National Aeronautics and
Space Administration

CHESAPEAKE BAY WATER RESOURCES II

Assessing Water Clarity to Identify Potential Areas of Submerged Aquatic Vegetation (SAV) in the Chesapeake Bay

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2017 Summer

NASA Applied Sciences

Discovering Innovative & Practical Applications of NASA Earth Science

- ***Partner*** *with public and private organizations*
- ***Discover*** *innovative NASA Earth science applications*
- ***Support*** *environmental decision-making activities*
- ***Demonstrate*** *practical benefits of NASA Earth science*
- ***Help*** *improve the quality of life and strengthen the economy*

Thematic Application Areas

Agriculture
Climate
Disasters
Eco Forecasting
Energy
Health & AQ
Oceans
Water Resources
Weather

Capacity Building

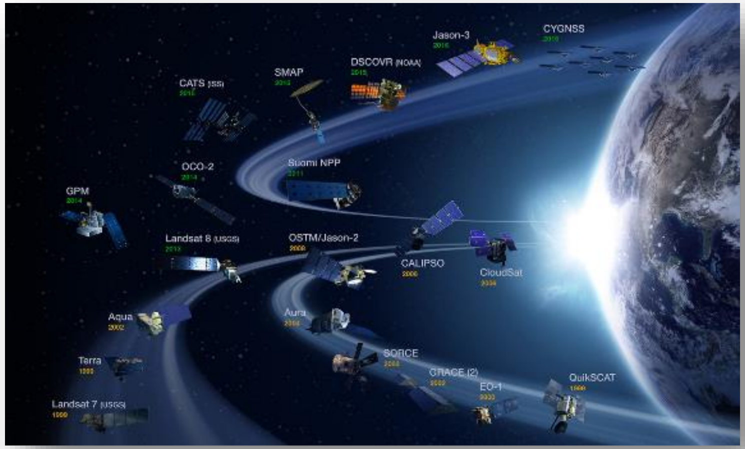
APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

DEVELOP

SERVIR GLOBAL
CONNECTING SPACE TO VILLAGE

What is DEVELOP?

DEVELOP collaborates with decision makers to conduct feasibility projects that apply NASA Earth observations to address environmental issues. These projects engage young professionals (students and recent graduates) and decision makers in 10-week projects that identify opportunities to use NASA satellite data to create methodologies and tools for project partners. This directly supports both individuals and institutions, and increases the use of Earth observation data and enhances decision and policy making.



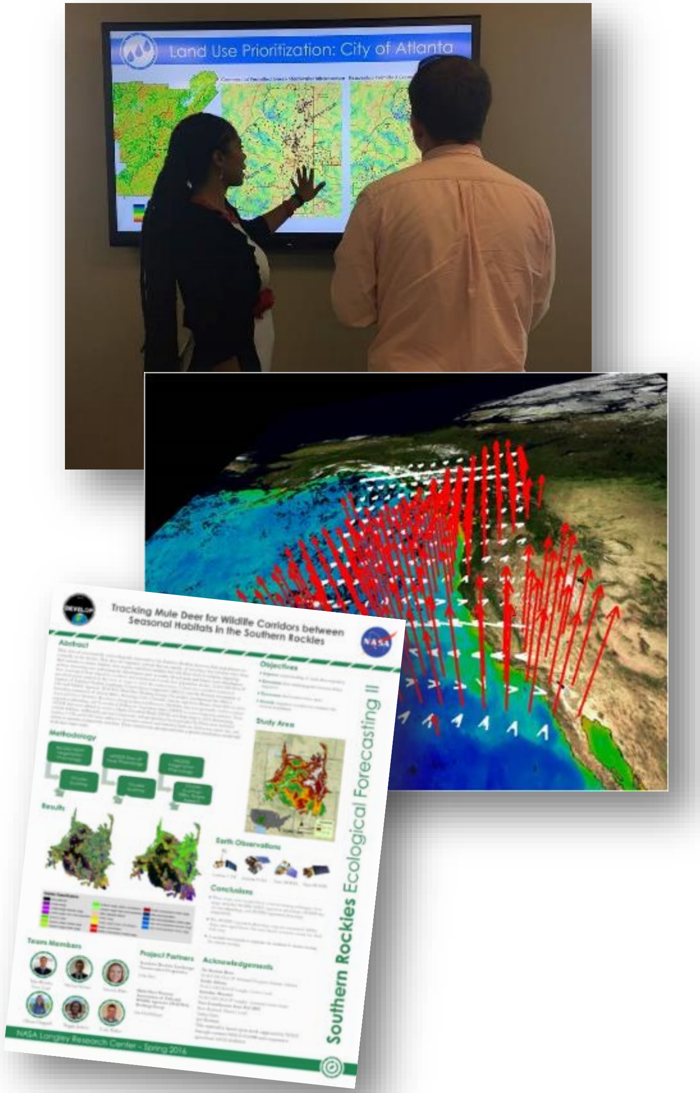
NASA DEVELOP

DEVELOP bridges the gap between NASA Earth Science and society, building capacity in both its participants and end-user organizations to better prepare them to handle the environmental challenges that face society.

DEVELOP Project Characteristics

70-80 projects take place each year – at their core they share these characteristics:

- Highlight the applications and capabilities of **NASA Earth observations**
- Address **community concerns** relating to decision-making for real-world environmental issues
- Partner with organizations who can benefit from using NASA Earth observations to **enhance decision-making** by providing decision support tools
- Align with at least one of the nine NASA Applied Sciences Program's thematic **Application Areas**
- Research is conducted by **interdisciplinary teams** under the scientific guidance of DEVELOP Science Advisors and Mentors from NASA and partner organizations
- Create a comprehensive set of **deliverables** in just 10 weeks!

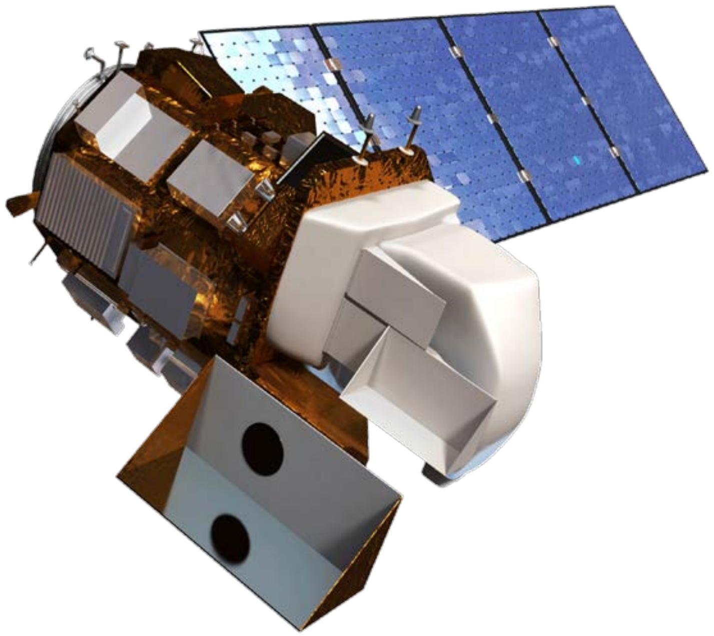


Project Objectives

- **Determine** feasibility of using remote sensing to monitor water clarity
- **Correlate** and model satellite derived water clarity metrics
- **Expedite** atmospheric correction process for satellite imagery
- **Produce** annual water clarity maps

Image Credit: Pixabay

NASA & ESA Earth Observations



Landsat 8

Operational Land Imager (OLI)

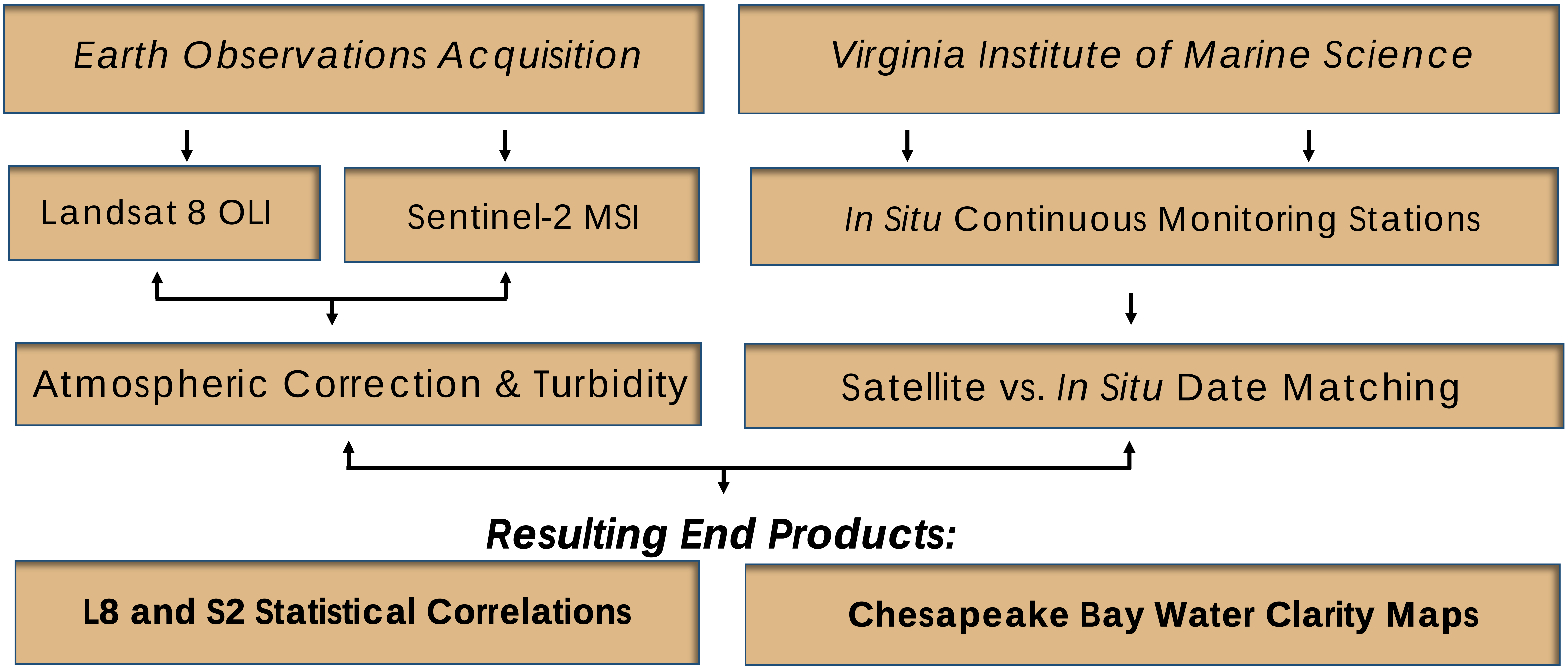
2013 - 2017

Sentinel-2

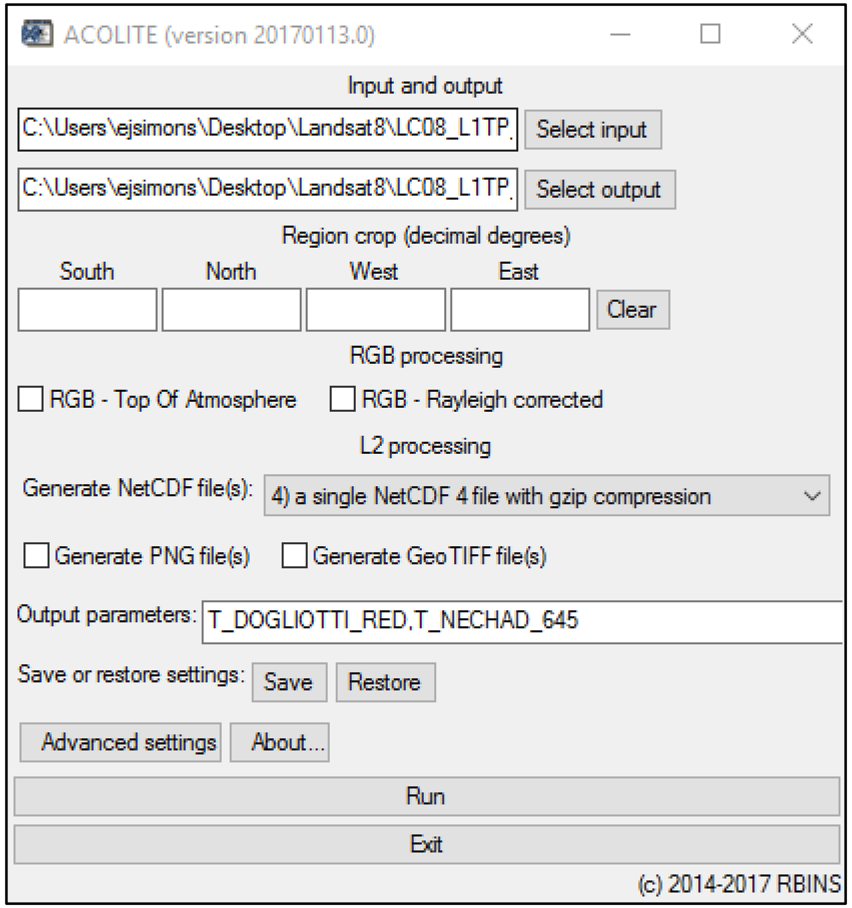
MultiSpectral Instrument (MSI)

