Practical 4:

Area of interest

This practical focuses on the western boundary of the Antarctic Peninsula, near the Bellingshausen Sea, with coordinates spanning 58°S to 70°S in latitude and 60°W to 85°W in longitude. I have always been fascinated by the Southern Ocean and its complex dynamics. Being a high-nutrient, low-chlorophyll area, this region provides an exciting opportunity to examine chlorophyll levels in greater detail and observe their patterns more closely.

My interest in this region comes from the important role the Southern Ocean plays in global productivity and global thermohaline circulation. Additionally, learning about the Endurance further fueled my curiosity and interest in this region. While several aspects interest me, I am particularly interested in the sea ice and productivity dynamics.

Data used:

The first dataset used was from the Global Multi-Resolution Topography Synthesis (GMRT). This bathymetry data was downloaded using the map application and selecting the data off the Antarctic Peninsula. The data is high resolution sounding data that is combined with the GEBCO reference chart. Reference: Ryan, W.B.F., S.M. Carbotte, J.O. Coplan, S. O'Hara, A. Melkonian, R. Arko, R.A. Weissel, V. Ferrini, A. Goodwillie, F. Nitsche, J. Bonczkowski, and R. Zemsky (2009), Global Multi-Resolution Topography synthesis, Geochem. Geophys. Geosyst., 10, Q03014, doi: 10.1029/2008GC002332 .

The second dataset, chlorophyll-a data, was obtained from the ESA-CCI Ocean Colour climatology dataset. The chlorophyll data is satellite sensed chlorophyll concentration for the world ocean. The data is taken from multiple satellites and complied into monthly averages for a specific region. This means that when using this data, the extent needs to be chosen to zoom in on a specific region of interest.
Reference: Sathyendranath, S, Brewin, RJW, Brockmann, C, Brotas, V, Calton, B, Chuprin, A, Cipollini, P, Couto, AB, Dingle, J, Doerffer, R, Donlon, C, Dowell, M, Farman, A, Grant, M, Groom, S, Horseman, A, Jackson, T, Krasemann, H, Lavender, S, Martinez-Vicente, V, Mazeran, C, Mélin, F, Moore, TS, Müller, D, Regner, P, Roy, S, Steele, CJ, Steinmetz, F, Swinton, J, Taberner, M, Thompson, A, Valente, A, Zühlke, M, Brando, VE, Feng, H, Feldman, G, Franz, BA, Frouin, R, Gould, Jr., RW, Hooker, SB, Kahru, M, Kratzer, S, Mitchell, BG, Muller-Karger, F, Sosik, HM, Voss, KJ, Werdell, J, and Platt, T (2019) An ocean-colour time series for use in climate studies: the experience of the Ocean-Colour Climate Change Initiative (OC-CCI). Sensors: 19, 4285. doi:10.3390/s19194285

A color-coded depth map was generated using Python to visualize bathymetry, offering a clear representation of underwater features. A separate map was created to overlay chlorophyll-a concentrations on the region of interest.

