Climate Change and Its Impact on Glaciers: A Case Study from the Indian Himalaya

Category-I University

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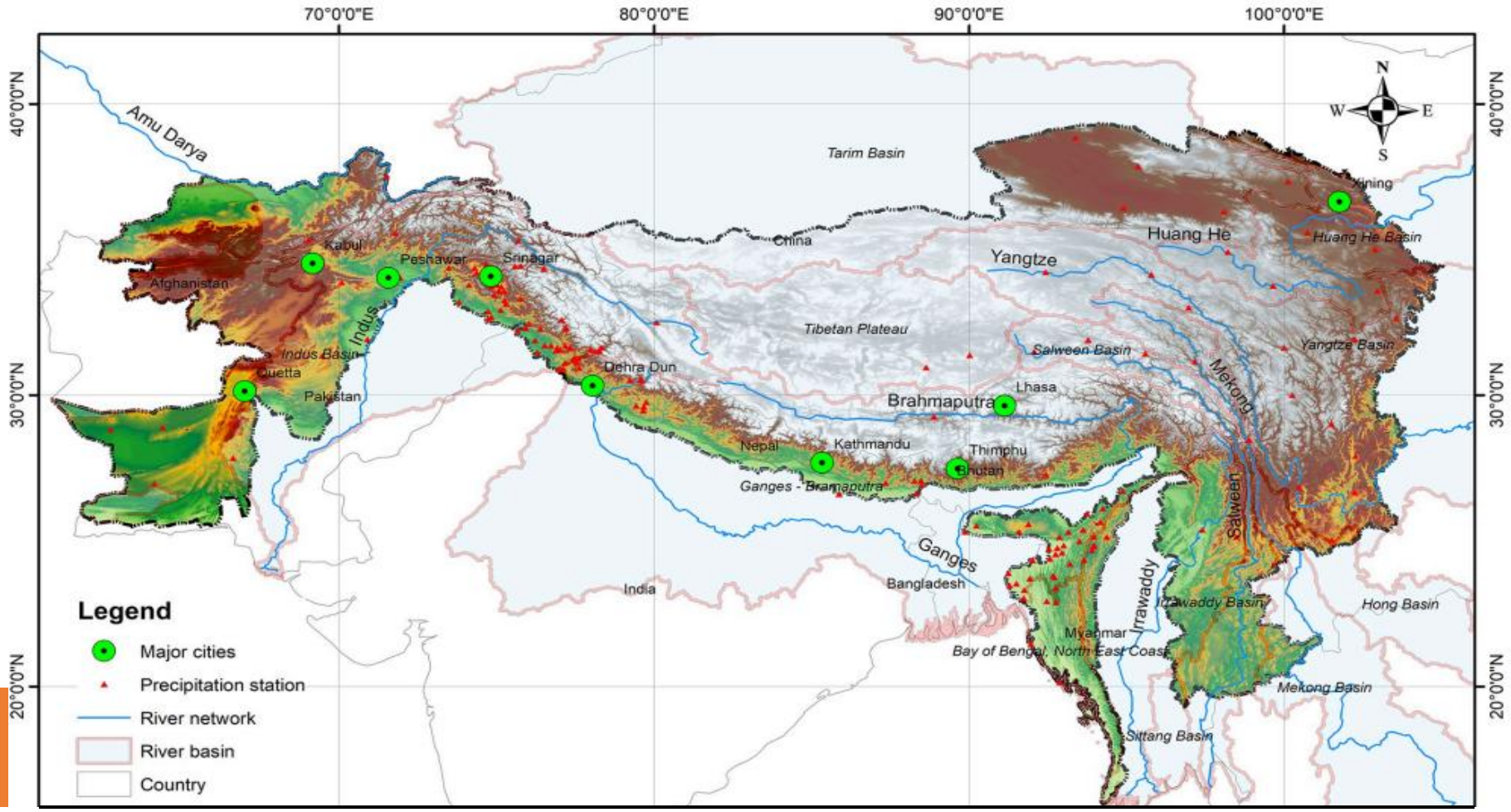
Third Pole Climate Forum (TPCF-3) 3-5 June 2025, Samrat Hotel, New Delhi

- Introduction
- Temperature Trend Globally
- Temperature trend analysis in two basins of the Himalaya
- Glacier mass balance study on Naradu glacier, Baspa basin, H.P.

Himalayas- The third pole



- Melting Glaciers
- Extreme Events and Disaster Risk
- Food and Water Security

– source of the 10 major river systems that form the lifeline of over 1.9 billion people in Asia, nearly 20% of the world's population.

Mishra et al., 2023

Global warming impacts by 2070

For over 6,000 years, humans restricted their settlements to a climate niche *(suitable* temperature and precipitation for the survival of the species*)*. But global warming could trigger the next wave of migration, and at least **3 billion people would be affected by 2070.**

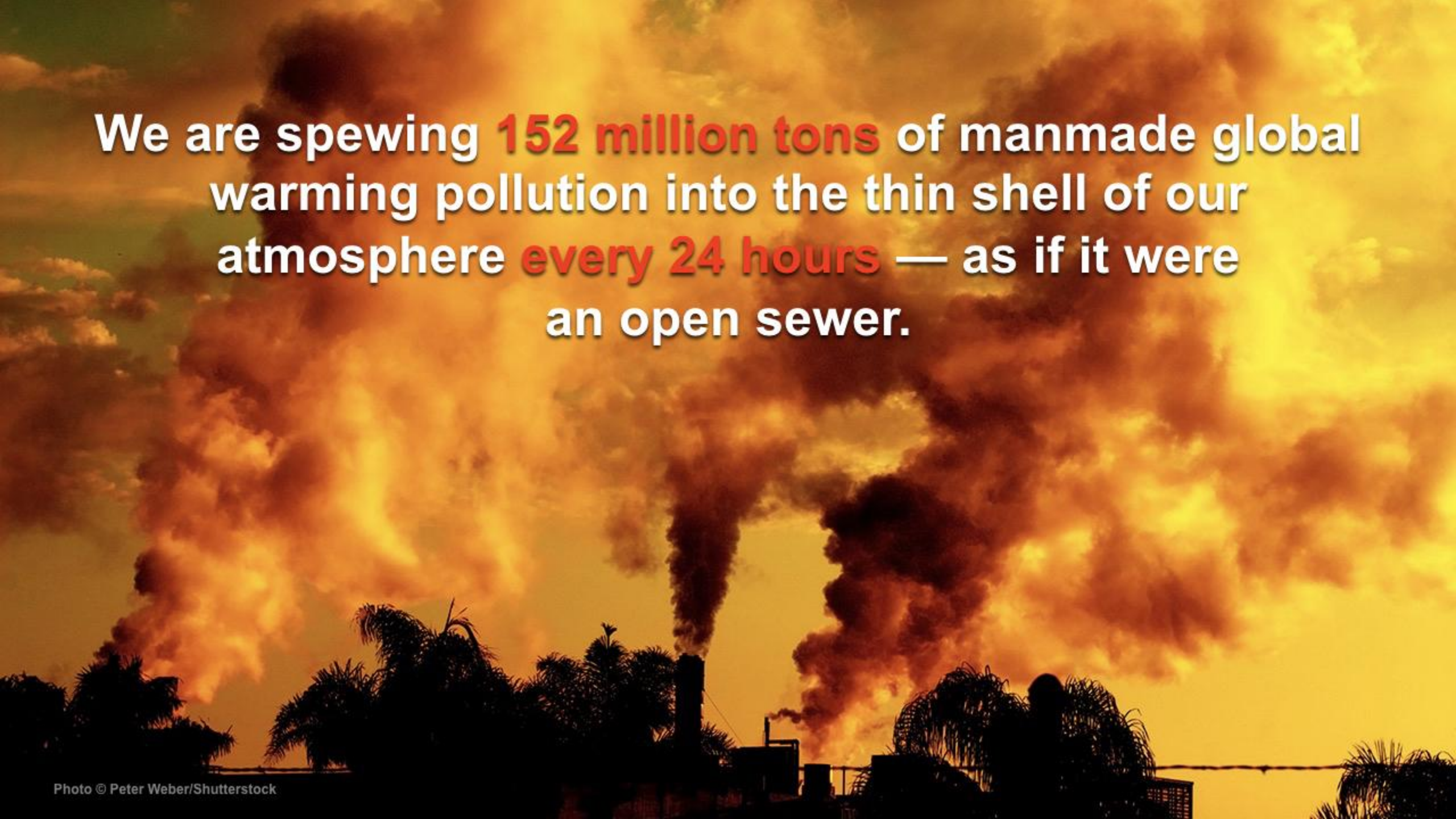
Future of the Human Climate Niche — It is projected that over 3 billion people currently living on 0.8 per cent of the Earth's surface that experience the average annual temperature of more than 29°C, would have to migrate to other places with suitable conditions.

The study was published in the *Proceedings of the National Academy of Sciences of the United States of America* in 2020.

https://www.downtoearth.org.in/news/climate-change/global-warming-to-hit-india-the-worst-in-asia-by-2070-80325?utm_source=Mailer&utm_medium=Email&utm_campaign=Climate%20Change%20Weekly-4674

DSCOVR Imagery via Blueturn.earth

Source: NASA




AIR TRANSPORT
THAWING PERMAFROST
COAL MINING
COAL PLANTS
OIL PRODUCTION
FERTILIZATION
INDUSTRIAL PROCESSES
LAND TRANSPORT
LANDFILLS
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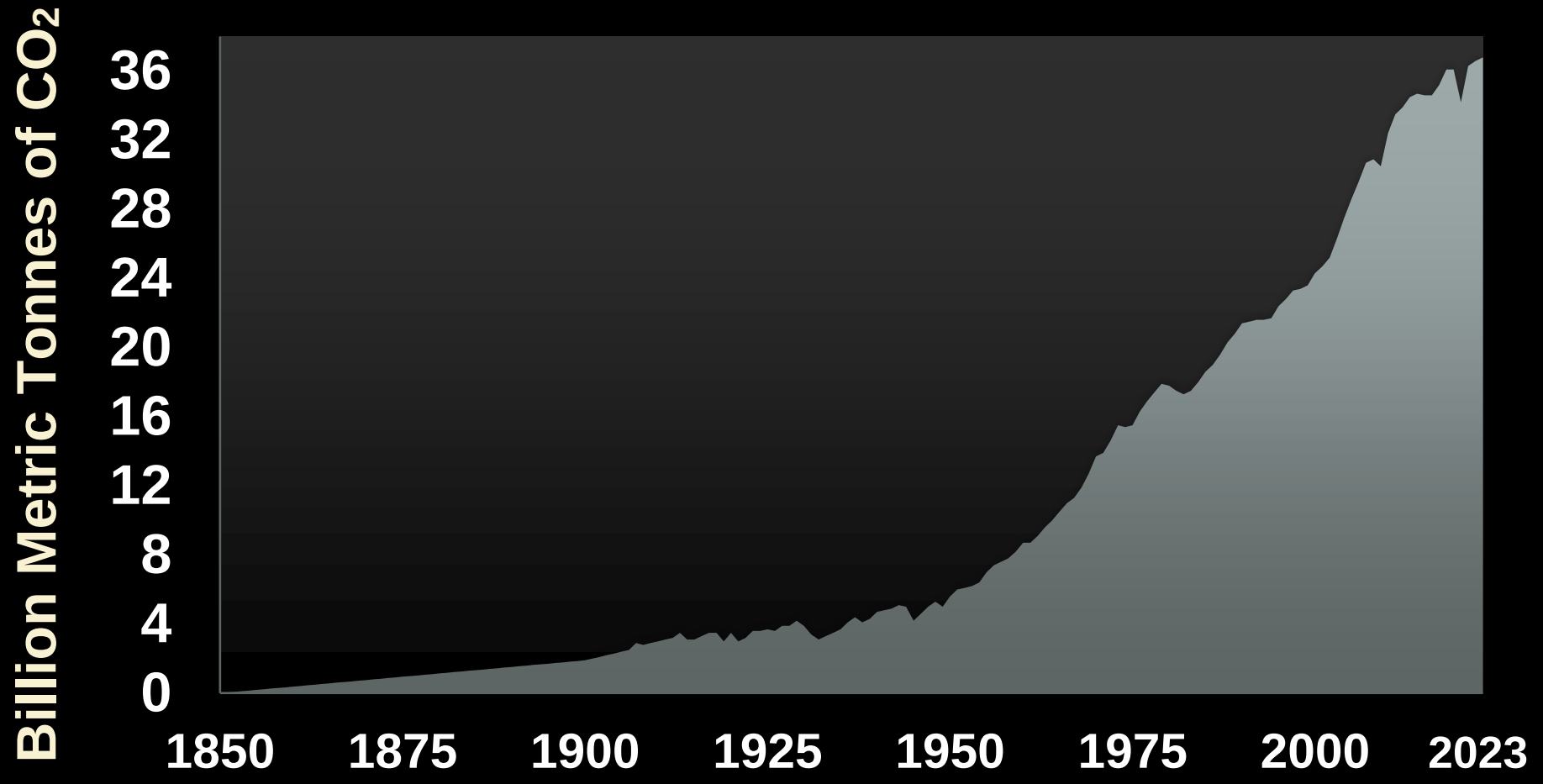
The Largest Source of Global Warming Pollution Is the Burning of Fossil Fuels



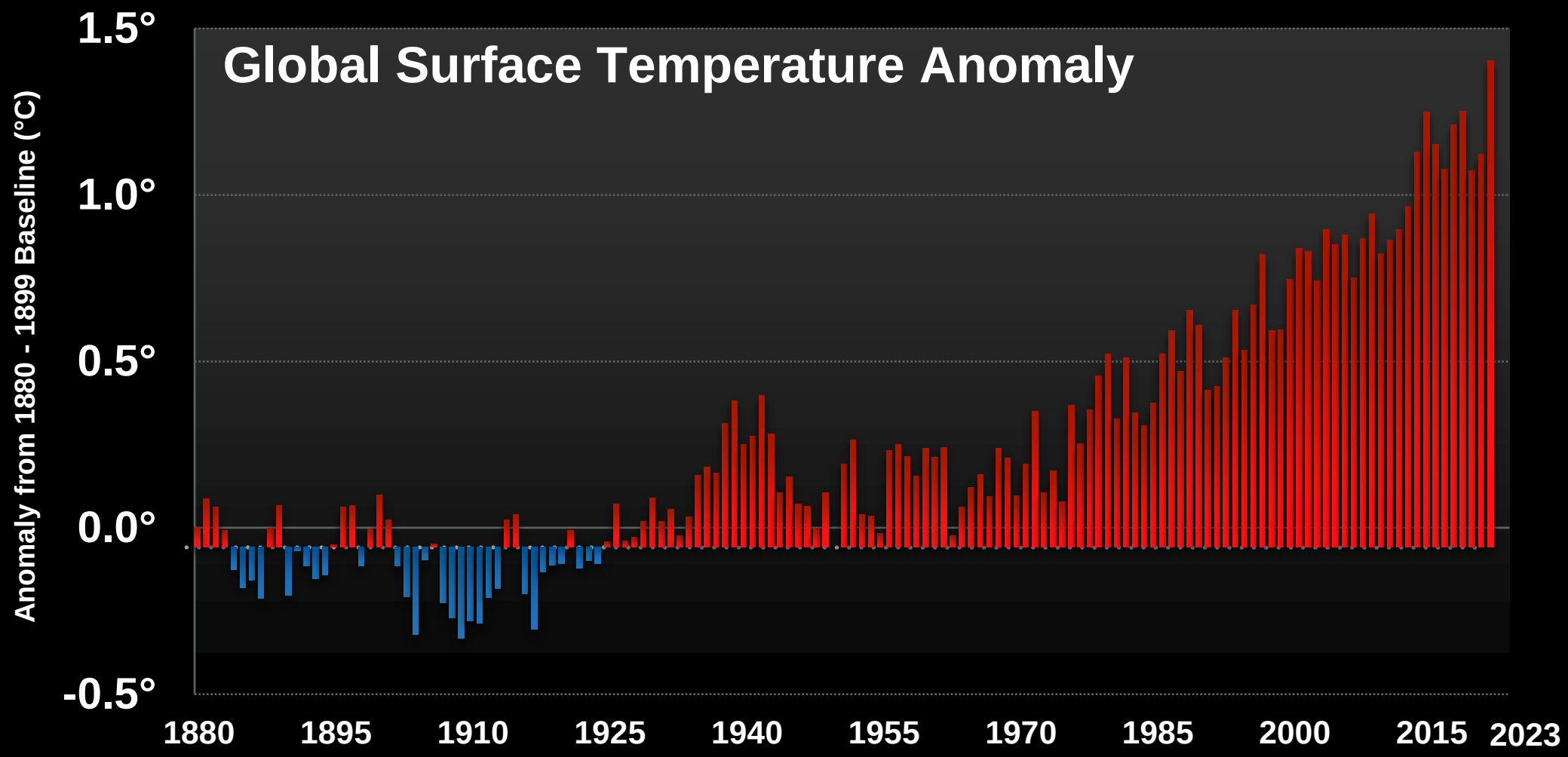
Data: International Energy Agency

The energy trapped by man-made global warming pollution is now "…equivalent to exploding

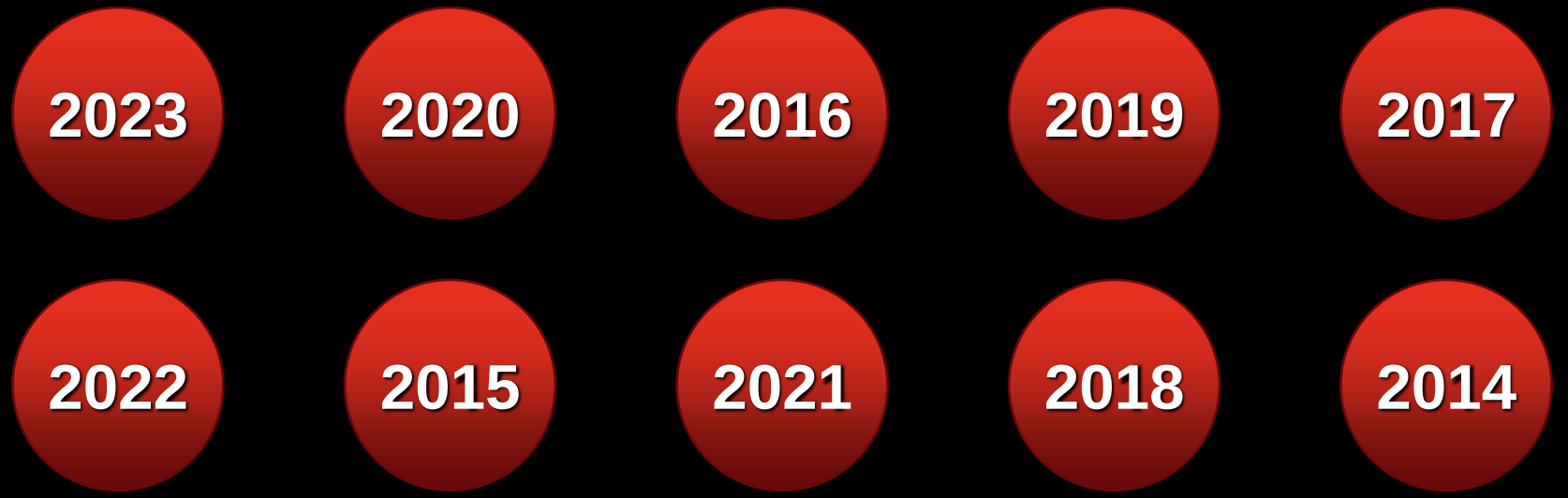
750,000

First-generation atomic bombs per day - 365 days per year."

