Leveraging Satellite-Based Earth Observations (SBEO) for Coastal Monitoring

April 29, 2022

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CEOS COAST Chesapeake Bay Team
Stakeholder Engagement Lead
Equity Considerations

• NOAA is centering equity in all we do: from developing our workforce to ensuring all communities are able to develop, use, and benefit from our resources. With equity as our lens:
  • How do we grow understanding of satellite-based applications?
  • How do we scale up projects and methods that put satellite data & information into the hands of more people?
Why now?

- SBEO are no longer too coarse for coastal applications (e.g. Sentinel-2 mission (polar-orbiting, multispectral high-resolution imaging) launched in 2015 (2A) and Sentinel-2B (2017) w 5 day repeat at 10m resolution)
- Accessibility is better than ever (e.g. Global Earth Engine, datacube framework)
- Continued significant global investments and collaboration in the advancement of sensors, algorithms and applications

However

...we still need to connect the data provider and user community to derive the most utility for SBEO.
Partnerships

Satellite data / imaging
Satellite data/imaging processing capabilities
Expertise in satellite algorithm development
Analytical tools/capabilities

Local knowledge/groundtruthing ability
In situ data, existing models
Understanding of local needs/applications
Analytical tools/capabilities
A system of 3 watersheds: York River, Piankatank River, Mobjack Bay

Area is experiencing:
- Decline in oyster reefs
- Climate change impacts on shorelines
- Restoration capacity limitations

Restoration here is a high priority for:
- NOAA
- National Fish & Wildlife Foundation
- US Army Corps of Engineers
- Commonwealth of Virginia
- Chesapeake Bay Program
Value of the HFA framework

Raise the visibility of an often-overlooked region - draw more resources to strengthen green infrastructure and enhance resilience through increased capacity.

Leverage external resources - USACE, NFWF, Virginia, Chesapeake Bay Program.

Develop framework for strategic coordination & communication across NOAA offices & partners = increased efficiency & effectiveness.

Opportunity for Impact

Advance regional climate resilience & support local blue economy
Promote locally relevant science and research
Connect NOAA expertise with cross-sector stakeholders
Within the HFA

- Providing existing and emerging satellite data for this area and the broader Chesapeake Bay region.
- Engage stakeholders in the co-design and co-development of satellite products to meet identified data gaps; leverage in situ data for product validation.
  - Focus on products supporting flooding and water quality applications
  - CoastWatch support through training, user engagement
- Develop and evaluate satellite-derived data products through an online toolbox - the coastal knowledge hub.
- Leverage the Committee for Earth Observation Satellites (CEOS) Coastal Observations Applications Services & Tools (COAST) to share lessons learned and capabilities from other agencies and regions.
Possible Restoration Applications

- Identifying flood prone areas and detect changes over time
- Optimizing and/or co-locating habitat restoration
- Targeting wetlands for large scale marsh restoration
- Combatting shoreline erosion with natural infrastructure
Engagement with Middle Peninsula Stakeholders

- Nov 2020 - Initial reach out to gauge interest in exploring new satellite data products
- April 2021 - High level summary of data needs providing to satellite product developers
- Summer 2021 - Mid-Atlantic interns added to explore satellite capabilities
- Fall 2021 to date - Satellite product exploration/development
- Today - stakeholder feedback
Questions to be thinking about
● Which of these products are most germane to your work in the Chesapeake Bay?

● Where do you see opportunities to contribute to co-development of these products, either with data or expertise?

● Are there other potential SBEO applications we have not considered or discussed?
Introduction to COAST: Coastal Observations, Applications, Services, and Tools
Coastal Observations, Applications, Services, and Tools

Who is CEOS? Committee on Earth Observation Satellites

What is CEOS COAST? Coastal Focused Team

- Use Earth Observation data (satellite + in situ) to tackle coastal problems affecting society - Coverage | Frequency | Resolution
- Engage with regional coastal stakeholders
  - Endorsed as a Contribution to the UN Ocean Decade, potential for funding to sustain this over the Decade

How might CEOS COAST help you?

