The Variability of Chlorophyll-a Concentration in the North-West Pacific Ocean in the Period from July 2002 to April 2022

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SEOAS, GOA UNIVERSITY TALEIGAO PLATEAU GOA

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled "The Variability of Chlorophyll-a Concentration in the North-West Pacific Ocean in the Period from July 2002 to April 2022" is based on the results of investigations carried out by me in the Discipline of Marine Sciences at the School of Earth, Ocean and Atmospheric Sciences, Goa University under the Supervision of Dr. Joshua Rosario D'Mello and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will be not be responsible for the correctness of observations / experimental or other findings given in the dissertation.

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COMPLETION CERTIFICATE

This is to certify that the dissertation report **"The Variability of Chlorophyll-a Concentration in the North-West Pacific Ocean in the Period from July 2002 to April 2022"** is a bonafide work carried out by **Ms. Mitali Ganpat Priolkar** under my supervision in partial fulfilment of the requirements for the award of the degree of **Master of Science** in the Discipline of Marine Sciences at the School of Earth, Ocean and Atmospheric Sciences, Goa University.

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PREFACE

The vast expanse of the Pacific Ocean, often described as the Earth's greatest oceanic basin, holds mysteries that continue to captivate scientists and researchers alike. Among its many secrets lies the intricate dance of chlorophyll-a concentration, a vital component in the ocean's complex web of life. Chlorophyll-a, the green pigment found in phytoplankton, serves as a primary indicator of marine productivity and the health of oceanic ecosystems.

The variability of chlorophyll-a concentration in the north-west Pacific Ocean is a subject of intense scientific scrutiny. From the cold, nutrient-rich waters of the subarctic regions to the warm, oligotrophic waters of the subtropics, the north-west Pacific Ocean offers a rich tapestry of environments where chlorophyll-a levels fluctuate in response to a myriad of biotic and abiotic factors.

Understanding the variability of chlorophyll-a concentration is not merely an academic pursuit; it has profound implications on our understanding of marine ecology, climate change, and sustainable fisheries management. Changes in chlorophyll-a levels can influence the entire marine food web, from phytoplankton to apex predators, and can serve as early indicators of environmental shifts that may have far-reaching consequences for both marine life and human societies that depend on the ocean for sustenance and livelihood. In the present era of climate change, it is important to understand the variability of chlorophyll-a concentration, in various parts of the world’s ocean too. This motivated me to study on the topic “The Variability of Chlorophyll-a concentration in north-west Pacific Ocean in the Period from July 2002 to April 2022.”

ACKNOWLEDGEMENTS

This academic year has been one of learning, enlightenment, hard work and perseverance. A large number of good people have contributed in some way or another to the completion of this dissertation work, I endeavor to thank each one of them.

Firstly, I would like to present my gratitude to God and also, I would like to thank my parents and family members for supporting and believing in me.

It gives me pleasure and honor to express my deep gratitude and heartiest thanks to my guide Dr. Joshua Rosario D'Mello, Assistant Professor, at the School of Earth, Ocean and Atmospheric Sciences, Goa University, for his valuable advice, time, patience and constant support throughout this year.

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Additionally, I would like to thank the data providers – The data is of chlorophyll-a concentration from Aqua MODIS. It is downloaded from the webpage https://oceanwatch.pifsc.noaa.gov/erddap/griddap/aqua_chla_monthly_2018_0.html on 05th December 2023.

I would like to express my sincere thanks to my friend Haysten D'costa for helping me with the installation of Ferret Software. Last but not the least, my sincere gratitude to all my friends and classmates for helping me and supporting me throughout my dissertation work.

CONTENTS

LIST OF ABBREVIATIONS

Entity	Abbreviation
Degree sign	°
Chlorophyll -a	Chl -a
Carbon dioxide	CO_2
Light Harvesting Complex	LHC
milligram per metre cube	mg/m^3
Moderate Resolution Imaging Spectroradiometer	MODIS
North	N
Nanometre	nm
Photosystem I	PS I
Photosystem II	PS II
Reaction Centers	RCs
Sea Surface Temperature	SST
West	W

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ABSTRACT

Aqua MODIS monthly chlorophyll data was used to study the variability of chlorophyll -a concentration in north-west Pacific Ocean (0°N to 40°N latitudes and 99°E to 170°W longitudes) in the period from July 2002 to April 2022. The data was averaged and the images were obtained showing the region (north-west Pacific Ocean) with variability in the chlorophyll-a distribution using Ferret Software and images of month-wise and season-wise were also obtained. Over all a negative trend of chlorophyll-a concentration was observed in north-west Pacific Ocean. The basin-average chlorophyll-a concentration in the north-west Pacific Ocean (0 ºN to 40 ºN, 99 ºE to 170 ºW) is 0.221 mg/m^3. Among the seasons the Boreal Spring Season shows the highest averaged chlorophyll-a concentration and among the months April has the highest basin-averaged chlorophyll-a concentration.

Keywords: Average, Chlorophyll-a, north-west, Pacific Ocean, Trends, Variability.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The green pigment known as chlorophyll aids plants in photosynthesis– the process by which they produce their own food. A substance or a molecule known as pigment is coloured and is capable of absorbing light at various wavelengths. Within the microscopic organelles called chloroplasts, found in plant cells, lies chlorophyll (https://education.nationalgeographic.org/resource/chlorophyll/).

Phytoplankton are microscopic, free-floating plants which contains chlorophyll pigment. They form the base of the entire marine food web. Chlorophyll absorbs sunlight. Waters with high concentration of presence of phytoplankton concentration makes the water appear greenish in colour. The process of photosynthesis helps in sustaining plants life. It also helps in production of oxygen for the entire planet earth (https://education.nationalgeographic.org/resource/chlorophyll/).

The term chlorophyll was given by French pharmacists, Joseph Bienaime Caventau and Pierre Joseph Pelletier in 1817. Chlorophyll absorbs light more strongly in the blue portion and red portion of electromagnetic spectrum. Conversely, it is poorly absorbed in green and near-green portions of the spectrum and hence chlorophyll-containing tissues appear green because green light is diffusively reflected by structures like cell walls (https://en.wikipedia.org/wiki/Chlorophyll).

With the chemical formula $C_{55}H_{72}MgN_4O_5$, chlorophyll is known as a chelating agent. Chelating agents are substances that undergo a chemical reaction with metal ions to produce a material that is soluble in water. A bigger organic molecule

called a chlorin ring is connected to the core magnesium (Mg) ion found in chlorophyll molecules. Another name for chlorophyll is the photoreceptor. Proteins with specific functions that detect and react to light are called photoreceptors. As it is a photoreceptor, chlorophyll is able to sense light. These photoreceptors gather solar energy and perform photosynthesis when light from the sun strikes them (https://study.com/academy/lesson/chlorophyll-in-plants-benefits-function-definition.html).

Plants contain structures called as cell wall which are rich in cellulose. Cellulose helps in reflecting green lights and also hinders chlorophyll to absorb green light very well. There are various benefits of chlorophyll for humans also. Chlorophyll helps in tissue repairing. Chlorophyll enhances wound healing and also reduces inflammation. Chlorophyll helps in reducing bacterial growth and also speeding up the healing process. Chlorophyll is a natural deodorant and is used for masking the odour of bed breath. It is claimed to have detoxifying effects and beneficial effects against certain cancers. (https://www.biologyonline.com/dictionary/chlorophyll).

TYPES OF CHLOROPHYLL

Initially chlorophyll was classified into four types, namely chlorophyll-a, chlorophyll-b, chlorophyll-c and chlorophyll-d. Later in western Australia a new type of chlorophyll was discovered within the stromatolites (a hard rock structure made by cyanobacteria), which was named as chlorophyll-f (Pareek et al., 2017)

Chlorophyll- a

Chlorophyll -a is a type of chlorophyll pigment which is present almost in all photosynthetic organisms, e.g. cyanobacteria, algae, aquatic species and plants.

Earlier chlorophyll -a was called as chlorophyll -α. It is found in both the Reaction Centres (RCs) in organisms, in all light harvesting complexes (LHC) and in Photosystem I (PS I) and Photosystem II (PS II). Chlorophyll -a mainly absorbs red light from the solar spectrum and the absorption peak is at 453 nm and 670– 480 nm in photosynthetic cells and 420 nm and 660 nm in organic solvents. The molecular formula of chlorophyll -a is $C_{55}H_{72}MgN_4O_5$ (Pareek et al., 2017).

Chlorophyll- b

The molecular formula of chlorophyll -b is $C_{55}H_{72}MgN_4O_6$. Earlier it was known as chlorophyll-β. Chlorophyll -b is found in green algae and higher plants. It assists chlorophyll -a in photosynthesis process. Chlorophyll -b is yellow in colour but it absorbs blue light from solar spectrum. The absorption peak of chlorophyll -b is 453 nm and 625 nm in-vitro and 480 nm and 650 nm in-vivo (Pareek et al., 2017).

Chlorophyll -c

Chlorophyll -c is a brownish-golden coloured pigment. Chlorophyll c1, c2, c3 are the three sub-classes of chlorophyll- c, out of which c1 is the most commonly found pigment. Chlorophyll -c has been also found in various algal species. It accompanies chlorophyll -a in photosynthetic processes and act as an accessory pigment. Chlorophyll -c is widely assimilated in different marine organisms like diatoms, brown algae and other marine algae. In the photosynthetic spectrum the absorption peak of chlorophyll -c was found to be 445 nm and 625 nm in organic solvents and 645 nm in vivo (Pareek et al., 2017).

Chlorophyll -d

Chlorophyll -d is the minor chlorophyll pigment which was discovered by Strain (1958) in red algae (Rhodophyta). It captures the sunlight of the extreme red end of the spectrum. The molecular formula of chlorophyll -d is $C_{54}H_{70}MgN_{406}$. The absorption spectra of chlorophyll -d was obtained at 450nm and 690nm in vitro condition and up to 740nm on red band in vivo (Pareek et al., 2017).

Chlorophyll -e

Chlorophyll -e is a rare type of pigment which was first identified in golden-yellow algae named *Vaucheria hamata* and *Tribonema bombycinum* (Pareek et al., 2017). There are some similarities found between chlorophyll -e and bacteriochlorophyll which is found in cyanobacteria. It also acts as an accessory pigment in various photosynthetic organisms. (https://thebiologynotes.com/chlorophyll/#chlorophyll-a).

Chlorophyll -f

The molecular formula of chlorophyll -f is $C_{55}H_{70}MgN_{406}$. It was the last main type of chlorophyll to be discovered. For the process of photosynthesis chlorophyll -f utilises the solar light from extreme end of the infrared spectrum (Pareek et al., 2017). It is the newest form of chlorophyll which was recently discovered in the year 2010 from the stromatolites. The function of chlorophyll -f is not yet known (https://thebiologynotes.com/chlorophyll/#chlorophyll-a).

IMPORTANCE OF CHLOROPHYLL

A vital biomolecule that is essential to photosynthesis that enables plants to absorb light's energy is chlorophyll. According to Gopi et al. (2014), it absorbs light

more intensely at 430 nm and 660 nm in the blue and red portions of the electromagnetic spectrum, respectively. The green spectrum is where chlorophyll reflects more strongly (Inanc, 2011). Chlorophyll is the most significant of these compounds, even though there are other photosynthetic pigments that absorb solar radiation, such as carotenoids and phycobilins. It transforms solar energy into chemical energy, which is then utilized to construct molecules of necessary carbohydrates (Hynninen and Leppäkases, 2002).

The amount of primary production in marine waters in response to nutrition and light availability is reflected by chlorophyll-a. Eutrophication is the result of over-enrichment of waterways with nutrients, either from natural or anthropogenic sources. This can lead to detrimental algal blooms, ecosystem degradation, biodiversity loss, and oxygen deprivation in bottom waters. To evaluate the progress made toward improving the quality of marine and coastal waters, it is essential to analyse the changes in chlorophyll-a levels over time (https://www.eea.europa.eu/en/analysis/indicators/chlorophyll-in-transitional-coastal-and#:~:text=Chlorophyll%2Da%20is%20an%20indicator,biological%20productivity%20in%20marine%20regions).

CHLOROPHYLL CONCENTRATION IN GLOBAL OCEAN

The number of photosynthetic plankton or phytoplankton in the ocean is indicated by its chlorophyll content. Winds and sea surface temperatures are two examples of the physical parameters that affect phytoplankton populations (https://www.globalchange.gov/browse/indicators/ocean-chlorophyll-concentrations#:~:text=The%20concentration%20of%20chlorophyll%20is,sea%20s

urface%20temperatures%20and%20winds). Light, carbon dioxide, and nutritional salts like phosphates and nitrates, together with a few other minor components, are necessary for photosynthesis to occur (Sverdrup, 1953).

Some of the areas with greater average amounts of chlorophyll are the continental coastline zones of the Pacific and Atlantic oceans. When the colour seems greener, there is a higher concentration of chlorophyll, indicating a higher phytoplankton population in that area. Chlorophyll concentration is used to quantify the population of phytoplankton. To transform solar energy into organic matter, phytoplankton require the pigment chlorophyll. Quantities of phytoplankton are necessary for primary production. Variables related to physics, however, can have an indirect impact on primary production. The temperature of the sea and surface winds are two examples of these variables. Nutrient availability is influenced by these factors as well. A few modifications to solar energy may potentially have an impact on primary production. Sunlight intensity variations can be brought about by cloud cover (https://www.globalchange.gov/browse/indicators/ocean-chlorophyll-concentrations#:~:text=The%20concentration%20of%20chlorophyll%20is,sea%20surface%20temperatures%20and%20winds.).

Chlorophyll -a concentrations reveal the phytoplankton biomass abundance in coastal and estuarine environments. It can therefore be applied or considered as a useful indicator of the trophic state. This may also be a sign of the maximal photosynthetic rate, which is a widely used water quality indicator, where the water's good and poor quality can be identified. High levels typically indicate poor water quality, while low levels frequently suggest good water quality. But in this setting, chlorophyll an isn't always a negative thing. Nevertheless, if the elevated levels persist over an extended period of time, it may become an issue

(https://ozcoasts.org.au/indicators/biophysicalindicators/chlorophyll_a/#:~:text=Chlorophyll%20a%20concentrations%20are%20an,used%20measure%20of%20water%20quality).

Naturally, the amounts of chlorophyll -a change with time. The concentration of chlorophyll -a is usually always higher after rain, especially if the rains have washed the nutrients into the waterbodies. On the other hand, higher light and temperature levels in the water also translate into larger concentrations of chlorophyll -a. Summers are a usual time for these increased concentrations and acts as an essential factor regulating algal biomass is the tidal regime. As the length of time that algae spend in the photic zone is shortened, the concentration of chlorophyll -a is lower in the strong tidal mixing zone. Due to tidal mixing, fine sediments are re-suspended in the water column. This results in an increase in the levels of turbidity. Thus, there is less light available for photosynthesis (https://ozcoasts.org.au/indicators/biophysicalindicators/chlorophyll_a/#:~:text=Chlorophyll%20a%20concentrations%20are%20an,used%20measure%20of%20water%20quality).

Studying the variability of chlorophyll-a concentration in the ocean is crucial for understanding various ecological and environmental processes. Monitoring changes in chlorophyll-a concentration helps researchers assess the health of marine ecosystems, track primary productivity, and understand the impacts of climate change, pollution, and other stressors on oceanic environments (Gregg and Conkright., 2002).

Various factors influence chlorophyll-a concentration, including nutrient availability, light availability, temperature, ocean currents, and mixing processes.

Identifying the primary drivers of variability helps elucidate the mechanisms governing phytoplankton dynamics (Henson et al., 2017).

Changes in chlorophyll-a concentration can have profound ecological implications, affecting the distribution and abundance of marine species, trophic interactions, and ecosystem functioning. Studying these ecological responses enhances our ability to predict the impacts of environmental change on marine biodiversity and ecosystem services (Sathyendranath et al., 2009).

Phytoplankton play a crucial role in the global carbon cycle by absorbing carbon dioxide during photosynthesis. Variability in chlorophyll-a concentration influences carbon sequestration rates and contributes to the regulation of atmospheric CO_2 levels. Understanding these biogeochemical processes is essential for predicting future climate dynamics (Behrenfeld and Falkowski, 1997).

Monitoring chlorophyll-a concentration is important for assessing the effectiveness of marine conservation and management strategies, such as marine protected areas and fisheries management. Integrating chlorophyll-a data into ecosystem models facilitates informed decision-making and sustainable resource management practices (Westberry et al., 2008).

Monitoring and analysing Chl-a concentrations can improve the ecological quality of water bodies, achieve sustainable water resource management, and provide essential scientific evidence for addressing climate change and protecting marine ecosystems (Zeng et al., 2023).

1.2 AIM AND OBJECTIVES

AIM

The aim of this dissertation work is to study the variability of chlorophyll -a concentration in north-west Pacific Ocean, in the period from July 2002 to April 2022.

OBJECTIVES

- To study the average monthly, seasonal and annual variability of chlorophyll-a concentration in north-west Pacific Ocean.
- To study the trends in the monthly, seasonal and annual variability of the chlorophyll-a concentration in the north-west Pacific Ocean.

1.3 SCOPE

The scope of this study is to study the variability of chlorophyll-a concentration in the north-west Pacific Ocean using a freely-available online dataset of monthly chlorophyll-a concentration. The study will include computing averages and the slopes of trendlines of chlorophyll-a. This is done at monthly, seasonal and for the entire time-period studied. However, the causes of the variability will not be studied.

CHAPTER 2: LITERATURE REVIEW

Marine phytoplankton generate roughly half the primary productivity (Field et al., 1998; Boyce et al., 2010). Chlorophyll a concentration can be considered as a good indicator of phytoplankton biomass due to its universal presence in all species of phytoplankton and is one of the best available approaches to evaluating physical and biological interactions in the sea and ocean (Lalli and Parsons, 1997). Since late 1997, the scanning of ocean colour is being done by sensors on satellites (Gómez-Jakobsen et al., 2022).

The concentration of chlorophyll-a varies from year to year. Processes like downwelling leads to decrease in chlorophyll-a concentrations (Annapurna and Krishna, 2021). The availability of essential nutrients, such as nitrogen and phosphorus, acts as a key factor influencing chlorophyll-a variability (Dunstan et al., 2018). In the equatorial Pacific, the ocean currents, upwelling events and water temperature are some of the factors which significantly influence chlorophyll-a distribution (Sasai et al., 2007).

The equilibrium between light penetration from the surface and nutrient delivery from the deep ocean determines the depth of the Chlorophyll-a maximum (Yasunaka et al., 2022). The vertical distribution patterns of chlorophyll in the upper ocean provide insights into the basic mechanisms governing the vertical distribution of phytoplankton abundance, which in turn influences several dynamic elements of pelagic ecosystems (Cullen et al., 1981). Chlorophyll-a concentration is maximum in the sub-surface layer rather than at the surface, in the Pacific Ocean *(*Yasunaka et al., 2022). Elevated Chlorophyll- a concentrations (≥0.2 mg m−3) were restricted to the layer above 140 m in both the northern and central regions of the South China Sea

basin. The Sub-surface Chlorophyll Maxima were visible and distinct, but in the northern winter it was superseded by a bloom of surface layer phytoplankton with a high Chl- a (Zhang et al., 2016).

The effect of reduced surface solar radiation on chlorophyll is larger in the central Pacific than in the eastern and western Pacific (Park et al., 2011). According to Sasai et al. (2007), the concentration of chlorophyll-a is high in Kuroshio and Kuroshio Extension regions and low in sub-tropical gyre. A study was conducted by Park et al. (2011) and it was found that when El Niño events occur, there is reduction in surface solar radiation and nutrient supply. This in turn results in a decrease in chlorophyll-a concentration.

Global phytoplankton concentration trends have shown a decline over the past century (Boyce et al., 2010). The North Pacific Ocean shows a declining trend over the past century (Boyce et al., 2010).

Some studies in the various regions of the north-west Pacific Ocean are given in the following paragraphs. The regions include the Bohai Sea, Yellow Sea, Taiwan Strait, near Vietnam, Malacca Strait, Celebes Sea, Sulu Sea, near Philippines and the Kuroshio Extension region near Japan.

The Chlorophyll-a in the Bohai Sea and Yellow Sea increased slowly in the recent 16 years with significant seasonal variations. Wind direction and increased human activity (e.g., river discharge) plays a significant role in changing the Chlorophyll-a distribution in the Bohai Sea and Yellow Sea (Zhao et al., 2019). A growth process from December to May was caused by the seasonal dynamics of Chlorophyll-a in the Yellow and Bohai Seas. When large swathes of the sea were at a relatively high level in the spring, the Chlorophyll-a grew gradually and peaked (Zhao et al., 2019).

Summertime saw the lowest level of Chlorophyll-a in the Bohai Sea and Yellow Sea, while September saw the highest level in the coastal areas. The deep sea's Chlorophyll-a gradually increased during the transition period, which spanned September to November, while the Bohai Sea and coastal waters showed a decreasing trend. Since the wind encourages phytoplankton aggregation and releases materials from seabed sediment, it is also one of the major factors influencing Chlorophyll-a. Another important element influencing the fluctuation of phytoplankton growth is waves (Zhao et al., 2019).

In autumn, according to the multiannual average of Chlorophyll-a data, the Chlorophyll- a distribution had a patch-shaped pattern in the Taiwan Strait (Zhang et al., 2013). In the southern Taiwan Strait, a high Chlorophyll- a water tongue in the Nan'ao–Dongsheng outer sea extending towards the Taiwan Bank was observed (Zhang et al., 2013). Tang et al. (2004) reported that the phytoplankton bloom near eastern Vietnam from June and decay in October. The higher chlorophyll- a concentration off south-eastern Vietnam may be associated with the advective transport of the colder water extending from the Karimata Strait to south-eastern Vietnam (Liu et al., 2012).

The highest values of chlorophyll-a during December–February shows the prominent signature of a "tongue" of chlorophyll-a, which extends into the Malacca Strait starting from the west of Malaysia. The generation of this tongue is observed during November, which intensifies later during December–February and then vanishes in April (Mandal et al., 2021). The temporal variation of the average chlorophyll concentration between 2007 and 2018 indicates that in December each year there is higher than normal magnitude of chlorophyll. Also, stronger winds are observed over the Malacca Strait during the north-easterlies monsoon along with the

highest wind stress magnitudes (~0.05 N/m^2) during the concurrent time and have a reasonable correlation of 0.58 (p-value <0.001) with chlorophyll-a concentration (Mandal et al., 2021). The seasonal evolution of surface wind stress curl spatial maps overlaid by chlorophyll-a concentration in the strait (Mandal et al., 2021). The seasonal chlorophyll- a variation in Malacca Strait suggests that it is similar to other Asian Monsoon regions, where the chlorophyll- a variation is related to the monsoon wind (Tan et al., 2006). Chlorophyll- *a* increased as much as twice during northeast monsoon compared to southwest monsoon in Malacca Strait (Tan et al., 2006). The coastal and southern waters in Malacca Strait have complex optical properties and these optical properties mislead the standard chlorophyll- a estimation (Tan et al., 2006).

High Chlorophyll- a waters frequently have lower temperatures than nearby waters, which suggests that cold subsurface water has been mixed or upwelled vertically. The biological productivity of the Sulu and Celebes seas may be significantly impacted by the extension of the high Chlorophyll- a waters from the Sulu Archipelago to the oligotrophic central basin area (Takeda et al., 2007). The chlorophyll- a reaches a peak of 0.9 mg/m^3 in August during South West Monsoons. In north-western of Luzon, the bloom starts in October, and reveals a strong peak (0.5 mg/m^3) in December (Liu et al., 2002).

Kuroshio intrusion is able to increase the phytoplankton chlorophyll in the open ocean of the northern South China Sea. Fronts induced by the interaction between Kuroshio intrusion and the South China Sea water can generate local upwelling and enhanced productivity. On interannual time scale, Kuroshio intrusion, local fronts, and high chlorophyll patches are dynamically linked (Guo et al., 2017).

CHAPTER 3: DATA AND METHODOLOGY

3.1 STUDY AREA:

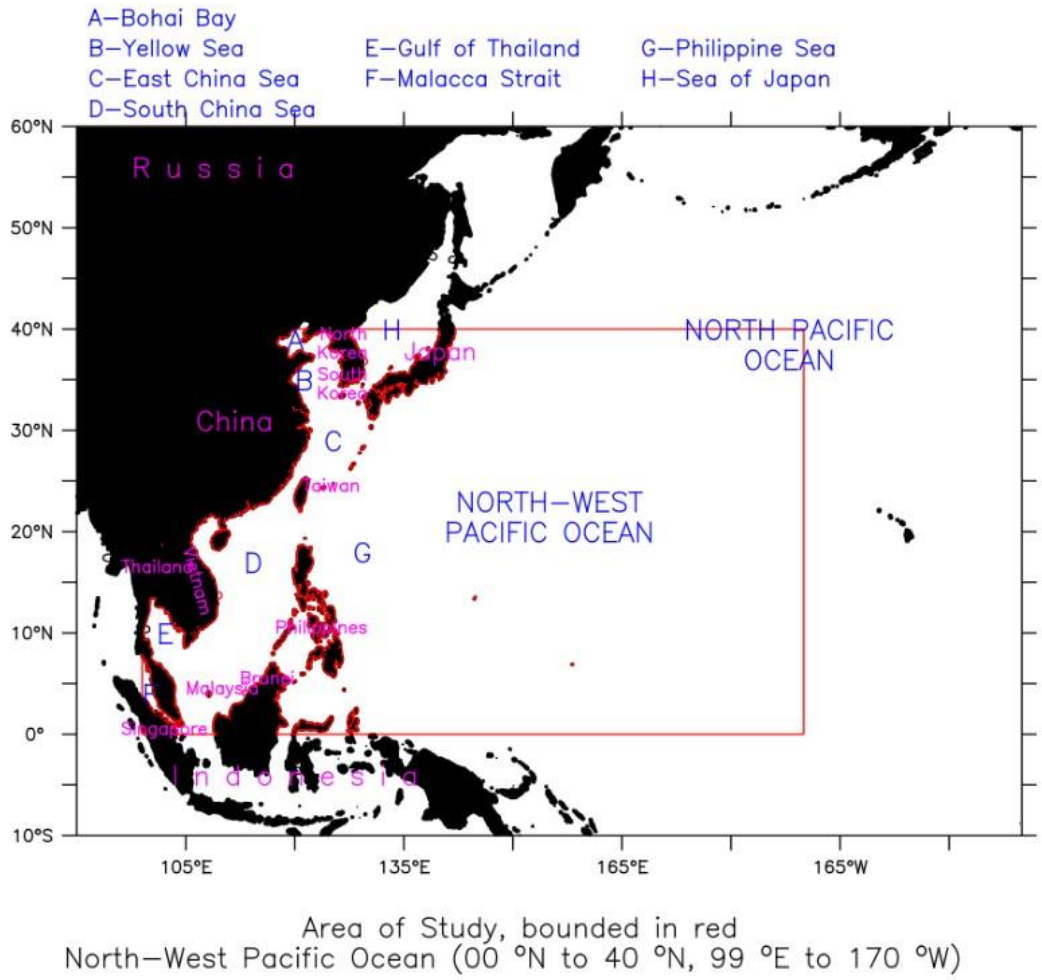


Figure 3.1 Area of study, bounded in red, in the north-west Pacific Ocean.

The area of study is the region from 0°N to 40°N latitudes and 99°E to 170°W longitudes. The north-west Pacific Ocean is a vast body of water situated in the northern hemisphere, bordered by the eastern coastlines of Asia and the western coasts of North America. It encompasses a significant portion of the Pacific Ocean basin and is known for its diverse ecosystems, marine life, and dynamic weather patterns.

Geographically, the northwest Pacific Ocean extends from the Bering Sea in the north, near the Arctic Ocean, to the tropical waters of south-east Asia in the south. It is bounded by countries such as Russia, Japan, China, South Korea, North Korea, the Philippines, and various island nations (https://www.britannica.com/place/Pacific-Ocean)

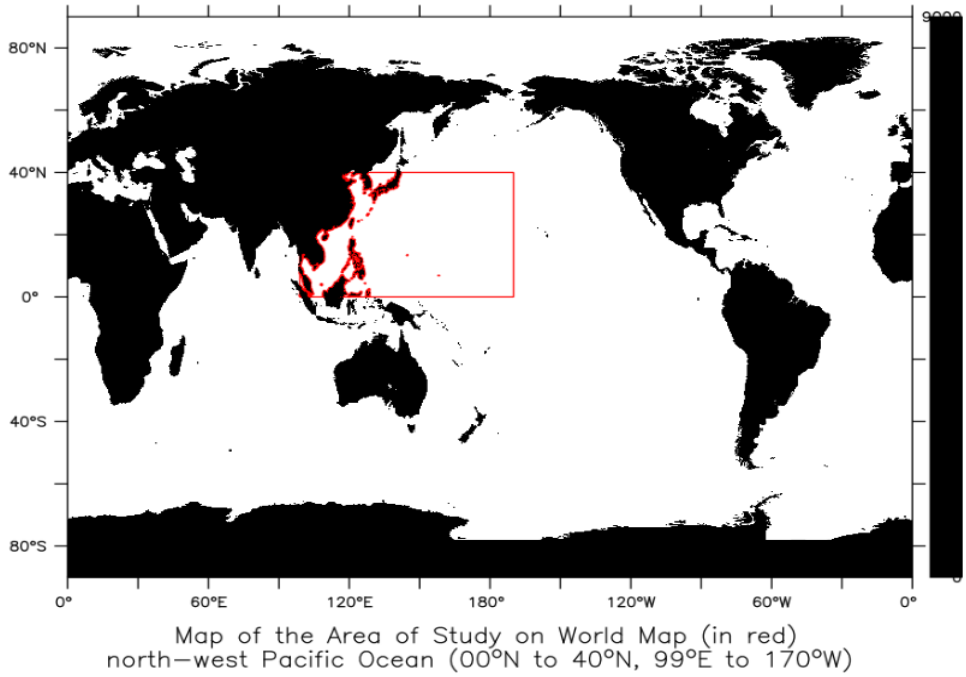


Figure 3.2 Area of study, bounded in red, in the north-west Pacific Ocean on world map.

3.2 DATA SOURCE

The data for chlorophyll-a is downloaded from the webpage https://oceanwatch.pifsc.noaa.gov/erddap/griddap/aqua_chla_monthly_2018_0.html on 05th December 2023. The data is of chlorophyll-a concentration, from Aqua MODIS. It is monthly data in the period from July 2002 to April 2022. The data is

from the Equator to 40 °N and from 99 °E to 170 °W, downloaded every 1 degree by 1 degree.

3.3 METHODOLOGY

The chlorophyll-a concentration data is downloaded from Aqua MODIS and is taken from the website https://oceanwatch.pifsc.noaa.gov/erddap/griddap/aqua_chla_monthly_2018_0.html on 05 December 2023.

The chlorophyll-a concentration data is from July 2002 to April 2022 i.e. for 19 years and is monthly. The data is from Aqua MODIS. The data was averaged and the images were obtained showing the region (north-west Pacific Ocean) with variability in the chlorophyll-a distribution using Ferret Software.

PROGRAM-3.1

The program below plots the area of study bounded in red, in north-west Pacific Ocean of Figure 3.1

```
! 02nd Feb 2024
! This program plots the study area region, i.e. north-west Pacific Ocean (00N to 40N, 99E to 170W) on the world map, to study the chlorophyll-a concentration
!This program also plots the magnified study area, and lables the various areas

SET WINDOW 2
SET Region/ x=90E:500W/ y=10S:60N
USE etopo05.cdf
! SET Mode metafile
! CONTOUR/ Level=(0)/ Title="Area of Study, bounded in red, in the north-west Pacific Ocean<nl>(00 N - 40 N, 99 E - 170 W)" rose
CONTOUR/ Level=(0)/ Nolab rose
```

SET Region/ x=99E:170W/ y=00N:40N

CONTOUR/ Overlay/ Level=(0)/ Colour=2/ Nolabel rose

GO box 99 190 00 40 02

SET Region/ x=90E:500W/ y=10S:60N

SHADE/ Overlay/ Level=(0 9000 9000)/ Palette=black/ Nolabel rose

LABEL 150 -20 0 0 0.16 " Area of Study, bounded in red<nl>North-West Pacific Ocean (00 ^oN to 40 ^oN, 99 ^oE to 170 ^oW)"

! Labels in Sea

LABEL 188 39 0 0 0.16 "@c004NORTH PACIFIC<nl>OCEAN"

LABEL 155 22 0 0 0.16 "@c004NORTH-WEST<nl>PACIFIC OCEAN"

! Labels on land

LABEL 117 30 1 0 0.16 "@c006China"

LABEL 120 55 1 0 0.16 "@c006R u s s i a"

LABEL 106 16 1 0 0.10 "@c006Thailand"

LABEL 106 15 0 285 0.10 "@c006Vietnam"

LABEL 105 04 -1 0 0.10 "@c006Malaysia"

LABEL 108 00 1 0 0.10 "@c006Singapore"

LABEL 120 05 1 0 0.10 "@c006Brunei"

LABEL 130 10 1 0 0.10 "@c006Philippines"

LABEL 121 24 -1 0 0.10 "@c006Taiwan"

LABEL 145 37 1 0 0.14 "@c006Japan"

LABEL 130 39 1 0 0.10 "@c006North<nl>Korea"

LABEL 130 35 1 0 0.10 "@c006South<nl>Korea"

LABEL 120 -5 0 0 0.16 "@c006I n d o n e s i a"

! Other label with codes

LABEL 117 038 -1 0 0.16 "@c004 A"

LABEL 090 070 -1 0 0.13 "@c004 A-Bohai Bay"

LABEL 118 034 -1 0 0.16 "@c004 B"

LABEL 090 067 -1 0 0.13 "@c004 B-Yellow Sea"

LABEL 122 028 -1 0 0.16 "@c004 C"

LABEL 090 064 -1 0 0.13 "@c004 C-East China Sea"

LABEL 111 016 -1 0 0.16 "@c004 D"

LABEL 090 061 -1 0 0.13 "@c004 D-South China Sea"

LABEL 099 009 -1 0 0.16 "@c004 E"

LABEL 128 067 -1 0 0.13 "@c004 E-Gulf of Thailand"

LABEL 097 003 -1 0 0.16 "@c004 F"

LABEL 128 064 -1 0 0.13 "@c004 F-Malacca Strait"

LABEL 126 017 -1 0 0.16 "@c004 G"

LABEL 166 067 -1 0 0.13 "@c004 G-Philippine Sea"

LABEL 130 039 -1 0 0.16 "@c004 H"

LABEL 166 064 -1 0 0.13 "@c004 H-Sea of Japan"

! CANCEL Mode metafile

FRAME/ File=Study_Area_North_West_Pacific_Ocean.gif

! sp Fprint -o "Study_Area_North_West_Pacific_Ocean.ps" -l cps -p portrait metafile.plt

PROGRAM-3.2

The program below plots the study area used to study the chlorophyll-a concentration on world map of Figure 3.2

! 02nd February 2024

! This program plots the study area region, i.e. north-west Pacific Ocean (00N to 40N, 99E to 170W) on the world map, to study the chlorophyll-a concentration

! This program also plots the study area, and labels the various areas

SET WINDOW 1

SET Mode verify

SET Region/ x=00E:360E/ y=90S:90N

USE etopo05.cdf

! SET Mode metafile

SHADE/ Level=(0 9000 9000)/ Palette=black/ Nolabel rose

CONTOUR/ Overlay/ Level=(0)/ Colour=02/ Nolabel rose[x=99E:170W, y=00N:40N]

GO box 99 190 00 40 02

SHADE/ Overlay/ Level=(1 9000 9000)/ Palette=black/ Nolabel rose

LABEL/Nouser 3.9 -0.7 0 0 0.16 " Map of the Area of Study on World Map (in red) <nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW)"

! CANCEL Mode metafile

FRAME/ File=Study_Area_North_West_Pacific_Ocean_00N40N99E190E.gif

<u>PROGRAM-3.3</u>

The program below plots the maps of chlorophyll-a concentration averaged in the entire period, month-wise and season-wise of Figure 4.1 to Figure 4.17

! Friday, 05 January 2024

! This programme plots the maps of average of chlorophyll-a, in the north-west Pacific Ocean (00 °N to 40 °N, 99 °W to 170 °W), in the period from July 2002 to April 2022.

