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Effects of dust storm and wildfire events on phytoplankton growth in the Southern Ocean and Tasman Sea, southeast Australia

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Abstract. Dust storms and wildfires occur frequently in southeastern Australia. Their effects on ecology, environment and population exposure have been the focus of many studies recently. Dust storms do not emit ground-sequestered carbon but wildfires emit significant quantities of carbon into the atmosphere. However, both natural events promote phytoplankton growth in water bodies because carbon, and other trace elements such as iron, deposit on the surface water of oceans and promote phytoplankton growth. Carbon di-oxide is reabsorbed by phytoplankton via photosynthesis. The carbon balance of dust storms and wildfires are not well known.This study focusses on the association of dust storms and wildfires in southeastern Australia with phytoplankton growth in the Southern Ocean and Tasman Sea due to the February 2019 dust storm event and the 2019-2020 black summer wildfires. The results show the similarities and differences in phytoplankton growth patterns and carbon reabsorption amount from these events.

Keywords. February 2019 dust storm; 2019-2020 wildfires; South East Australia; phytoplankton; Southern Ocean; Tasman Sea; WRF-Chem model

1 Introduction

Dust from dust storm and smoke aerosols from biomass burnings contain elemental metals including iron (Fe). The deposition of dust and aerosols on ocean increases the concentration of soluble Fe in marine water as these particles are transported from land sources over the ocean. The increase in concentration of Fe stimulates the growth of phytoplankton (especially diatoms) which absorb CO_2 during photosynthesis. This results in an increase of CO_2 transferred from the atmosphere into the ocean. Phytoplankton as microalgae plants contain the chlorophyll pigment. Like other land-based plants, phytoplankton grows by absorbing carbon dioxide in sea water producing glucose and oxygen through photosynthesis. Therefore, chlorophyll concentration can be used as an index of phytoplankton biomass. It is estimated that marine phytoplankton capture almost an equal amount of carbon as does photosynthesis by land vegetation.

The global climate change models take into account the ocean important role of carbon sequestration in the Global Carbon Cycle. Absorption of CO_2 via phytoplankton life cycle is part of this process. The near-surface concentration of chlorophyll-a (milligrams of chlorophyll pigment/m^3) in the ocean is detected via colour change from blue to green and measured daily by sensors on polar-orbited MODIS Terra/Aqua satellites with high resolution at 1 (km) x 1 (km) and geostationary Himawarri satellite over Australia to Japan at time resolution of minutes. Phytoplankton grows when nutrients, including Fe, in the water are sufficient and temperature and light are favourable.

For some of the most significant dust storms on the east coast Australia such as the September 2009 "Red Dawn" dust storm event, Gabric et al. (2015) found that surface chlorophyll concentrations in the southern Tasman Sea during the austral spring of 2009 were well above the climatological mean, with positive anomalies as high as 0.5 mg/m^3. Earlier dust storms in late 2002 and early 2003 were also studied by Gabric et. al. (2010). They found that during February 2003 there was strong evidence for a large-scale natural dust fertilization event in the Australian sector of the Southern Ocean.

The most recent major dust storm occurred in February 2019. In the austral summer of 2019, from 11 and 15 February 2019, under persistent westerly and south westerly winds, a dust storm started in the deserts of Central Australia carried large volume of dust in an extensive front of approximately 1500 km moving to the western re-gion of the state of New South Wales (NSW) then to the coast including the metropolitan area of Sydney causing extreme high particle pollution. The dust continued to be transported across the Tasman Sea to New Zealand and to Antarctica (Nguyen et al., 2019).

While dust iron dominates the absolute deposition magnitude, wildfire iron is an important contributor to temporal variability. The recent large wildfires (Black Sum-mer) on the East Coast of Australia in late spring and summer period of 2019/2020 has been shown by Tang et al. (2021) to contribute significant growth of phytoplankton in the Pacific part and South Australia part of the Southern Ocean.

The 2019/2020 wildfires totally burned 5.68 million ha in NSW and 1.58 million hectares (ha) in Victoria (Davey et al., 2020), and thirty-three people lost their lives (AIHW, 2020). The megafire of 2019/2020 emitted approximately 400 megatons (tril-lion or 1012 grams) of CO_2 into the atmosphere as estimated by ECMWF (European Centre for Medium-Range Weather Forecasts). Smoke aerosols rose to the upper trop-osphere and to the stratosphere and travelled at high speed to the South Pacific, South America to South Africa and back to the Australian continent.