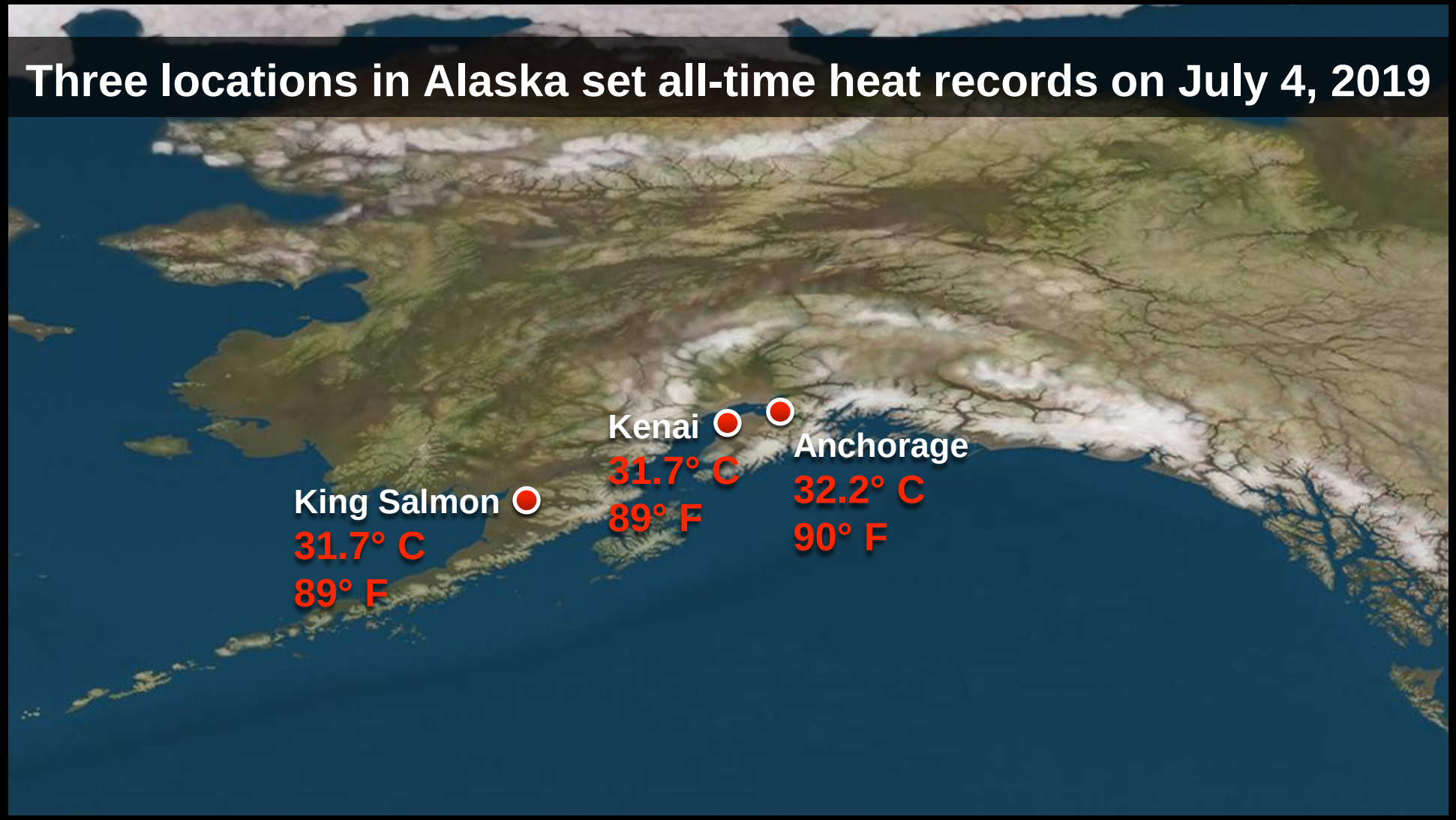
James Hansen
Former Director, NASA Goddard Institute for Space Studies


Global Surface Temperature Anomaly
Anomaly from 1880 - 1899 Baseline (°C)
1.5°
1.0°
0.5°
0.0°
-0.5°
1880
1895
1910
1925
1940
1955
1970
1985
2000
2015
2023
Data: NASA

The Ten Hottest Years on Record Have Been the Last Ten Years



Data: NASA/GISS



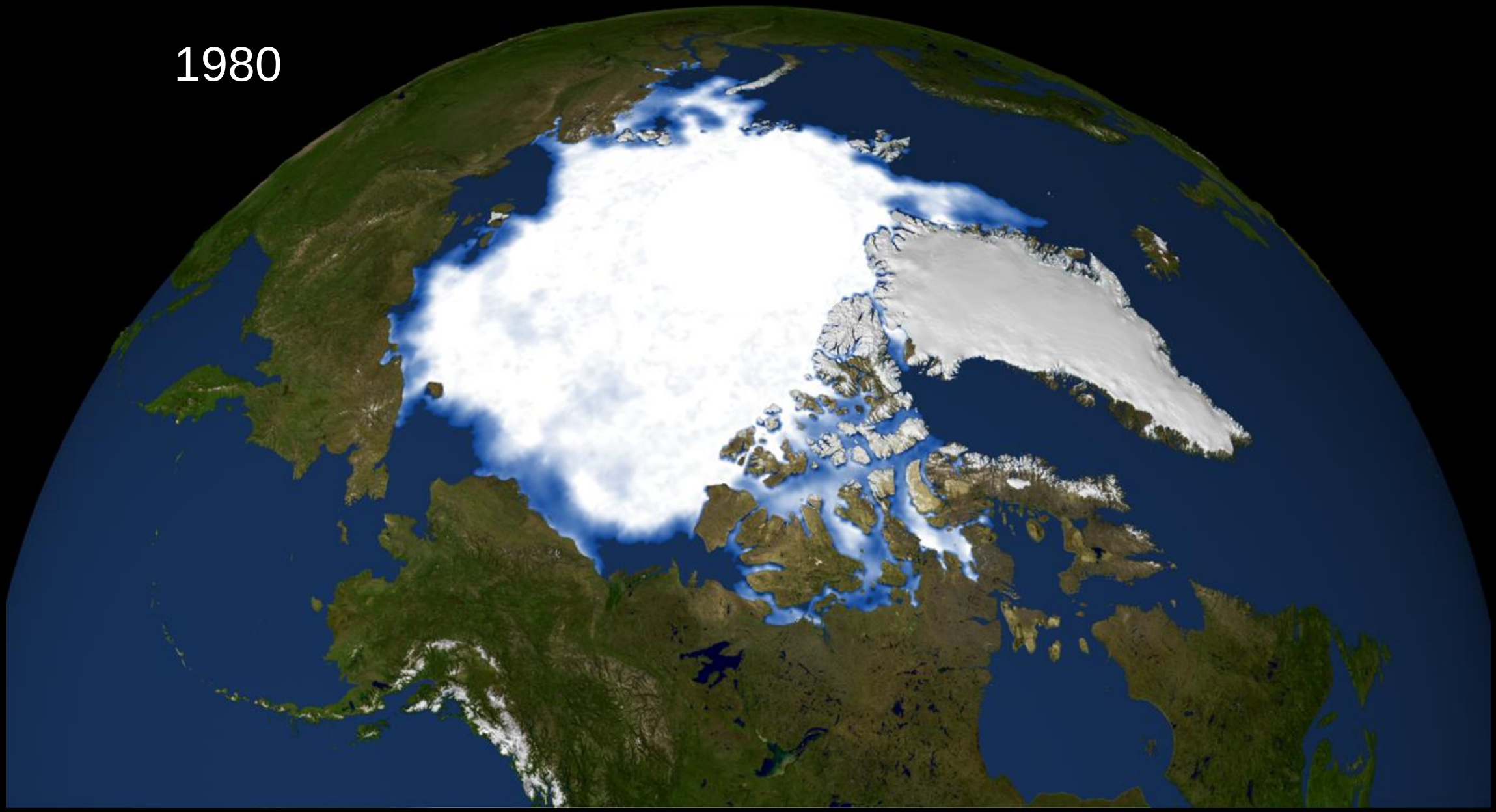
Data: National Weather Service

The North Pole has now experienced mid-winter heatwaves three years in a row:

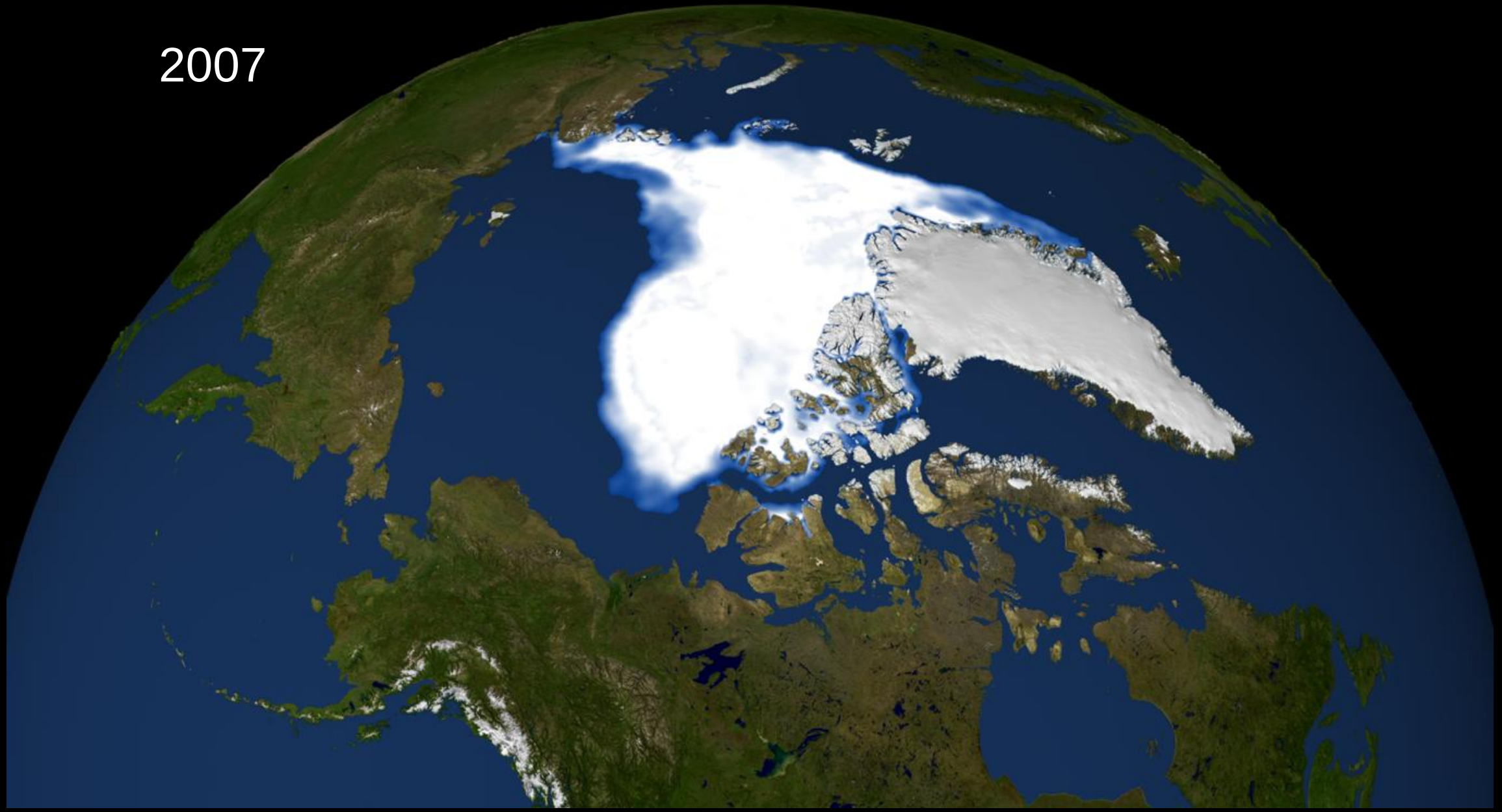
2016

2017

2018

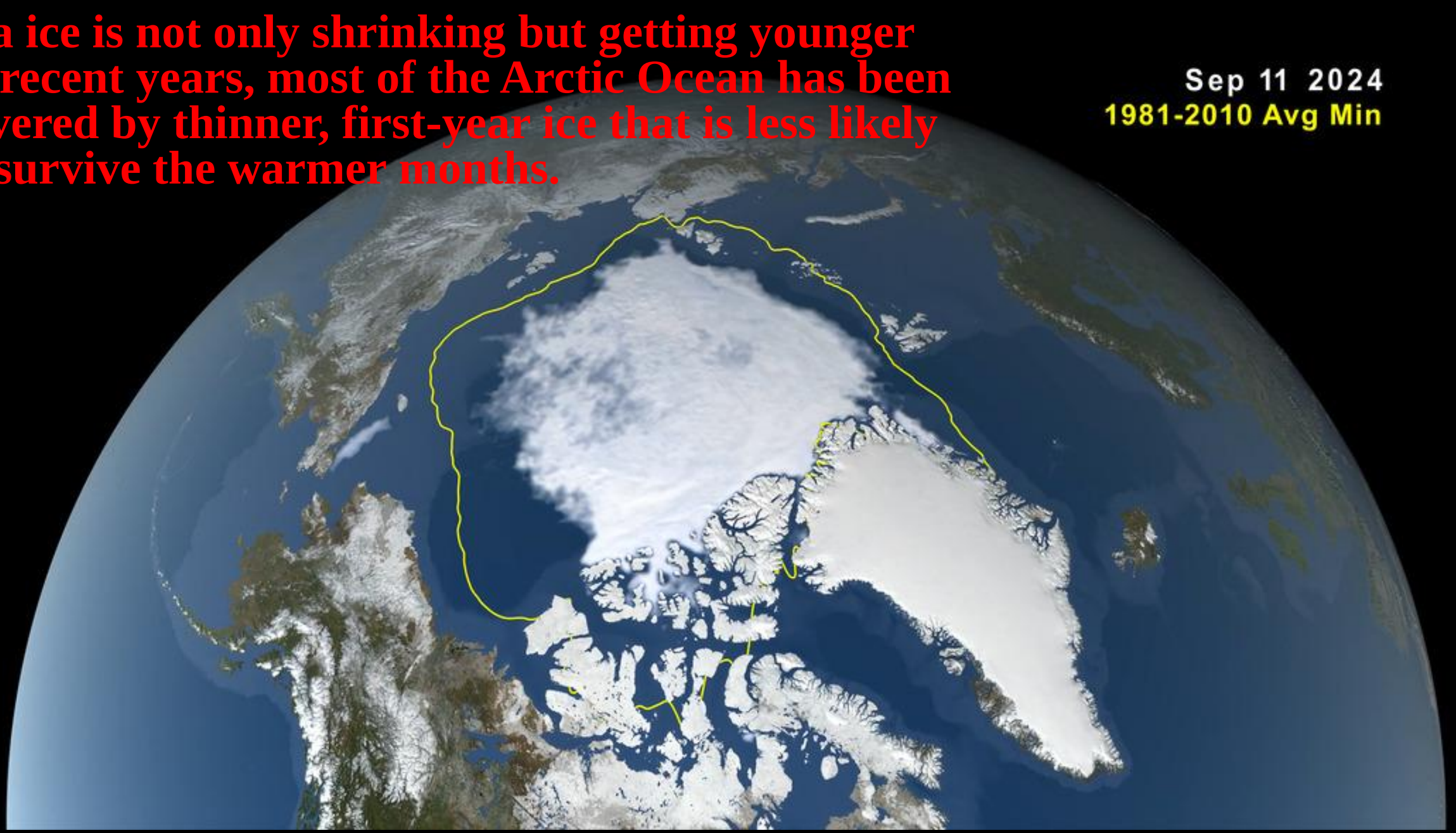


Arctic sea ice extent from September 1980



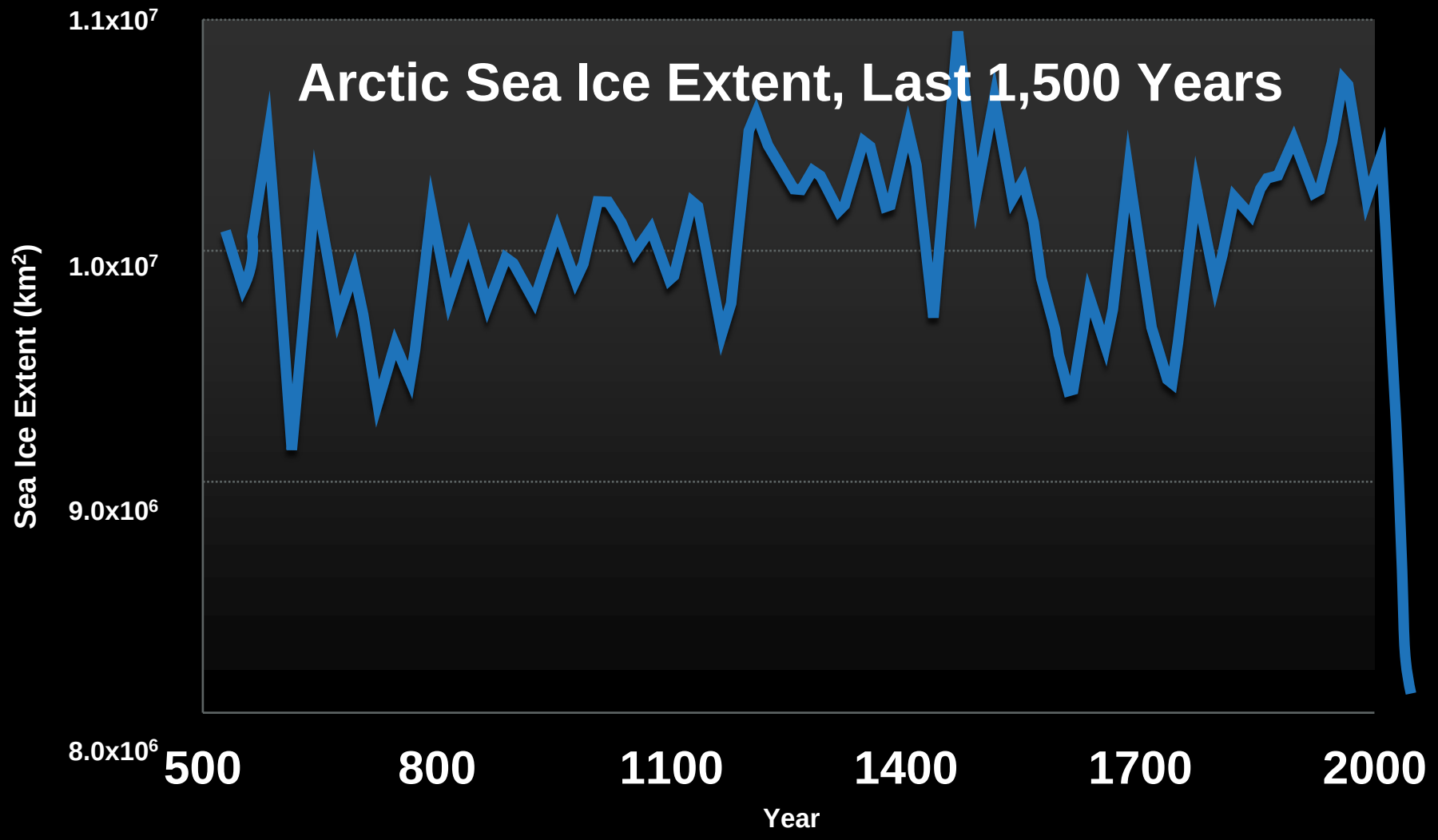
Arctic sea ice extent from September 2007

Sea ice is not only shrinking but getting younger
In recent years, most of the Arctic Ocean has been covered by thinner, first-year ice that is less likely to survive the warmer months.



Arctic sea ice extent from September 2024- Near Historic Low

Source - NASA's Scientific Visualization Studio: svs.gsfc.nasa.gov/5382

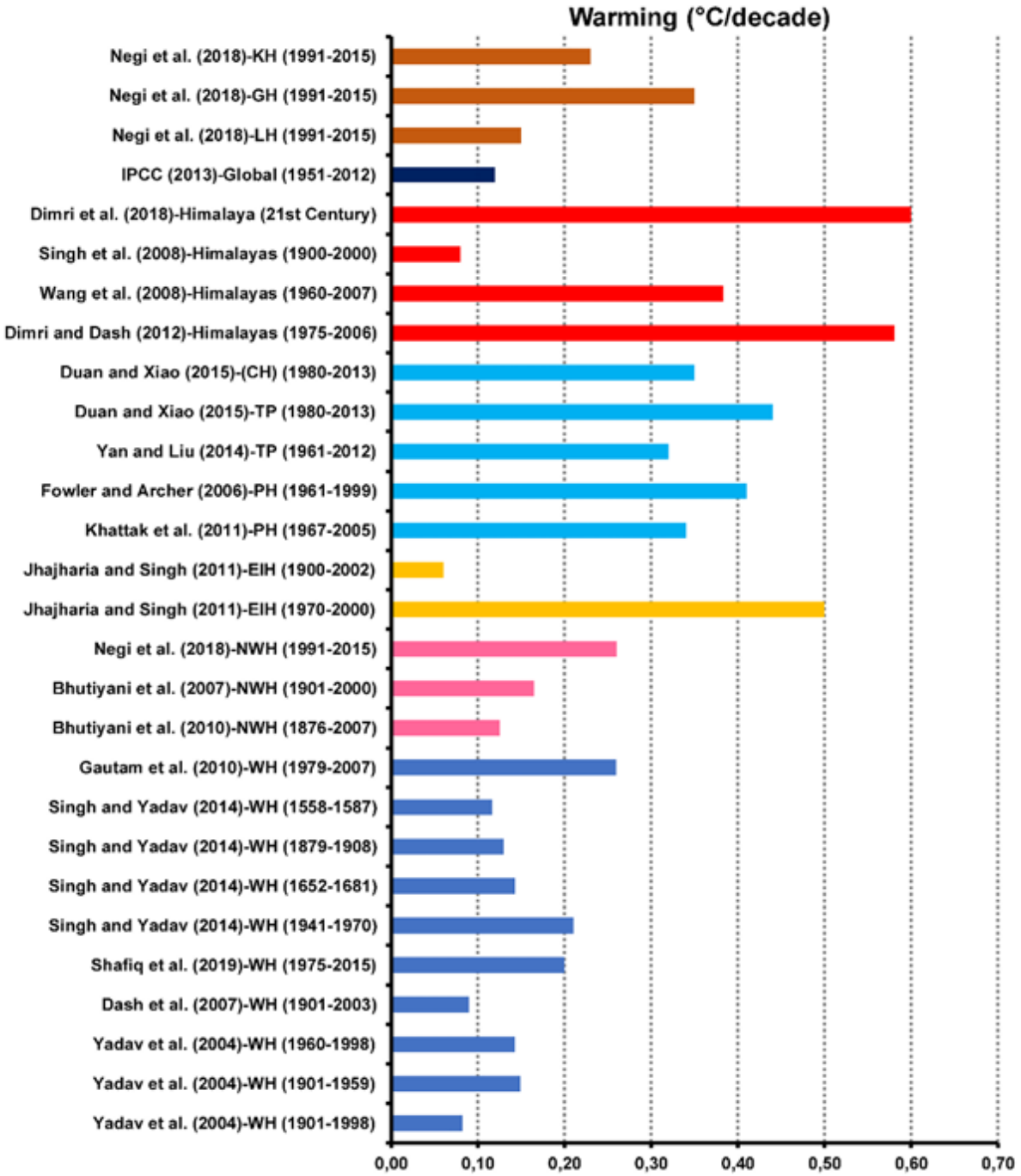


Data: Kinnard, C., C.M. Zdanowicz, D.A. Fisher, E. Isaksson, A. de Vernal and L.G. Thompson. (2011). Reconstructed change in Arctic sea ice over the last 1,450 years. Nature letter, DOI:10.1038/nature10581, Fig. 3


Unnamed Glacier, Southwest Greenland
Summer 1935
Images courtesy Anders Bjørk, © Natural History Museum of Denmark/Tholstrup (2013) and Danish Geodata Agency (1935).

The rate of ice melt in the Himalayas has doubled since the year 2000.

Data: Columbia University's Lamont-Doherty Earth Observatory



Temperature Trend observed by numerous studies in different parts of the Indian Himalayan Region.

- The warming trend is compared with global **(dark blue colour)** and important studies from the Himalayas.

WH -Western Himalaya,
NWH -Northwestern Himalaya,
EIH - Eastern Indian Himalaya,
PH -Pakistan Himalaya,
TP- Tibetan Plateau,
CH- China Himalaya,
LH- Lower Himalaya,
GH- Greater Himalaya,
KH- Karakoram Himalaya

Yadav et. al., 2021

Study from Ravi Basin, Northwest Himalaya

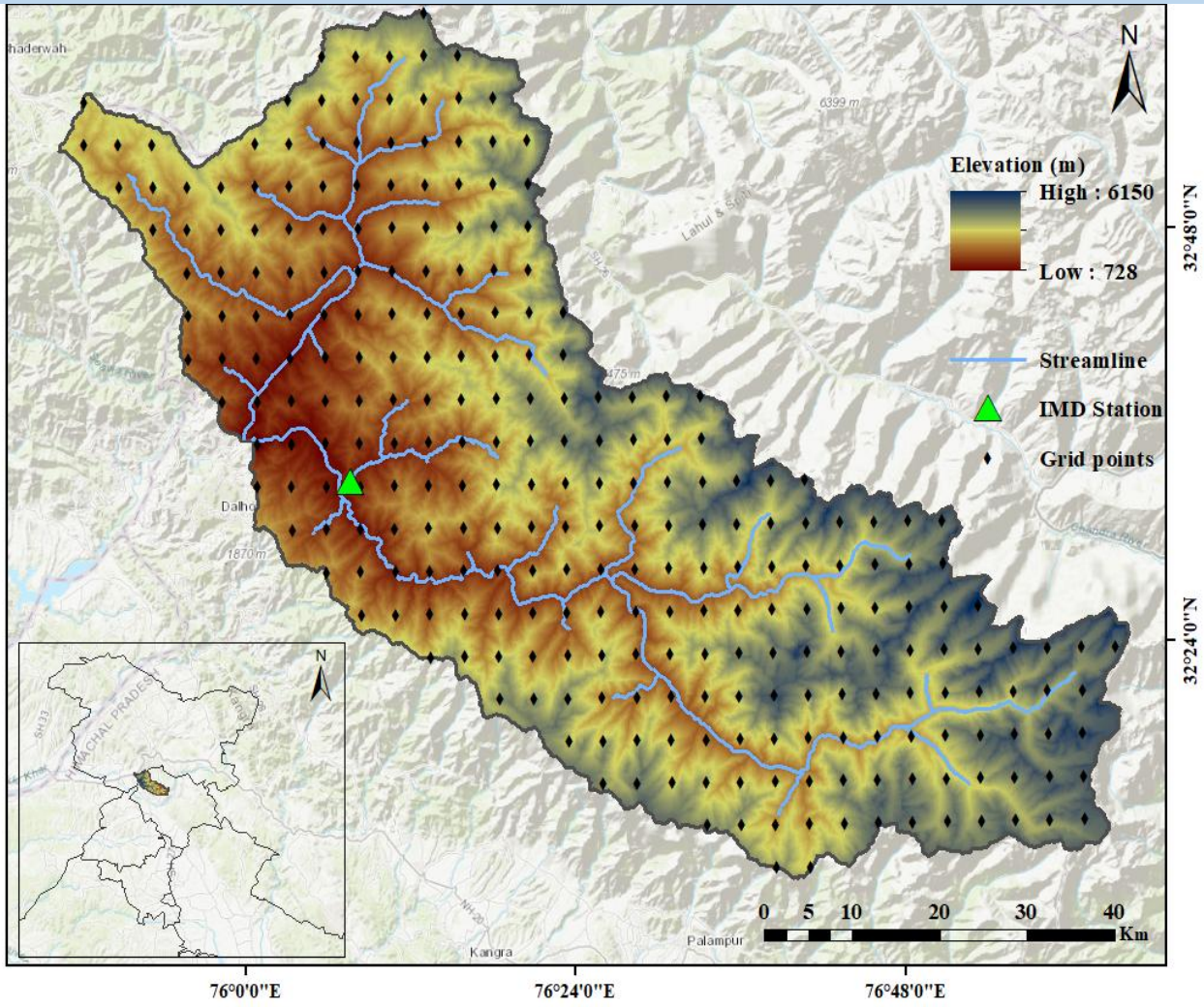


Figure 1: Location of the Ravi River Basin falling in Himachal Pradesh, India. The map shows the basin's extent within the state and variation in elevation across the basin.

The Ravi basin lies between the south-eastern part of Chamba district and the north-eastern part of Kangra district in Himachal Pradesh.

- Covers the transition zone of the maximum (Dharamshala) and minimum (Lahaul) precipitation areas of Himachal Pradesh.
- The total area is **~4900 km^2,** with altitude varying from **728 to 6150 m**

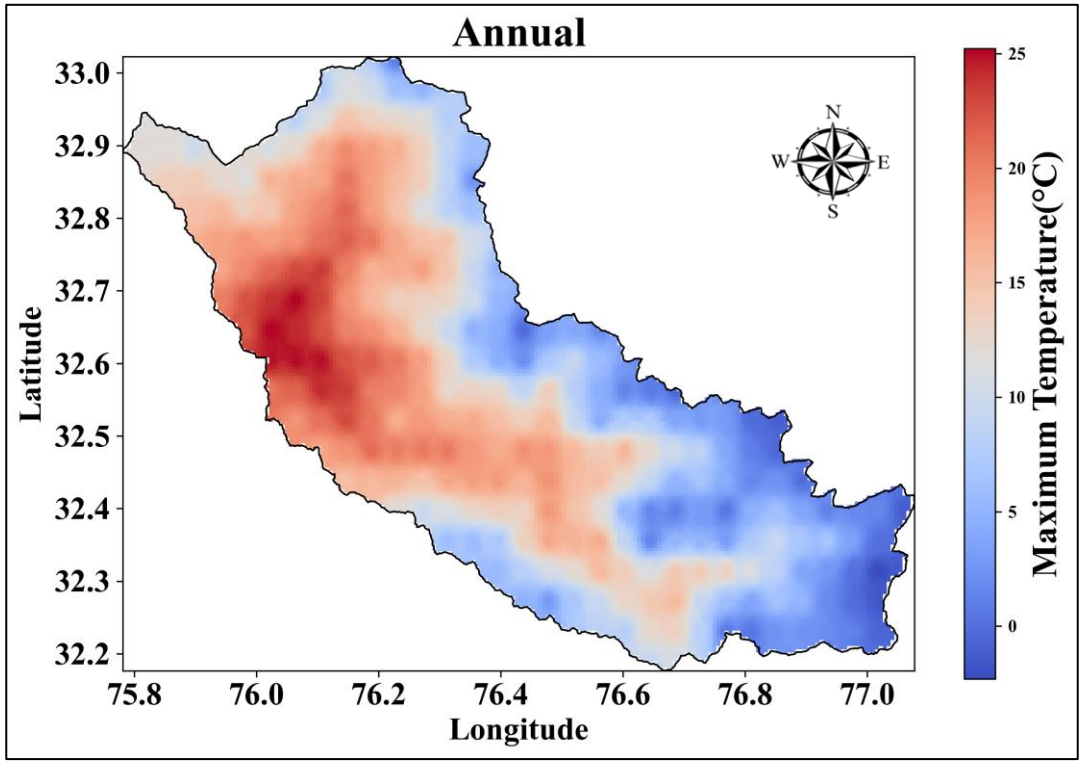
The Ravi Basin is characterised by steep topography, glaciated zones, and forested valleys, contributing to its complex hydrological and climatic regime.

