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Global Spatio-Temporal Analysis of Surface Temperature Anomalies

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Abstract: Surface temperature refers to the measurement of the temperature at the Earth's surface. It represents the heat energy present in the immediate vicinity of the ground or other surfaces. This study aimed to assess surface temperature anomalies at a global scale using NASA data. Data was categorized into four time periods: 1981-1990, 1991-2000, 2001-2010, and 2011-2022. Each period was further divided into four quarters, allowing for a detailed analysis of temperature variations throughout the year. The analysis focused on calculating the minimum, maximum, and mean surface temperature anomalies based on latitude. The results revealed notable findings regarding specific countries and regions. Firstly, countries such as Brazil, USA, Canada, Russia, Algeria, and several European nations were identified as the most affected by increasing surface temperatures, with measurements reaching up to 4.0 ºC. Furthermore, the study highlighted substantial temperature increases in the Arctic belt, ranging from 1.0 ºC to 2.0 ºC. This warming trend signified the rapid melting of glaciers, posing a significant threat to the northern hemisphere. In contrast, the Antarctic belt exhibited uneven temperature variations. The western part displayed a positive anomaly of 1.0 ºC to 2.0 ºC, the middle part showed a negative anomaly of 0.2 ºC to 1.0 ºC, and the eastern part experienced little to no positive anomaly of 0.2 ºC to 1.0 ºC. Overall, this study provides valuable insights into global surface temperature patterns. Study highlighted significant impacts and alarming temperature rise in specific countries, especially the Arctic belt, posing risks of accelerated glacier melting and environmental consequences in the northern hemisphere.

1. Introduction

Global surface temperature (GST) is an important parameter that represents the average temperature of both the sea surface and the air temperature over land (Sun *et al.*, 2022; Huang *et al.* 2023). Surface temperature varies across the world due to a variety of factors, including latitude, elevation, proximity to water bodies, and regional climate patterns. Climate change has widely impacted human society and the natural environment, and an increasing number of studies have researched global warming. According to the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), the average global surface temperature increased by approximately 0.85 ºC from 1880 to 2010. Air temperature had an obvious warming trend over the global land surface, particularly in northern mid-latitudes (Neog, 2022). Meanwhile, the population of the world is increasing gradually, which may result in more consumption of fossil fuel and aggravates the global warming. Land surface temperature

(LST), the temperature of the Earth's skin, plays an important role in heat and energy exchange between land surfaces and the atmosphere (Song *et al.,* 2018). Human activities, like burning fossil fuels and deforestation, are causing global warming through increased greenhouse gas emissions (Feng and Zou, 2019) , (Dutta *et al.,* 2019). Climate change is evident in various regions, with land use change, greenhouse gases, and human activities playing significant roles in altering land surface temperature and overall warming trends (Hereher, 2016), (Basha *et al.,* 2017). Volcanic activity and oceanic processes also play a role in shaping global temperature patterns. (Zorita *et al.,* 2005), found that the leading mode of temperature variability in the preindustrial era exhibited coherent global patterns, with greater amplitudes over continents and the Northern Hemisphere. Surface temperature increases in the Northern Hemisphere are likely unprecedented in the context of the past 2,000 years (Mann *et al.,* 2008). The rate of global warming has remained consistent, with the past decade experiencing a comparable rate of temperature increase as the previous two decades(Hansen *et al.,* 2010).Developing countries, notably China and India, play an increasing role in global temperature change, while urban thermal environments are influenced by land surface materials and vegetation abundance (Rohde *et al.,* 2013). Das and Angadi, (2020) found that land use change in Beijing led to increased land surface temperature, while (Liebmann *et al.,* 2010), emphasized that short-term cooling trends lack statistical significance and should not be misinterpreted as indicative of long-term temperature patterns. The expansion of urban areas in Lagos, Nigeria, as observed by Igun and Williams, (2018), has led to varying temperature increases across highly dense, moderately dense, and less dense areas, while (Khandelwal *et al.,* 2018), found a strong correlation between elevation and land surface temperature in Jaipur, India, with variations of 3.5 ℃ to 4.6 ℃ per 1000 meters. Additionally, (Mahato and Pal, 2018), discovered a notable average rise of 3.5 °C in land surface temperature over the past 25 years in the Chandrabhaga River basin, characterized by pronounced seasonality. The studies by (Guha *et al.,* 2020), (Liu *et al.,* 2020) explored the relationship between land surface temperature (LST) and various land surface indices, such as NDVI, NDWI, NDBI, and NMDI in different regions of India and globally. The present study aimed to achieve the objective of determining statistical spatio-temporal variation in surface temperature anomalies (STA) followed by analyzing latitudinal variation in STA.

2. Methodology

2.1 Study Area

To study the spatial and temporal variation in temperature, the entire land surface of earth was taken into consideration. The location map of various countries is shown in **Figures 1**. There are total 193-member countries and 2 recognized independent nations (Vatican City and Palestine) in the world. Some countries are close to Arctic and others close to Antarctic. The largest country in the world by land area is Russia. It spans across Eastern Europe and northern Asia, covering approximately 17.1 million square kilometers (6.6 million square miles). On the other hand, the smallest country in the world, in terms of both land area and population, is Vatican City. It is an independent city-state located within Rome, Italy, and covers an area of only 0.44 square kilometers (0.17 square miles).

2.2 Data Collection

For the present study, temperature data has been used. Temperature data from 1981 to 2022 on monthly scale has been taken from NASA website National Aeronautics and Space Administration Goddard Institute for Space Studies, GISS surface temperature analyses (v4). The data has been

collected in the form of quarters of a timeline of 10 years that are in anomaly with the temperature data of (1951-1980) using smoothing radius of 1200 km and Robinson map projection. A year has been subdivided into 4 quarters namely, January to March [1st Quarter], April to June [2nd Quarter], July to September [3rd Quarter], October to December [4th Quarter].

