Seasonal changes (Temporary)

Abstract

The importance of phytoplankton can not be overlooked as it is the fondation of the aquatic food web and the largest source of transferring carbon dioxide between the atmosphere and ocean. As an effect of climate change, we have seen drastic changes in the Arctic ocean. We have especially seen a significant decrease in the Arctic sea ice cover.Phytoplankton is dependent on sunlight, and the retreat of arctic sea ice leads to more accessible sunlight and changes in the bloom of phytoplankton. In this notebook, looking at three different study areas in the Arctic, data from NorESM2 is used to look at the changes in seasonal variations in sea ice, phytoplankton, and zooplankton.

Introduction

The arctic ocean is the world smallest ocean and have mostly been covered in ice. One of the more well-known consequences of climate change is the drastic change in sea ice concentration in area. Changes in the arctic ice are not only amplifying the warming, but does also have a great influence on the arctic ecosystem. Considering the importance of algal life it is especially interesting to understand how it affects phytoplankton.

Phytoplanktons are small organisms living just underneath the water surface both in fresh and salt water. Just like plants they have a photosynthesis and capture sunlight and carbon dioxide to produce chemical energy and oxygen. Hence, their growth is very dependent on their access to sunlight, carbon dioxide, and nutrients.(Lindsey Et Al., 2010).

The importance of phytoplankton can not be overlooked.They are the fondation of the aquatic food web. Without phytoplankton, zooplankton would not have something to eat, and if zooplanktons have nothing to eat small fish won't have it, and so on. Phytoplanktons are also the main reason for the transfer of carbon dioxide between the atmosphere and the ocean and are the cause of transferring about 10 gigatons of carbon dioxide between the two each year. So small changes in the population of phytoplankton could have great consequences for future climate and sea life. Hence, it is very important to understand how phytoplankton will react and affect future climate change.(Lindsey Et Al. , 2010)

Since phytoplankton is dependent on nutrients and sunlight, growth varies from season to season. In the arctic region, we can see the bloom of the phytoplankton have been seen in the early spring as the sun comes back and the sea ice melts. The blooming last for a few weeks before it decreases as the phytoplankton uses up the nutrients that have built up over the winter and the production decreases til the next bloom the next spring. As the sea ice retreat, we get more open water and more surface water to absorb net shortwave downward radiation. When the phytoplanktons have earlier access to sunlight the blooming will likely start earlier in that the season cycle will shift. The shift in the seasonal cycles of phytoplankton is also likely to affect the seasonal cycle of zooplankton. As most zooplankton eats phytoplankton it is likely to see a similar shift in the zooplankton concentration. (Lindsey et al., 2010)

In this notebook, we look into different areas in the Arctic to see if we can see any differences in the seasonal cycles of phytoplankton in correlation to the sea ice retreat. We are using NorESM2 to study three different areas of the Arctic that have experienced the shrinking of sea ice at different levels.

Methode

Importing phyton packages:

In [1]:
```
import xarray as xr
xr.set_options(display_style='html')
import intake
import cftime
import numpy as np
import matplotlib.pyplot as plt
import cartopy.crs as ccrs
import s3fs
%matplotlib inline

import xesmf as xe

#Importing functions from function file:
from myfuctions import *
%reload_ext autoreload
%autoreload 2

#Ignoring phyton warnings when plotting
import warnings
warnings.filterwarnings('ignore')
```

In [2]:
```
modelname = 'NorESM2-LM'
```

In [3]:
```
#Open area and data
```

```
areacello = getareacello(modelname)
```

```
--> The keys in the returned dictionary of datasets are constructed as follows:
	'activity_id.institution_id.source_id.experiment_id.table_id.grid_label'
```

100.00% [1/1 00:00<00:00]

Selecting variables and reading the data: I used sea ice concentration (siconc), and chlorophyll concentration as the concentration of phytoplankton (chlos), net downward shortwave radiation on the sea surface(rsntds), and surface carbon zooplankton concentration (zoocos) from the NorESM2-LM. The ensemble member I used was r1i1plfl.