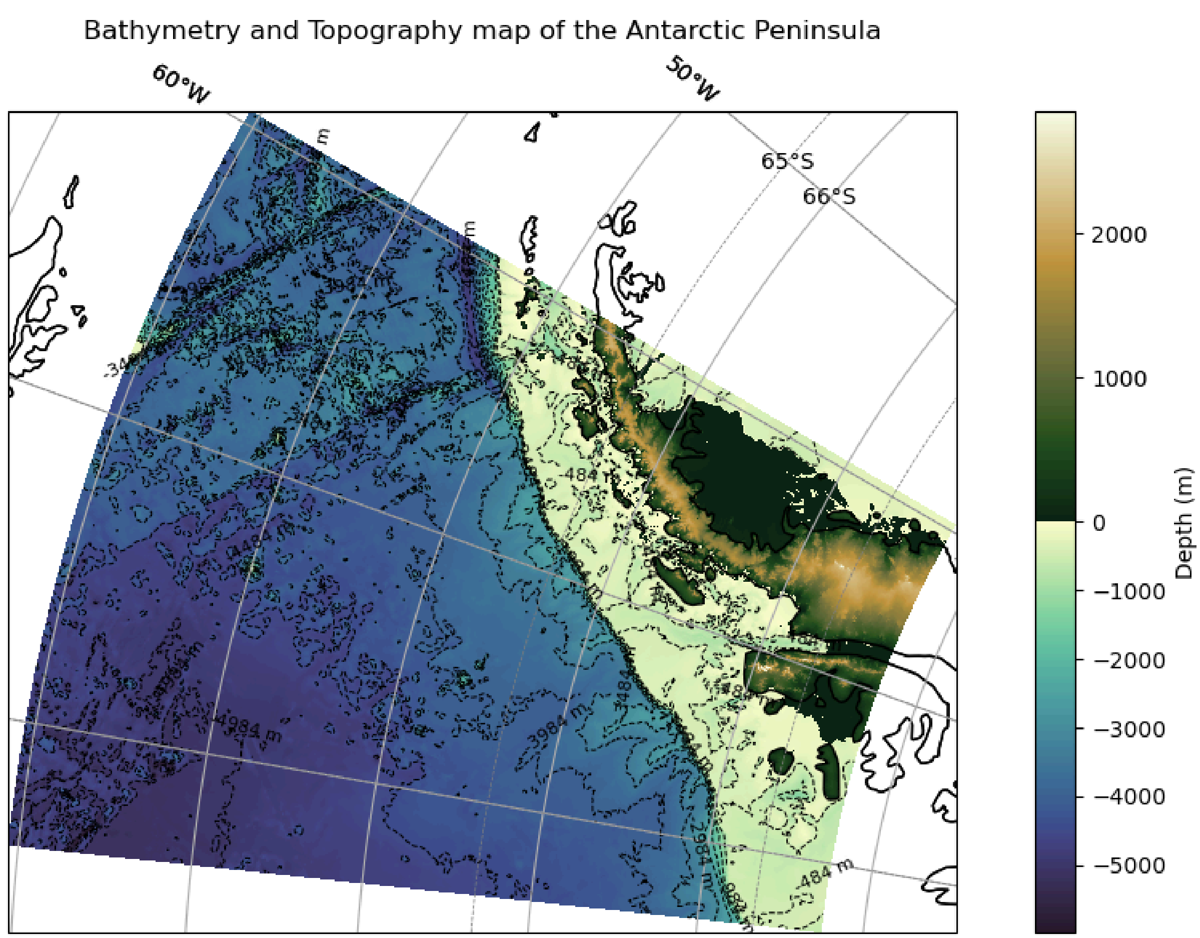
In [2]:
```
#Importing all the necessary programs:
import matplotlib.pyplot as plt
import matplotlib.colors
import cartopy.crs as ccrs
import cartopy.feature as cfeature
import cartopy.io.shapereader as shpreader
import cmocean
import numpy as np
import xarray as xr
import io
import zipfile
import requests
import glob
import os
import gzip
import shutil
from matplotlib.colors import TwoSlopeNorm
from matplotlib.colors import LogNorm
import matplotlib.ticker as mticker
```

Plot 1

A large figure with the map of the region bathymetry, using an adequate colormap.

