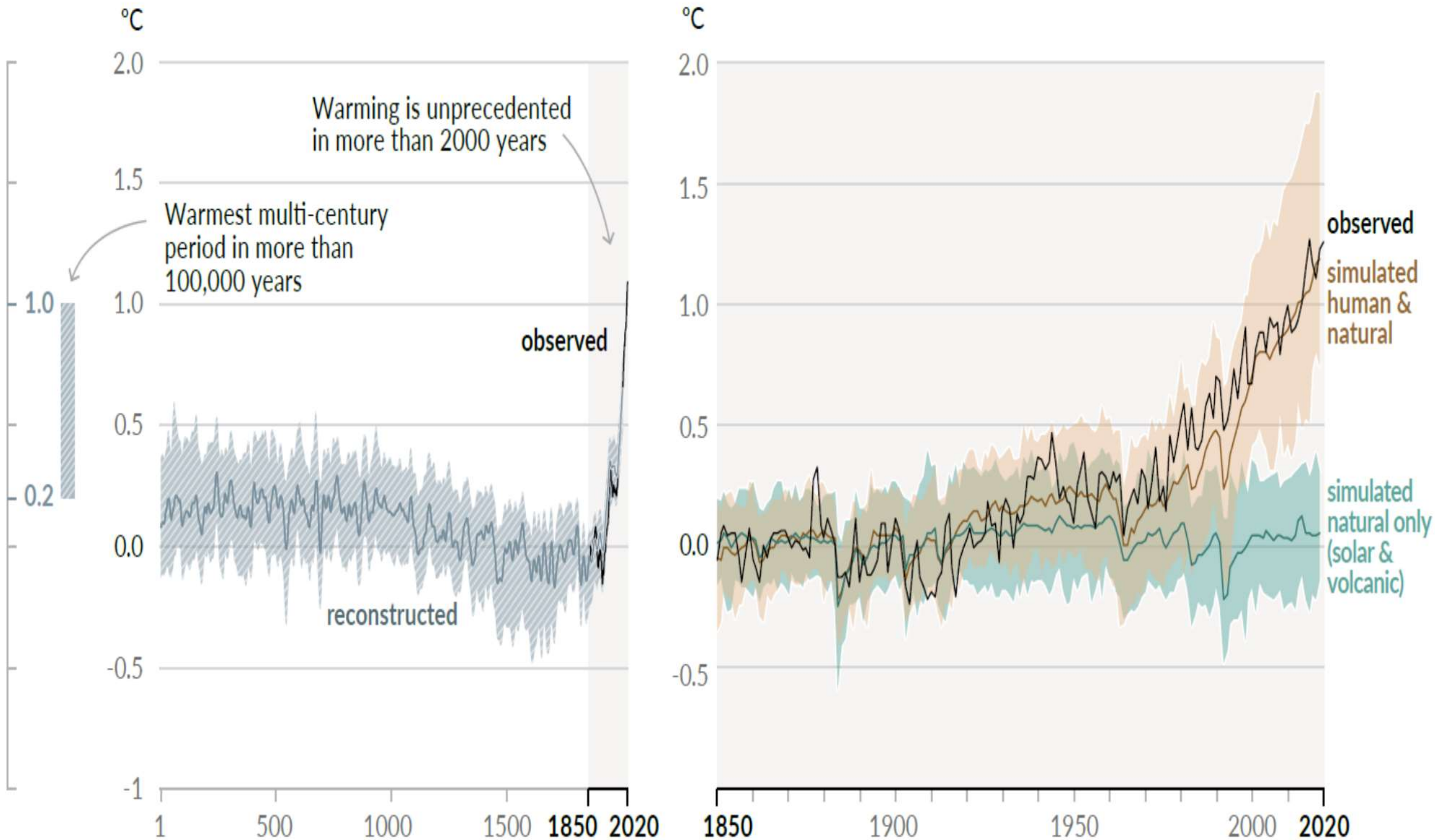
Climate Change And Its Implications (CCI)

Dr. Raji P

Lecture-7

Evidences of climate change



°C
2.0
1.5
1.0
0.5
0.0
-0.5
-1
1.0
0.2
Warming is unprecedented in more than 2000 years
Warmest multi-century period in more than 100,000 years
observed
reconstructed
1
500
1000
1500
1850
2020
°C
2.0
1.5
1.0
0.5
0.0
-0.5
observed
simulated human & natural
simulated natural only (solar & volcanic)
1850
1900
1950
2000
2020

- Extreme heat: India is already experiencing a warming climate

- Unusual and unprecedented spells of hot weather are expected to occur far more frequently and cover much larger areas

- Under 4°C warming, the west coast and southern India are projected to shift to new, high-temperature climatic regimes with significant impacts on agriculture

- Change in rainfall pattern:

- ➢ A decline in monsoon rainfall since the 1950s has already been observed. The frequency of heavy rainfall events has also increased

- ➢ A 2°C rise in the world's average temperatures will make India's summer monsoon highly unpredictable

- ➢ At 4°C warming, an extremely wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century

- An abrupt change in the monsoon could precipitate a major crisis, triggering more frequent droughts as well as greater flooding in large parts of India

- India’s northwest coast to the south eastern coastal region could see higher than average rainfall

- Dry years are expected to be drier and wet years wetter

- Drought: Evidence indicates that parts of South Asia have become drier since the 1970s with an increase in the number of droughts

➢ In 1987 and 2002-2003, droughts affected more than half of India's crop area and led to a huge fall in crop production

➢ Droughts are expected to be more frequent in some areas, especially in north-western India

- Groundwater: More than 60% of India's agriculture is rain-fed, making the country highly dependent on groundwater
- Even without climate change, 15% of India's groundwater resources are overexploited

- Glacier melt: At 2.5°C warming, melting glaciers and the loss of snow cover over the Himalayas are expected to threaten the stability and reliability of northern India's primarily glacier-fed rivers, particularly the Indus and the Brahmaputra

- Sea level rise: With India close to the equator, the sub-continent would see much higher rises in sea levels than higher latitudes

- Sea-level rise and storm surges would lead to saltwater intrusion in the coastal areas, impacting agriculture, degrading groundwater quality, contaminating drinking water, and possibly causing a rise in diarrhea cases and cholera outbreaks, as the cholera bacterium survives longer in saline water

- Kolkata and Mumbai, both densely populated cities, are particularly vulnerable to the impacts of sea-level rise, tropical cyclones, and riverine flooding

- Agriculture and food security: Seasonal water scarcity, rising temperatures, and intrusion of sea water would threaten crop yields, jeopardizing the country's food security

- Should current trends persist, substantial yield reductions in both rice and wheat can be expected in the near and medium term

- Under 2°C warming by the 2050s, the country may need to import more than twice the amount of food-grain than would be required without climate change

- Energy security: The increasing variability and long-term decreases in river flows can pose a major challenge to hydropower plants and increase the risk of physical damage from landslides, flash floods, glacial lake outbursts, and other climate-related natural disasters

- Decreases in the availability of water and increases in temperature will pose major risk factors to thermal power generation

- Water security: An increase in variability of monsoon rainfall is expected to increase water shortages in some areas

- Studies have found that the threat to water security is very high over central India, along the mountain ranges of the Western Ghats, and in India's northeastern states

- Health:

- Migration & conflict: Climate change impacts on agriculture and livelihoods can increase the number of climate refugees

The Intergovernmental Panel on Climate Change (IPCC)

- The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change

- The IPCC provides regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation

- Created in 1988 by the WMO and the United Nations Environment Programme (UNEP), the objective of the IPCC is to provide governments at all levels with scientific information that they can use to develop climate policies

- IPCC reports are key input into international climate change negotiations

- The IPCC is an organization of governments that are members of the United Nations or WMO

- The IPCC currently has 195 members. Thousands of people from all over the world contribute to the work of the IPCC

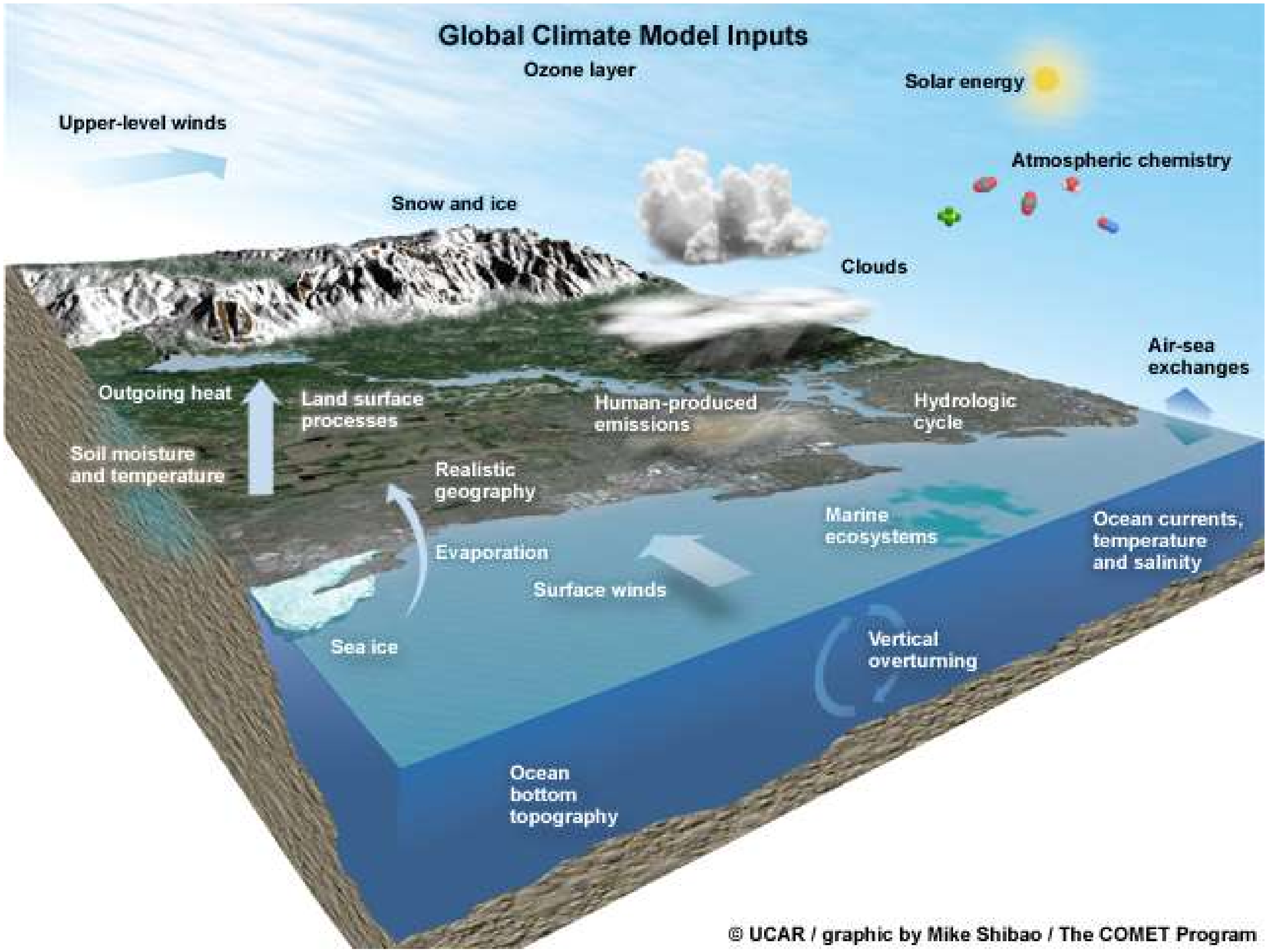
- Since 1988, the IPCC has six assessment cycles and delivered six Assessment Reports, the most comprehensive scientific reports about climate change produced worldwide
- In 1990, the First IPCC Assessment Report (FAR) underlined the importance of climate change as a challenge with global consequences and requiring international cooperation
- The Second Assessment Report (SAR) (1995) provided important material for governments to draw from in the run-up to adoption of the Kyoto Protocol in 1997
- The Third Assessment Report (TAR) (2001) focused attention on the impacts of climate change and the need for adaptation

- The 4th Assessment Report (AR4) (2007) laid the ground work for a post-Kyoto agreement, focusing on limiting warming to 2°C
- The 5th Assessment Report (AR5) was finalized between 2013 and 2014. It provided the scientific input into the Paris Agreement
- Global Warming of 1.5°C (SR15), was requested by world governments under the Paris Agreement

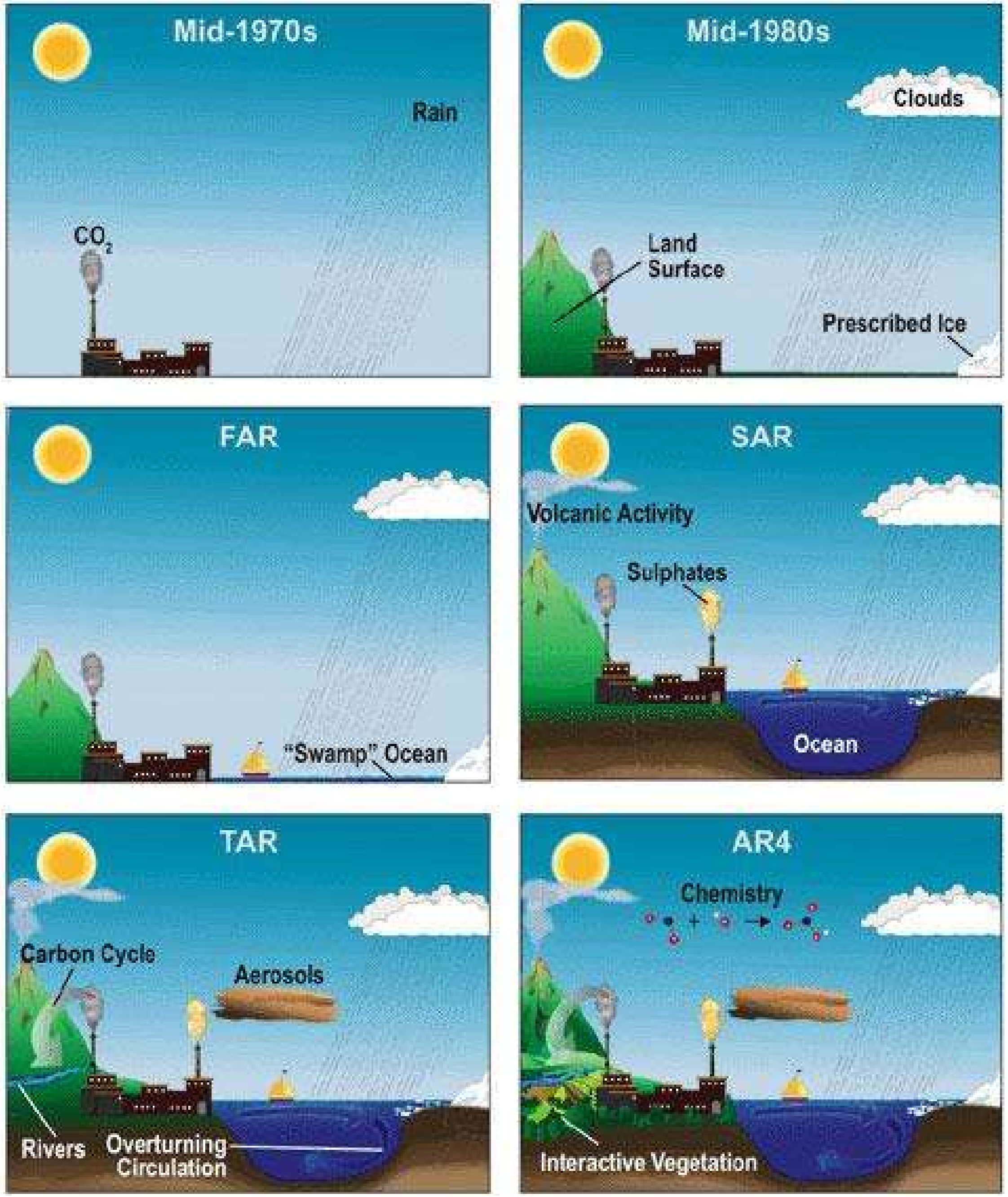
- The IPCC is currently released its Sixth Assessment Reports (9 August 2021)

Climate models

Coupling with Earth System components



The World in Global Climate Models

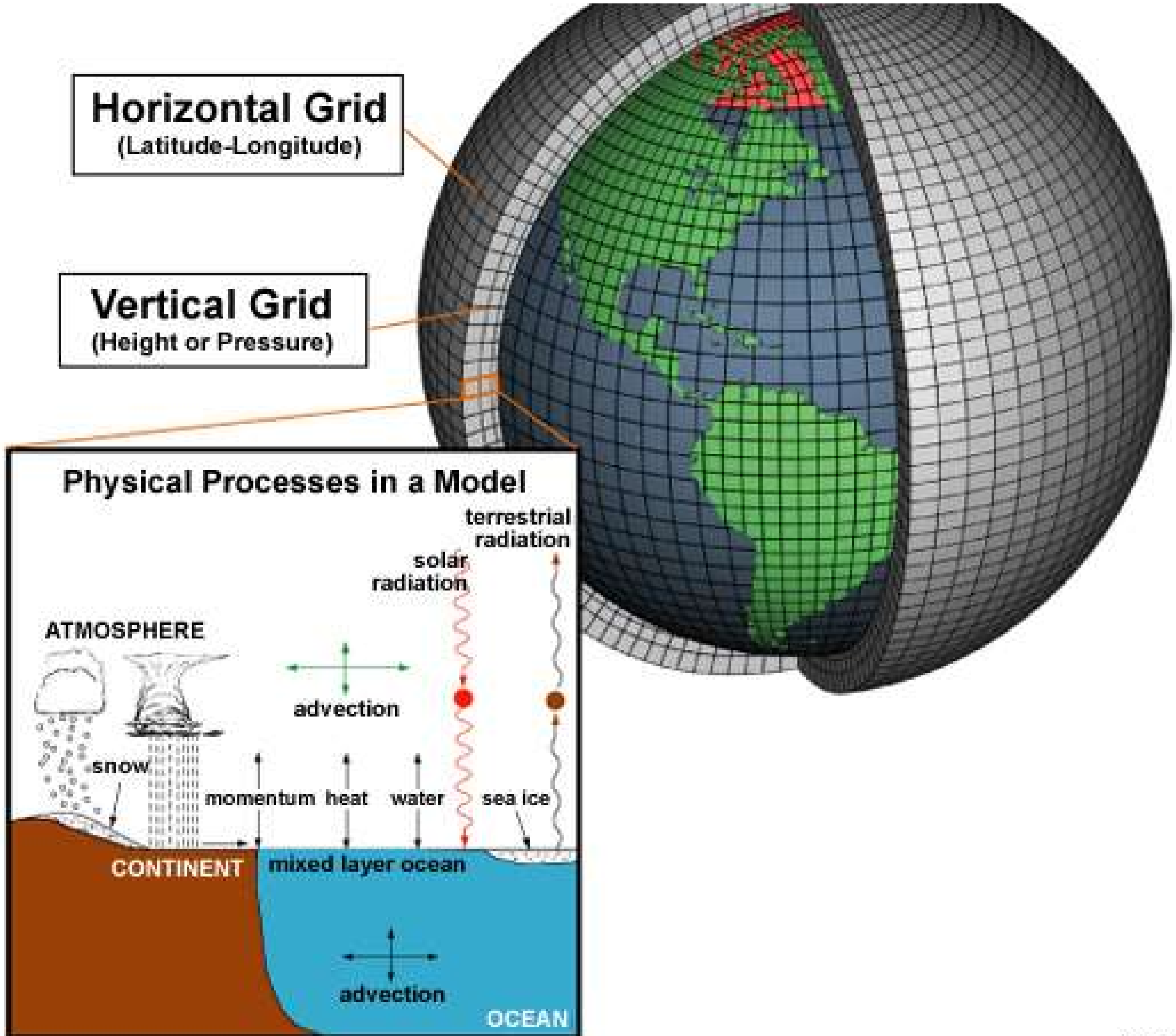


Time Scale of Interaction

Timescale

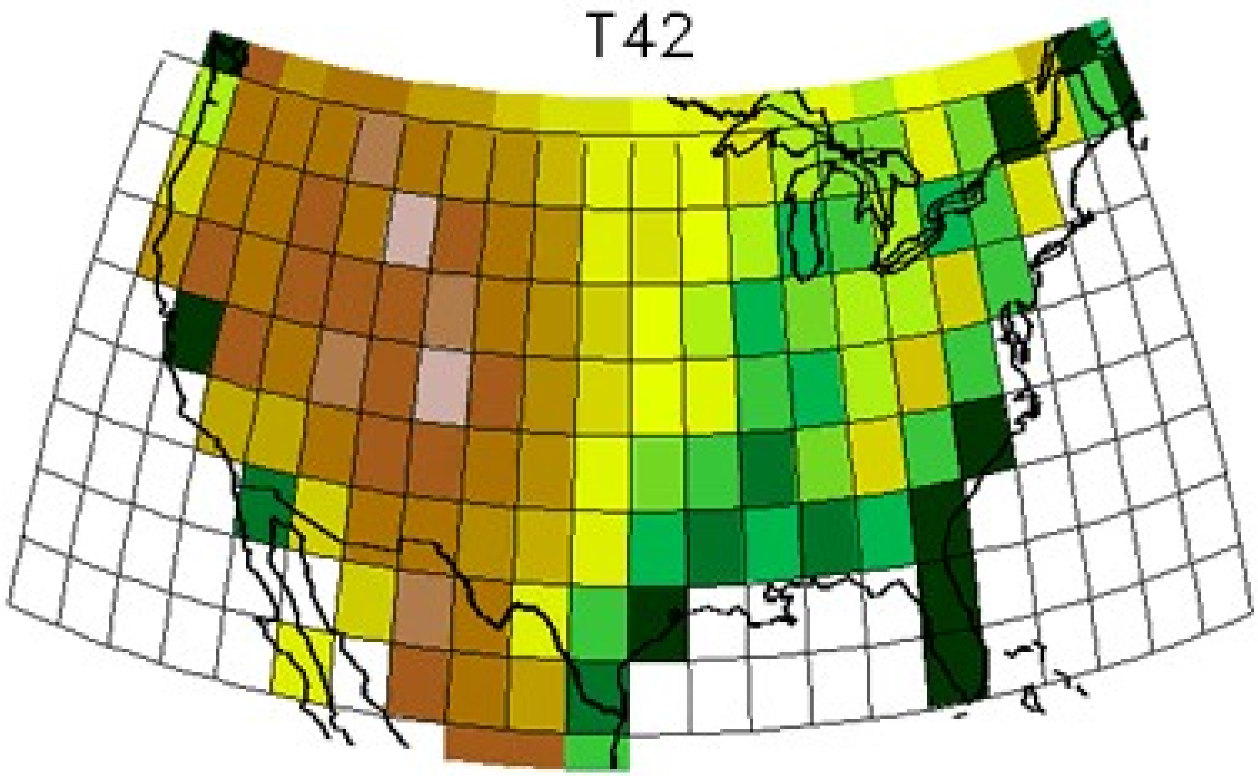
Processes	days			years			thousands of years			millions of years	
	h/d	w	m	y	10 y	10^2y	10^3y	10^4y	10^5y	10^6y	10^9y
Weather	■	■									
Land surface	■	■	■								
Ocean mixed layer	■	■	■								
Sea ice		■	■	■							
Volcanos		■	■	■							
Vegetation	■	■	■	■	■	■	■	■	■	■	
Thermocline				■	■	■					
Mountain glaciers					■	■					
Deep ocean						■	■	■			
Ice sheets						■	■	■	■		
Orbital forcing								■	■		
Tectonics										■	■
Weathering									■	■	■
Solar "constant"				■	■	■	■	■	■	■	■

