CEOS-COAST: Coastal Observations and Application Study Team

Phase 1 Progress, Assessments and Deliverables

Executive Summary:

This compilation was reviewed by the COAST membership and summarizes contributions of the entire COAST study team. It contains summary information on the COAST Team and its Phase 1 deliverables to be completed by the CEOS Plenary in October, including three whitepapers summarizing the state of the science and accomplishments to date that will benefit the two COAST Pilot Projects (Sea to Land Impacts and Land to Sea Impacts) as well as cross-cutting infrastructure needs. Also addressed in this document are gaps, challenges and opportunities identified by the Study Team to date.

Although not captured in this document, Candidate Pilot project locations were compiled during the first year and selection criteria were contributed and approved by all members, with emphasis placed on suggestions made by WGCapD to emphasize project impact to users, and WGDisasters to choose joint pilot location(s). A shortlist of pilot locations was determined. Crucial to COAST pilot execution will be the Study Team members and their agencies assuming leadership or contributor roles for data and resources; we are pleased several have expressed interest.

Table of Contents:

COAST Team Members:

- CEOS COVERAGE: Jorge Vazquez (JPL), Vardis Tsontos (JPL)
- CEOS Executive Officer: Kerry Sawyer (NOAA)
- CEOS SEC Support: George Dyke, Matt Steventon (Symbios)
- CEOS Systems Engineering Office (SEO): Brian Killough (NASA)
- CEOS VCs: Edward Armstrong (JPL), SST-VC; Eric Leuliette (NOAA), OST-VC, Steve Labahn (USGS), LSI-VC
- CEOS WGCapD: Nancy Searby, Lauren Childs-Gleason (NASA)
- CEOS WGClimate: Albrecht von Bargen (DLR-DE), Joerg Schultz (EUMETSAT)
- CEOS WGCV: Philippe Goryl (ESA)
- CEOS WGISS: Rob Woodcock (CSIRO)
- CEOS WG Disasters: David Green (NASA), David Borges (NASA)
- CEOS SDG AHT: Flora Kerblat (CSIRO)
- CNES: Aurelien Carbonniere
- CSIRO: Janet Anstee
- ESA: Jérôme Benveniste
- EUMETSAT: Estelle Obligis
- European Commission: Astrid-Christina Koch, Fabienne Jacq
- GEO AquaWatch Initiative: Steve Greb (University of Wisconsin)
- GEO Blue Planet Initiative: Emily Smail (University of Maryland), Leah Segui (NOAA)
- GEO Secretariat: Douglas Cripe
- Geoscience Australia: Stephen Sagar
- ISRO: Rashmi Sharma, **Raj Kumar (Co-Chair)**
- JAXA: Ko Hamamoto and Osamu Ochiai
- NASA: Laura Lorenzoni (OCR-VC)
- NOAA: **Paul M. DiGiacomo (Co-Chair)**; Merrie Beth Neely (Project Manager)
- USGS: Tom Cecere

Summary of COAST Deliverables

(as of 07 October 2020)

- Established - CEOS-COAST website: http://ceos.org/ourwork/ad-hoc-teams/ceos-coast/
- Delivered – Annotated COAST Bibliography; available at CEOS-COAST website
- Delivered - COAST Pilot Location Selection Criteria; available upon request
- Delivered – Compilation of COAST-related international projects and activities; accessible at CEOS-COAST website
- Delivered – draft satellite data requirements inventory for SDG 14.1.1a (coastal eutrophication); available upon request
- Delivered - CEOS-COAST Phase 1 White Paper #1: "*Sea to Land Impacts: User Needs, Observations, and Services*" (contained within this document)
- Delivered - CEOS-COAST Phase 1 White Paper #2: "*Land to Sea Impacts: User Needs, Observations, and Services*" (contained within this document)
- Delivered - CEOS-COAST Phase 1 White Paper #3: "*Cross-Cutting Tools, Systems and Services*" (contained within this document)

CEOS-COAST Phase 1 White Paper #1

Sea to Land Impacts: User Needs, Observations, and Services

Overview

The first of the two thematic components that comprise the CEOS-COAST effort is focused on monitoring and assessing, and ultimately forecasting, the coastal hazards that occur where the sea meets land. These physical processes include episodic, temporary coastal *flooding* events (e.g., storm-driven), and sustained submergence in the form of coastal *inundation* associated with mean sea level rise and subsidence (IGOS, 2006; Flick et al., 2012).

Coupled with erosion in coastal zones, these hazards are increasingly a ubiquitous global concern. They represent a tremendous threat to both life and property given much of the global population lives within close proximity of the ocean). Furthermore, saltwater intrusion represents an increasing risk, affecting both groundwater and riverine supplies of freshwater. In addition to their significant impacts at continental scales, these hazards are of even greater concern for small island states – both developed and especially developing.

Aside from these physical impacts, there are also significant concerns from a biological and biogeochemical perspective. Coastal areas are extremely productive regions, estimated to provide at least 40% of the value of the world's ecosystem goods and services (Barbier et. al., 2011). This intrusion of water from flooding and inundation greatly impacts the loading and delivery of materials from adjacent watersheds to coastal receiving waters. These materials include nutrients, sediments, and various contaminants (pollutants and pathogens) which in turn have significant ecological impacts,

Aside from ocean observations (e.g., tides, waves, winds), changes in land cover and land use, driven by anthropogenic (e.g., deforestation; increases in impervious surface cover due to urbanization) as well as natural and climatic impacts (e.g., changes in precipitation, discharge; desertification, erosion), affect the quantity and quality of these loadings and as a result must also be considered.

The study team identified diverse CEOS observations and capabilities as needed to monitor, assess, and ultimately forecast the sea-to-land impacts as above. Multi-sensor satellite observations are required for both the terrestrial as well as aquatic components of the coastal zone, likewise cross-cutting approaches, systems and services to effectively analyze and integrate these observations across the land-sea interface and over time, and to extract timely and fit for purpose information in support of user needs and decision-making.

