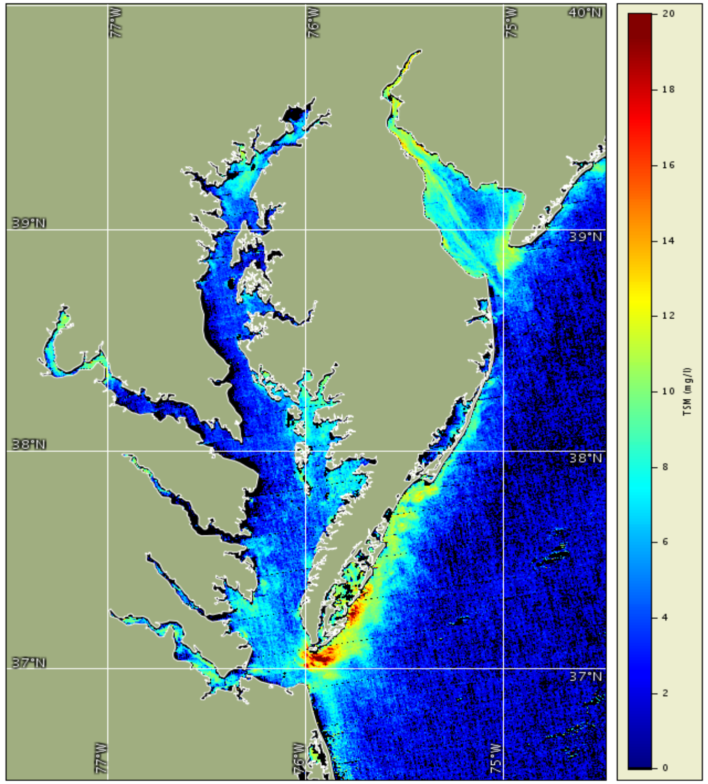
NOAA satellite products for water clarity

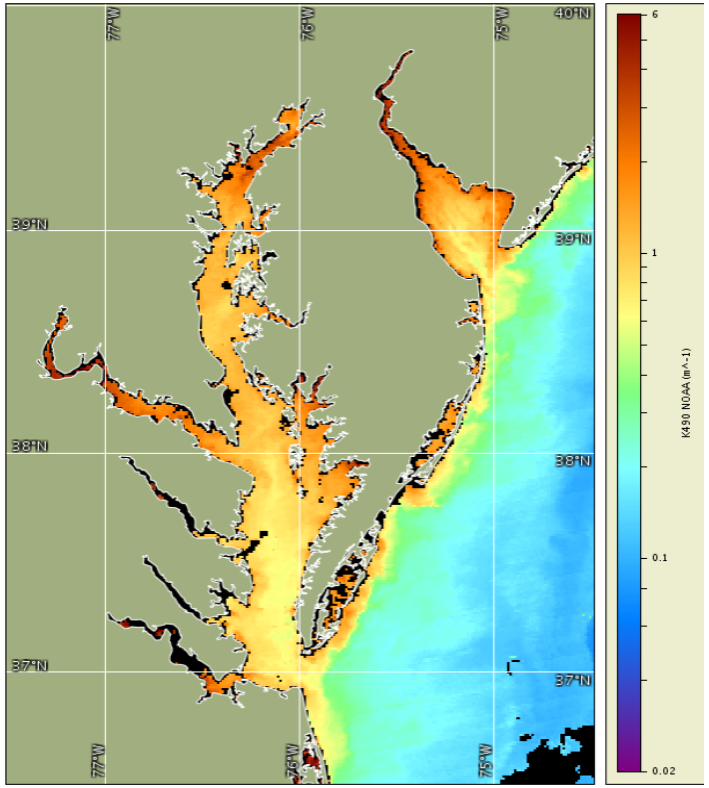
Total Suspended Matter

Suspended Matter Concentration



Kd: Kd490, KdPAR

Diffuse Light Attenuation



Contact: Ron Vogel (UMD/ESSIC & NOAA/STAR), ronald.vogel@noaa.gov

NOAA CoastWatch/OceanWatch Program: coastwatch.noaa.gov

Outline

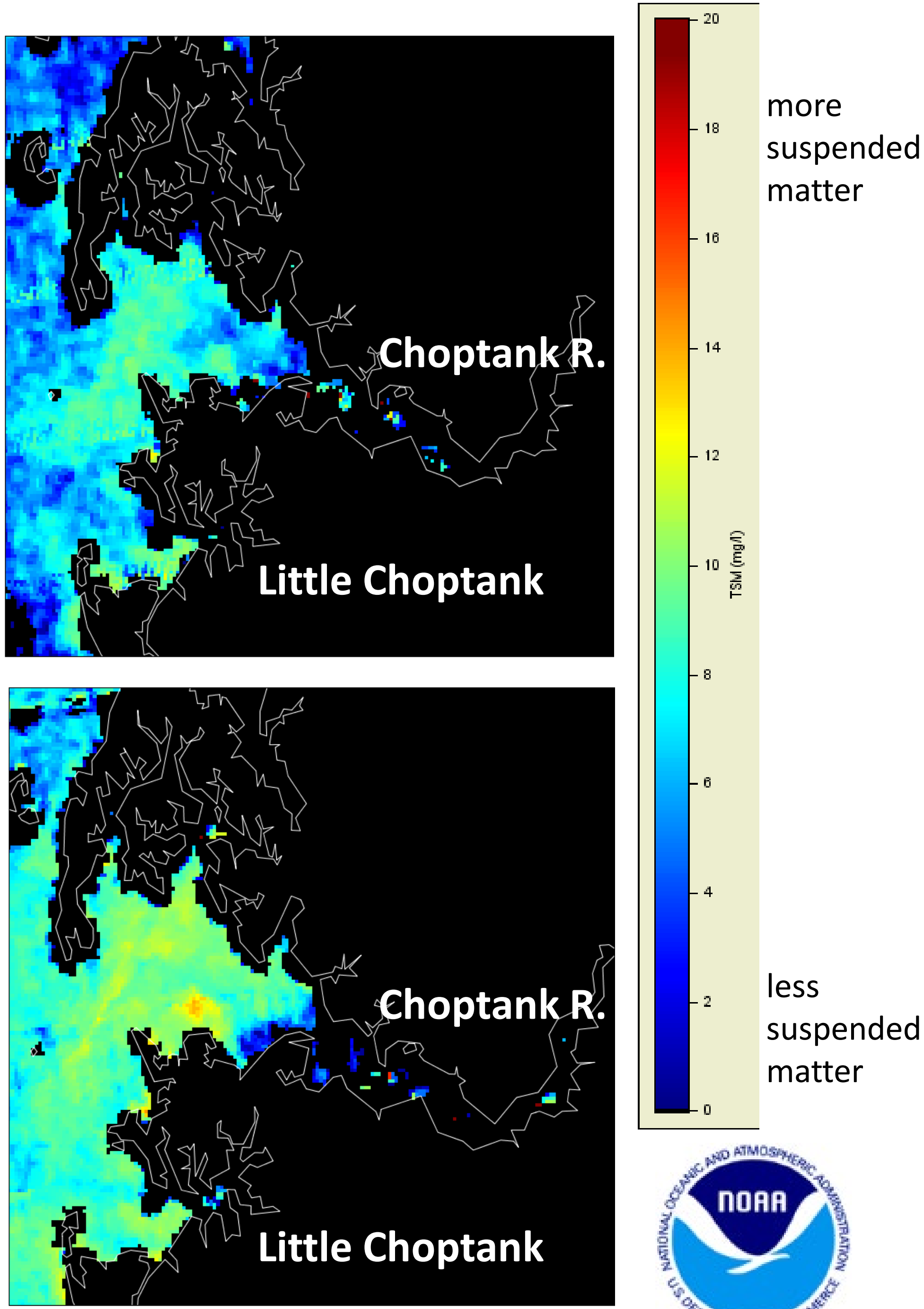
- Satellite product definitions & characteristics
- Some use cases
- Spatial resolution
- Satellite product accuracy
    1. Published algorithm accuracy statements
    2. Example product comparison in Bay
- Summary: Products, Data Considerations
- Possibilities to push the state of the art
- Opportunities in forthcoming satellite technologies

Total Suspended Matter (TSM) from Satellite

- **Suspended matter concentration (mg/L) in surface water (depth of euphotic zone)**
- Satellites provide spatial overview
  - Detect spatial patterns
- Once daily observation (from each satellite)
  - Monitor change over time
- 250, 300, 375, 1000 m spatial resolution
- 13+ year time series: 2009 – 2022 and ongoing
- Data from 3 instruments on 5 satellites: NASA, NOAA, EUMETSAT
  - Instruments: MODIS (1), VIIRS (2), OLCI (2)
- Clouds cause missing data in daily overpasses
- MODIS & VIIRS algorithms specifically developed for Chesapeake Bay by NOAA (Ondrusek et al., 2012).
  - OLCI not specific to Bay. VIIRS 1km not specific to Bay.
- Other terms used: Suspended Particulate Matter, Total Suspended Solids

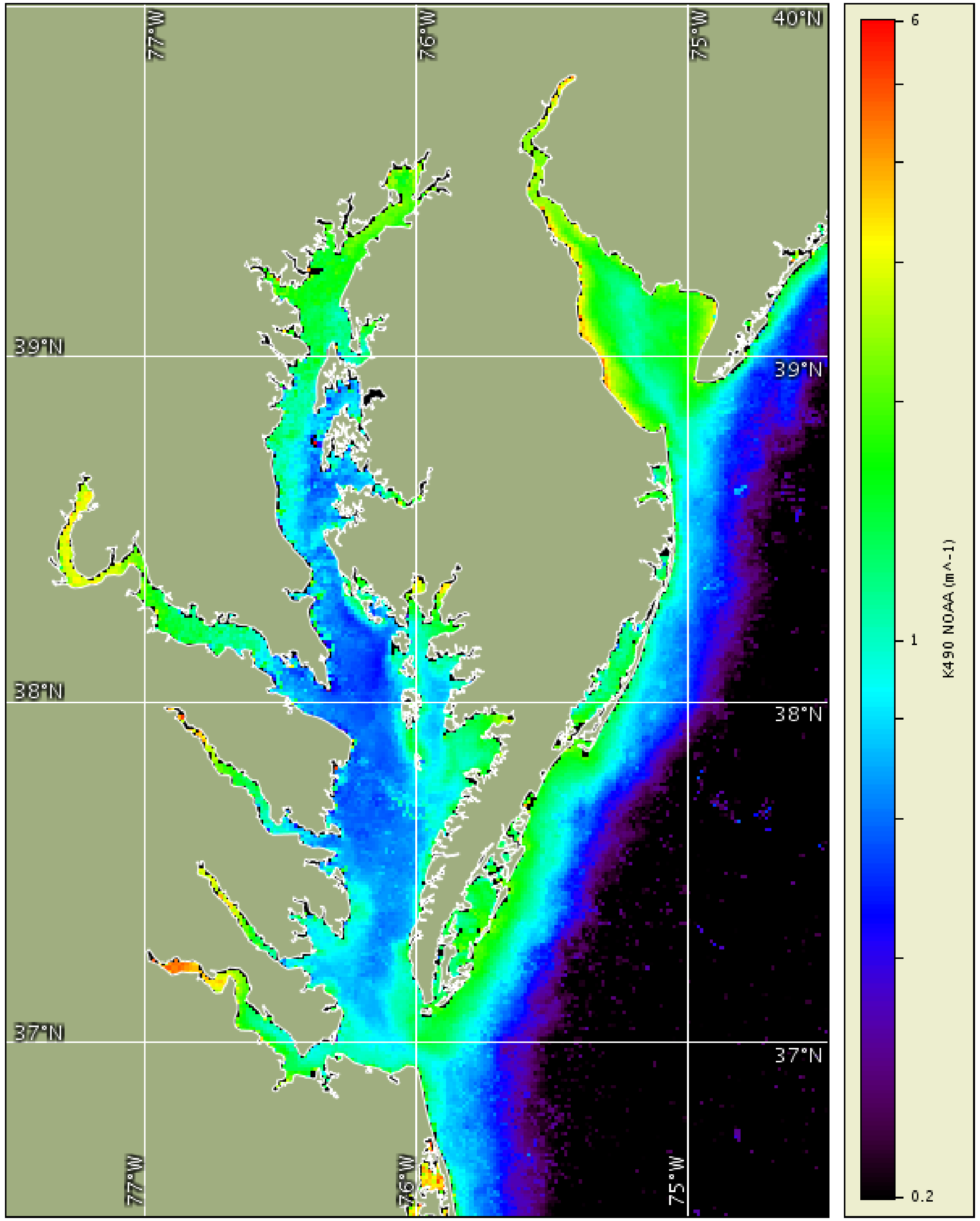
June 24, 2013

June 26, 2013



Kd from Satellite: Kd490

- **Diffuse Light Attenuation Coefficient at 490nm, Kd490** (m^{-1})
  - Definition: reduction in diffuse light, downward through a water depth, at wavelength 490 nm
  - Depth of measurement: varies with amount of particles in the water, i.e. euphotic zone
  - Instruments: MODIS (1), VIIRS (2), OLCI (2)
  - Measured by 5 satellites: NASA, NOAA, EUMETSAT
  - Each passes over Chesapeake Bay once per day
  - Clouds cause missing data
- 250, 300 or 1000 m spatial resolution
- MODIS algorithms (specific to Ches Bay):
  - 1 km: Wang et al., JGR, 2009
    - Separate algorithms for clear open ocean and turbid coastal waters weighted into combined product
  - 250 m: Tomlinson et al., Rem Sens Letters, 2018
    - High-resolution bands regressed to match Wang
- VIIRS algorithm: MODIS-Wang applied to VIIRS
- OLCI algorithm: not specific to Chesapeake Bay