Climate Models: discretize the space



NOAA

Climate Models: Resolution



GCM output

- Temperatures and humidity of different layers of the atmosphere from the surface to the upper stratosphere

- Temperatures, salinity and acidity (pH) of the oceans from the surface down to the sea floor

- Estimates of snowfall, rainfall, snow cover and the extent of glaciers, ice sheets and sea ice

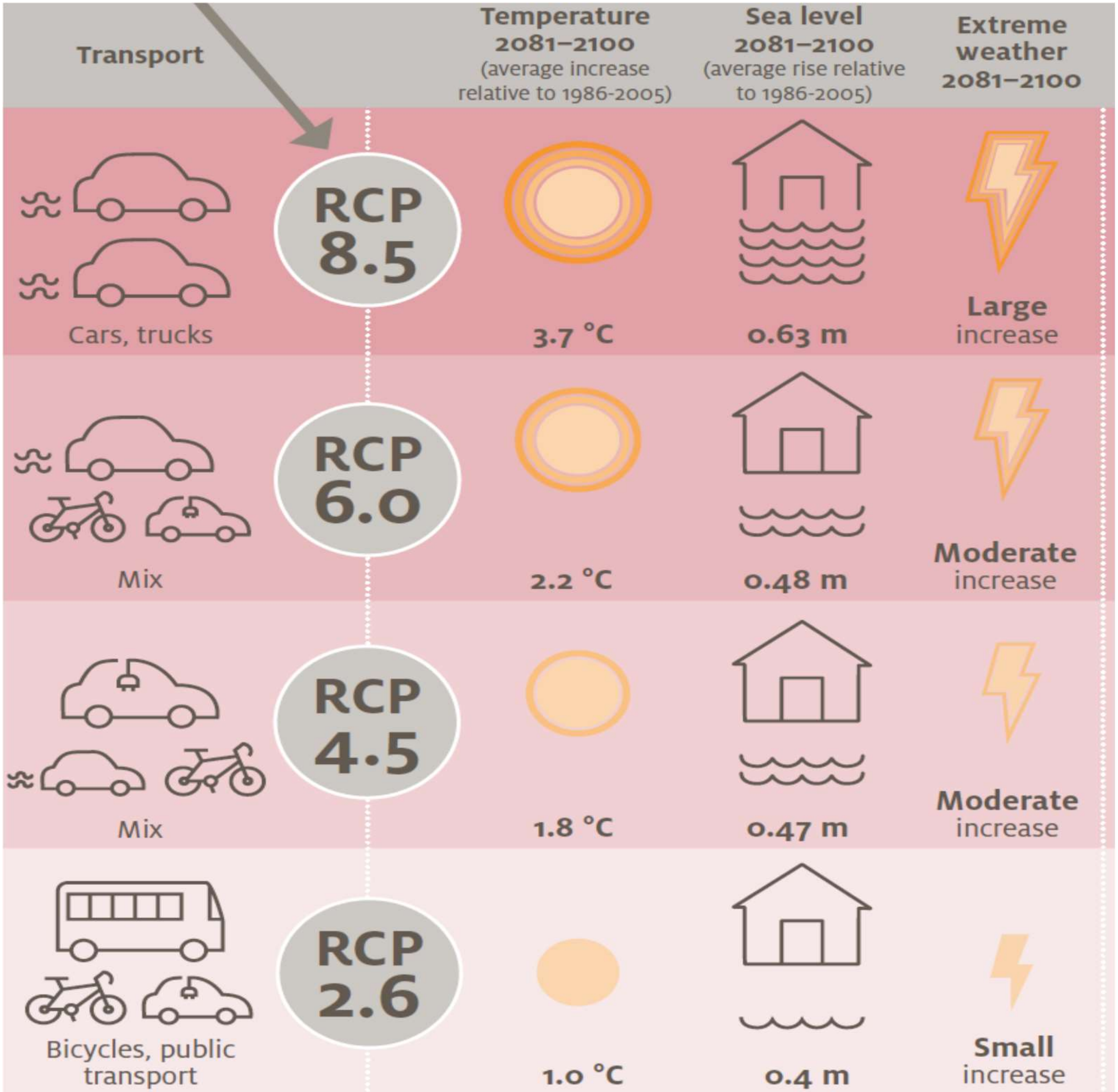
- They generate wind speed, strength and direction, as well as climate features, such as the jet stream and ocean currents

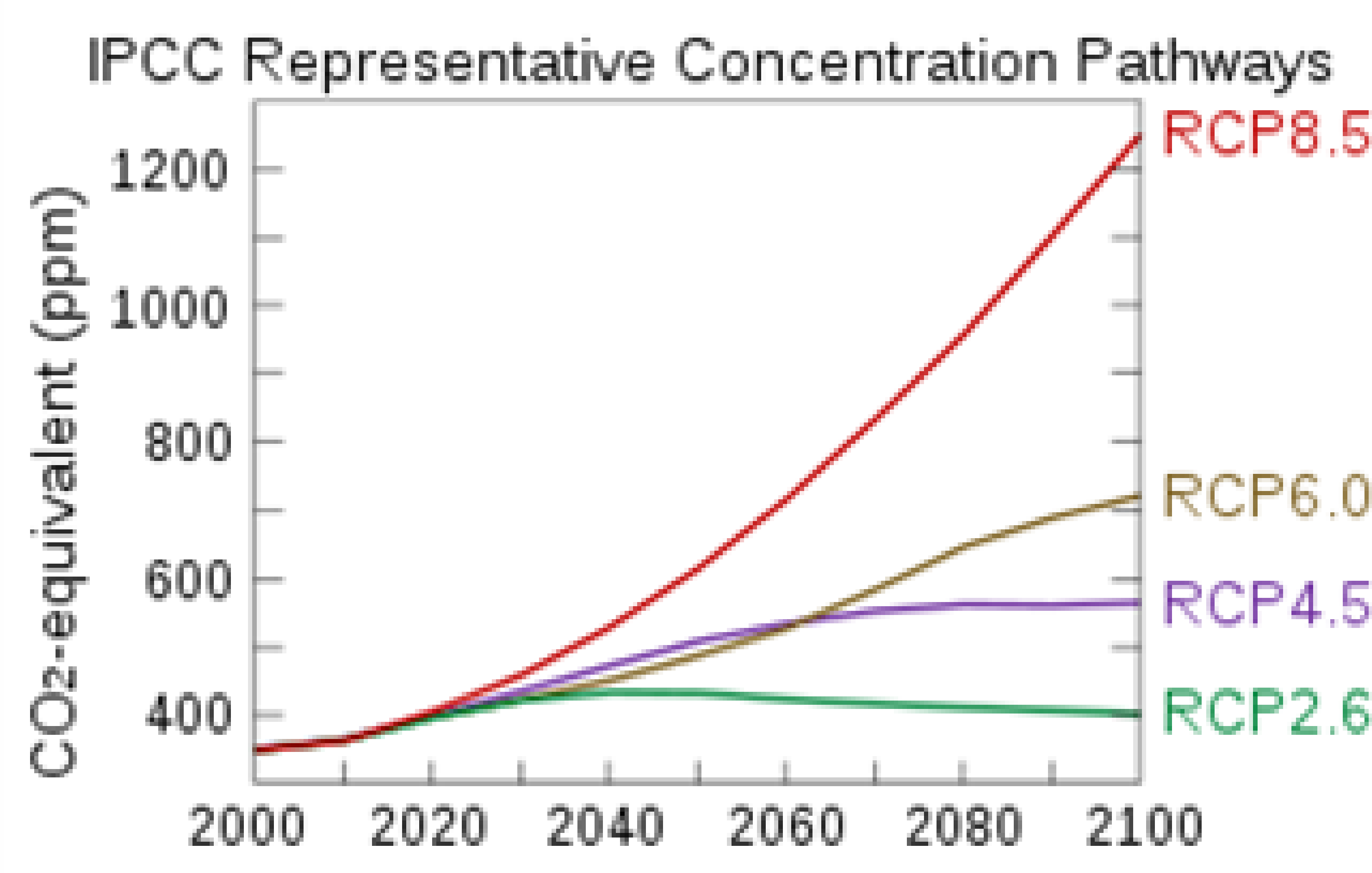
- Cloud cover and height

- Produce an estimate of climate sensitivity. They calculate how sensitive the Earth is to increases in greenhouse gas concentrations

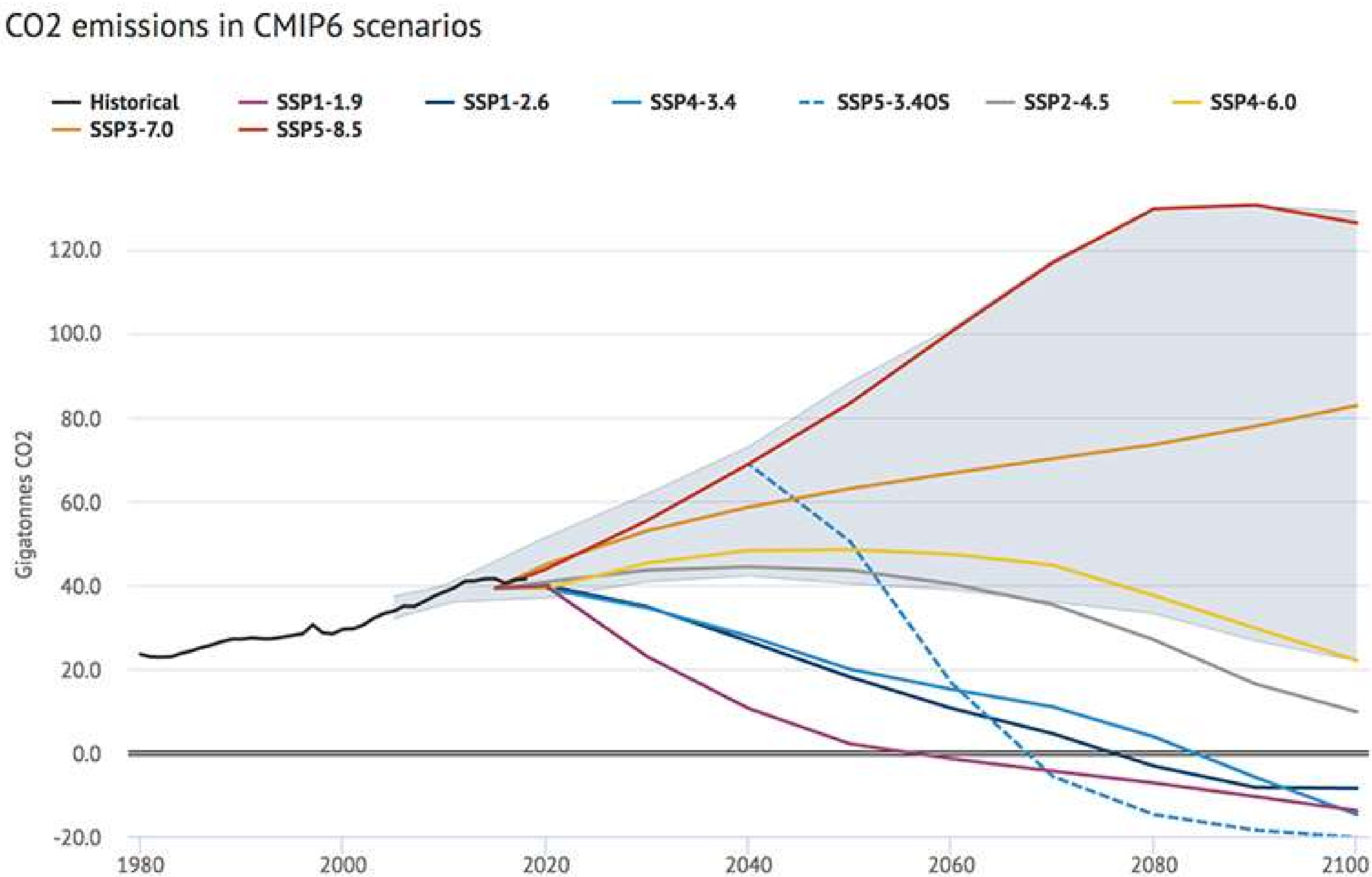
Representative Concentration Pathways (RCP)

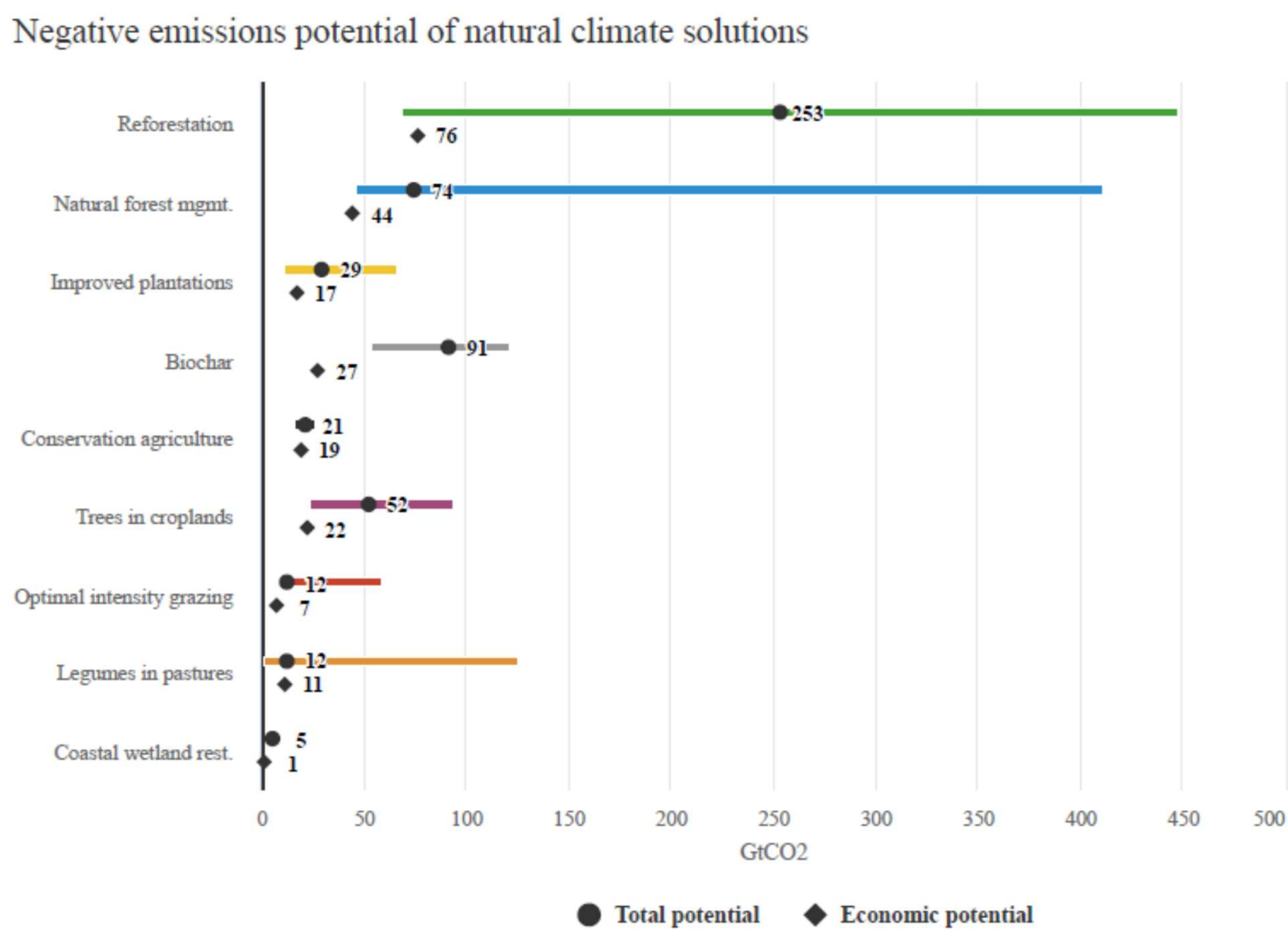
- A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC
- Four pathways were used for climate modeling and research for the IPCC 5fth Assessment Report (AR5) in 2014
- The pathways describe different climate futures, all of which are considered possible depending on the volume of GHG emitted in the years to come
- The RCPs – originally RCP2.6, RCP4.5, RCP6, and RCP8.5 – are labelled after a possible range of radiatve forcing values in the year 2100 (2.6, 4.5, 6, and 8.5 W/m^2, respectively)


Transport
Temperature 2081–2100 (average increase relative to 1986-2005)
Sea level 2081–2100 (average rise relative to 1986-2005)
Extreme weather 2081–2100
Cars, trucks
RCP 8.5
3.7 °C
0.63 m
Large increase
Mix
RCP 6.0
2.2 °C
0.48 m
Moderate increase
Mix
RCP 4.5
1.8 °C
0.47 m
Moderate increase
Bicycles, public transport
RCP 2.6
1.0 °C
0.4 m
Small increase



All forcing agents' atmospheric CO_2-equivalent concentrations (ppm) according to the four RCPs used by the fifth IPCC Assessment Report to make predictions


CO2 emissions in CMIP6 scenarios
Historical
SSP1-1.9
SSP1-2.6
SSP4-3.4
SSP5-3.4OS
SSP2-4.5
SSP4-6.0
SSP3-7.0
SSP5-8.5
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-20.0
Gigatonnes CO2
1980
2000
2020
2040
2060
2080
2100



Negative emissions potentials from different sources, in cumulative Gt CO2 between 2018 and 2100. Bars show uncertainties in total potential, while black circles show best-estimates of total potential and diamonds show economic potential at a cost of less than $100 per ton CO2. Estimates are based on both the rate of sequestration and the time horizon over which the sequestration can continue from [Griscom et al. 2017]

IPCC 6th Assessment Report

SSP	Scenario	Estimated warming (2041–2060)	Estimated warming (2081–2100)	Very likely Range in °C (2081–2100)
SSP1-1.9	very low GHG emissions: CO_2 emissions cut to net zero around 2050	1.6 °C	1.4 °C	1.0 – 1.8
SSP1-2.6	low GHG emissions: CO_2 emissions cut to net zero around 2075	1.7 °C	1.8 °C	1.3 – 2.4
SSP2-4.5	intermediate GHG emissions: CO_2 emissions around current levels until 2050, then falling but not reaching net zero by 2100	2.0 °C	2.7 °C	2.1 – 3.5
SSP3-7.0	high GHG emissions: CO_2 emissions double by 2100	2.1 °C	3.6 °C	2.8 – 4.6
SSP5-8.5	very high GHG emissions: CO_2 emissions triple by 2075	2.4 °C	4.4 °C	3.3 – 5.7