Progress to Date

Expansion of CEOS Flood Pilot to include SAR Imagery and Coastal Pilot Sites

Under the auspices of WGDisasters, CEOS established the GEO/LEO Flood Pilot to facilitate timely utilization and integration of satellite data for flood mapping and monitoring. Assisted by timely intervention and facilitation of the COAST Chair (P. DiGiacomo) in 2019, synthetic aperture radar (SAR) data/imagery was added to this effort, which expanded to become the GEO/LEO/SAR Flood Pilot (see http://ceos.org/ourwork/workinggroups/disasters/floods/). SAR data products complement the optical imagery by providing high-resolution, all-weather (i.e., cloud penetrating) observations – of great value during hurricanes and other coastal storms.

With the formal initiation of COAST later in 2019, CEOS WGDisasters and Flood Pilot Co-Leads (D. Green, D. Borges) joined the COAST team, and collectively have worked with the broader COAST Team as part of this "Sea to Land Impact" thematic component – with its focus on coastal flooding and inundation. Coordination between WGDisasters and COAST for the CEOS Flood Pilot is anticipated to include at least two shared coastal pilot sites.

As documented in the CEOS Flood Pilot Overview, the objectives of the flood effort are to explore and demonstrate best practices for combining information from a growing constellation of optical and SAR and GEO satellite methodologies for flood mapping and response at regional and local scales by:

A. Use 5-6 regional case studies representing large-scale, long-lasting flood events where repeated mapping by multi-frequency SAR and multi-platform optical remote sensing can demonstrate the unique value of SAR in complementing LEO/GEO efforts to map water extent. Through these case studies, demonstrate how multi-frequency SAR can contribute additional mapping of water extent, and develop, document, and share potential best practices for merging their analyses in time and space.

B. Demonstrate methodologies within the community for deriving supplemental water depth estimation, using local and regional case studies as an opportunity for calibration and validation. Develop, document, and share potential best practices for communicating uncertainties and additional layer of depth estimation in combination with extent mapping.

C. Engage with product developers, data services, and end users to characterize their needs for flood mapping and water depth products, feedback on value and utility of combined optical and SAR approaches and develop "best practice" standards for data products, mapping and sharing.

What COAST brings to the CEOS Flood Pilot, beyond simple inclusion and focus on coastal flooding sites, is consideration of and integration with coupled processes and phenomena at the land-sea interface, with particular focus on water quality (i.e., nutrient and sediment loadings) and other ecological impacts as discussed in the next chapter (COAST Phase 1 WP #2).

Flooding has impacts above and beyond life and property, and these need to be considered in a holistic, synergistic manner. The broader COAST effort is documented in the COAST Phase 2 Implementation Plan.

Development of framework for the WaveFoRCE Project

The *Wave-driven Flood-forecasting on Reef-lined Coasts Early warning system* (WaveFoRCE) project has been conceptualized and scoped to date and will provide nations and people living on coral reef-lined coasts anywhere in the world with an up to 7 day forecast of wave-driven coastal flood events (i.e. all forms of marine flooding except tsunamis). WaveFoRCE is a GEO Blue Planet project to be facilitated by COAST with the lead science team comprising NOAA, USGS and Deltares. Other team members currently consist of CSIRO and SPC, working in active collaboration with other COAST members.

The lead science team has to date implemented a hindcast demonstration of WaveFoRCE on Roi-Namur, Kwajalein Atoll in the Republic of the Marshall Islands, which demonstrated that on average, the simplified flood model (upon which WaveFoRCE is based) has an average error that is within 7% of the error of a fully-implemented high-resolution XBeach flood model.

USGS and Deltares have also been developing the BEWARE (Bayesian Estimator for Wave Attack in Reef Environments) model that underpins predictions of wave runup within WaveFoRCE. The result will be a significant improvement in accuracy over a wide range of coral reef profiles.

The CEOS COAST team has identified satellite parameters and derived products that are needed for the implementation of this project:

<u>Altimeters</u>: wave statistics (significant wave height, wave period); sea surface height anomalies

<u>SAR</u>: direction of significant wave; including refraction of waves near the shore; period of significant wave, wave spectra

<u>High resolution satellites</u> (including ICESAT-2): island elevations; shallow water bathymetry, including identification of which algorithm to use via ocean colour and turbidity; shoreline detection; flood extent

<u>SST and ocean color</u> (for reef health): SST and solar insolation for prediction of mortality due to coral bleaching; ocean color for water quality monitoring during and after the flood events

Engagement with potential users in selected pilot locations is currently underway in collaboration with the GEO Blue Planet Initiate.

Gaps, Needs, Challenges and Opportunities; Toward Phase 2

Relative to the above issues, there are several priority areas where multi-sensor satellite data can be exploited to a much greater extent to address existing information gaps for users. Leveraging advances in algorithm development, extended time series and enhanced capabilities from recent and upcoming sensors/platforms, new and improved satellite-derived products are (or soon will be) available. These also need to be transitioned from limited research and development modes into routine, sustained and widespread operational usage.

Satellite-derived coastal bathymetry products

One area of opportunity is that of satellite-derived bathymetry. Direct measurement of ocean depths from shipborne echo sounders has mapped only a few percent of the seafloor. Over the last 25 years satellite radar altimetry data has been extensively used to provide bathymetry of the ocean basins in open ocean by using sea surface slopes to infer the gravity signals of topography features. Recent advances in radar altimeter precision and the increased density of observations from new missions and "geodetic phases" near the end of the Jason missions have continued to improve satellite-based bathymetric models. That said, these products are generally inadequate to resolve bathymetry at space (and time) scales required to support coastal applications.

The paper "Satellite Derived Coastal Bathymetry" presented at CGMS-47 (2019) detailed the need for such improved coastal data, concluding with the action "CGMS to provide advice on the need for satellite-derived bathymetry data expressed by the Tropical Cyclone community and to foster the acquisition of the satellite-derived bathymetric data where applicable and promote the sharing of datasets in order to improve the storm surge and coastal wave modelling and consequently, the coastal inundation warnings."

