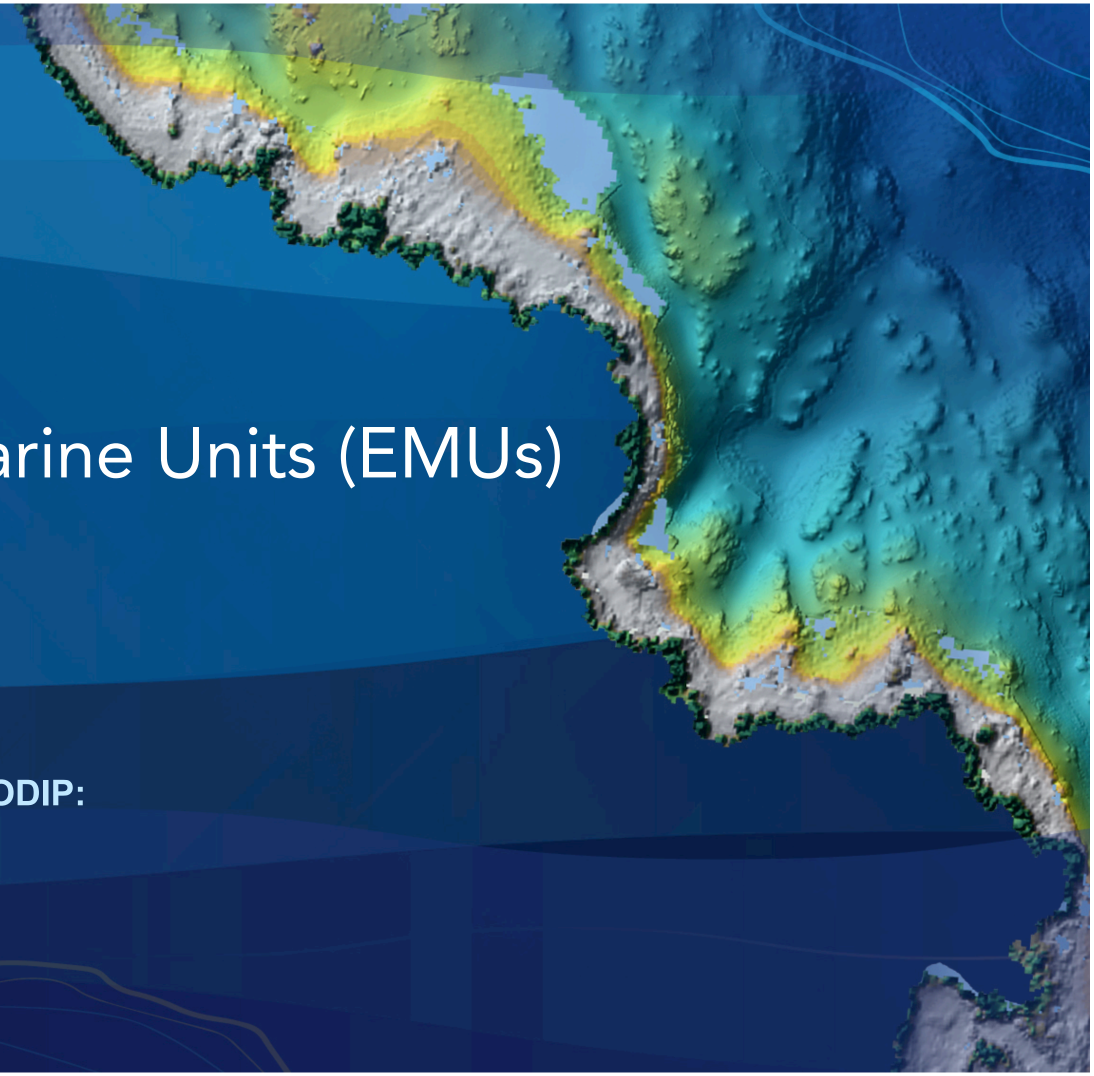
ODIP II Workshop
Boulder, CO
May 3, 2016

Progress Report:
Global Ecological Marine Units (EMUs)

Presenter:
Dawn Wright, Esri Chief Scientist

Vertical Profiler Prototype Available to ODIP:
chrismahlke.github.io/emu
Username: emuuser
Password: 24clusters



The work to produce the map and data was commissioned by the Group on Earth Observations, a mini "United Nations" of sorts consisiting of almost 100 nations collaborating to build the Global Earth Observation System of Systems (GEOSS) in 9 Societal Benefit Areas (Agriculture, Biodiversity, Climate, Disasters, Ecosystems, Energy, Health, Water, and Weather). The global ecosystem mapping task, as defined here, is a key program within the GEO Biodiversity Observation Network (GEO BON) and the GEO Ecosystems Initiative (GEO ECO).