2015 - 2017

Methodology

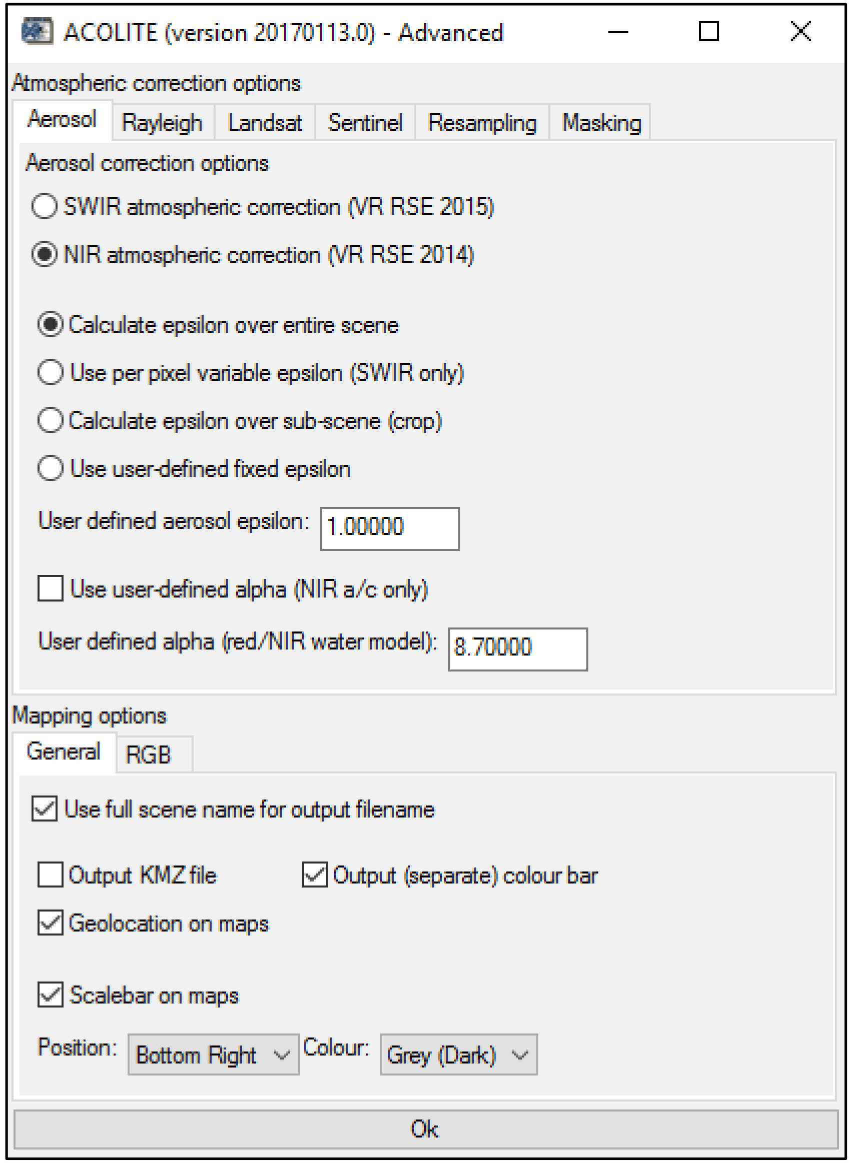


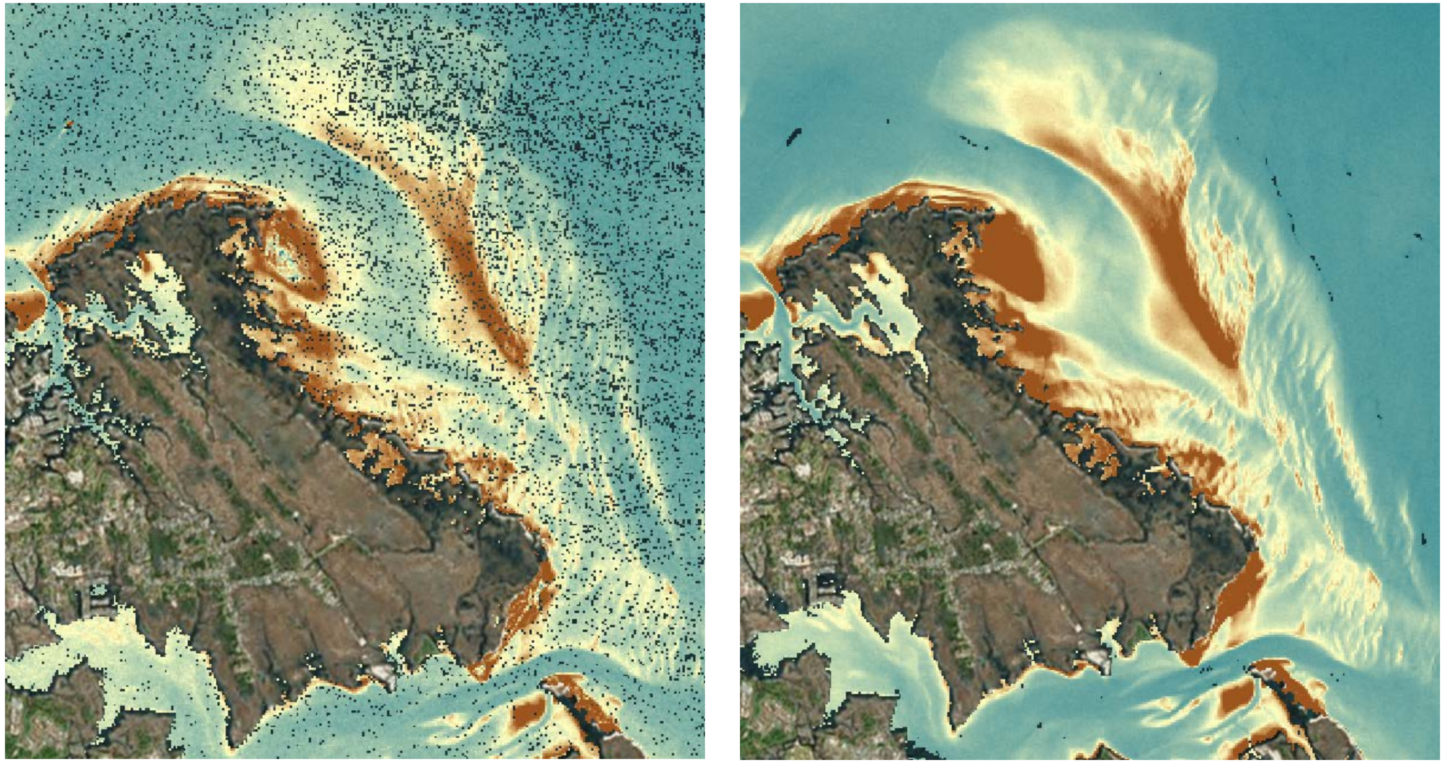
ACOLITE



- ACOLITE is an atmospheric correction and processor for satellite imagery, including:
  - Landsat 8
  - Sentinel-2
- Developed at the Royal Belgian Institute of Natural Sciences (RBINS)
- ACOLITE allows simple and fast processing of L8 and S2A images for marine and inland water applications

ACOLITE Advanced Settings





SWIR vs. NIR atmospherically corrected ACOLITE products, derived from Landsat 8 imagery captured April 9th, 2017

ACOLITE Turbidity Algorithms

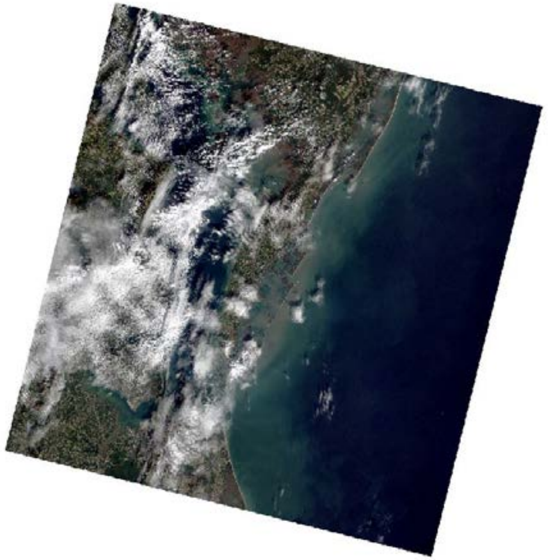
- **T_DOGLIOTTI_RED**: red-band turbidity from (Dogliotti et al., 2015) using the 645 nm setting from their paper with the OLI 655 nm band or the MSI 665 nm band.
- **T_GARABA_645_LIN**: turbidity from (Garaba et al., 2014) using the linear 645 nm model from their paper with the OLI 655 nm band or the MSI 665 nm band.
- **T_NECHAD_645**: turbidity from (Nechad et al., 2009) using the 645 nm setting from their paper with the OLI 655 nm band or the MSI 665 nm band.

- Single band retrieval algorithms relate turbidity and water reflectance at a predefined wavelength chosen by the user – In our case, the red band

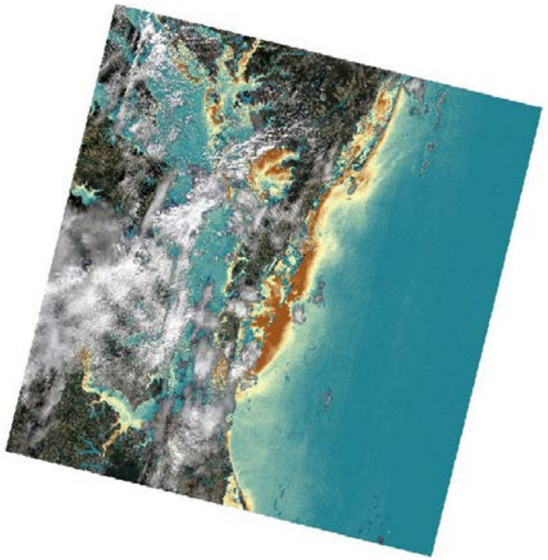
ACOLITE Output Limitations

- Limited satellite data availability for imagery with heavy cloud cover

- Limited satellite data availability around monitoring stations close to land/inland



RGB Overview with Cloud Cover



Turbidity Product over RGB with Cloud Cover

ACOLITE processed Turbidity Product

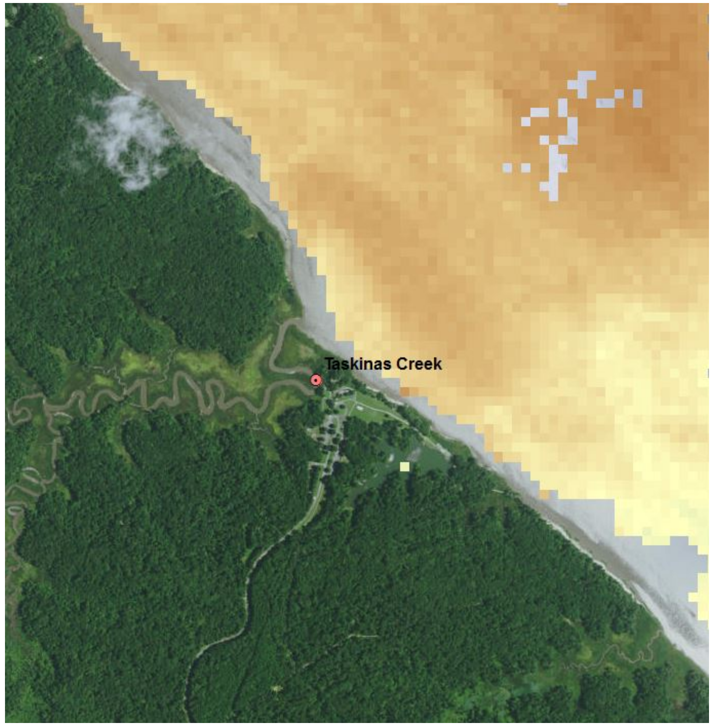


Image Credit: Pixabay

Analysis & Results

Statistical Correlations By Station

NIR Corrected by Station Statistical Analysis		ACOLITE Turbidity Products (R Values)				
		RRS Red	Dogliotti Red	Dogliotti Blended	Garaba	Nechad
Continuous Monitoring Stations	Cherrystone				0.398	
	Ashland Circle					0.949
	Claybank		0.174			
	Dividing Creek					0.570
	First Landing		0.867			0.867
	Gloucester					0.332
	Goodwin Island				0.145	
	Hungars Creek	0.903				
	Hunting Creek					0.375
	Indian Creek					
	Ingram Bay		0.507			
	Jamestown Buoy			0.732		
	James River					0.562
	Nassawadox Creek					0.623
	Norfolk Yacht					0.466
	Stingray Point		0.984			
	Tallpines				0.999	
	White House Landing					0.198
	Sweet Hall Marsh	1.000				

