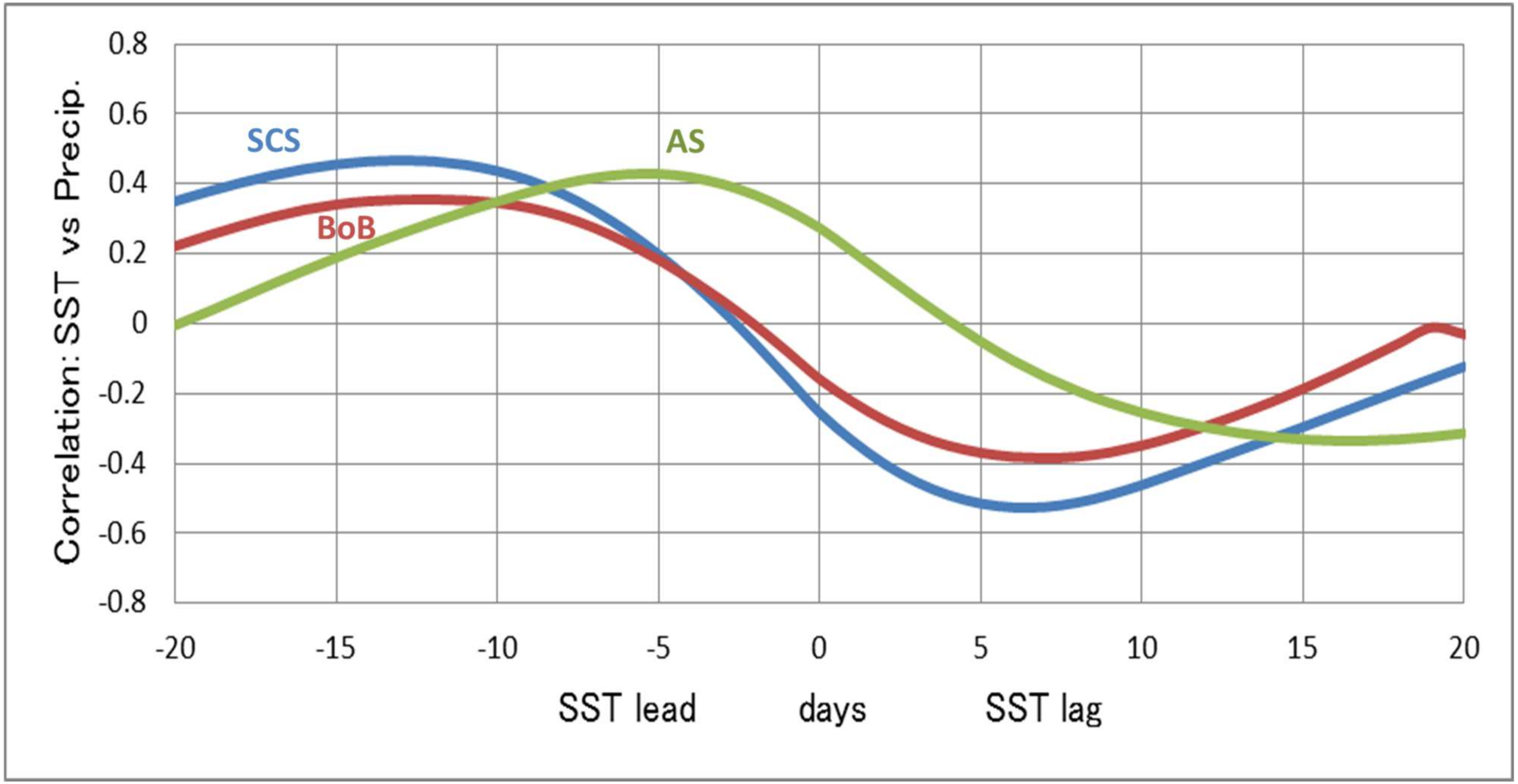
FIG. 3. OLR–SST (W m^{-2} and °C with ordinate scale reversed) pairs for (a) the tropical Pacific Ocean in the region 5°S–5°N, 120°E–90°W, (b) the northern Indian Ocean for the region equator–20°N, 55°–80°E, and (c) the northern Indian Ocean, equator–20°N, 80°–100°E. The geographical areas are depicted by the areas within the shaded boxes on map panel. Mean monthly values are plotted for Mar, Apr, and May for all points in the boxes. Data are from 1972–89.

Earlier studies: Precipitation increases monotonously at SSTs beyond **26°C**,
but limited to: **Upper threshold of 28 - 29°C**

Explanation given: Precipitation tends to occur where
positive convective available potential energy (CAPE) exists
-> the occurrence of deep convection will tend to squelch CAPE?

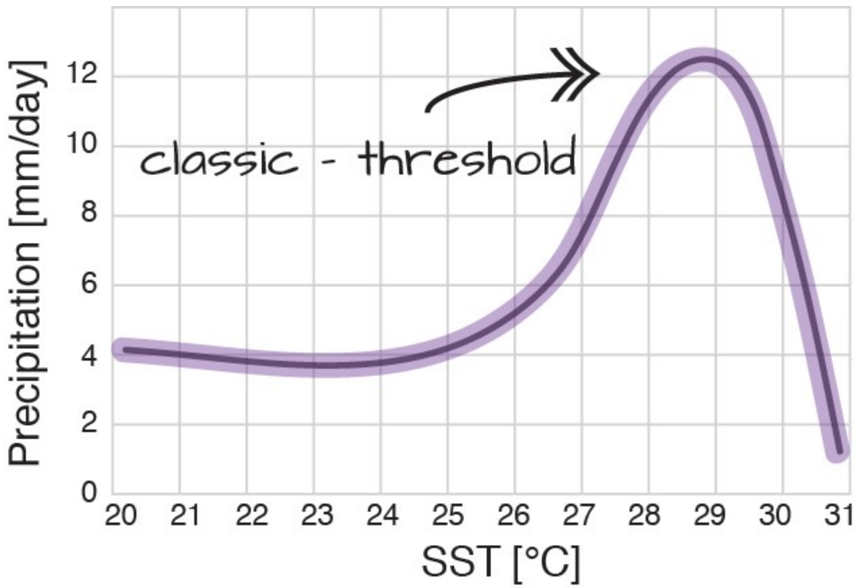
Gadgil et al., *Nature*, 1984; Loschnigg and Webster, *J.Climate*, 2000

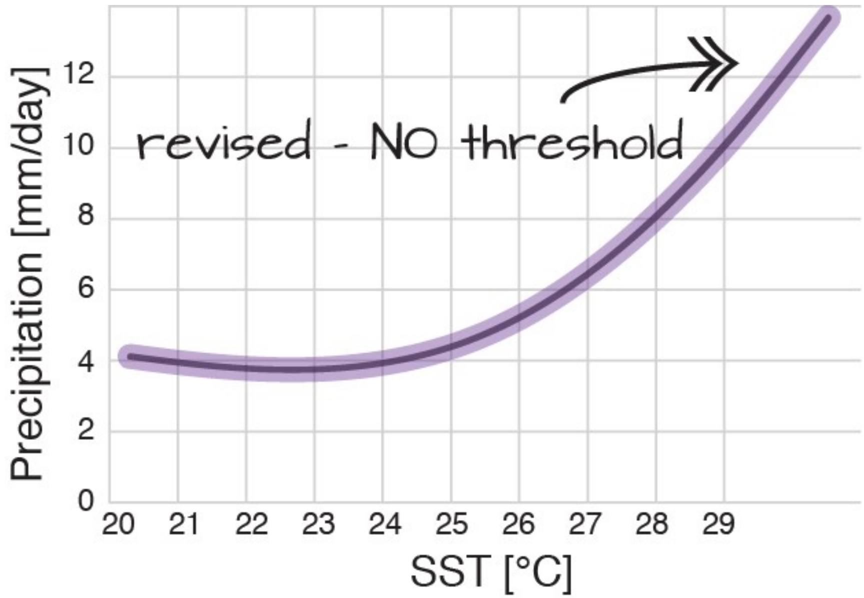
SST-Precipitation relationship leads/lags by several days



