Vulnerability of Our Water Resources in a Changing Climate: *Imperatives and Options…..*

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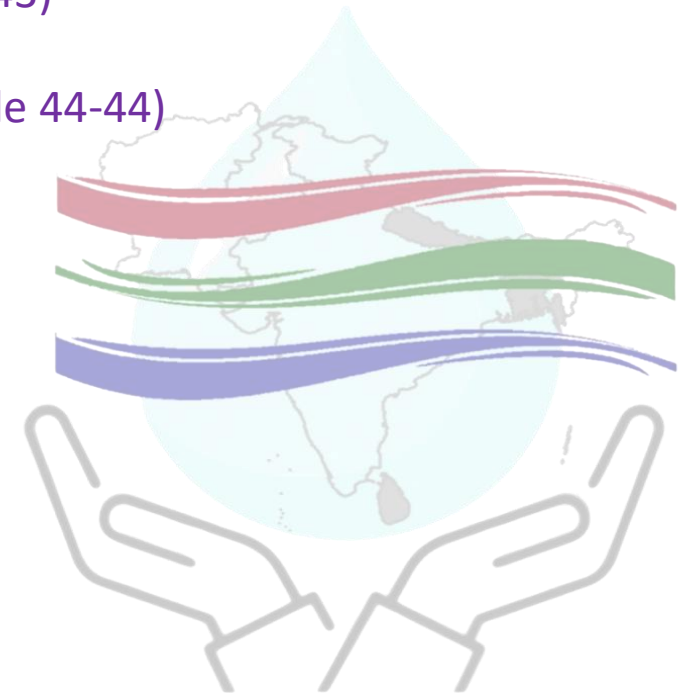
Outline



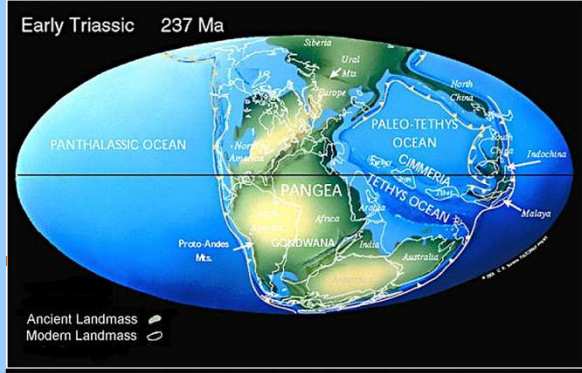
Change is Inevitable….

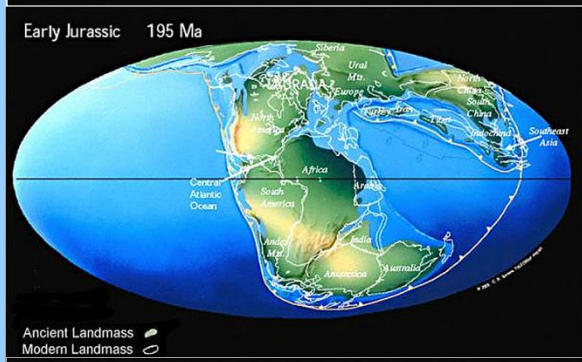
Things are constantly changing and cannot be avoided. It's a truth that applies to many aspects of life, including people, relationships, and the world around you….

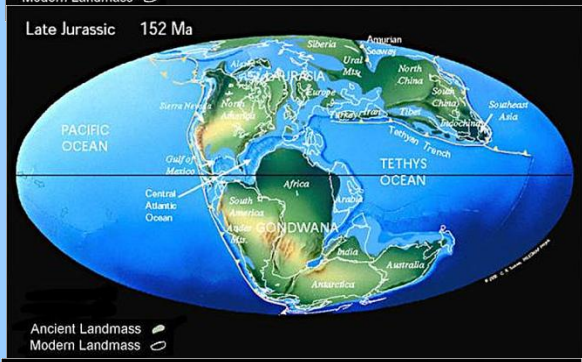
It's human nature to want to feel safe and secure. Change can threaten our sense of stability and, when the change is unexpected, it can throw us into chaos. Those who thrive on change are the smart planners.

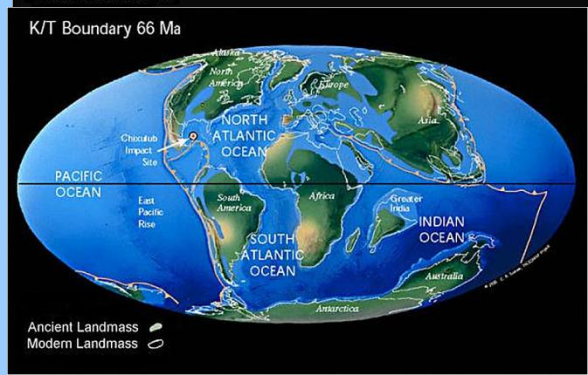
From the birth of the Earth, Climate has been changing.....


Eurasia
North America
Africa
South America
India
Antarctica
Australia

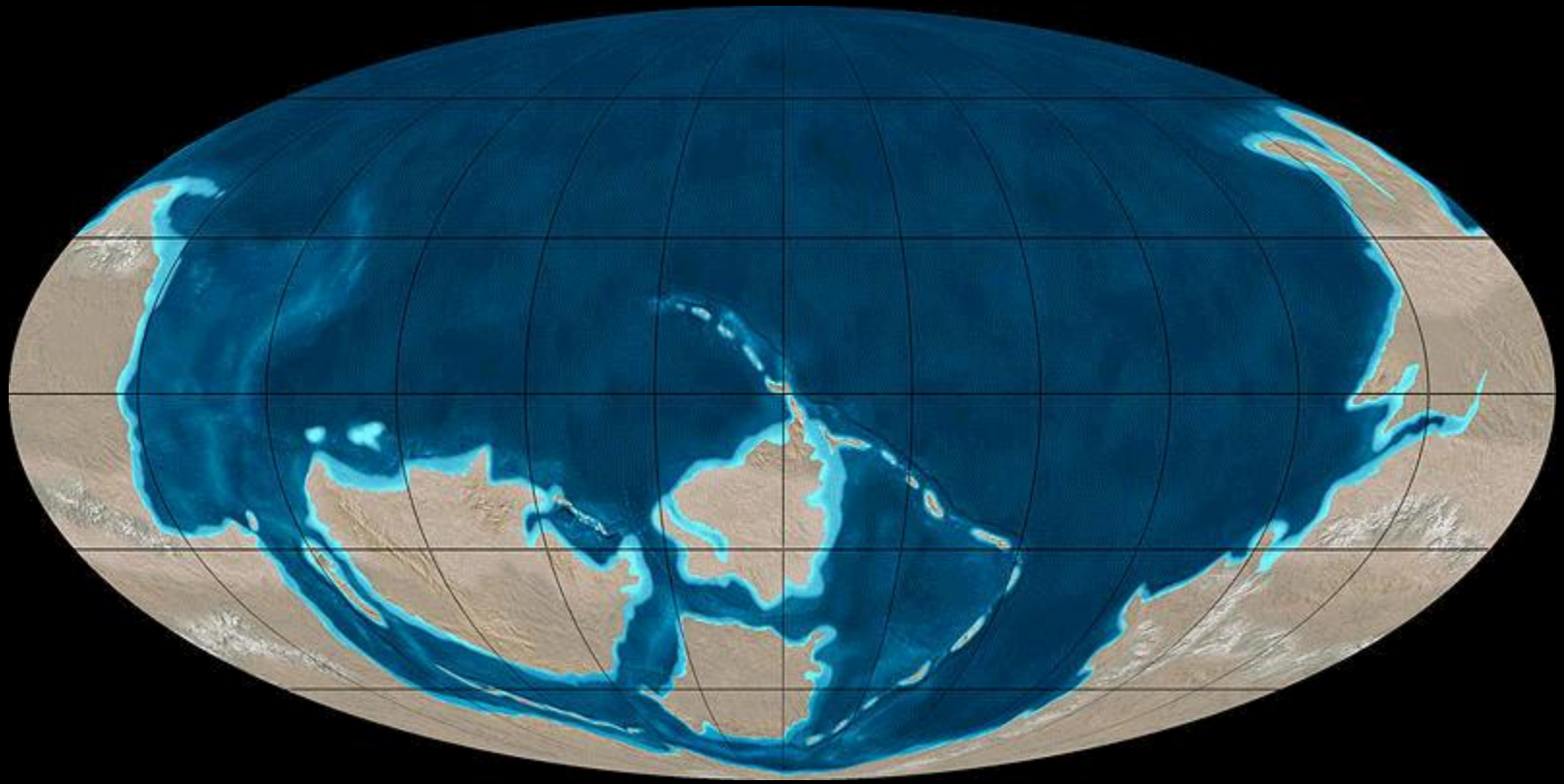

Early Triassic 237 Ma
PANTHALASSIC OCEAN
PALEO-TETHYS OCEAN
CIMMERIA
TETHYS OCEAN
PANGEA
GONDWANA
Proto-Andes Mts.
Ancient Landmass
Modern Landmass


Early Jurassic 195 Ma
LAURASIA
Central Atlantic Ocean
Ancient Landmass
Modern Landmass


Late Jurassic 152 Ma
PACIFIC OCEAN
TETHYS OCEAN
Central Atlantic Ocean
GONDWANA
Ancient Landmass
Modern Landmass


K/T Boundary 66 Ma
NORTH ATLANTIC OCEAN
Chicxulub Impact Site
PACIFIC OCEAN
East Pacific Rise
SOUTH ATLANTIC OCEAN
INDIAN OCEAN
Ancient Landmass
Modern Landmass

Continuous Natural Changes….



Climate Change

Any long-term significant change in the "average weather" that a given region experiences.

Average weather may include average temperature, precipitation and wind patterns.

It involves changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years.

These changes can be caused by dynamic processes on Earth, external forces including variations in sunlight intensity, and more recently by human activities.