Best Combined Analysis	
Station	Product
Cherrystone	Nechad
Tallpines	Nechad
Ashland Circle	Nechad
Dividing Creek	Nechad
Hunting Creek	Nechad
James River	Nechad
Nassawadox Creek	Nechad
Norfolk Yacht	Nechad
First Landing	Nechad/Dogliotti Red
Hungars Creek	Dogliotti Red
Sweet Hall Marsh	Dogliotti Red
Claybank	Dogliotti Red
Ingram Bay	Dogliotti Red
Jamestown Buoy	Dogliotti Red
Stingray Point	Dogliotti Red

NO STATION AVAILABLE	POSITIVE CORRELATIONS
NEGATIVE CORRELATIONS	***BEST POSITIVE CORRELATION***

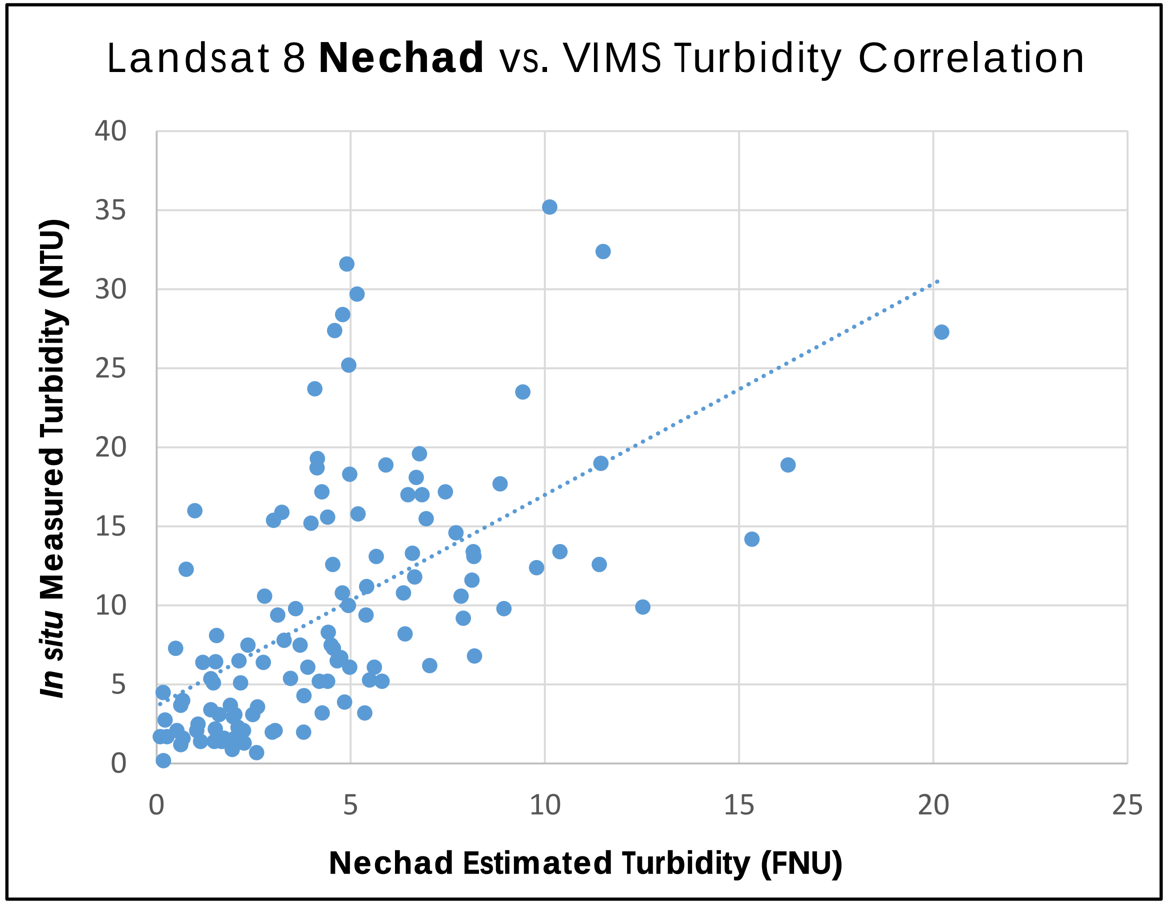
Overall Analysis

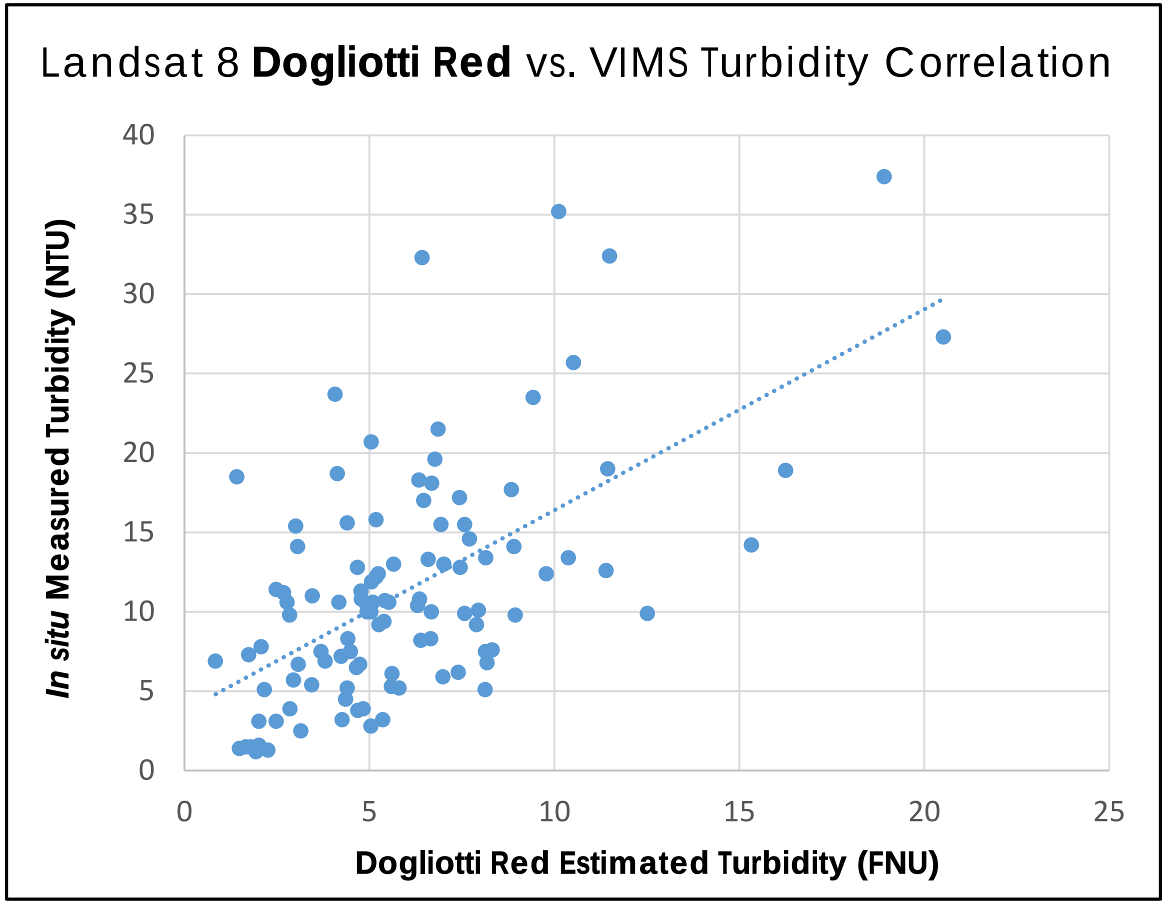
Best Analysis		
Station	Product	Location Description
Cherrystone	**Garaba**	Open Water
Goodwin Island	**Garaba**	Shallow Water, Sandy Bottom, Clear Conditions
Tallpines	**Garaba**	Open Water in Basin, Close to Shore
Indian Creek	**N/A**	Near Dock, Shallow Water, Sandy Bottom
Ashland Circle	**Nechad**	Tucked In, Small Sandy Bottom
Dividing Creek	**Nechad**	Near Dock, Shallow Water
Gloucester	**Nechad**	Adjacent to VIMS Coastline, Near bridge and Land
Hunting Creek	**Nechad**	In Creek, No Bottom Effect
James River	**Nechad**	Near building, No Sandy Bottom
Nassawadox Creek	**Nechad**	In Creek, Small Sandy Bottom
Norfolk Yacht	**Nechad**	Tucked Away in Norfolk Marina, Adjacent to Bridge
White House Landing	**Nechad**	Far up on Pamunkey, Near Bridge, Lots of SSD
First Landing	**Nechad/Dogliotti Red**	Out in Open Bay Waters
Hungars Creek	**RRS Red**	In Creek, Little Bottom
Sweet Hall Marsh	**RRS Red**	Up in Pamunkey River, Off land
Claybank	**Dogliotti Red**	Out in York, No Bottom
Ingram Bay	**Dogliotti Red**	Shallow Clear, Constant Conditions, Coastal, Away from Shore
Jamestown Buoy	**Dogliotti Blend**	Out in James River, Open Water
Stingray Point	**Dogliotti Red**	Open Water, Mouth of Rhappahannok

Best Combined Analysis	
Station	Product
Cherrystone	**Nechad**
Tallpines	**Nechad**
Ashland Circle	**Nechad**
Dividing Creek	**Nechad**
Hunting Creek	**Nechad**
James River	**Nechad**
Nassawadox Creek	**Nechad**
Norfolk Yacht	**Nechad**
First Landing	**Nechad/Dogliotti Red**
Hungars Creek	**Dogliotti Red**
Sweet Hall Marsh	**Dogliotti Red**
Claybank	**Dogliotti Red**
Ingram Bay	**Dogliotti Red**
Jamestown Buoy	**Dogliotti Red**
Stingray Point	**Dogliotti Red**