! The maps are for the entire period's time-series, and also month-wise and season-wise.

!!!

! The dataset is Aqua MODIS Chlorophyll-a, 1°, Global, Monthly, July 2002-present, v. 2018.0

! The datafile Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc was downloaded from

! https://oceanwatch.pifsc.noaa.gov/erddap/griddap/aqua_chla_monthly_2018_0.html , on 05 December 2023.

! The dataset contains the variable chlorophyll-a (chl-a).

! The chlorophyll-a data is global (90 °N to 90 °S, 180 °W to 180 °E), and is 1° by 1° spatially. A stride of 12 was given while downloading the data from the website.

! The chlorophyll-a data is on the sea surface.

! The citation is Hu, C., Z. Lee, and B. Franz. (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, Journal of Geophysical Research, 117, C01011. d.o.i.: 10.1029/2011JC007395.

!!

USE Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc ! Dataset of Chlorophyll-a in the period from July 2002 to April 2022

SHOW Data

KEYMARK 1 ! This command gives the maximum value and minimum value of the variable, above and below the colour bar, respectively

```
LET Chlorophyll_a_filled = Chlor_a[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, l=1:238@fln:12]
! Average Chlorophyll-a Map in the period from July 2002 to April 2022
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_filled[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_filled[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.15 "Chlorphyll-a concentration (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_17_Time_Series_00N40N099E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_Concentration_17_Time_Series_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Month-wise plots
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
LET Chlorophyll_a_Jan = Chlorophyll_a_filled[l=7:238:12]
LET Chlorophyll_a_Feb = Chlorophyll_a_filled[l=8:238:12]
LET Chlorophyll_a_Mar = Chlorophyll_a_filled[l=9:238:12]
LET Chlorophyll_a_Apr = Chlorophyll_a_filled[l=10:238:12]
LET Chlorophyll_a_May = Chlorophyll_a_filled[l=11:238:12]
LET Chlorophyll_a_Jun = Chlorophyll_a_filled[l=12:238:12]
LET Chlorophyll_a_Jul = Chlorophyll_a_filled[l=1:238:12]
LET Chlorophyll_a_Aug = Chlorophyll_a_filled[l=2:238:12]
LET Chlorophyll_a_Sep = Chlorophyll_a_filled[l=3:238:12]
```

```
LET Chlorophyll_a_Oct = Chlorophyll_a_filled[l=4:238:12]
LET Chlorophyll_a_Nov = Chlorophyll_a_filled[l=5:238:12]
LET Chlorophyll_a_Dec = Chlorophyll_a_filled[l=6:238:12]
! Average Chlorophyll-a Map in January
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" "
Chlorophyll_a_Jan[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-
2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Jan[x=99E:170W,
y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "January Chlorophyll-a (mg/m^3) in the<nl>north-
west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period
from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_01_Month_Jan_00N40N99E170W_200207_202204.
gif"
sp Fprint -o "Chlorophyll_a_01_Month_Jan_00N40N99E170W_200207_202204.ps"
-l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in February
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" "
Chlorophyll_a_Feb[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-
2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Feb[x=99E:170W,
y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "February Chlorophyll-a (mg/m^3) in the<nl>north-
west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period
from July 2002 to April 2022"
GO land
USE etopo05.cdf
```

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_02_Month_Feb_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_02_Month_Feb_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in March
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Mar[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Mar[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "March Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_03_Month_Mar_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_03_Month_Mar_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in April
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Apr[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Apr[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "April Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_04_Month_Apr_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_04_Month_Apr_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in May
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_May[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_May[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "May Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_05_Month_May_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_05_Month_May_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

```
! Average Chlorophyll-a Map in June
SET MODE Metafile

SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Jun[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Jun[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "June Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land

USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_06_Month_Jun_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_06_Month_Jun_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! Average Chlorophyll-a Map in July
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Jul[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Jul[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "July Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
```

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_07_Month_Jul_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_07_Month_Jul_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in August
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Aug[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Aug[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "August Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_08_Month_Aug_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_08_Month_Aug_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! Average Chlorophyll-a Map in September
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Sep[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Sep[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

LABEL/Nouser 3.9 -0.8 0 0 0.14 "September Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_09_Month_Sep_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_09_Month_Sep_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in October
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Oct[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Oct[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "October Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_10_Month_Oct_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_10_Month_Oct_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! Average Chlorophyll-a Map in November
SET MODE Metafile

SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Nov[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Nov[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

LABEL/Nouser 3.9 -0.8 0 0 0.14 "November Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_11_Month_Nov_00N40N99E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_11_Month_Nov_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in December

SET MODE Metafile

SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_Dec[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_Dec[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

LABEL/Nouser 3.9 -0.8 0 0 0.14 "December Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_12_Month_Dec_00N40N99E170W_200207_202204.gif"

```
sp Fprint -o "Chlorophyll_a_12_Month_Dec_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Season-wise plots
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
LET Chlorophyll_a_FMA = Chlorophyll_a_feb[l=1:19:1] * (28.25/89.25) + Chlorophyll_a_mar[l=1:19:1] * (31/89.25) + Chlorophyll_a_apr[l=1:19:1] * (30/89.25)	! Boreal Spring Season
LET Chlorophyll_a_MJJ = Chlorophyll_a_may[l=1:18:1] * (31/92) + Chlorophyll_a_jun[l=1:18:1] * (30/92) + Chlorophyll_a_jul[l=2:19:1] * (31/92)	! Boreal Summer Season
LET Chlorophyll_a_ASO = Chlorophyll_a_aug[l=1:19:1] * (31/92) + Chlorophyll_a_sep[l=1:19:1] * (30/92) + Chlorophyll_a_oct[l=1:19:1] * (31/92)	! Boreal Autumn Season
LET Chlorophyll_a_NDJ = Chlorophyll_a_nov[l=1:19:1] * (30/92) + Chlorophyll_a_dec[l=1:19:1] * (31/92) + Chlorophyll_a_jan[l=1:19:1] * (31/92)	! Boreal Winter Season

! Average Chlorophyll-a Map in Boreal Spring Season
 SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_FMA[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_FMA[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "Boreal Spring Season Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
```

```
FRAME/File="Chlorophyll_a_13_Season_FMA_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_13_Season_FMA_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in Boreal Summer Season
 SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_MJJ[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_MJJ[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "Boreal Summer Season Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_14_Season_MJJ_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_14_Season_MJJ_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in Boreal Autumn/ Fall Season
 SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_ASO[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_ASO[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
```

LABEL/Nouser 3.9 -0.8 0 0 0.14 "Boreal Autumn Season Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_15_Season_ASO_00N40N99E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_15_Season_ASO_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Average Chlorophyll-a Map in Boreal Winter Season
SET MODE Metafile
SHADE/ Level=(0 1 0.25)(1 2 1)(inf)/ Palette=rainbow/ Title=" " Chlorophyll_a_NDJ[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 50 5)/ Nolab Chlorophyll_a_NDJ[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
LABEL/Nouser 3.9 -0.8 0 0 0.14 "Boreal Winter Season Chlorophyll-a (mg/m^3) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022"
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_16_Season_NDJ_00N40N99E170W200207_202204.gif"
sp Fprint -o "Chlorophyll_a_16_Season_NDJ_00N40N99E170W_200207_202204.ps" -l cps -p portrait metafile.plt

PROGRAM-3.4

The program below plots maps of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) for the entire time-period, month-wise and season-wise from Figure 4.18 to Figure 4.34

```
! 10th of February 2024
! This program plots the chlorophyll-a trendlines from July 2002 to April 2022.
! The Chlorophyll -a data used was downloaded from the webpage:https://oceanwatch.pifsc.noaa.gov/erddap/griddap/aqua_chla_monthly_2018_0.html, on 5th December 2023
! The dataset contains the variable chlorophyll-a (chl-a).
! The chlorophyll-a data is global (90 °N to 90 °S, 180 °W to 180 °E), and is 1° by 1° spatially. A stride of 12 was given while downloading the data from the website.
! The chlorophyll-a data is on the sea surface.
! The citation is Hu, C., Z. Lee, and B. Franz. (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, Journal of Geophysical Research, 117, C01011. d.o.i.: 10.1029/2011JC007395
USE Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc
                    ! Dataset of Chlorophyll-a in the period from July 2002 to April 2022
SHOW Data
KEYMARK 1                    ! This command gives the maximum value and minimum value of the variable, above and below the colour bar, respectively.
LET Chlorophyll_a_filled = Chlor_a[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, l=1:238@fln:12]
! Months
LET Chlorophyll_a_Jan = Chlorophyll_a_filled[l=7:238:12]
LET Chlorophyll_a_Feb = Chlorophyll_a_filled[l=8:238:12]
LET Chlorophyll_a_Mar = Chlorophyll_a_filled[l=9:238:12]
LET Chlorophyll_a_Apr = Chlorophyll_a_filled[l=10:238:12]
LET Chlorophyll_a_May = Chlorophyll_a_filled[l=11:238:12]
```

```
LET Chlorophyll_a_Jun = Chlorophyll_a_filled[l=12:238:12]
LET Chlorophyll_a_Jul = Chlorophyll_a_filled[l=1:238:12]
LET Chlorophyll_a_Aug = Chlorophyll_a_filled[l=2:238:12]
LET Chlorophyll_a_Sep = Chlorophyll_a_filled[l=3:238:12]
LET Chlorophyll_a_Oct = Chlorophyll_a_filled[l=4:238:12]
LET Chlorophyll_a_Nov = Chlorophyll_a_filled[l=5:238:12]
LET Chlorophyll_a_Dec = Chlorophyll_a_filled[l=6:238:12]
! Seasons
! Boreal Spring Season
LET Chlorophyll_a_FMA = Chlorophyll_a_feb[l=1:20:1] * (28.25/89.25) +
Chlorophyll_a_mar[l=1:20:1] * (31/89.25) + Chlorophyll_a_apr[l=1:20:1] *
(30/89.25)
! Boreal Summer Season
LET Chlorophyll_a_MJJ = Chlorophyll_a_may[l=1:19:1] * (31/92) +
Chlorophyll_a_jun[l=1:19:1] * (30/92) + Chlorophyll_a_jul[l=2:20:1] * (31/92)
! Boreal Autumn Season
LET Chlorophyll_a_ASO = Chlorophyll_a_aug[l=1:20:1] * (31/92) +
Chlorophyll_a_sep[l=1:20:1] * (30/92) + Chlorophyll_a_oct[l=1:20:1] * (31/92)
! Boreal Winter Season
LET Chlorophyll_a_NDJ = Chlorophyll_a_nov[l=1:20:1] * (30/92) +
Chlorophyll_a_dec[l=1:20:1] * (31/92) + Chlorophyll_a_jan[l=1:20:1] * (31/92)
! For entire time-period
SET MODE Metafile
LET p =
t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc,
gl=1:238:1]
LET q = Chlorophyll_a_filled[l=1:238:1]
SET Grid q
GO regresst
! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it
into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope*60*60*24*365.25
SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab
Slope_per_year[x=99E:170W, y=00N:40N]
```

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in the<nl>north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_17_Time_Series_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_17_Time_Series_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Month-wise

! January

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Jan[l=1:20:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>January in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_Slope_01_Jan_00N40N099E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Jan_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! February
SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Feb[l=1:20:1]
SET Grid q
GO regresst
! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope*60*60*24*365.25
SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]
CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare
LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>February in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."
GO land

USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_Slope_01_Feb_00N40N099E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Feb_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! March
SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Mar[l=1:20:1]
SET Grid q
GO regresst
! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope*60*60*24*365.25
SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]
CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare
LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>March in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_Slope_01_Mar_00N40N099E170W_200207_202204.gif"

```
sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Mar_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! April
SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Apr[l=1:20:1]
SET Grid q
GO regresst
! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope*60*60*24*365.25
SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]
CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare
LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>April in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_Slope_01_Apr_00N40N099E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_Concentration_Slope_01-Apr_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! May
SET MODE Metafile
```

```
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:19:1]
LET q = Chlorophyll_a_May[l=1:19:1]
SET Grid q
GO regresst
! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope*60*60*24*365.25
SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]
CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare
LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>May in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_Slope_01_May_00N40N099E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_May_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! June
SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:19:1]
LET q = Chlorophyll_a_Jun[l=1:19:1]
SET Grid q
```

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>June in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_Jun_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Jun_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! July

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Jul[l=1:20:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>July in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_Jul_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Jul_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! August

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Aug[l=1:20:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>August in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_Aug_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Aug_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! September

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Sep[l=1:20:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>September in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE

to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_Sep_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Sep_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! October

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:19:1]

LET q = Chlorophyll_a_Jun[l=1:19:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>June in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_Jun_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Jun_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! November

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Nov[l=1:20:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>November in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_Nov_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Nov_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

```
! December
SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Dec[l=1:20:1]
SET Grid q
GO regresst
! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope*60*60*24*365.25
SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]
CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare
LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>December in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_Slope_01_Dec_00N40N099E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_Dec_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! Season-wise plots
! Boreal spring season
SET MODE Metafile
```

```
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_FMA[l=1:20:1]
SET Grid q
GO regresst
! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope*60*60*24*365.25
SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]
CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]
CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare
LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>Boreal Spring Season in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."
GO land
USE etopo05.cdf
SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose
CANCEL MODE Metafile
FRAME/File="Chlorophyll_a_Concentration_Slope_01_FMA_00N40N099E170W_200207_202204.gif"
sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_FMA_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! Boreal Summer Season
SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:19:1]
LET q = Chlorophyll_a_MJJ[l=1:19:1]
```

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>Boreal Summer Season in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_MJJ_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_MJJ_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Boreal Autumn Season

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_ASO[l=1:20:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>Boreal Autumn Season in the north-west Pacific Ocean (00^oN to

40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_ASO_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_ASO_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Boreal Winter Season

SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_NDJ[l=1:20:1]

SET Grid q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope*60*60*24*365.25

SHADE/ Level=(-inf)(-0.2 0.2 0.1)(inf)/ Palette=no_green/ Nolab Slope_per_year[x=99E:170W, y=00N:40N]

CONTOUR/ Over/ Level=(0)/ Nolab Slope_per_year[x=99E:170W, y=00N:40N, T="16-JUL-2002":"16-APR-2022"@ave]

CONTOUR/ Over/ Level=(0 1 0.25)/ Colour=3/ Nolab Rsquare

LABEL/Nouser 3.9 -0.6 0 0 0.15 "Map of slopes of trendlines of Chlorophyll-a concentration ((mg/m^3)/year) in<nl>Boreal Winter Season in the north-west Pacific Ocean (00^oN to 40^oN, 99^oE to 170^oW),<nl>averaged in the period from July 2002 to April 2022.<nl>Coefficient of Determination (R^2) is contoured at 0.25 interval."

GO land

USE etopo05.cdf

SHADE/ Overlay/ Palette=black/ Level=(0 9000 9000)/ Nolab rose

CANCEL MODE Metafile

FRAME/File="Chlorophyll_a_Concentration_Slope_01_NDJ_00N40N099E170W_200207_202204.gif"

sp Fprint -o "Chlorophyll_a_Concentration_Slope_01_NDJ_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

PROGRAM-3.5

The program below plots the line plots of chlorophyll-a concentration basin-averaged from July 2002 to April 2022 for entire time-period, month-wise and season-wise from Figure 4.35 to Figure 4.51

! 23 February 2024.

! The program below plots the line plots of chlorophyll-a concentration basin-averaged from July 2002 to April 2022.

! This program plots the chlorophyll-a concentration and its trendlines, basin-averaged in the region (0N to 40 N, 99E to 170 W), in the period from July 2002 to April 2022.

! The dataset is Aqua MODIS chlorophyll-a, 1°, Global, Monthly, July 2002-present, v.2018.0

! The datafile Chlorophyll-a_Concentration_MODIS_Aqua_90S90N180W180E_200207_202204.nc was downloaded from

https://oceanwatch.pifsc.noaa.gov/erddap/griddap/aqua_chla_monthly_2018_0.html , on 05 December 2023.

! The dataset contains the variable Chlorophyll-a (chlor-a).

! The Chlorophyll-a data is global (90 °N to 90 °S, 180 °W to 180 °E), and is 1° by 1° spatially. A stride of 12 was given while downloading this data from the website.

! The chlorophyll-a data is on the sea surface.

! The citation is Hu, C., Z. Lee and B. Franz. (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference. Journal of Geophysical Research, 117, C01011. d.o.i.: 10.1029/2011JC007395.

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
USE Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc
                                   ! Dataset of Chlorophyll-a in the period from July 2002 to April 2022
SET REGION/ X=99E:170W/ Y=00N:40N
                         ! North-west Pacific Ocean
SHOW Data
LET Chlorophyll_a_filled = Chlor_a[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, l=1:238@fln:12]
! SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:238:1]
LET q = Chlorophyll_a_filled[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:238:1]
SET GRID q
GO regresst
 ! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25          ! To calculate slope in units per year, as originally it was in units per second.  LET
```

```
Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)" )
LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)" )
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)" )
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_filled[x=99E:170W@ave, y=00N:40N@ave, l=1:238@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_filled[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]
LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
! CANCEL Mode Metafile FRAME/ File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_00N40N099E170W_200207_202204.gif
! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Months
LET Chlorophyll_a_Jan = Chlorophyll_a_filled[l=7:238:12]
LET Chlorophyll_a_Feb = Chlorophyll_a_filled[l=8:238:12]
LET Chlorophyll_a_Mar = Chlorophyll_a_filled[l=9:238:12]
LET Chlorophyll_a_Apr = Chlorophyll_a_filled[l=10:238:12]
```

```
LET Chlorophyll_a_May = Chlorophyll_a_filled[l=11:238:12]
LET Chlorophyll_a_Jun = Chlorophyll_a_filled[l=12:238:12]
LET Chlorophyll_a_Jul = Chlorophyll_a_filled[l=1:238:12]
LET Chlorophyll_a_Aug = Chlorophyll_a_filled[l=2:238:12]
LET Chlorophyll_a_Sep = Chlorophyll_a_filled[l=3:238:12]
LET Chlorophyll_a_Oct = Chlorophyll_a_filled[l=4:238:12]
LET Chlorophyll_a_Nov = Chlorophyll_a_filled[l=5:238:12]
LET Chlorophyll_a_Dec = Chlorophyll_a_filled[l=6:238:12]
! Seasons
! Boreal Spring Season
LET Chlorophyll_a_FMA = Chlorophyll_a_feb[l=1:20:1] * (28.25/89.25) +
Chlorophyll_a_mar[l=1:20:1] * (31/89.25) + Chlorophyll_a_apr[l=1:20:1] *
(30/89.25)
! Boreal Summer Season
LET Chlorophyll_a_MJJ = Chlorophyll_a_may[l=1:19:1] * (31/92) +
Chlorophyll_a_jun[l=1:19:1] * (30/92) + Chlorophyll_a_jul[l=2:20:1] * (31/92)
! Boreal Autumn Season
LET Chlorophyll_a_ASO = Chlorophyll_a_aug[l=1:20:1] * (31/92) +
Chlorophyll_a_sep[l=1:20:1] * (30/92) + Chlorophyll_a_oct[l=1:20:1] * (31/92)
! Boreal Winter Season
LET Chlorophyll_a_NDJ = Chlorophyll_a_nov[l=1:20:1] * (30/92) +
Chlorophyll_a_dec[l=1:20:1] * (31/92) + Chlorophyll_a_jan[l=1:20:1] * (31/92)
! Month-wise
! January
!SET MODE Metafile
LET p =
t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc,
gl=1:20:1]
LET q =
Chlorophyll_a_Jan[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207
_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]
SET GRID q
GO regresst
```

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Jan[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_Jan[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of January<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."

LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3" !CANCEL Mode Metafile

FRAME/ File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Jan_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Jan_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! February

!SET MODE Metafile

```
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Feb[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]
SET GRID q
GO regresst
 ! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.
LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)" )
LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)" )
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)" )
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Feb[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_Feb[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]
LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of February<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
!CANCEL Mode Metafile
```

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Feb_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Feb_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! March

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Mar[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Mar[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_Mar[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of March<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."

LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"

!CANCEL Mode Metafile

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Mar_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Mar_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! April

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Apr[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Apr[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_Apr[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of April<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."

LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"

!CANCEL Mode Metafile

FRAME/ File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Apr_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Apr_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! May

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:19:1]

LET q = Chlorophyll_a_May[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:19:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_May[x=99E:170W@ave, y=00N:40N@ave, l=1:19@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_May[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of May<nl>inthe period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."

LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"

!CANCEL Mode Metafile

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_May_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_May_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! June

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:19:1]

```
LET q = Chlorophyll_a_Jun[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_20020
7_202204.nc, x=99E:170W, y=00N:40N, l=1:19:1]
SET GRID q
GO regresst
 ! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.
LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)" )
LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)" )
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)" )
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Jun[x=99E:170W@ave, y=00N:40N@ave, l=1:19@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_Jun[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]
LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of June<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
!CANCEL Mode Metafile
FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Jun_00N40N099E170W_200207_202204.gif
```

```
! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Jun_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! July
!SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Jul[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]
SET GRID q
GO regresst
 ! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.
LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)" )
LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)" )
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)" )
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Jul[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_Jul[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]
LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of July<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
```

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"

!CANCEL Mode Metafile

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Jul_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Jul_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! August

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Aug[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Aug[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_Aug[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of August<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."

LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"

!CANCEL Mode Metafile

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Aug_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Aug_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! September

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Sep[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Sep[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_Sep[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of<nl> September in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
!CANCEL Mode Metafile
FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Sep_00N40N099E170W_200207_202204.gif
! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Sep_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! October
!SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Oct[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

```
SET GRID q
GO regresst
 ! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.
LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)" )
LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)" )
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)" )
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Oct[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_Oct[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]
LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of <nl>October in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
!CANCEL Mode Metafile
FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Oct_00N40N099E170W_200207_202204.gif
! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Oct_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
 ! November
```

```
!SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_Nov[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]
SET GRID q
GO regresst
 ! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.
LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)" )
LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)" )
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)" )
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Nov[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_Nov[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]
LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month of November<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
```

!CANCEL Mode Metafile

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Nov_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Nov_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! December

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_Dec[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_Dec[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_Dec[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the month

of December<nl>in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."

LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"

!CANCEL Mode Metafile

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Dec_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_Dec_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Boreal Spring Season

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_FMA[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_FMA[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_FMA[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the<nl>Boreal Spring Season in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
!CANCEL Mode Metafile
FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_FMA_00N40N099E170W_200207_202204.gif
! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_FMA_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt
! Boreal Summer Season
!SET MODE Metafile
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:19:1]
LET q = Chlorophyll_a_MJJ[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:19:1]
SET GRID q
GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_MJJ[x=99E:170W@ave, y=00N:40N@ave, l=1:19@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_MJJ[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the<nl>Boreal Summer Season in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."

LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"

LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"

LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"

!CANCEL Mode Metafile

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_MJJ_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_MJJ_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Boreal Autumn Season

!SET MODE Metafile