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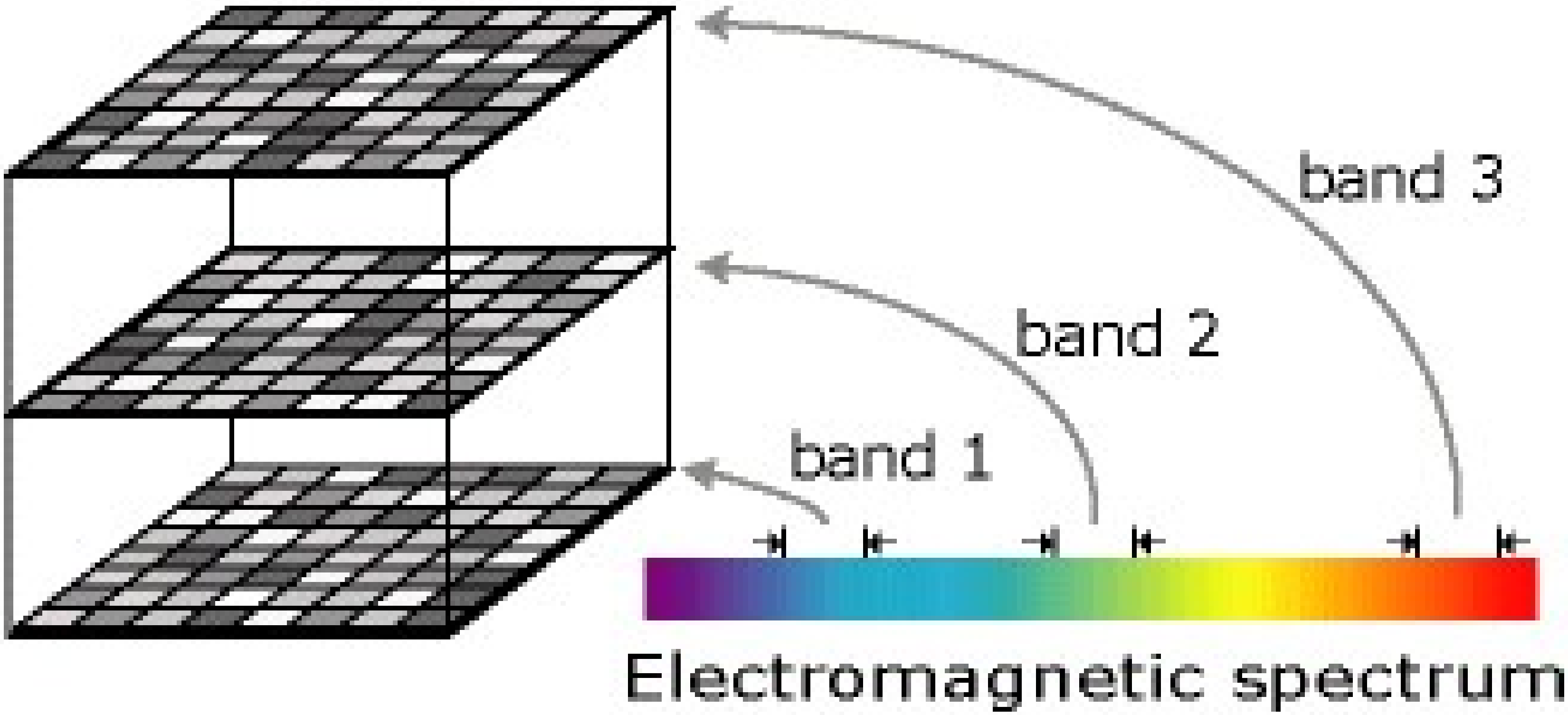
Lecture-10&11


band 3
band 2
band 1
Electromagnetic spectrum

IPCC 6th Assessment Report

SSP	Scenario	Estimated warming (2041–2060)	Estimated warming (2081–2100)	Very likely Range in °C (2081–2100)
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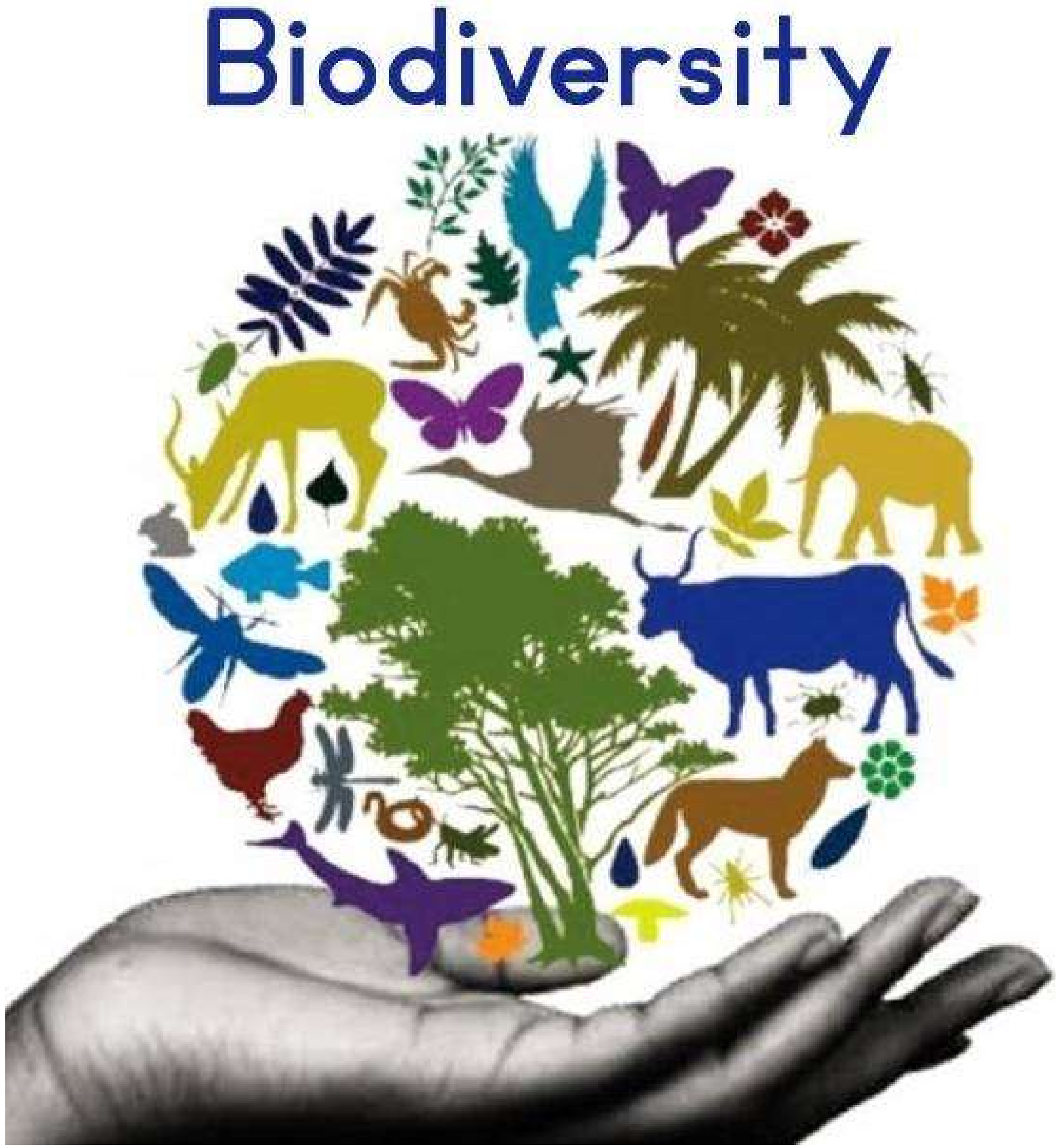
Assignment-2

Briefly discuss the impact of climate change on surface temperature, precipitation, ocean pH, sea-level, Arctic sea-ice extent in global level using the IPCC-AR6 report.

Submission due date: 28/02/2022


Biodiversity

Climate Change & Biodiversity

- Biodiversity is the 'Full variety of Life on Earth'

- It includes diversity within species, between species and of ecosystem

- The sum total of species richness, *i.e*. the number of species of plants, animals and micro-organisms occurring in a given region, country, continent of the entire globe

- Biodiversity includes genetic diversity (Diversity of genes within a species), species diversity (Diversity among species), ecosystem diversity (Diversity at the level of community/ecosystem) and habitat diversity

Importance

- Biodiversity is the very basis of human survival and economic development

- It helps in maintaining the ecological balance

- It plays an important role in the function of an ecosystem by providing many services like nutrients and water cycling, soil formation and retention, resistance against invasive species, pollination of plants, regulation of climate, as well as pest and pollution

- Biodiversity is also the source of non-material benefits like spiritual and aesthetic values, knowledge system, cultural diversity and spiritual inspiration

- It is source of inspiration to musicians, painters, writers and other artists

- At least 40% of the world’s economy, and 80% of the economy of less industrialized nations, is derived directly from biological resources as a function of ecosystem service

- India is one of the 12 mega biodiversity countries in the world and divided into 10 biogeographic regions

- Our country accounts for two hotspots out of the 35 global biodiversity hotspots: the Indo-Malayam which includes the Eastern Himalayas, North-east India and Andaman Islands, and the Western Ghats

- It is estimated that over 46,000 species of plants and 81,000 species of animals are found in India

- The flowering plants comprise 15,000 species of which about 7000 species are endemic

- Among the animal species diversity more than 50,000 species of insects, 4,000 molluscs, 6,500 other vertebrates, 2,546 fishes, 197 amphibians, 408 reptiles, 1224 birds and 350 species of mammals are found in different habitats

- The important causes of threats to biodiversity are the habitat destruction, invasive species, pollution, population and overexploitation of natural resources

- Other prominent factor for the depletion of biodiversity is the rampant poaching

- At the global level, the MEA documented that over 60% of ecosystem services were deteriorating or already overused (Larigauderie and Cesario et al., 2009), and it has been worsened by the impact of increasing climate change

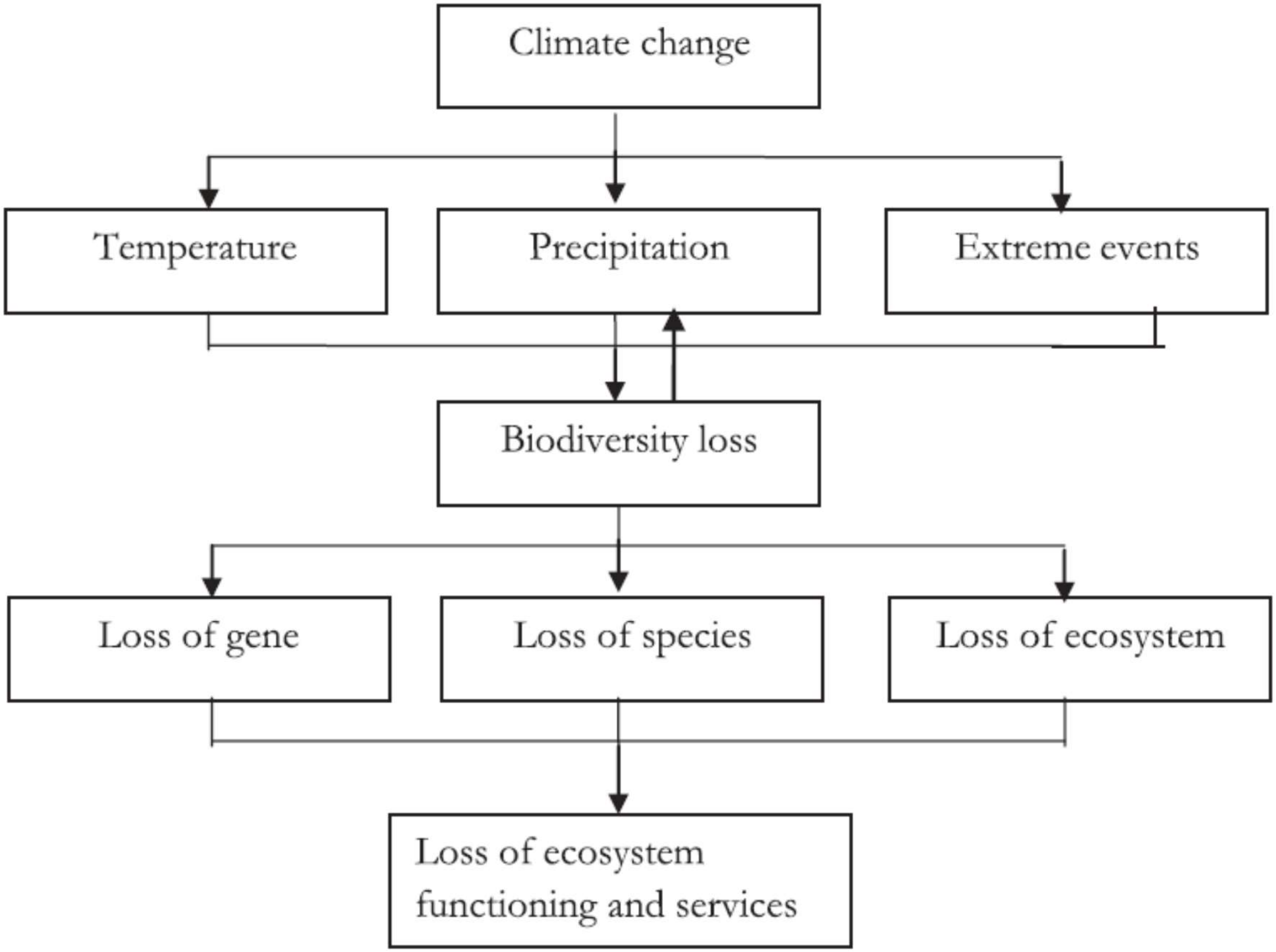
Pressure on biodiversity from human activities

1. Increased demand for resources
2. Selective exploitation or destruction of species
3. Land use and land cover change
4. Accelerated rate of anthropogenic nitrogen deposition
5. Soil, water and air pollution
6. Introduction of non-native species
7. Urbanization and industrialization

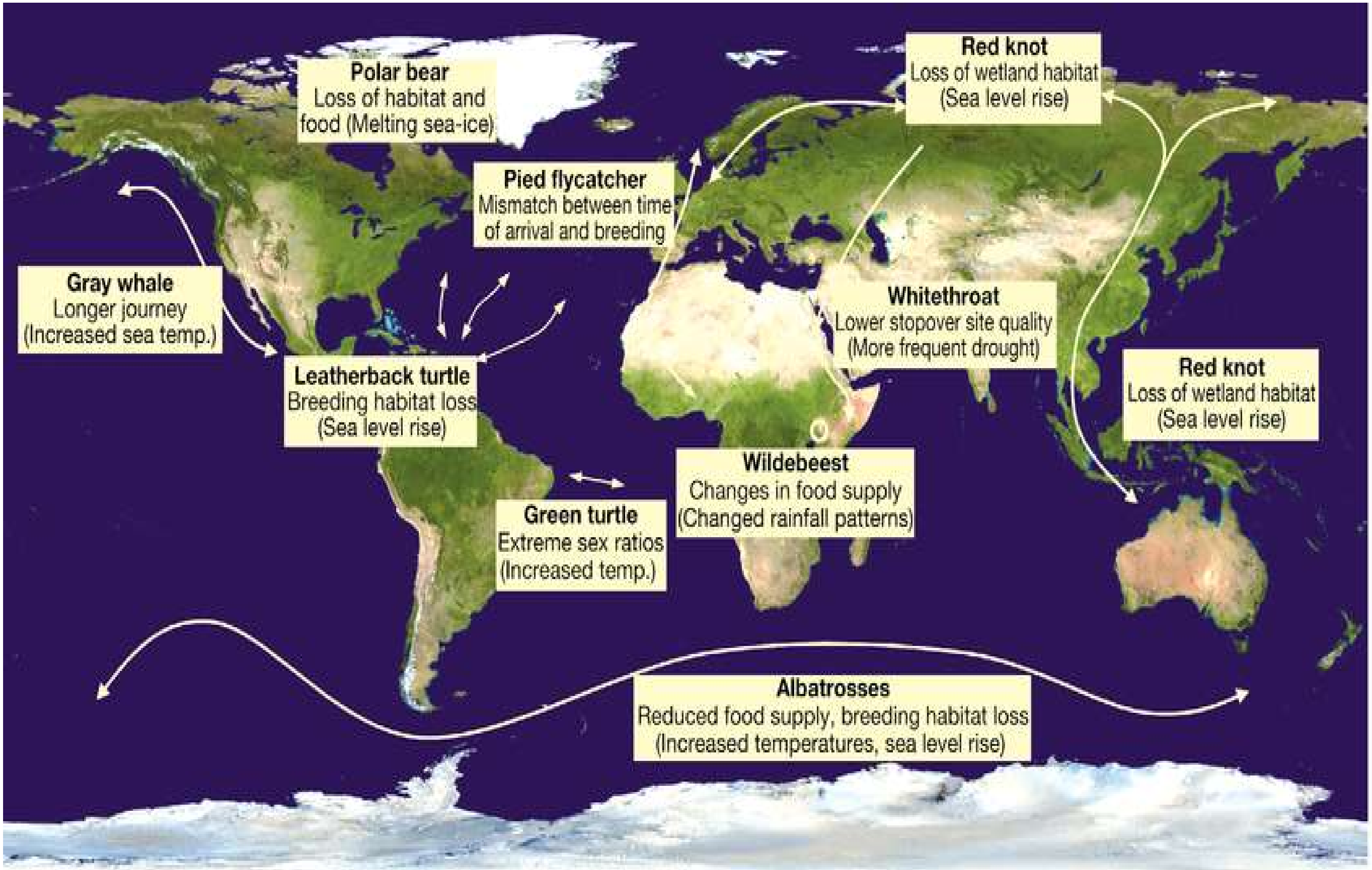
- Climate change

- Climate change affects individual species and the way they interact with other organisms and their habitats, which alters the structure and function of ecosystems and the goods and services that natural systems provide to society

- Periodic assessments of current and future climate change impacts on ecosystems are important for developing and updating natural resource management plans and evaluating adaptation actions


Climate change
Temperature
Precipitation
Extreme events
Biodiversity loss
Loss of gene
Loss of species
Loss of ecosystem
Loss of ecosystem functioning and services

Impact


Polar bear
Loss of habitat and food (Melting sea-ice)
Red knot
Loss of wetland habitat (Sea level rise)
Pied flycatcher
Mismatch between time of arrival and breeding
Gray whale
Longer journey (Increased sea temp.)
Whitethroat
Lower stopover site quality (More frequent drought)
Leatherback turtle
Breeding habitat loss (Sea level rise)
Red knot
Loss of wetland habitat (Sea level rise)
Wildebeest
Changes in food supply (Changed rainfall patterns)
Green turtle
Extreme sex ratios (Increased temp.)
Albatrosses
Reduced food supply, breeding habitat loss (Increased temperatures, sea level rise)

- In the Northwest, abnormally warm temperatures have led to losses of migrating and spawning salmon in the Columbia River (NOAA Fisheries, 2016)

- In Alaska, some salmon populations have benefited from warmer temperatures, earlier spring, and increased density of zooplankton prey (Schindler et al., 2005)

- Coho salmon on the west coast of the U.S. are expected to shift their range north by 2050 (Cheung et al.,2015)

- Under a high greenhouse gas emissions scenario, projected stream temperature increases could lead to a 22% reduction in salmon habitat in Washington by late century (Niemi et al., 2009)

1. Ocean Acidification:

- We can only blame ourselves for the 30% drop in the pH of
- oceans—they absorb nearly a third of the carbon released into the atmosphere through human activity
- This acidification renders some crustaceans and coral unable to produce their protective shells and skeletons
- Coral reefs, which serve as habitat for thousands of marine species, are being destroyed by bleaching due to ocean acidification
- This destruction of marine life is a threat to the entire ecosystem including humans

2. Water resources: Climate change affects the water resources

- Increased evaporation rates are expected to reduce water supplies in many regions
- The greatest deficits are expected to occur in the summer leading to be decreased soil moisture levels and more frequent and severe agriculture drought
- More frequency and severe droughts arising from climate change will have serious and management implication for water resource users
- Such droughts also impose costs in terms of wildfires both in control costs and lost timber and related resources

- In drought areas, habitats are altered, and plants and forests suffer from the lack of water
- Increased wildfire activity due to hot, dry conditions poses a risk for safety of wildlife
- It destroys important wildlife habitats, like the nesting habitat for Mexican spotted owls and forest habitat of endangered Amur tigers and critically endangered Amur leopards in Russia
- Stronger and more frequent storms affect the distribution and concentration of the low links on the marine food chain—plankton and krill—thus having a domino effect on many ocean species

3. Melting Sea Ice:

- Arctic temperatures are rising twice as quickly of the rest of the world and sea ice is melting at an alarming rate
- Some of the world's iconic species like polar bears, ringed seals, emperor penguins, and beluga whales all experience distinct pressures due to melting sea ice
- For these and other species, disappearing ice disrupts the food chain, hunting habits, reproduction, protection from predators, and the ability to travel long distances—in other words, the foundations of their existence

4. Sea-Level Rise:

- Coastal wetlands are among the most productive of all natural ecosystems and so the impacts of climate change will be extremely important in coastal regions and have ramifications far beyond them

- The Sundarbans is the largest natural low-lying mangrove ecosystem in the world, distributed over 10000 square kilometres

- The sea level rise recorded over the past 40 years is responsible for the loss of 28 percent of the mangrove ecosystem

5. Disease and Pests:

- Not only does climate change affect disease in human populations, it also alters the disease behavior in animals as well
- The devastating amphibian disease chytrid fungus, likely exacerbated by warmer temperatures, has left many amphibian populations dwindling or extinct
- Seasonal pests, like bark beetles in the US, breed longer in warmer weather and thirsty, drought affected trees are more susceptible to infestation