Deleted Stations
Goodwin Island
Gloucester
White House Landing
Indian Creek

Earth Observations vs. *In Situ* Data





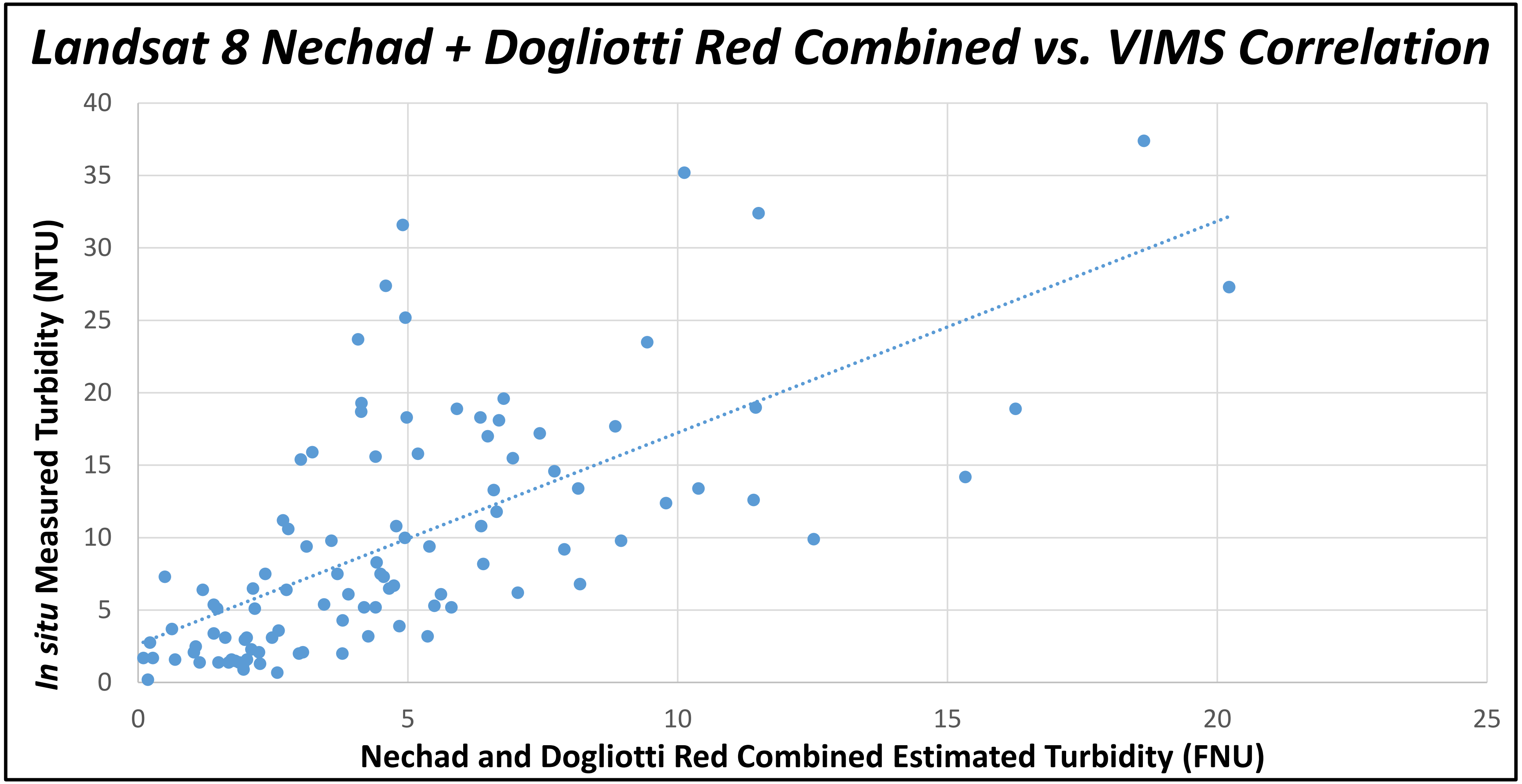
Nechad: R = 0.5929

y = 1.3356x + 3.6444

Dogliotti Red: R = 0.5997

y = 1.2647x + 3.7365

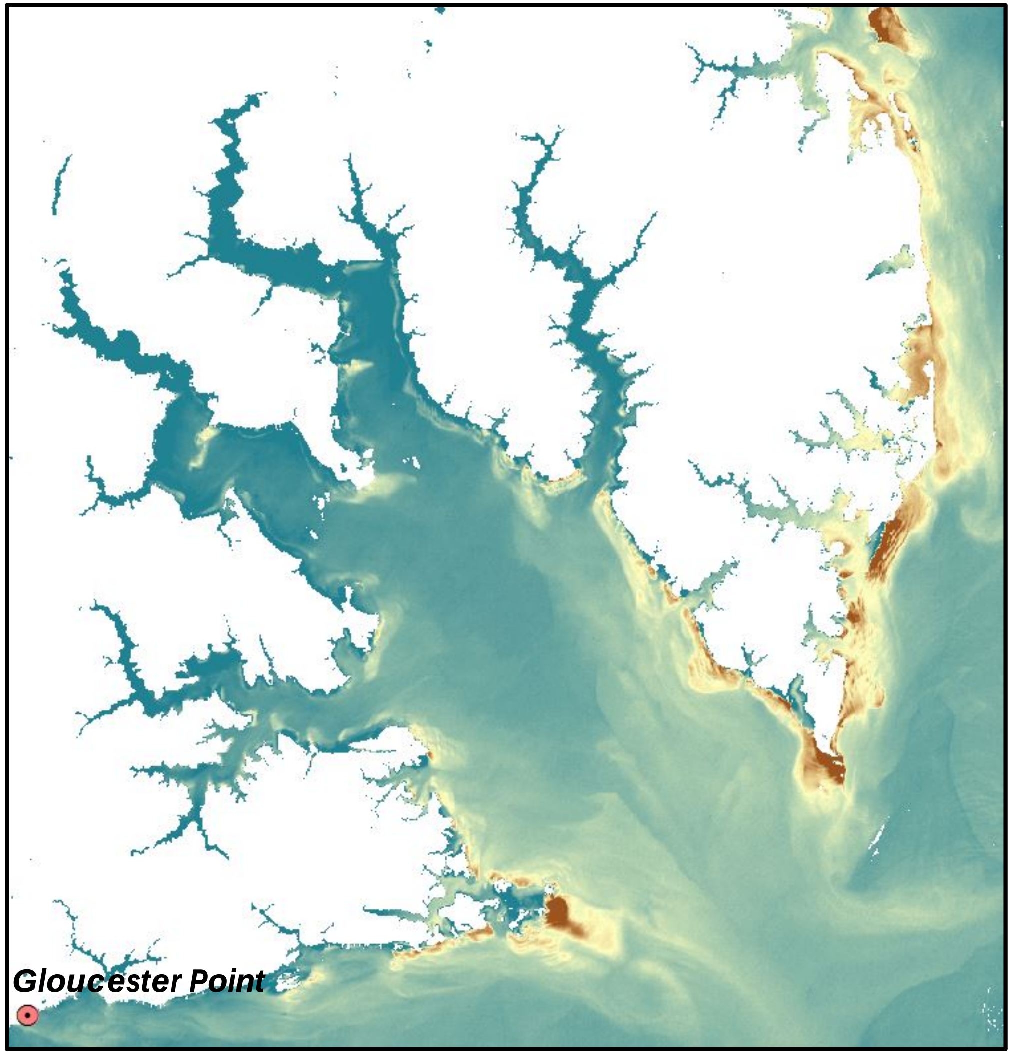
Combined Nechad and Dogliotti Red



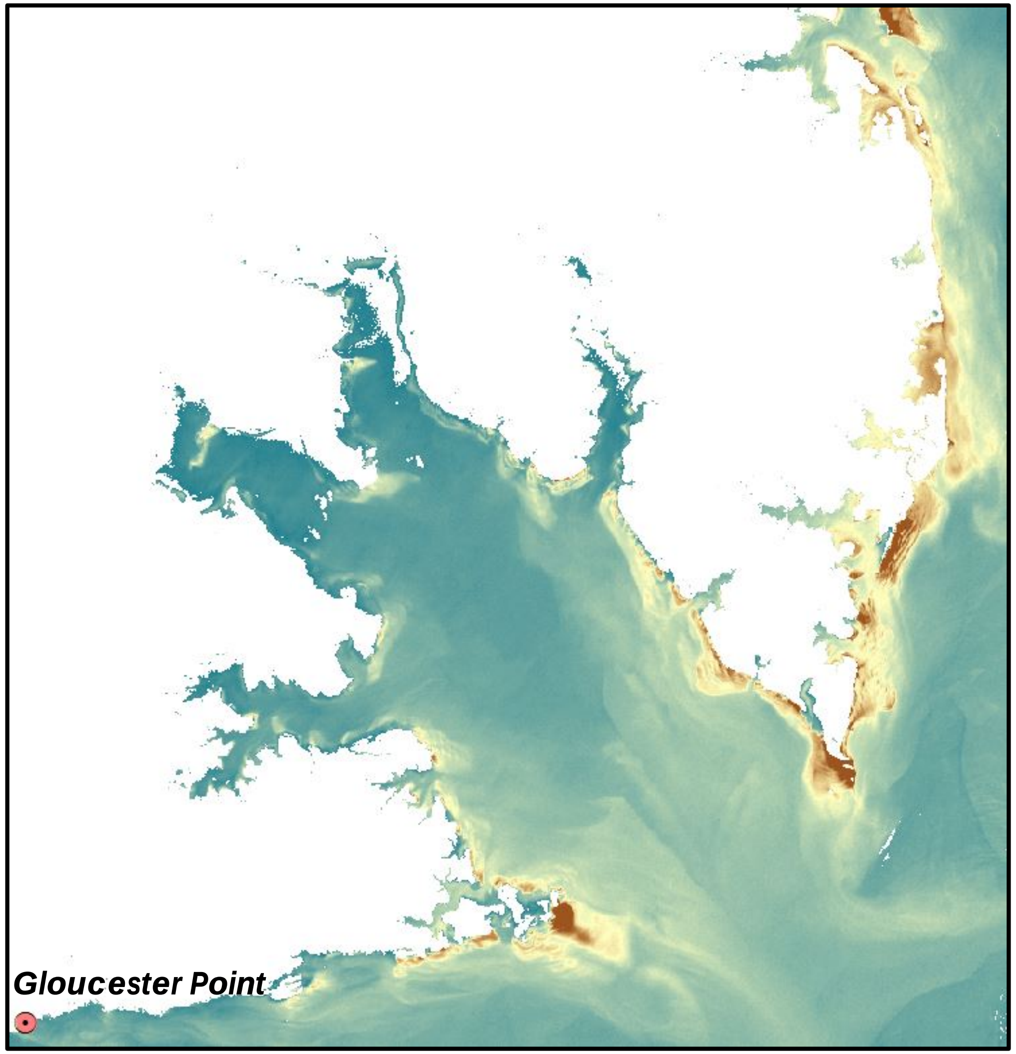
Nechad** and **Dogliotti Red: R = 0.6727

y = 1.4605x + 2.6439

Nechad vs. Dogliotti Red: Tributaries



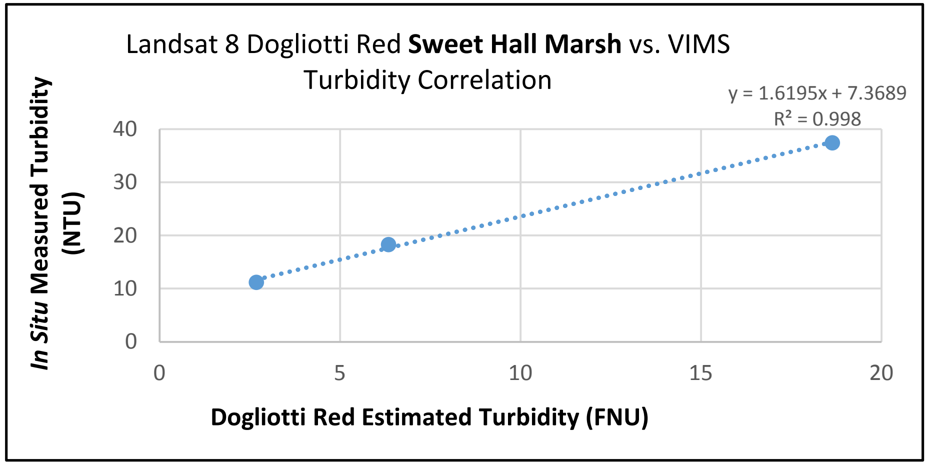
Landsat 8 Nechad Turbidity Product (07/19/13)

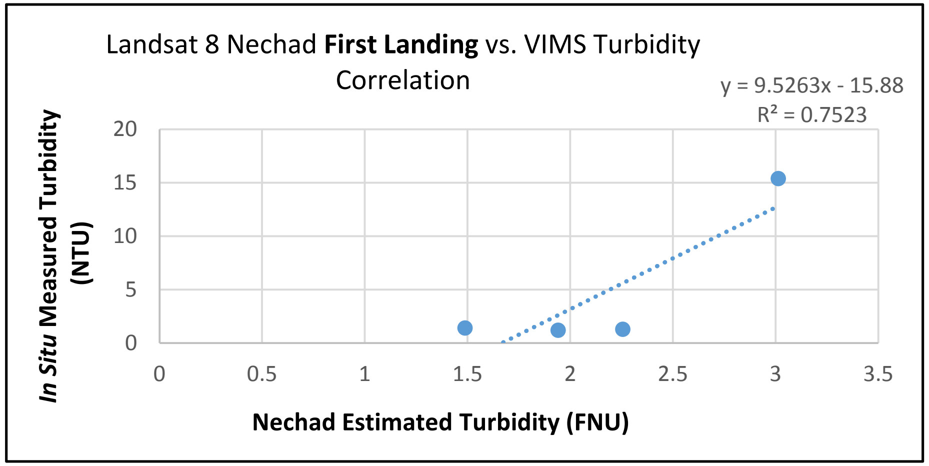


Landsat 8 Dogliotti Red Turbidity Product (07/19/13)

Strength Coefficient

Strength Coefficient					
Nechad	Cherrystone	0.440	T Dogliotti Red	Cherrystone	0.279
	Ashland Circle	1.784		Ashland Circle	N/A
	Claybank	0.159		Claybank	0.350
	Dividing Creek	1.824		Dividing Creek	-0.021
	First Landing	0.993		First Landing	1.584
	Gloucester	1.456		Gloucester	1.424
	Goodwin Island	0.011		Goodwin Island	-0.052
	Hungars Creek	1.450		Hungars Creek	1.468
	Hunting Creek	0.464		Hunting Creek	-0.145
	Indian Creek	2.253		Indian Creek	-2.404
	Ingram Bay	-0.062		Ingram Bay	1.351
	Jamestown Buoy	1.938		Jamestown Buoy	3.047
	James River	2.189		James River	1.222
	Nassawadox Creek	1.408		Nassawadox Creek	0.911
	Norfolk Yacht	1.001		Norfolk Yacht	0.058
	Stingray Point	2.381		Stingray Point	3.056
	Tallpines	0.988		Tallpines	N/A
	White House Landing	0.181		White House Landing	N/A
	Sweet Hall Marsh	1.102		Sweet Hall Marsh	1.576





