Automating the Quantification of Submerged Aquatic Vegetation from High Resolution Satellite Imagery

Chesapeake Bay Program's (CBP)
Scientific and Technical Advisory Committee (STAC) Workshop
Advancing Monitoring Approaches to Enhance Tidal Chesapeake Bay Habitat Assessment Water Clarity/SAV
9 December 2021

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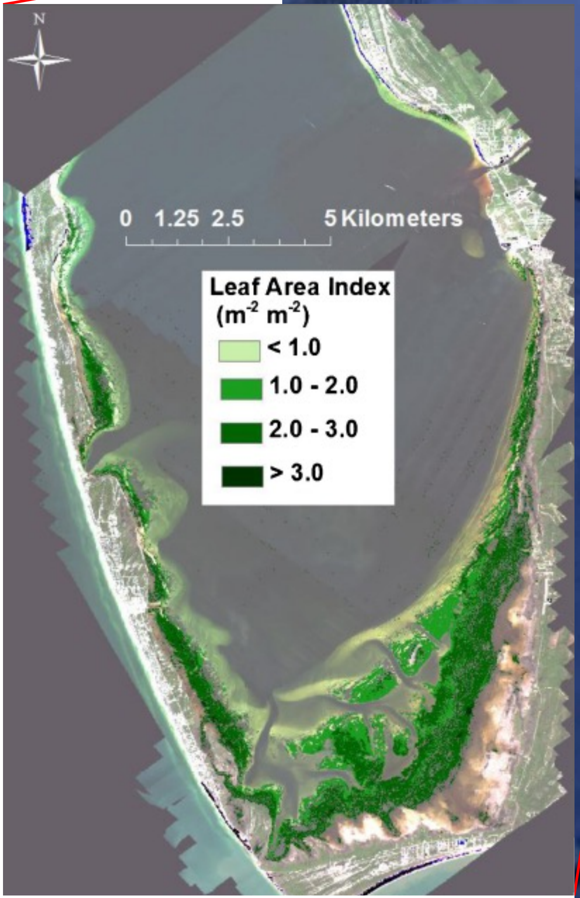
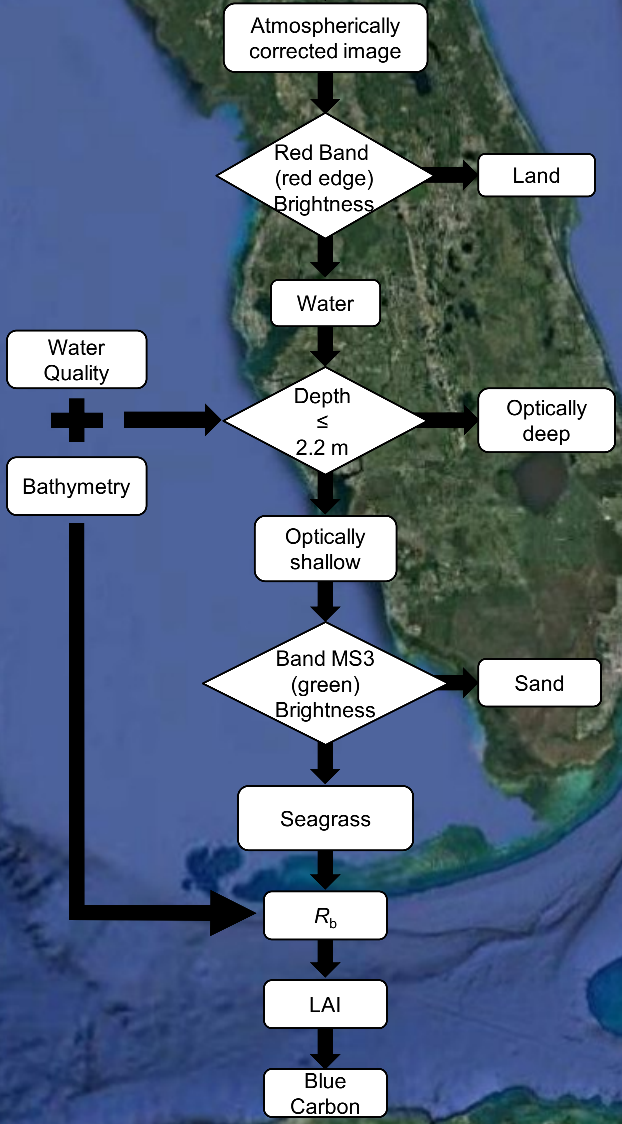
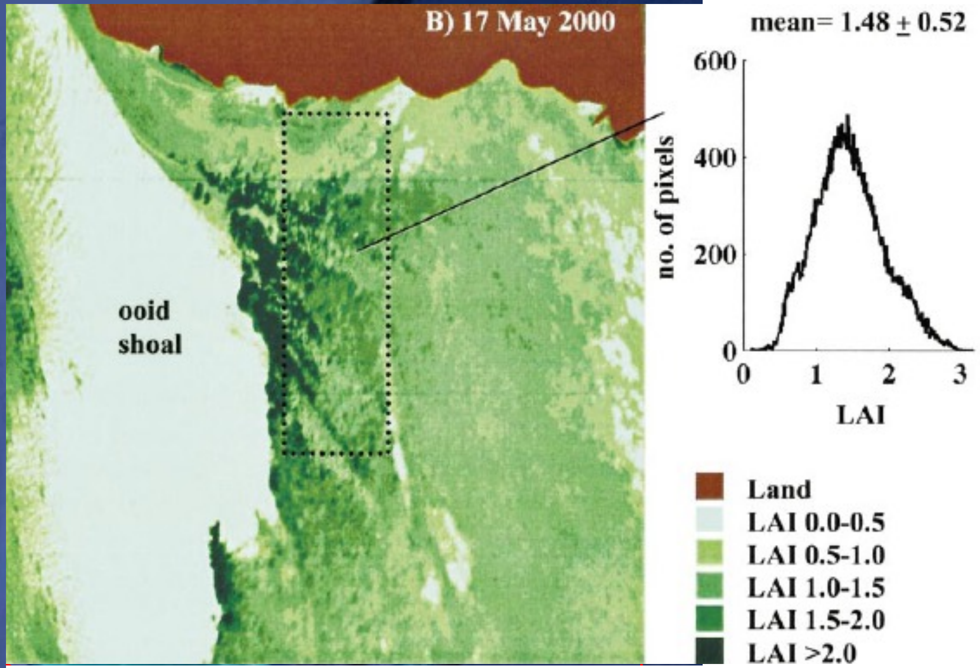
Earth Sciences Division
Research & Analysis Program
Applied Sciences Program

Seagrass extent and absolute abundance can be mapped with high fidelity from aircraft carrying hyperspectral sensors



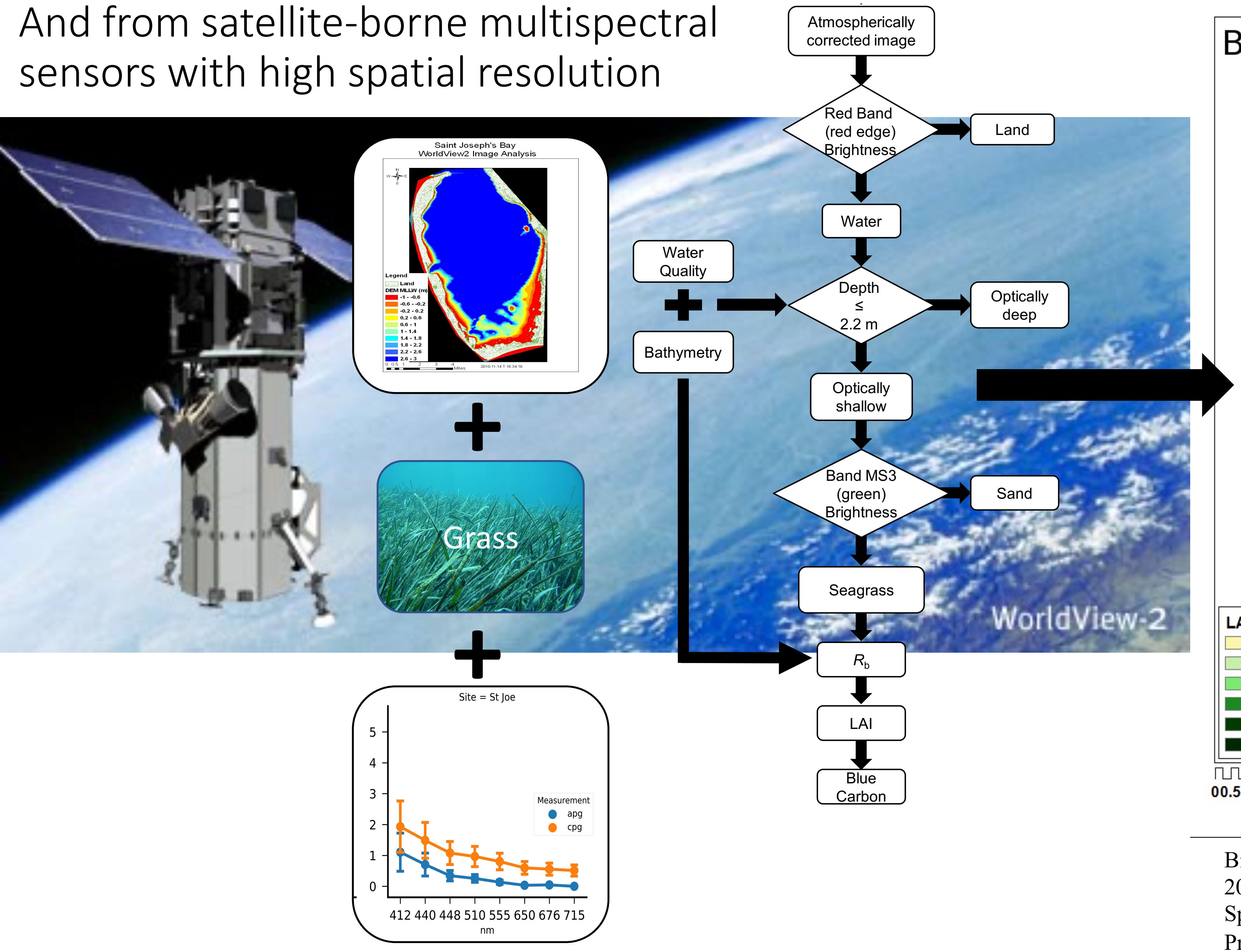
Hill, V.J., R.C. Zimmerman, W.P. Bissett, H. Dierssen, and D.D. Kohler. 2014. *Estuaries and Coasts* 37: 1467-1489.

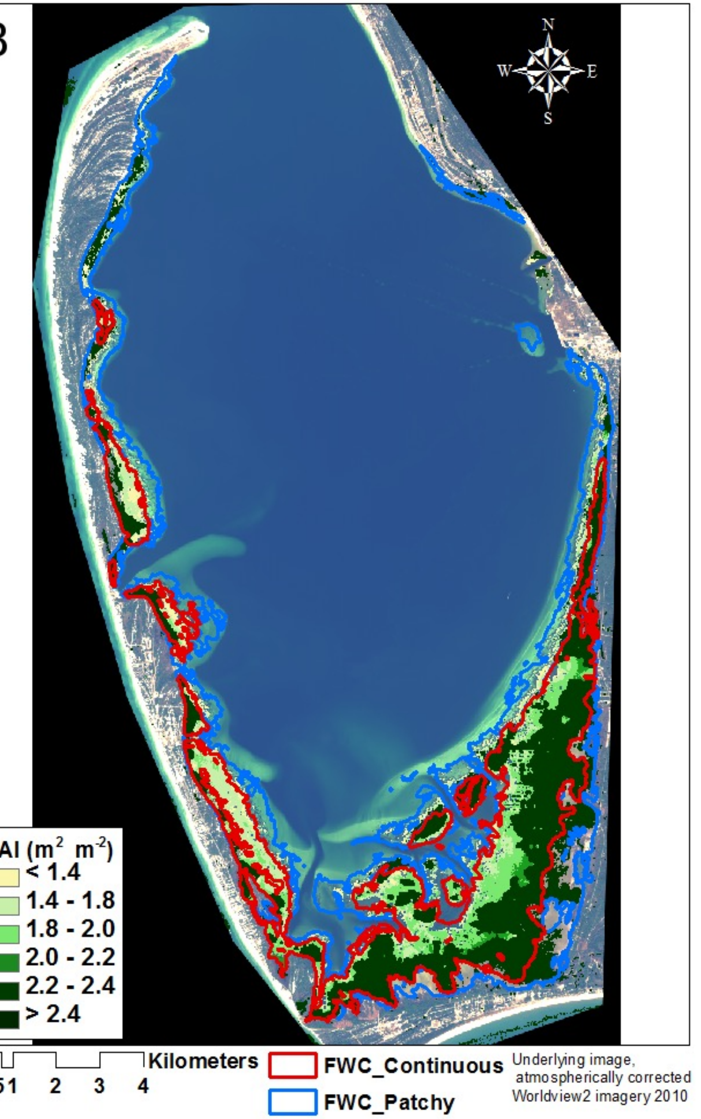




Dierssen, H., R. Zimmerman, R. Leathers, T. Downes, and C. Davis. 2003. *Limnol. Oceangr.* 48: 444-455.

And from satellite-borne multispectral sensors with high spatial resolution

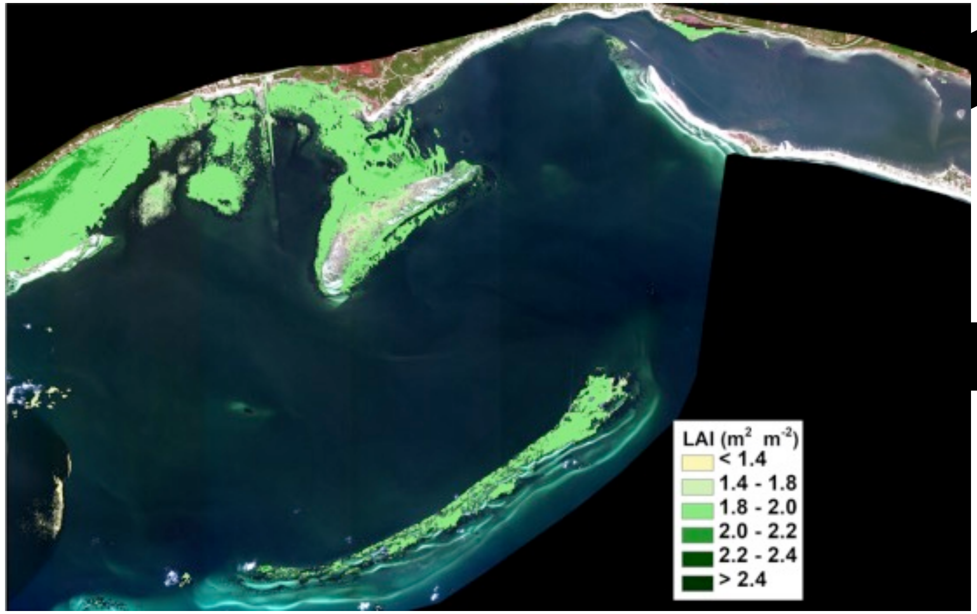




Bissett, W., R. Zimmerman, V. Hill, and D. Kohler. 2011. Saint Josephs Bay Aquatic Preserve Imaging Spectroscopy: Florida Department of Environmental Protection. Office of Coastal and Aquatic Managed Areas. Contract No RM055.