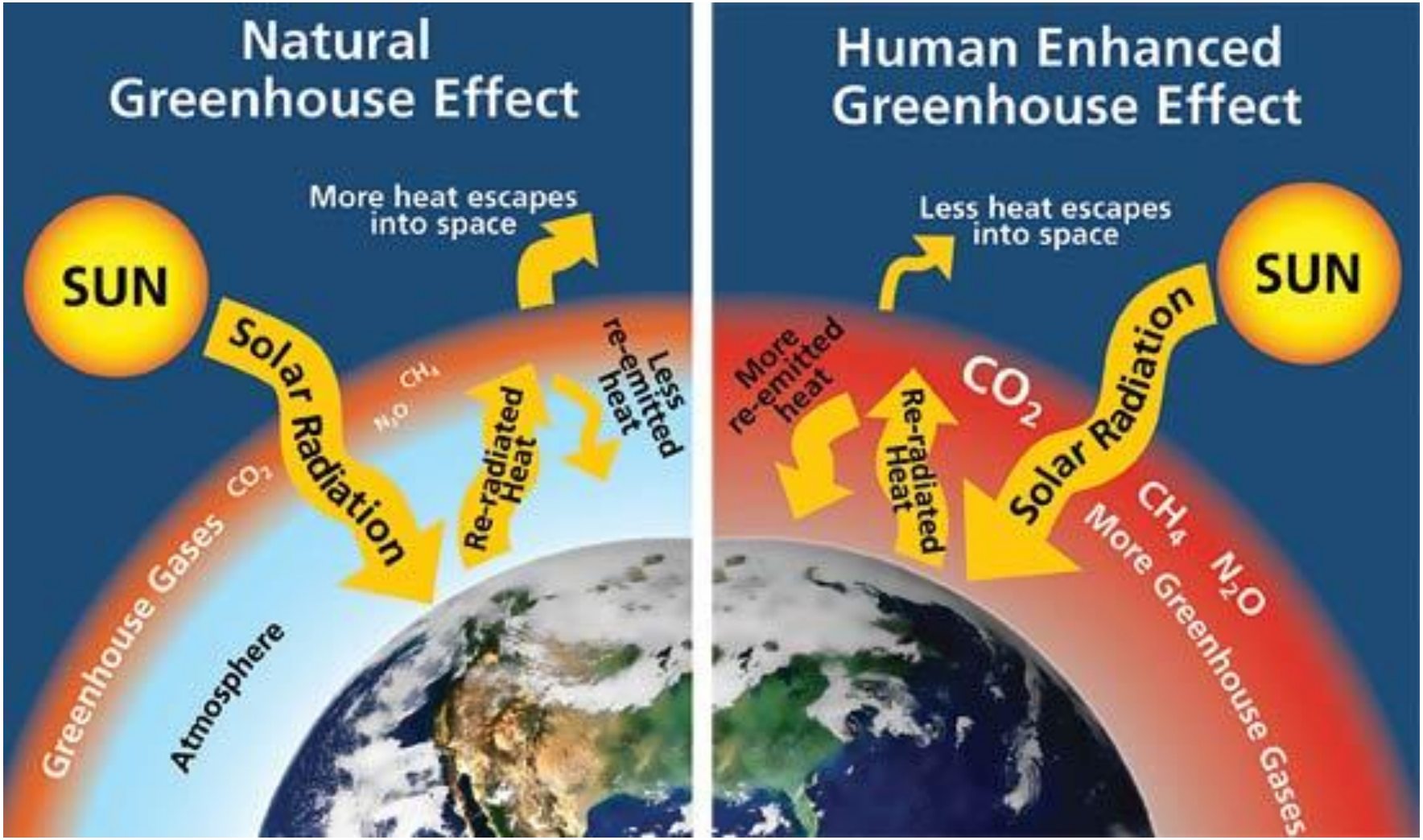
Climate Change

Climate change is affecting our planet in many ways. Average temperatures are increasing; rainfall patterns are shifting; snow lines are retreating; glaciers and ice sheets are melting; permafrost is thawing; sea levels are rising; and severe weather is becoming more frequent.

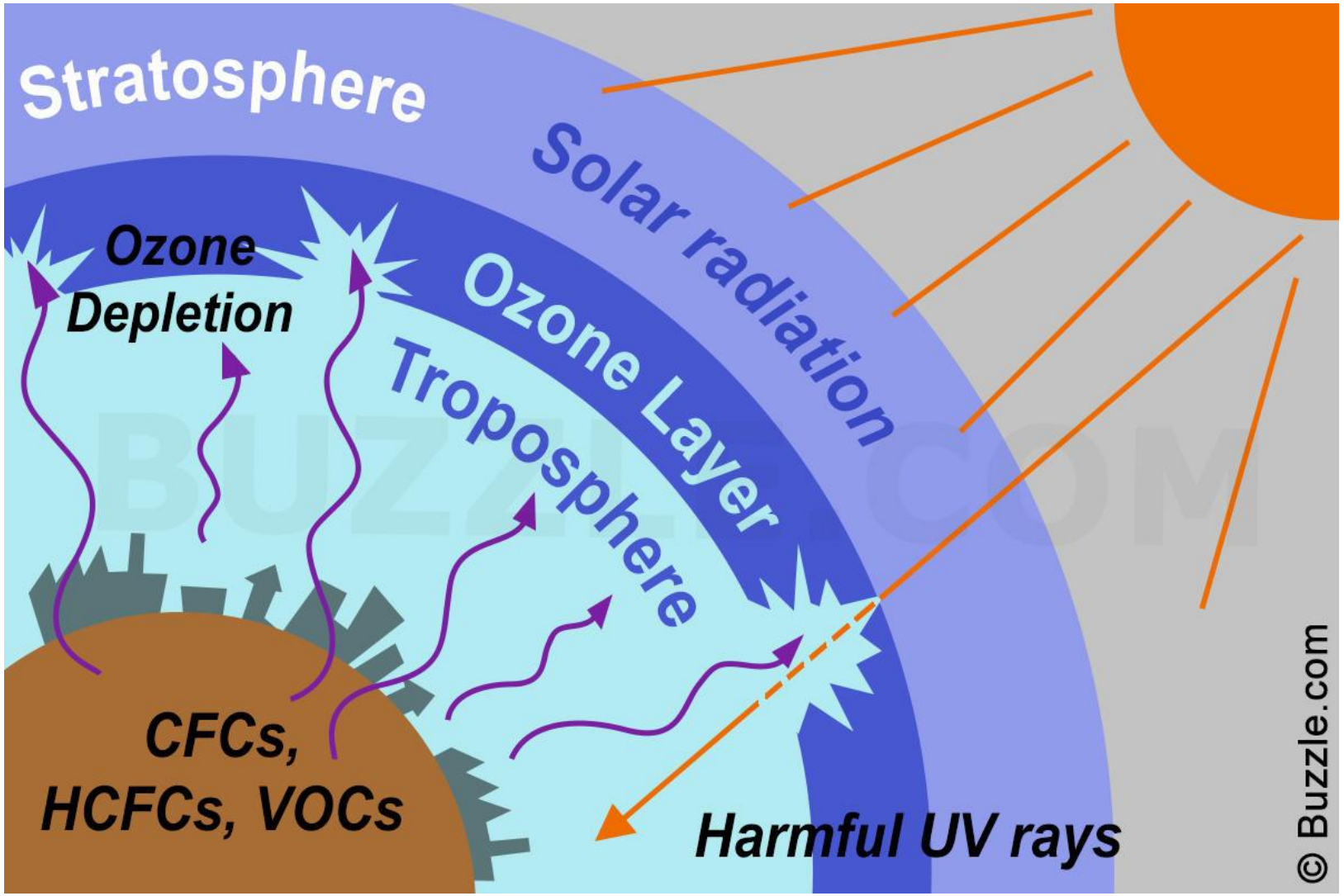
Overcoming impacts…..

Evolution, Adaptation and Resilience

Natural Process or Human Influenced..



Ozone layer depletion..



“human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in future.”
Roger R. Revelle, 1957.

Earth's biosphere has significantly altered its atmosphere.

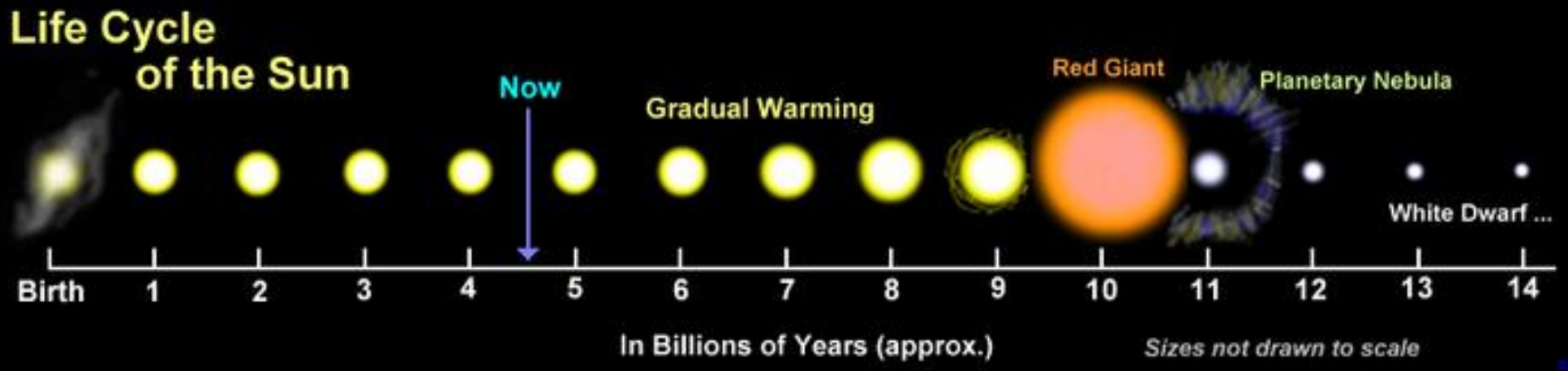
Oxygenic photosynthesis evolved 2.7 billion years ago, forming the today's primarily nitrogen-oxygen atmosphere.

This enabled the proliferation of aerobic organisms as well as the formation of the ozone layer which, together with Earth's magnetic field, blocks ultraviolet solar radiation, permitting life on land.