In this study, the dust storms of February 2019, October 2018 and Black Summer 2019-2020 wildfires events and their effects on atmospheric and marine environment are studied by using WRF-Chem 4.2 model to simulate the dust fluxes generated from wind erosion, the dust transport and dispersion in the atmosphere as well as the dust deposition on land surface or ocean. Similarly, the wildfires event of summer 2019-2010 on east coast of Australia was also simulated using WRF-Chem and FINN (Fire Emission Inventory from NCAR) datasets (Nguyen et al., 2021) on the dispersion and deposition of smoke aerosols associating with the phytoplankton growth and the sub-sequent carbon sequestration.

Temporal and spatial quantities of $PM_{2.5}$ and PM_{10} from wildfires and dust emitted from these natural events and their deposition on the Tasman Sea off the southeast coast of Australia will be estimated from the simulation. The simulated results from WRF-Chem model will be compared with the observed patterns of phytoplankton growth as measured by polar-orbited MODIS Aqua/Terra and geo-stationary Himawarri satellites. The performance of the models will also be assessed.

2 Material and Method

In this study we use the WRF-Chem V4.2 to simulate the dust events of February 2019. The WRF-Chem dust emission scheme used is the AFWA (Air Force Weather Agency of the US) version of GOCART (Goddard Chemistry Aerosol Radiation and Transport) model. This dust emission scheme is one of several dust emission options available in WRF-Chem. In AFWA-GOCART emission scheme (dust_opt=3), the emis-sion fluxes for the 5 particle size bins are stored in 4-dim DUST1, DUST2, DUST3, DUST4 and DUST5 variables with unit in µg/kg-dry air. The dust emission calculated over the domain is calculated following Ukhov et al., (2020).

The wildfires event simulation is performed using WRF-Chem with fire emission data from FINN. In the previous study, Nguyen et al., (2021), the simulation of the Black Summer wildfires 2019-2020 event was shown to be performing well in term of air quality prediction. This study uses the same domain configuration and chemistry op-tion (MOZCART) as in the previous simulation study but includes extra deposition variables as described above to estimate the deposition of $PM_{2.5}$ and PM_{10} which contain trace particles such as Fe. We assume that the amount of Fe is proportional to the amount of $PM_{2.5}$ and PM_{10}. The deposition velocity is used to estimate the particle flux to the ground.

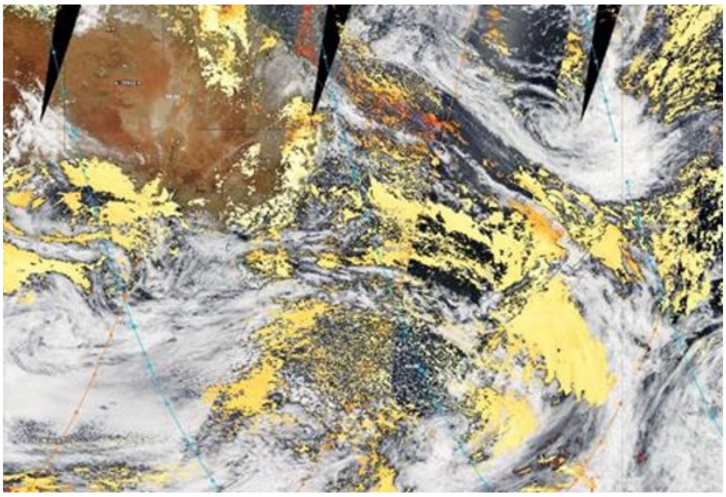
Spatial data on chlorophyll-a was obtained from NASA MODIS Aqua/Terra satel-lite chlorophyll-a product and from Himawarri geostationary satellite of Japan Aero-space Exploration Agency (JAXA). The Ocean Colour - Climate Change Initiative (OC-CCI) Project by the European Space Agency (ESA) in 2019 provided a merged multi-sensor record spanning 22 years timeseries of chlorophyll-a data from various satellite products of reflectance sensors. The data can be downloaded from https://rsg.pml.ac.uk/thredds/ncss/grid/CCI_ALL-v5.0-8DAY/dataset.html.