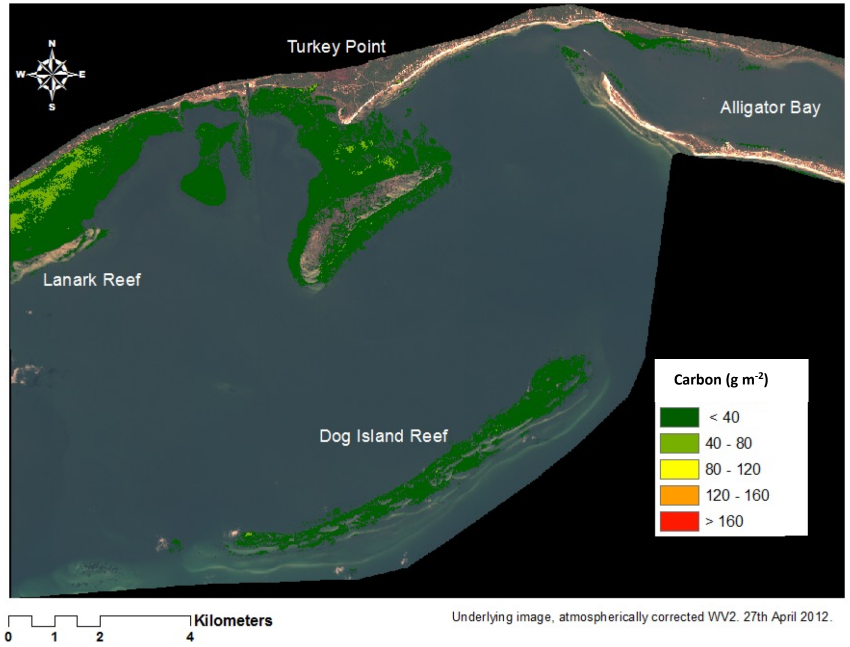
And the LAI maps can be used to derive seagrass carbon using known values of

- Leaf Area:Leaf Mass
- Shoot:Root Ratios

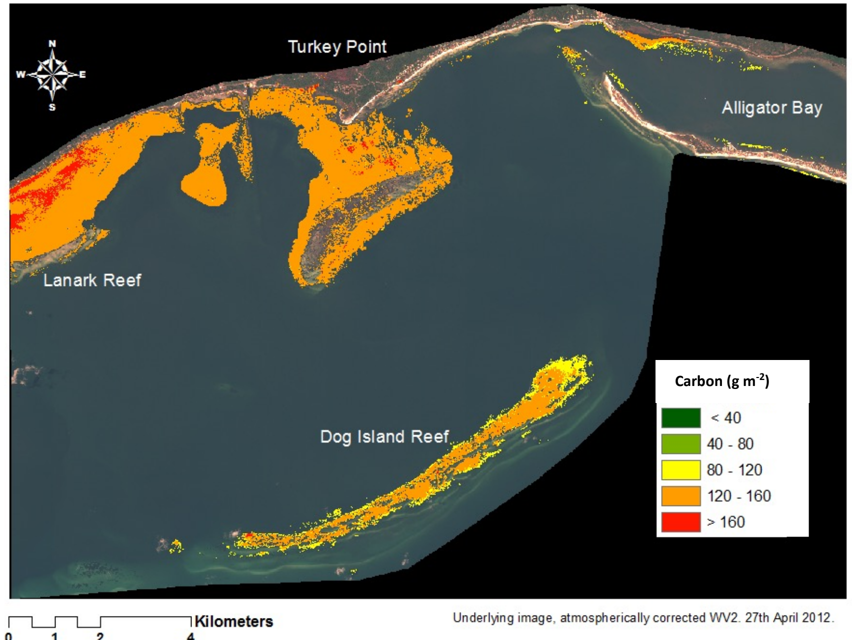


St. George Sound, FL

Above-ground biomass

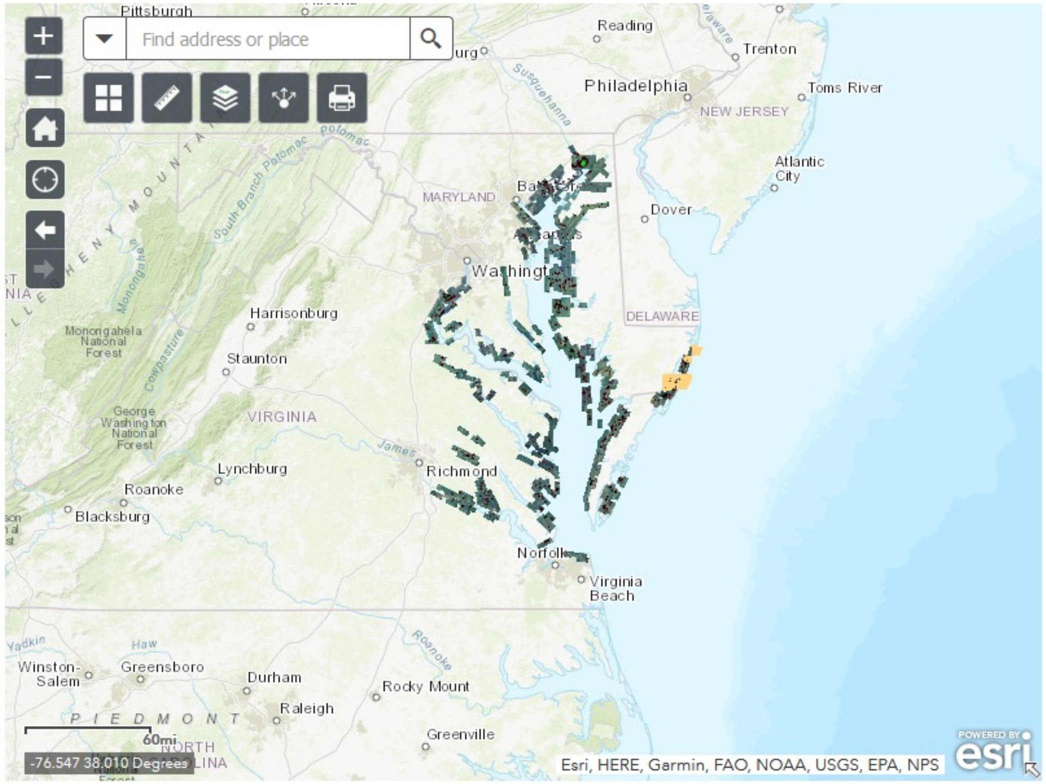


Below-ground biomass



The Need

- Maps of SAV distribution and abundance are critical for:
  - Management
    - estuarine/coastal water quality



VIMS SAV Monitoring Program

https://www.vims.edu/research/units/programs/sav/access/maps/index.php

The Need

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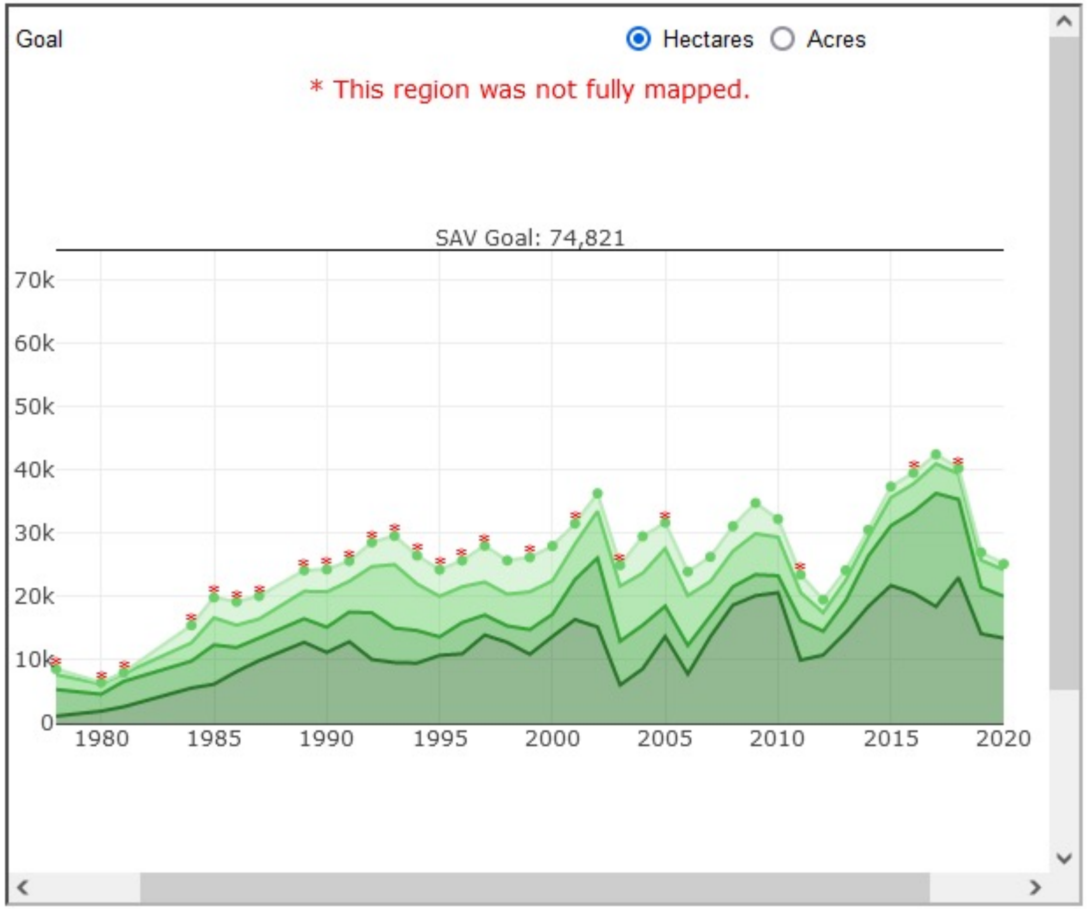
    - natural resources

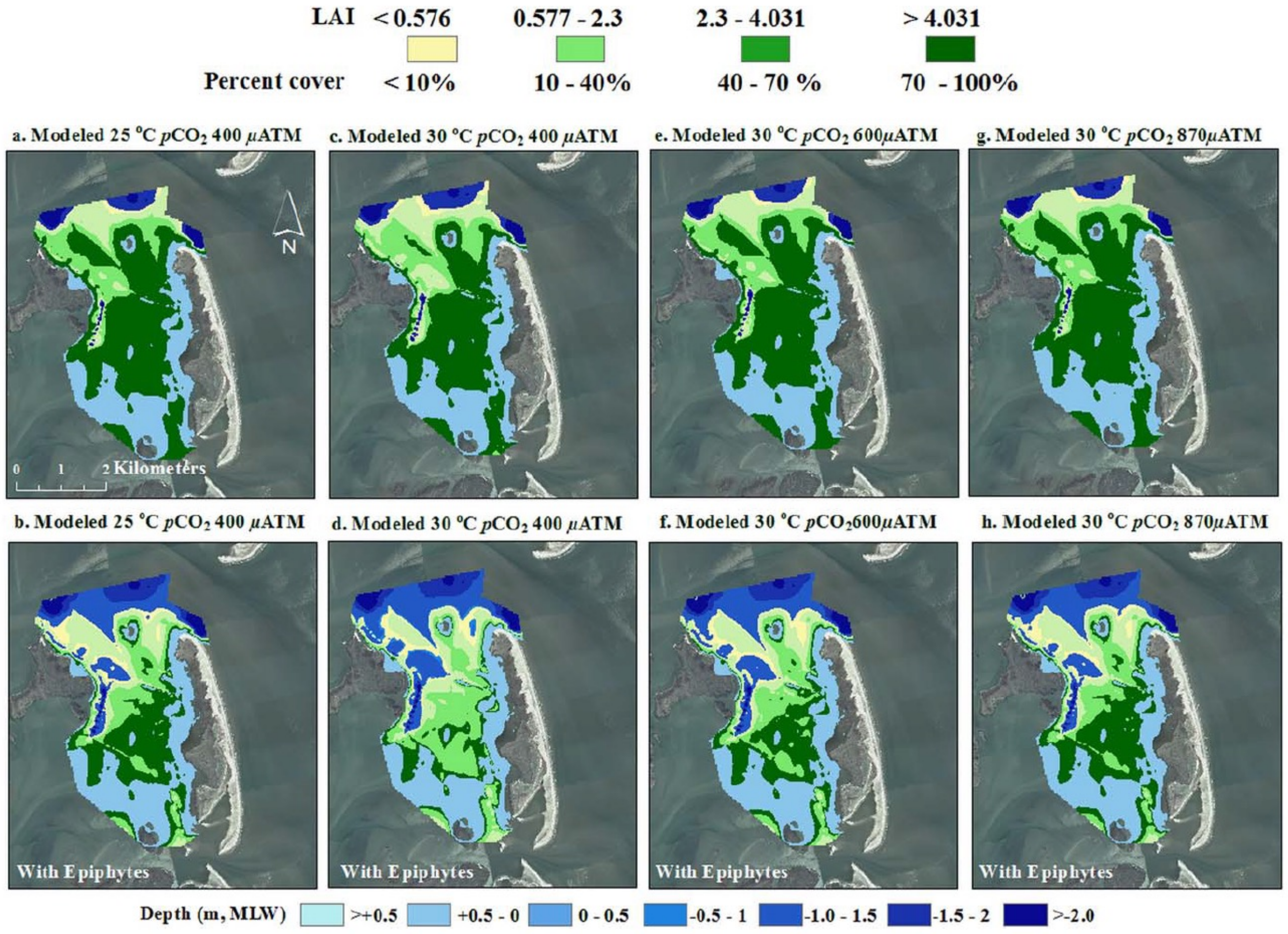


VIMS SAV Monitoring Program Annual Report 2020
https://www.vims.edu/research/units/programs/sav/reports/2020/exec_sum.php

The Need

- Maps of SAV distribution and abundance are critical for:
  - Management
    - estuarine/coastal water quality
    - natural resources
  - Ecological Modeling & Forecasting
    - Climate warming
    - Ocean acidification

Fig. 7 from Zimmerman, R., V. Hill, and C. Gallegos. 2015. Predicting effects of ocean warming, acidification and water quality on Chesapeake region eelgrass. *Limnol. Oceanogr. 60: 1781-1804.*



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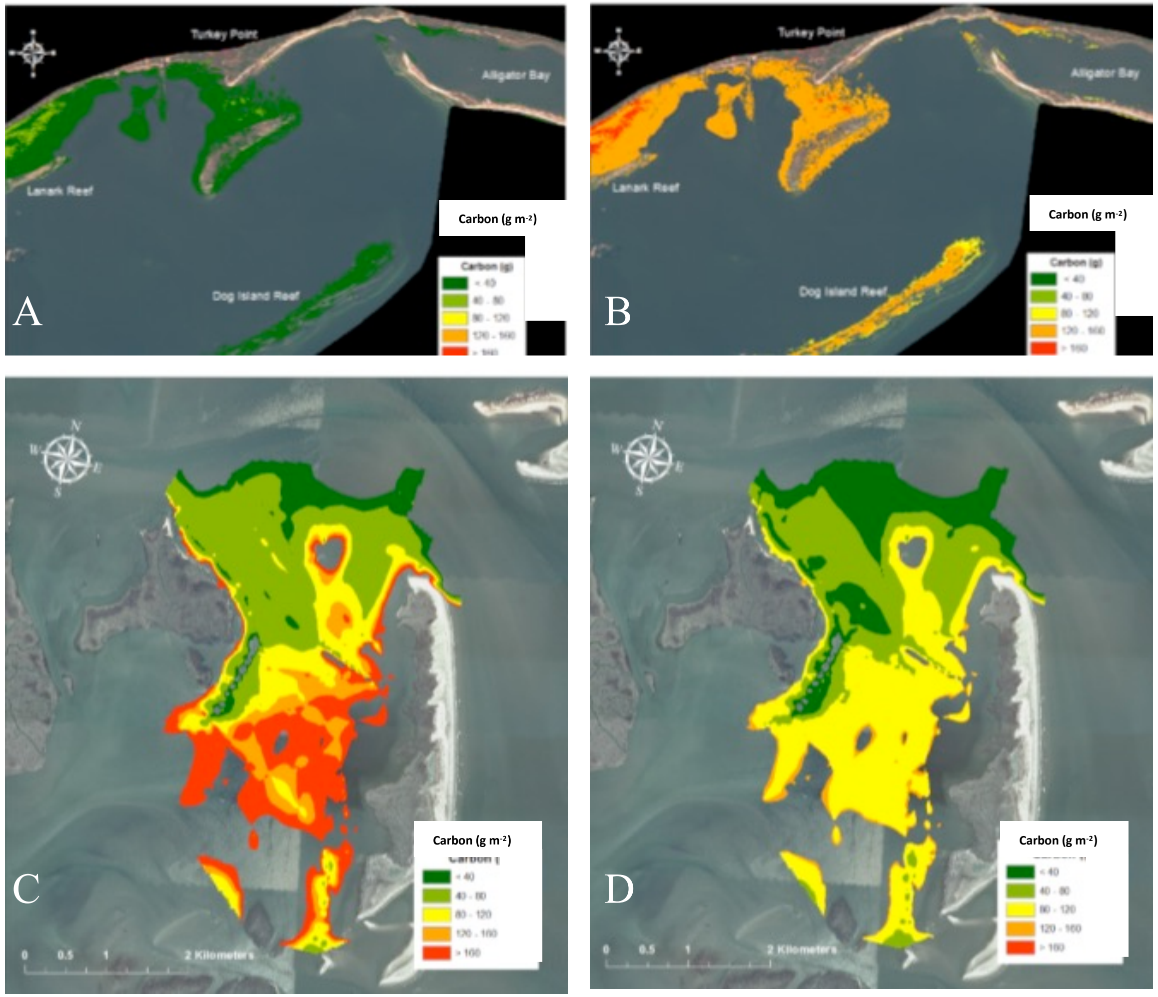
    - Climate warming
    - Ocean acidification
  - Blue Carbon Estimates