Strength Coefficient

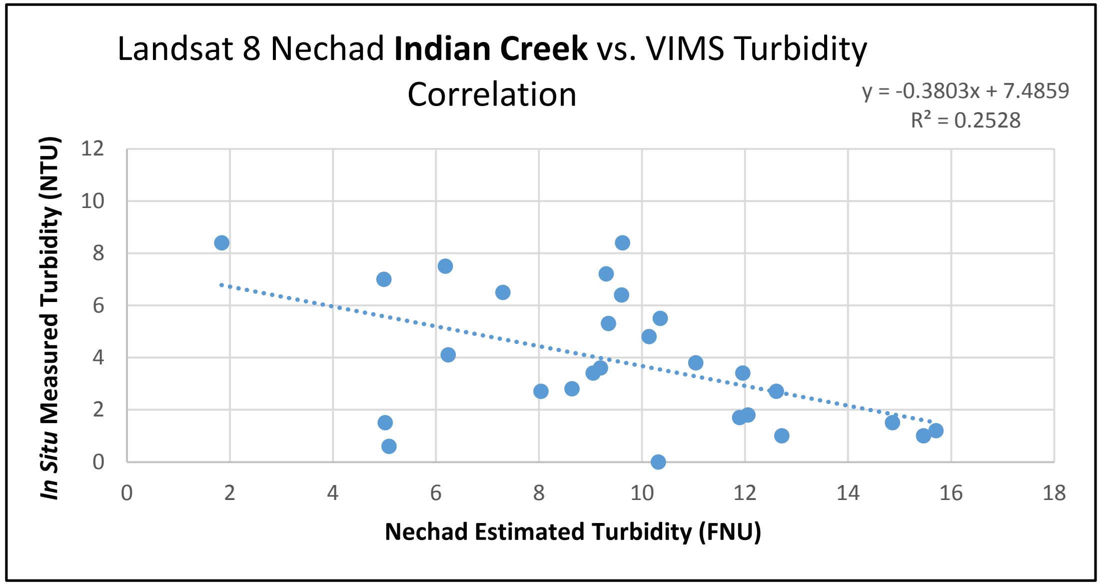
Strength Coefficient Performance					
Nechad			T Dogliotti Red		
Top 3	**Stingray Point**	2.381	Top 3	**Stingray Point**	3.056
	James River	2.041		First Landing	1.584
	Jamestown Buoy	1.806		Sweet Hall Marsh	1.576
Bottom 3	**Indian Creek**	-2.100	Bottom 3	**Indian Creek**	-2.404
	Goodwin Island	0.011		Hunting Creek	-0.145
	Ingram Bay	0.058		Dividing Creek	-0.021

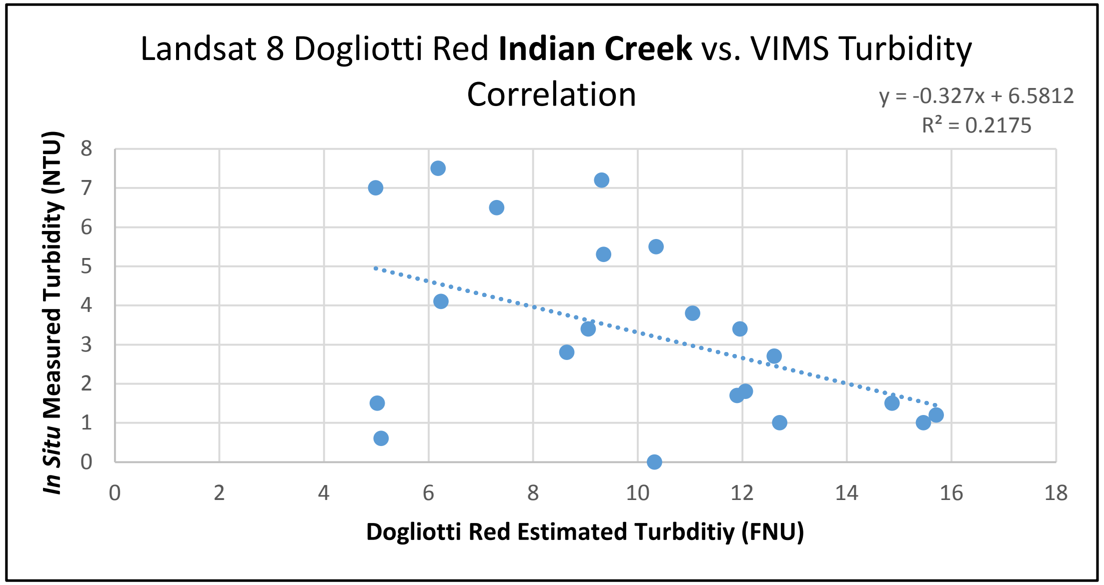
$$\text{Strength Coefficient} = \frac{N' * R^2}{N} * 100$$

- Where:
  - N' is the number of points matched at the specific station
  - R^2 is the coefficient of determination at the specific station
  - N is the total points matched with the turbidity product

Strength Coefficient

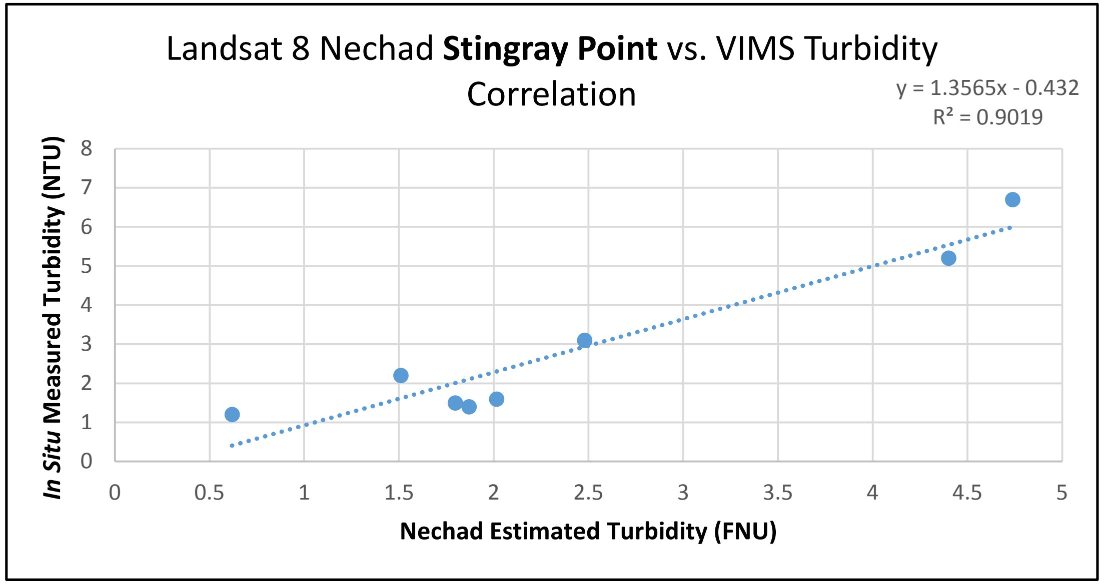
Strength Coefficient Performance					
Nechad			T Dogliotti Red		
Top 3			Top 3		
Bottom 3	Indian Creek	-2.100	Bottom 3	Indian Creek	-2.404

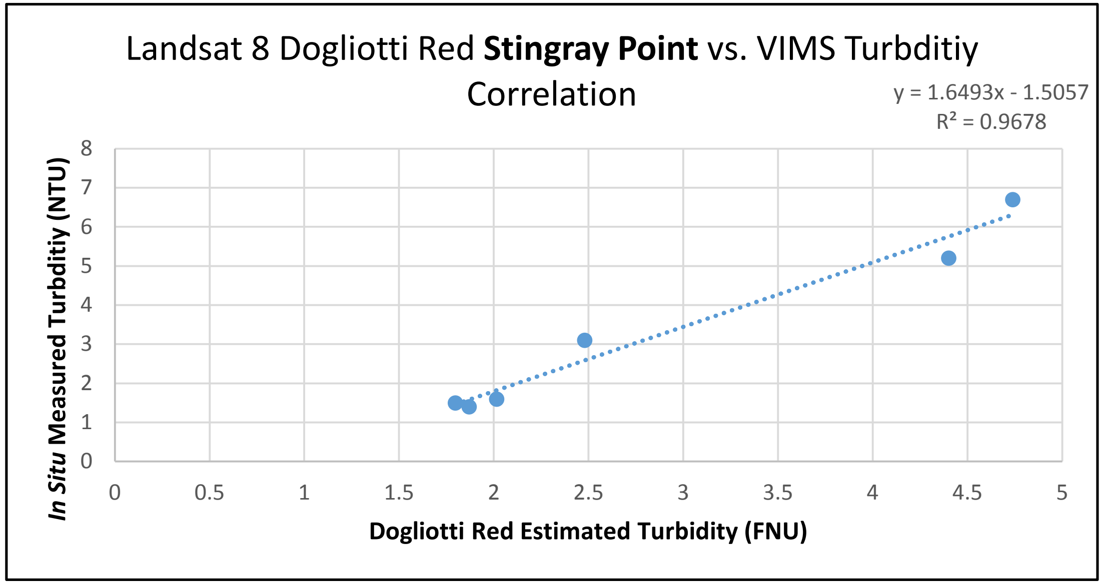




Strength Coefficient

Strength Coefficient Performance					
Nechad			T Dogliotti Red		
Top 3	Stingray Point	2.381	Top 3	Stingray Point	3.056
Bottom 3			Bottom 3		





Empirical Correction Comparison

Average Turbidity = 2.42 FNU

Mobjack Bay (2013-2017)

Original Dogliotti Turbidity Product

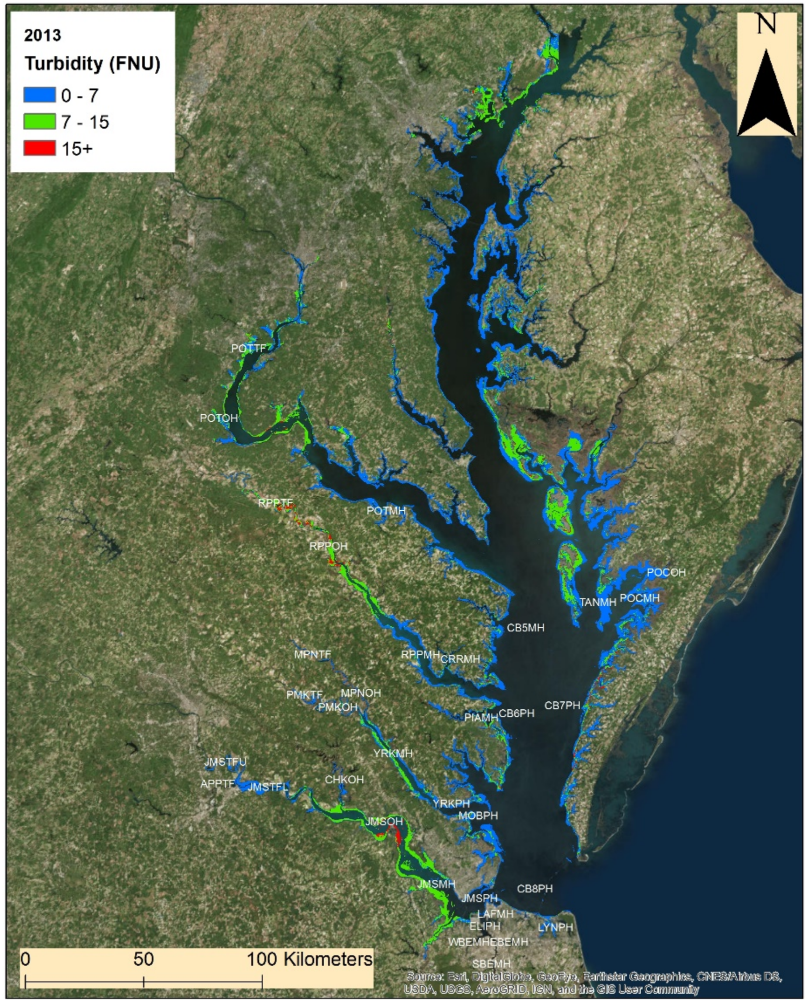
Average Turbidity = 6.81 FNU

Mobjack Bay (2013-2017)

Empirically Corrected Dogliotti Turbidity Product

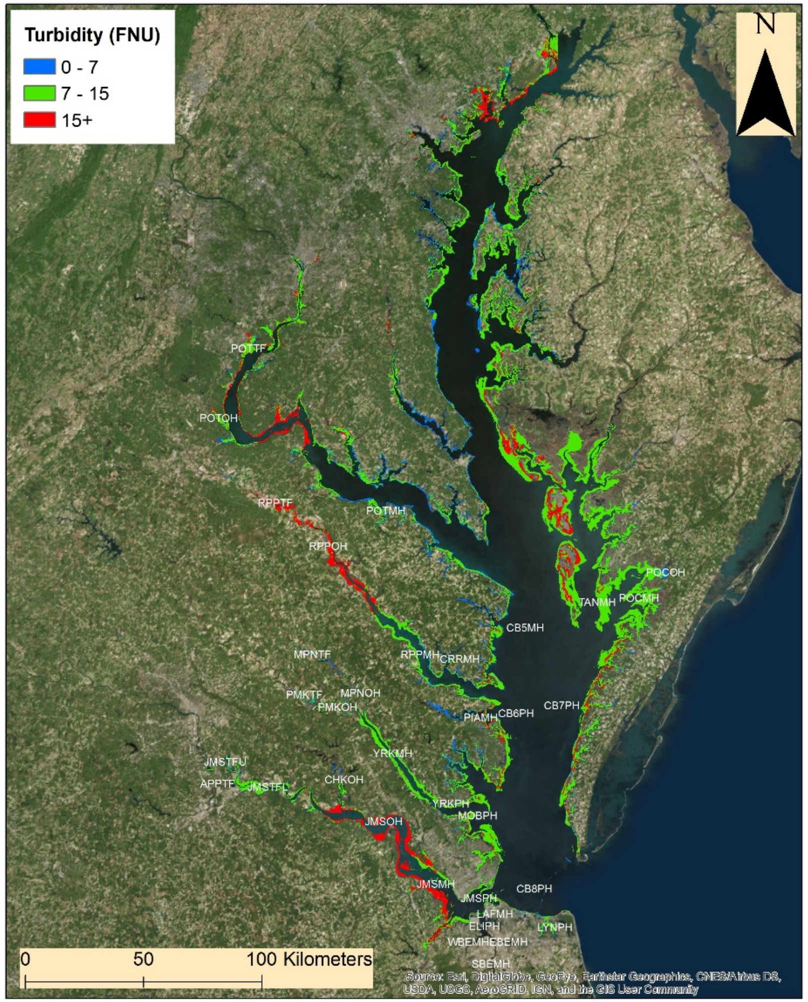
Effect of Empirical Correction on Standards