- Leverage global satellite data for high impact issues affecting YOUR community.
- Co-develop coastal information products to solve YOUR information needs.
- Advance products and features YOU want and will be easy for you to use
Identified 2 Pilot Projects to develop coastal products, services and tools

Themes:
- Shoreline mapping
- Bathymetry/
- Flooding
- Turbidity & Sediment Loading
- Coastal Eutrophication

Phase 2: 2020-2022
Initial COAST Pilot Locations

**Continental:**
Chesapeake Bay (USA)
Odisha/Bay of Bengal
West Coast of Africa
Rio de la Plata region (Latin America)

**Small Island Nations:**
Caribbean: USVI
Pacific: Marshall Islands
Why CoDevelopment?

- Build something useful and user-friendly
- unique coastal satellite data products, low barrier of entry skillwise
- One-Stop-Shopping Access to various data types, including in situ data (cal/val) YOU can supply!
- Enhanced access to trusted data sources
  - help seeking a funding source for sustainment of products
- Free and open source products enables customization by anyone.
- Regional Pilots enable product testing for scalability

WHEN? May-July 2022……
CEOS COAST DATA NEEDS

Shoreline mapping/coastal elevation
  island elevations
  Shore line validation data
  Flood maps/Flood extent data
  Bathymetry data
  Coastal elevation & Intertidal Mapping -
    Optical EO data, validation (GPS, LiDAR, in-situ)
Precipitation temporal & spatial
  antecedent moisture conditions (soil moisture)
Digital Elevation Models
River Discharge/Dam location & specs
Land Use/Cover datasets
Water Temperature
Salinity - river discharge/mixing models/Density
  gradients - plume dispersal (i.e. settling velocity)

Tidal Data - altimetry, winds
Wave Data - statistics from Altimeters & buoys
  significant wave height/direction/periodicity
  wave spectra data
  Wave refraction nearshore
Ecosystem Status/Change
  Habitat maps
  coral health data
  SAV classification
  mangrove classification & health
  coastal sediment maps - deposition & rate of accumulation
Eutrophication Indicators (in situ data)
  Turbidity/Sediment data & loadings datasets
    Point source discharges (volume & conc.)
  Nutrient loadings datasets
  water quality maps
  Water color maps (airborne or in situ)
Coastal Eutrophication and Sediment Products
Coastal Eutrophication and Sediment Products

- **Codevelopment product:**
  - Seagrass habitat suitability mapping

- **Products from CEOS partners**
  - GEO Blue Planet: Coastal Eutrophication indicator products
  - Chlorophyll-a anomaly / chlorophyll-a anomaly ratio
  - Suspended particulate matter product
  - GEO Aquawatch turbidity products

- **Future work**
  - AI-based satellite chlorophyll model
  - AI-based hypoxia model for Chesapeake Bay
Codevelopment: Seagrass Habitat Mapping

- Exploration of water quality impacts on habitats
- High resolution images: better understanding of sediment conditions in the bay
- Codevelopment with partners with VIMS for product on seagrass habitat conditions
Satellite derived turbidity, chlorophyll, light attenuation, and sea surface temperature

Layers useful in characterizing seasonal habitat conditions

Providing both temporal and spatial resolution

Period from 2015-present
Future steps in development
- Extend geography with Landsat imagery
- Incorporate hourly sea surface temperature
- Evaluate findings with known SAV beds

Looking forward:
- Any similar areas of habitat characterization that could benefit from satellite imagery?
Partner Work: Coastal Eutrophication Product

- GEO Blue Planet - Coastal Eutrophication product
- Developed in conjunction with NOAA Coastwatch, ESRI, and UN Environment
- Development of two sub-indicator products
  - Chl-a deviation relative to baselines from 2000-2004
  - Chl-a anomalous areas within each year