Above-ground Carbon | **Below-ground Carbon**

St. George Sound FL Turtlegrass

South Bay VA Eelgrass

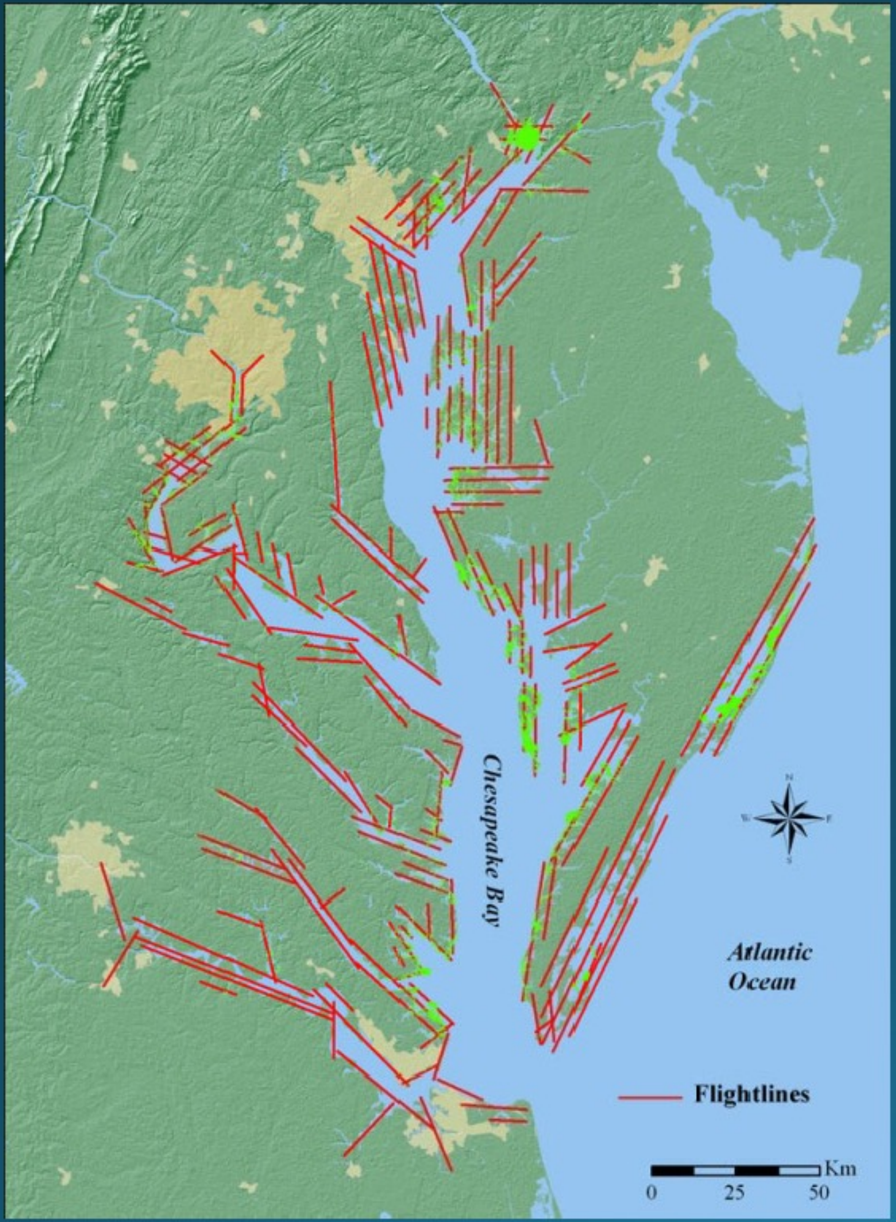


Zimmerman, R., V. Hill, J. Li, B. Schaeffer. 2019. Quantification of Blue Carbon Burial in Seagrass Ecosystems and the Impact of Projected Climate Change. Annual Technical Progress Report 2. NASA Grant/Cooperative Agreement No. NNX17AH01G

Chesapeake Bay
Annual SAV Monitoring Program
1974 to Present

Landry, B., P. Tango, C. Bisland, M. Coffer, W. Dennison, V. Hill, C. Lebrasse, J. Li., R. Orth, C. Patrick, B. Schaeffer, P. Witman, D. Wilcox, and R. Zimmerman. 2021. Exploring Satellite Image Integration for the Chesapeake Bay SAV Monitoring Program –A STAC Workshop, 1-45. Edgewater Maryland: STAC.

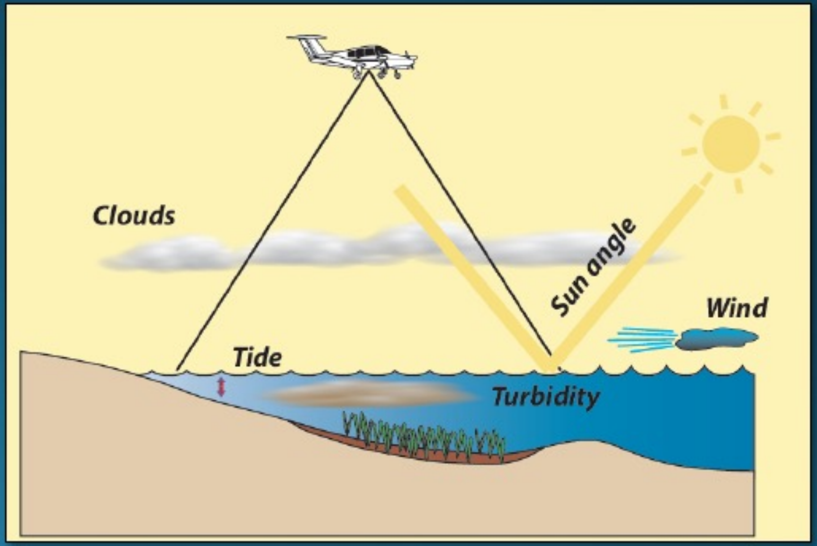
Acquisition of Aerial Imagery



Aerial multispectral digital imagery is acquired from flight lines flown over the entire bay

Flights require low wind, minimal cloud cover, low tide,
low turbidity, low sun angle.

VIMS and Air Photographics staff monitor these conditions 24/7



The Problem

- Maintenance of aerial survey program for Chesapeake Bay is under pressure from
  - Aircraft costs and scheduling
  - Labor costs for manual photointerpretation
  - Increasingly limited access to restricted airspace
- Maps of relative abundance are not easily translated into absolute units of mass required for biogeochemical models or Blue Carbon estimates

The Opportunity

- Can satellite remote sensing replace or at least augment aerial surveys?
  - Reduce aircraft costs
  - Access airspace-restricted locations
- Can machine learning algorithms be used to automate the classification process?
  - Reduce costs & time required to produce SAV maps
- Can we generate more quantitative abundance data?
  - Biogeochemical models and Blue Carbon require absolute abundances (mass per area), not relative abundance (% cover)

An Important Challenge

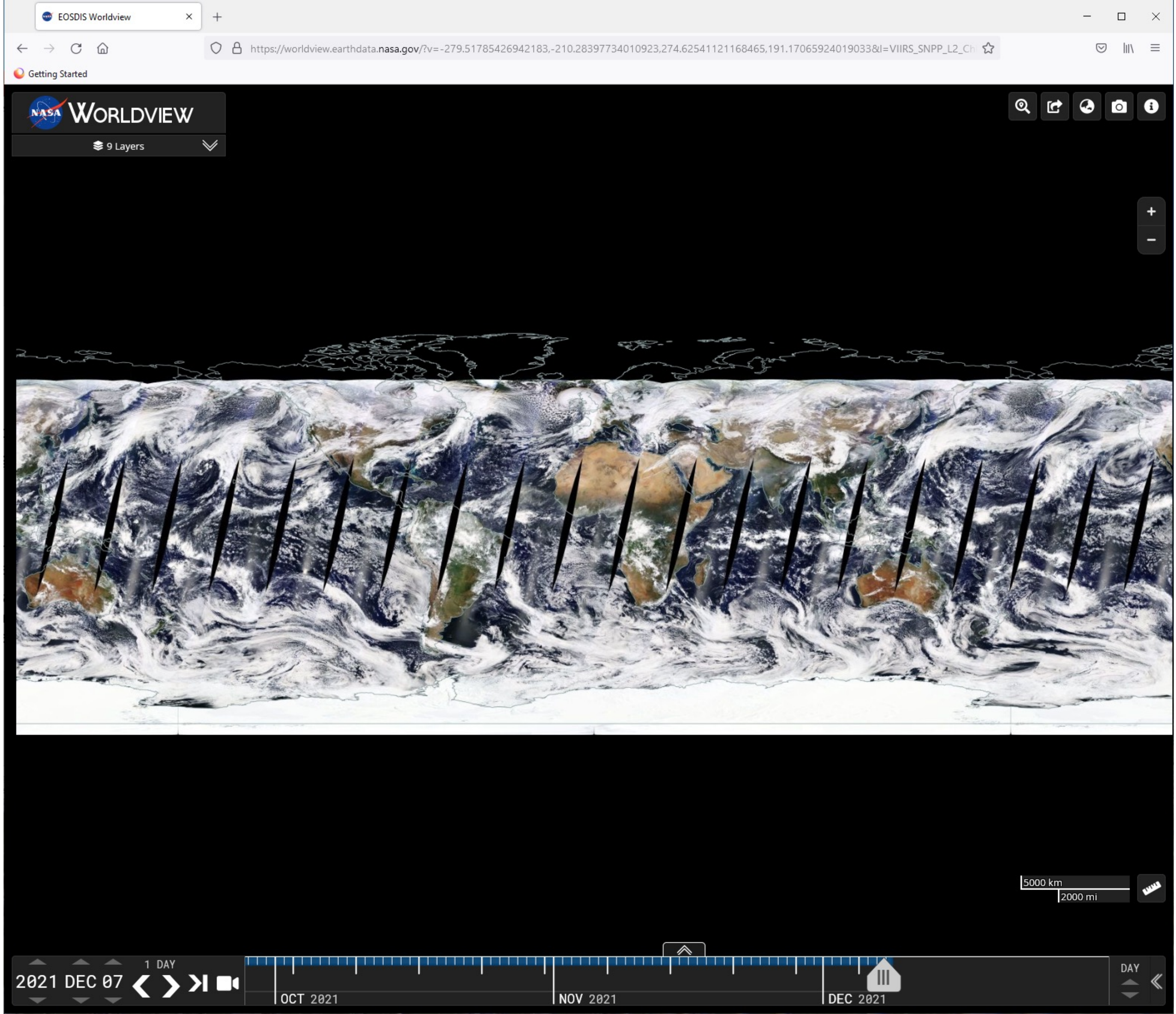
- How to integrate SAV maps derived from pixel-based classification algorithms with those historically derived from polygons?
- Pixel-based maps likely to return fewer hectares of SAV cover than polygon-based maps
  - Areas of low cover (<50%) are mostly sand, even though they contribute to the calculation of SAV area based on polygons
  - Pixel-based classifications omit sand pixels from the SAV area calculations
- Integration/resolution of these different approaches needs to be explored

Orbiting sensors, capabilities and availability

Sensor	Operator	Bands	Nadir Spatial Resolution (m)	Operational Status	View Angle	Swath (km)	Coverage	Repeat Cycle	Radiometric Calibration	Atmospheric Correction	Data Availability	Archive Available
CZCS	NASA	4 Vis, 2 NIR	1 Km	1978-1986	0 to 20°	1566	Global	16 days	Provided	Provided	**Public**	Yes
Sea_WiFS	NASA	6 Vis, 2 Nir	1 Km	1997 - 2010	0 to 20°	2806	Global	16 days	Provided	Provided	**Public**	Yes
MODIS	NASA	7 Vis, 2 NIR	1 Km	2002 - present	0 to 65°	2330	Global	16 days	Provided	Provided	**Public**	Yes
VIIRS	NASA/NOAA	7 Vis, 8 NIR 5 MIR	750 m	2011 - present	0 - 113°	3060	Global	16 days	Provided	Provided	**Public**	Yes
LandSat	NASA/USGS	4 Vis 1 NIR	30 multi 15 pan	L5+ since 1984	Nadir	185	Global	16 Days	User-applied	Use-applied	**Public**	Yes
Sentinel	ESA	4 Vis, 3 Red Edge, 3 NIR	10	S-2A in 2015	Nadir	290	Global	10 Days	Provided	Provided	**Public**	Yes
WorldView 2,3	Maxar	5 Vis, 1 Red Edge 2 NIR, Pan	WV2: 1.8 Multi 0.46 Pan WV3: 1.24 Multi 0.31 Pan	WV2: Since 2009 WV3: Since 2014	Taskable	WV2: 16.4 WV3:13.1	Requires Tasking	Infrequent, requires tasking	User-applied	User-applied	**Propreitary** Free through NGA for limited academic research	Yes
Dove PlanetScope	Planet	3 Vis, 1 Red Edge, 1 NIR	3.9	Since 2017	Nadir	5	Global Land Mass, Daily Image	Daily	Provided	Provided	**Propreitary** Free through NGA and Planet for academic research	Yes

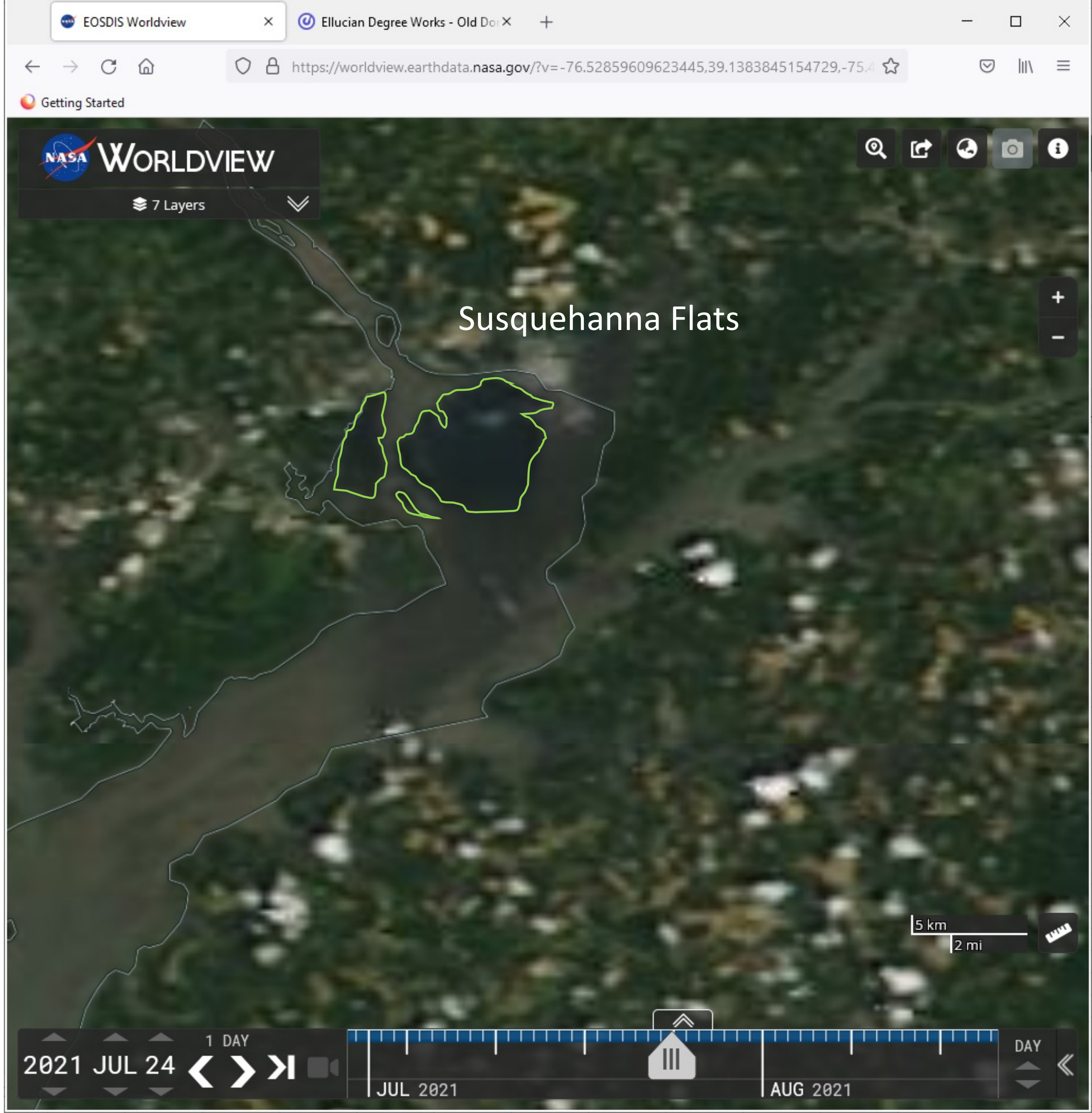
SeaWiFS, MODIS & VIIRS

- Global coverage
- Highly quality data
  - Radiometrically calibrated
  - Atmospherically corrected
  - Geo-referenced
- Data well curated and available to the public