Highlights of Change – not uncommon

- **5 billion years ago**: earth is formed, along with the other planets
- **3.5 billion years ago**: first life appears in oceans
- **3.25 billion years ago**: photosynthesis begins in oceans
- **2.4 billion years ago**: oceans contain significant amounts of oxygen
- **1.9 billion years ago**: first cells with nuclei appear in oceans
- **0.65 billion years ago**: first multi-cellular organisms appear
- **0.5 billion years ago**: first land plants with inner vessels
- **250 million years ago**: mass extinction of 99% of all life
- **245 million years ago**: Age of Dinosaurs begins
- **150 million years ago**: Supercontinent breaking up; continents drifting apart
- **65 million years ago**: Age of Dinosaurs ends, with mass extinction of 70% of all living things
- **100,000 years ago**: First Homo sapiens appears
- **10,000 years ago**: Recorded human history begins

The future of the planet is closely tied to that of the Sun. Due to steady accumulation of helium ash at the Sun's core, sun’s & star's total luminosity will slowly increase.



After another billion years, all surface water will have disappeared and the mean global temperature will reach 70°C. Earth is expected to be effectively habitable for about another 500 million years.

Change is obvious…

All pleasurable and delightful things in this world are impermanent, impersonal and miserable.

Lord Buddha

Why climate should be an exception ? ?

1. Climate is changing
2. Anthropogenic activities do contribute for CC through GHG
3. Temporal scale vs magnitude of CC is important
4. Natural warming is obvious at centennial scale

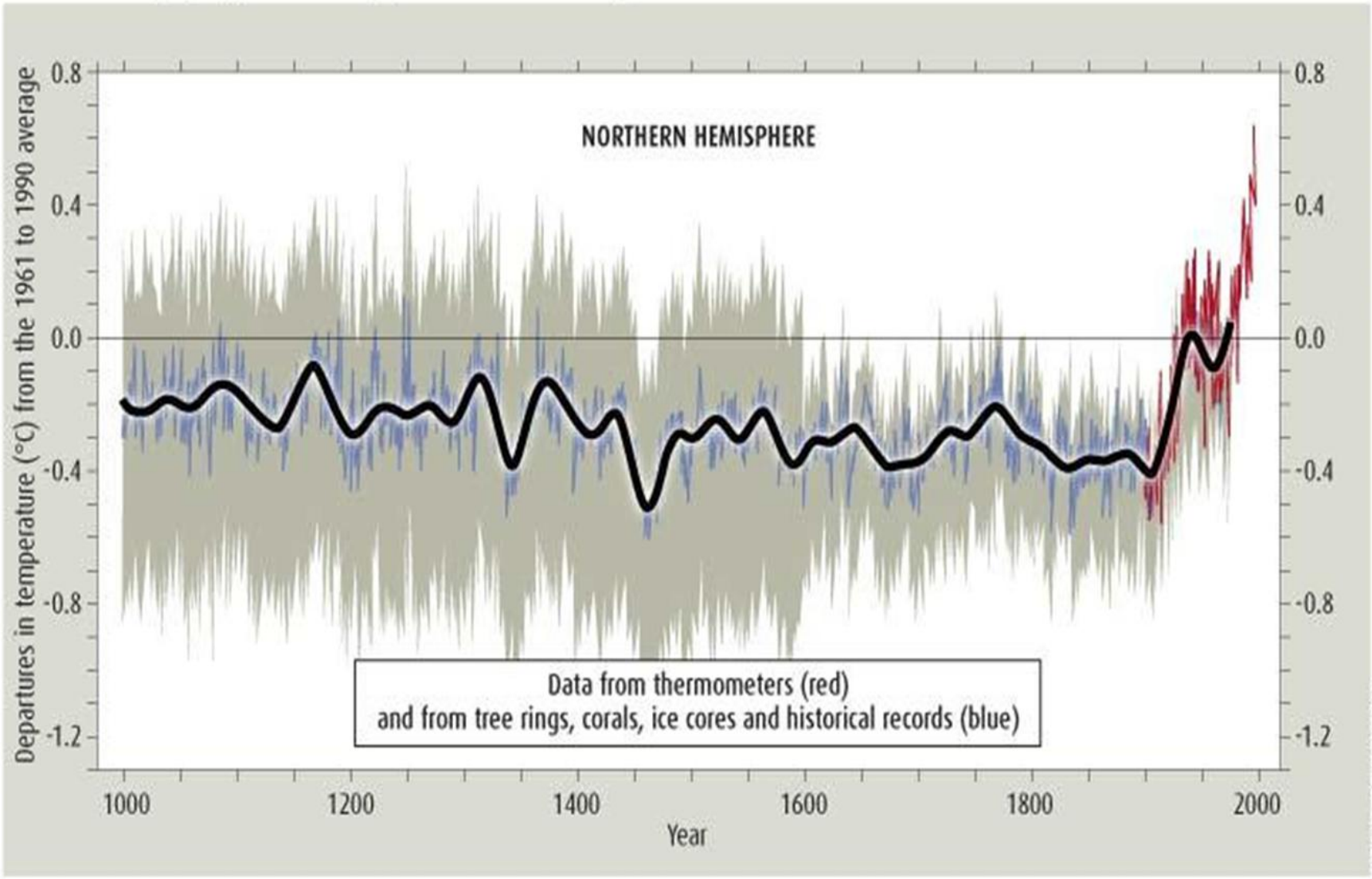
Historical evidence for climate change

- Evidence for climatic change is taken from a variety of sources that can be used to reconstruct past climates.

- Most of the evidence is indirect— climatic changes are inferred from changes in indicators that reflect climate, such as vegetation, dendrochronology, ice cores, sea level change, and glacial retreat (Palaeoclimatology – climatology from the beginning of the earth).

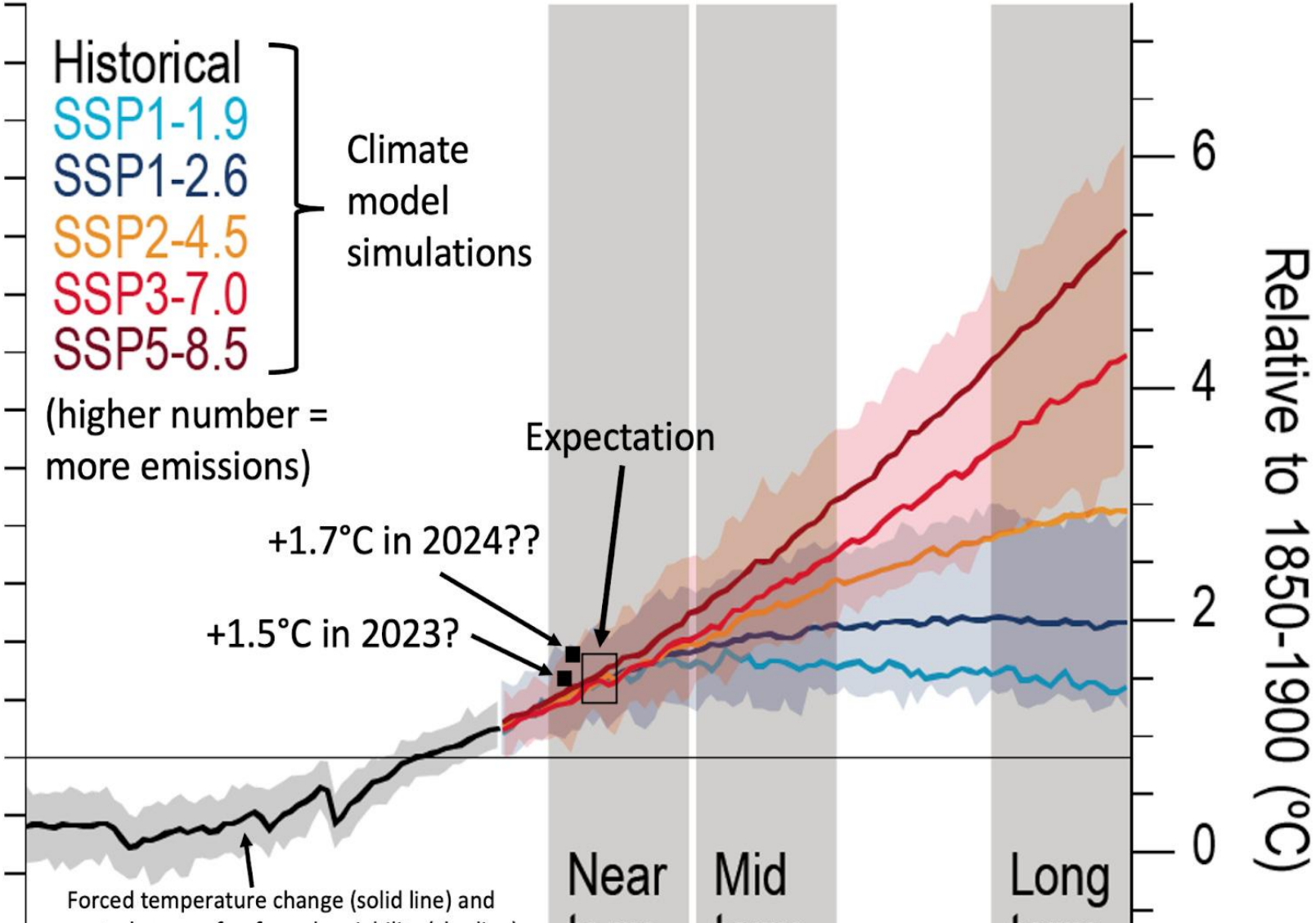
Temperature Trends in the Lower Atmosphere:

The 2001 IPCC version: "Variations of the Earth's surface temperature over the past 1000 years"
The error bars (in grey) show the 95 per cent confidence range