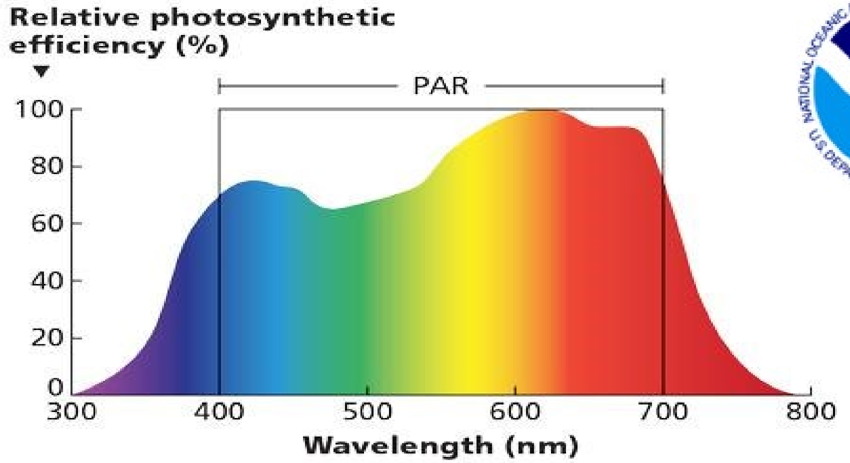


more turbid

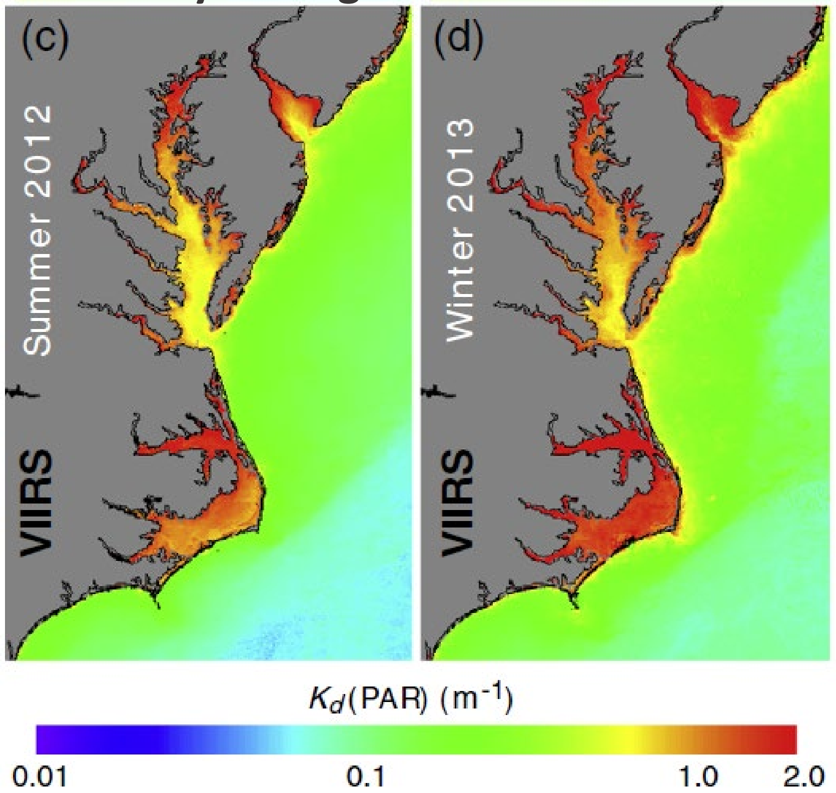
less turbid

Kd from Satellite: KdPAR

- **Diffuse Light Attenuation Coefficient at PAR wavelengths, KdPAR** (m^{-1})
    - *Light Available for Photosynthesis*
    - Definition: reduction in diffuse light, downward over a water depth, at wavelengths available for photosynthesis: 400 – 700 nm (visible light range)
    - Depth of measurement: varies with amount of particles in the water, i.e. euphotic zone, Ches Bay approximate range 0.1 – 2.0 m, on average ~1.0 m
- Measured by VIIRS instrument, one of each of 2 satellites (NOAA)
    - Each passes over Chesapeake Bay once per day
    - Clouds cause missing data
- 750 m spatial resolution
- 10+ year time series: 2012 – 2022 an ongoing
- Algorithm: Son & Wang, Rem Sens of Envt, 2015
    - Estimated from Kd490
    - Separate algorithms for clear open ocean and turbid coastal waters weighted into combined product. Validation against Chesapeake Bay Program data.



Seasonally Averaged KdPAR

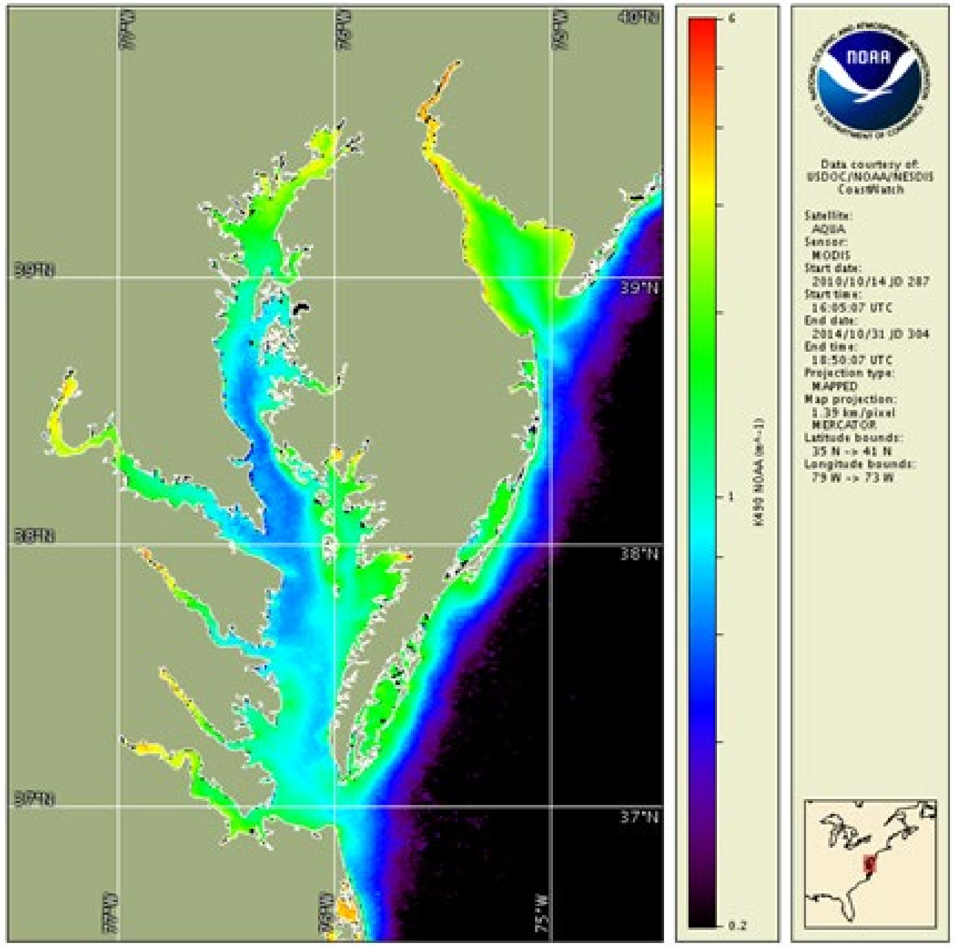


Son & Wang, 2015

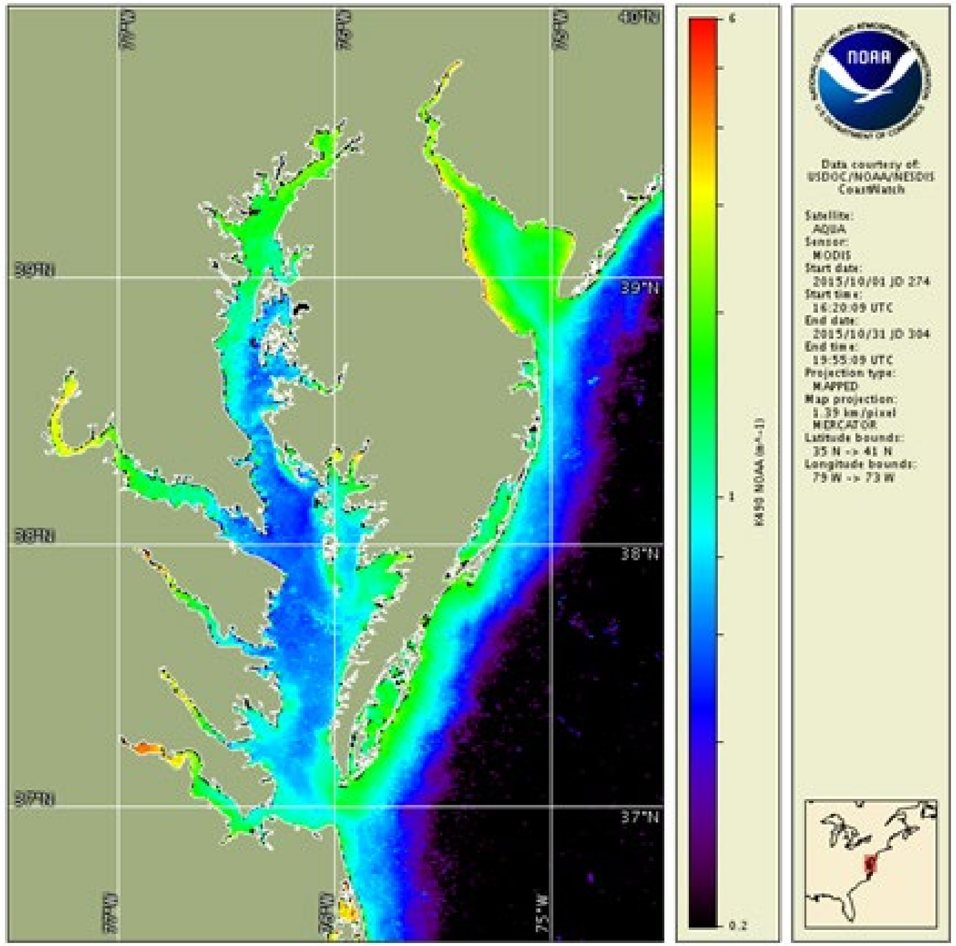
Two Brief Satellite Product Use Cases

Unusually clear water in Fall of 2015

Satellite Kd490 shows October 2015 is clearer than average October of previous 5 years



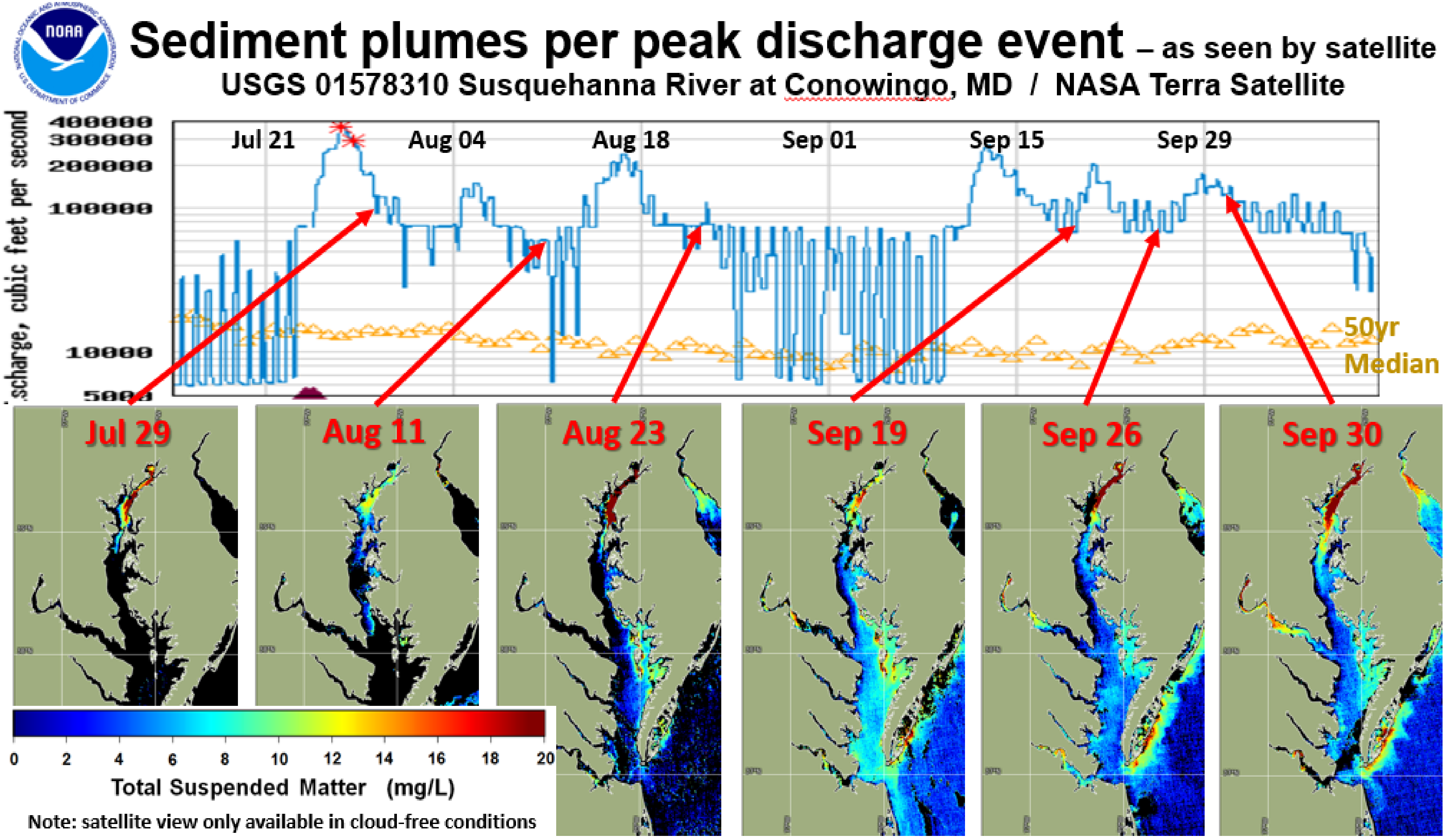
October monthly average: 2010-2014



October monthly average: 2015

From joint MD DNR - NOAA briefing to CBP STAR on "clear water event"

2nd Half 2018 Wettest Period in Historical Record for Mid-Atlantic Region

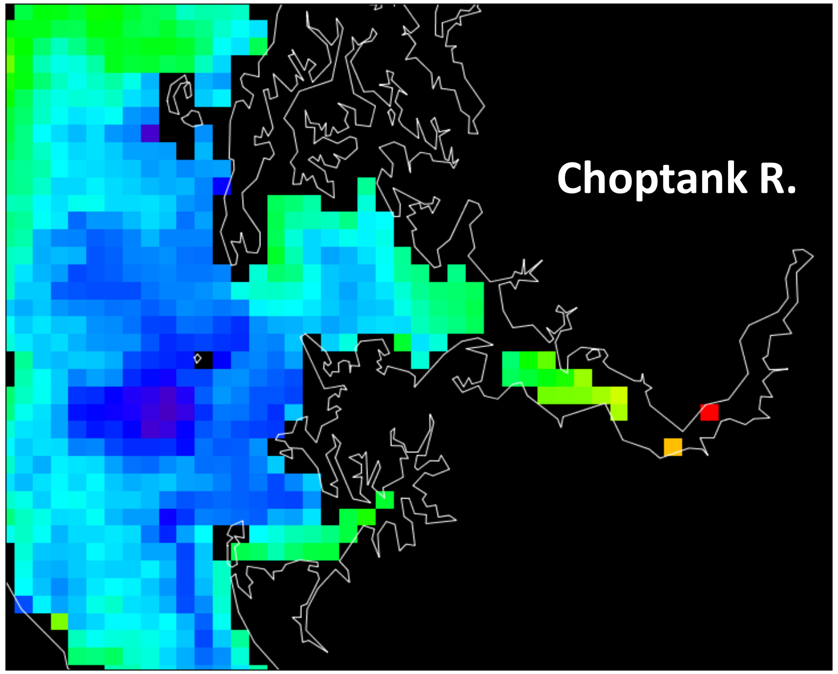


Spatial Resolution Examples

Spatial Resolution (images from MODIS)