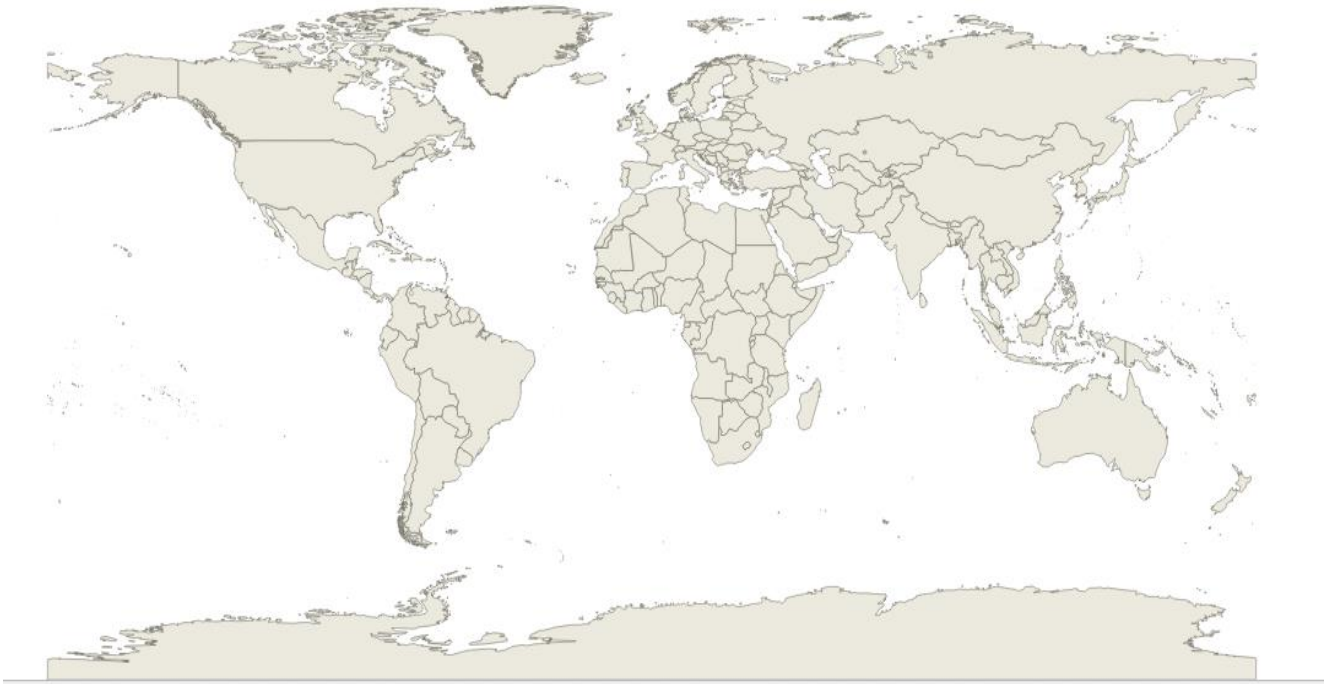


Figure 1. Layout of World Map

2.3 Anomaly

An anomaly refers to an observation or data point that deviates significantly from what is considered normal or expected within a given context. It represents an unusual pattern or behavior that stands out from the majority of the data. **Eqn. 1** was used in this study to calculate anomaly

$$Anomaly = X_0 - X_a \qquad \textbf{Eqn. 1}$$

where, X_0 is Observed value and X_a is long term average value. In

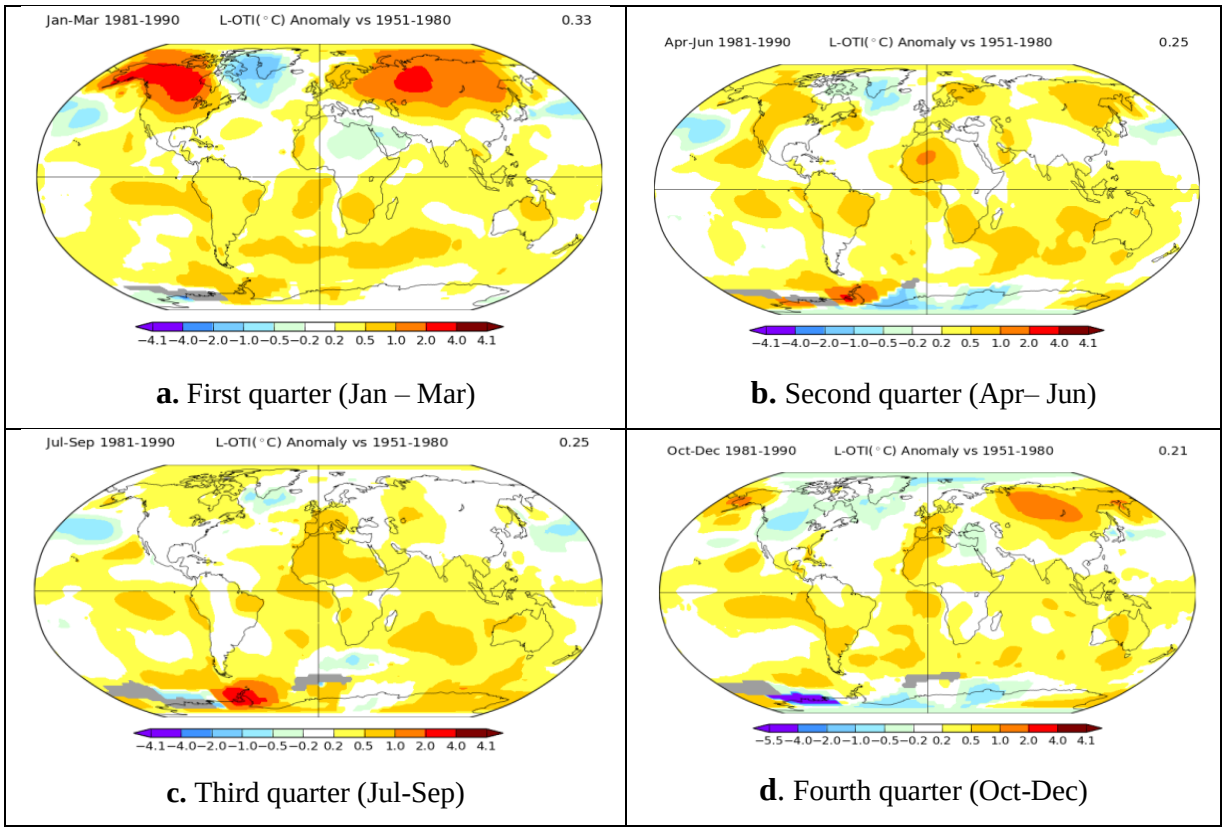
this section we have calculated anomalies for the time period of 1981-1990. 1991-2000,2001-2010,2011-2022 using the base period 1951-1980 on the quarterly basis i.e., January to March, April to June, July to September and October to December.