Dataset used for the assessment in the Ravi Basin

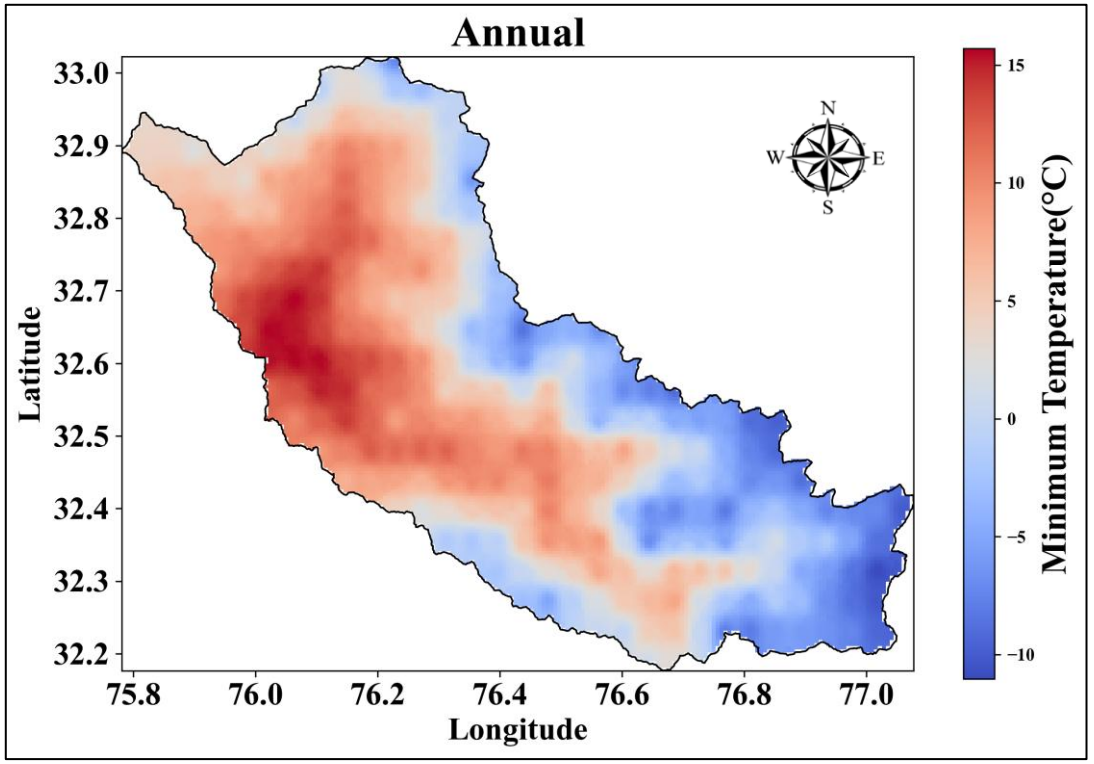
Dataset Used	Datatype	Spatial Resolution	Source
Terra-climate	Reanalysis	4 km	https://www.climatologylab.org/TerraClimate.html
Landsat series	Satellite Data	60, 30m	https://earthexplorer.usgs.gov/
ASTER DEM	Geomorphic	30 m	https://www.earthdata.nasa.gov/news/new-aster-gdem

- The Terra-Climate dataset is formed by merging high-resolution climatological normals from WorldClim with time-varying data from CRU Ts4.0 and JRA55.
- This dataset offers a monthly temporal resolution and is available at a spatial resolution of 4 km.

Average Annual Temperature conditions in the Ravi Basin



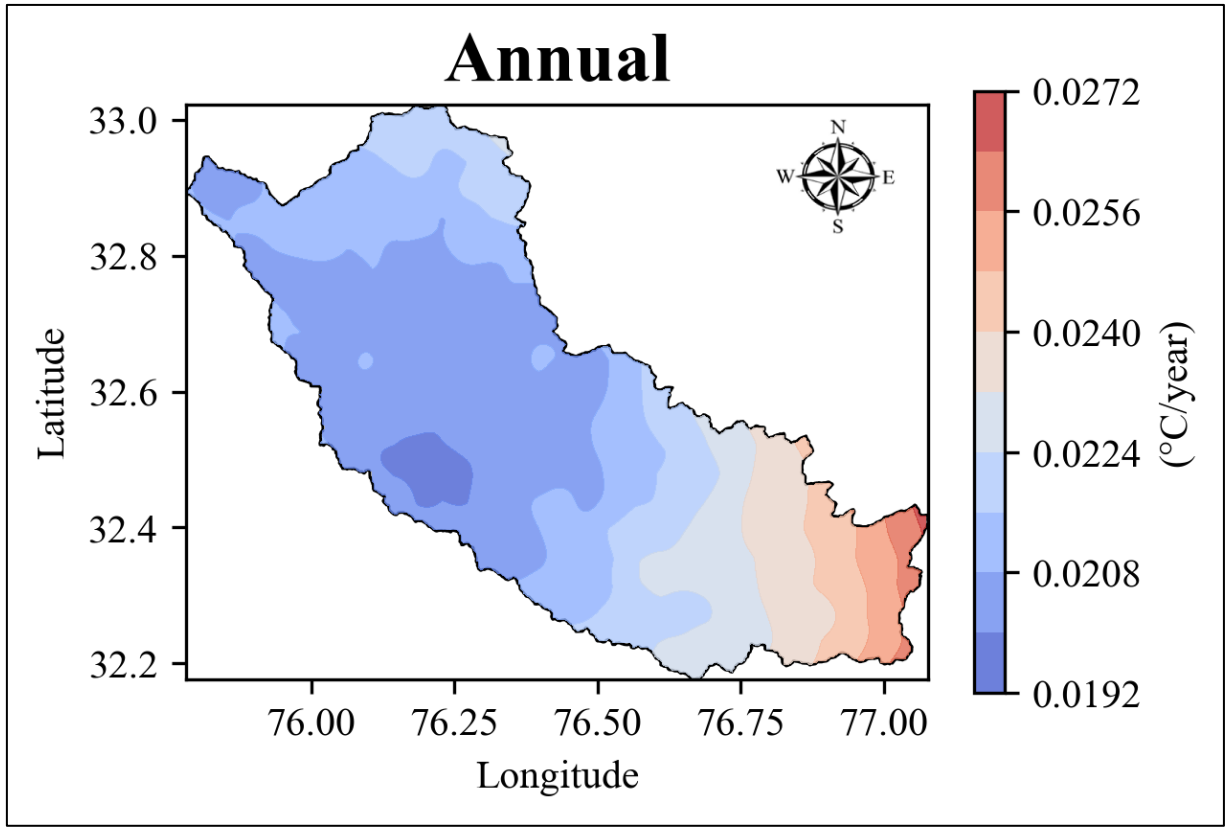
(a) Annual Maximum Temperature (Tmax)



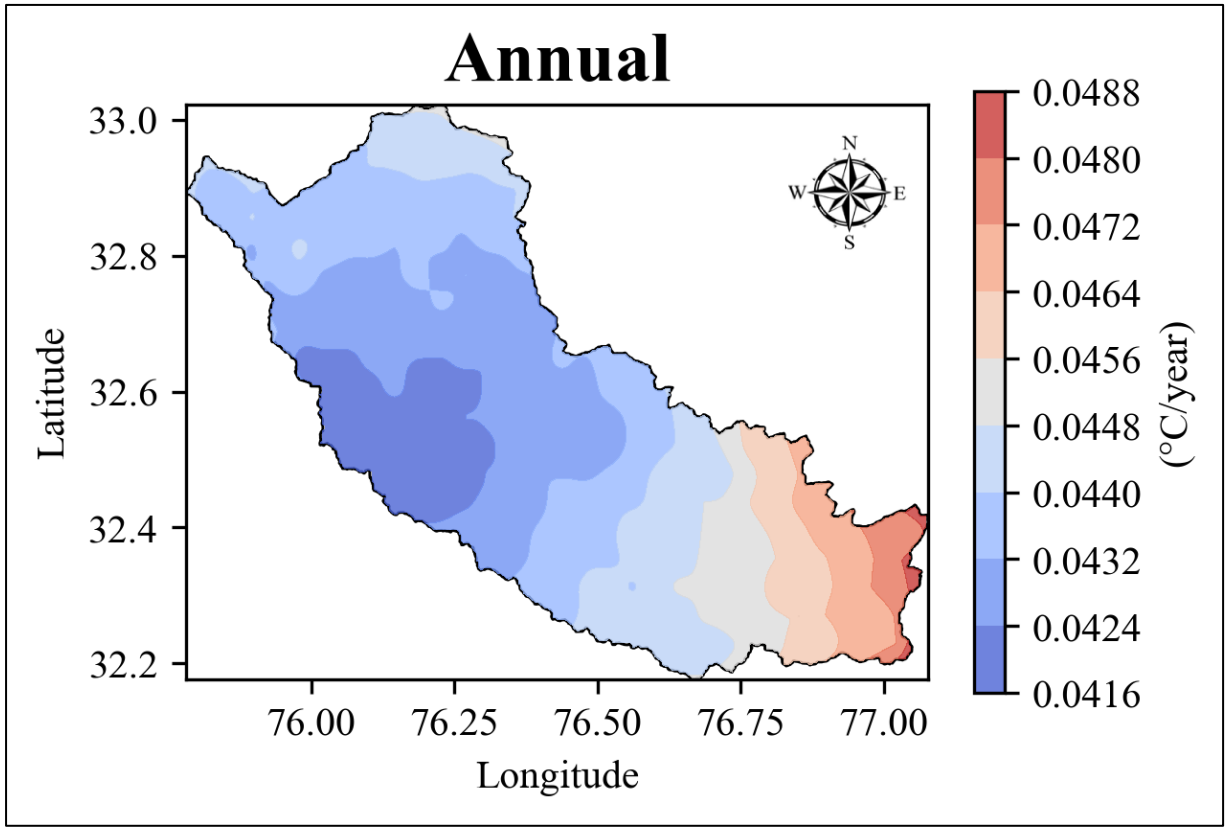
(b) Annual Minimum Temperature (Tmin)

Spatial variation in average (a) Maximum Temperature (Tmax) and (b) Minimum Temperature (Tmin) during the period 1980–2024 over the Ravi Basin using TerraClimate reanalysis datasets (4 km)

Trends in Maximum and Minimum Temperature over the past 45 Years



(a)

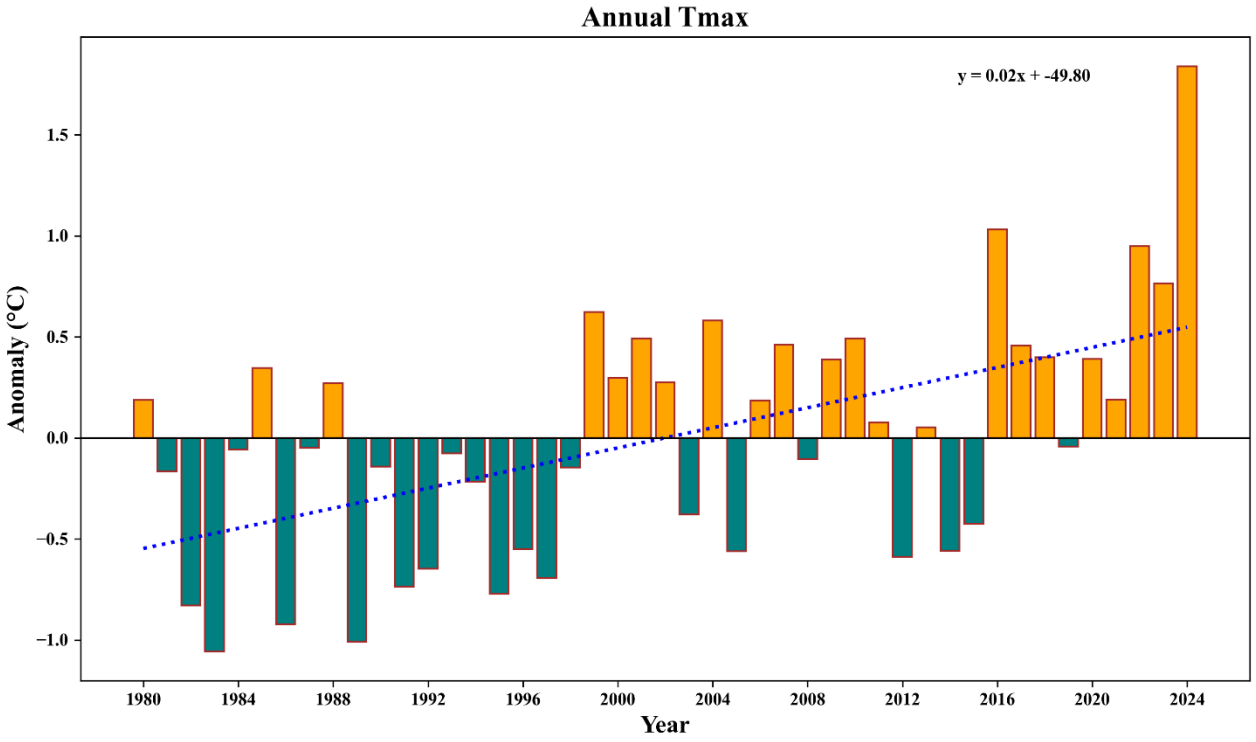


(b)

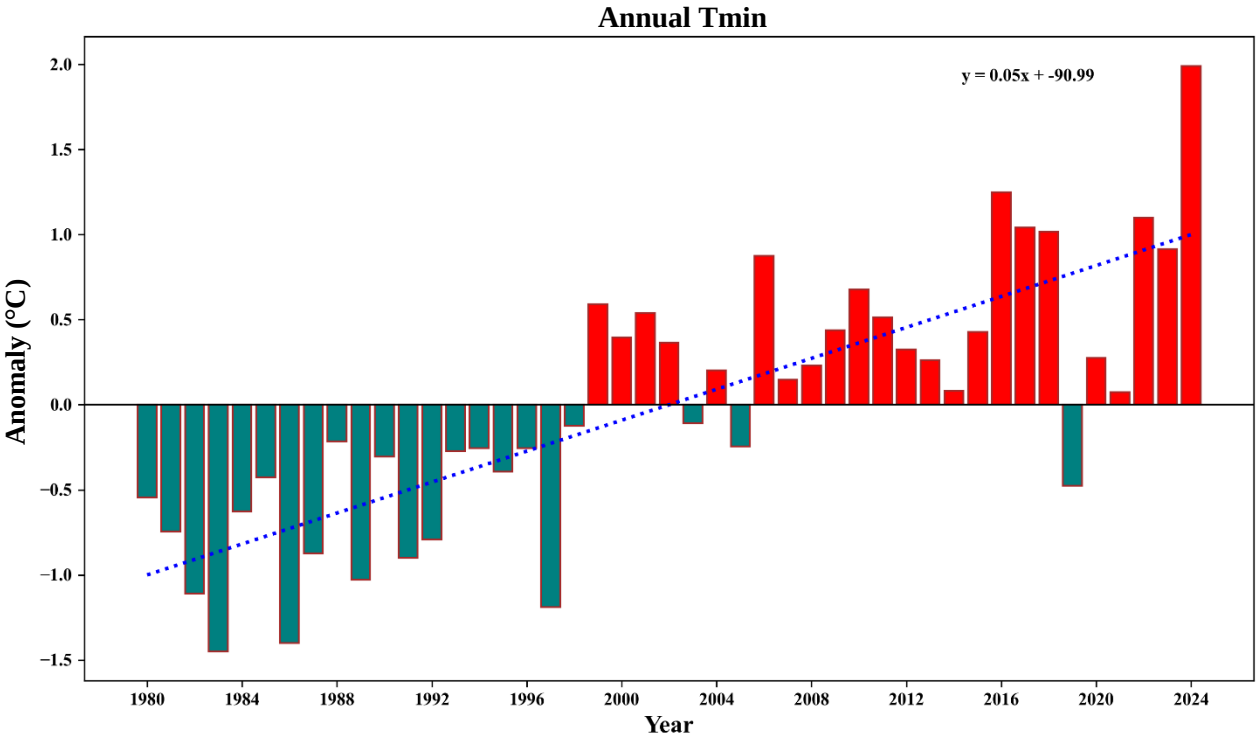
Sen's slope estimation of Annual trends using (a) Tmax and (b) Tmin across the Ravi Basin using TerraClimate datasets for the period 1980-2024

- Both maps highlight a distinct eastward intensification of warming, indicating greater thermal sensitivity in these glaciated regions.