During CGMS-48 (2020), P. DiGiacomo introduced the CEOS-COAST activity and indicated that the need for satellite derived coastal bathymetry was an area that CEOS, through COAST, could support. At coastal scales, there has been work done within NOAA and other agencies to optically derive coastal bathymetry in clear waters from Landsat-8, and more recently Sentinel-2, observations (Stump et al. 2003). These provide higher-resolution data sets, and given the expanding constellation of enhanced imagers, more frequent viewing opportunities. The latter is crucial given frequent cloud cover in coastal regions, as well as the impact that storms, human activities et al. can have in greatly altering nearshore bathymetry. That said, these products have only been developed for a limited number of regions, largely in the developed world.

Synthetic aperture radar can complement and enhance these optical measurements (X. Liu et al. 2019), and given the increasing availability of SAR data from Sentinel series and the Radarsat Constellation Mission, this is an area where CEOS-COAST can potentially contribute through SAR product development, demonstration and distribution. Likewise, a significant opportunity to exploit is the use of global ocean color imagery (e.g., VIIRS, OLCI, SGLI) for satellite-derived bathymetry. Ocean color sensors provide exceptional synoptic coverage and frequent revisits - allowing for weekly (or better) satellite-derived bathymetry products (M. Wang and Philpot, 2007, Wei et al. 2020) - albeit at lesser space scales (e.g., 750 M from VIIRS). The VIIRS-based bathymetry products from NOAA are generated globally but presently only in an experimental/demonstration mode.

Satellite-based characterisation of the coastal interface

The accurate characterisation of the interface between land and sea is a crucial component of flood and inundation modelling studies, as well as providing important information for the management of issues such as coastal erosion and habitat conservation. However, coastal environments are constantly changing, and monitoring and mapping these dynamic regions with traditional surveying techniques or airborne surveys is challenging from both cost and logistical perspective. This is where satellite remote sensing and publicly available data from agencies such as the USGS (Landsat) and ESA (Sentinel-2) has the potential to fill the gap, particularly at a continental scale and for developing nations.

Projects being completed at Geoscience Australia (GA) as part of the Digital Earth Australia (DEA) program have focused on two components of the coastal interface:

- Modelling the elevation of the intertidal zone
- Historical mapping of coastlines and coastal change analysis

The vast potential of remote sensing to monitor the intertidal zone has been demonstrated at a continental scale in Australia (Sagar et al., 2017) and China (Murray et al., 2012), and globally using Landsat data in Google Earth Engine (Murray et al., 2019). The National Intertidal Digital Elevation Model (NIDEM) project at GA extends these methods to integrate tidal modelling capabilities, enabling an 30m resolution elevation model of the exposed intertidal zone (the region exposed between high and low water) to be generated using Landsat data for the full Australian continent (Bishop-Taylor et al., 2019b).

The NIDEM product can support the mapping and management of important ecological habitats and help to better understand the threats on this region from coastal erosion, land reclamation and sea level rise. Importantly, elevation data in the intertidal zone fills a crucial gap similar to satellite derived shallow water bathymetry, and often in muddy or turbid waters where satellite derived bathymetry is difficult to implement. This continuity of elevation data across the land-sea interface is crucial to inundation and flood modelling studies such as those proposed in the COAST program.

The DEA Coastlines project at GA aims to support coastal decision-makers by identifying national trends of coastal change and Australia's most vulnerable shoreline geomorphologies. Sub-pixel analysis techniques are applied to the Landsat archive (Bishop-Taylor et al., 2019a) to develop the DEA Coastlines product: (1) Annual coastline vectors from 1988 to 2019 that represent the median or ‘typical’ position of the coastline at approximately mean sea level, and

(2) A point dataset providing robust rates of coastal change statistics for every 30 m along Australia's coastlines. This DEA product will underpin research into the influence of various environmental and anthropogenic drivers on coastal erosion and geomorphic change and can potentially assist planning and forecasting for future scenarios.

These coastal products are made possible by leveraging the analytical infrastructure and EO Analysis Ready Data (ARD) provided by Australian implementation (DEA) of the Open Data Cube (ODC) initiative (Dhu et al., 2017; Lewis et al., 2017; Killough, 2018).. Recent developments flowing from this initiative include the establishment of the Digital Earth Africa (DE Africa) program (https://www.digitalearthafrica.org/) in early 2019, funded by the Helmsley Charitable Trust Fund and the Department of Foreign Affairs and Trade (DFAT), and supported through CEOS and GEO.

A common goal of the DEA and DE Africa programs is to take ODC compatible workflows such as those developed for NIDEM and DEA Coastlines, and port them to the DE Africa ODC, enabling application and uptake by in-country partners of DE Africa. Testing has already begun on the application of these methods on DE Africa, and with CEOS support through COAST, robust methods that cater for the specific conditions of the African continent can be developed in conjunction with DE Africa and participating countries and institutions in Africa.

Satellite-based assessments of land cover/use in coastal regions

Land cover/use information can be derived from remote sensing assuming different types of surface are spectrally distinguishable. From a global perspective, there is ESA's Land Cover (LC) project that is part of their Climate Change Initiative (CCI). Per the CCI-LC project website, https://www.esa-landcover-cci.org, the CCI-LC team has successfully produced and released its 3-epoch series of global land cover maps at 300m spatial resolution, where each epoch covers a 5-year period (2008-2012, 2003-2007, 1998-2002). Further per this site, the maps were produced using a multi-year and multi-sensor strategy to make use of all suitable data and maximize product consistency.

While invaluable from a broader global perspective, higher resolution of land cover/use is required for coastal zone applications. For example, the NOAA Coastal Change Analysis Program (C-CAP) produces national standardized land cover and change products for coastal regions of the U.S. based on Landsat Thematic Mapper imagery, and can be used to track changes in the landscape through time with spatial resolution of 30 m. These analyses (see https://coast.noaa.gov/digitalcoast/data/ccapregional.html) date back to 1975 and are nominally updated every five years.