```
LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]
LET q = Chlorophyll_a_ASO[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]
SET GRID q
GO regresst
 ! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25
LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.
LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)" )
LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)" )
LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)" )
LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_ASO[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")
PLOT/ Nolab Chlorophyll_a_ASO[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]
PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]
LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in the<nl>Boreal Autumn Season in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
!CANCEL Mode Metafile
```

FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_ASO_00N40N099E170W_200207_202204.gif

! sp Fprint -o "Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_ASO_00N40N099E170W_200207_202204.ps" -l cps -p portrait metafile.plt

! Boreal Winter Season

!SET MODE Metafile

LET p = t[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, gl=1:20:1]

LET q = Chlorophyll_a_NDJ[d=Chlorophyll_a_Concentration_MODIS_Aqua_Global_200207_202204.nc, x=99E:170W, y=00N:40N, l=1:20:1]

SET GRID q

GO regresst

! The slope of the chlorophyll-a concentration is in [(mg/m^3)/second]. To convert it into (mg/m^3)/year, the slope value is written multiplied by 60 x 60 x 24 x 365.25

LET Slope_per_year = Slope * 60 * 60 * 24 * 365.25 ! To calculate slope in units per year, as originally it was in units per second.

LET Slope_per_year_NW_Pacific = FLOATSTR(Slope[x=99E:170W@ave, y=00N:40N@ave]*60*60*24*365.25, "(f9.4)")

LET Intercept_NW_Pacific = FLOATSTR(intercep[x=99E:170W@ave, y=00N:40N@ave], "(f6.2)")

LET Coeff_Determination = FLOATSTR(rsquare[x=@ave, y=@ave], "(f7.3)")

LET Chlorophyll_ave_NW_Pacific = FLOATSTR(Chlorophyll_a_NDJ[x=99E:170W@ave, y=00N:40N@ave, l=1:20@ave], "(f7.3)")

PLOT/ Nolab Chlorophyll_a_NDJ[x=99E:170W@ave, y=0:40N@ave, t="16-JUL-2002":"16-APR-2022"]

PLOT/vs/ Over/ Line/ Title="Trendline" p, qhat[x=@ave, y=@ave]

LABEL/Nouser 3.9 -0.6 0 0 0.12 "Chlorophyll-a Concentration basin-averaged in the north-west Pacific Ocean<nl>(0^oN-40^oN, 99^oE- 170^oW) averaged in

the<nl>Boreal Winter Season in the period from July 2002 to<nl>April 2022 (in black). Trendlines ((mg/m^3)/year) are plotted in red."
LABEL/Nouser 0 6.8 -1 0 0.15 "y = `Slope_per_year_NW_Pacific` x + `Intercept_NW_Pacific`"
LABEL/Nouser 3.5 6.8 -1 0 0.15 "Coefficient of Determination (R^2) = `Coeff_Determination`"
LABEL/Nouser 0 6.3 -1 0 0.15 "Chlorophyll_a_v = `Chlorophyll_ave_NW_Pacific` mg/m^3"
!CANCEL Mode Metafile
FRAME/File=Chlorophyll_a_Concentration_Trendline_Slope_basin_averaged_NDJ_00N40N099E170W_200207_202204.gif

CHAPTER 4: OBSERVATIONS

4.1 MAPS OF CHLOROPHYLL-A CONCENTRATION AVERAGED FROM JULY 2002 TO APRIL 2022

4.1.1 Map of Chlorophyll-a Concentration Averaged for the Entire Time-Period from July 2002 to April 2022

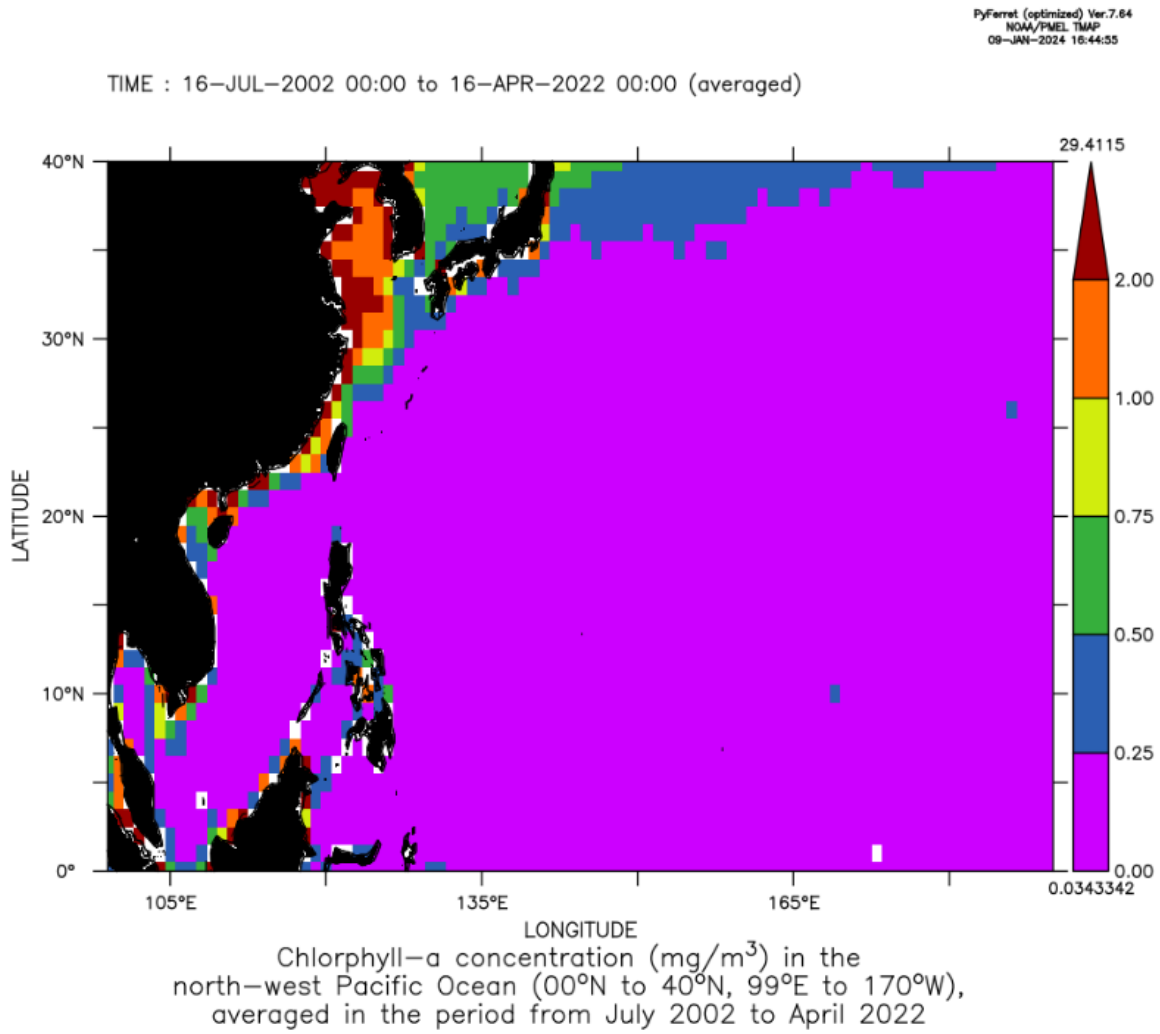


Figure 4.1 – Chlorophyll-a concentration map (mg/m^3) in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the period from July 2002 to April 2022

The chlorophyll-a concentration map in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the period from July 2002 to April 2022, is shown in Figure 4.1. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.41 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea, and also between the 30 °N and 35 °N latitudes along the Yellow Sea coast of China. There are also smaller regions along the coast of southern China and in parts of the Malacca Strait region, with values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, coastal Borneo, north coast of Sulawesi and coastal waters of Philippines. The north Pacific Ocean waters to the east of Japan, between 35 °N and 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

4.1.2 Map of Chlorophyll-a Concentration Averaged Month-wise from July 2002 to April 2022

a. *January:*

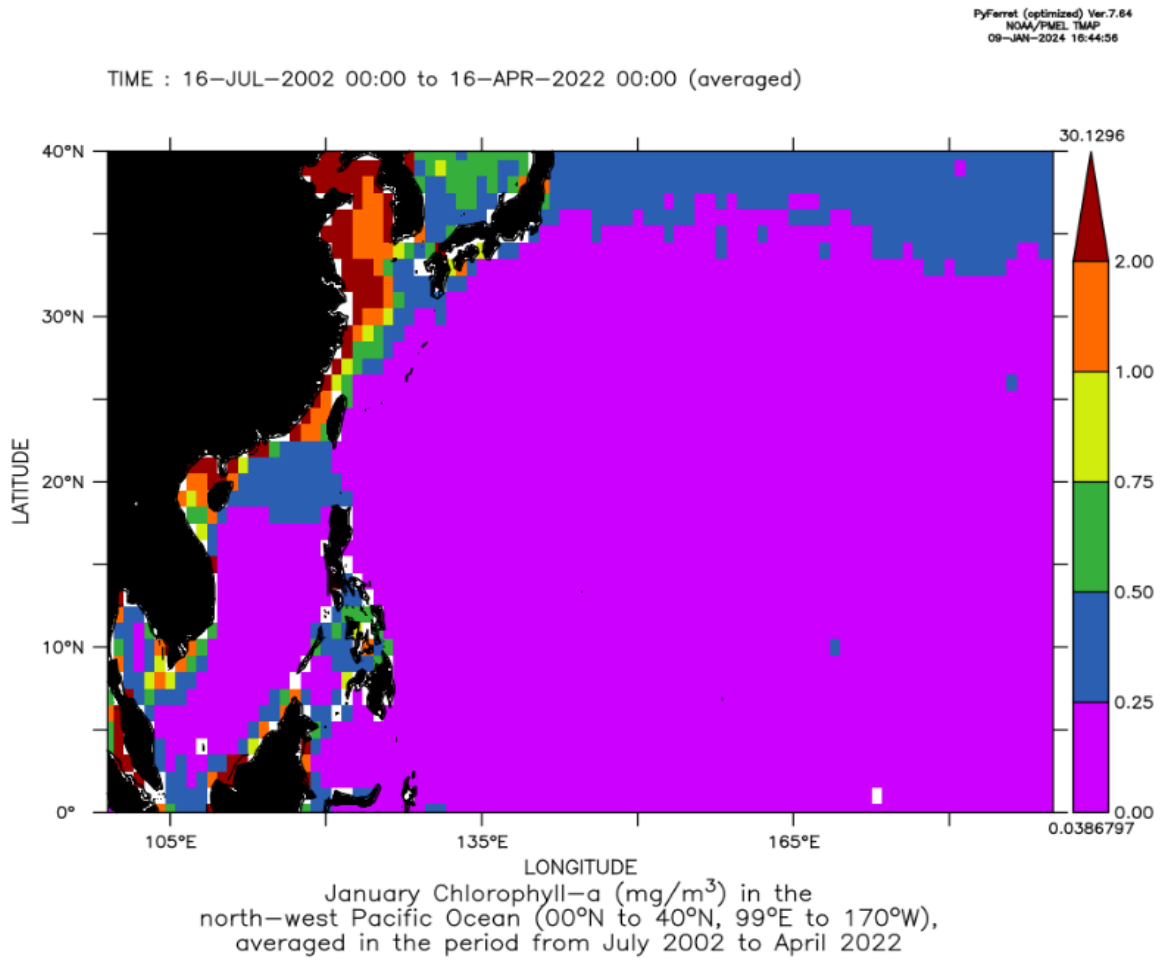


Figure 4.2 – Chlorophyll-a concentration (mg/m^3) map averaged in the month of January in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

The map of the chlorophyll-a concentration averaged in the months of January, in the period from July 2002 to April 2022, is shown in the Figure 4.2. The chlorophyll-a concentration map shows a minimum value of 0.04 mg/m^3 and a maximum value of 30.13 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea and also between the 30 °N and 35 °N latitudes along the Yellow Sea coast of China. There are also smaller regions along the coast of southern China, parts of the Malacca Strait region and parts of the coast of Sarawak on Borneo Island, with values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, coastal Borneo, north coast of Sulawesi and coastal waters of Philippines. The north Pacific Ocean waters to the east of Japan, between 33 °N and 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

b. *February:*

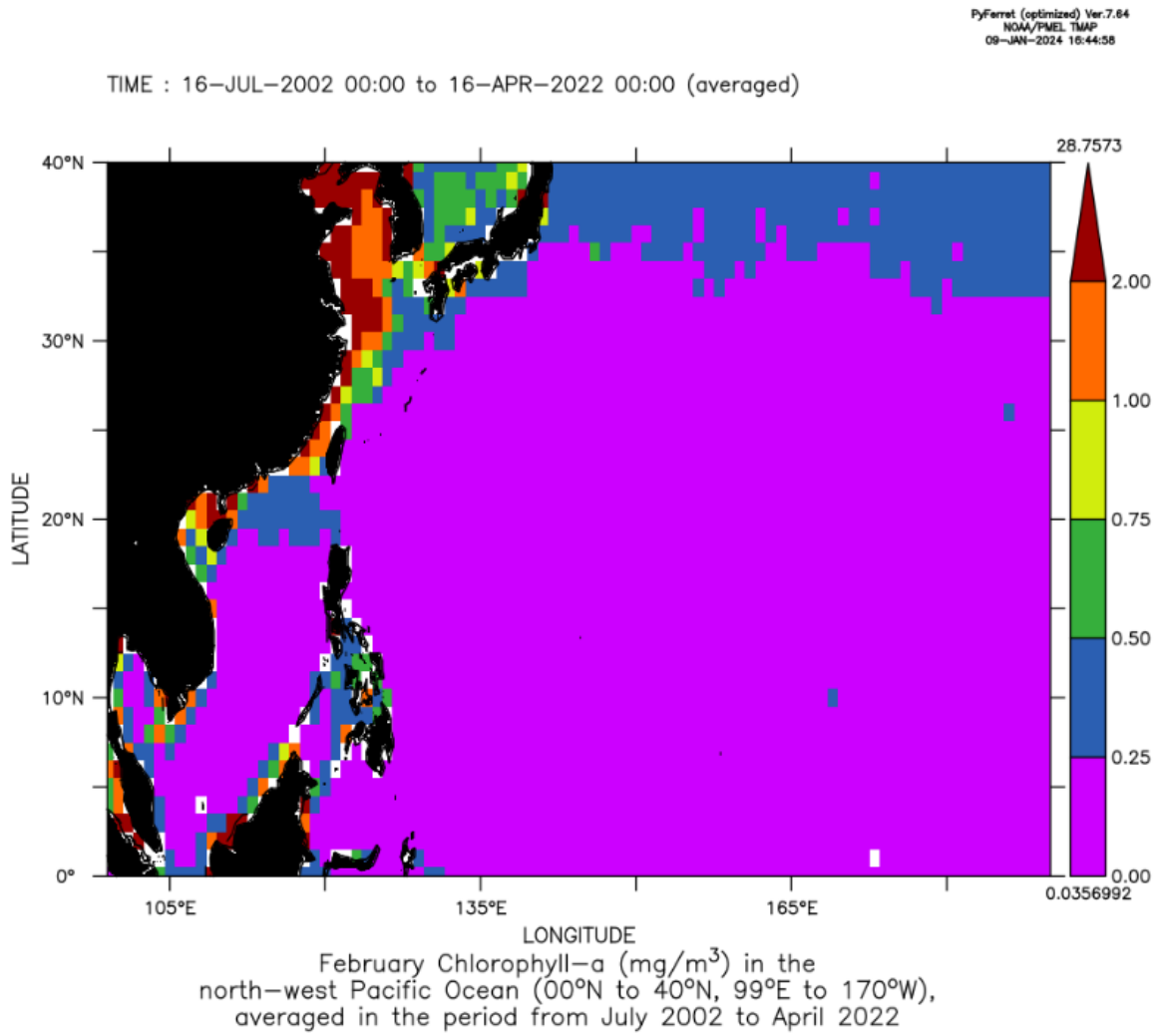


Figure 4.3 – Chlorophyll-a concentration (mg/m^3) map averaged in the month of February in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

The map of chlorophyll-a concentration averaged in the months of February in the period from July 2002 to April 2022 is shown in the Figure 4.3. The chlorophyll-a concentration map shows a minimum value of 0.04 mg/m^3 and a maximum value of 28.76 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea and also between the 30 °N and 35 °N latitudes along the Yellow Sea coast of China. There are also smaller regions along the coast of southern China, in parts of the Malacca Strait region and a part of the coast of Sarawak on the island of Borneo, with values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, coastal Borneo, north coast of Sulawesi and Philippines. The north Pacific Ocean waters to the east of Japan, to the north of around 33 °N, also shows values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

c. *March:*

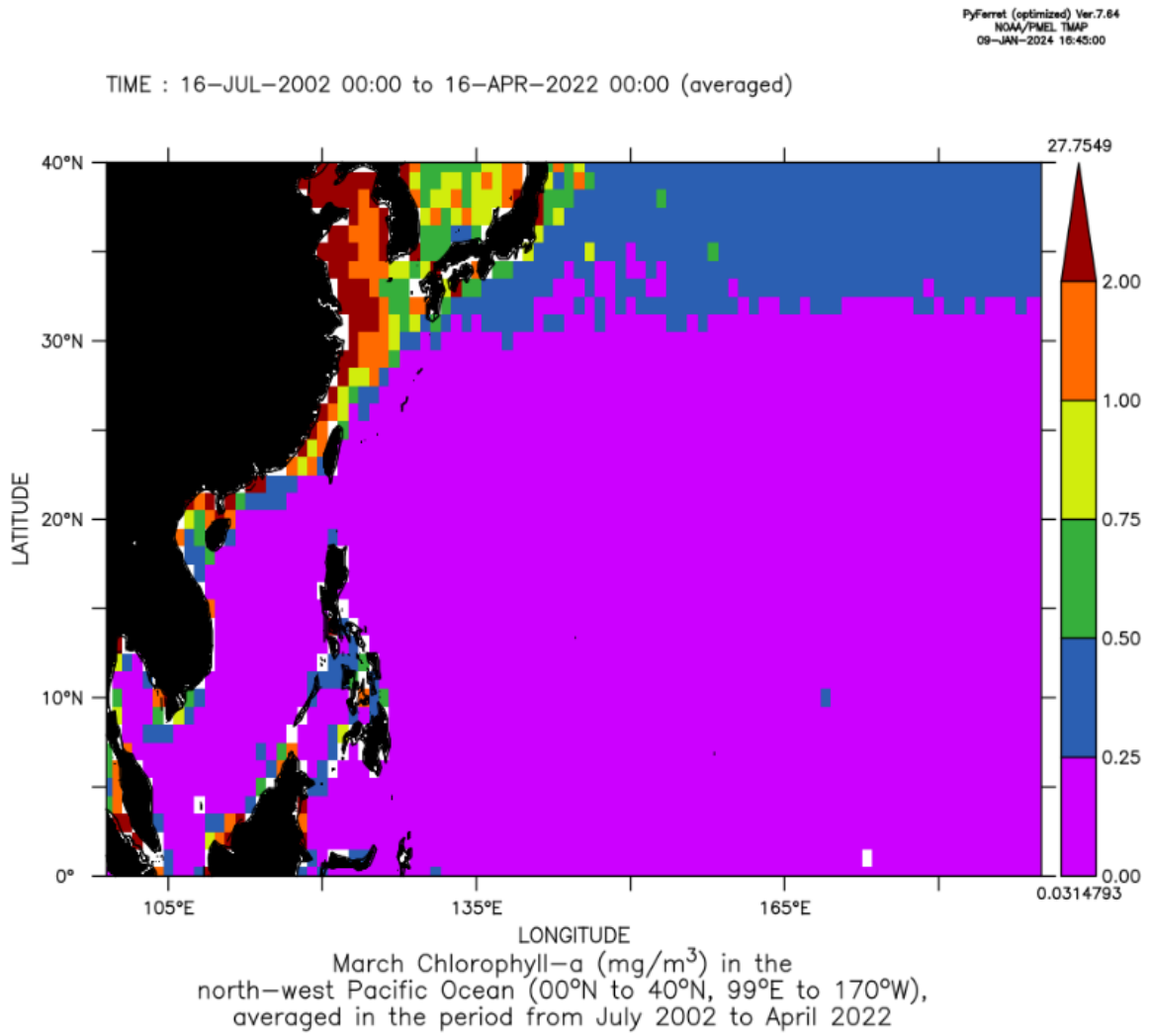


Figure 4.4 – Chlorophyll-a concentration (mg/m^3) map averaged in the month of March in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

The map of chlorophyll-a concentration averaged in the months of March in the period from July 2002 to April 2022 is shown in the Figure 4.4. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 27.76 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea and also between the 30 °N and 35 °N latitudes along the Yellow Sea coast of China. There are also smaller regions along the coast of southern China, parts of the Gulf of Tonkin, in parts of the Malacca Strait region and on parts of the north-east and also the north-west coasts of Borneo with values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Thailand, Strait of Malacca, coastal Borneo, north coast of Sulawesi and Philippines. The north Pacific Ocean waters to the east of Japan, to the north of about 33 °N, also show values above 0.25 mg/m^3. Also values ranging from 0.50 mg/m^3 to 1.00 mg/m^3 were seen in the north Pacific Ocean waters to the east of Japan. The waters near the location of about (10 °N, 170 °E) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

d. *April:*

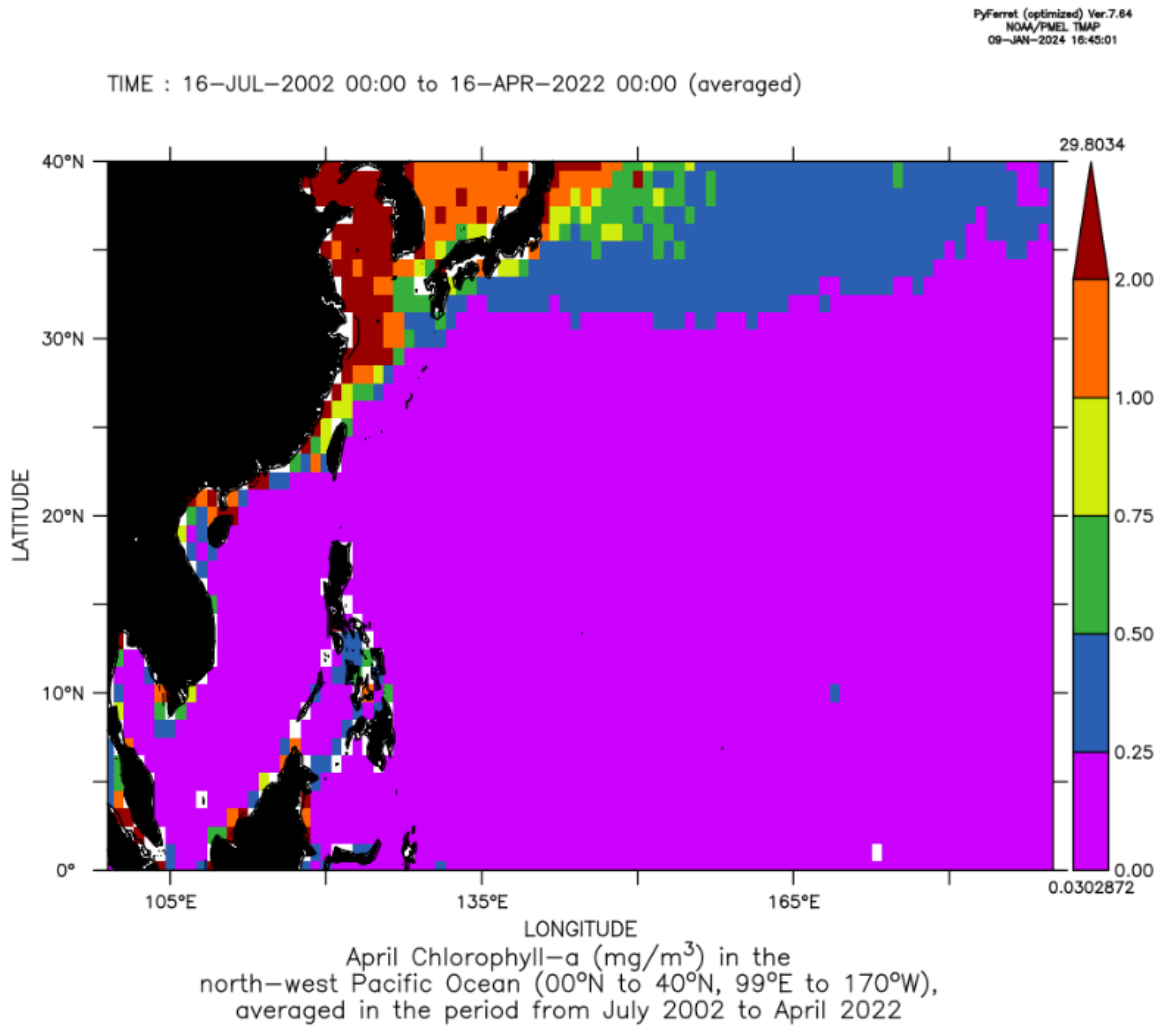


Figure 4.5 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of April in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

The map of the chlorophyll-a concentration, averaged in the months of April in the period from July 2002 to April 2022, is shown in the Figure 4.5. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.80 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea, Korea Bay, Yellow Sea and also parts of the coastal waters of the East China Sea. There are also smaller regions along the coast of southern China, in a small area of the Gulf of Thailand, in parts of the Malacca Strait region, some coastal parts of Borneo and also near Japan, with values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Yellow Sea, Taiwan Strait, East China Sea, Strait of Malacca and the plotted region of the Sea of Japan, and also over smaller parts of the South China Sea, Gulf of Thailand, coastal Borneo, north coast of Sulawesi and Philippines. The north Pacific Ocean waters to the east of Japan, between 33 °N and 40 °N, also shows a large region with values of chlorophyll-a concentration above 0.25 mg/m^3. The waters near the location of about (10 °N, 170 °E) shows values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3. However, this minimal range of chlorophyll-a concentration has among the least areal spread when comparing among the 12 months.

e. *May:*

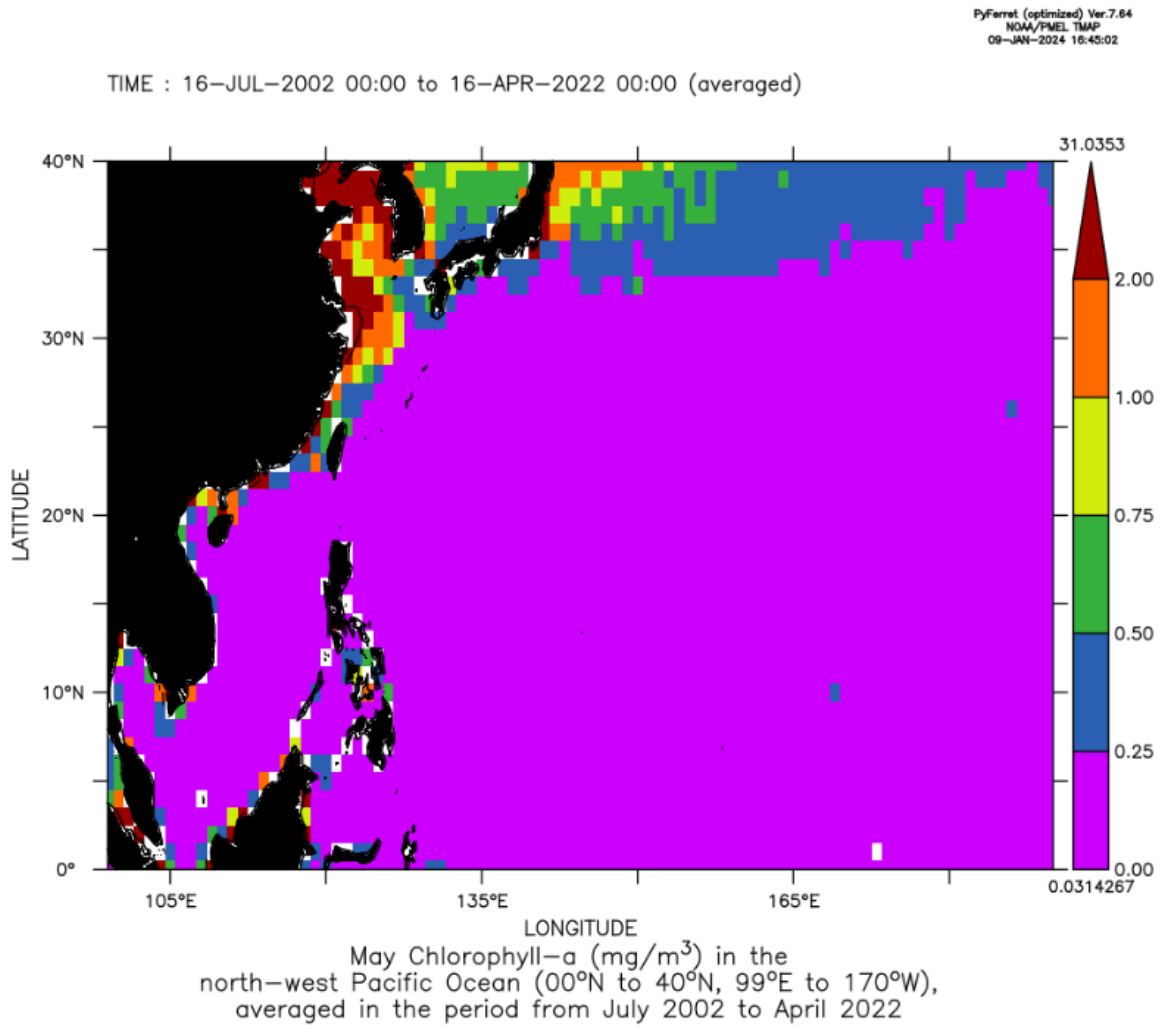


Figure 4.6 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of May in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