Roxy, *Clim.Dyn.*, 2013

SST-Precipitation relationship considering the lag

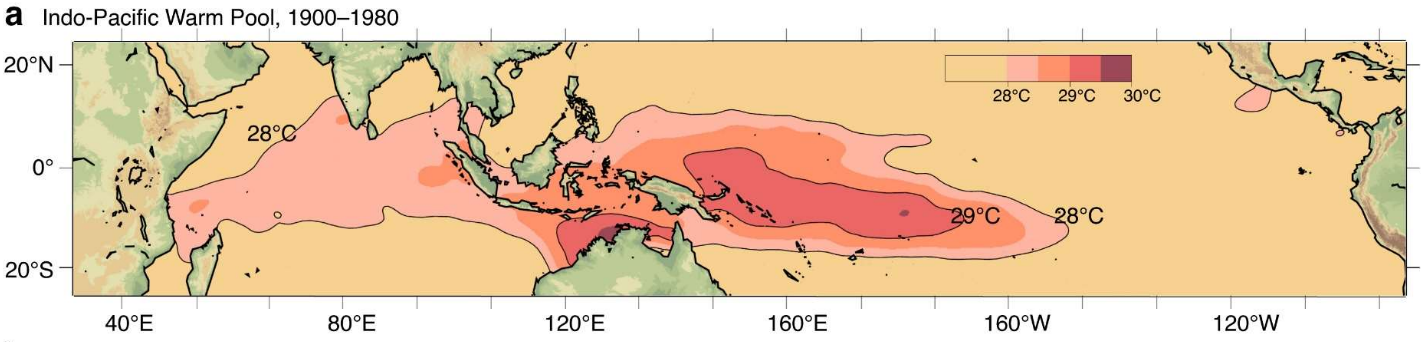




Roxy, *Clim.Dyn.*, 2013

Indo-Pacific Warm Pool, Heat Engine of the Globe

Indo-Pacific warm pool – Sea Surface Temperatures (SST) above 28°C

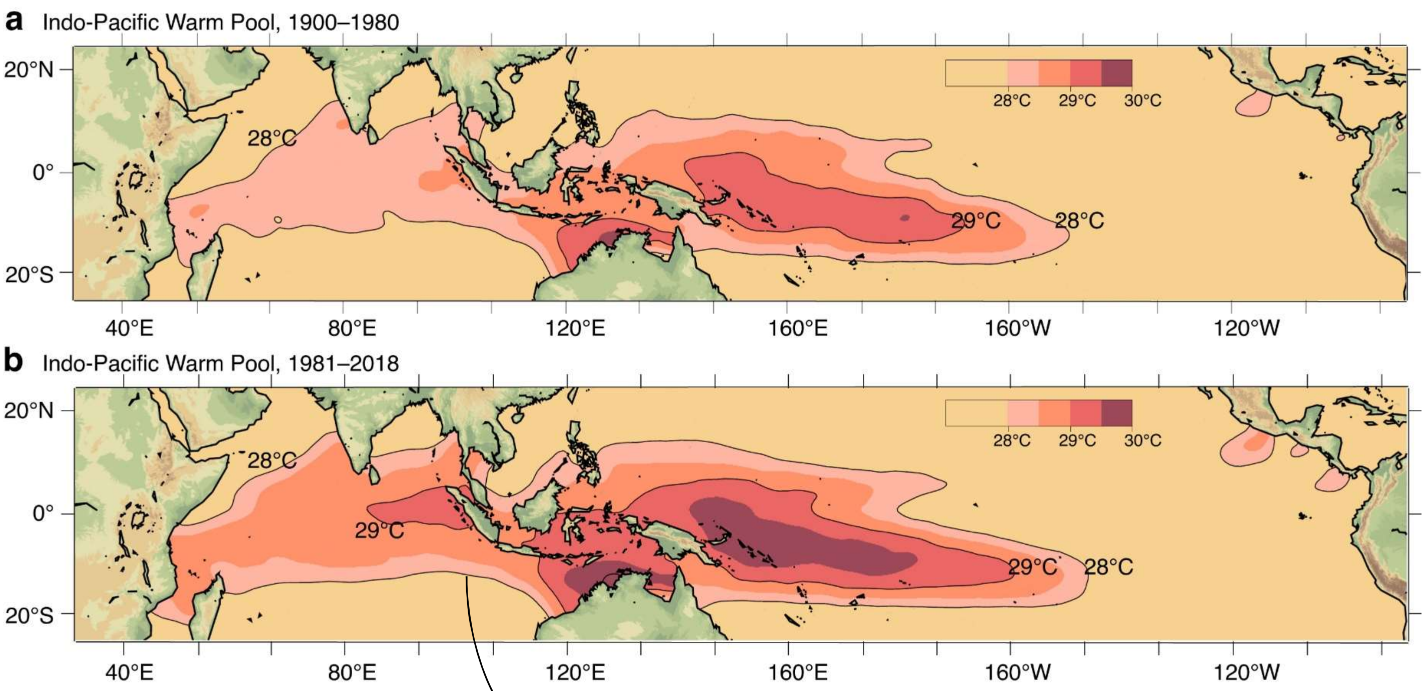


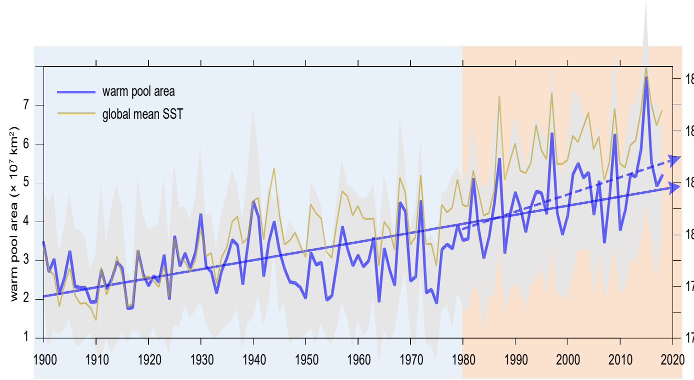
red colors indicate warm pool
—above 28°C

Roxy, Dasgupta, et al., *Nature*, 2019

Indo-Pacific Warm Pool, Heat Engine of the Globe

Indo-Pacific warm pool – Sea Surface Temperatures (SST) above 28°C has expanded zonally and meridionally in the recent decades





red colors indicate warm pool —above 28°C

rate of expansion: 40 million sq.km per year

Marine Heatwaves in the Warm Pool

Bay of Bengal
15 May 2010

Driver: Possible links to central Pacific El Niño*

Impacts: Coral bleaching in the Andaman Sea

Northeast Pacific (The Blob)
8 January 2014

Driver: Persistent high pressure linked to tropical–extratropical teleconnections

Impacts: Low ocean productivity; large marine mortalities; toxic algal blooms

Northwest Atlantic
20 May 2012

Driver: Extensive high pressure linked to jet-stream shift

Impacts: Fishery disruptions; species-range shifts; low ocean productivity

1997/98 El Niño
25 December 1997

Driver: Coupled air–sea interactions

Impacts: Suppressed equatorial and coastal productivity; fishery losses

Mediterranean Sea
14 June 2003

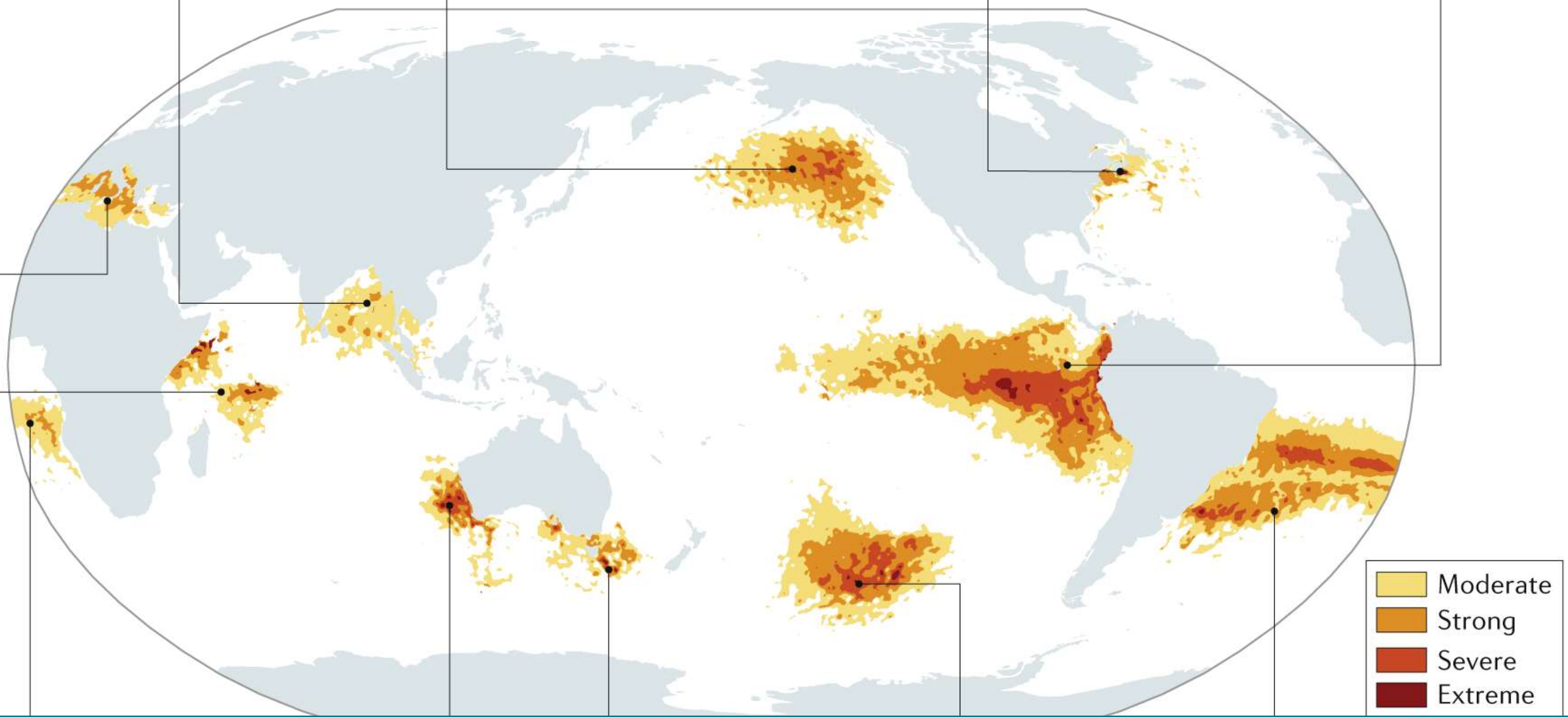
Driver: Blocking high and corresponding terrestrial heatwave

Impacts: Mass mortality of rocky benthic communities

Seychelles
17 January 1998

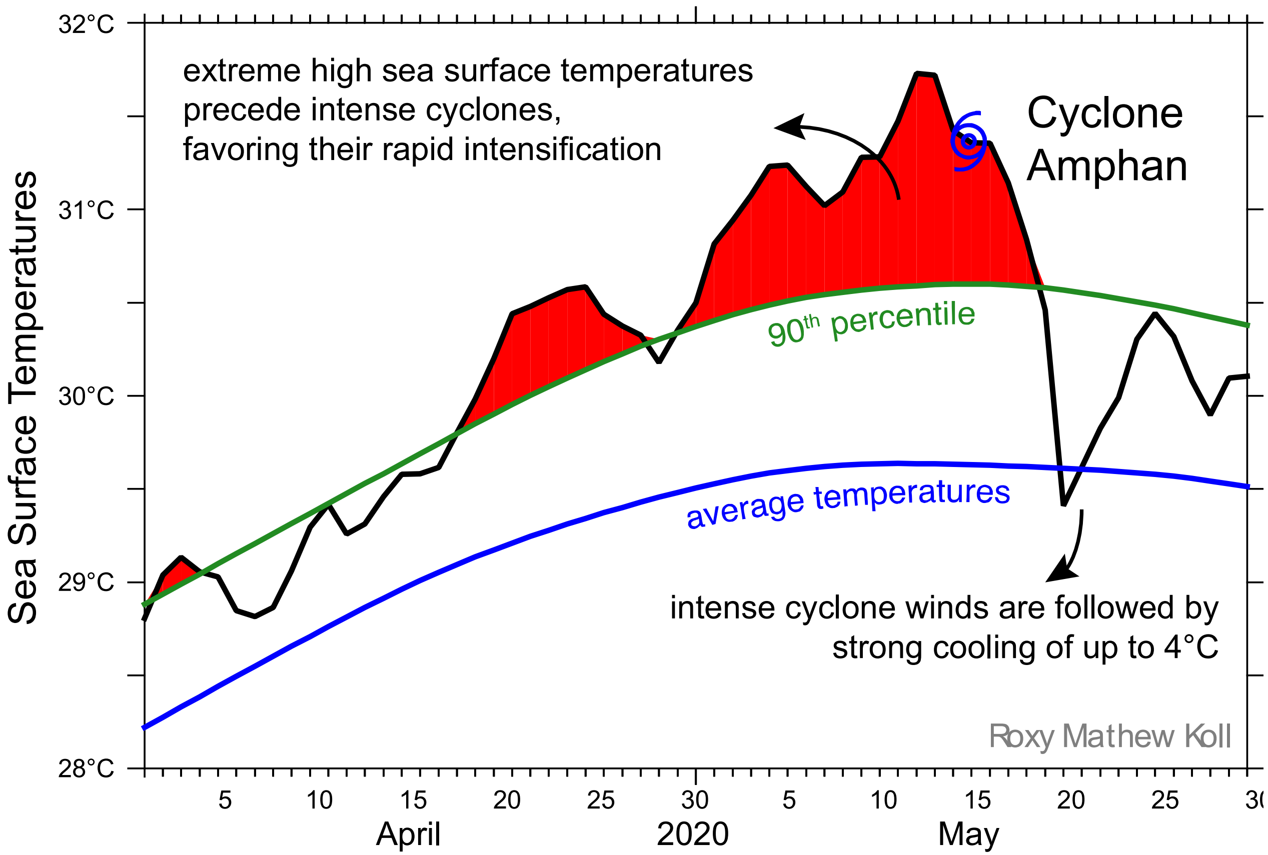
Driver: Atmospheric teleconnections linked to 1997/98 extreme El Niño