In [7]:
```
# Reding the dataset and choosing variables:
varlist = ['rsntds', 'chlos', 'zoocos']
ds_ocn=xr.merge([read_omip_bucketdata(modelname, realm='Omon', var=var ) for var in varlist])
ds_ice = read_omip_bucketdata(modelname, realm='SImon', var='siconc')
varlist = ['siconc'] + varlist
```

```
rsntds
chlos
zoocos
siconc
```

To understand the effect of sea ice on the seasonal cycles of phytoplankton and zooplankton, I wanted to look at three different areas in the Arctic that have experienced different levels of sea ice retreat. To do this I started by plotting an anomaly map of the Arctic.

First I choose two time periods. The first 20 and the last 20 years of the dataset.

In [8]:
```
#Finding the seasonal mean of the sea ice consentration of the two periodes
var = 'siconc'
dsStart=make_seasonmean(ds_ice[var].sel(time=slice('1948-01-01','1967-12-31')))  #1948-1968
dsEnd=make_seasonmean(ds_ice[var].sel(time=slice('1988-01-01', '2007-12-31')))   #1988-2008
```

In [9]:
```
#Gridding the data
ds_out = xe.util.grid_global(1, 1)
regridder = xe.Regridder(dsStart.to_dataset(name = var), ds_out, 'bilinear')
```

In [10]:
```
dr_out = regridder(dsEnd) - regridder(dsStart)
```

In [11]:
```
dr_out = xr.where(dr_out==0,np.nan,dr_out)
```

In [13]:
```
#Plotting an sea-ice consentration anomaly map for each season.

f, axs = plt.subplots(2,2 ,subplot_kw=dict(projection=ccrs.Orthographic(0,90)))
f.suptitle('Seasonal anomaly of sea ice concentration in the Arctic', y=1.1, x=0.4)
axs=axs.flatten()
levels=np.arange(-40, -.1,1)
i=0

for season in dr_out.season.values:
    cf=plotmap(axs[i], dr_out, season, levels)
    i= i+1

cax = f.add_axes([.04, .07, .7, .04])
plt.colorbar(cf, cax=cax, orientation='horizontal', label='%')
plt.subplots_adjust(left=0.1, bottom=.15, top= .92, right=.7, wspace=0.7, hspace=.4)
```

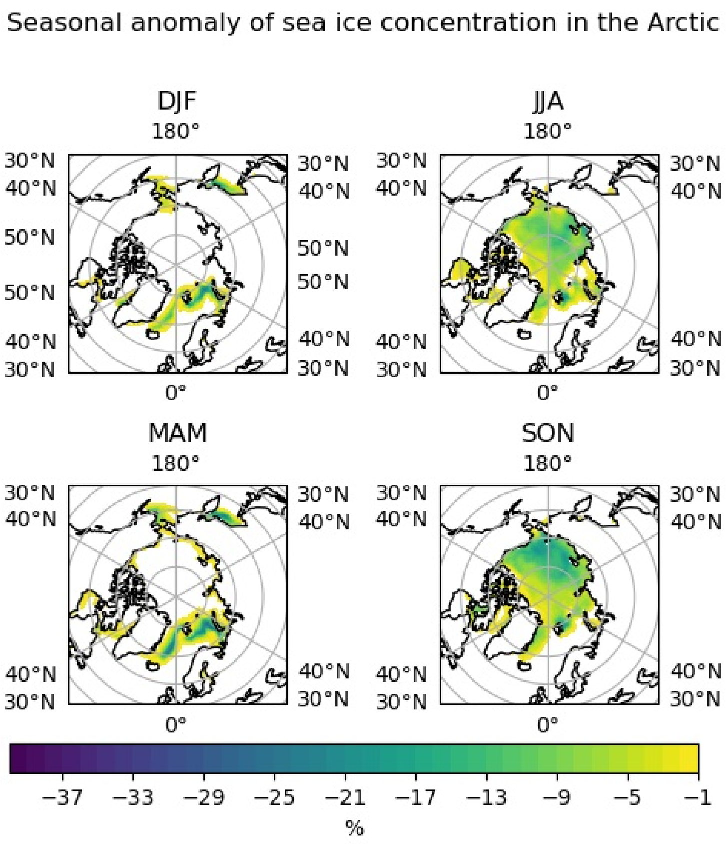

Figure 1: *A plotted map of the anomalies of sea ice concentration for each season in the Arctic. The plot shows a significant decrease in sea ice concentration in the Baren sea from 1948-1968 to 1988-2008.*

Choosing my study areas:
When finding my area I was especially interested in where we could see the largest decrease in the different seasons. I choose the Barnets sea as the area with a large retreat in sea ice during spring, the Laptev sea with a small decrease in the spring, but the largest decrease in summer and Autumn, and the Kara sea with very little decrease in sea ice compared to the rest of the Arctic.