3. Results and Discussion

3.1 Spatial and Temporal Variations in Surface Temperature Anomalies

The surface temperature anomalies during the time period of 1981-1990 were analyzed and presented in **Figure 2**. In the first quarter (January to March), the Arctic Circle experienced the highest temperature anomaly ranging from 2 ^{o}C to 4 ^{o}C. In the second quarter (April to June), regions including Russia, Canada, USA, Brazil, and North and South Africa had variations of 0.2 ^{o}C to 2.0 °C, with no significant change observed in North India. The third quarter (July to September) showed temperature anomalies of 0.2 ^{o}C to 1.0 ^{o}C in North African countries, Brazil, Australia, and European nations while

high variations of 2.0 ºC to 4.0 ºC were observed in the Southern Ocean .The fourth quarter (October to December) displayed a decrease of 0.2 ºC to 0.5 ºC in Southern European countries and the Arctic region ,while Russia experienced a disturbing variation of 0.2 ºC to 4.0 ºC .Annual surface temperature variations showed positive anomalies of 1.0 ºC to 2.0 ºC in Russia, northeast regions of Africa, parts of North America, and Brazil, while Australia, South America, Europe, and Africa exhibited variations of 0.2 ºC to 0.5 ºC .The Arctic and Antarctic regions had negligible temperature changes. Some parts of the Pacific, Arctic, and Southern Oceans experienced a decrease in temperature variation of 0.2 ºC to 1.0 ºC, while the Indian Ocean, Atlantic Ocean, and Pacific Ocean displayed an overall anomaly of 0.2 ºC to 1.0 ºC.



a. First quarter (Jan – Mar)

b. Second quarter (Apr– Jun)

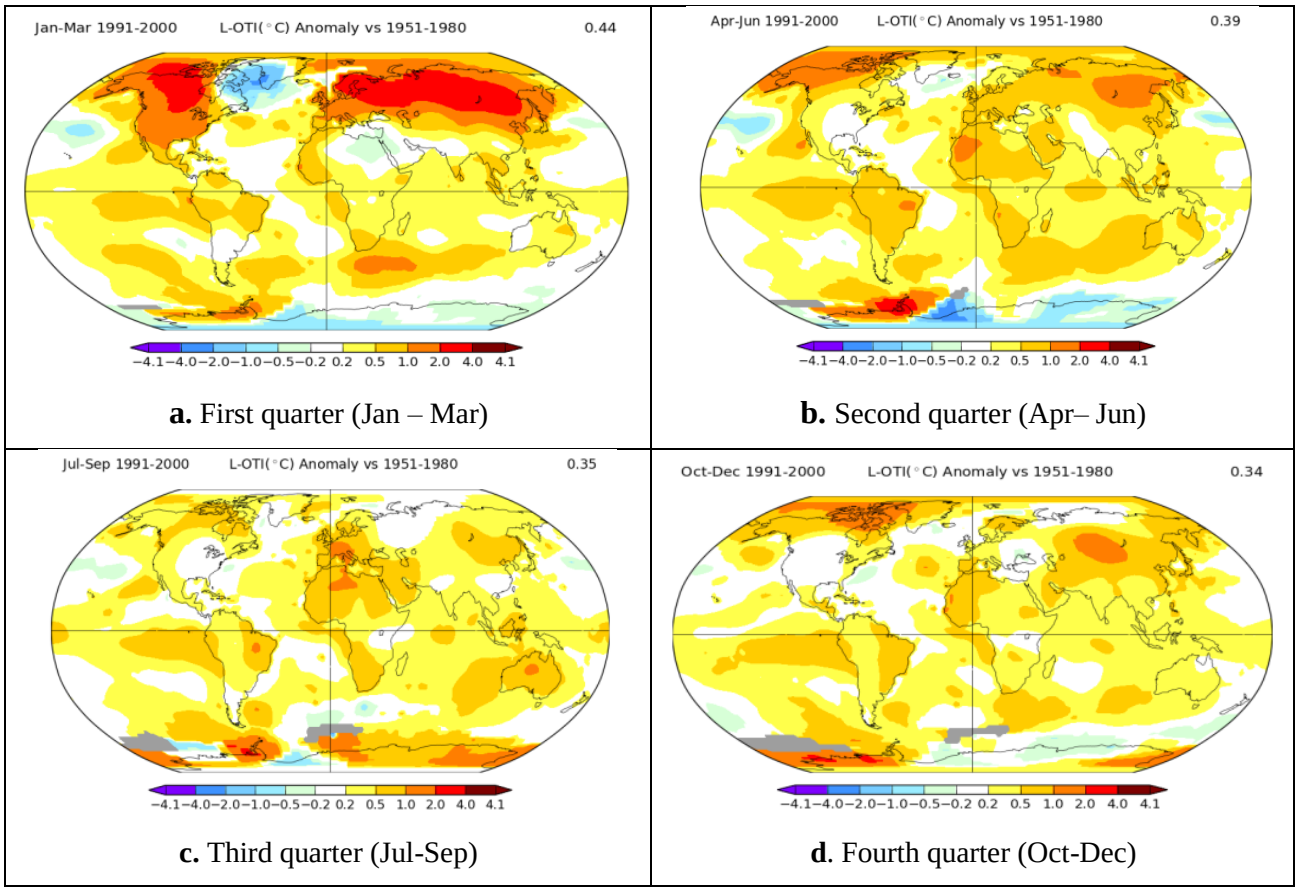
c. Third quarter (Jul-Sep)

d. Fourth quarter (Oct-Dec)

Figure 2. Surface temperature anomalies for 1981-1990

The surface temperature anomalies during the time period of 1991-2000 were analyzed and presented in **Figure 3** .In the first quarter (January to March), significant temperature changes were observed in North America, Europe, Northern Asia, and the Arctic region, with increases ranging from 1.0°C to 4.0°C. Greenland and surrounding countries, on the other hand, experienced a decrease of 0.2°C to 0.4°C. Africa, South America, and Australia showed relatively constant temperature variations, while the Atlantic Ocean, Indian Ocean, and Pacific Ocean exhibited positive changes. The Southern Ocean, however, displayed a negative change. South India stood out with a temperature anomaly of 1.0°C to 2.0°C. Moving to the second quarter (April to June), temperature rises of 0.2°C to 3.0°C were observed in Asia, South America, and Africa. Central Asia showed minimal variation, and the Antarctic region experienced a drop of 0.5°C to 3.0°C, while the western part of the Antarctic belt showed a significant increase of 1.0°C to 4.0°C. India did not show notable changes. In the third quarter (July to September), temperatures continued to increase worldwide, but at a slower pace compared to previous anomalies. Surprisingly, the Antarctic region showed a temperature rise of -0.5°C to 2.0°C. Finally, in the fourth

quarter (October to December), temperature rises of 1.0°C to 3.0°C were noticed in parts of North America and the Arctic belt, while Canada, the USA, and some European countries displayed almost no changes. When considering the annual data of 1991-2000, Canada and parts of Russia exhibited the highest temperature variations, ranging from 1.0°C to 2.0°C (Kouman *et al.* 2022). The Arctic belt showed a warming trend of 0.5°C to 1.0°C, while the surface of the Antarctic belt experienced no major variations. Positive anomalies of 0.2°C to 1.0°C were observed across all continents and in the Indian Ocean, Pacific Ocean, and Atlantic Ocean. The Arctic Ocean and Southern Ocean experienced little to no temperature decrement, ranging from 0.2°C to 1.0°C (Mo *et al.* 2023), while certain parts of the Southern Ocean witnessed a significant rise in surface temperature anomalies of 0.5°C to 2.0°C.



a. First quarter (Jan – Mar)

b. Second quarter (Apr– Jun)