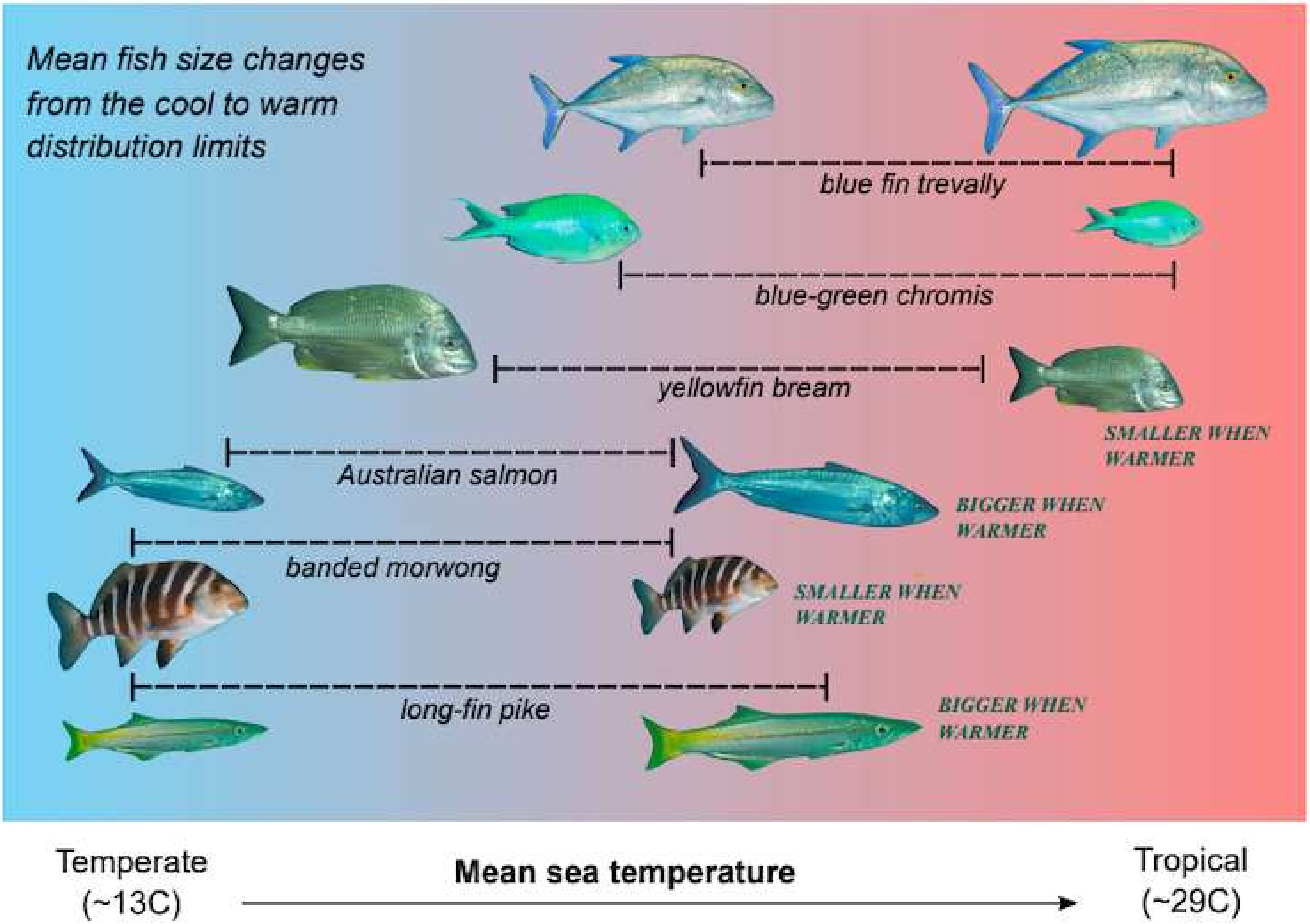
Possible adaptations

1) Behaviour and morphology:

- One way that organisms cope with changes in climate is by altering their behavior or morphology

- Behavioral responses: seeking shades, altering feeding timings, changing site use etc

- Morphology: changes in body size


Mean fish size changes
from the cool to warm
distribution limits
blue fin trevally
blue-green chromis
yellowfin bream
SMALLER WHEN
WARMER
Australian salmon
BIGGER WHEN
WARMER
banded morwong
SMALLER WHEN
WARMER
long-fin pike
BIGGER WHEN
WARMER
Temperate
(~13C)
Mean sea temperature
Tropical
(~29C)

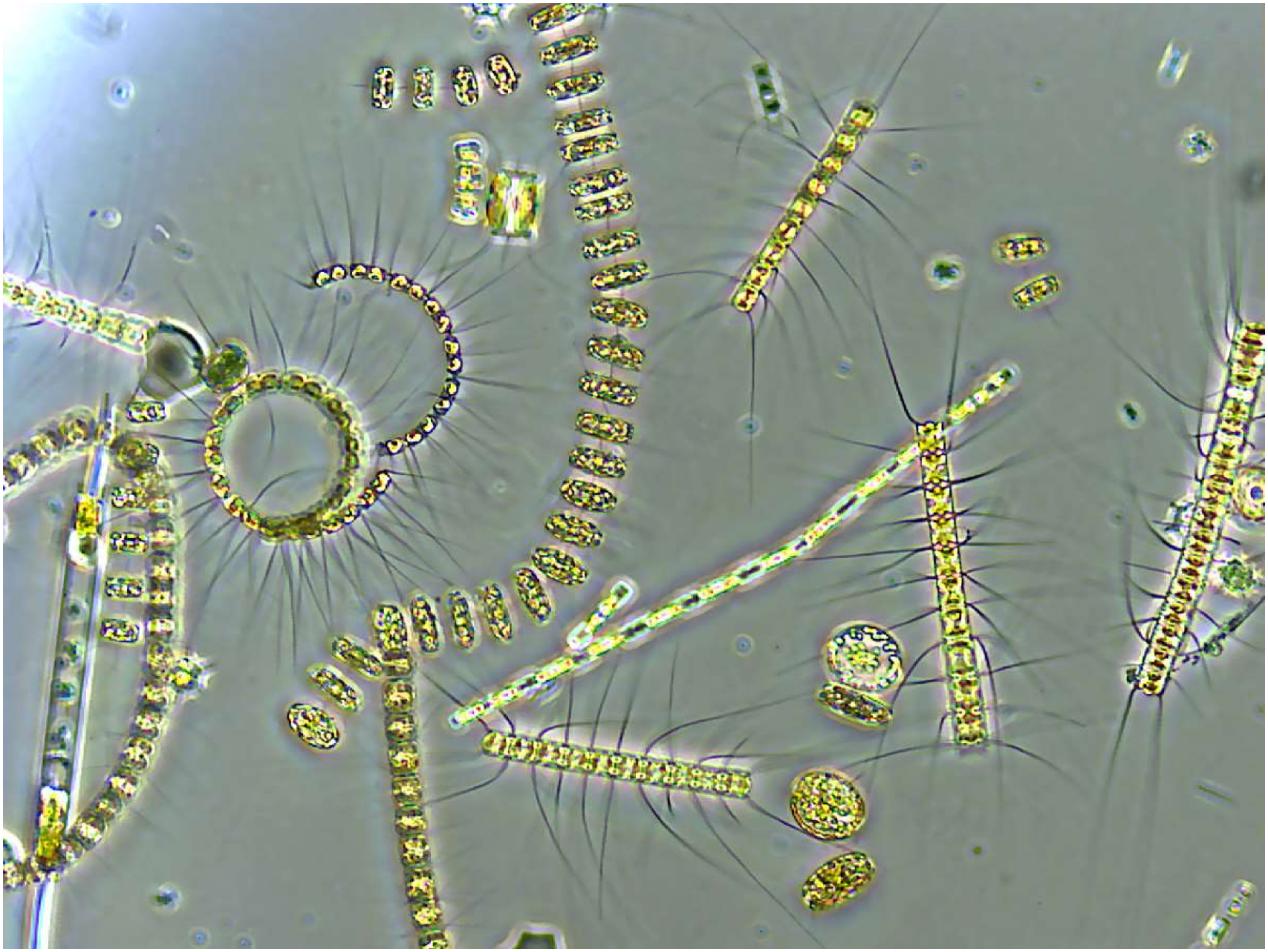
2) Phenological shift:

- Changes in phenology or the seasonal timing of life events have been observed in response to variations in temperature, precipitation, and photoperiod

- Phenological events include changes in leaf growth, flowering and blooming in plants, and shifts in the timing of spawning, reproduction, and migrations in animals

- Marine phytoplankton can respond rapidly to such abiotic changes, resulting in altered timing of phytoplankton blooms (Wasmund et al., 2019), which in turn can create a mismatch with secondary consumers and change the food web structure

- Phytoplankton, also known as microalgae, are similar to terrestrial plants in that they contain chlorophyll and require sunlight in order to live and grow. Most phytoplankton are buoyant and float in the upper part of the ocean, where sunlight penetrates the water

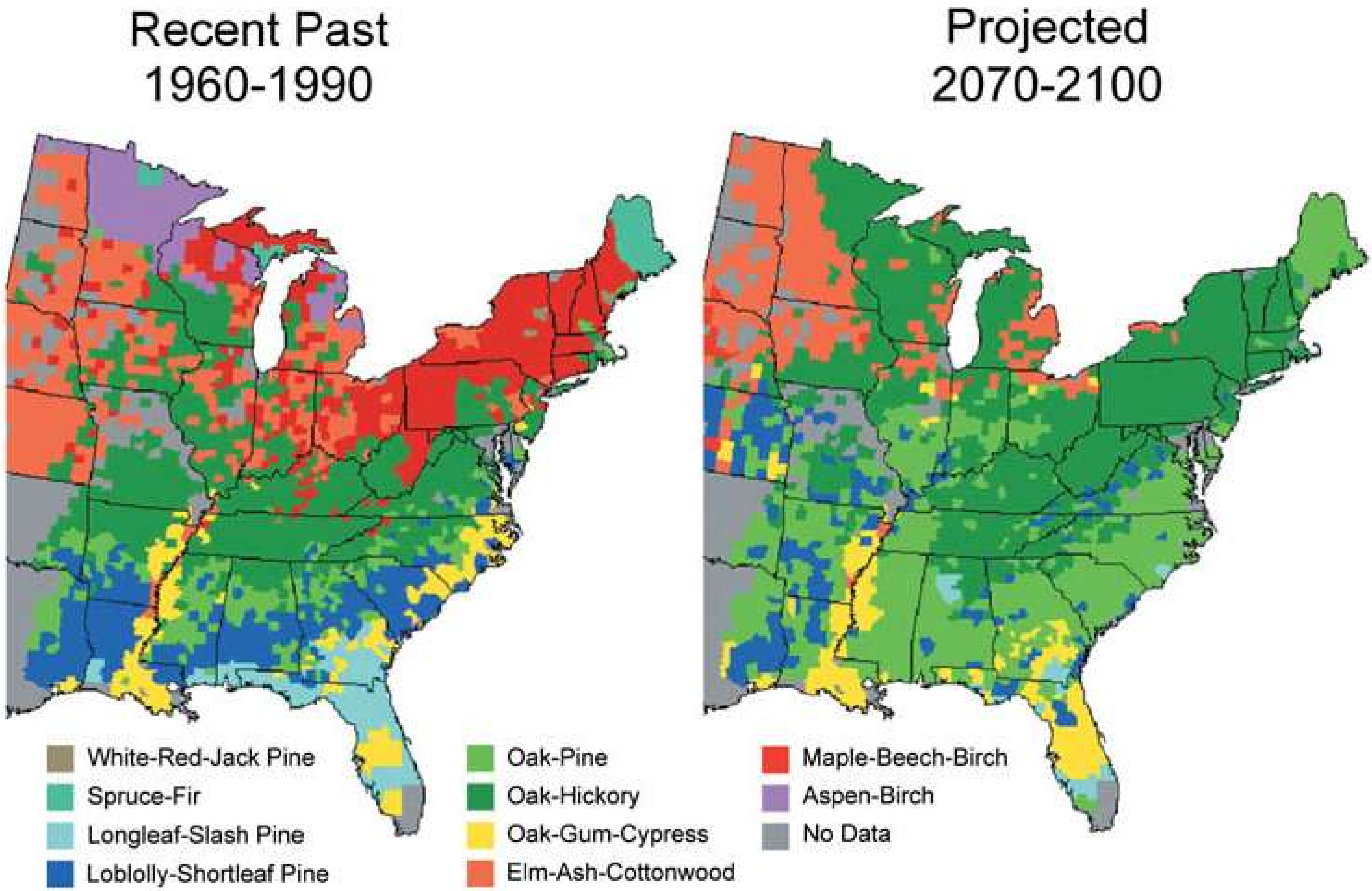


3) Shifts in species distribution:

- Studies show that many species have shifted their geographic ranges in response to rapid changes in temperature and precipitation regimes

- The current rates of migration of species will have to be much higher than rates during postglacial periods in order for species to adapt to the changing climate

- Climate change has the potential to alter migratory routes (and timings) of species that use both seasonal wetlands (e.g., migratory birds) and track seasonal changes in vegetation (e.g., herbivores), which may also increase conflicts with humans, particularly in areas where rainfall is low



Forest species distribution

- Due to increase in temperature, several plant species like *Berberisa siatica, Taraxacum officinale, Jasminum officinale* etc. have shifted towards higher altitude in Nainital

- Teak dominated forests are predicted to replace the Sal trees in central India and also the conifers may be replaced by the deciduous types

- According to Gates (1990) 3°C increase in temperature may leads to the forest movement of 2.50 km/year which is ten times the rate of natural forest movement.

4) Demographic responses:

- Loss of natural habitats and shifting habitat leads to destruction of species
- Shift in species distribution can also result in rapid decline in species population/size

- Slight change in climatic condition leads to the extinction of animal species

✓ For example climate change has resulted in *extinction* of animals like golden toad and Monteverde harlequin frog

✓ Polar bears are in danger due to reduction in Arctic ice cover; North Atlantic whale may become extinct, as planktons which are its main food have shown declination due to climate change

Mitigation

- Mixed plantings have the additional benefit that they are likely to be more resilient to future societal (cultural, economical) and environmental (stability facing global change, biodiversity conservation) challenges, including climate change

✓ For example, mixed species stands have been found to be more resistant to various forms of damage, and to be more diverse in their fauna and flora than pure, single-species stands

✓ Less diversified systems, such as monoculture plantations, may also be less resistant and resilient to natural disturbance or pests something that global change may exacerbate

- Crop rotation length
- Removal of residual biomass for bioenergy
- Changes to silvicultural management
- Afforestation/reforestation

MaxEnt model- species distribution model

https://biodiversityinformatics.amnh.org/open_source/maxent/

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Lecture-13&14


Indian
Agriculture

Share to total economy of India

2019-20	18.4%
2020-21	20.2%

Classification of crops

- Field crops: crop other than fruit and vegetables

wheat

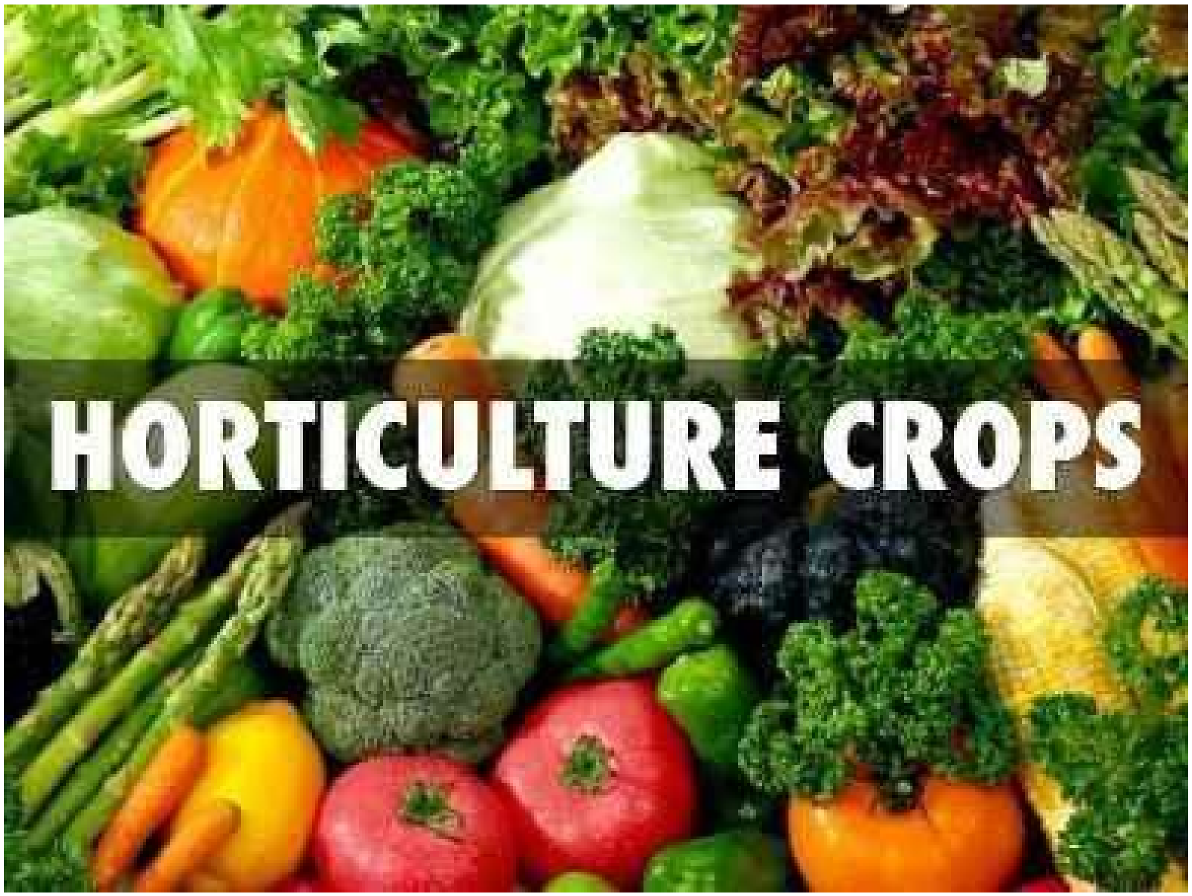
rice

barely

- Commercial crops/cash crops

- Oil seed crops:

- Horticultural crops:



- Tree, bush and perennial vine fruits

- Perennial bush and tree nuts

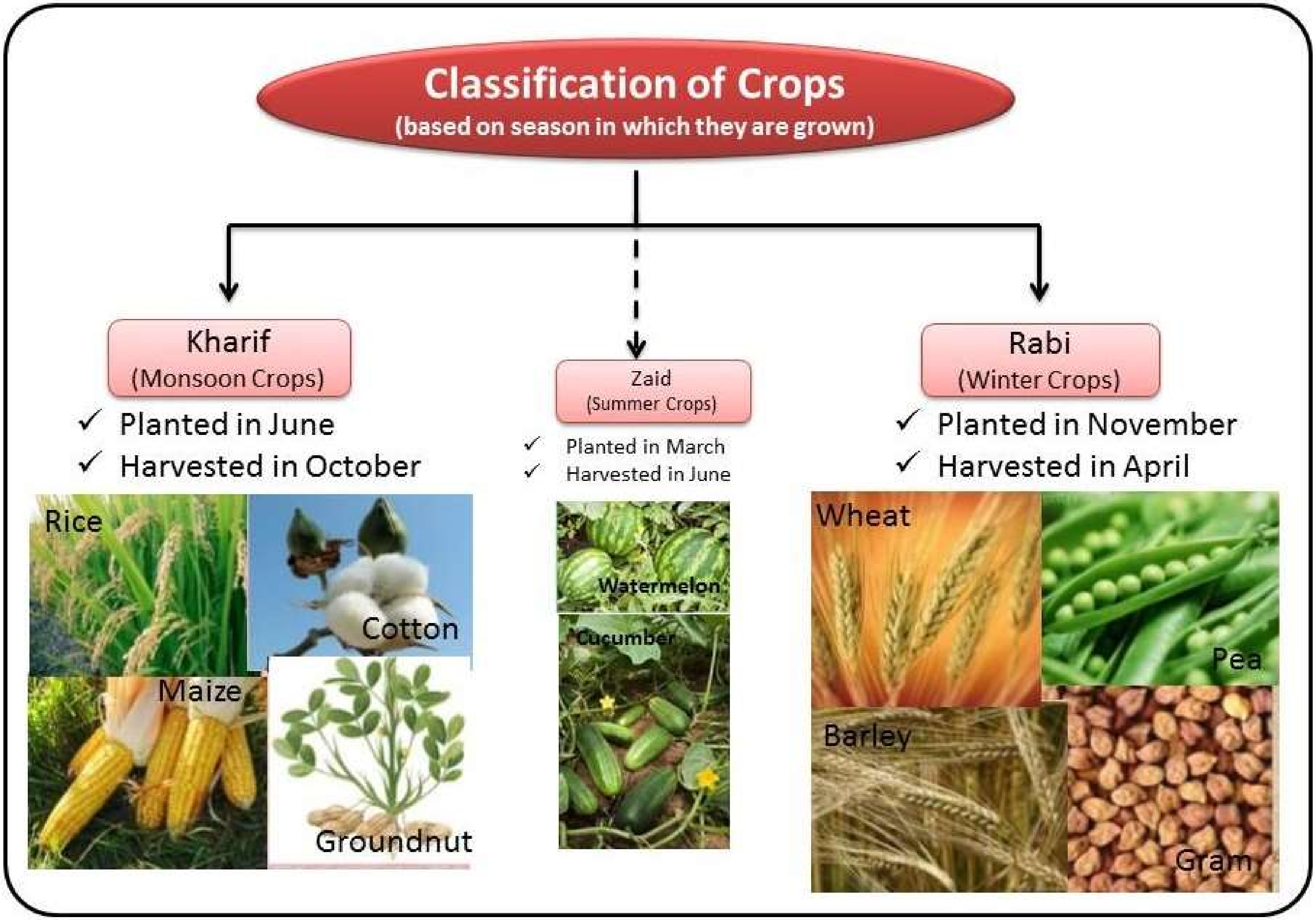
- Vegetables (roots, tubers, shoots, stems, leaves, fruits and flowers of edible and mainly annual plants)

- Trees, shrubs, turf and ornamental grasses propagated and produced in nurseries for use in landscaping or for establishing fruit orchards or other crop production units

- Plantation crops:

Coffee, tea, rubber, cocnut, banana, tobacco

Cropping seasons in India



State	Season	Local name	Growing month
Andhra Pradesh	Kharif	Serva or Abi	July – December
	Rabi	Dalwa or Tabi	December – April
	Summer	In limited areas	March/April – June
Assam	Pre-monsoon	Ahu	Mar/April– June/july
	-	Sali	June/July- Nov/Dec
	-	Boro	Nov - May
Bihar	Summer	-	March – July/Aug
	Autumn	-	May/June–

