

**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.

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

Advantage of remote sensing over traditional methods:

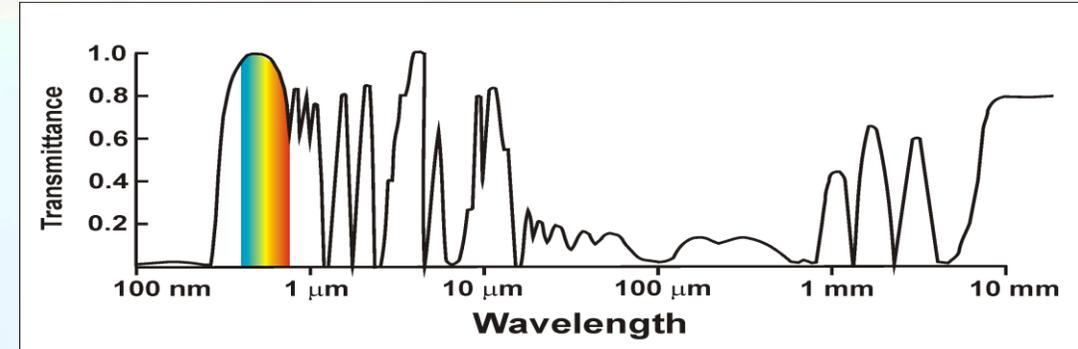
- **Synoptic view**, because satellites collect huge amount of information much exceeding the data collected by contact oceanographic observations;
- Satellite observations cover wide **areas** of the World Ocean **hardly accessible** for field observations.

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:

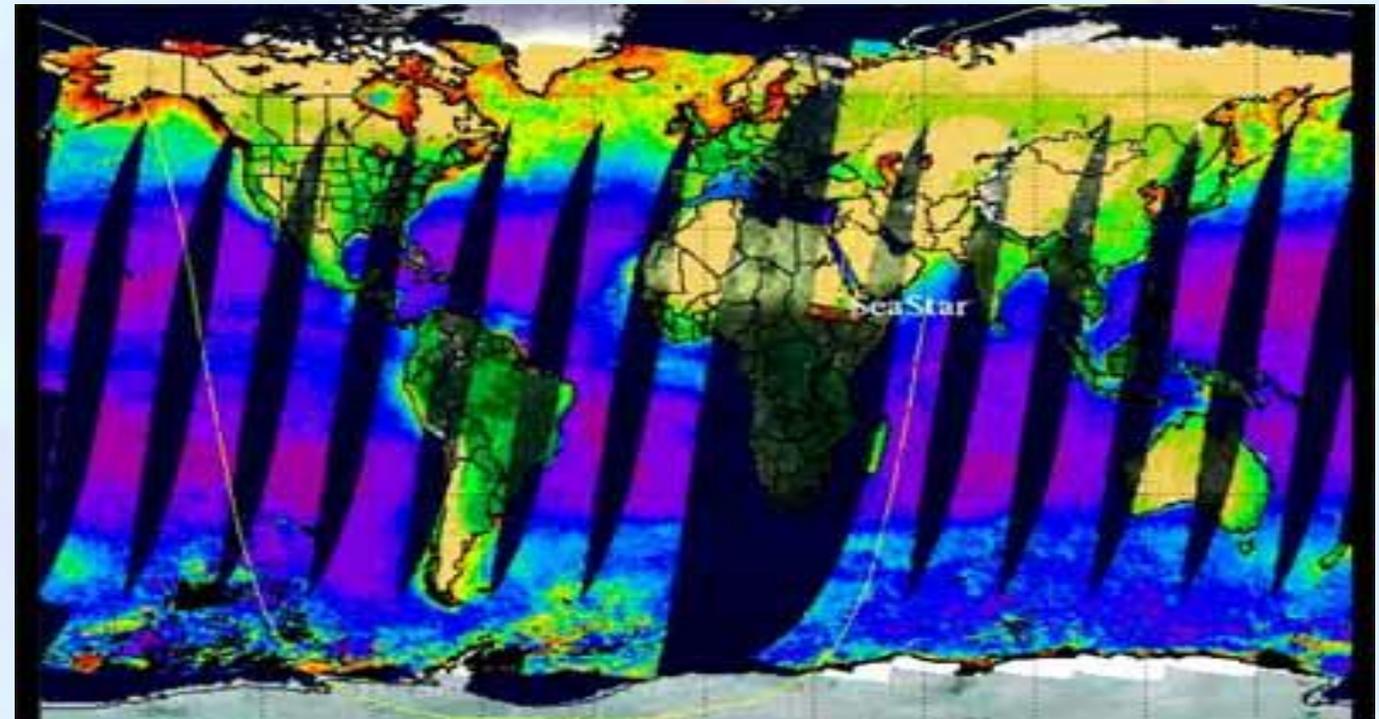
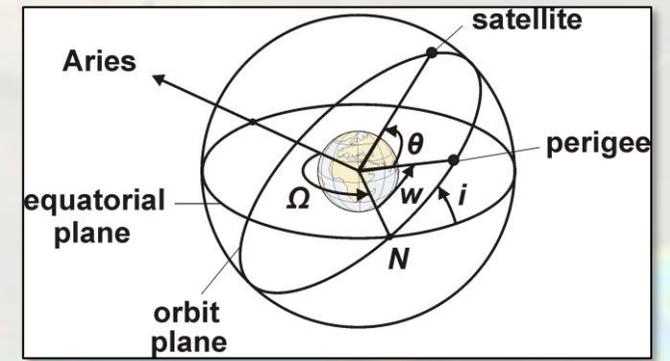
- **sunlight** transmitted through the atmosphere
- dissolved and suspended **water constituents**



Satellites and sensors

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

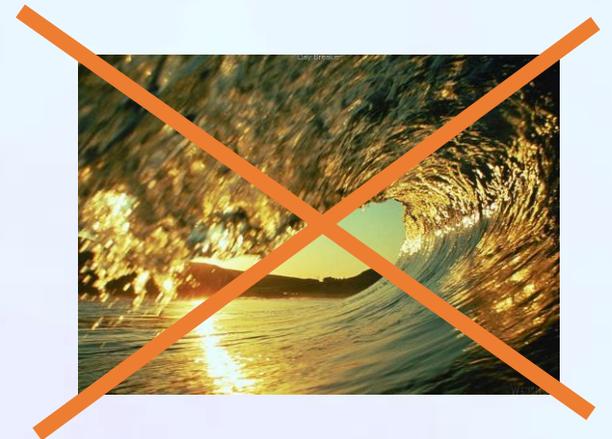
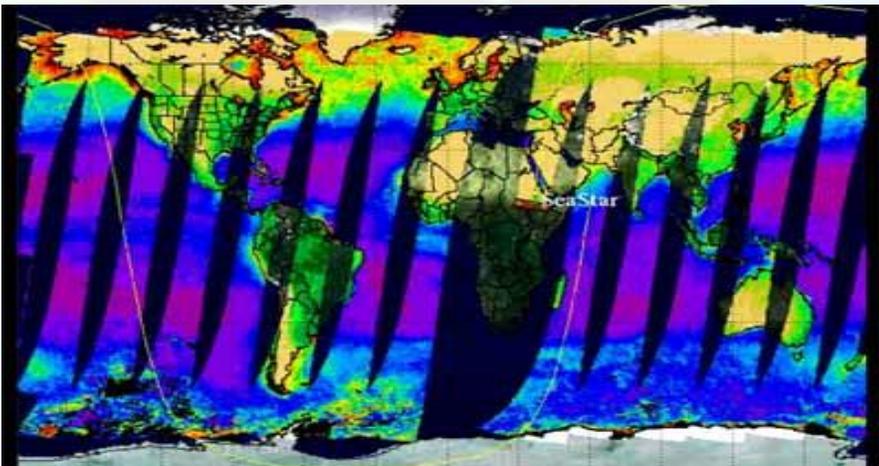
Near-polar satellites have orbit inclination $\sim 90^\circ$. Usually these satellites have altitude between 500 and 2,000 km and a period of about 1 to 2 hours. As the Earth rotates under this orbit the satellite effectively scans from north to south over one face and south to north across other face 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

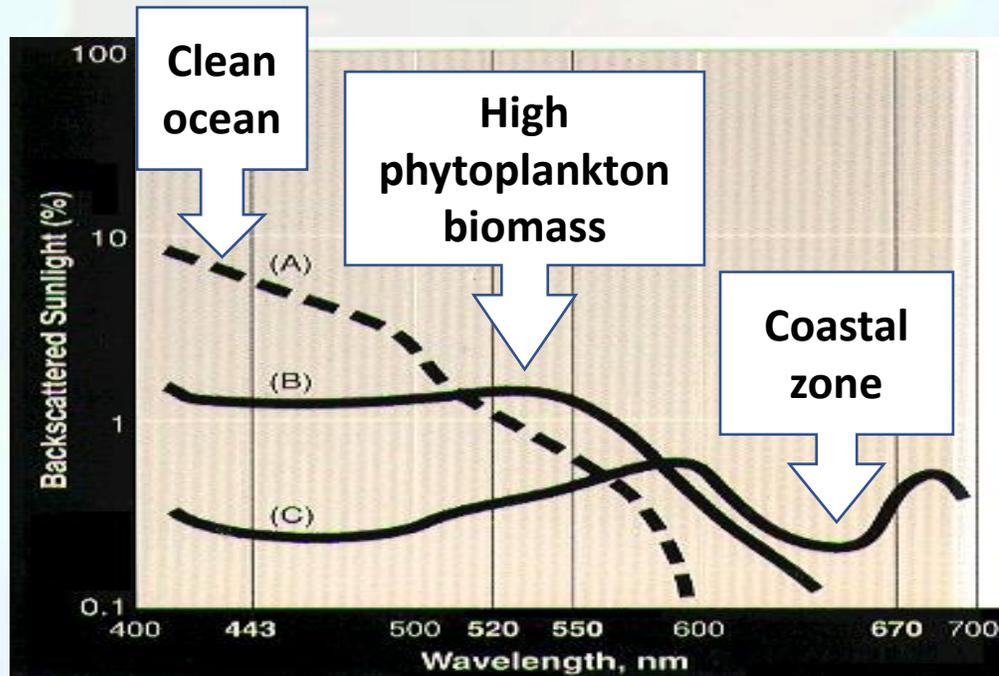
The sources of color change in seawater include:

- 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.

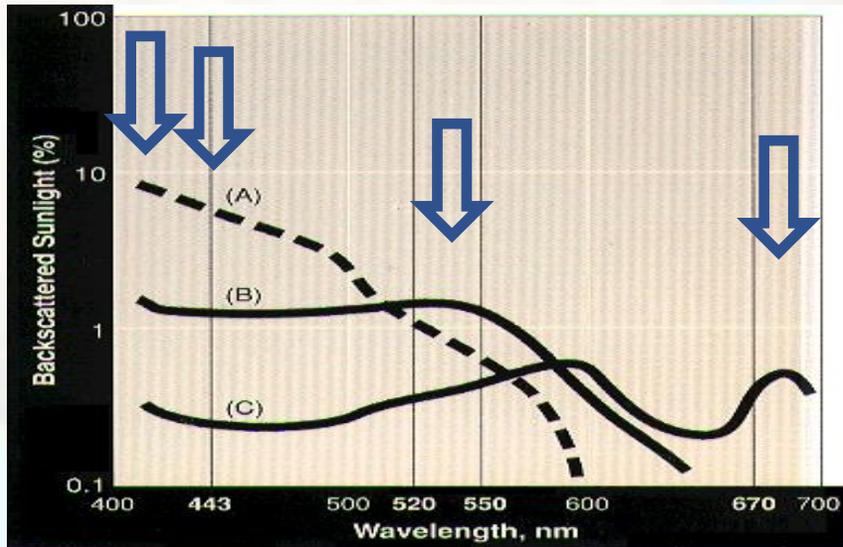


Clean ocean water absorbs red light and transmits and scatters the light of short wavelength.

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 $R(\lambda)$ depends on backscattering $b(\lambda)$ and absorption $a(\lambda)$ 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.

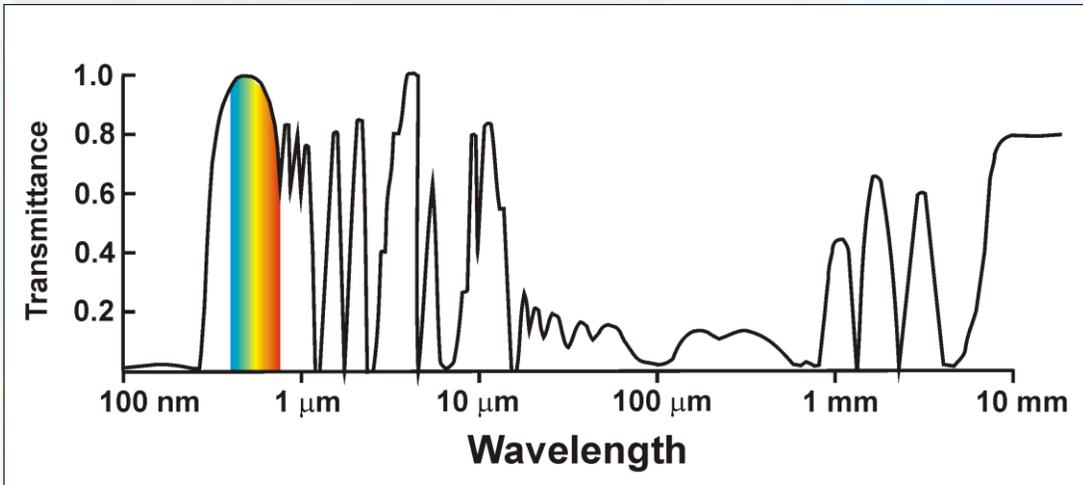
Different wavelengths are important to observe CDOM, chlorophyll and fluorescence.

- 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.

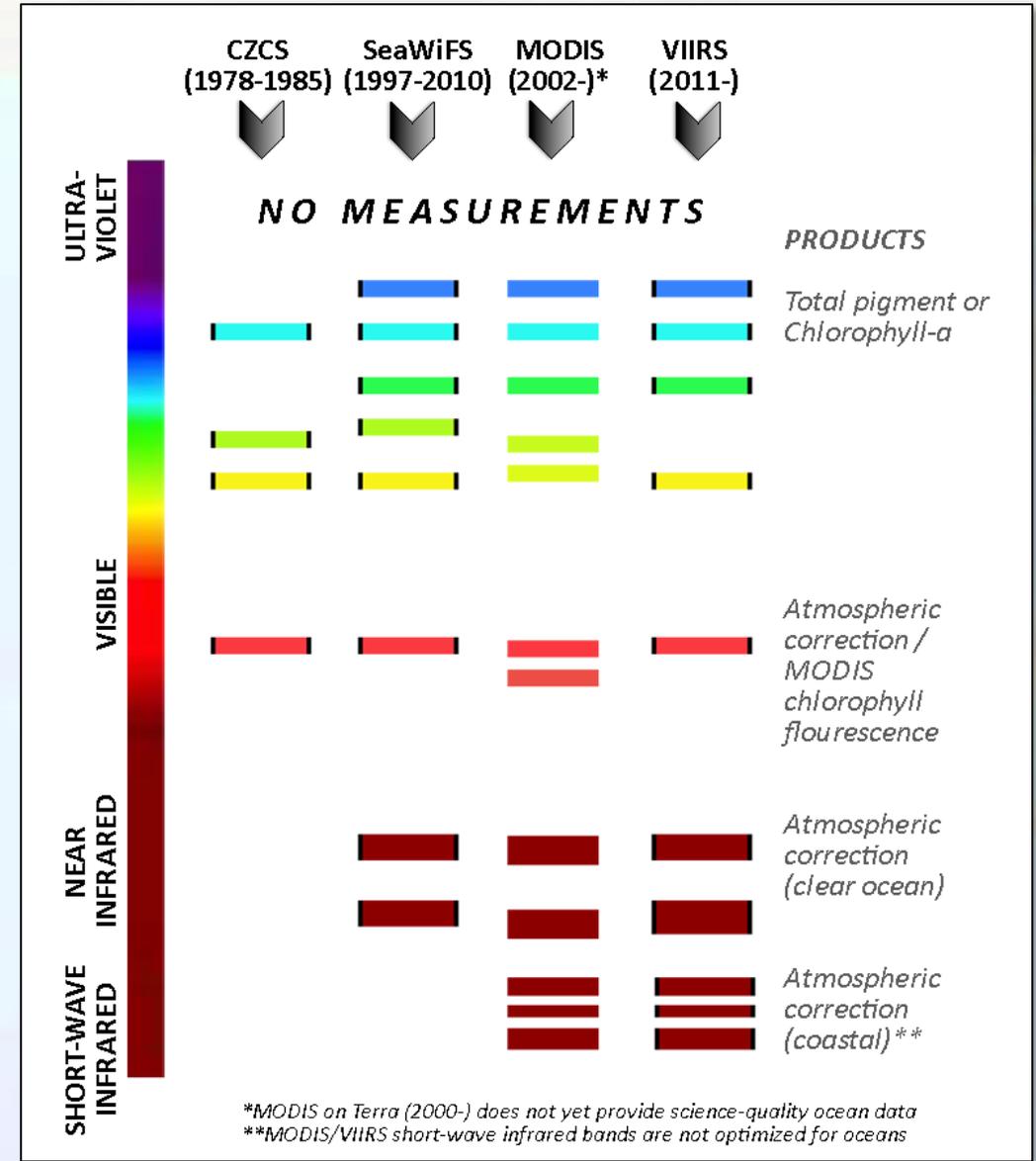
Satellites and sensors

The ocean color satellite sensors are designed to

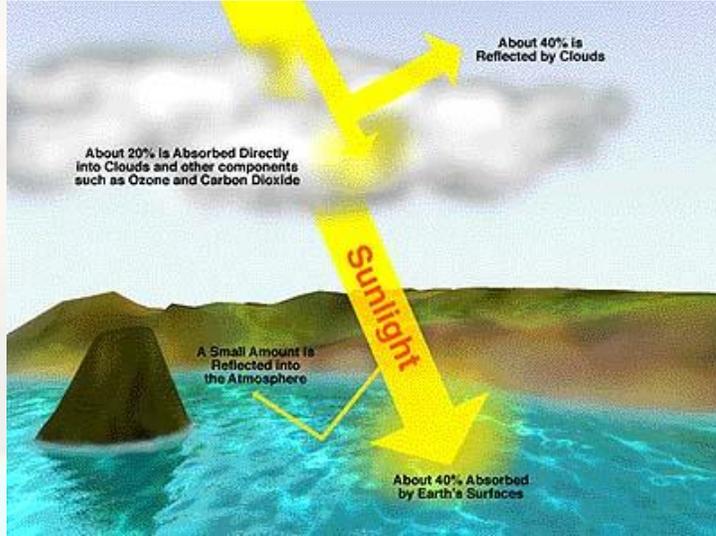
- Assess the concentrations of water constituents including
 - Chlorophyll-a
 - Suspended sediments
 - Colored dissolved organic matter (CDOM), etc.
- Provide data for atmospheric correction



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-infrared** 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

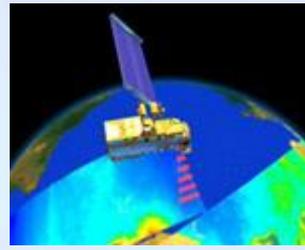
First step of atmospheric correction is cloud detection, based on a threshold in the near-infrared waveband.

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

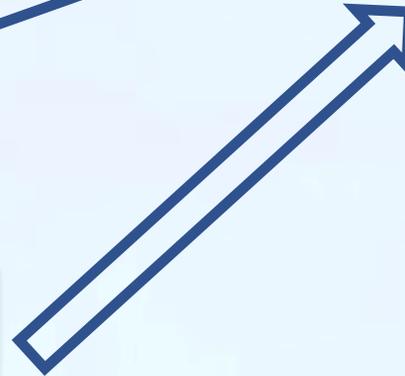
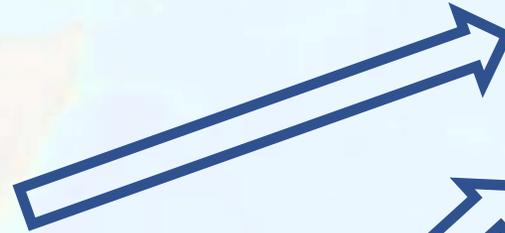
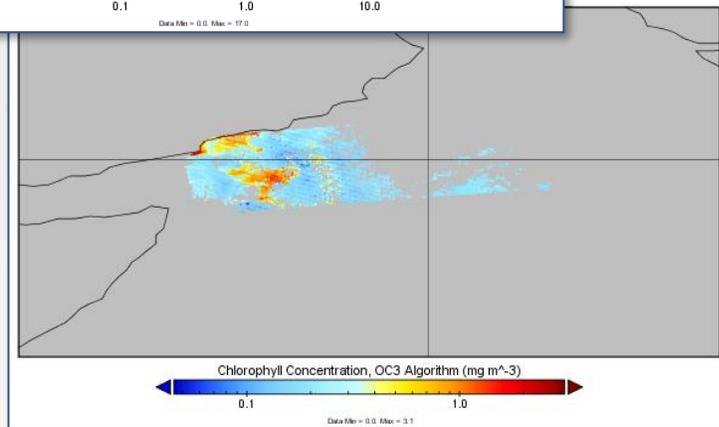
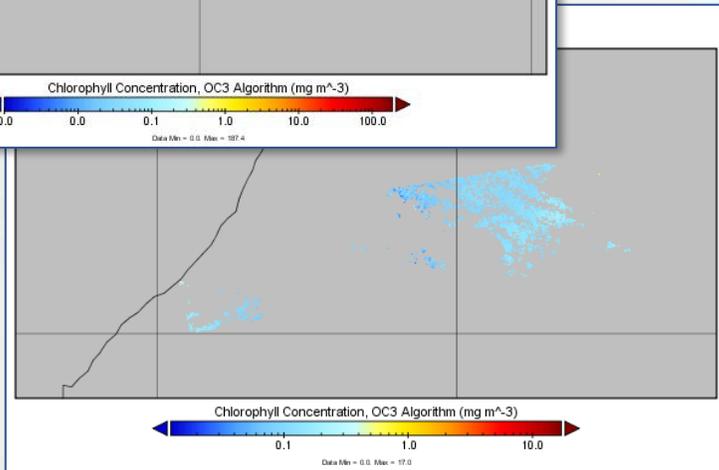
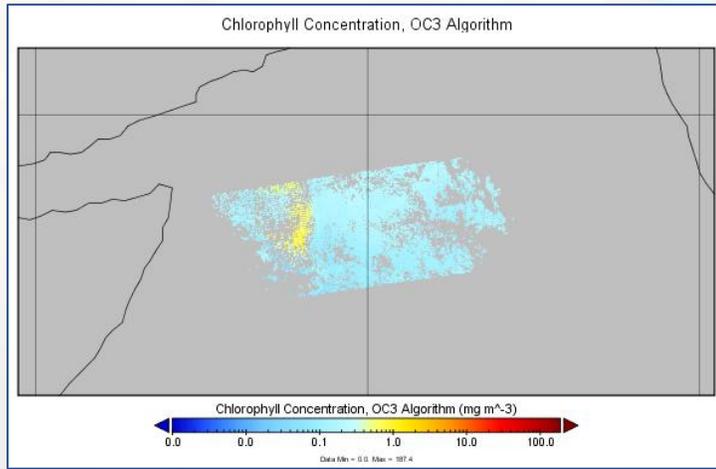
	<u>Scanner</u>	<u>Spacecraft</u>	<u>Period</u>
CZCS	Coastal Zone Color Scanner	Nimbus-7	1978 - 1986
SeaWiFS	Sea-viewing Wide-Field-of-view Sensor	OrbView-2 (SeaStar)	1997 - 2010
Terra-MODIS	Moderate Resolution Imaging Spectroradiometer	Terra	1999 - present
Aqua-MODIS	Moderate Resolution Imaging Spectroradiometer	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



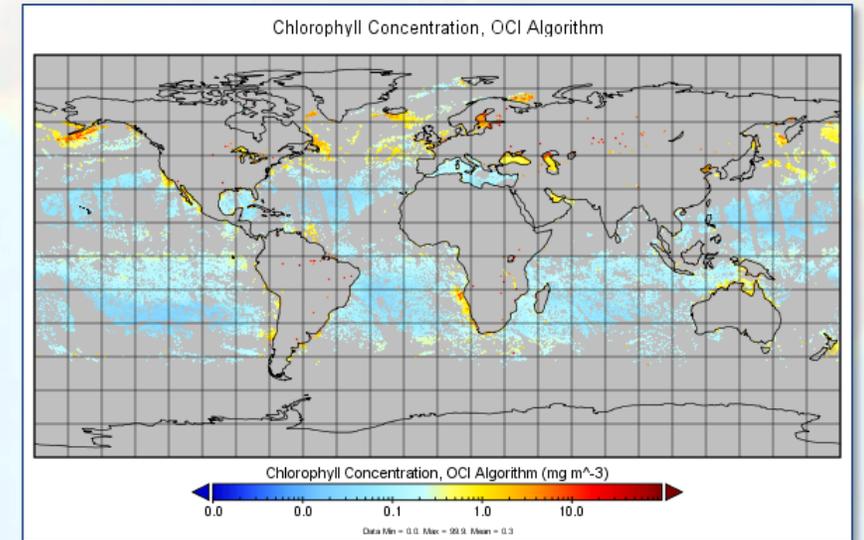
The levels of satellite data processing

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

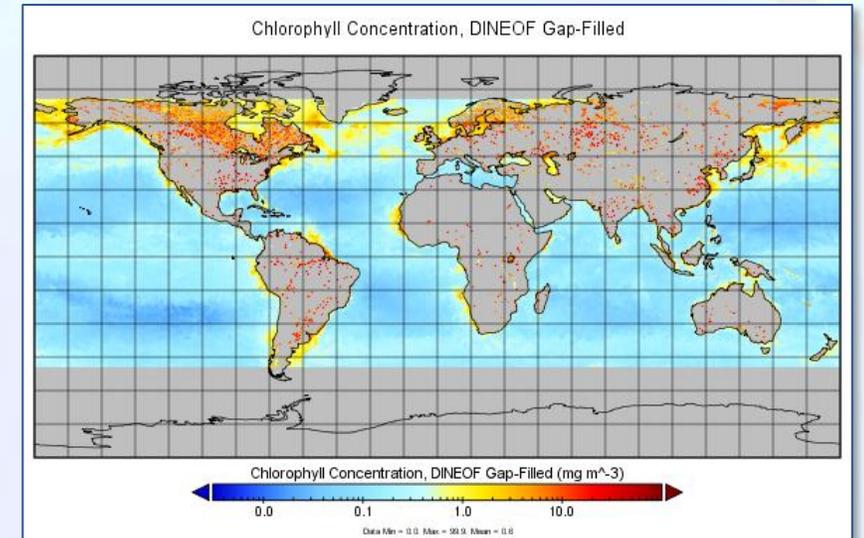
Level 2



Level 3

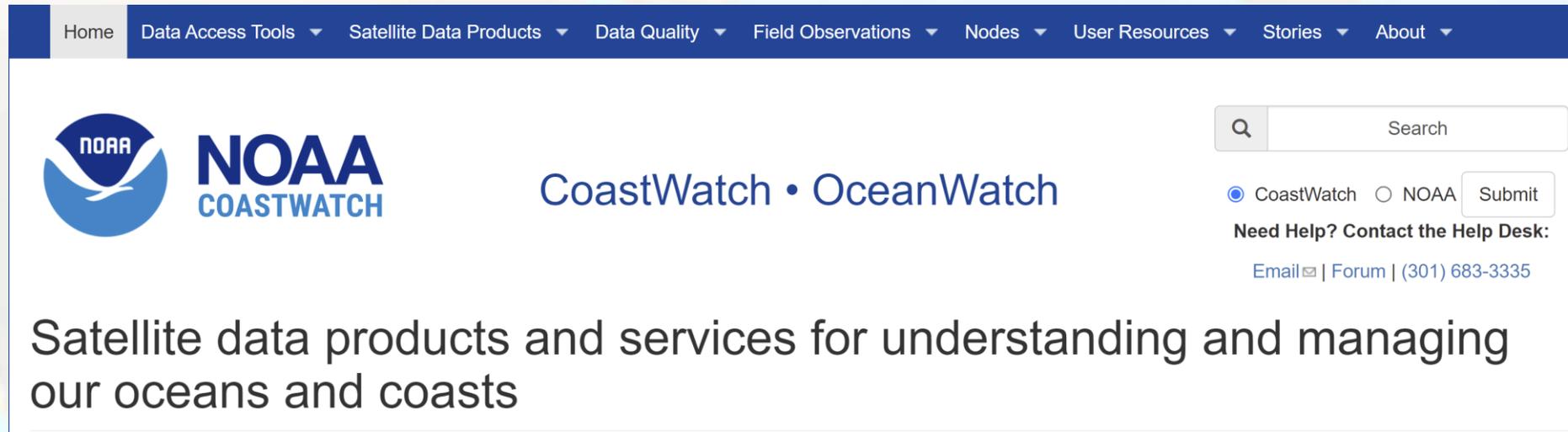


Level 4



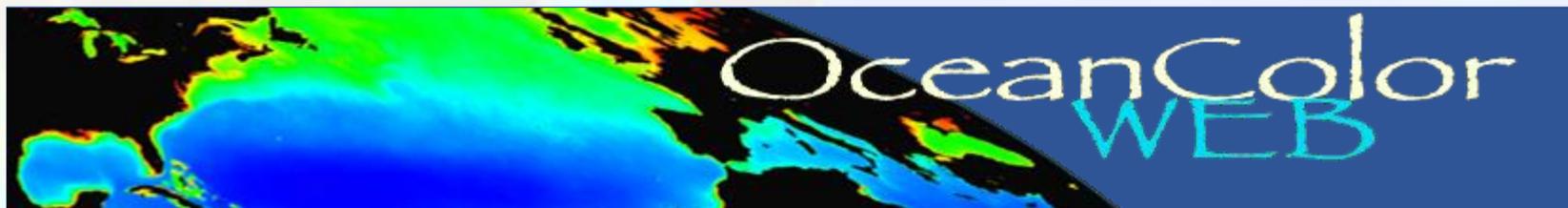
Available sources of ocean color data :

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

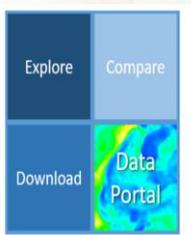


The screenshot shows the NOAA CoastWatch website. At the top is a dark blue navigation bar with white text for 'Home', 'Data Access Tools', 'Satellite Data Products', 'Data Quality', 'Field Observations', 'Nodes', 'User Resources', 'Stories', and 'About'. Below the navigation bar is the NOAA logo and the text 'NOAA COASTWATCH'. To the right of the logo is the text 'CoastWatch • OceanWatch'. Further right is a search bar with a magnifying glass icon and the word 'Search'. Below the search bar are radio buttons for 'CoastWatch' (selected) and 'NOAA', followed by a 'Submit' button. Below the search bar is the text 'Need Help? Contact the Help Desk:' and links for 'Email', 'Forum', and '(301) 683-3335'. The main content area below the header contains the text 'Satellite data products and services for understanding and managing our oceans and coasts'.

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



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

Getting Level-1/2 (swath) data:

Select dates

Click Polygon and draw

Select the product

Click Search Results

The screenshot shows the NOAA CoastWatch web interface. On the left, a 'Date / Calendar' panel is open, showing a date range from May 2, 2022, to May 7, 2022. Below it, the 'CoastWatch Data Layers' panel is active, displaying 'L1/L2 Spatial Search' and a 'User drawn area to search Level-1 or -2 data'. A green polygon is drawn on the map. The 'Near real-time:' section lists various data products with radio buttons, including 'S-NPP: Ocean Color', 'SST', 'N-20: Ocean Color', 'S-3A: Ocean Color', 'S-3B: Ocean Color', 'S-1A/B: NRCS', 'S-2A: True Color', 'MCI', 'Chlor:', and 'S-2B: True Color'. The 'Science Quality / RAN / Delayed:' section also lists 'S-NPP: Ocean Color' and 'SST'. A 'Search Results' button is visible at the bottom of the panel. On the right, a 'User Data' panel is open, showing a 'Drag-n-Drop CSV file to map' section and a 'Search Results' section with a list of results. The results list includes 'FTP List' and several 'S-NPP PNG NetCDF' entries with timestamps and 'Show spatial extent' links.

Browse the results and click PNG or NetCDF links

Software for data visualization

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



National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

[GISS Home](#)

[News & Features](#)

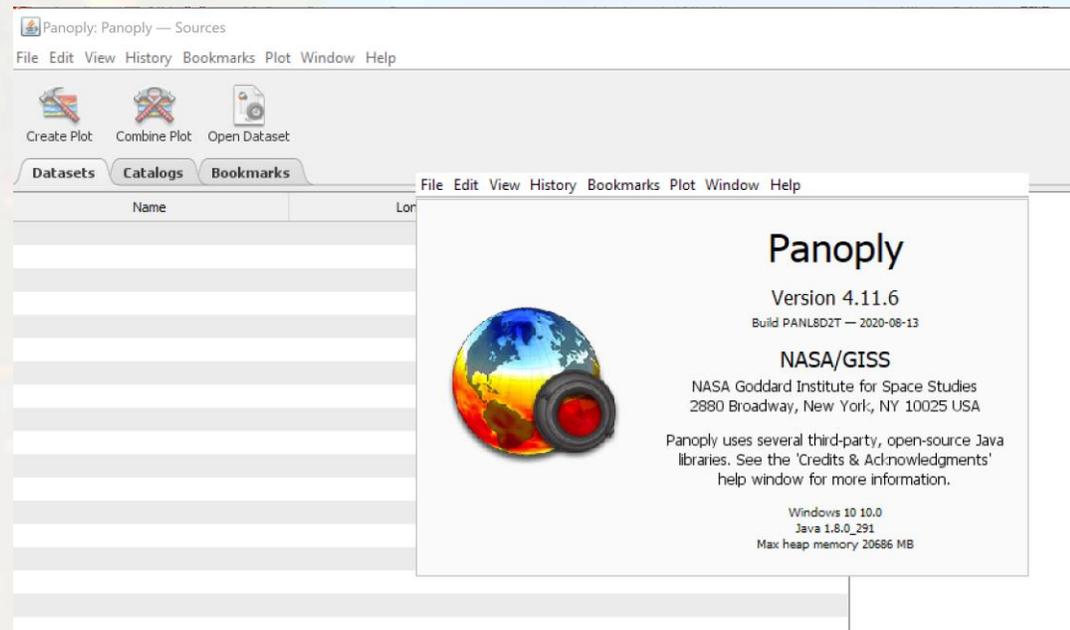
[Projects & Groups](#)

[Datasets](#)

Panoply netCDF, HDF and GRIB Data Viewer

panoply \PAN-uh-plee\, noun: 1. A splendid or impressive array. ...

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



Panoply: Panoply — Sources

File Edit View History Bookmarks Plot Window Help

Create Plot Combine Plot Open Dataset

Datasets Catalogs Bookmarks

Name Lon

Panoply

Version 4.11.6
Build PANL8D2T — 2020-08-13

NASA/GISS
NASA Goddard Institute for Space Studies
2880 Broadway, New York, NY 10025 USA

Panoply uses several third-party, open-source Java libraries. See the 'Credits & Acknowledgments' help window for more information.

Windows 10 10.0
Java 1.8.0_291
Max heap memory 20686 MB

- 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



Panoply: Panoply — Sources

File Edit View History Bookmarks Plot Window Help

Create Plot Combine Plot Open Dataset Remove Remove All Hi

Datasets Catalogs Bookmarks

Name	Long Name	Type
V2022137_a1_WW00_chlora.nc	DINEOF gap filled L4 data	Local File
altitude	Altitude	—
chlor_a	Chlorophyll Concentration, DINEOF Gap-Filled	Geo2D
coord_ref	coord ref	
lat	Latitude	
lon	Longitude	
palette	palette	
processing_control	processing_control	
input_parameters	input_parameters	
time	Time	

Variable "chlor_a"
In file "V2022137_a1_WW00_chlora.nc"

```

=1, altitude=1, lat=2160, lon=43
3";
"mass_concentration_of_chloroph
99.0f; // float
01f; // float
.0f; // float
\\'Reilly J. E. et al. (1998), C
"log";
.01f; // float
0.0f; // float
"coord_ref";

:long_name = "Chlorophyll Concentration, DINEOF
:C_format = "%.4g";
:ioos_category = "Ocean Color";
:cell_methods = "time:mean";
:coverage_content_type = "physicalMeasurement";
:_ChunkSizes = 1U, 1U, 1034U, 2068U; // uint

```

Create Plot

More than one type of plot can be created from the variable 'chlor_a'. What type would you like to create?

Georeferenced Longitude-Latitude color contour plot

Georeferenced Zonal Average line plot

Color contour plot using lat for X axis and lon for Y axis

Line plot using lat for the horizontal axis

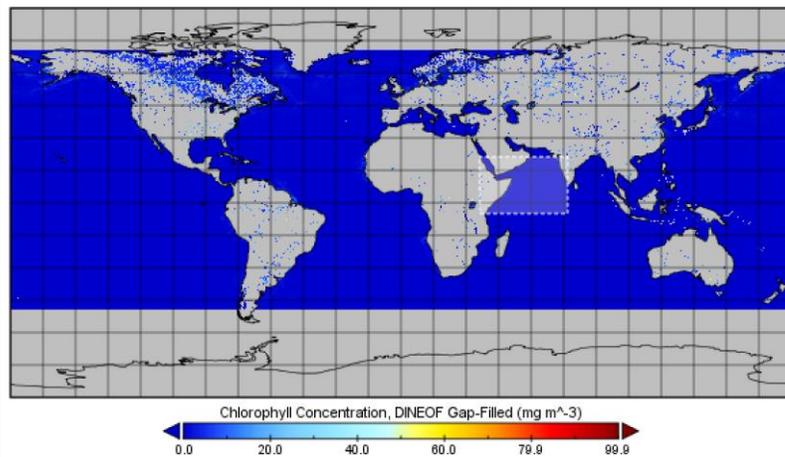
Create Cancel

Show: All variables



Plot Array 1

Chlorophyll Concentration, DINEOF Gap-Filled

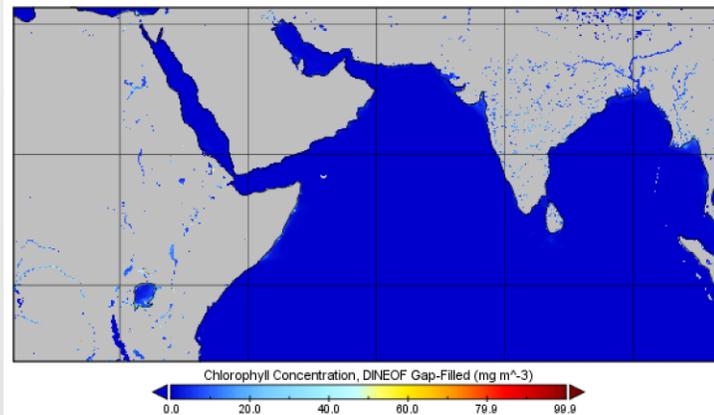


Array(s) Scale Map Overlays Shading Contours Vectors Labels

Plot Array 1 Only Interpolate

Press Ctrl and draw rectangle

Chlorophyll Concentration, DINEOF Gap-Filled



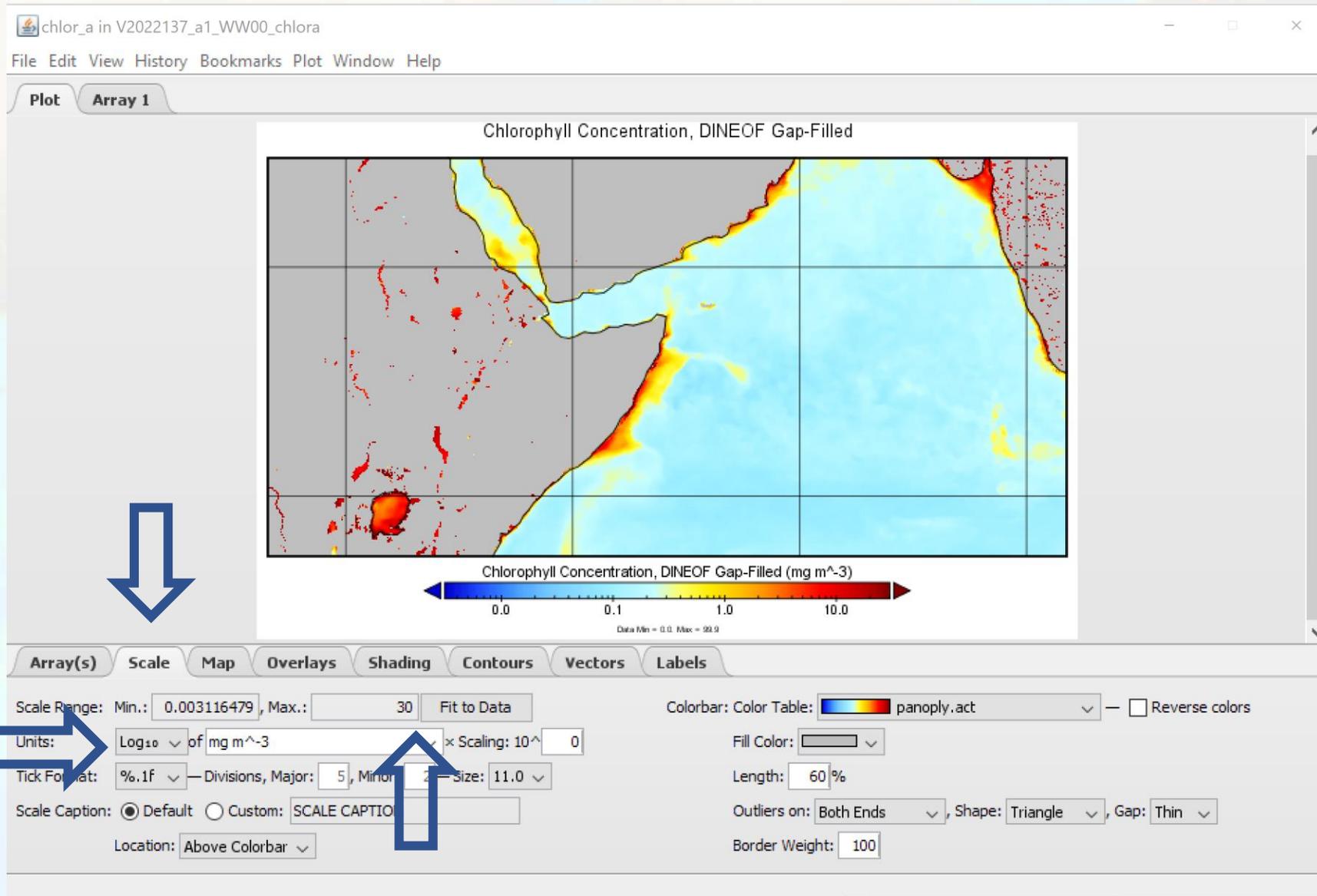
Array(s) Scale Map Overlays Shading Contours Vectors Labels

Projection: Equirectangular Regional
Center o...Lon. 59.0625 °E, Lat. 11.5625 °N
Width: 82.933 °, Height: 40.625 °

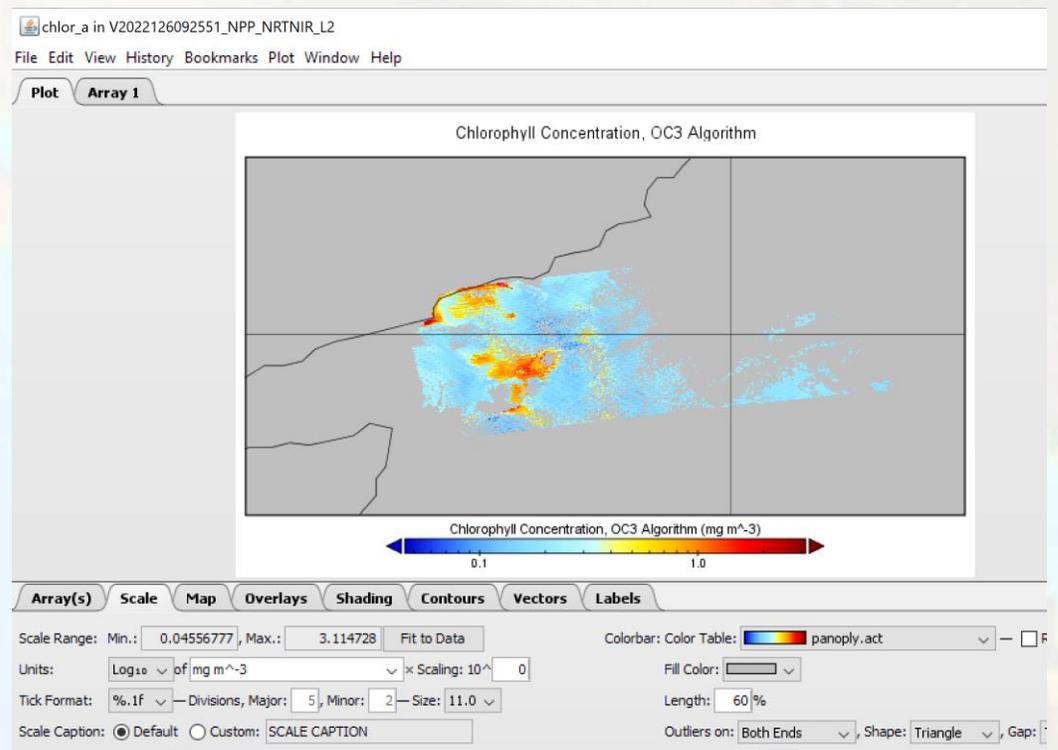
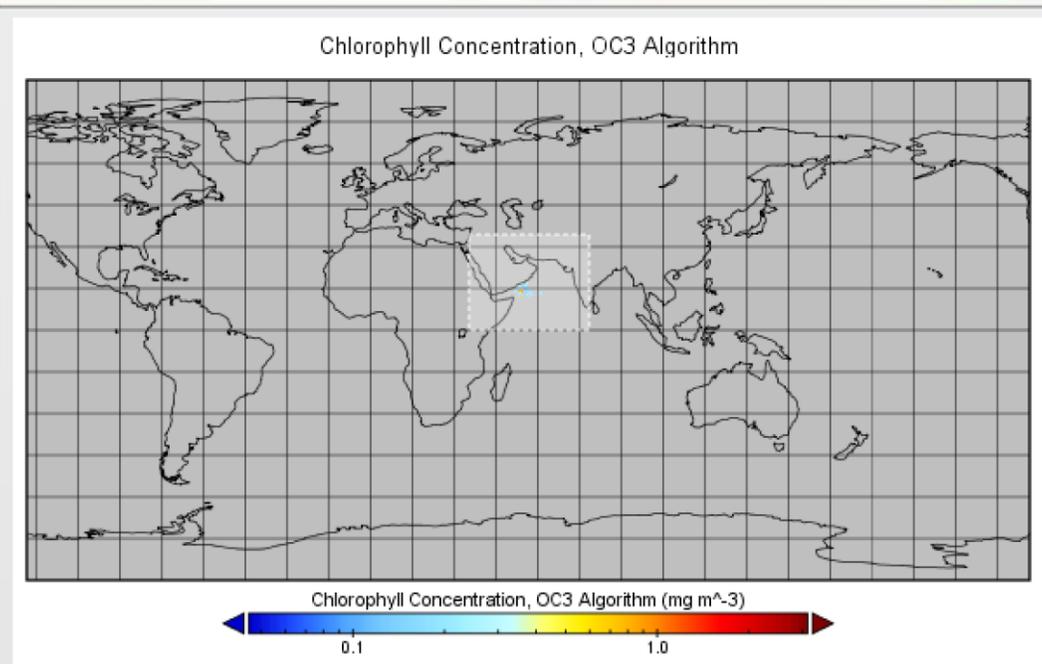
Grid: Spacing: 15.0 °E-W x 15.0 °N-S
 Offset parallels
Style: Solid, Color: Black, Weight: 1
Labels: None, Size: 6.5



- Select 'Map' tab
- Select 'Equirectangular Regional' projection
- Click 'Fix proportions'

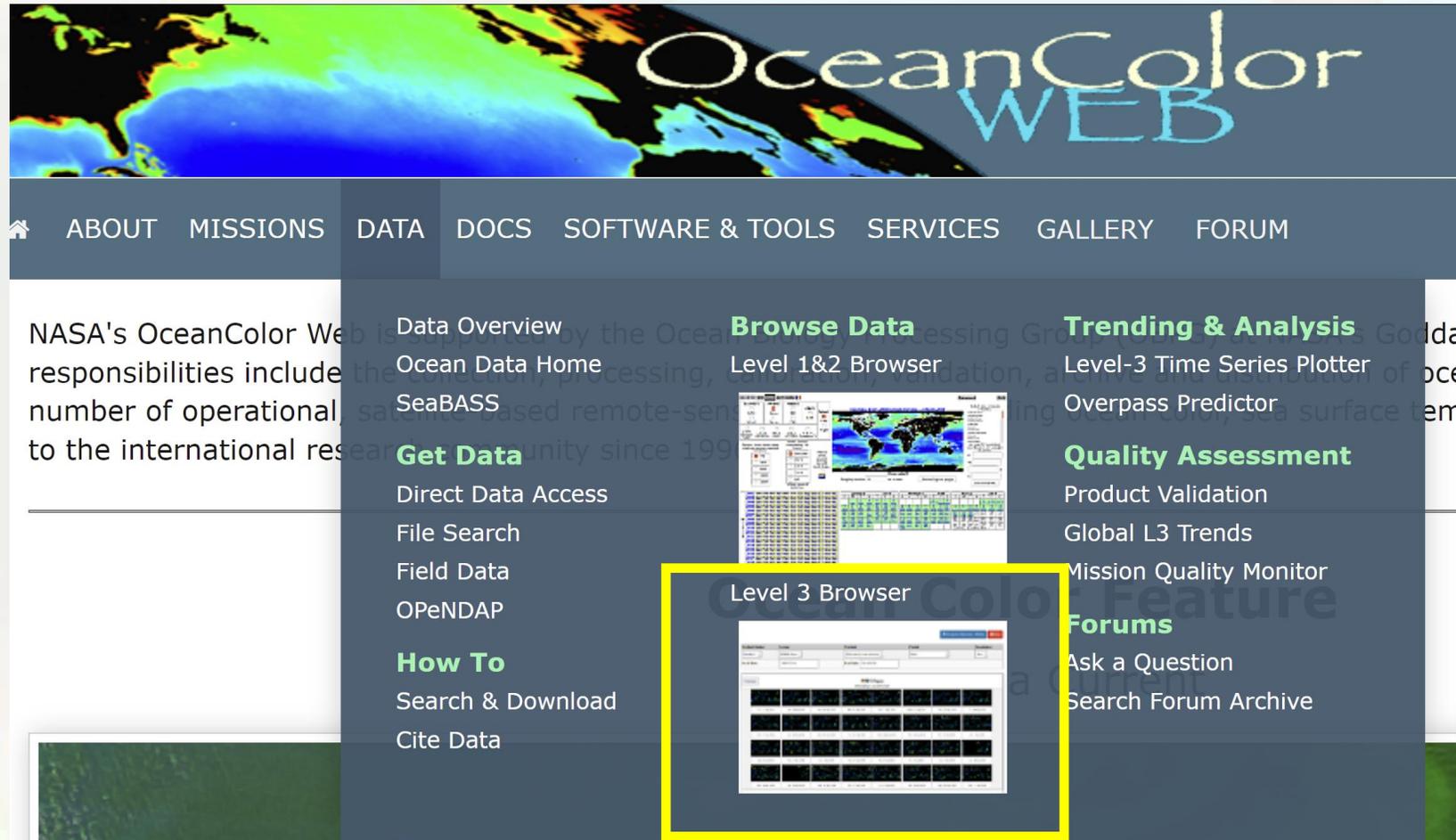


- Open 'Scale' tab
- At 'Units', select 'Log10'
- Correct 'Max'
- Click 'File' and 'Save Image As'



- 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"...

Get Level 3 data

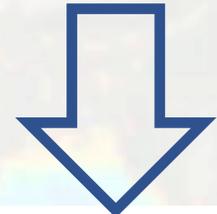
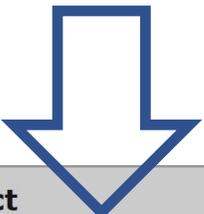


The screenshot displays the NASA OceanColor Web interface. At the top, a banner features a satellite image of the ocean with the text "OceanColor WEB". Below this is a navigation menu with the following items: ABOUT, MISSIONS, DATA, DOCS, SOFTWARE & TOOLS, SERVICES, GALLERY, and FORUM. The "DATA" menu is expanded, showing several sub-sections:

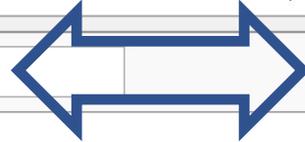
- Browse Data**
 - Level 1&2 Browser
 - Level 3 Browser** (highlighted with a yellow box)
- Trending & Analysis**
 - Level-3 Time Series Plotter
 - Overpass Predictor
- Quality Assessment**
 - Product Validation
 - Global L3 Trends
 - Mission Quality Monitor
- Forums**
 - Ask a Question
 - Search Forum Archive

On the left side of the page, there is a sidebar with the following text: "NASA's OceanColor Web responsibilities include a number of operational... to the international res...". Below this text are several links under the heading "Get Data": Direct Data Access, File Search, Field Data, and OPeNDAP. Under the heading "How To", there are links for Search & Download and Cite Data. A small thumbnail image of a satellite view of the ocean is visible at the bottom left of the page.

Level 3



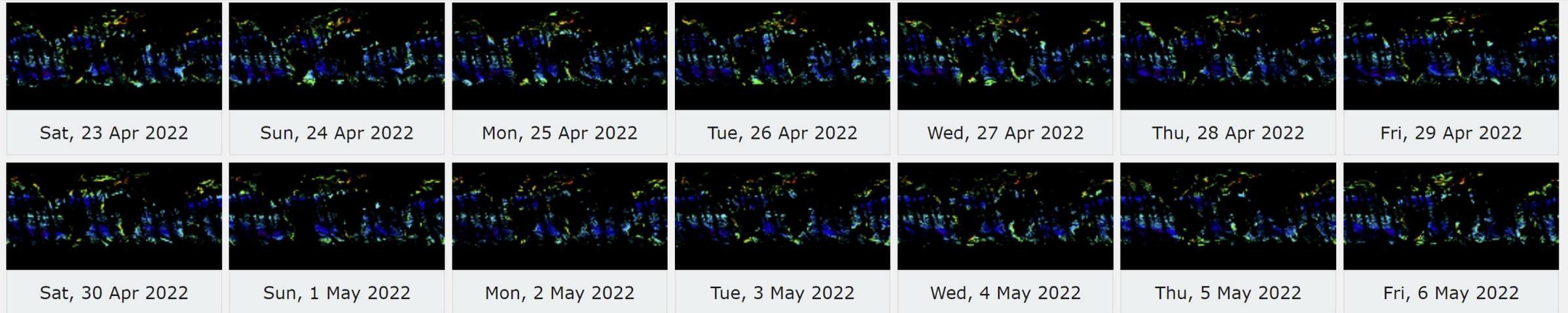
Extract or Download L3 Data [? Help](#)



Product Status	Sensor	Product	Period	Resolution
Standard	MODIS-Aqua	Chlorophyll concentration	Daily	4km
Start Date	2002-07-04	End Date	2022-05-26	

Previous

MODIS-Aqua
Chlorophyll concentration



Help

Product Status	Sensor	Product	Period	Resolution
Standard	MODIS-Aqua	Chlorophyll concentration	Monthly	4km
Start Date: 2021-01-01		End Date: 2022-05-26		Type: <input type="checkbox"/> Binned <input checked="" type="checkbox"/> Mapped <input type="checkbox"/> PNG
Data Retrieval Method: <input checked="" type="radio"/> Download <input type="radio"/> Extract				

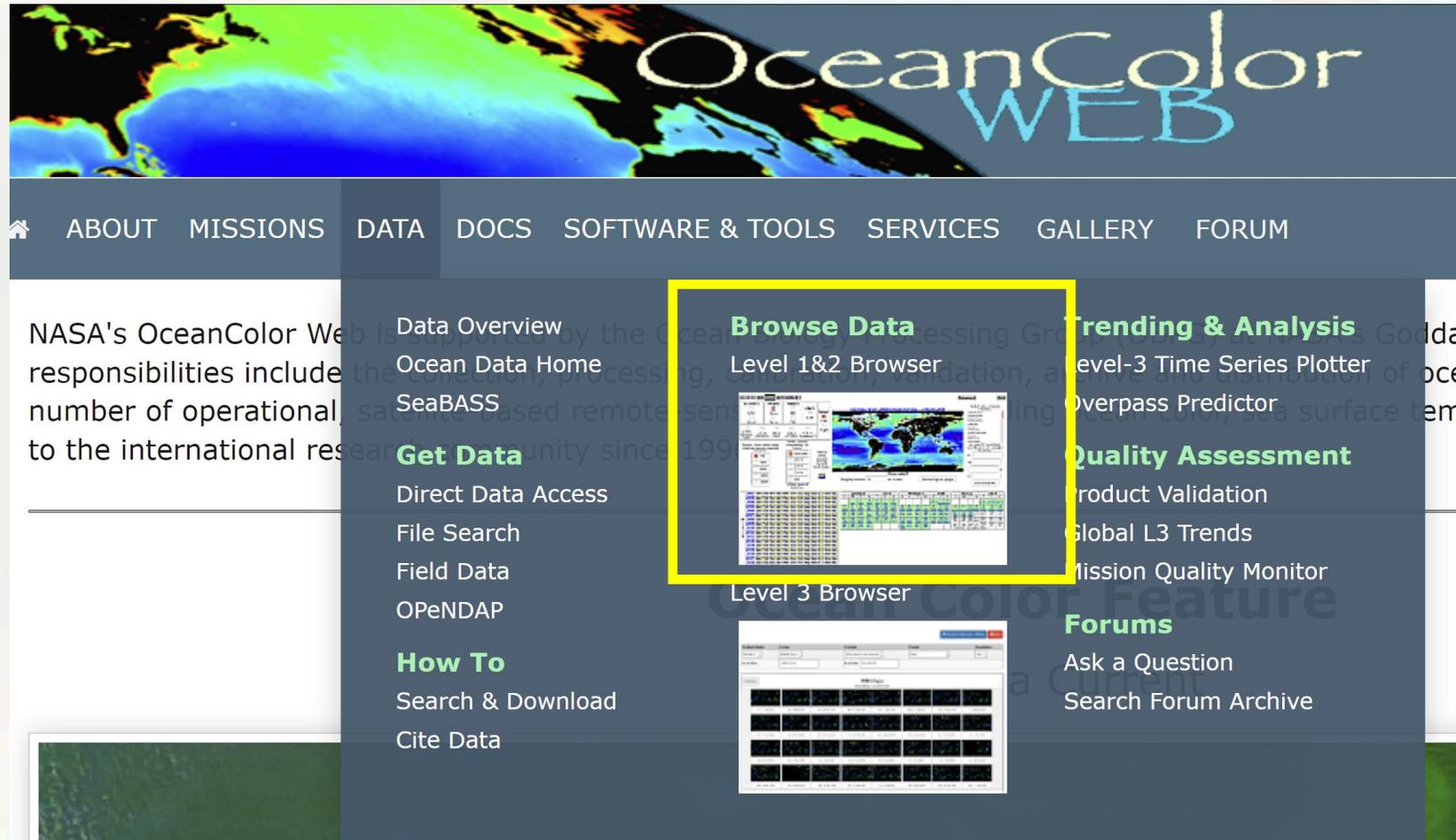
Apps | Inbox - nikolay.nezl... | GST Mail - Nikolay... | My Drive - Google... | Google Maps | News | RE

https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20210012021031.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20210322021059.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20210602021090.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20210912021120.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20211212021151.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20211522021181.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20211822021212.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20212132021243.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20212442021273.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20212742021304.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20213052021334.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20213352021365.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20220012022031.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20220322022059.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20220602022090.L3m_MO_CHL_chlor_a_4km.nc
https://oceandata.sci.gsfc.nasa.gov/cgi/getfile/A20220912022120.L3m_MO_CHL_chlor_a_4km.nc

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

Use Panoply or other soft.

Get Level 2 data



The image shows a screenshot of the NASA OceanColor Web homepage. The header features a satellite image of the ocean with the text "OceanColor WEB" overlaid. Below the header is a navigation menu with the following items: ABOUT, MISSIONS, DATA, DOCS, SOFTWARE & TOOLS, SERVICES, GALLERY, and FORUM. The main content area is divided into several sections. On the left, there is a paragraph about NASA's responsibilities. In the center, there is a section titled "Browse Data" which is highlighted with a yellow box. This section includes a sub-section "Level 1&2 Browser" and a screenshot of the browser interface. Below this is another sub-section "Level 3 Browser" with a screenshot of its interface. On the right, there are sections for "Trending & Analysis" and "Quality Assessment", each with a list of tools and services. At the bottom, there is a "Forums" section with links to "Ask a Question" and "Search Forum Archive".

NASA's OceanColor Web is responsible for the collection, processing, validation, archive and distribution of ocean color data from satellite-based remote sensing systems. The OceanColor Web has been a key component of the Earth Observing System since 1997.

Browse Data

- Level 1&2 Browser
- Level 3 Browser

Trending & Analysis

- Level-3 Time Series Plotter
- Overpass Predictor

Quality Assessment

- Product Validation
- Global L3 Trends
- Mission Quality Monitor

Forums

- Ask a Question
- Search Forum Archive



Questions?

Nikolay Nezlin
nikolay.nezlin@noaa.gov