This and related approaches can and should be applied to other coastal regions, especially for developing regions where long term, consistent field surveys and assessments are frequently lacking. Having detailed characterizations of land cover and use over time and space are crucial to identify increasing urbanization in coastal zones, particularly as manifest by greater extents of impervious surface cover. This in turn leads to greater risk of flooding, as well as increasing quantities of loadings (sediments, nutrients, and contaminants) to coastal receiving waters. In addition to the long-term Landsat time series, other emerging higher resolution global data sets such as from Sentinel-2 will provide complementary data for these coastal zone analyses.

Transdisciplinary Integration

Increasingly, the greatest unmet need for coastal zones continues to be a lack of data integration, particularly from a transboundary perspective. This includes integration of multi-sensor remote sensing products and in situ data across the land-sea interface, as well as effective coupling of environmental data with social science data. Regarding the former, CEOS agencies can greatly facilitate these efforts through generation of analysis ready data in support of the applications described here. Furthermore, the COAST effort will contribute to the increasing understanding of transboundary issues by coupling sea to land phenomena and impacts (this white paper) with land to sea phenomena and impacts (next section).

(See Annotated Bibliography for References)

CEOS-COAST Phase 1 White Paper #2

Land to Sea Impacts: User Needs, Observations, and Services

Overview

The second primary component of the CEOS-COAST effort is to monitor, and ultimately forecast, loadings from coastal watersheds into receiving waters and assess their biological, biogeochemical, and ecological impacts. Presently, loadings of interest include nutrients as well as sediments. Future efforts for COAST might also include examination of pathogens, oil spills and other contaminants.

Specific impacts from these loadings can include eutrophication, (harmful) algal blooms, and changes in light availability due to sedimentation impacting benthic habitats such as coral reefs and submerged aquatic vegetation. These effects can significantly impact the ability of coastal marine and estuarine ecosystems to deliver crucial goods and services, noting these are among the most productive and ecologically valuable regions on Earth.

Aside from aquatic observations, changes in land cover and land use, driven by anthropogenic activities (e.g., deforestation; increases in impervious surface cover due to urbanization) as well as natural and climatic impacts (e.g., changes in precipitation, discharge; desertification, erosion) affect the quantity and quality of these loadings and as a result must be considered.

Likewise, coastal hazards as described in the previous chapter - COAST Phase 1 WP #1 (i.e., flooding, inundation) must also be considered as these episodic, albeit increasing, coastal events can have direct as well as indirect impacts on loadings of nutrients, sediments et al., at both continental scales as well as for small island states.

A diversity of CEOS observations and capabilities are needed to monitor, assess, and ultimately forecast the land to sea impacts described above. Multi-sensor satellite observations are required for both the terrestrial as well as aquatic components of the coastal zone. Likewise approaches, systems and services to effectively analyze and integrate these observations across the land-sea interface over time, and to extract timely and fit for purpose information in support of user needs and decision-making are required.

Progress to Date

Indicator Developed for SDG 14.1.1

At the United Nations (UN) General Assembly in September 2015, Heads of States and Governments agreed on 17 Sustainable Development Goals (SDGs) as framework for the 2030 Agenda for Sustainable Development including one specifically devoted to the ocean, SDG 14: Conserve and sustainable use the oceans, seas and marine resources.

Specifically, COAST supported Target 14.1, i.e., "by 2025, prevent and significantly reduce marine pollution of all kinds (...)", which provides a deadline for progress on reducing marine pollution and is informed by SDG indicator 14.1.1a, Index of Coastal Eutrophication.

The primary indicator used for measuring coastal eutrophication is direct measurements of nutrients and modeling of land-based sources of pollution. However, as many countries lack the resources to regularly collect this type of data, CEOS COAST is working in collaboration with UN Environment (the custodian agency for target 14.1), GEO Blue Planet and AquaWatch to derive satellite-derived sub-indicators for 14.1.1a. Chlorophyll-a, a proxy for phytoplankton biomass, can be used as an indicator for coastal eutrophication. Simply stated, more nutrient inputs can fuel more phytoplankton growth. Ocean color sensors provide quantitative assessments of chlorophyll-a, and thus can provide a synoptic indicator of potential sites of coastal eutrophication for further analysis and follow up action at the country level.

While this approach does not provide a definitive method to differentiate land-based sources of pollution (i.e., nutrient inputs) and their direct environmental impacts, it does provide invaluable data across spatio-temporal scales, spanning daily to interannual and local to global, providing accurate and consistent products for use by nations to report on SDG 14.1.1, in partnership with UN Environment as the Custodian Agency.

Specifics of the methodology developed by members of COAST for this indicator are beyond the scope of this document; further details are documented in the Global Manual on Ocean Statistics. The methodology has been adopted by the UN and 14.1.1 is now considered a Tier 2 Indicator (i.e., the indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries). The methodology is broken down into three levels: 1) global sub-indicators, 2) national sub-indicators and 3) supplemental indicators.

In this context, CEOS chlorophyll-a observations and derived global products from multiple agency (ESA, NASA, NOAA) sensors are being utilized, including a merged time-series product from ESA (Ocean Colour-Climate Change Initiative; Sathyendranath et al., 2018), and a 60-day global chlorophyll anomaly product from NOAA. These global products have demonstrated significant value from CEOS observations in support of the UN SDGs. CEOS COAST is currently working to identify higher-level national/regional products that could be used to report on the level 2 chlorophyll-a sub-indicator through the production of a satellite data requirements analysis in collaboration with the CEOS SDG AHT (Ad hoc team). 2) *Framework Developed for New Indicator for SDG 14.1.1*

The above indicators are quite valuable in support of UN Environment and SDG 14.1.1 data and information requirements, but there is a need to develop a more comprehensive and inclusive indicator that directly reflects the complex geophysical, biogeochemical and anthropogenic processes and drivers behind coastal eutrophication, whose inherent time and space scales can vary significantly.