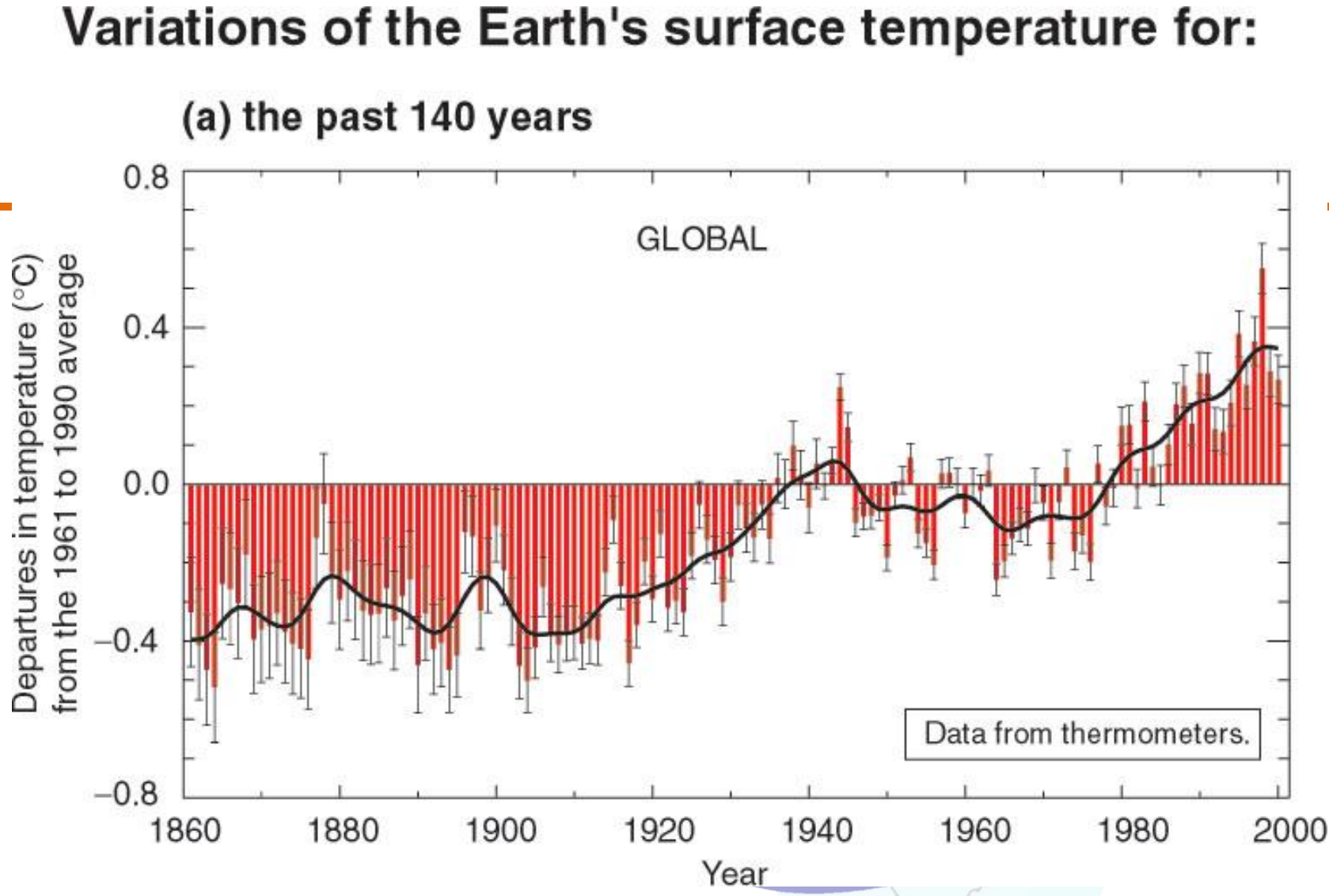


The IPCC version compared with some other northern hemisphere temperature reconstructions*

Temperature Trends in the Lower Atmosphere:

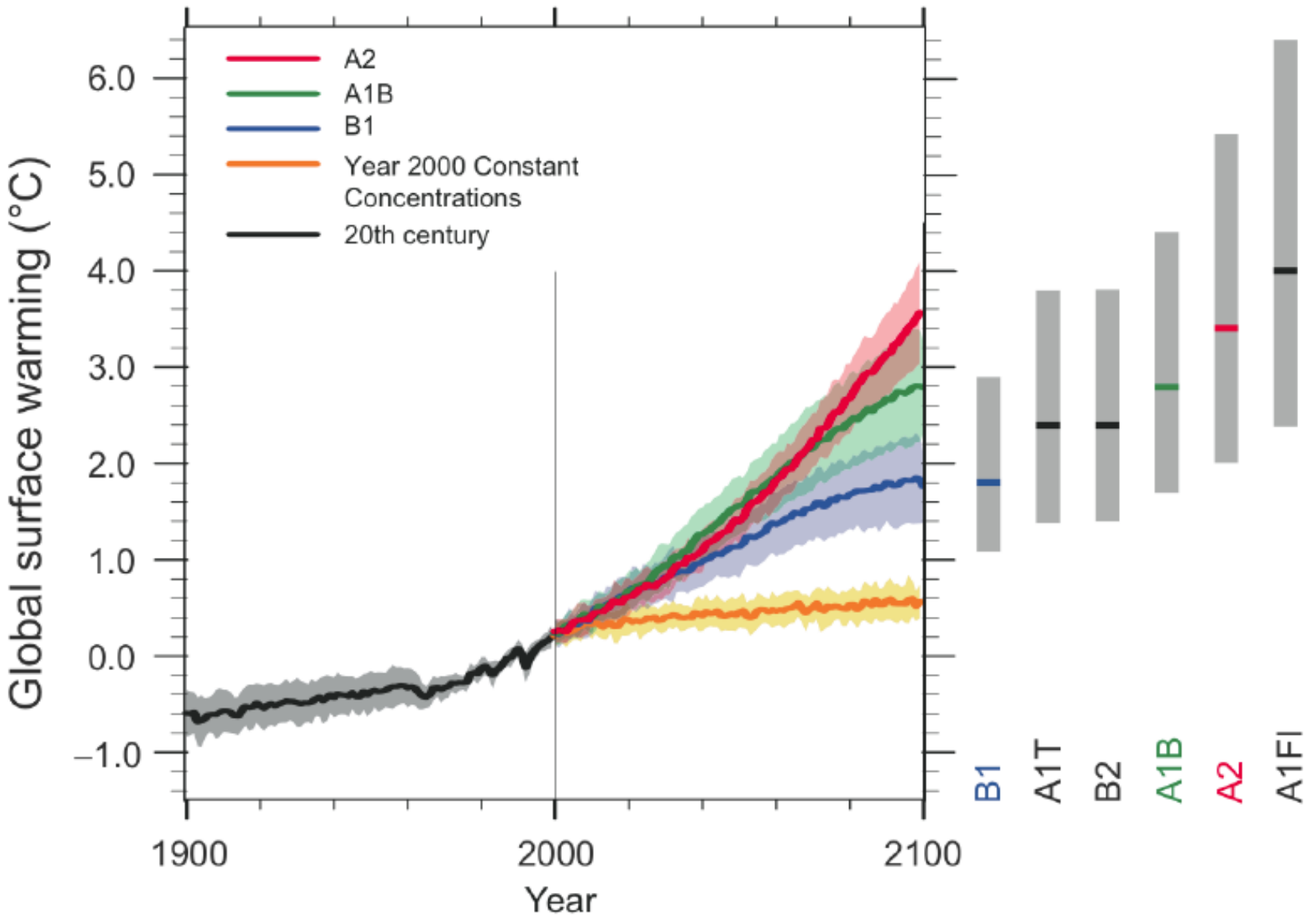


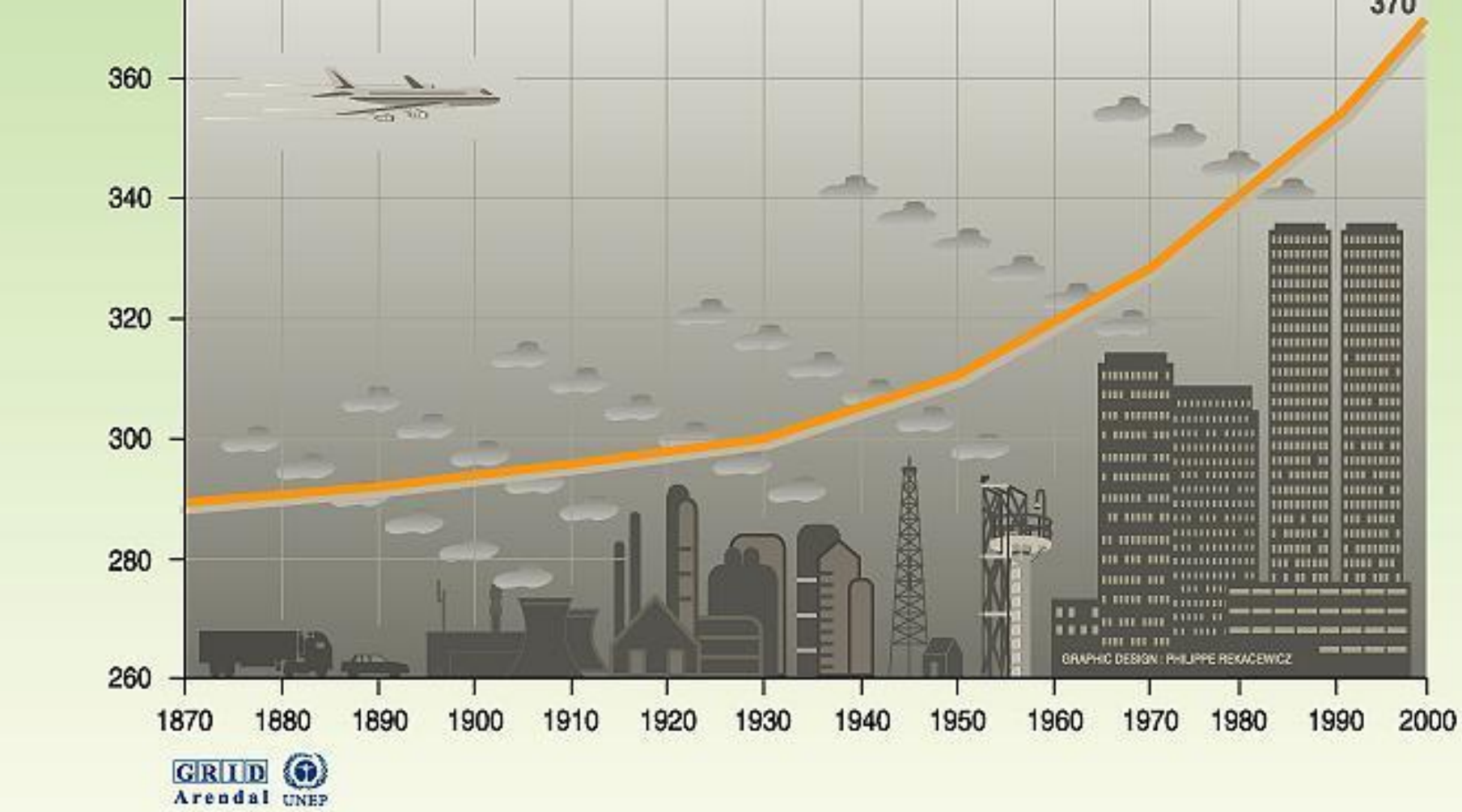
Source: The Breakthroughnstitute 2023



The best estimate is that the global average surface temperature has increased by 0.6 +- 0.2 ^{o}C

Multi-model Averages and Assessed Ranges for Surface Warming





Sources: TP Whorf Scripps, Mauna Loa Observatory, Hawaii, institution of oceanography (SIO), university of California La Jolla, California, United States, 1999

Useful Climate Change Statistics

- Annual average Arctic sea ice extent shrunk by 2.7 per cent per decade. Sea-ice decreases overall in summer by 7.4 per cent.
- Temperatures at the top of permafrost layer have generally increased since the 1980s by up to 3°C.
- The maximum area covered by seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900 — in spring by up to 15 per cent.
- Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years.