EMU under the new **GEO Global Ecosystems initiative (GECO)**. This is out of the GEO 2016 Transitional Workplan. The former Ecosystems Societal Benefit Area and the former Biodiversity Societal Benefit Area have been combined into a new Biodiversity and Ecosystems Sustainability SBA.
The GECO is a new task, and it has four pieces to it related to 1) the European Horizon 2020 ECOPOTENTIAL project, 2) the H2020 SWOS (Satellite-based Wetlands Observation System) project, 3) global EMUs, and 4) global EFUs.

So why do we need a global ecosystem map anyway? Such a map, and more importantly, the data, will provide scientific support for planning and management, and enable understanding of impacts to ecosystems from climate change and other disturbances. The map and data should also prove useful as an ecologically meaningful spatial accounting framework for assessments of the economic and social values of ecosystem goods and services.

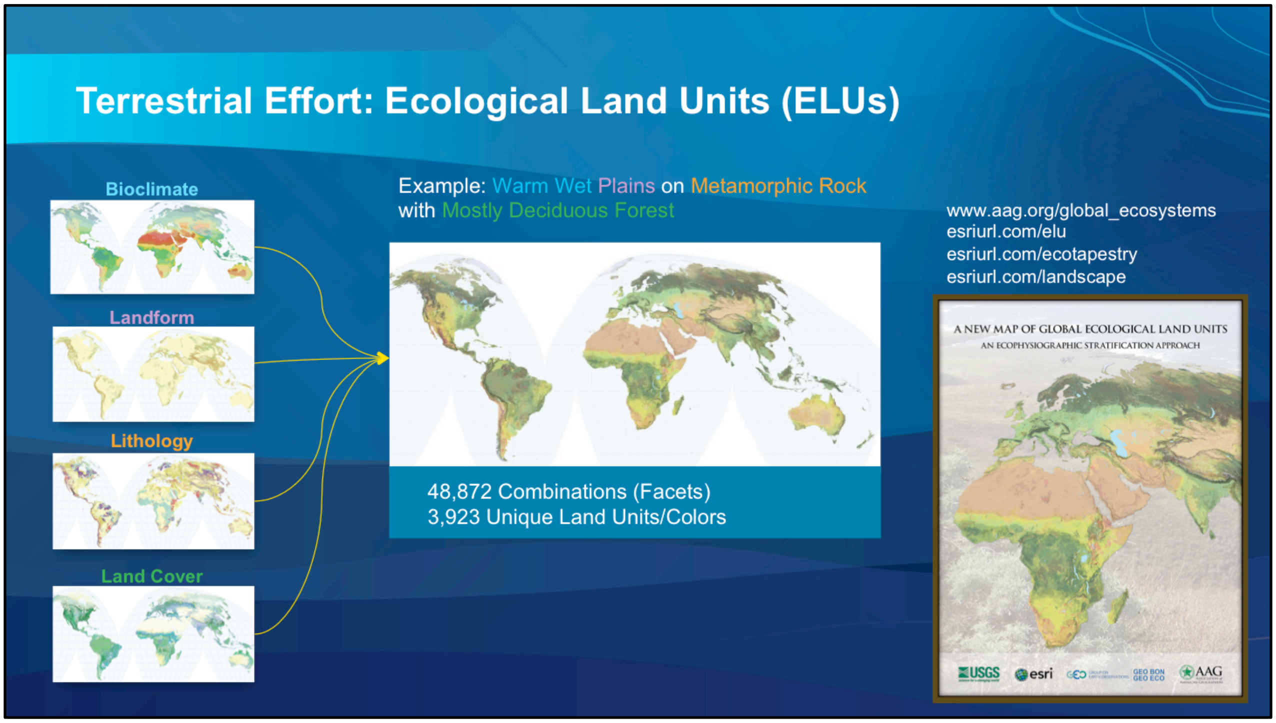
- Should aid in REPEATABLE landscape mgmt - a platform for geo-accounting (instead of reducing so much by national boundaries, we are using real ecological units)

A standard repeatable accounting framework

A global view of environmental diversity

Ecosystems defined by humans for humans as opposed to ecosystem HEALTH, a healthy ecosystem vs a service that the ecosystem provides - the next level to resilient ecosystems rather than ecosystem services
Research goal in future? what are the indicators that if merged together in a better way would provide better services; one can still be SICK and provide services
Example – indicators may be relative to the status of the fish stock but not indicators as to how the ecosystem is working.