Many gaps and challenges to the SDG 14.1.1 effort exist in this context, and will be discussed here (gaps, challenges and opportunities are recapitulated later in this chapter). These include the lack of routine, synoptic and consistent nutrient measurements in the coastal zone. Further, while many potentially relevant data sets exist, there has been limited direct coupling of parameters across the land-sea interface, owing in part to technical challenges of integrating these diverse and large data sets in a timely and efficient manner. These issues are exacerbated by the lack of adequate technical capacity and infrastructure in developing nations.

The use of artificial intelligence (AI) can potentially be transformative in this regard. COAST has initiated work with key partners and stakeholders (including potential private sector entities) to develop an improved indicator and predictive capabilities for coastal eutrophication in support of UN Environment/SDG 14.1.1 and other important global and regional users.

The COAST Team will facilitate and utilize AI approaches, leveraging and integrating existing (synoptic) data sets both terrestrial and aquatic, satellite and in situ, physical and biological, toward development of this new coastal eutrophication indicator. By leveraging these disparate yet complementary data sets, particularly multi-sensor satellite data from CEOS agencies, a more direct and timely assessment of coastal eutrophication can be made.

In terms of initial deliverables (see Appendix A), the COAST Team identified a suite of essential atmospheric, terrestrial and aquatic data sets, particularly focused on multi-sensor satellite observations, that will be required for the proposed Phase 2 AI project (predicated upon COAST receiving approval to proceed).

These parameters include precipitation, soil moisture, land use/cover, river/stream discharge, ocean color, et al. Representative datasets for machine learning training have also been identified, including from Australia (eReefs Project), the U.S. (Chesapeake Bay), Europe et al.

Initiation of Coastal Water Quality Product and Portal System: Sediments et al.

Humans are having profound effects on the amount of sediment carried by rivers to coastal areas, with consequences for marine habitats and productivity, human health, and efficient maritime operations. These local anthropogenic impacts, particularly due to population growth and urbanization in coastal zones, are exacerbated by increasingly ubiquitous physical phenomena such as flooding and inundation as well as coastal erosion (see COAST Phase 1 White Paper #1).

Increased sediment loading is severely impacting coastal zones across the globe, affecting submerged aquatic vegetation (SAV) and spawning grounds for fisheries (sustenance and commercial), primary and higher level productivity (e.g., shellfish beds, aquaculture) via light attenuation and contaminant loading, and ecotourism opportunities (e.g., degradation of coral reefs). Elevated global sediment loads, now estimated at 15 billion tons annually, also impact coastal maritime operations such as dredging, flood control and coastal erosion mitigation efforts, restoration of coastal habitats, and sustainability planning as part of climate change.

Toward providing crucial information for monitoring and forecasting sediment loading, COAST has been actively supporting the efforts of GEO AquaWatch. This includes initiating cataloging a global inventory of suspended sediment data and putting it into a common database and portal that is leveraging and tailoring the existing University of Wisconsin-Madison RealEarth system.

Supporting COAST, these efforts are creating an open, accessible visualization tool embedded within the GEOAquaWatch website, with capabilities that include map displays of satellite-derived sediment information, in situ data sources, graphs, and charts. This integrated assembly of disparate and hard-to-find information in one, easy-to-use web portal for comparison and evaluation will benefit coastal water quality stakeholders in developing and developed regions.

COAST members also supported AquaWatch with its successful proposal submission to a joint announcement of opportunity from GEO and Google Earth Engine (GEE). On 13 July 2020, it was announced that AquaWatch was awarded one of 32 projects from 22 countries selected as part of this joint GEO and GEE initiative (see http://earthobservations.org/article.php?id=447): "Development of Global Water Quality Geospatial Products and Tools For Coasts, Lakes, Reservoirs and Large Rivers" (PI is S. Greb, University of Wisconsin-Madison).

The goal of the COAST-supported AquaWatch project is to provide global-scale, open access, freely available fit-for-purpose total suspended matter products (sediments etc.) and information derived from CEOS satellite observations for coastal and inland waters. The project outputs will benefit diverse users and stakeholders, including water resource managers, industry, the global science community, and the public.

Work is already underway on this collaborative effort between the GEO AquaWatch community, the World Bank, Conservation International, and Google Earth Engine to partner with an international algorithm advisory panel comprised of satellite and water quality experts from multiple CEOS agencies (i.e., CSIRO, EUMETSAT, INPE, JAXA, NASA, and NOAA). COAST will continue to directly support this important effort.

Gaps, Needs, Challenges and Opportunities; Toward Phase 2

In addition to those already described above regarding SDG Indicator 14.1.1, the gaps and needs identified in the previous chapter (COAST Phase 1 WP #1) are all equally germane, particularly the need for satellite-based characterisation of the coastal interface, satellite-based assessments of land cover/use in coastal regions and integration of diverse data sets.

Additional needs include locating and gaining access to in-situ coastal, estuarine, and riverine water quality data. Additionally, the general lack of optical and water quality data, particularly in developing countries, represents a significant challenge that CEOS should be able to help address. Similarly, there is a need for coordinate field (aquatic) sampling with satellite overpasses for calibration/validation efforts.

Regarding integration of diverse data sets, ARD approaches will be crucial to bridge the transdisciplinary and frequently transboundary data sets. Furthermore, AI/ML approaches will provide a powerful framework and approach to bring together aquatic and terrestrial data, particularly toward development of an improved coastal eutrophication indicator as discussed above. These and other modeling efforts will be required to integrate multiple sets of disparate data types, some time series, others static. The COAST Phase 2 efforts will address these and other priority user needs.

(See Annotated Bibliography for References)

CEOS-COAST Phase 1 White Paper #3

Cross-Cutting Tools, Systems and Services

Underlying Tool and Services Infrastructure Needs Analysis to Enable COAST Pilots

COAST members represent a geographically dispersed and globally data-rich community, with diverse drivers and agency interests relative to the coastal domain. However, data and/or derived products are often lacking regionally and especially locally (~coastal zone); opportunities for technology transfer are abundant and crucial in this regard.