The Barents sea is located between the north- Norwegian coast, the west Russian coast, and the southern coast of Svalbard. It's known for its high concentration of primary producers and its very diverse ecosystem.(Martishov et al. 2004)

Laptev sea is located on the coast of northern Siberia and in between Severnaya Zemlya on the west and the New Siberian Islands on the east. The sea is a part of the shallow part of the Siberian sea and is characterized by strong seasonal freshwater input. (Peters et al,2004)

Kara sea is located just in between the Barnets sea and Laptev sea on the north Siberian coast. The sea is known for being extremely cold and stratified. (Flint et al. 2018)

Latitudes and longitudes of the areas:

In [15]:
```
#Laptev sea latitude and longitude:
Llat_min=70
Llat_max=80

Llon_max=160
Llon_min=120

#Kara sea latitude and longitude:
BBlat_min=74
BBlat_max=81

BBlon_max=97
BBlon_min=58

#Baren sea latidtude and longitude:
lat_min = 65.9
lat_max= 81.9

lon_min=16.6
lon_max=68.6
```

Plotting the locations on a map:

In [76]:
```
#Plotting the locations to show on the map
ax = plt.axes(projection=ccrs.Orthographic(0,90))
ax.stock_img()
ax.coastlines()
```

```
plt.plot([Llon_max, Llon_min],[Llat_max, Llat_min],  color='lightgreen', transform=ccrs.Geodetic(), label='Lapt
plt.plot([lon_max, lon_min],[lat_max, lat_min],  color='hotpink', transform=ccrs.Geodetic(), label='Barents sea
plt.plot([BBlon_max, BBlon_min],[BBlat_max, BBlat_min],  color='orange', transform=ccrs.Geodetic(),label='Kara
plt.legend()
```

Out[76]:

```
<matplotlib.legend.Legend at 0x7fb2002b3f40>
```

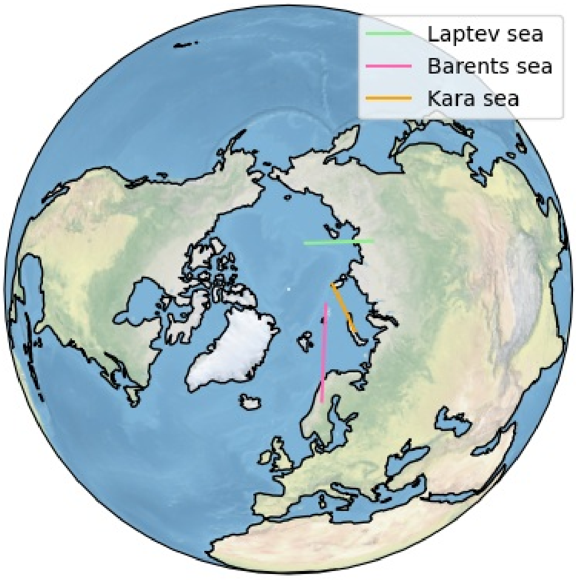

Figure 2: *The plot is showing the locations of my study areas*

After choosing my locations I calculated the monthly means in the NorESM2 for every variable in all three study areas. I used this to look at the changes in each variable. I also plotted the anomalies for all three areas to see if it was any similar pattern in the changes of the variables in the different areas.

Results

In [74]:

```
#Plotting the seasonal cycle of every varible for Barents sea

fig, axs = plt.subplots(2, 2)
axs = axs.flatten()
fig.suptitle('Seasonal variations in Barnesea' )

i = 0
for var in varlist:
    if var == 'siconc':
        ds = ds_ice
    else:
        ds = ds_ocn

    dsStart=make_monthlymean(ds[var].sel(time=slice('1948-01-01','1967-12-31'))).to_dataset(name = var)
    dsEnd=make_monthlymean(ds[var].sel(time=slice('1988-01-01', '2007-12-31'))).to_dataset(name = var)
    dsStartBS = regional_avg(dsStart, areacello, var,  lat_min, lat_max, lon_min, lon_max)
    dsEndBS = regional_avg(dsEnd, areacello, var,  lat_min, lat_max, lon_min, lon_max)

    ax = axs[i]

    ax.plot(dsStartBS.month, dsStartBS, color='palevioletred', label='1948-1968')
    ax.plot(dsEndBS.month, dsEndBS, color='pink', label='1988-2008' )

    ax.set_ylabel(ds[var].units)
    ax.set_xlabel('Month')
    ax.set_xticks(np.arange(1,13,2))
    ax.legend(loc='lower left')
    ax.set_title(var)

    i = i+1

plt.subplots_adjust(left=0.05, bottom=.15, top=.9, right=.99, wspace=.3, hspace=.5)
plt.savefig('figures/sesav.png')
```