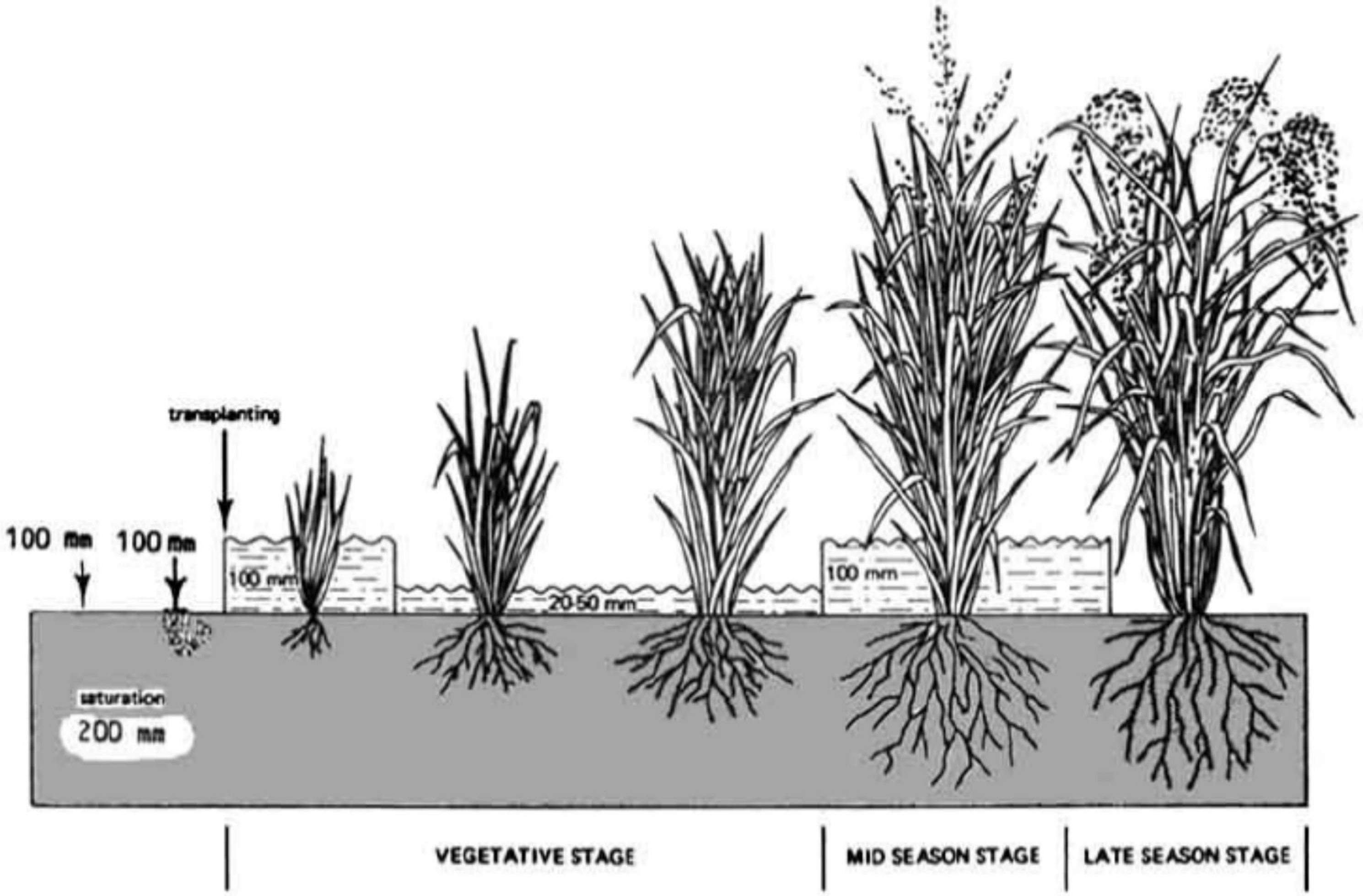
			Sept/Oct
	Winter	-	June – Nov/Dec
Gujarat	Kharif	Chomasu Dangar	June/July-Oct/Nov
	-	Unala Dangar	Dec – June
Haryana	Kharif	-	May/June–Sept/Oct
Himachal Pradesh	Kharif	-	June/July-Sept/Oct
Jammu & Kashmir	-	-	Jammu: June-Nov Kashmir: Last week of April - October
Karnataka	Kharif	-	June – Dec
	Summer	-	Jan-May/June
Kerala	first crop	Virippu	April-May/Sept-Oct
	Second crop	Mundakan	Sept-Oct/Dec-Jan
	Third crop	Punja	Dec/Jan-Mar/April
Madhya Pradesh	Kharif	-	June/July-Dec
Maharashtra	Kharif	-	June/July-Dec
Manipur	Kharif	-	Mar/June-Sept/Oct

Meghalaya	Kharif	-	May/June-Aug/Sept
	Rabi	-	----------------
Nagaland	Kharif	-	May/June-Nov/Dec
	Rabi	-	Feb - May
Orissa	-	Sarad	June-Dec
	-	Dalua	Dec-April
	-	Beali (short Duration)	April/May –Sept (Only in uplands)
Punjab	Kharif	-	May – Nov
Rajasthan	Kharif	-	June/July-Sept/oct

Tamil Nadu	-	Navarai	Jan-April
	-	Sornavari	April – July
	-	Kar or Kuruvai	June – August
	-	Samba	June/July-Nov/Dec
	-	Thaladi or Pishanam	Sept/Oct-Feb/March
Uttar Pradesh	Kharif	-	June – Oct
West Bengal	Pre-Kharif	Aus	April-Sept
	Kharif	Aman	June-Dec
	Summer	Boro	End Nov-Mid June

How climate influences agricultural production?

1. Crop water requirement



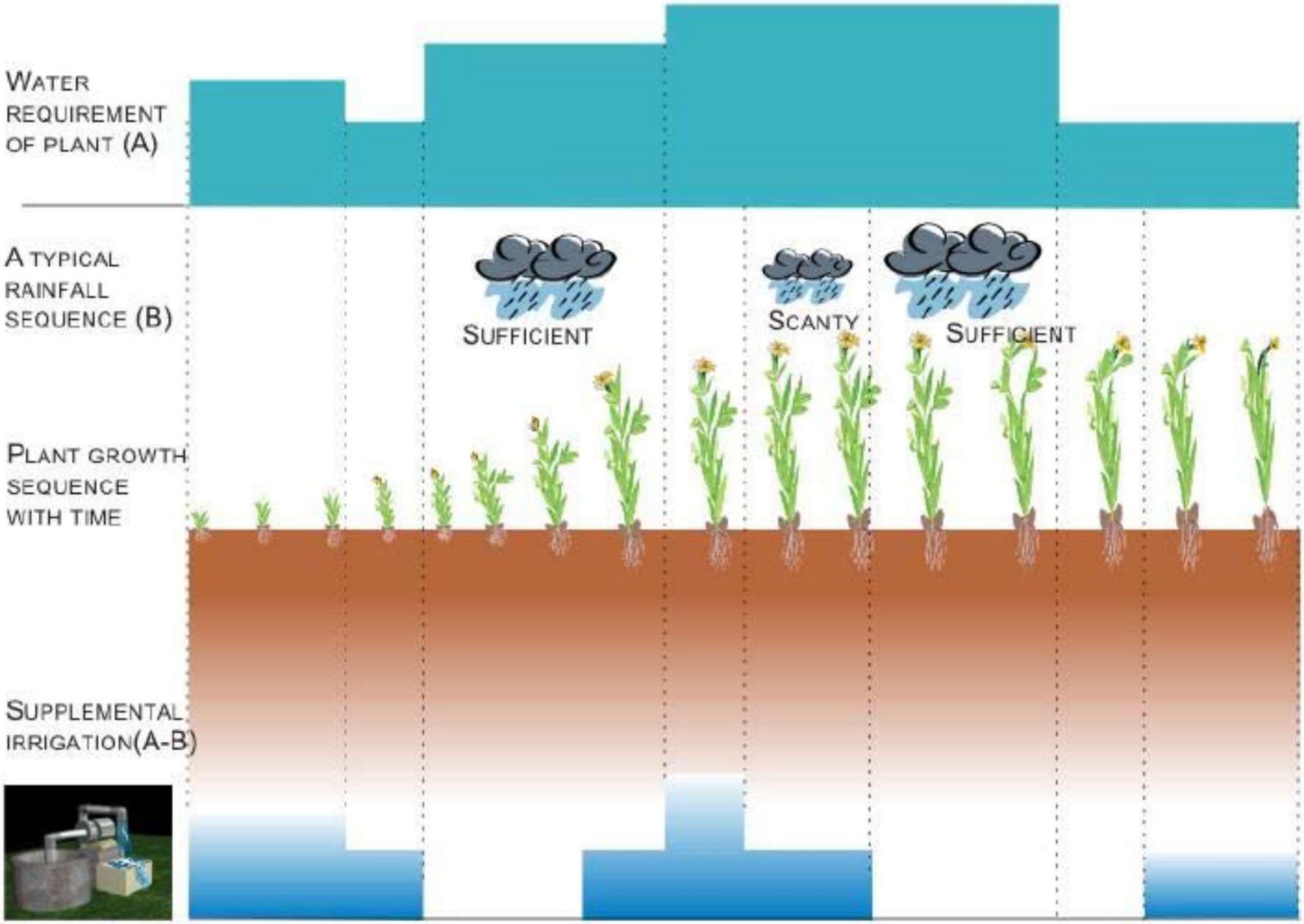
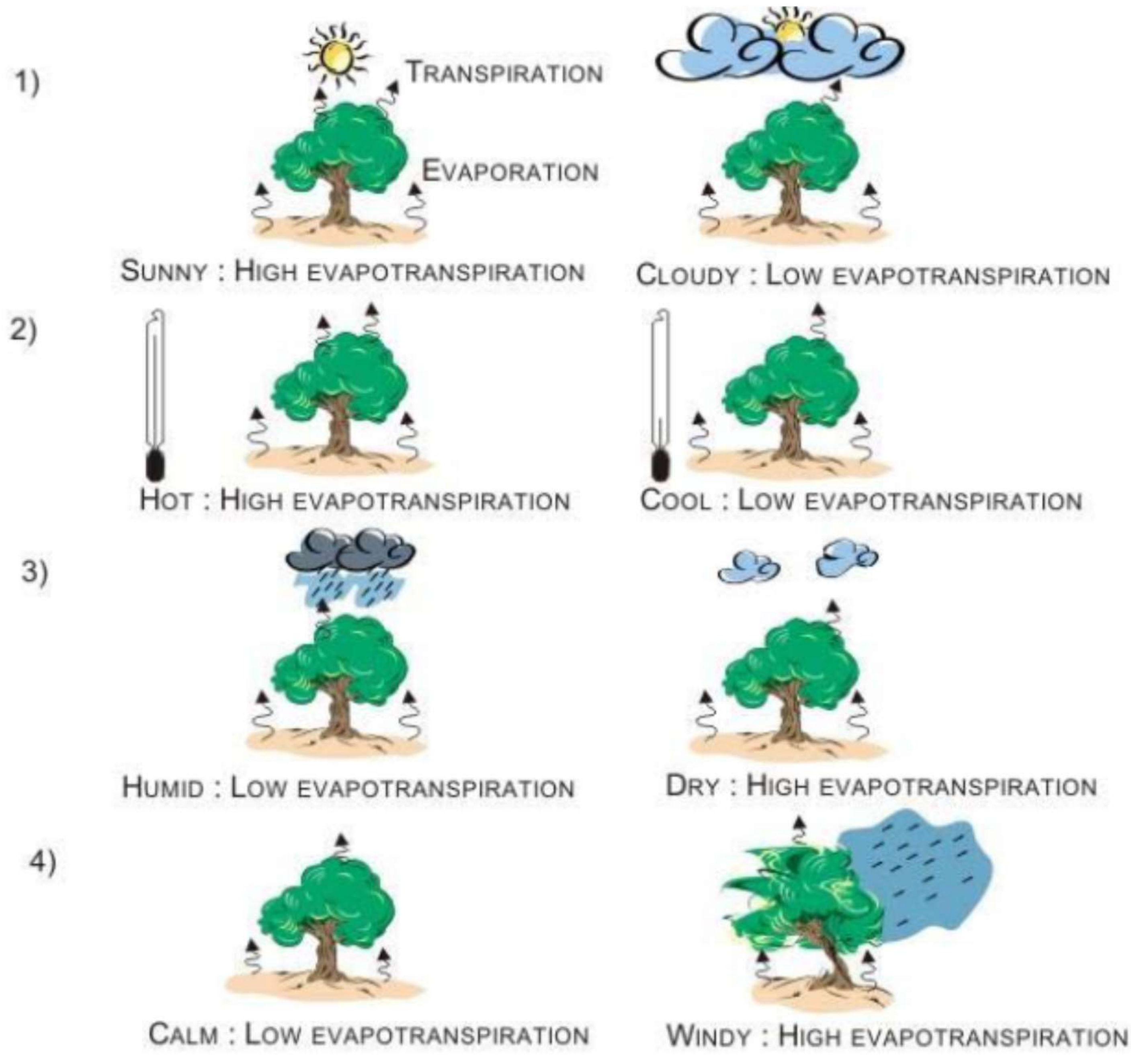


FIGURE 5 . Typical irrigation requirement of a crop and water provided naturally by rain or artificially by pumping

Major factors influencing irrigation requirement

- Sunshine
- Temperature
- Humidity
- Wind speed


1)
TRANSPIRATION
EVAPORATION
SUNNY : HIGH EVAPOTRANSPIRATION
CLOUDY : LOW EVAPOTRANSPIRATION
2)
HOT : HIGH EVAPOTRANSPIRATION
COOL : LOW EVAPOTRANSPIRATION
3)
HUMID : LOW EVAPOTRANSPIRATION
DRY : HIGH EVAPOTRANSPIRATION
4)
CALM : LOW EVAPOTRANSPIRATION
WINDY : HIGH EVAPOTRANSPIRATION

Irrigation scheduling

Estimating crop water requirement

CROPWAT (FAO model)

- CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO
- CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data
- The program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns
- Model can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions.

Software

http://www.fao.org/land-water/databases-and-software/cropwat/en/

http://www.fao.org/3/X0490E/X0490E00.htm

CLIMWAT

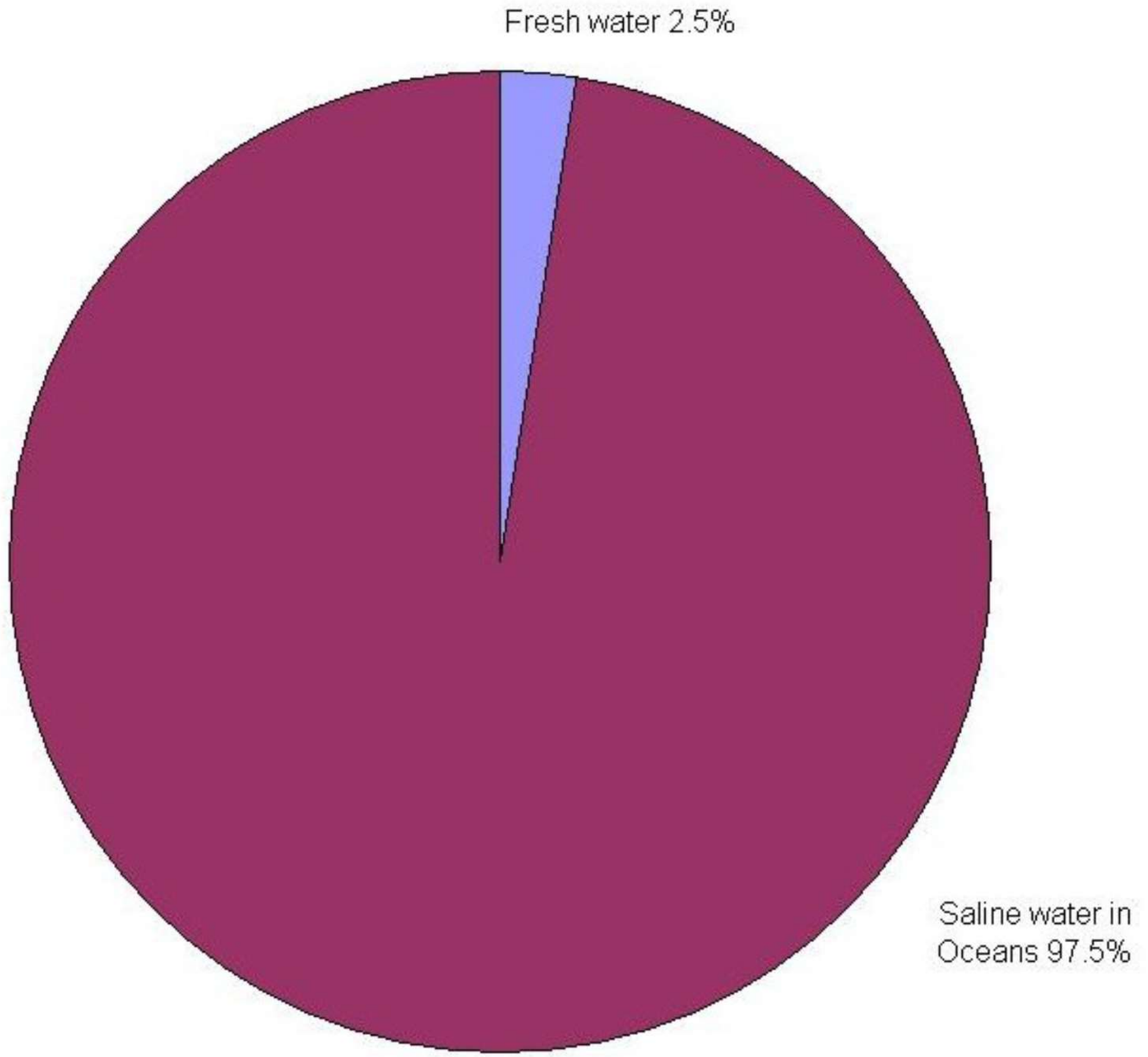
CROPWAT

Climate Change And Its Implications (CCI)