Data integration represents another compelling need, and as such is a priority focus area of the COAST effort. Since CEOS data infrastructure efforts relative to the coastal zone will be informed by COAST, but to a considerable extent executed by CEOS Working Groups and Virtual Constellations, initial efforts have focused on establishing baseline requirements for COAST through a tools, system and services needs analysis.

There is a need for foundational and integrated remote sensing and in situ datasets in the coastal zone as well as the analytics and workflows to support them. Anything CEOS COAST develops should integrate EO analytics on the 'back end', providing a mechanism to easily incorporate in situ data (for assessments and analyses as well as validation), model output, etc.

This approach will provide the transdisciplinary framework much needed by the user community and represent a transformative outcome of CEOS-COAST above and beyond the priority thematic applications to be demonstrated by COAST pilot projects as part of the Phase 2 implementation plan. Following are results of the initial COAST Team infrastructure analyses.

Leverage What Is Available from CEOS & Partners and Capitalize on R&D Technology Trends

COAST should leverage the CEOS Analysis Ready Data (ARD) framework and WGISS Interoperability Lab (Jupyter notebooks, GitHub code repository) and COVERAGE-developed tools as much as possible, as well as GEO AquaWatch, CEOS Carbon, and other existing Data Portals. COAST should embrace use of the cloud and cloud computing, demonstrated research and development techniques and approaches, and the level of data that application developers desire, referred to as Analysis and Access of ARD in the CEOS Interop Terminology Report, likewise other emerging technologies, approaches and analyses of EO data and products.

Other approaches, products and services under consideration/development or implementation, such as the Copernicus Coastal Roadmap, GEO Knowledge Hub and extant satellite algorithms and products as above should be leveraged by COAST for technology transfer in support of coastal user needs, particularly for developing regions. Available in situ data for validation as well as analysis purposes should be leveraged to the greatest extent possible. That said, the availability of these data is quite variable from a regional and local perspective, and often lacking, particularly for developing nations.

What defines 'Success' in a pilot project for a great product, and how will it be measured? Does it have to be transferable or scalable?

In planning of the COAST pilots, minimum requirements were discussed and articulated as to what constitutes a 'successful product', including essential issues such as user needs and what is considered "fit for purpose", addressing QA/QC, algorithms, spatial and temporal frequency of products, in situ data needed for validation, etc.

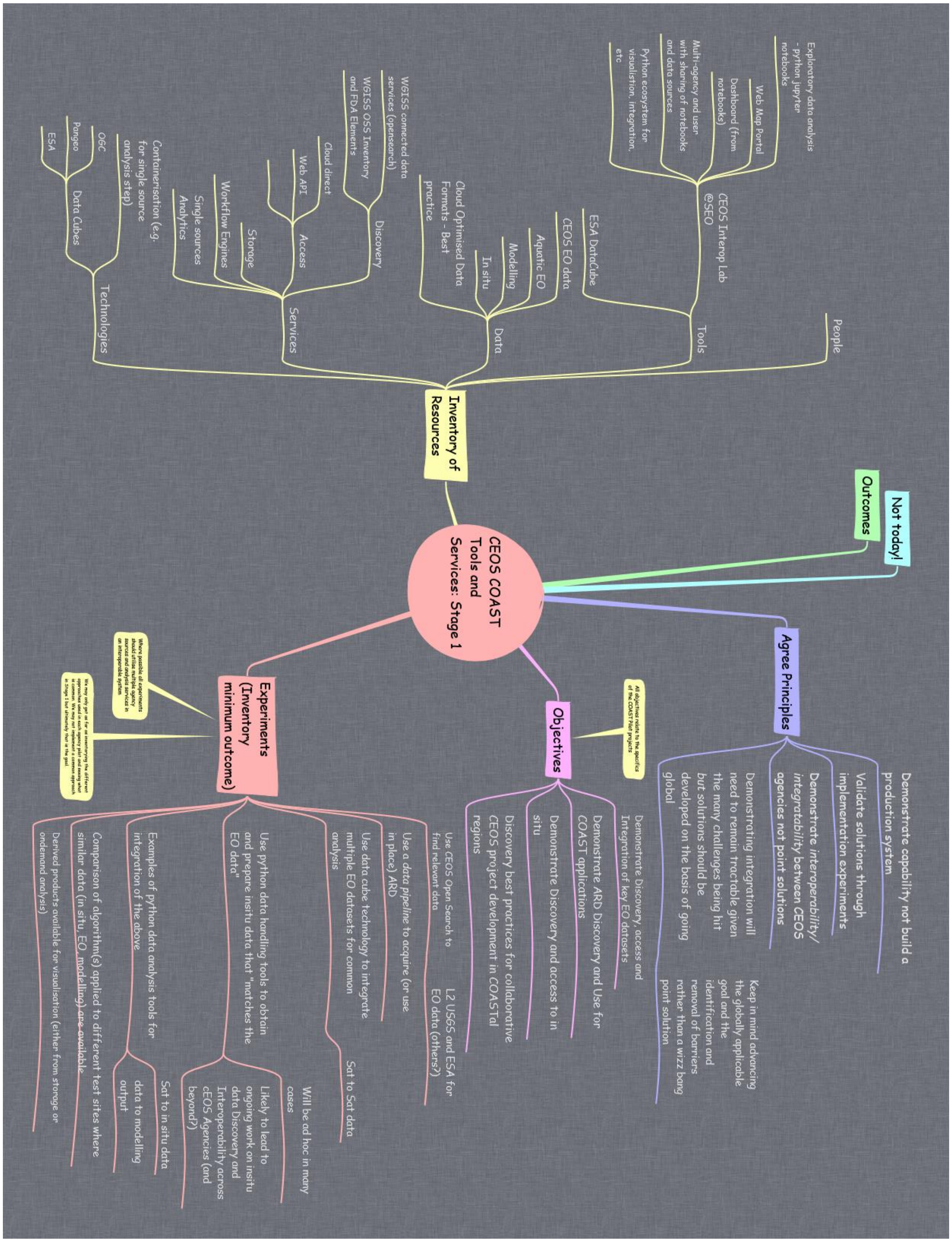
Evaluation of success should be performed at key stages in the pilot, utilizing predetermined measurements and metrics. CEOS data framework and infrastructure must be scalable, and transferable to deliver a product's functionality anywhere (ideally 75% complete with pilot infrastructure), with regional/local modifications required to improve accuracy and reliability.