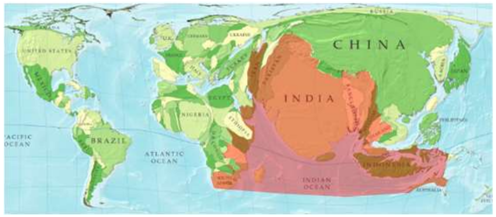
Impacts: Extensive coral bleaching

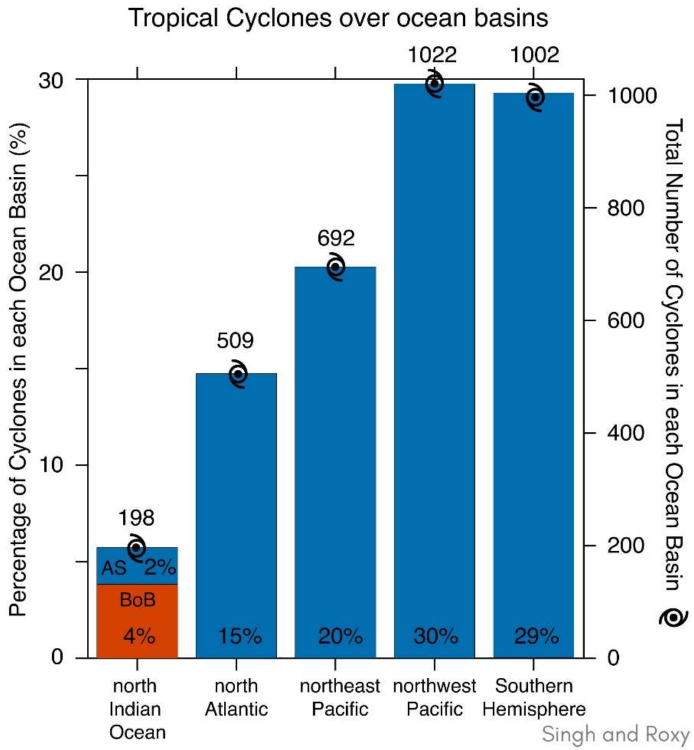


Holbrook et al., *Nature Rev. Earth. Env.*, 2023

Marine Heatwaves and Cyclones

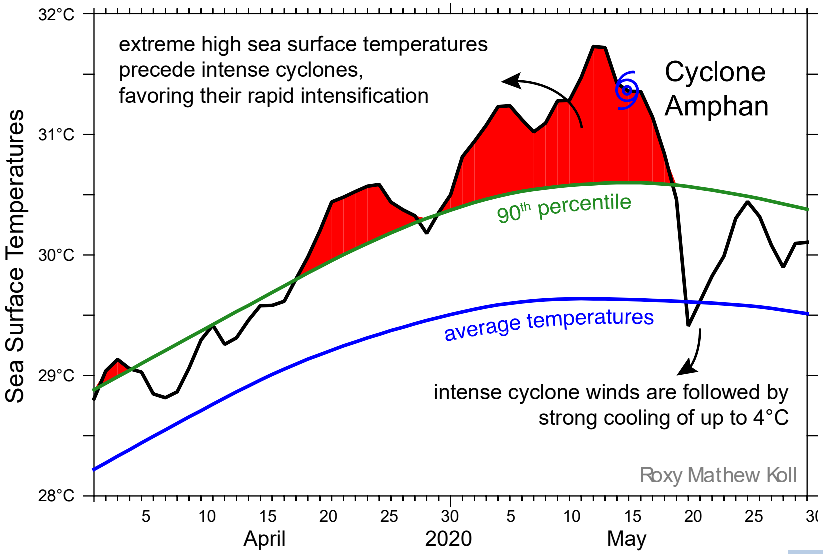


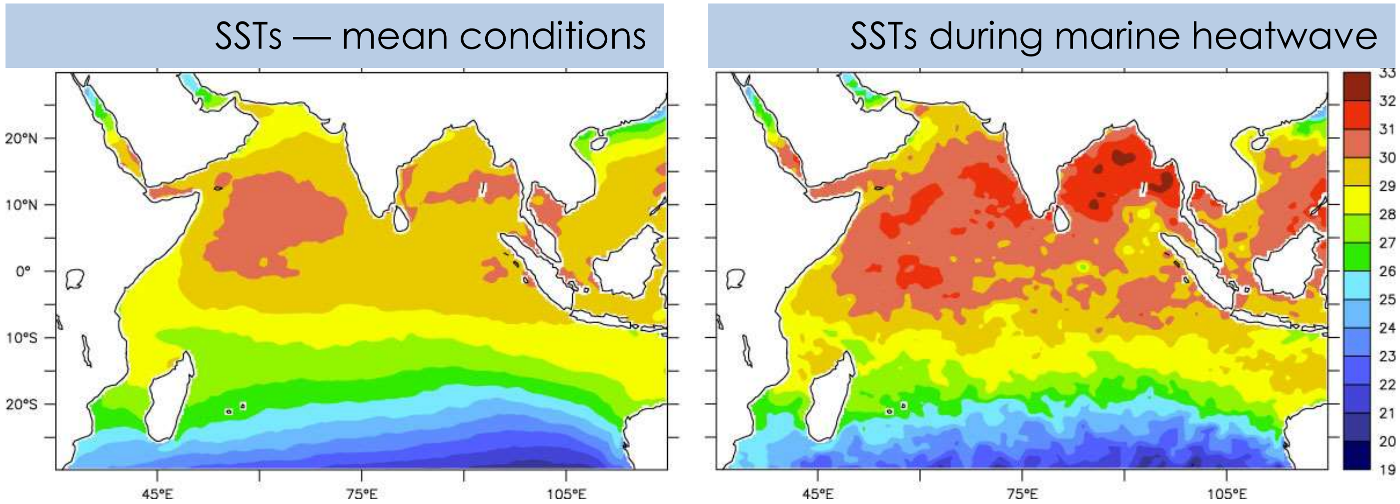




Singh and Roxy
Earth Science Reviews, 2022

Marine Heatwaves and Cyclones





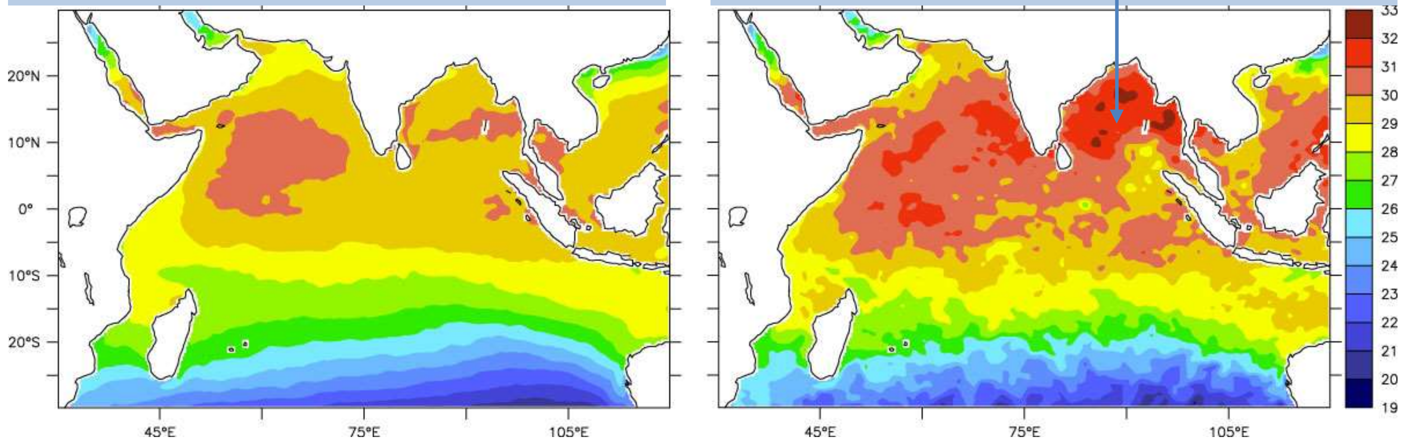
Marine Heatwaves and Corals

Corals have a mucus membrane — known as **zooxanthellae** — which acts as their shield and gives the color. Warm temperatures bleach it away.

These **marine heat waves** led to coral bleaching in Gulf of Mannar.

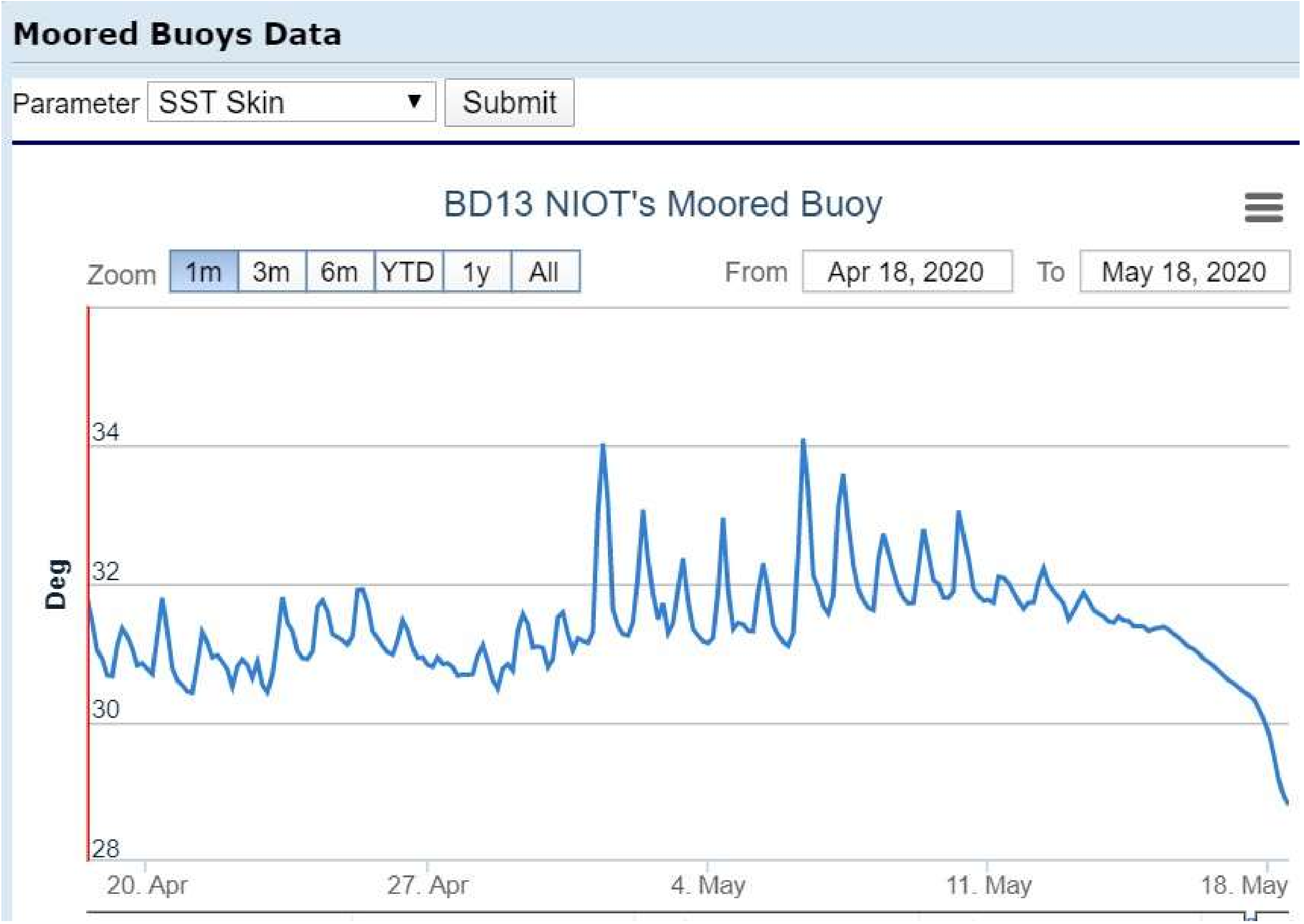
SSTs — mean conditions

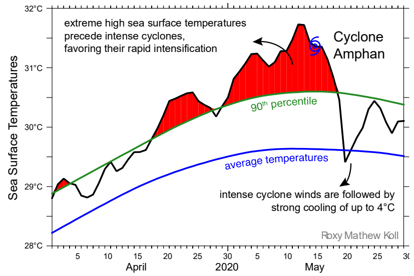
SSTs during marine heatwave



Marine Heatwaves and Cyclones

In-situ observations show much higher temperatures.