Regional EEZ Chlorophyll-a Deviation from Baseline (2005 – 2021)

Distribution of Deviating Pixels in the Australian Region for June/July 2021
Partner Work: Coastal Eutrophication Product

- You can be a beta tester!
  - Early access to satellite derived product
  - Customized refinement of product on your region of interest
  - Contribution to the production of peer-reviewed publication on indicators
  - Be a part of next phase: machine learning model for satellite-derived chlorophyll
Chlorophyll-α Products: Available to CEOS COAST

NOAA STAR Chlorophyll-α Anomaly - daily product
Blended images from VIIRS (Visible Infrared Imaging Radiometer Suite)
https://www.star.nesdis.noaa.gov/socd/mecb/color/ocview/
NOAA STAR Suspended Particulate Matter (SPM) - daily, 8-day, monthly product
Blended images from VIIRS and OLCI-S3A (Ocean and Land Colour Instrument)
https://www.star.nesdis.noaa.gov/socd/mecb/color/ocview/
European Space Agency: Copernicus Global Land Service
10-day Turbidity Product from Sentinel-2 MultiSpectral Instrument (MSI)
Access via University of Wisconsin RealEarth Portal https://realearth.ssec.wisc.edu/
Turbidity and Sediments Products: Available to CEOS COAST

• Next steps in turbidity products
  • A collaborative project between GEO AquaWatch, the World Bank, Conservation International, UNESCO and Google Earth Engine (GEE) to provide fit-for-purpose water quality information for inland and coastal waters
  • Enable processing turbidity data on the cloud in real time through GEE
  • Expected later this summer
Artificial Intelligence-based satellite chlorophyll model
Given a Top-of-Atmosphere (TOA) spectrum, estimate the chlorophyll concentration

Feature:
1. Satellite optical data

Stage 1: Atmospheric Correction

Stage 2: Chlorophyll Models

Target:
Surface Chlorophyll concentration

Features:
2. Sun and sensor viewing angles
3. Atmospheric composition
4. Algal pigment packaging
5. Land/cloud effect

Objectives:
- Robust; resilient to terrestrial interferences
- End (TOA) to end (chl); with implicit atmospheric correction
- One algorithm fits all sensors
AI for Hypoxia prediction: Data and Preprocessing

1. MODIS-Aqua Satellite:
   - Rayleigh-corrected reflectance at 16 bands
   - Weekly minimum (1st percentile)
   - 2002-2020

2. Virginia Institute of Marine Science (VIMS):
   - Chesapeake Bay Environmental Forecast System (CBEFS)
     - Currents (u, v, & w)
     - Water temperature (T), Salinity (S)
     - 3-D reprojected to fixed grids.
     - Weekly mean

3. ECMWF ERA5:
   - Wind (u & v)
   - Hourly data
   - Wind rose tabular data

4. Chesapeake Bay Program (CBP):
   - Field-measured Dissolved Oxygen concentration
   - Mainstem stations only

[Bever et al., Environ. Model. Soft., 2021]
HypoxAI - prediction of Chesapeake Bay Hypoxia with deep learning

Features

- Reflectance
- wind
- Currents
- Temperature
- Salinity

8 weeks ago

3 weeks ago

2 weeks ago

1 week ago

CNNs

CNNs

CNNs

CNNs

LSTM

LSTM

LSTM

LSTM

DNN

Target depth

Bottom Depth

DO at target depth

CNN: Convolutional Neural Network
LSTM: Long and Short Term Memory
DNN: Deep Neural Network
Model Evaluation on Testset (2019-2020)

- HypoxAI outperforms CBEFS
- HypoxAI generally predicts realistic DO profiles

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Questions and Feedback

- What features or aspects work are of the most interest to you?
- Are there any new products that you would like to see developed that would be useful to you?
- What suggestions do you have in order to improve products?
GEO / LEO / SAR Coastal Inundation Pilot