Annual Anomalies in Maximum (Tmax) and Minimum Temperature (Tmin) in Ravi basin



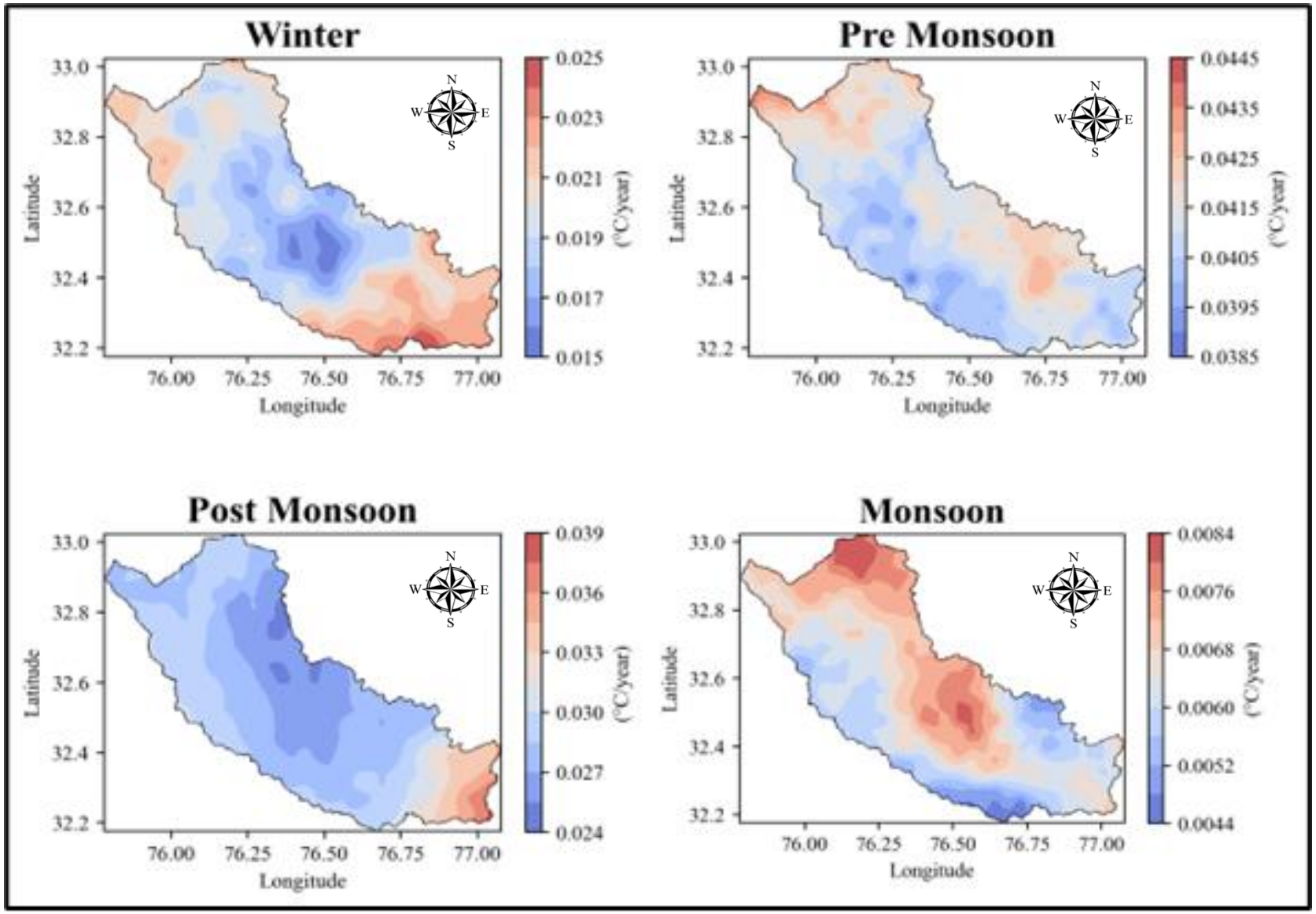
(a)



(b)

Graph shows anomalies in in average annual (a) Tmax and (b) Tmin during the period 1980–2024 over the Ravi Basin using TerraClimate reanalysis datasets (4 km)

Seasonal Trends in Maximum Temperature

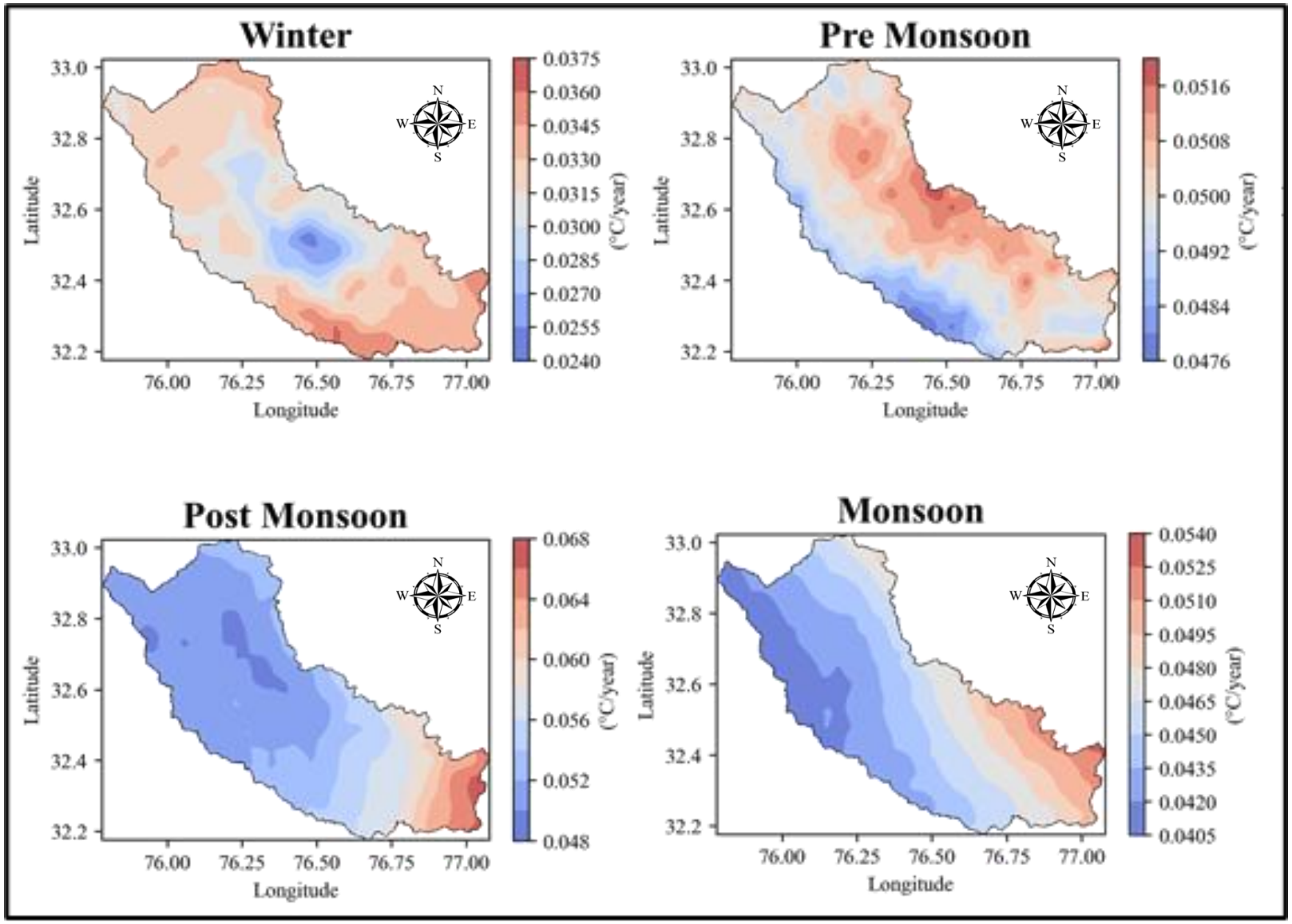


(a) Seasonal Trend in Tmax

Magnitude of season-wise trends using Sen's Slope estimation in **Tmax** across the Ravi Basin using TerraClimate datasets (4 km) for the period 1980–2024

- The spatial patterns exhibit distinct seasonal and geographic variability.
- The most pronounced increase in Tmax is during the pre-monsoon and winter periods.
- Higher rates of warming are prominently limited to the easternmost in winter, highlighting their potential susceptibility to climate-driven thermal stresses
- While the central region shows a slower warming rate

Seasonal Trends in Minimum Temperature

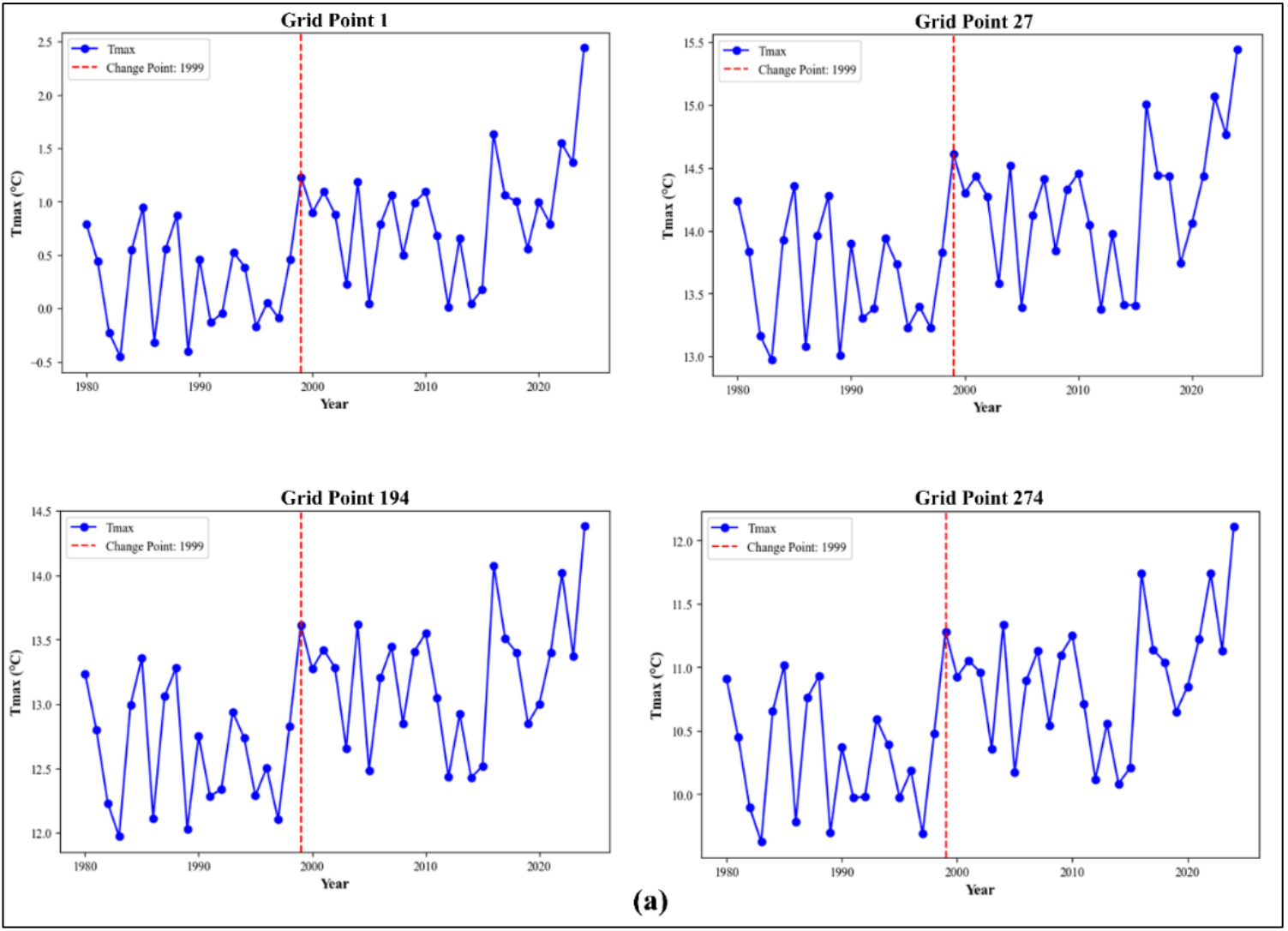


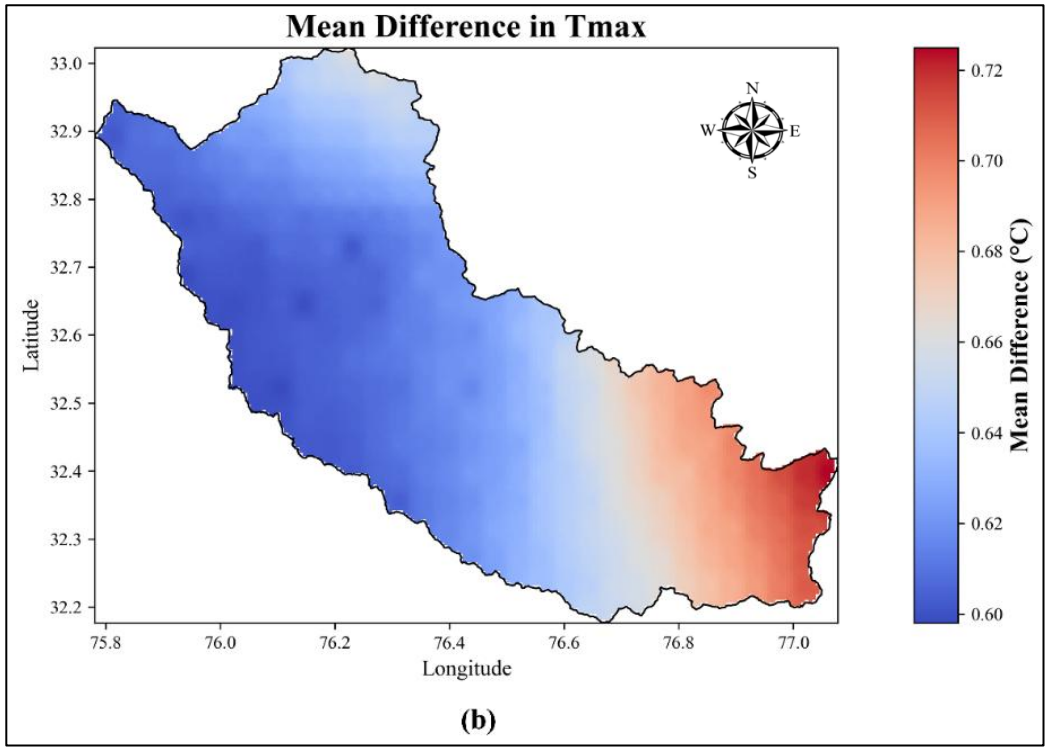
(b) Seasonal Trend in Tmin

Figure : Magnitude of season-wise trends using Sen's slope estimation in Tmin across the Ravi Basin using TerraClimate datasets (4km) for the period 1980–2024

- During **winter,** a warming trend **up to 0.038 °C/year** is noted in most of the Ravi Basin. The central region shows a slower warming rate.
- During **pre-monsoon, warming intensifies to 0.052 °C/year,** prominently affecting the north-central and southeastern areas
- During the monsoon and post monsoon, the eastern parts record the most significant warming, while the central and western zones experience comparatively lower warming.

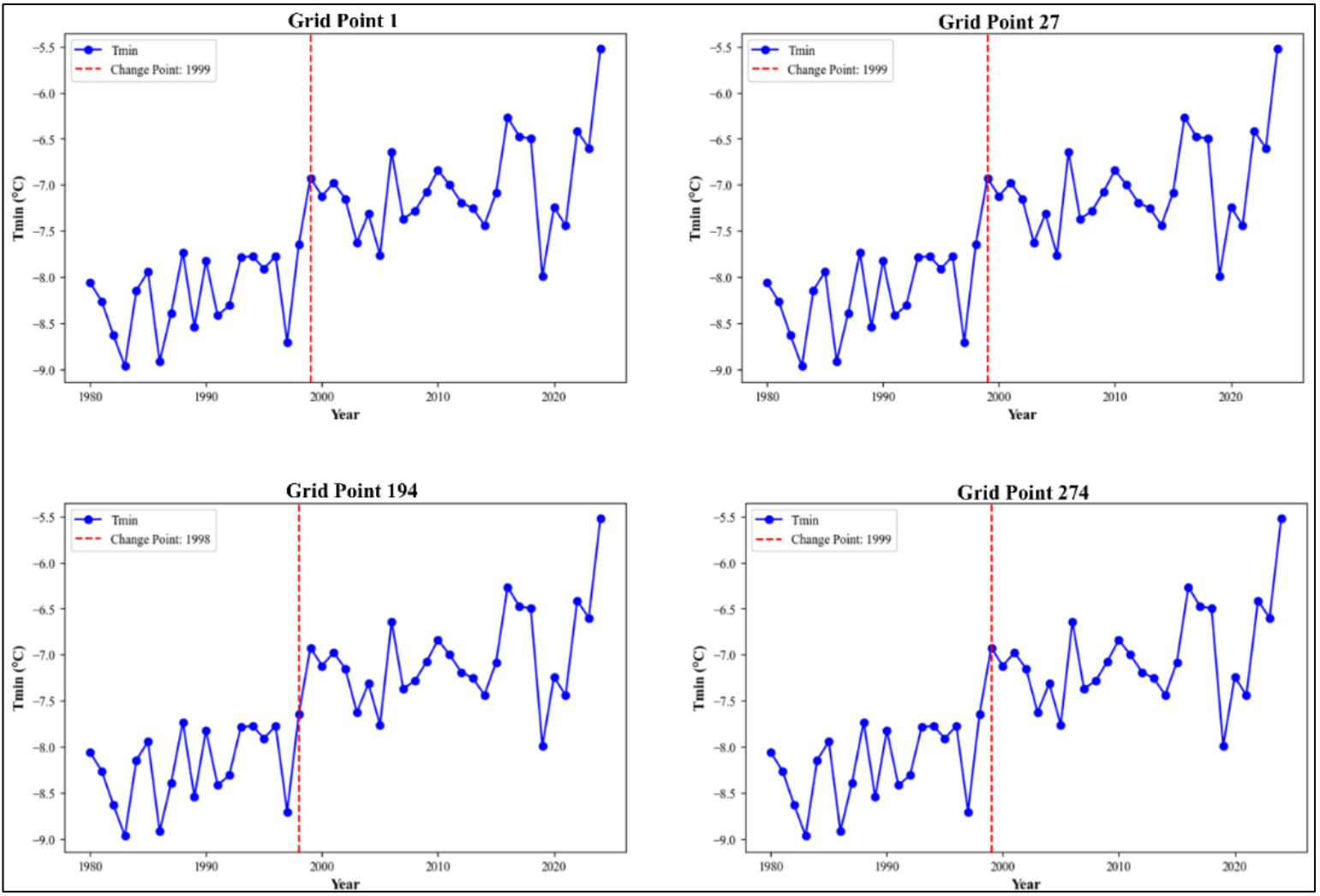
Change point detection in Maximum Temperature(1980-2024)