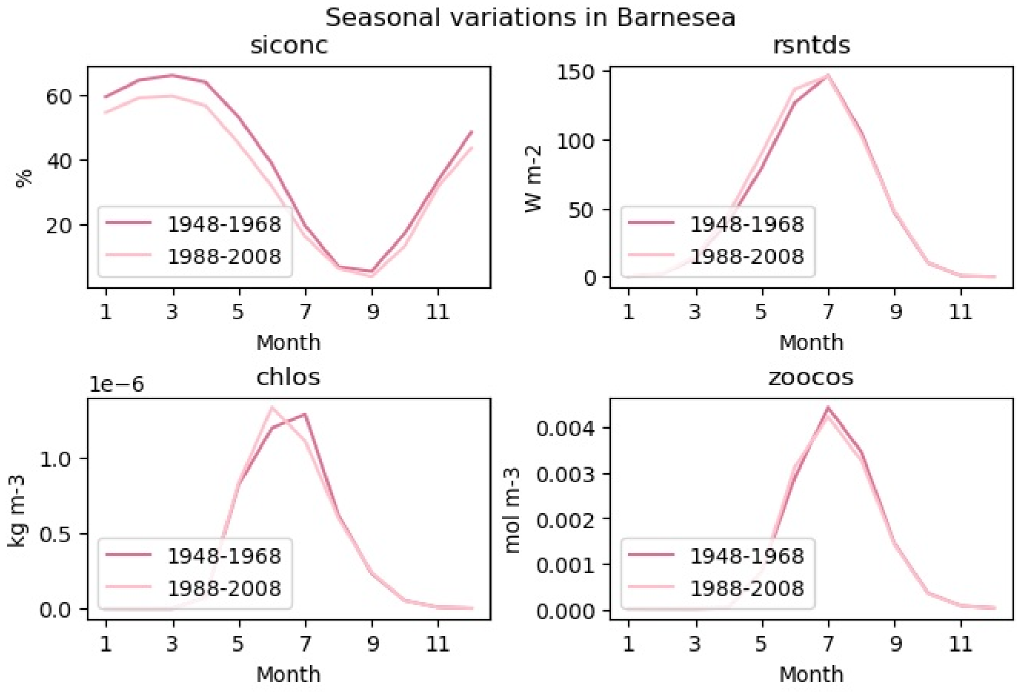

Figure 3: *The figure shows 4 plots for seasonal variances in sea ice concentration(siconc), net downward shortwave radiation(rsntds), chlorophyll concentration(chlos), and zooplankton concentration (zoocos) in the Barents sea.*

In [59]:

```
fig, axs = plt.subplots(2, 2)

gr = fig.add_gridspec(ncols=2, nrows=2)
axs = axs.flatten()
fig.suptitle('Seasonal variations in Laptev' )

i = 0

for var in varlist:

    if var == 'siconc':
        ds = ds_ice
    else:
        ds = ds_ocn

    dsStart=make_monthlymean(ds[var].sel(time=slice('1948-01-01','1967-12-31'))).to_dataset(name = var)
    dsEnd=make_monthlymean(ds[var].sel(time=slice('1988-01-01', '2007-12-31'))).to_dataset(name = var)
    dsStartL = regional_avg(dsStart, areacello, var,  Llat_min, Llat_max, Llon_min, Llon_max)
    dsEndL = regional_avg(dsEnd, areacello, var,  Llat_min, Llat_max, Llon_min, Llon_max)


    ax = axs[i]
    ax.plot(dsStartL.month, dsStartL, color='darkgreen', label='1948-1968')
    ax.plot(dsEndL.month, dsEndL, color='lightgreen', label='1988-2008' )
    ax.legend(loc='lower left')
    ax.set_ylabel(ds[var].units)
    ax.set_xlabel('Month')
    ax.set_xticks(np.arange(1,13,2))
    ax.set_title(var)

    i = i+1

plt.subplots_adjust(left=0.05, bottom=.15, top=.9, right=.99, wspace=.3, hspace=.5)
plt.savefig('figures/sesav.png')
```