Sean Helfrich, Josef Kellndorfer, Sanmei Li Frank Monaldo, William Straka, Ian Olthof, and Vincent Decker, Rachel Lazzaro, Olivia Fey, Mitch Goldberg, Bill Sjoberg, Qingyuan Zhang, Xinyi Chen, Christopher Jackson, Tyler Ruff, and Nicole Bartlett

CEOS COAST Chesapeake Pilot Region
April 29, 2022
Topics

- CEOS GEO / LEO / SAR goals and partners (Flood & COAST)
- Flood and Inundation Mapping Algorithms
  - VIIRS / ABI
  - SAR
- SAR Flood and Inundation Product Development in Pilot Regions
  - Red River of the North CEOS Flood pilot
  - Coastal Inundation Mapping – Chesapeake Bay Pilot Region
- Coastal Erosion
- Hurricane Dorian
Flood Pilot Goals

• The CEOS WGDisasters Pilot seeks to bring together CEOS partnering agencies to address the following goals:
  o Learn about the current and upcoming efforts to map water and flood extent from a diversity of low-Earth orbit (LEO), geostationary (GEO) and synthetic aperture radar (SAR)
    ▪ From this, understand the technical requirements and future needs for sustaining and improving upon these efforts
  o Using regional events from Pilot partners, demonstrate how LEO, GEO, and SAR can be combined most effectively
    ▪ Canada / US Red River of the North
    ▪ Chesapeake Bay.
NOAA Flood / Coastal Inundation Mapping Development Products

- VIIRS Flood Detection - US (3 products)
  - NWS NRT; NWS Daily Composite; NWS 5-day Composite
- VIIRS Flood Detection - Global (3 products)
  - Global NRT; Global Daily composite; Global 5-day Composite
- Synthetic Aperture Radar (SAR) (1 Product)
  - (Sentinel 1, RadarSat Constellation Mission (RCM), RadarSat 2, ALOS 4 (2023), and NISAR (2023)
- ABI US Flood Detection Products (2 products)
  - Hourly Composite; Daily Composite
- Blended Flood Detection - VIIRS/ABI and VIIRS/SAR (2 products)
- Downscaled VIIRS and Blended VIIRS/SAR (2 Products)
LEO/GEO’s VIS/NIR + SAR Capabilities

GEO and LEO provides larger areal extent – limited by cloud cover

SAR often provides view through clouds

Good agreement when both are available

From: AMS (Virtual) Annual Meeting, 2021
• All NRT VIIRS and ABI Flood Fraction Products are available
• Flood Data can be compared with other datasets to leverage the utility of the data
• Working to operationalize this product to ensure routine production, sustained development, and archival.

https://realearth.ssec.wisc.edu/#
GEO and LEO provides larger areal Extent but is limited by cloud cover and has limitations under dense vegetation.

Gray = Clouds
Due to the need for street and local level flood monitoring, NOAA is testing to generate finer-scale VIIRS and ABI Flood Extent:

- spectral unmixing water fractions
- downscaling using DEM data

Currently, JPSS provides daily (unmixed) water fractions at a global scale, while generation of downscaled extents and flood depths is semi-operational over selected sites. By integrating SAR data, can we improve VIIRS water fraction estimates? Can different DEM data and downscaling techniques be used to improve downscaled flood extents?
Daily automated Sentinel-1 processing of all pilot regions to add to time series data stacks
Check for new available scenes at NASA DAAC
Process new available scenes with restitute precision orbit
Automated updates of MGRS tiles at

http://remotesensing.earth

-> enables visual check on detected flood events or river openings from ice

In order to test backscatter over flood areas, the performance SAR Flood Mapping Algorithms and demonstrate the algorithms to customers; STAR in collaboration with Earth Big Data developed a SAR Flood testing portal.
Sentinel-1 C-Band VV Polarization multi-temporal image composites