3 Results and discussion

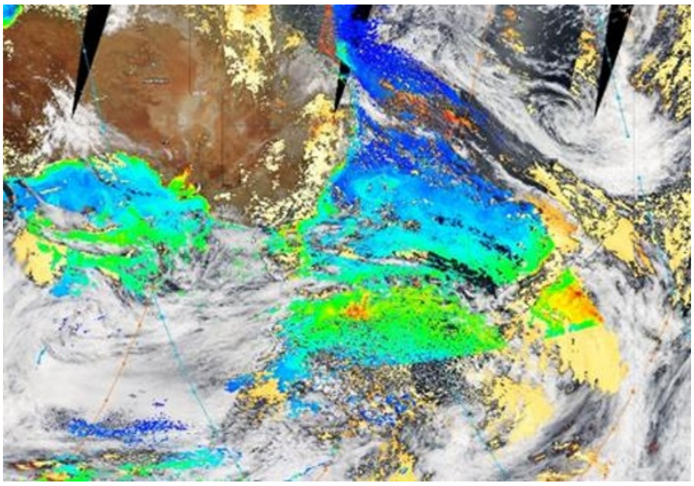
3.1 Case study 1: Dust storm of 14-16 February 2019

Remote sensing data from polar-orbited MODIS Aqua/Terra satellites and geostationary Himawarri satellite before and after the dust storm event provide observation on chlorophyll-a concentration in the Tasman Sea between Australia and

New Zealand which are used to correlate with the dust deposition patterns. The dust storm of 14 to 16 February 2019 originated in desert areas of Lake Eyre in Central Australia. The progress of the dust storm from the sources in Central Australia, western New South Wales to the east coast of Australia, across the Tasman Sea to New Zealand and Antarctica was analysed in detail by Nguyen et al., (2019).



(a)



(b)

Fig 1 - AOD (a) and chlorophyll-a (b) on 15 February 2019 as detected by MODIS Terra/Aqua satellites (source: NASA Worldview AOD and chlorophyll-a MODIS products)

Fig. 1 shows the column Aerosol Optical Depth (AOD) and chlorophyll-a concentration in the ocean as detected by MODIS Terra/Aqua satellites on the 15 Feburary 2019. The historical chlorophyll-a concentration data has been compiled recently by the Ocean Colour - Climate Change Initiative with support from the European Space Agency. The time series of these data over the Tasman Sea and Southern Ocean near New Zealand as bounded in the defined area is shown in Figure 2 for the period from 1 January 2019 to 31 December 2019. There are 2 pronounced increases in chlorophyll-a concentration: February and December 2019 corresponding to the dust storm (February) and wildfires (December).