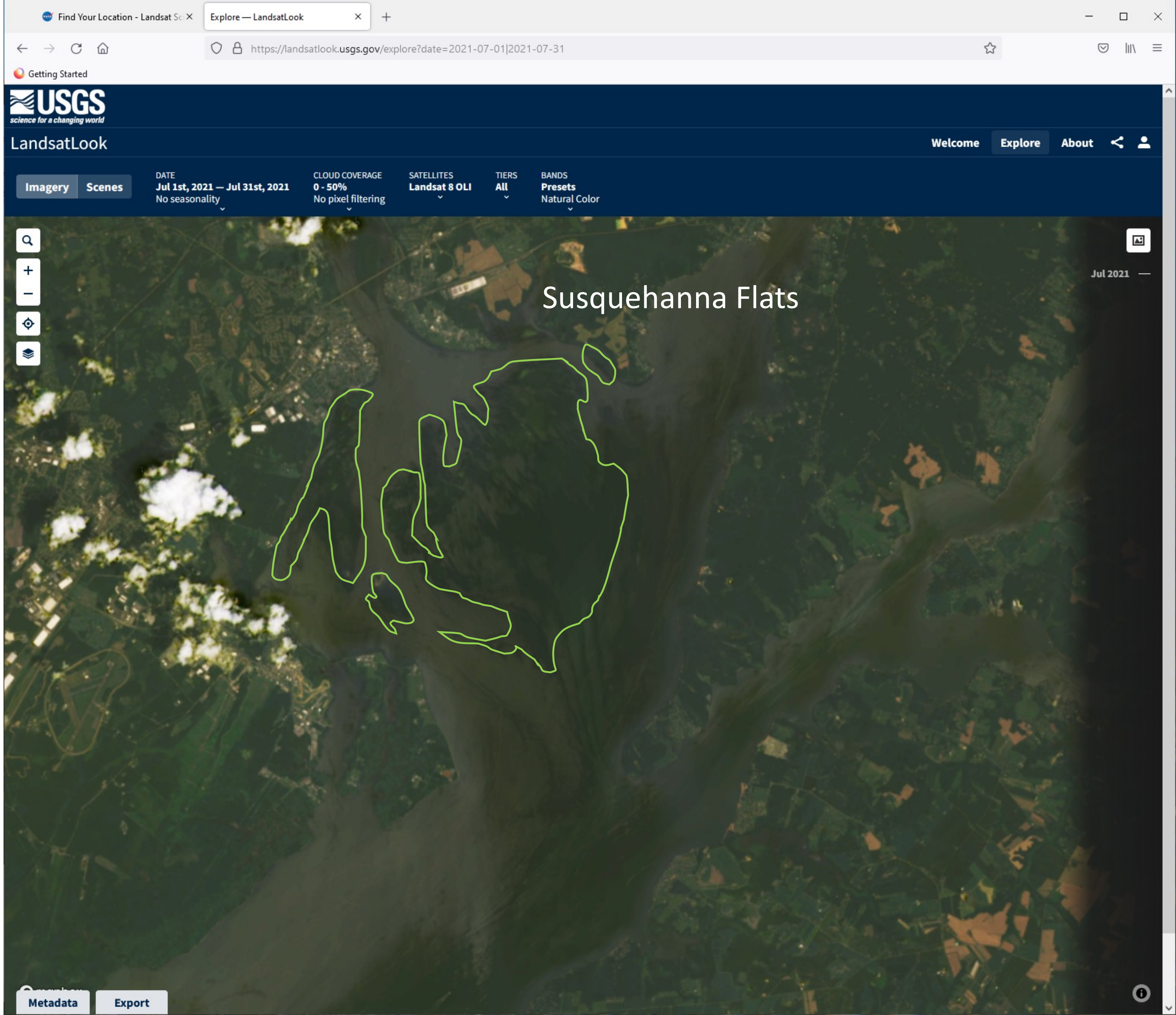
SeaWiFS, MODIS & VIIRS

- Global coverage
- Highly quality data
  - Radiometrically calibrated
  - Atmospherically corrected
  - Geo-referenced
- Data well curated and available to the public
- Coarse spatial resolution (1 Km) limits utility to a few very large areas/meadows



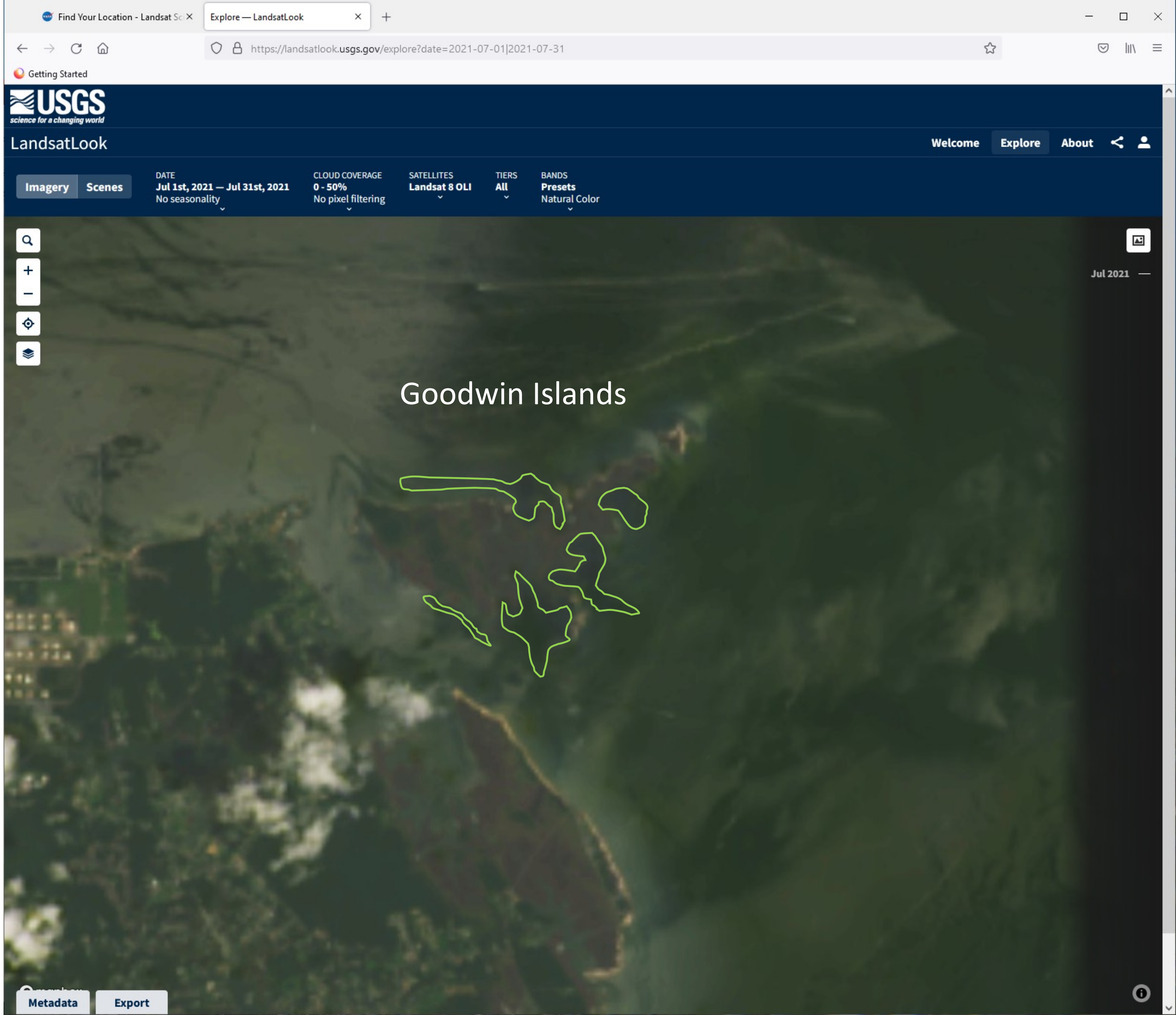
Landsat and Sentinel

- Provide time series potential going back to at least 1990
- 10 to 30 m enables mapping of relatively large meadows/systems



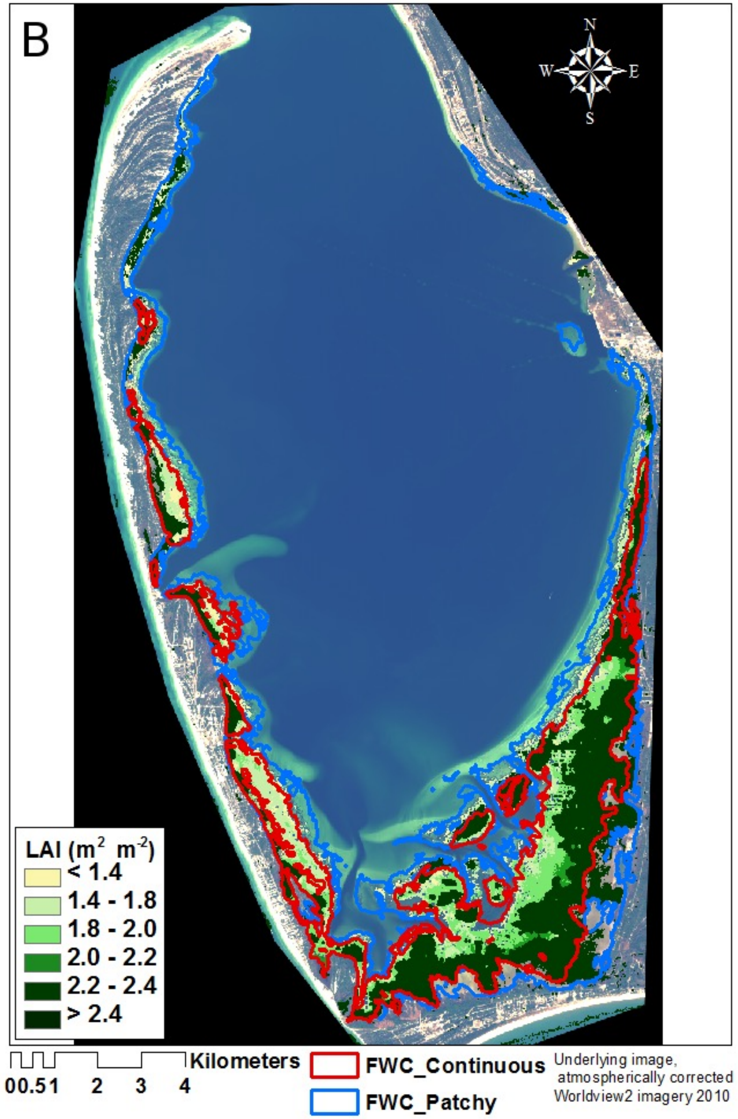
Landsat and Sentinel

- Provide time series potential going back to at least 1990
- 10 to 30 m enables mapping of relatively large meadows/systems
- Not good at mapping small SAV meadows



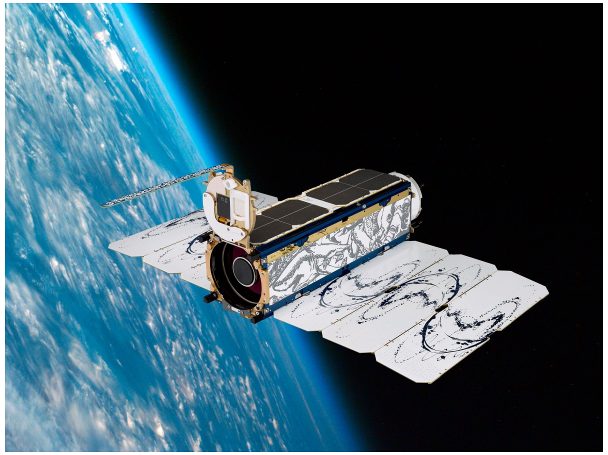
WorldView 2 & 3

- Provide high resolution data capable of quantifying smaller SAV patches
  - excellent spatial resolution (1 – 3 m)
  - 8 color bands
- But image acquisition requires tasking/scheduling
  - Logistically challenging
  - Subject to priority competition with other customers
    - E.g., DOD
- Radiometric calibration and atmospheric correction of each scene must be performed by the user
- Maxar restricts public sharing/use of the imagery

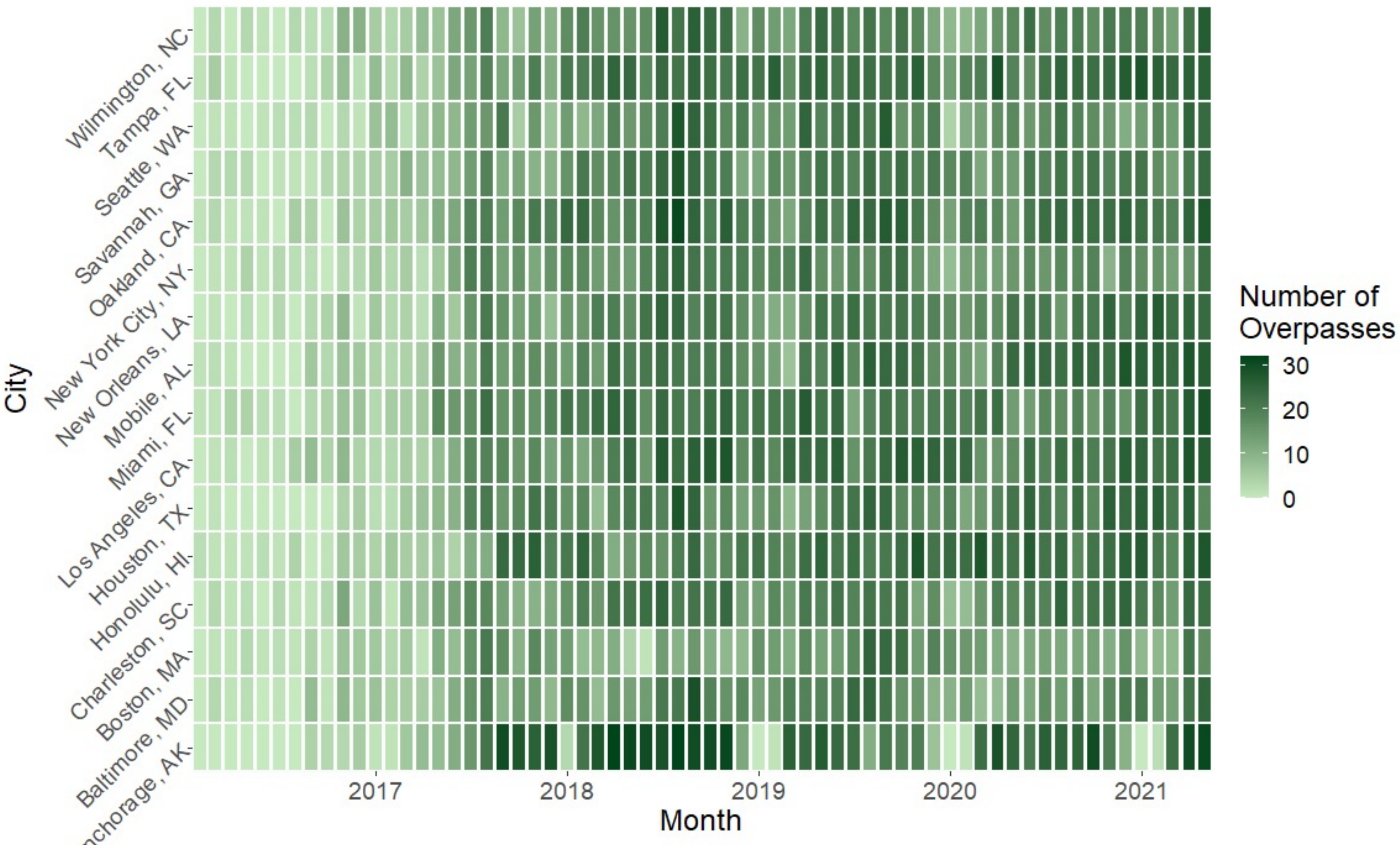


Bissett, W., R. Zimmerman, V. Hill, and D. Kohler. 2011. Saint Josephs Bay Aquatic Preserve Imaging Spectroscopy: Florida Department of Environmental Protection. Office of Coastal and Aquatic Managed Areas. Contract No RM055.