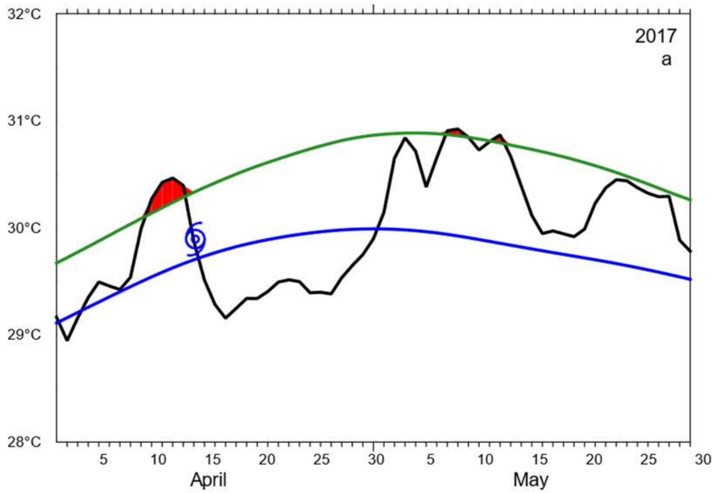


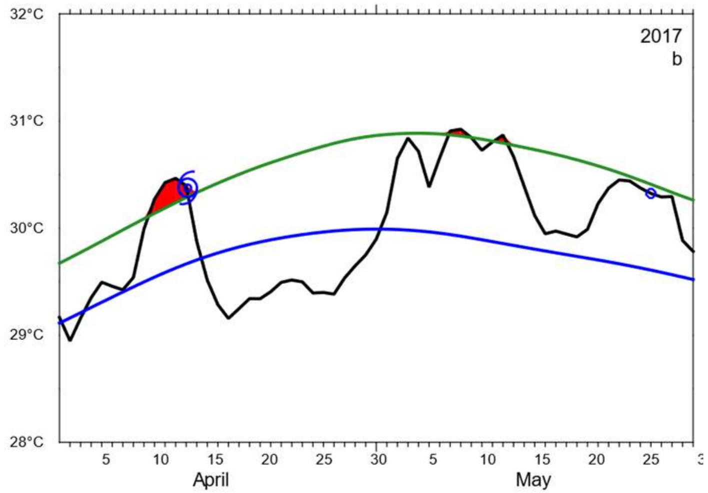
Bay of Bengal recorded surface temperatures of 32-34°C, before Cyclone Amphan.

We have never seen such high values until now.

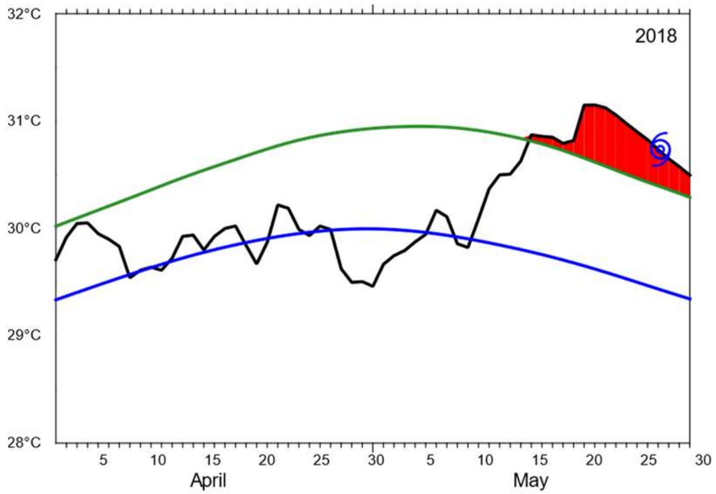
We need better ocean observations — and that needs regional partnership!

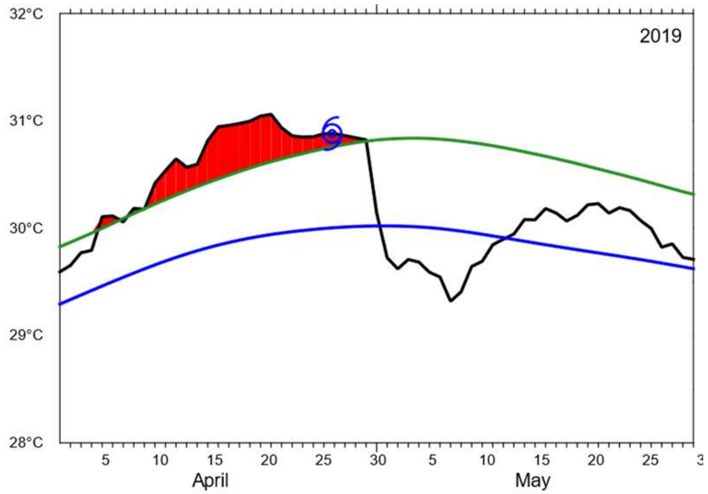
Marine Heatwaves and Cyclones

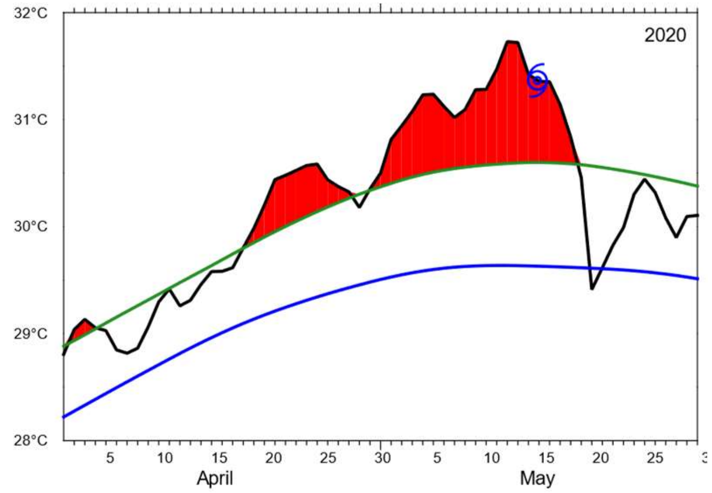




About 90% of the cyclones during pre-monsoon season were preceded by marine heatwaves