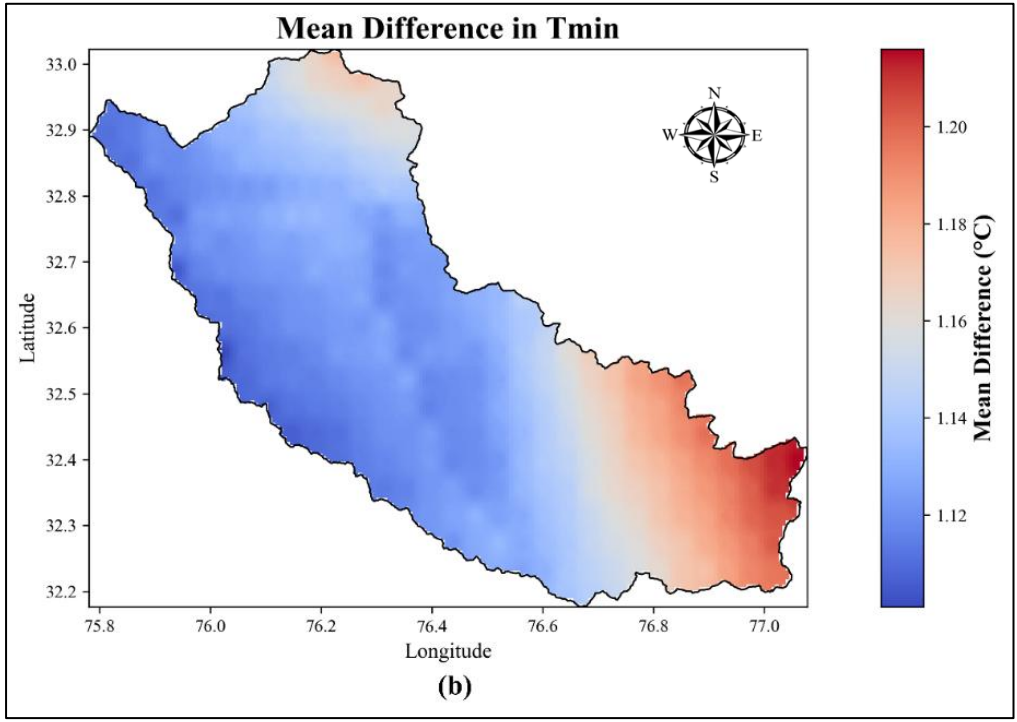




(a) detected change point across various grid points and (b) the mean difference in maximum and minimum temperature between the years before and after the change point, highlighting spatial patterns of temperature variations across the Ravi Basin.

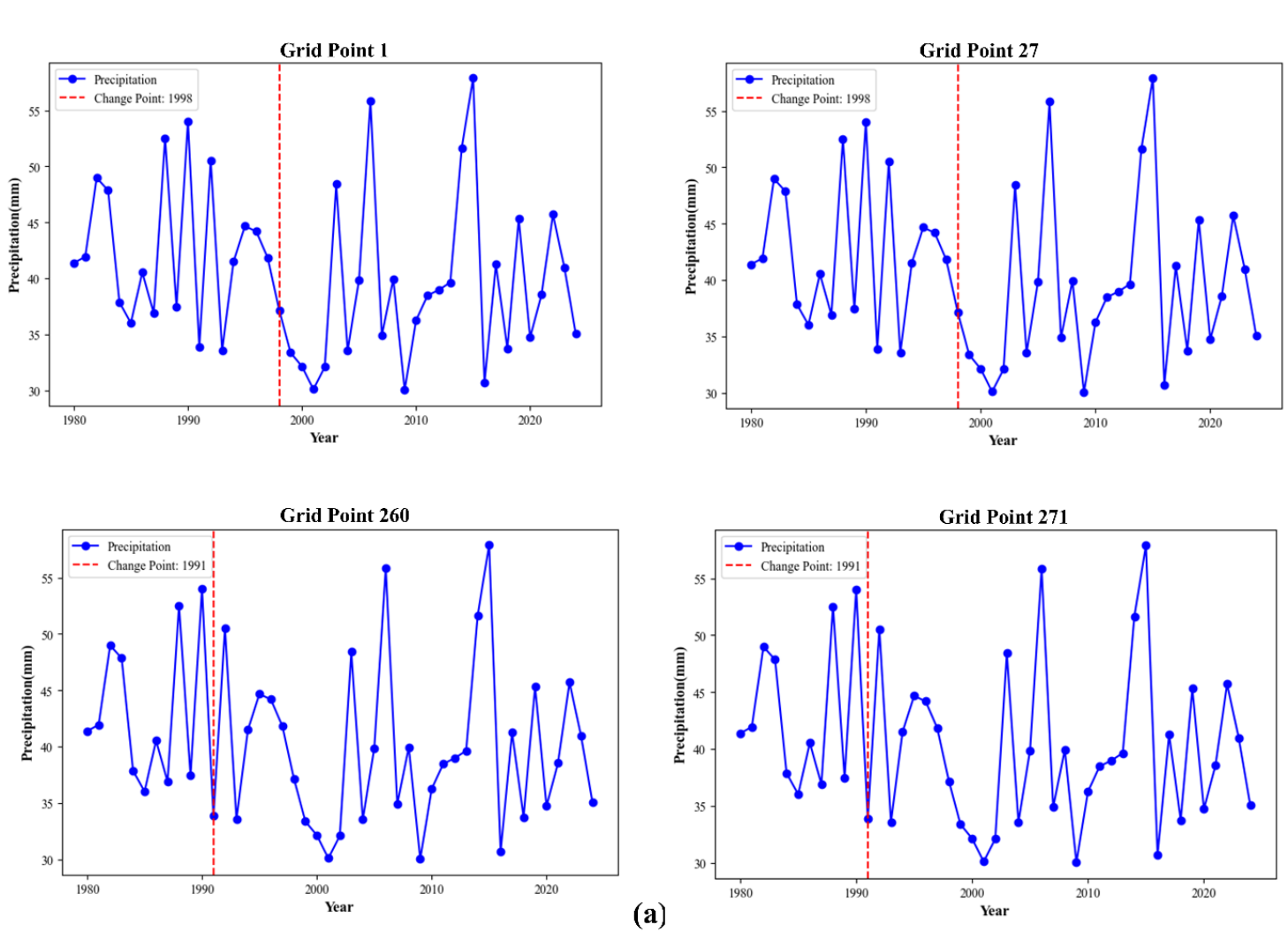
Change point detection in Minimum Temperature(1980-2024)

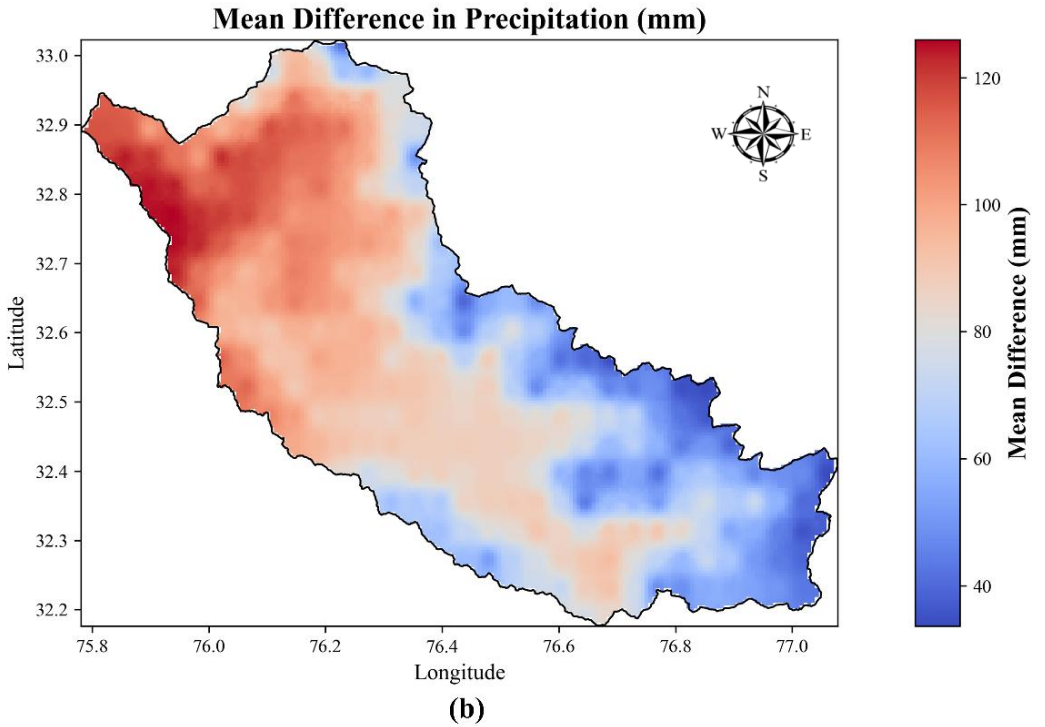




(a) detected change point across various grid points and (b) the mean difference in minimum temperature between the years before and after the change point, highlighting spatial patterns of temperature variations across the Ravi Basin.

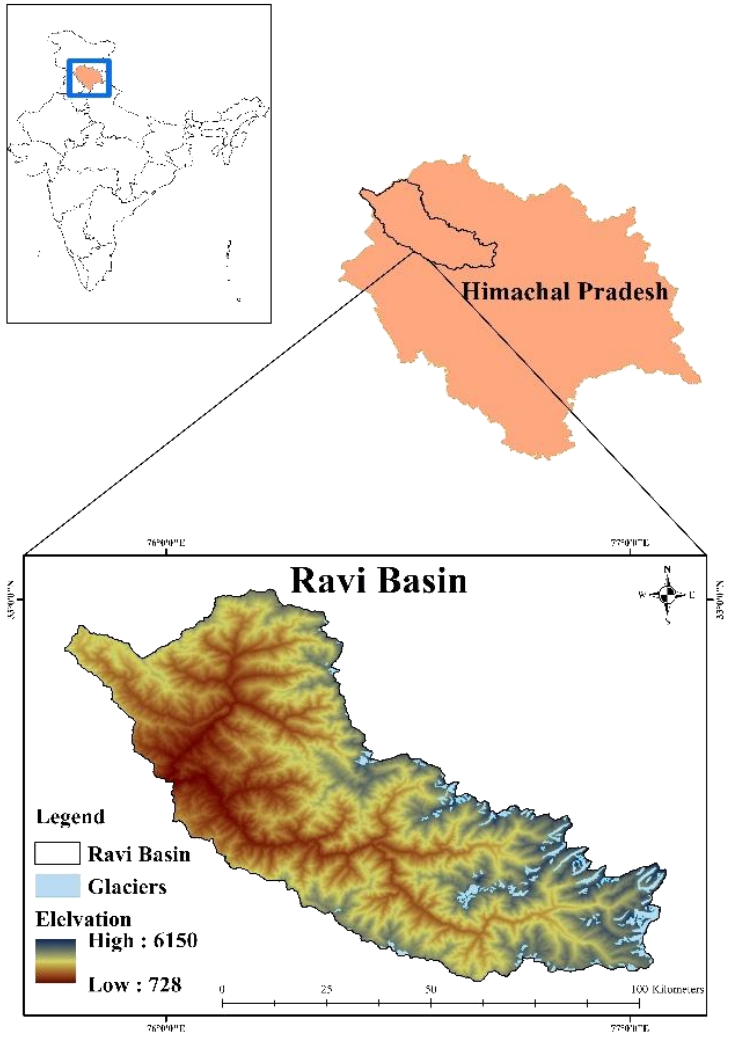
Change point detection in Precipitation



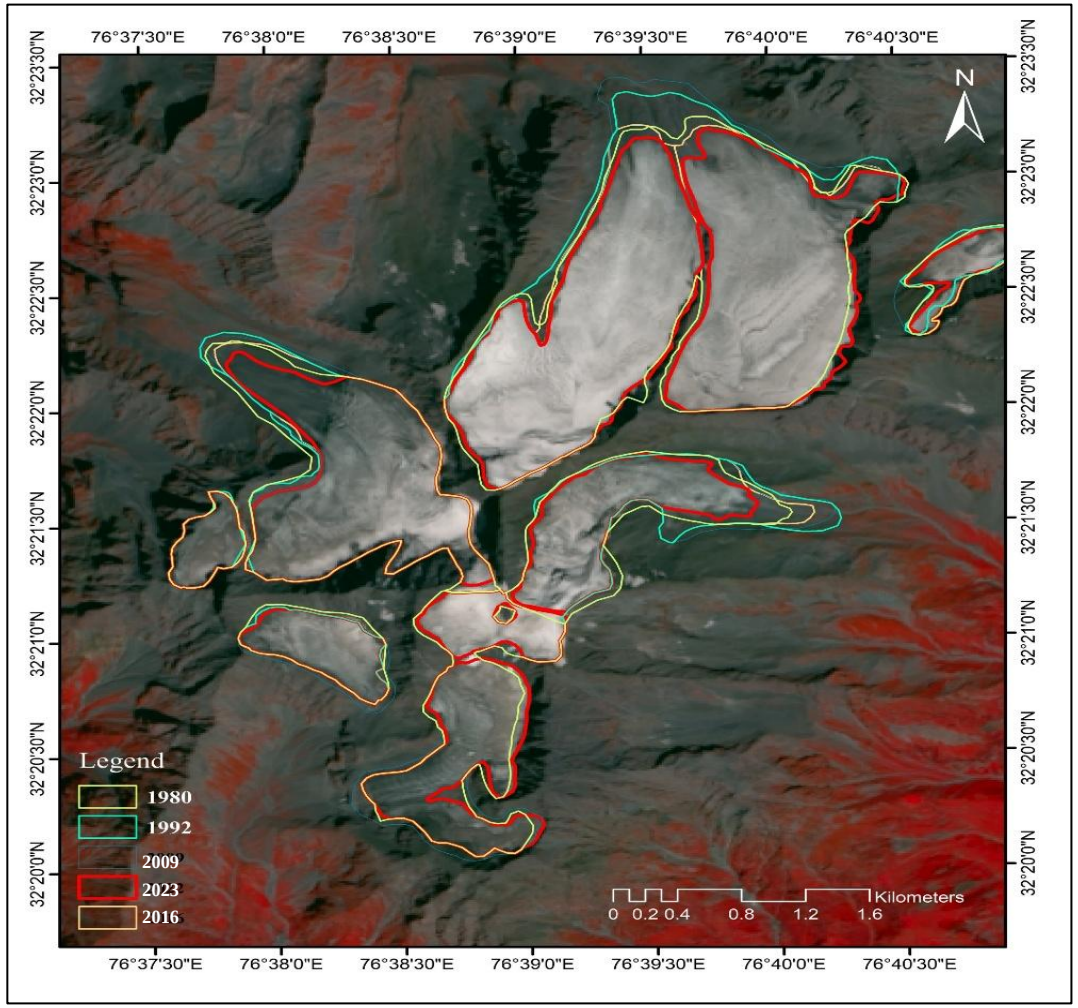


Spatial distribution of Pettitt's Test results showing (a) the change point at various grid points and (b) mean difference in precipitation after the change point across the Ravi Basin using TerraClimate Datasets.