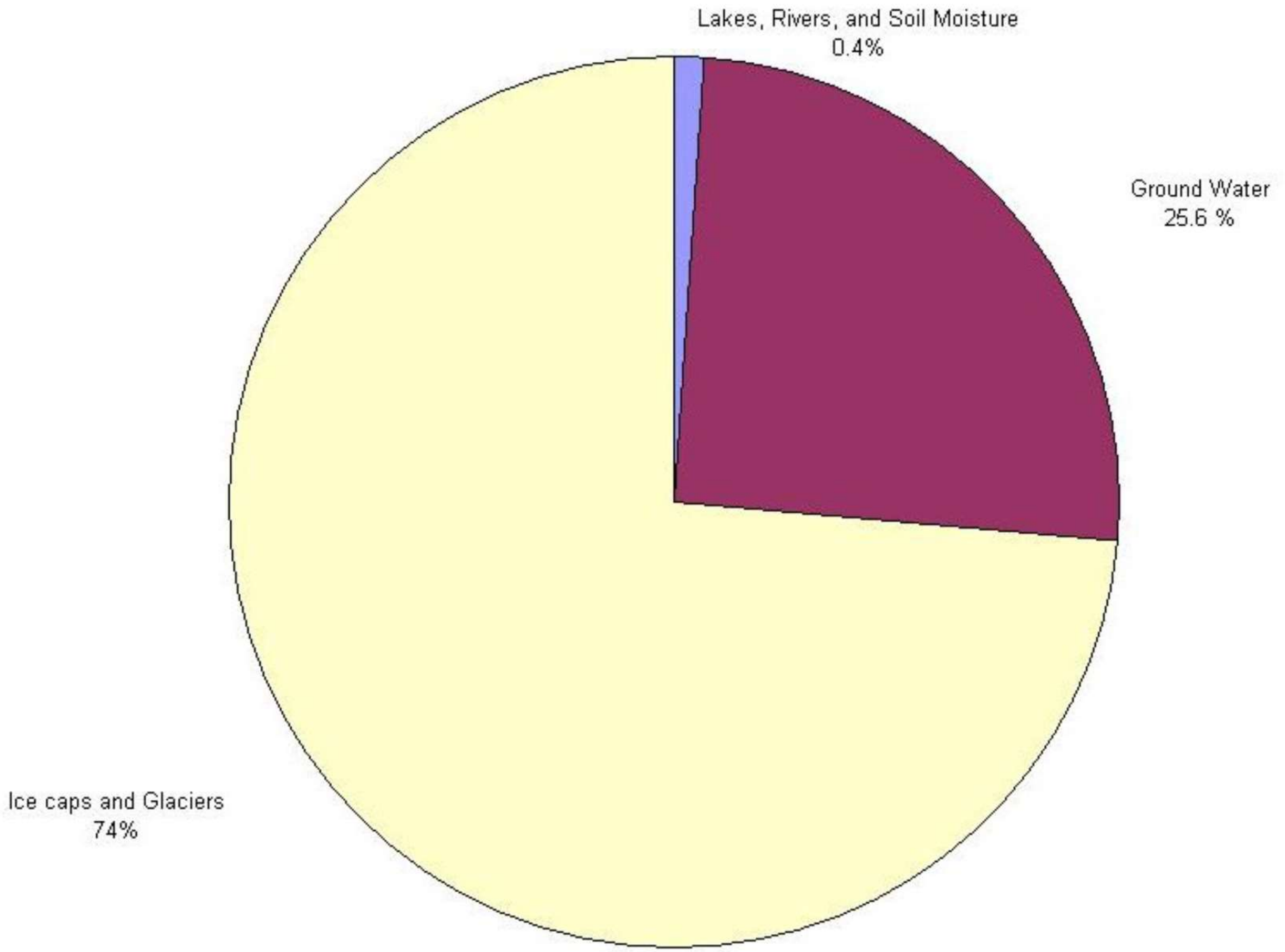
Dr. Raji P

Lecture-16&17

Climate change on water resources

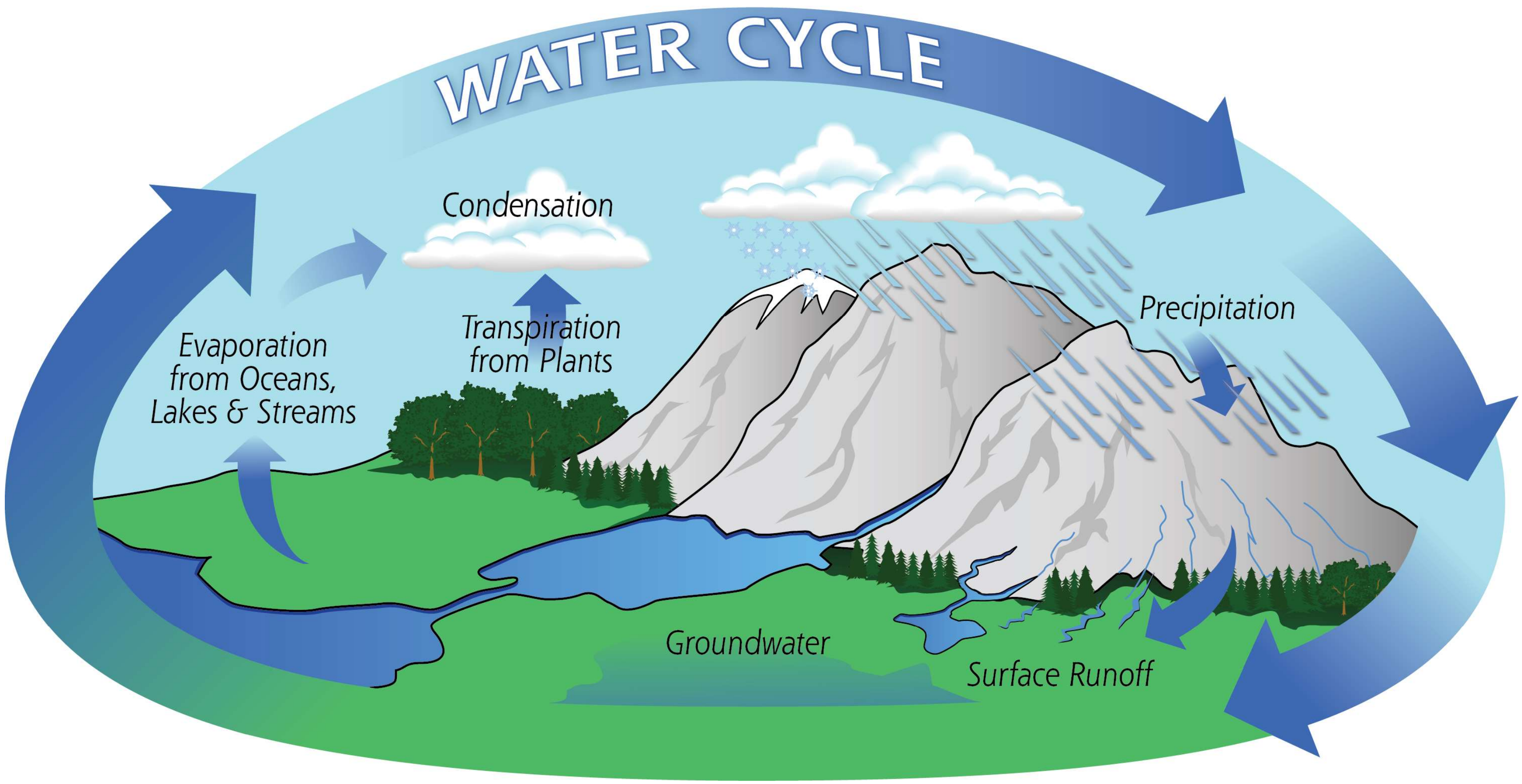


Total global water content



Global fresh water distribution

Introduction-Hydrology



The hydrologic cycle consists of four key components

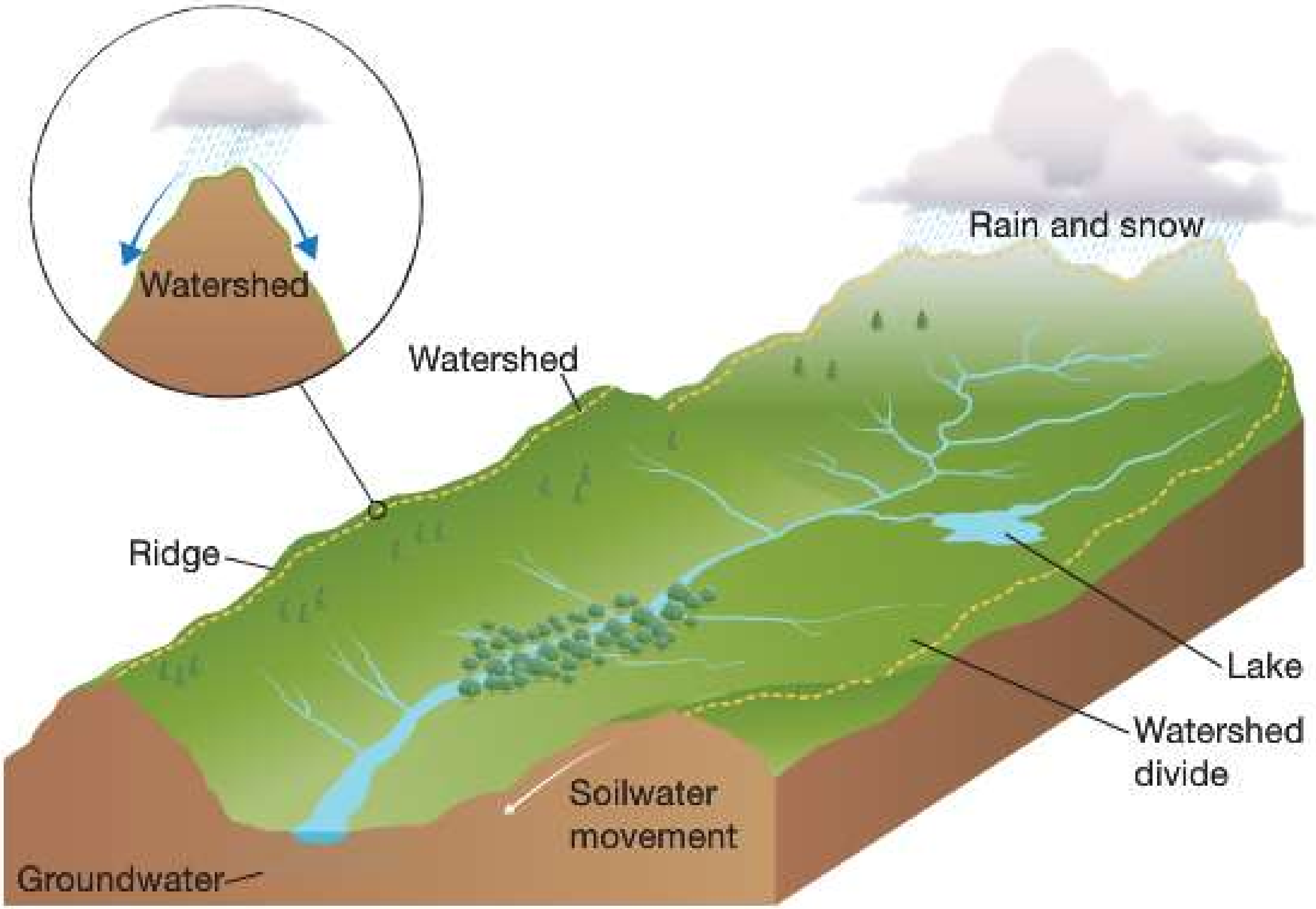
1. Precipitation

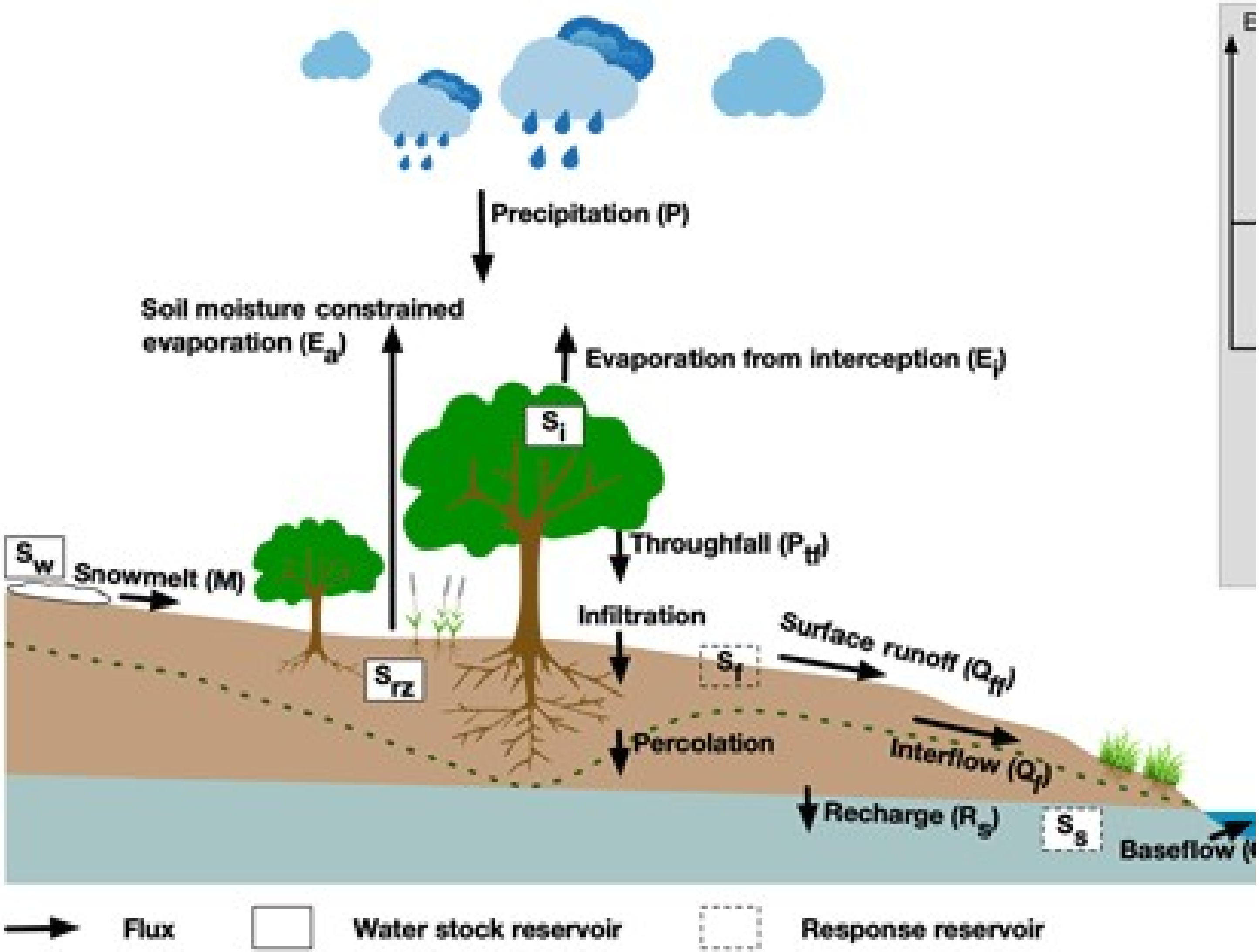
2. Runoff

3. Storage (lake, rivers, ground water)

4. Evapotranspiration

Watershed


Watershed
Rain and snow
Watershed
Ridge
Lake
Watershed
divide
Soilwater
movement
Groundwater



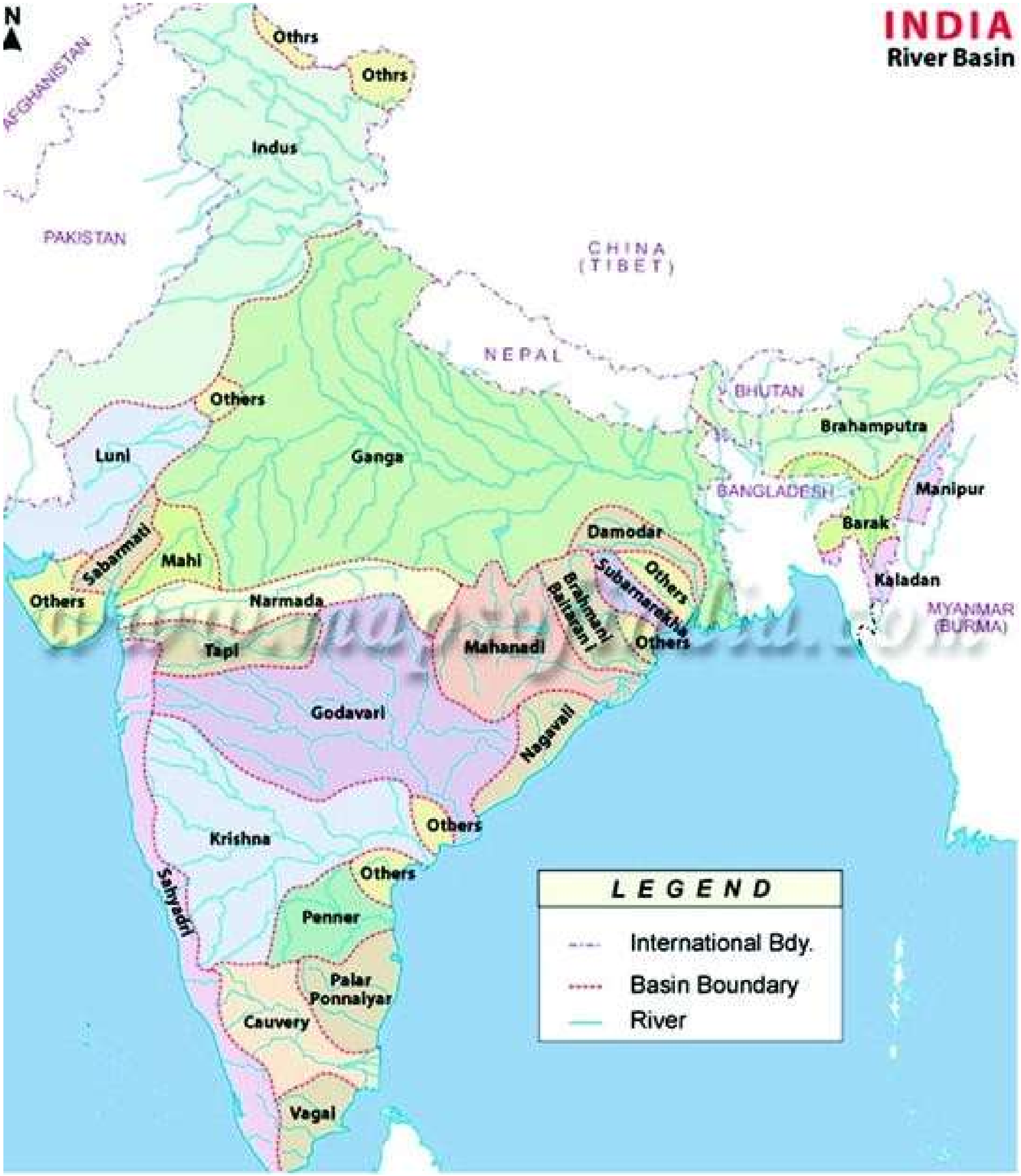
Precipitation (P)
Soil moisture constrained evaporation (E_a)
Evaporation from interception (E_i)
S_i
S_w
Snowmelt (M)
Throughfall (P_{tf})
Infiltration
S_f
Surface runoff (Q_{ff})
S_{rz}
Percolation
Interflow (Q_f)
Recharge (R_s)
S_s
Baseflow
Flux
Water stock reservoir
Response reservoir

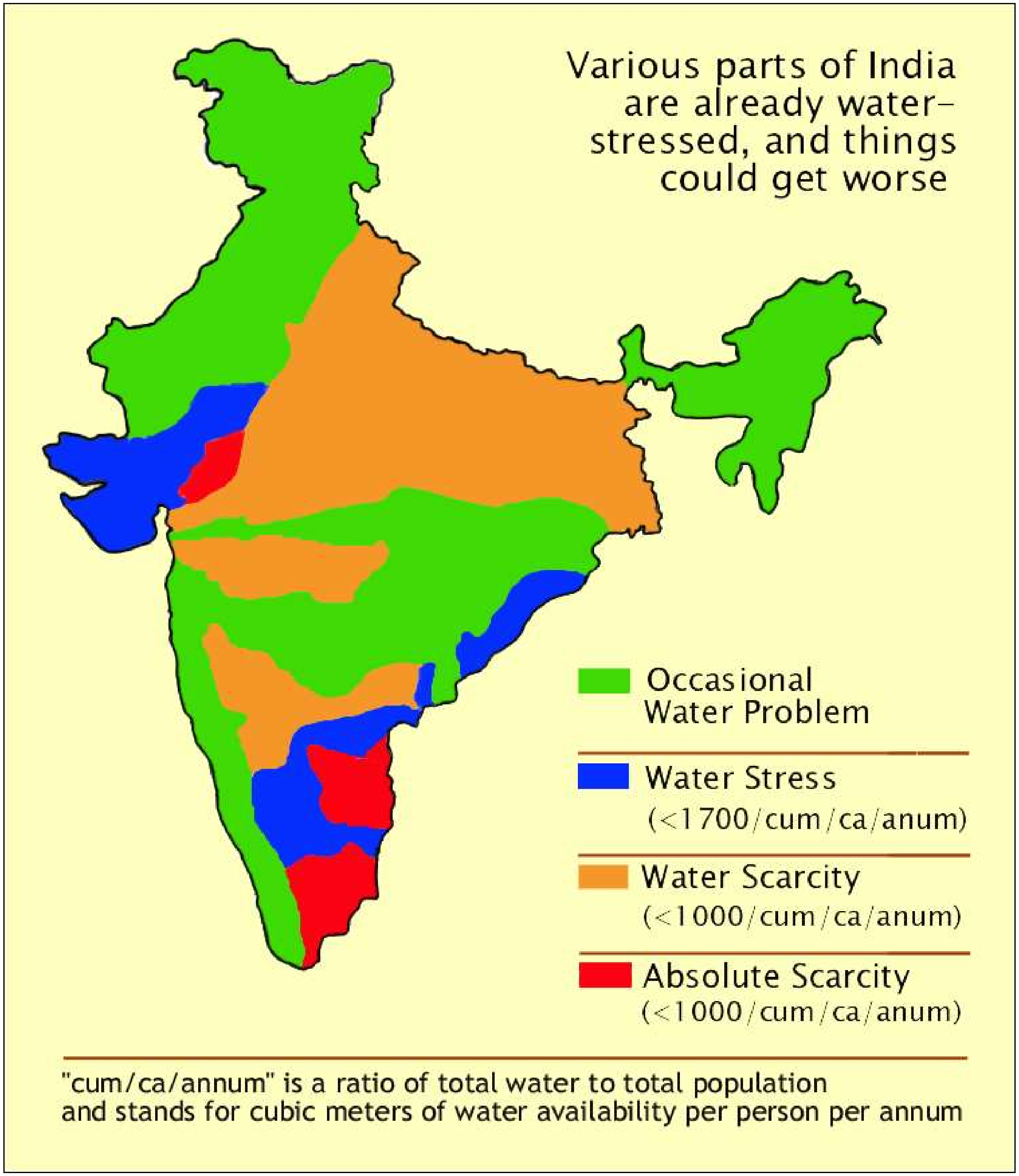
Water Resources – India at a Glance

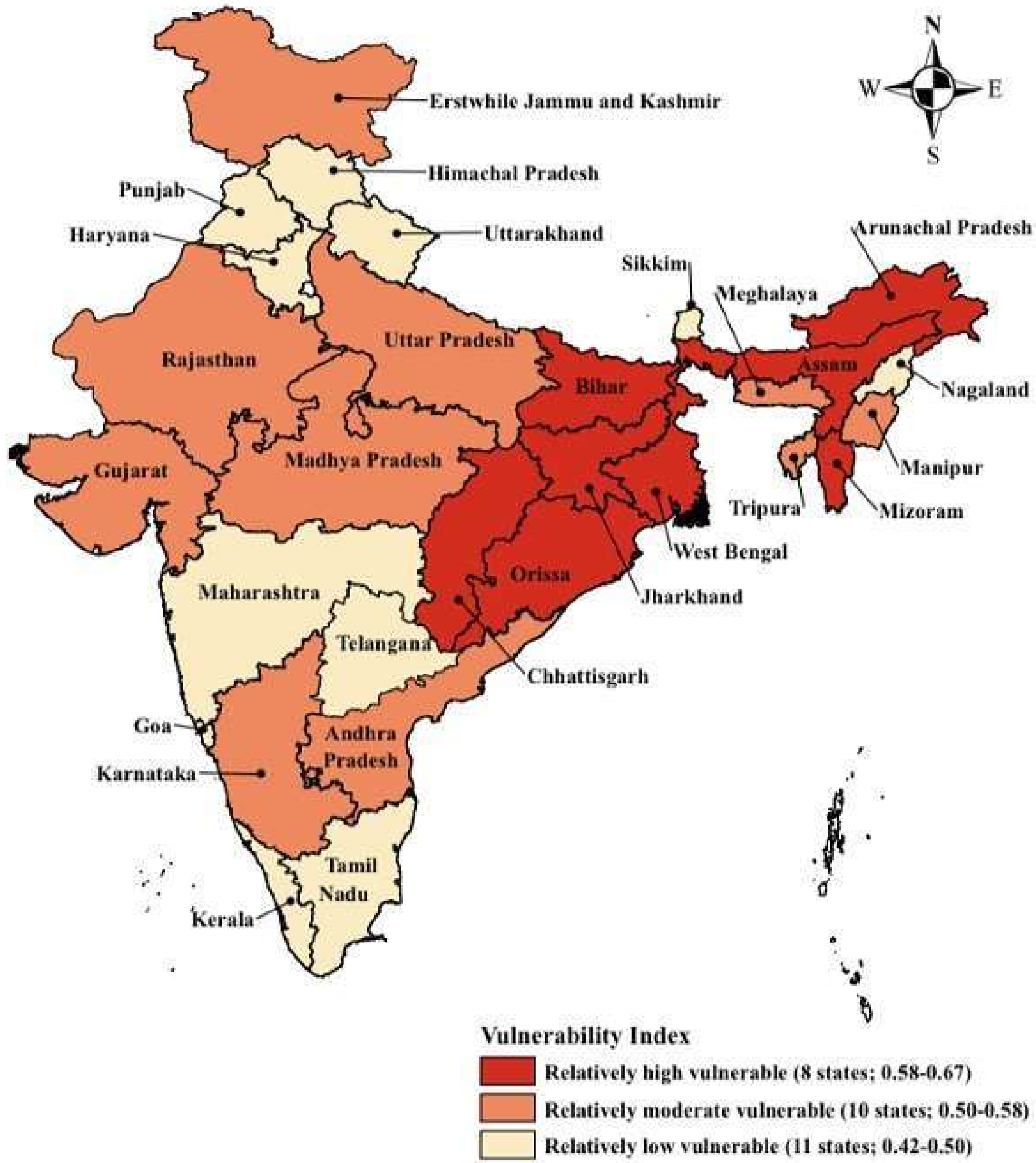
- Area of the country as % of World Area : 2.4%
- Population as % of World population : 17.1%
- Water as % of World Water : 4%
- Rank in per capita availability : 132
- Rank in water quality : 122