Sentinel-1 VV Time Series Metrics
R Minimum
G Minimum
B Median

Sentinel-1 VV
R 2019-04-17
G 2019-04-17
B 2019-04-05
• 5 Test Areas to examine differing flood causes
  • Iowa
  • Central Alaska
  • Gulf Coast
  • Red River of the North
  • Chesapeake Bay

http://remotesensing.earth
Sentinel-1 C-Band Time Series: Red River
Deep Learning Algorithm Prediction

randomForest (with Sieve)  Unet

2019-04-17 SAR RGB (with 4/5)
North Tile 14UPU
NRCan Emergency Geomatics Services Canada

- EGS maps floods in Canada and US from RadarSat 2 and RCM as primary data sources
  - open water
  - flooded vegetation
  - urban on a best-effort basis by combining other sources of data
Gulf Coast Erosion

Source: https://earthengine.google.com/timelapse
Gulf Coast Erosion

Source: https://earthengine.google.com/timelapse
Sentinel-1 Observations

Timeseries at (-92.5901W, 29.5826N)

Data Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
New Point Comfort, VA Time Series
New Point Comfort, VA Time Series
2019 Hurricane Dorian: 
August 24 – September 10
Middle Peninsula Impact: Sept. 6

2020 Hurricane Isaias: 
July 30 – August 5
Middle Peninsula Impact: Aug
SAR Backscatter Before & After Dorian
Ongoing and Future Work for Satellite Flood Mapping

- Implement VIIRS and ABI into NOAA operations
- Test downscaling approaches
- Continue evaluation and validation of SAR flood algorithms
- Expand integration of more SAR Satellites into Production
- Examine Flood Algorithm Performance for Chesapeake Bay pilot area
- Generate historical inundation maps and frequencies for validation and downscaling
- Generate flood depth maps in Chesapeake Bay
- Examine temporal changes for coastal inundation and impacts on periodic flooding
- Integrate into Knowledge Hub and Real Earth Environments
Hello We are on a short 10 minute break

We are reconvening at 14:30pm
Satellite Derived Bathymetry for shallow coastal water

Rick Stumpf, Gretchen Imahori
NOAA National Ocean Service

Isabel Caballero,
Instituto de Ciencias Marinas de Andalucia (ICMAN-CSIC)
Our goal, to mostly automate SDB at 10 m resolution, with national and global application. Improvements support NOAA and potentially international community through IHO.

**common SDB Methodology**

- Step by Step cookbook, all manual
- ArcGIS
- Stumpf et al. (2003) bathymetric algorithm
- Typically do not convert to absolute depths
Pearl & Hermes Atoll, NW Hawaiian Islands

Chart and first SDB map from NCCOS
Value of SDB

Reconnaissance of remote areas

Monitoring of shoals

Storm response

Infilling of lidar/multi-beam

Mission planning
Operational Planning

NOAA Ship Thomas Jefferson SDB validation in Nantucket Sound

Courtesy: LCDR Anthony Klemm
Automating process to retrieve more data

Clouds, atmospheric haze, sunglint on the water, transient turbidity in the water are all factors in impacting SDB retrieval.
We are not trying to pick a single optimal scene, example Cape Lookout
Composite multiple days to reduce turbidity
Change detection around Oregon Inlet NC
Chesapeake Bay

SDB: if you cannot “see” the bottom, cannot retrieve a depth.

Residual turbidity affects calibration to absolute depth. Variations in turbidity cause false shoaling.

We need to refine “Extinction depth”: maximum depth retrievable. This depends on turbidity (and the water depth)
Mouth of Rappahannock and Piankatank Rivers

Rick Stumpf
Richard.Stumpf@noaa.gov
Questions and Discussion?
See the Shoreline Mapping Slides and Knowledge Hub Video
What next??

Proposing to meet with interested CB stakeholders (as available) regularly throughout May, June, and July (perhaps into August if needed).

• To introduce and refine existing products and the portal based on your feedback
• This could also include outreach and training development

Any other thoughts? Better ideas?