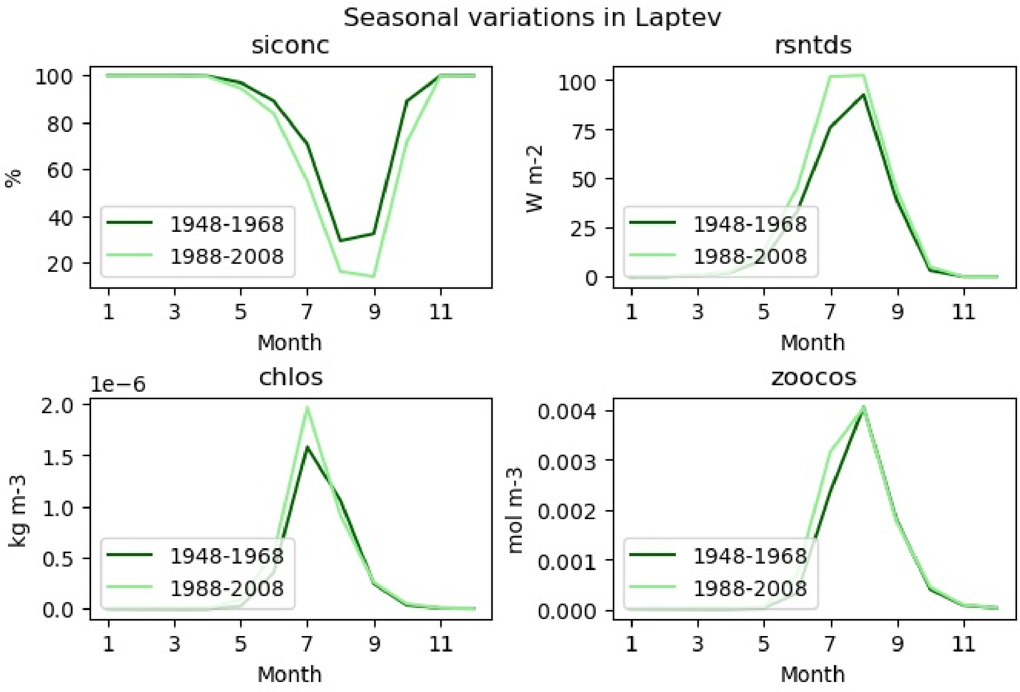

Figure 4: *The figure shows 4 plots for seasonal variances in sea ice concentration(siconc), net downward shortwave radiation(rstdns) , chlorophyll concentration(chlos), and zooplankton concentration(zoocos) at the sea surface in the Laptev sea.*

In [16]:
```
fig, axs = plt.subplots(2, 2)
axs = axs.flatten()
fig.suptitle('Seasonal variations in Kara sea ' )

i = 0
for var in varlist:
    if var == 'siconc':
        ds = ds_ice
    else:
        ds = ds_ocn

    dsStart=make_monthlymean(ds[var].sel(time=slice('1948-01-01','1967-12-31'))).to_dataset(name = var)
    dsEnd=make_monthlymean(ds[var].sel(time=slice('1988-01-01', '2007-12-31'))).to_dataset(name = var)
    dsStartBB = regional_avg(dsStart, areacello, var,  BBlat_min, BBlat_max, BBlon_min, BBlon_max)
    dsEndBB = regional_avg(dsEnd, areacello, var,  BBlat_min, BBlat_max, BBlon_min, BBlon_max)

    ax = axs[i]

    ax.plot(dsStartBB.month, dsStartBB, color='moccasin', label='1948-1968')
    ax.plot(dsEndBB.month, dsEndBB, color='orange', label='1988-2008' )

    ax.set_ylabel(ds[var].units)
    ax.set_xlabel('Month')
    ax.set_xticks(np.arange(1,13,2))
    ax.legend(loc='lower left' )

    i = i+1
    ax.set_title(var)

plt.subplots_adjust(left=0.05, bottom=.15, top=.9, right=.99, wspace=.3, hspace=.5)
plt.savefig('figures/sesav.png')
```