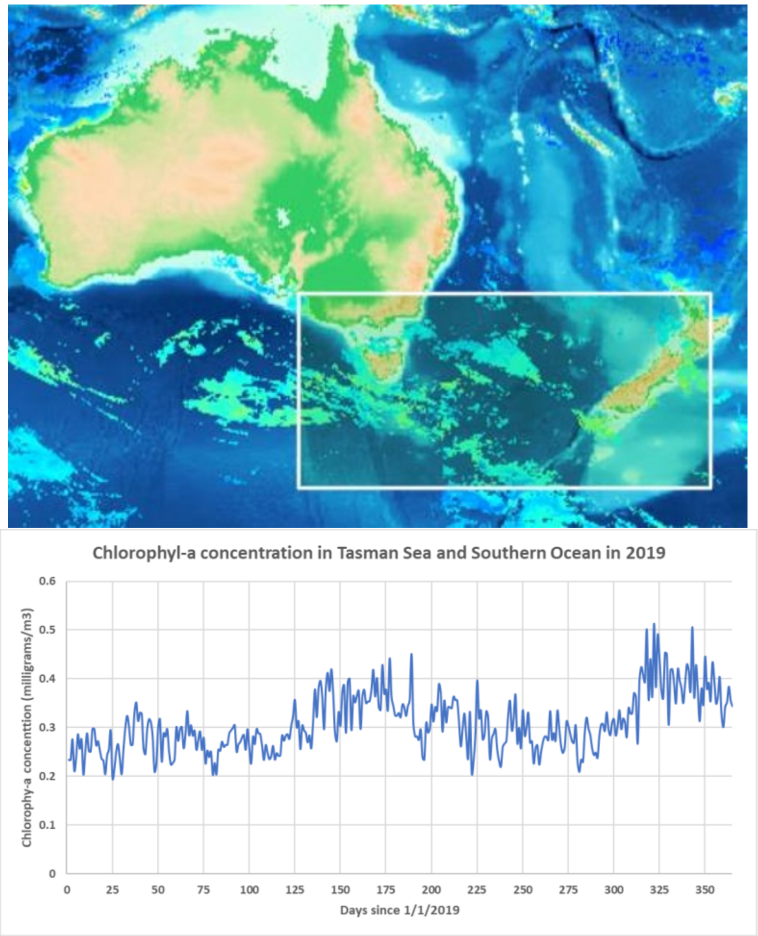


Fig 2 - Bounding box (138.797, -53.367, 176.625, -35.508) within which daily chlorophyll-a mean concentration (milligrams/m3) was measured from 1 January 2019 to 31 December 2019 (Chl-a V4.2 data from European Space Agency – Ocean Colour https://www.oceancolour.org/portal/#Accessed 23 June 2023)

3.2 Case study 2: Wildfires event, Black Summer 2019-2020 wildfires

In terms of the effect on greenhouse emissions, wildfires have more impact than dust storms as they emit large amount of CO_2 into the atmosphere. In their study of the effect of the 2019-2020 wildfires on phytoplankton growth, Tang et al. 2021 have identified strong association of the AOD from this wildfires event above the Southern Ocean, south of Australia, and above the Pacific Southern Ocean (between New Zealand and South America) with the chlorophyll-a concentration in those ocean areas.

The monthly average chlorophyll-a concentration as detected by Himawarri sensor in December 2019 and January 2020 as compared with those of the previous year showed a relative increase in chlorophyll-a concentration in the Tasman Sea and Southern Ocean south of Australia. A clearer indication of phytoplankton blooms is shown by plotting the anomaly chlorophyll-a concentration across the southern hemisphere, includ-ing the Pacific part of the Southern Ocean, as shown in Figure 3. The images show massive phytoplankton growth from high chlorophyll-a concentration over most of water bodies in the southern hemisphere from Australia to South America, South Africa and back to Australia. This massive growth of phytoplankton lasted from January to early March 2010.