The chlorophyll-a concentration map averaged in the months of May in the period from July 2002 to April 2022 is shown in the Figure 4.6. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 31.04 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea, Korea Bay, parts of the Yellow Sea and parts of the East China Sea near the mouth of the Yangtze River. There are also smaller regions along the coast of southern China, i.e. in the Taiwan Strait and near the Pearl River Delta, Gulf of Tonkin, Gulf of Thailand, parts of the Malacca Strait region, parts of the coast of Borneo and also the east central coast of Honshu in Japan, with values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Thailand, Strait of Malacca, coastal Borneo, north coast of Sulawesi and coastal waters of Philippines. The north Pacific Ocean waters to the east of Japan, between 33 °N and 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

f. *June:*

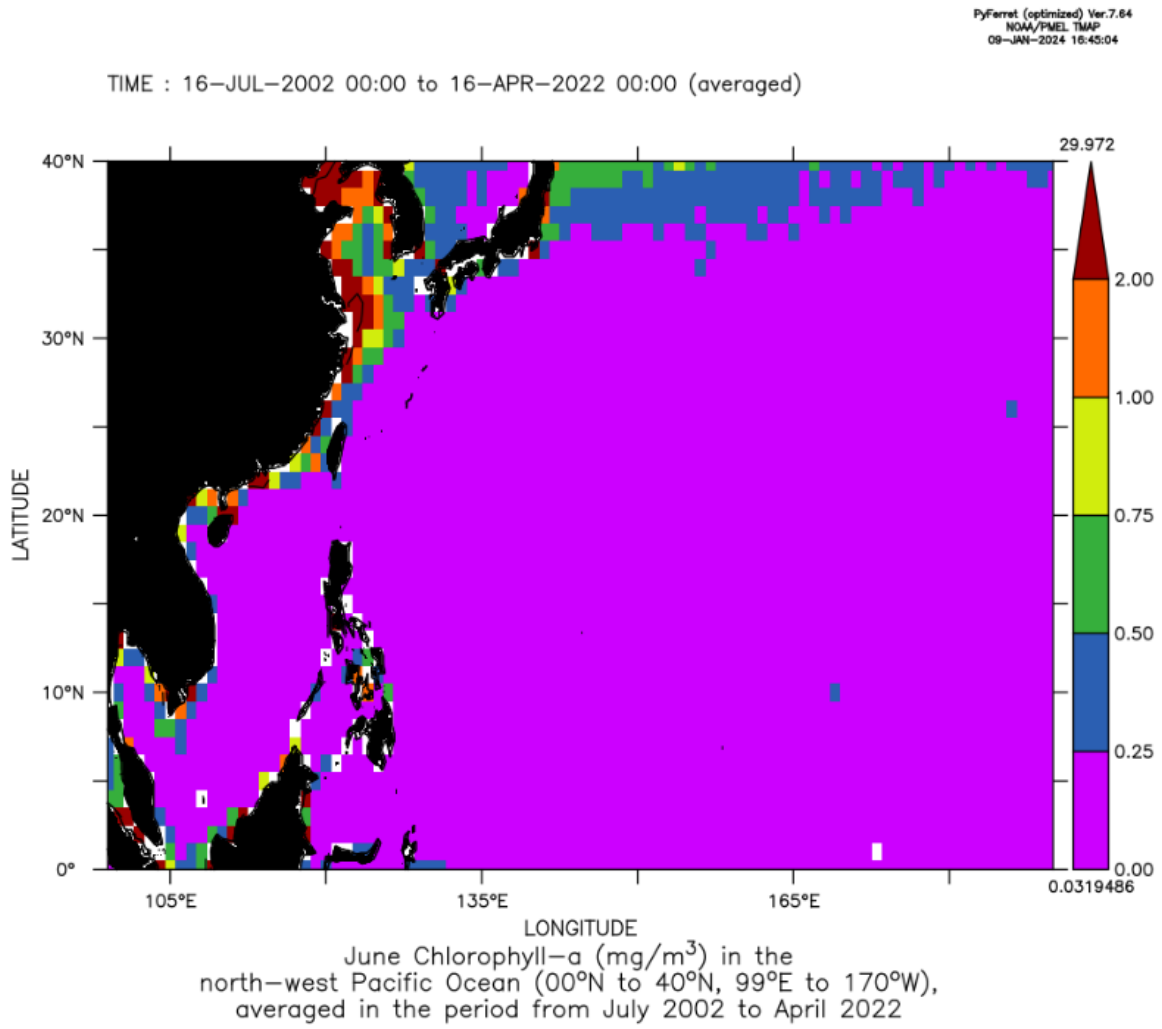


Figure 4.7 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of June in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the months of June in the period from July 2002 to April 2022 is shown in the Figure 4.7. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.97 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of

China, especially in the Bohai Sea and also between the 30 °N and 35 °N latitudes along the Yellow Sea coast and East China Sea coast. There are also smaller regions along the coast of the Korean Peninsula, southern China, i.e. near Taiwan Strait, near the mouth of the Pearl River, Gulf of Tonkin, southern Vietnam, Gulf of Thailand, and in parts of the Malacca Strait region, Borneo, Philippines and near Honshu in Japan, with values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Yellow Sea, Taiwan Strait, Strait of Malacca, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, coastal Borneo, north coast of Sulawesi and coastal waters of Philippines. The north Pacific Ocean waters to the east of Japan, between 3 °N and 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

g. *July:*

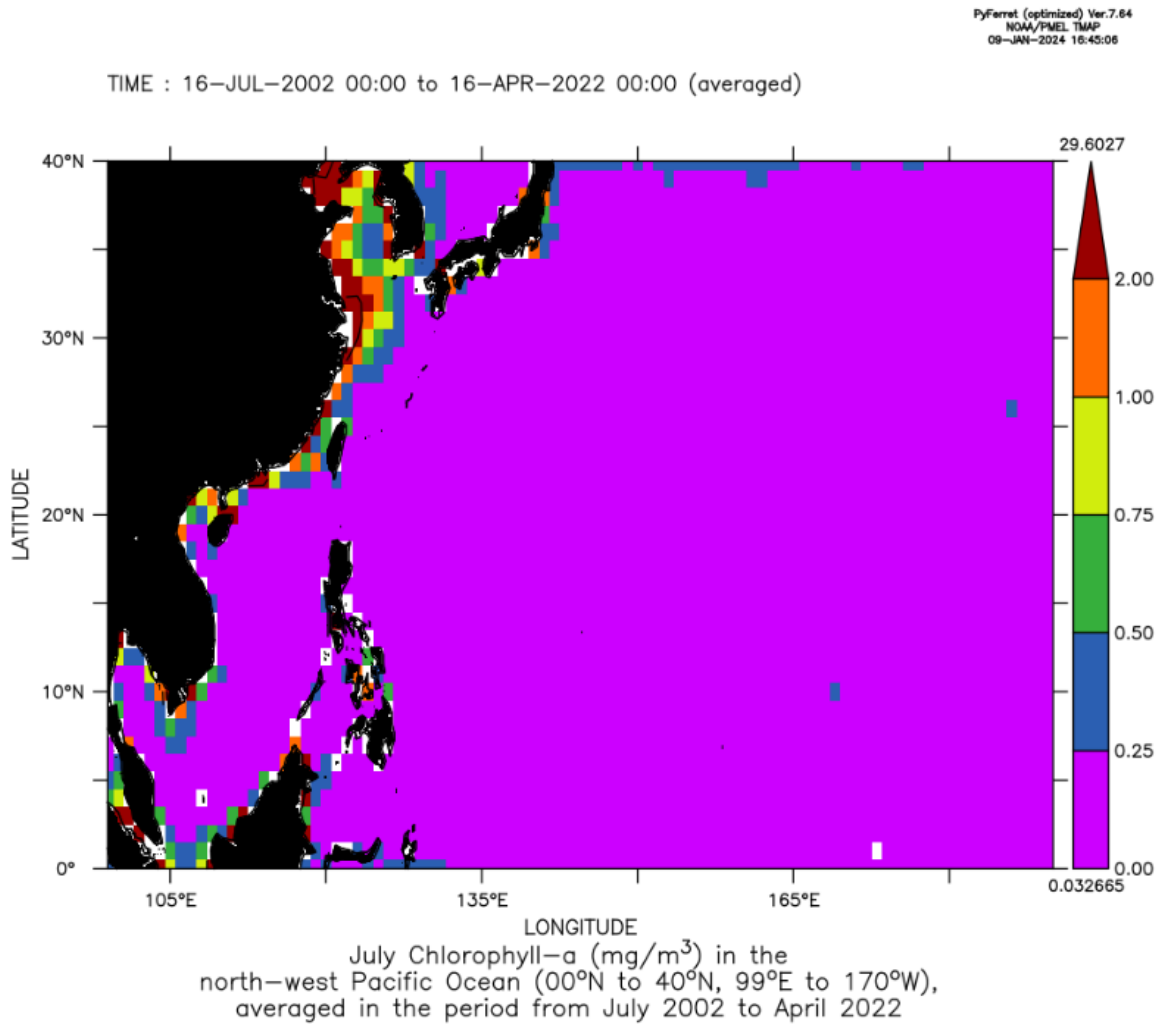


Figure 4.8 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of July in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the months of July in the period from July 2002 to April 2022 is shown in the Figure 4.8. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.60 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of

China, especially in the Bohai Sea and also between the 30 °N and 35 °N latitudes along the Yellow Sea coast and East China Sea coast. There are also smaller regions along the coast of southern China, ie. in the Taiwan Strait and in parts of the Qiongzhou Strait or Hainan Strait, Gulf of Tonkin, Gulf of Thailand, Malacca Strait region, parts of the coasts of Sumatra and also of Borneo, Korean Peninsula and also near the Kanmon Straits or the Straits of Shimonoseki which separate the islands of Honshu and Kyushu in Japan. These above-mentioned regions have values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Thailand, Strait of Malacca, coastal Borneo, north coast of Sulawesi, coastal waters of Philippines and coastal waters of Japan. The north Pacific Ocean waters to the east of Japan, at around 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3. The areal extent of waters showing a chlorophyll-a concentration, ranging between 0 to 0.25 mg/m^3, is among the largest when compared between the months.

h. *August:*

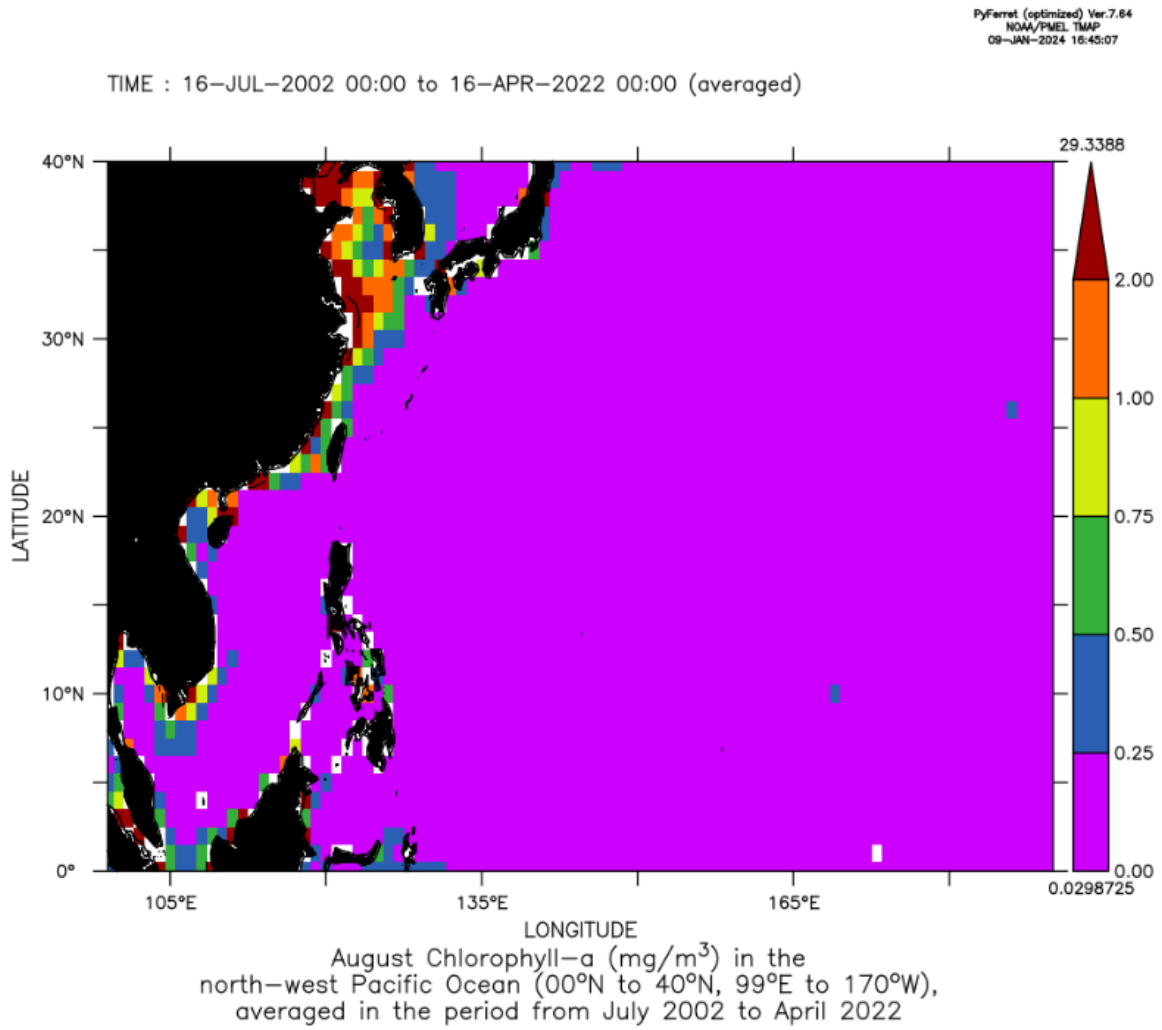


Figure 4.9 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of August in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the months of August in the period from July 2002 to April 2022 is shown in the Figure 4.9. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.34 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea and also between the 29 °N and 35 °N latitudes along the Yellow Sea coast and East China Sea coast. There are also smaller regions along the coast of southern China, i.e. in the Taiwan Strait, near the mouth of the Pearl River Delta or Canton River and near the Hainan Strait, Gulf of Tonkin, near the mouths of River Mekong in southern Vietnam, Gulf of Thailand, parts of the Malacca Strait region, parts of the coasts of Sumatra and also Borneo, parts of the coasts of the Korean Peninsula and also in Japan on eastern Honshu and in the Kanmon Straits. In the above-mentioned regions, the values of chlorophyll-a concentration exceed 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, parts of the plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, Molucca Sea, Halmahera Sea, coastal waters of Philippines and coastal waters near Japan. The waters near the locations of about (40 °N, 145 °E), (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

i. *September:*

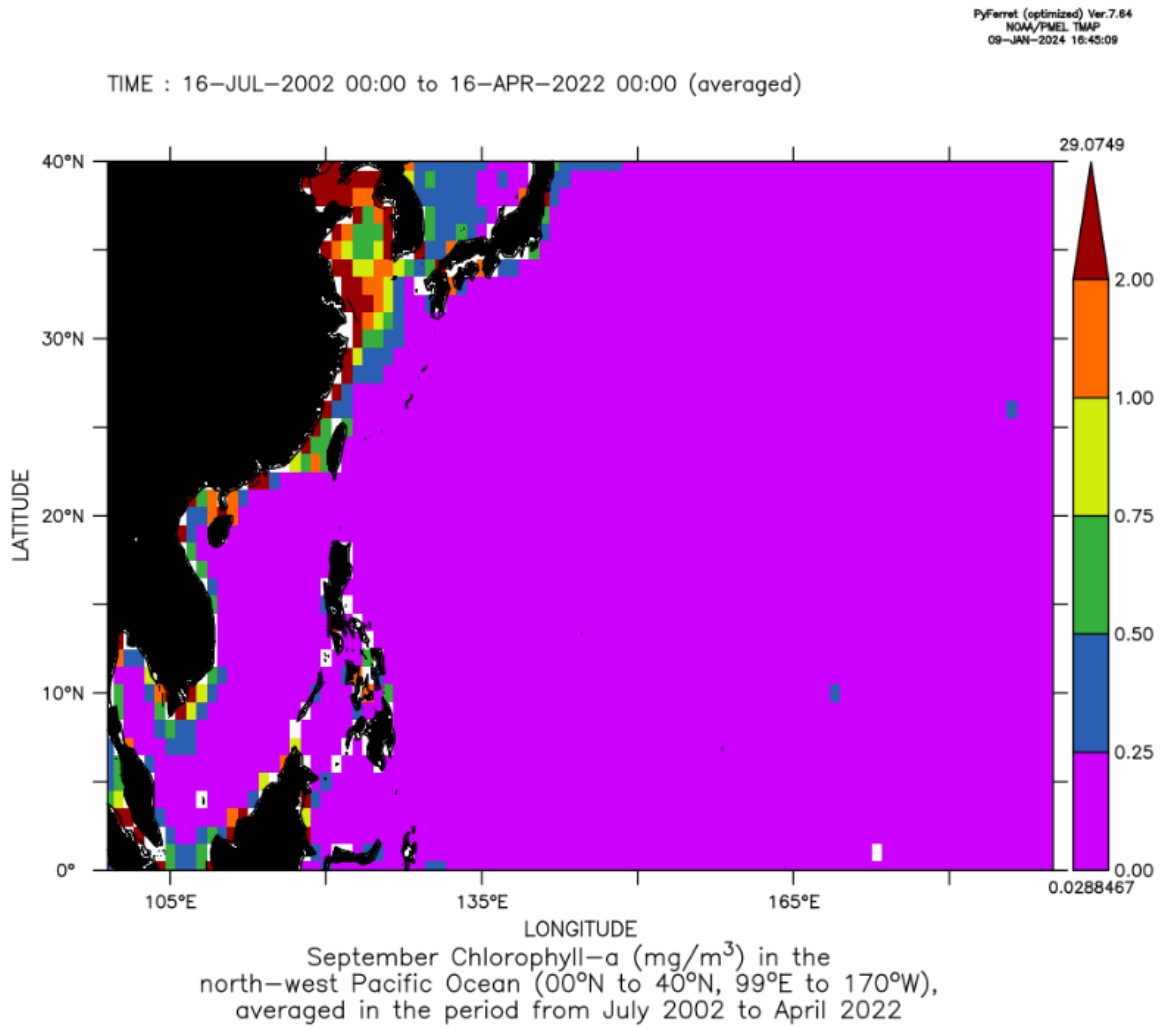


Figure 4.10 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of September in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the months of September in the period from July 2002 to April 2022 is shown in the Figure 4.10. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.08 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen in the Bohai Sea, Korea Bay, Yellow Sea, East China Sea, especially near the mouth of Yangtze River. There are also smaller parts along the coast of south-western China, Taiwan Strait, near the mouth of the Pearl River Delta near Hong Kong and Macau, Gulf of Tonkin, near the mouths of River Mekong in southern Vietnam, Gulf of Thailand, in parts of the Malacca Strait, Sumatra, Borneo, south-western coast of South Korea and near the coast of Sendai in eastern Japan, all showing values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Strait of Malacca, coastal Borneo, north coast of Sulawesi and coastal waters of Philippines and coastal waters of Japan. The waters near the locations of about (40 °N, 145 °E), (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

j. *October:*

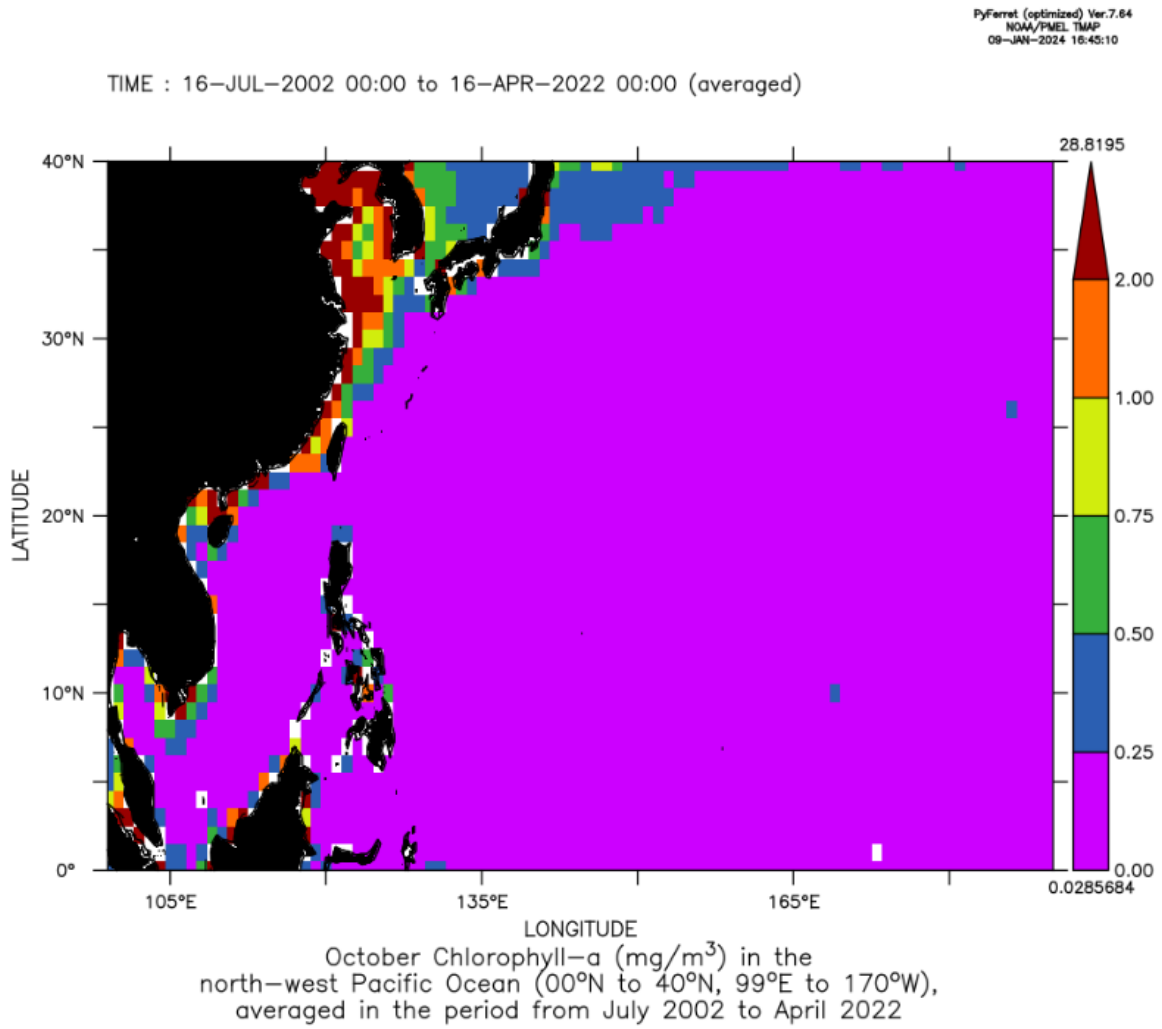


Figure 4.11 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of October in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the months of October in the period from July 2002 to April 2022 is shown in the Figure 4.11. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 28.82 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen along many parts of the coast of China, especially in the Bohai Sea, Korea Bay, Yellow Sea and the coast near the mouth of River Yangtze in the East China Sea. There are also smaller regions along the coast of south-western China, Taiwan Strait, near the mouth of Pearl River Delta, Hainan Strait, Gulf of Tonkin, near the mouths of River Mekong, Gulf of Thailand, in parts of the Malacca Strait region, Sumatra coast, coast of Borneo, Guimaras Strait and Visayan Sea region near the islands of Panay and Negros in Philippines. All these above-mentioned regions show values of chlorophyll-a concentration exceeding 2 mg/m^3. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, Taiwan Strait, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, Halmahera Sea and coastal waters of Philippines. The north Pacific Ocean waters to the east of Japan, between 35 °N and 40 °N, also show values above 0.25 mg/m^3. This region of the Pacific Ocean water to the east of Japan is much larger than in the previous month. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

k. *November:*

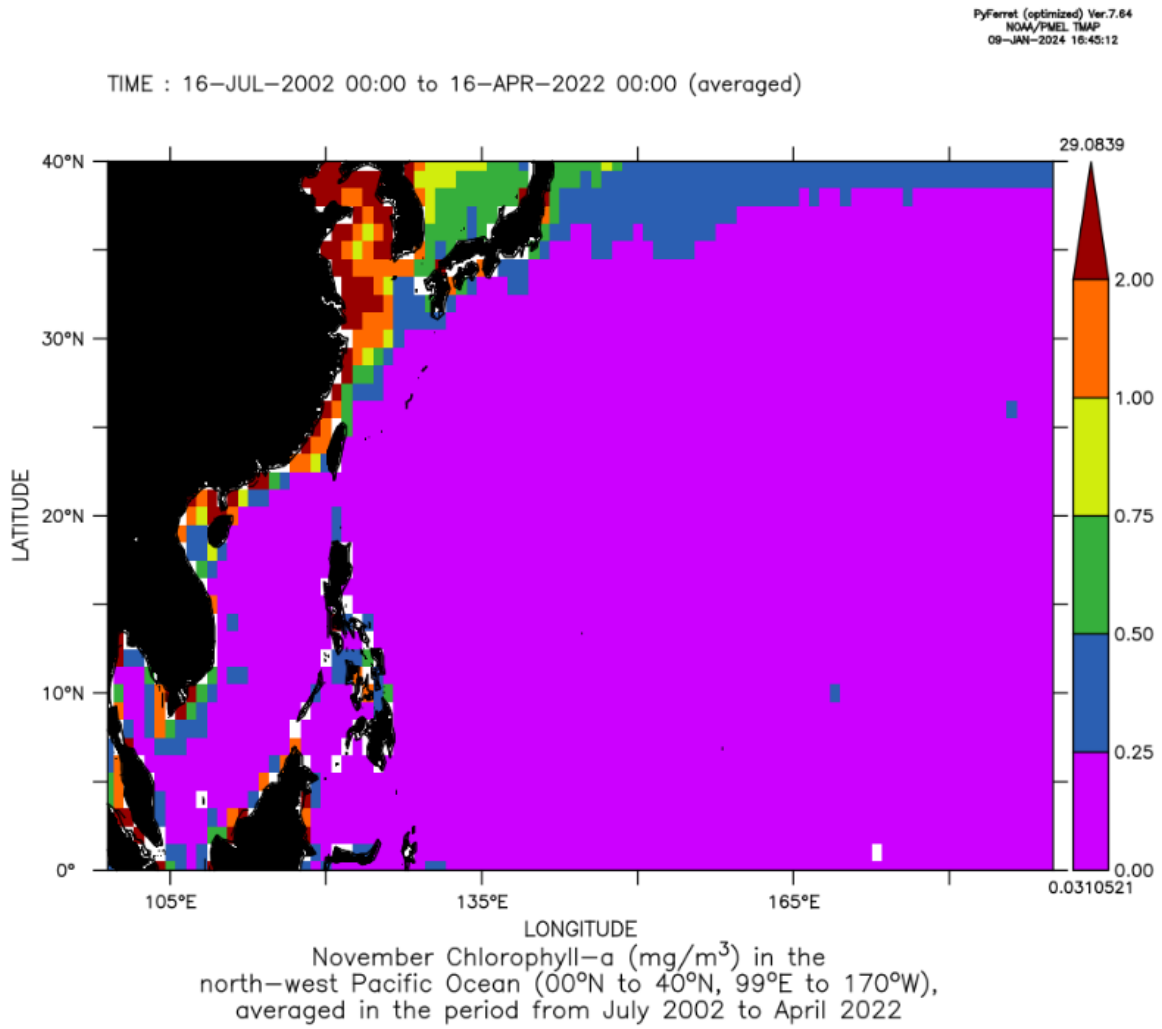


Figure 4.12 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of November in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

The chlorophyll-a concentration map averaged in the months of November in the period from July 2002 to April 2022 is shown in the Figure 4.12. The chlorophyll-a concentration map shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.08 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen in parts of various regions, like the Bohai Sea, Korea Bay, Yellow Sea, East China Sea especially near the mouth of River Yangtze, along the coast of south-western China and in parts of the Malacca Strait region, Taiwan Strait, near the mouth of the Pearl River near Hong Kong, Hainan Strait region, Gulf of Tonkin, near the mouths of River Mekong, Gulf of Thailand, South China Sea, Malacca Strait, coast of Sumatra, coast of Borneo, in the Kanmon Strait and also on the coast of Honshu in Japan and Korean Peninsula. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, north coast of Sulawesi, Halmahera Sea and Philippines. The north Pacific Ocean waters to the east of Japan, between 35 °N and 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) also show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

l. *December:*

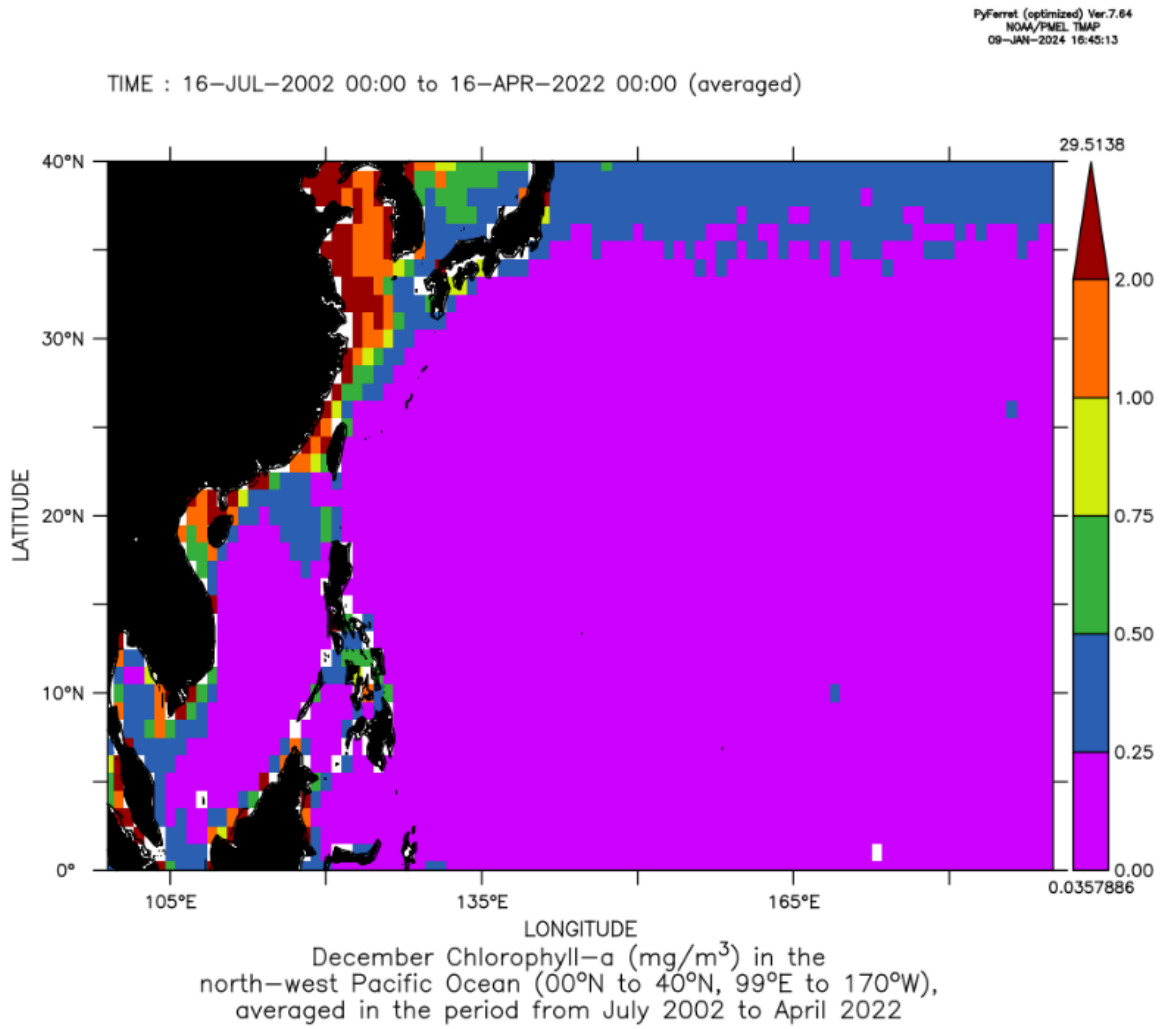