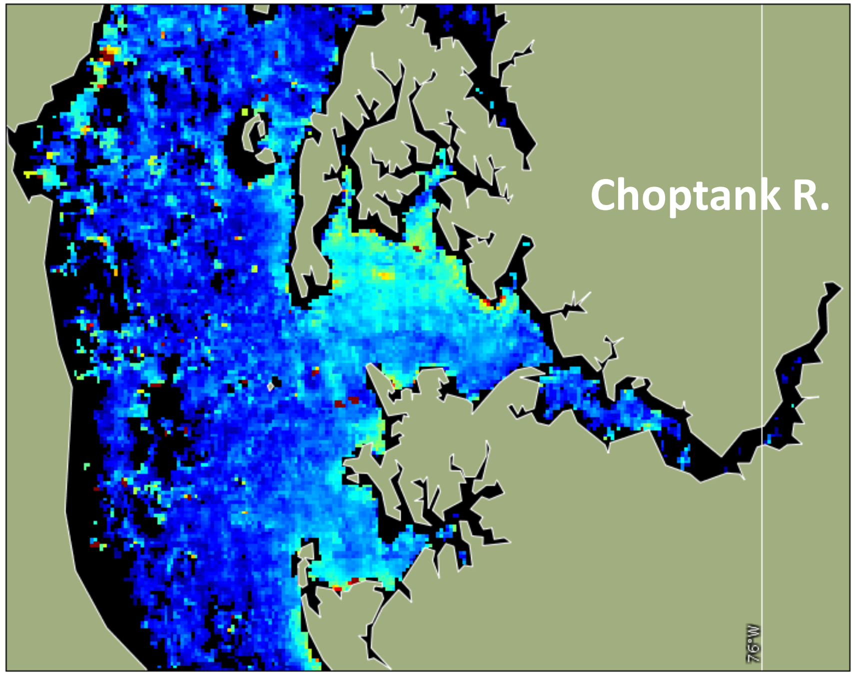
Coarser

1 km (750 m similar)



Finer

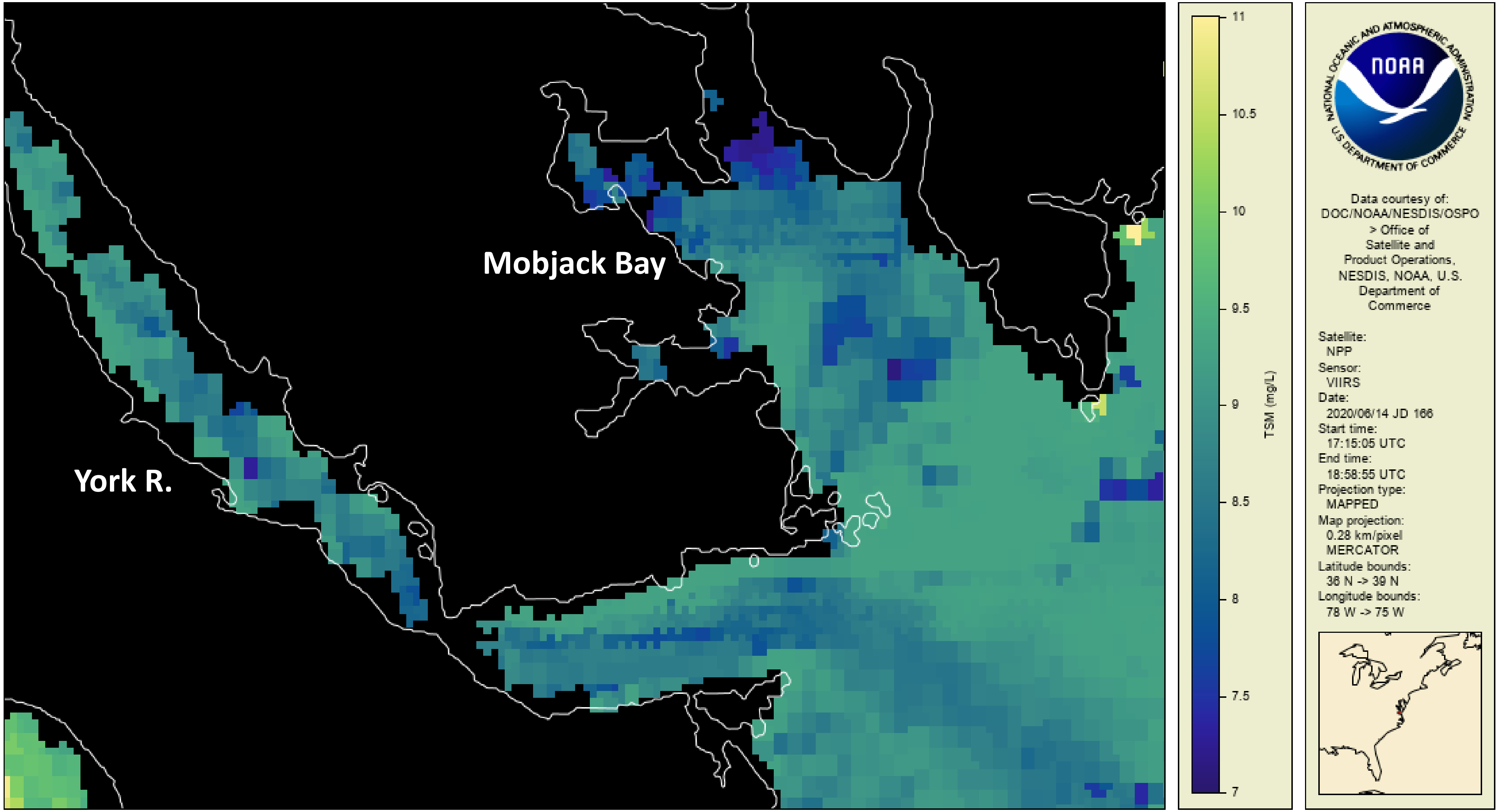
250 m (300 & 375 m similar)



More spatial detail at finer resolution

MODIS:	Kd490	@ 1km, 250m	Total Suspended Matter @ 250m
VIIRS:	Kd490,PAR	@ 750m	Total Suspended Matter @ 1km, 375m
OLCI:	Kd490	@ 300m	Total Suspended Matter @ 300m

Spatial Resolution, 375m (from VIIRS)



TSM (VIIRS), **June 14, 2020**

7-11 mg/L

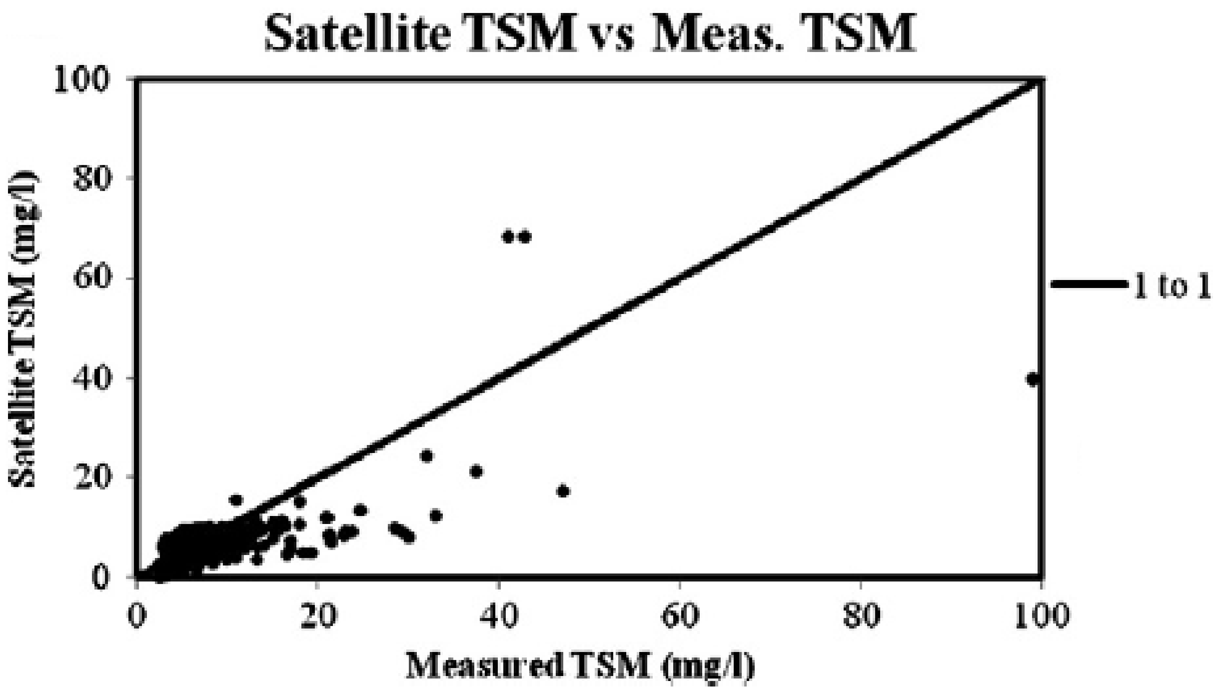
Satellite Product Accuracy:

1) Published algorithm accuracy statements

Satellite TSM Accuracy (MODIS, Ondrusek algorithm)

Chesapeake Bay Program in-water TSM samples were spatially & temporally matched to MODIS satellite TSM values, Bay-wide, for one year: 2009

(Ondrusek et al., 2012, Remote Sensing of Environment)

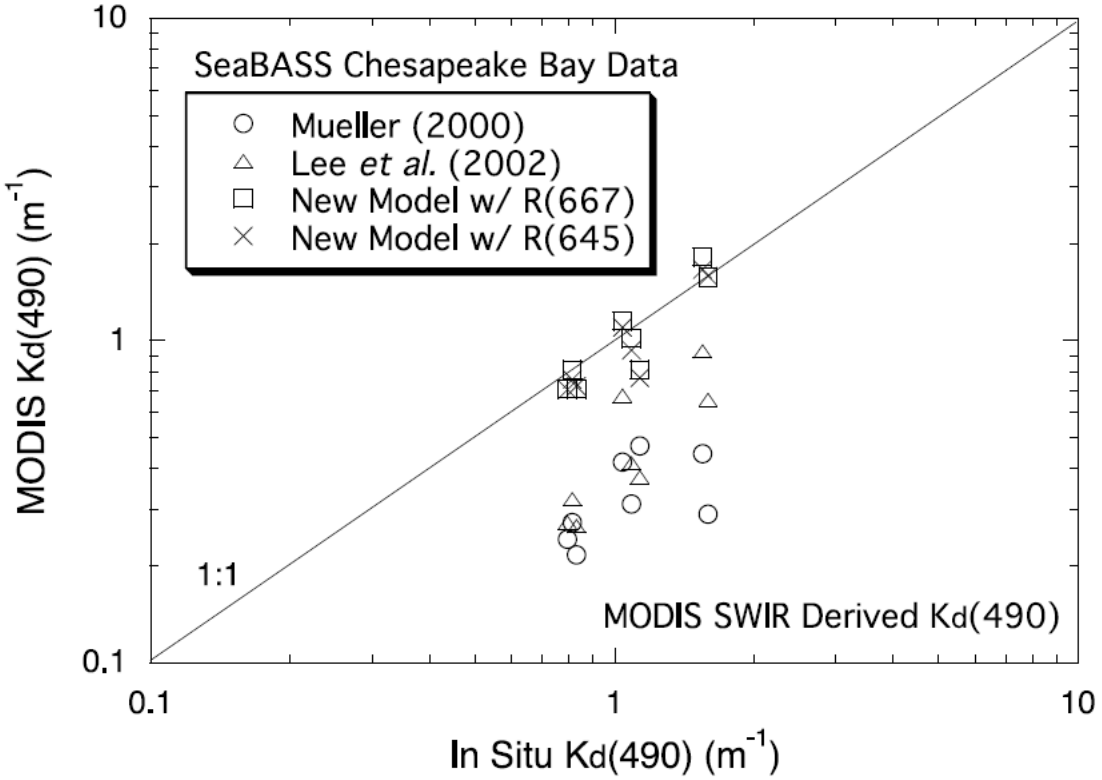


Bias (mg/L):	-1.82443
RMSE (mg/L):	6.93795
Mean Rel Diff:	-4.2%
Mean Rel Abs Diff:	36%
N:	241

TSM values <20 mg/L are more accurate than values >20 mg/L

Satellite Kd490 Accuracy (MODIS, Wang algorithm)

NASA SeaBASS database in-water Kd490 samples for Chesapeake Bay were spatially & temporally matched to satellite Kd490 values
(Wang et al., 2009, Journal of Geophysical Research)

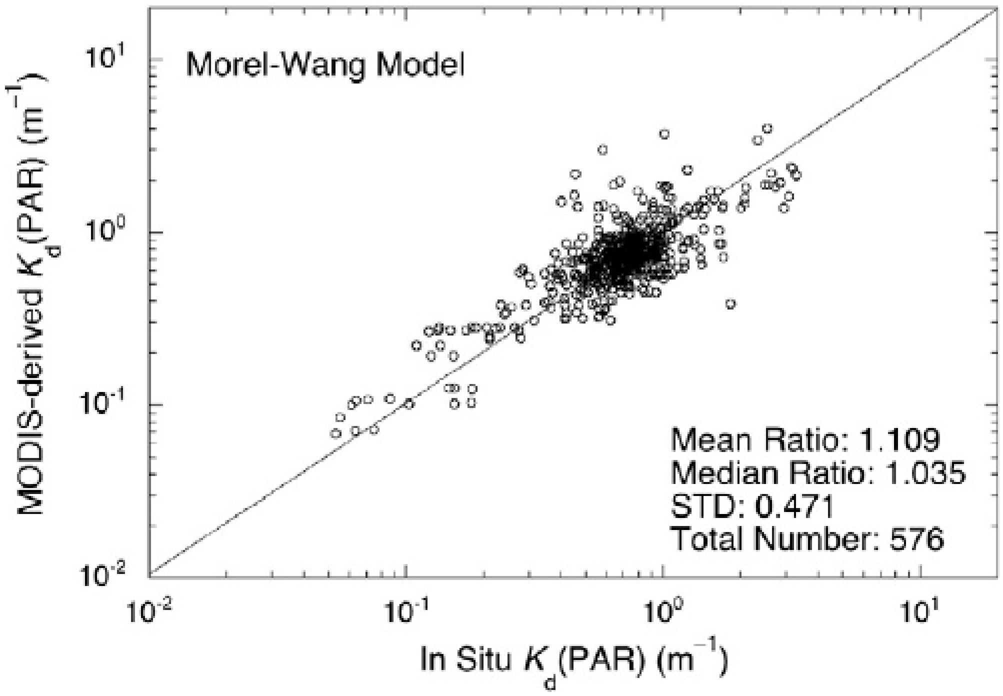


Comparison of 4 satellite Kd490 algorithms

	Mean Ratio
Mueller (open ocean):	0.31
Lee (open ocean):	0.43
Wang (turbid, 667nm):	0.96
Wang (turbid, 645nm):	0.92
N:	8

Satellite KdPAR Accuracy (MODIS, Son & Wang algorithm)

Chesapeake Bay Program and NASA SeaBass in-water KdPAR samples were spatially & temporally matched to MODIS satellite KdPAR values, Bay-wide, for 2002-2009 (Son & Wang, 2015, Remote Sensing of Environment)



Mean Ratio:	1.109
Median Ratio:	1.035
Std Dev:	0.471
N:	576

Satellite Product Accuracy:

2) Example product comparison in Bay

TSM: MODIS vs VIIRS

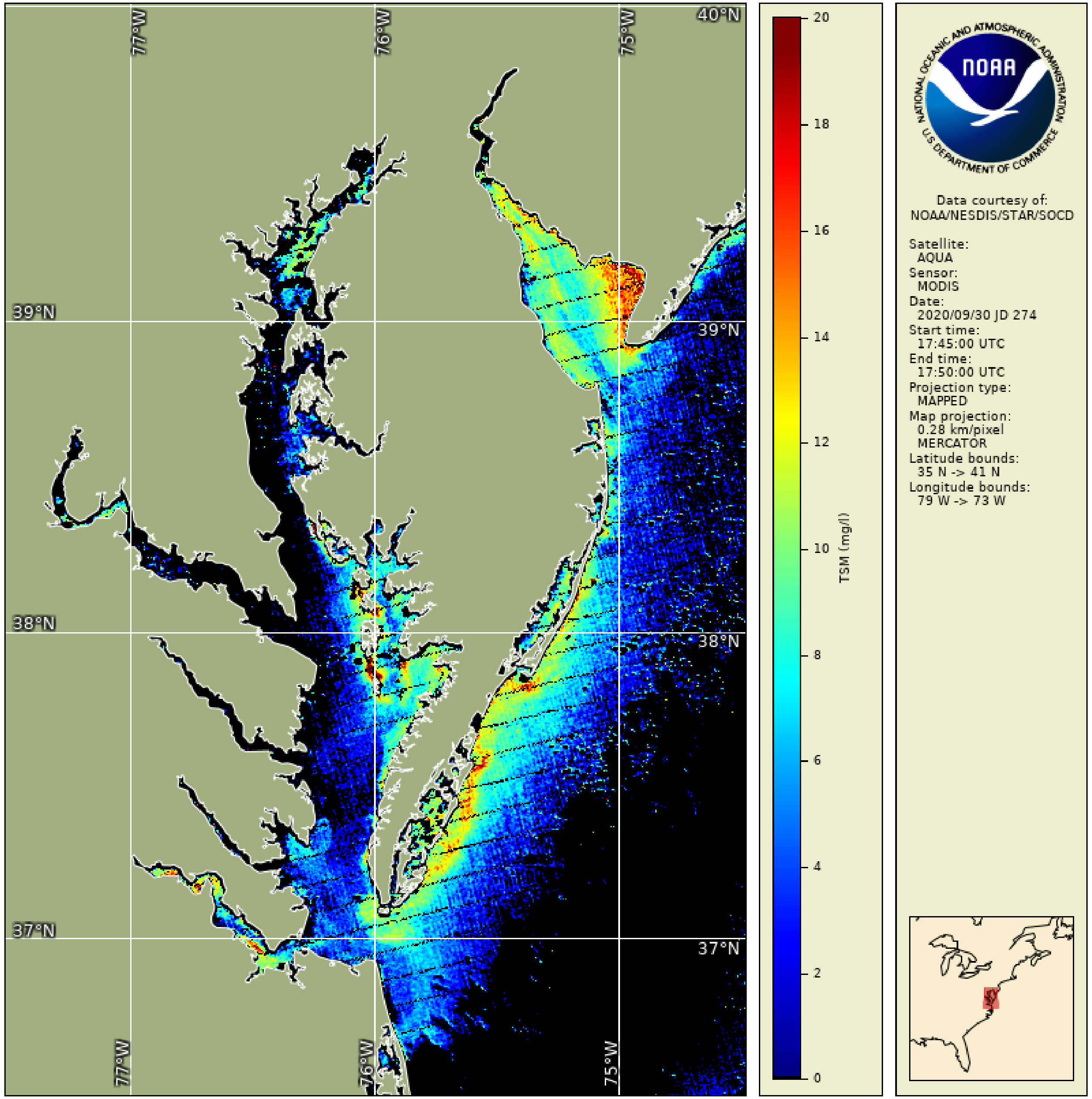
Total Suspended Matter

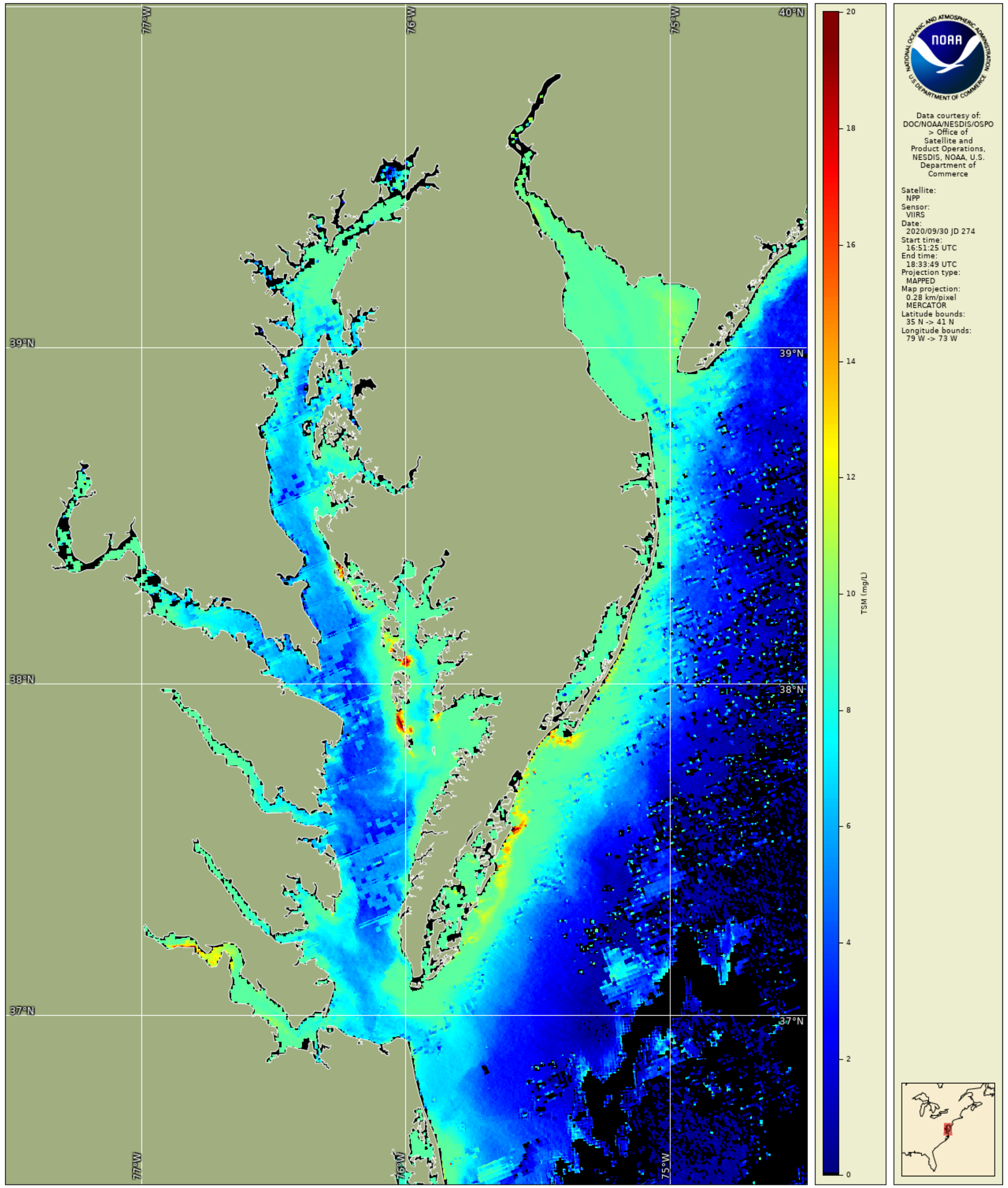
Sep 30, 2020

MODIS 17:45

same color scale

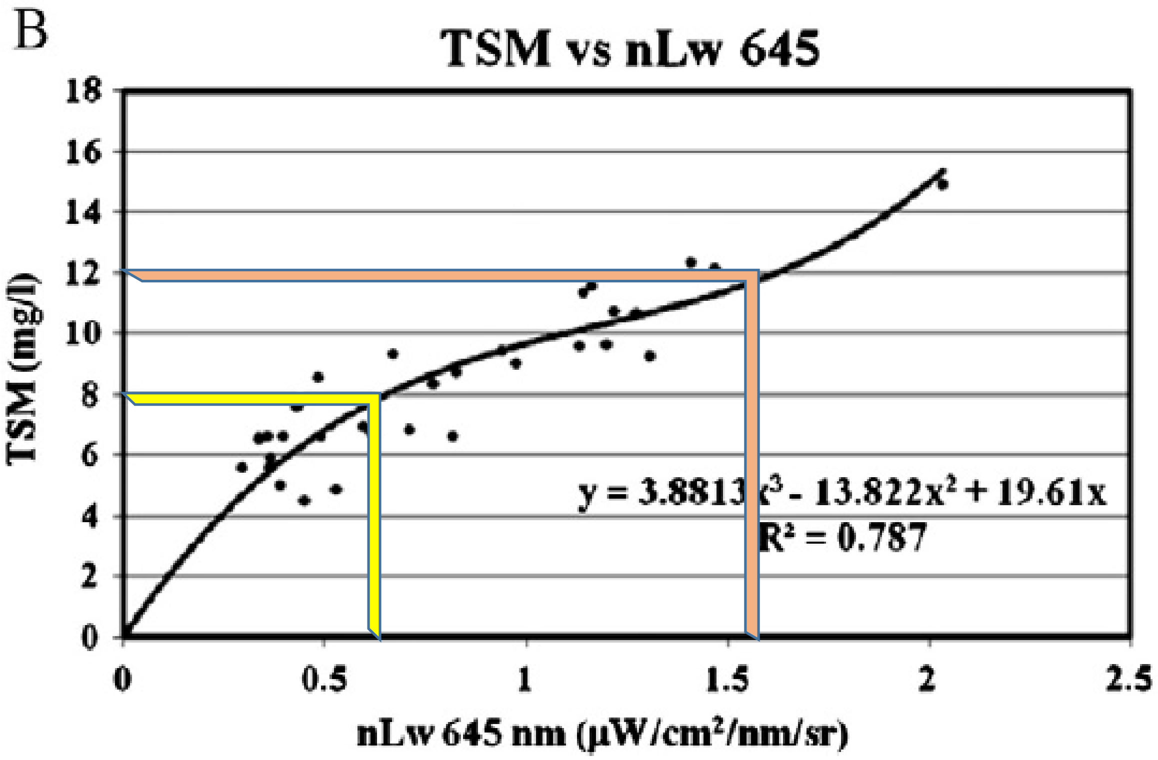
VIIRS 16:51



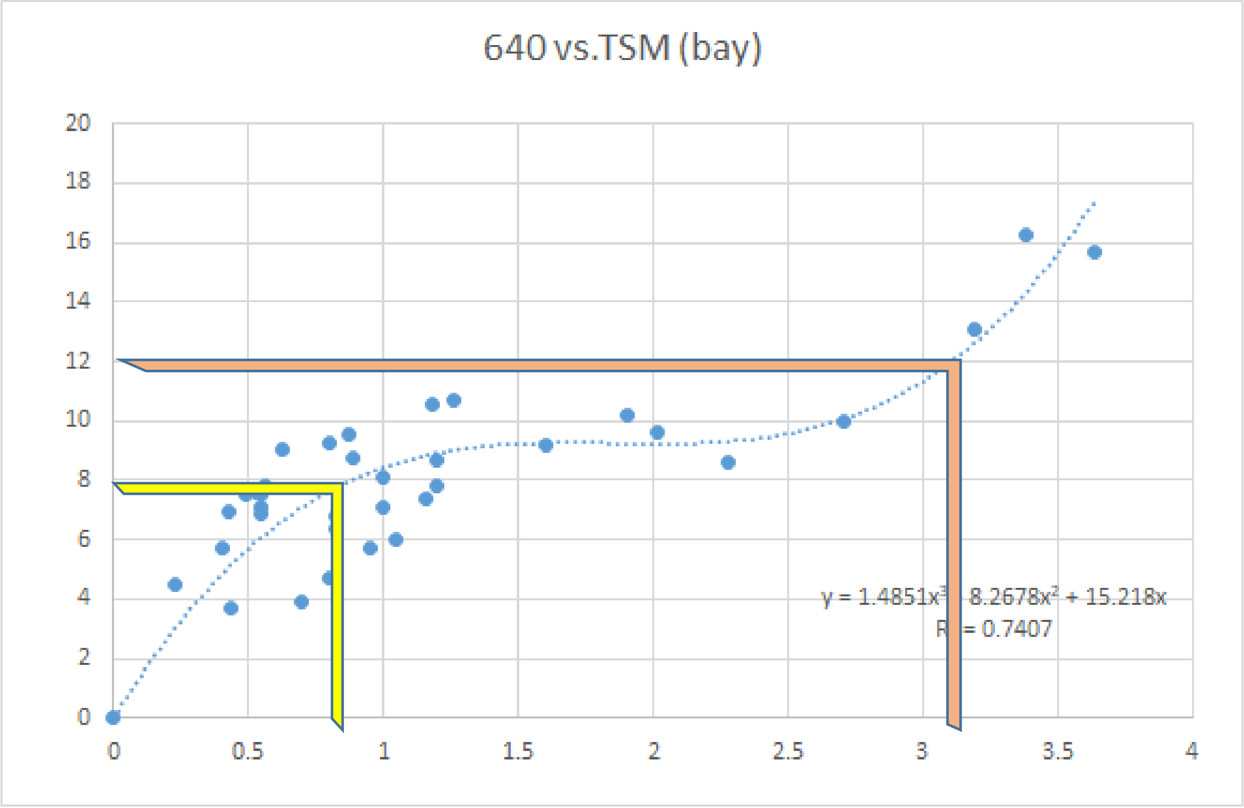


MODIS and VIIRS TSM algorithms depart into higher concentrations at different measured light radiances

MODIS

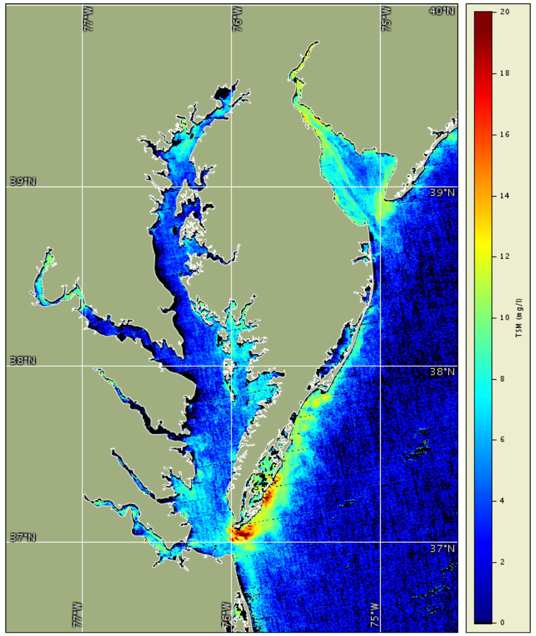


VIIRS

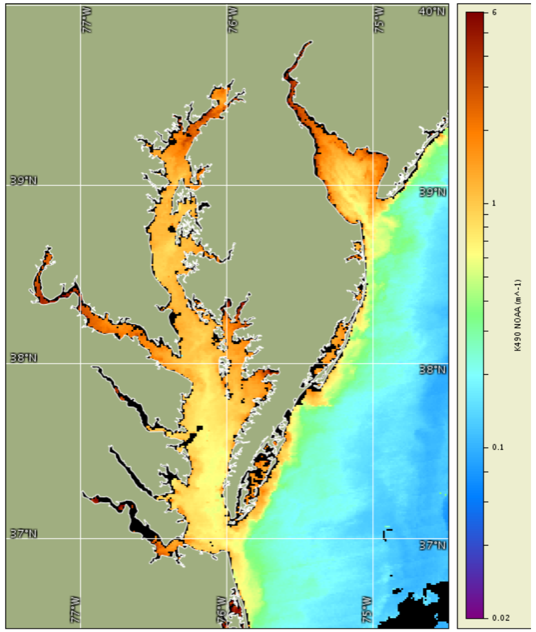


MODIS is validated; VIIRS is not. Is VIIRS better???