Dove PlanetScope Cubesat Constellation



- Daily global coverage eliminates tasking logistics
- 4 m spatial resolution, RGB + NIR
- Radiometrically calibrated and atmospherically corrected images simplify the processing
- The on-line catalog is easy to use
- Proprietary requirements less restrictive Maxar
- Higher spatial resolution and 8-band color systems now on orbit

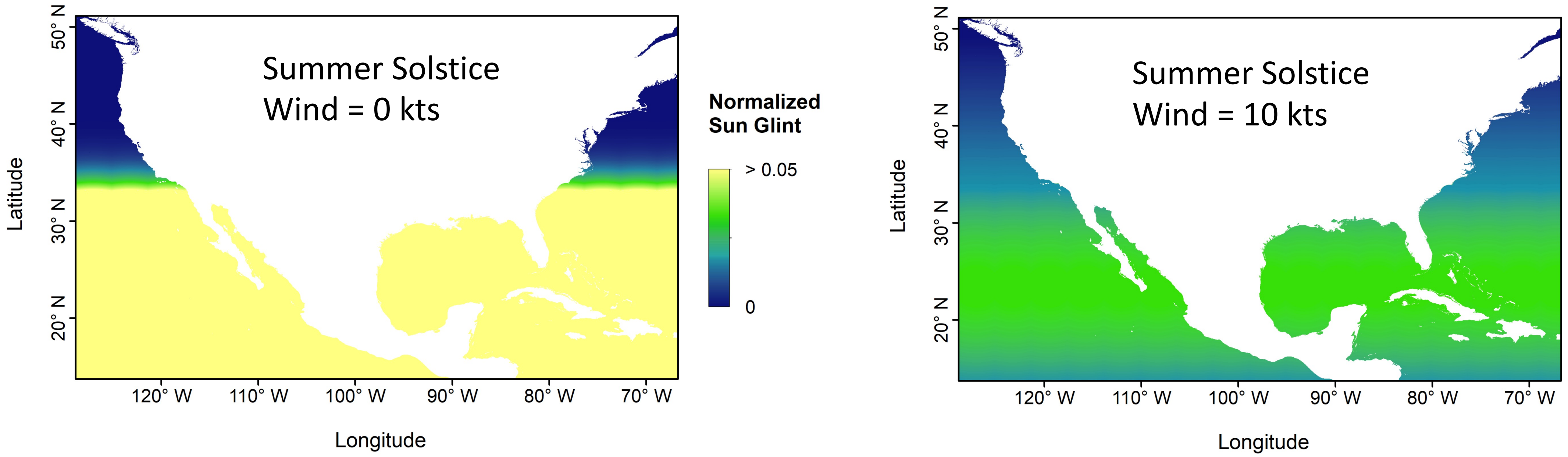


Schaeffer & Whitman et al (In Prep) Marine Pollution Bulletin.

This work was supported by the NASA Commercial Smallsat Data Acquisition.

- Dove PlanetScope sensors are nadir-viewing
- But sunglint at 35° N appears manageable

assuming a normalized sunglint threshold similar to MODIS (0.05)

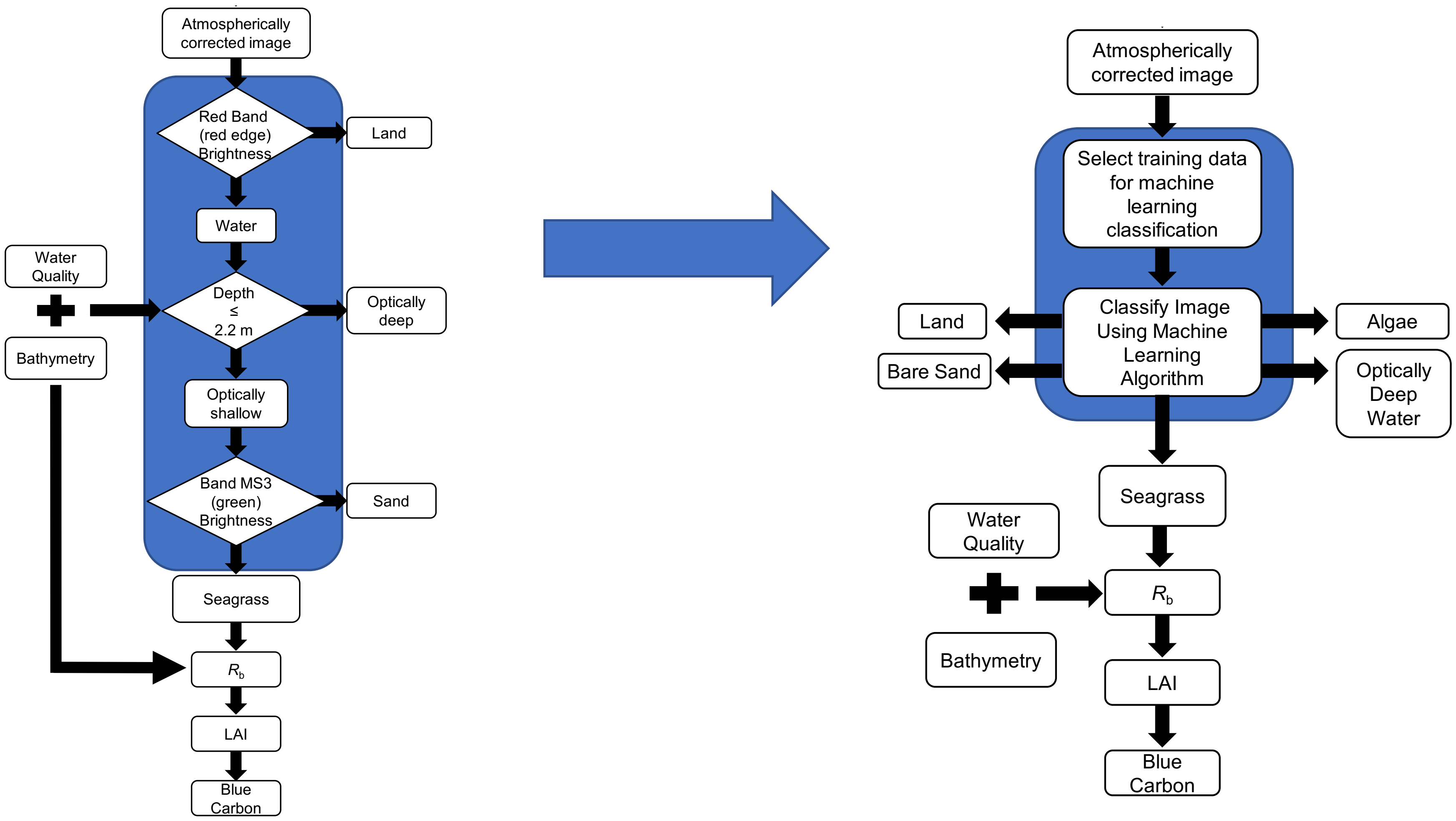


Schaeffer & Whitman et al (In Prep) Marine Pollution Bulletin.
This work was supported by the NASA Commercial Smallsat Data Acquisition.

Can we train machine learning algorithms to classify SAV in these complex coastal waters?

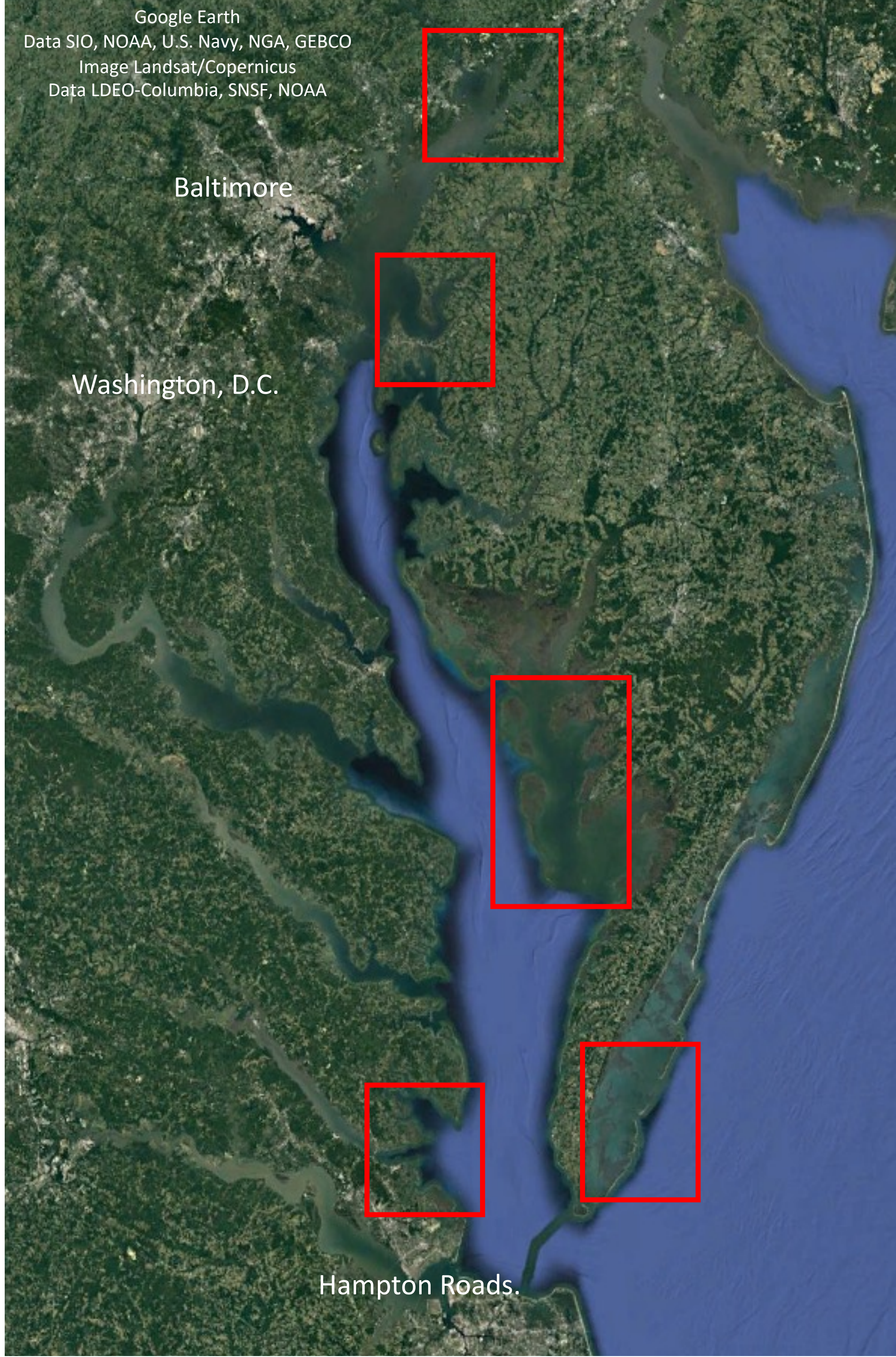
Physics-based classification:

Machine learning classification:

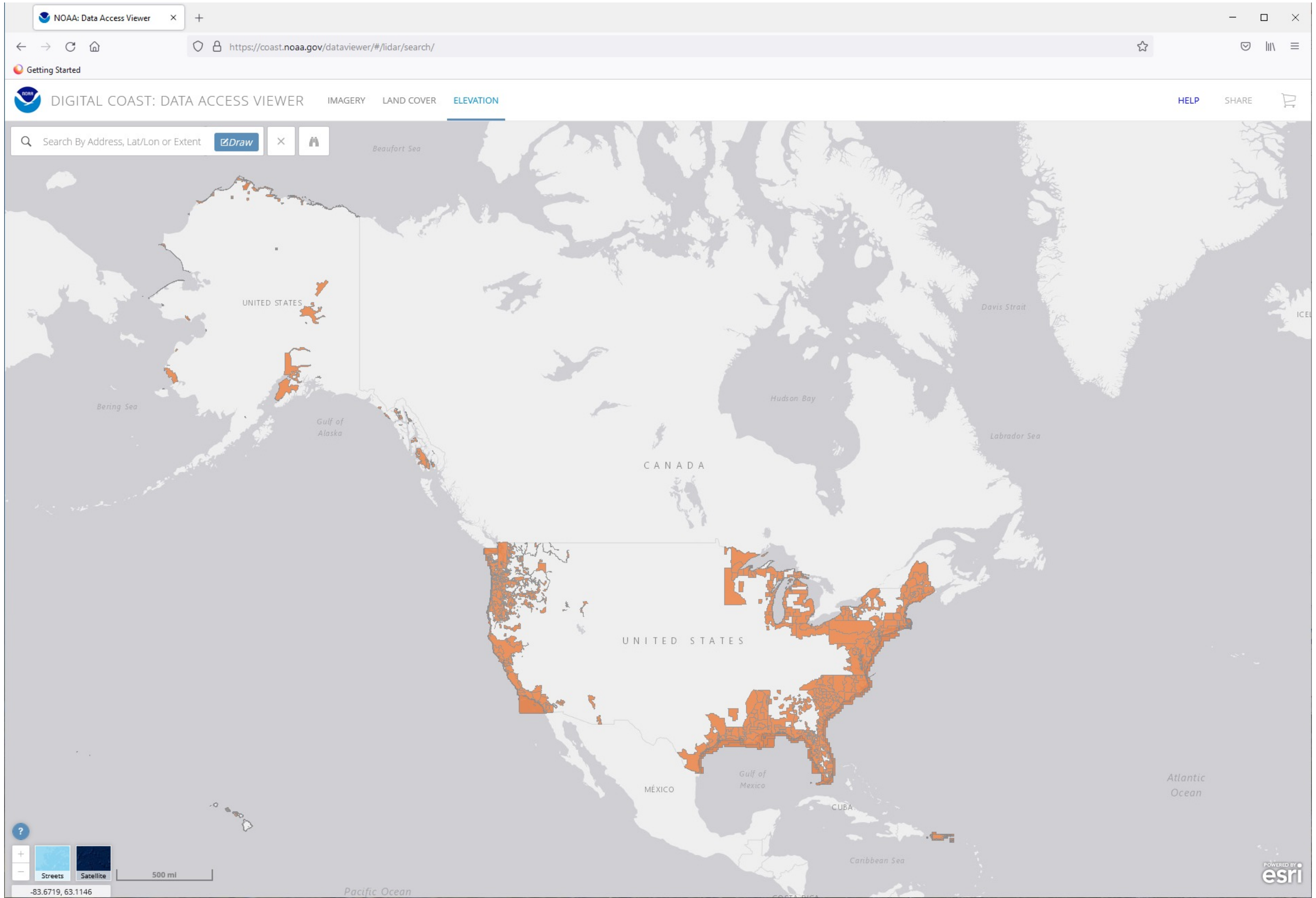


Can machine learning algorithms be used to automate SAV classification in Chesapeake Bay using commercial satellite data?