Specific needs include:
•*Assessments of Economic and Social Value of Ecosystem Goods and Services*
•*Biodiversity Conservation Planning*
•*Analysis of Climate Change Impacts to Ecosystems* (*and other impacts e.g. fire, invasive species, land use, etc.*)
•*Resource Management*
•*Research*



Bioclimate, Landform, and Lithology = Drivers of Ecological Character (physical setting)
Land Cover = Response to the Physical Setting

We found 48,872 unique combinations aggregated to 3923 ELUs. In 2015 106,959 unique combos thanks to the updated land forms and land cover, 2010 epoch, Global Land Cover, v. 1.4

Bioclimate, Landform, and Lithology = Drivers of Ecological Character (physical setting)
Land Cover = Response to the Physical Setting

Bioclimates - Global Environmental Stratification (GEnS), U. of Edinburgh **-** 50 year avg of temp/precip from met stations throughout world

30 arc sec raster, down-sampled to 250-m raster

Landforms – USGS – 250-m raster, derived from GMTED2010

Surficial Lithology - Global Lithological Map (GLiM), Hamburg University, Vector Polygons converted to 250-m raster

Land Cover - GlobCover, 2009, European Space Agency - MARIS satellite, 300 m rez resampled to 250 m

Version 2 recently released in 2015 with updated land cover, 2010 epoch, Global Land Cover, v. 1.4

Only layer that we had an option: GlobCover 2009, GlobeLand30 or MDA's NaturalVue

GlobCover 2009 offered a richer, more flexible classification, which is compatible with USGS NLCD

NaturalVue was too old.

Both had significant quality issues relative to broad audience acceptance

Today, there are more options. Globeland30 continues to be improved. MDA has produced BaseVue

How did we make the map? Again, we define ecosystems as distinct physical environments and their associated vegetation, so we map ecosystems by first mapping, and then combining in a GIS, global bioclimates, global landforms, global geology, and global land cover.

1. Characterize the principle ecological land components of the terrestrial surface of the earth in a micro-scale, bottom-up, hierarchical classification process.
2. Subdivide the land surface of the earth into macro-scale physiographic (geomorphological) areas in a top-down, hierarchical regionalization process.
3. Combine the physiographic regionalization process with the ecological classification process to develop a hierarchical, ecophysiographic segmentation of the planet.

Ocean Effort: Ecological *Marine* Units (EMUs)

Who wants one?

- GEO & GEOSS
- Global Ocean Refuge System (GLORES)
- IUCN, WWF, CI, Mission Blue Sylvia Earle Alliance
- FAO and ICES
- OOI and IOOS/GOOS
- Essential Ocean Variables community (e.g., World Climate Research Program)
- Researchers
- Educators
- Local agencies who want the global context
- Natl science agencies
- Editors of textbooks

Why?