Total Suspended Matter



Diffuse Light Attenuation



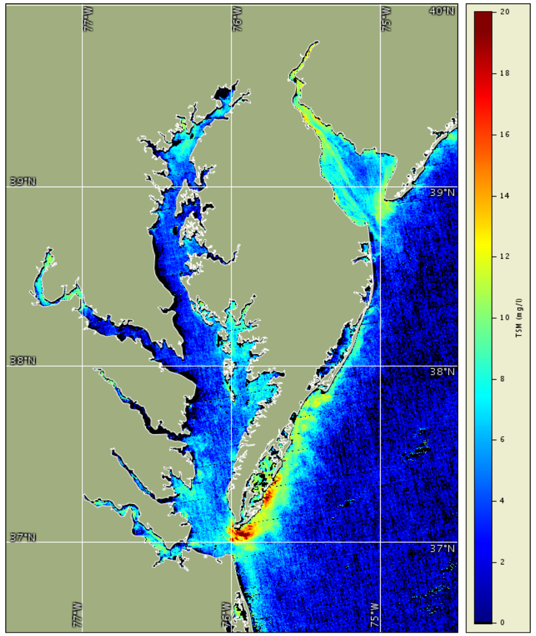
Summary: Data Products

Product	Instrum.	Spatial Resol.	Length (start, to present)	Algorithm	Algorithm ChesBay developed	Algorith. ChesBay validated
KdPAR	VIIRS	750 m	**2012**	Son & Wang	N	Y
Kd490	MODIS	1 km	**2010**	Wang	Y	Y
Kd490	MODIS	250 m	2016	Tomlinson	Y	N
Kd490	VIIRS	750 m	**2012**	Wang	N	N
Kd490	OLCI	300 m	2018	ESA (MERIS)	N	N
TSM	MODIS	250 m	**2009**	Ondrusek	Y	Y
TSM	MODIS	1 km	new	Wei & Wang	N	N
TSM	VIIRS	375 m	2020	Ondrusek	Y	N
TSM	OLCI	300 m	2020	ESA (Neural Net)	N	N

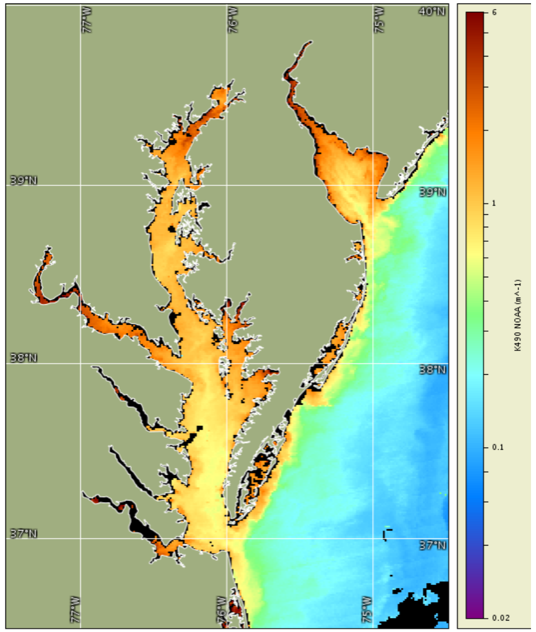
Bold Length = significant enough for time series trend studies

Sweet Spot? Fine resolution, alg developed with Bay data, validated, long record

Total Suspended Matter



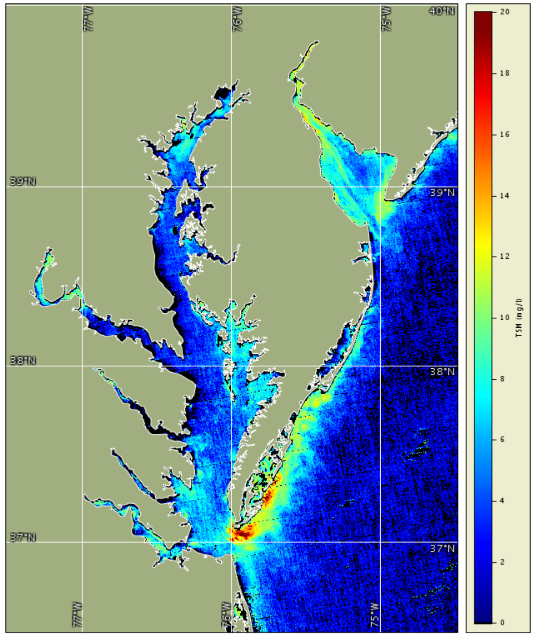
Diffuse Light Attenuation



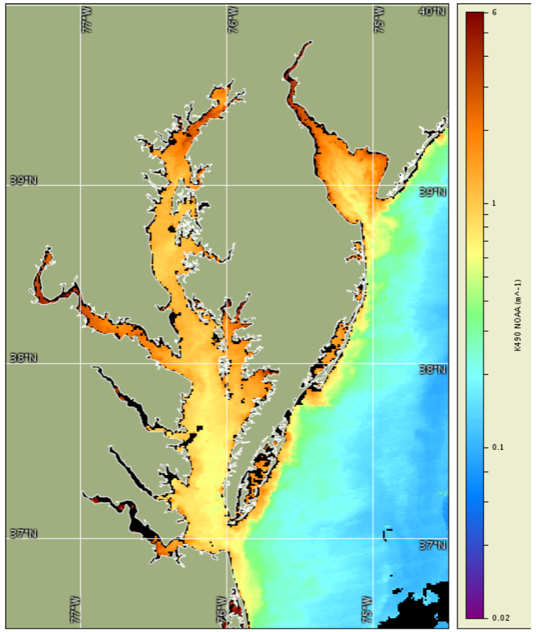
Summary: Data Considerations

- Broad geographic coverage for overview of spatial patterns
- Daily overpasses from 5 satellites
  - instruments: MODIS (1), VIIRS (2), OLCI (2)
- Overpass times:
  - OLCI: ~10:30 AM local time
  - MODIS & VIIRS: ~3:00 PM local time
- Spatial resolutions: 1 km, 750 m **coarser**
  375 m, 300 m, 250 m **finer**
- Surface measurement only (euphotic zone)
- Clouds cause gaps, mitigations possible
- Algorithms: Some algs developed with Bay in-situ data
- Validation: Accuracies published for some products
- Length of record: MODIS 2009, VIIRS 2012, OLCI 2018
  - Mission-length reprocessing needed for full records

Total Suspended Matter



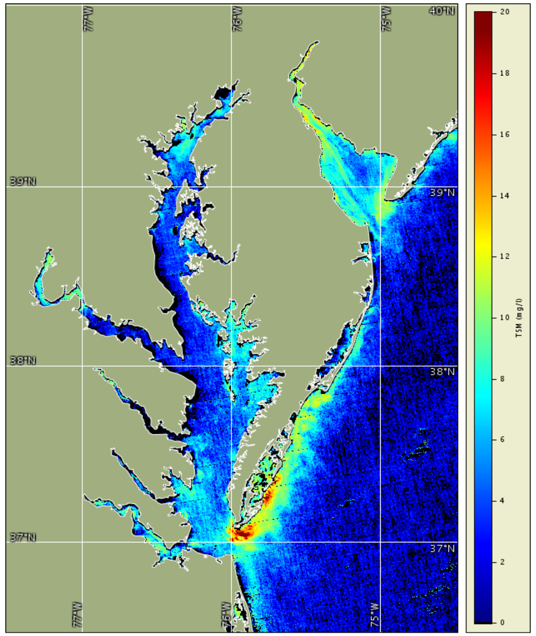
Diffuse Light Attenuation



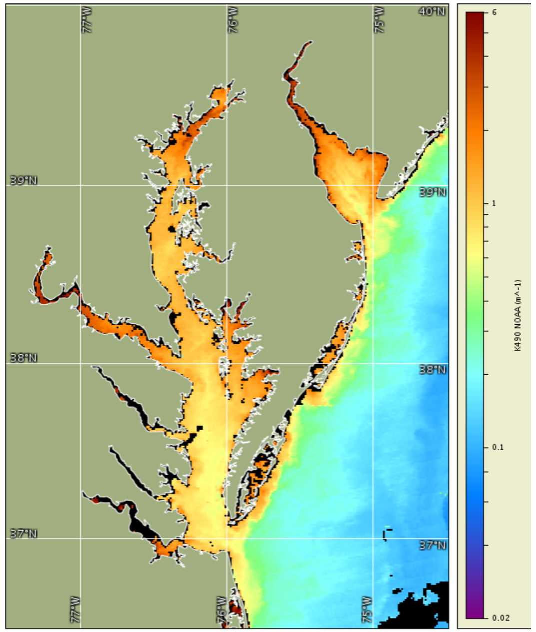
Possibilities to push the state of the art (1 of 2)

- Conduct cross-product validation study
  - see chlorophyll comparison talk from Tomlinson
- Reprocess current satellite product(s) for entire mission length for augmenting CBP trend analyses
- Develop multi-satellite continuity product, especially for bridging between satellite missions
- Dedicated in-situ monitoring for satellite algorithm development, e.g. to match satellite overpasses

Total Suspended Matter



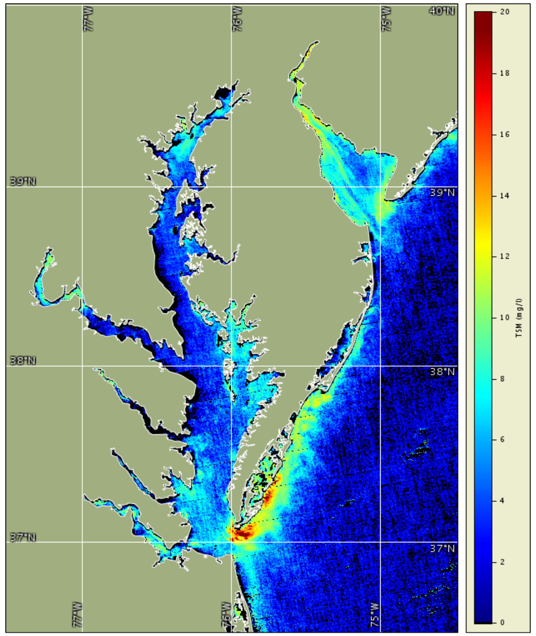
Diffuse Light Attenuation



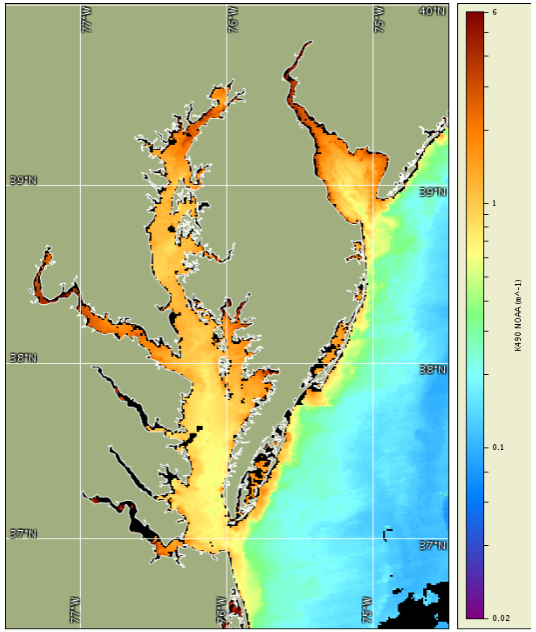
Possibilities to push the state of the art (2 of 2)

- Investigate higher resolution satellite options – 10’s m or less BUT WITH TRADE-OFF of lower temporal frequency
  - Landsat 8/9 (USGS)
  - Sentinel-2a/2b (ESA/EUMETSAT)
  - Commercial
- Research to improve atmospheric corrections, specifically for Chesapeake Bay
- Research to improve algorithms
  - OLCI, with additional bands, shows promise but current algorithms neither developed nor validated for Chesapeake Bay
  - Intelligent algorithms
  - NOAA-NASA-Academic engagement?
- ***Strong statement from CBP to NOAA articulating specific needs***

Total Suspended Matter



Diffuse Light Attenuation



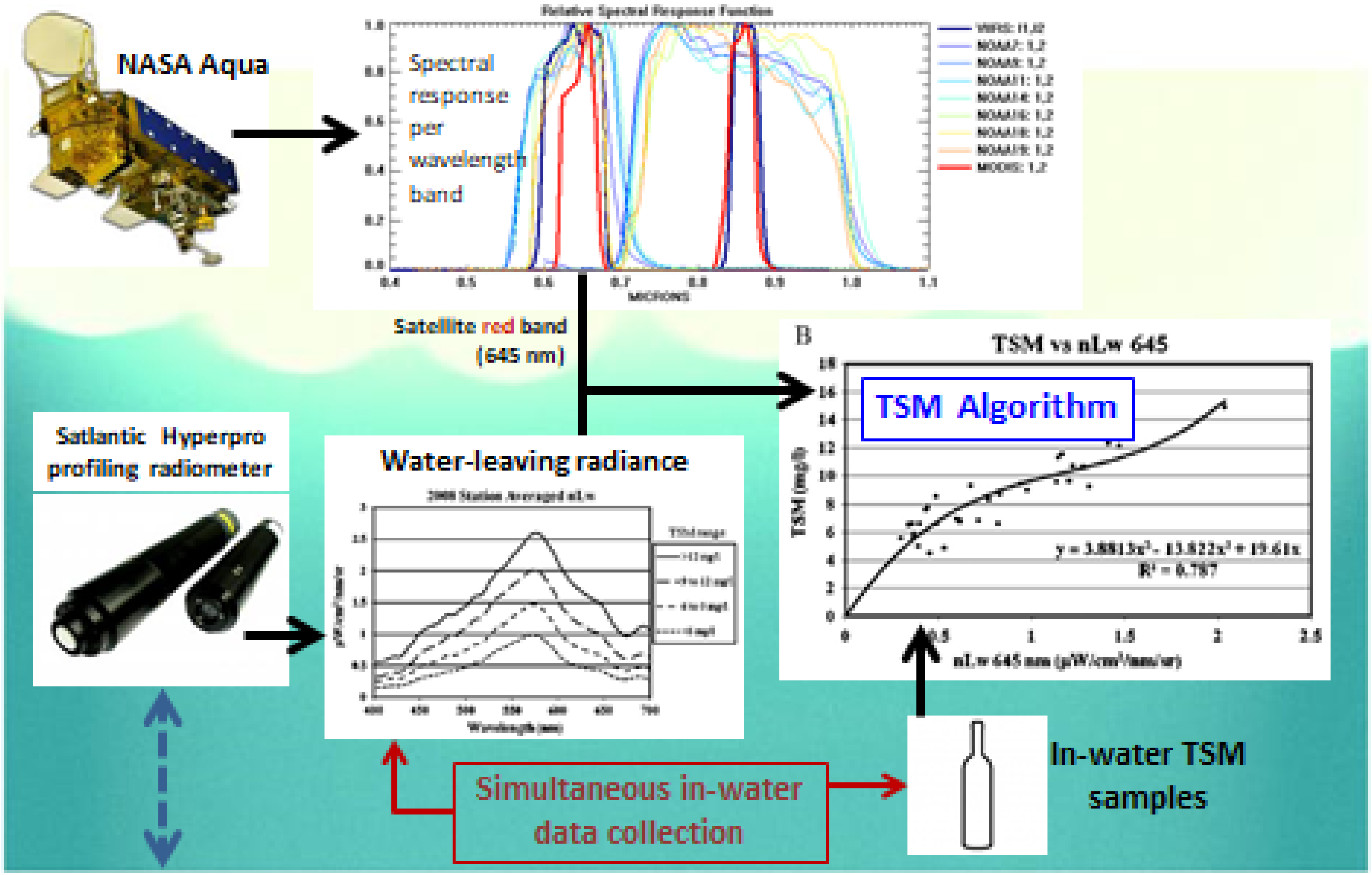
Opportunities in forthcoming satellite technologies