Average 2m Turbidity (2013)



Original 2m Nechad Turbidity Product

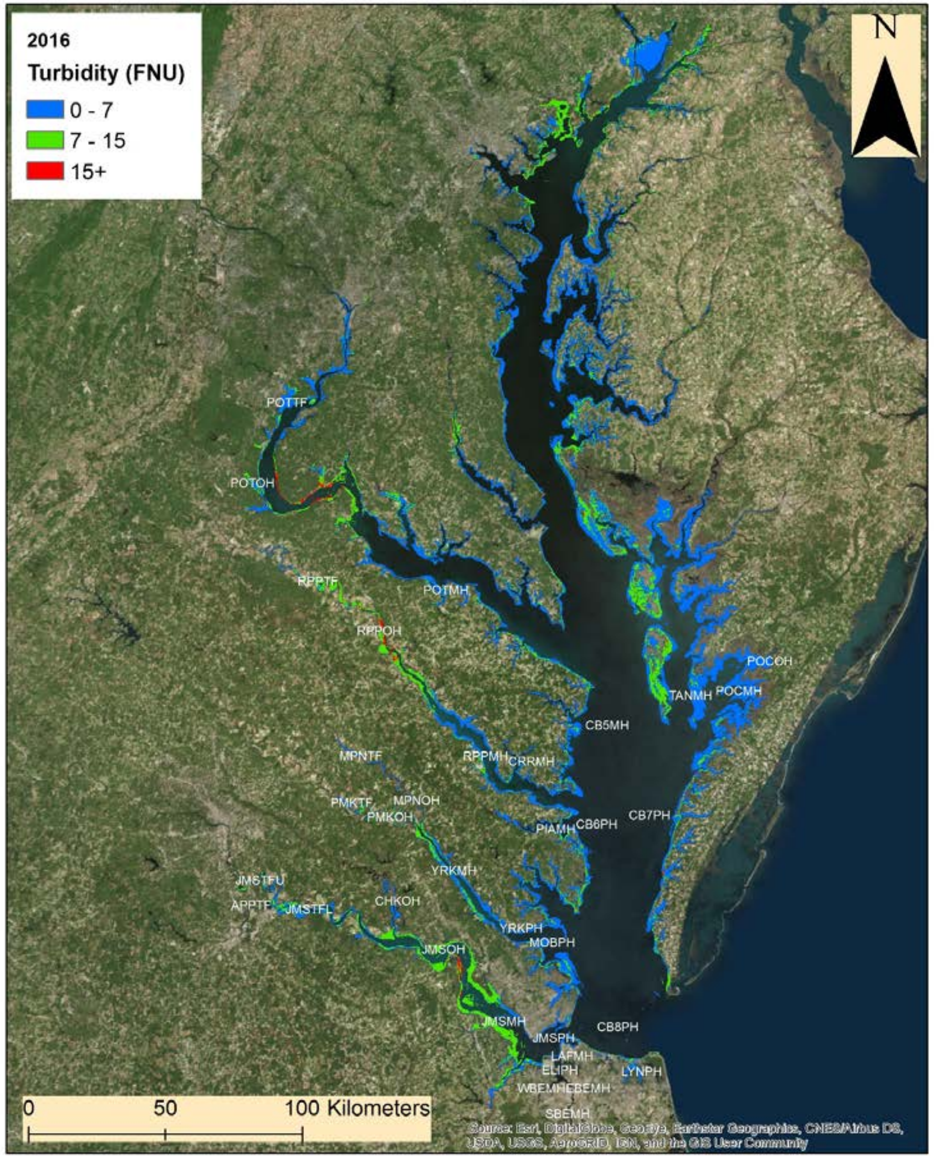
Average 2m Turbidity (2013)



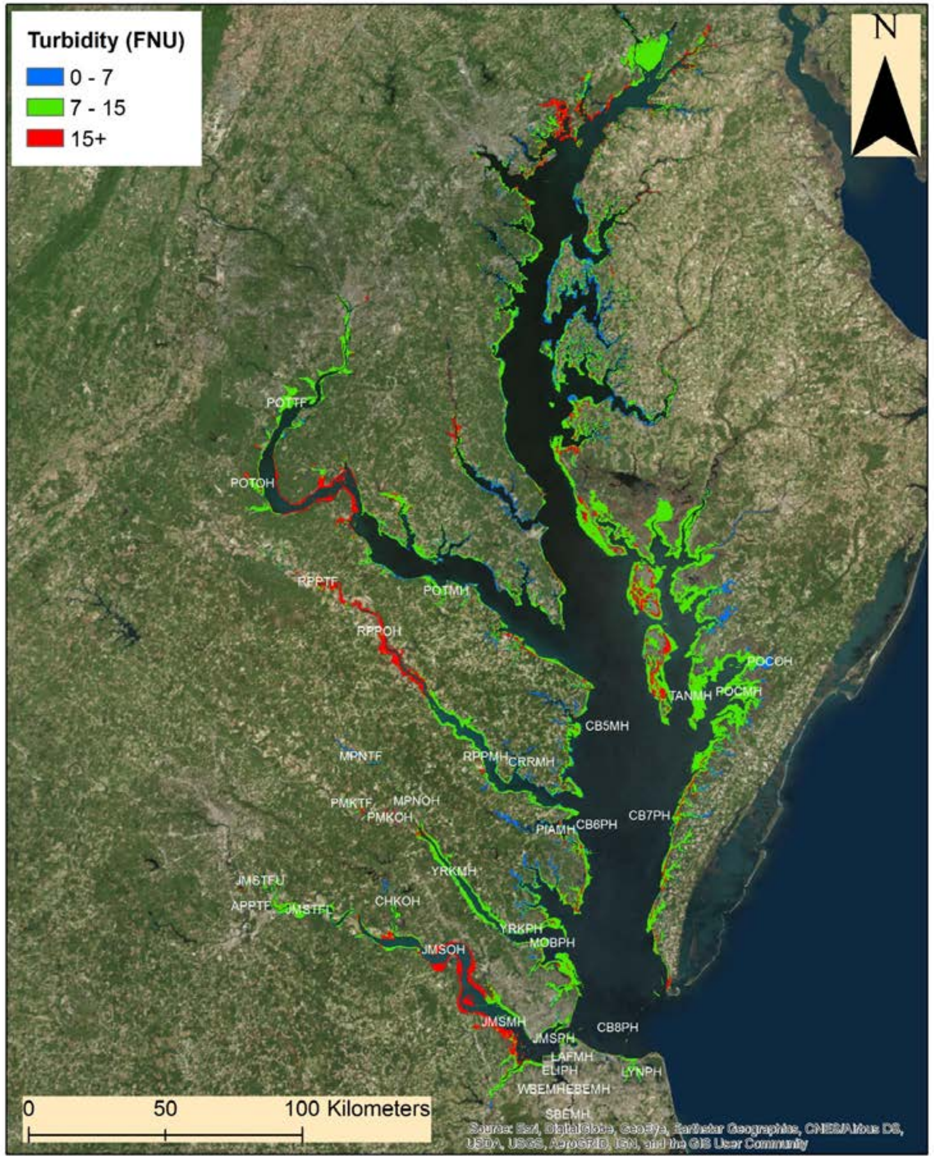
Empirically Corrected 2m Nechad Turbidity Product

Empirical Correction (2016)

Average 2m Turbidity (2016)

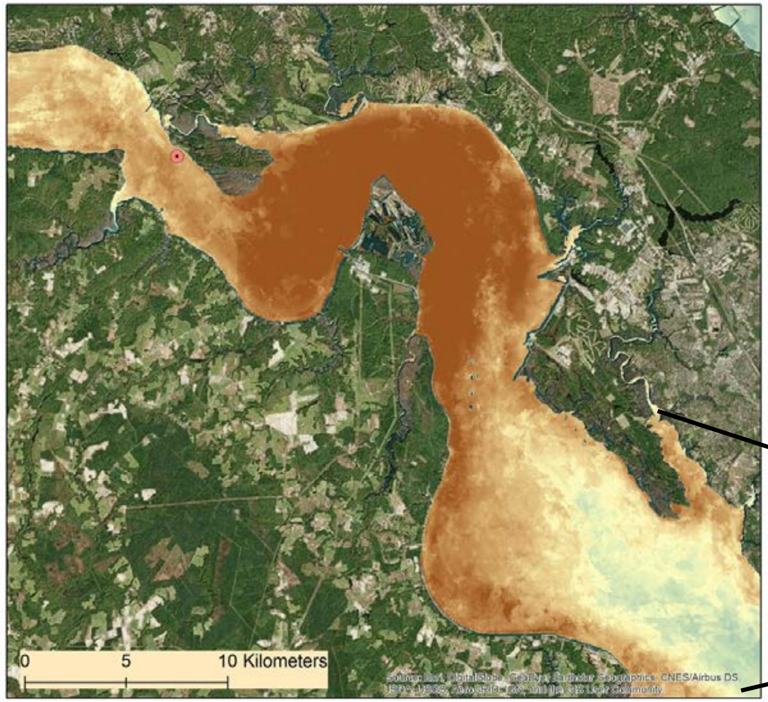


Average 2m Turbidity (2016)