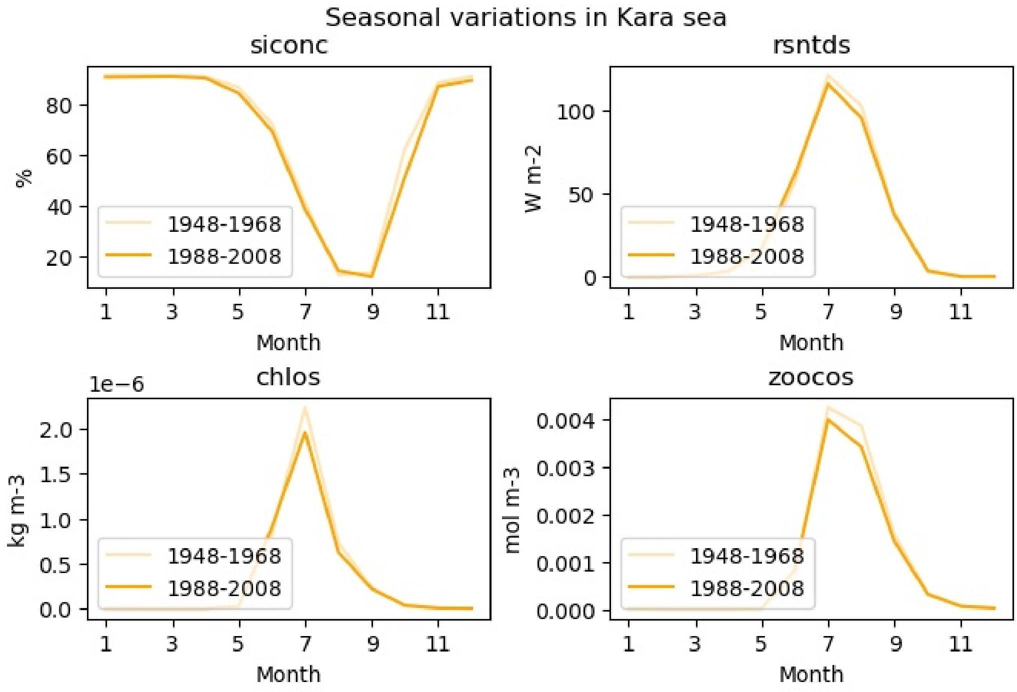

Figure 5: *The figure shows 4 plots for seasonal variances in sea ice concentration(siconc), net downward shortwave radiation(rsndts), chlorophyll concentration(chlos), and zooplankton concentration(zoocos) at the sea surface in Kara sea.*