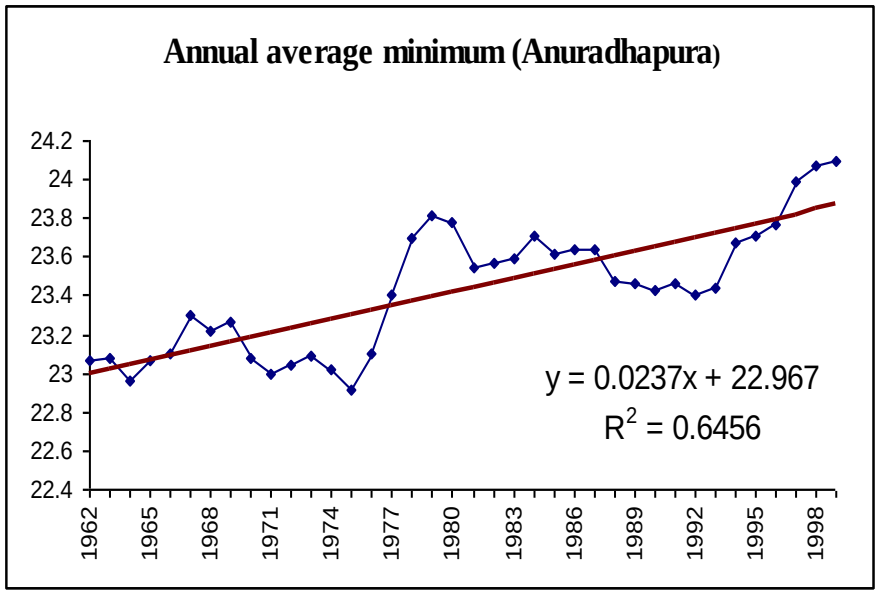
Useful Climate Change Statistics

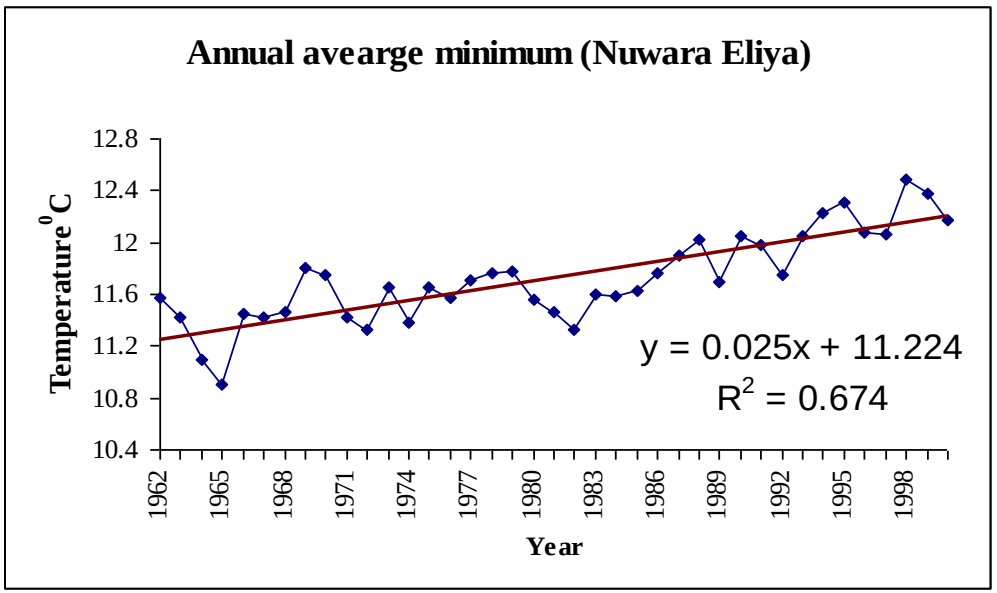
- The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise.
- Annual fossil CO_2 emissions increased from an average of 6.4 gigatons of carbon (GtC) per year in the 1990s, to 7.2 GtC per year in 2000-2005.
- CO_2 radiative forcing increased by 20 per cent from 1995 to 2005, the largest in any decade in at least the last 200 years.

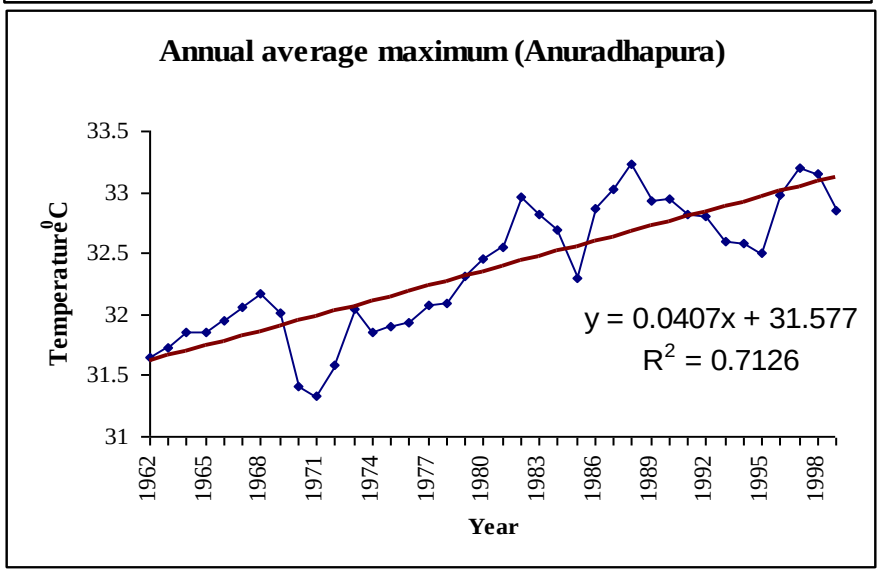
Useful Climate Change Statistics

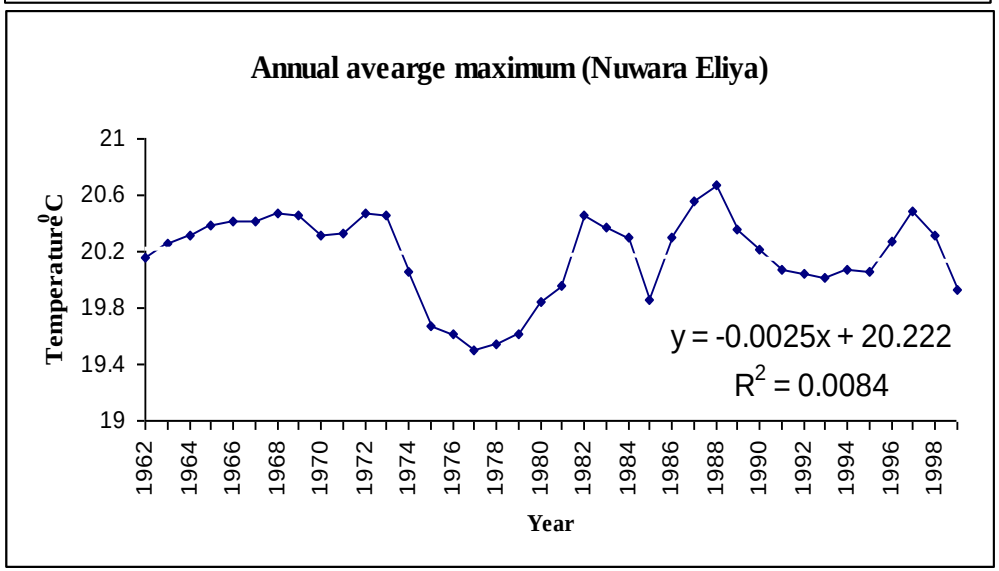
- For the next two decades a warming of about 0.2°C per decade is projected for a range of emission scenarios.
- Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.
- Temperatures in excess of 1.9 to 4.6°C warmer than pre-industrial sustained for millennia will lead to eventual melt of the Greenland ice sheet. This would raise sea level by 7 metres.

Monitoring annual temperature trends….