- Five different locations
  - Highly turbid oligohaline upper Bay
    - Susquehanna Flats - large stable meadow of *Valisneria americana*
    - Chester River – small & variable patches of SAV (multiple spp.) along river banks
  - Moderately turbid mesohaline central Bay
    - Smith and Tangier Islands – variable patches of SAV (*Ruppia americana* and *Zostera marina*)
  - Polyhaline York River
    - Goodwin Island & Mobjack Bay – variable meadows of *Ruppia americana* and *Zostera marina*
    - *Less turbid than upper*
  - Oceanic coastal lagoons
    - South Bay – extensively restored meadow of *Zostera marina*
    - Highest salinity, lowest turbidity

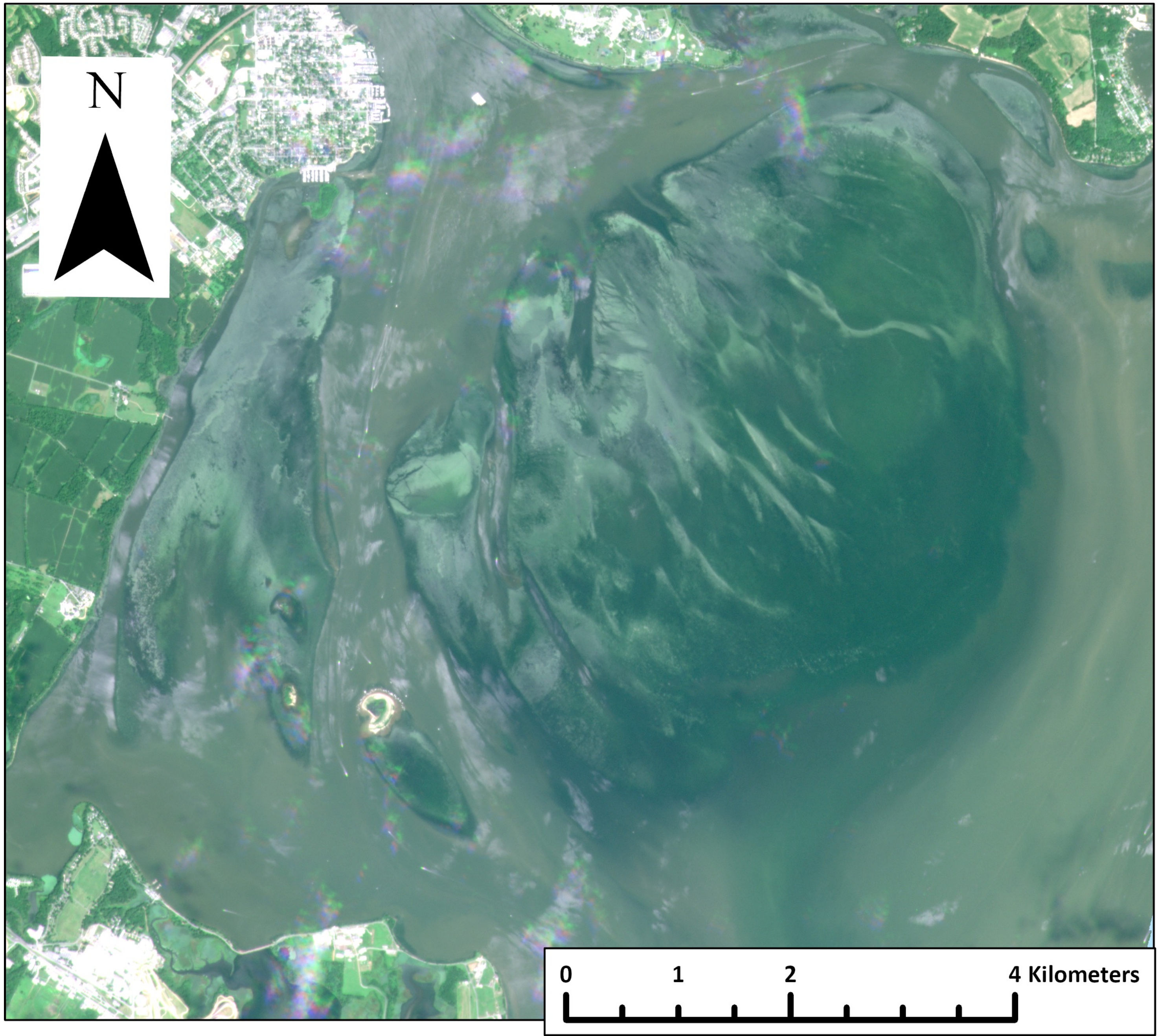


NOAA Digital Coast (https://coast.noaa.gov/digitalcoast/) now provides 10 m (or better DEMs) for the US Coast



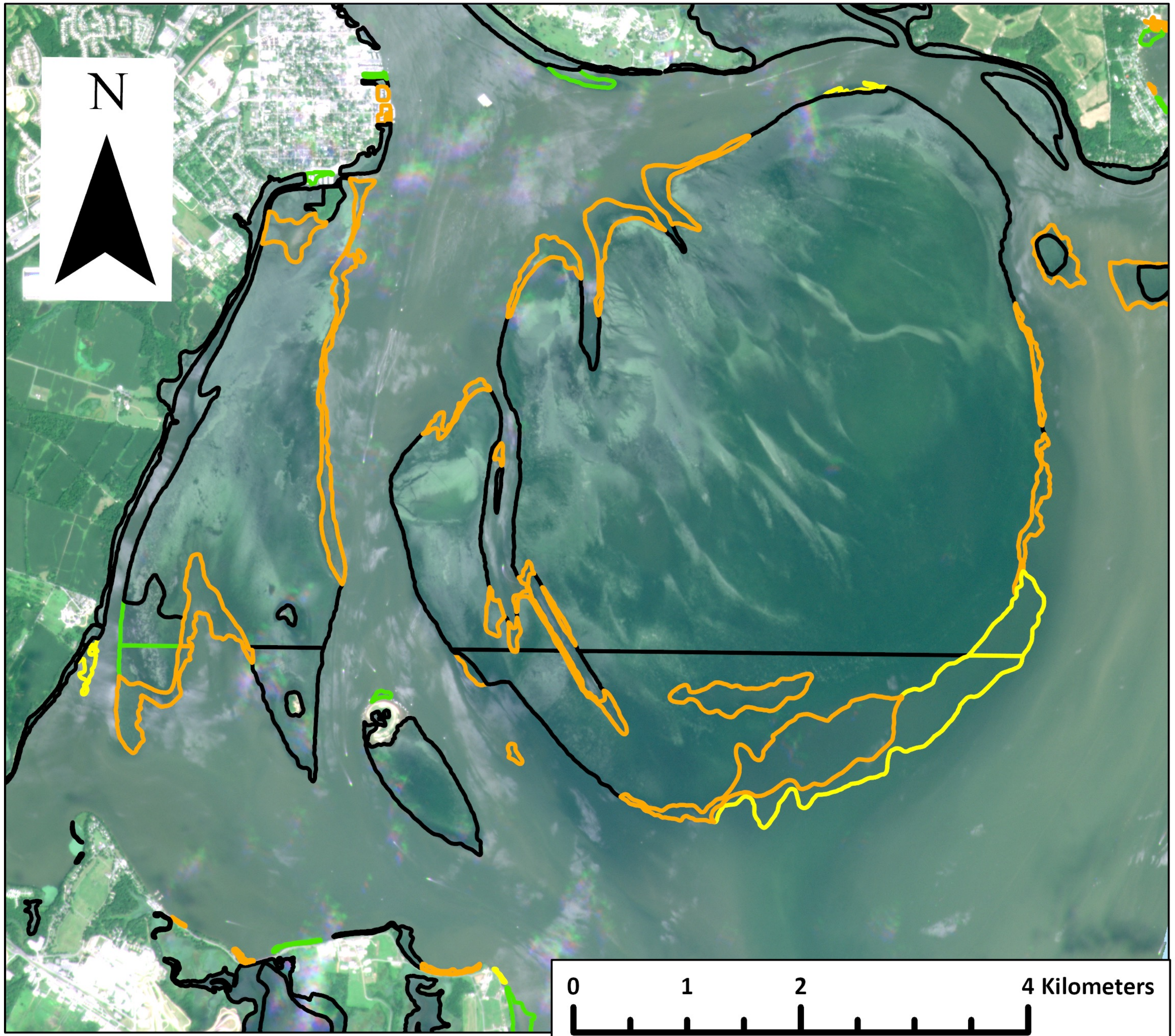
Susquehanna flats - 31st Aug 2021

- Planet RGB image



Susquehanna flats - 31st Aug 2021

- Planet RGB image
- Manually drawn polygons from 2020 VIMS SAV Survey



VIMS SAV density

1
2
3
4

Susquehanna flats - 31st Aug 2021

- Planet RGB image from 31 July 2021
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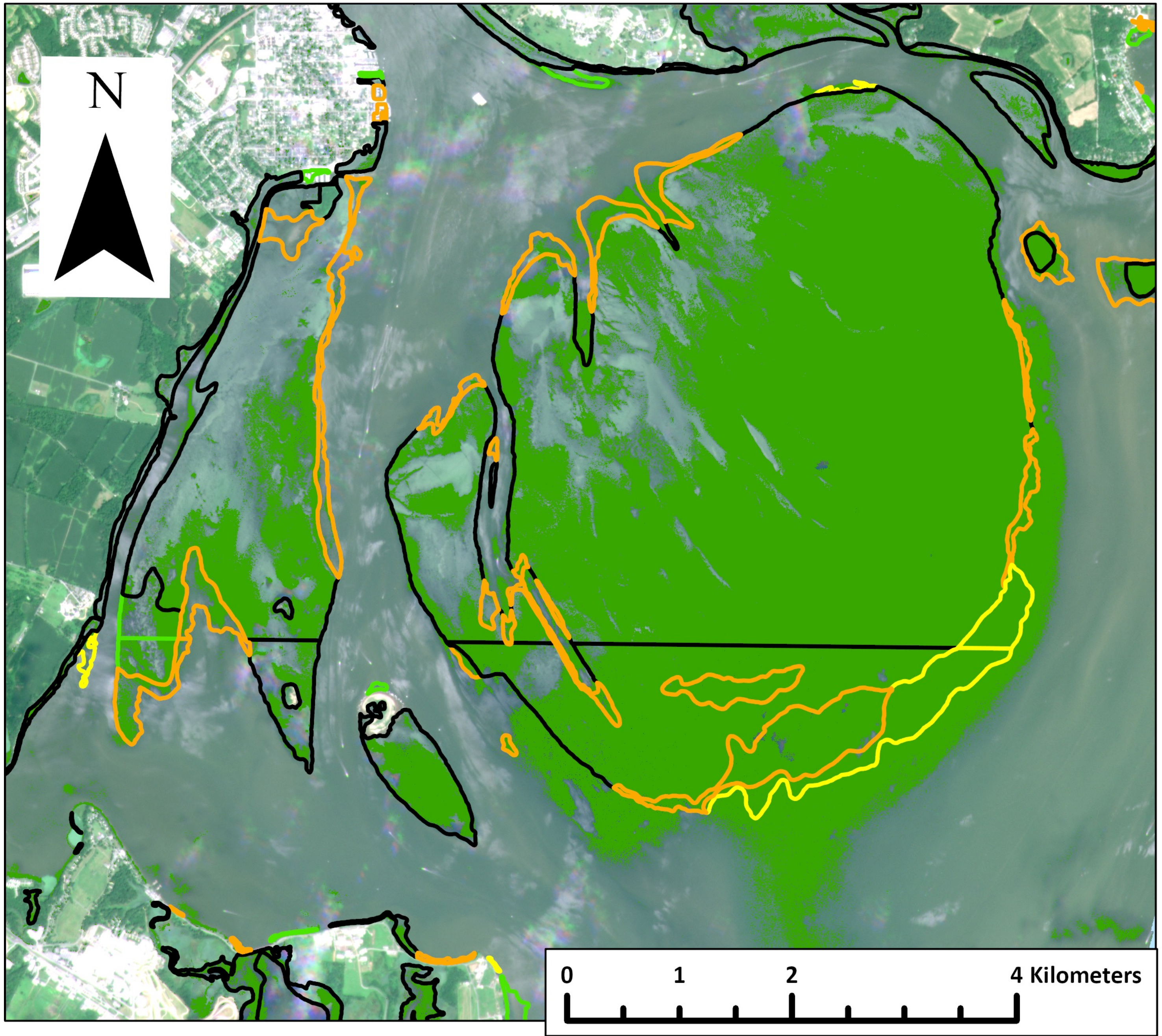
- Our automated classification of SAV using the Support Vector Machine Classifier in ArcGIS



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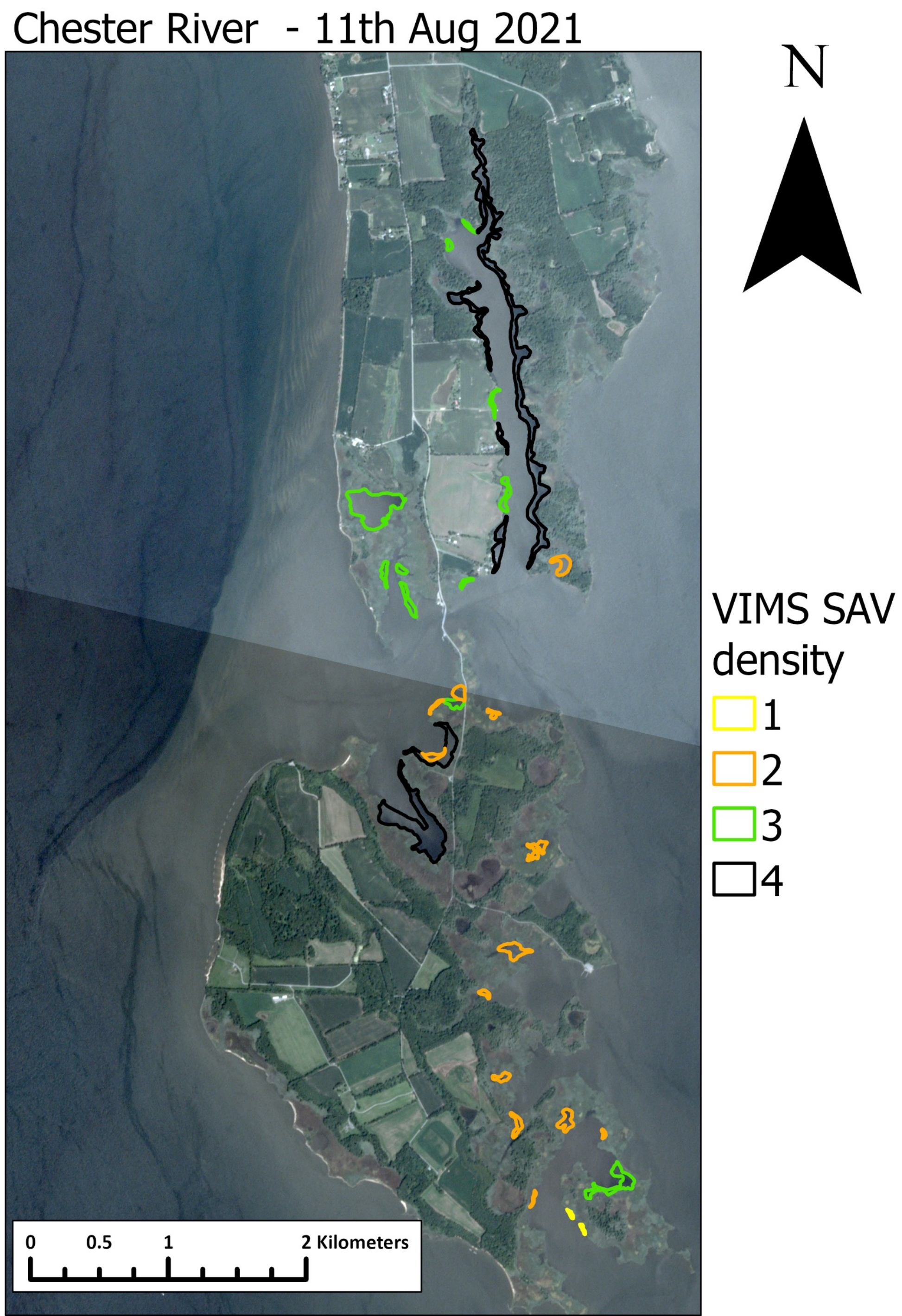