Figure 4.13 – Chlorophyll-a concentration map (mg/m^3) averaged in the month of December in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the months of December in the period from July 2002 to April 2022 is shown in the Figure 4.13. The chlorophyll-a concentration map shows a minimum value of 0.04 mg/m^3 and a maximum value of 29.51 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen in parts of the Bohai Sea, Korea Bay, Yellow Sea, East China Sea especially near the mouth of River Yangtze, coast of south-western China, Taiwan Strait, mouth of the Pearl River Delta near Hong Kong, near the Hainan Strait, Gulf of Tonkin, South China Sea, Gulf of Thailand, Malacca Strait region, Borneo, Kanmon Strait, east coast of Honshu in Japan and the cost of the Korean Peninsula. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, north coast of Sulawesi, Halmahera Sea and coastal waters of Philippines. The waters to the north-west of Philippines and to the south of Vietnam show large larger areas of chlorophyll-a concentration in this range. The north Pacific Ocean waters to the east of Japan, between around 34 °N and 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

4.1.3 Map of Chlorophyll-a Concentration Averaged Season-wise from July 2002 to April 2022

a. *Boreal Spring Season:*

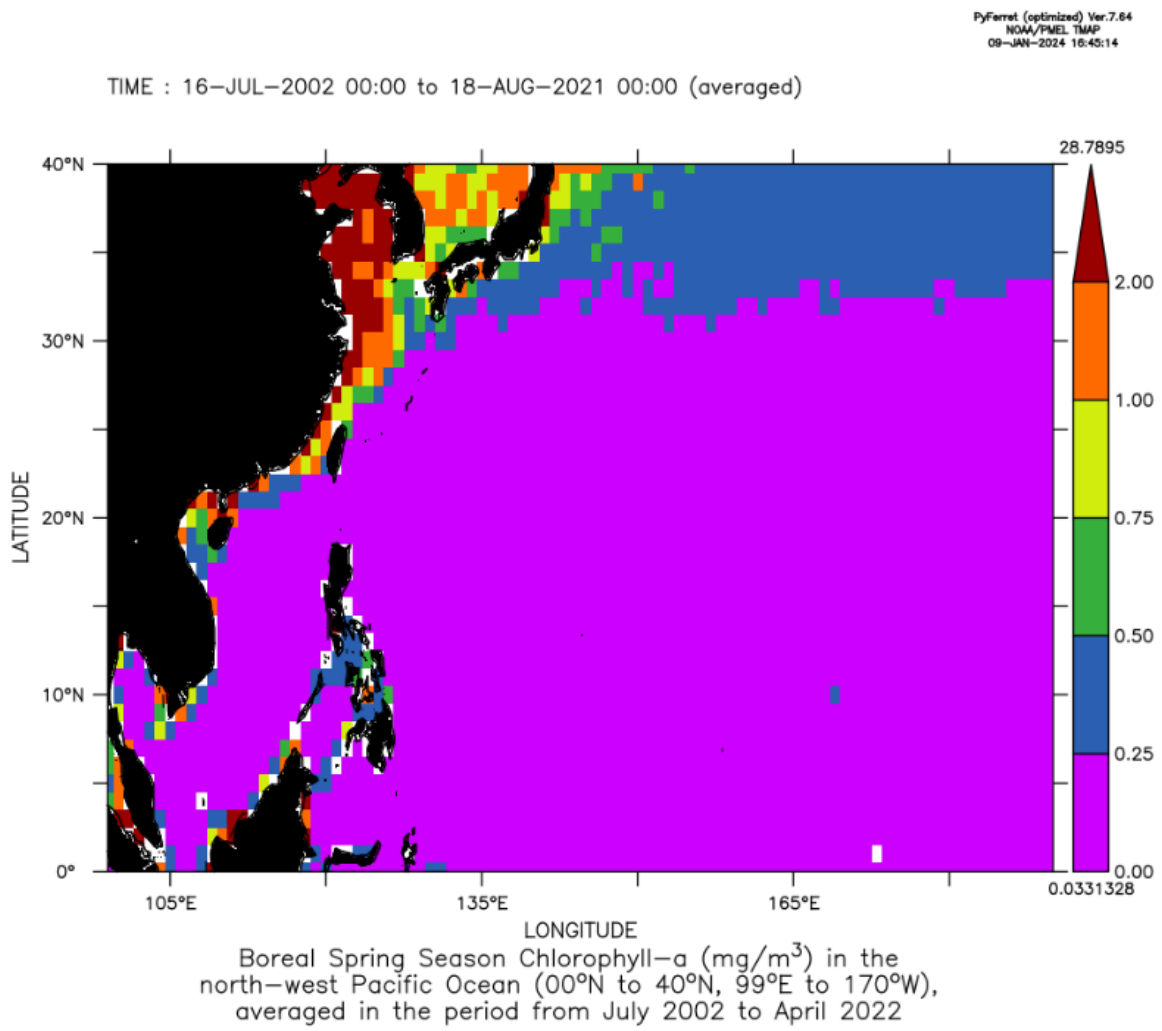


Figure 4.14 – Chlorophyll-a concentration map (mg/m^3) averaged in the Boreal Spring season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a a concentration map averaged in the Boreal Spring season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022 is shown in the Figure 4.14. Chlorophyll-a concentration map for

Boreal Spring season shows a minimum value of 0.03 mg/m^3 and a maximum value of 28.79 mg/m^3.

Higher values of chlorophyll-a are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen in the Bohai Sea, Korea Bay, Yellow Sea, East China Sea especially near the mouth of the Yangtze River, south-western China, Taiwan Strait, Hainan Strait, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, Borneo, Kanmon Strait in Japan, Honshu in Japan and south-west tip of the Korean Peninsula. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, north coast of Sulawesi, Halmahera Sea and coastal waters of Philippines. The north Pacific Ocean waters to the east of Japan, between around 33 °N and 40 °N, also shows a large area with values above 0.25 mg/m^3, which is largest among the four seasons. The waters near the locations of about (10 °N, 170 °E) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

b. *Boreal Summer Season:*

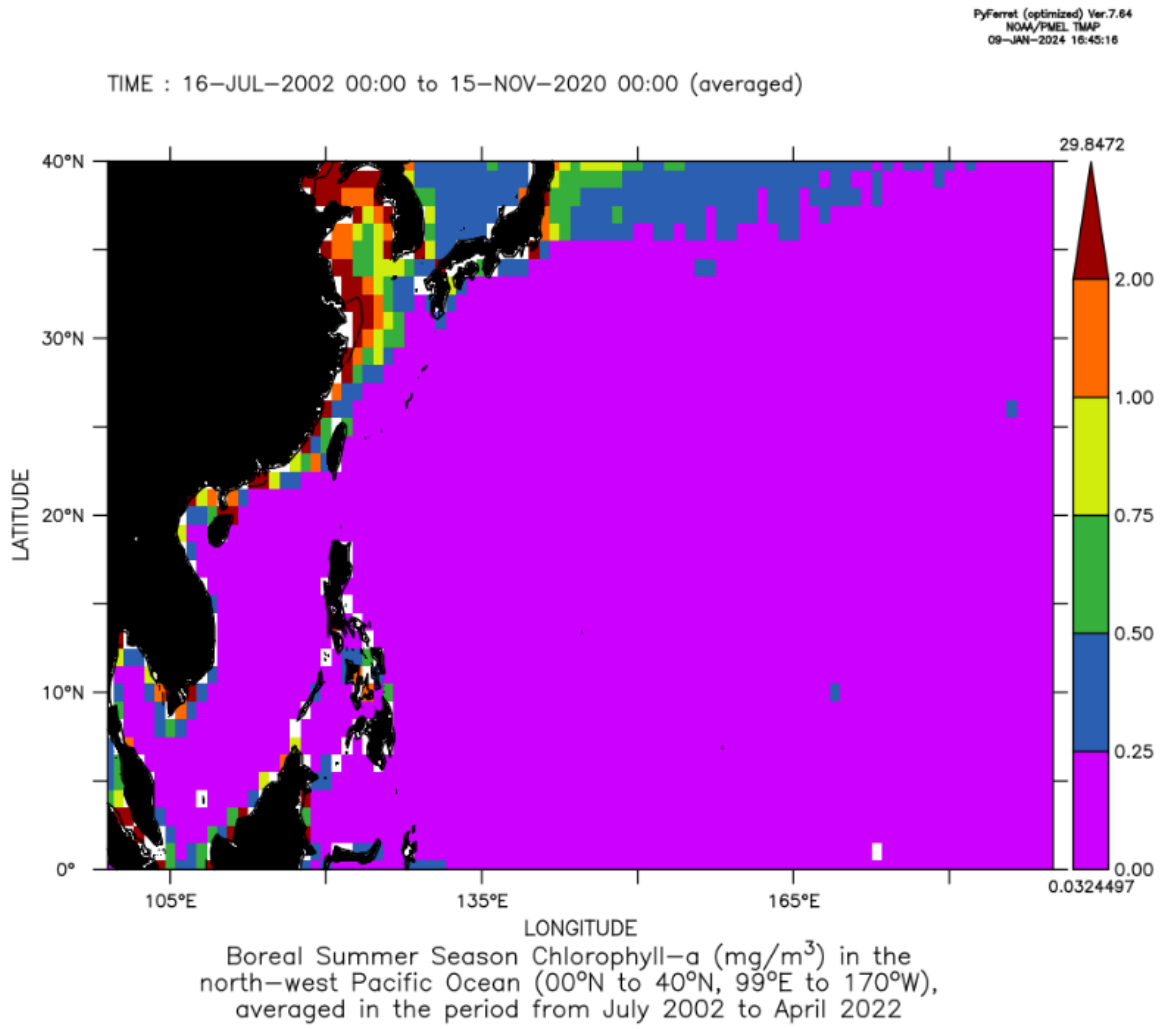


Figure 4.15 – Chlorophyll-a concentration map (mg/m^3) averaged in the Boreal Summer season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the Boreal Summer season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022 is shown in the Figure 4.15. Chlorophyll-a concentration map for Boreal Summer season shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.85 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen in the Bohai Sea, Korea Bay, Yellow Sea, East China Sea especially near the mouth of River Yangtze, the coast of south-western China, Taiwan Strait, mouth of the Pearl River Delta near Hong Kong and Macau, Hainan Strait, Gulf of Tonkin, mouths of River Mekong in southern Vietnam, Gulf of Thailand, Malacca Strait, Borneo, Kanmon Strait in Japan, east coast of Honshu in Japan and Korean Peninsula. Values above 0.25 mg/m^3 are seen over the large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, north coast of Sulawesi, Halmahera Sea and coastal waters of Philippines. The north Pacific Ocean waters to the east of Japan, between around 35 °N and 40 °N, also shows a large area with values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

c. *Boreal Autumn Season:*

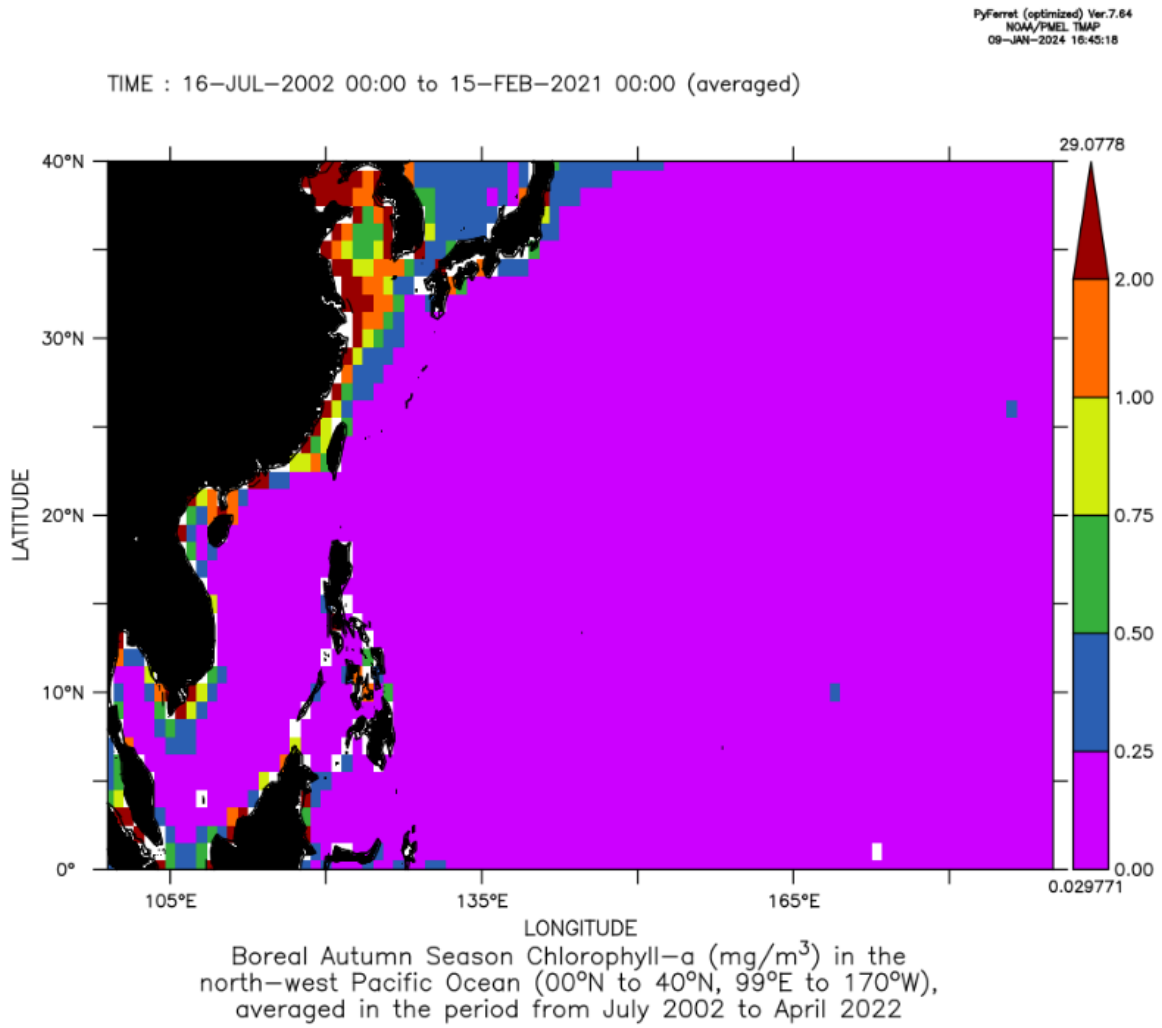


Figure 4.16 – Chlorophyll-a concentration map (mg/m^3) averaged in the Boreal Autumn season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the Boreal Autumn season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022 is shown in the Figure 4.16. Chlorophyll-a concentration map for Boreal Autumn season shows a minimum value of 0.03 mg/m^3 and a maximum value of 29.08 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen in the Bohai Sea, Korea Bay, Yellow Sea, East China Sea especially near the mouth of River Yangtze, the coast of south-western China, Taiwan Strait, mouth of the Pearl River Delata in Hong Kong and Macau, Hainan Strait, Gulf of Tonkin, mouths of River Mekong, Gulf of Thailand, Malacca Strait, east coast of Sumatra, parts of the coast of Borneo, Kanmon Strait in Japan, Sendai Bay in Honshu in Japan and parts of the coast of south-east South Korea. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, north coast of Sulawesi, Moluccas Sea, Halmahera Sea and Philippines. The north Pacific Ocean waters close to the east of Japan, between around 33 °N and 40 °N, also show values above 0.25 mg/m^3. Further to the east of Japan in the north Pacific Ocean, the waters have the lowest values of chlorophyll-a concentration among the four seasons. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

d. *Boreal Winter Season:*

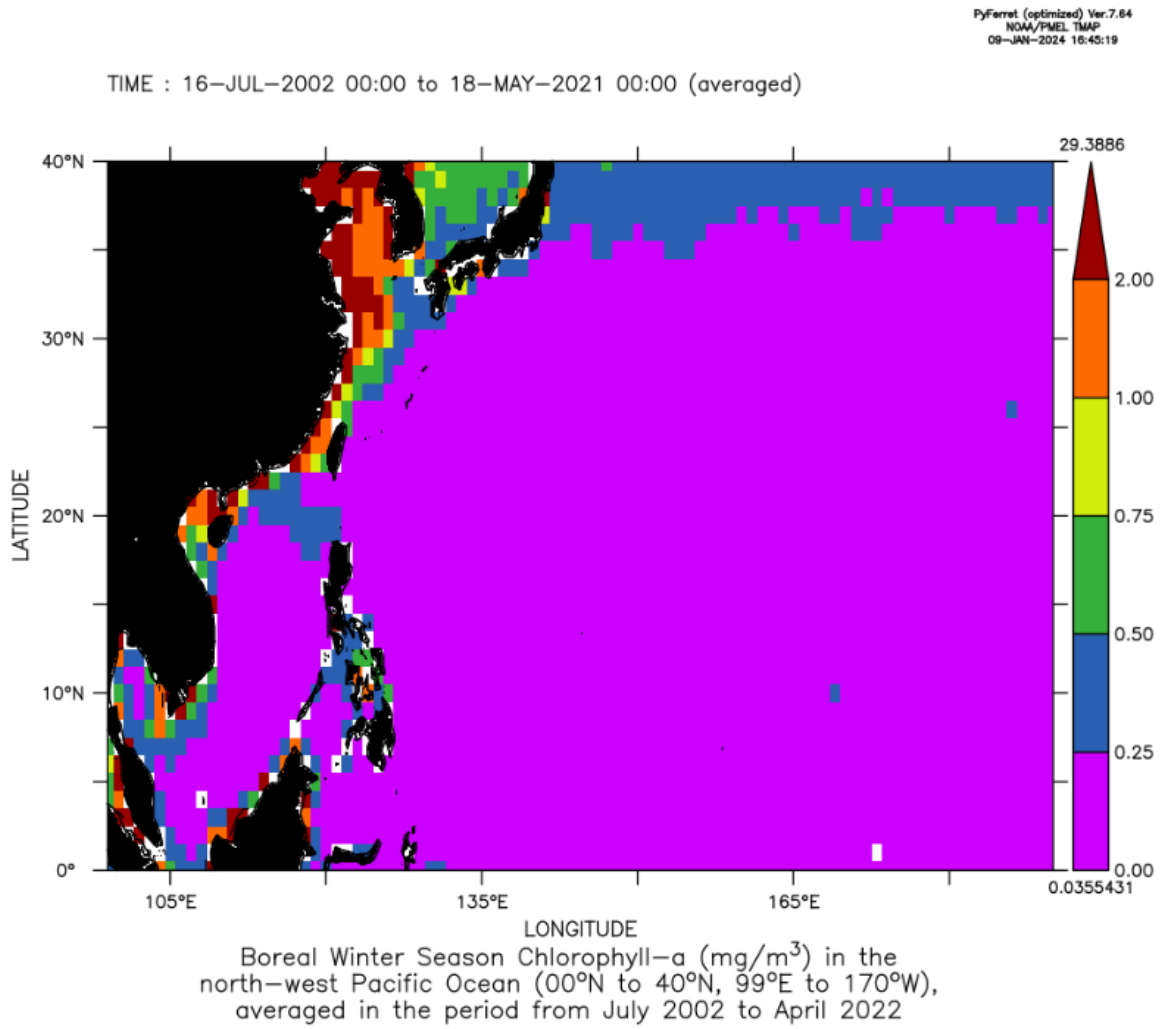


Figure 4.17 – Chlorophyll-a concentration map (mg/m^3) averaged in the Boreal Winter season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022

Chlorophyll-a concentration map averaged in the Boreal Winter season in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), in the period from July 2002 to April 2022 is shown in the Figure 4.17. Chlorophyll-a concentration map for Boreal Autumn season shows a minimum value of 0.04 mg/m^3 and a maximum value of 29.39 mg/m^3.

Higher values of chlorophyll-a concentration are seen closer to the coastal regions in general. Values above 2 mg/m^3 are seen in the Bohai Sea, Korea Bay, Yellow Sea, East China Sea especially near the mouth of River Yangtze, coast of south-western China, Taiwan Strait, mouth of the Pearl River Delata in Macau and Hong Kong, Hainan Strait, Gulf of Tonkin, near the mouth of River Mekong, Gulf of Thailand, Malacca Strait, Boreno, Kanmon Strait in Japan, Sendai Bay in Honshu in Japan and in the Sea of Japan near North Korea. Values above 0.25 mg/m^3 are seen over large regions of the Bohai Sea, Korea Bay, Yellow Sea, Taiwan Strait, plotted region of the Sea of Japan, and over smaller parts of the coastal East China Sea, South China Sea, Gulf of Tonkin, Gulf of Thailand, Malacca Strait, coastal Borneo, north coast of Sulawesi, Halmahera Sea, coastal waters of Philippines and to the north-west of Philippines. The north Pacific Ocean waters to the east of Japan, between around 35 °N and 40 °N, also show values above 0.25 mg/m^3. The waters near the locations of about (10 °N, 170 °E) and (26 °N, 173 °W) show values above 0.25 mg/m^3. Most of the parts of north-west Pacific Ocean show low values of chlorophyll-a concentration ranging between 0 to 0.25 mg/m^3.

4.2 MAPS OF SLOPES OF TRENDLINES OF CHLOROPHYLL-A CONCENTRATION AVERAGED FROM JULY 2002 TO APRIL 2022

4.2.1 Map of Slopes of Trendlines of Chlorophyll-a Concentration Averaged for the Entire Time-Period from July 2002 to April 2022

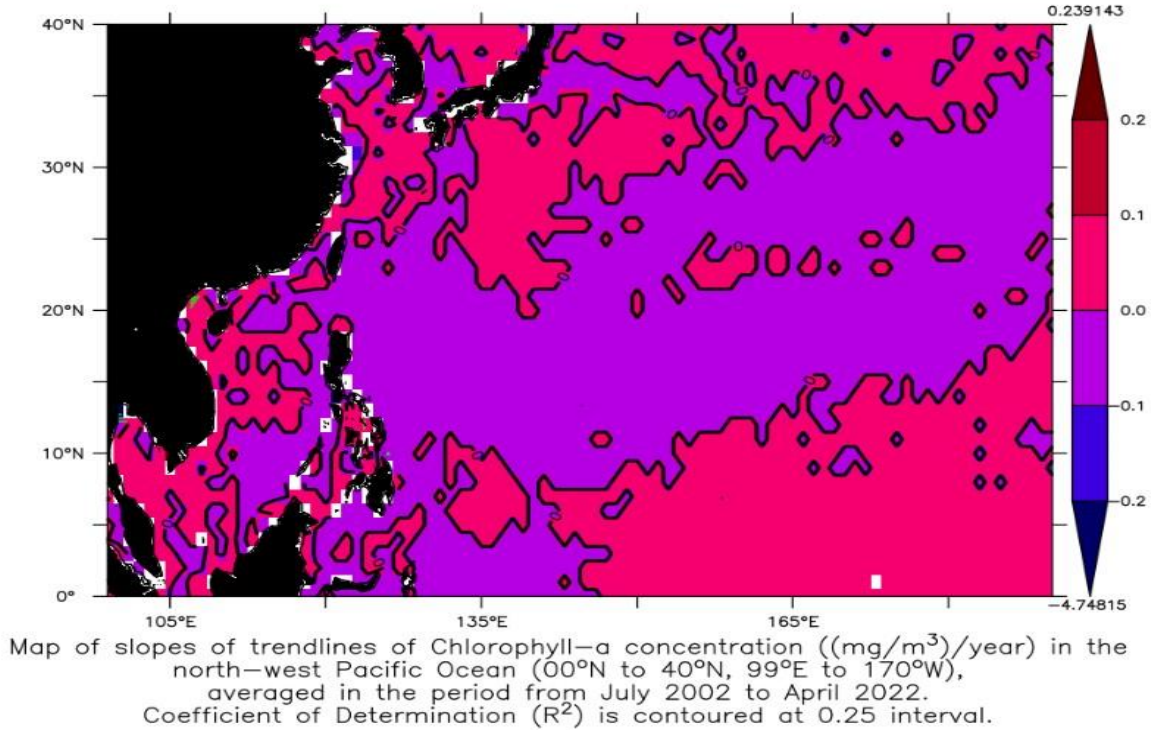


Figure 4.18 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the entire period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the entire period from July 2002 to April 2022, is shown in Figure 4.18.

The slope of chlorophyll-a concentration has a highest positive value of 0.239 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward.

4.2.2 Map of Slopes of Trendlines of Chlorophyll-a Concentration Averaged Month-wise from July 2002 to April 2022

a. *January*:

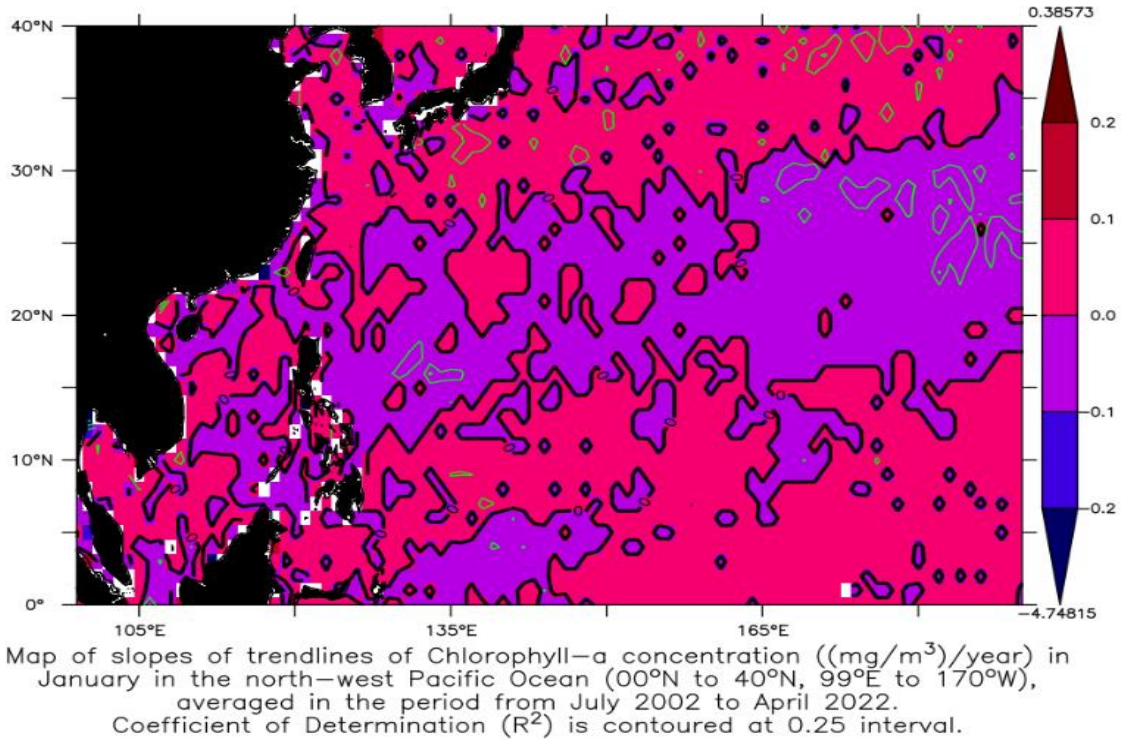


Figure 4.19 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of January in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of January from July 2002 to April 2022, is shown in Figure 4.19.

The slope of chlorophyll-a concentration has a highest positive value of 0.239 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. The values ranging from 0.1 to 0.2 (mg/m^3)/year is observed near the coast of North Korea, Malacca Strait and in Celebes Sea. Values ranging from -0.1 to -0.2 (mg/m^3)/year is observed in Gulf of Thailand and Malacca Strait and values above -0.2 (mg/m^3)/year is observed near Hong Kong, Gulf of Thailand and near Sarawak in Malaysia.

b. *February:*

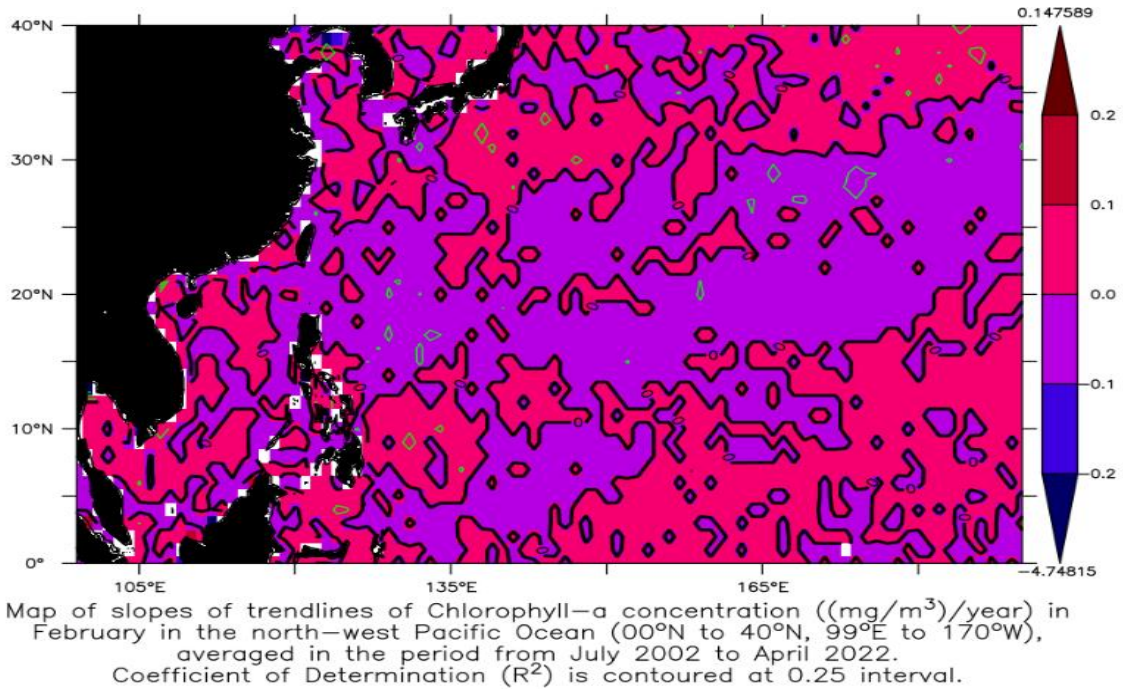


Figure 4.20 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of February in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of February from July 2002 to April 2022, is shown in Figure 4.20.

The slope of chlorophyll-a concentration has a highest positive value of 0.147 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1

to 0.2 (mg/m^3)/year is observed in Malacca Strait. The values ranging from -0.1 to -0.2 (mg/m^3)/year is observed in Bohai Bay and Yellow Sea near west coast of North Korea and values above -0.2 (mg/m^3)/year is observed near the west coast of North Korea.

c. *March:*

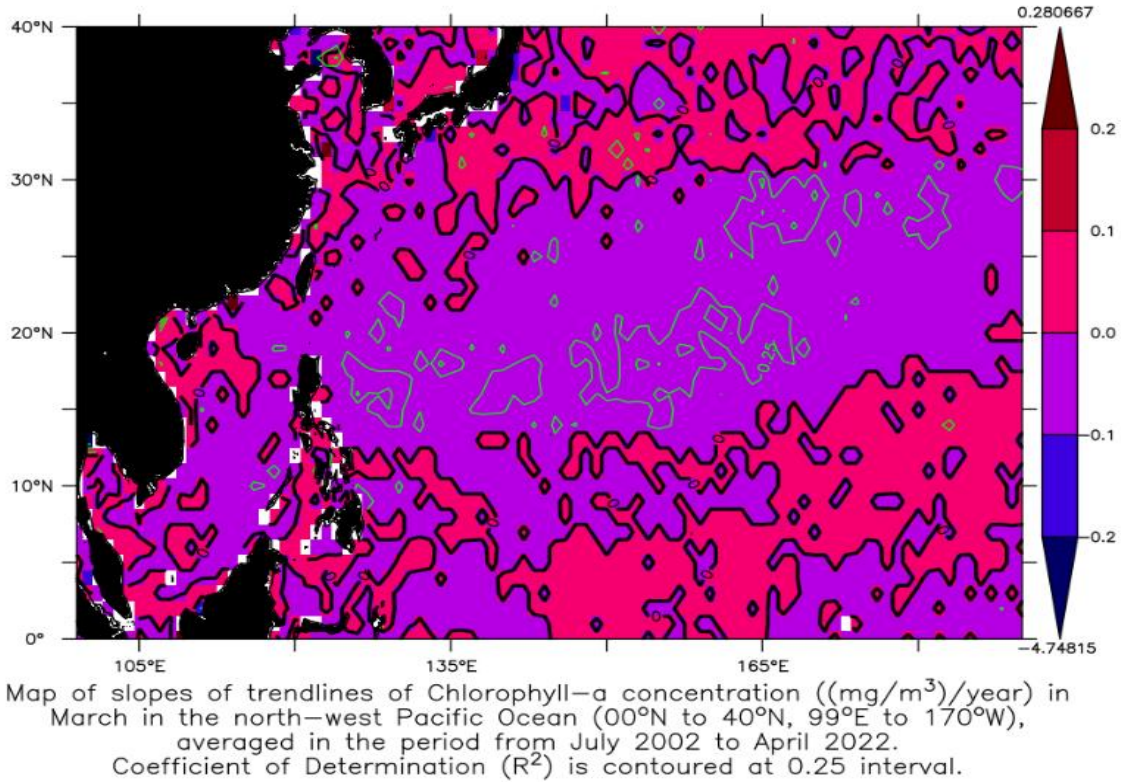


Figure 4.21 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of March in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of March from July 2002 to April 2022, is shown in Figure 4.21.