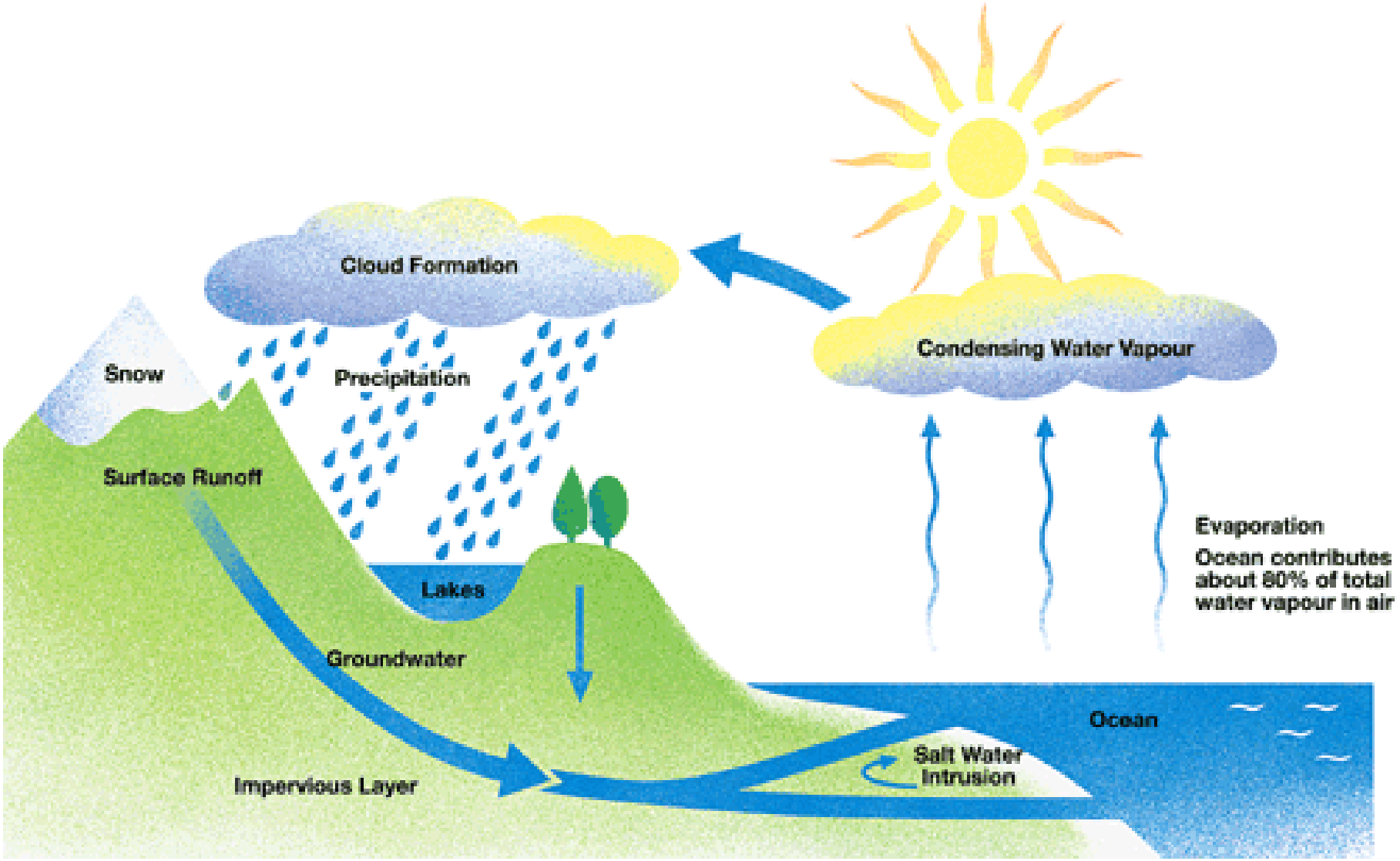




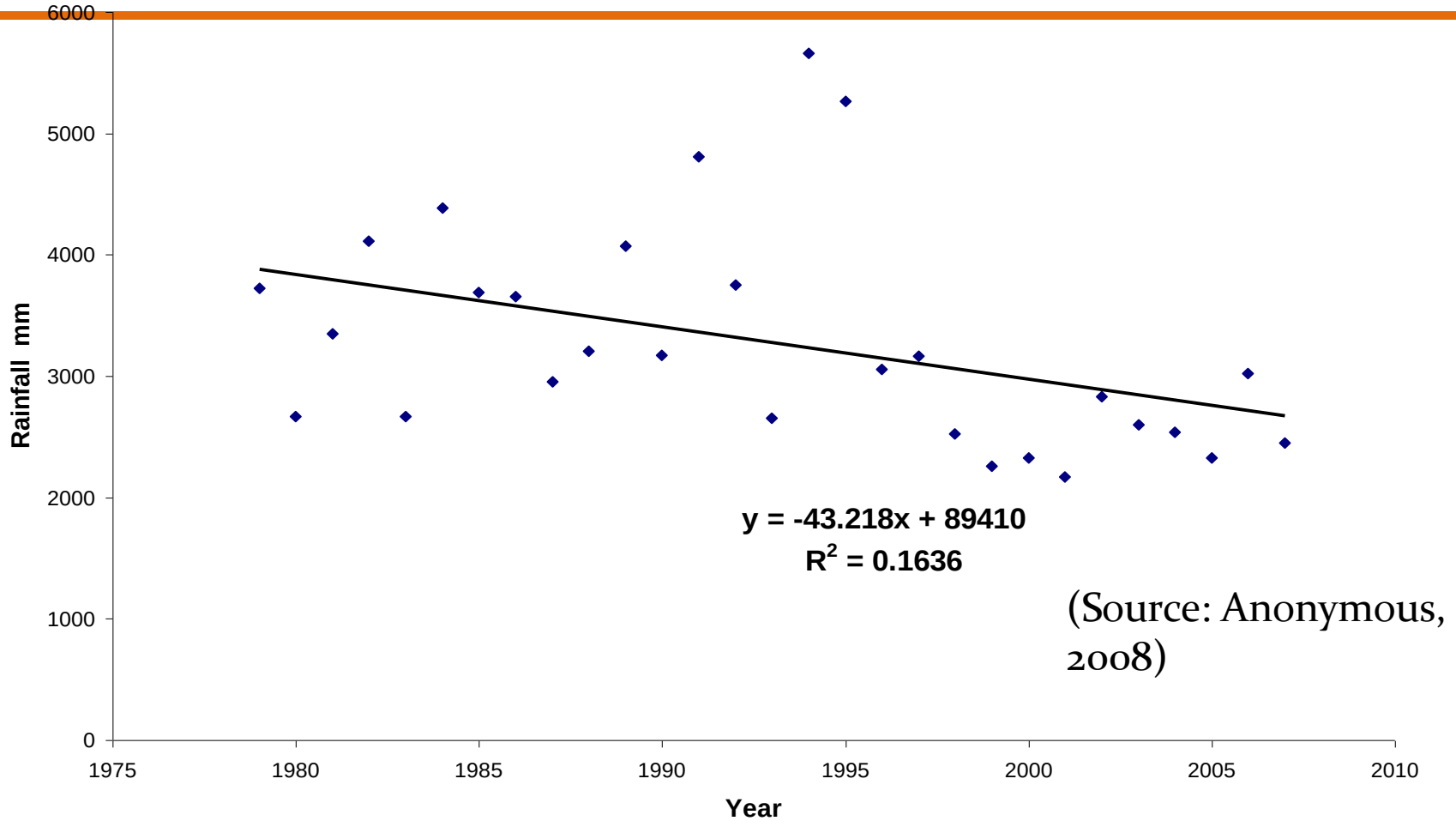




Impact on Hydrological Cycle



Climate Change and Rainfall: our focus

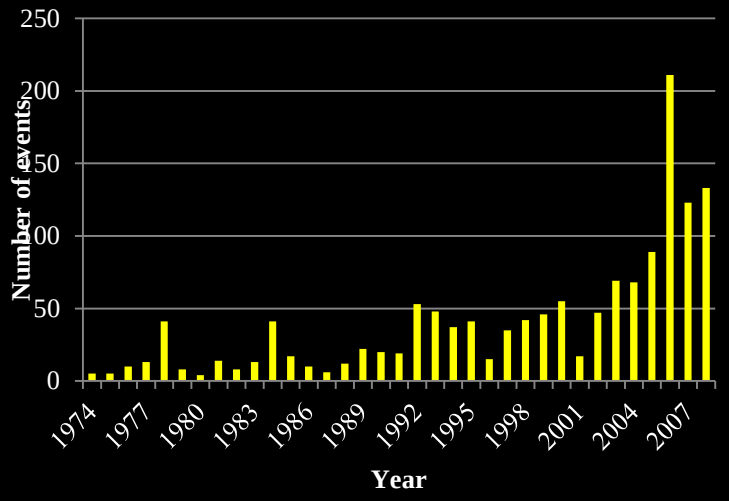


(Source: Anonymous, 2008)

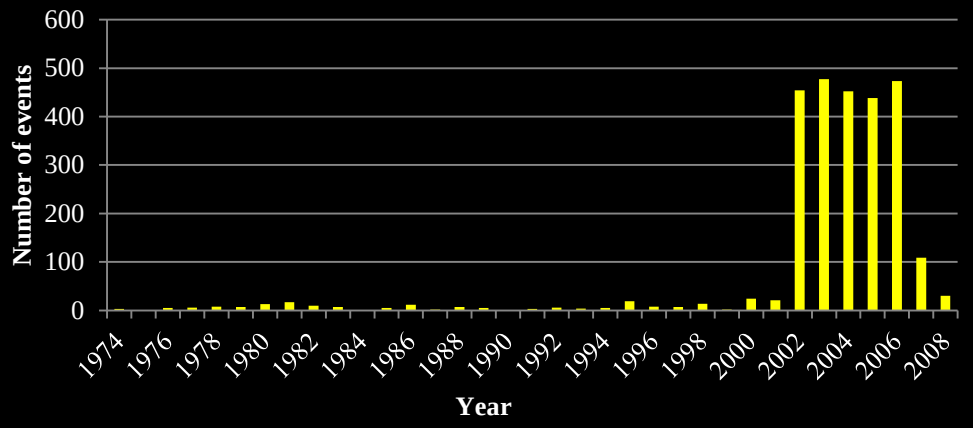
1979 – 2007 Rainfall at a subwatershed of Upper Mahaweli

Analyzing trend in the rainfall annual time series

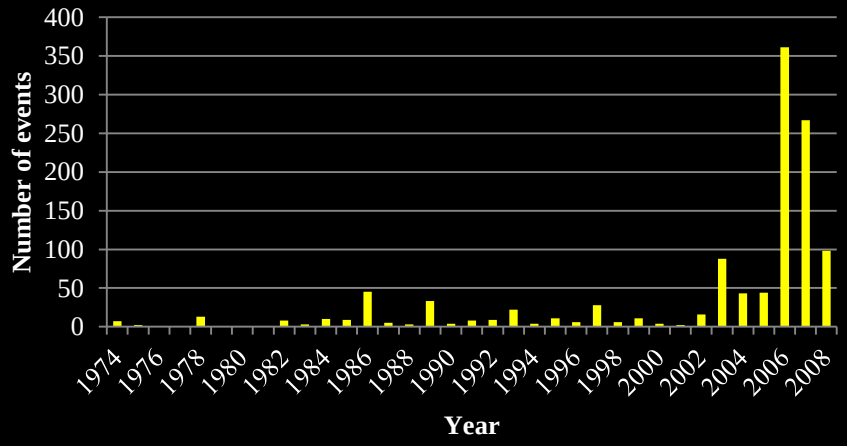
Annual time series distribution of flooding