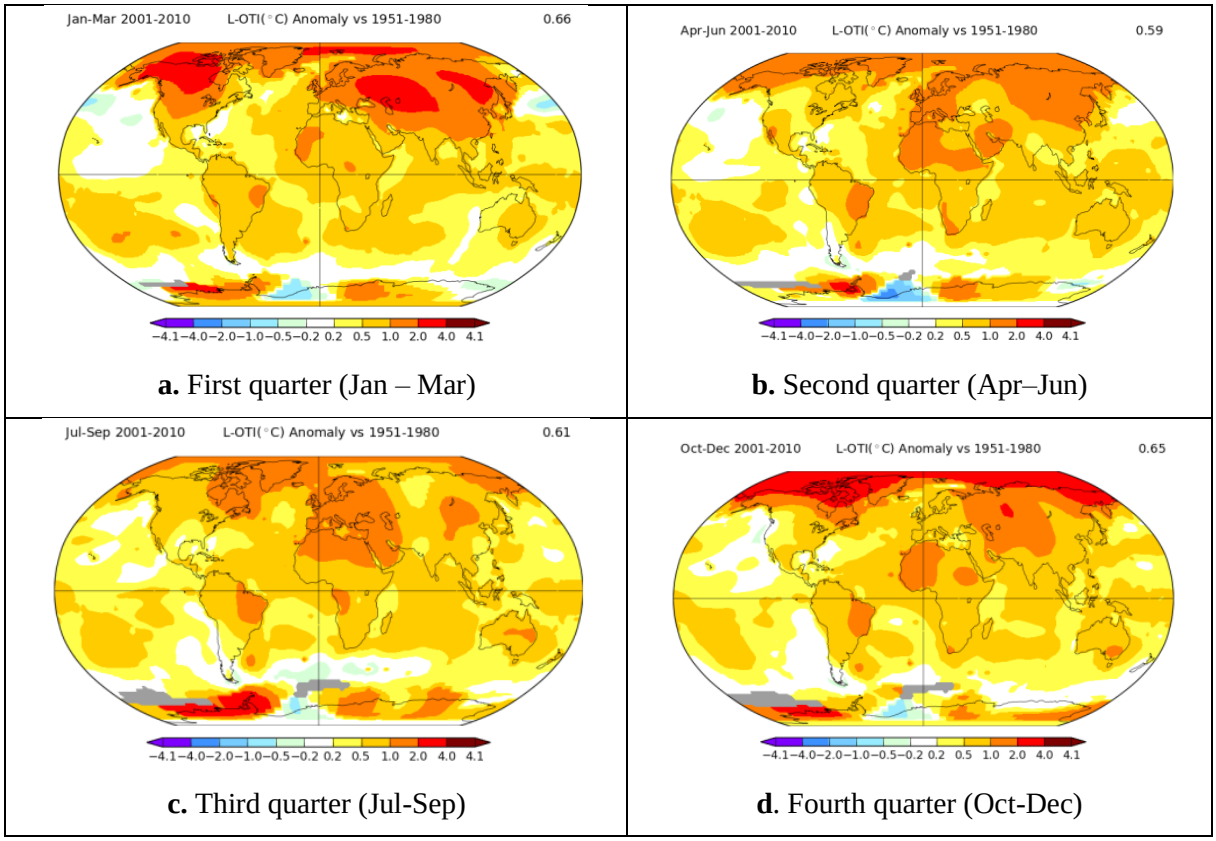
c. Third quarter (Jul-Sep)

d. Fourth quarter (Oct-Dec)

Figure 3. Surface temperature anomalies for 1991-2000

The surface temperature anomalies for the period of 2001-2010 were analyzed and presented in **Figure 4**. In the first quarter (January to March) regions across Africa and South America experienced an increase of 0.5°C to 1°C, while European and Asian countries saw a larger temperature rise of 2°C to 3°C. Notably, Russia witnessed a continuous temperature increase, and the Arctic Ocean exhibited significant changes compared to the relatively minor variations in the Atlantic Ocean. During the second quarter (April to June) shown in the Arctic Belt showed minor temperature changes of 1.0°C to 2.0°C, while South Africa, Namibia, and Brazil experienced a temperature increase of 1.0°C to 2.0°C, with surrounding countries having milder rises. In the third quarter (July to September) the Arctic and European regions displayed a temperature increment of 1.0°C to 2.0°C, and the eastern part of the Antarctic experienced a significant rise of 2.0°C to 4.0°C. The fourth quarter (October to December) witnessed a surge in surface temperature variation, ranging from 1.0°C to 4.0°C. Brazil, Algeria, Russia, and several West Asian countries saw temperature increases of 1.0°C to 2.0°C, while

India observed a variation of 0.5°C to 1.0°C. Overall, the annual study for 2001-2010 revealed temperature increments of 1.0°C to 2.0°C in Europe, Asia, Brazil, parts of North America, North-West Africa, and the Arctic belt. Notably, temperature variations were observed worldwide, with Australia, Africa, Asia, South America, and North America experiencing at least a 0.2°C to 1.0°C change. Certain parts of the Arctic Ocean, Pacific Ocean, and Southern Ocean exhibited negative anomalies, while the westernmost part of the Southern Ocean showed warming trends of 0.5°C to 2.0°C over time.



a. First quarter (Jan – Mar)

b. Second quarter (Apr–Jun)