Should COAST strive for a great regional project or a somewhat less amazing regional effort that is more broadly applicable? Is the driver in COAST the product's science outcome or striving to develop the technology and framework? Can these be balanced?

Need to balance both. COAST products and approaches should be globally applicable in terms of solving problems and functionality with existing data streams while informing users what product uses are possible and appropriate, i.e., what is fit for purpose. Existing capabilities and approaches should be leveraged to the great extent possible, albeit with ample consideration paid to regional and local capacity for technology transfer. That said, singular, locally tuned solutions are not desired; these can better be pursued by regional entities, private sector et al.

Progress to Date

In addition to undergoing the Needs Analysis described above, COAST can leverage the outcomes of other CEOS efforts. Much of the outcome of these are captured in the MindMap figure presented on the next page, which will aid development of CEOS architecture supporting COAST and leveraging the many other CEOS contributions. The COAST teams spent over two months compiling lists of datasets needed for the Inventory of Resources mentioned below.



CEOS COAST Architecture Mind map (Courtesy Rob Woodcock and Brian Killough)

Analysis Ready Data: Assisting GEO AquaWatch and engagement with CEOS ARD Strategy

A fundamental goal of CEOS-COAST is to identify and leverage both existing and emerging remote sensing data sets, tools and services that will help address ubiquitous global coastal issues (e.g., flooding/inundation and water quality), with approaches and solutions that have ample transparency, guidance and information to inspire user's confidence.

Presenting the availability of uncertainty measurements, transformation capabilities, and data quality flagging are ongoing goals of the WGISS and LSI-VC, as presented during SIT-35, and will be mutually beneficial to COAST. Throughout 2020, ARD discussions were initiated or continued within the sub-communities (CEOS/WGISS, GEO AquaWatch, GHRSST) with COAST a likely benefactor of streamlined, open source, formats trending toward achievement of FAIR data principles (Findable, Accessible, Interoperable, and Reusable/Reproducible).

GEO AquaWatch, a COAST member, has been a global leader in 2019-20 discussions on what defines ARD and hosted a community technical workshops in January 2019 and May 2020 to support discussion between data providers and users for water quality et al. applications. In this context, GEO AquaWatch and COAST are providing recommendations to CEOS for core ARD requirements to be adopted for the aquatic side. This includes addressing when available land requirements or approaches incompletely characterize or fulfill aquatic data product needs, or are not applicable, at least not without a corollary modification to suit the aquatic realm.

Among satellite data product entities, GHRSST is quite advanced relative to ARD, and COAST will utilize their templates, outreach methods et al. to focus on the data formats and metadata structures, variables, and services that best enable ARD implementation. In addition, work to date by CSIRO on the Interoperability Laboratory (via WGISS) has leveraged ARD, optimized cloud storage, and data recipes (Jupyter notebooks). As learned during SIT-35, LSIV-VC is also working to integrate ARD principles within and across the SST and OC VCs to help coordinate across the land-sea interface, which will lay the groundwork for more projects to align and integrate with COAST's planned ARD capability.

CEOS COAST and WGISS-CEOS Earth Analytics Interoperability Lab

During the WGISS-49 meeting, CEOS-SEO and WGISS jointly put forward a proposal to provide a CEOS Earth Analytics Interoperability Lab (EAIL). The EAIL proposal was developed in response to increasing need from CEOS project activities for enhanced data discovery and analytics interoperability resulting from the ARD and FDA initiatives which are developing innovative practices not yet operational in CEOS agencies.

The CEOS community has reached a point where such advances need to become testable and demonstrable in a live service ecosystem to validate interoperability throughout the EO value chain from Discovery through to Analytics outcome across the CEOS ecosystem. The EAIL, as its name implies, is intended to support CEOS projects by demonstrating capability and validating solutions through implementation experiments. The results of which can then be developed into Best Practices and adopted by CEOS agencies in operational systems. Further details on the CEOS EAIL can be obtained from WGISS or CEOS SEO.

CEOS-COAST expressed early interest in the EAIL proposal to help meet its requirements for interoperable data integration and analysis in a collaborative exploratory data analytics environment. A significant amount of activity in CEOS COAST is experimental and not readily supported directly by existing infrastructure in CEOS agencies. The CEOS EAIL assists in filling this gap by augmenting the existing CEOS agency capabilities in a collaborative way where all participants in COAST have access to the same capabilities. Specific capabilities identified by CEOS COAST and supported in the EAIL are:

- multi-sensor satellite data access and analysis via the CEOS Open Data Cube (including via WGISS CEOS Open Search and agency specific interfaces) In-situ data access and analysis via Python geospatial libraries Shared Jupyter Labs Exploratory Analysis environment with notebook sharing and development Scalable on-demand compute resources for data analysis
- Ability to publish Web Dashboards directly from the Jupyter notebooks for "no source code visible" dashboard applications Ability to host mid-scale data storage for data sources not readily available in interoperable, online forms but required by CEOS COAST Data pipeline and analysis automation tools
- Examples and shared library of visualisation and analytics tools to assist Capability Development
- Derived products can be shared using OGC Web Mapping Services Hosting for project web portals in a robust IT environment Support from CEOS SEO and WGISS on identification and development of interoperability best practices Potential for expansion of the EAIL to includes nodes and services from multiple CEOS agencies as interoperability is improved

CEOS COAST requirements and collaboration with EAIL

WGISS and CEOS SEO have received a stronger than expected response from CEOS Projects to the EAIL proposal. To date 5 CEOS projects have expressed strong interest in using the EAIL as part of their development. CEOS COAST has incorporated the EAIL into its formal planning and includes WGISS and CEOS SEO representatives in its regular meetings. Initial meetings have identified key features that are required and an initial approach to identifying specific data, analysis, and interface requirements.