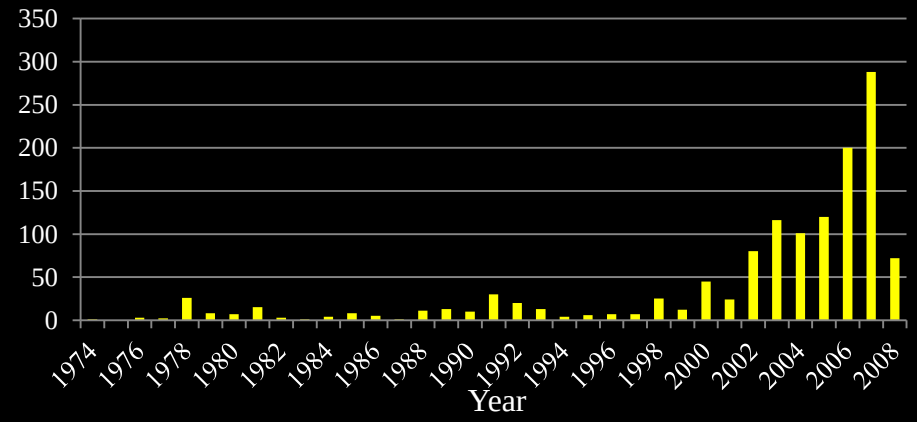
Annual time series distribution of fire events



Annual time series distribution of landslides



Annual time series distribution of extreme wind events



Climate Change and Rainfall: our focus

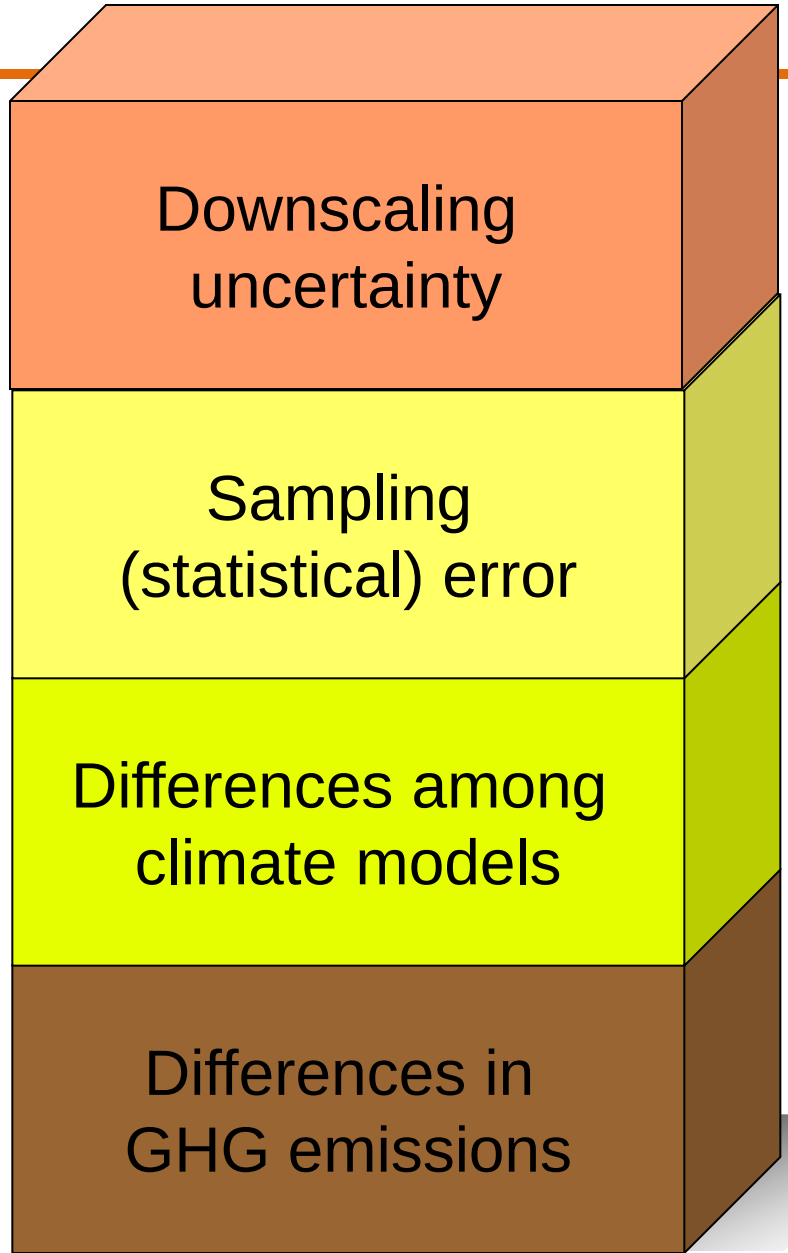
- *CV of seasonal rainfall in Sri Lanka*

Season	1931-1960	1961-1990
FIM	23%	27%
SWM	21%	16%*
SIM	22%	23%
NEM	31%	42%
Annual	11%	14%

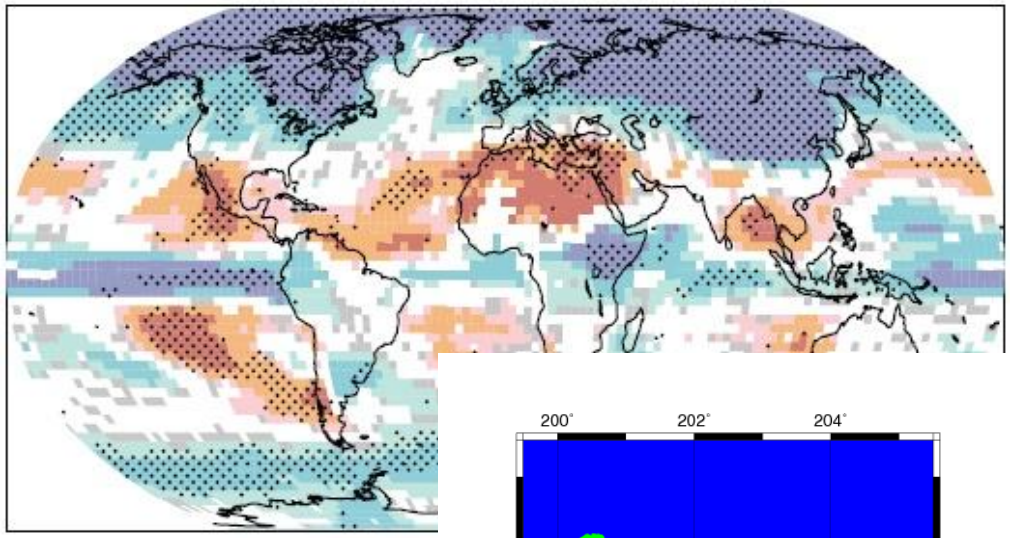
*SWM during recent times shows higher variability

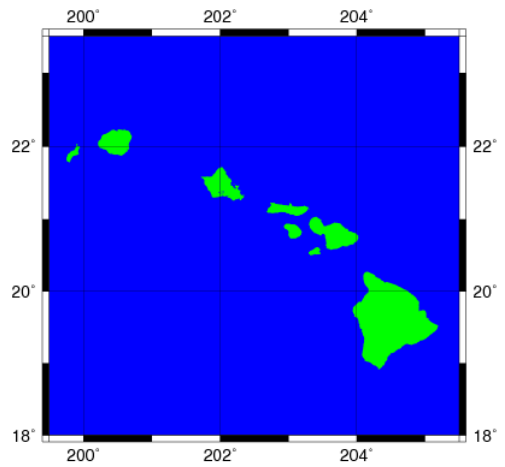
Analyzing trend in the spatial aggregation of seasonal rainfall time series

Climate models and statistics



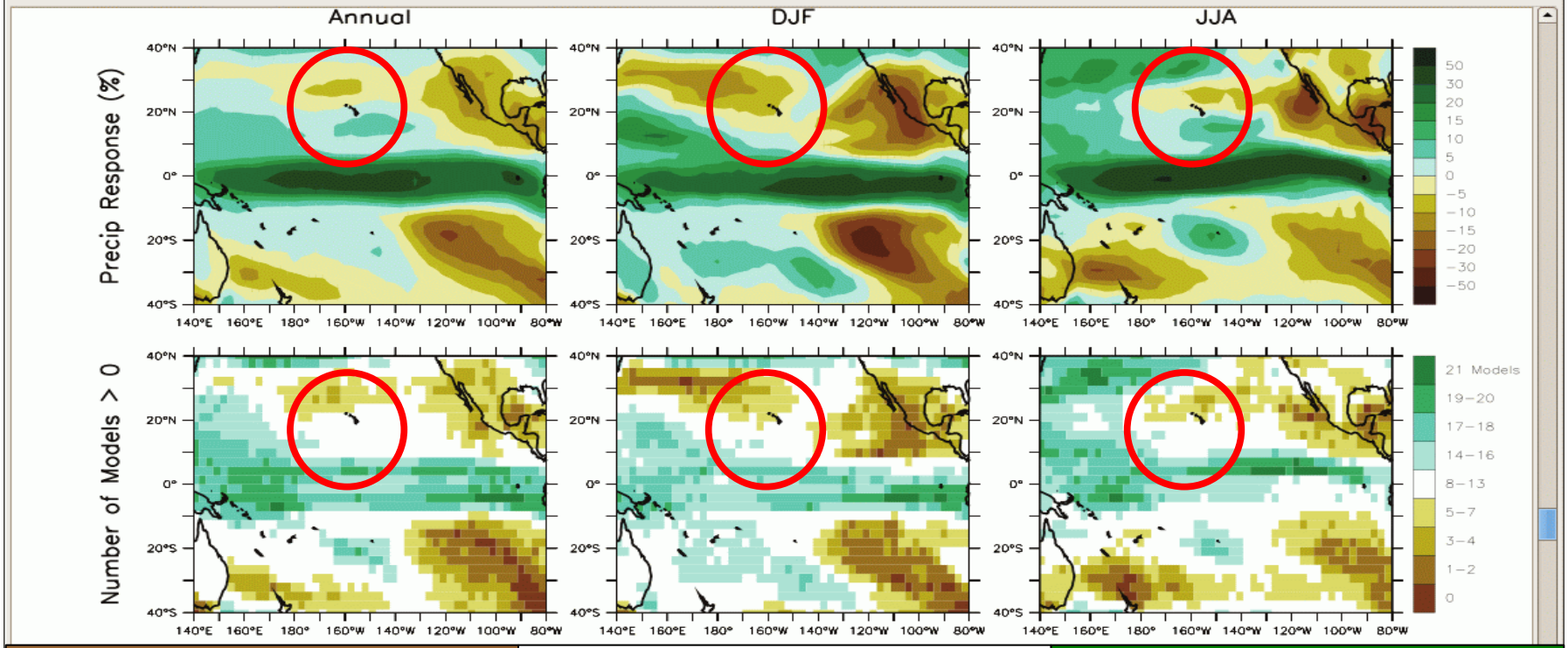
Linkage between large-scale and regional climate changes