Annual Water Clarity Maps: Dogliotti Red

James River 2013

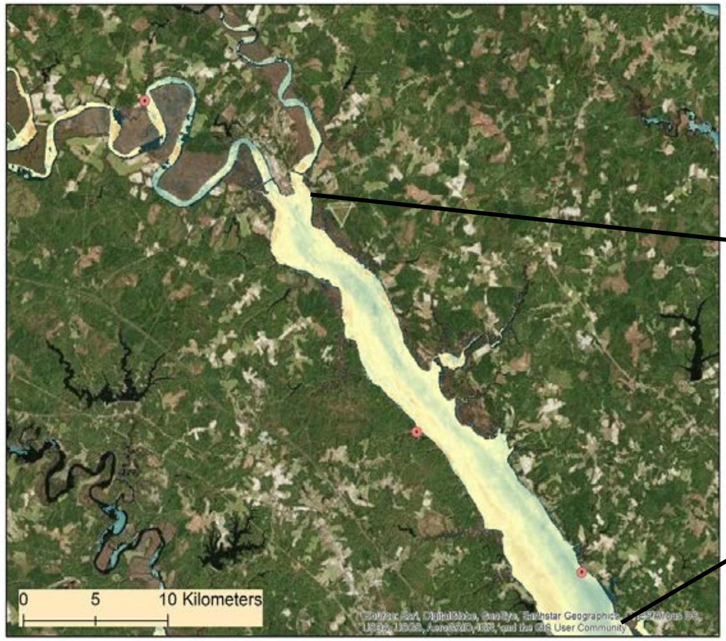


Landsat 8 Virginia Chesapeake Baywide Mosaic

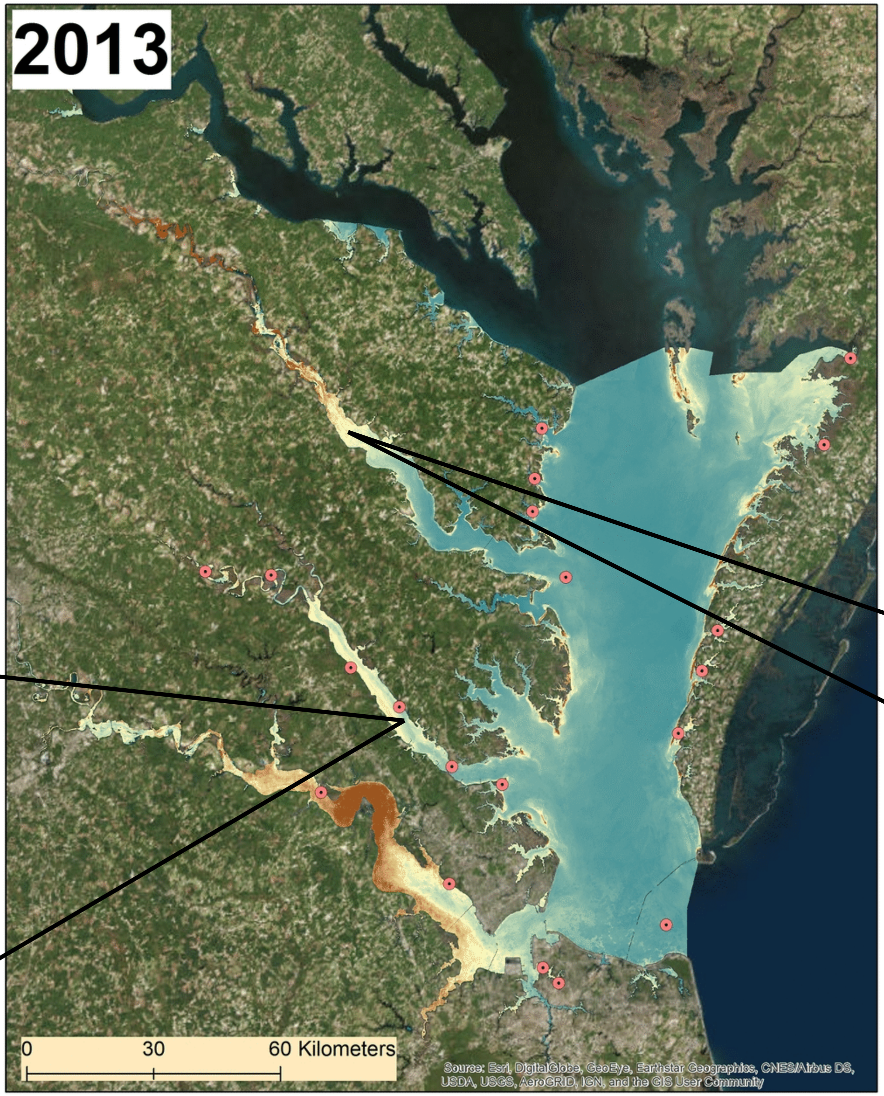
Pocomoke Sound 2013

Annual Water Clarity Maps: Dogliotti Red

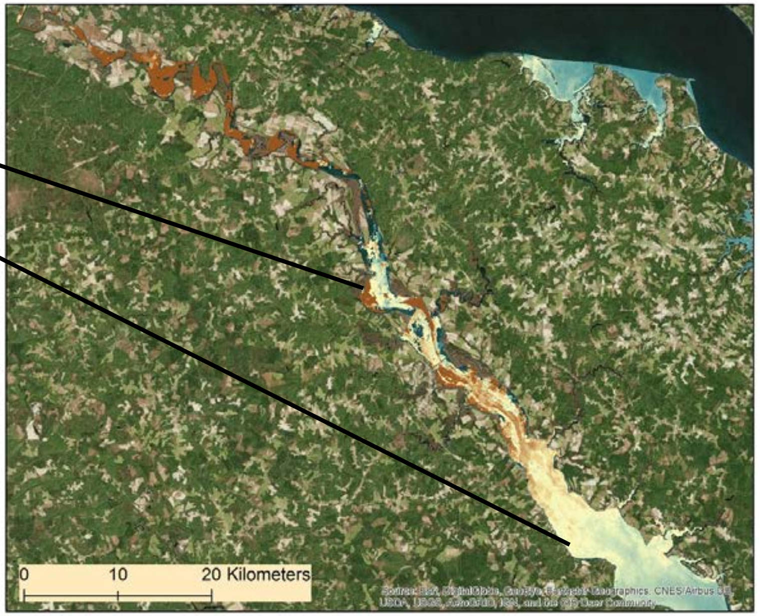
York River 2013



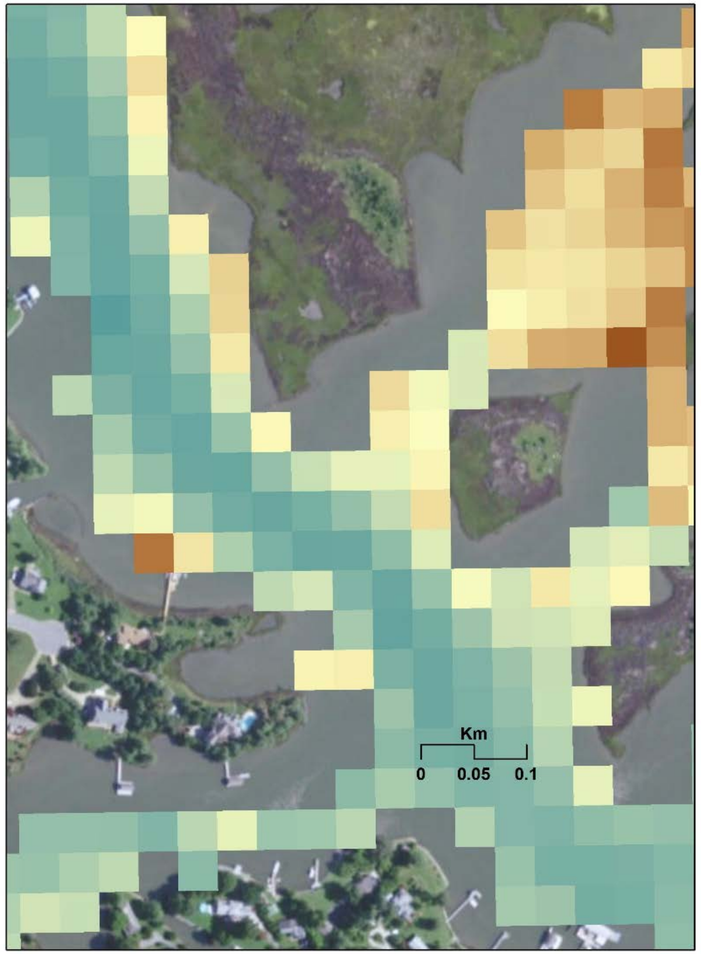
Landsat 8 Virginia Chesapeake Baywide Mosaic



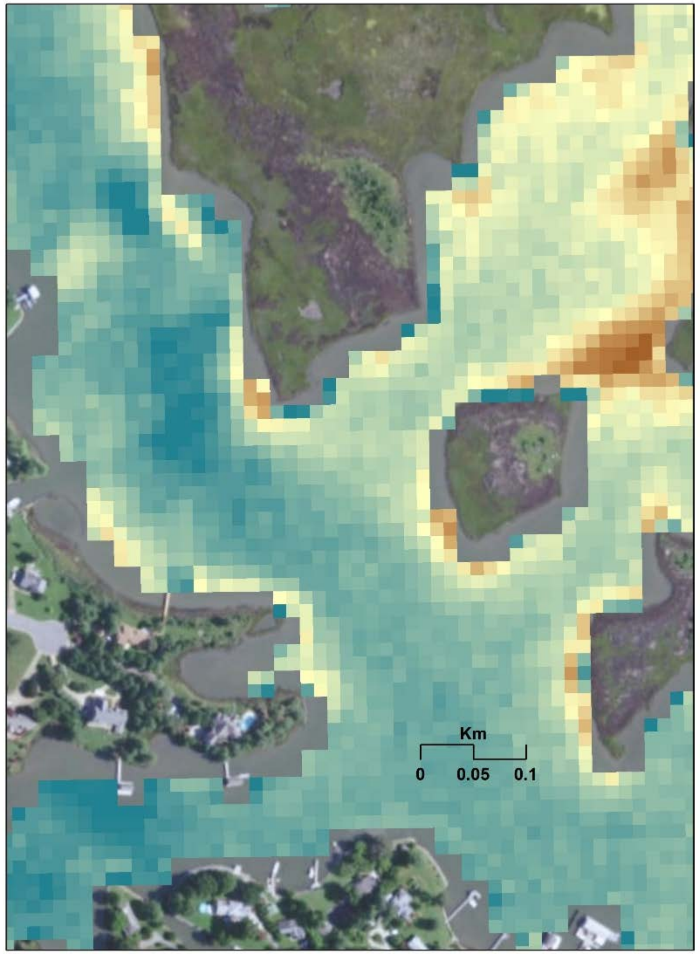
Upper Rappahannock 2013



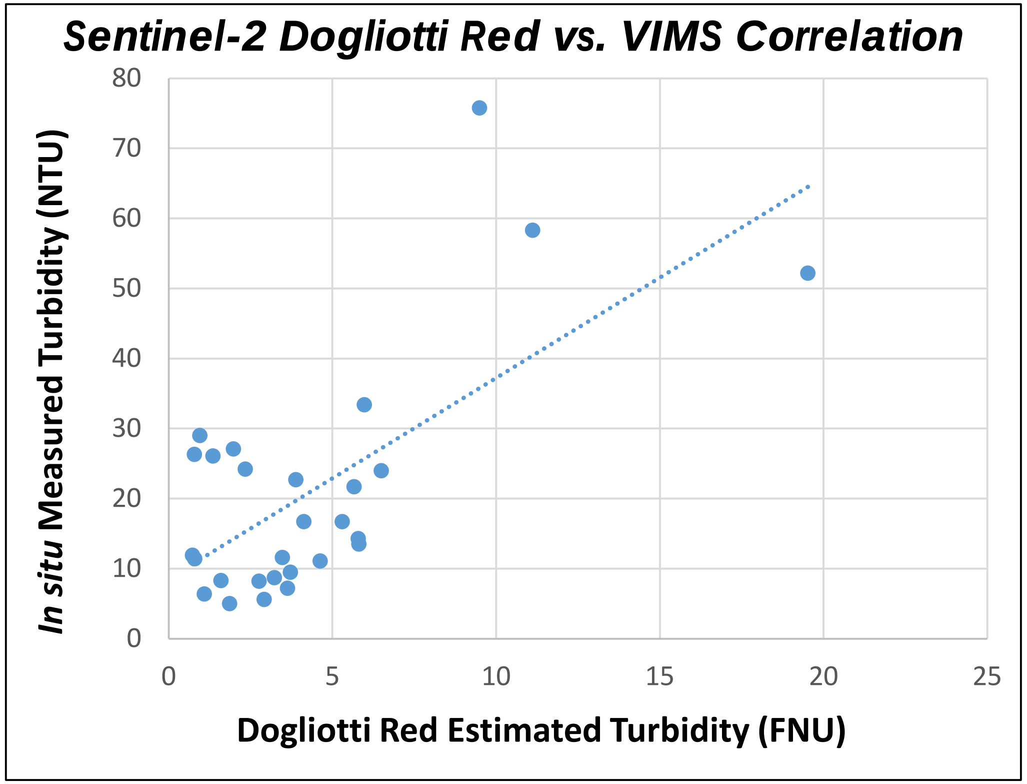
Sentinel-2: Spatial Resolution & Results



Landsat 8 Dogliotti Red Turbidity Product (03/24/17)



Sentinel-2 Dogliotti Red Turbidity Product (03/17/17)



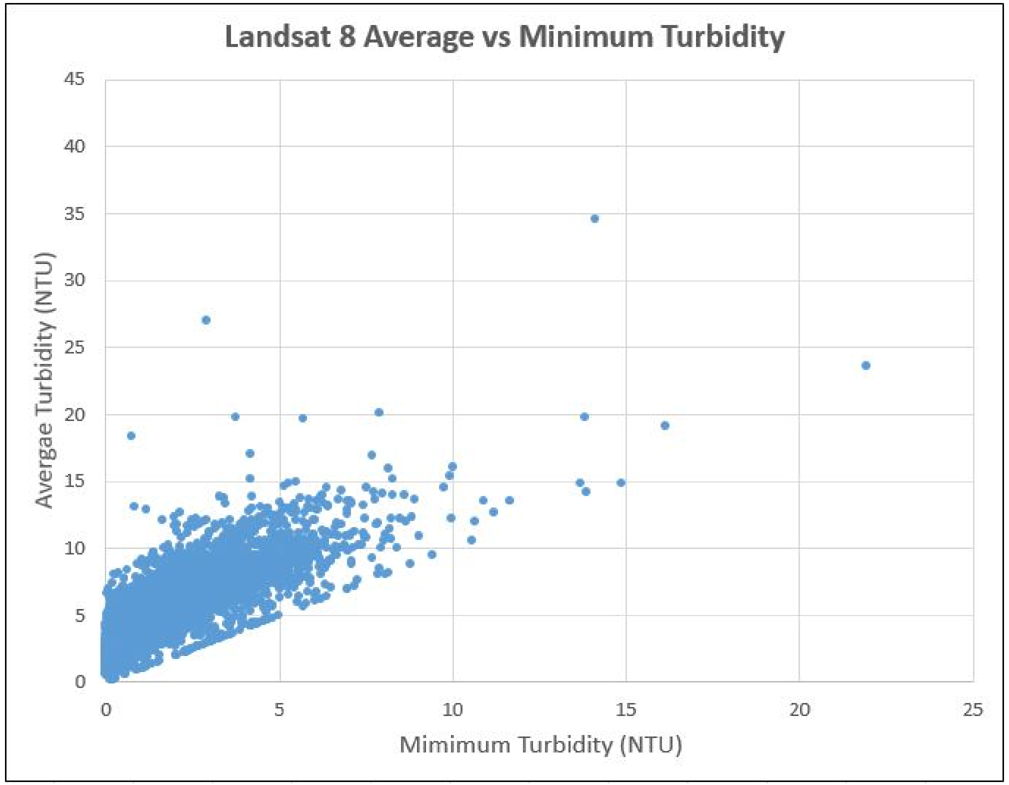
Dogliotti Red: R = 0.6672

y = 2.8667x + 8.577

Identifying Bottom Interactions

Piankatank River – ACOLITE turbidity product vs Google Earth imagery

Observed high satellite turbidity estimates over clear, shallow waters with sandy bottoms