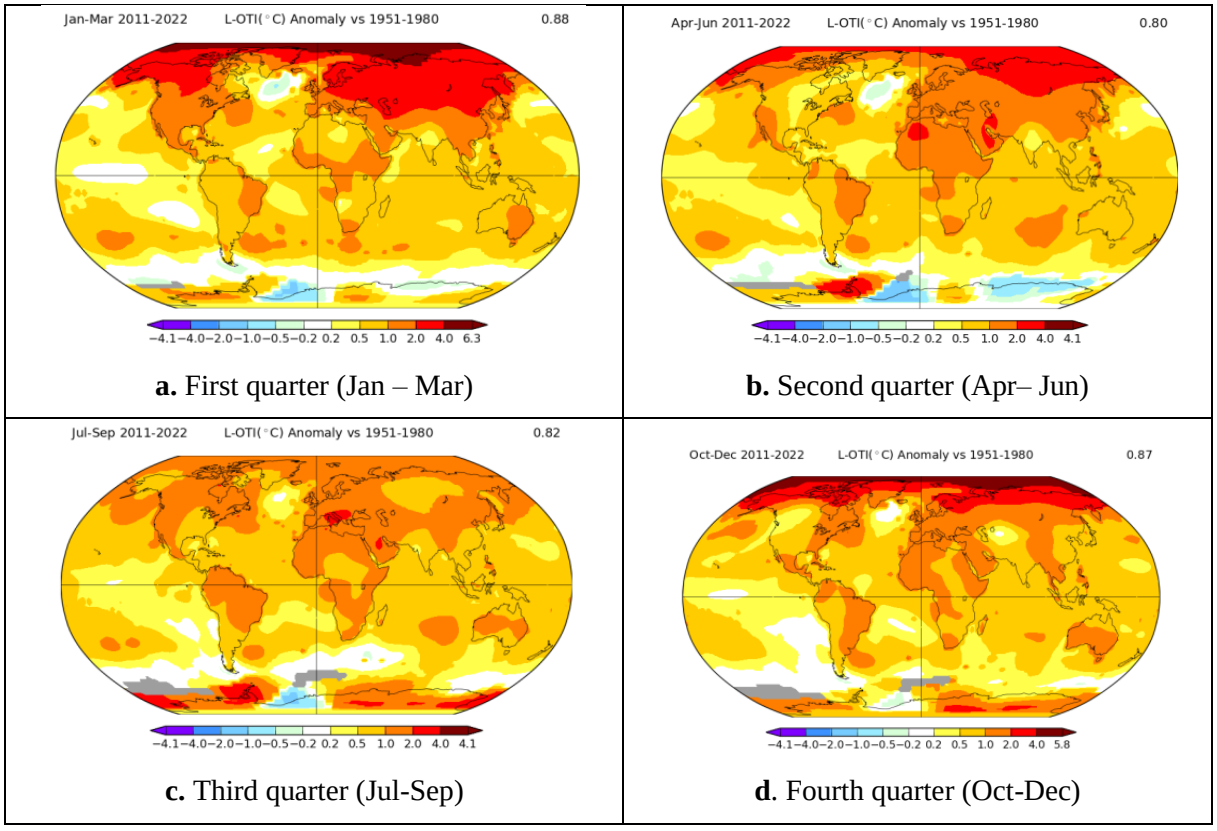
c. Third quarter (Jul-Sep)

d. Fourth quarter (Oct-Dec)

Figure 4. Surface temperature anomalies for 2001-2010

The surface anomalies for the time period 2011-2022 have been shown in **Figure 5**. The observations interpreted from the First Quarter i.e., January to March a sudden hike has been observed in the Arctic region from 4.0 °C to 6.3°C, which is cause of great concern. The temperature in Russia, European Nation and some part of North America has continuously increased and have reached a level from 2.0 °C to 4.0 °C South Australia and New South Wales experienced a positive anomaly of 1.0 °C to 2.0 °C while other parts showed a slight variation in temperature anomaly. A relief have been observed in the Southern Ocean as there was no surface temperature anomaly. In second quarter i.e., April to June Saudi Arabia and Iran showed a comparatively high surface temperature variation of 2.0 °C to 4.0 °C The surface temperature variation in North America was 0.2 °C to 1.5 °C North Eastern part of India showed a decline in surface temperature as compared to previous ones but the anomaly is positive i.e., 0.2 °C to 0.5 °C There was no to slight decrease in surface temperature observed in smaller parts of Arctic and Pacific Ocean. A decrement of 0.5 °C to $2.^{0}$ C have been observed in some parts of Southern Ocean along with Antarctic region. Third quarter i.e., July to September depicted an overall increase in temperature anomaly of 1.0 °C to 2.0 °C in the arctic belt, Europe, East Asia and major parts of North America and South America. The temperature in Antarctic region was again rising and the temperature anomaly have reached from 1.0 °C to 2.0 °C Indian Ocean, Pacific Ocean, Arctic

Ocean and Atlantic Ocean showed a temperature change of 0.1 °C to1 °C Fewer parts of Southern Ocean depicted no surface temperature variation. In the fourth quarter i.e., October to December the temperature in Arctic belt have again raised to a level of 4.0 °C to 5.8 °C Antarctic region also experiencing temperature rise and the figure showed an anomaly of 0.5 °C to 3.0 °C Northern region of Earth is witnessing temperature variation on a large scale as compared to southern region of Earth that can be a major concern for the Asian and European countries. Southern region of Pacific Ocean showed no surface temperature variation. On analyzing the temperature variation for the time period of 2011-22 annually we observed that the temperature of the whole world was gradually increasing. Arctic belt was heating on a great scale of 2.0 °C to 4.0 °C and some part showed a variation change up to 4.2°C. Major parts of North America, South America, Asia, Europe and Africa have experienced a positive anomaly of 1.0 °C to 2.0 °C The surface temperature of Indian Ocean was increasing evenly in the range of 0.5 °C to 1.0 °C while Pacific Ocean, Arctic Ocean and Atlantic Ocean showed a positive anomaly of 0.2 °C to 1.0 °C .Minor parts of Southern Ocean and Arctic Ocean witnessed a decline in temperature variation of 0 .2 °C to 1.0 °C. When we consider the data of all the four periods annually, we figured out that for the time period of 1981-2022, Brazil, USA, Canada, Russia, Algeria and European Nation were affected the most and the surface temperature increased up to 4.0 °C and rest of the countries showed a positive anomaly of 0.5 °C to 1.0 °C The temperature of Arctic belt has magnificently increased in the range of 1.0 °C to 2.0 °C which implied rapid melting of glaciers that can be a threat to the northern hemisphere. On the other hand, Antarctic belt experienced uneven variation such as a positive anomaly of 1.0 °C to 2.0 °C was observed in western part, a negative anomaly of 0.2 °C to 1.0 °C in the middle part and no to little positive anomaly of 0.2 °C to 1.0 °C in eastern part. The Southern part of India witnessed high positive anomaly as compared to northern part. Pacific, Arctic and Atlantic Ocean noticed an anomaly ranging between 0 °C and 0.7 °C while the anomaly of Indian Ocean is slightly more and that of 0.2 °C to 1.0.



a. First quarter (Jan – Mar)

b. Second quarter (Apr– Jun)

c. Third quarter (Jul-Sep)

d. Fourth quarter (Oct-Dec)

Figure 5. Surface temperature anomalies for 2011-2022

3.2 Latitudinal Variation of Global Surface Temperature Anomalies

In this section Global surface temperature anomalies were presented across different latitudes on a quarterly basis from 1951 to 1980.

3.2.1 GSTA for the time period of 1981-1990

Global Variation of surface temperature for period 1981-1990 was presented in **Figure 6**. During the first quarter i.e., January to March shown, the graph varied linearly from latitude -37º to -90º. The minimum surface temperature anomaly was 0.042 ℃ at -77º latitude and the maximum surface temperature anomaly was 1.570 ℃ at +89º latitude. 0.804 ℃ was the average temperature variation. In second quarter i.e., April to June a linear variation of graph was shown from -83º to -75º latitude. At -83º the surface temperature anomaly was minimum which was -0.441 ℃ and at -17º the surface temperature anomaly was maximum which was 0.371 ℃. The average temperature variation calculated was 0.206 ℃. For third quarter i.e., July to September the graph varied linearly from -83º to -81º and non-linearly from -81º to 89º. The minimum and maximum surface temperature variation was -0.033 ℃ and 0.651 ℃ respectively. The average temperature anomaly seen was 0.255 ℃. The graph variation for fourth quarter i.e., October to December was non-linear thoroughly. -0.809 ℃ was the minimum surface temperature anomaly observed at -73º and 0.383 ℃ was the maximum surface temperature anomaly observed at 63º. The mean temperature variation calculated was 0.109 ℃.