The slope of chlorophyll-a concentration has a highest positive value of 0.280 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values above 0.2 (mg/m^3)/year is observed in East China Sea and near Zhuhai in China. Values ranging from 0.1 to 0.2 (mg/m^3)/year is observed near west coast of Japan and south east coast of South Korea. The values ranging from -0.1 to -0.2 (mg/m^3)/year is observed in Bohai Bay, Gulf of Thailand, Malacca Strait, east coast of Japan and near Shikoku and values above -0.2 (mg/m^3)/year is observed near Shandong.

d.*April:*

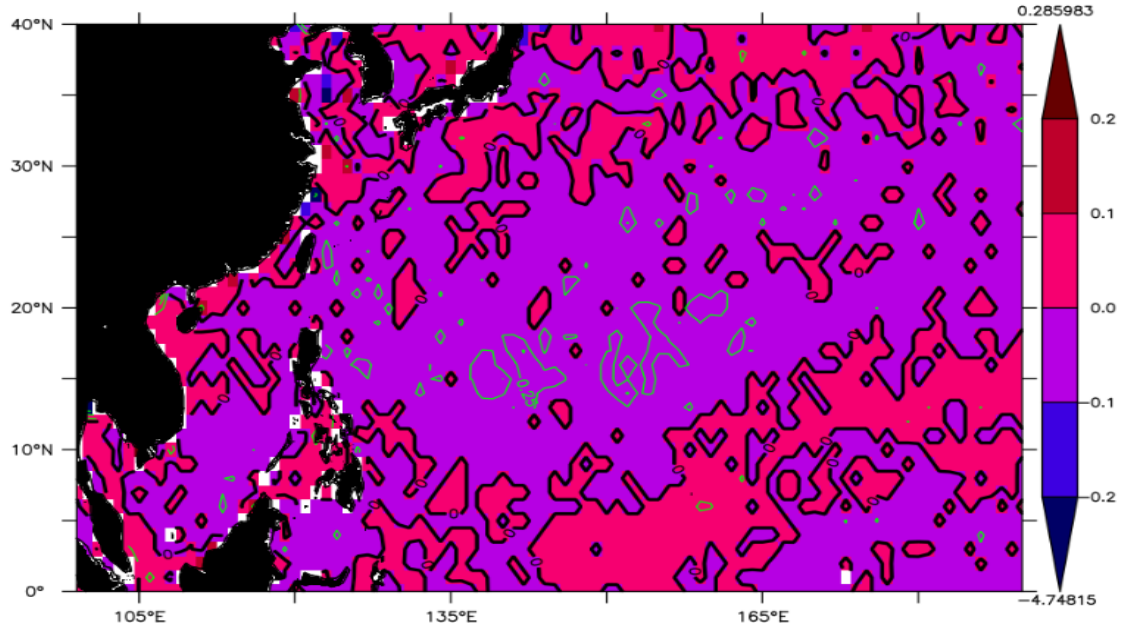


Figure 4.22 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of April in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of April from July 2002 to April 2022, is shown in Figure 4.22.

The slope of chlorophyll-a concentration has a highest positive value of 0.285 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1 to 0.2 (mg/m^3)/year is observed in Yellow Sea, East China Sea, South China Sea and near the coast of Sarawak in Malaysia. The values ranging from -0.1 to -0.2 (mg/m^3)/year is observed in Bohai Bay, Yellow Sea, East China Sea and north-west coast of Japan and values above -0.2 (mg/m^3)/year is observed in Yellow Sea and East China Sea.

e.*May:*

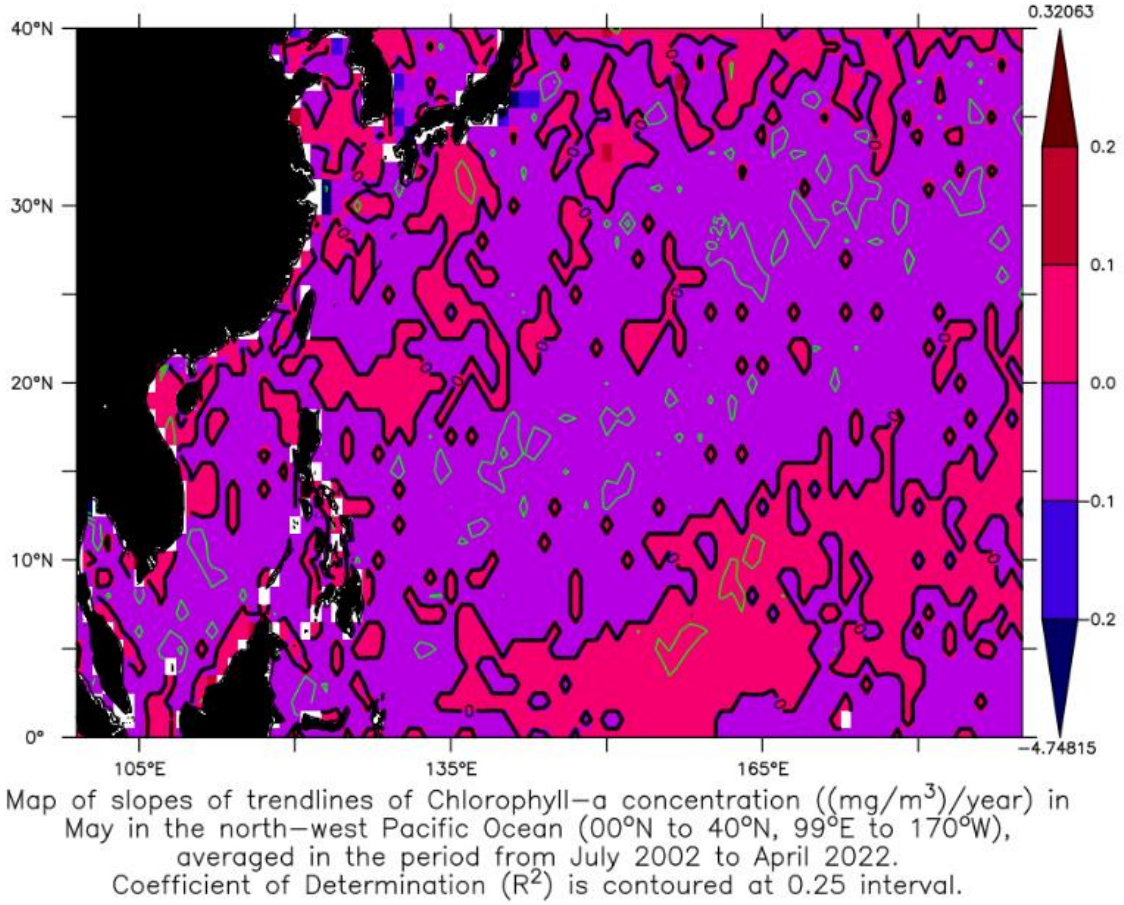


Figure 4.23 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of May in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of May from July 2002 to April 2022, is shown in Figure 4.23.

The slope of chlorophyll-a concentration has a highest positive value of 0.320 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and

Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1 to 0.2 (mg/m^3)/year is observed in Yellow Sea and between 30° N to 40° N, 135° E to 165° E. The values ranging from -0.1 to -0.2 (mg/m^3)/year is observed in Bohai Bay, Yellow Sea, Sea of Japan, west coast of Japan and values above -0.2 (mg/m^3)/year is observed in East China Sea and on the west coast of Japan.

f.*June:*

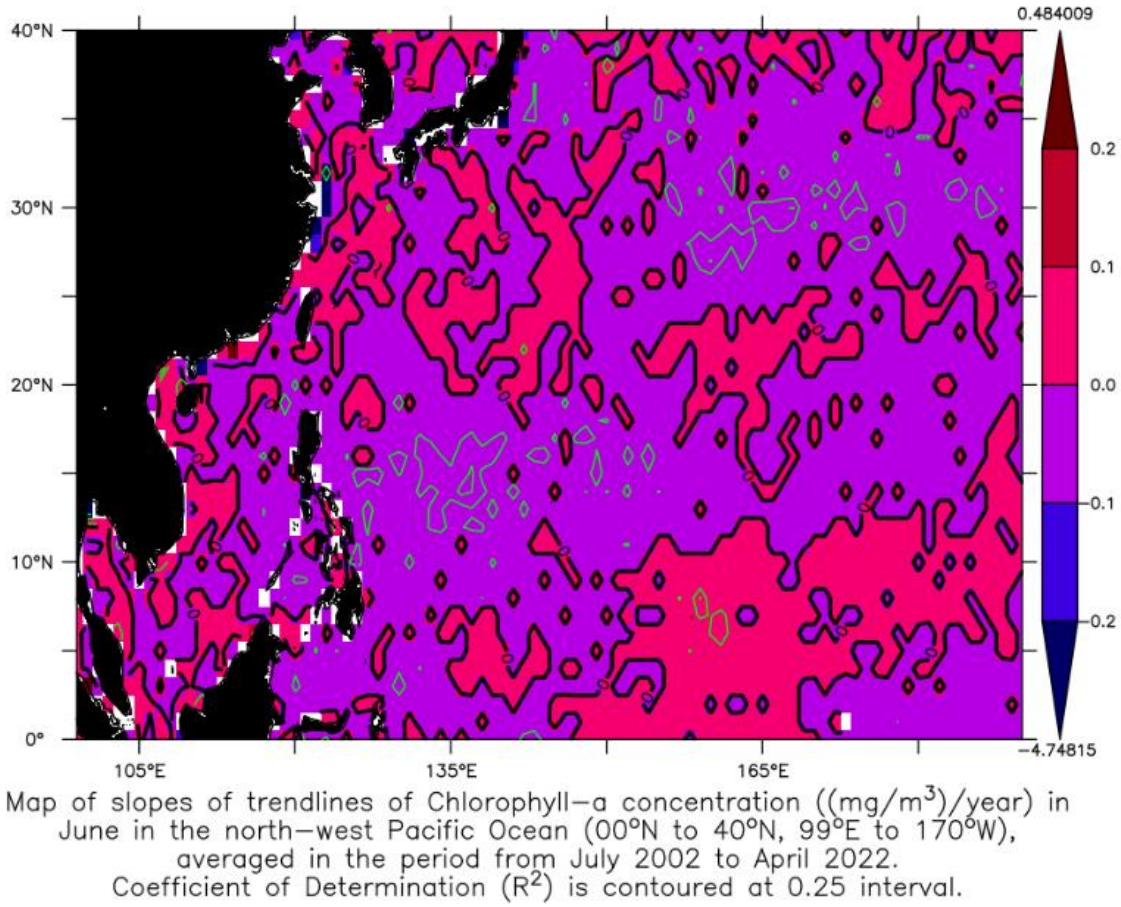


Figure 4.24 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of June in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of June from July 2002 to April 2022, is shown in Figure 4.24.

The slope of chlorophyll-a concentration has a highest positive value of 0.484 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values above 0.2 (mg/m^3)/year is observed near the coast of Hong Kong and in Malacca Strait. The values ranging from -0.1 to -0.2 (mg/m^3)/year is observed in Bohai Bay, Yellow Sea and in East China Sea. Sea of Japan, and values above -0.2 (mg/m^3)/year is observed in East China Sea, on the coast of Zhanjiang in China and in Gulf of Thailand.

g. *July:*

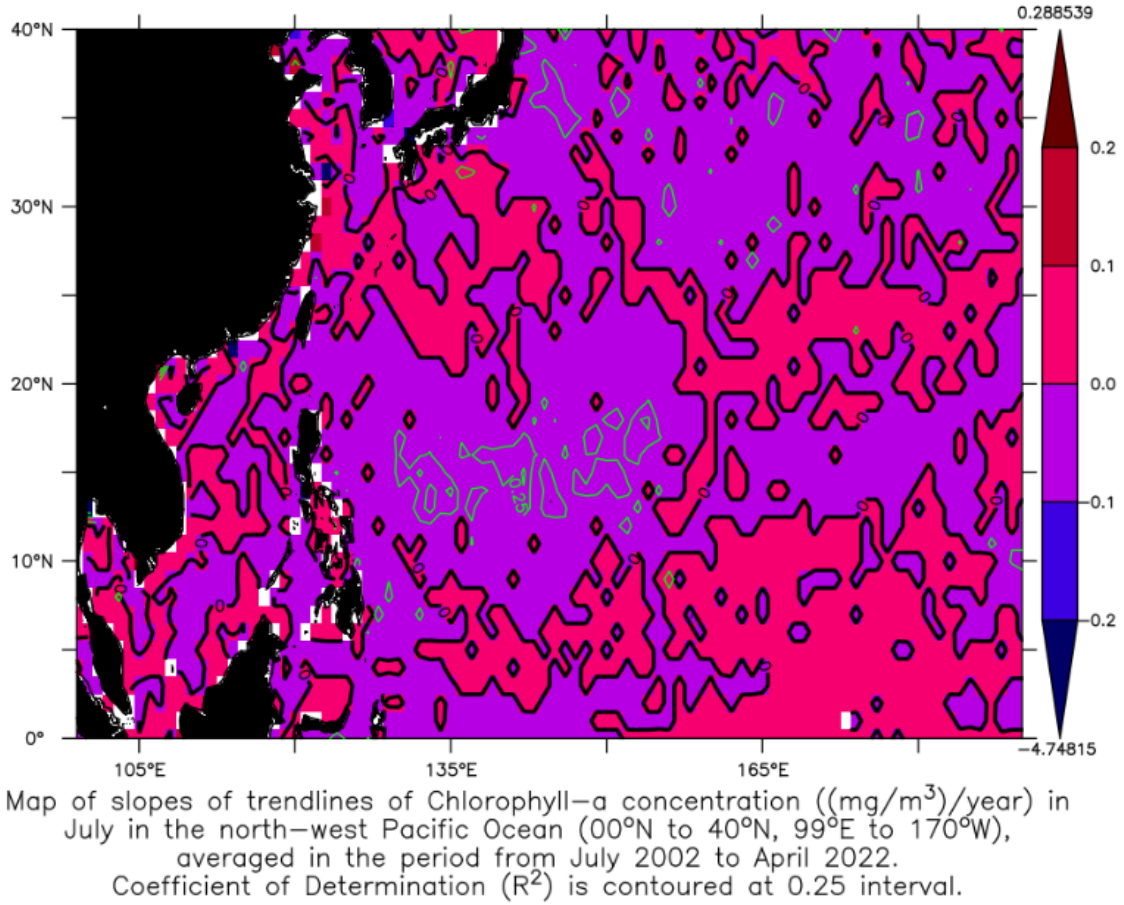


Figure 4.25 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of July in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of July from July 2002 to April 2022, is shown in Figure 4.25.

The slope of chlorophyll-a concentration has a highest positive value of 0.288 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The

map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. The values ranging from 0.1 to 0.2 (mg/m^3)/year is observed in Bohai Bay and in East China Sea. The values ranging from -0.1 to -0.2 (mg/m^3)/year is observed in Bohai Bay and near south coast of South Korea and values above -0.2 (mg/m^3)/year is observed near the coast of Shanghai, Hong Kong and in Gulf of Thailand.

h. *August:*

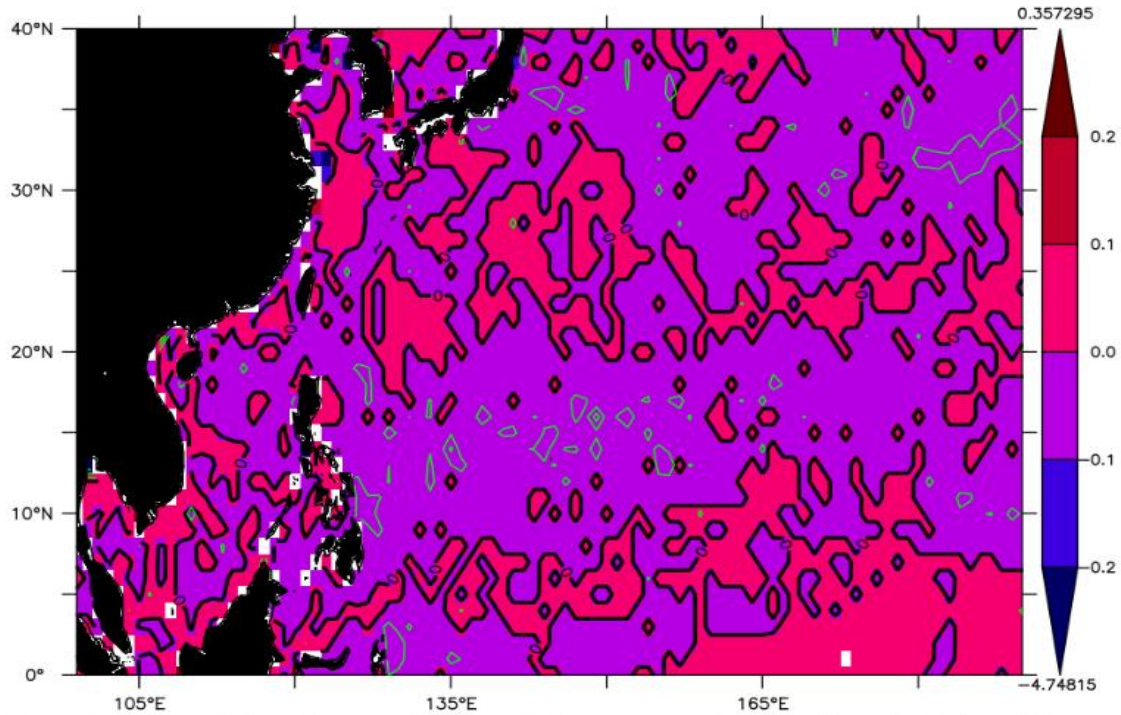


Figure 4.26 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of August in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of August from July 2002 to April 2022, is shown in Figure 4.26.

The slope of chlorophyll-a concentration has a highest positive value of 0.357 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values above 0.2 (mg/m^3)/year was observed in Bohai Sea. Values ranging from 0.1 to 0.2 (mg/m^3)/year was observed near the north-west coast of Japan. Values ranging from -0.1 to -0.2 (mg/m^3)/year was observed near the coast of Shanghai and values above -0.2 (mg/m^3)/year as observed in Yellow Sea, near the coast of Shanghai and in the Gulf of Thailand.

i.*September:*

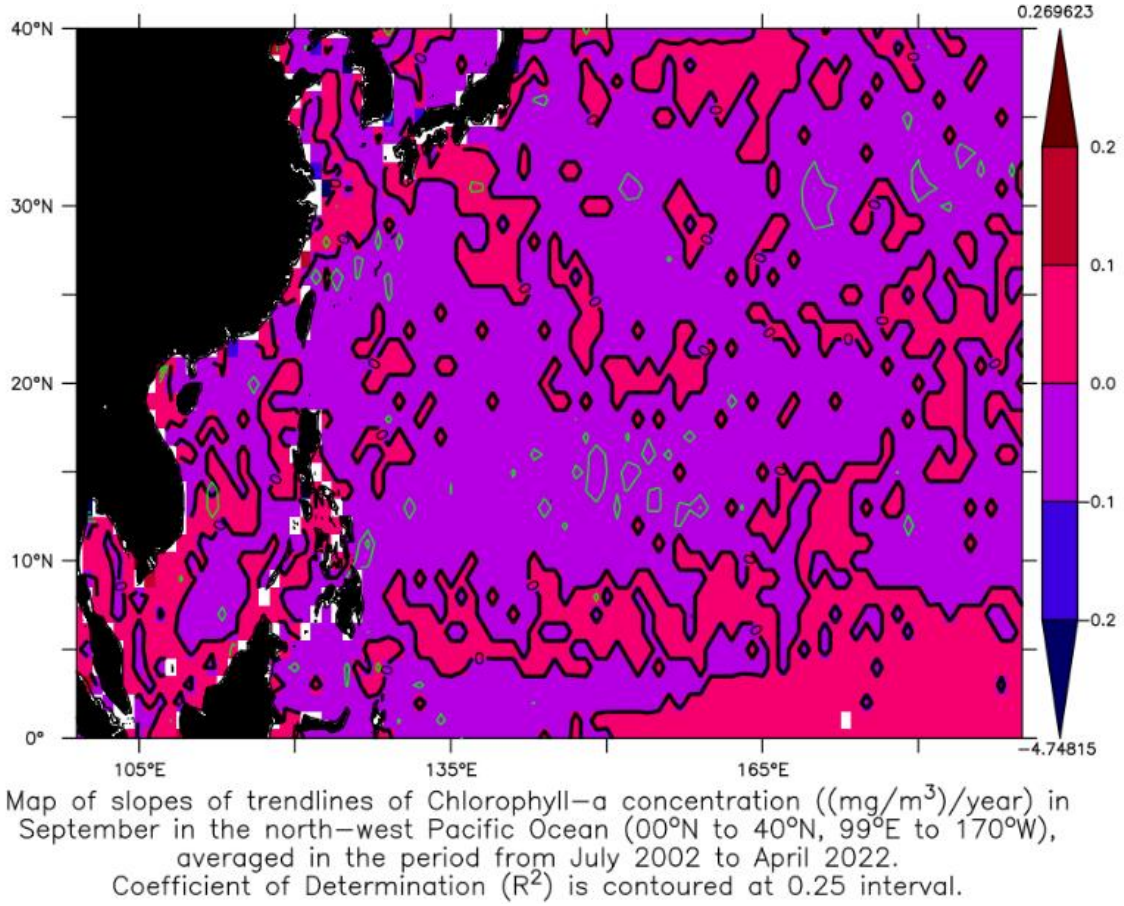


Figure 4.27 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of September in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of September from July 2002 to April 2022, is shown in Figure 4.27.

The slope of chlorophyll-a concentration has a highest positive value of 0.269 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The

map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1 to 0.2 (mg/m^3)/year was observed in Bohai Bay, East China Sea, coast of Vietnam and Malacca Strait. Values ranging from -0.1 to -0.2 (mg/m^3)/year was observed in Yellow Sea, near the coast of Shanghai and Hong Kong and in Sea of Japan. Values above -0.2 (mg/m^3)/year was observed near the coast of Shanghai.

j.*October:*

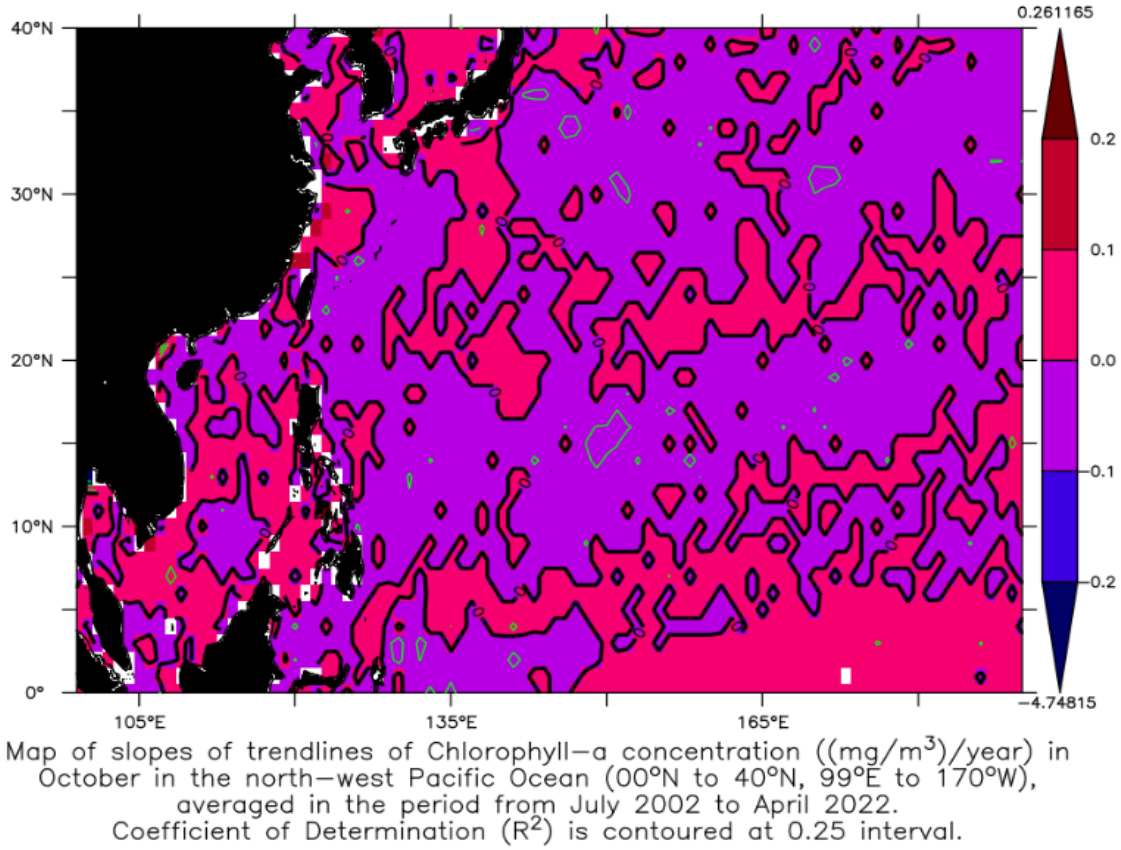


Figure 4.28 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of October in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of October from July 2002 to April 2022, is shown in Figure 4.28.

The slope of chlorophyll-a concentration has a highest positive value of 0.261 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1 to 0.2 (mg/m^3)/year was observed in Yellow Sea, East China Sea, along the coast of South China Sea near the coast of Vietnam and in the Gulf of Thailand. Values ranging from -0.1 and above were not observed.

k.*November:*

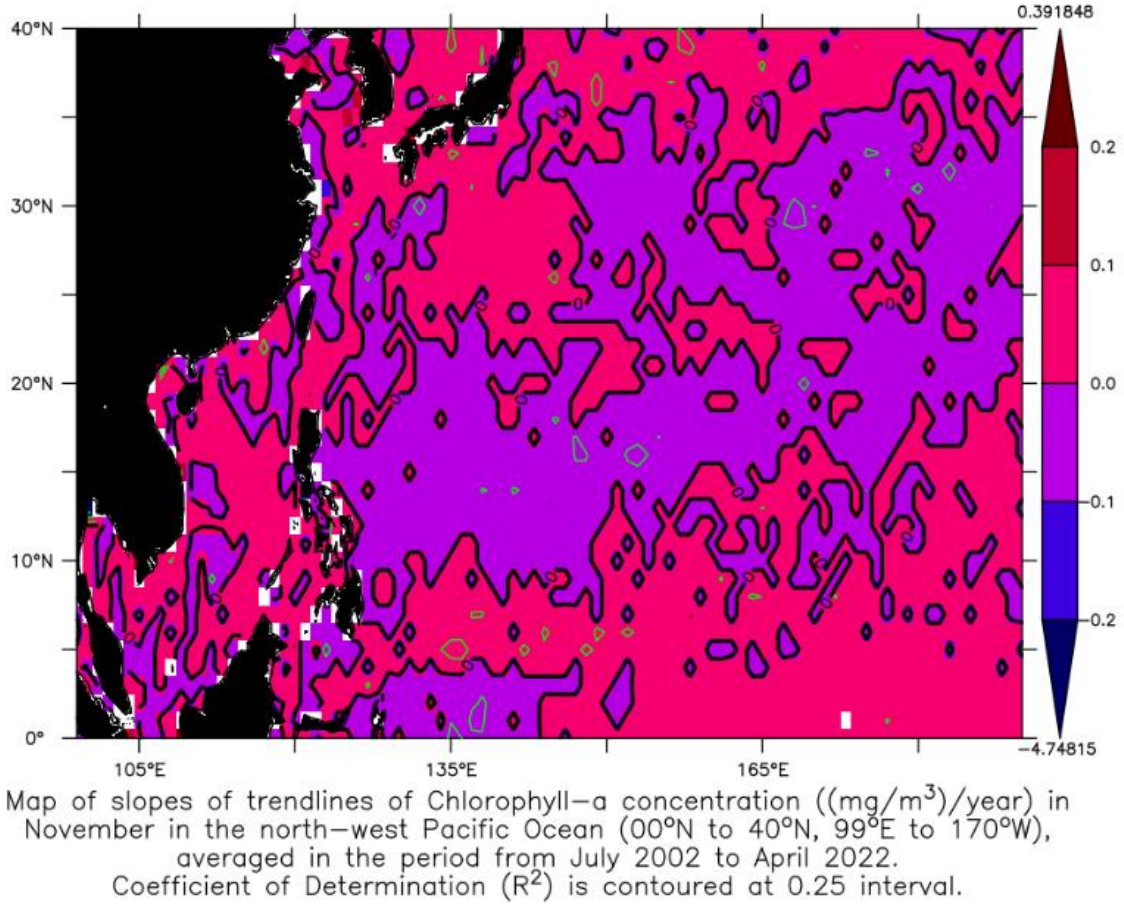


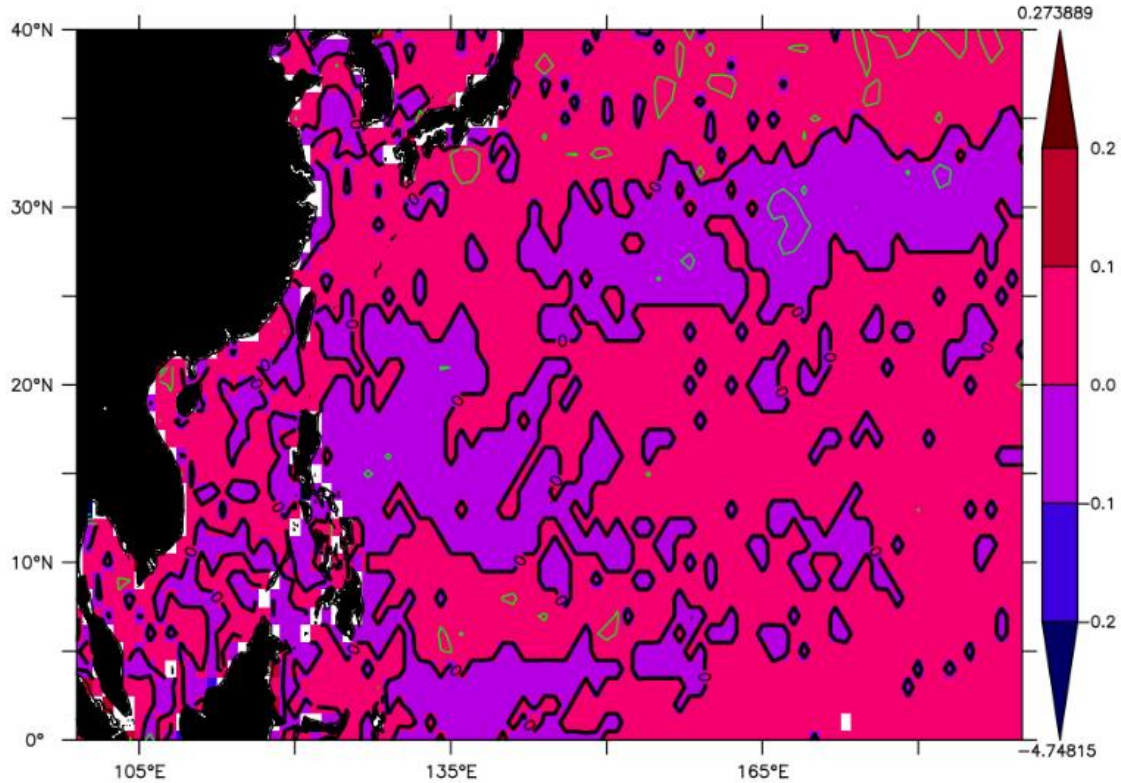
Figure 4.29 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of November in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of November from July 2002 to April 2022, is shown in Figure 4.29.

The slope of chlorophyll-a concentration has a highest positive value of 0.391 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The

map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1 to 0.2 (mg/m^3)/year was observed in Bohai Bay and in Yellow Sea. Values ranging from -0.1 to -0.2 (mg/m^3)/year was observed in East China Sea.

l.*December:*



Map of slopes of trendlines of Chlorophyll–a concentration ((mg/m^3)/year) in December in the north–west Pacific Ocean (00°N to 40°N, 99°E to 170°W), averaged in the period from July 2002 to April 2022. Coefficient of Determination (R^2) is contoured at 0.25 interval.

Figure 4.30 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of December in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the month of December from July 2002 to April 2022, is shown in Figure 4.30.

The slope of chlorophyll-a concentration has a highest positive value of 0.274 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values above 0.2 (mg/m^3)/year was observed south of North Korea. Values ranging from 0.1 to 0.2 (mg/m^3)/year was observed in Malacca Strait. Values ranging from -0.1 to -0.2 (mg/m^3)/year was observed near the coast of Sarawak.

4.2.3 Map of Slopes of Trendlines of Chlorophyll-a Concentration Averaged Season-wise from July 2002 to April 2022

a. *Boreal Spring Season:*

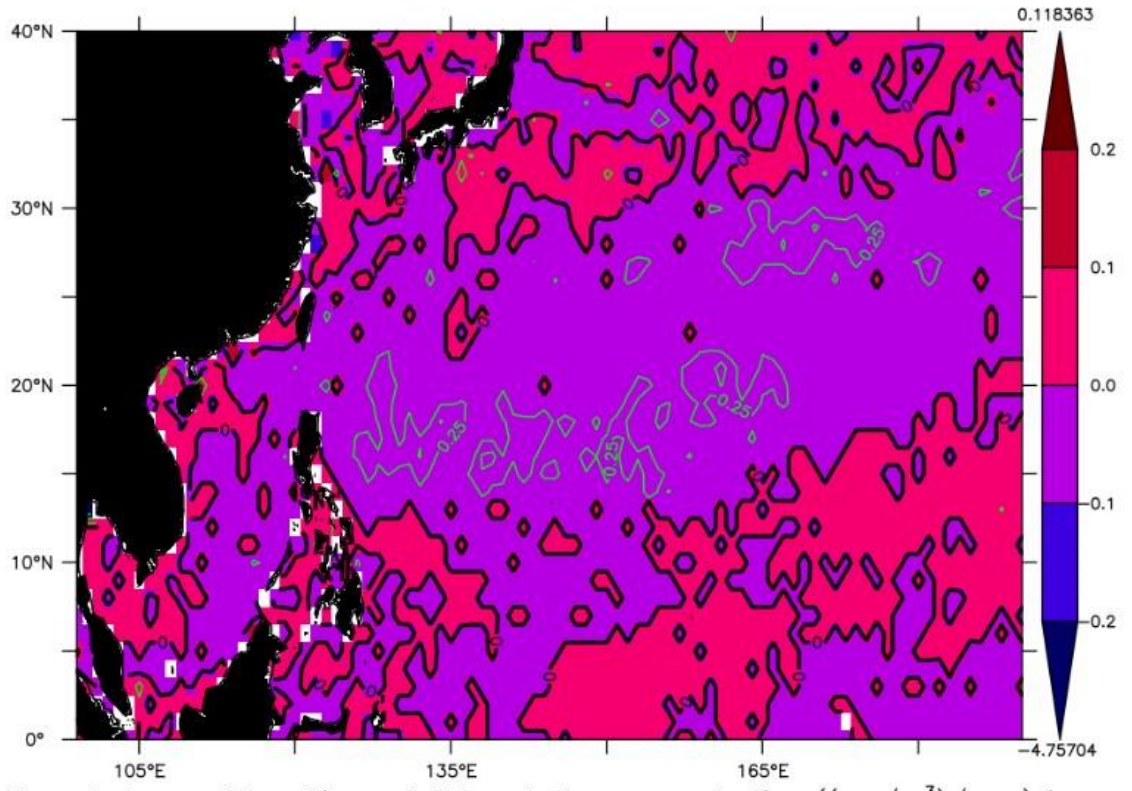


Figure 4.31 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the Boreal Spring Season in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W),

averaged in the Boreal Spring Season from July 2002 to April 2022, is shown in Figure 4.31.

The slope of chlorophyll-a concentration has a highest positive value of 0.118 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1 to 0.2 (mg/m^3)/year were observed in East China Sea and near the coast of Hong Kong. Values ranging from -0.1 to -0.2 (mg/m^3)/year were observed in Bohai Bay and in Yellow Sea.

b. *Boreal Summer Season:*

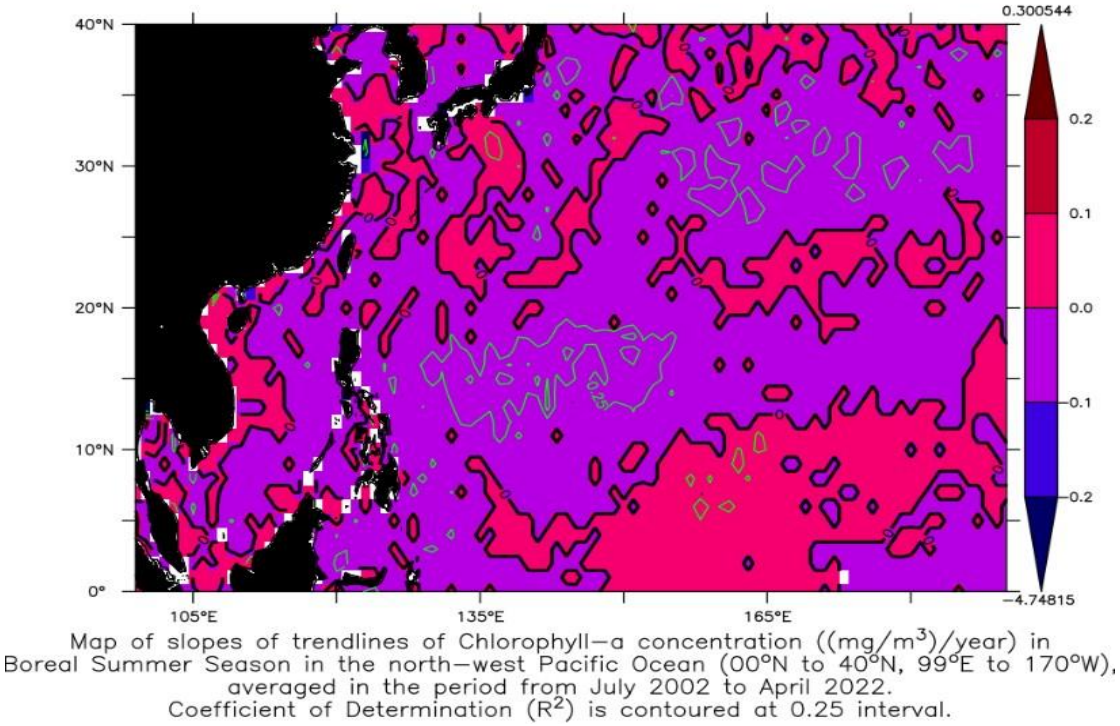


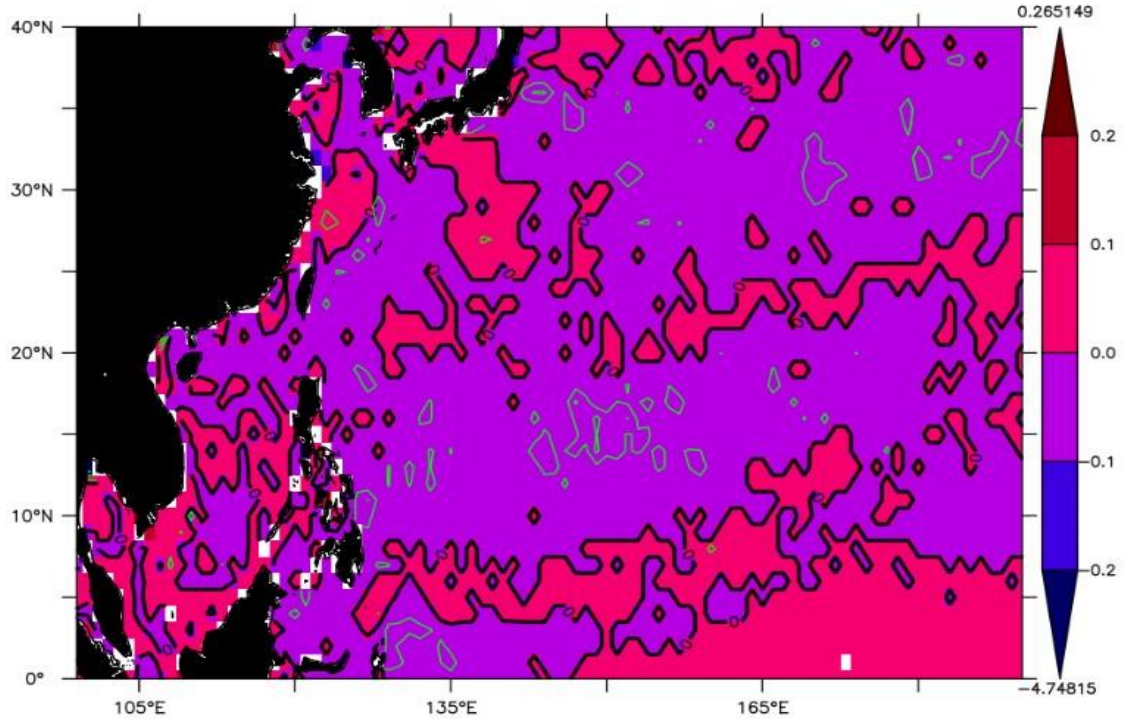
Figure 4.32 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the Boreal Summer Season in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the Boreal Summer Season from July 2002 to April 2022, is shown in Figure 4.32.

The slope of chlorophyll-a concentration has a highest positive value of 0.300 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific

Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values above 0.1 (mg/m^3)/year were not observed. Values ranging from -0.1 to -0.2 (mg/m^3)/year were observed in Bohai Bay, in East China Sea, near the coast of Guangdong Province and near the coast of Honshu and values above -0.2 (mg/m^3)/year was observed in East China Sea.

c. *Boreal Autumn Season:*



Map of slopes of trendlines of Chlorophyll–a concentration ((mg/m^3)/year) in Boreal Autumn Season in the north–west Pacific Ocean (00°N to 40°N, 99°E to 170°W), averaged in the period from July 2002 to April 2022. Coefficient of Determination (R^2) is contoured at 0.25 interval.

Figure 4.33 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the Boreal Autumn Season in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the Boreal Autumn Season from July 2002 to April 2022, is shown in Figure 4.33.

The slope of chlorophyll-a concentration has a highest positive value of 0.265 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values above 0.1 to 0.2 (mg/m^3)/year were observed near the coast of North Korea and near the coast of Vietnam. Values ranging from -0.1 to -0.2 (mg/m^3)/year were observed near the coast of Liaoning in China, Yellow Sea and East China Sea.