Spatial extent of (a) the Ravi Basin, Northwestern Himalaya & (b) changes in glacier extent of Manimahesh Glacier in the Ravi Basin (1980-2023)

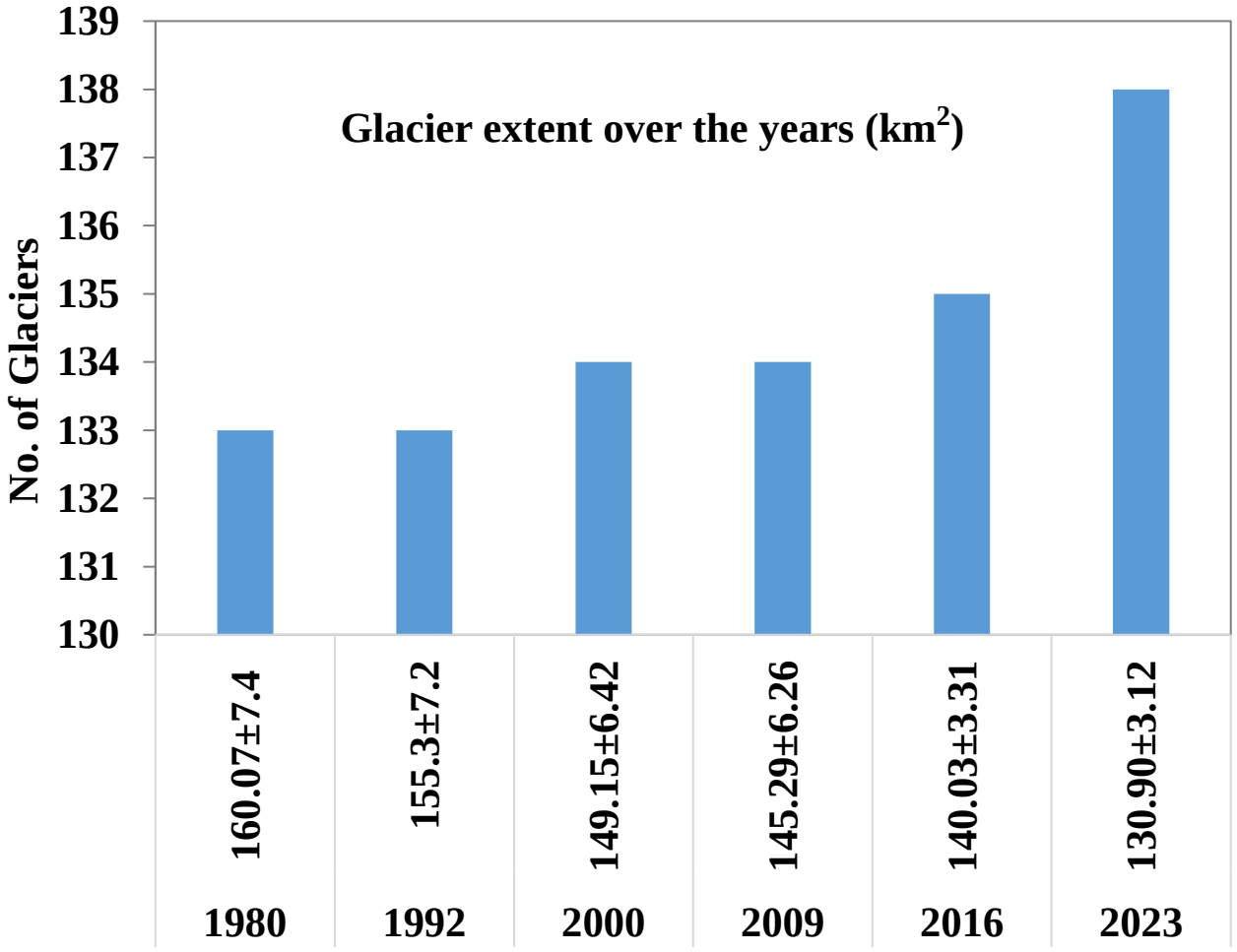


(a) The glacier extent of the Ravi basin (2023) using Landsat8 and Aster DEM



(b) Changes in the extent of Manimahesh Glacier in the Ravi basin over the years on the Landsat 8 imagery from 2023

Glacier extent and change per year in Ravi Basin, Himachal Pradesh between 1980-2023

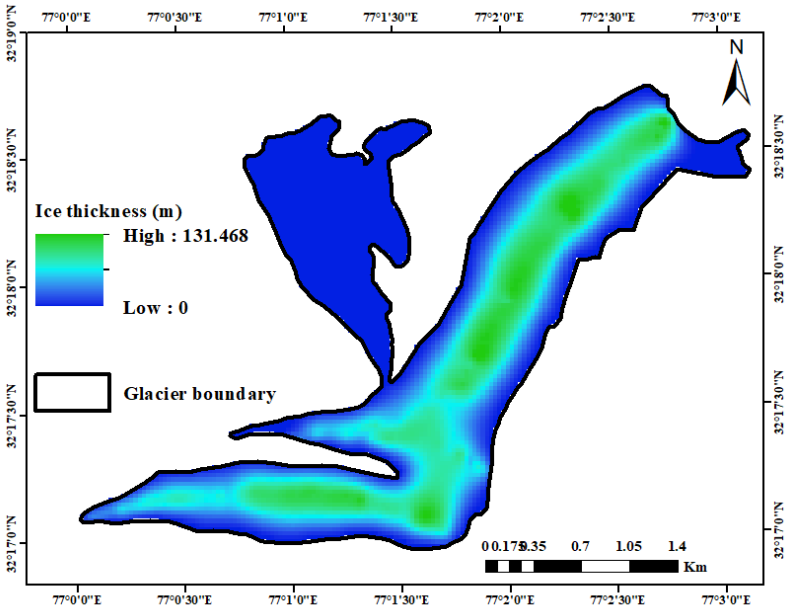


Sr no.	Period	Surface area (km^2)	Change per year (km^2)
1	1980-1992	-5.07	0.422
2	1992-2000	-5.85	0.325
3	2000-2009	-3.86	0.428
3	2009-2016	-5.27	0.753
4	2016-2023	-8.11	1.158

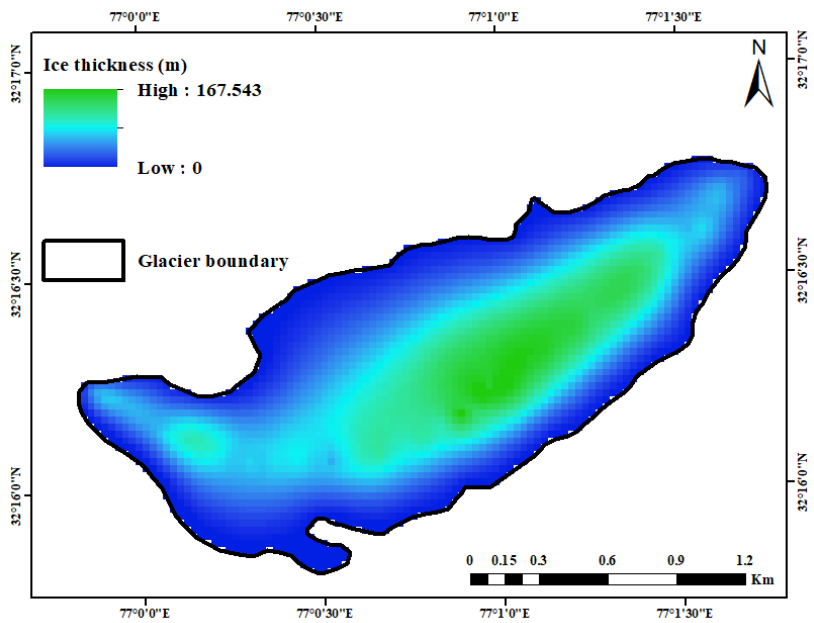
Change in Glacier extent, number of glaciers over the years and change per year of glaciers in the Ravi basin

Ice thickness of selected glaciers in the Ravi Basin

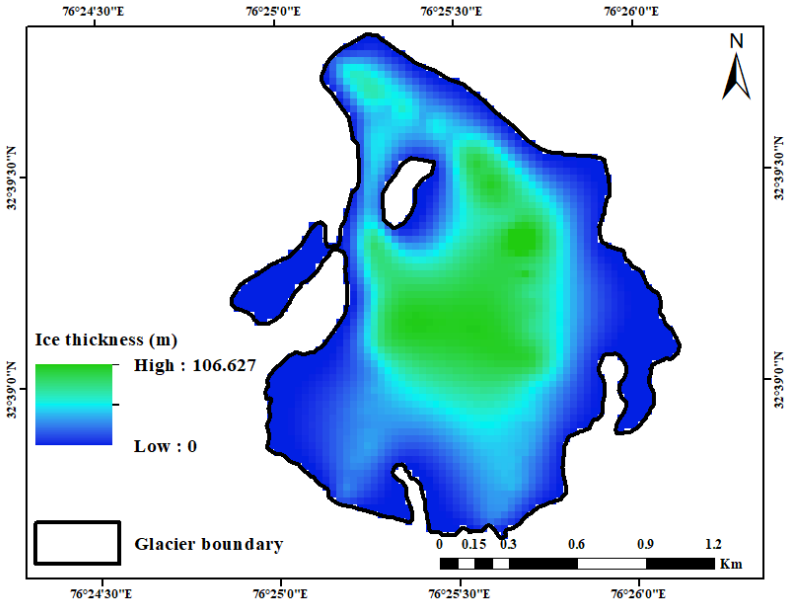
- Volume estimates were computed for glaciers larger than 2 km² as of the most recent observation year (2024).
- The color scale indicates ice thickness, from 0 meters in blue to a maximum ranging from 106 to 167.5 meters in green.
- For instance, Glacier 4 reaches up to 131 meters, while Glacier 13 peaks at 125 meters.
- These outputs help us understand the spatial variation in ice thickness, a critical factor for assessing glacier retreat and stability



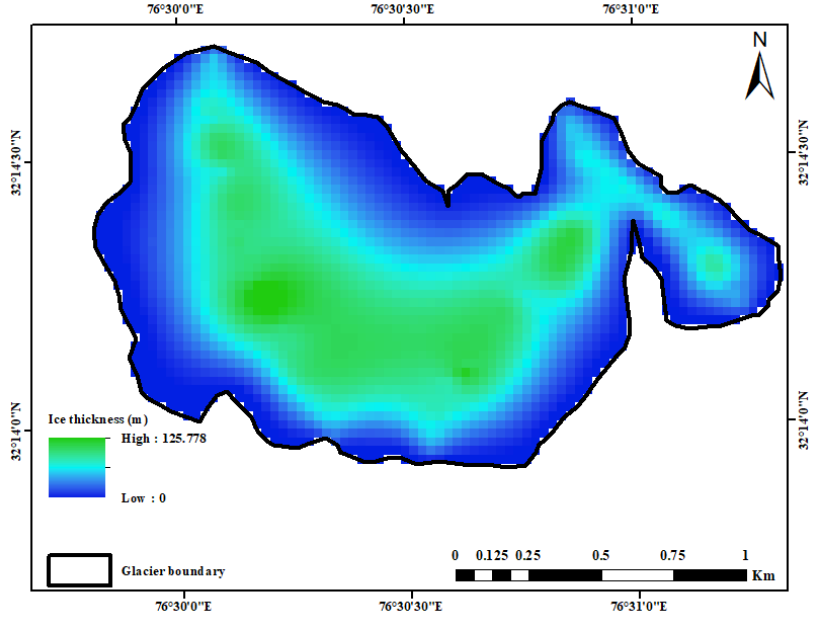
(a) Glacier 4



(b) Glacier 10



(c) Glacier 11



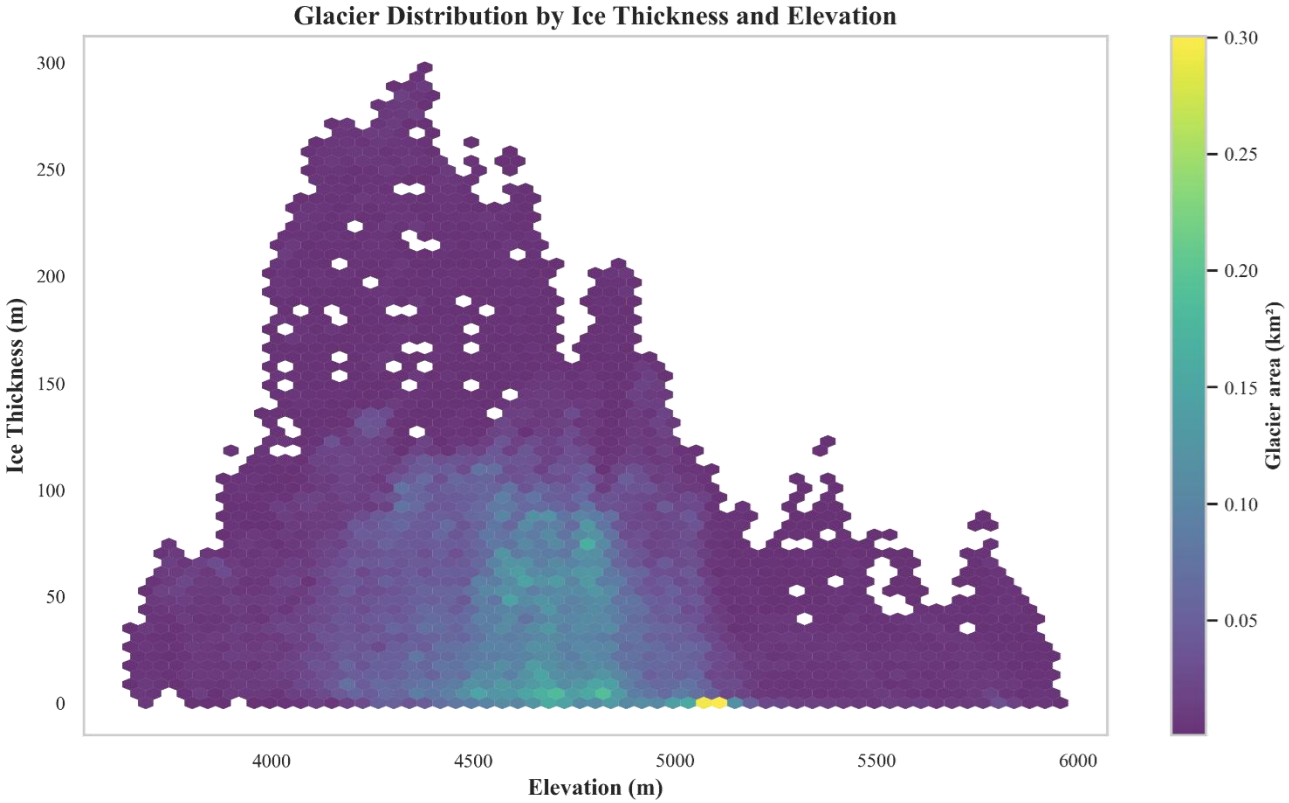
(d) Glacier 13

Distribution of glacier ice thickness across selected glaciers (>2 Km^2) in the Ravi basin from the year 2024 done using Landsat 8 Imagery .

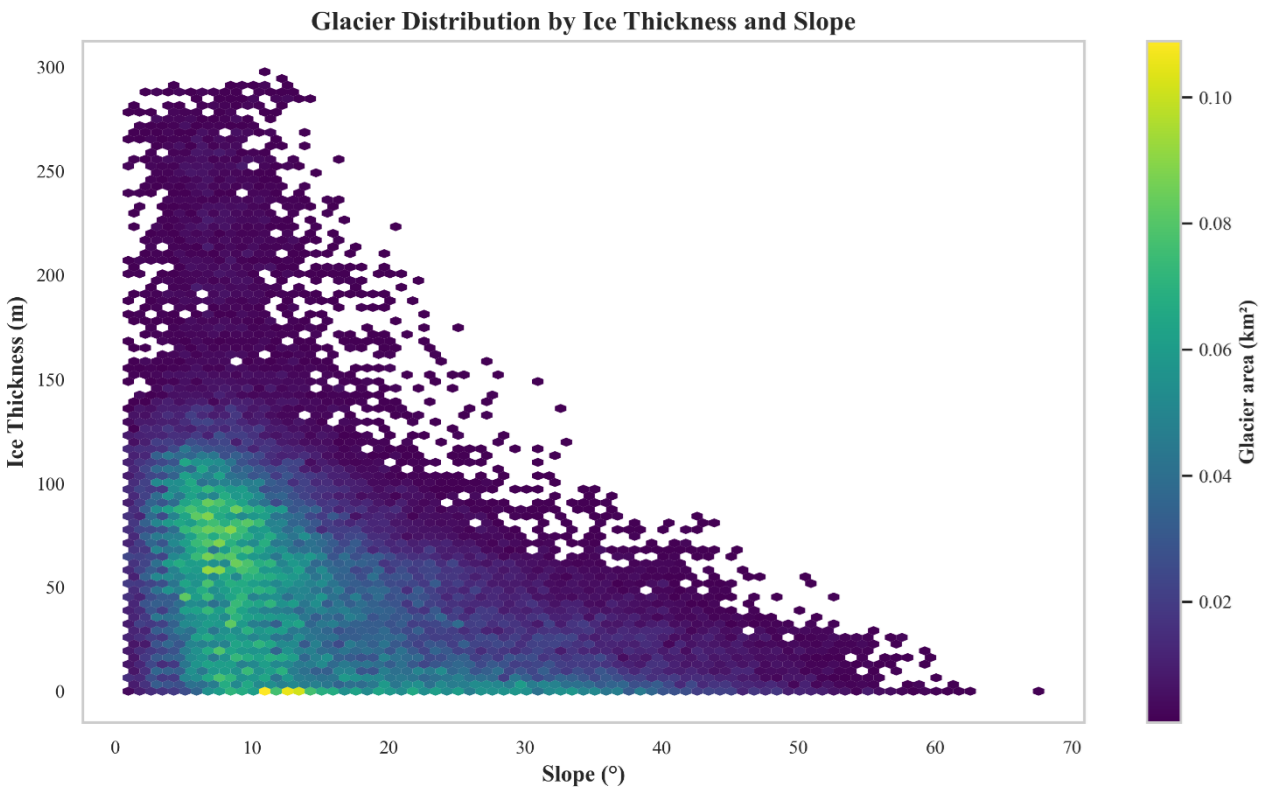
Key physical parameters and volume estimates for glaciers analyzed, including elevation and slope characteristics derived from DEM data.

Glacier ID	Glacier Volume (km^3)	Mean Thickness (m)	Max Thickness (m)	Mean Elevation (m)	Max Elevation (m)	Mean Slope (degree)	Max Slope (degree)
Glacier 6	0.49	109.22	301.1	4468.2	5805	14.7	63.3
Glacier 3	0.40	45.46	142.75	4527.3	5224	13.2	59.6
Glacier 5	0.23	47.27	156.66	4940.8	5961	18.5	59
Glacier 7	0.22	49.81	142.42	4356.5	5638	14.6	59.9
Glacier 1	0.20	47.63	158.94	4747.5	5128	13.4	64.3
Glacier 4	0.19	35.19	131.47	4889.3	5472	13	57
Glacier 9	0.18	48.65	142.74	4659.1	5141	14.3	52
Glacier 8	0.15	35.29	119.11	4462.5	5209	20.9	70.7
Glacier 10	0.14	54.36	167.54	4887.7	5171	13.9	55.5
Glacier 12	0.11	49.72	139.61	4384.1	4862	11.3	48.9
Glacier 13	0.10	46.46	125.78	4558.2	4715	15.9	44.1
Glacier 14	0.08	40.89	107.99	4599.7	5586	20.2	60
Glacier 15	0.08	38.57	108.71	4639	4855	14.1	47.8
Glacier 11	0.08	32.71	106.63	4719.7	5270	24.1	59.1

Distribution of glacier ice thickness as a function of (a) elevation and (b) slope in the Ravi basin.