Given the tight collaboration between the EAIL platform, operators and the CEOS COAST activity it is important to note that the EAIL is not intended as a long-term sustainable platform for CEOS COAST (or other projects). Nor does WGISS and CEOS SEO become responsible for CEOS COAST project outcomes. Neither WGISS nor CEOS SEO have a budget for such endeavours. It will provide the design blueprint and implementation which once understood can be more readily sustained through a more appropriate mechanism. It will also help inform the development of WGISS Best Practices in interoperability and potential services improvements from CEOS SEO.

Committee on
Earth Observation Satellites

CEOS EAIL node deployed to AWS

NASA (via CEOS SEO) and CSIRO (via WGISS) have proposed an agreement to deploy and jointly operate the CEOS EAIL on AWS initially through to June 30th, 2021. At the time of writing the agreement is still being finalised but CSIRO has deployed the EAIL to help maintain momentum on the project activities. This is especially important given some of the features involved are new to many members of the CEOS COAST project team and some demonstration and experience with capabilities is necessary to inform project planning.

The EAIL has been deployed to the AWS US West region. This is to facilitate direct access to the soon to be released USGS Landsat Collection 2 and Sentinel archives being stored in this region. The EAIL will thus provide a demonstration and tooling for these newer direct-Cloud based access mechanisms.

It is hoped additional CEOS Agencies might choose to host an EAIL node using their particular technology choices to support multi-agency interoperability experiments with CEOS COAST and other projects. This would enable regional focus on dataset collection and leverage existing agency partnerships for data sharing and capacity building to deliver COAST data product solutions to users and train them.

COVERAGE tools/capabilities and data infrastructure for oceans; evolution for coasts

Recent accomplishments by the COVERAGE initiative resulted in the following tool development which can be leveraged to benefit COAST pilot projects:

- prototype distributed data system infrastructure providing integrated access to interagency satellite and in-situ data from remote repositories in support of applications
- associated value added data services including search, integrated satellite-in situ visualization, subsetting/extraction, and analytics, and
- coherent set of global, reduced resolution gap free (L4) interagency satellite data products representative of the range of key parameters for the Ocean VCs (SST, Ocean Surface Vector Winds, Ocean Surface Topography, Ocean Color Radiometry).

The product lineup could potentially be expanded to include select, higher resolution and more regionally focused datasets in support of targeted coastal applications. Aside from multi-sensor imagery, a high priority consideration could be to add synthetic aperture radar (SAR) data. These data are already populated within CEOS agency portals, e.g., the NOAA CoastWatch Program, and as such this and other agency portals should also be leveraged for COAST. An assessment of requirements, target thematic ecosystem application, and resources necessary for possible future COVERAGE utilization in support of COAST is recommended.

Gaps, Needs, Challenges and Opportunities; Toward Phase 2

CEOS COAST and EAIL Joint implementation planning

CEOS COAST, WGISS and CEOS SEO will continue joint implementation planning and system design in line with the work program being developed by CEOS COAST. CEOS SEO in particular will be seeking to add suitable data and training materials to assist CEOS COAST projects in getting started on the EAIL.

WGISS 50 EAIL collaboration session

The high interest in the EAIL has resulted in WGISS 50 inviting presentations from the CEOS Projects engaging with the EAIL and a collaborative session to discuss the way forward. Whilst all projects are in their formative stage there is sufficient interest and desire to support an early design discussion and further refine the operating model of the EAIL and engage more broadly in WGISS to assist CEOS COAST and the other projects.

Other (non-ARD) Data Incorporation

A gap identified during the SIT-35 COAST Side Event was capability to 'on-ramp' available data (in situ or remote sensing) that does not meet the 'Analysis Ready' requirements. There was concern current and future projects not incorporating ARD into their planning would be left behind or ignored by COAST. A parallel concern was the wealth of available historical data and local data made available by countries and entities unfamiliar with ARD, and who have little to no capacity or desire to incorporate ARD into project planning, would not inform COAST pilot projects. During the SIT35, supporting COAST and identifying data gaps, challenges, and needs for interoperability were stated as focus areas of the LSI-VC (a COAST member).

Seeking data interoperability among the Ocean Color community (among others) is likely to be a challenge due to diversity of derived products and access to satellite data/sensors. Difficulties resolving and refining products for optically complex inland and coastal waters will remain a challenge.

Opportunities abound in the diverse international partnerships that COAST members bring to the table. Phase 2 COAST collaborations will enable access to datasets and technology most individual agencies and projects could never engage alone, and pledges to share data for pilots have already been put forward by several agencies. COAST pilots will be vibrant test beds to demonstrate and iteratively improve technology developed in other areas of CEOS and establish communication networks between the land and sea domains.

(See Annotated Bibliography for References)

Summary and Request to Continue COAST Through September 2021

The COAST Team has made significant progress to date, including meeting, and exceeding its initial deliverables as identified in its Phase 1 work plan for 2020. Furthermore, it has identified compelling user needs and opportunities that CEOS can readily address via COAST.

As such, we request continuation of CEOS-COAST activities through September 2021, with endorsement at the CEOS Plenary to transition into a CEOS-COAST (Coastal Observations, Applications, Services and Tools) Ad Hoc Team (AHT), and proceed into Phase 2 and its high impact pilot project activities. The CEOS-COAST AHT Terms of Reference will be submitted and finalized within two months of endorsement by the CEOS Plenary, as will the CEOS-COAST Phase 2 Implementation Plan.

Finally, we request CEOS consider submitting CEOS-COAST to the UN Decade of Ocean Science for Sustainable Development as a potential Decade Programme, which could be executed in partnership with GEO, International Oceanographic Commission/Global Ocean Observing System, World Meteorological Organization, UN Environment and other appropriate international partners and stakeholders.