Major river basins in India

1. Indus
2. Ganges
3. Brahmaputra
4. Krishna
5. Godavari
6. Mahanandi
7. Sabarmati
8. Tapi
9. Brahmani-Baitarani
10. Narmada
11. Pennar
12. Mahi

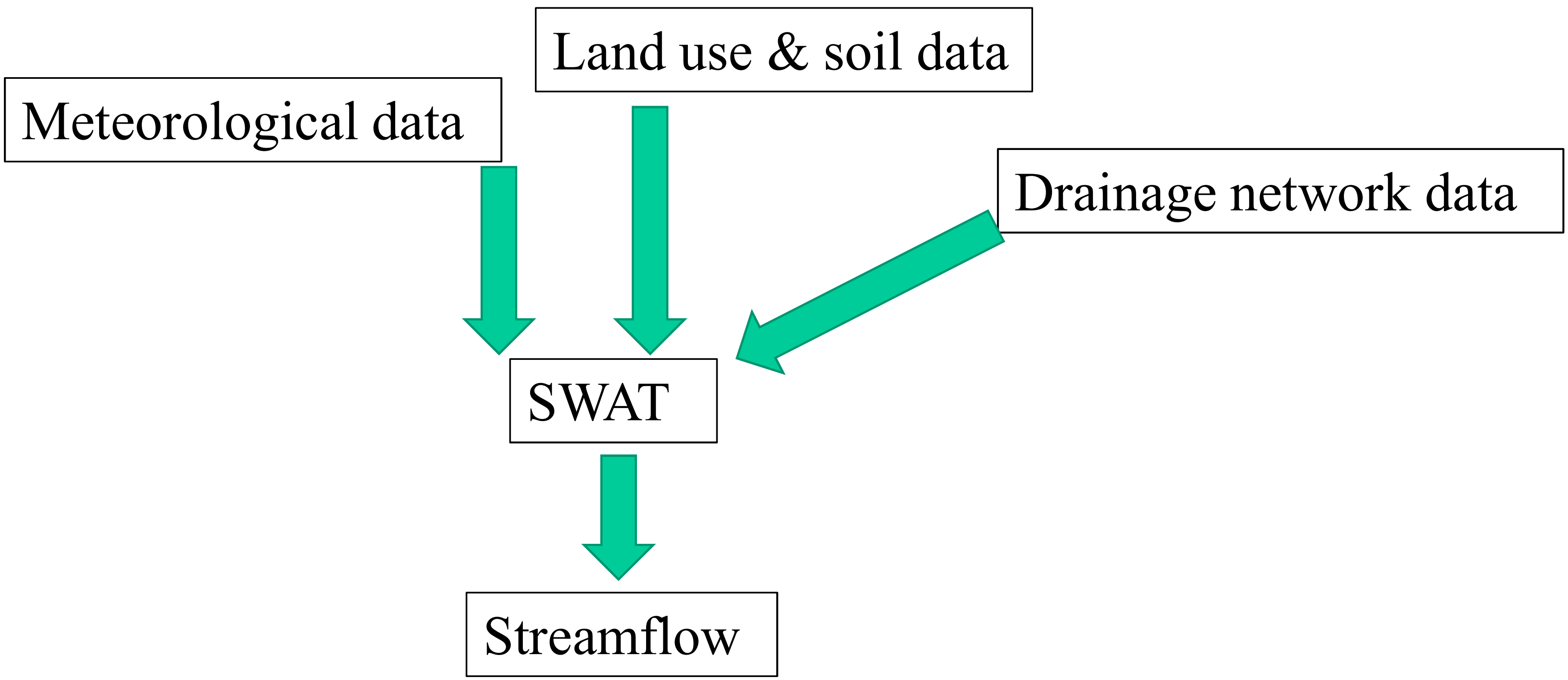

N
INDIA
River Basin
AFGHANISTAN
PAKISTAN
CHINA (TIBET)
NEPAL
BHUTAN
BANGLADESH
MYANMAR (BURMA)
Othrs
Othrs
Indus
Others
Luni
Ganga
Brahamputra
Manipur
Barak
Kaladan
Damodar
Others
Subernarekha
Brahmani Baitarani
Others
Sabarmati
Mahi
Others
Narmada
Tapi
Mahanadi
Godavari
Nagavali
Others
Krishna
Others
Sahyadri
Penner
Palar Ponnaiyar
Cauvery
Vagai
LEGEND
International Bdy.
Basin Boundary
River

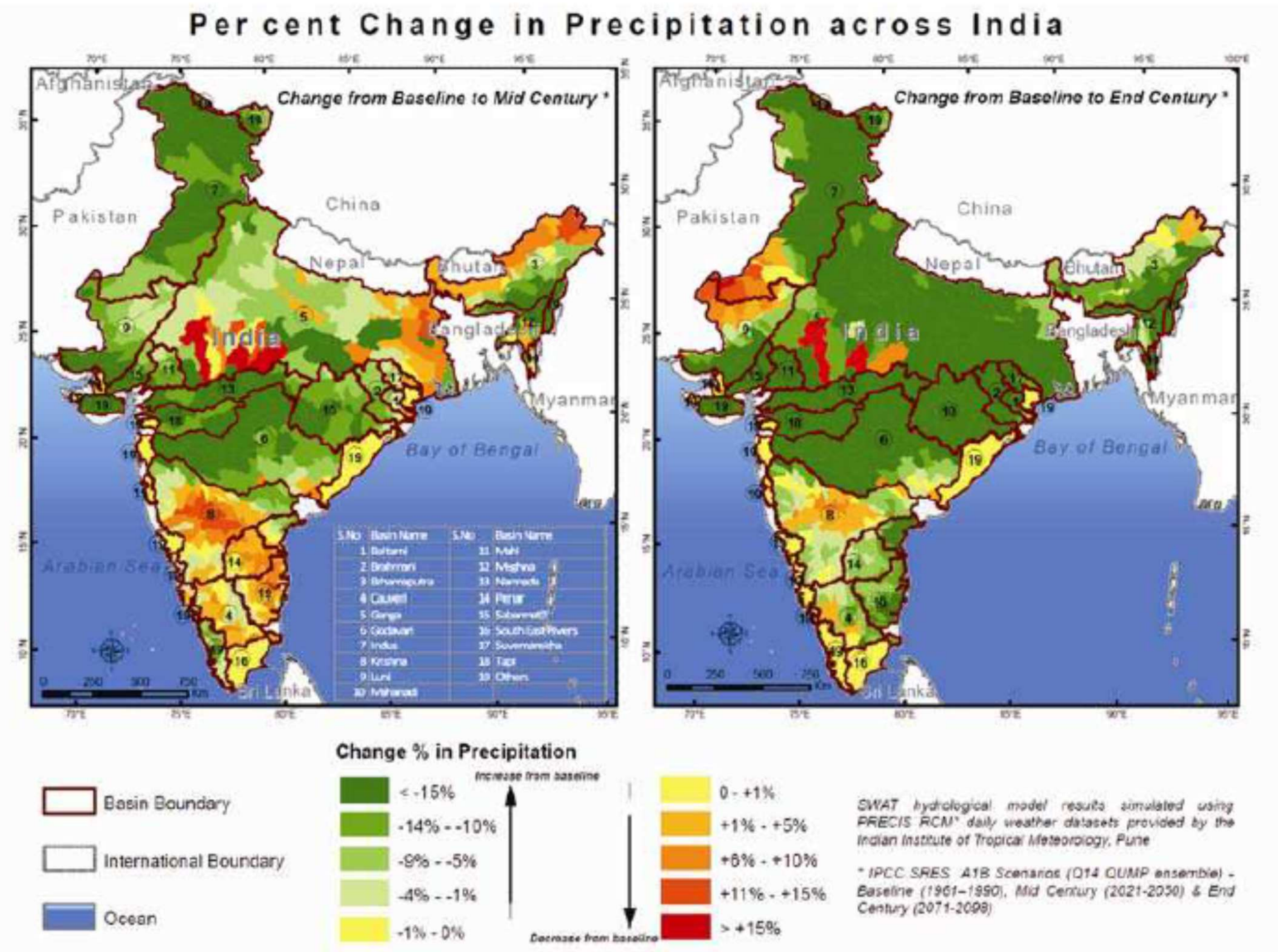

Various parts of India are already water-stressed, and things could get worse
Occasional Water Problem
Water Stress
(<1700/cum/ca/anum)
Water Scarcity
(<1000/cum/ca/anum)
Absolute Scarcity
(<1000/cum/ca/anum)
"cum/ca/annum" is a ratio of total water to total population and stands for cubic meters of water availability per person per annum



N
W
E
S
Erstwhile Jammu and Kashmir
Himachal Pradesh
Punjab
Haryana
Uttarakhand
Arunachal Pradesh
Sikkim
Meghalaya
Uttar Pradesh
Rajasthan
Bihar
Assam
Nagaland
Gujarat
Madhya Pradesh
Manipur
Tripura
Mizoram
West Bengal
Orissa
Maharashtra
Jharkhand
Telangana
Chhattisgarh
Goa
Andhra Pradesh
Karnataka
Tamil Nadu
Kerala
Vulnerability Index
Relatively high vulnerable (8 states; 0.58-0.67)
Relatively moderate vulnerable (10 states; 0.50-0.58)
Relatively low vulnerable (11 states; 0.42-0.50)

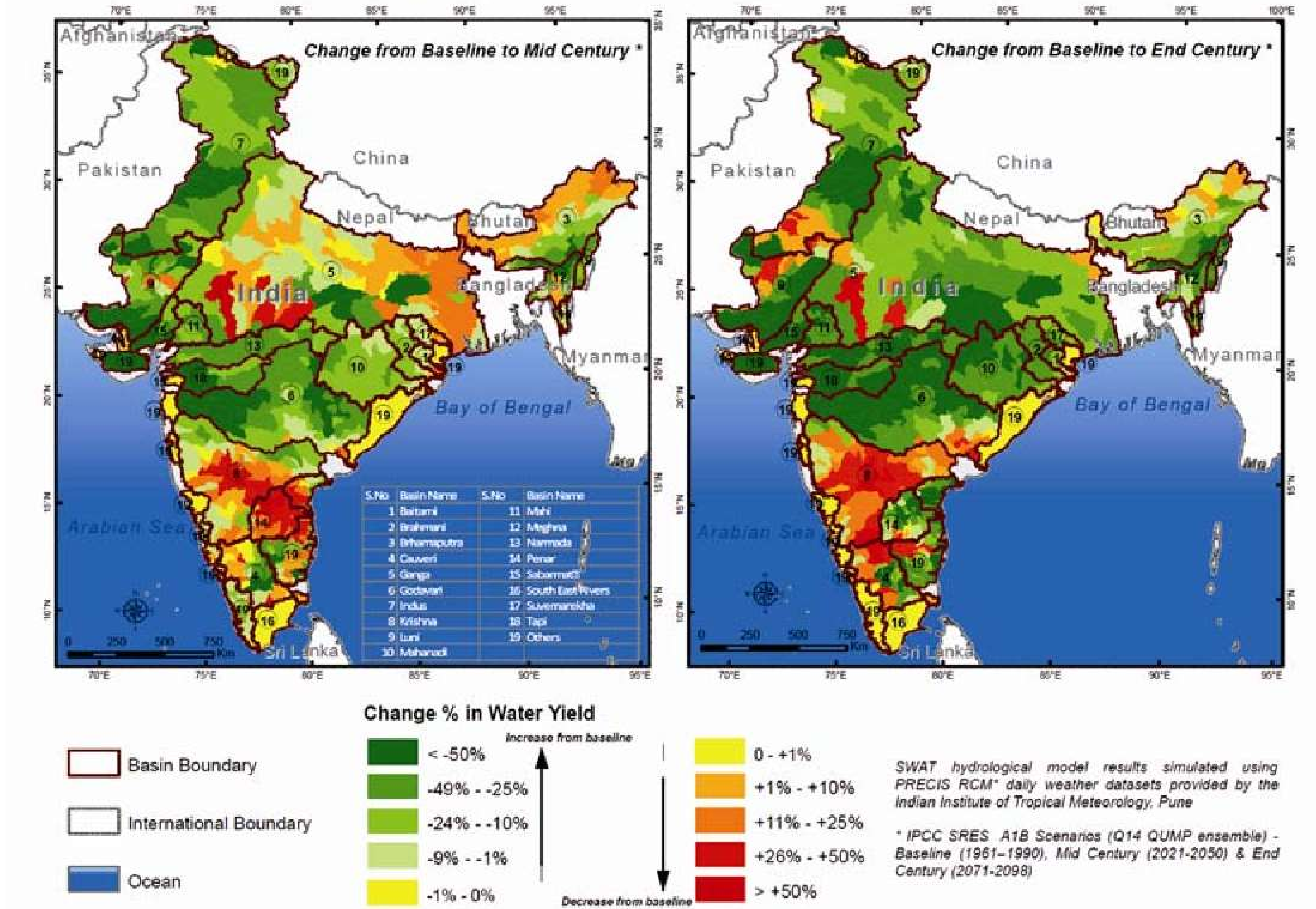
Impact analysis



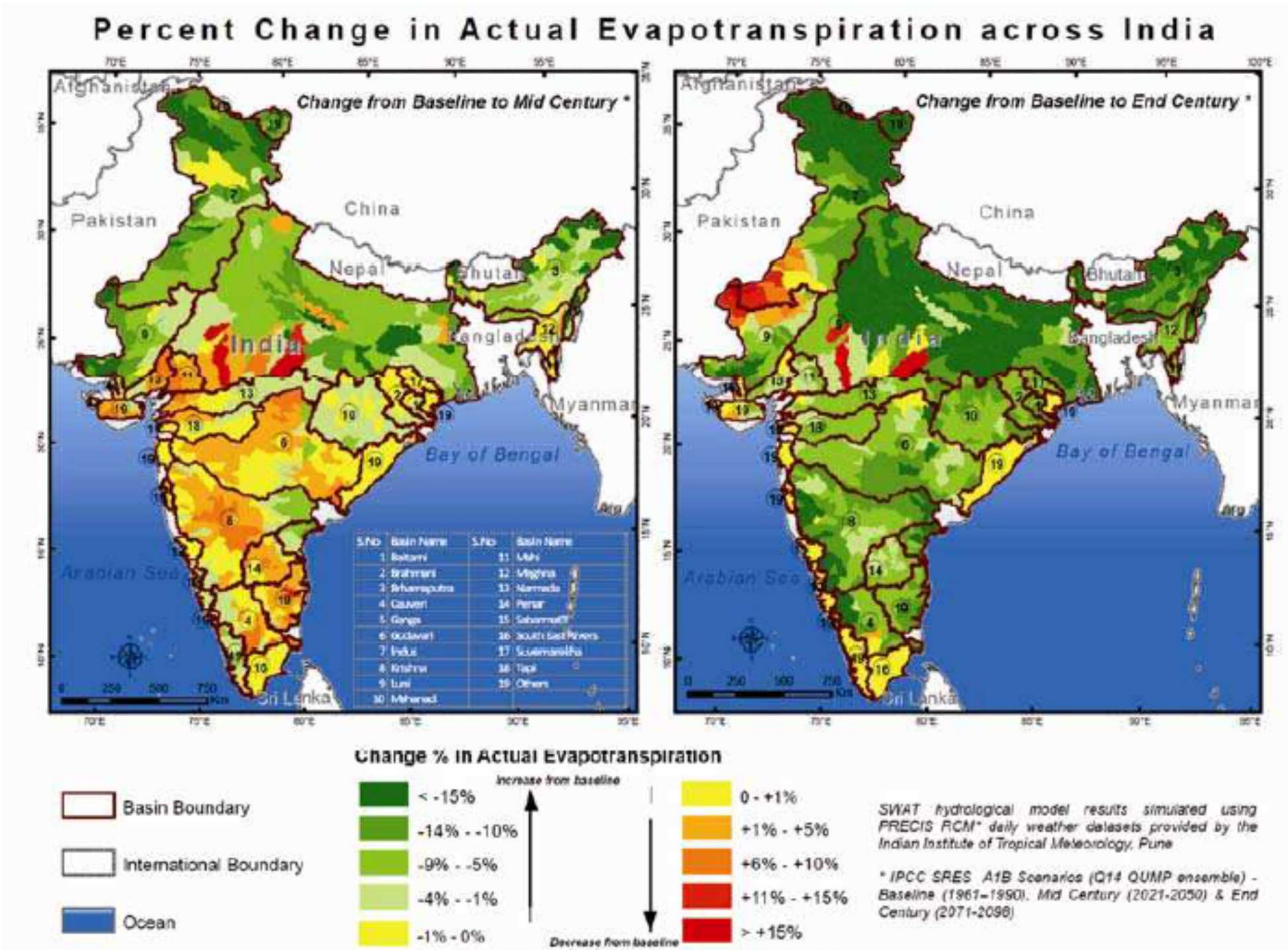


Per cent Change in Precipitation across India
Change from Baseline to Mid Century *
Change from Baseline to End Century *
Afghanistan
Pakistan
China
Nepal
Bhutan
Bangladesh
Myanmar
India
Bay of Bengal
Arabian Sea
Sri Lanka
S.No Basin Name
1 Baitarni
2 Brahmani
4 Cauveri
5 Ganga
6 Godavari
7 Indus
8 Krishna
9 Luni
10 Mahanadi
11 Mahi
12 Meghna
13 Narmada
14 Penar
15 Sabarmati
16 South East Rivers
17 Suvarnarekha
18 Tapi
19 Others
Change % in Precipitation
Basin Boundary
International Boundary
Ocean
< -15%
-14% - -10%
-9% - -5%
-4% - -1%
-1% - 0%
0 - +1%
+1% - +5%
+6% - +10%
+11% - +15%
> +15%
Increase from baseline
Decrease from baseline
SWAT hydrological model results simulated using PRECIS RCM* daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
* IPCC SRES A1B Scenarios (Q14 QUMP ensemble) - Baseline (1961–1990), Mid Century (2021-2050) & End Century (2071-2098)