- Hyperspectral satellite missions
  - "Thin" continuous wavelengths rather than "wide" discrete multispectral bands
  - Opportunity for leap forward in accuracy
    - Research into using intelligent algorithms
  - PACE mission from NASA to launch in Nov 2023 – BUT WITH TRADE-OFF in reduced spatial resolution (1km)
- Geosynchronous satellites
  - High temporal frequency, e.g. 8 to 24 views per day, increases coverage
  - NOAA Geo continuity: GEO-XO
  - NASA/UNH mission: GLIMR (also hyperspectral)
- Aeronet-OC in Chesapeake Bay
  - Above-water radiometer instrument for improving calibration of satellite radiances
  - Possibility to help improve atmospheric correction
  - Reduces inherent radiance uncertainty in coastal/inland water

Backup

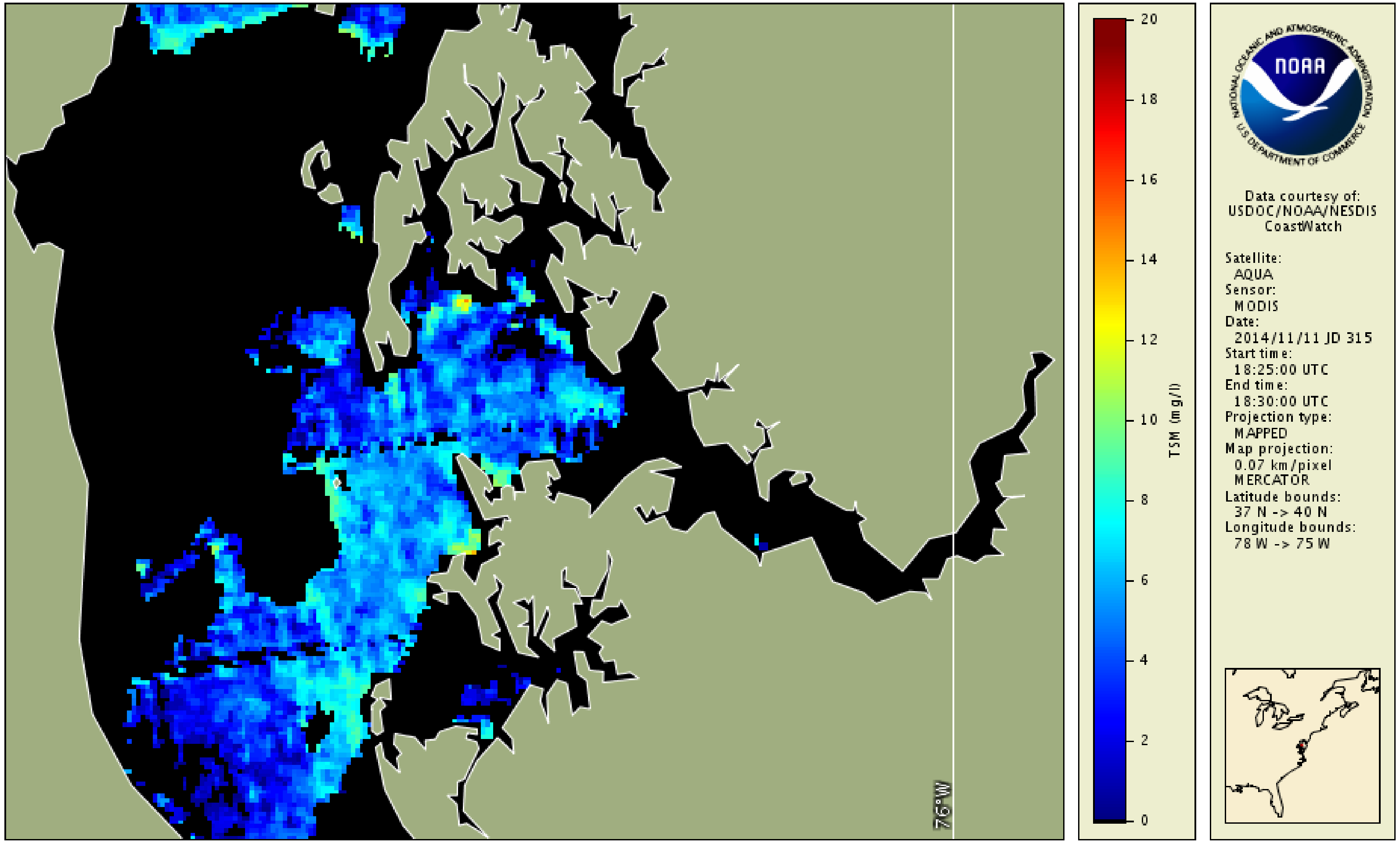
MODIS TSM Algorithm Description

Ondrusek et al., 2012, Remote Sensing of Environment



Effect of clouds!

Example Daily Scene: data not available everywhere on a daily basis

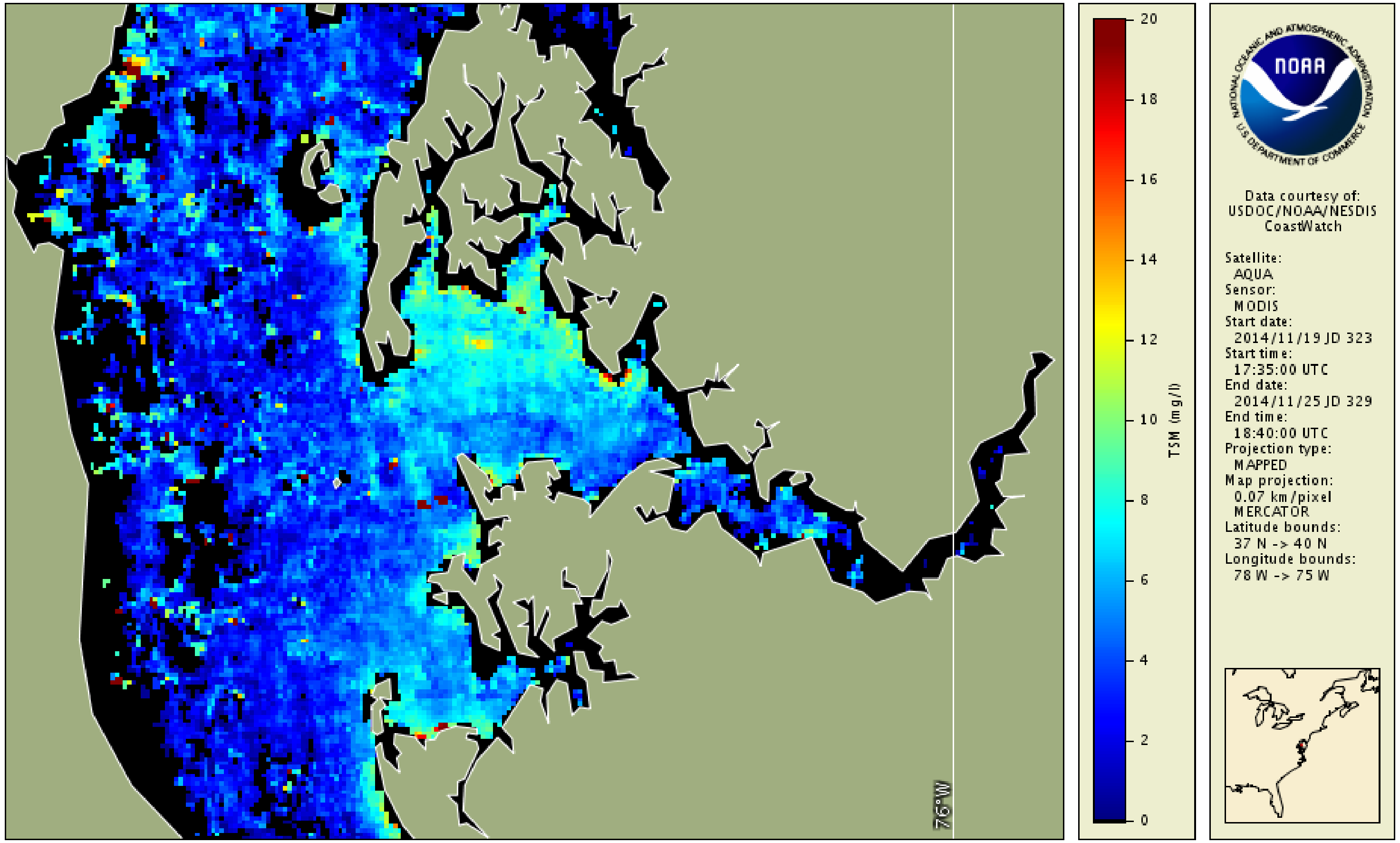


Nov 11, 2014

Mitigate effect of clouds by averaging into temporal intervals:

3-day, 7-day, monthly, seasonal, annual available

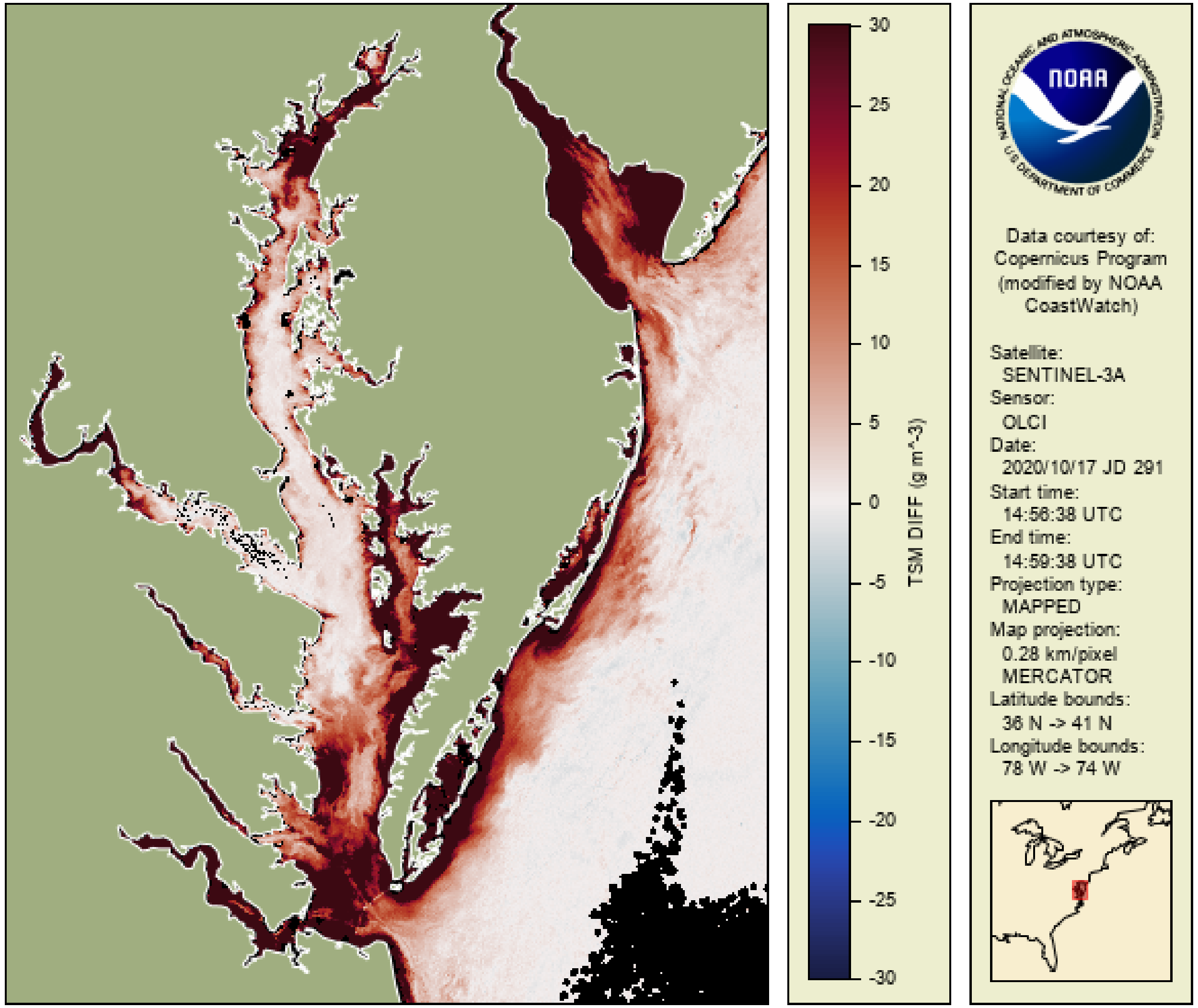
Example 7-day average:

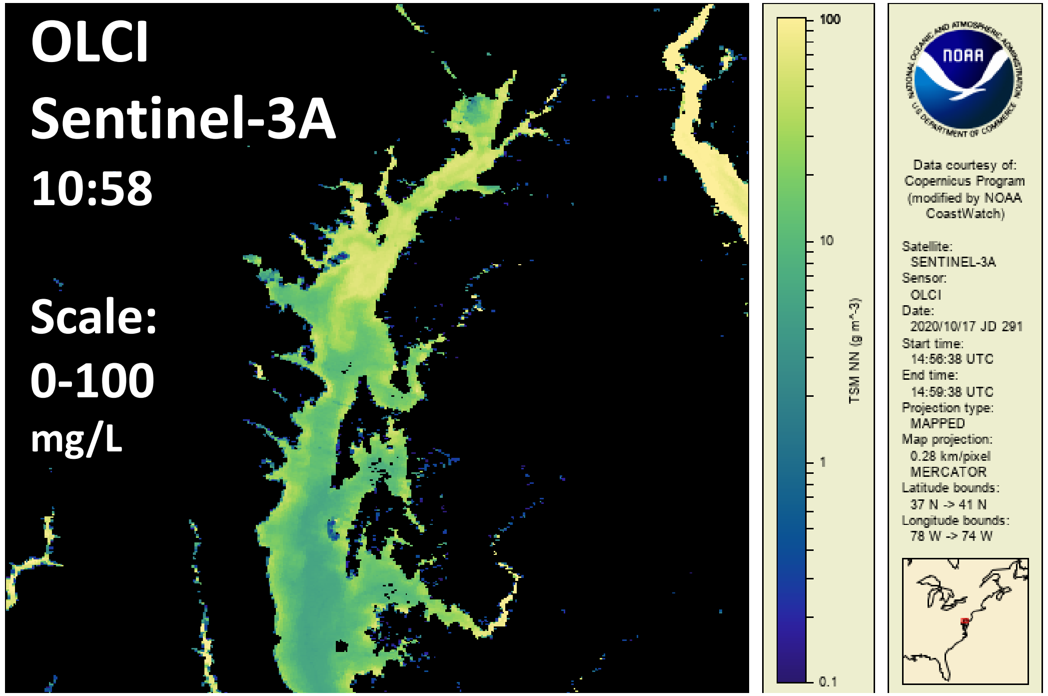


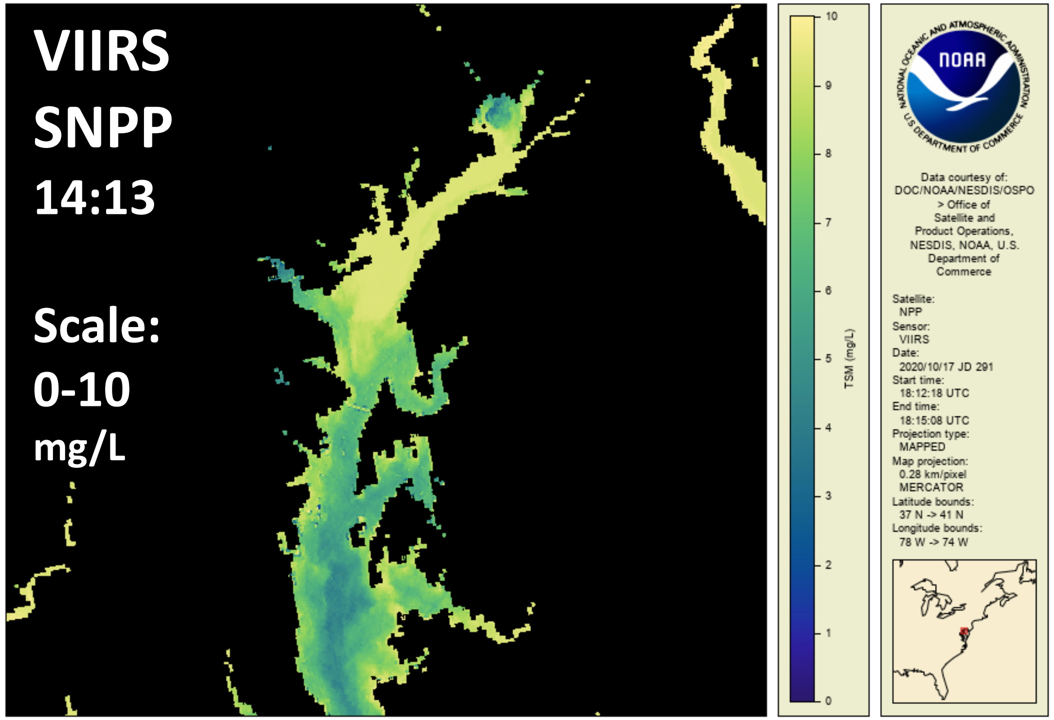
Trade-off: daily instantaneous measurement more accurate vs. more coverage when averaging several days

Other methods to estimate missing values & create gap-filled products exist: DINEOF, numerous data assimilation techniques, etc.

TSM: OLCI minus VIIRS difference, **Oct 17, 2020**







VIIRS: Bay in-situ data derived algorithm (Ondrusek)

OLCI: Intelligent neural-net global algorithm (ESA)

Neither product validated with Bay data

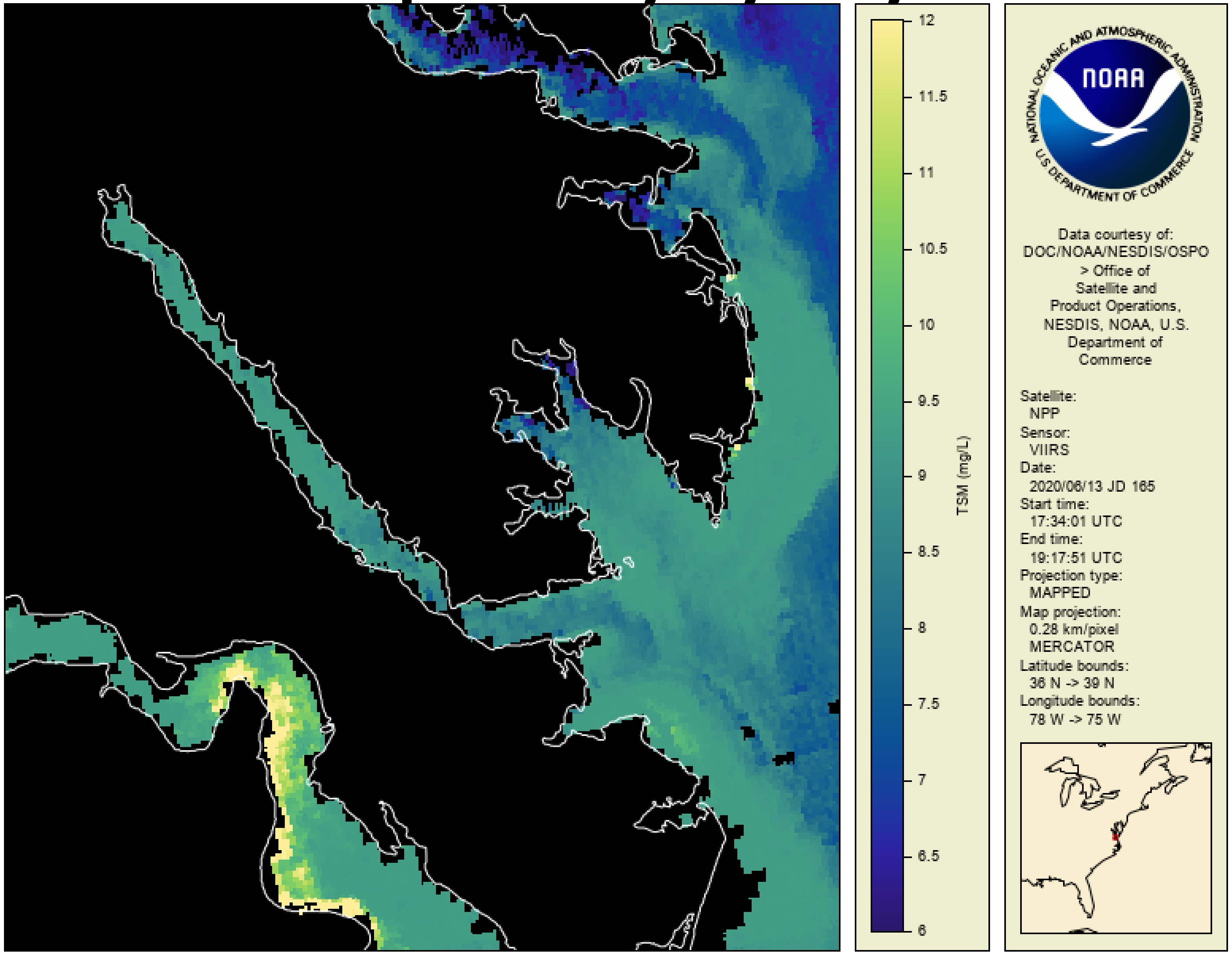
Use Case Example: Day-by-Day Monitoring

TSM (VIIRS)

June 13, 2020

375m

6-12 mg/L

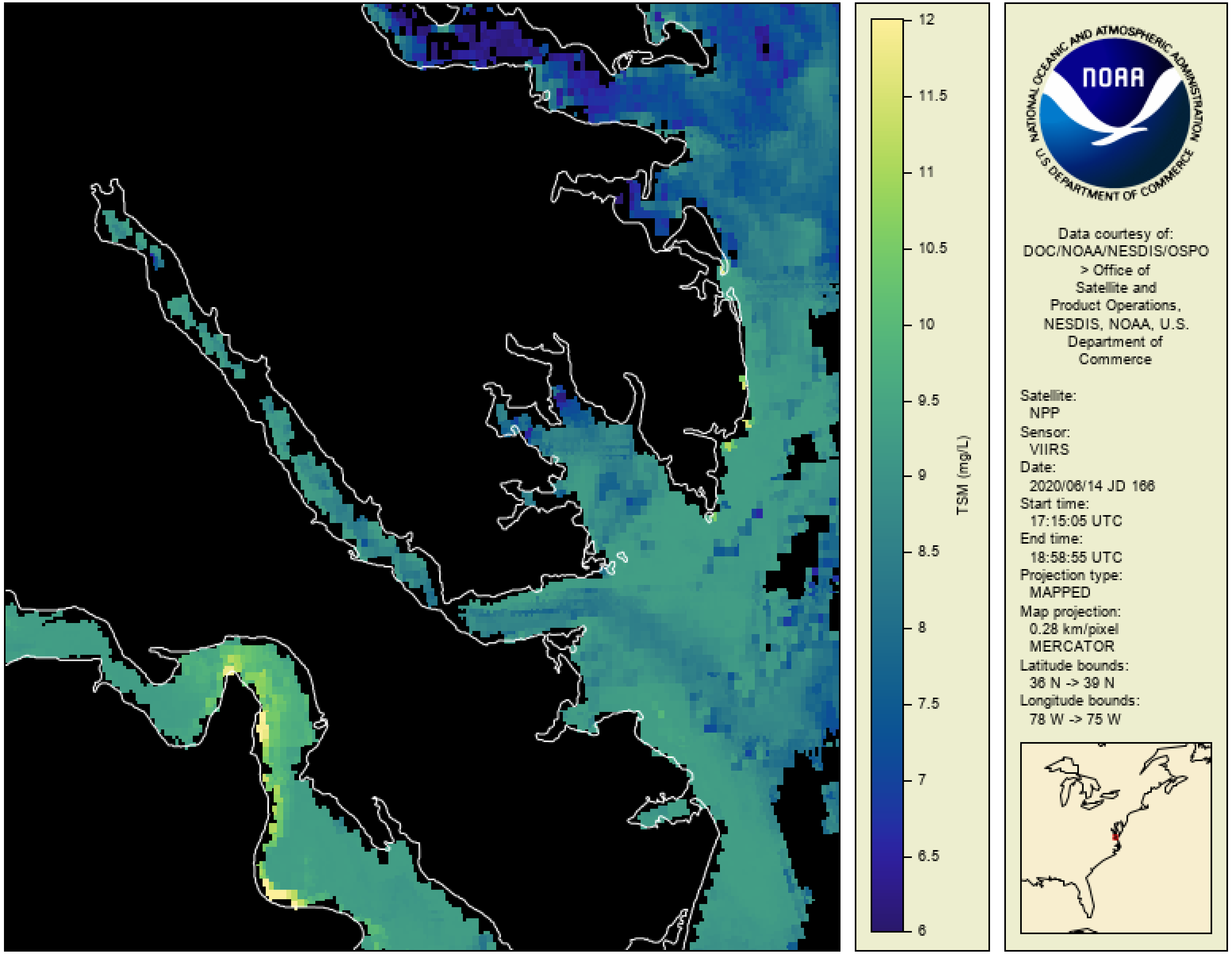


TSM (VIIRS)

June 14, 2020

375m

6-12 mg/L

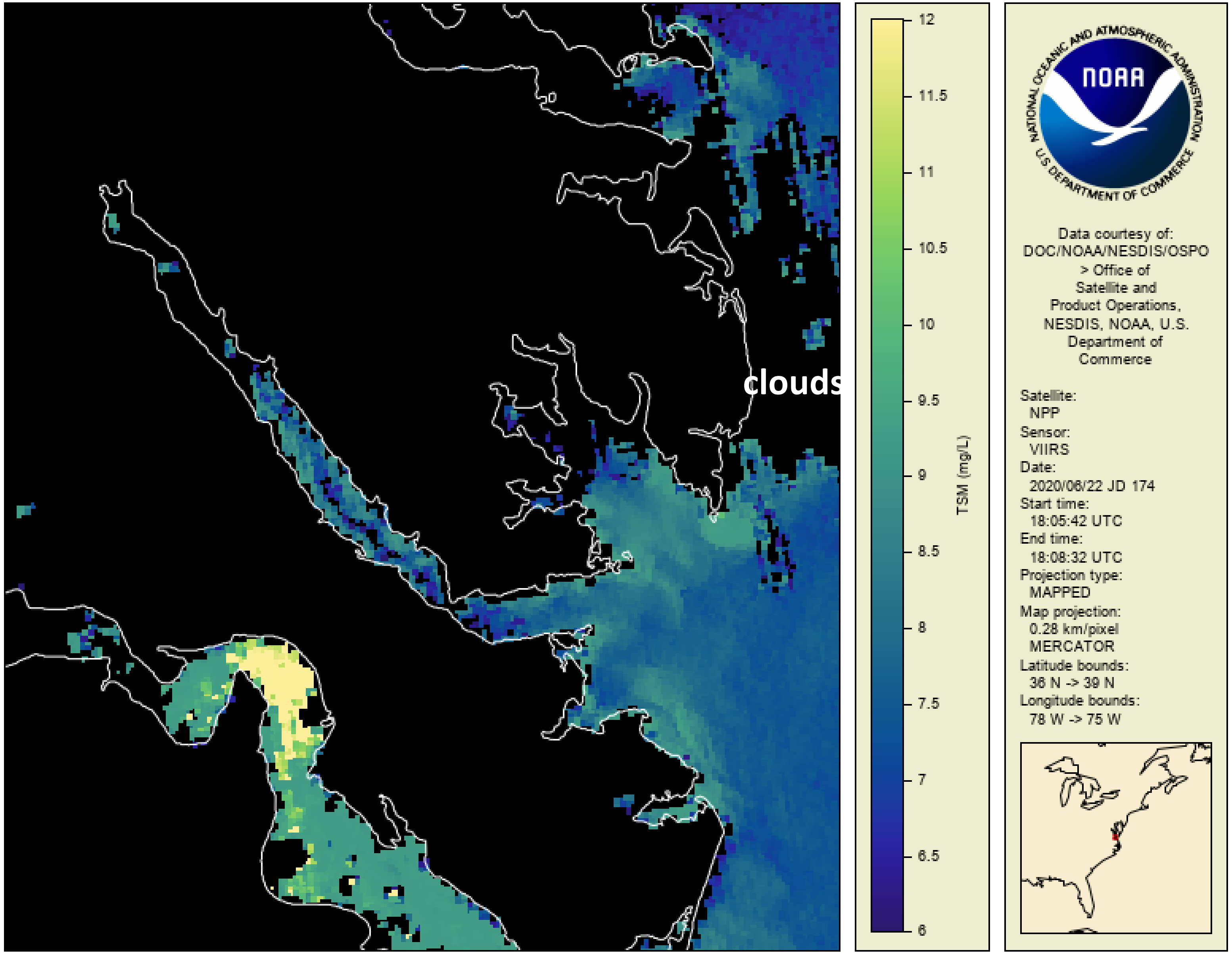


TSM (VIIRS)