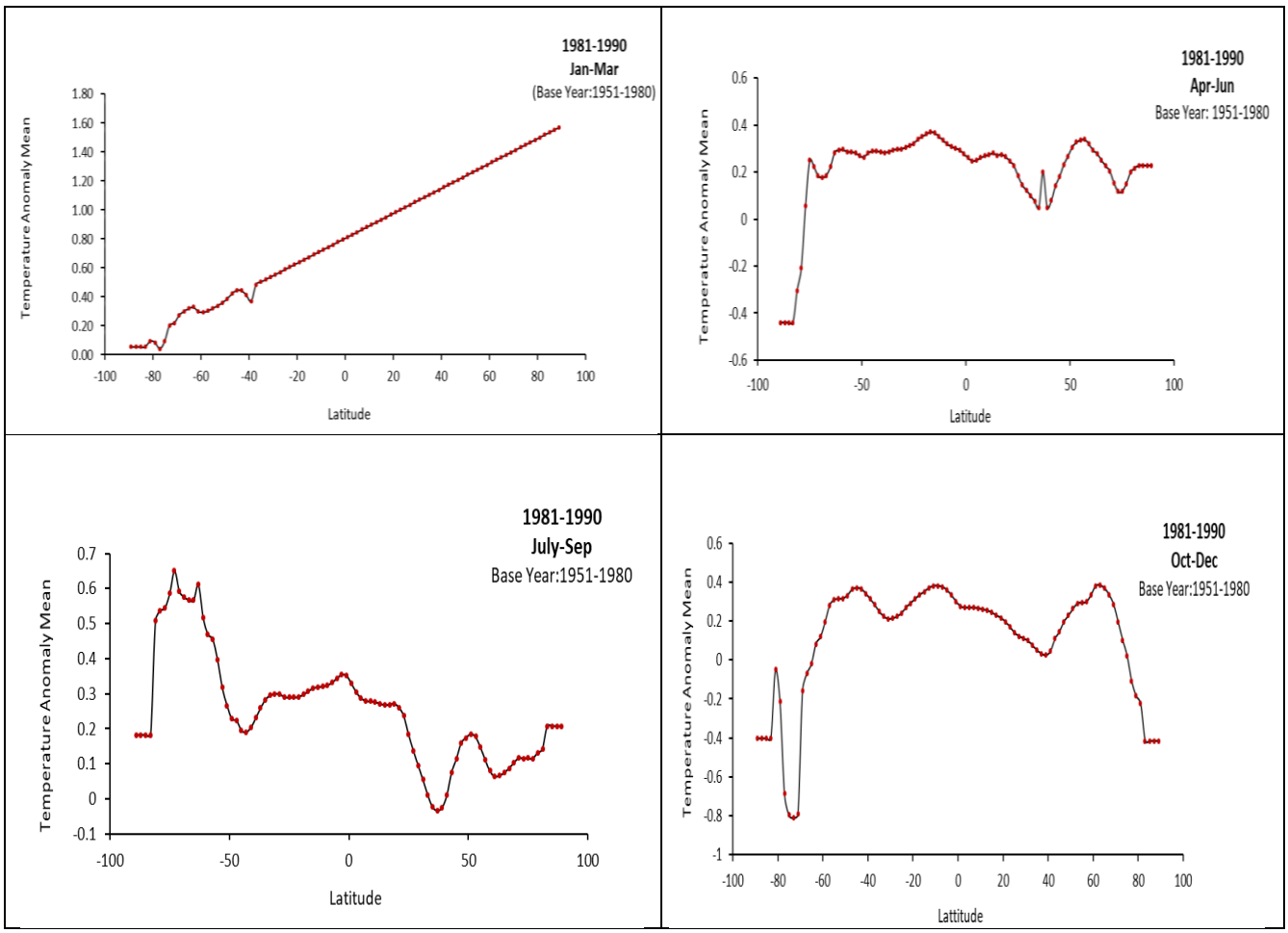


Figure 6. Global Variation of surface temperature for period for 1981-1990

3.2.2 GSTA for the time period of 1991-2000

Global Variation of surface temperature for period 1991-2000 was presented in **Figure 7**. During first quarter i.e., January to March shown the graph variation was non-linear. The average surface temperature anomaly was 0.435 ℃. The minimum surface temperature anomaly reached a negative value of -0.554 ℃ at -89º and the maximum surface temperature anomaly reached up to 1.348 ℃ at 59º.Temperature anomalies of second quarter was depicted i.e., April to June, we observed that the minimum anomaly was -0.554 ℃ at -90º to -80º, while the maximum anomaly was 0.91 ℃ at 83º to 89º. The mean surface temperature anomaly for the given time was 0.363 ℃. The temperature variation for July to September and the following results were calculated, the minimum and maximum surface temperature variation observed were 0.177 ℃ and 0.792 ℃ respectively. 0.351 ℃ was the mean anomaly during this period. In time period October to December -77º the maximum anomaly of 0.846 ℃ was noticed and at -67, the minimum anomaly was noticed. The mean surface anomaly noticed during this period was 0.372 ℃.