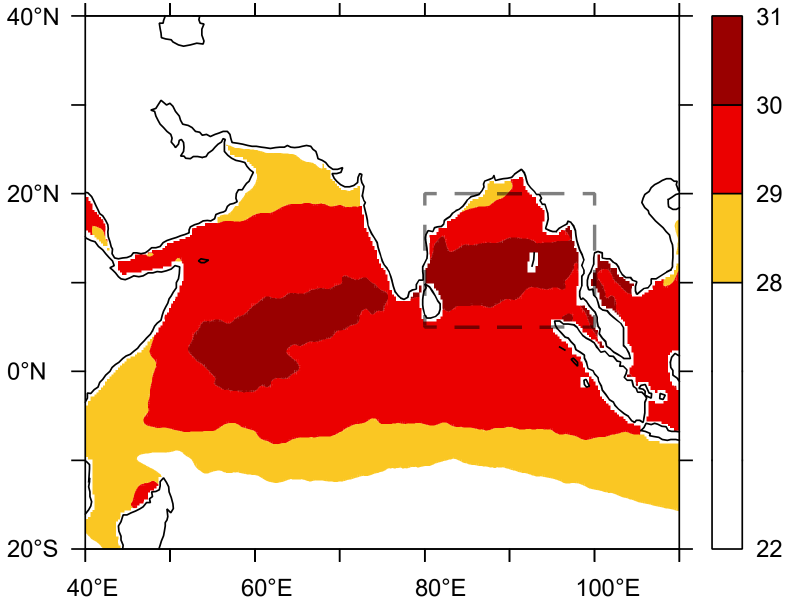


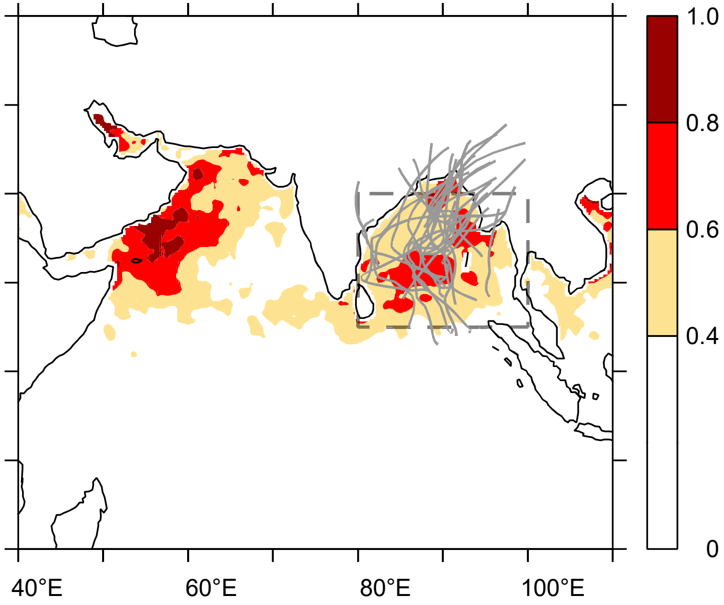




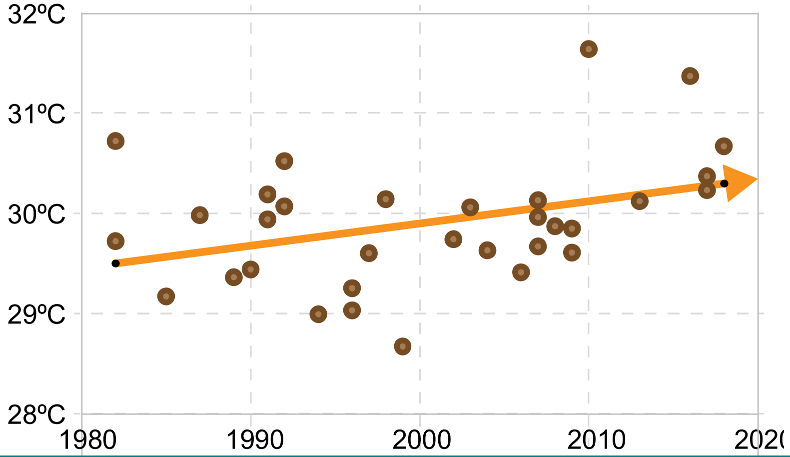
Roxy et al. 2023

Marine Heatwaves and Cyclones

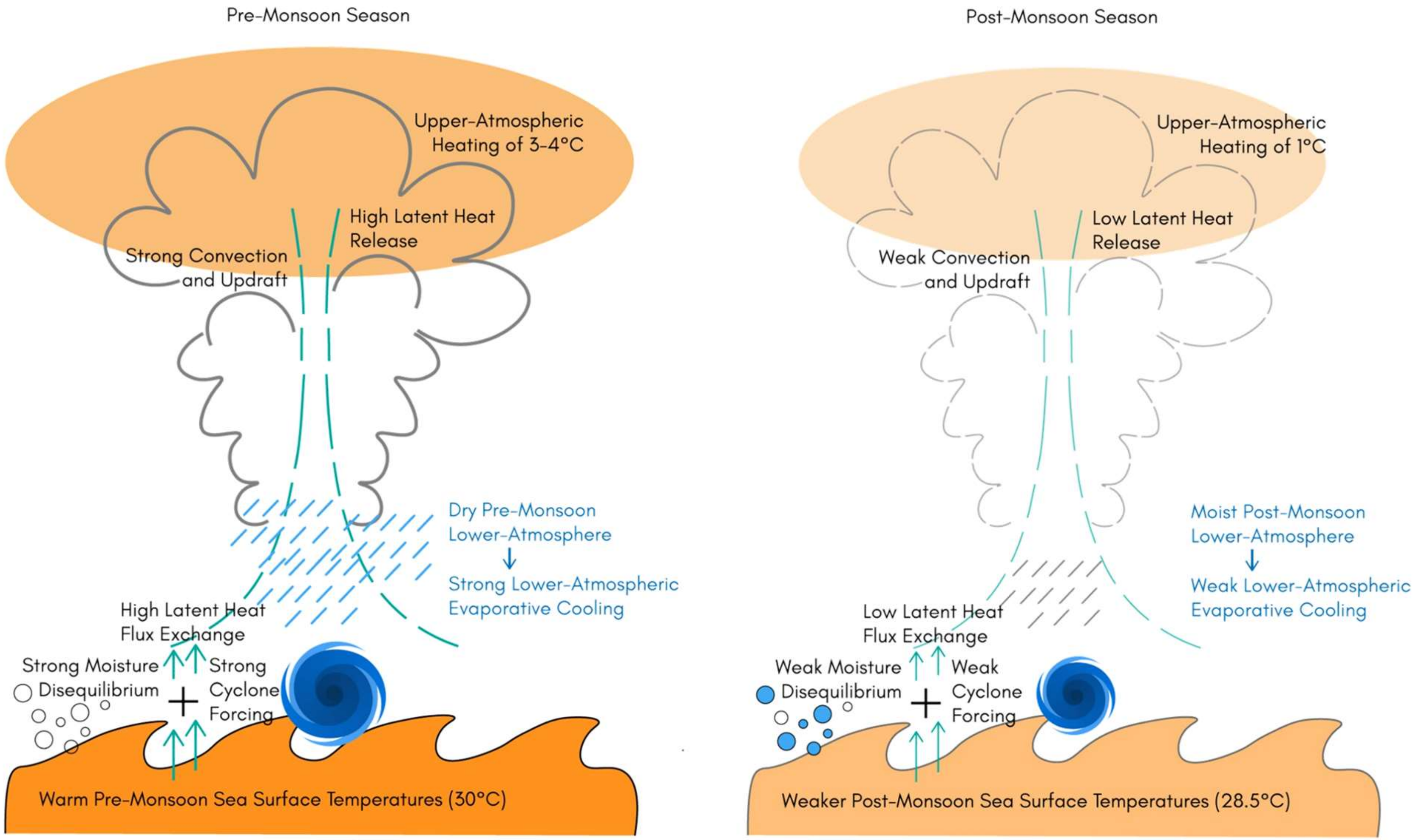




High SSTs and MHWs precede cyclogenesis, and these SSTs have been increasing in the Bay of Bengal



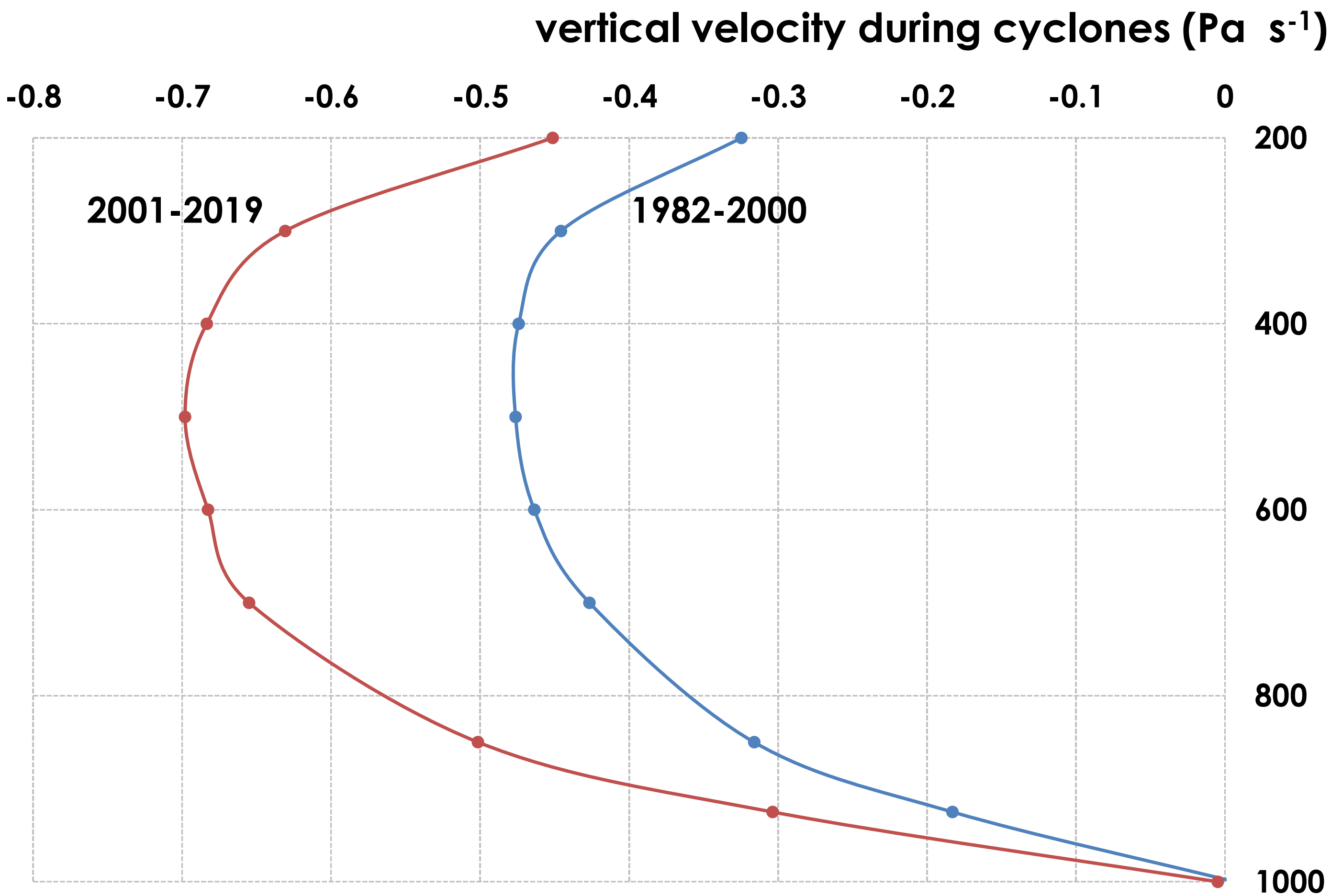
Upper Atmospheric Heating during Cyclone Seasons



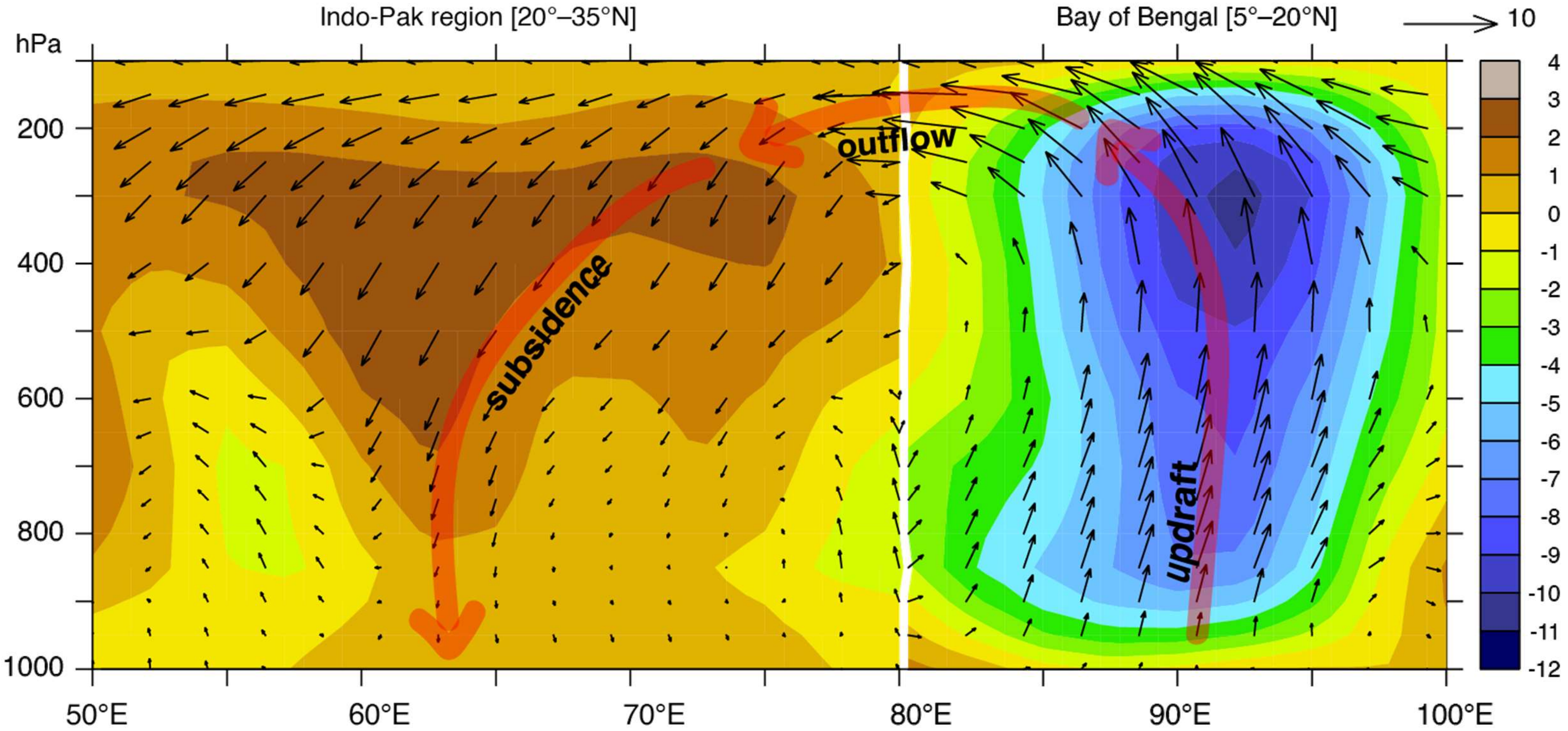
Singh et al. 2023

Cyclones and Enhanced Updraft

High SSTs and latent heat flux from cyclones lead to enhanced updraft (vertical velocity)