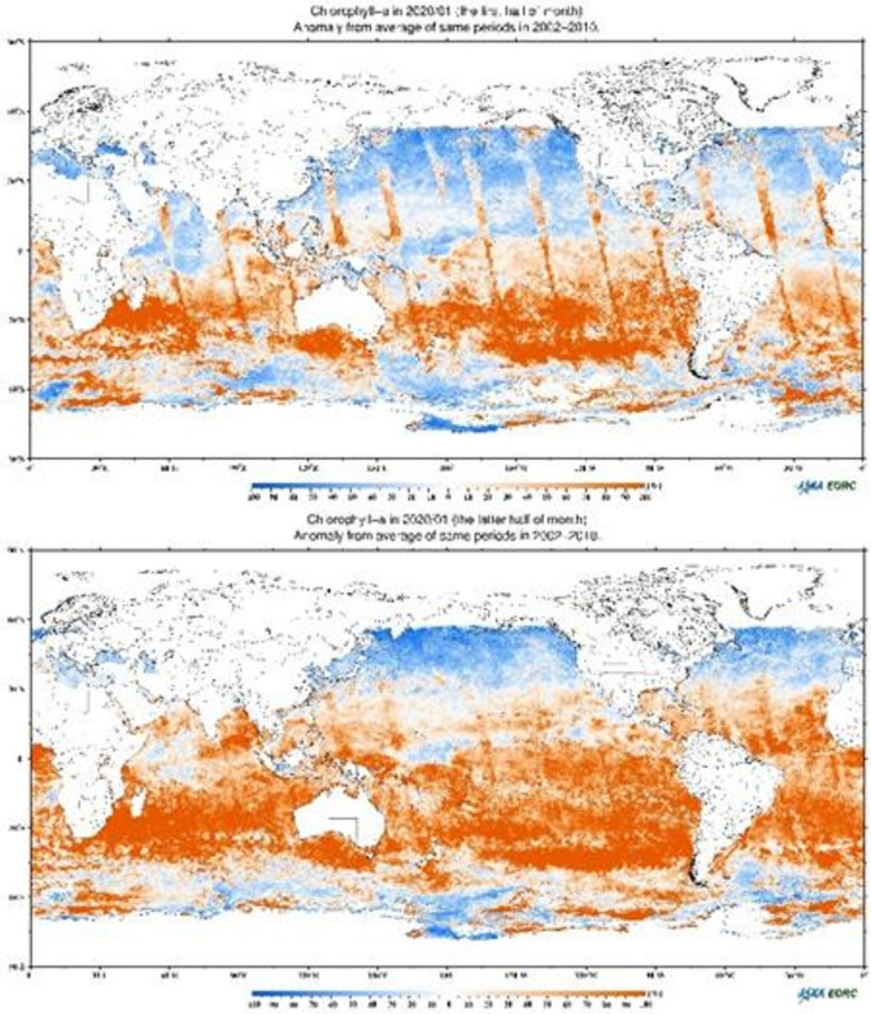


Fig 3 - Chlorophyll-a anomaly in January, February and March 2020 from the same period in 2002-2010. First half of January 2020 (a), later half of January 2020 (b). (source: JAXA Satellite Monitoring for Environment Studies, https://www.eorc.jaxa.jp/cgi-bin/jasmes/monthly/jasmes_list_v3.cgi?area=GL&lang=en&prod=CHLA&type=anomaly&year=2020)

WRF-Chem simulation in November 2019 showed the transport of smoke aerosols and deposition of $PM_{2.5}$ and PM_{10} are shown in Fig 4.

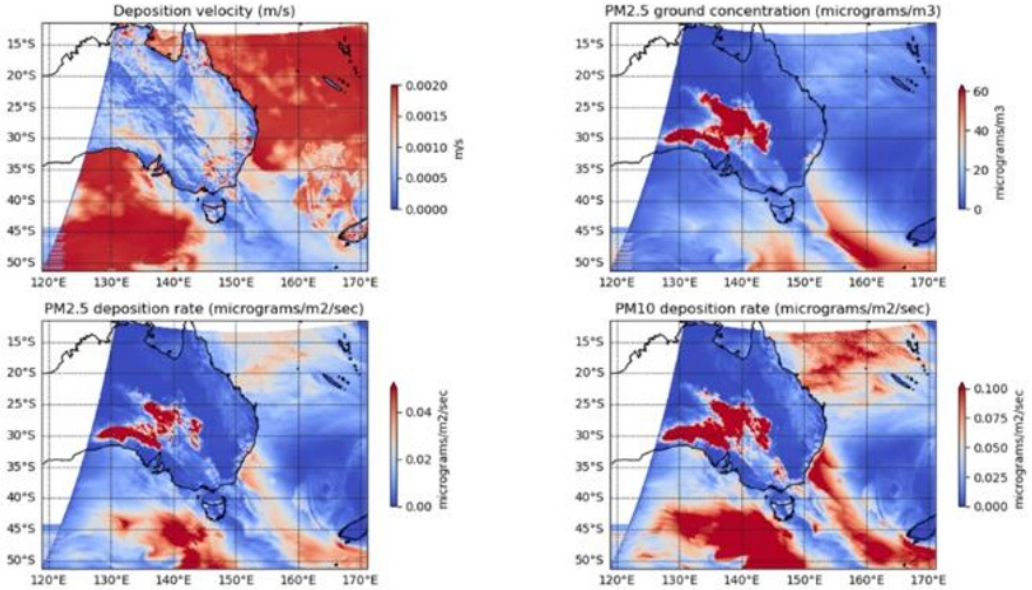


Fig 4 - WRF-Chem prediction of deposition velocity (m/s), $PM_{2.5}$ ground concentration (μg/m^3), $PM_{2.5}$ deposition rate (μg/m^2/sec) and PM_{10} deposition rate on 2/11/2019 13 UTC

Figures 4 shows the wildfires in northern NSW in early November resulted in a deposition of smoke aerosols $PM_{2.5}$ and PM_{10} from 1 to 7 November 2019 mostly in the Southern Ocean south of Tasmania and the Tasmania Sea between Australia and New Zealand.

4 Conclusion

In this study, there is strong evidence that the sequestration of CO_2 by enhanced biological pump occurred during the February 2019 dust storm and the Black Summer 2019/2019 wildfires events. This is important for policy makers wanting to account for the carbon absorbed and sequestered in the ocean to formulate response to climate change.

We have chosen the February 14-16 of 2019 dust storm and the megafires in November to January 2019-2020 for comparison of phytoplankton growth in the Tasman Sea and Southern Ocean as case studies. The phytoplankton growth absorbed CO_2 via photosynthesis and hence acted as carbon sink. Both events promoted phytoplankton growth but the megafires triggered a massive growth all around the southern hemisphere. The phytoplankton blooms occurred from January to early March 2020, shortly following the wildfire events. After that the growth disappeared and is largely attributed to being reabsorbed by the ocean.

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