In [69]:
```
plt.figure(figsize=(16,6))

#Plotting anamolies for Baren sea
plt.subplot(1,3,1)
for var in varlist:
    if var == 'siconc':
        ds = ds_ice
    else:
        ds = ds_ocn
    dsStart=make_monthlymean(ds[var].sel(time=slice('1948-01-01','1967-12-31'))).to_dataset(name = var)
    dsEnd=make_monthlymean(ds[var].sel(time=slice('1988-01-01', '2007-12-31'))).to_dataset(name = var)
    dsStartBS = regional_avg(dsStart, areacello, var,  lat_min, lat_max, lon_min, lon_max)
    dsEndBS = regional_avg(dsEnd, areacello, var,  lat_min, lat_max, lon_min, lon_max)

    plt.plot(dsEndBS.month, ((dsEndBS-dsStartBS)/dsStartBS.mean())*100, label=var)
    plt.title('Anomaly Baren sea')
    plt.xlabel('month')
    plt.ylabel('%')
    plt.legend()
plt.grid()

#Plotting anamolies for the Kara sea
plt.subplot(1,3,2)
for var in varlist:
    if var == 'siconc':
        ds = ds_ice
    else:
        ds = ds_ocn

    dsStart=make_monthlymean(ds[var].sel(time=slice('1948-01-01','1967-12-31'))).to_dataset(name = var)
    dsEnd=make_monthlymean(ds[var].sel(time=slice('1988-01-01', '2007-12-31'))).to_dataset(name = var)
    dsStartBB = regional_avg(dsStart, areacello, var,  BBlat_min, BBlat_max, BBlon_min, BBlon_max)
    dsEndBB = regional_avg(dsEnd, areacello, var,  BBlat_min, BBlat_max, BBlon_min, BBlon_max)

    plt.plot(dsEndBB.month, ((dsEndBB-dsStartBB)/dsStartBB.mean())*100, label=var)
    plt.title('Anomaly Kara sea ')
    plt.ylabel('%')
    plt.xlabel('month')
    plt.legend()
plt.grid()


#Plotting anamolies for the Laptev sea
plt.subplot(1,3,3)
for var in varlist:
    if var == 'siconc':
        ds = ds_ice
    else:
        ds = ds_ocn
    dsStart=make_monthlymean(ds[var].sel(time=slice('1948-01-01','1967-12-31'))).to_dataset(name = var)
    dsEnd=make_monthlymean(ds[var].sel(time=slice('1988-01-01', '2007-12-31'))).to_dataset(name = var)
    dsStartC = regional_avg(dsStart, areacello, var,  Clat_min, Clat_max, Clon_min, Clon_max)
    dsEndC = regional_avg(dsEnd, areacello, var,  Clat_min, Clat_max, Clon_min, Clon_max)

    plt.plot(dsEndC.month, ((dsEndC-dsStartC)/dsStartC.mean())*100, label=var)
```

```
    plt.title('Anomaly Laptev')
    plt.ylabel('%')
    plt.xlabel('month')
    plt.legend()
plt.grid()
```

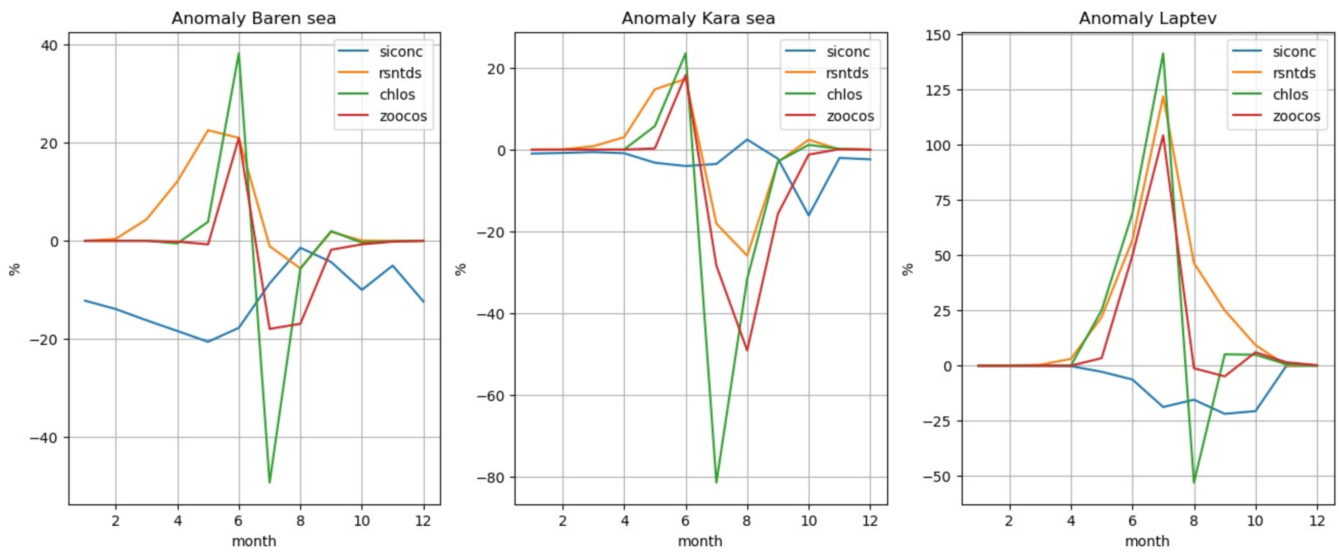

Figure 6: *The plots show the anomalies of different variables at all three locations. The blue lines are the sea ice concentration(siconc), the yellow is the shortwave radiation(rsntds), the green is the concentration chlorophyll(chlos) and the red is the surface consentration of zooplankton(zoocos).*

The plots show a significant change in sea ice concentration, net primary production, and zooplankton.