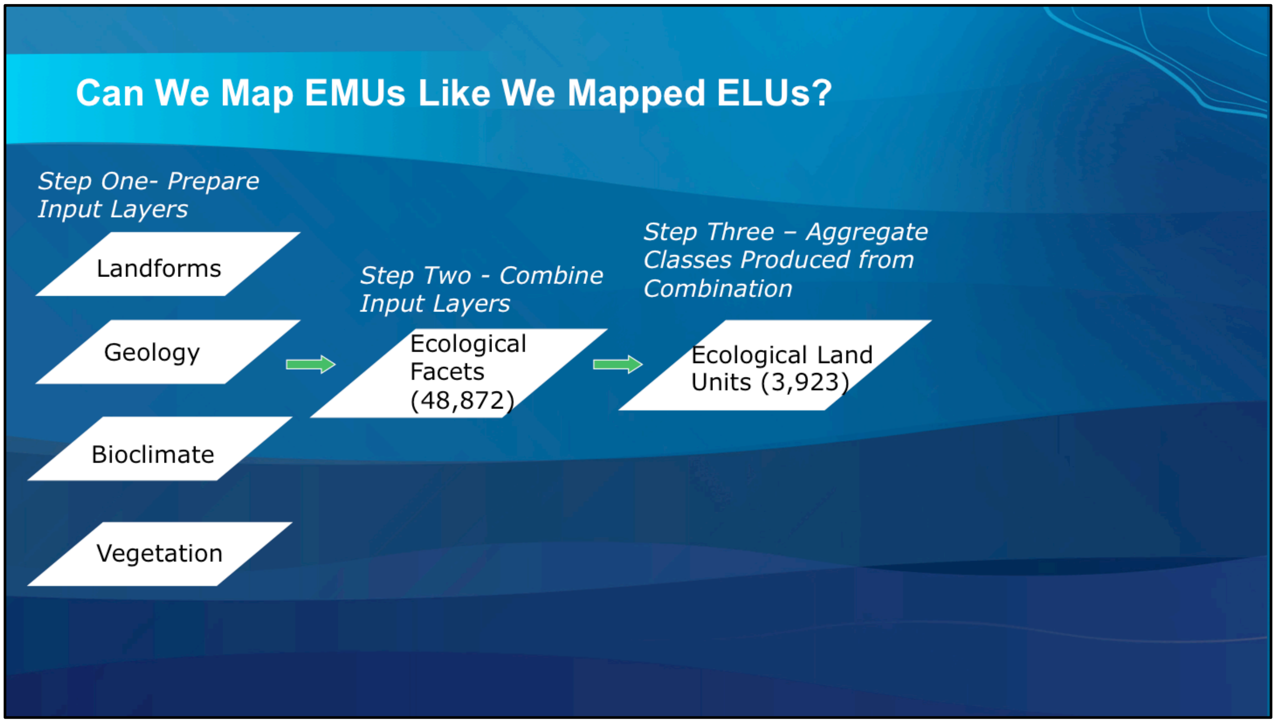
- **Contextualize MPAs and Siting Process**
- **Ecosystem Health, Resilience, Ecosystem Goods & Services; Ecosystem Services Valuation**
- Nature Conservation Reporting
- Conservation planning
- Ecosystem Classification
- Ecosystem Based Management
- Fisheries Management
- Marine Data Management
- Indicating Species Distributions
- Explaining and Understanding Nature
- Risk Reduction
- Context: Local related to Global
- System Connectivity

Abstract presented at GeoHab 2014 with this author group: The Group on Earth Observations (GEO), a consortium of nearly 100 nations seeking to advance earth observation approaches for addressing societal challenges related to food, water, energy, and the environment, has commissioned a new global map of terrestrial, freshwater, and marine ecosystems. The new map is to be based on data, rather than socio-political considerations or expert opinion. A data-derived, ecological stratification-based ecosystem mapping approach was recently demonstrated for terrestrial ecosystems, resulting in a standardized map of 3,923 global ecological land units (ELUs) at a base spatial resolution of 250 m. We now present a similar environmental stratification approach for extending the global ecosystems map into the oceans through the delineation of analog global ecological marine units (EMUs). The EMUs will be developed in a three step process: 1) create an empty, volumetric column-based mesh as a global, spatial reference standard and analytical framework, 2) populate the spatial framework with relevant marine physical environment data including water column variables and seabed topographic features, and 3) cluster the abiotic data into ecologically meaningful, 3D regions represented as volumetric polygons. The EMUs will subsequently be analyzed against species distribution data to assess strength of relationship between distinct abiotic environments and species biogeography. The data framework to be developed will provide new opportunities for correlating physical, chemical, biological, and ecological variables in a 3D environment. The work will be undertaken in a government/NGO/academic/private-sector partnership which includes a large group of international marine experts in an advisory capacity. The global ecosystems data are intended to be useful in a variety of applications including climate change impacts assessments, ecosystem goods and services valuation assessments, conservation planning, resource management, and scientific research.

Additional Collaborators

Maria Cavanaugh, Ph.D. Pelagic Seascape Ecology & Biogeochemistry WHOI	**Dick Feely, Ph.D.** Carbon Program NOAA PMEL - Seattle	**Mike Williams, Ph.D.** Physical Oceanography NIWA, New Zealand	**Rob Brumbaugh, Ph.D.** The Nature Conservancy
Liqing Jiang, Ph.D. NOAA NCEI – Silver Spring	**Simone Alin, Ph.D.** Carbon Program NOAA PMEL - Seattle	**Nina Bednarsek, Ph.D.** Carbon Program Postdoc NOAA PMEL - Seattle	**Rodolphe Devillers, Ph.D.** Geography, Marine Geomatics Research Memorial University of Newfoundland, Canada
Noel Cressie, Ph.D. Distinguished Prof of Math & Applied Statistics U. of Wollongong, Australia Distinguished Visiting Scientist, NASA JPL (formerly at U. of Iowa and Ohio State)			

More are welcome!



