Regional Training Workshop on Observing the Coastal and Marginal Seas in the Western Indian Ocean including the Arabian/Persian Gulf and the Sea of Oman

7th - 9th June, 2022

Satellite observations and value for ocean science: Ocean color

Nikolay Nezlin

Global Science & Technology, Inc. (NOAA affiliate)

Satellite observations and value for ocean science: Ocean color

Ocean Color is the water property which is
- remotely sensed
- associated with biological rather than physical properties of ocean water

Ocean Color is the water hue due to the presence of tiny plants containing the pigment chlorophyll within phytoplankton and other oceanic particles such as sediments, and colored dissolved organic material (DOM). Phytoplankton consists of small, single-celled ocean plants which constitute the base of the oceanic food web and produce organic carbon through photosynthesis. The rate at which photosynthesis proceeds is known as primary productivity.

Satellite observations and value for ocean science: Ocean color

The areas of studies reported to benefit from sustained ocean-color observations include:

- The global carbon cycle and its fluctuations at many time scales;
- Ocean acidification;
- Marine biodiversity and function;
- Marine pollution;
- Validation and improvement of Earth System and ocean biogeochemical models;
- Data assimilation to improve model performance;
- Data for assessing impact and adaptation of marine ecosystem to climate change;
- Bio-feedback mechanisms, understanding Earth System;
- Flow of material through the marine food webs, implications for marine resources; etc.

Groom et al., 2019, Front. Mar. Sci., https://doi.org/10.3389/fmars.2019.00485

Compare satellite remote sensing and the traditional sources of oceanographic information:

Advantage of remote sensing over traditional methods:

- **Synoptic view**, because satellites collect huge amount of information much exceeding the data collected by contact oceanographic observations;

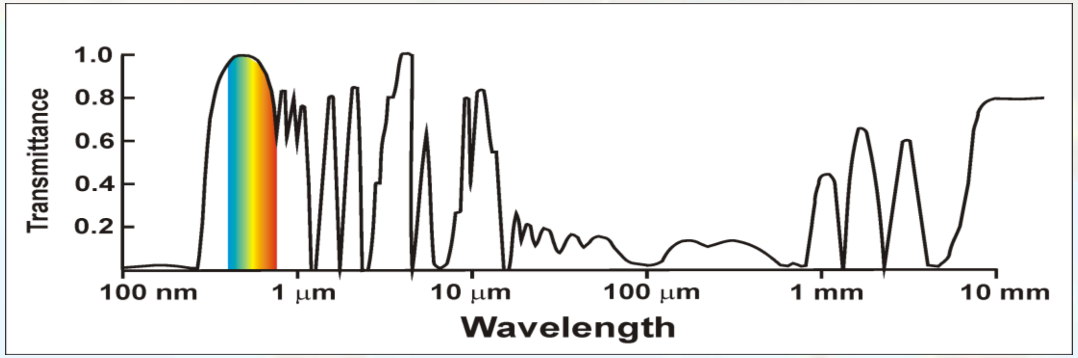
- Satellite observations cover wide **areas** of the World Ocean **hardly accessible** for field observations.

Disadvantage of remote sensing:

- The parameters measured by the satellites **cannot be directly attributed** to traditionally measured oceanographic characteristics;

- Most satellite observations (including ocean color) are more **sensitive to unfavorable** meteorological conditions than traditional oceanographic methods.

Ocean color



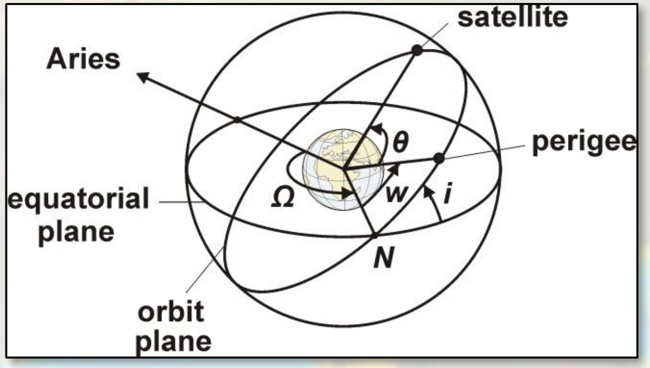
The measurements of ocean color are based on electromagnetic energy of 400-700 nm wavelength. This energy is emitted by the sun, transmitted through the atmosphere and reflected by the water surface.

The color of water surface results from sunlight that has entered the ocean, been selectively absorbed, scattered and reflected by phytoplankton and other suspended material in the upper layers, and then backscattered through the water surface.

The color of ocean surface depends on:

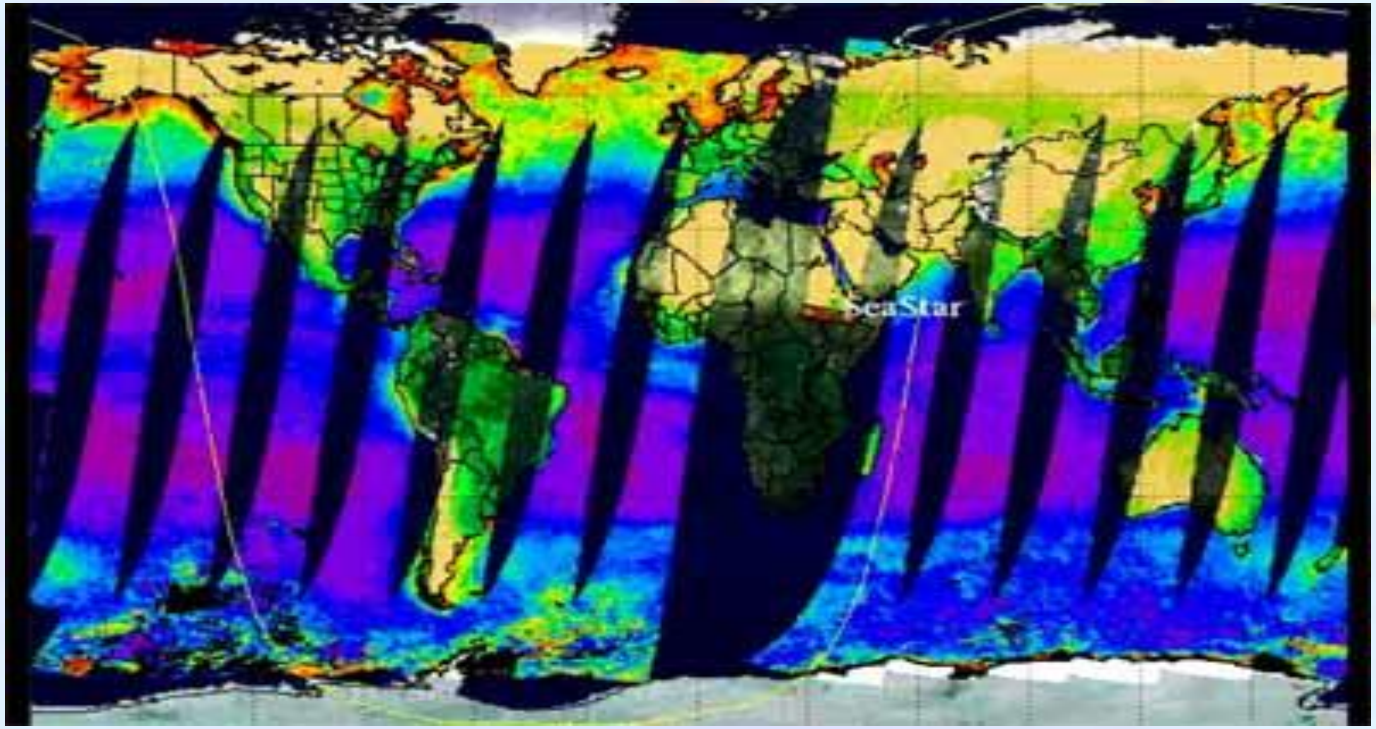
- **sunlight** transmitted through the atmosphere
- dissolved and suspended **water constituents**

Satellites and sensors



Most satellite oceanographic data is collected from satellites operating at **near-polar sun-synchronous** orbits

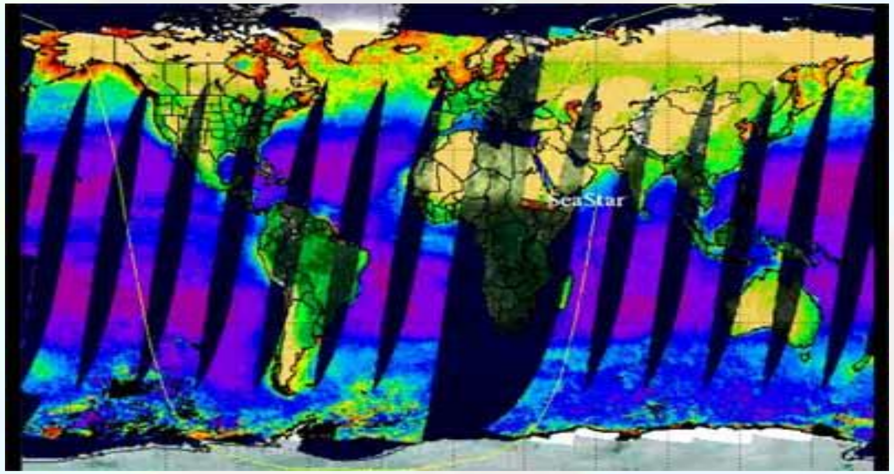
Near-polar satellites have orbit inclination ~90°. Usually these satellites have altitude between 500 and 2,000 km and a period of about 1 to 2 hours. As the Earth rotates under this orbit the satellite effectively scans from north to south over one face and south to north across other face of the Earth, several times each day, achieving much greater surface coverage than if it were in a non-polar orbit.

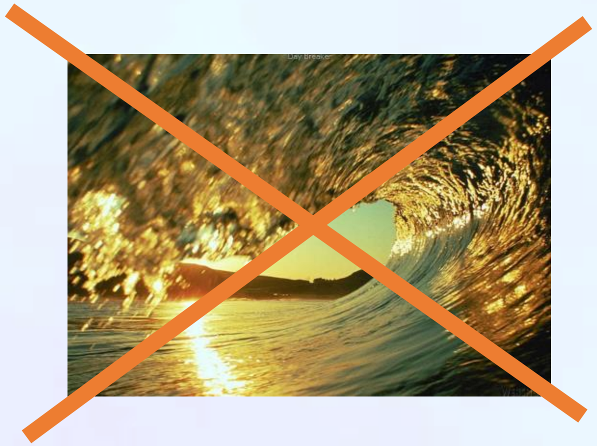


Satellites and sensors

The goal of **sun-synchronous orbit** is to collect data at **similar sunlight conditions**.

By a suitable selection of the orbit inclination it is possible to achieve rotation of the orbit plane 0.986° per day, which is equivalent to one rotation of the orbit plane per year.
In this way the orbit plane is not fixed relative to stars, but fixed relative to the sun. The result is sun-synchronous orbit, in which the satellite crosses the equator at the same local solar time on each pass throughout the year.





Ocean color

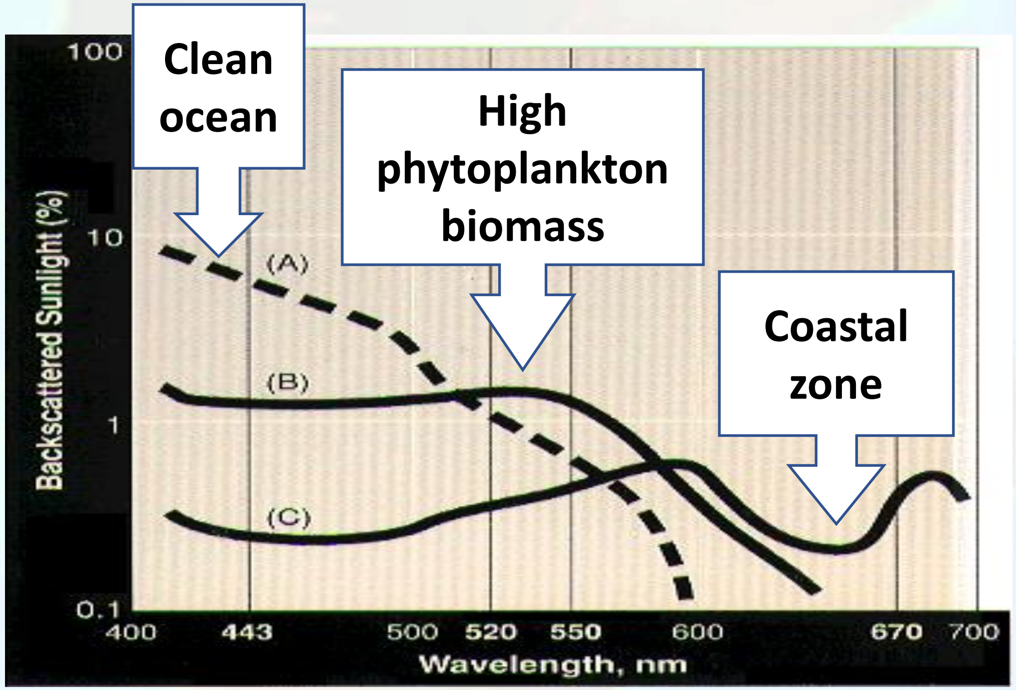
The sources of color change in seawater include:

- Phytoplankton and its **pigments**
- Dissolved organic material
  - Colored Dissolved Organic Material (**CDOM**, or yellow matter, or gelbstoff) is derived from decaying vegetable matter (land) and phytoplankton degraded by grazing or photolysis.
- Suspended particulate matter
  - The organic particulates (**detritus**) consist of phytoplankton and zooplankton cell fragments and zooplankton fecal pellets.
  - The **inorganic particulates** consist of sand and dust created by erosion of land-based rocks and soils. These enter the ocean through:
    - River runoff.
    - Deposition of wind-blown dust.
    - Wave or current suspension of bottom sediments.

Ocean color

The color of water surface is regulated by the color of pure ocean water and the concentrations of different types of particles suspended in the upper water layer.

In “clean” ocean waters (Case 1), water color depends on chlorophyll concentration, which in turn depends on phytoplankton biomass.

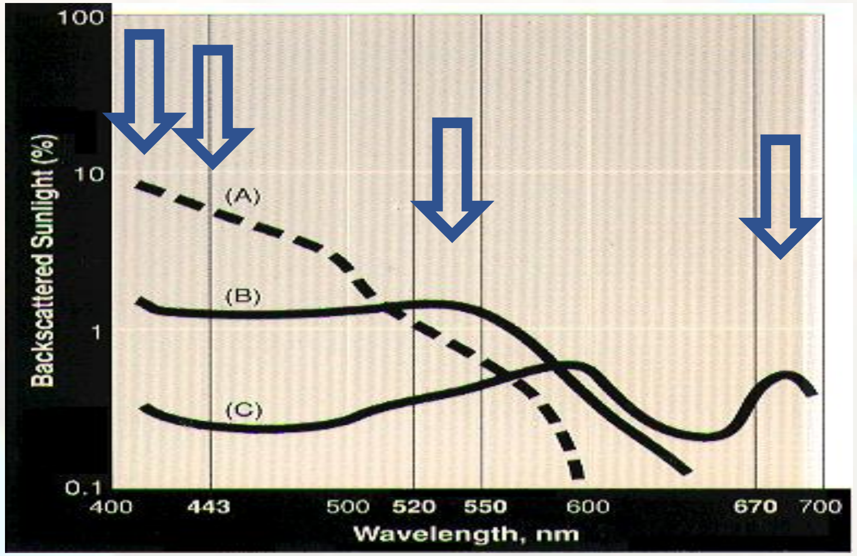


Clean ocean water absorbs red light and transmits and scatters the light of short wavelength.

Phytoplankton cells contain chlorophyll that absorbs blue and red and contributes green color to ocean water.

In coastal waters (Case 2), suspended organic and inorganic matter backscatters sunlight, contributing green, yellow and brown to water color.

Ocean color



Subsurface reflectance *R(λ)* depends on backscattering *b(λ)* and absorption *a(λ)* of different compounds.

$$R(\lambda) = G \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

G is a constant that depends on the incident light field.

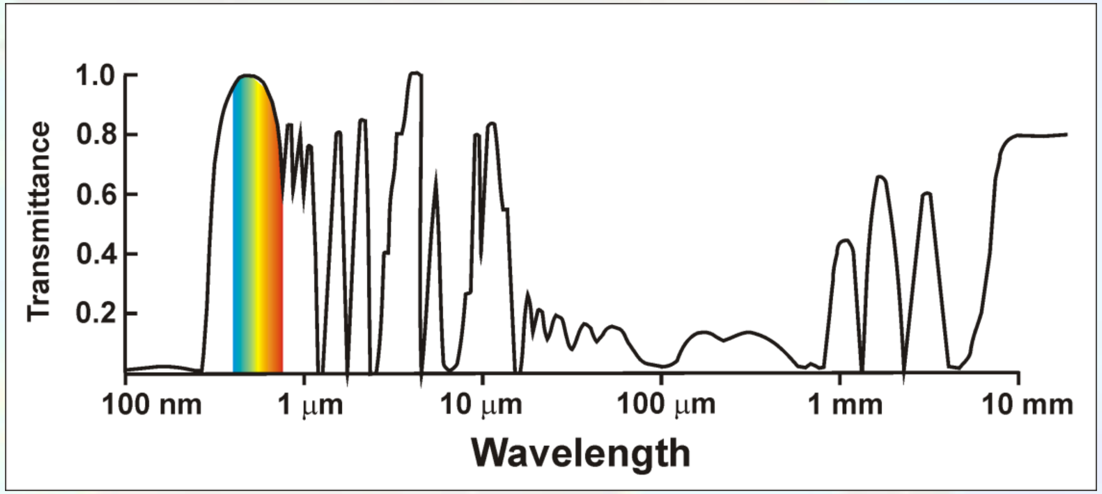
Different wavelengths are important to observe CDOM, chlorophyll and fluorescence.

- Chlorophyll absorption peak is at 443 nm.
- CDOM-dominated wavelength is at 410 nm.
- Measurements must also be made in the 500-550 nm range where the chlorophyll absorption is zero and the absorption of other plant pigments (I.e., carotenoids) dominate.
- Fluorescence requires observations in the vicinity of 683-nm peak.

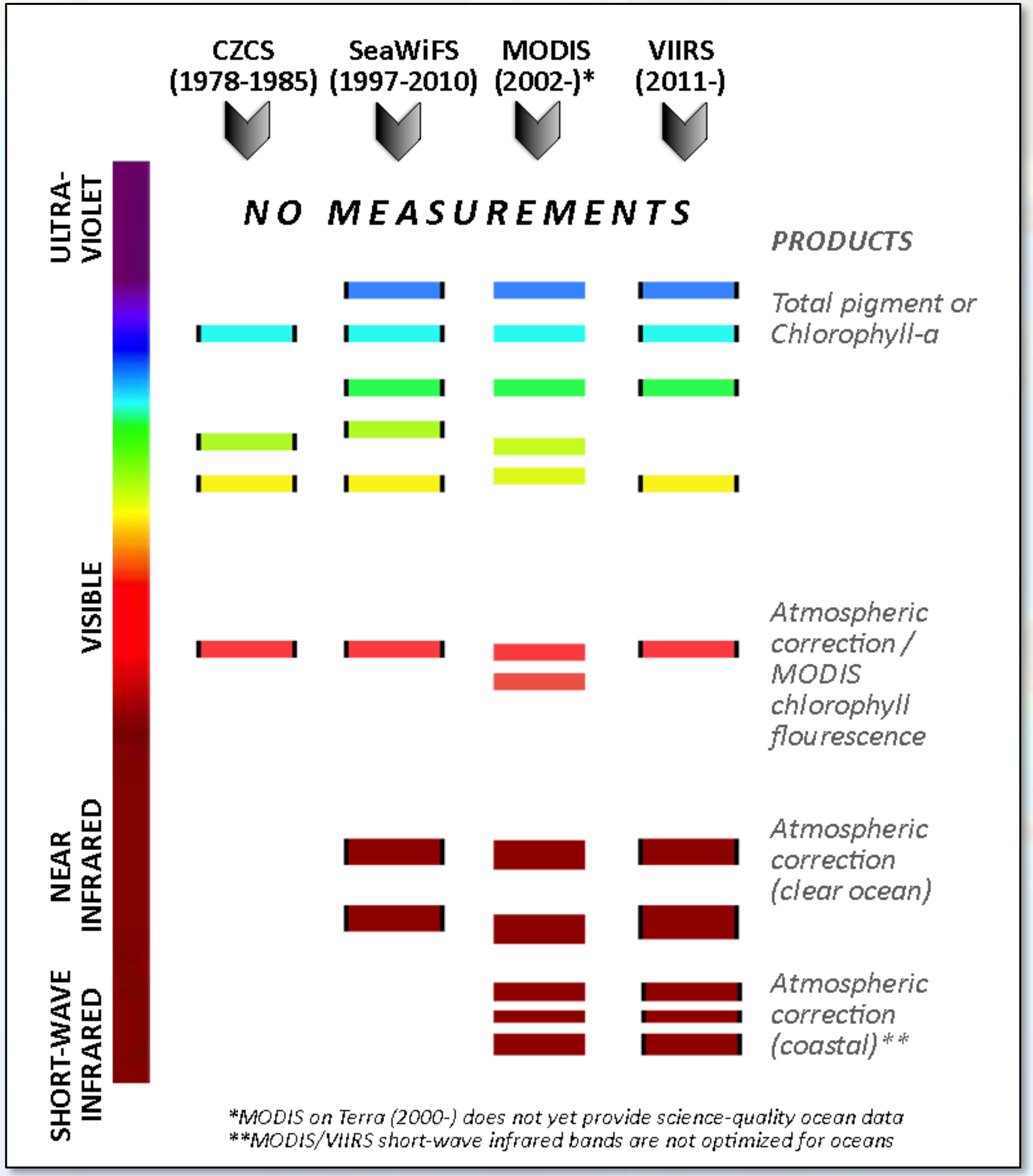
Satellites and sensors

The ocean color satellite sensors are designed to

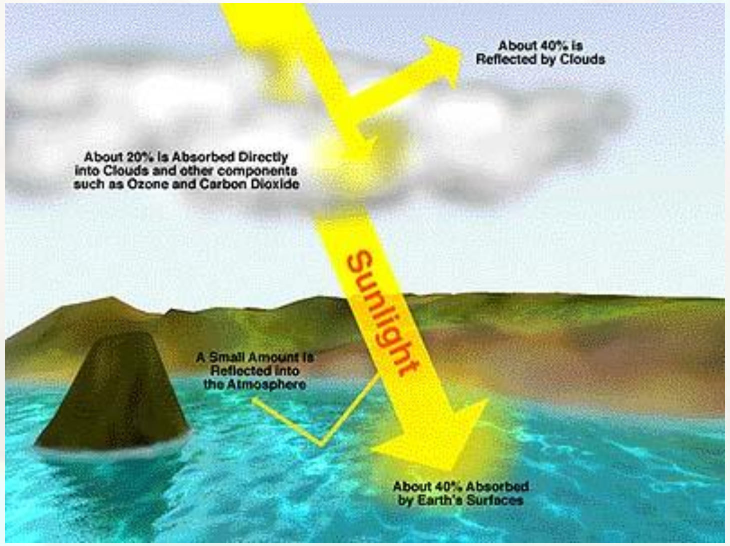
- Assess the concentrations of water constituents including
  - Chlorophyll-a
  - Suspended sediments
  - Colored dissolved organic matter (CDOM), etc.
- Provide data for atmospheric correction



The atmosphere is opaque to electromagnetic radiation at many wavelengths, and there are only certain wavelengths through which radiation may be fully or partly transmitted.



Ocean color – atmospheric correction



Sunlight backscattered by the atmosphere contributes 80-90% of the radiance measured by a satellite sensor at visible wavelengths. Such scattering arises from dust particles and other aerosols, and from molecular (Rayleigh) scattering.

The atmospheric contribution can be calculated and removed if additional measurements are made in the **red** and **near-infrare**d spectral regions (e.g., 670 and 750 nm). Since blue ocean water reflects very little radiation at these longer wavelengths, the radiance measured is due almost entirely to scattering by the atmosphere. Long-wavelength measurements, combined with the predictions of models of atmospheric properties, can therefore be used to remove the contribution to the signal from aerosol and molecular scattering.

Ocean color – atmospheric correction

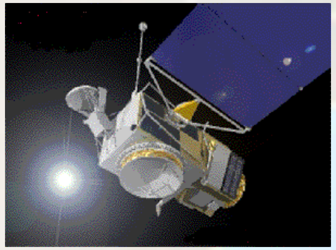
First step of atmospheric correction is cloud detection, based on a threshold in the near-infrared waveband.

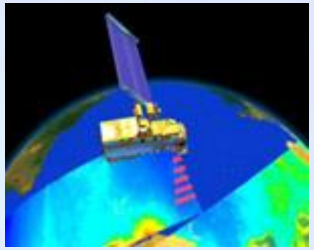
The algorithms of atmospheric correction estimate the contribution to the signal:

- Ozone
  - The distribution of ozone is determined by Total Ozone Mapping Spectrometer (TOMS) instrument on the Earth probe satellite and similar instrument on EOS-AURA satellite launched in 2004
- Sun glint
  - Is a function of sun angle and wind speed
- Foam
  - Also depends on wind speed and to less extent on sun angle
- Rayleigh path radiances (i.e., scattering by air molecules)
- Aerosol path radiances (most complex part of the algorithm)
  - Based on “black pixel” assumption
- Diffuse transmittance
  - Estimates signal contamination from land and ice

Satellites and sensors collecting ocean color data

Scanner		Spacecraft	Period
CZCS	Coastal Zone Color Scanner	Nimbus-7	1978 - 1986
SeaWiFS	Sea-viewing Wide-Field-of-view Sensor	OrbView-2 (SeaStar)	1997 - 2010
Terra-MODIS	Moderate Resolution Imaging Spectroradiometer	Terra	1999 - present
Aqua-MODIS	Moderate Resolution Imaging Spectroradiometer	Aqua	2002 - present
MERIS	Medium Resolution Imaging Spectrometer	ENVISAT	2002 - 2012
SNPP-VIIRS	Visible and Infrared Imager/Radiometer Suite	Suomi National Polar-orbiting Partnership (SNPP)	2011 - present
NOAA20-VIIRS	Visible and Infrared Imager/Radiometer Suite	Joint Polar Satellite System (JPSS) (NOAA-20)	2017 - present
S3A-OLCI	Ocean and Land Colour Instrument	Sentinel-3A	2016 - present
S3B-OLCI	Ocean and Land Colour Instrument	Sentinel-3B	2018 - present

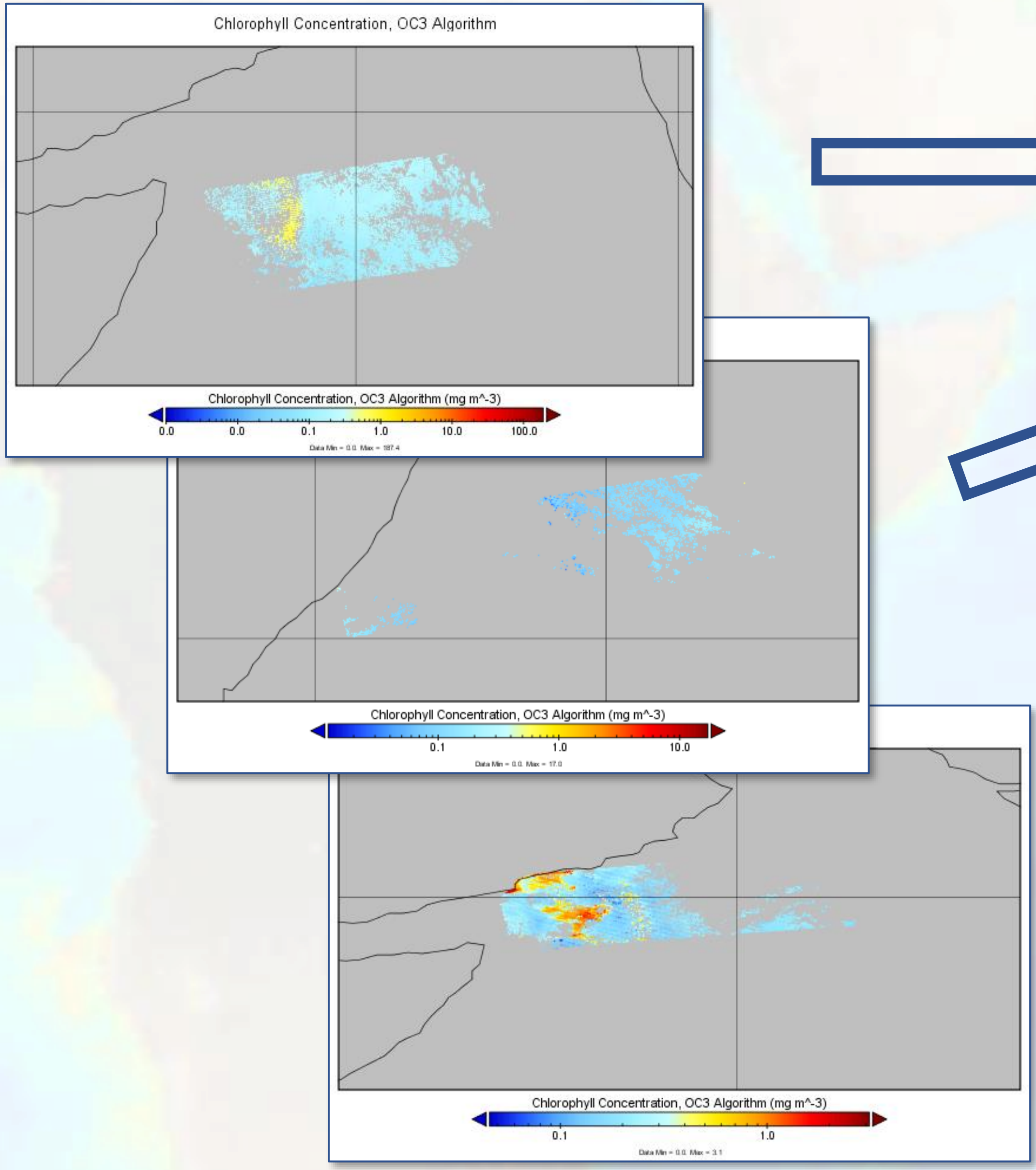





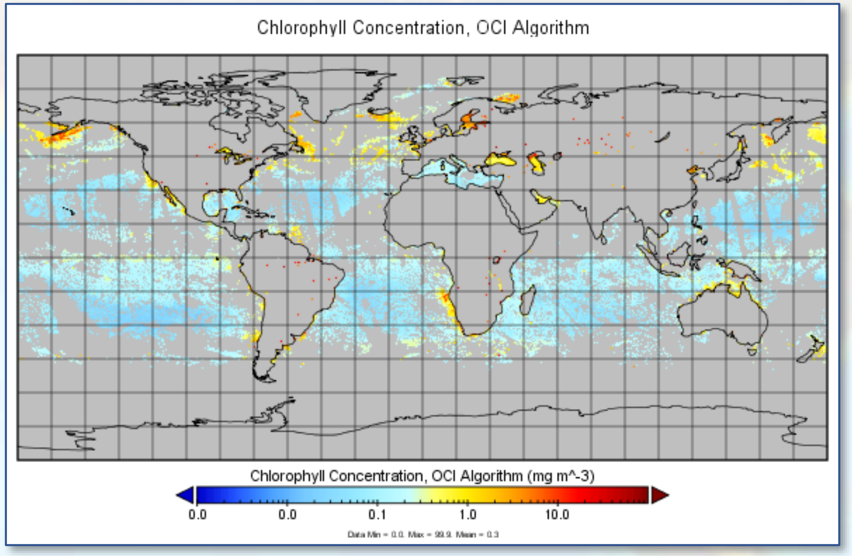
The levels of satellite data processing

Level 0	Raw data received from satellite, in standard binary form
Level 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters
Level 1B	Image data in sensor coordinates, containing individual calibrated channels
Level 2	Derived oceanic variable, atmospherically corrected and geolocated, but presented in **sensor coordinates**
Level 3	Composite images of derived ocean variable **resampled onto standard map** base and averaged over a certain time period (may contain gaps)
Level 4	Image representing an ocean variable averaged within each grid cell as a result of data analysis, e.g., **modeling or filling the gaps**

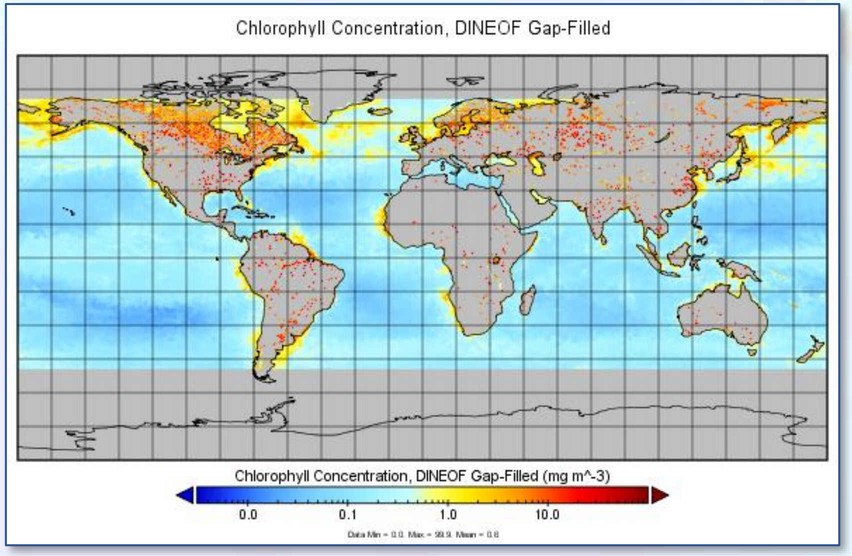
Level 2



Level 3

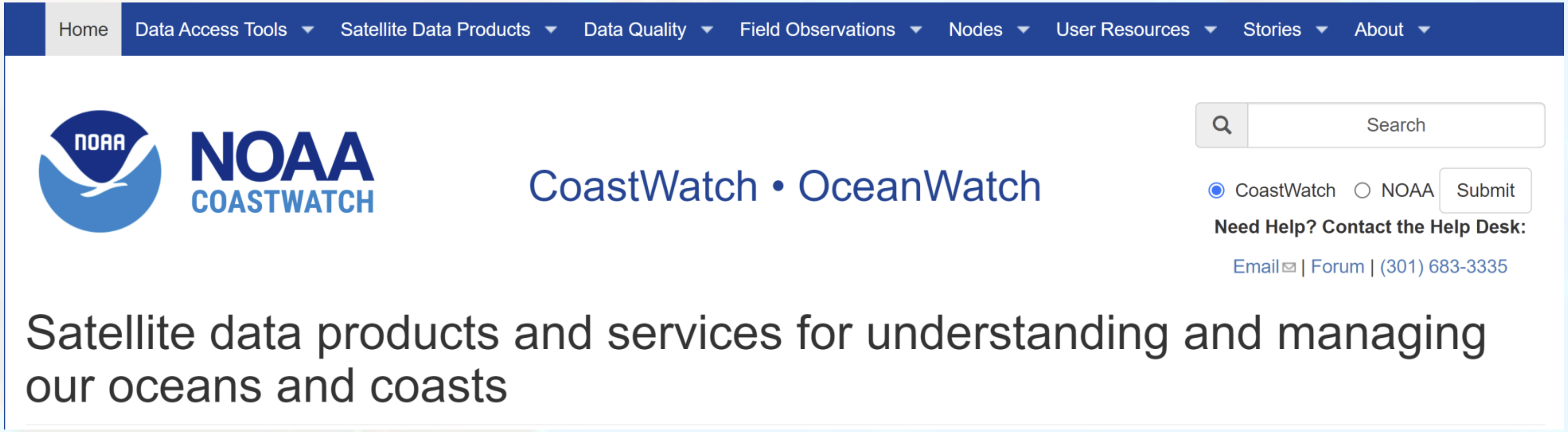


Level 4

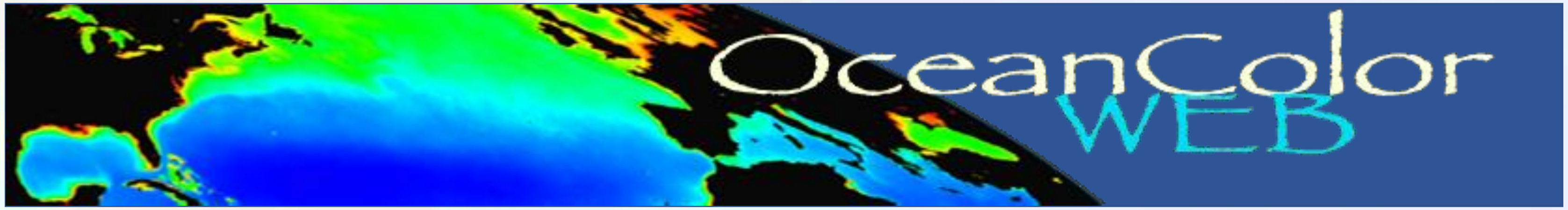


Available sources of ocean color data :

https://coastwatch.noaa.gov/cw/index.html - NOAA



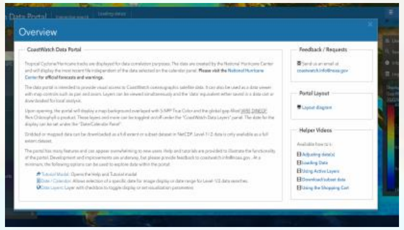
https://oceancolor.gsfc.nasa.gov/ - NASA



https://coastwatch.noaa.gov/cw/index.html - NOAA

Start CoastWatch click Data Portal

Remove "Overview" window



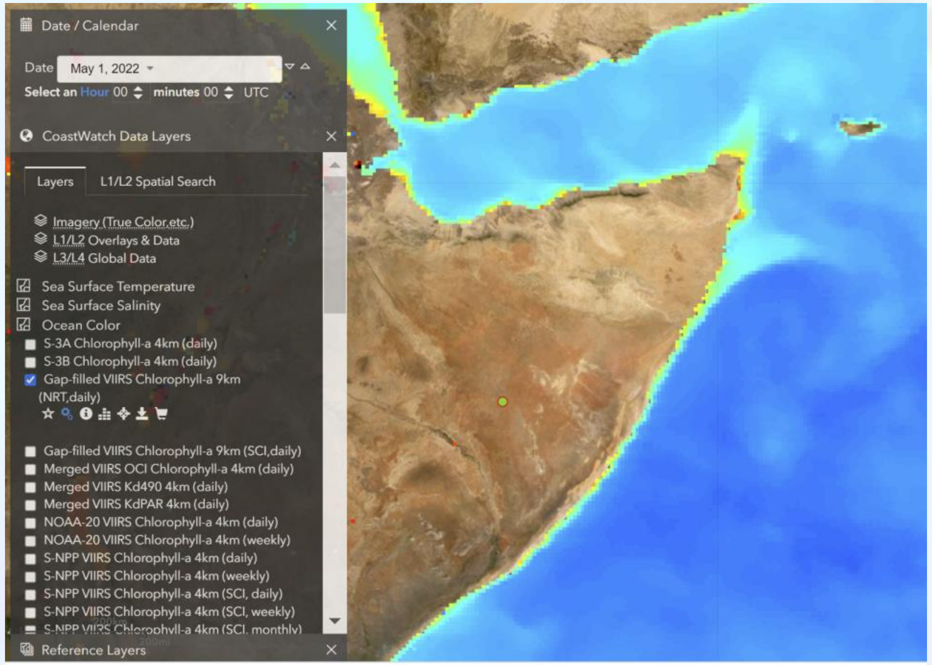
Zoom to the area of interest

Getting Level-3/4 (gridded) data:

Select the date

Expand L3/L4 Global Data

Expand Ocean Color and select the product



Click "Download" icon and save NetCDF file https://coastwatch.noaa.gov/cw/index.html - NOAA

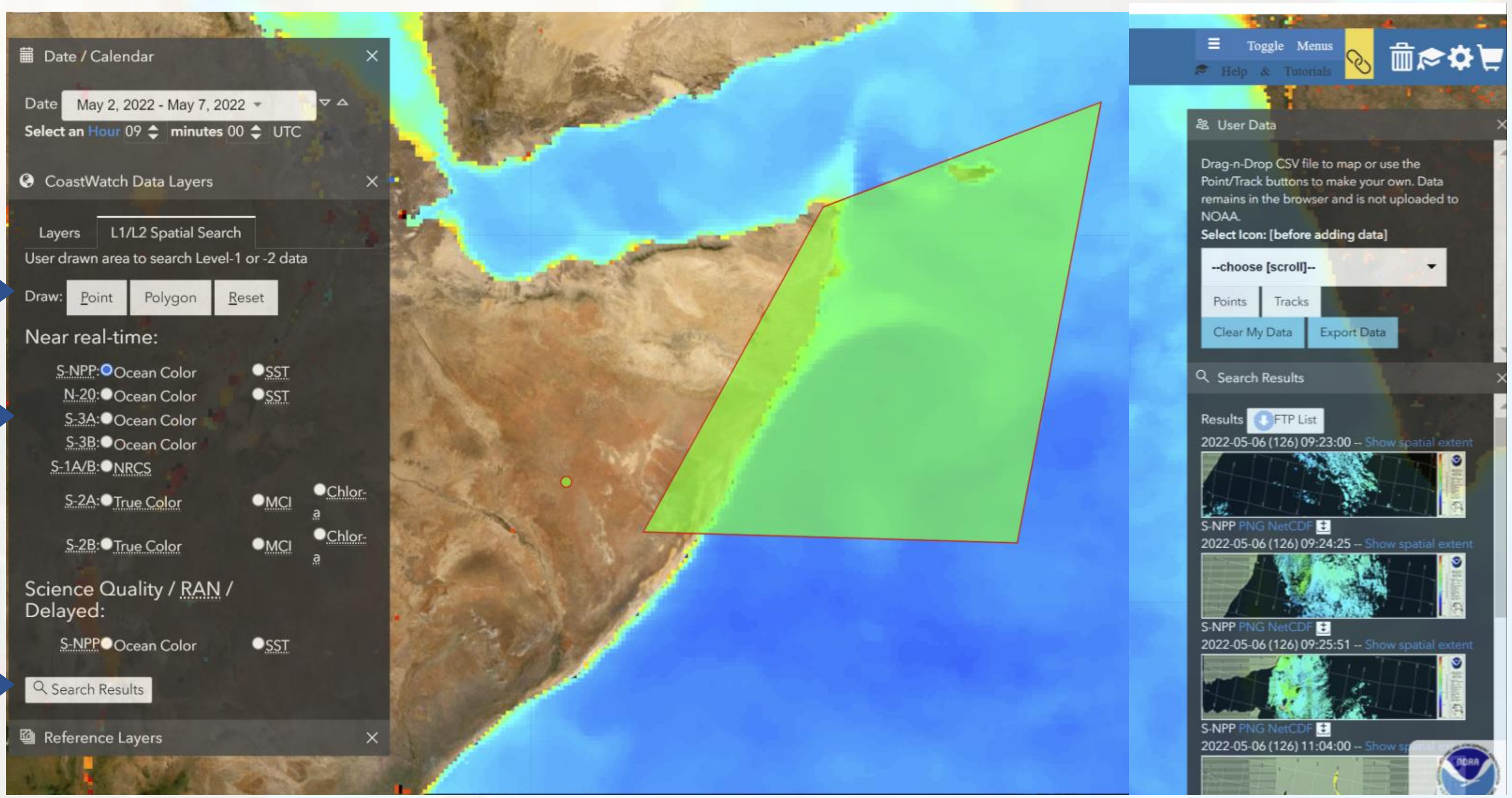
Getting Level-1/2 (swath) data:

Select dates

Click Polygon and draw

Select the product

Click Search Results

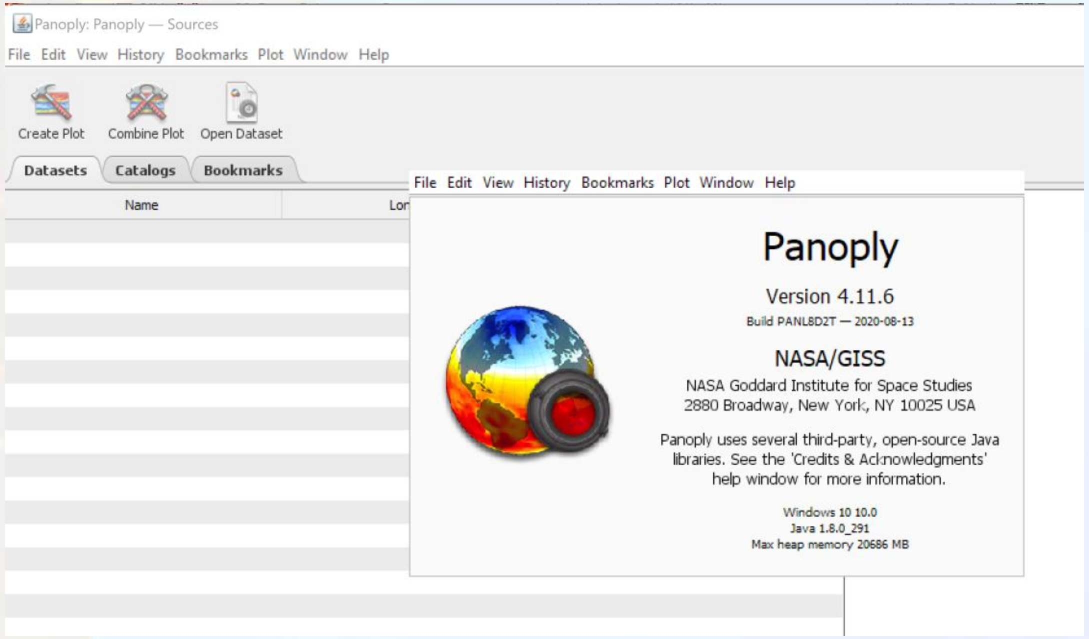


Browse the results and click PNG or NetCDF links

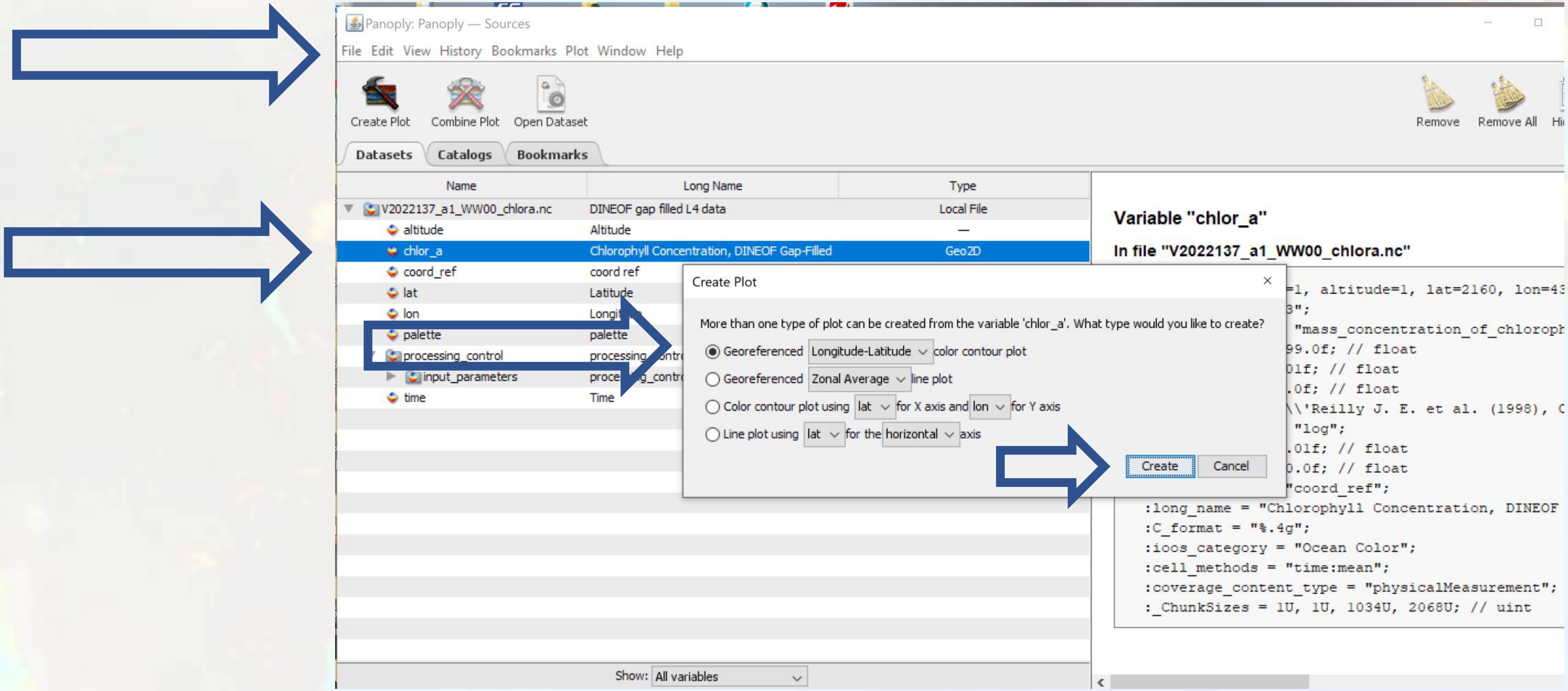
Software for data visualization

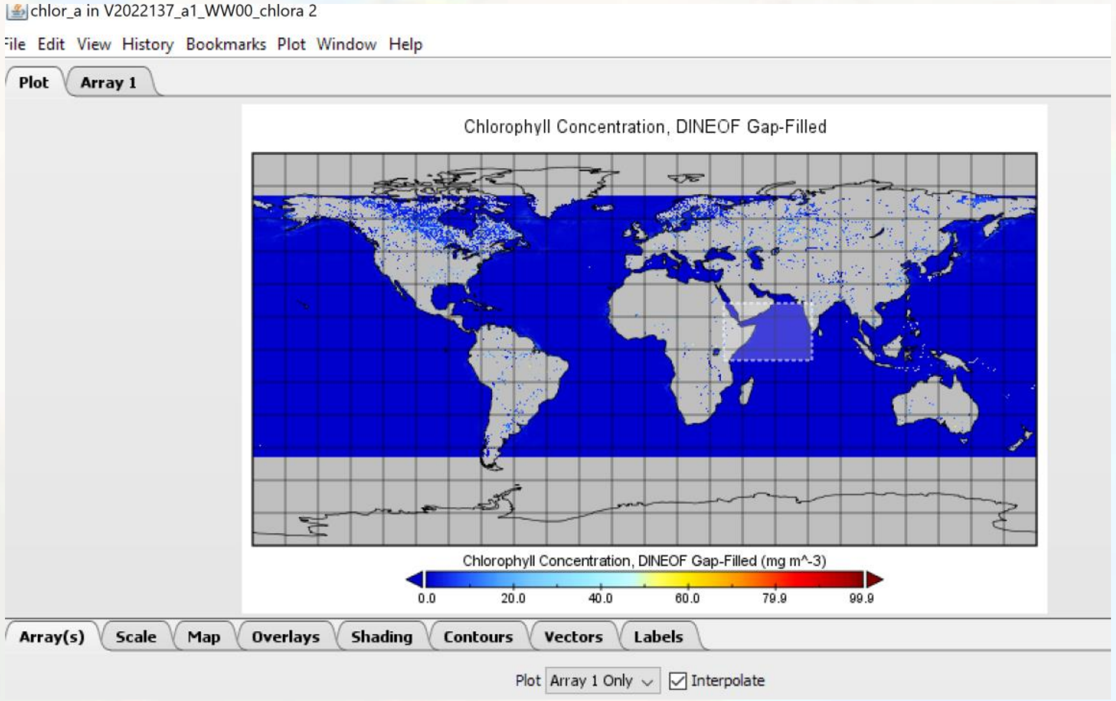
https://www.giss.nasa.gov/tools/panoply/

Panoply requires that your computer have **Java 9** (or later version) installed.

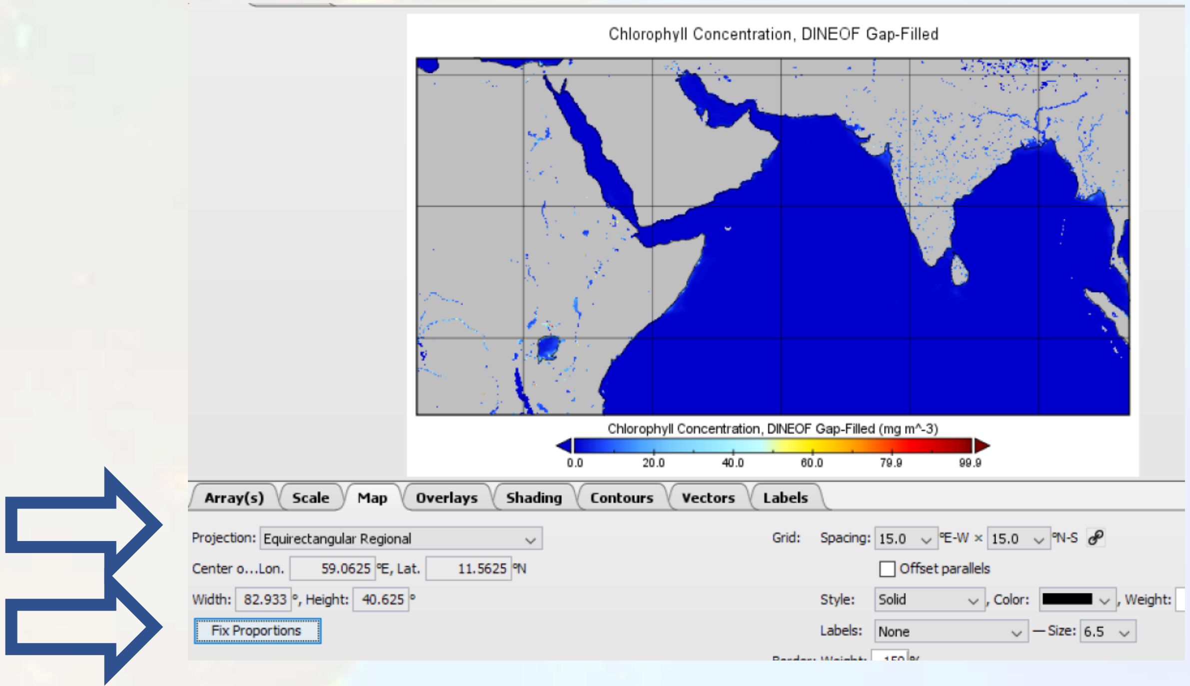


- **Open Level 3 file**
- **Select the variable (chlor_a)**
- **Right-click and select ‘Create Extra Small Plot’**
- **Select ‘Georeferenced Longitude-Latitude color contour plot’**
- **Click Create**

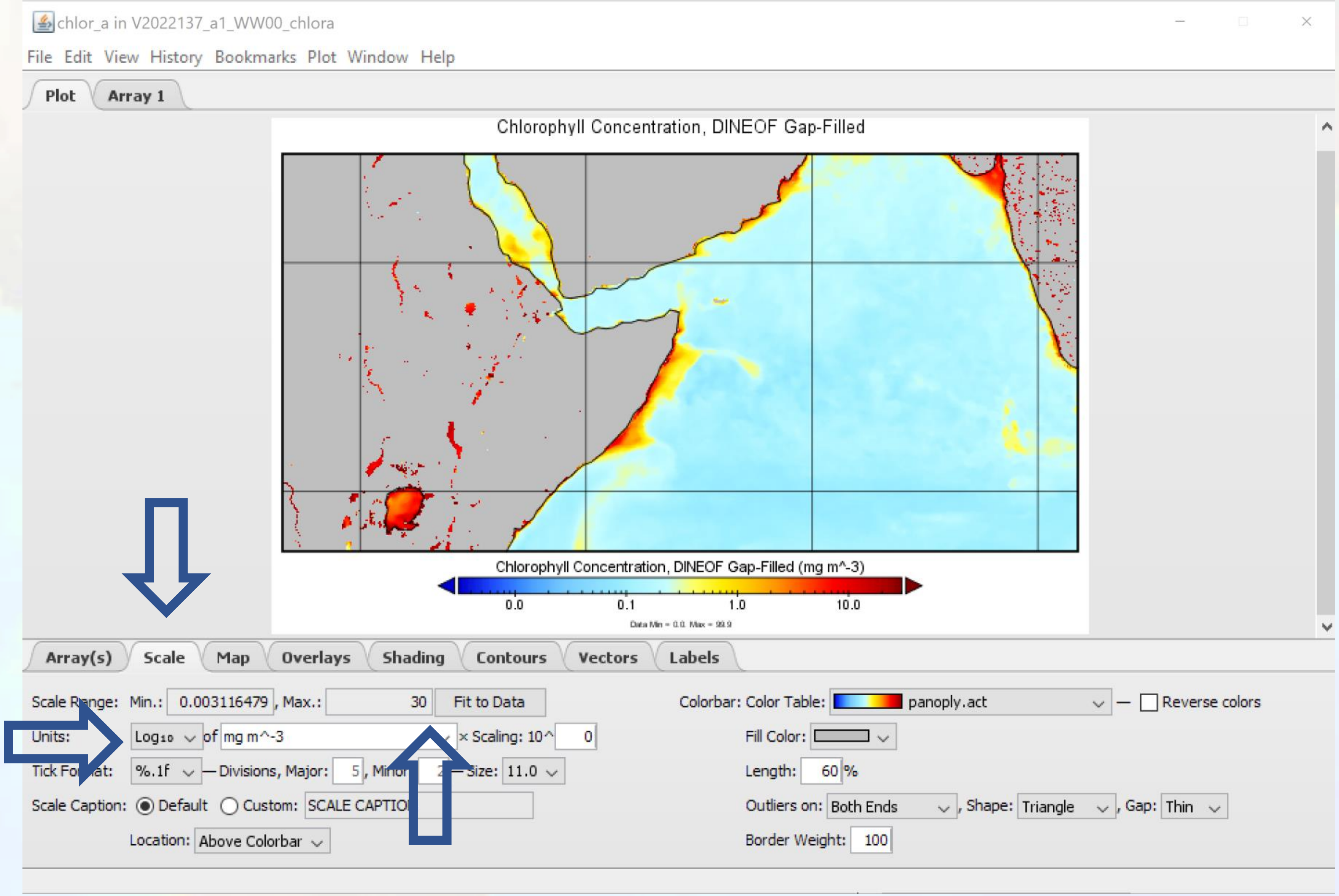




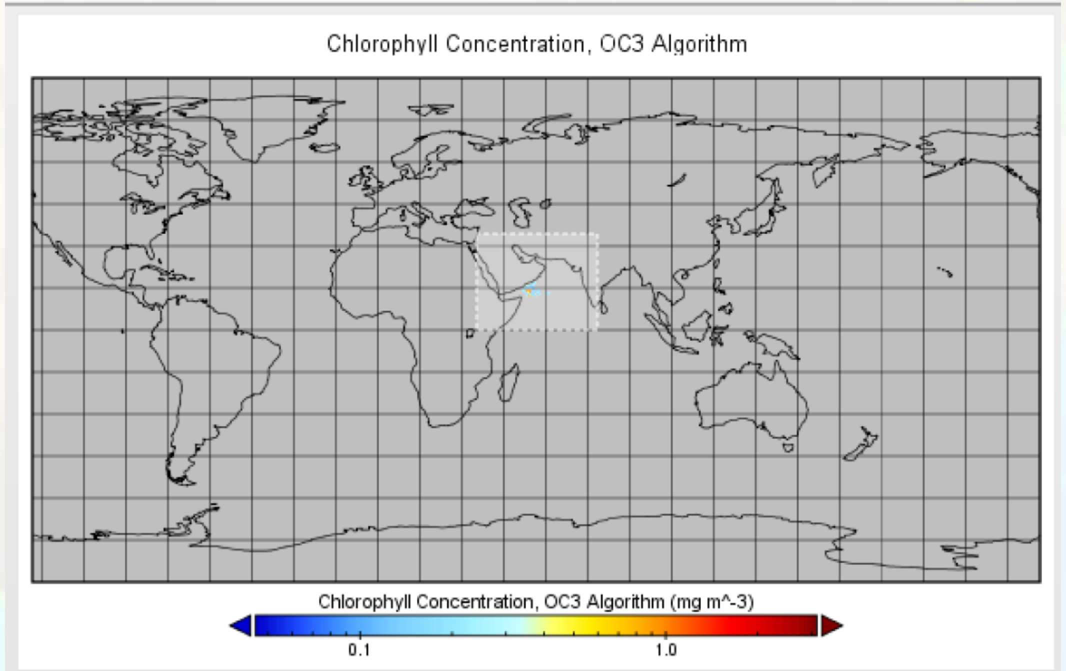
Press Ctrl and draw rectangle

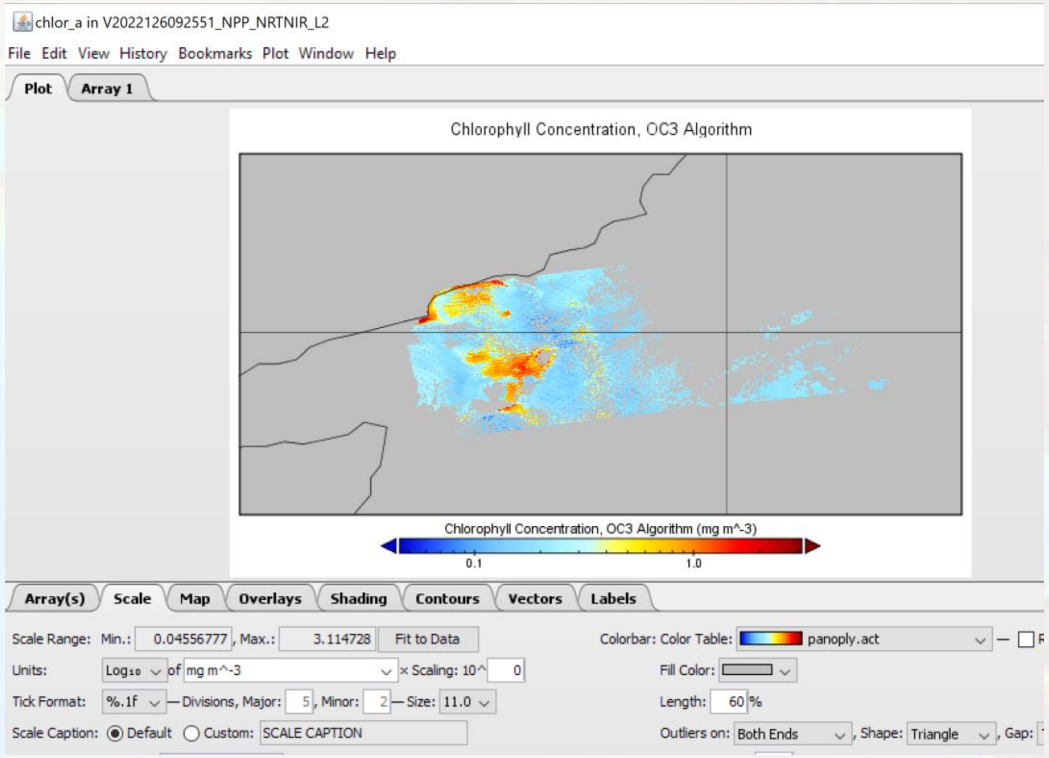


- Select ‘Map’ tab
- Select ‘Equirectangular Regional’ projection
- Click ‘Fix proportions’



- **Open ‘Scale’ tab**
- **At ‘Units’, select ‘Log10’**
- **Correct ‘Max’**
- **Click ‘File’ and ‘Save Image As’**





- **Open first Level 2 datafile**
- **Plot the satellite swath**
- **Open second Level 2 file**
- **Click ‘Combine Plots’ …**
- **In the tab ‘Array(s) select “Plot – Merge”…**

https://oceancolor.gsfc.nasa.gov/ - NASA

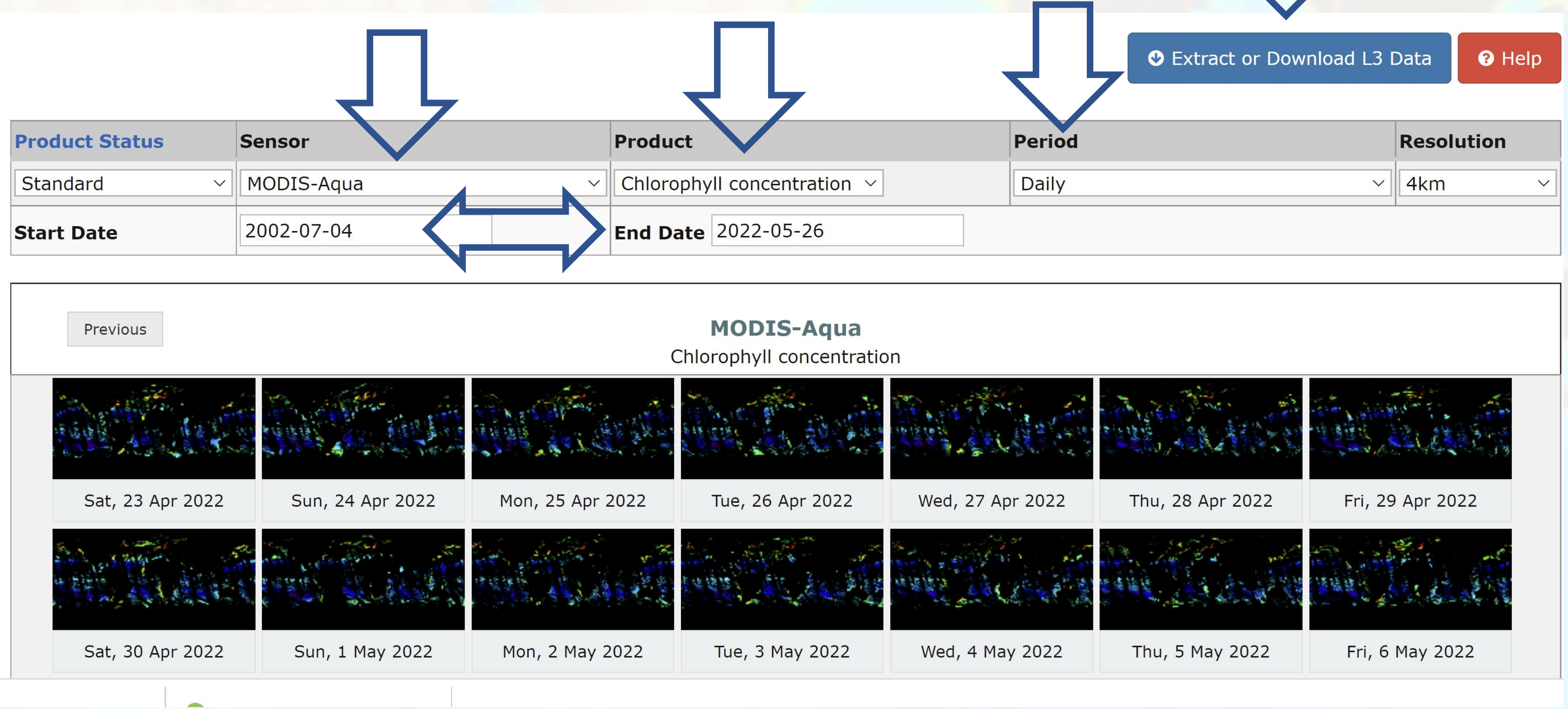
Read about satellites and sensors

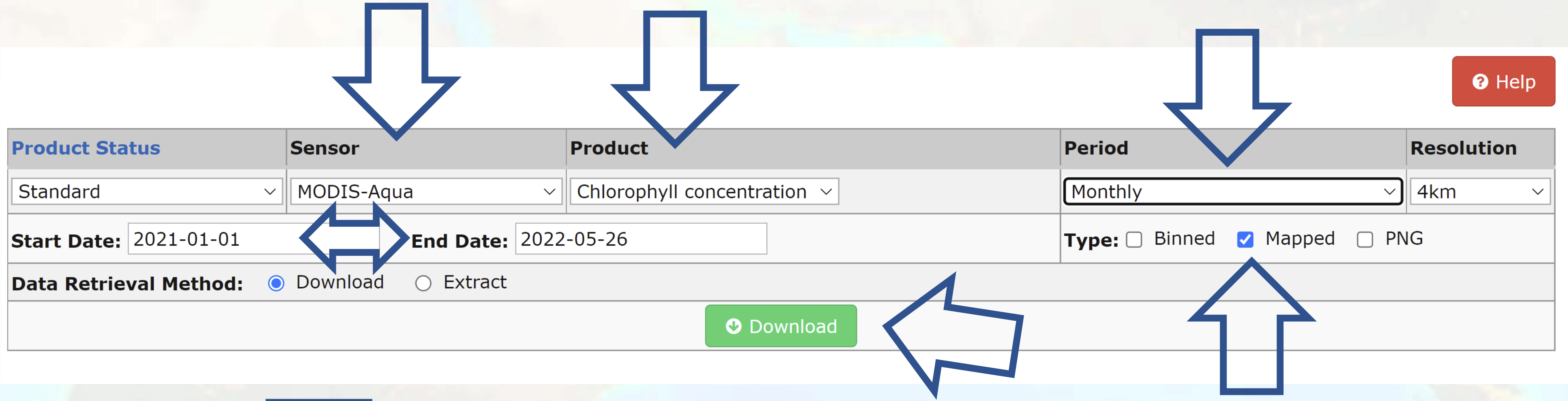
https://oceancolor.gsfc.nasa.gov/ - NASA

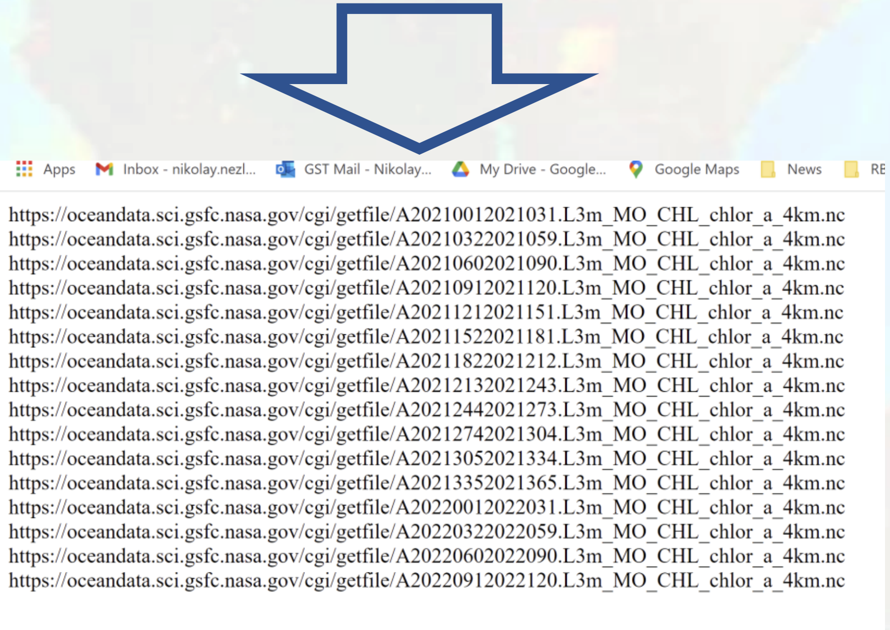
Get Level 3 data

https://oceancolor.gsfc.nasa.gov/ - NASA

Level 3





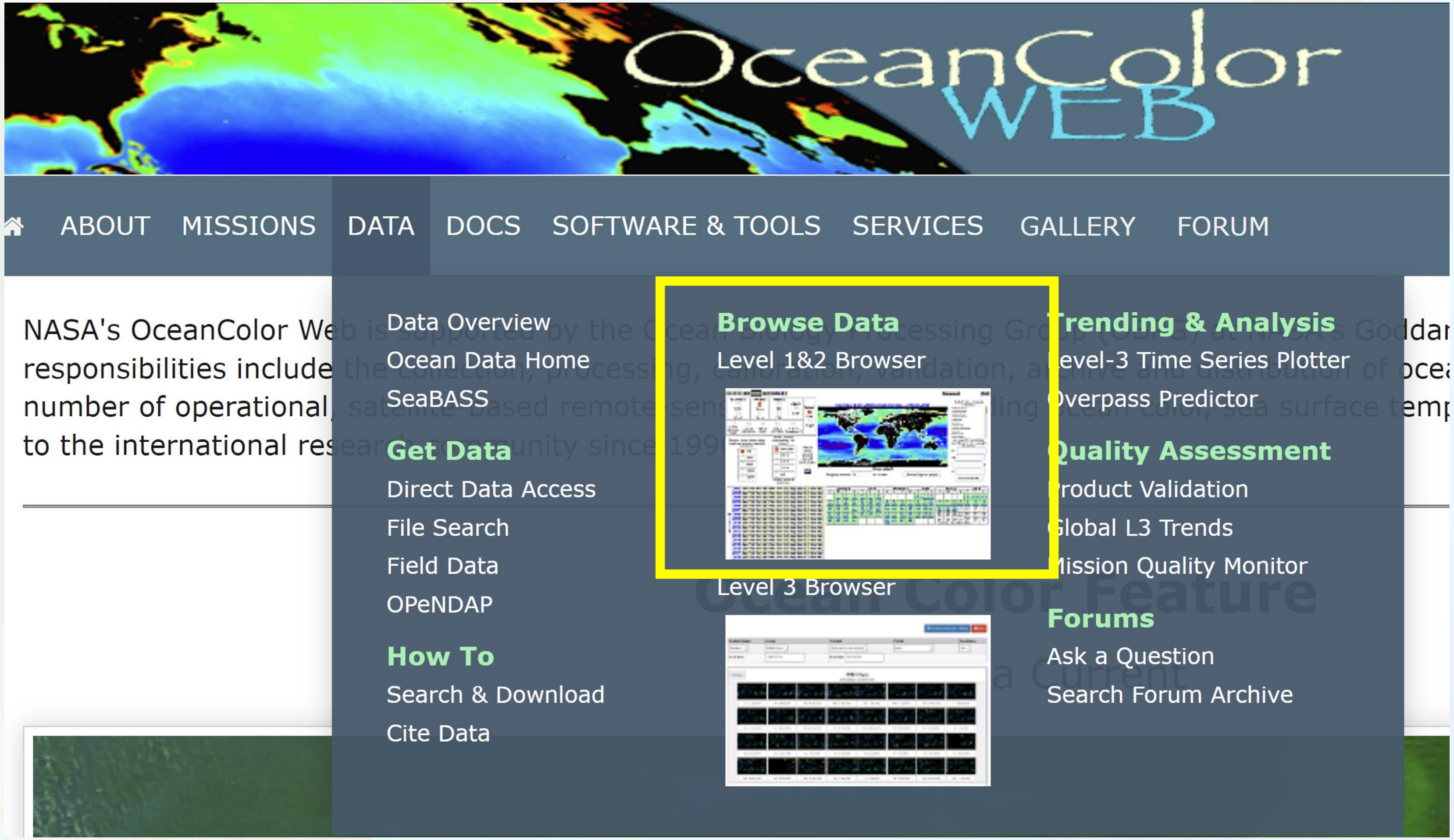


Put the links one by one to your browser's address bar and download the NetCDF files.

Use Panoply or other soft.

https://oceancolor.gsfc.nasa.gov/ - NASA

Get Level 2 data



Questions?

Nikolay Nezlin
nikolay.nezlin@noaa.gov