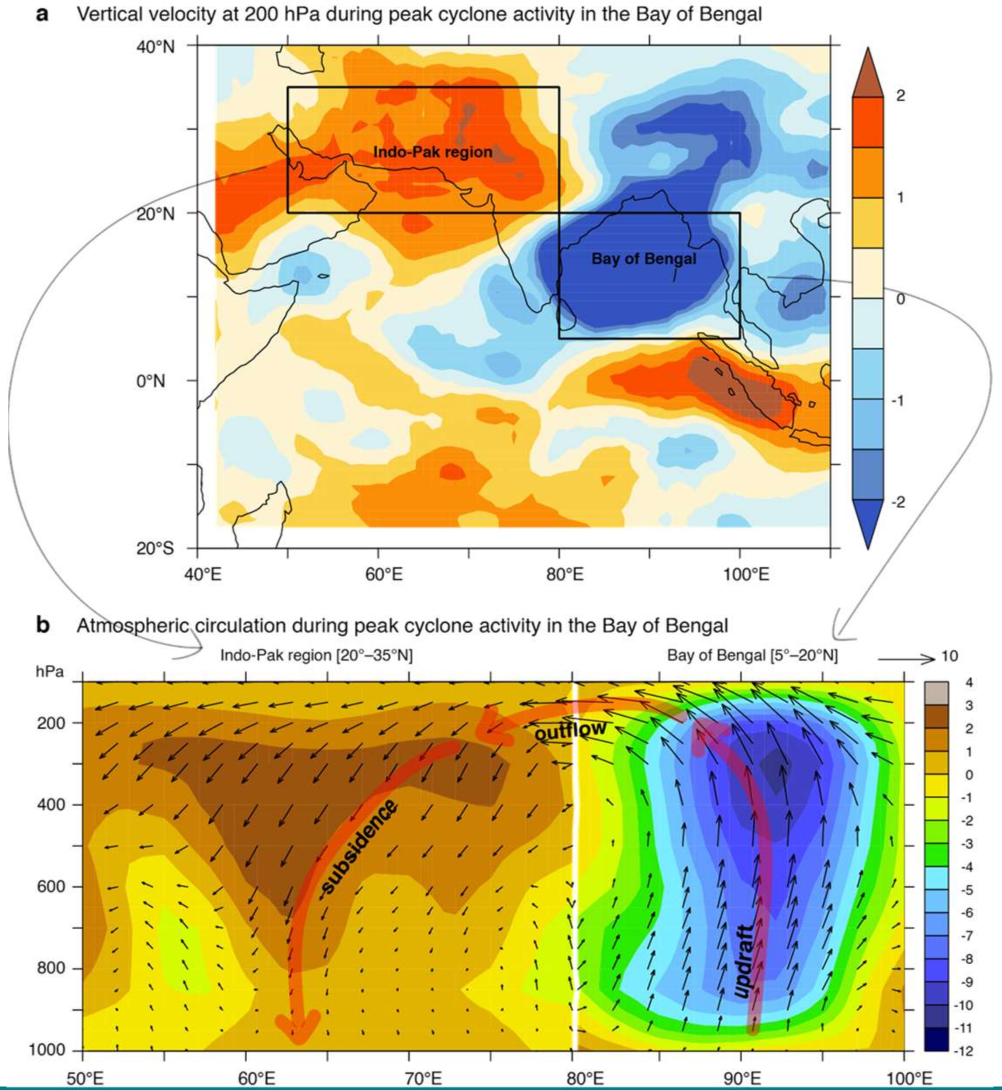


Cyclones and Enhanced Updraft



Roxy et al. 2023

Enhanced updraft over BoB and subsidence over Indo-Pak

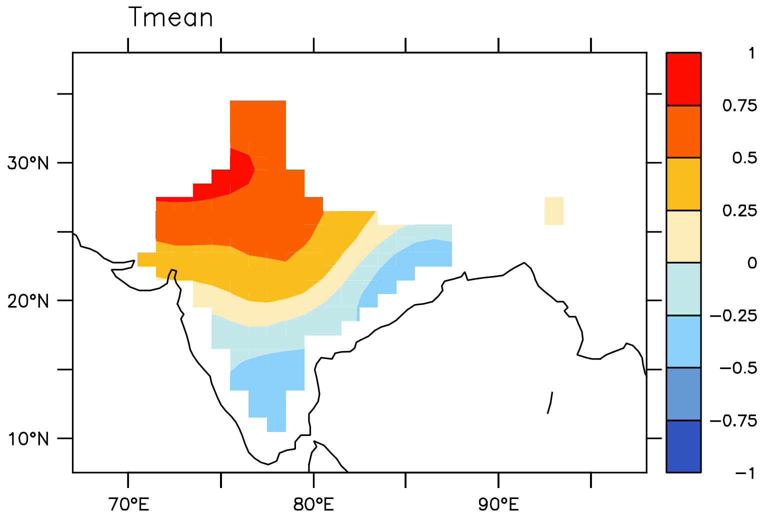


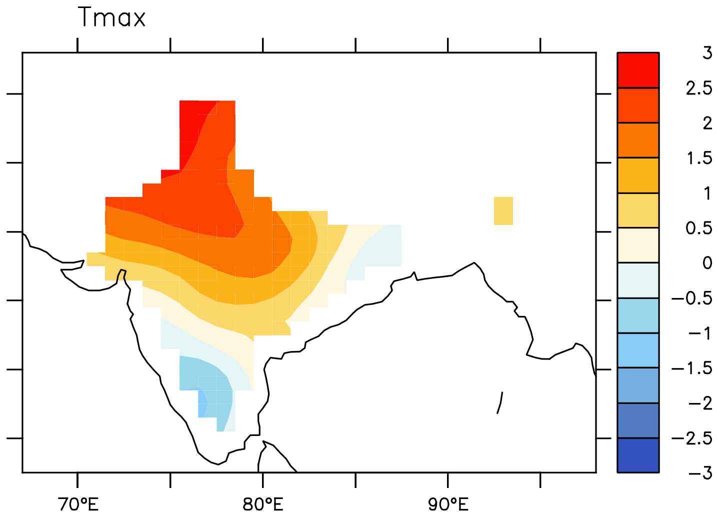
The spatial distribution of the circulation cells show enhanced updraft over the Bay of Bengal and subsidence over the Indo-Pak region

Subsiding air heats the atmosphere by adiabatic compression, inhibiting convection and preventing the formation of clouds. Reduction of clouds increases shortwave radiation reaching the surface, facilitating heatwaves.

Roxy et al. 2023

Temperature anomalies following BoB Cyclones





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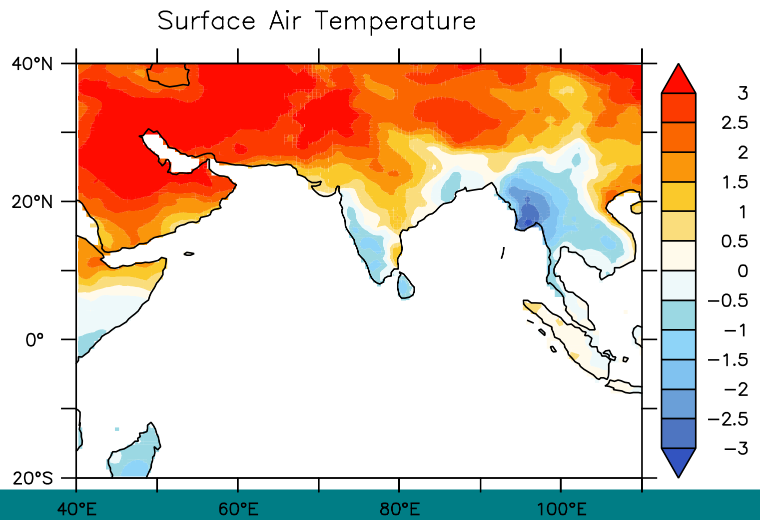
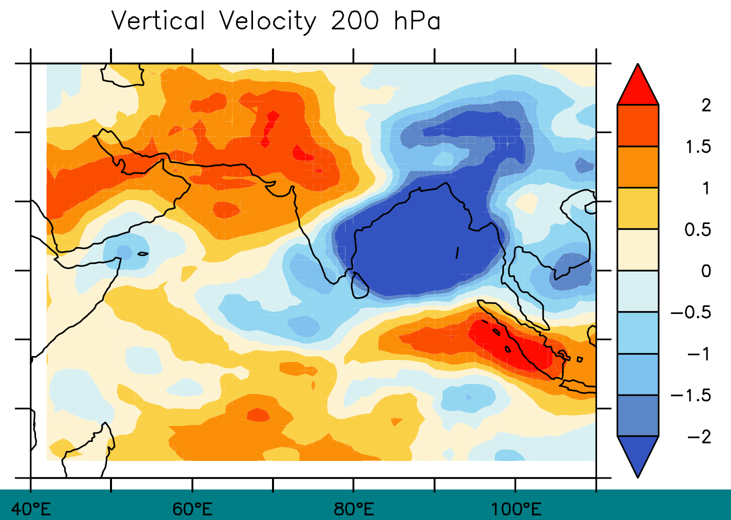
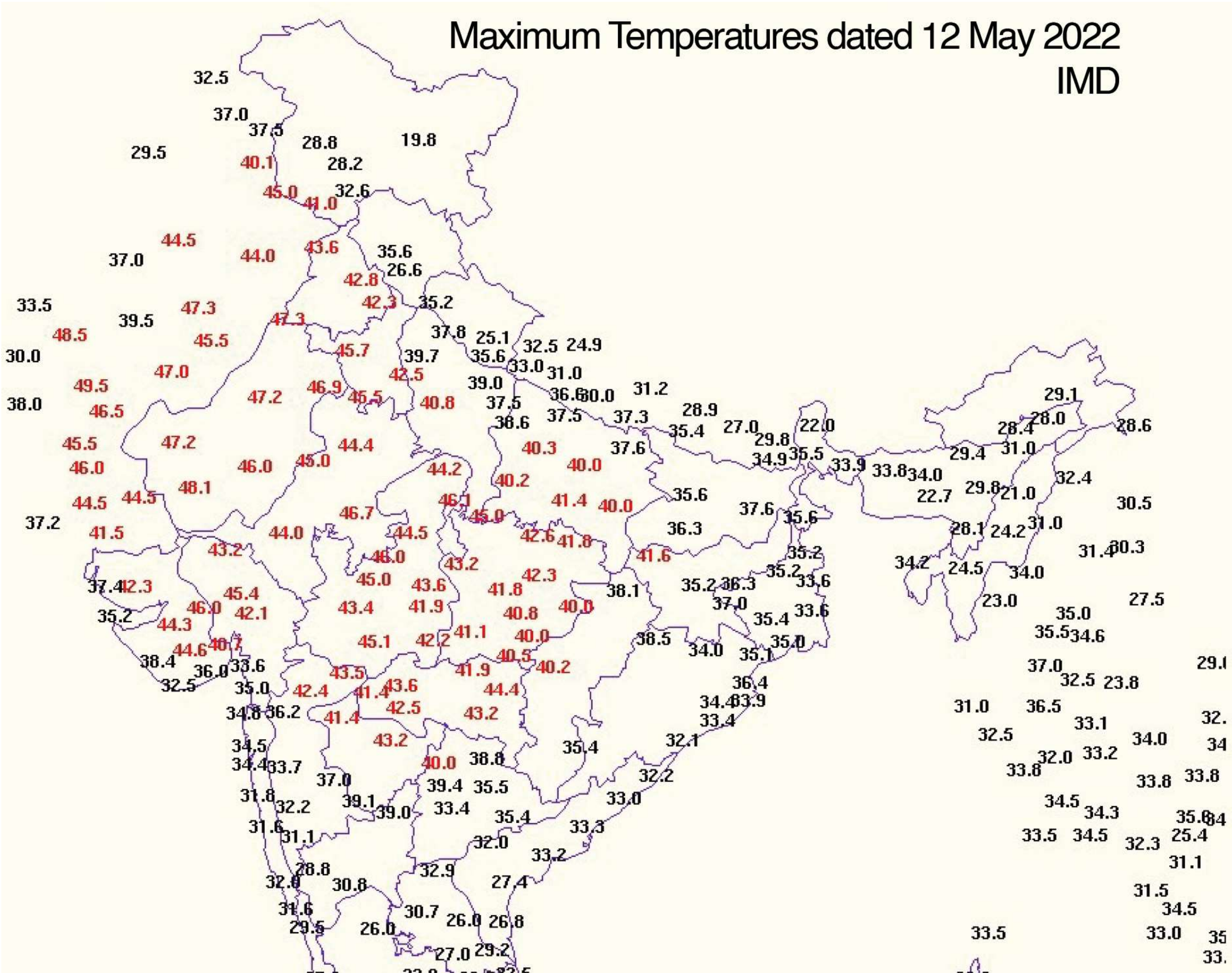
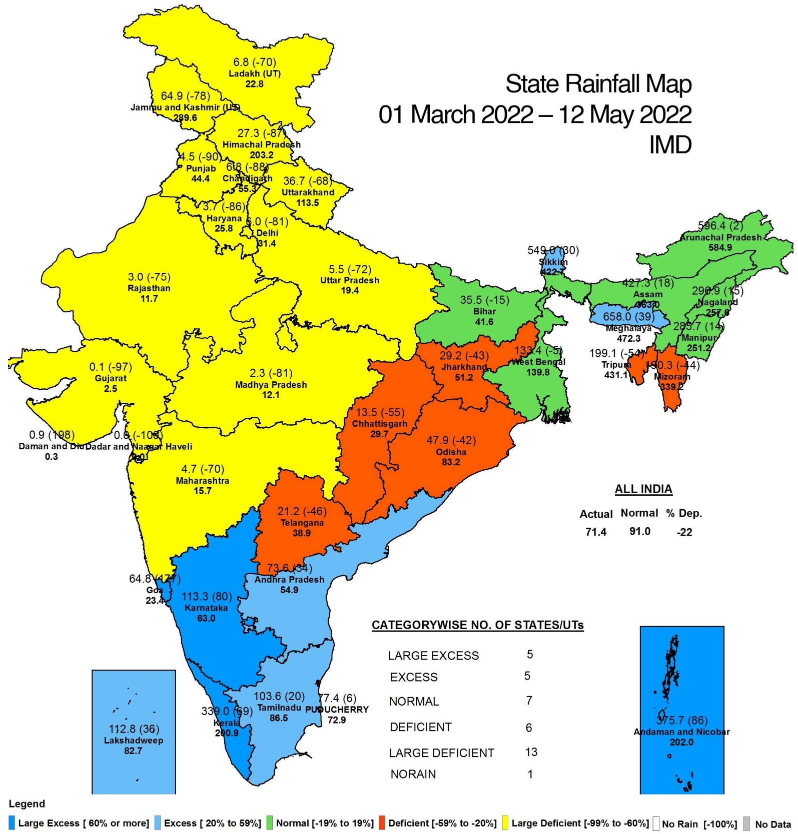