Figure 1 shows the significant decrease in the Arctic sea ice concentration that has been happening for the past 70 years. We can see that there are differences in how much of a decrease from area to area, however, the general trend for the arctic is that the sea ice is retreating - especially in the autumn and summer months.

Figure 3 shows the seasonal variations of the variables in question in the Barents sea. As expected we can see that there has been a decrease in sea ice and an increase in net downward solar radiation on the sea surface. We can also see a shift in the start production of chlorophyll that indicates the concentration of phytoplankton. We can say the same about zooplankton which also is experiencing an earlier increase.

Figure 4 shows the seasonal variation of the Laptev sea. Just as in the Barents sea we can see a significant decrease in sea ice concentration. However, In this area, the decrease is more significant in every month of the year, while we in the Barents sea can see it more clearly in spring and early summer. We can also see a large increase in net shortwave radiation at the sea surface and phytoplankton which have increased in concentration and bloom earlier than before. However, we can not see a significant increase in the concentration of zooplankton, but just like phytoplankton, there is an earlier increase in concentration,

Figure 5 shows the seasonal variations of the variables in the Kara sea. Of all the areas this is the one with the smallest change in sea ice concentration the concentration is even increasing in the late summer which we also can see in the net downwards shortwave radiation. The plots also show a decrease in both phytoplankton and zooplankton and there is no change in the period of the blooming of phytoplankton.

Figure 6 is showing the percentage of change for each variable in each study area. In all areas, we see a decrease in sea ice in the winter season, while we see an increase in chlorophyll and zooplankton concentration in spring. The net incoming shortwave radiation also as expected increase as the sea ice decrease. The plot shows just how dependent sea ice concentration and net shortwave sea surface concentration are and how dependent zooplankton are on phytoplankton.

Discussion

The fact that we can see a more significant shift at the start of the blooming season in areas with a more significant decrease in sea ice may indicate that there is a great correlation between the two variables. However, there are still other factors to take into consideration when discussing primary production.

As mentioned phytoplankton are dependent on sunlight, carbon dioxide, and nutrients to grow and these are also factors needed to be taken into consideration when studying the seasonal cycles of the primary producers. Considering Laptev sea also is known for having a strong freshwater input it is also likely that the area has a lot of nutrients giving the phytoplankton an optimal environment to grow in. (Peters at al., 2004)

Looking at the seasonal variation in every study area we can see that there are bigger changes in phytoplankton when there are bigger changes in the sea ice concentration. Laptev sea is the study area where we have seen the largest decrease in sea ice concentration and also the largest change in phytoplankton. The phytoplankton in this area have both increased a lot in concentration and the blooming period comes a little earlier in the last period compared to the first. The same has happened in the Barents sea, however, the increase in concentration is not as significant as in Laptkev. In the Kara sea, there has not been a significant decrease in the sea ice(in some periods the sea ice has increased) and in this area, we can see a decrease in the concentration of phytoplankton. As mentioned this area is known for being very cold and stratified. Stratified oceans are usually a good thing for phytoplanktons because it is bringing more nutrients to the surface, however, it still seems like the lack of sunlight has a great effect on the plankton in the area.

Since most zooplankton eats phytoplankton there is no surprise that we can see a correlation in the anomalies of phytoplankton and zooplankton. It makes sense that there also will be a seasonal shift in zooplankton concentration when there is an earlier increase and decrease in phytoplankton concentration. In figure _ we can see that the trend in zooplankton is following the trend in phytoplankton.

In this study (*so far?*) only the NorESM2-LM has been used. Climate models are not necessarily accurate so they should be compared to other models/scenarios and observations to validate the results of the study. There are also important to mention that different types of phytoplankton react differently to sunlight and not all phytoplankton are represented in the model. (....)

Looking at the seasonal variations of the variables of the plots we can conclude that there likely is a correlation between the sea ice retreat and the seasonal changes in phytoplankton. We can also conclude that the pattern of the seasons in zooplankton follows the phytoplankton. However, there has only one model has been used in this study, and observations and other models are needed to validate the results.

Acknowledgments

Thanks to Michael and Paul for organizating a great cours. Thanks to the Plankton group for helping me out whenever I needed and thanks to Ada for helping me so much with the code.

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In [ ]: