New data, imageries, and tools in support of global ocean color research and monitoring

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NOCCG Seminar

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Outline

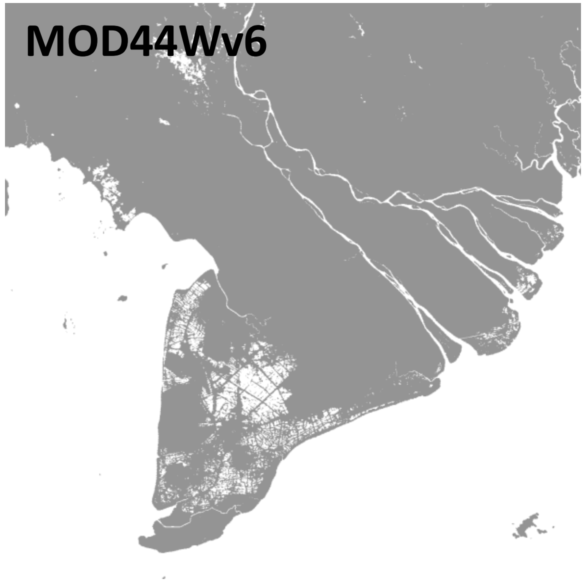
1. Global land mask for ocean color
   a) Existing and previously used land mask data sources
   b) Combining existing land masks
   c) Results and comparisons
2. Global false color imagery and applications
3. Clear sky imagery from daily global imagery series
   a) Methodology (how to derive)
   b) Results and example applications
4. OCView updates
5. Summary & Demos

Global land mask for ocean color

Existing land mask data sources: MOD44Wv5 & MOD44Wv6 (~230m)

- MODIS + SRTM data (early 2000s)
- Complete global coverage
- Many artifacts (missing islands, etc.)
- Based on bedrock elevation data for Antarctica

Carroll, M. L., Townshend, J. R., DiMiceli, C. M., Noojipady, P., and Sohlberg, R. A. (2009), A new global raster water mask at 250 m resolution, *Int. J. Digit. Earth*, *2*, 291–308.

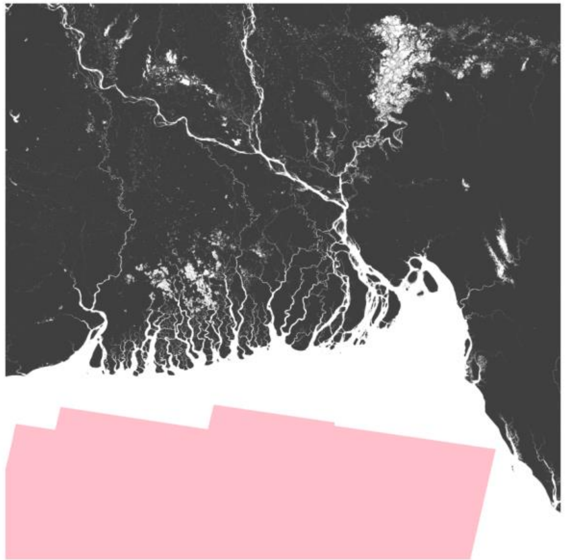


- MODIS + SRTM data (2000–2015)
- More heavily biased toward water (includes seasonal waters such as rice fields)
- No data south of 60°S

Carroll, M. L., *et al.* (2017), Development of an operational land water mask for MODIS Collection 6, and influence on downstream data products, Int. J. Digit. Earth, 10, 207–218.

Global land mask for ocean color

Existing land mask data sources:
Global Surface Water and Global Forest Cover (~30m)



- Landsat data (1984–2015) + machine learning
- Include various metrics, such as seasonality, occurrence, recurrence, extent, change.
- Some artifacts present, especially in the Arctic
- No data south of 60°S

Pekel, J. F., Cottam, A., Gorelick, N., and Belward, A. S. (2016), High-resolution mapping of global surface water and its long-term changes, Nature, 540, 418–422.

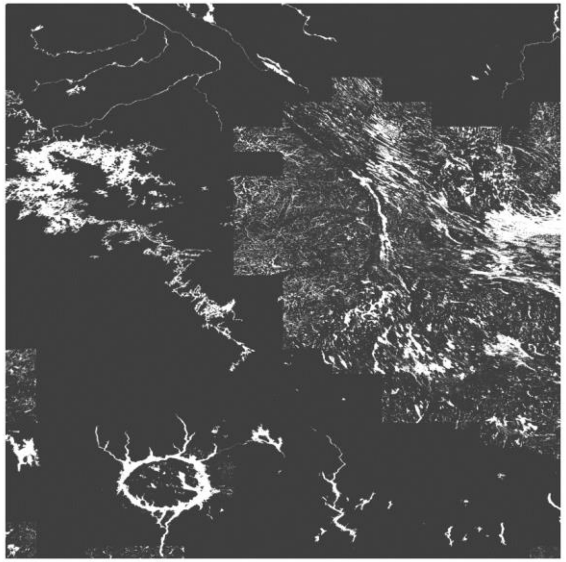
- Landsat data (2000–2015) for global forest cover studies
- Significantly biased toward more water
- No data in polar regions (Antarctica & Greenland)

Hansen, M. C., *et al*. (2013), High-resolution global maps of 21st-century forest cover change, *Science*, *342*, 850–853.

Global land mask for ocean color
Existing land mask data sources:
OpenStreetMap

- Derived from various data sources as an open community project
- Vector data – some regions in very high resolution
- Inconsistent level of detail on a global scale

www.openstreetmap.org



How can we combine all these data sets to get an improved, complete global land mask with consistent quality?

Global land mask for ocean color

Deriving a combined land mask data: Methodology

1. Medium resolution MOD44Wv5 and MOD44Wv6 data sources:

   Introduce a land-water indicator Λ: $\Lambda^{Mv5,6} = \begin{cases} -1 & (land) \\ +1 & (water) \\ 0 & (no\ data) \end{cases}$

2. High resolution GSW, GFC, and OSM data down-sampled to a common 230m resolution providing fractional values for water (n_W) and land (n_L)

3. Water threshold (f) and smoothing (Δ) parameters used to map the land and water fractions to a fractional land-water indicator:

   $\Lambda^{GFC} = (n_W + n_L)\tanh\left[\frac{n_W - f^{GFC}(n_W + n_L)}{\Delta^{GFC}}\right]$ (for GFC, GSW, and OSM data sources)

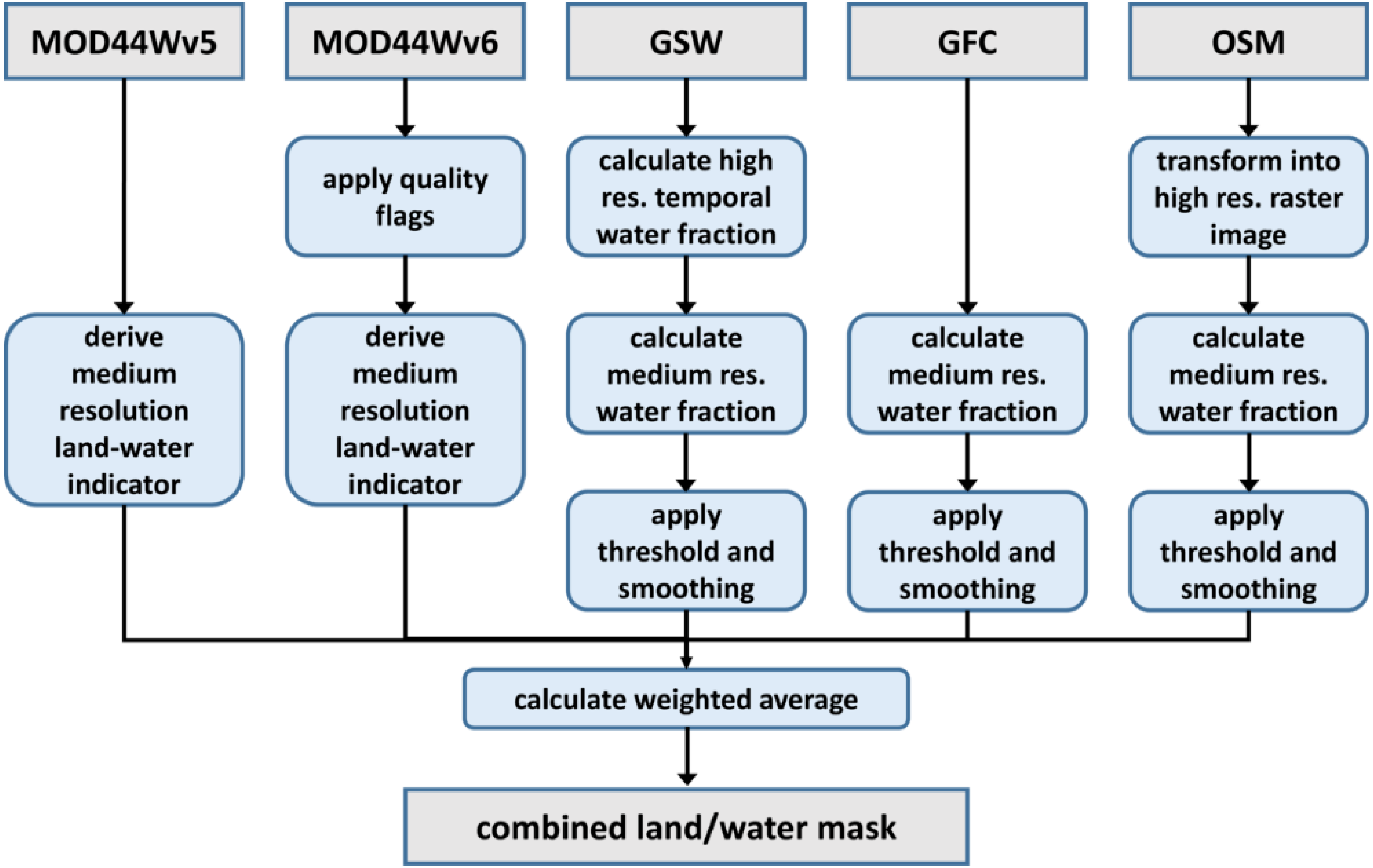
4. All data combined by weighted average of land-water indicators (weights empirically adjusted based on age and overall quality of each data source):

$$\Lambda = \frac{\Lambda^{GSW}w^{GSW} + \Lambda^{GFC}w^{GFC} + \Lambda^{Mv5}w^{Mv5} + \Lambda^{Mv6}w^{Mv6} + \Lambda^{OSM}w^{OSM}}{w^{GSW} + w^{GFC} + w^{Mv5} + w^{Mv6} + w^{OSM}}$$

5. $\Lambda < 0$ → land; otherwise water

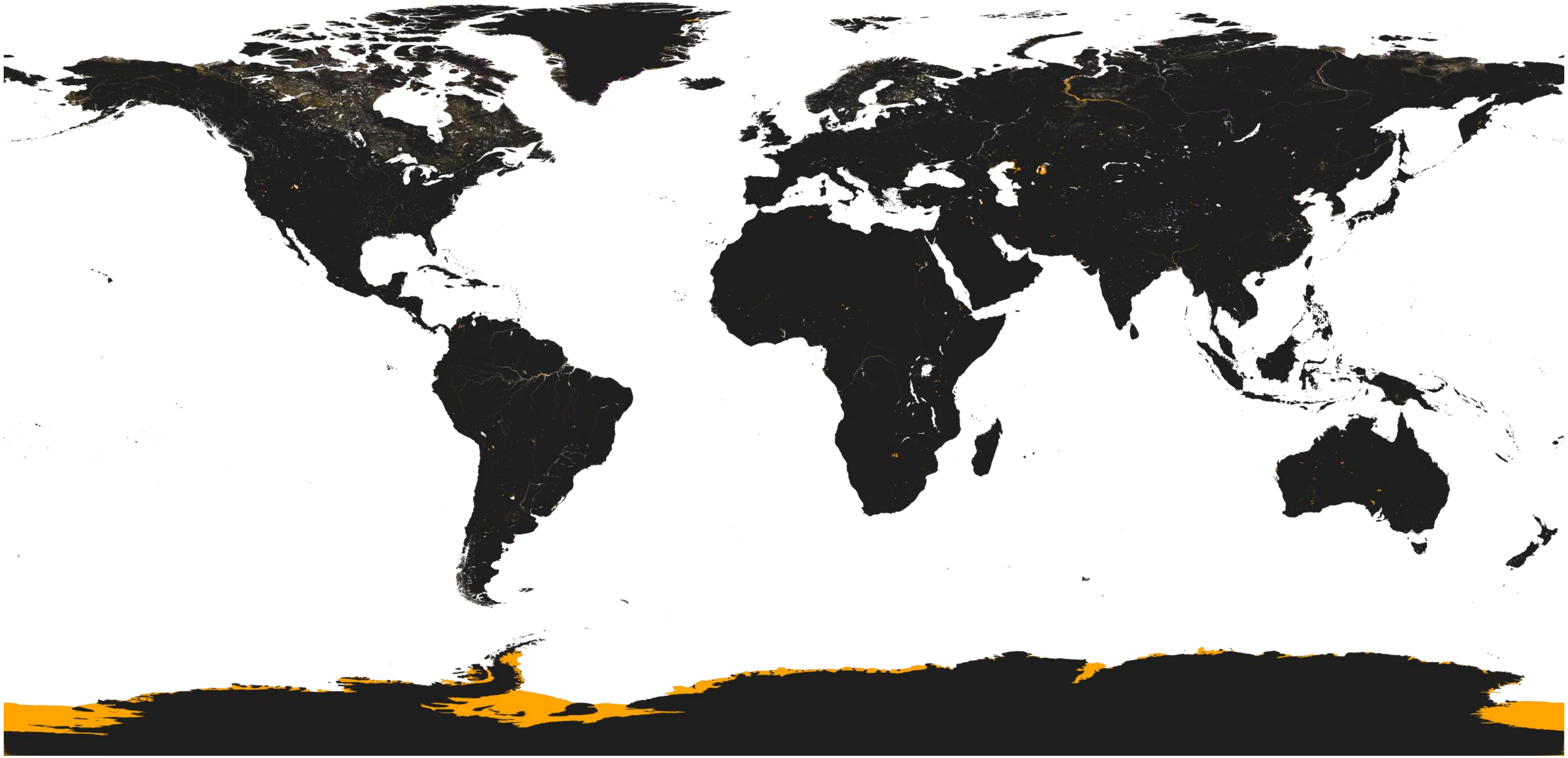
Global land mask for ocean color

Deriving a combined land mask data: Methodology



Global land mask for ocean color

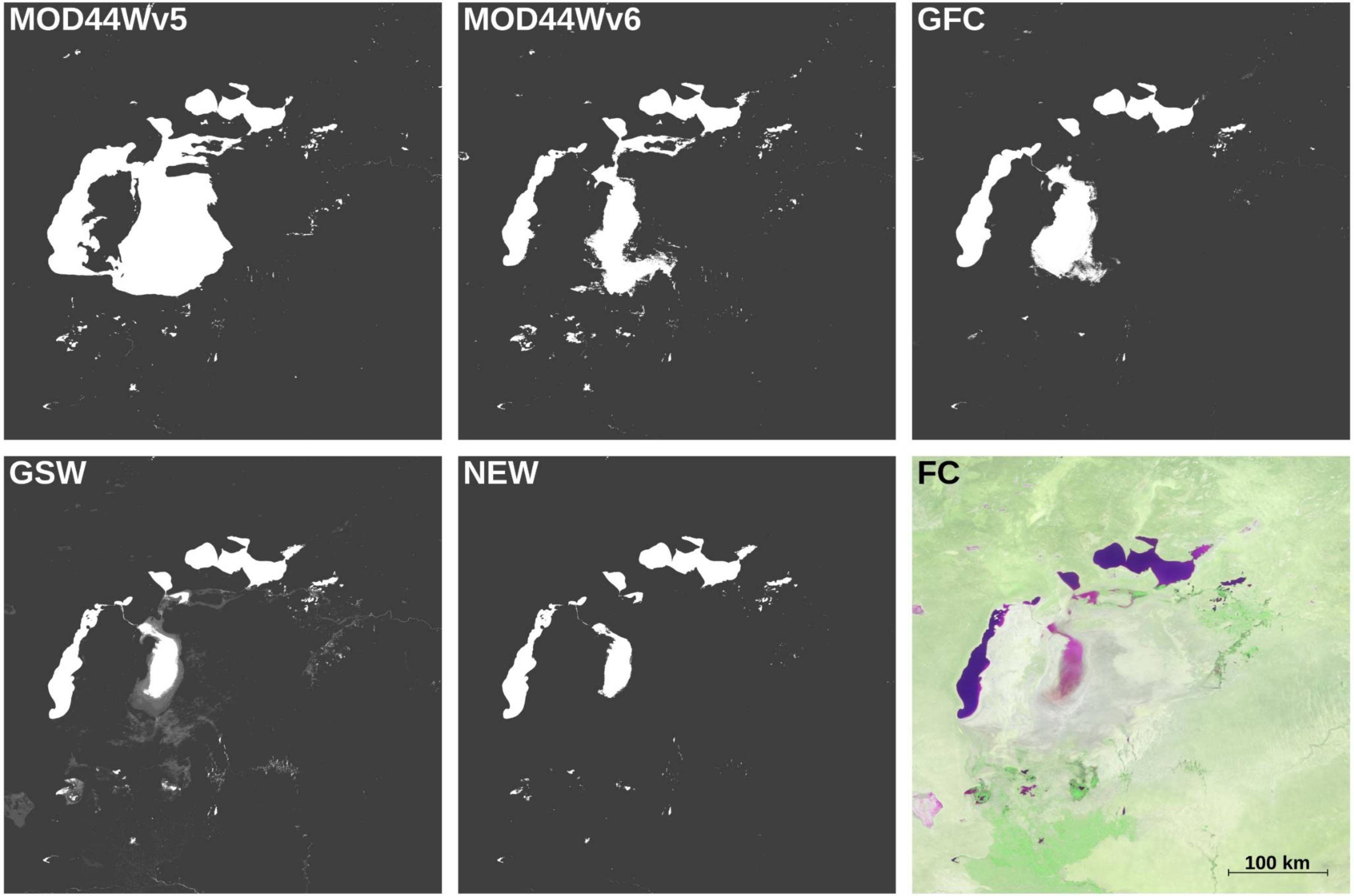
Results: Differences from MOD44Wv5



Orange = Water in MOD44Wv5, land in the New land mask

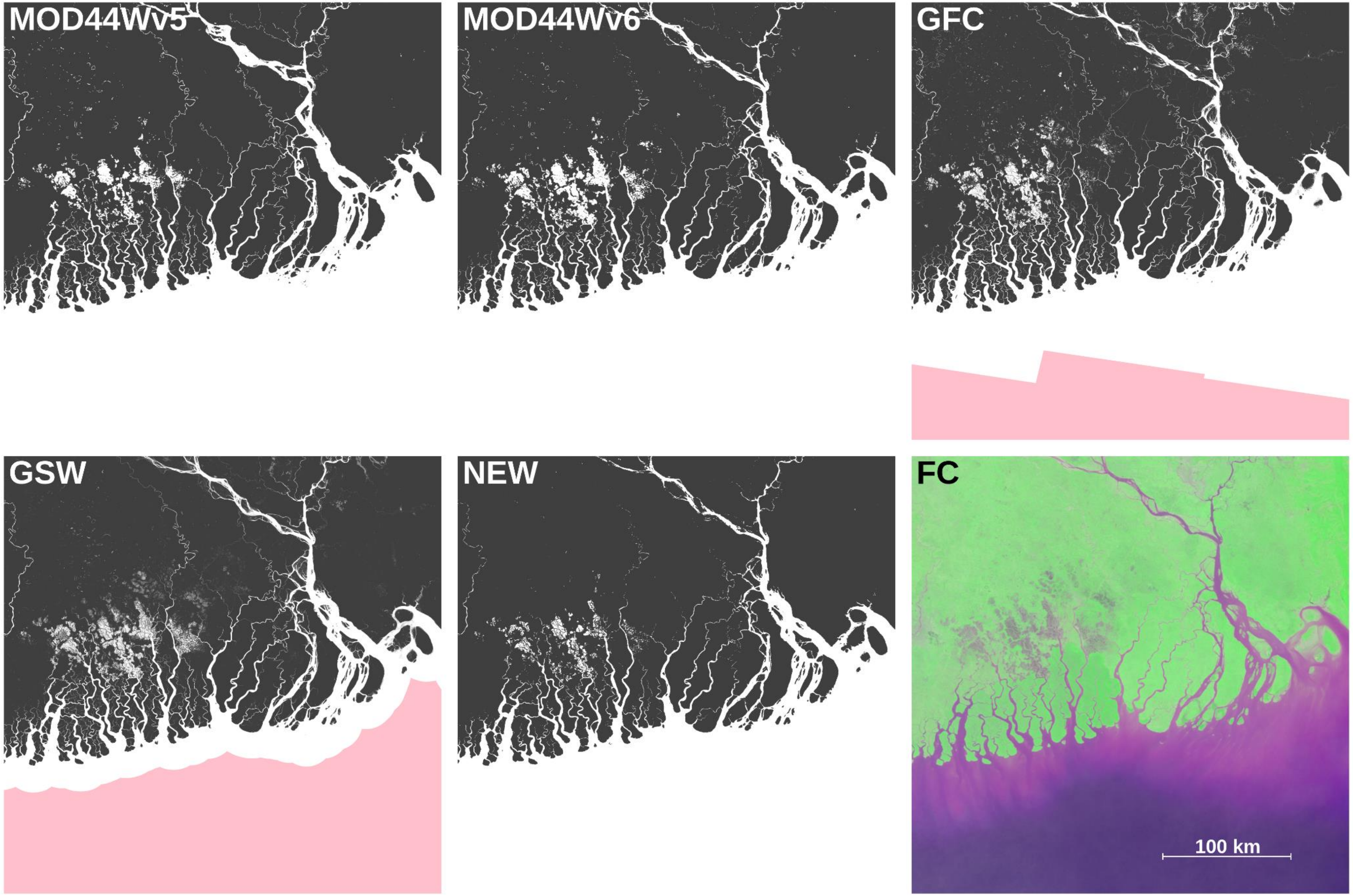
Global land mask for ocean color

Results: Comparison with false color imagery – Aral Sea



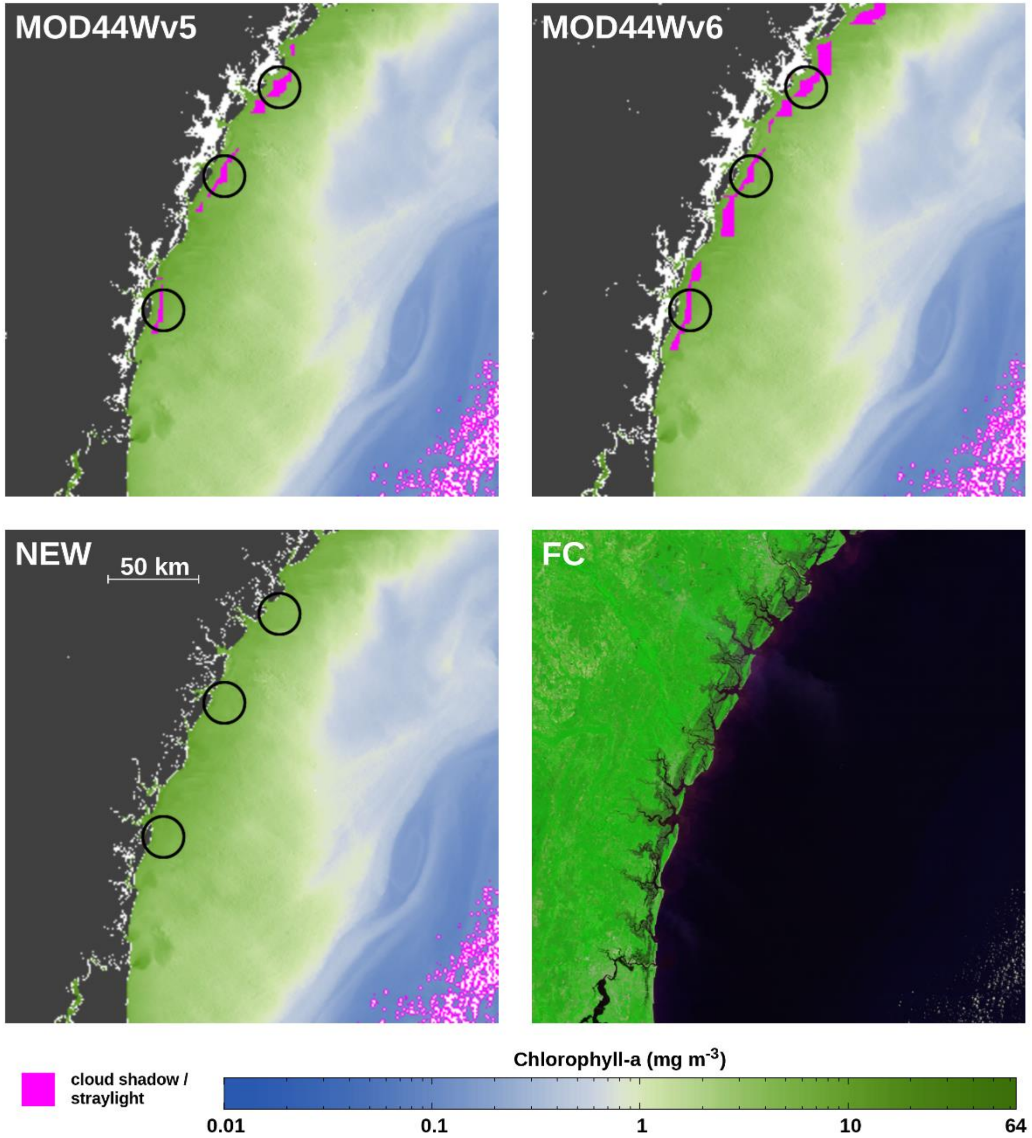
Global land mask for ocean color

Results: Comparison with false color imagery – Ganges Delta



Global land mask for ocean color

Results: Impact on ocean color retrievals
Southeast US (Georgia) on April 15, 2019, 18:42UTC



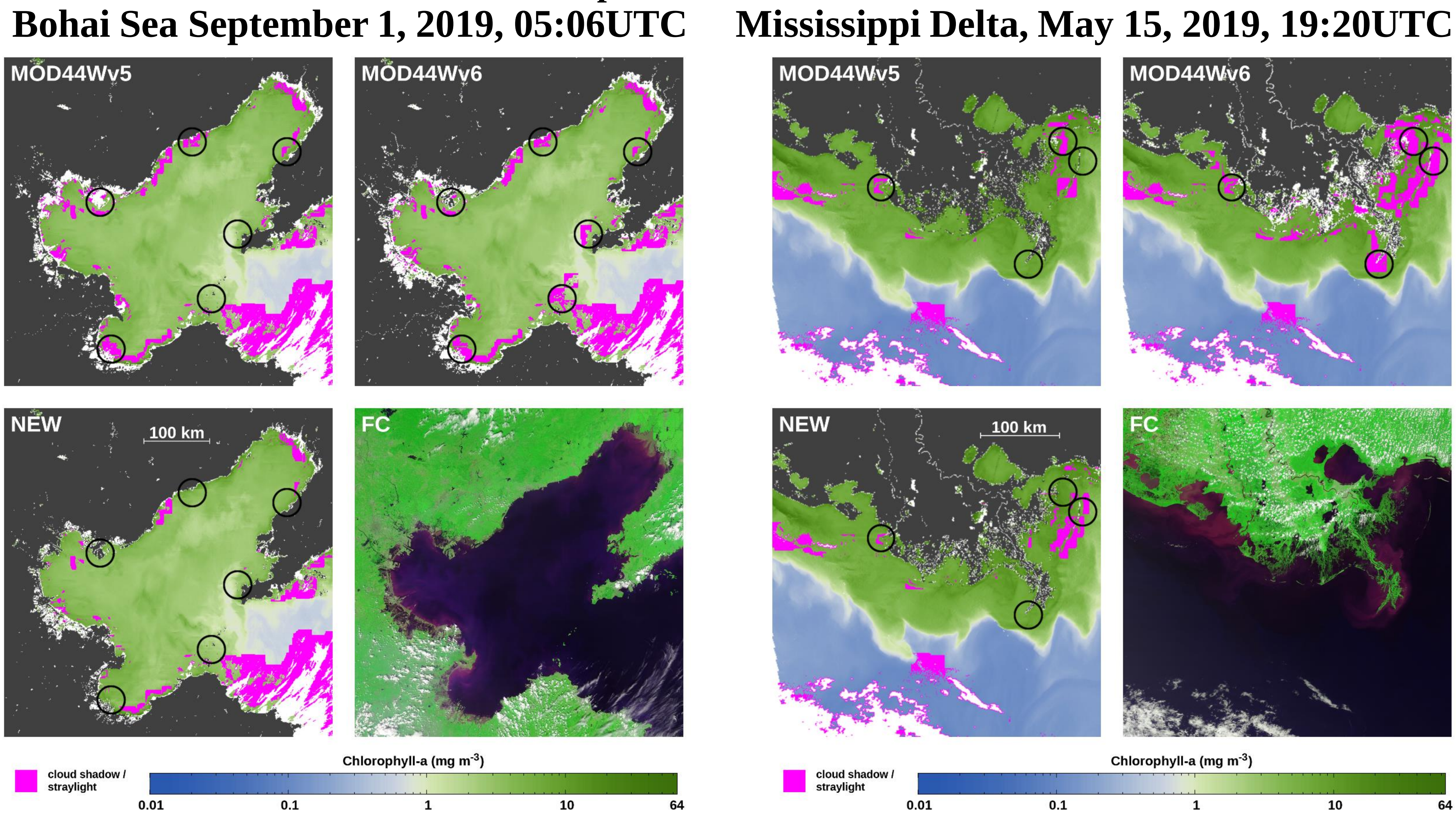
Gray = Land
Magenta = Water; Straylight or cloud shadow flags
White = Water; no retrievals (no data or due to other flags)

Areas that are misclassified as water, but are actually land cause the MSL12 retrieval algorithm to misinterpret higher reflectance as cloud contamination,
masking out surrounding areas
with straylight and cloud shadow flags

Result:
MOD44Wv5 and MOD44Wv6 has more water pixels in the land mask, but fewer ocean color retrievals

Global land mask for ocean color

Results: Impact on ocean color retrievals



Global land mask for ocean color

Summary

1. New improved global land mask derived from the existing data sources for the satellite ocean color studies
2. Most of the artifacts in data sources minimized or eliminated
3. Ice covered regions in Antarctic now classified as land
4. Improved ocean color retrieval coverage and consistency
5. Same methodology applicable to derive land masks for other studies and purposes
6. The updated land mask incorporated into NOAA MSL12 and used in OCView

K. Mikelsons, M. Wang, X. Wang, and L. Jiang (2021), "Global land mask for satellite ocean color remote sensing," *Remote Sens. Environ.*, **257**, 112356, https://doi.org/10.1016/j.rse.2021.112356.

False color and floating vegetation
(in collaboration with Prof. Chuanmin Hu's group at USF)

- Many types of false color imagery are used for various applications
- Most common type of false color imagery used for vegetation monitoring swaps NIR for the green band:

True Color Imagery:

Image Color Channel	VIIRS Sensor Band	Wavelength (nm)
Red	I1 (red)	638
Green	M5 (green)	551
Blue	M3 (blue)	486

False Color Imagery:

Image Color Channel	VIIRS Sensor Band	Wavelength (nm)
Red	I1 (red)	638
Green	**I2 (NIR)**	**865**
Blue	M3 (blue)	486

- VIIRS medium resolution (750m) bands M3 & M5 in TC, and M3 in FC sharpened to 375m resolution using I1 band
- Rayleigh corrected reflectances used to form true or false color imagery
- A logarithmic color stretch can be applied to enhance the contrast at low reflectances (for false color)
- SNPP VIIRS global false color routinely produced by NOAA Ocean Color Team and displayed in OCView
- Global survey of floating vegetation conducted using SNPP VIIRS false color imagery from 2019 (and other sources):

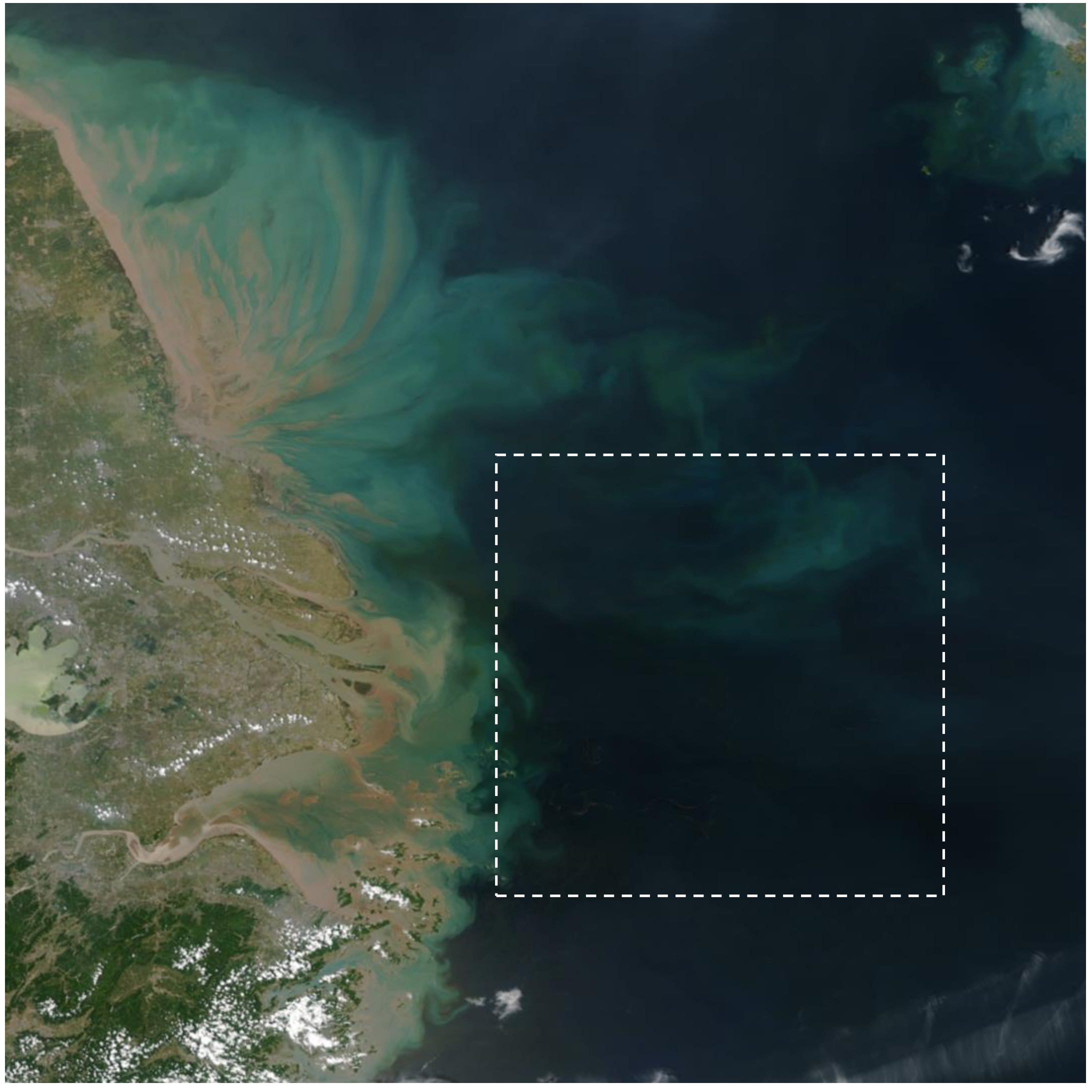
L. Qi, C. Hu, K. Mikelsons, M. Wang, V. Lance, S. Sun, B.B. Barnes, J. Zhao, D. Van der Zande (2020), "In search of floating algae and other organisms in global oceans and lakes", *Remote Sens. Environ.*, **239**, 111659, https://doi.org/10.1016/j.rse.2020.111659

False color and floating vegetation

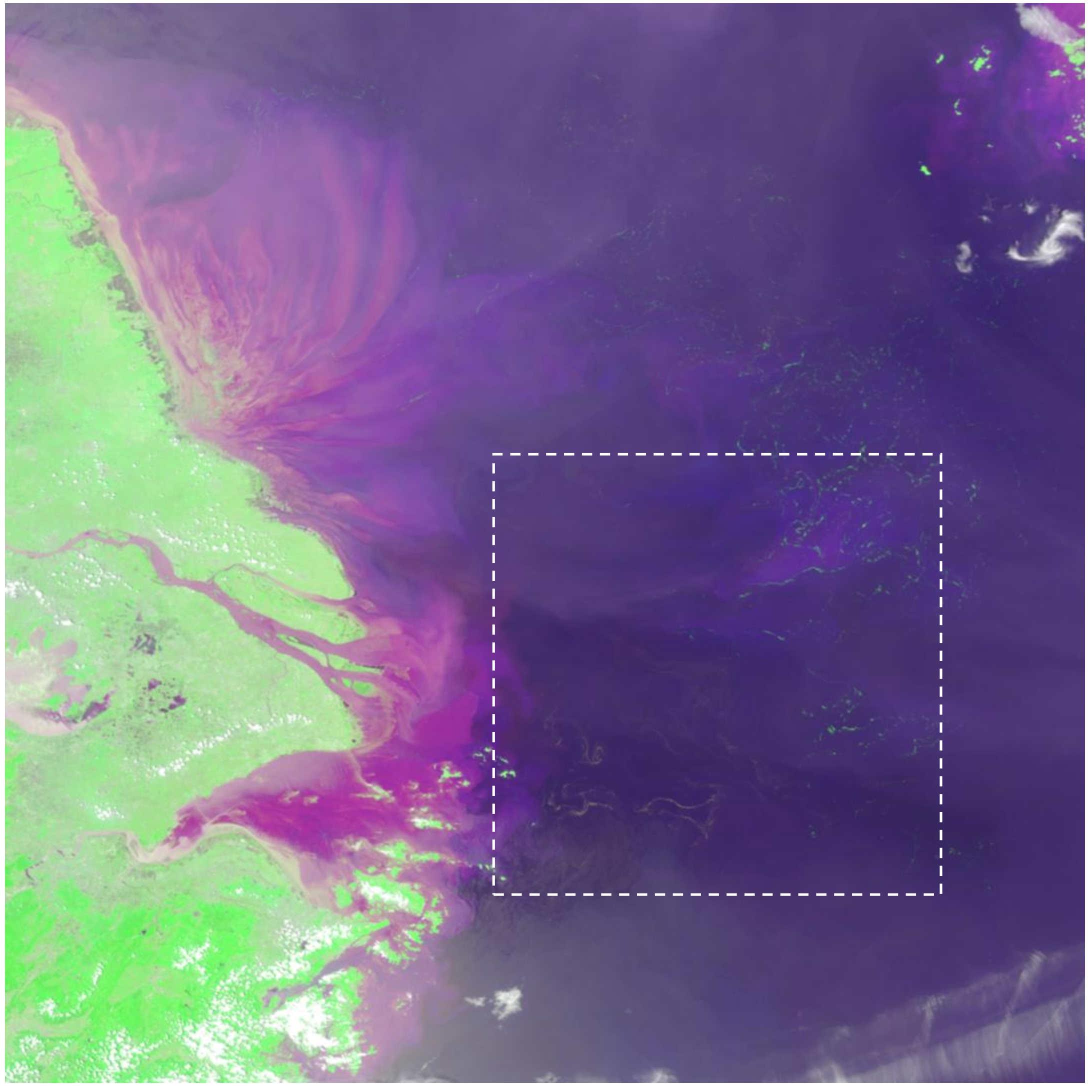
What can we see in false color?

May 17, 2017, East China Sea

True Color

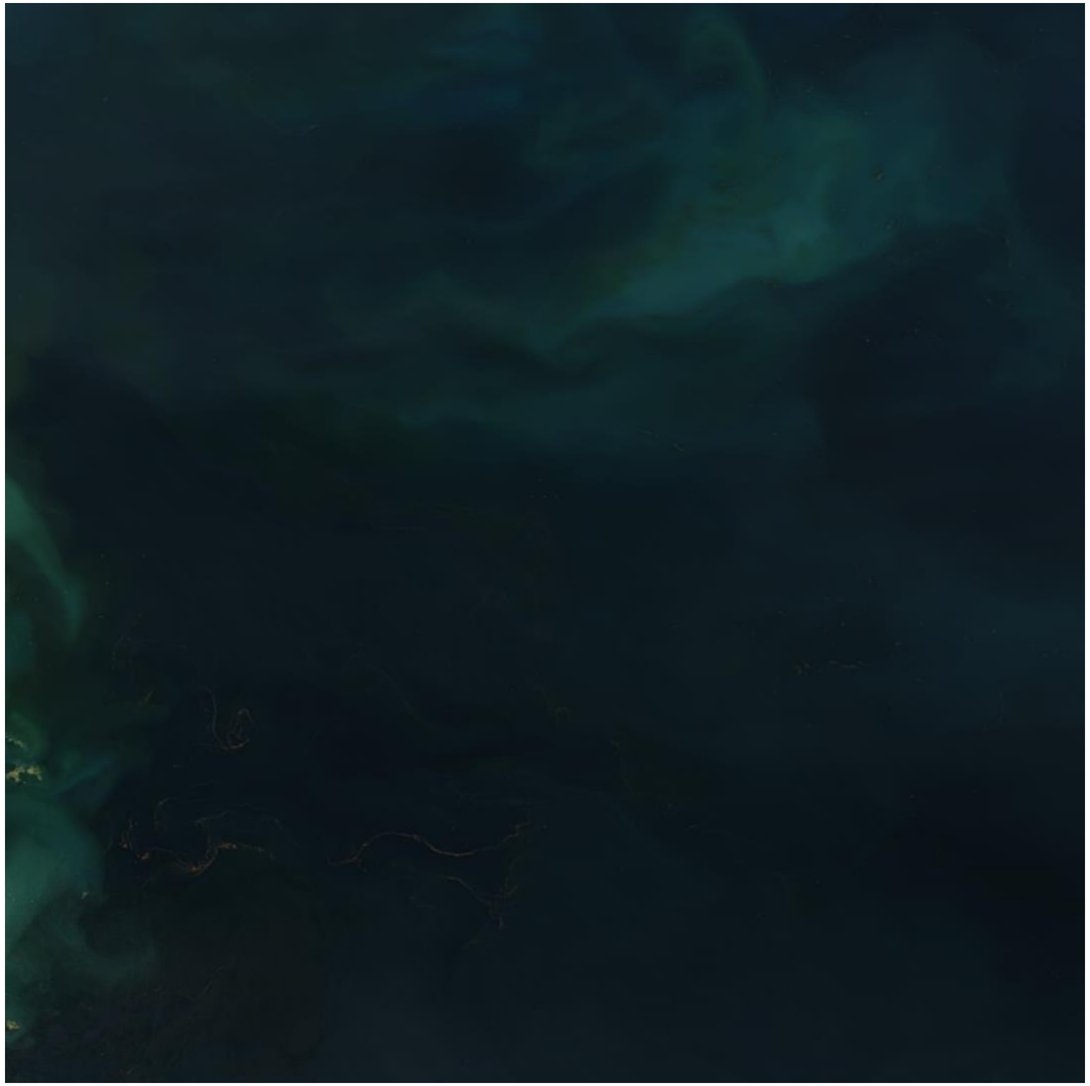


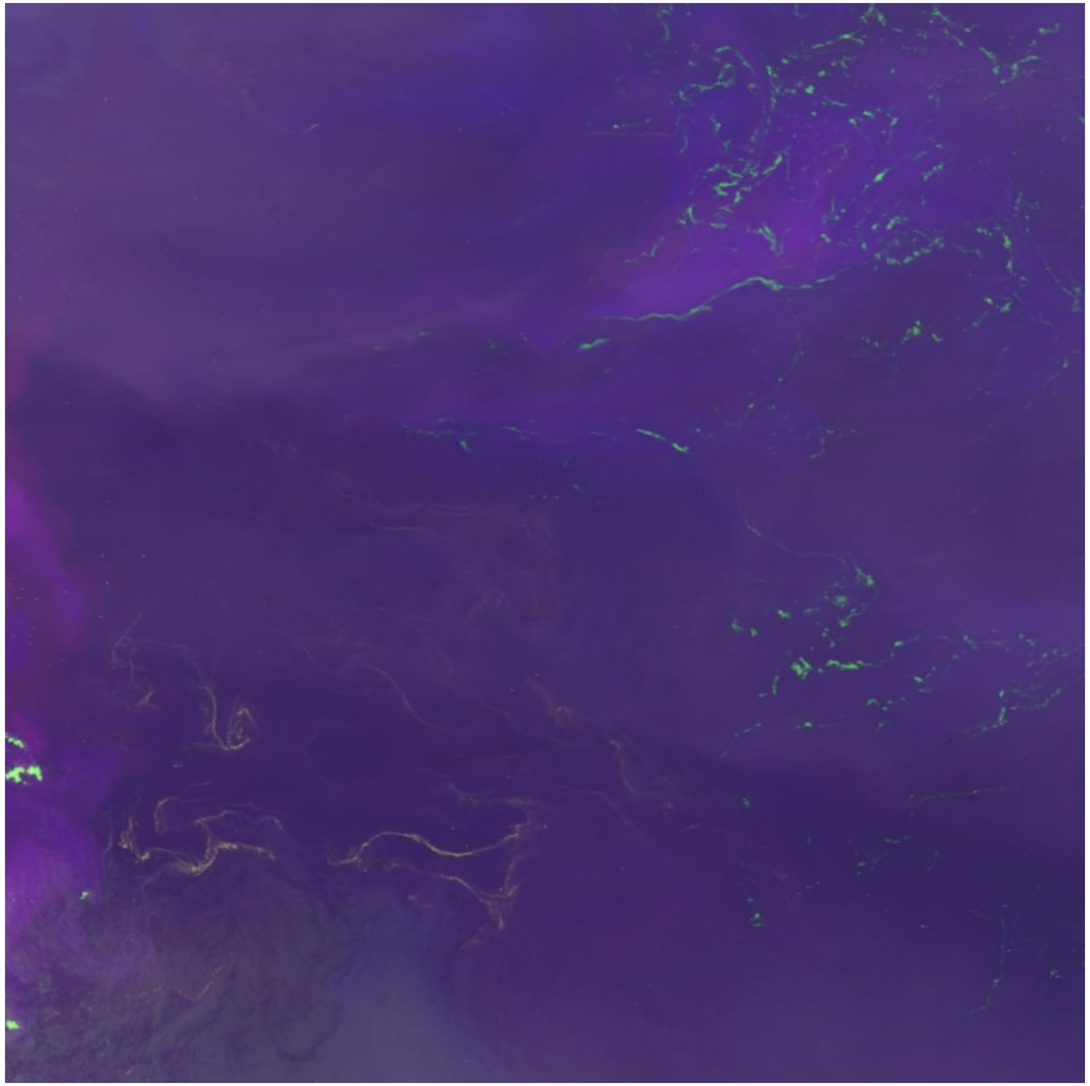
False Color



False color and floating vegetation

May 17, 2017, East China Sea (detail)
Red Noctiluca and Sargassum Horneri

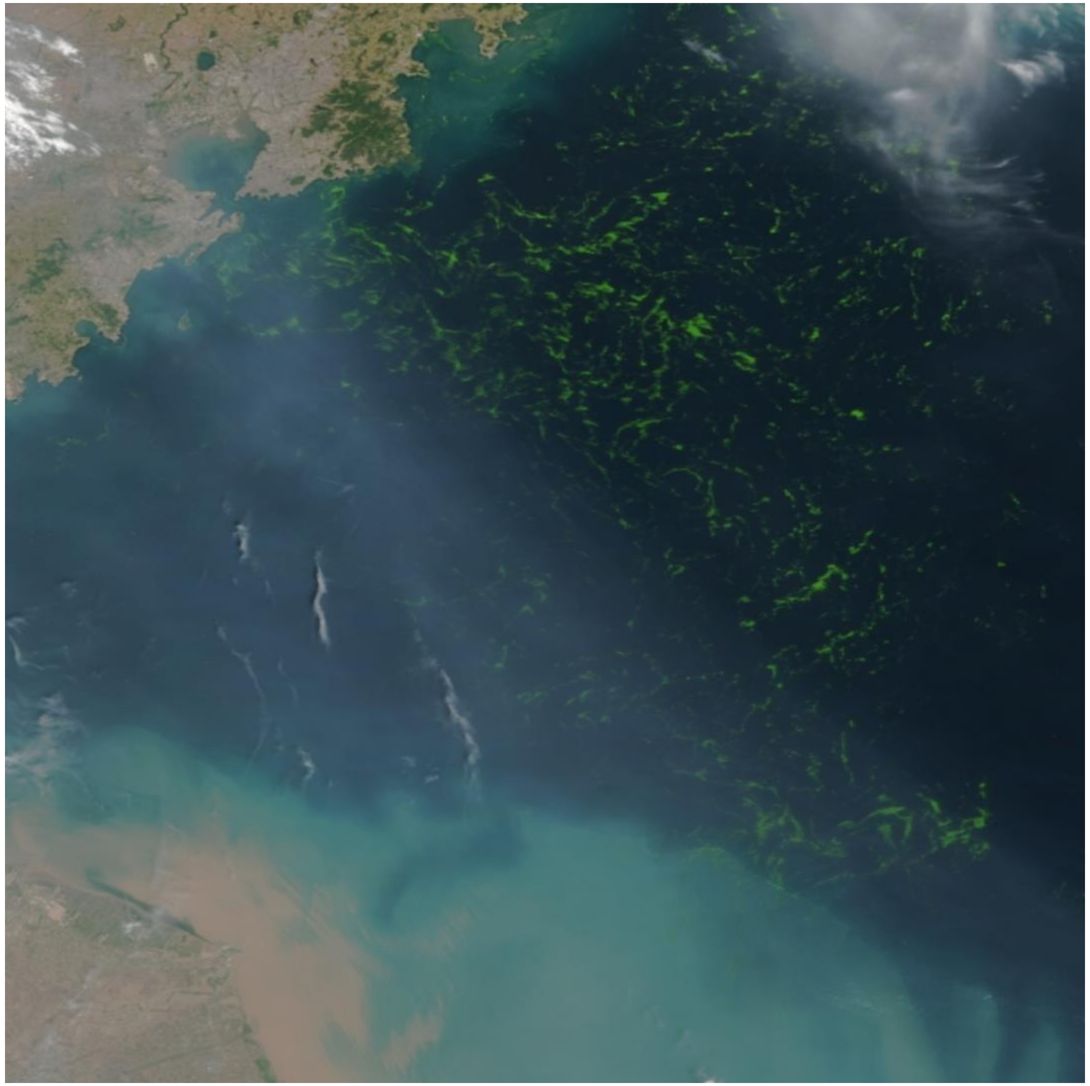


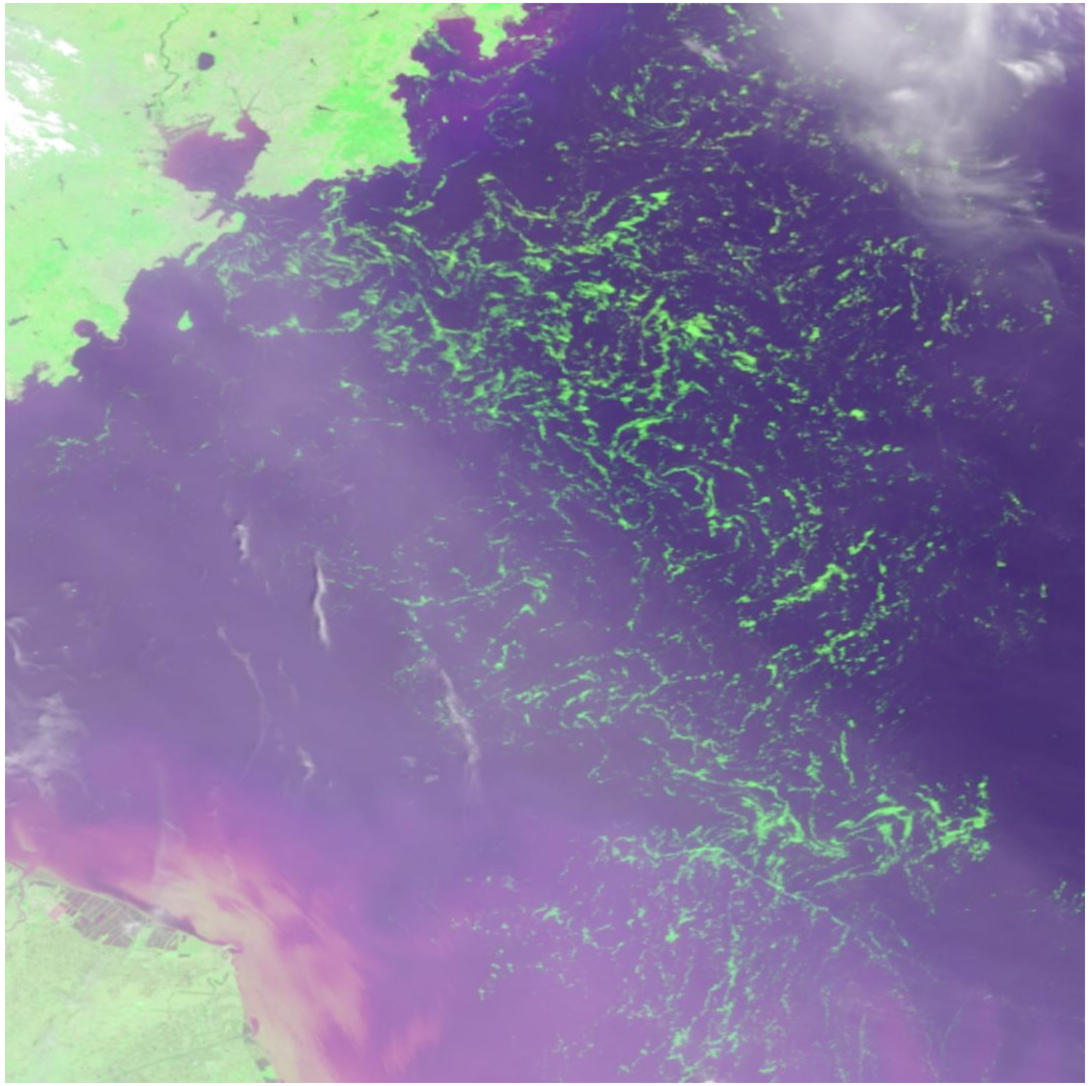


False color and floating vegetation

May 17, 2021, Yellow Sea

Ulva Prolifera

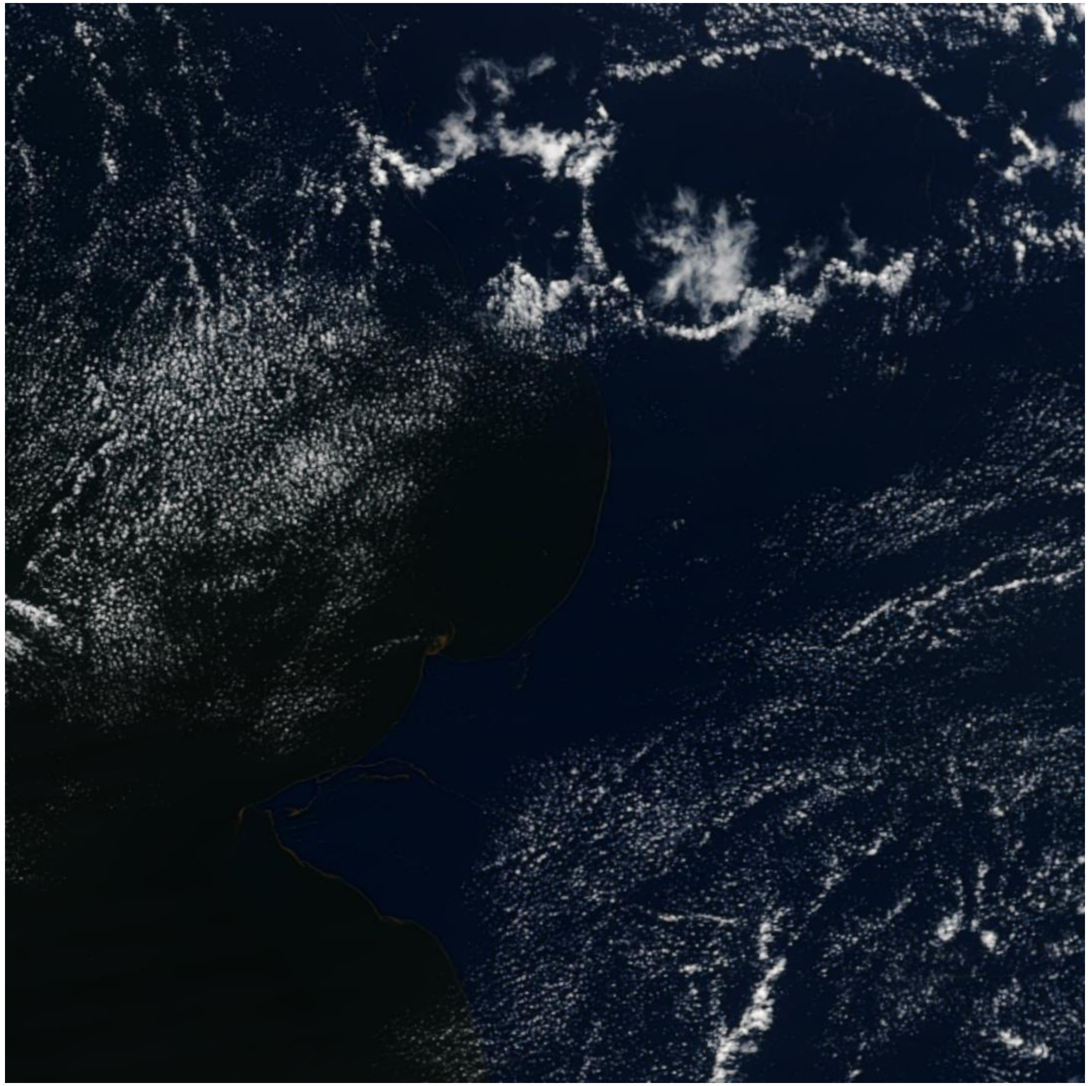


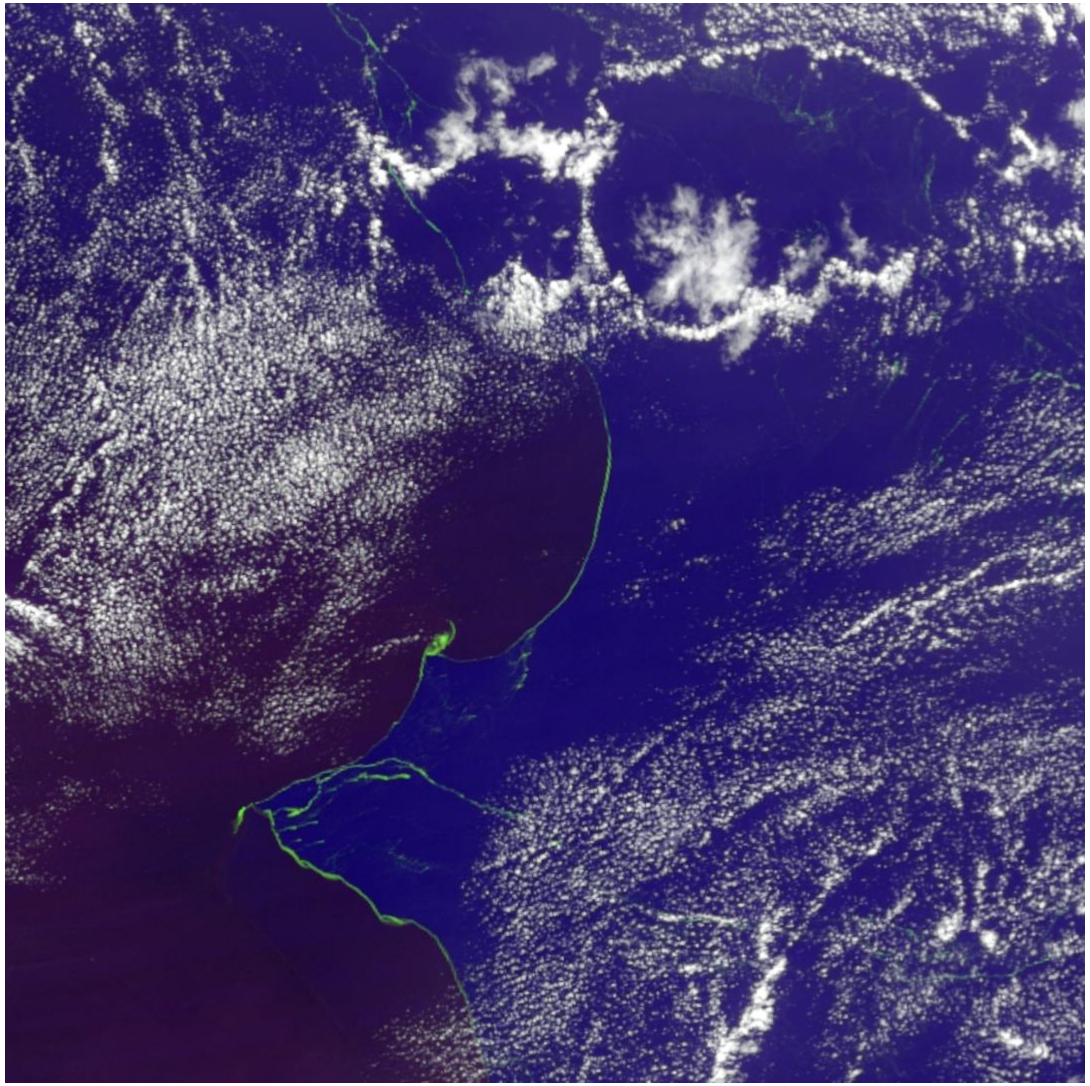


False color and floating vegetation

June 13, 2021, Atlantic Ocean near Amazon River Delta

Sargassum

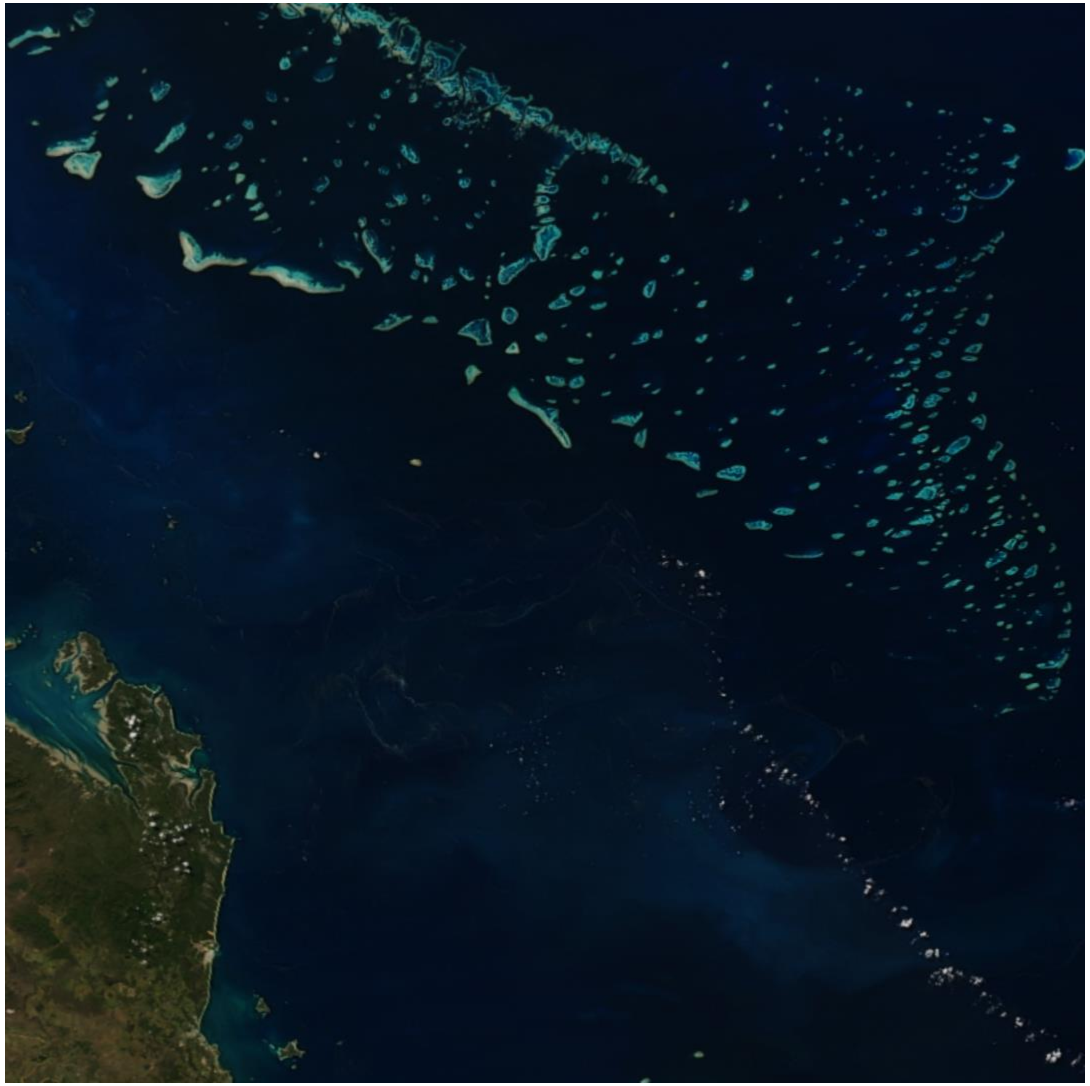


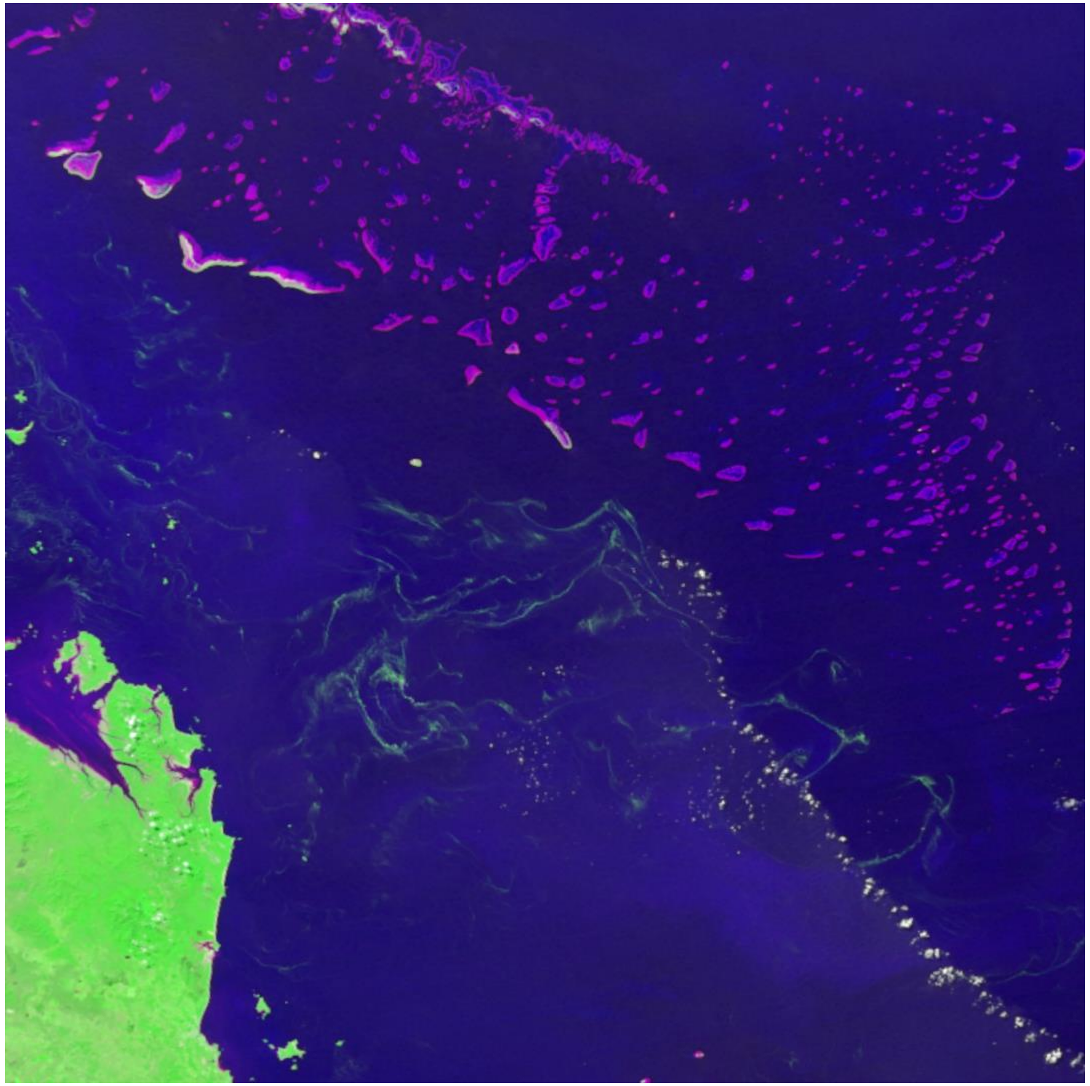


False color and floating vegetation

July 19, 2021, Great Barrier Reef

Trichodesmium

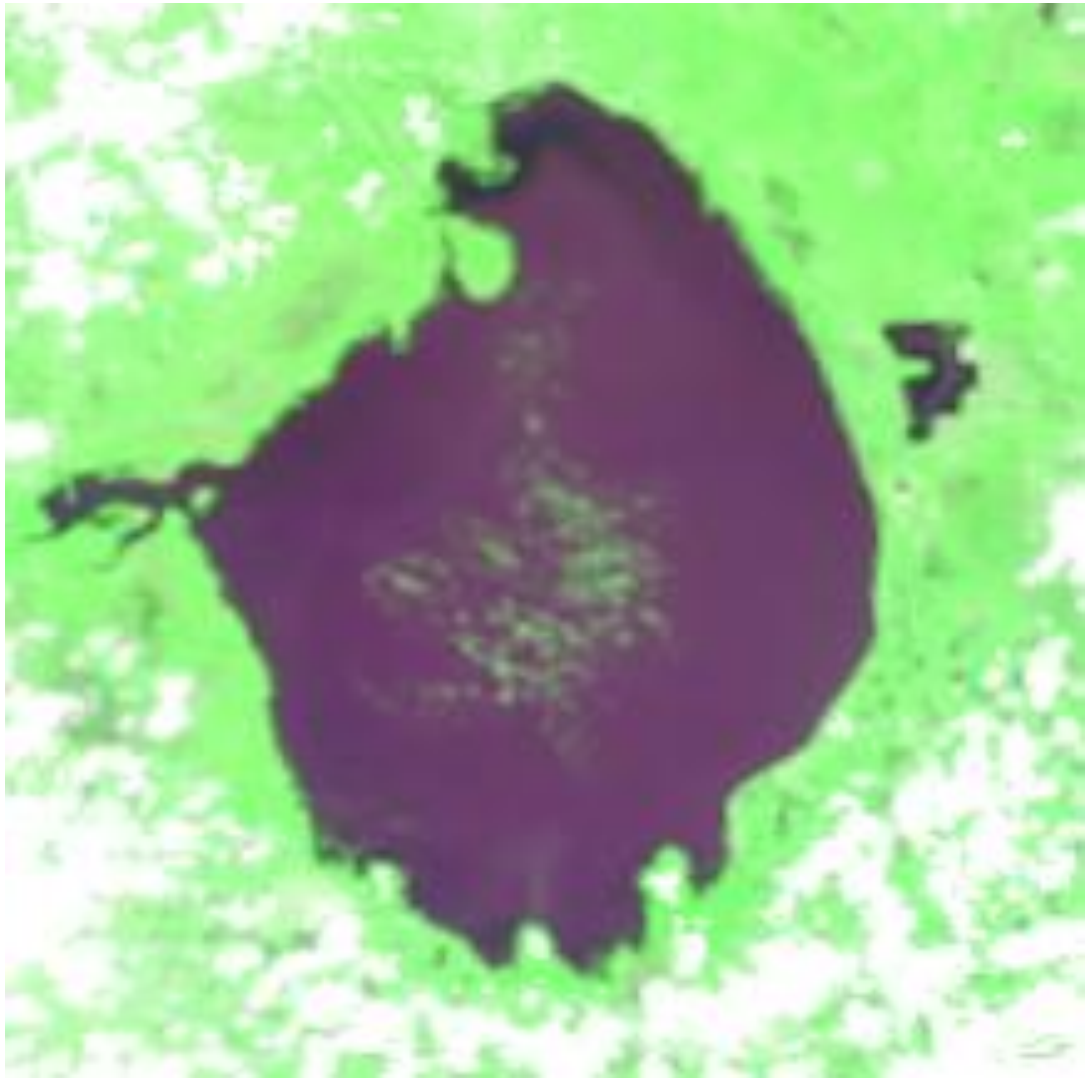




False color and floating vegetation

June 20, 2020, Lake Okeechobee, Florida

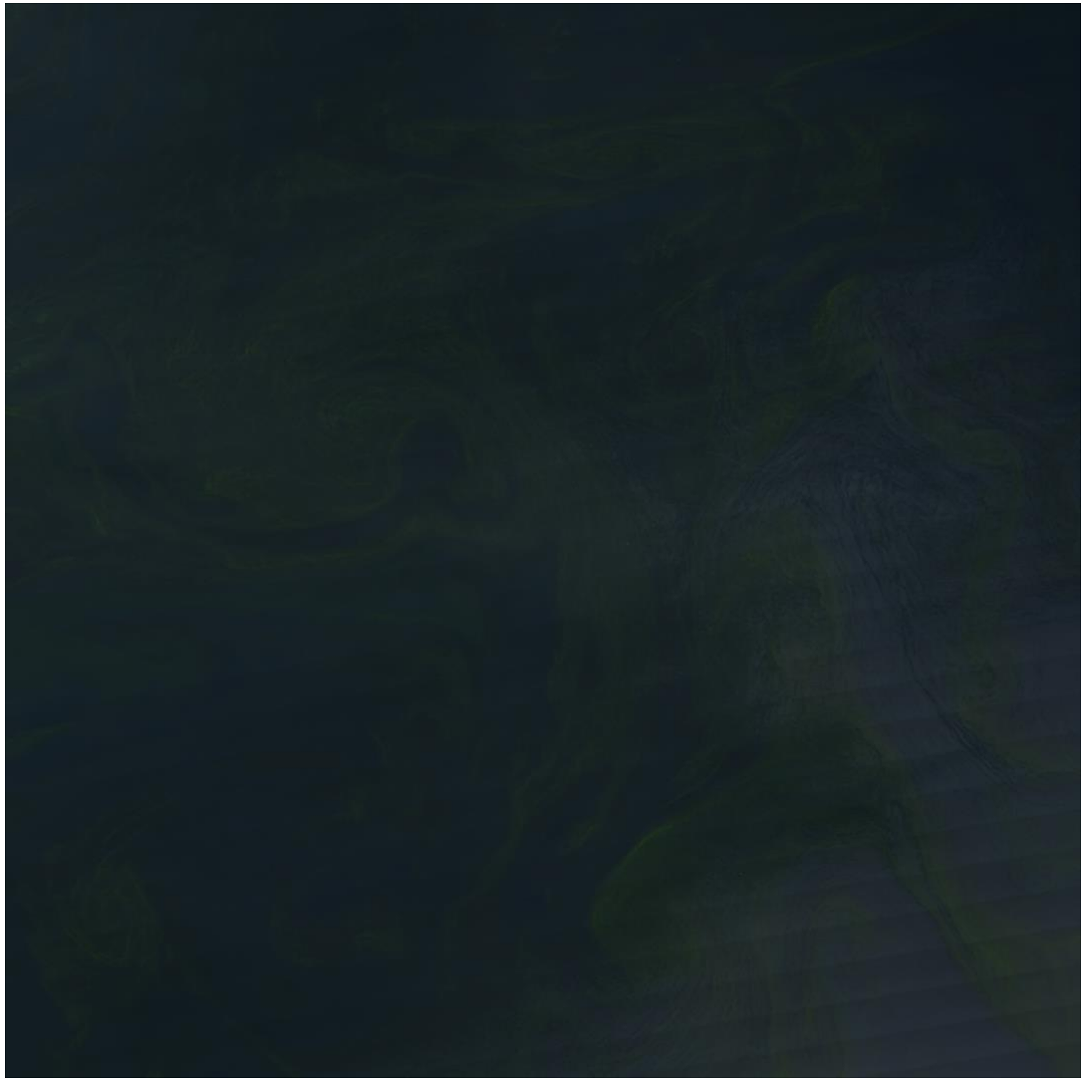
Microcystis

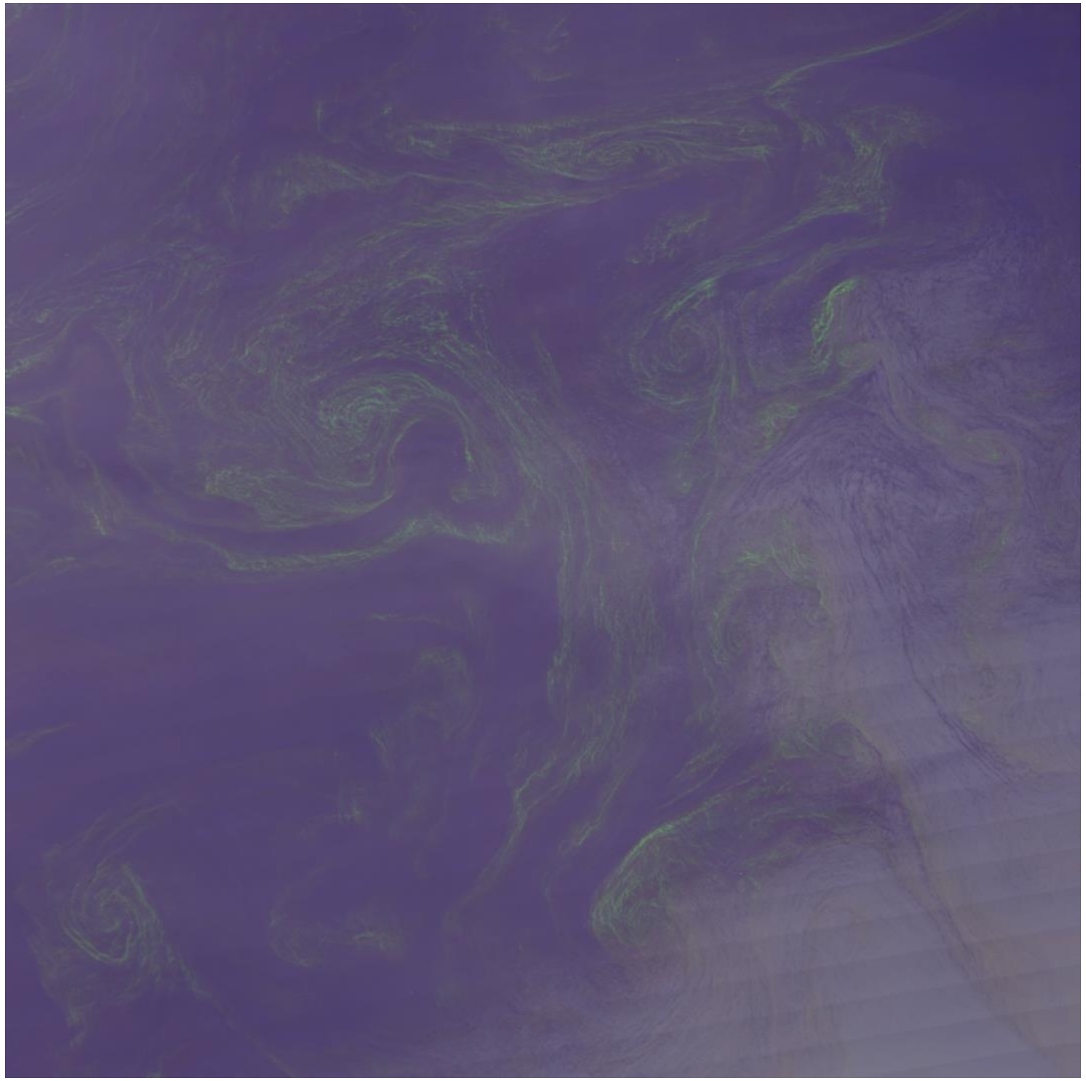


False color and floating vegetation

March 3, 2021, Arabian Sea

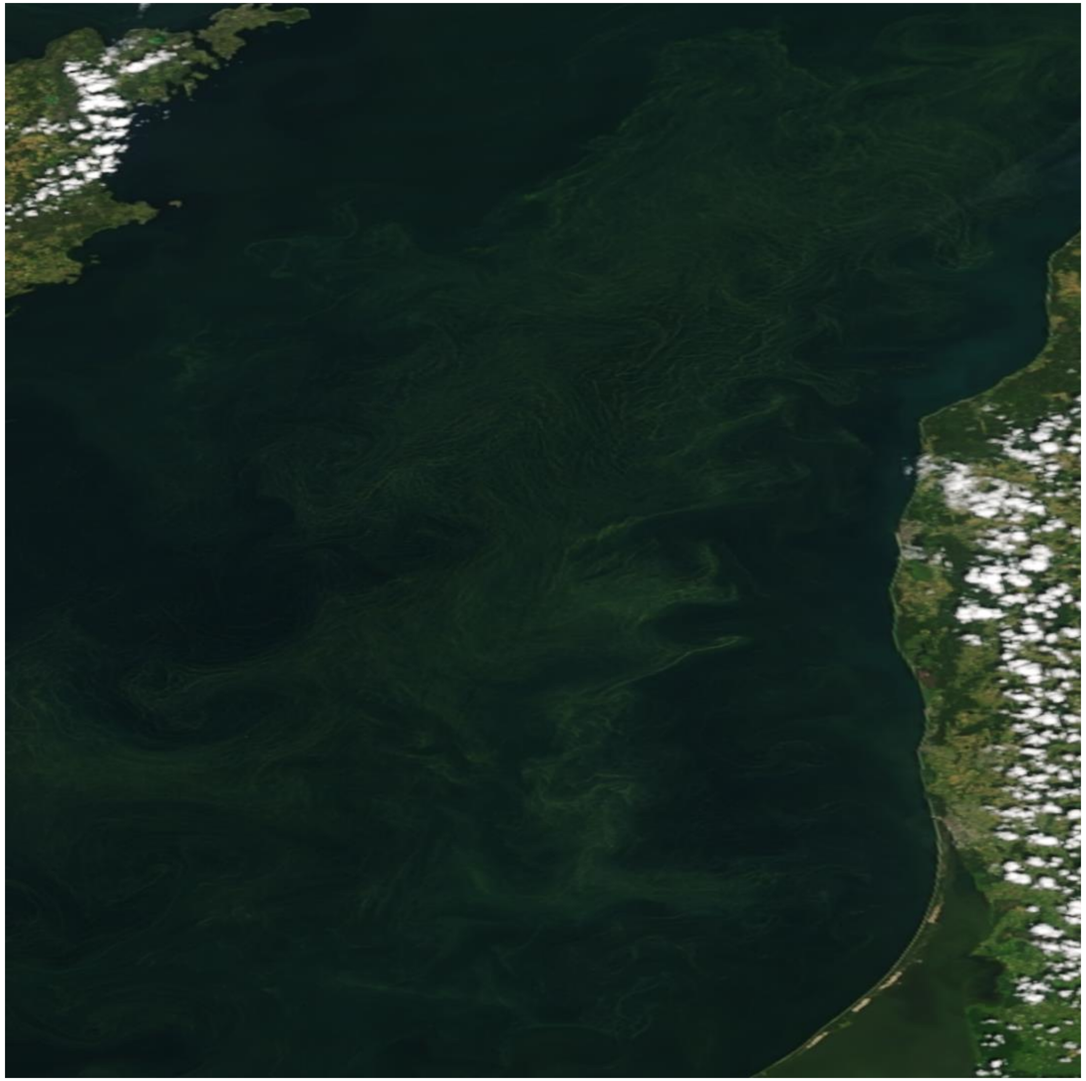
Noctiluca Scintillans

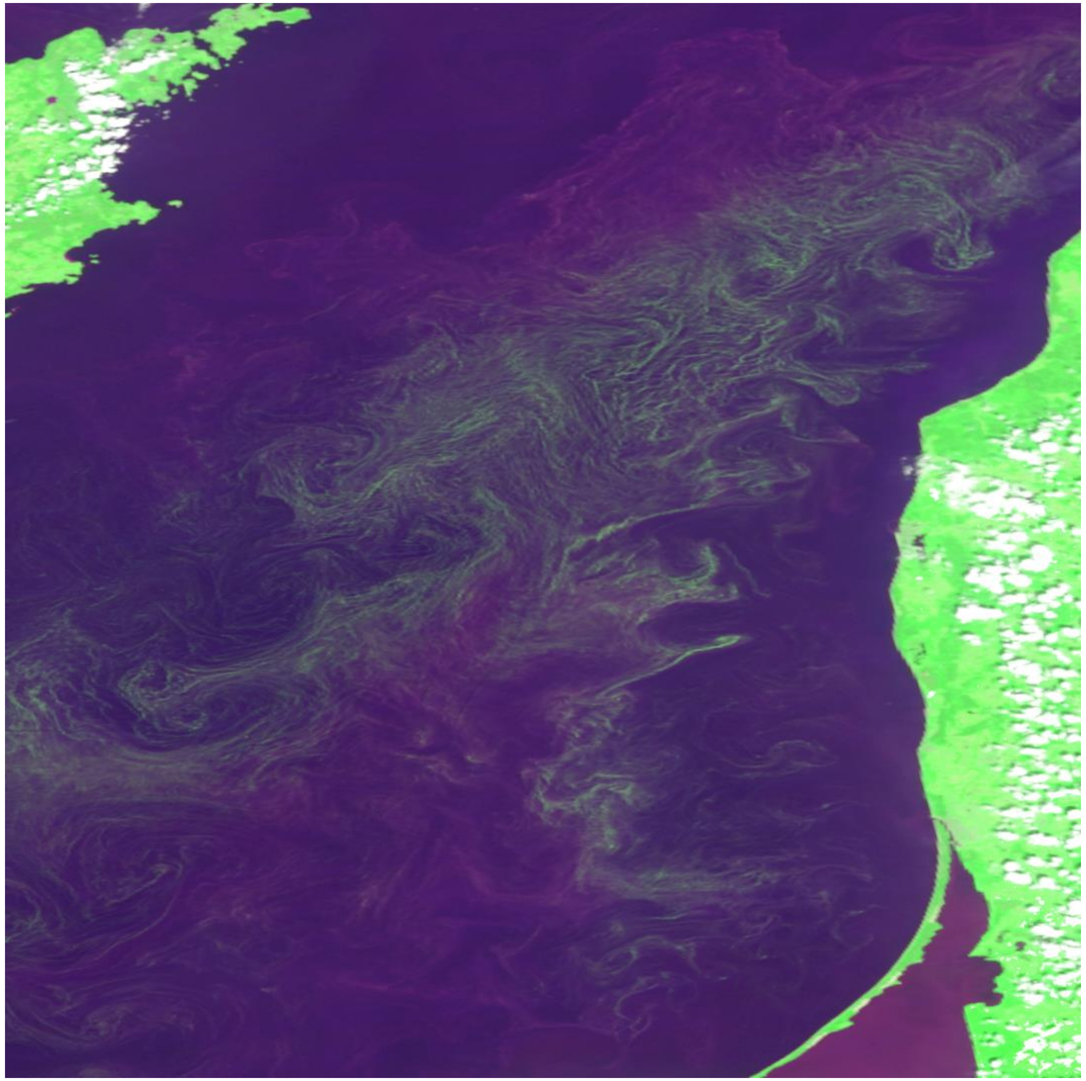




False color and floating vegetation

July 18, 2020, Baltic Sea

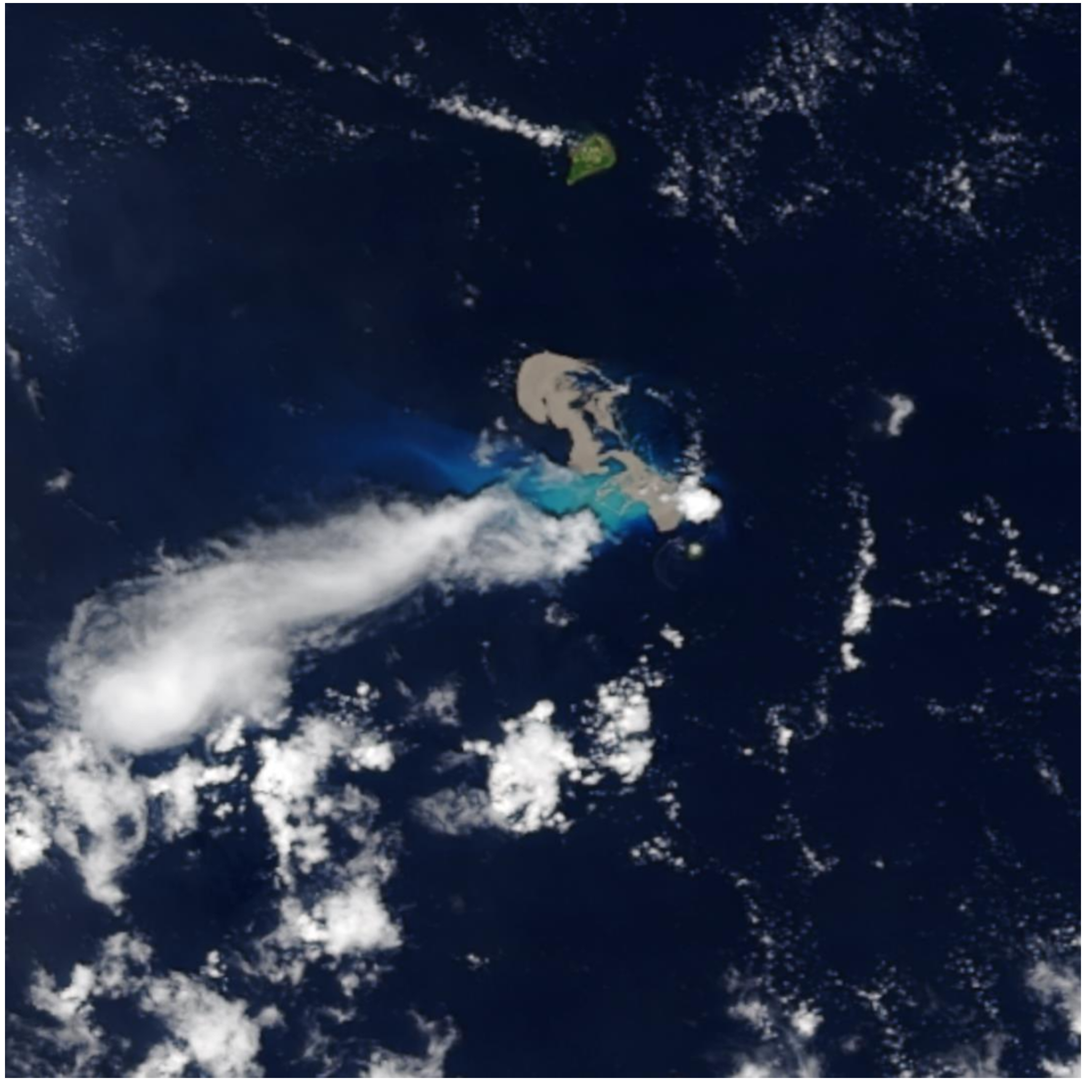


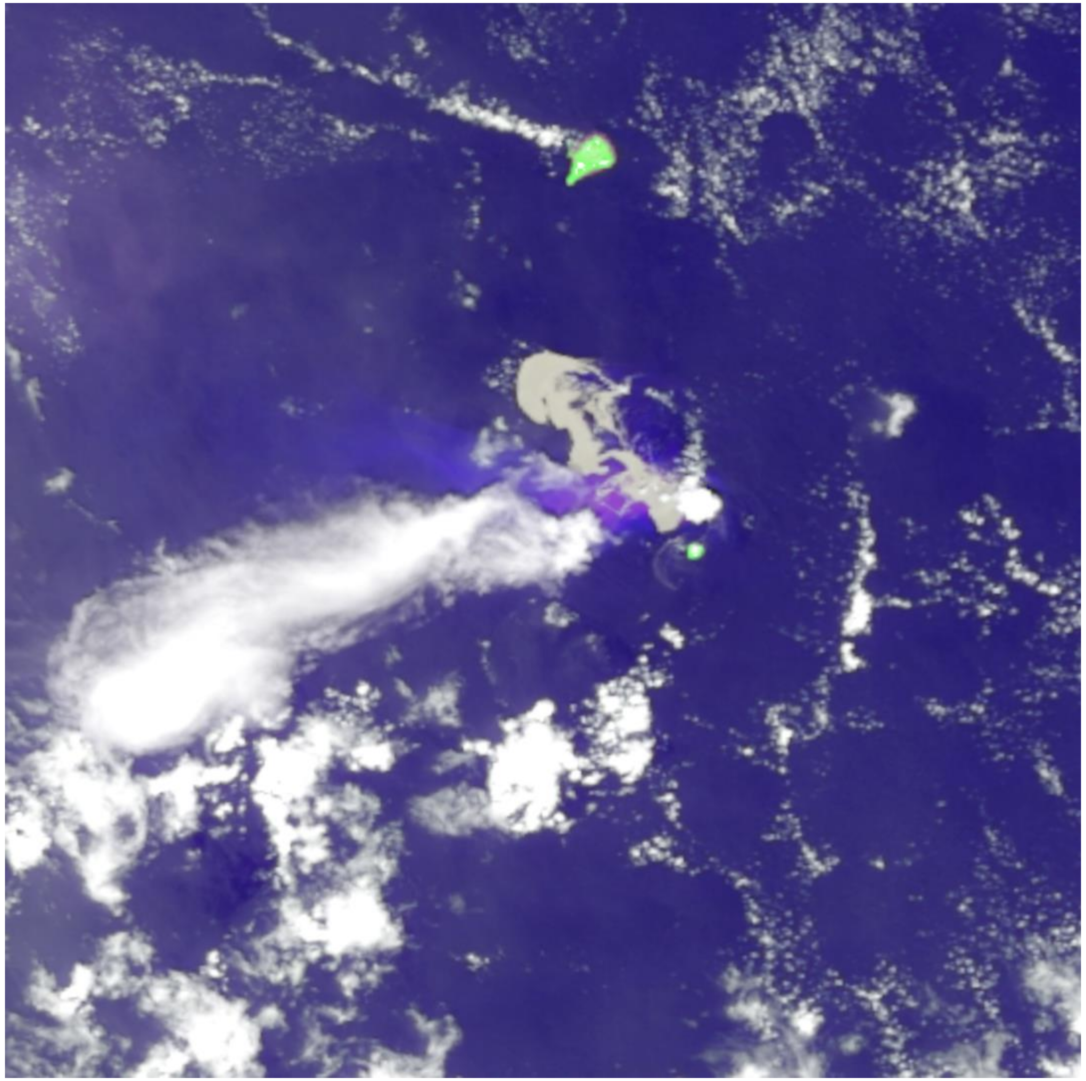


False color and floating material

August 14, 2021, South Iwo Jima, Japan

Volcanic Pumice





False color and floating vegetation

Summary

1. False color imagery is valuable tool for surveying global floating algae, and identifying and distinguishing land and water cover
2. SNPP VIIRS global false color imagery routinely produced by NOAA Ocean Color Team and displayed in OCView
3. Current SNPP VIIRS false color imagery archive on OCView goes back to 2012 and covers nearly entire SNPP VIIRS mission

L. Qi, C. Hu, K. Mikelsons, M. Wang, V. Lance, S. Sun, B.B. Barnes, J. Zhao, D. Van der Zande (2020), "In search of floating algae and other organisms in global oceans and lakes", *Remote Sens. Environ.*, **239**, 111659, https://doi.org/10.1016/j.rse.2020.111659

Clear Sky Imagery from Daily Global Imagery Time Series

Motivation

1. NOAA Ocean Color Team maintained OCView can display global medium resolution true color imagery from multiple sensors (VIIRS SNPP + NOAA-20, Sentinel-3A/B OLCI, GCOM-C SGLI, GOCI, and more coming).
2. However, clouds are very common, but not desirable for land and water surface studies
3. Deriving clear sky imagery is an active field of research, usually coupled with cloud detection, multitude of techniques exist, including machine learning, etc.
4. Cloud detection itself is a nontrivial problem and typically requires multiple spectral bands.
5. But we already have a large daily global true color imagery archive; is there something we can do?

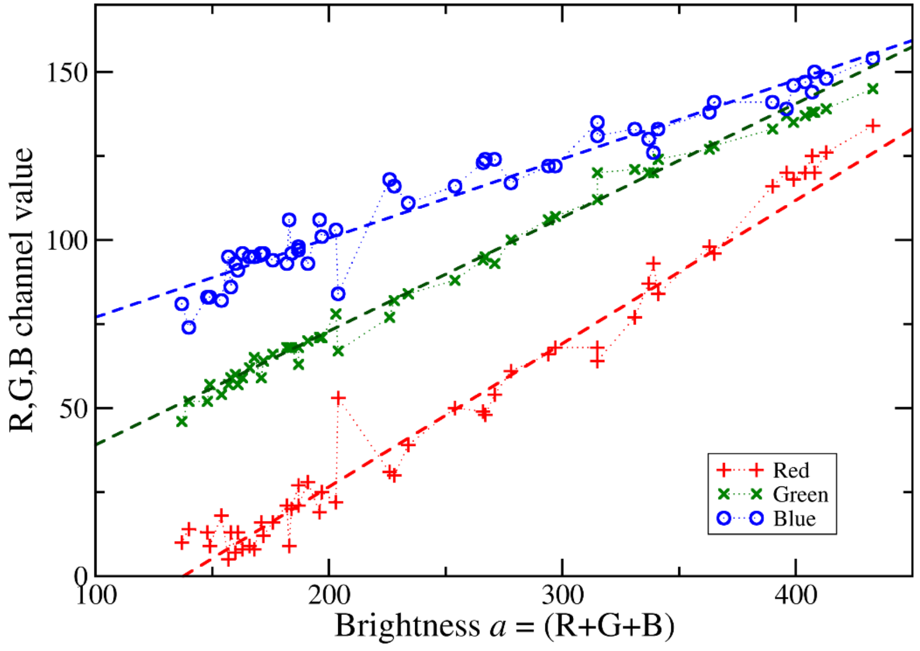
Clear Sky Imagery: Methodology

(Statistically-Robust Adaptive Regression Method (**SARM**))

1. Use existing global daily true color imagery from SNPP + NOAA-20 VIIRS + Sentinel-3A/B OLCI sensors mapped and sampled 300 m resolution, and spanning a time period (8 days, monthly, etc.).
2. For each location, discard samples with no data (outside swath for OLCI, polar night, etc.).
3. Discard the brightest samples with thick cloud cover.
4. Use remaining samples to derive clear sky imagery.

Red, Green, and Blue band surface reflectances are highly correlated in time series data (thin clouds, aerosols, and even cloud shadows affect all bands proportionally).

We can do a (statistically robust) linear fit for each color vs. brightness, and find the principal direction in the (R,G,B) space.



Clear Sky Imagery: Methodology (continued)

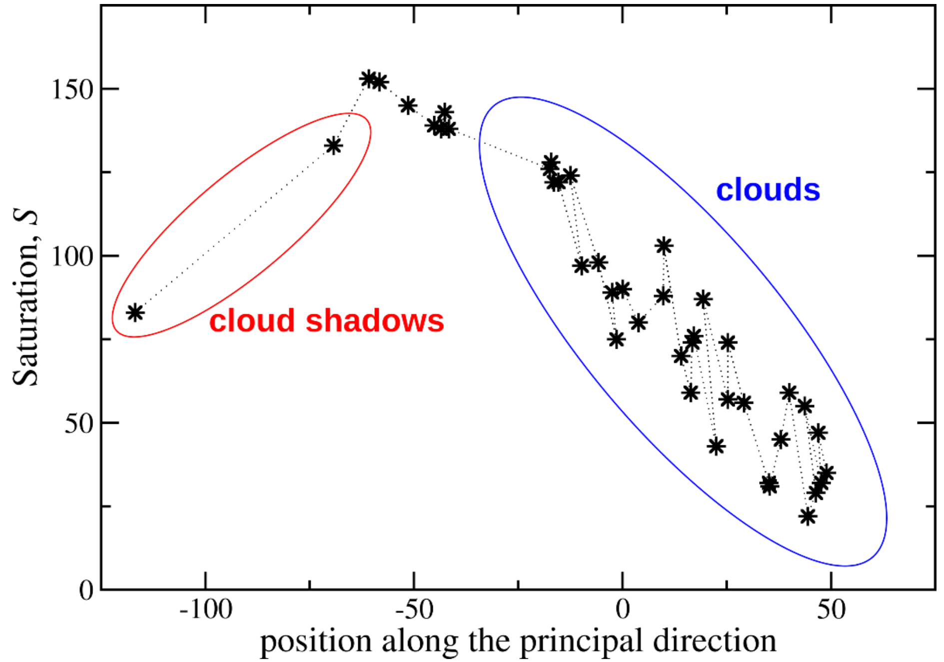
(Statistically-Robust Adaptive Regression Method (**SARM**))

Q: But how to identify and avoid cloud shadows?

Let's look at color saturation: $S = [max(R,G,B) - min(R,G,B)]/max(R,G,B)$

	Brightness	Saturation
Clouds, aerosols	increase	decrease
Cloud shadows	decrease	decrease

We can identify cloud shadows by plotting saturations vs. brightness;
And select the optimal brightness accordingly

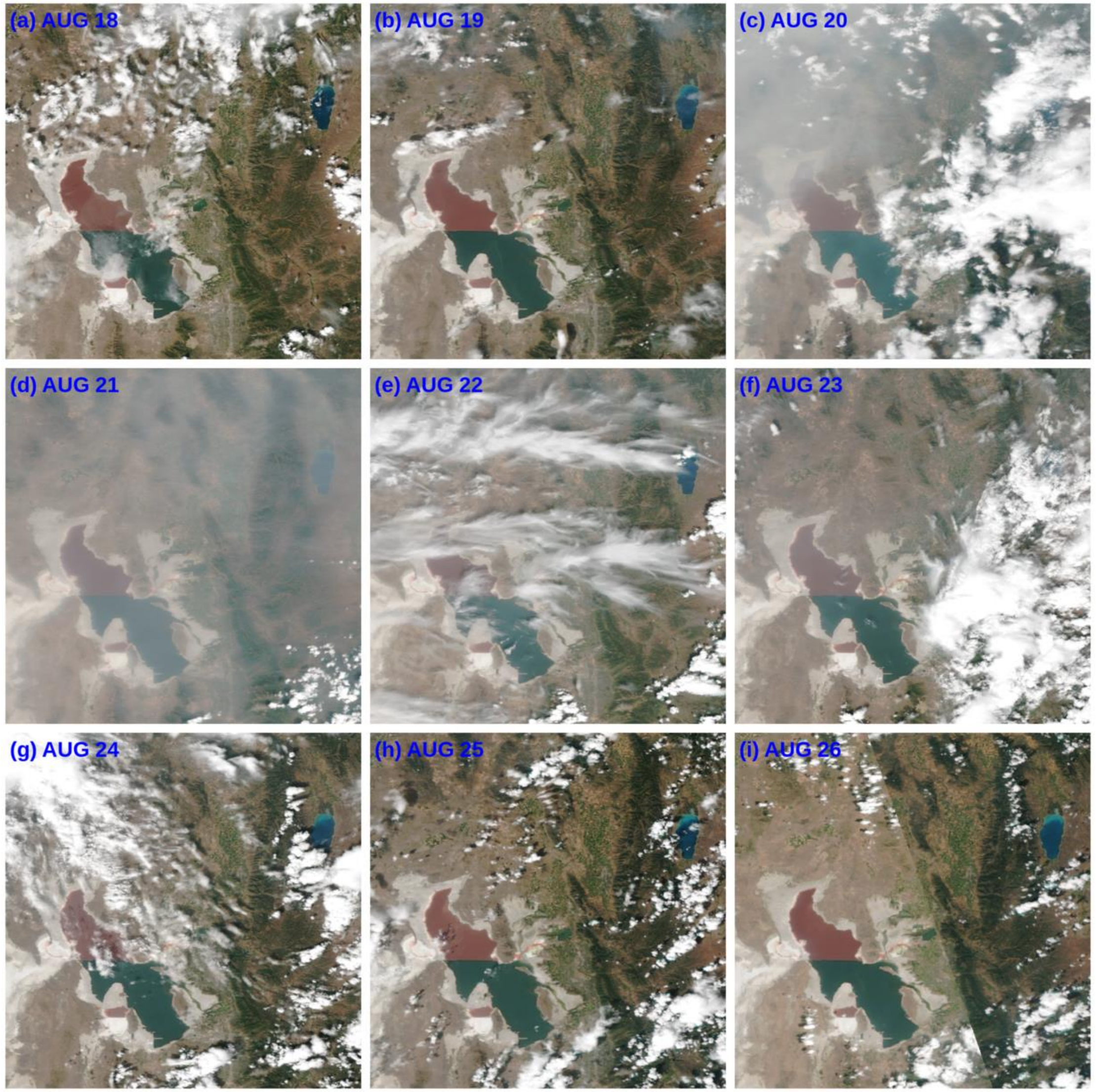


For technical details, please see:
K. Mikelsons and M. Wang, "Global clear sky near-surface imagery from multiple satellite daily imagery time series", *ISPRS Journal of Photogrammetry and Remote Sensing*, **180**, 238-254 (2021). doi:10.1016/j.isprsjprs.2021.08.013

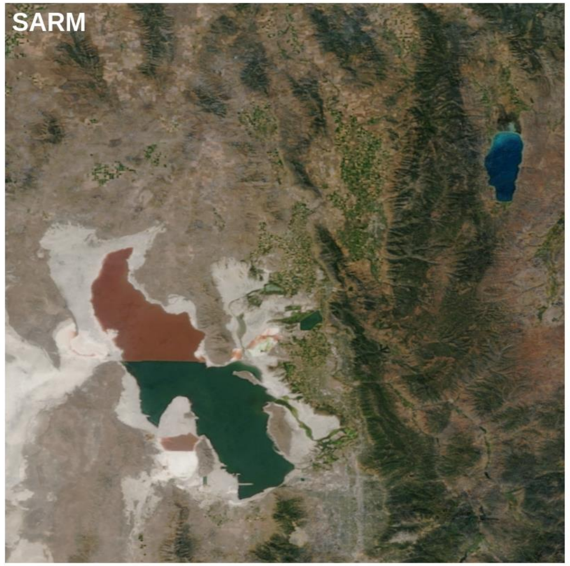
Clear Sky Imagery: Results – Validation

(Great Salt Lake Area, August 2020)

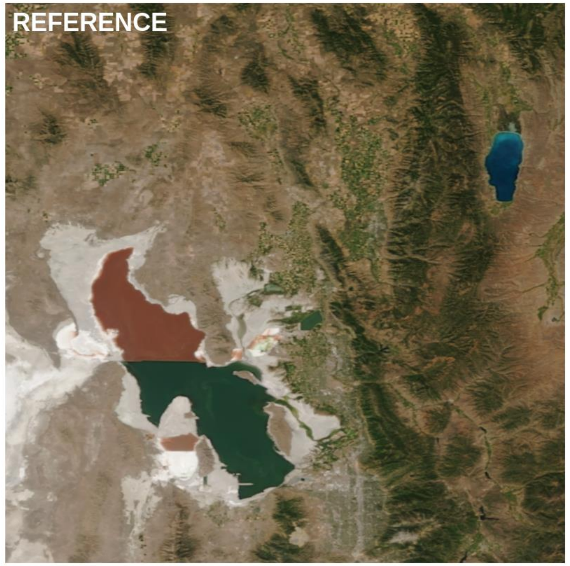
SNPP VIIRS daily imagery (similar for NOAA-20, and S3A/B OLCI)

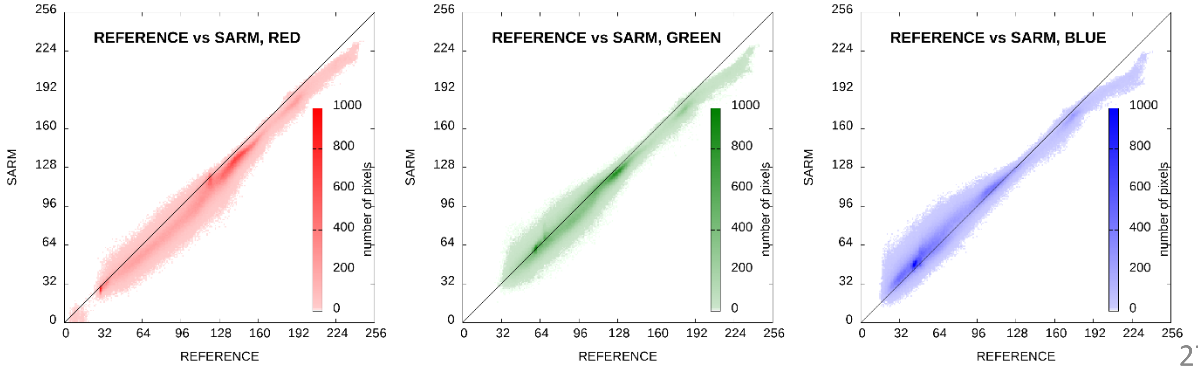


SARM result from cloudy days
August 18–26 (9 days)
SNPP + NOAA-20 VIIRS
Sentinel-3A/B OLCI



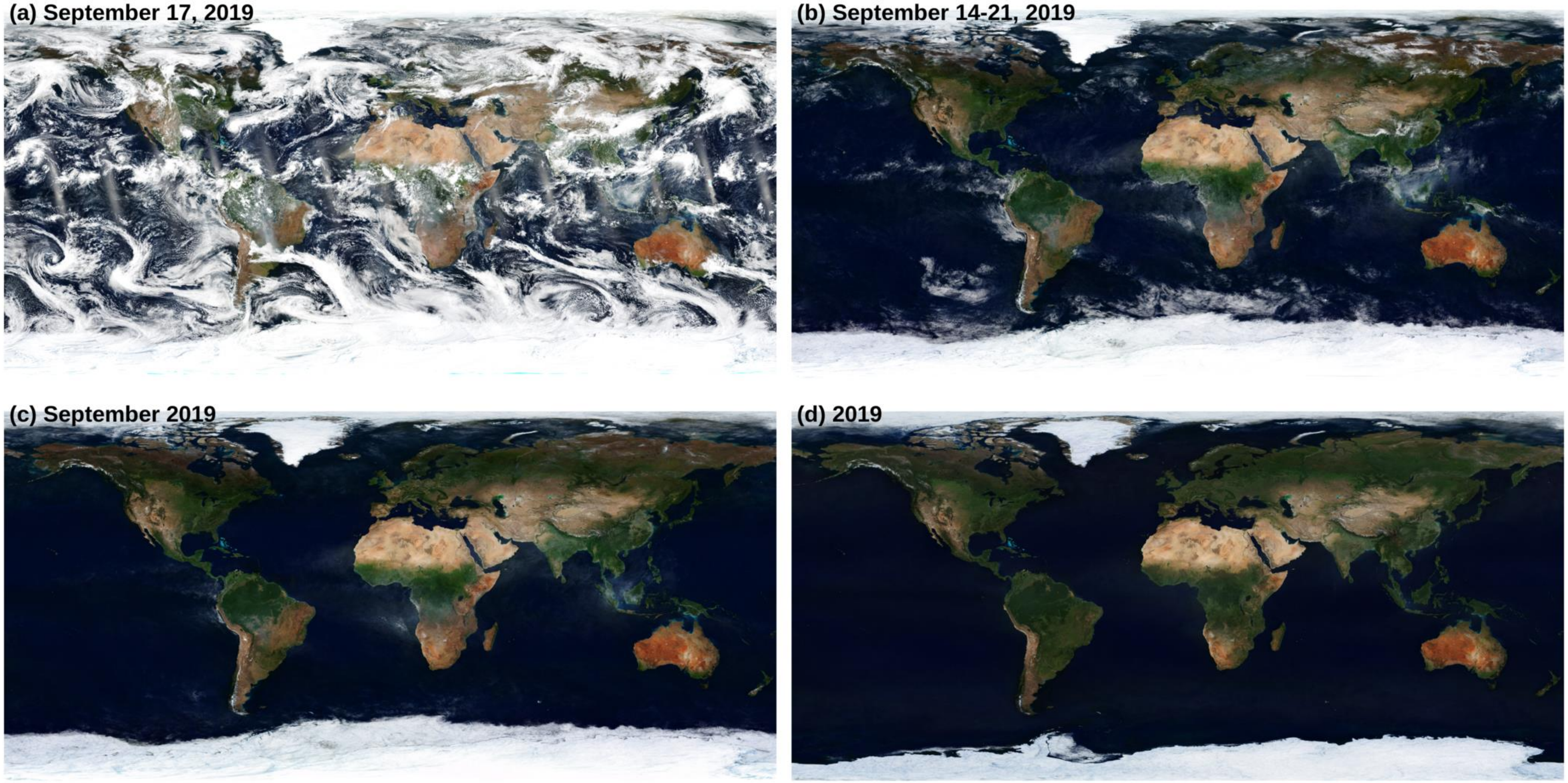
REFERENCE:
SNPP + NOAA-20 VIIRS
August 14 + September 1
(clear skies both days)





Clear Sky Imagery: Results

Global Time Averages



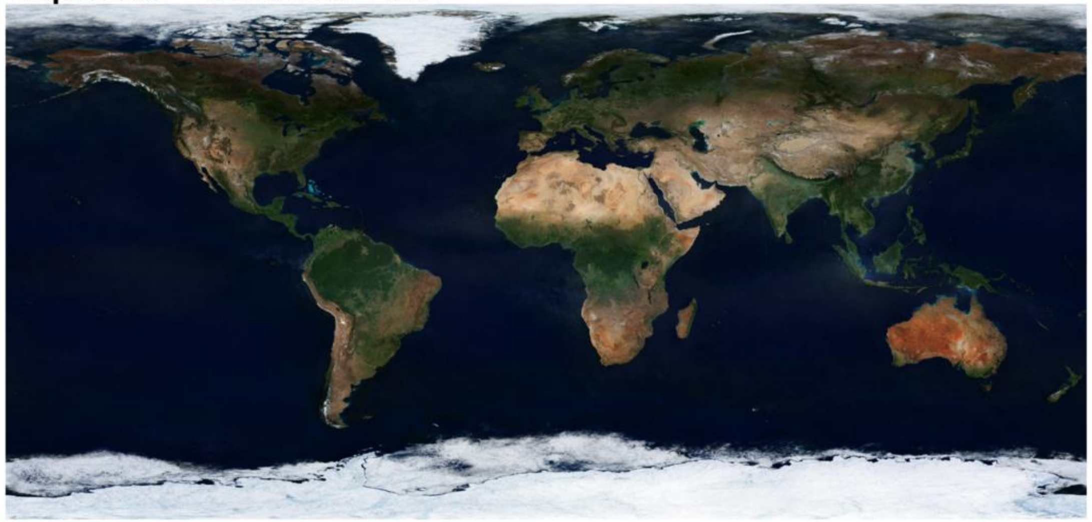
Clear Sky Imagery: Results

Global Seasonal Change

March - May 2019

June - August 2019

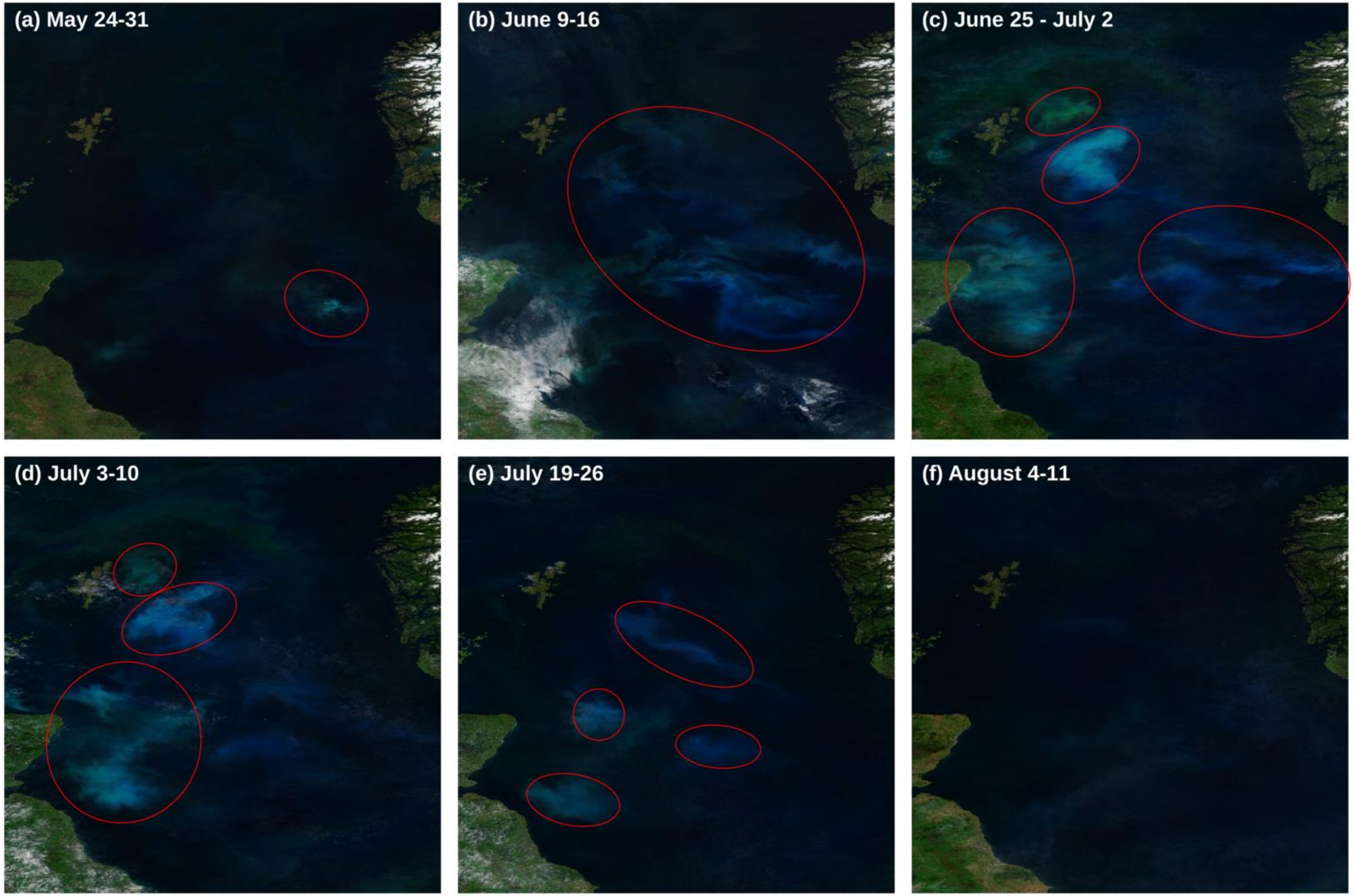
September - November 2019



December 2019 - February 2020

Clear Sky Imagery: Results

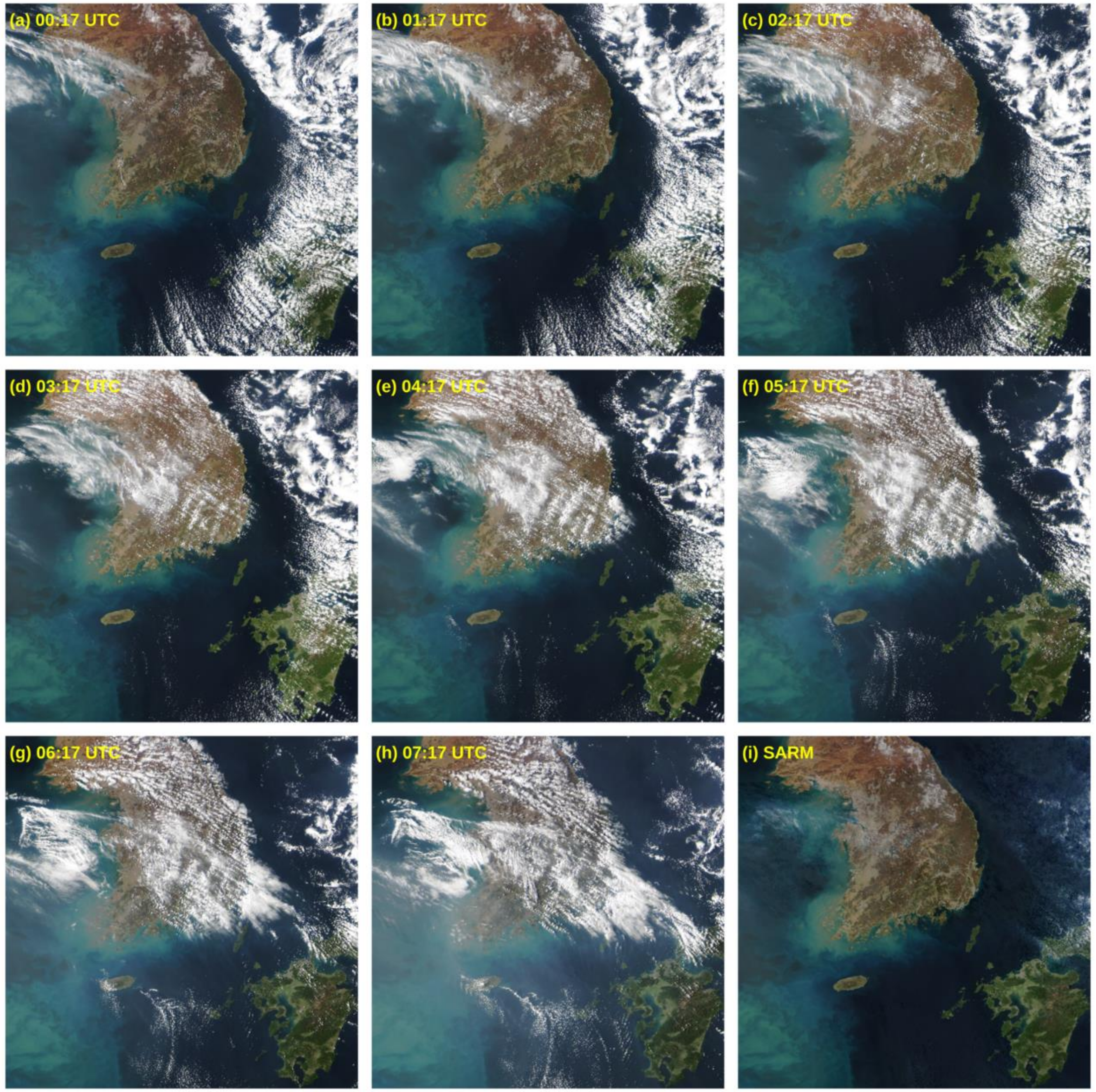
North Sea Algae Bloom (Summer 2020)



Clear Sky Imagery: Results

GOCI daily clear sky imagery (April 1, 2019)

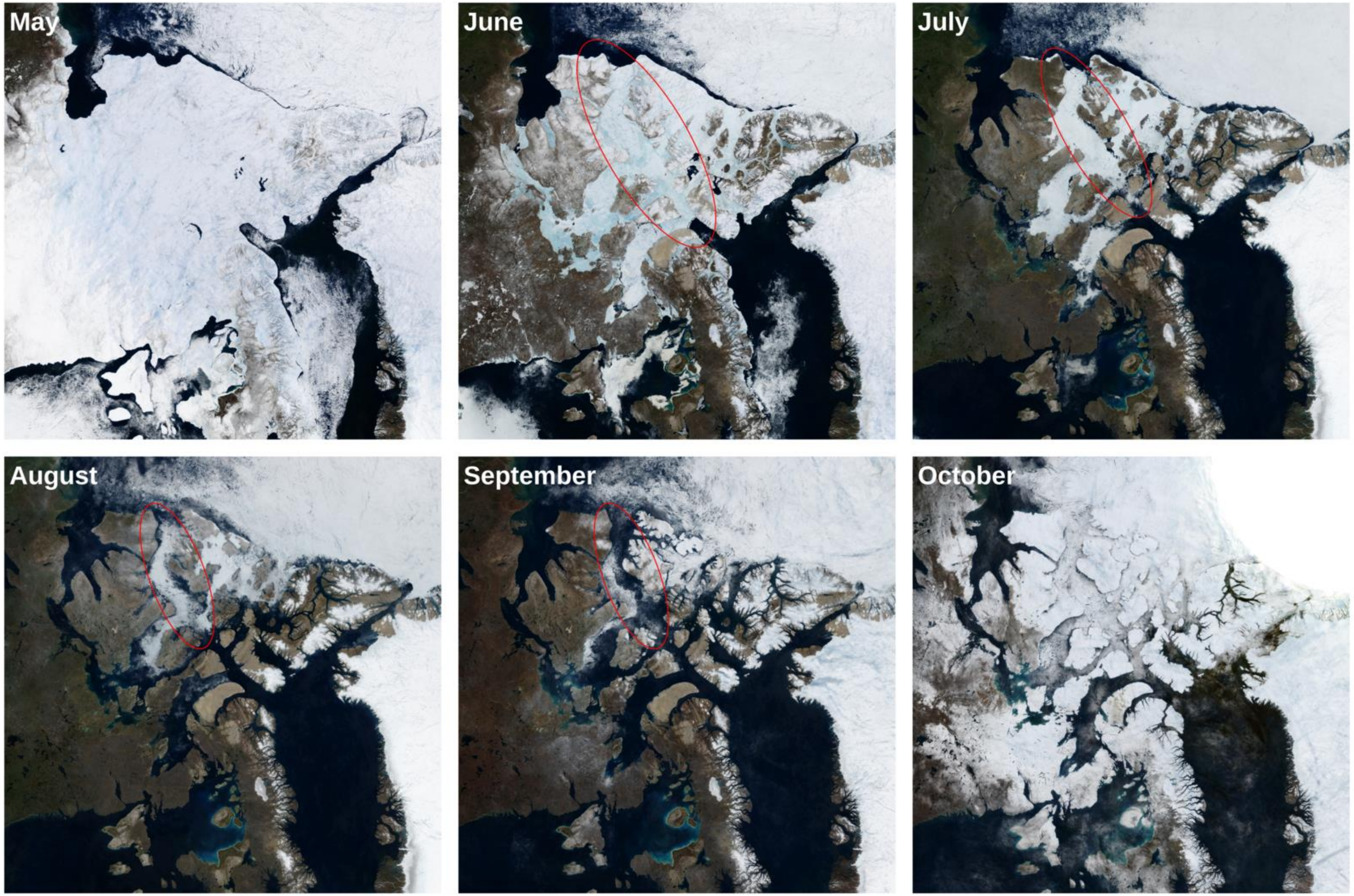
8 hourly images (a - h)



daily clear sky imagery

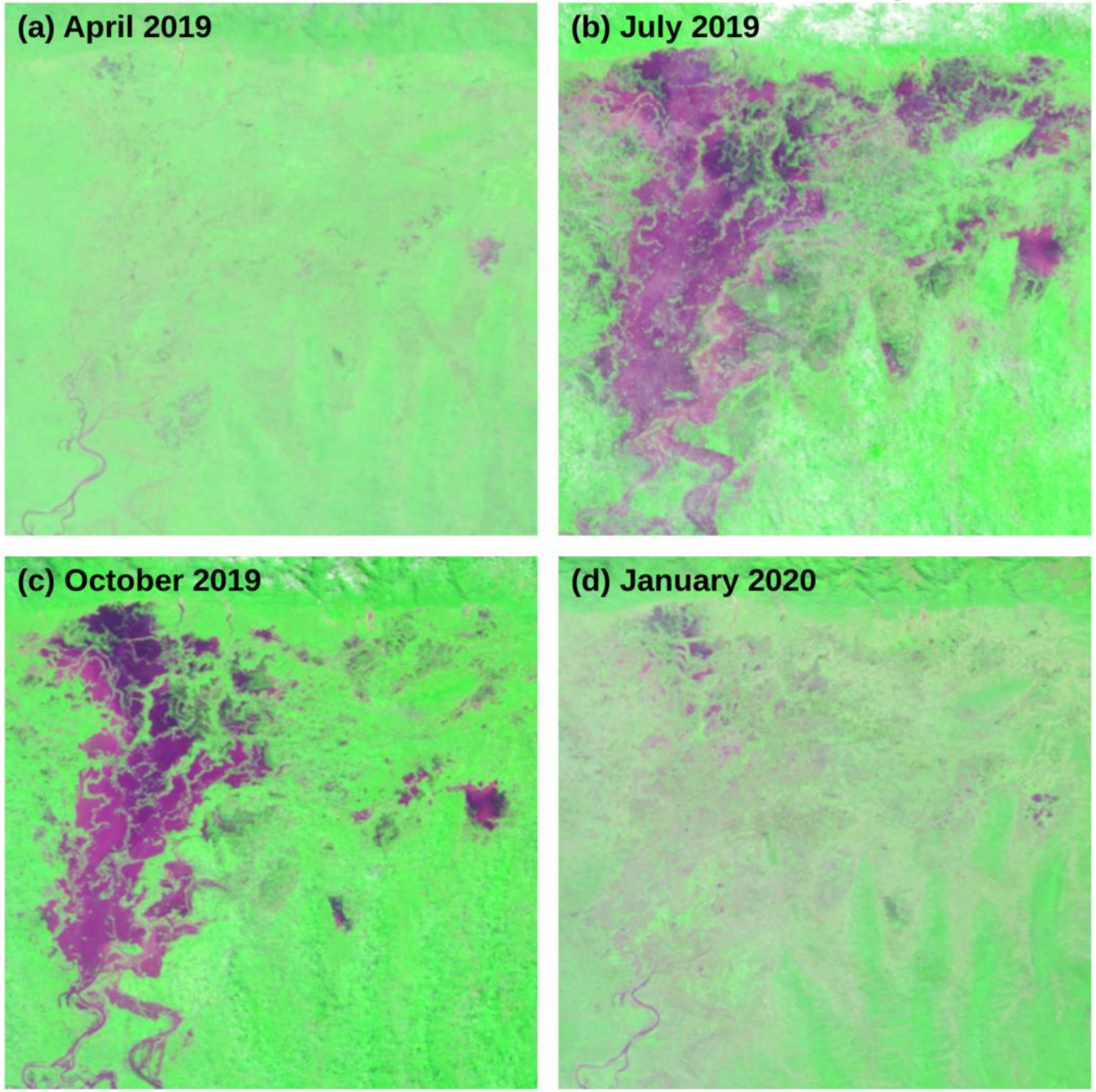
Clear Sky Imagery: Results

Ice Coverage in Arctic Canada (2019)



Clear Sky Imagery: Results

False Color Imagery (Bangladesh, 2019–2020)



False color imagery:

Image Color	VIIRS Sensor Band
Red	I1 (red)
Green	**I2 (NIR)**
Blue	M3 (blue)

Vegetation: NIR = high → **green** in false color
Water: NIR = 0 → **purple** in false color

Monthly clear sky false color imagery from SNPP VIIRS daily false color only

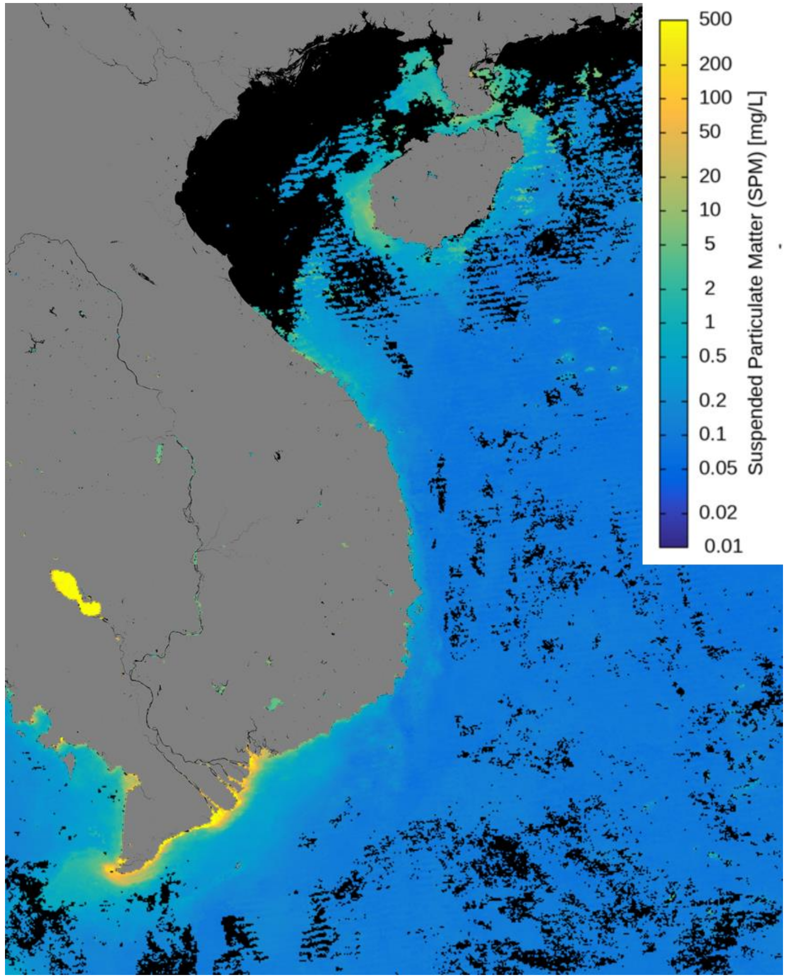
Monsoon season June – November frequent daily cloud cover

Clear Sky Imagery: Results

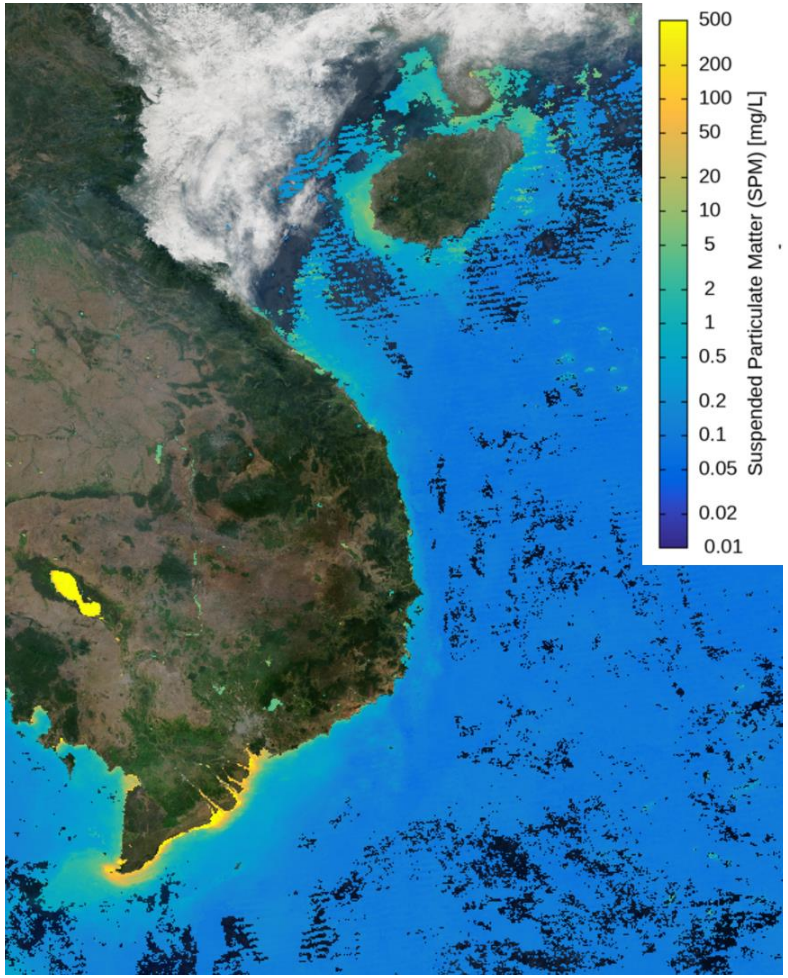
Improved Ocean Color Visualizations

Suspended Particulate Matter (SPM), February 26 – March 5, 2021, Vietnam

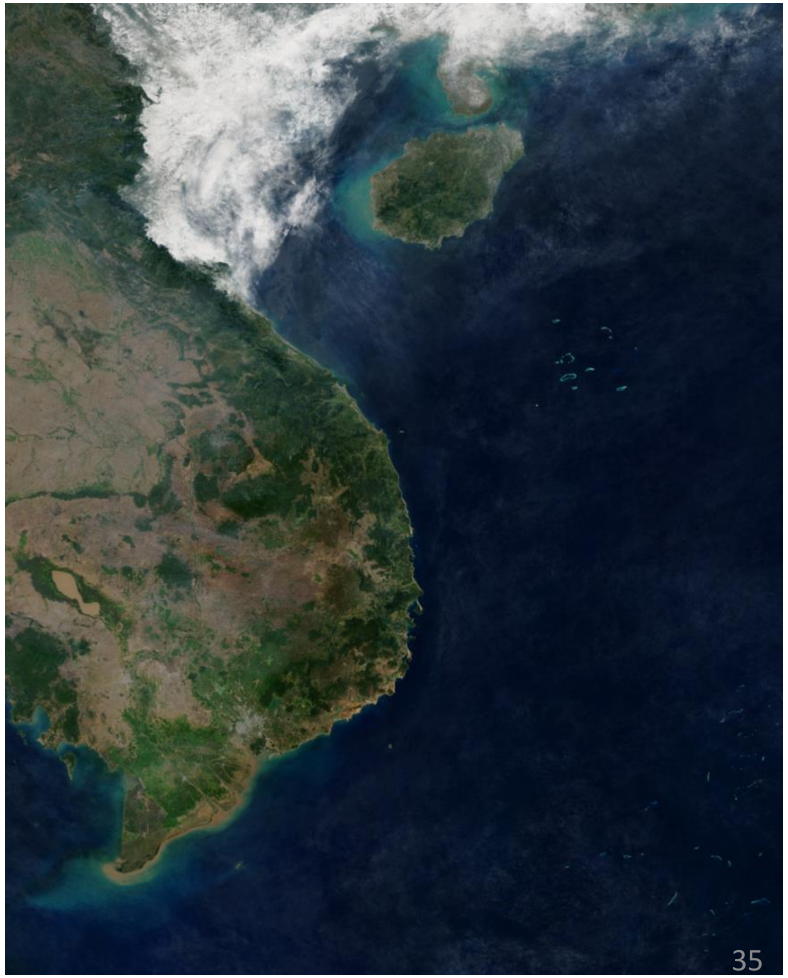
Background: Land Mask
Foreground: 8-day median SPM



Background: 8-day "clear sky" imagery
Foreground: 8-day median SPM



8-day "clear sky" true color imagery



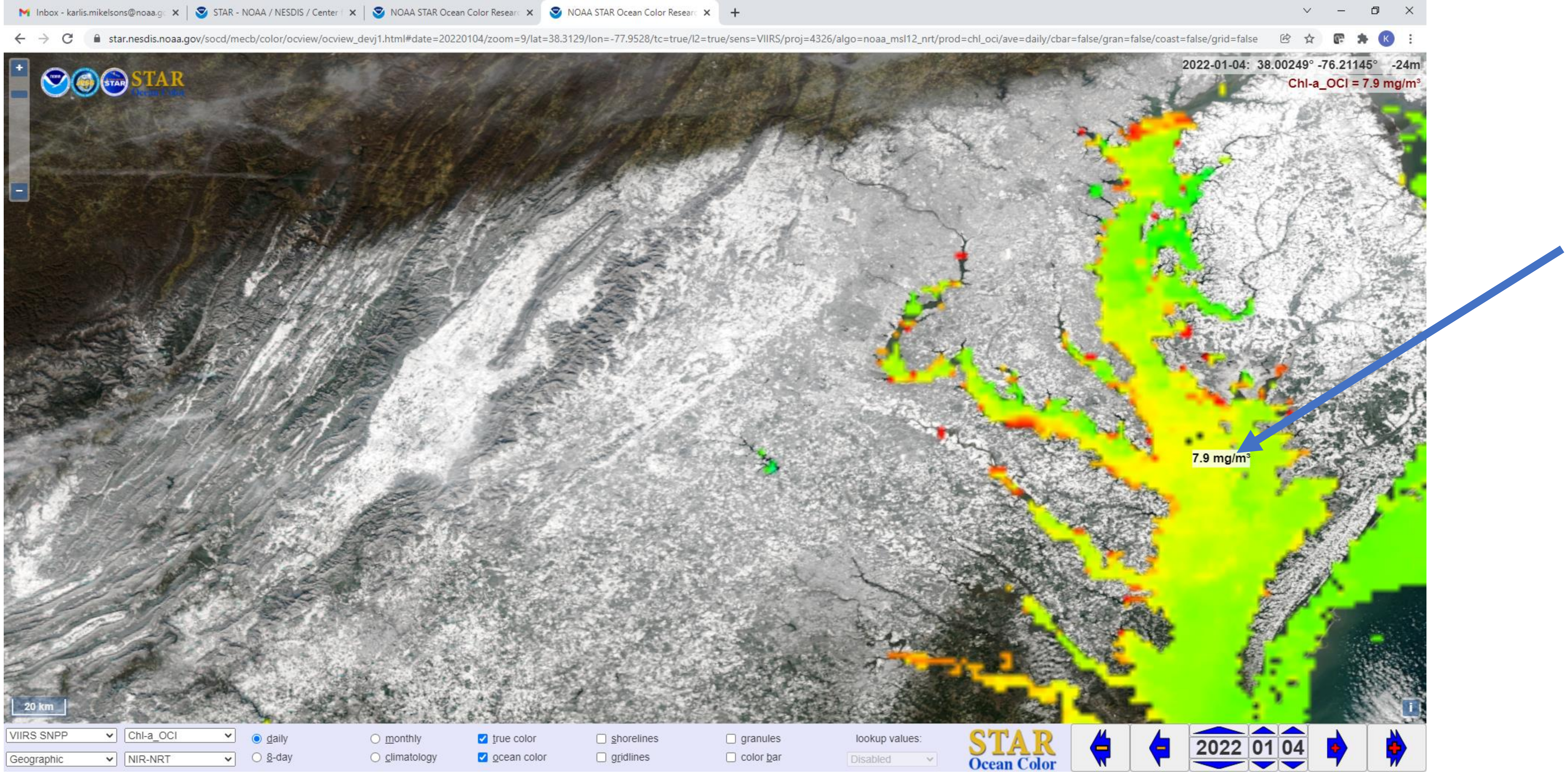
Clear Sky Imagery: Summary

1. A new method (SARM) has been developed for deriving the clear sky imagery directly from the daily multi-sensor true color imagery series.
2. Some cloud remnants may not be removed for short time interval imagery.
3. Evolution of algae blooms (also snow/ice cover) can be monitored in cloudy areas on weekly/monthly time scales.
4. Daily clear sky imagery feasible from geostationary observations of clouds is sparse and fast moving.
5. False color clear sky imagery is useful for water extent and vegetation cover monitoring.
6. Over longer time periods, the clear sky imagery may have bias towards darker surface conditions (dense vegetation, water as opposed to dry land, snow, ice, etc.).
7. Clear sky imagery can be combined with ocean color data for better visualizations.

K. Mikelsons and M. Wang, "Global clear sky near-surface imagery from multiple satellite daily imagery time series", *ISPRS Journal of Photogrammetry and Remote Sensing*, **180**, 238-254 (2021). doi:10.1016/j.isprsjprs.2021.08.013

OCView updates: Ocean Color value lookup

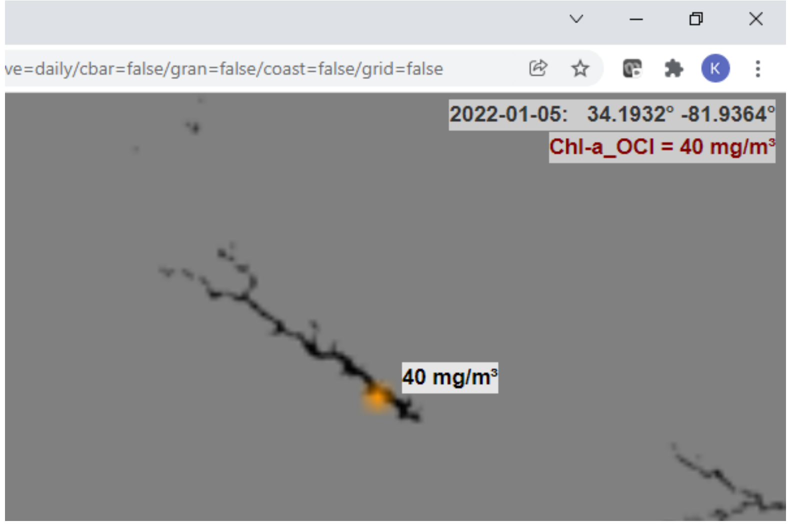
now works with true color; and has improved accuracy

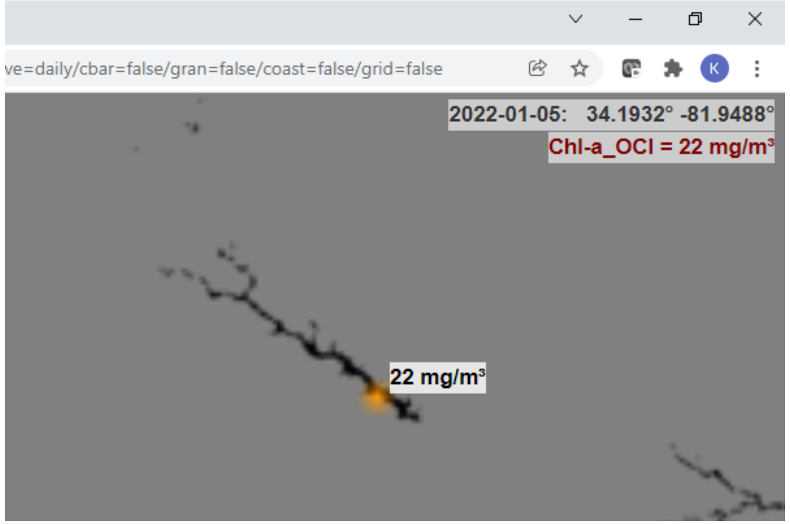


OCView updates: Ocean Color value lookup

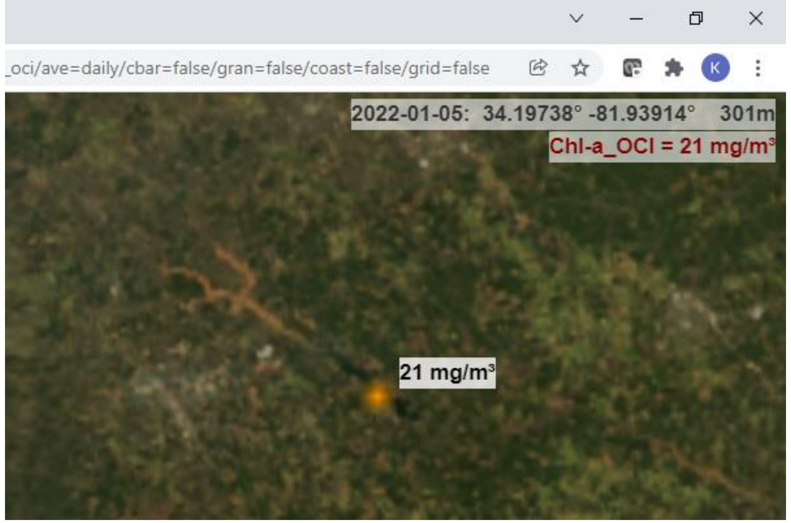
Improved accuracy

old value lookup





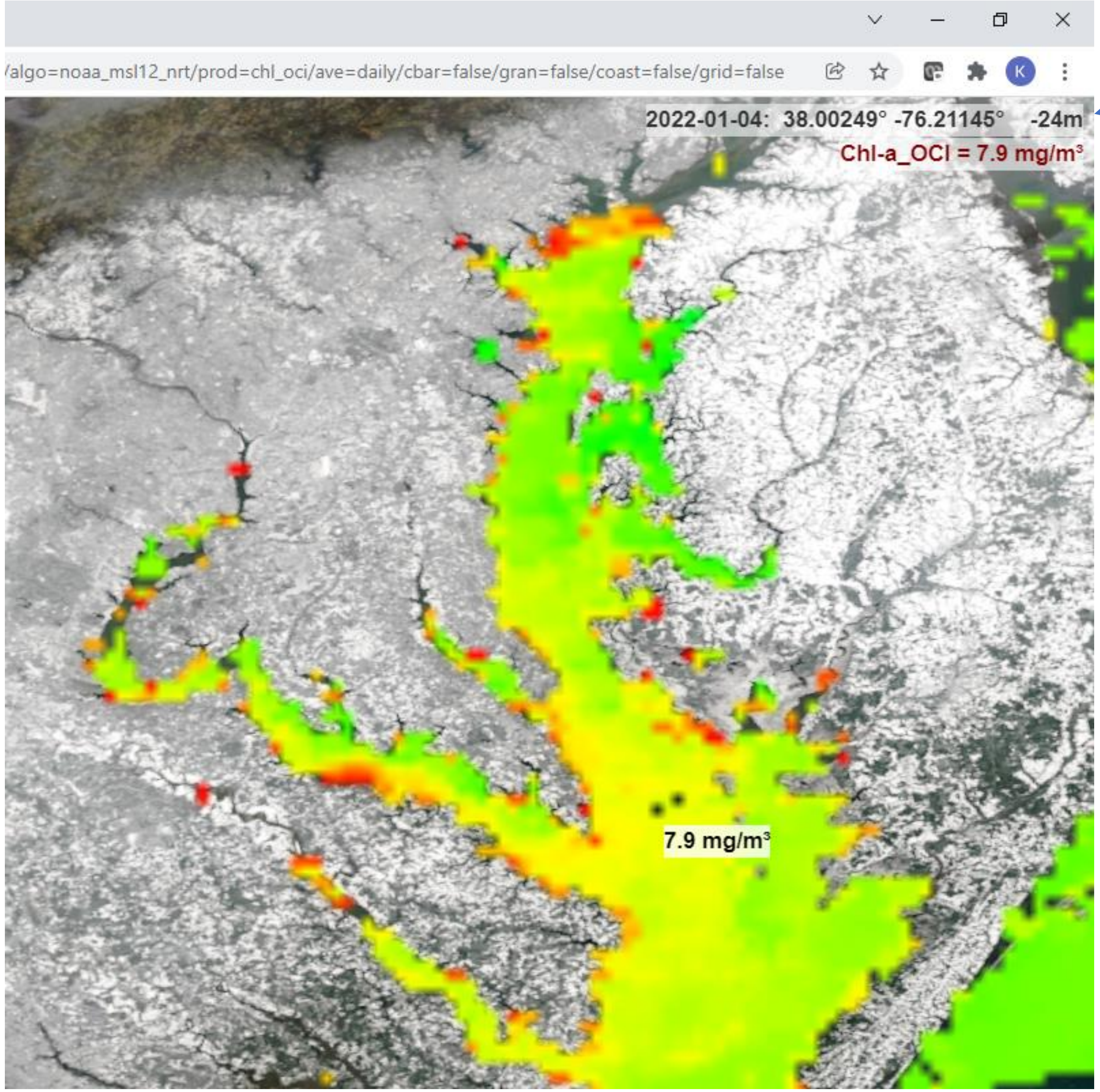
new value lookup

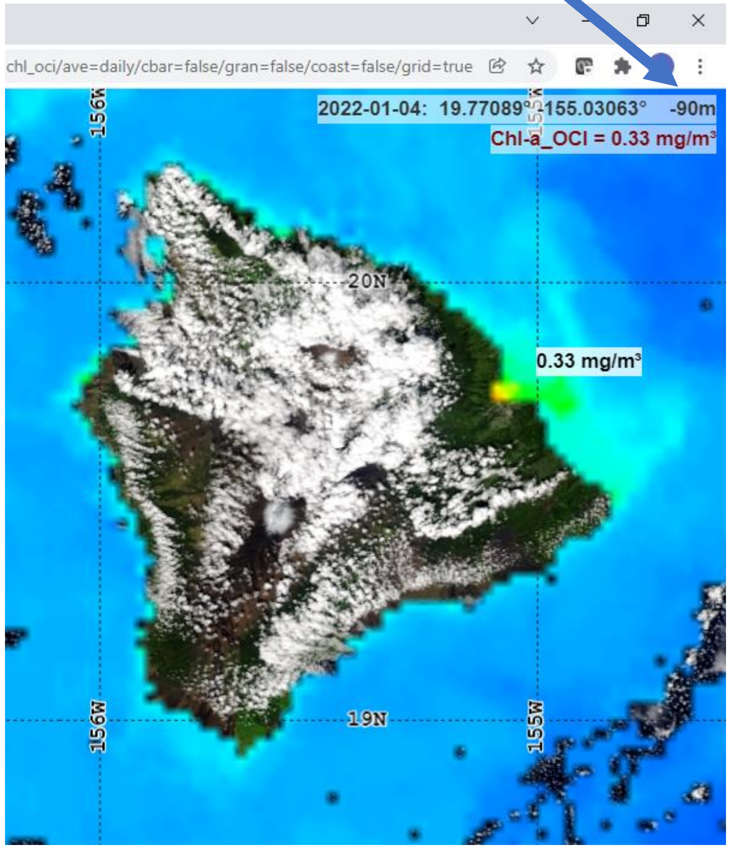


- The old value lookup relied on color on screen, which is interpolated by the browser and thus not accurate, nor consistent
- The new, updated value lookup is sourced directly from the image, which is much more accurate and consistent.
- The new value lookup is also independent from other imagery layers (can be shown together with true color)

OCView updates

Bathymetry and Elevation lookup





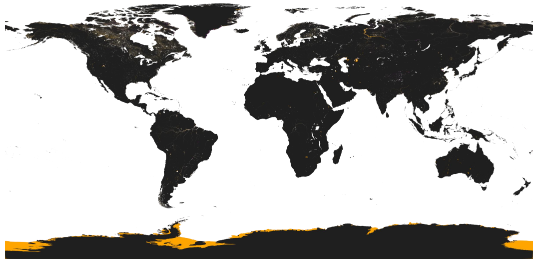
[currently not yet available for polar projections, but coming soon]

Questions & Comments

References:

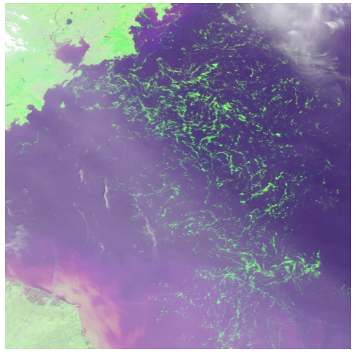
Land Mask:

K. Mikelsons, M. Wang, X. Wang, and L. Jiang (2021), “Global land mask for satellite ocean color remote sensing,” *Remote Sens. Environ.*, **257**, 112356, https://doi.org/10.1016/j.rse.2021.112356.



False Color & Floating Vegetation:

L. Qi, C. Hu, K. Mikelsons, M. Wang, V. Lance, S. Sun, B.B. Barnes, J. Zhao, D. Van der Zande (2020), “In search of floating algae and other organisms in global oceans and lakes”, *Remote Sens. Environ.*, **239**, 111659, https://doi.org/10.1016/j.rse.2020.111659



Clear Sky Imagery:

K. Mikelsons and M. Wang, "Global clear sky near-surface imagery from multiple satellite daily imagery time series", *ISPRS Journal of Photogrammetry and Remote Sensing*, **180**, 238-254 (2021). doi:10.1016/j.isprsjprs.2021.08.013

OCView:

https://www.star.nesdis.noaa.gov/socd/mecb/color/ocview/ocview.html