- IPCC's Fourth Assessment Report, 2007: (more than 20 climate models took part)
- **precipitation change: likely to decrease**

Models show a drier climate	No significant change	Models show a wetter climate



Most models: drier climate	Models results inconsistent	Most models: wetter climate

Change detection – point of change

- When the time of change is specified, standard statistical problem
- unknown change- point in a sequence of random variables - Bayesian approach : stationary autoregressive model for a time series and the contemporary detection of a change in its mean
- Spatial change vs. tabular representation of change
- Non-detectable rate of change – hidden by increased variability or slow process

High dimensional data analysis

- Multi-dimensional observational data and difficult to visualize and analyze.
- Commonly-used principal components analysis (empirical orthogonal functions analysis).
- Can miss the nonlinear and non-Gaussian attributes associated
- Need improved analytic techniques for interpreting geophysical data. Dimension reduction and data presentation techniques are needed for comparing spatial maps, explaining what is being presented, and determining how to describe the confidence levels associated with projections obtained from noisy and spatially incomplete data.

Spatial Interpolation

1. Point Interpolation/Areal Interpolation
2. Global/Local Interpolators
3. Exact analysis/ (kriging, variograms, splines) Approximate Interpolators (Trend Surface Analysis, Fourier Series, Moving average/distance weighted average)
4. Stochastic/Deterministic Interpolators
5. Gradual/Abrupt Interpolators

Missing data estimation

- dummy variables to code for missing observations -*does not produce unbiased parameter estimates*
- Regression Models versus ANOVA models
- Maximum Likelihood (substitute a predicted value) and Multiple Imputation (substitute random data)

Time series expansion and forecasting

- Mostly through autoregressive moving averages (ARMA)autoregressive integrated moving averages (ARIMA)

i.) *Model identification*

ii.) *Parameter estimation*

iii.) *Diagnostic checking*

Trend analysis

- using simple linear regression

$$Y = B0 + B1(T)$$

where Y = a hydrologic variable
T = time, in years; and

B_0 and B_1 = least-squares estimates of the intercept and slope coefficients.

If the slope is significantly different from zero, the trend in the hydrologic variable is equal to the magnitude of the slope and the direction of the trend is defined by the sign of the slope

Only detects linear trends

Trend analysis

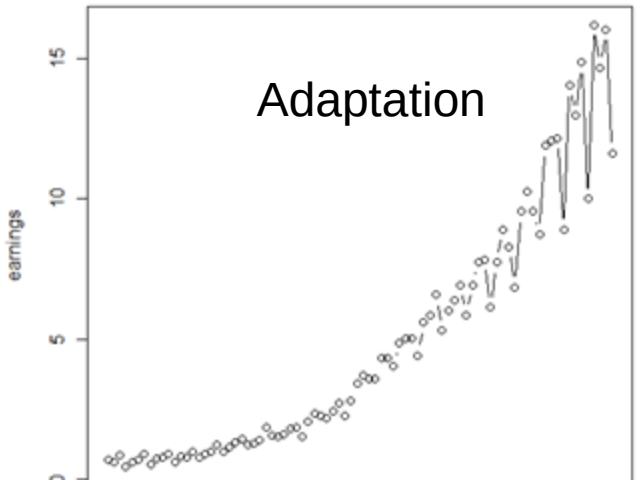
- linear trend assumption is not appropriate for temperature series and that a non-linear function may better characterize trends in temperature
- residuals from linear trend models tend to be serially correlated and that the standard t-statistic used to determine the significance of the trend parameter may thus be inflated
- higher-order trends and lag patterns

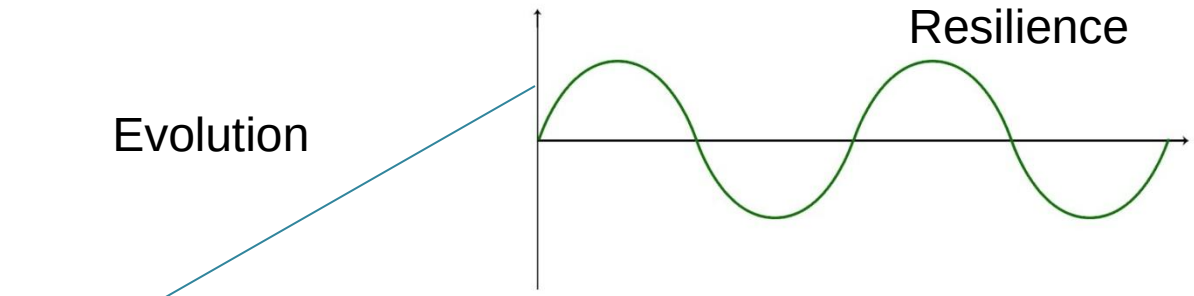
Climate change research in Sri Lanka

- Our issues…

Scale Issues…

- Climate change – temporal scale
- the bigger picture of weather: at least the average over 30 years
- Reasonably accurate predictions are a matter of choosing the right time scale: days in the case of weather, decades in the case of climate
- Change: a dynamic status vs. uni-directional adverse trends
- Change: Changes in the perspective of spatial scale - Cosmological, global, regional, national, local and community scale





Climate Change: A conflict in our understanding

- intrinsic or unforced change or variability - dynamic interactions between the oceans and atmosphere under the influence of gravity
- result of "forcings" such as changes in solar irradiance or greenhouse gases
- unforced variability occurs within a relatively narrow range – setting thresholds

  rains in a 2-3 consecutive dry seasons

  more rains in dry season than rainy season

Focus of our climate change research

- Application of GCMs : usually downscaling using various mathematical and statistical approaches eg. Neural networks

  Precipitation is highly variable in time and geographic location, the prediction of this critical variable by global models tends to be inadequate for use in evaluating the national consequences of precipitation changes for agriculture and/or water resources.

- Analysis of climatological time series and forecasting through extension of records
- Nano-scale field plot experiments – empirical ?

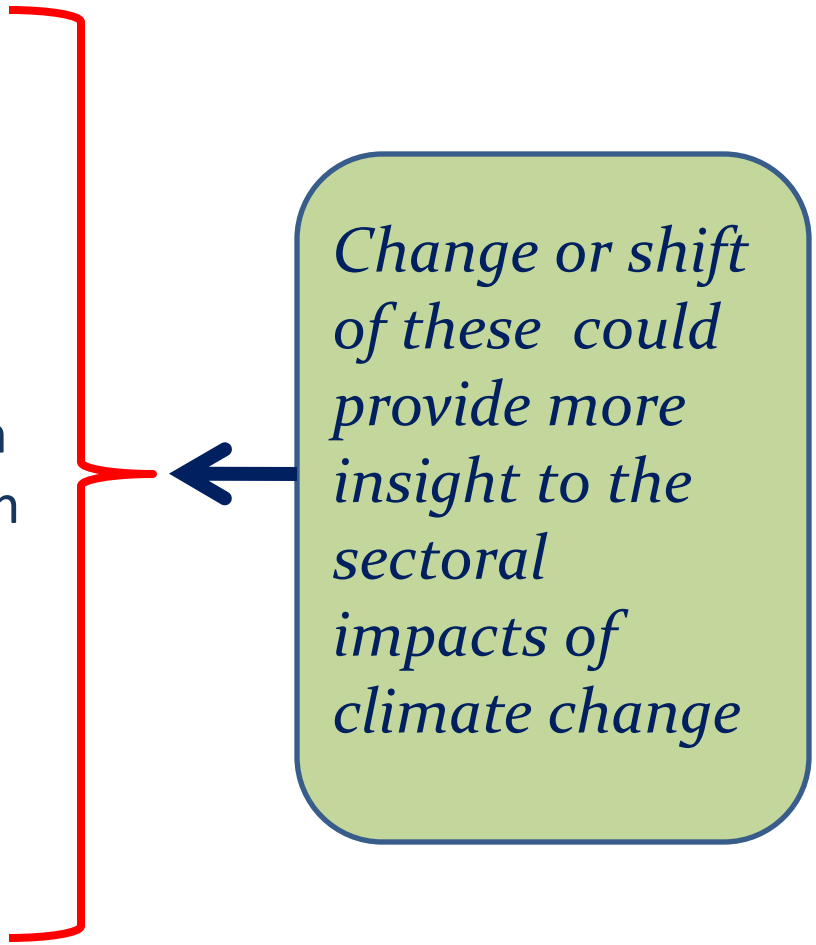
Primary research focus is to verify global thematic hypothesis….

let us see some examples…

Impact based assessments of vulnerability and adaptation are rare.

Climate Change and Rainfall: what to look for ?

- Shift of onset of monsoons
- Shift of withdrawal of monsoons
- Duration of monsoons
- No of storms per season
- Average duration of storms
- Inter-arrival time of storm events
- No of consecutive dry days in a season
- No of consecutive wet days in a season
- No of total dry days in a season
- No of total wet days in a season
- Distribution of rainfall lag time
- Average intensity of rain storms
- Maximum intensity of rainstorms
- Maximum 24 hour rainfall



Our focus on climate change is sufficiently comprehensive ????

Climate Change and temperature: what to look for ?

- Difference in day and night T
- Highest temperature
- Lowest temperature
- Spatial distribution of T
- Length of high temperature period
- Intensity of change of T
- No of consecutive low temperature days below average in a month
- No of consecutive high temperature days above average in a month

Change or shift of these could provide more insight to the sectoral impacts of climate change

Our focus on climate change is sufficiently comprehensive ????

Thank you !!!