(a)



(b)

- The plot reveals the variation in ice thickness with (a) elevation and (b) slope ranges in the Glaciers of Ravi basin in 2024
- The peak density around 4500 meters, indicates that mid-elevation glaciers hold the most ice volume
- the majority of glaciers have slopes between 0 and 30 degrees
- As slopes exceed 40 degrees, the ice thickness drops sharply to below 50 meters, shown in the sparse purple dots, indicating that steeper terrains lead to thinner ice

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Climatic shifts in the Beas Basin: A spatio-temporal analysis of time series of temperature and precipitation of TerraClimate dataset

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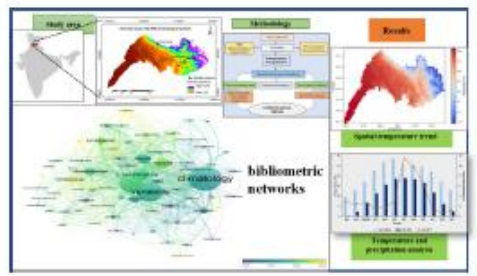
HIGHLIGHTS

- Tmax and Tmin increased by 0.02 °C & 0.04 °C per year, indicating significant warming.
- Seasonal climatology of Tmax, Tmin & precipitation analyzed over the Beas Basin.
- Pettitt's test detected an abrupt temperature shift in 1999 at all five stations.
- Dharamshala shows the highest Tmin and Tmax variability among all stations.
- TerraClimate was selected for its 4 km resolution, and strong IMD station correlation was applied.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding the spatio-temporal variations in temperature and precipitation is pivotal for evaluating the impacts of climate change, particularly in ecologically sensitive and topographically complex regions such as mountains. These variations impact hydrology, biodiversity, and livelihoods, requiring targeted adaptation strategies. The study was done over the Beas Basin in the Northwestern Himalayas from 1980 to 2023, utilizing TerraClimate reanalysis datasets of 4 km resolution. The monthly, seasonal climatology of Temperature Maximum (Tmax), Temperature Minimum (Tmin), and Precipitation has been built over the Basin. The statistical analysis used the Mann-Kendall test to identify the trends and shifts. The Pettitt test was also done to find out the point of abrupt change. The spatial trend analysis of Tmax and Tmin has been conducted on monthly and seasonal scales. The results show that Tmax and Tmin have been increasing at rates of 0.02 to 0.04 °C per year, respectively, over 43 years in the Beas Basin, with the trends being statistically significant. The Long-Term Average (LTA) anomaly analysis for temperature variables exhibited a negative trend from 0 to −1.5 °C during 1980–2000, while an increasing trend from 0 to +1.5 °C during 2001–2023. A notable abrupt change was identified by Pettitt's test in 1999 for the temperature across all five meteorological stations. The rugged terrain limits observational data, requiring high-resolution datasets for accuracy. This study enhances the understanding of climate dynamics and underscores the need for precise data in climate modeling and regional planning.

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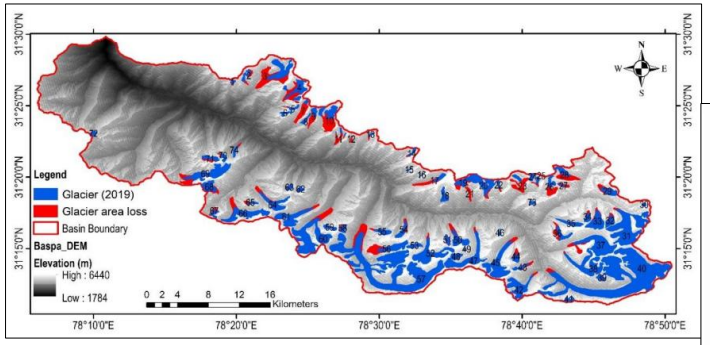
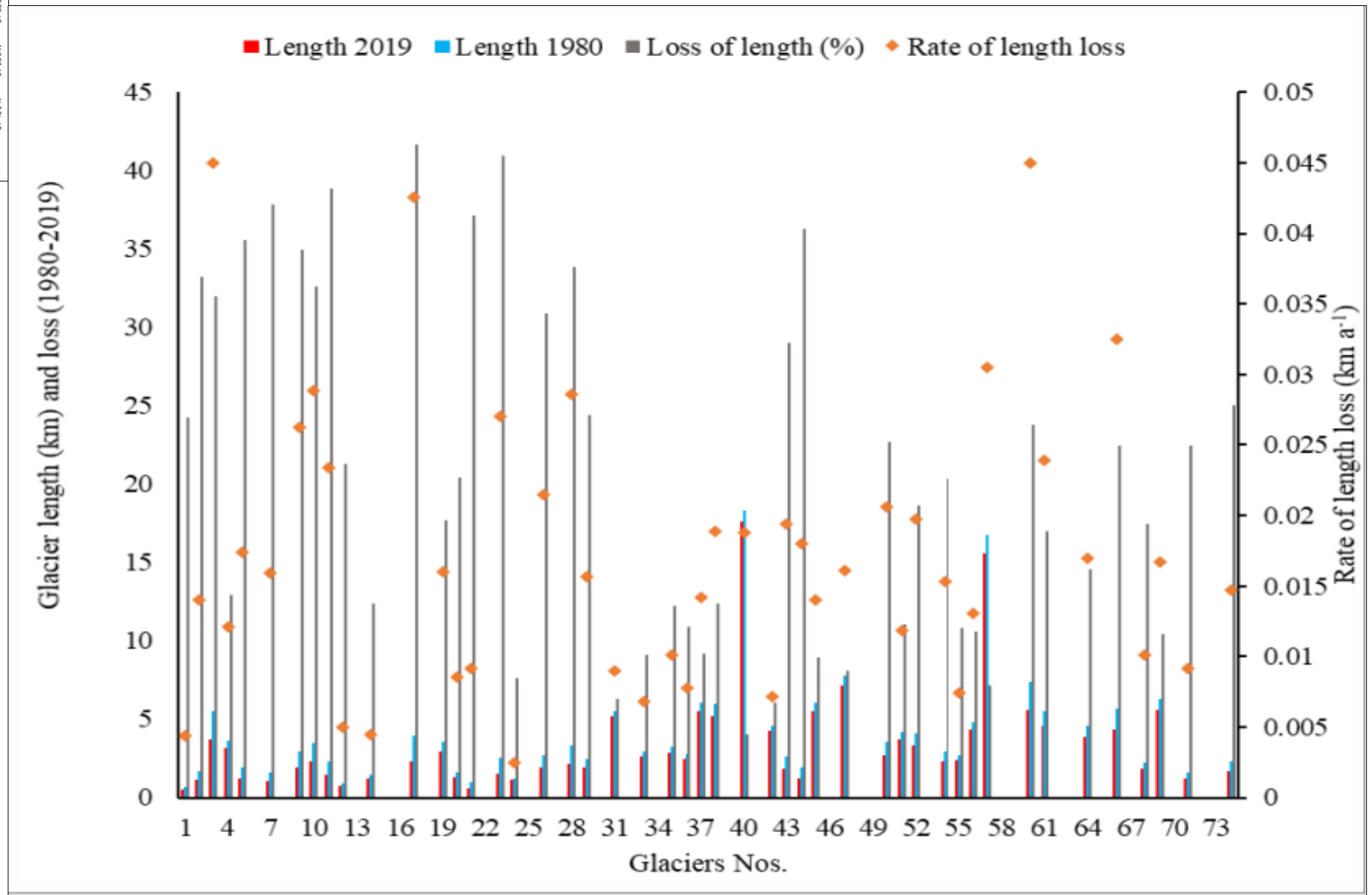
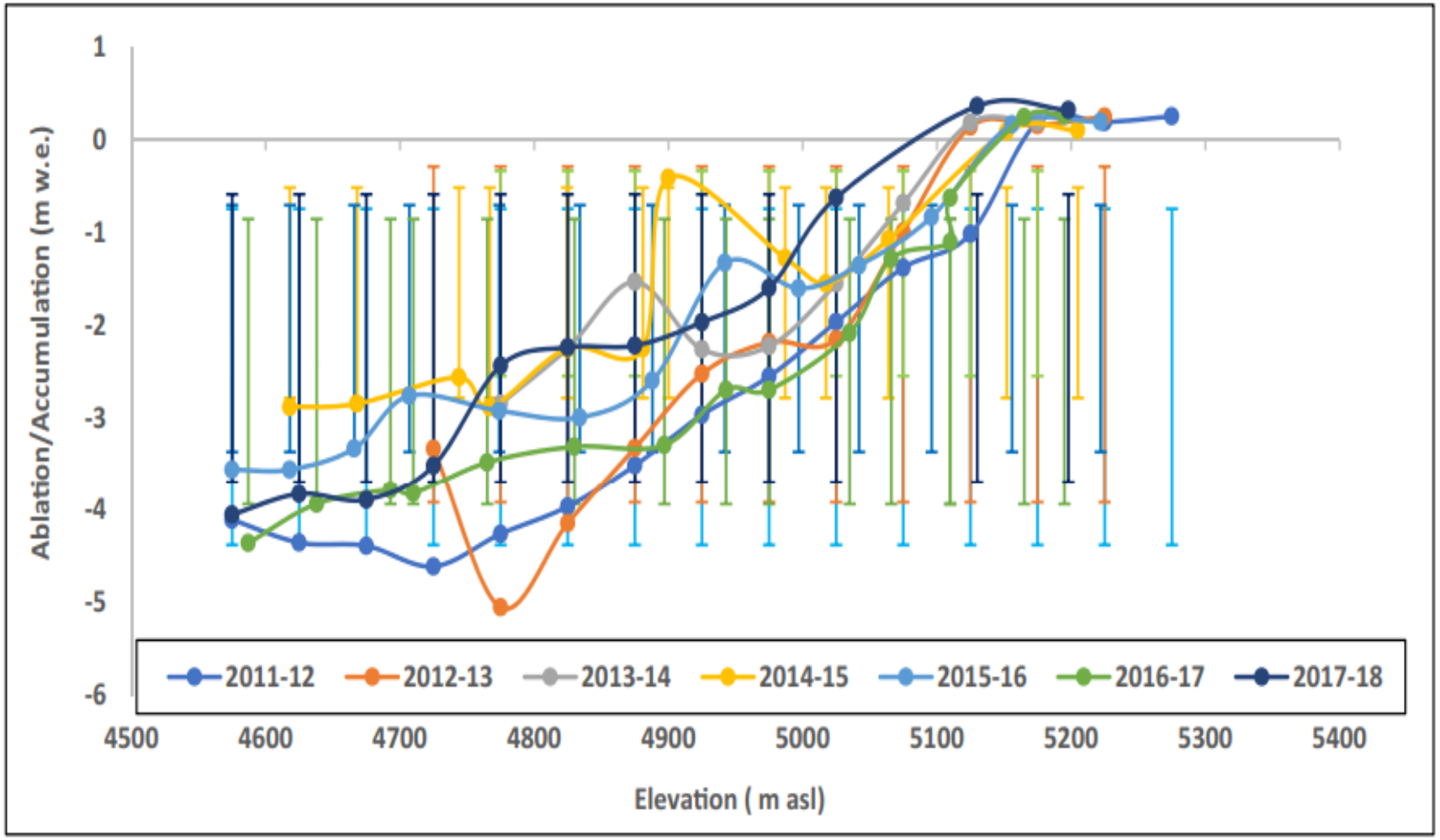
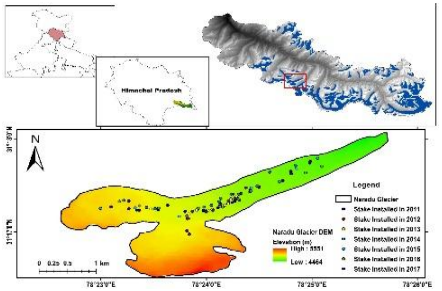
Glacier area loss and retreat in the Baspa basin over 39 years, from 1980 to 2019





Specific accumulation/ablation with elevation during the ablation years 2011–12 to 2017–18 at Naradu glacier





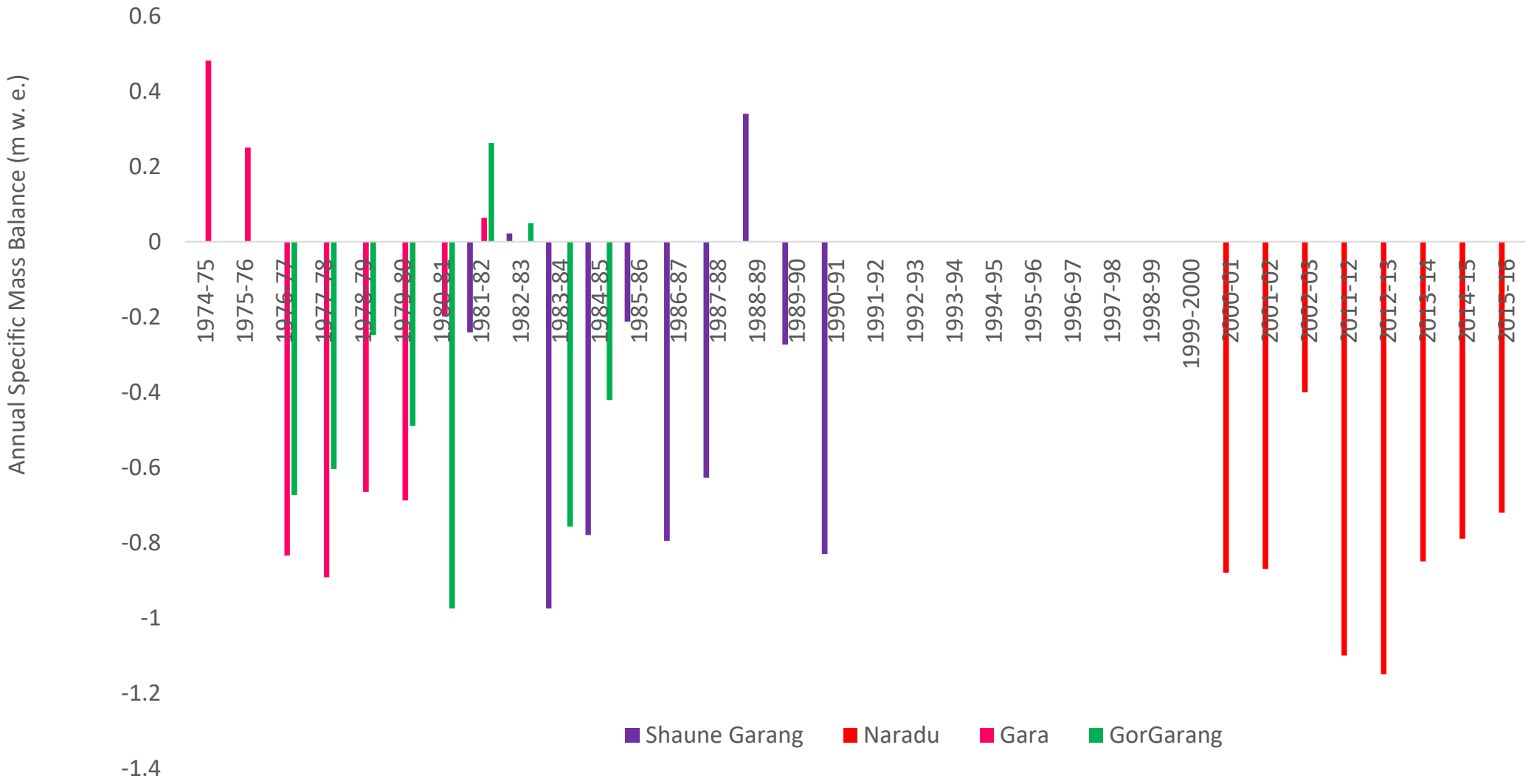
Year	Net balance (10^5 m^3)	ELA (m a.s.l.)	Sp. Bal. (m w.e.)	Uncertainty (%)
2011/12	−3.5	5209	−1.09	2.6%
2012/13	−3.7	5225	−1.15	2.3%
2013/14	−2.7	5196	−0.86	1.3%
2014/15	−2.5	5152	−0.79	3.4%
2015/16	−2.4	5135	−0.77	1.6%
2016/17	−2.0	5086	−0.63	2.4%
2017/18	−2.2	5127	−0.69	2.1%
Average	−2.71	5161	−0.85	2.24%

The highest annual Mass balance -1.15 m w.e. (2012-13) and the lowest was -0.63 m w.e. (2016-17)

Average mass balance -0.83 m w.e. ; SD= ±0.21

Kumar et al., 2021
Scientific Reports

Specific Annual Mass Balance of Glaciers (Baspa Valley)



Final thoughts

- The Himalayan glaciers are crucial not only to the surrounding regions but also to the billions of people whose lives are affected by them.
- Recent global warming and climate change have seen these glaciers melting at an unprecedented rate, and the effects are devastating.

- The TPCF could be helpful in further facts finding and solution driven approaches.

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Thank You

For Attention