In [5]:
```
# Loading bathymetry dataset
bathy = xr.open_dataset('GMRTv4_3_0_20250318topo (1).grd')

#Getting the data:
lon = bathy['lon']
lat = bathy['lat']
bathymetry = bathy['altitude']

# Colour normalization with zero (sea level) as the midpoint
vmin, vmax = float(bathymetry.min()), float(bathymetry.max())
midpoint = 0  # Sea level at 0m

norm = TwoSlopeNorm(vmin=vmin, vcenter=midpoint, vmax=vmax)

# Contrast for land and sea
cmap = cmocean.cm.topo

# Creating figure with correct projection
fig, ax = plt.subplots(figsize=(10, 6), subplot_kw={'projection': ccrs.South

# Plot bathymetry and land elevation
pcm = ax.pcolormesh(lon, lat, bathymetry, cmap=cmap, norm=norm, transform=cc

# Add bathymetry contours
```

```
contour = ax.contour(lon, lat, bathymetry, levels=np.arange(vmin, 0, 500),
                     colors="black", linewidths=0.7, transform=ccrs.PlateCa
ax.clabel(contour, fmt='%d m', colors='black', fontsize=8)

# Add map features
ax.add_feature(cfeature.LAND, edgecolor='black', facecolor='none')
ax.coastlines()
ax.gridlines(draw_labels=True)

#Adding contours
gl = ax.gridlines(draw_labels=True, linestyle="--", linewidth=0.5, color="gr
gl.ylocator = mticker.FixedLocator(np.arange(-90, -60, 5))

# Colorbar
cbar = plt.colorbar(pcm, ax=ax, orientation='vertical', label='Depth / Eleva
cbar.set_label("Depth (m)")
# Elevation is positive for land, negative for depth (ocean)

# Title
plt.title("Bathymetry and Topography map of the Antarctic Peninsula")
plt.tight_layout()
plt.savefig("plot1.jpg", dpi=300, bbox_inches='tight', pad_inches=0)
plt.show()
```



This plot has stereographic south polar CRS as this projection aims to decrease the distortion near the poles and is able to preserve this area's shape well. This plot demonstrates the high topography of the Antarctic Peninsula towards the center and lower topography closer to the coastline. The large dark green spot to the right of the Peninsula is the Larsen Ice Shelf and is noticeable at sea level. The ocean depth is shallower closer to the continent and depth increases further from the continent. The shallowest depth is reported at 484m and the deepest depth is 4984m. There are some bathometric features visible between 60*W and 70*W, as there are varying depths.

Plot 2:

In [12]:
```
#Loading the chlorophyll data:
chl_data = xr.open_dataset("/Users/chloelevey/Documents/LVYCHL001-SCDM25/P4/

chl_data
```

Out[12]: xarray.Dataset

▶ Dimensions:	(**time**: 12, **lon**: 8640, **lat**: 4320)			
▼ Coordinates:				
time	(time)	datetime64[ns]	1998-01-01 ... 1997-12-...	
lon	(lon)	float64	-180.0 -179.9 ... 179.9 1...	
lat	(lat)	float64	89.98 89.94 89.9 ... -89...	
▼ Data variables:				
crs	()	int32	...	
chlor_a	(time, lat, lon)	float32	...	
▶ Indexes: (3)				
▶ Attributes: (53)				

In [14]:
```
#Making a data array:
da_chl_data = chl_data['chlor_a']
```

In [16]:
```
#Log transforming the data:
da_chl_log = np.log(da_chl_data)
```

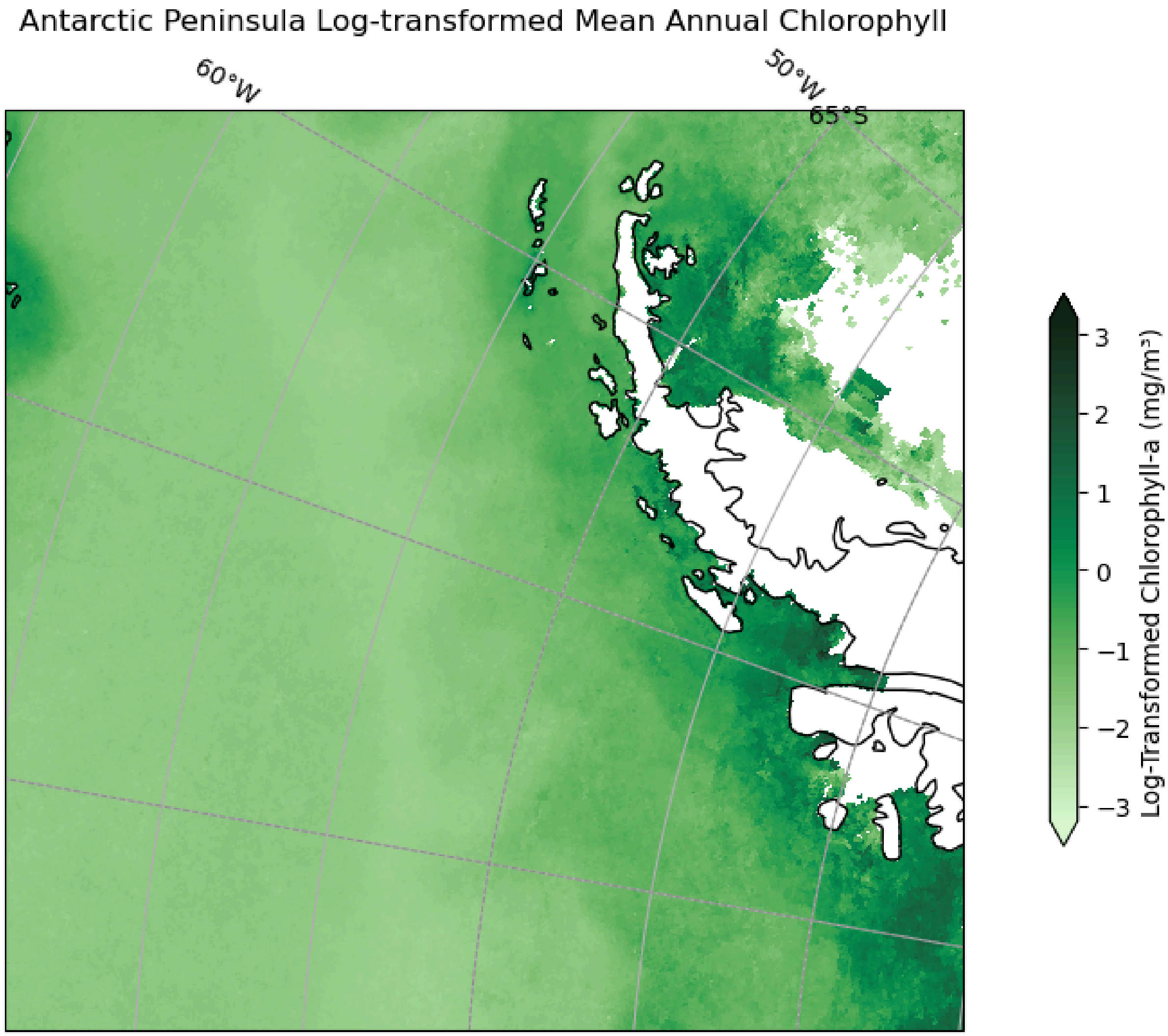
In [17]:
```
#Checking min and max values:
print(da_chl_data.min(),da_chl_data.max(),da_chl_data.mean())

#Making an array for the mean:
da_chl_mean = da_chl_data.mean(dim='time')
```

```
<xarray.DataArray 'chlor_a' ()>
array(0.001) <xarray.DataArray 'chlor_a' ()>
array(99.48895264) <xarray.DataArray 'chlor_a' ()>
array(0.40058345, dtype=float32)
```

In [20]:
```
##Using the log transformed data for the plot:
```

```
#Log mean:
da_chl_log_mean = da_chl_log.mean(dim='time')

#Setting extent:
extent = [-60, -85, -58, -70]
central_lon = np.mean(extent[:2])
central_lat = np.mean(extent[2:])

#Masking NANs in data set:
da_chl_log_mean_masked = da_chl_log_mean.where(~np.isnan(da_chl_log_mean))
```

In [22]:
```
#Plotting:
# Figure and axis:
fig, axis = plt.subplots(figsize=(10, 6), subplot_kw={'projection': ccrs.Sou

# Plot chlorophyll data
da_chl_log_mean_masked.plot(ax=axis, transform=ccrs.PlateCarree(),cmap=cmoce
                            cbar_kwargs={'orientation': 'vertical', 'shrink'

#Coastlines and gridlines:
axis.set_extent(extent, crs=ccrs.PlateCarree())
axis.coastlines()
gl = axis.gridlines(draw_labels=True)
gl.right_labels = False
gl.top_labels = False

gl = axis.gridlines(draw_labels=True, linestyle="--", linewidth=0.7, color="

#making sure that the lat and long points are evenly spaced:
gl.xlocator = mticker.FixedLocator(np.arange(-180, 180, 10))
gl.ylocator = mticker.FixedLocator(np.arange(-90, -60, 5))

#Title and saving:
plt.title("Antarctic Peninsula Log-transformed Mean Annual Chlorophyll")
plt.tight_layout()
plt.savefig("plot2.jpg", dpi=300, bbox_inches='tight', pad_inches=0)
plt.show()
```



The chlorophyll data has been log transformed as the data spans a few orders of magnitude and this allows for the best representation of the data. There is higher productivity closer to the continent and decreasing productivity away from the continent. The white spot next to the continent is again the Larsen Ice Shelf. There does seem to be a distinct gradient of decreasing productivity, which could indicate the presence of fronts which cause mixing and therefore higher productivity.

Plot 3:

In [24]:
```
#Grouping the log-chlorophyll data by month:
monthly_mean_chl = da_chl_log.groupby('time.month').mean()
```

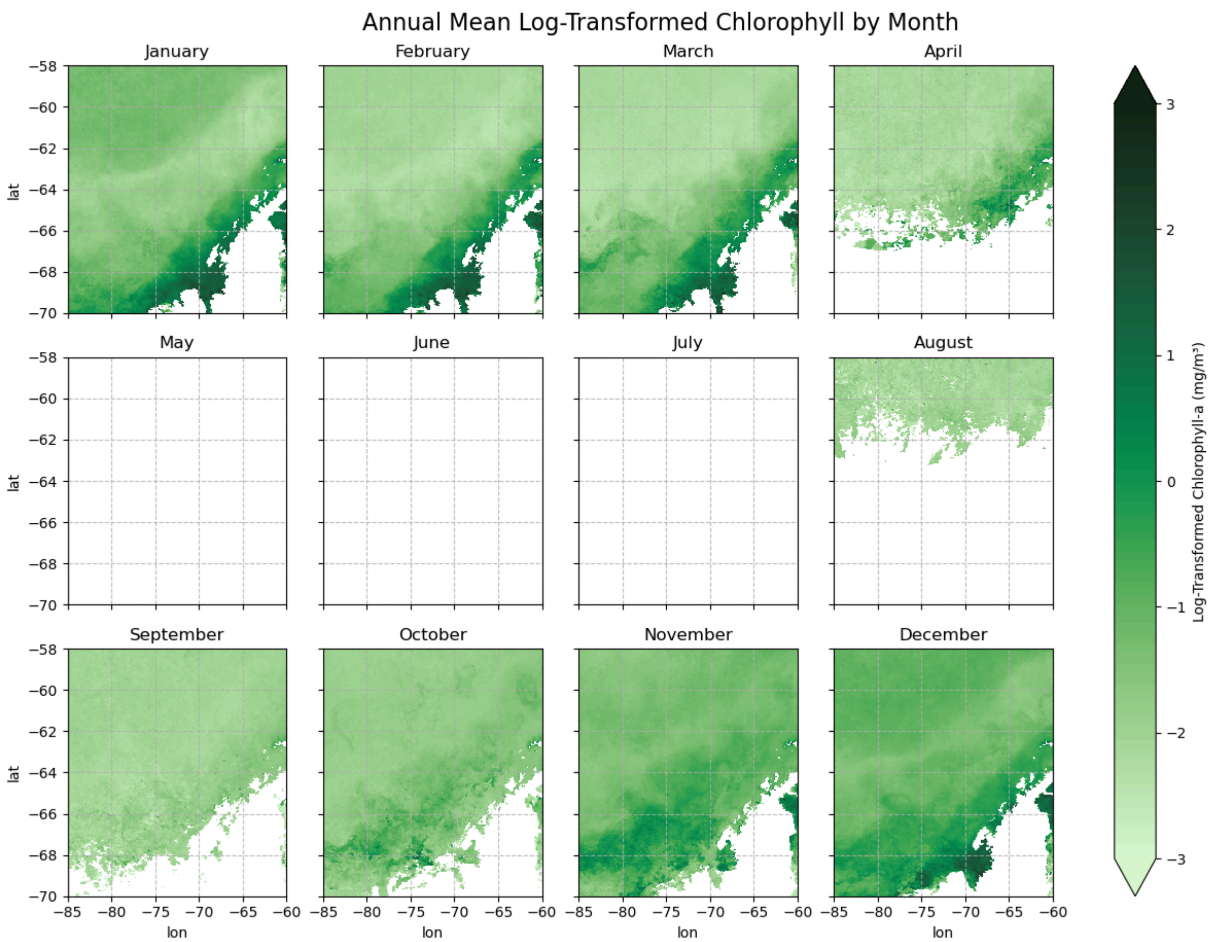
In [25]:
```
#Adding months:
month_names = ["January", "February", "March", "April", "May", "June", "July

monthly_mean_chl = monthly_mean_chl.assign_coords(month=("month", month_name
```

In [26]:
```
#Setting the extent
region_extent = dict(lon=slice(-85, -60), lat=slice(-58, -70))
```

```
monthly_mean_chl_region = monthly_mean_chl.sel(**region_extent)
```

In [27]:
```
#Plotting the figure:
fig = plt.figure(figsize=(14, 12))

g = monthly_mean_chl_region.plot(col='month', col_wrap=4, cmap=cmocean.cm.al

# Looping through each axis to set titles and gridlines:
for ax, name in zip(g.axes.flat, month_names):
    ax.set_title(name)
    ax.grid(True, linestyle='--', alpha=0.8)

plt.suptitle("Annual Mean Log-Transformed Chlorophyll by Month", fontsize=16
plt.savefig("plot3.jpg")
plt.show()
```

```
/var/folders/w8/mpdvw0cn1n310fwby2rvy00m0000gn/T/ipykernel_26378/2263774185.
py:7: DeprecationWarning: self.axes is deprecated since 2022.11 in order to
align with matplotlibs plt.subplots, use self.axs instead.
  for ax, name in zip(g.axes.flat, month_names):
<Figure size 1400x1200 with 0 Axes>
```



This data has been log-transformed to account for the large orders of magnitude in the datasets. The FaceTGrid allows the average per month to be seen, making it easier to determine the seasonality of chlorophyll in this region.

From May to June, there is no data available for this region, which is expected since it is winter in the Southern Hemisphere, and sea ice forms in the Southern Ocean. In April, a larger white region appears, marking the beginning of this sea ice formation. Then from August to September, the white areas start to decrease, showing the sea ice melting during this part of the season.

September to November is the start of spring, which explains the increasing amount of chlorophyll as nutrients are more readily available (after winter) and light levels increase. In summer, from December to February, productivity peaks, especially around the continent, which makes sense as sunlight is at its highest during this period. At the start of autumn in March, productivity is still high. December is the peak productivity time, as shown by the chlorophyll gradient extending far from the continental region into the sea. September and October, on the other hand, show relatively low productivity.

Plot 4:

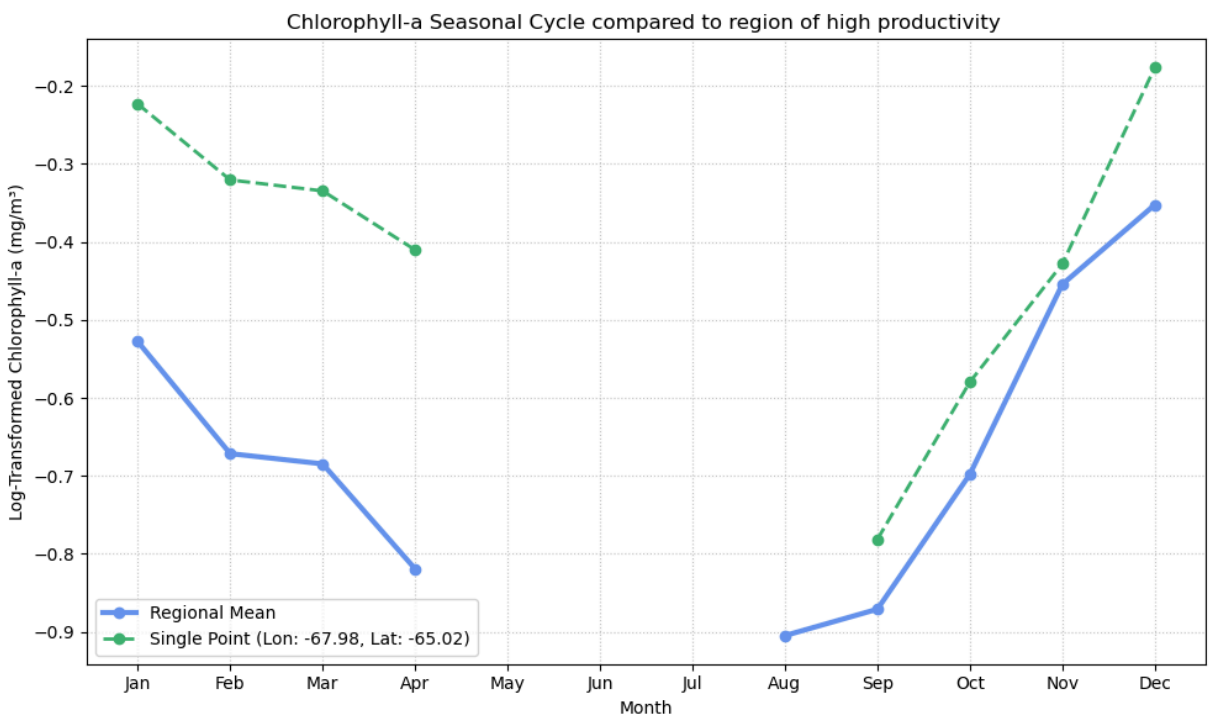
In [29]:
```
# Log transforming chlor_a for extent:
log_chlor_a = np.log10(chl_data['chlor_a'].sel(lon=slice(-85, -60), lat=slic

# Monthly mean for the extent:
regional_mean = log_chlor_a.groupby('time.month').mean(dim=['lat', 'lon'])

#Single point near high chlorophyll area:
single_point = log_chlor_a.sel(lon=-68, lat=-65, method='nearest')
# Printing coordinates
print(f"Exact Longitude: {single_point.lon.values}")
print(f"Exact Latitude: {single_point.lat.values}")

#Monthly mean for the single point:
single_point_mean = single_point.groupby('time.month').mean()
```

```
Exact Longitude: -67.97916666666667
Exact Latitude: -65.02083333333331
```

In [30]:
```
# Remove NaNs before finding max value
log_chlor_a_clean = log_chlor_a.where(~np.isnan(log_chlor_a), drop=True)

#Finding index of max log-transformed chlorophyll
max_idx = log_chlor_a_clean.argmax(dim=["lat", "lon"])

# Extract the corresponding latitude and longitude
max_lat = log_chlor_a_clean.lat[max_idx["lat"].values].values
max_lon = log_chlor_a_clean.lon[max_idx["lon"].values].values

print(f"Max log chlor_a at lat: {max_lat}, lon: {max_lon}")
```

```
Max log chlor_a at lat: [-67.4375     -69.10416667 -68.35416667 -65.72916667
-61.02083333
 -67.8125     -68.14583333 -62.60416667 -68.85416667], lon: [-68.02083333 -6
8.4375     -67.22916667 -67.14583333 -71.6875
 -75.72916667 -74.1875     -60.64583333 -67.72916667]
```

In [31]:
```
#Plotting:
plt.figure(figsize=(10, 6))
plt.plot(range(1, 13), regional_mean.values,
             label='Regional Mean', linewidth=3, color='cornflowerblue', mar
plt.plot(range(1, 13), single_point_mean.values,
             label=f'Single Point (Lon: {single_point.lon.values:.2f}, Lat:
             linewidth=2, color='mediumseagreen', linestyle='--', marker='o'

plt.title('Chlorophyll-a Seasonal Cycle compared to region of high productiv
plt.xlabel('Month', fontsize=10)
plt.ylabel('Log-Transformed Chlorophyll-a (mg/m³)', fontsize=10)
plt.xticks(range(1, 13), ['Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun','Jul', 'A
plt.legend()
plt.grid(True, linestyle=':', alpha=0.7)

#Saving
plt.tight_layout()
plt.savefig("plot4.jpg")
plt.show()
```



The seasonality of productivity in the Southern Ocean is displayed by this plot. Productivity is linked to chlorophyll concentration, as chlorophyll is necessary for primary production. For the whole region, productivity decreases from January to April, from about -0.5 mg/m3 to -0.8 mg/m3. From April until August, there is no productivity in the region as it is winter time and therefore there is ice formation and low light. From August to September, there is a small increase in productivity. As Spring starts, from September to November, there is a rapid increase in chlorophyll as light availability increases and there are nutrients present from winter. There is a steady increase from November to December, where chlorophyll reaches its maximum at -0.35.

The single point of highest productivity (65.02*S, 67.98*W) demonstrates a similar pattern to the whole region, although with higher productivity. This point has a peak chlorophyll concentration at roughly -0.15 mg/m3. This region follows the same pattern as the whole region for January to April, but with higher values from -0.2 mg/m3 in January and a drop to -0.4 mg/m3 in April. This region demonstrates a sharp increase in chlorophyll from September (-0.8mg/m3) until December, where it reaches it's peak. However, this point does not have any chlorophyll values for August, as it could be in a region that still has ice cover in August.

References:

1. National Snow and Ice Data Center (NSIDC) (n.d.) A Guide to NSIDC's Polar Stereographic Projection. Available at: https://nsidc.org/data/user-resources/help-center/guide-nsidcs-polar-stereographic-projection#:~:text=NSIDC%27s%20Polar%20Stereographic%20Projection%20was,usec (Accessed: 25 March 2025).
2. OpenAI (2025) ChatGPT [Online]. Available at: https://openai.com (Accessed: 25 March 2025).
3. Ryan, W.B.F., Carbotte, S.M., Coplan, J.O., O'Hara, S., Melkonian, A., Arko, R., Weissel, R.A., Ferrini, V., Goodwillie, A., Nitsche, F., Bonczkowski, J., & Zemsky, R. (2009) Global Multi-Resolution Topography synthesis. Geochem. Geophys. Geosyst., 10, Q03014. doi: 10.1029/2008GC002332.
4. Sathyendranath, S., Brewin, R.J.W., Brockmann, C., Brotas, V., Calton, B., Chuprin, A., Cipollini, P., Couto, A.B., Dingle, J., Doerffer, R., Donlon, C., Dowell, M., Farman, A., Grant, M., Groom, S., Horseman, A., Jackson, T., Krasemann, H., Lavender, S., Martinez-Vicente, V., Mazeran, C., Mélin, F., Moore, T.S., Müller, D., Regner, P., Roy, S., Steele, C.J., Steinmetz, F., Swinton, J., Taberner, M., Thompson, A., Valente, A., Zühlke, M., Brando, V.E., Feng, H., Feldman, G., Franz, B.A., Frouin, R., Gould, R.W. Jr., Hooker, S.B., Kahru, M., Kratzer, S., Mitchell, B.G., Muller-Karger, F., Sosik, H.M., Voss, K.J., Werdell, J., & Platt, T. (2019) An ocean-colour time series for use in climate studies: The experience of the Ocean-Colour Climate Change Initiative (OC-CCI). Sensors, 19, 4285. doi: 10.3390/s19194285.
5. Southern Ocean Productivity (n.d.) NIWA. Available at: https://niwa.co.nz/antarctica/southern-ocean-productivity#:~:text=Phytoplankton%20%E2%80%93%20microscopic%20plants%20th (Accessed: 25 March 2025).
6. Trachyte et al. (1963) Plt.show() does nothing when used for the second time. Stack Overflow. Available at: https://stackoverflow.com/questions/50452455/plt-show-does-nothing-when-used-for-the-second-time (Accessed: 24 March 2025).
7. Xarray.DataArray.sel (2025) xarray. Available at: https://docs.xarray.dev/en/latest/generated/xarray.DataArray.sel.html (Accessed: 24 March 2025).

```
In [ ]:
```