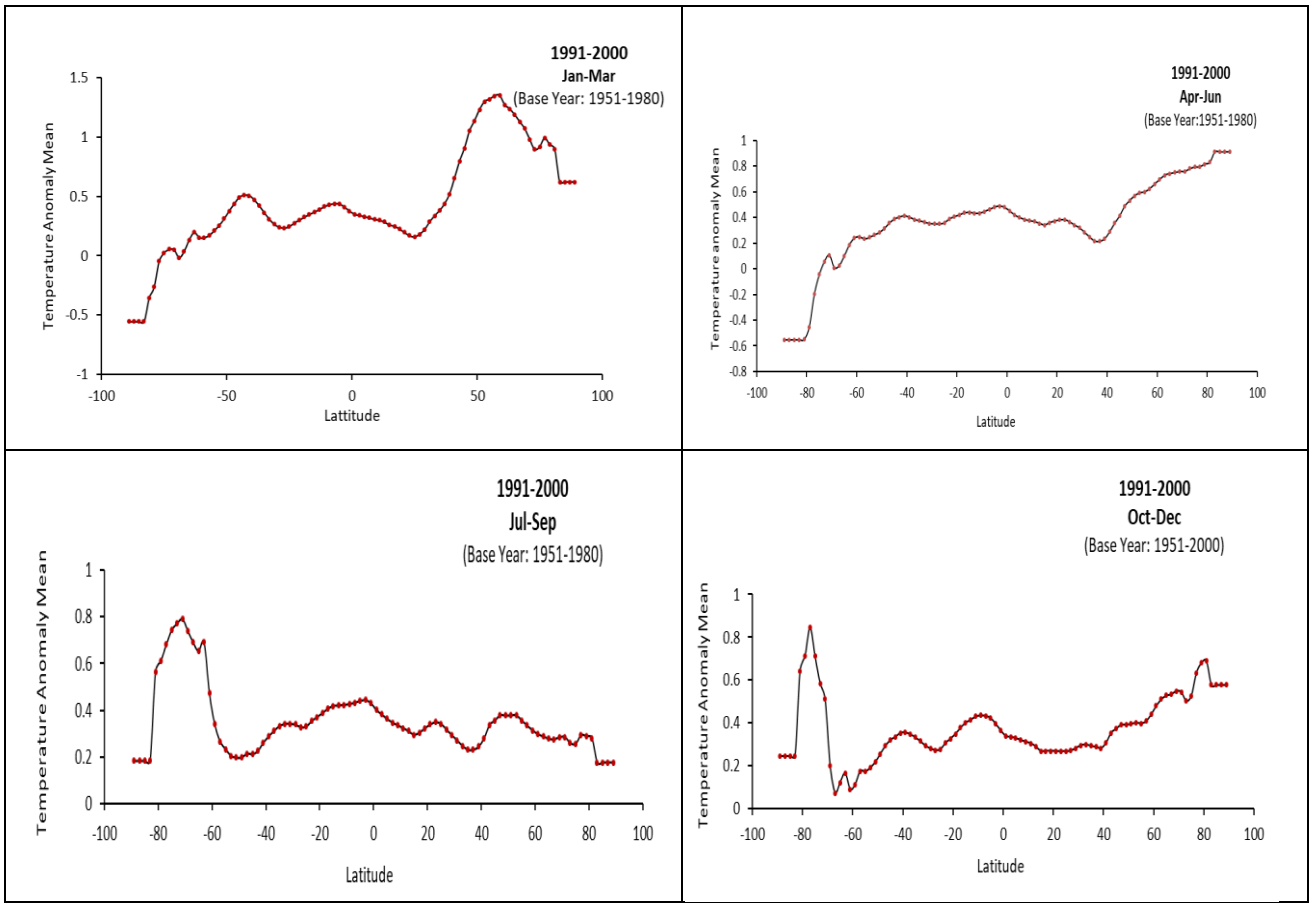


Figure 7. Global Variation of surface temperature for period 1991-2000

3.2.3. GSTA for the time period of 2001-2010

Global Variation of surface temperature for period 2001-2010 was presented in **Figure 8**. During the first quarter of this time period i.e., January to March the following results were calculated, the minimum and maximum anomaly was reached up to 0.102 ℃ and 1.971 ℃ respectively. The mean anomaly in this given period was 0.777 ℃. During the period from April to June, the surface

temperature anomaly ranged from a minimum of -0.157 ℃ to a maximum of 1.454 ℃. The mean surface temperature anomaly for this period was 0.618 ℃. The maximum value of surface temperature anomaly was 1.319 ℃ and the minimum surface temperature anomaly reached a negative value of -0.139 ℃. The average surface temperature anomaly was 0.654 ℃ during this period. The global variation of surface temperature for October to December the graph was gradually increasing from 40º to 89º latitude. -55º had the lowest temperature anomaly while 89º had the greatest temperature anomaly of 0.129 ℃ and 2.87 ℃ respectively. The mean variation was 0.843 ℃ during this quarter.