d. *Boreal Winter Season:*

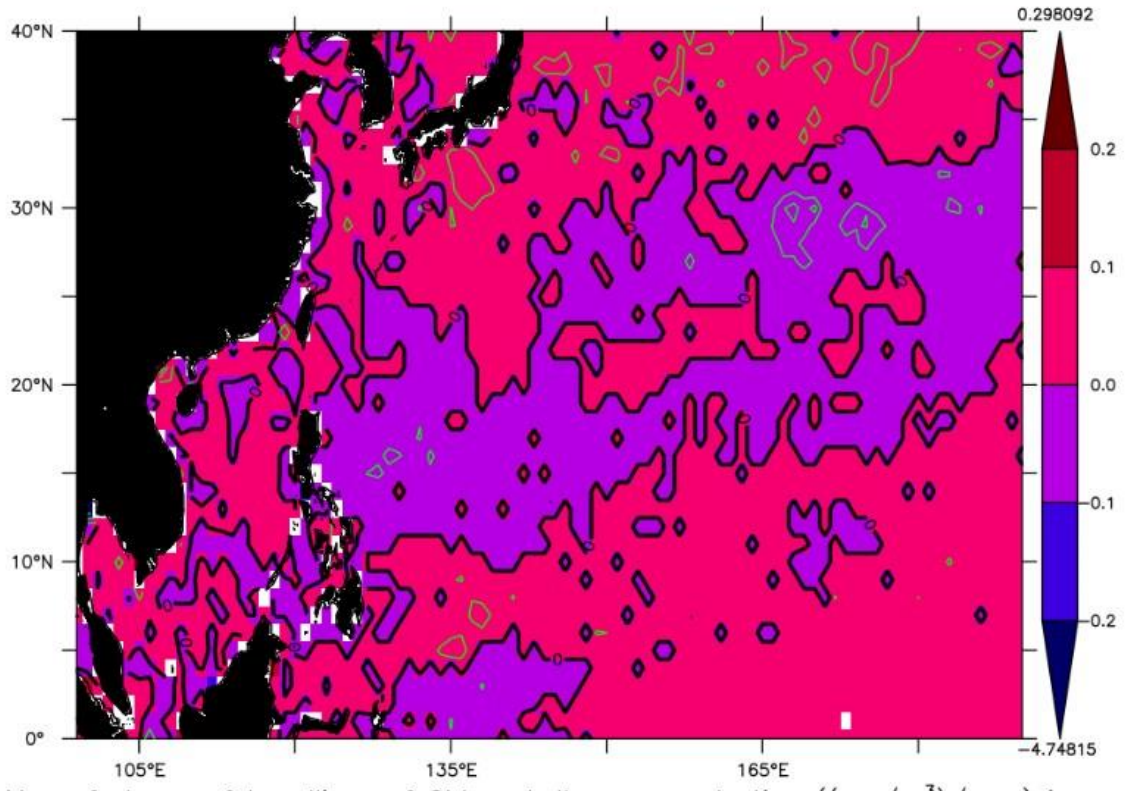


Figure 4.34 – Map of slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the Boreal Winter Season in the period from July 2002 to April 2022

The map of the slopes of trendlines of chlorophyll-a concentration [(mg/m^3)/year] in the north-west Pacific Ocean (0 °N to 40 °N, 99 °E to 170 °W), averaged in the Boreal Winter Season from July 2002 to April 2022, is shown in Figure 4.34.

The slope of chlorophyll-a concentration has a highest positive value of 0.298 (mg/m^3)/year and a highest magnitude of negative value of -4.748 (mg/m^3)/year. The map shows a general band of decreasing trends from the South China Sea and Philippines which extends north-eastward. The major part of the north-west Pacific Ocean shows values ranging from 0.1 to -0.1 (mg/m^3)/year. Values ranging from 0.1 to 0.2 (mg/m^3)/year were observed near the coast of North Korea and in Malacca Strait and values ranging from -0.1 to -0.2 (mg/m^3)/year was observed near the coast of Sarawak in Malaysia.

4.3 BASIN-AVERAGED OF CHLOROPHYLL-A CONCENTRATION FROM JULY 2002 TO APRIL 2022

4.3.1 Chlorophyll-a Concentration Basin-Averaged for the Entire Time-Period from July 2002 to April 2022

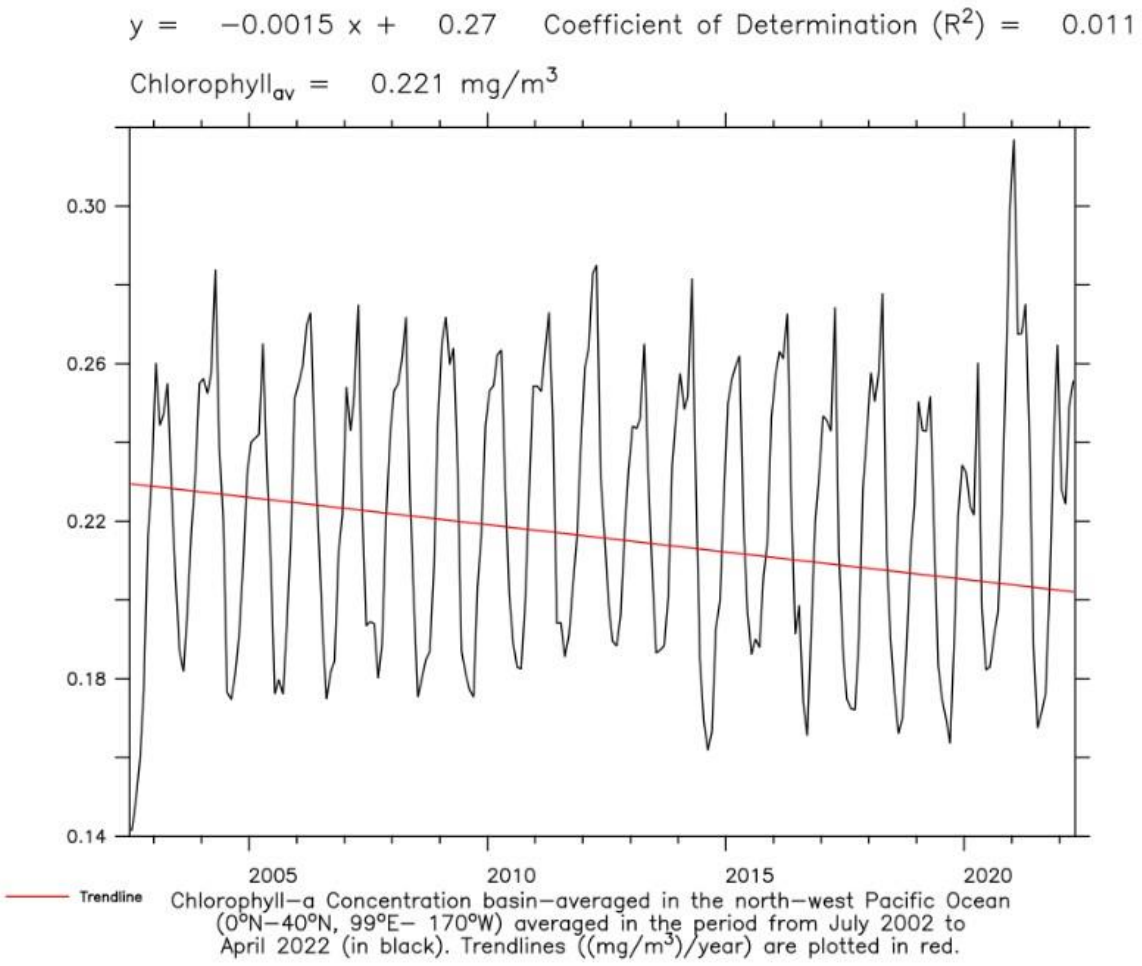


Figure 4.35 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the period from July 2002 to

April 2022 is shown in the Figure 4.35. The chlorophyll-a concentration ranges between approximately 0.14 mg/m^3 to 0.32 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0015 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.011. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.221 mg/m^3. The basin-averaged chlorophyll-a concentration shows a strong annual cycle.

4.3.2 Chlorophyll-a Concentration Basin-Averaged Month-wise from July 2002 to April 2022

a. *January*:

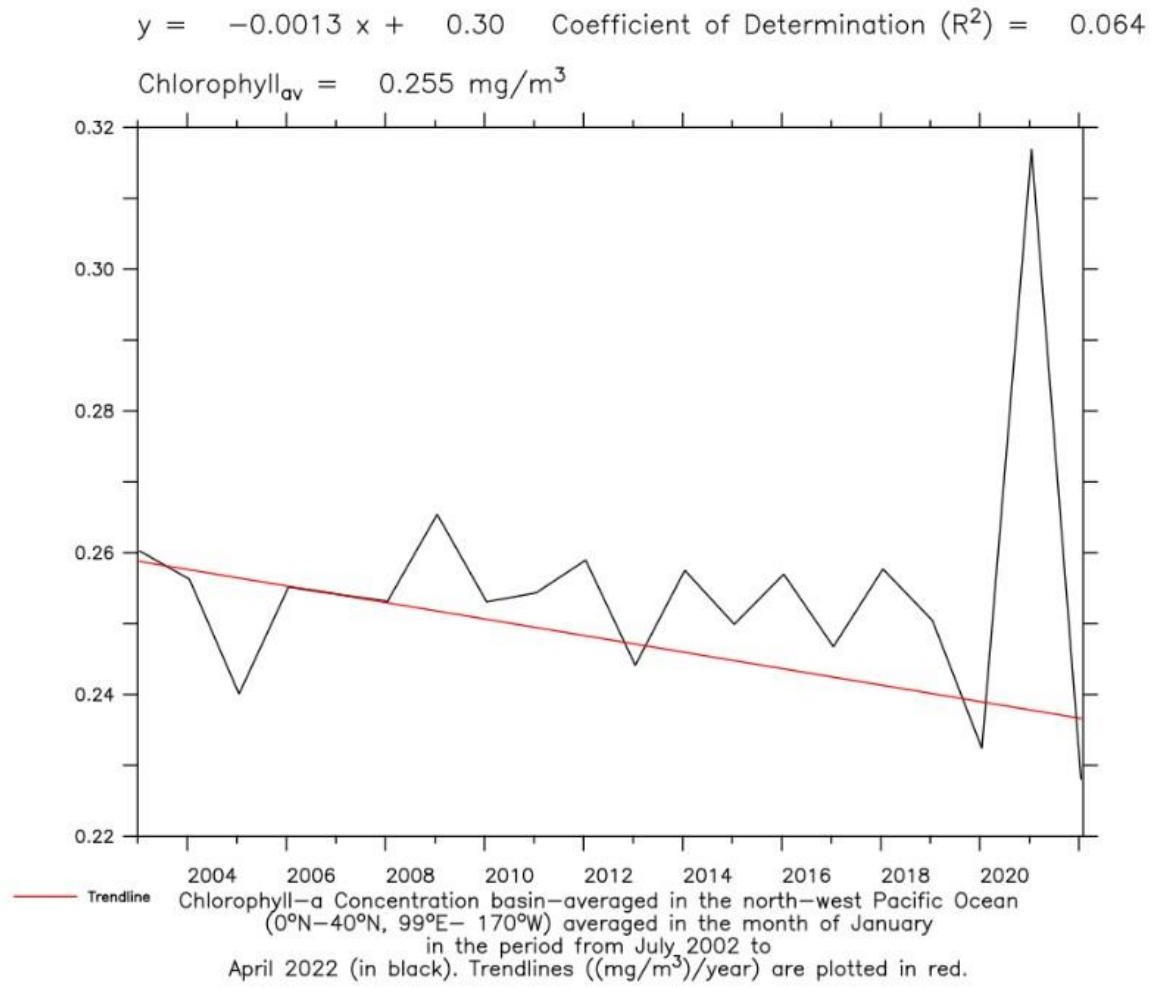


Figure 4.36 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of January in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of January in the period from July 2002 to April 2022 is shown in the Figure 4.36. The chlorophyll-a

concentration ranges between approximately 0.22 mg/m^3 to 0.32 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0013 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.064. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.255 mg/m$^{3.}$

b. *February*:

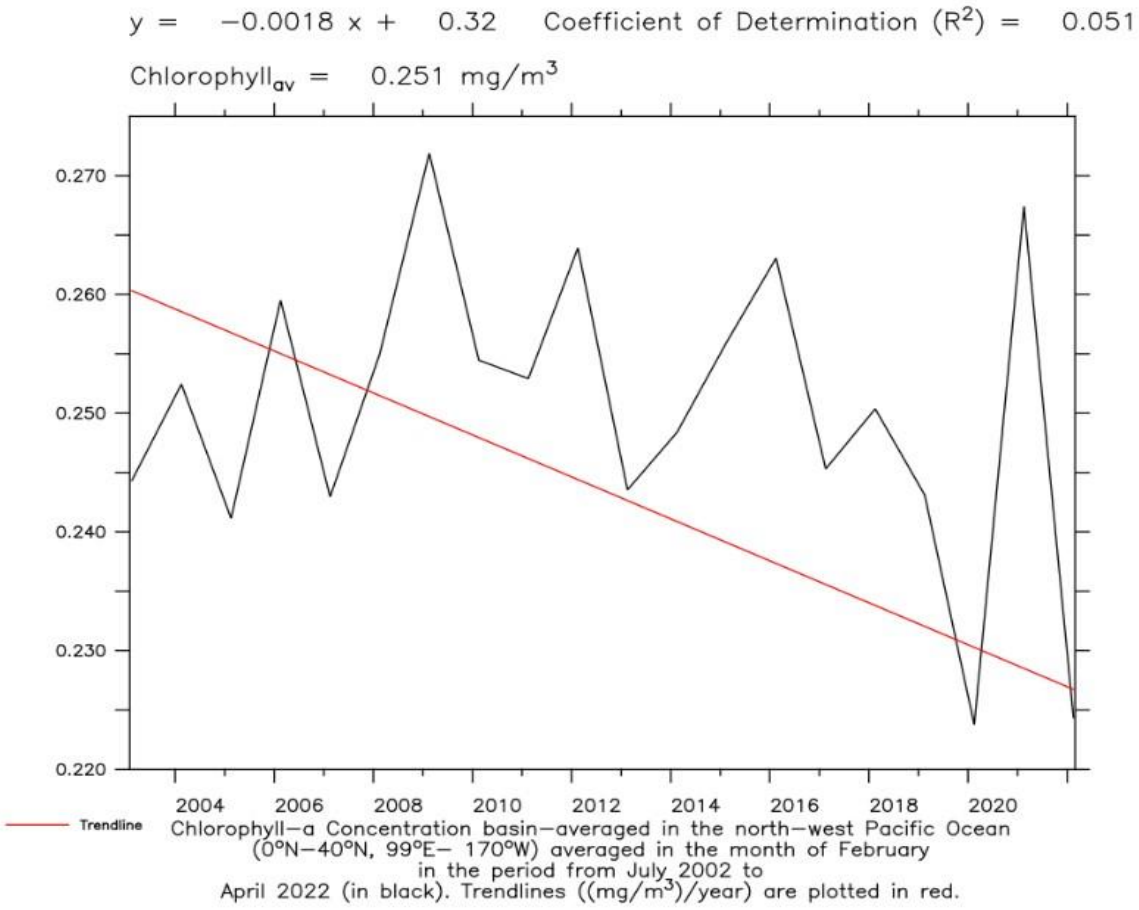


Figure 4.37 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of February in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of February in the period from July 2002 to April 2022 is shown in the Figure 4.37. The chlorophyll-a concentration ranges between approximately 0.220 mg/m^3 to 0.275 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0018 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.051. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.251 $mg/m^{3.}$

c. *March:*

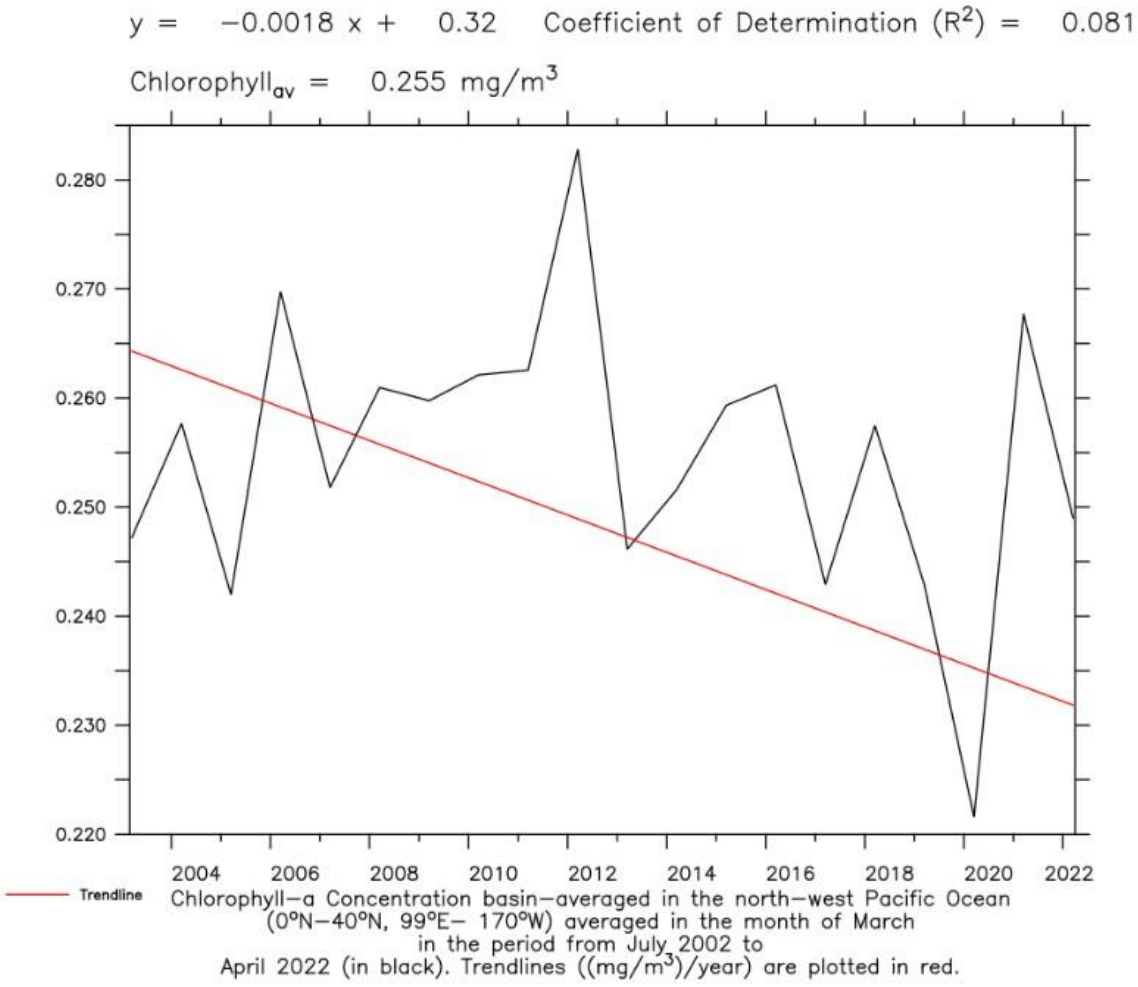


Figure 4.38 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of March in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of March in the period from July 2002 to April 2022 is shown in the Figure 4.38. The chlorophyll-a concentration ranges between approximately 0.220 mg/m^3 to 0.285 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of

-0.0018 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.081. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.255 mg/$m^{3.}$

d. *April:*

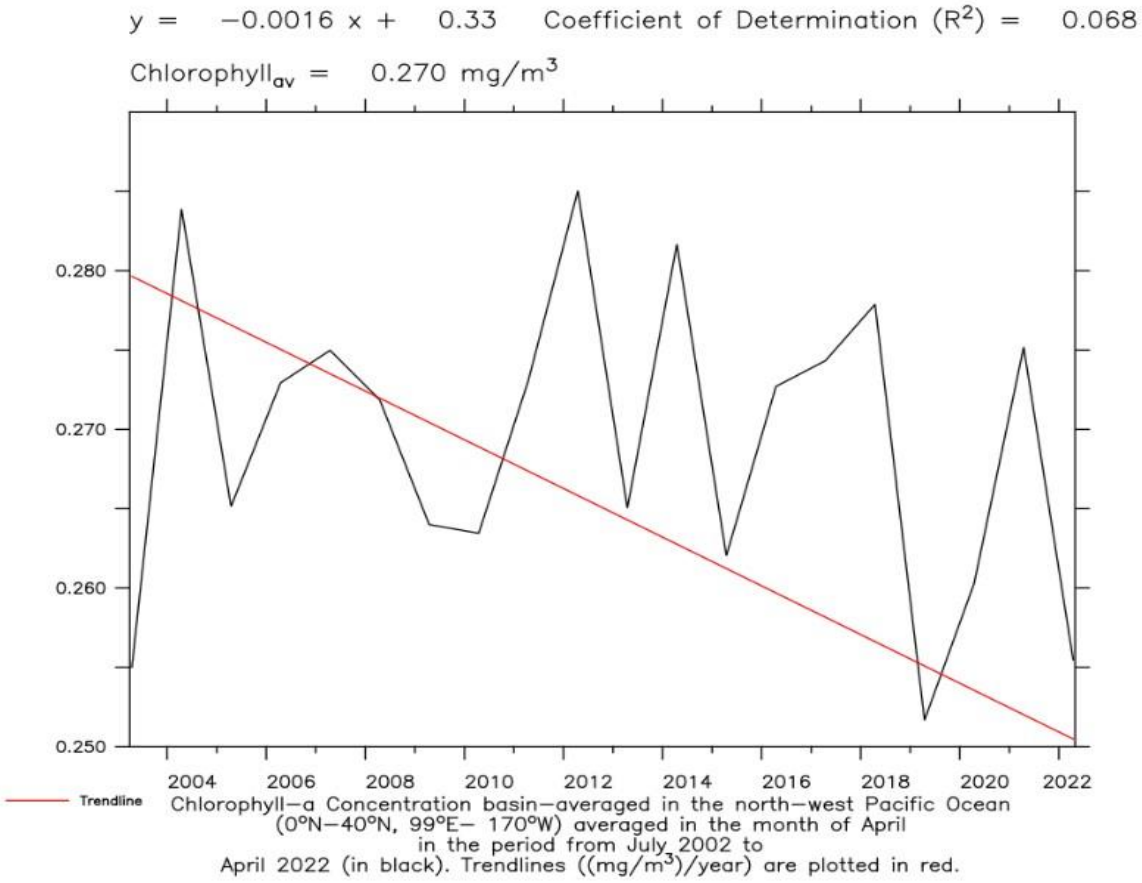


Figure 4.39 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of April in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of April in the period from July 2002 to April 2022 is shown in the Figure 4.39. The chlorophyll-a concentration ranges between approximately 0.250 mg/m^3 to 0.290 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0016 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.068. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.270 $mg/m^{3.}$

e. *May:*

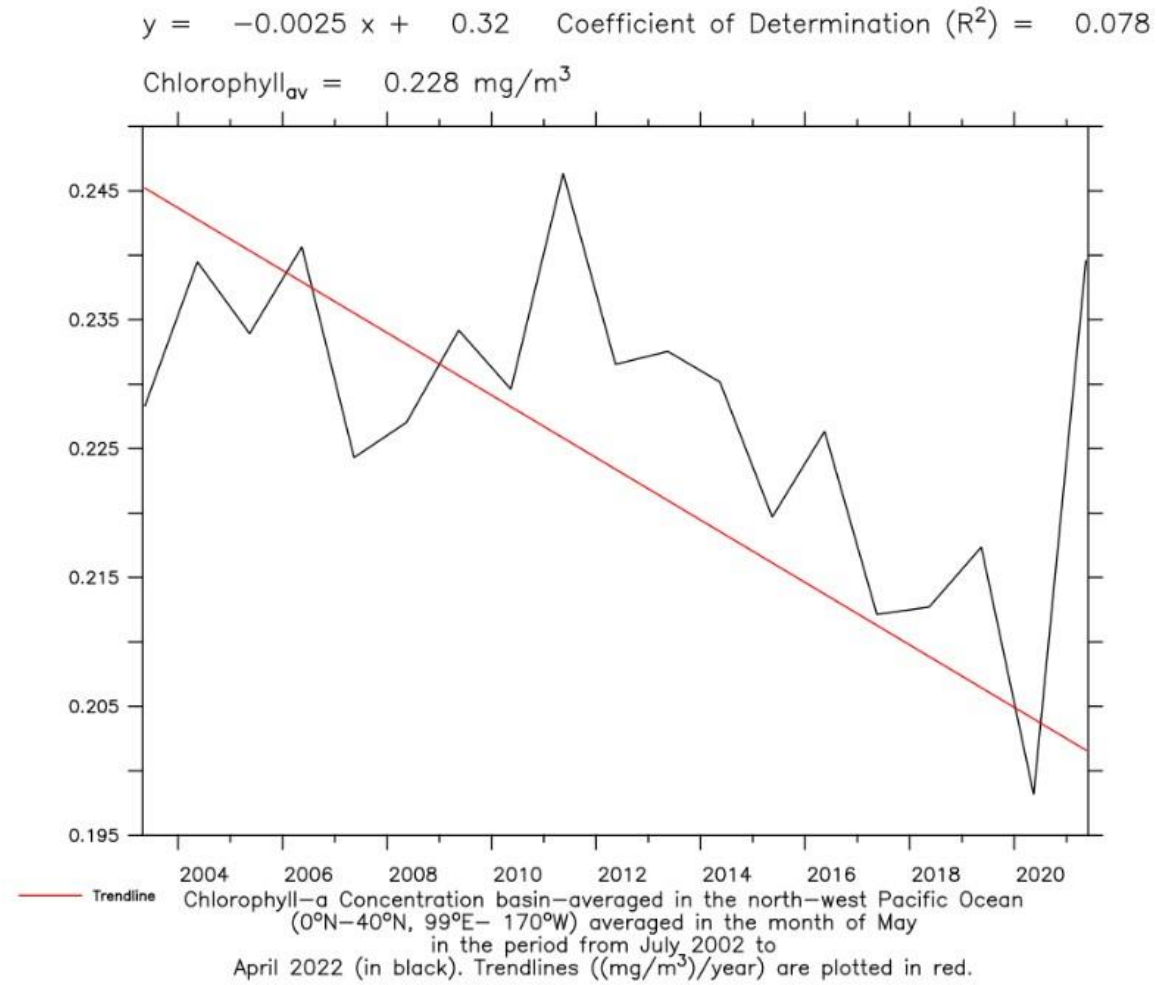


Figure 4.40 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of May in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of May in the period from July 2002 to April 2022 is shown in the Figure 4.40. The chlorophyll-a concentration ranges between approximately 0.195 mg/m^3 to 0.250 mg/m^3. The

trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0025 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.078. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.228 $mg/m^{3.}$

f. *June:*

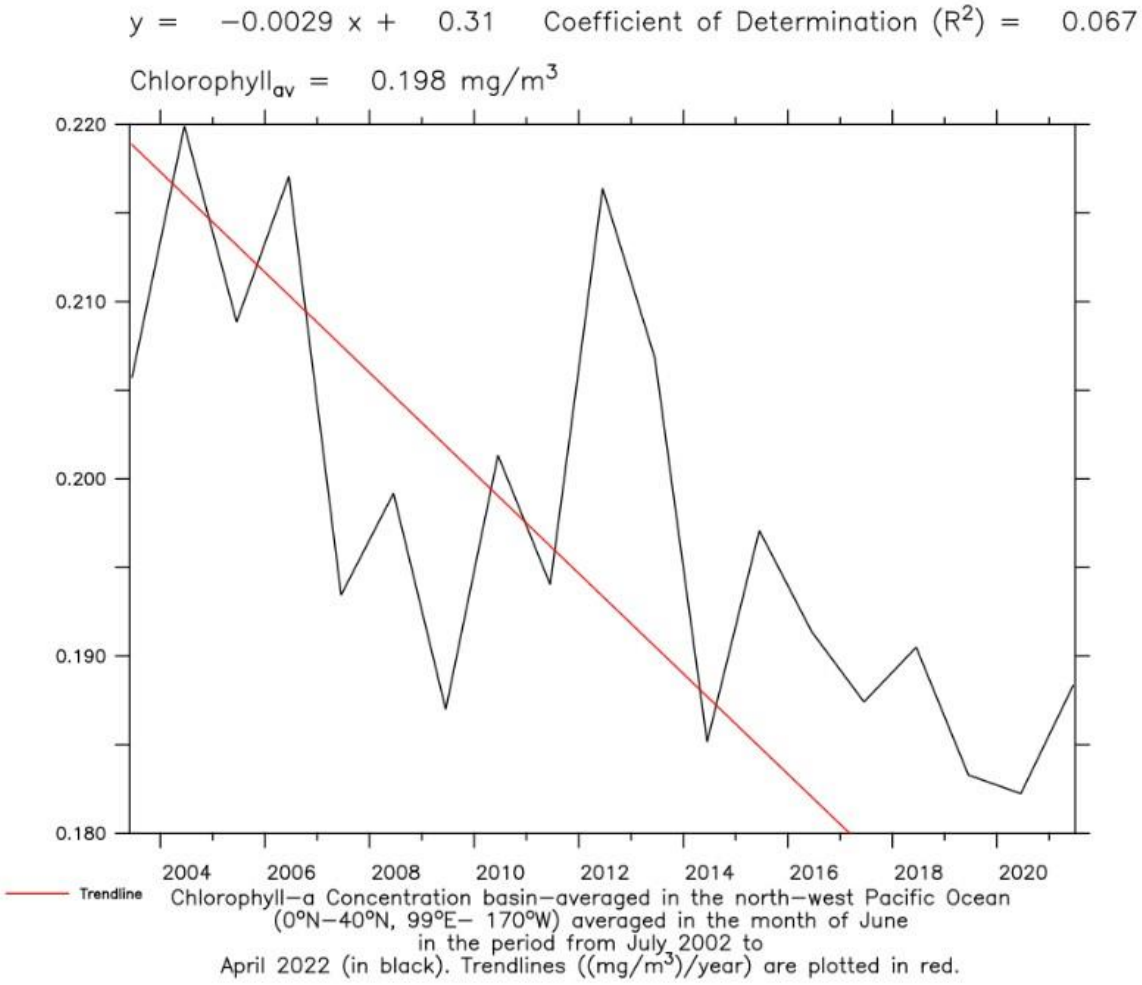


Figure 4.41 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of June in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of June in the period from July 2002 to April 2022 is shown in the Figure 4.41. The chlorophyll-a concentration ranges between approximately 0.180 mg/m^3 to 0.220 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0029 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.067. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.198 $mg/m^{3.}$

g. *July:*

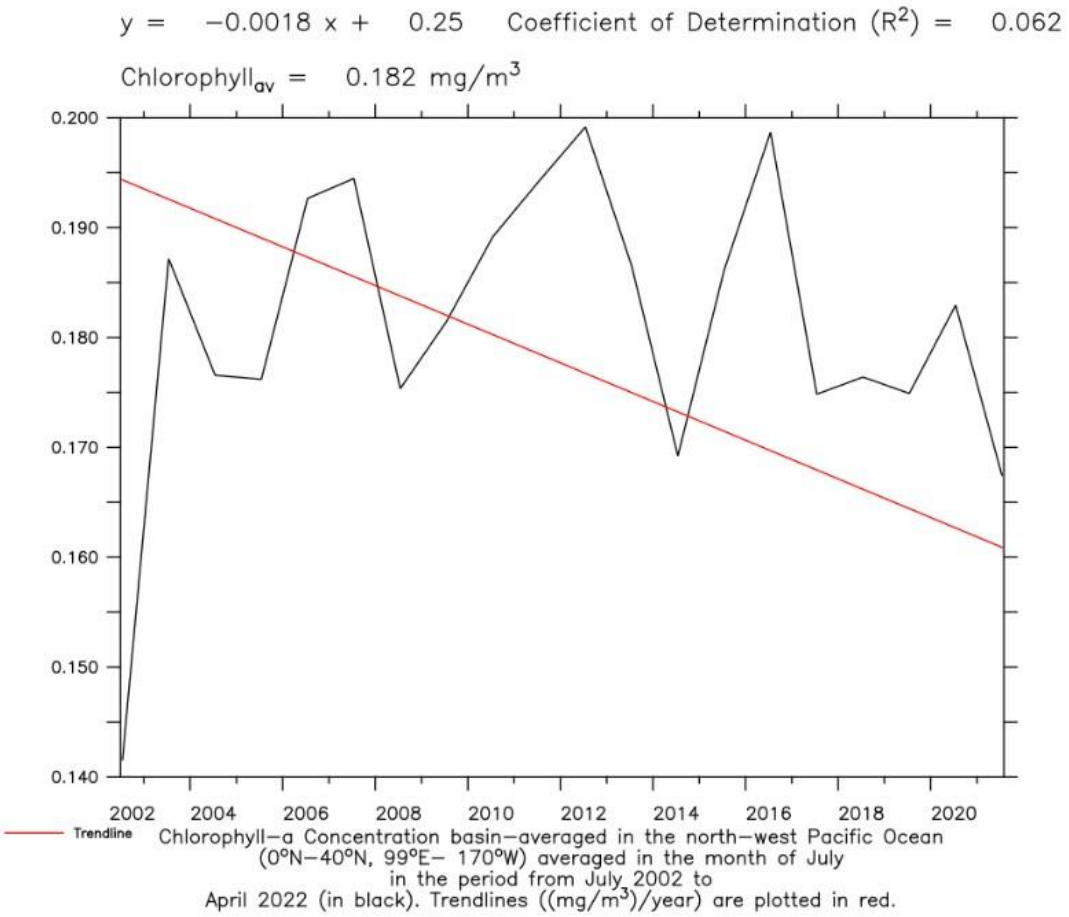


Figure 4.42 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of July in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of July in the period from July 2002 to April 2022 is shown in the Figure 4.42. The chlorophyll-a concentration ranges between approximately 0.140 mg/m^3 to 0.200 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0018 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.062. The

averaged chlorophyll-a concentration in the entire period and region gives a value of 0.182 mg/m^3

g. *August:*

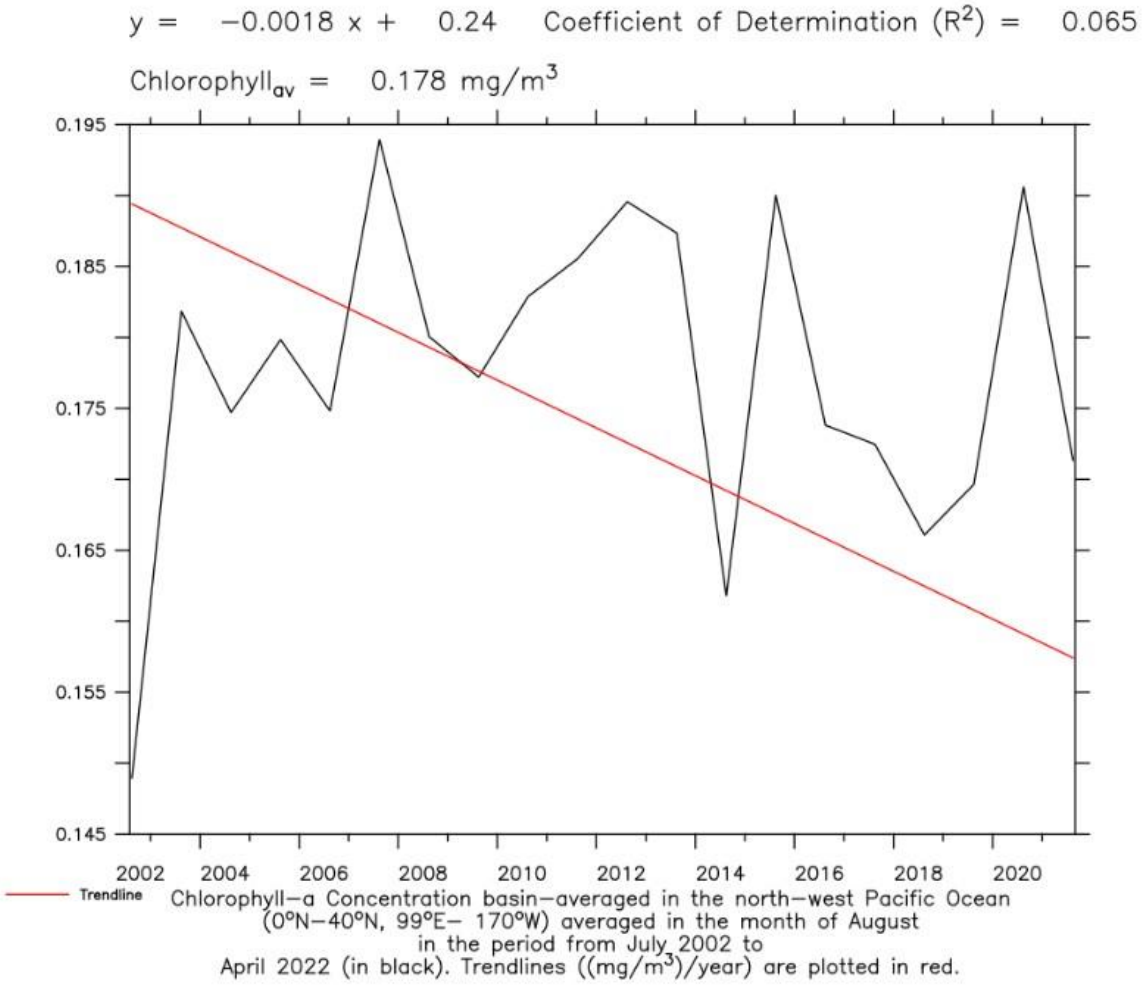


Figure 4.43 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of August in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of August in the period from July 2002 to April 2022 is shown in the Figure 4.43. The chlorophyll-a concentration ranges between approximately 0.145 mg/m^3 to 0.195 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0018 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.065. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.178 mg/m^3

h. *September:*

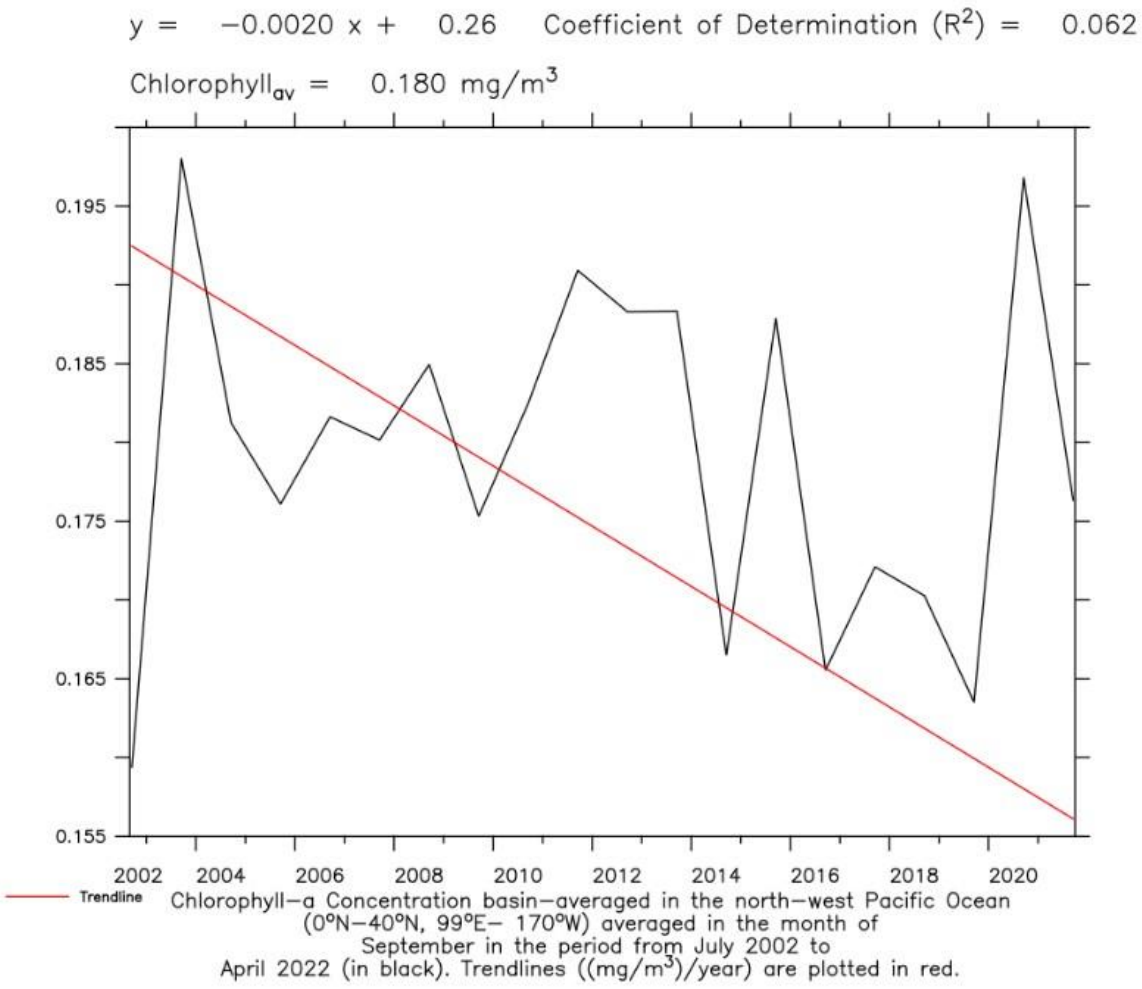


Figure 4.44 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of September in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of September in the period from July 2002 to April 2022 is shown in the Figure 4.44. The chlorophyll-a concentration ranges between approximately 0.155 mg/m^3 to 0.200 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of

-0.0020 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.062. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.180 mg/m^3

i. *October:*

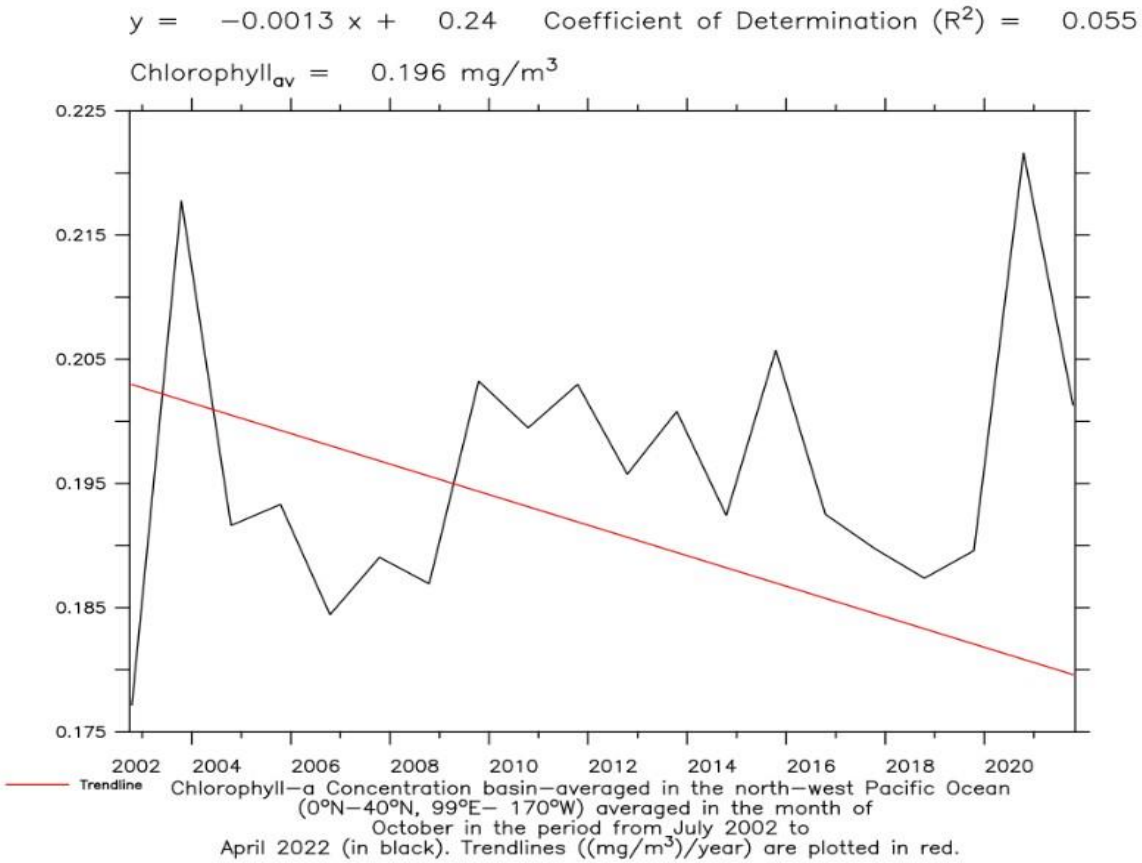


Figure 4.45 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of October in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of October in the period from July 2002 to April 2022 is shown in the Figure 4.45. The chlorophyll-a concentration ranges between approximately 0.175 mg/m^3 to 0.225 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0013 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.055. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.196 mg/m^3

j. *November:*

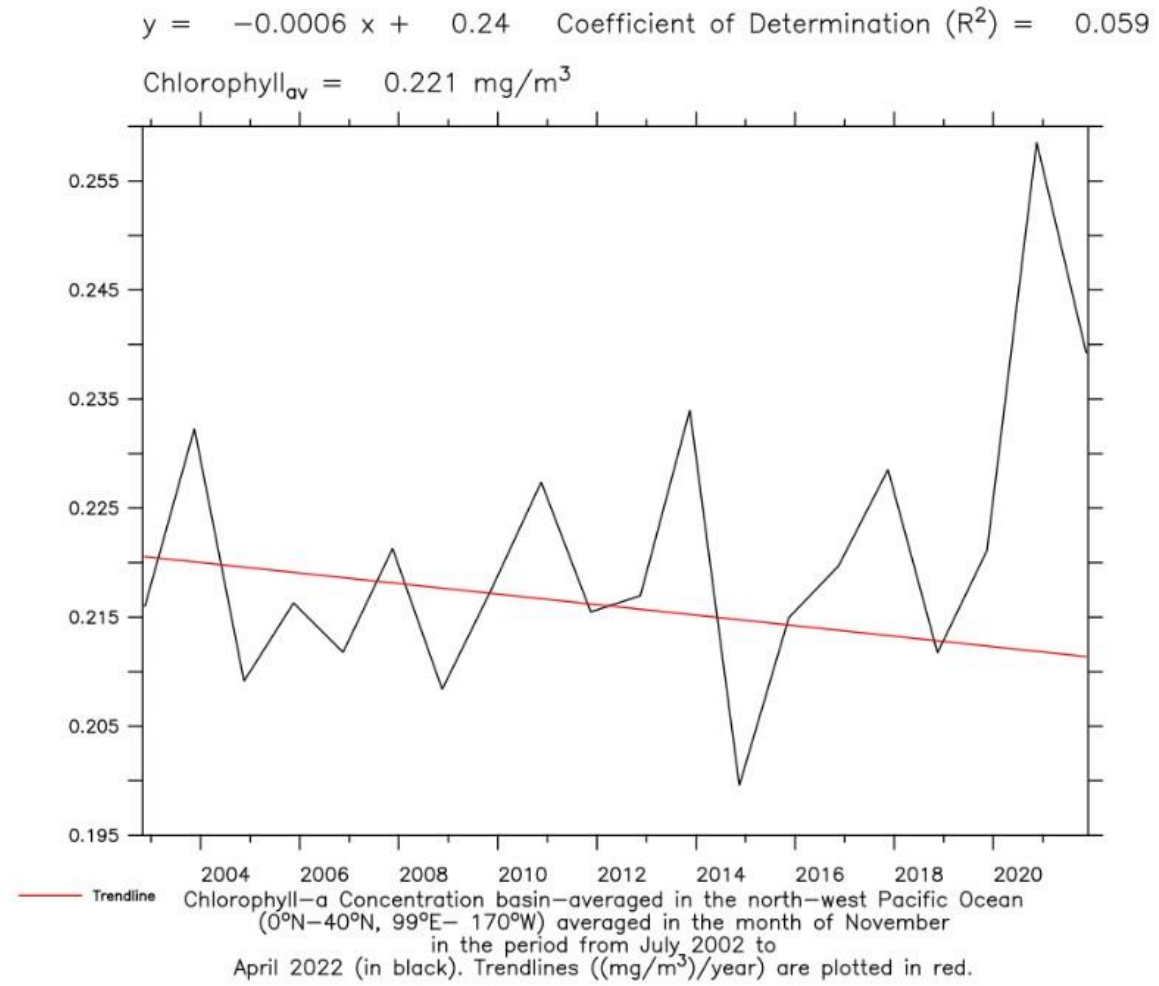


Figure 4.46 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of November in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of November in the period from July 2002 to April 2022 is shown in the Figure 4.46. The chlorophyll-a concentration ranges between approximately 0.195 mg/m^3 to 0.260 mg/m^3. The

trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0006 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.059. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.221 mg/m^3

k. *December:*

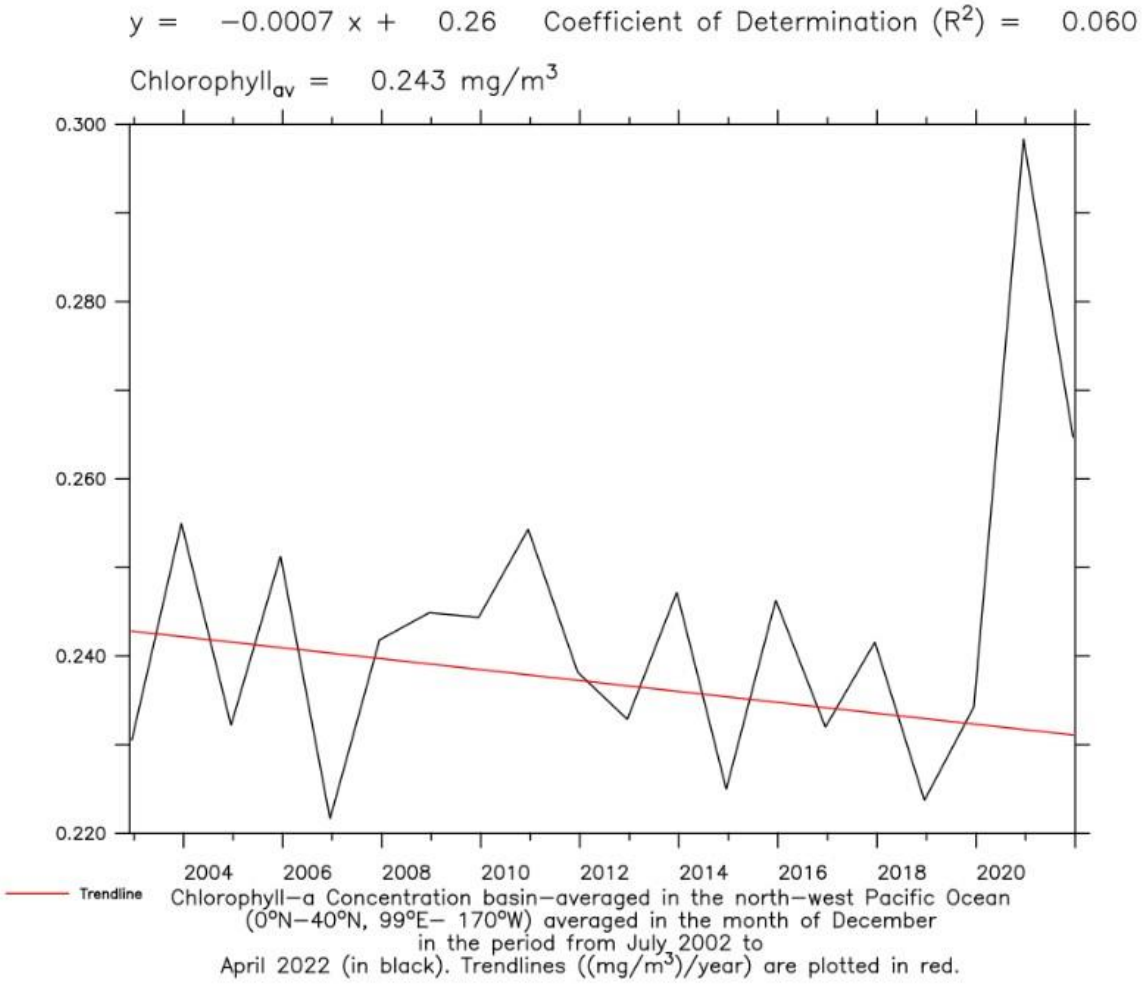


Figure 4.47 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in month of December in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in the month of December in the period from July 2002 to April 2022 is shown in the Figure 4.47. The chlorophyll-a concentration ranges between approximately 0.220 mg/m^3 to 0.300 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0007 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.060. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.243 mg/m^3

4.3.3 Chlorophyll-a Concentration Basin-Averaged Season-wise from July 2002 to April 2022

a. *Boreal Spring Season:*

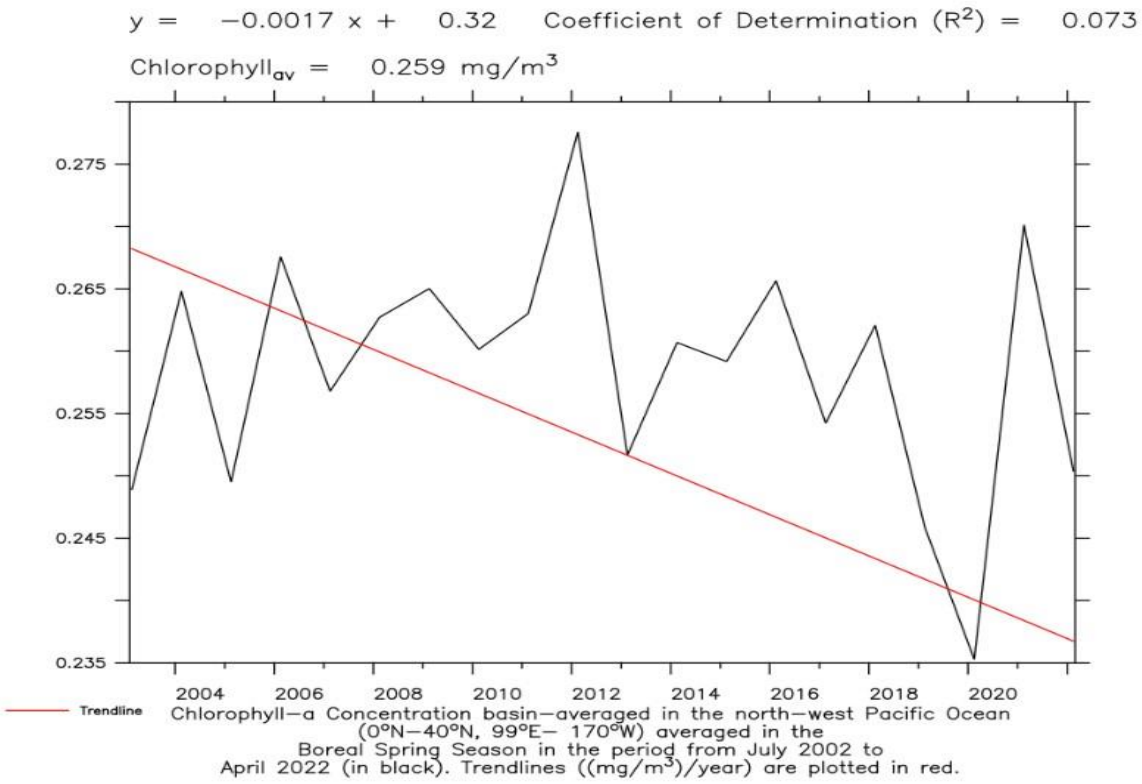


Figure 4.48 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Spring Season in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Spring Season in the period from July 2002 to April 2022 is shown in the Figure 4.48. The chlorophyll-a concentration ranges between approximately 0.235 mg/m^3 to 0.280 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0017 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.073. The