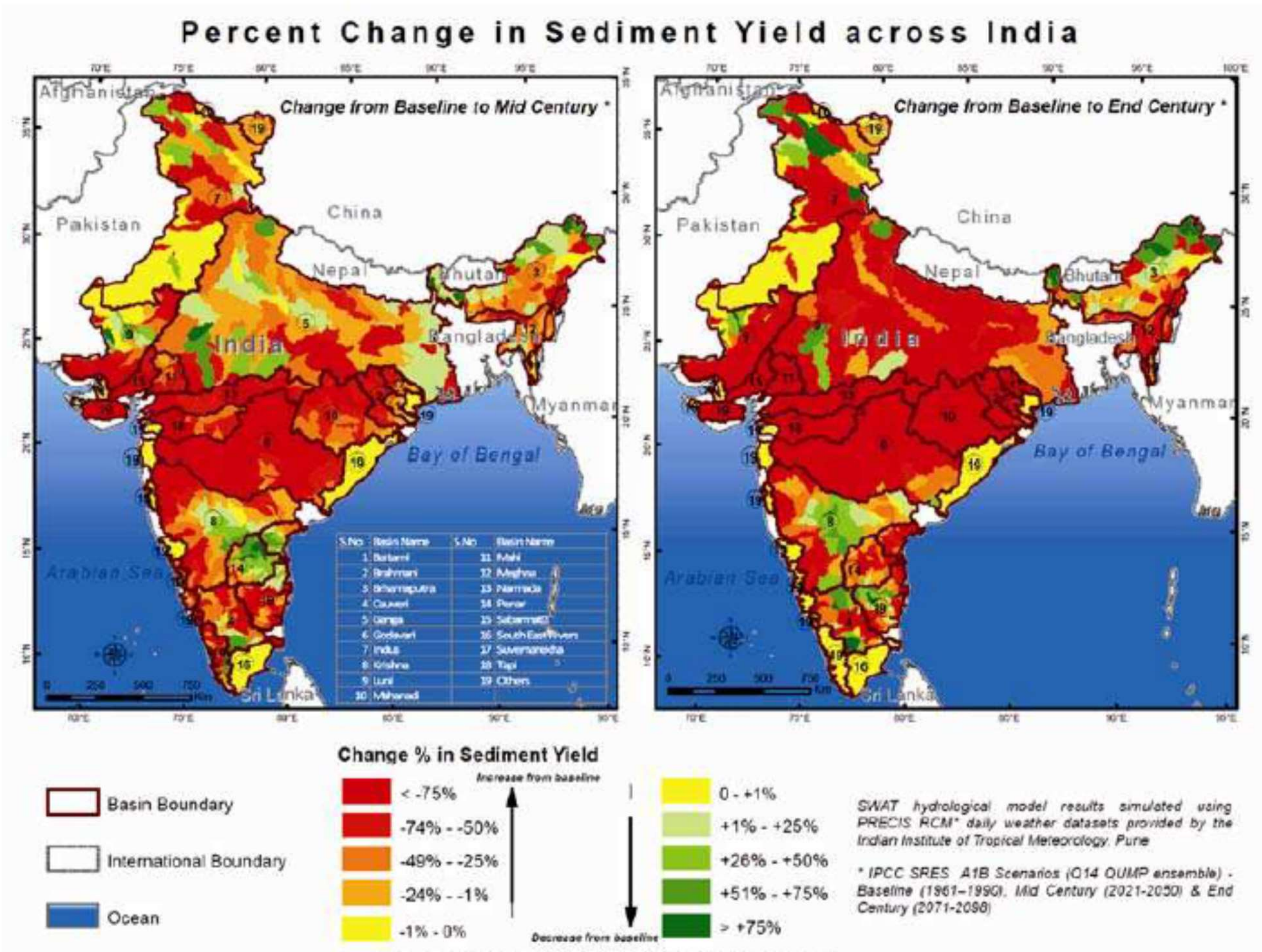
Per cent Change in Water Yield across India



S.No	Basin Name	S.No	Basin Name
1	Baitarni	11	Mahi
2	Brahmani	12	Meghna
3	Brhamaputra	13	Narmada
4	Cauveri	14	Penar
5	Ganga	15	Sabarmati
6	Godavari	16	South East Rivers
7	Indus	17	Suvernarekha
8	Krishna	18	Tapi
9	Luni	19	Others
10	Mahanadi		



Percent Change in Actual Evapotranspiration across India
Change from Baseline to Mid Century *
Change from Baseline to End Century *
Afghanistan
Pakistan
China
Nepal
Bhutan
India
Bangladesh
Myanmar
Bay of Bengal
Arabian Sea
Sri Lanka
S.No Basin Name S.No Basin Name
1 Baitarni 11 Mahi
2 Brahmani 12 Meghna
3 Brahmaputra 13 Narmada
4 Cauveri 14 Pennar
5 Ganga 15 Sabarmati
6 Godavari 16 South East Rivers
7 Indus 17 Subarnarekha
8 Krishna 18 Tapi
9 Luni 19 Others
10 Mahanadi
Change % in Actual Evapotranspiration
Basin Boundary
International Boundary
Ocean
Increase from baseline
Decrease from baseline
< -15%
-14% - -10%
-9% - -5%
-4% - -1%
-1% - 0%
0 - +1%
+1% - +5%
+6% - +10%
+11% - +15%
> +15%
SWAT hydrological model results simulated using PRECIS RCM* daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
* IPCC SRES A1B Scenarios (Q14 QUMP ensemble) - Baseline (1961-1990), Mid Century (2021-2050) & End Century (2071-2098)


Percent Change in Sediment Yield across India
Change from Baseline to Mid Century *
Change from Baseline to End Century *
Afghanistan
Pakistan
China
Nepal
Bhutan
Bangladesh
Myanmar
India
Bay of Bengal
Arabian Sea
Sri Lanka
S.No Basin Name S.No Basin Name
1 Baitarni 11 Mahi
2 Brahmani 12 Meghna
3 Brahmaputra 13 Narmada
4 Cauveri 14 Penar
5 Ganga 15 Sabarmati
6 Godavari 16 South East Rivers
7 Indus 17 Suvarnarekha
8 Krishna 18 Tapi
9 Luni 19 Others
10 Mahanadi
Change % in Sediment Yield
Increase from baseline
Decrease from baseline
Basin Boundary
International Boundary
Ocean
< -75%
-74% - -50%
-49% - -25%
-24% - -1%
-1% - 0%
0 - +1%
+1% - +25%
+26% - +50%
+51% - +75%
> +75%
SWAT hydrological model results simulated using PRECIS RCM* daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
* IPCC SRES A1B Scenarios (Q14 QUMP ensemble) - Baseline (1961–1990), Mid Century (2021-2050) & End Century (2071-2098)

- In northern India, a declining trend in 41 years (1970–2010) of daily streamflow records for Sutlej River has been observed at three gauging locations (Kasol, Sunni, and Rampur)

- The basin has importance in the high potential for hydroelectricity power generation and agricultural practices (Singh et al. 2014a)

- A significantly declining trend in mean annual streamflow in the Beas River and a decreasing but insignificant trend for the Ravi River is observed, while winter streamflow in the Chenab River showed a statistically significant increase during 1961–1995 attributed to variability in snow and glacier melting (Bhutiyani et al. 2008)

- A declining trend in the historical annual streamflow data (1982–2012) of Gomti River (total area of 30,437 km2), a tributary of the Ganges River in northern India, has been observed at four gauging stations (Neemsar, Sultanpur, Jaunpur, and Maighat) and is attributed to a high dependency on the monsoon rainfall (Abeysingha et al. 2016)

- In the Upper Cauvery basin of southern India (catchment area of 36,682 km^2), no significant trend has been observed in the monthly streamflow data of a 30-year period (1981–2010) for four gauging stations except one (T. Narasipur), where an annual decrease of 0.778 m^3/s in the period 2001–2010 has been observed (Raju and Nandagiri 2017)

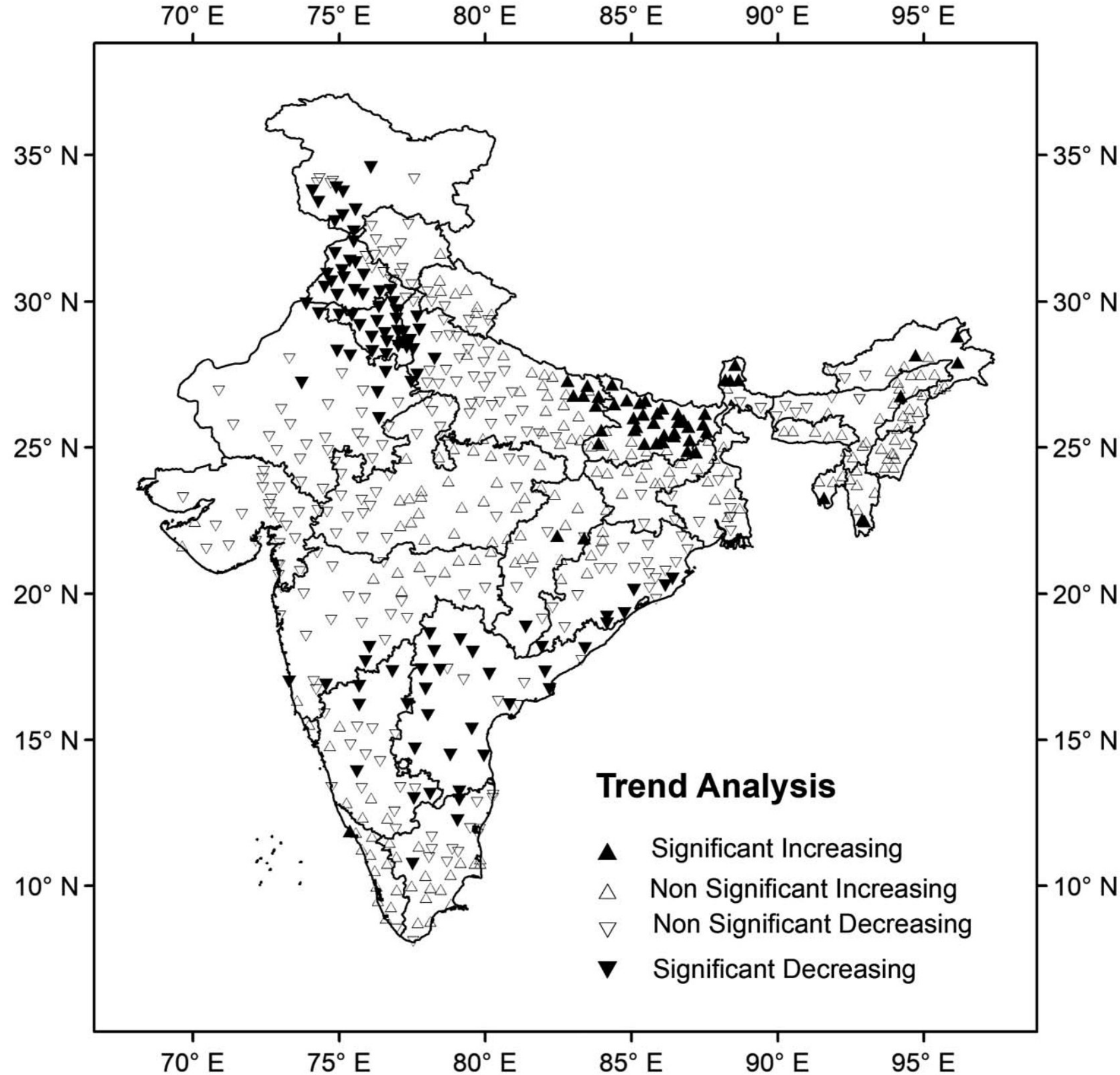
- In peninsular India, the streamflow at the outlet (Tikerpara) of the Mahanadi River basin (catchment area of 141,589 km^2) declined at a rate of 3,388 million cubic meters per decade for the period of 1972–2007 (Panda et al. 2013)

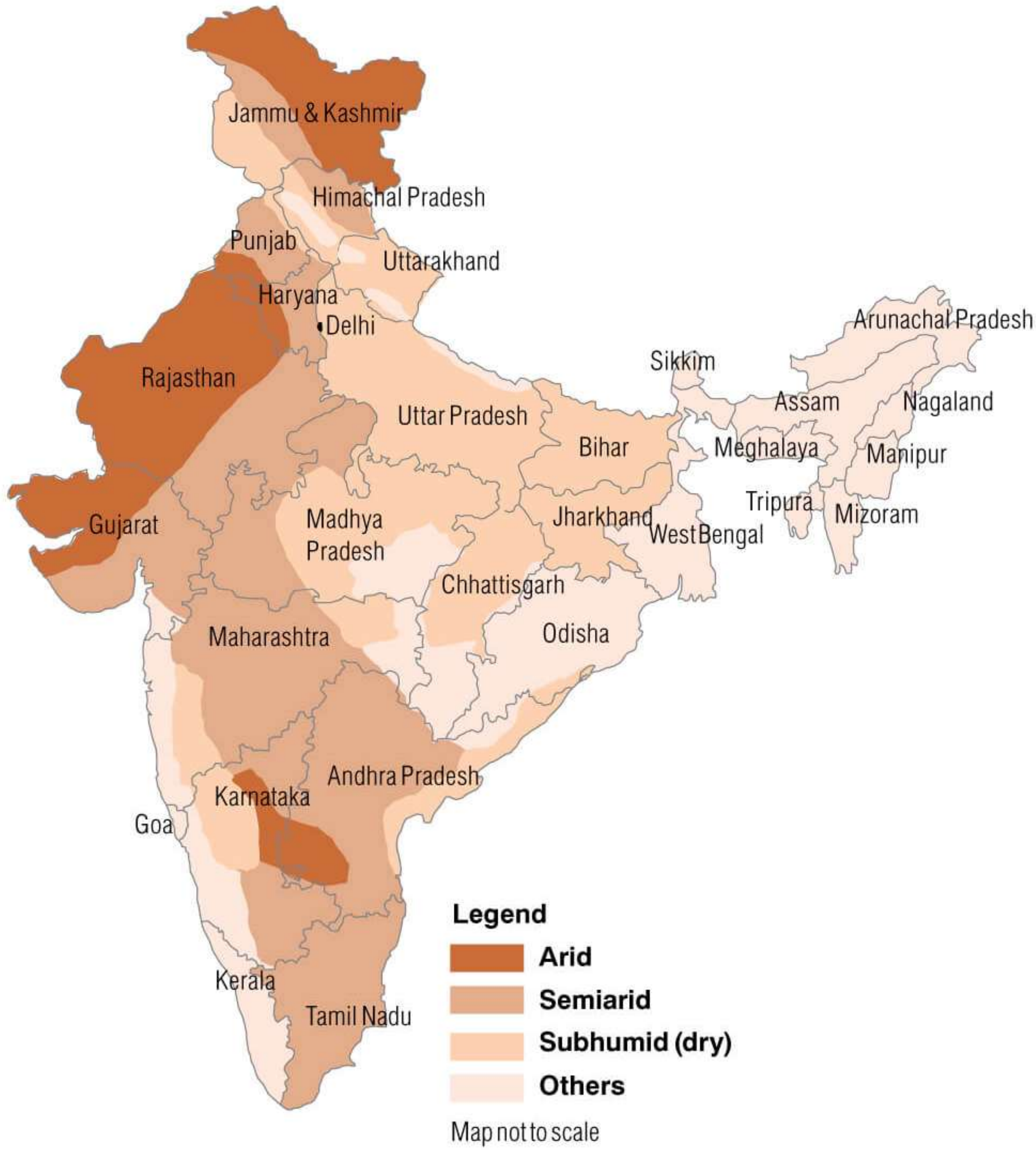
- An increase during 1956–2007 in the number of particular flood occurrences in Bahadurabad in the Brahmaputra River has been recorded (Climate Change Cell 2009).

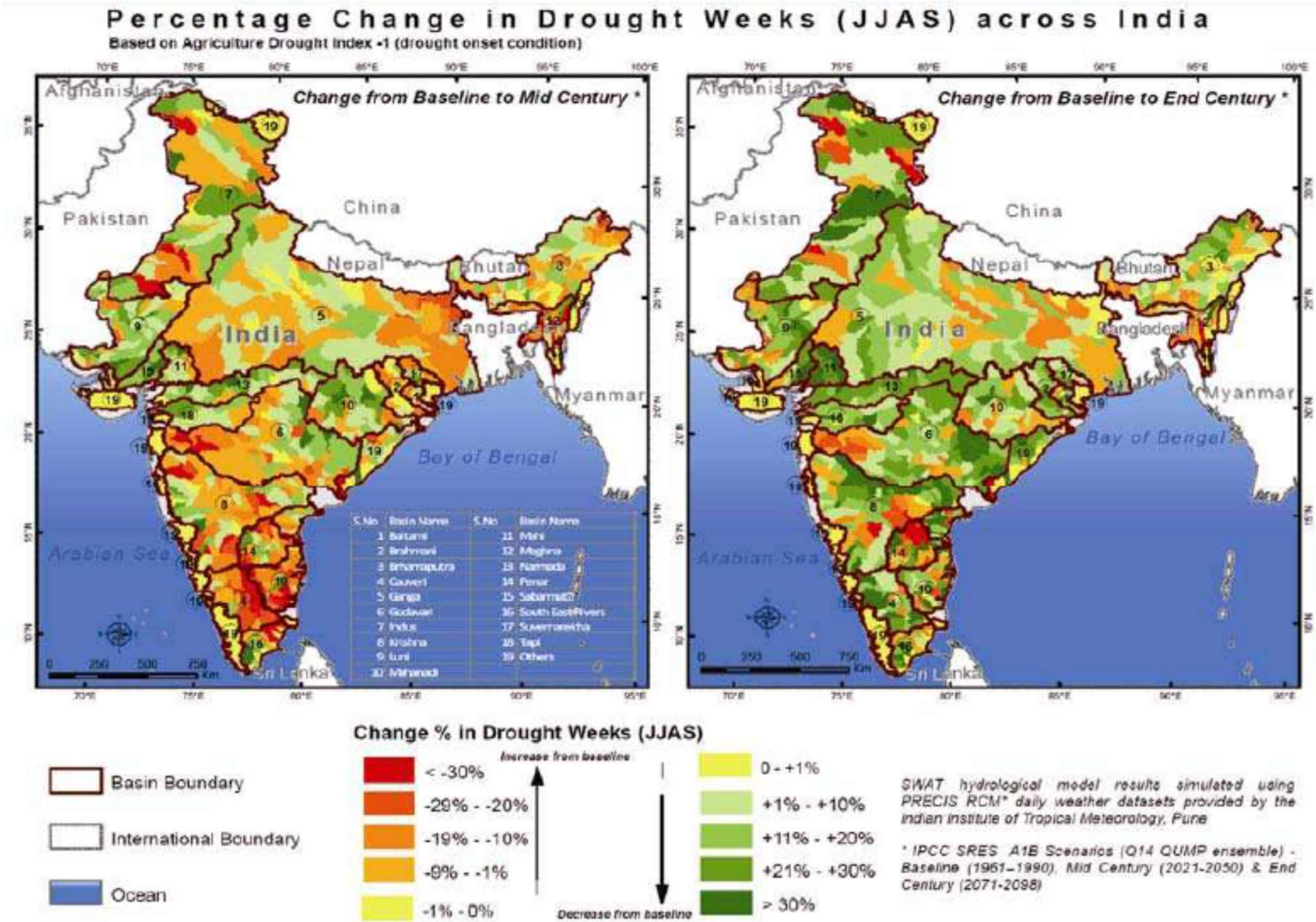
- Dadhwal et al. (2010) reported an increase by 4.53% in the annual stream flow at the Mundali outlet in the Mahanadi basin attributed to a reduction in forest cover by 5.71% for the period 1972–2003

- For the Ganges-Brahmaputra-Meghna (GBM) basin, the longterm mean runoff is projected to increase by 33.1, 16.2, and 39.7% in the Ganges, Brahmaputra, and Meghna basins, respectively (Masood et al. 2015), by the end of the 21st century

Trend analysis of annual drought severity (ADS) across 566 stations in India over 1901–2002


70° E
75° E
80° E
85° E
90° E
95° E
35° N
30° N
25° N
20° N
15° N
10° N
Trend Analysis
Significant Increasing
Non Significant Increasing
Non Significant Decreasing
Significant Decreasing


Jammu & Kashmir
Himachal Pradesh
Punjab
Uttarakhand
Haryana
Delhi
Arunachal Pradesh
Sikkim
Rajasthan
Uttar Pradesh
Assam
Nagaland
Bihar
Meghalaya
Manipur
Tripura
Mizoram
Gujarat
Madhya Pradesh
Jharkhand
West Bengal
Chhattisgarh
Odisha
Maharashtra
Andhra Pradesh
Karnataka
Goa
Kerala
Tamil Nadu
Legend
Arid
Semiarid
Subhumid (dry)
Others
Map not to scale


Percentage Change in Drought Weeks (JJAS) across India
Based on Agriculture Drought Index -1 (drought onset condition)
Change from Baseline to Mid Century *
Change from Baseline to End Century *
Afghanistan
Pakistan
China
Nepal
Bhutan
India
Bangladesh
Myanmar
Bay of Bengal
Arabian Sea
Sri Lanka
S.No Basin Name
1 Baitarni
2 Brahmani
3 Brhamaputra
4 Cauveri
5 Ganga
6 Godavari
7 Indus
8 Krishna
9 Luni
10 Mahanadi
11 Mahi
12 Meghna
13 Narmada
14 Pennar
15 Sabarmati
16 South East Rivers
17 Suvernarekha
18 Tapi
19 Others
Change % in Drought Weeks (JJAS)
Basin Boundary
International Boundary
Ocean
Increase from baseline
Decrease from baseline
< -30%
-29% - -20%
-19% - -10%
-9% - -1%
-1% - 0%
0 - +1%
+1% - +10%
+11% - +20%
+21% - +30%
> 30%
SWAT hydrological model results simulated using PRECIS RCM* daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
* IPCC SRES A1B Scenarios (Q14 QUMP ensemble) - Baseline (1961–1990), Mid Century (2021-2050) & End Century (2071-2098)

- Enhancement of the capabilities of long-range forecasts to climate modelling and weather forecasting

- In 1989, the National Centre for Medium Range Weather Forecasting started to forecast weather on a medium-term basis (3-10 days in advance)

- Monitoring of storage position of reservoirs: 76 important reservoirs of the country having a total live storage capacity of 131.22 billion m^3 are being monitored

- A further 49 have also been identified for inclusion in the monitoring system, which will increase storage capacity of the monitored reservoirs to 156.69 billion m^3, i.e. about 74 per cent of the total capacity of 213 billion m3 created so far

- Efforts are under way to improve the efficiency of the irrigation system
- The National Agricultural Drought Assessment and Monitoring System became operational in 1989
- The National Centre for Disaster Management was set up in 1995 to undertake human-resource development, research, building a database and providing information services and documentation on disaster management
- Setting-up of a National Data Bank under the All India Co-ordinated Project on Agrometeorology at the Crop Research Institute for Dry Land Agriculture, Hyderabad
- Setting-up of a National Disaster Management Authority

Approach to flood management

The following structural measures are generally adopted for flood protection:

- Embankments, flood walls, sea walls
- Dams and reservoirs
- Natural detention basins
- Channel improvement
- Drainage improvement
- Diversion of flood waters.

Non-structural measures include:

- Flood forecasting and warning
- Flood plain zoning-regulate land use
- Flood insurance.