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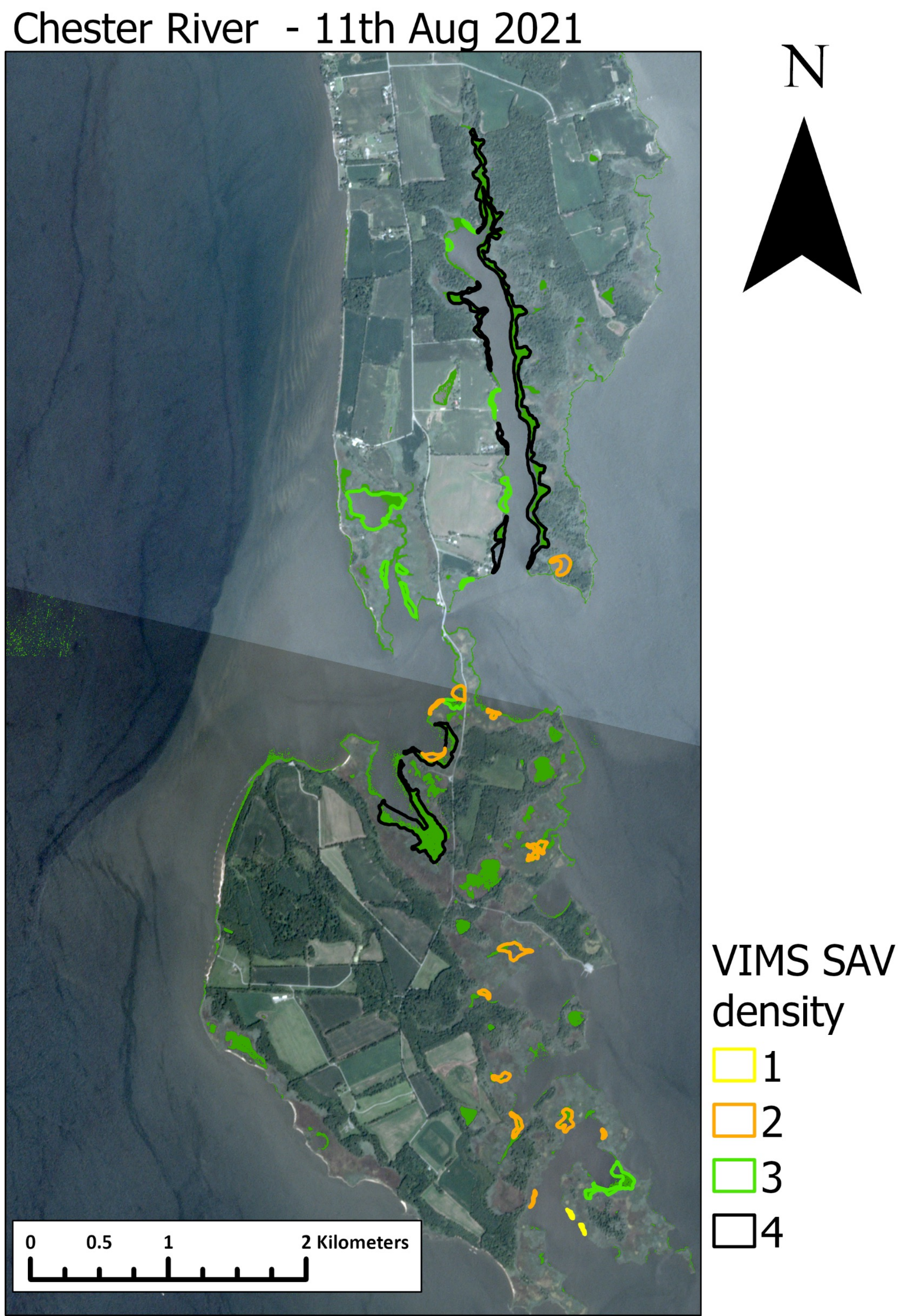
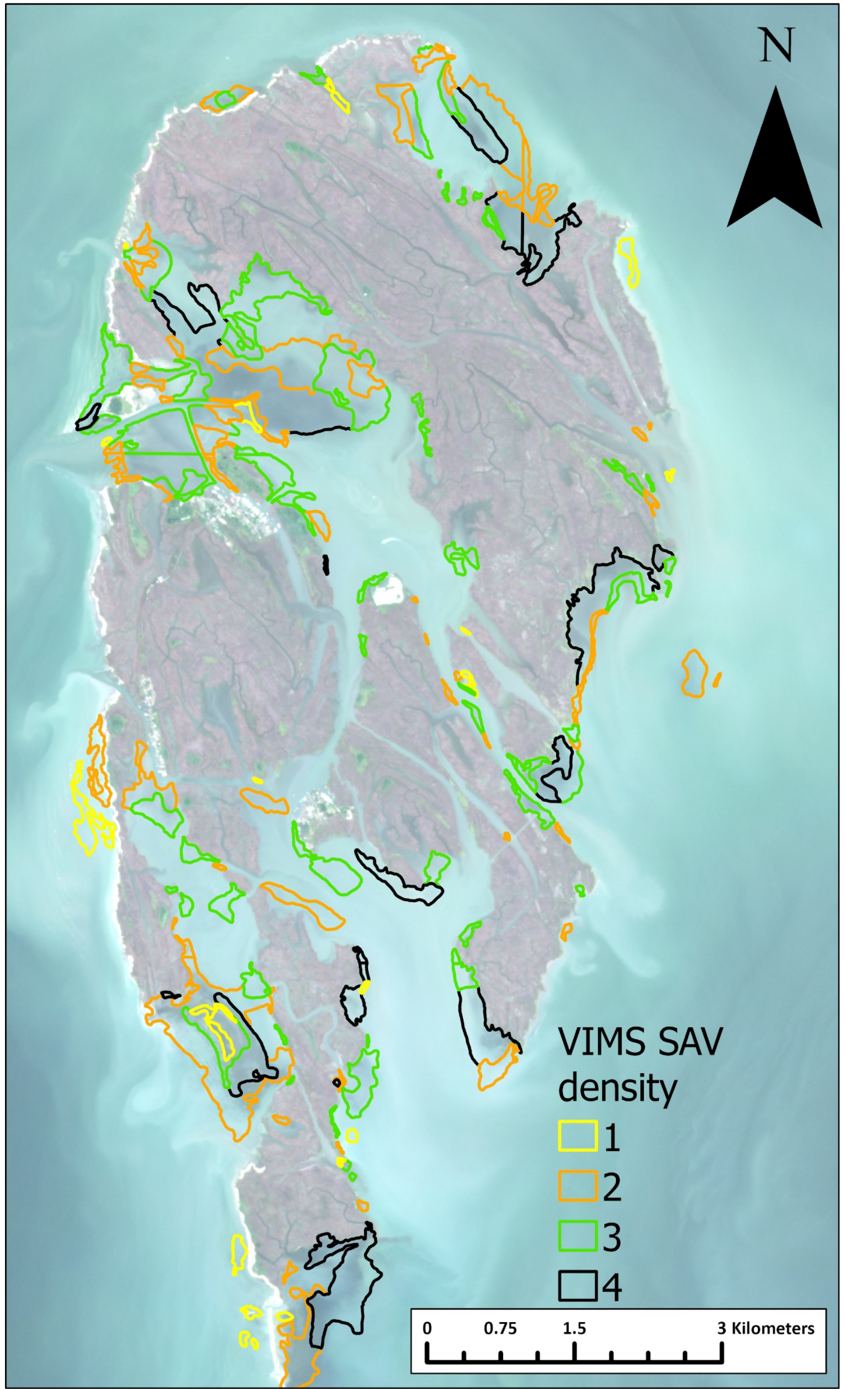


- Planet RGB image

Smith Island - 17th July 2021

- Planet RGB image from
- Manually drawn polygons from 2020 VIMS SAV Survey

Smith Island - 17th July 2021



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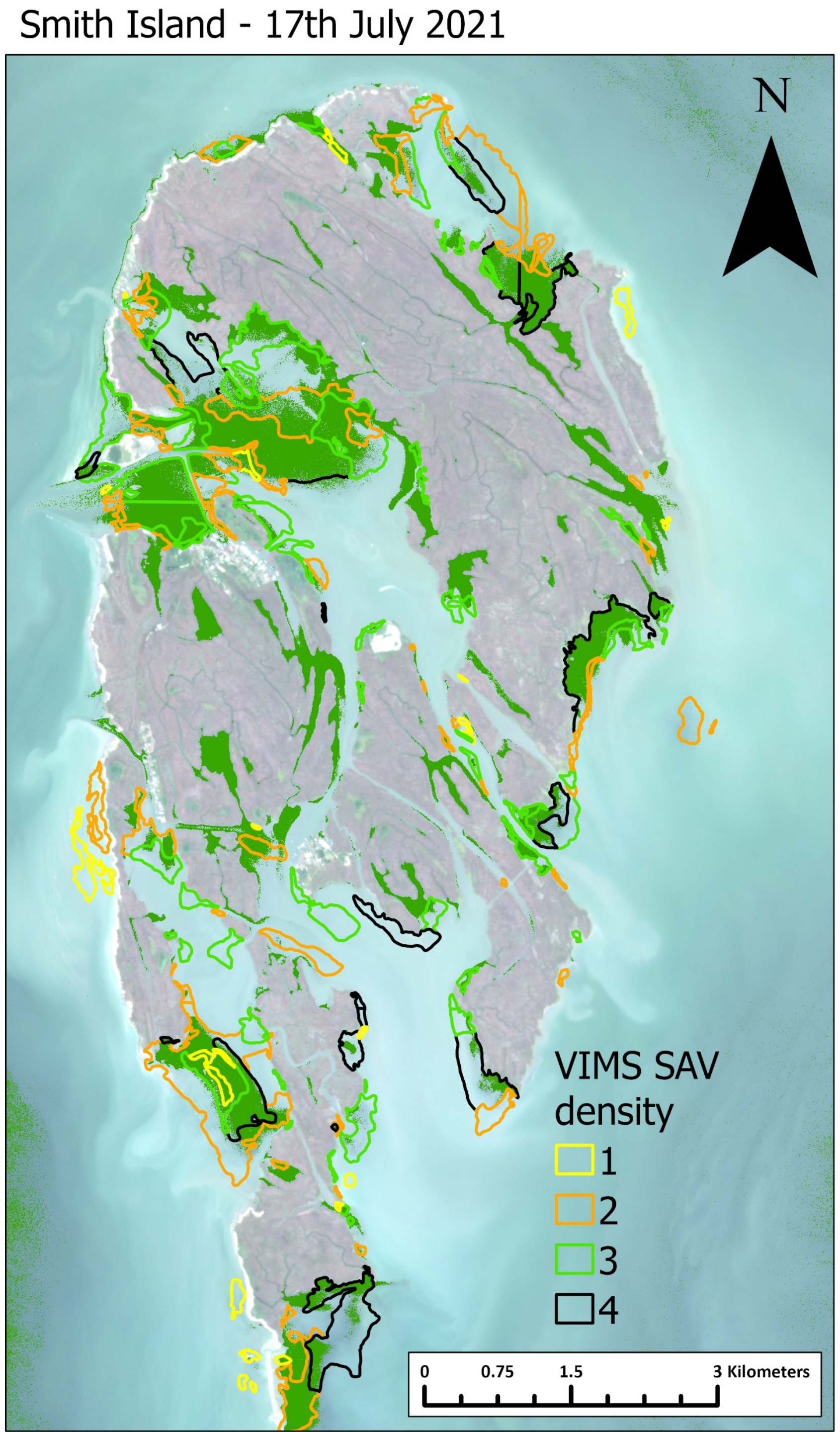
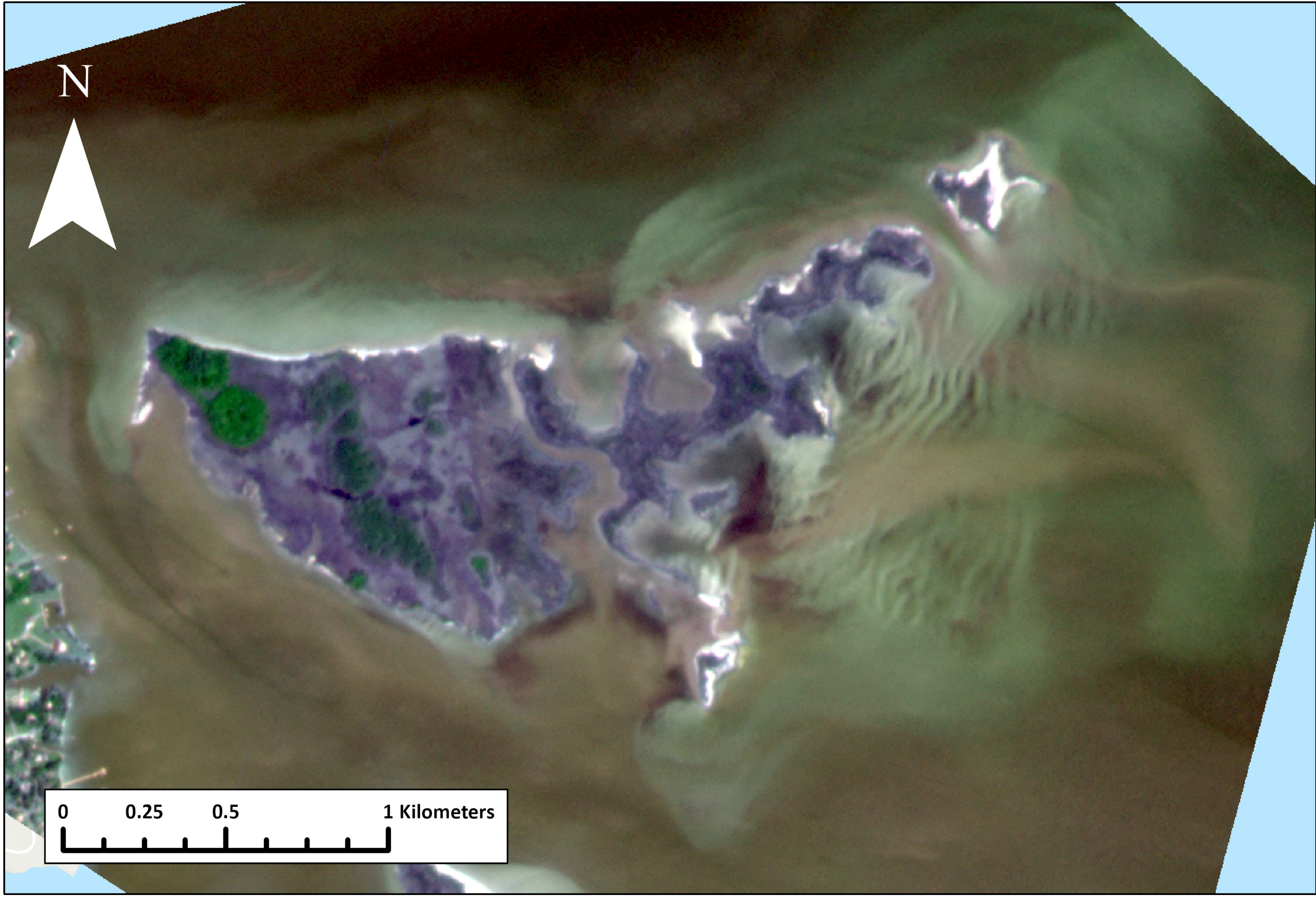


- Planet RGB image from 4 May 2021



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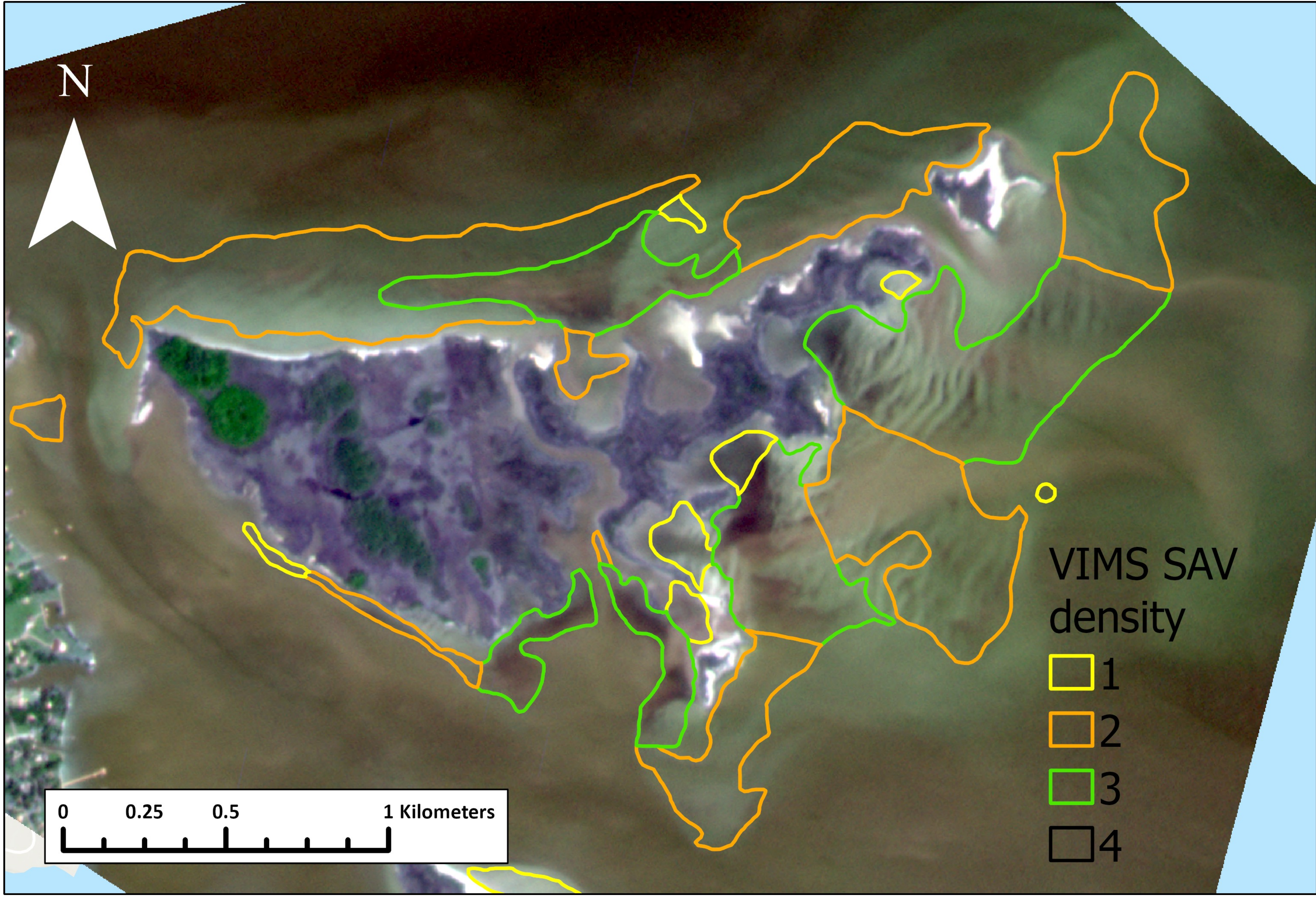