Roxy et al. 2023

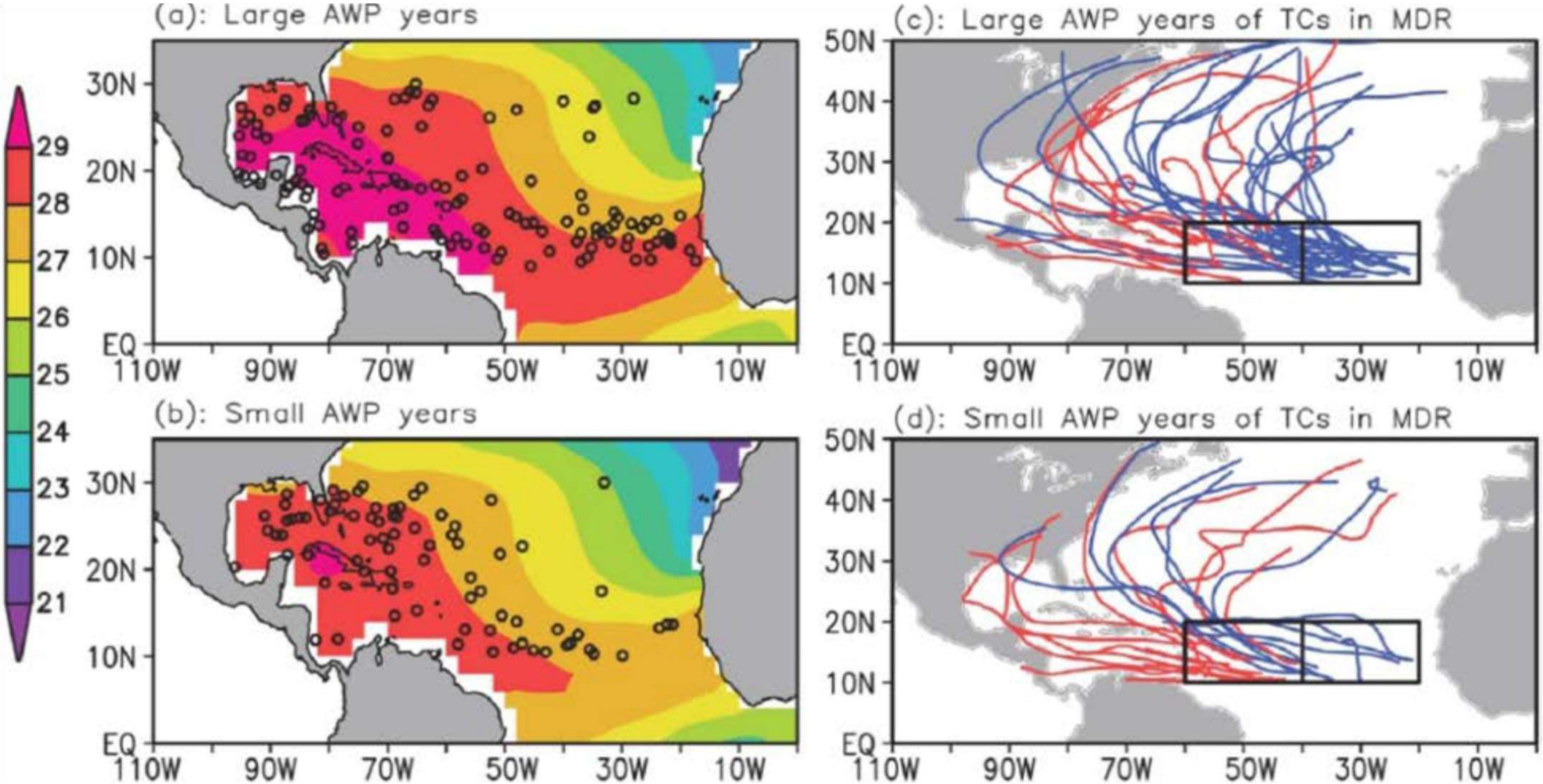
Heat and Rainfall Deficits following BoB Cyclone Asani