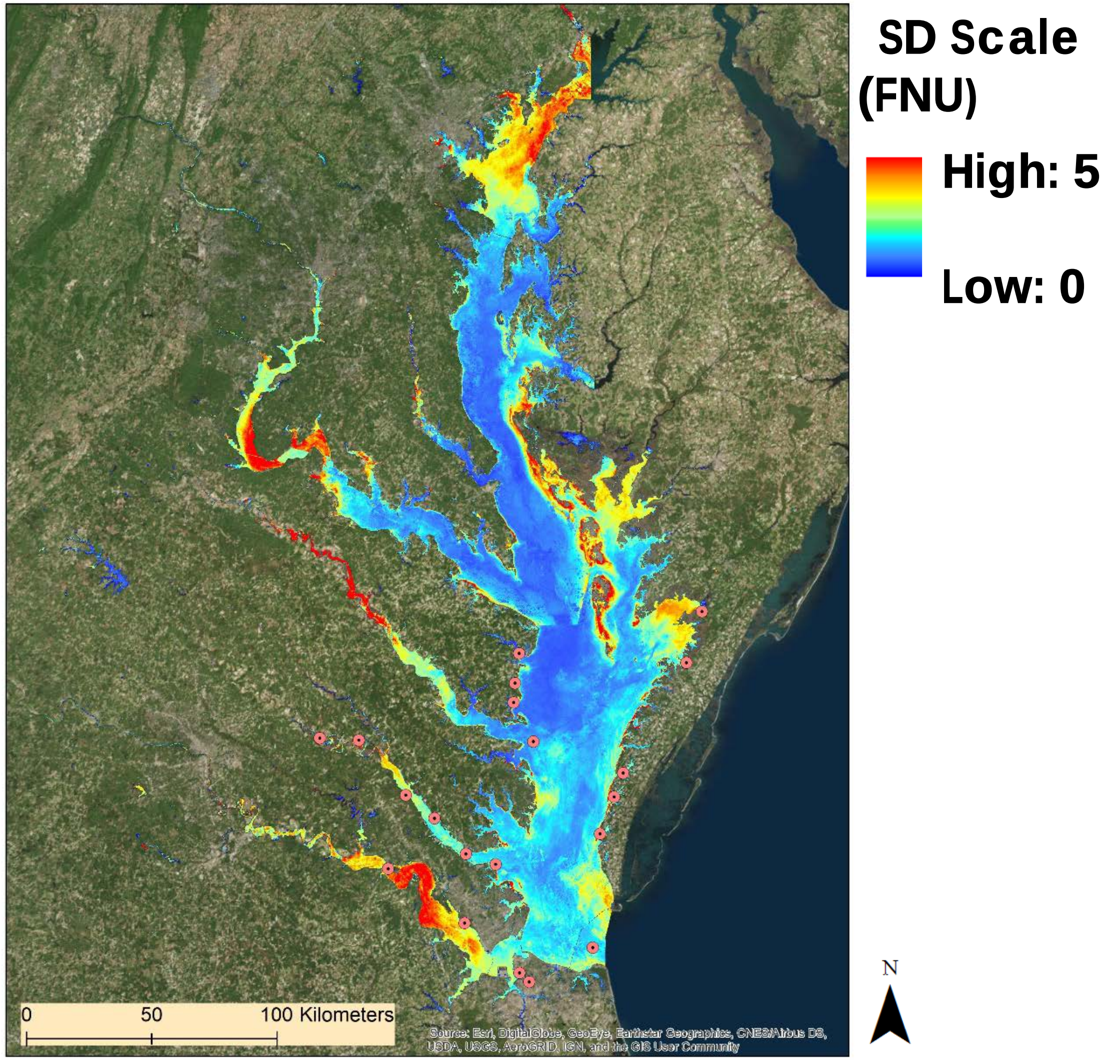


Points with high average and high minimum turbidities can potentially be indicators of bottom effects

Baywide Turbidity Variation

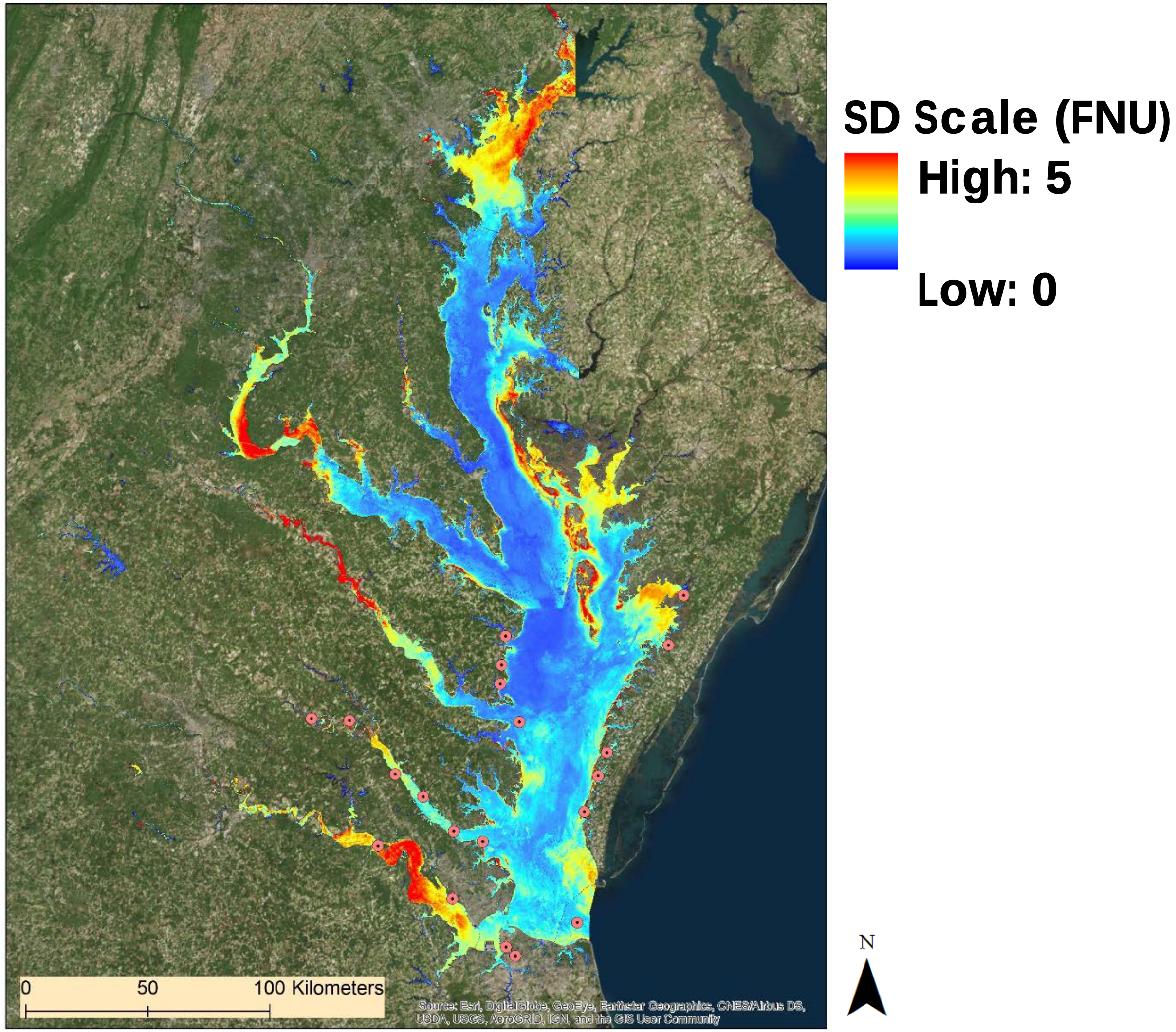
- **Standard deviation** used to visualize variation & examine bottom effects
- High SD + low Coefficient of Variation for turbidity potentially influenced by **sandy bottoms**

Baywide Standard Deviation (2013 - 2017)

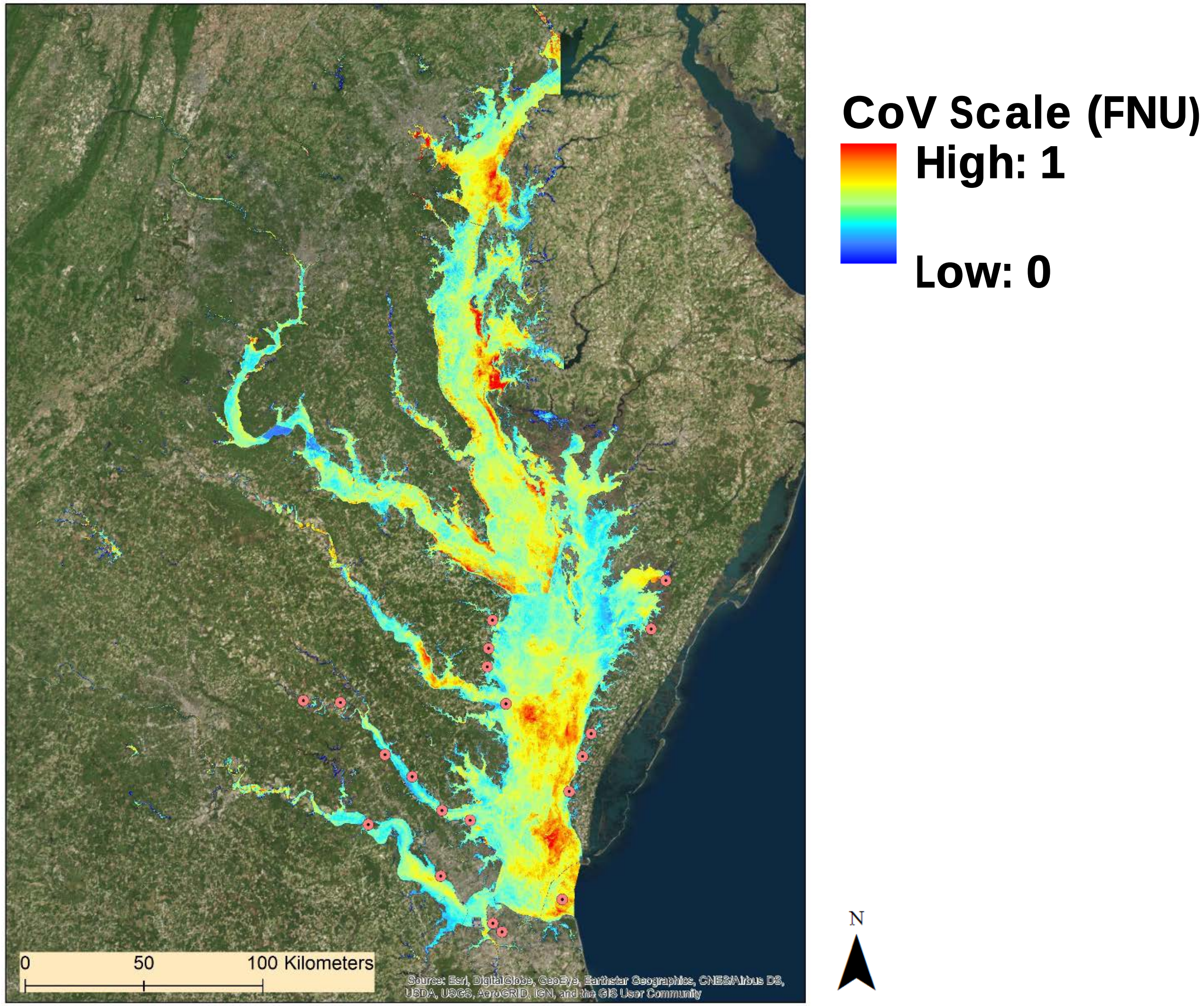


Landsat 8 SD vs. CoV

Baywide Standard Deviation (2013 - 2017)



Baywide Coefficient of Variation (2013 - 2017)



Future Work

- Finding effective methods to distinguish bottom effects
- Utilizing satellite data from Landsat 5 and Landsat 7
- Exploring different advanced settings within ACOLITE

Video Credit: Sean Robison, NASA DEVELOP

Conclusions

- **Landsat 8** was used to produced the most confident correlations with *in situ* data.
- Dogliotti and Nechad: turbidity products provide the most accurate water clarity assessment
  - **Dogliotti Red** over open waters
  - **Nechad** within tributaries
- Models and maps produced can be **applied in future monitoring** to identify areas of high turbidity

Image Credit: Pixabay

Acknowledgements

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Antonio Alvarado
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