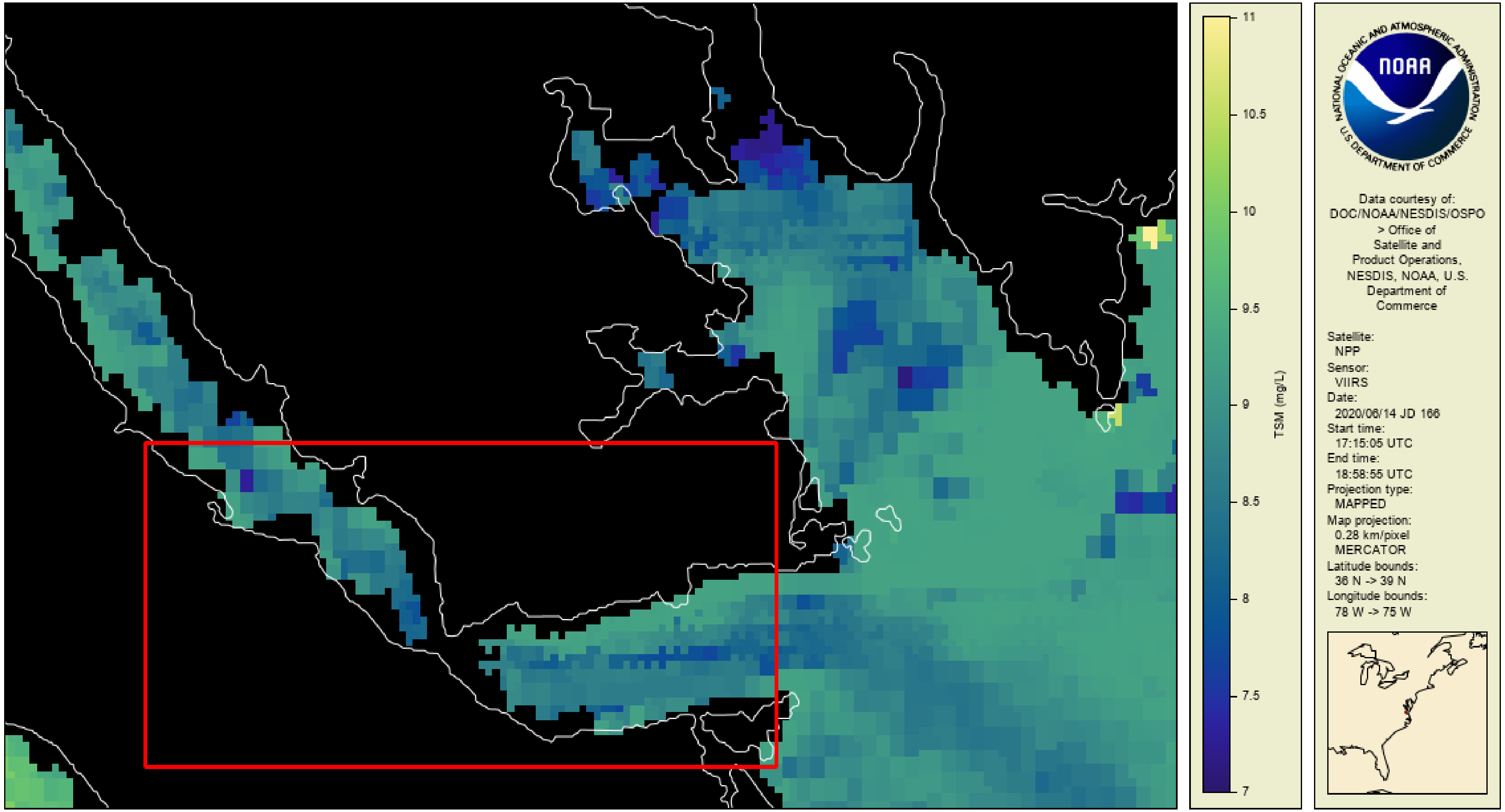
June 22, 2020

375m

6-12 mg/L

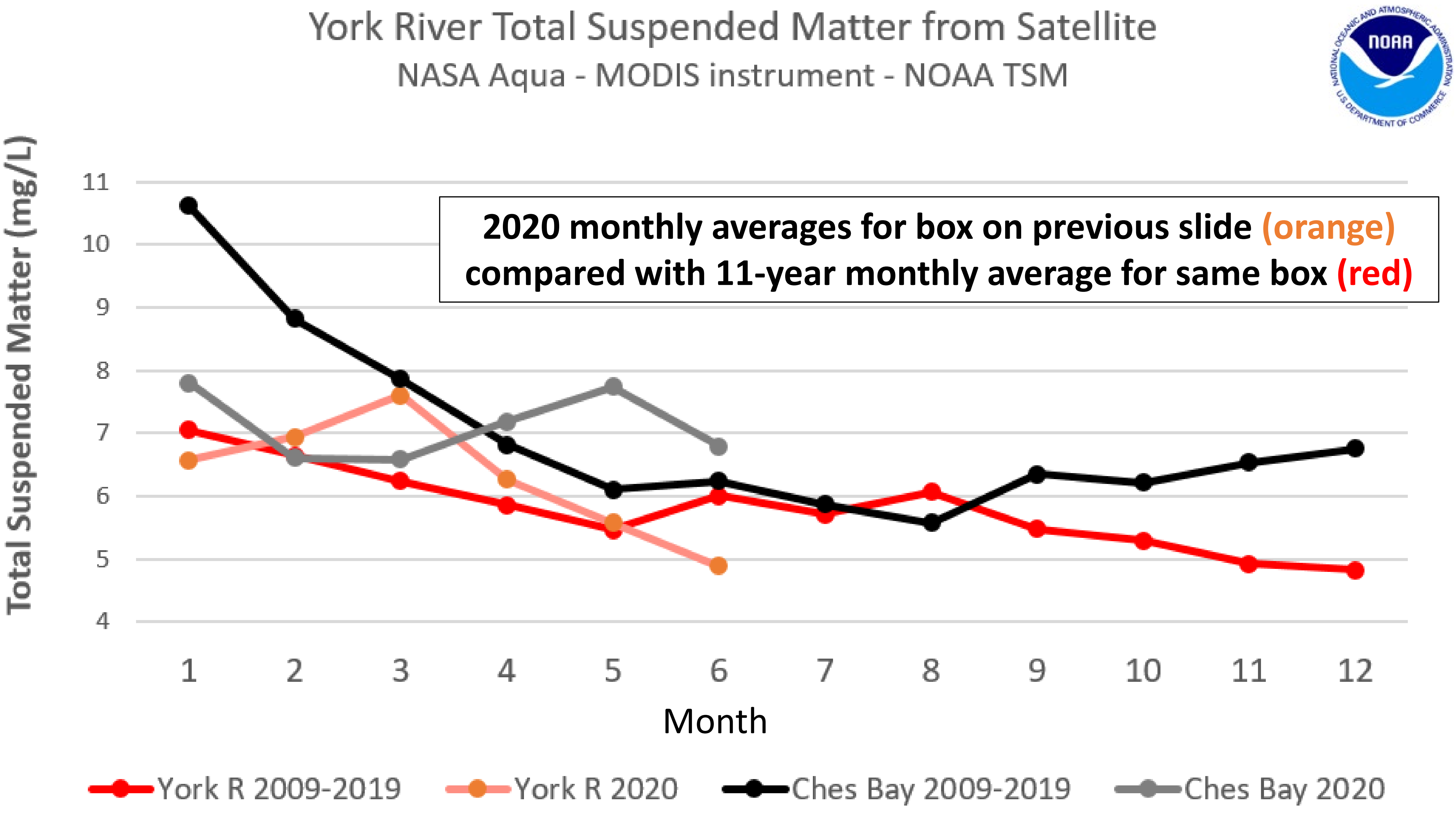


Use Case Example: Time series by averaging all pixels in region of interest (box or polygon)



TSM (VIIRS), **June 14, 2020**

7-11 mg/L

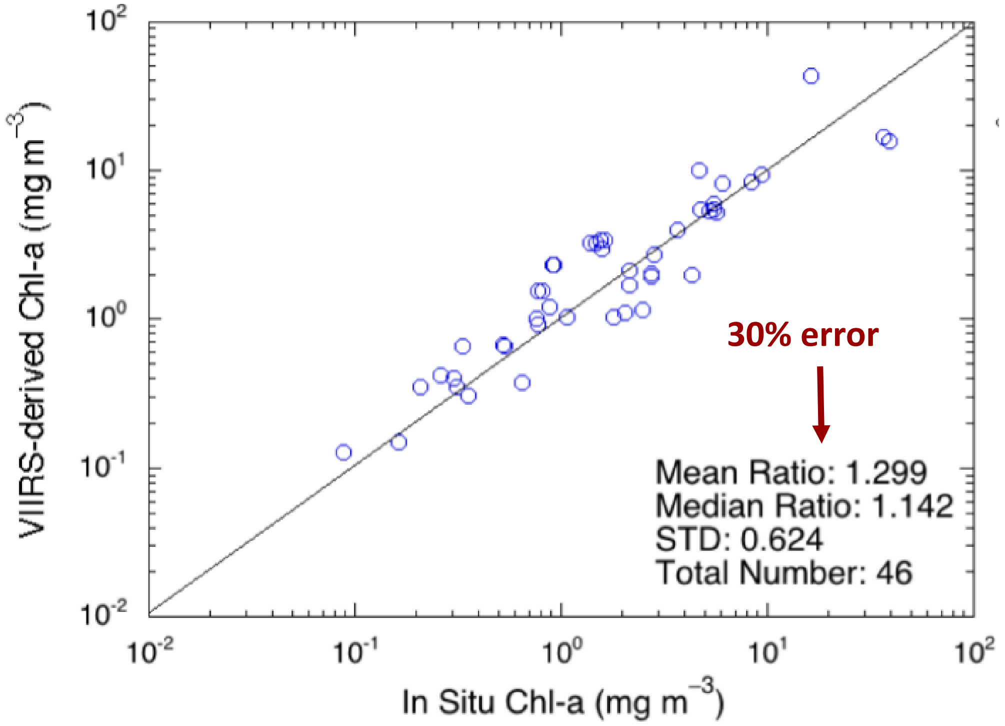

York River Total Suspended Matter from Satellite
NASA Aqua - MODIS instrument - NOAA TSM
2020 monthly averages for box on previous slide (orange)
compared with 11-year monthly average for same box (red)
Total Suspended Matter (mg/L)
11
10
9
8
7
6
5
4
1
2
3
4
5
6
7
8
9
10
11
12
Month
York R 2009-2019
York R 2020
Ches Bay 2009-2019
Ches Bay 2020

Satellite Data Accuracy

Data products are released after validation studies

- Satellite data are validated (ground-truthed) against *in-situ* data
- Comparison must be temporally & spatially representative
- Results are presented as comparison statistics (e.g. ratio, bias, standard deviation, RMS)
- Products termed Experimental may not have been validated
- Validation studies are published
  - In the scientific literature
  - As Algorithm Theoretical Basis Documents (ATBD) maintained by the producing agency (e.g. NASA, NOAA)
  - Usually with the algorithm description

Chl-a Measurements: VIIRS-SNPP vs. In-situ



→ *In-situ* data from the NASA SeaBASS database

→ Satellite data $\pm$3 hours of *in-situ* sampling time

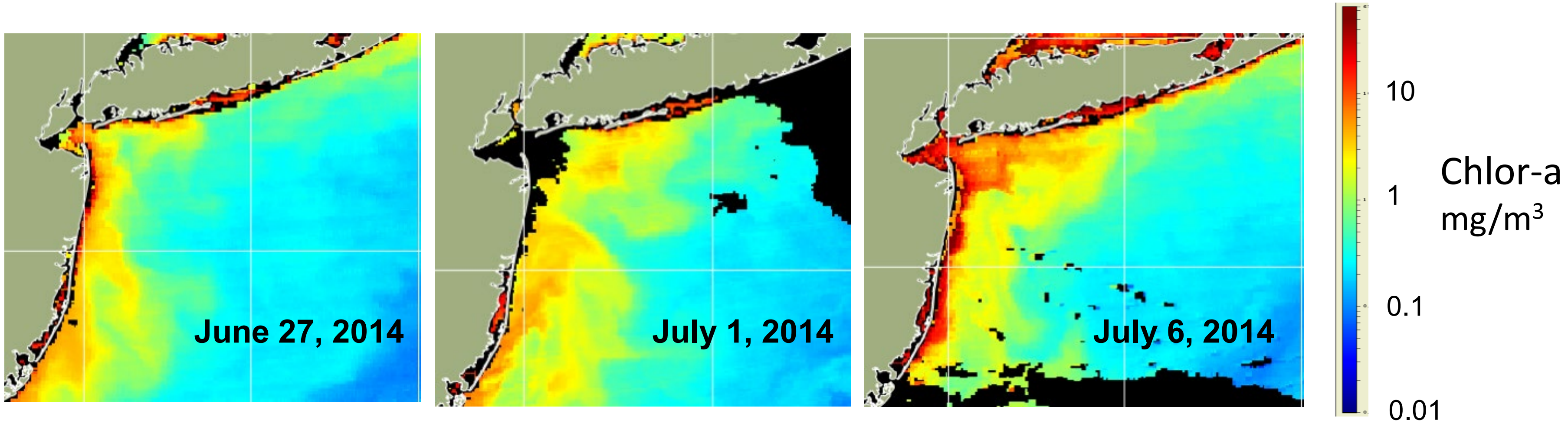
→ Satellite value is mean of 3X3 pixel box centered on *in-situ* sampling location

→ Source: NOAA VIIRS Ocean Color ATBD, Wang et al., 2017

Satellite Data Accuracy cont.

- The validation study describes the degree of accuracy. It *does not* mean the data are accurate!
- Your application defines what level of accuracy you can accept.
    - **Low accuracy applications:** detecting spatial patterns, averaged trend over time. Absolute data value is less important than detecting features or trends.
    - **High accuracy applications:** model input, environmental studies at single point locations. Absolute data value is important.

Example of low accuracy application: Imagery detects location and changes in plume, without needing to know absolute chlorophyll value. (Chlorophyll values are not accurate for coasts unless specially tuned for a location.)



Turbidity vs. Light Attenuation

Turbidity (units are NTUs, FTUs)

- Turbidity indicates the amount of scattering of light by particles
- Measured *in-situ* using nephelometers, turbidometers and similar instruments
- Turbidity is usually measured in Red-NIR
- Turbidity can be a better indicator for assessing visibility than light attenuation

Light Attenuation (Kd) units m^{-1}

- How rapidly sunlight is lost with depth in the water
- Caused by both absorption and scattering
- Estimated for diffuse light at a specific wavelength: e.g., 490 nm for Kd490
- How deep light penetrates matters for benthic plants and for photosynthesis

In places with a lot of sediment in the water, turbidity and Kd are closely correlated.
Both are correlated to the inverse of Secchi depth (SD), and Kd ~ 1/SD

Turbidity is also used colloquially as a term in conjunction with Water Clarity

Turbidity / Water Clarity can be a catch-all term related to:

- Light attenuation (absorption & scattering)
- *In-situ* measured turbidity
- Visibility
- Other assessments of particles in the water (e.g. detritus, sediment, organic particles)

TURBIDITY

Low → **High**

High ← **Low**

CLARITY