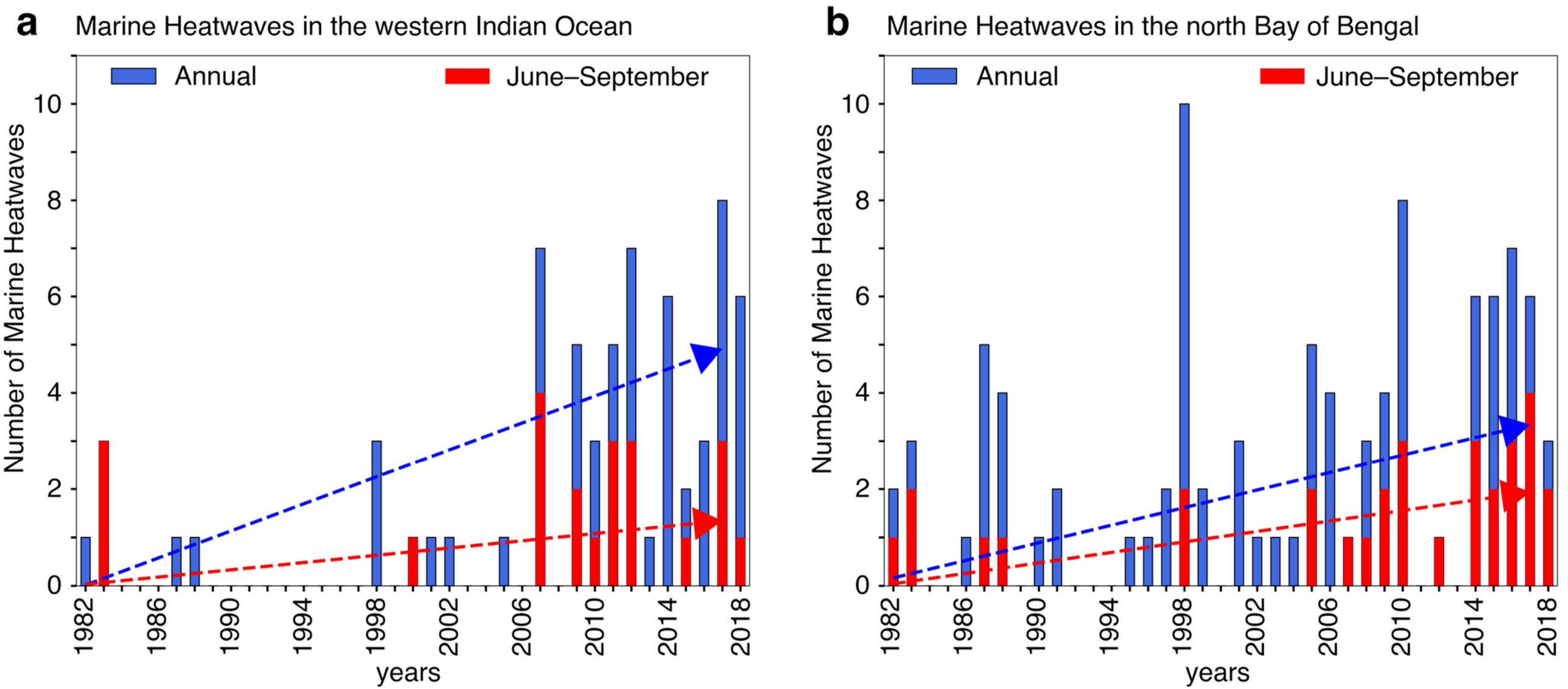
Roxy et al. 2023

Atlantic Warm Pool and Cyclones



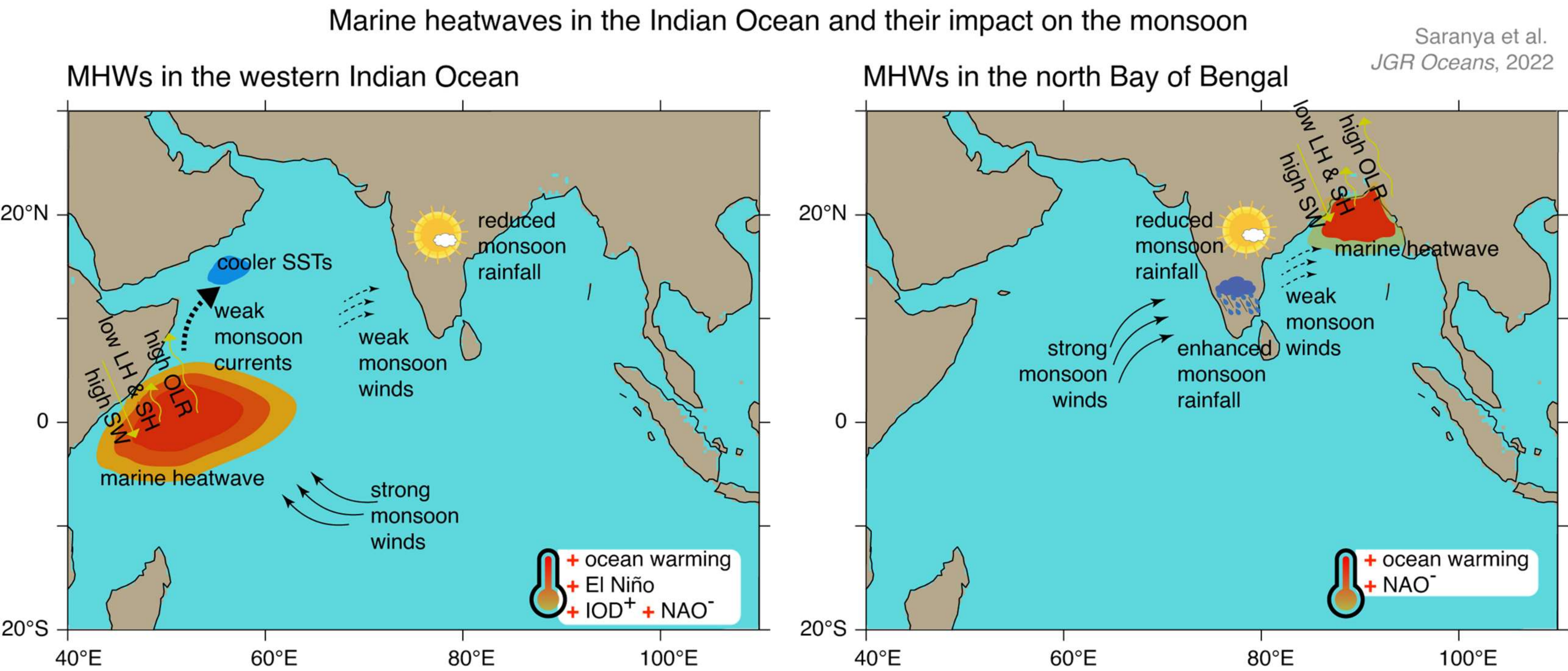
Lee et al., *NOAA Reports*, 2019

Marine Heatwaves and the Monsoon

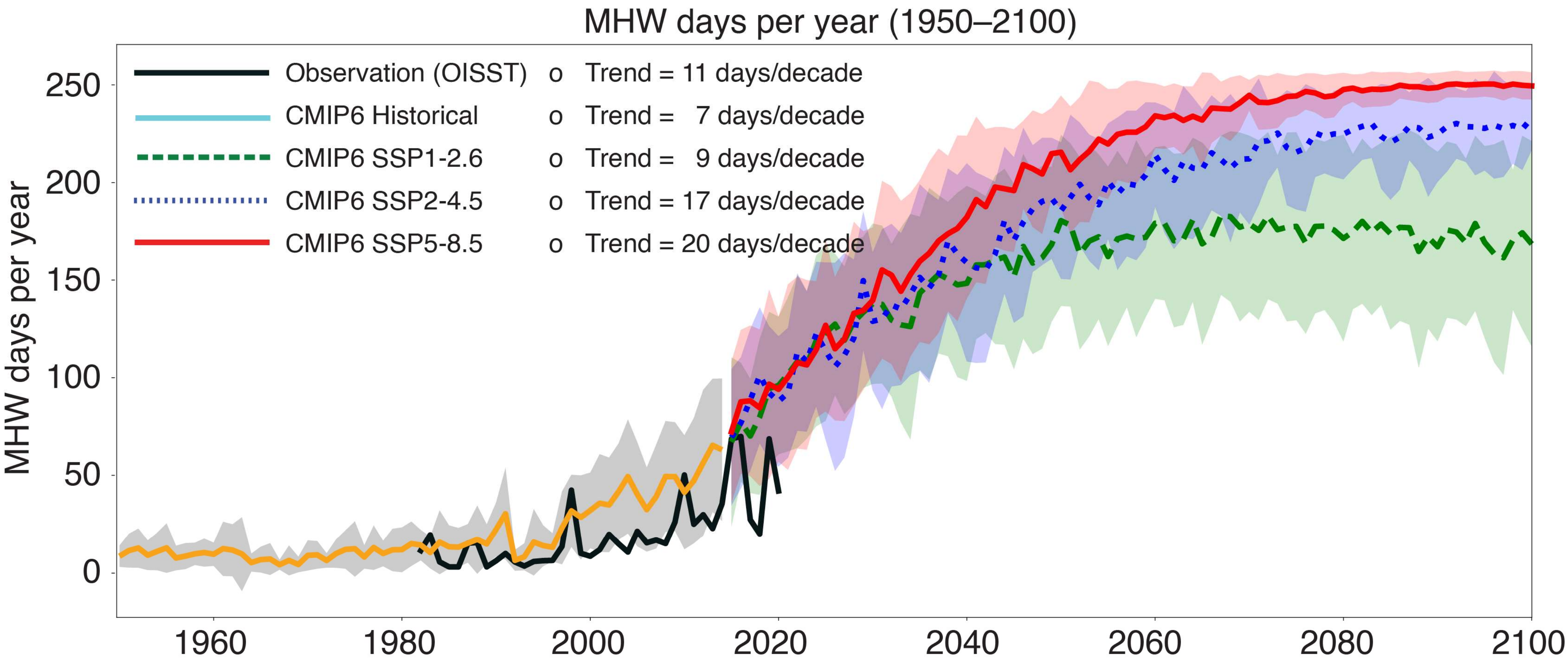


Saranya et al., *JGR Oceans*, 2022

Marine Heatwaves and the Monsoon



Indian Ocean gearing up for a near-Permanent MHW state



Roxy et al. 2023

Call to Action

THE HINDU
TUESDAY, FEBRUARY 8, 2022

Marine heatwaves on the rise around India, says study

These events are linked to coral bleaching, seagrass destruction, and loss of kelp forests; they also affect fisheries sector

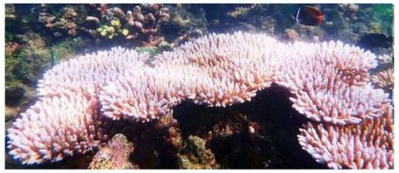
JACOB KOSHY
NEW DELHI

Heatwaves on the land are well known. But marine heatwaves – or the ones that form on oceans – have been on the rise in the waters around India, says a study.

Marine heatwaves are periods of extremely high temperatures in the ocean. These events are linked to coral bleaching, seagrass

85% of the corals in the Gulf of Mannar near the Tamil Nadu coast got bleached after the marine heatwave in May 2020. Emerging studies have reported their occurrence and impacts in the global oceans, but are little understood in the tropical Indian Ocean. The study appears in the journal *JGR Oceans*.

The Western Indian Ocean region experienced the lar-



Hot topic: 85% of the corals in the Gulf of Mannar got bleached after the marine heatwave in May 2020.

…ay of Bengal had 94 events, …he study notes.

The marine heatwaves in …he Western Indian Ocean

and the Bay of Bengal increased drying conditions over the central Indian subcontinent. Correspondingly, there is a significant increase in the rainfall over south peninsular India in response to the heatwaves in the north Bay of Bengal.

" This is the first time that a study has demonstrated a close link between marine heatwaves and atmospheric circulation and rainfall," the authors note.

"Climate model projections suggest further warm-

ing of the Indian Ocean in the future, which will very likely intensify the marine heatwaves and their impact on the monsoon rainfall," Roxy Mathew Koll, among the authors of the study and a scientist at the Indian Insti-

तापमानवाढीचा भारतीय मॉन्सूनवर परिणाम

हिंदी महासागरात वाढलेल्या उष्णतेच्या लाटांचा प्रभाव; 'आयआयटीएम'चा निष्कर्ष

पुणे, ता. ५ : लांबलेला पाऊस, काही ठिकाणी पावसाची कमतरता, तर काही भागात धुवाधार पावसाच्या सरी. सातत्याने होत असलेले हवामान बदल, त्यात पावसाचे चक्रदेखील बदलले आहे. हिंदी महासागरात उष्णतेच्या लाटांचे (मराईन हिटव्हेव) वाढत असलेले प्रमाण व सागरी तापमानवाढ याचा प्रभाव भारतीय मॉन्सूनवर प्रामुख्याने होत असल्याची बाब नुकतीच एका अभ्यासातून समोर आली आहे. पुण्यातील भारतीय उष्णकटिबंधीय हवामानशास्त्र संस्थेच्या (आयआयटीएम) वतीने हा अभ्यास करण्यात आला आहे.

हवामान बदल, मॉन्सूनचे बदलते स्वरूप, यामुळे होणारा परिणाम यामागे

"हवामान मॉडेलच्या अंदाजानुसार भविष्यात हिंद महासागरात आणखी तापमानवाढीची शक्यता आहे. यामुळे सागरी उष्णतेच्या घटना आणि मॉन्सूनवर याचा परिणाम होऊ शकतो. महासागरात उष्णतेच्या लाटांची वारंवारता, तीव्रता आणि त्याचे क्षेत्र वाढत असल्यामुळे या घटनांचे अचूक निरीक्षण करण्यासाठी आपल्याला महासागर निरीक्षण व्याप्ती वाढवणे आवश्यक आहे. त्याचबरोबर तापमानवाढीबाबत जगाने मांडलेल्या आव्हानांचा कुशलतेने अंदाज लावण्यासाठी हवामानविषयक मॉडेल अद्ययावत करणे आवश्यक आहे.
- रॉक्सी मॅथ्यू कोल, शास्त्रज्ञ, आयआयटीएम

- हिंदी महासागराचे तापमान वेगाने वाढत आहे
- यामुळे सागरी गवत नष्ट होणे, प्रवाळांचे रंग बदलणे
- सागरी जैवविविधतेचे नैसर्गिक अधिवास नष्ट होतात
- सागरी जैवविविधतेवर परिणाम
- मत्स्यपालन क्षेत्रावर प्रतिकूल परिणाम

अभ्यासातील निष्कर्ष

१ सागरी भागात केलेल्या सर्वेक्षणानुसार मे २०२० मधील उष्ण लाटेच्या घटनेनंतर तमिळनाडू किनाऱ्याजवळील मन्नारच्या आखातातील ८५ टक्के प्रवाळाचा रंग बदलला
२ उष्णकटिबंधीय हिंदी महासागरात अशा उष्णतेच्या लाटांचे घटनांचे प्रमाण पूर्वी दुर्मिळ होते, आता दरवर्षी आढळतात
३ मागील चार दशकांमध्ये पश्चिम हिंदी महासागरात उष्णतेच्या लाटांच्या घटना चार पटीने वाढल्या
४ बंगालच्या उत्तरेकडील उपसागरात त्या २ ते ३ पटींनी वाढल्या
५ १९८२ ते २०१८ या कालावधीत बंगालच्या उपसागरात ९४, तर पश्चिमी हिंदी महासागरात एकूण ६६ वेळा असे घडले

Heatwaves in IOR may be affecting monsoon: Study

Vaishnavi Chandrashekhar | TNN

Mumbai: Marine heatwaves in the Indian Ocean have risen in frequency and size since the 1980s, with the largest increases seen in the western Indian Ocean and the Bay of Bengal, as per a new study.

The trend has implications not only for the region's fisheries but also, potentially, the monsoon —the study found marine heatwaves reduced rainfall over central India and increased rain over the southern peninsula.

The rise is due to rising ocean temperatures and El Nino events, as well as local factors, the study said, and is in line with global trends.

The western Indian Ocean saw a four-fold increase in heatwaves betwe-

Indian Institute of Tropical Meteorology's study found that marine heatwaves caused less rain in central India and more in the south

ne heatwaves only recently. Indian Ocean heatwaves are among the least understood despite the ocean being among the fastest warming in the world, says Roxy Mathew Koll of the Indian Institute of Tropical Meteorology in Pune who led the study. Surface temperature in these waters rose by 1°C on average

both regions led to less rain over central India, while heatwaves in the northern Bay of Bengal appeared to drive more rain to south India.

How can a heatwave in the ocean control rainfall in the sky? "The distribution of heat can influence the course of winds," explains Koll. Strong heating over the western Indian

കടലിൽ ചൂ

തെക്കേയിന്ത്യയിൽ

പവിഴപ്പുറ്റുകളെ ഇല്ലാതാക്കും

എം.എസ്. ഗോപകുമാർ
ആലപ്പുഴ

▸ ഇന്ത്യൻ മഹാസമുദ്രത്തിലും ബംഗാൾ ഉൾക്കടലിലും താപതരംഗങ്ങൾ വർധിക്കുകയാണെന്നും ഇത് ഇന്ത്യയിലെ കാലവർഷത്തെ സ്വാധീനിക്കുമെന്നും പഠനം. തെക്കേയിന്ത്യയിൽ മഴക്കൂടുതലിനും മധ്യേന്ത്യയിൽ മഴക്കുറവിനും വരൾച്ചയ്ക്കും ചുഴലിക്കാറ്റുകളുടെ വ്യതിയാനത്തിനും ഇതുകാരണമാകും. പെട്ടെന്നു തീവ്രമാകുന്ന ചുഴലിക്കാറ്റുകൾ രൂപപ്പെ

GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
RAJYA SABHA
UNSTARRED QUESTION NO. - 2428
ANSWERED ON – 24/03/2022

INCREASE IN TEMPERATURE OF OCEAN SURFACE

2428. Shri Ripun Bora:

Will the Minister of EARTH SCIENCES be pleased to state:

(a) whether it is a fact that marine heat waves (MHW) have increased temperatures over seas and oceans of the country and have increased significantly in the past few decades;

(b) whether it is also a fact that the year 2021 broke all previous records of ocean heat which worstly affected the Western Indian Ocean and Northern Bay of Bengal impacting the southwest monsoon over the Indian subcontinent; and

(c) if so, plan of action of Government to overcome the disruption in India's monsoon patterns and normalise the temperature of the ocean surface?