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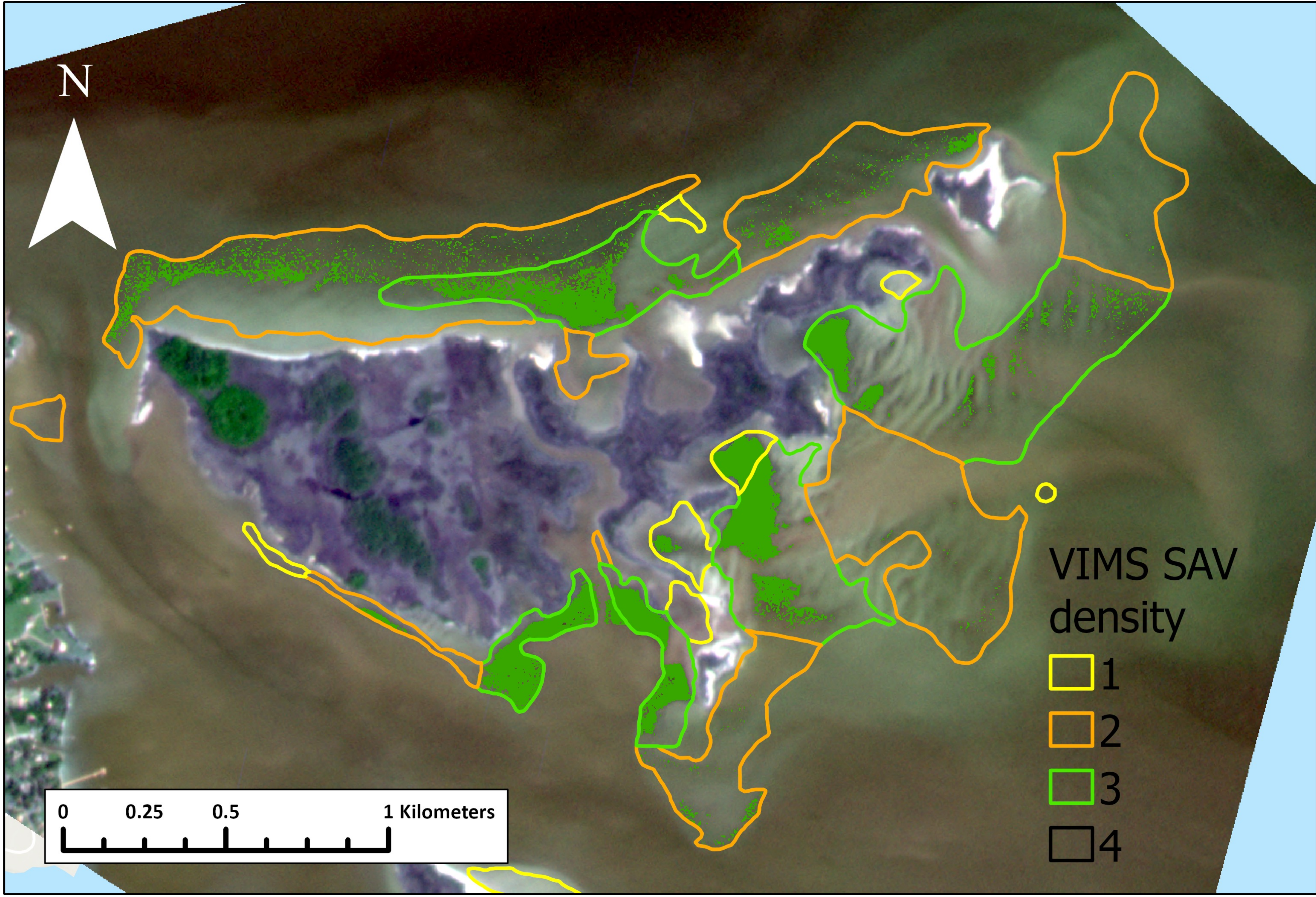
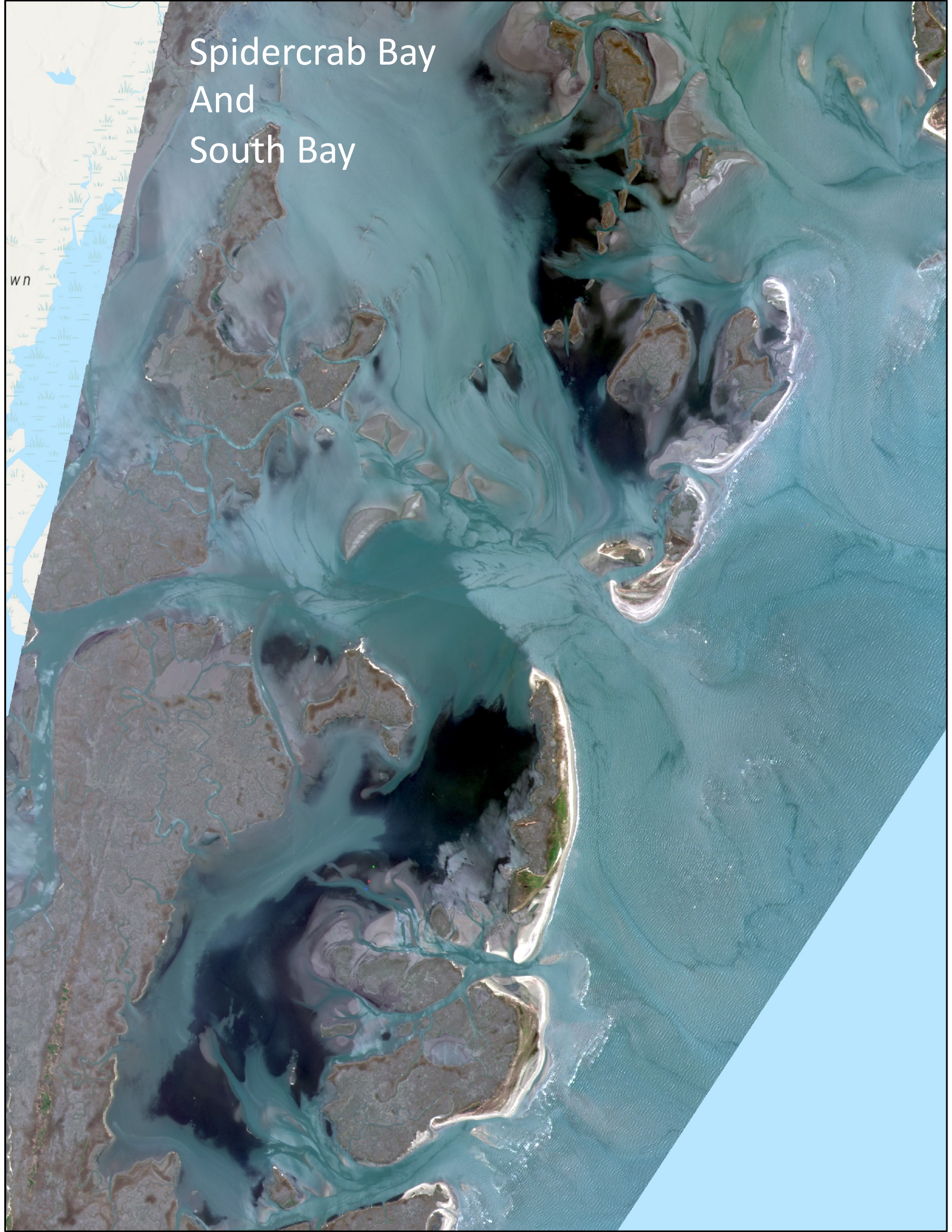


- Planet RGB image from 5 June 2021



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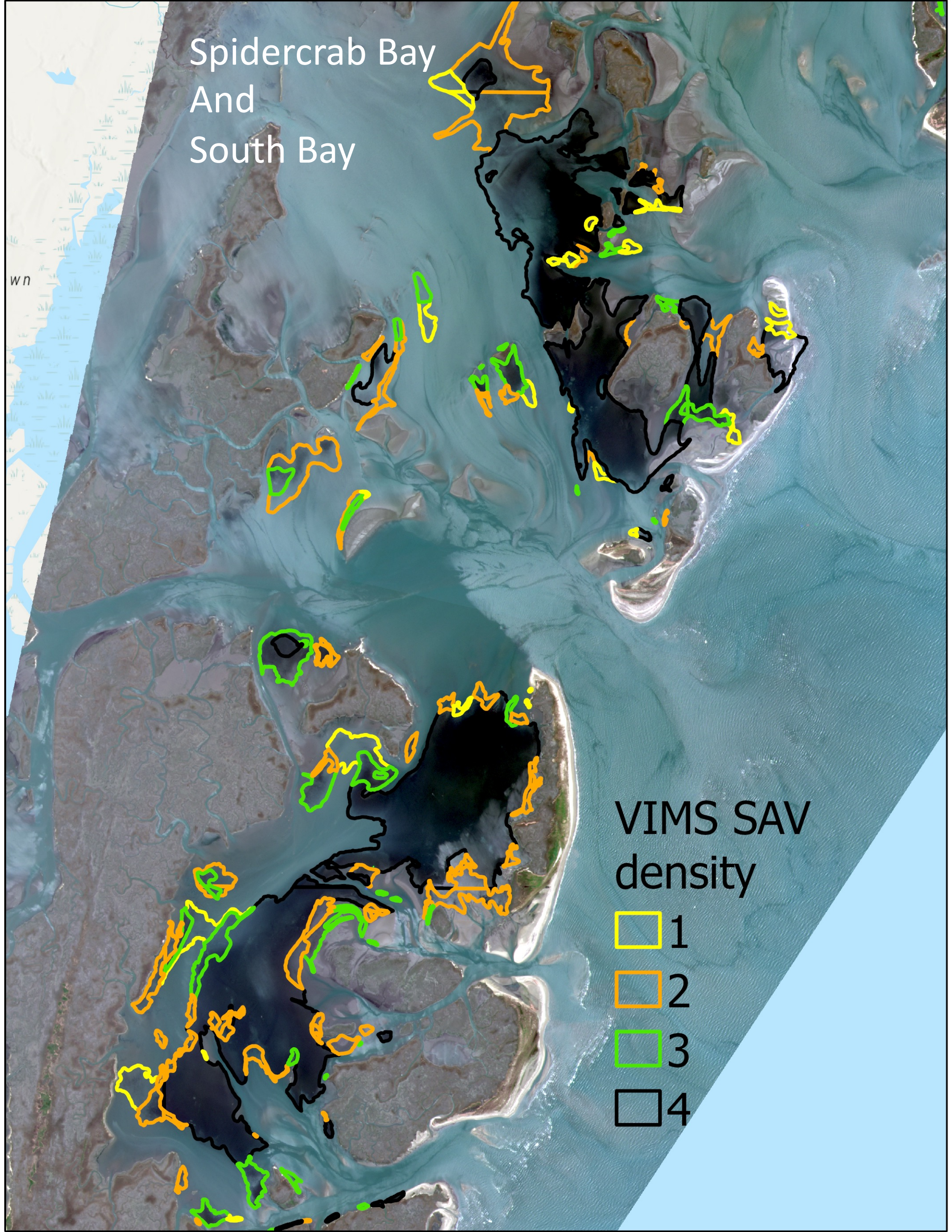

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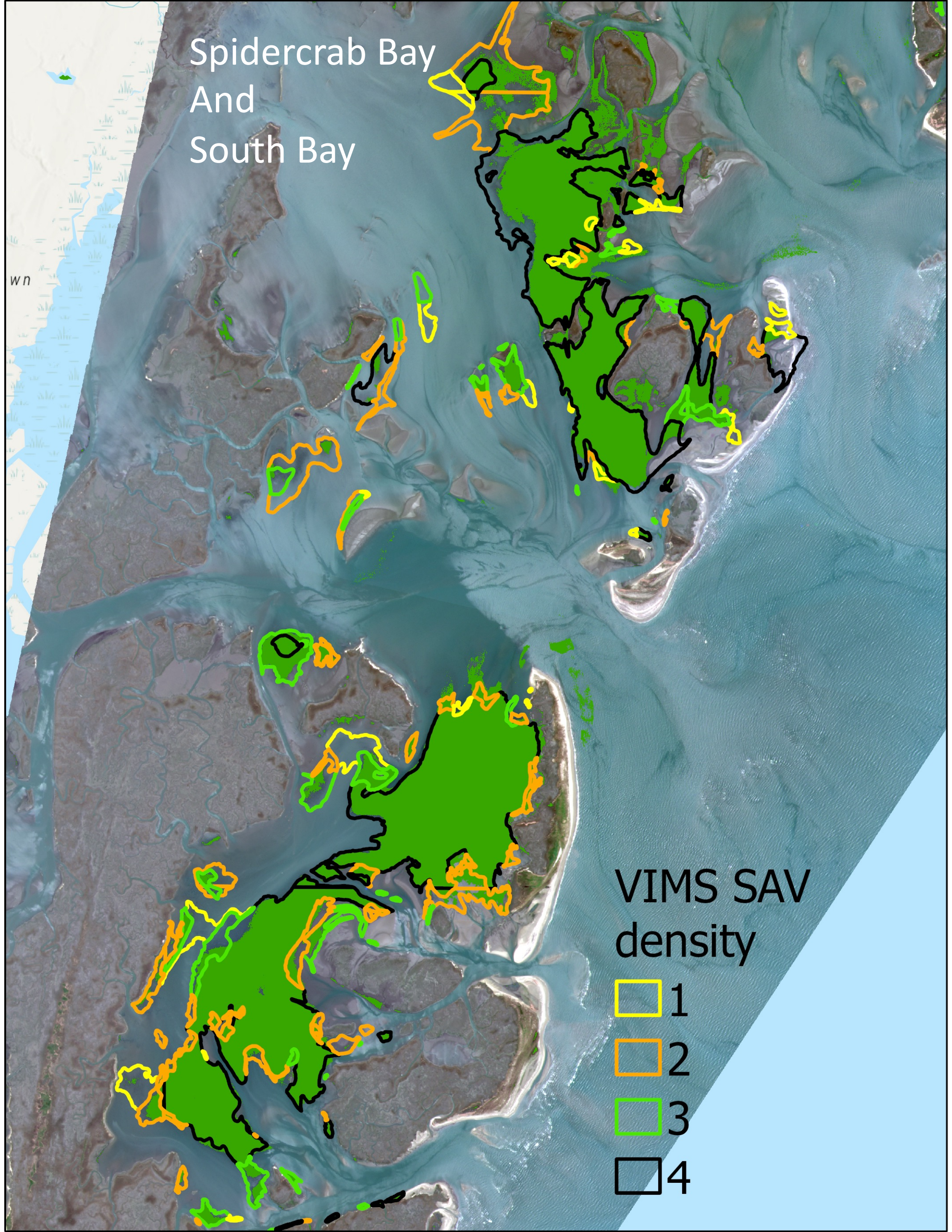

Conclusions

- Satellite image quality & quantity are improving for SAV mapping
  - Radiometrically calibrated and atmospherically products are readily available from several public & commercial sources
- WorldView2/3 produce excellent high resolution images, but
  - Tasking requirements makes their use for routine monitoring difficult
  - Radiometric calibration and atmospheric correction are not standardized across scenes
  - Maxar imposes considerable restrictions on public distribution of image data
- Dove PlanetScope images
  - are amenable to automated classification
    - Results from 4 m satellite imagery are consistent with hand-drawn polygons derived from VIMS 0.25 m aircraft imagery
  - Support Vector and Convolutional Neural Network algorithms perform similarly
    - Local training is required, but training data can be provided from standardized locations
  - Daily images of Chesapeake Bay eliminate the tasking problem
    - 1 image per day acquisition yields 1 -2 usable images per month
    - Enables repeated classification and seasonal time series

Continuing work

- Refine our machine learning algorithm
  - Compare different approaches – e.g., Random Forest vs. CNN
  - Can we eliminate training on each image?
- Reduce mis-classifications through the use of
  - Water quality flags for high turbidity, CDOM, etc.
  - Repeated classification of multiple scenes to eliminate single pixel errors
- Automate the workflow from image acquisition through classification to biogeochemical products