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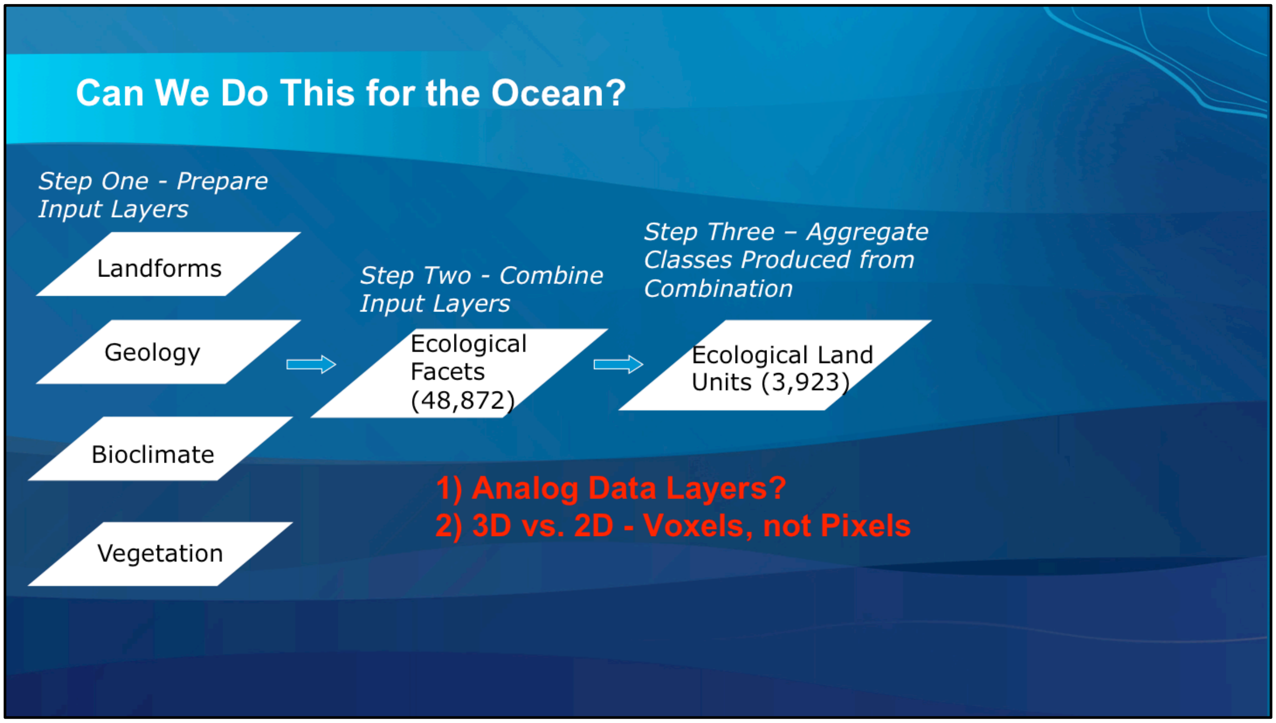
Task description:
"The goal is to provide a web enabled framework of data, tools and workflows that will be used to create and publish authoritative physiographic and ecological land classifications of the earth's surface at several scales. Scientists, managers, and planners will be able to use the framework to update and evolve classifications as new data becomes available."
The tools and maps will be publicly available to support the wise use of the planet's natural resources and the preservation of environmental resilience.