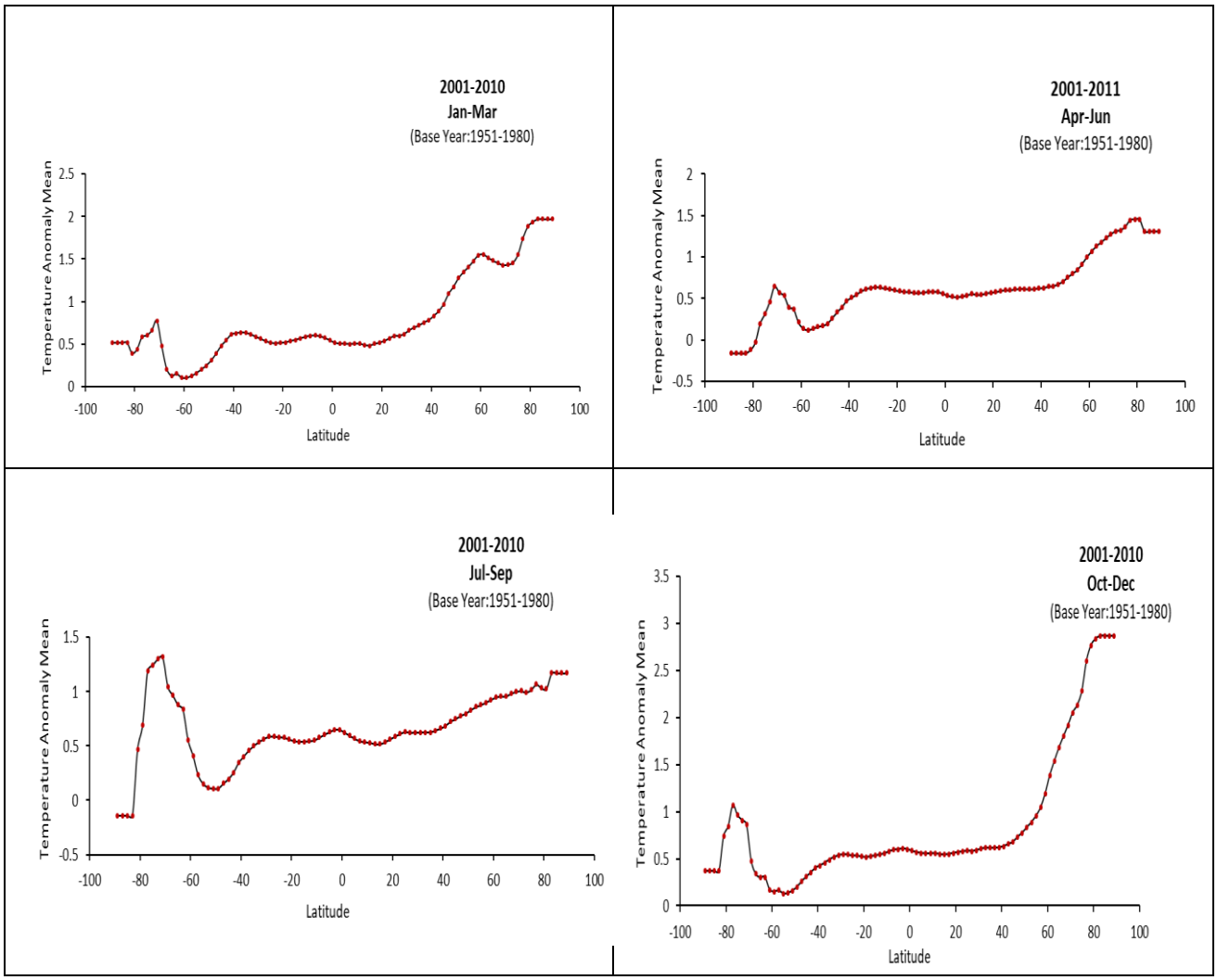


Figure 8. Global Variation of surface temperature for period 2001-2010

3.2.4 GSTA for the time period of 2011-2022

Global Variation of surface temperature for period 2011-2022 was presented in **Figure 9**. During the period of January to march the mean surface temperature anomaly observed was 1.150 ℃. The maximum and minimum values for anomaly were 4.932 ℃ and -0.019 ℃ respectively. For second quarter i.e., April to June shown the following results were calculated. The minimum surface temperature anomaly was -0.032 ℃ at -81º, the maximum was 2.287 ℃ at 81º and the mean surface anomaly was 0.865 ℃. The fourth quarter i.e., October to December is represented which showed the average temperature variation of 1.180 ℃. The maximum anomaly has reached to a peak value of 4.69 ℃ at 83º latitude and the minimum temperature anomaly was 0.155 ℃ at -57º latitude**.**

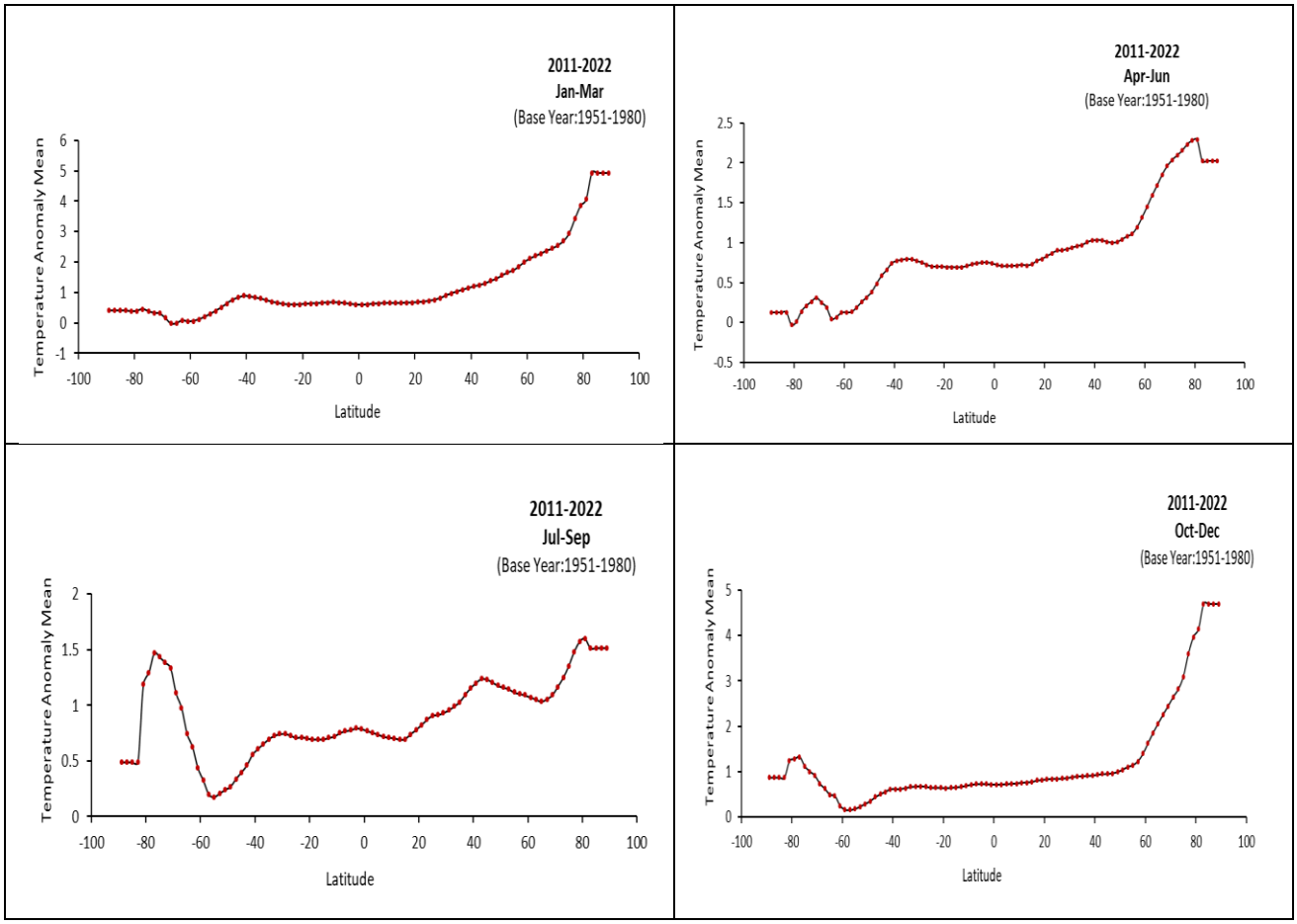


Figure 9. Global Variation of surface temperature for period for 2011-2022

Conclusion

In this study, surface temperature estimation has been done at the world level Surface temperature refers to the measurement of the temperature at the Earth's surface. It represents the heat energy present in the immediate vicinity of the ground or other surfaces. In the present study NASA data has been used to assess the surface temperature. To study the surface temperature, it has been categorized into four time periods i.e., 1981-1990, 1991-2000, 2001-2010 and 2011-2022. Furthermore, these periods are divided into 4 quarters each i.e., Jan to Mar, Apr to Jun, Jul to Sep and Oct to Dec. A detailed analysis of surface temperature on a global scale has been performed and the minimum, maximum and mean surface temperature anomalies on the latitudinal basis were calculated. The conclusions of the study are as follows:

I. Brazil, USA, Canada, Russia, Algeria and European Nation were affected the most and the surface temperature increased up to 4.0 ºC.

II. The temperature of Arctic belt has magnificently increased in the range of 1.0 ºC to 2.0 ºC which implies rapid melting of glaciers that can be a threat to the northern hemisphere. On the other hand, Antarctic belt experienced uneven variation such as a positive anomaly of 1.0 ºC to 2.0 ºC was observed in western part, a negative anomaly of 0.2 ºC to 1.0 ºC in the middle part and no to little positive anomaly of 0.2 ºC to 1.0 ºC in eastern part.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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