averaged chlorophyll-a concentration in the entire period and region gives a value of 0.259 mg/m^3

b. *Boreal Summer Season:*

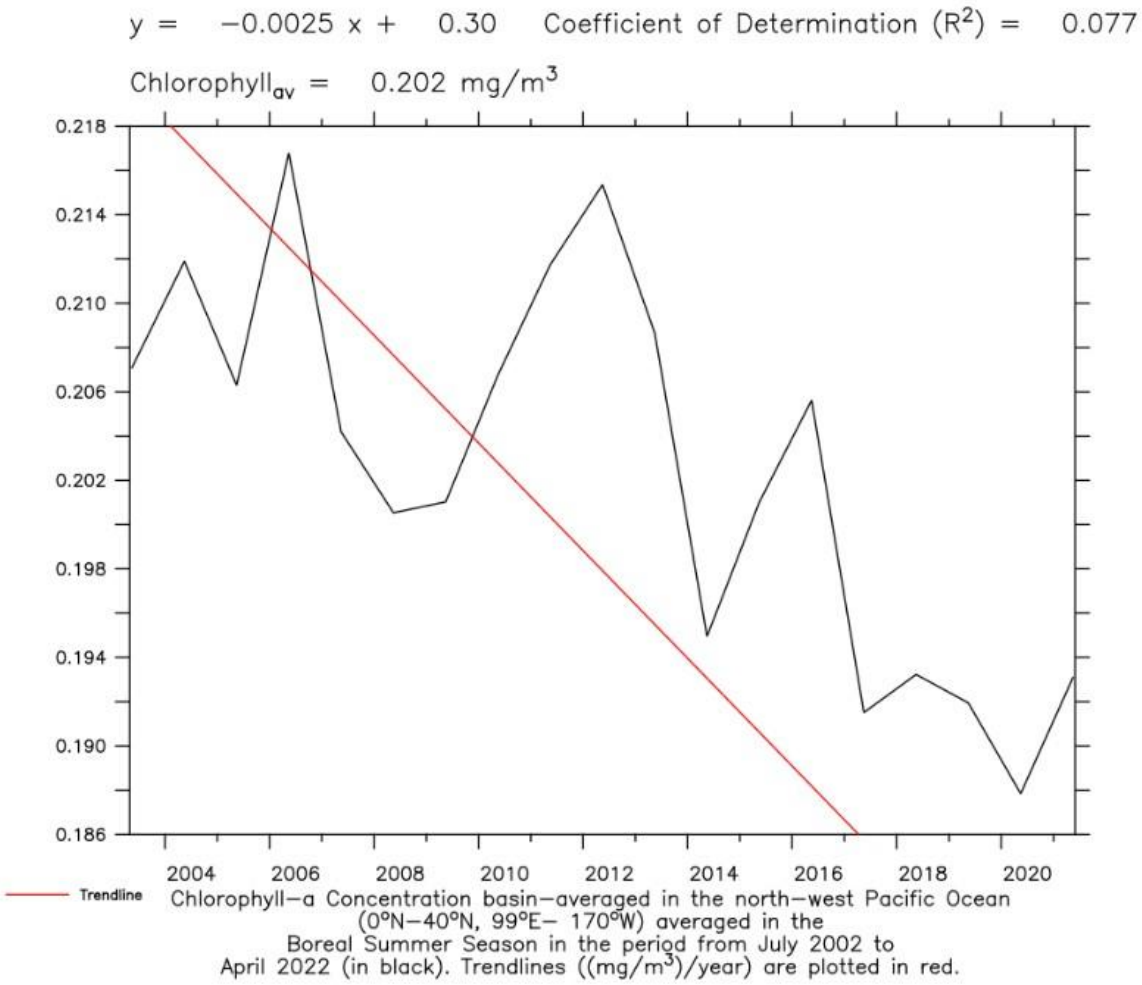


Figure 4.49 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Summer Season in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Summer Season in the period from July 2002 to April 2022 is shown in the Figure 4.49. The chlorophyll-a concentration ranges between approximately 0.186 mg/m^3 to 0.218 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0025 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.077. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.202 mg/m^3

c. *Boreal Autumn Season:*

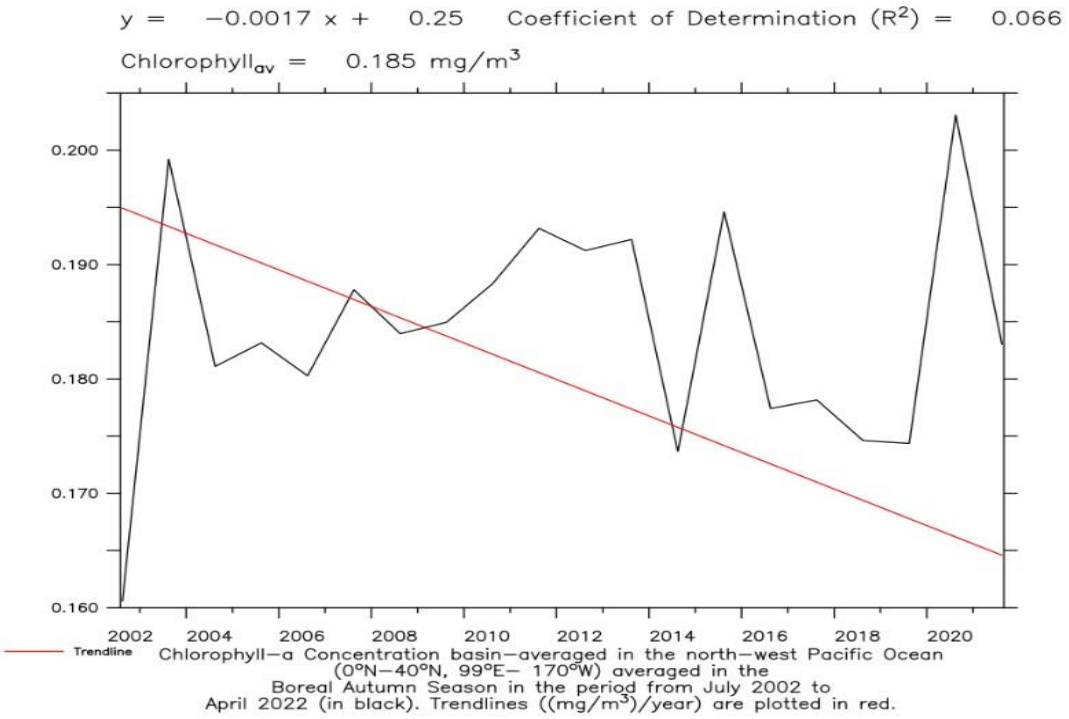


Figure 4.50 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Autumn Season in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Autumn Season in the period from July 2002 to April 2022 is shown in the Figure 4.50. The chlorophyll-a concentration ranges between approximately 0.160 mg/m^3 to 0.205 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0017 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.066. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.185 mg/m^3

d. *Boreal Winter Season:*

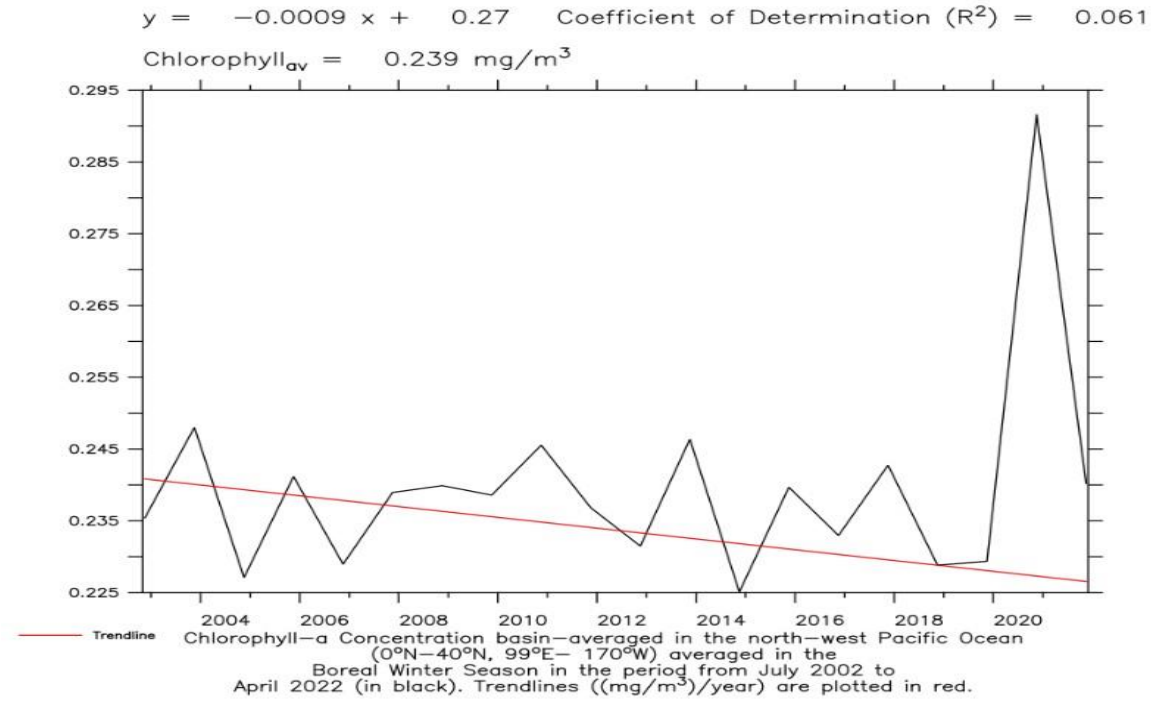


Figure 4.51 – Basin-averaged Chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Winter Season in the period from July 2002 to April 2022

The plot of basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean (0°N– 40°N, 99°E– 170°W) averaged in Boreal Winter Season in the period from July 2002 to April 2022 is shown in the Figure 4.51. The chlorophyll-a concentration ranges between approximately 0.225 mg/m^3 to 0.295 mg/m^3. The trendline of chlorophyll-a concentration shows a decreasing trend, with a decrease of -0.0009 (mg/m3)/year. The coefficient of determination (R^2) has a value of 0.061. The averaged chlorophyll-a concentration in the entire period and region gives a value of 0.239 mg/m^3

CHAPTER 5: DISCUSSION

The values of the basin-averaged chlorophyll-a concentration, slopes of trend-lines, intercepts and coefficients of determination (R^2), in the north-west Pacific Ocean (0°N to 40°N, 99°E to 170°W), are shown averaged for entire time-period, month wise, season wise, in the period from July 2002 to April 2022, in Table 5.1.

Table 5.1 – Values of the north-west Pacific Ocean (0°N to 40°N, 99°E to 170°W) basin-averaged chlorophyll-a concentrations, slopes of the trendlines, intercepts and coefficients of determination (R^2) time-series, month-wise and season-wise, in the period from July 2002 to April 2022.

Entire Time-period / Month-wise /Season-wise	Averaged Chlorophyll-a Concentration (mg/m^3)	Slopes of Trendline ((mg/m^3)/year)	Intercept of Trendline	Coefficient of Determination (R^2)
Entire Time- period	0.221	-0.0015	0.27	0.011
January	0.255	-0.0013	0.03	0.064
February	0.251	-0.0018	0.32	0.051
March	0.255	-0.0018	0.32	0.081
April	0.270	-0.0016	0.33	0.068
May	0.228	-0.0025	0.32	0.078

June	0.198	-0.0029	0.31	0.067
July	0.182	-0.0018	0.25	0.062
August	0.178	-0.0018	0.24	0.065
September	0.180	-0.0020	0.26	0.062
October	0.196	-0.0013	0.24	0.055
November	0.221	-0.0006	0.24	0.059
December	0.243	-0.0007	0.26	0.060
Boreal Spring Season	0.259	-0.0017	0.32	0.073
Boreal Summer Season	0.202	-0.0025	0.30	0.077
Boreal Autumn Season	0.185	-0.0017	0.25	0.066
Boreal Winter Season	0.239	-0.0009	0.27	0.061

The averaged chlorophyll-a concentration in the period from July 2002 to April 2022, in the north-west Pacific Ocean shows a value of 0.221 mg/m^3. The basin averaged values are highest in the boreal Spring season and lowest in the boreal autumn. Among the months the highest basin-averaged Chlorophyll-a values in the north-west Pacific Ocean are in April while the lowest are in August.

The trendlines show a negative value in the Chlorophyll-a concentration with a slope of –0.0015 (mg/m^3)/year. All the seasons and months show a decreasing

trend in the Chlorophyll-a concentration. The largest magnitude in the decreasing trend was in the boreal summer season and in the month of June. The decreasing trend had the least magnitude in the boreal winter season and in the month of November.

From the Figure 4.5 we can see that the chlorophyll-a concentration in the month of April is high in the Bohai Sea, Yellow Sea and East China Sea and the basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean is also high, having a value of 0.270 mg/m^3. Lie et al. (2022) also found similar results. The wind-driven upwelling increases the nutrients released from the Yellow Sea Cold Water Mass and therefore Chlorophyll-a concentrations in the upper layer increases in these regions.

Chlorophyll-a concentration in the Bohai Sea and Yellow Sea increased slowly in the recent 16 years with significant seasonal variations. Wind direction and increased human activity (e.g., river discharge) plays a significant role in changing the Chlorophyll-a distribution in the Bohai Sea and Yellow Sea (Zhao et al., 2019).

From the Figure 4.9 we can see that the chlorophyll-a concentration in the months of August is low and the basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean is also low, having a value of 0.178 mg/m^3.

From Figure 4.14, Boreal Spring Season shows highest value of chlorophyll-a concentration in Bohai Sea, Yellow Sea and East China Sea and the basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean is also high, having a value of 0.259 mg/m^3. From Figure 4.16, Boreal Autumn Season shows low value of chlorophyll-a concentration and the basin-averaged chlorophyll-a concentration in the north-west Pacific Ocean is also low, having a value of 0.185 mg/m^3. Hou et al. (2014)

found high values of chlorophyll-a concentration in Boreal Winter Season and low value of chl-a concentration in Boreal Summers Season.

The slope of trendline of the basin-average chlorophyll-a concentration is –0.0015 (mg/m^3)/year, indicates a decreasing trend in the north-west Pacific Ocean. The North Pacific Ocean shows a declining trend over the past century (Boyce et al., 2010). Boyce et al. (2010) estimated a global rate of decline of ∼1% of the global median per year. Declining trends of chlorophyll-a concentrations are related to increasing sea surface temperature. Their analysis suggests that global Chl-a concentration has declined since the beginning of oceanographic measurements in the late 1800s. Multiple lines of evidence suggest that these changes are generally related to climatic and oceanographic variability and particularly to increasing Sea Surface Temperature over the past century. The negative effects of SST on Chl-a trends are particularly more pronounced in tropical and subtropical oceans, where increasing stratification limits nutrient supply.

CHAPTER 6: CONCLUSIONS

From Table 5.1, time-series, month-wise and season-wise basin-averaged values of chlorophyll-a concentration, slopes of trendlines, intercepts and coefficients of determination (R^2) in the north-west Pacific Ocean (0 ºN to 40 ºN, 99 ºE to 170 ºW), from July 2002 to April 2022 are seen. The basin-average chlorophyll-a concentration in the north-west Pacific Ocean (0 ºN to 40 ºN, 99 ºE to 170 ºW) is 0.221 mg/m^3. The slope of trendline of the basin-average chlorophyll-a concentration is –0.0015 (mg/m^3)/year, indicates a decreasing trend in the north-west Pacific Ocean. The basin-averaged chlorophyll-a concentration shows a strong annual cycle.

Among the four seasons, that is, Boreal Spring (February to April), Boreal Summer (May to July), Boreal Autumn (August to October) and Boreal Winter (November to January), the Boreal Spring Season has the highest averaged chlorophyll-a concentration, with a value of 0.259 mg/m^3 and Boreal Autumn Season has the least averaged chlorophyll-a concentration, with a value of 0.185 mg/m^3. All the four seasons are showing decreasing trend of chlorophyll-a concentration. The highest magnitude of the decreasing trend occurs in Boreal Summer Season having slope value of -0.0025 ((mg/m^3)/year) and the least magnitude of -0.0009 ((mg/m^3)/year) occurs in Boreal Winter Season. Both Boreal Spring and Boreal Autumn season have same values of slopes i.e. -0.0017 ((mg/m^3)/year).

Among the months i.e. from January to December, April has the highest basin-averaged chlorophyll-a concentration showing a value of 0.270 mg/m^3 and August has the least basin-averaged chlorophyll-a concentration showing a value of 0.178 mg/m^3. All the 12 months show a decreasing trend of chlorophyll-a concentration. The month

of June show largest magnitude of the decreasing trend with a value of -0.0029 ((mg/m^3)/year), while the least magnitude in the decreasing trend was seen in the month of November, with a value of -0.0006 (mg/m^3)/year.

The map of the values of Chlorophyll-a Concentration, in the entire study period averaged from July 2002 to April 2022, showed largest values of Chlorophyll-a concentration in the Bohai Sea, Yellow Sea and East China Sea. The Sea of Japan and the coastal regions of southern China showed moderately high values of Chlorophyll-a Concentration.

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