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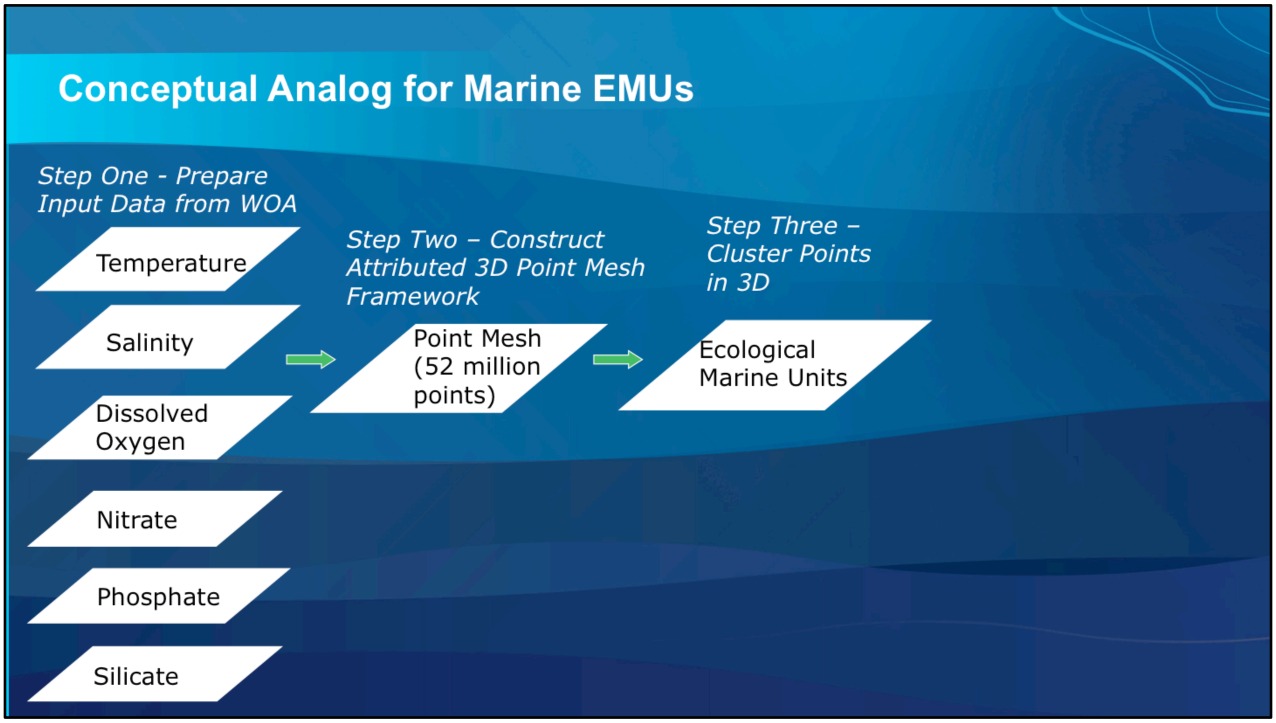
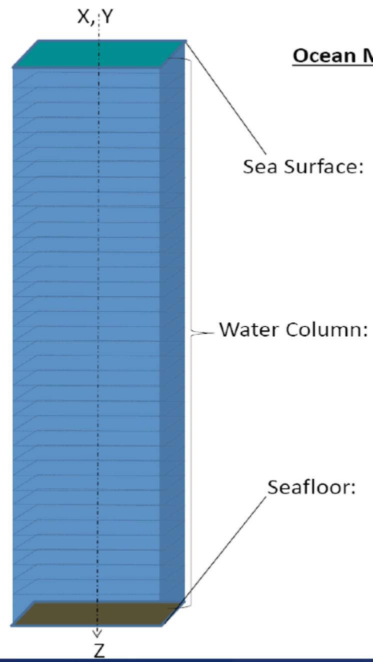

Conceptual Analog for Marine EMUs
Step One - Prepare Input Data from WOA
Temperature
Salinity
Dissolved Oxygen
Nitrate
Phosphate
Silicate
Step Two – Construct Attributed 3D Point Mesh Framework
Point Mesh (52 million points)
Step Three – Cluster Points in 3D
Ecological Marine Units

Point mesh framework



Ocean Mesh and Primary Attributes

Sea Surface: Longitude (x), latitude (y), depth (z), temperature (T), salinity (SAL), dissolved oxygen (DO), apparent oxygen utilization (AOU), percent oxygen saturation (POS), phosphate (P), silicate (SIL), nitrate (N), and ocean color (OC)

Water Column: Longitude (x), latitude (y), depth (z), temperature (T), salinity (SAL), dissolved oxygen (DO), apparent oxygen utilization (AOU), percent oxygen saturation (POS), phosphate (P), silicate (SIL), and nitrate (N)

Seafloor: Longitude (x), latitude (y), depth (z), temperature (T), salinity (SAL), dissolved oxygen (DO), apparent oxygen utilization (AOU), percent oxygen saturation (POS), phosphate (P), silicate (SIL), nitrate (N) seafloor physiographic region (SFPR), and seafloor terrain feature (SFTR)

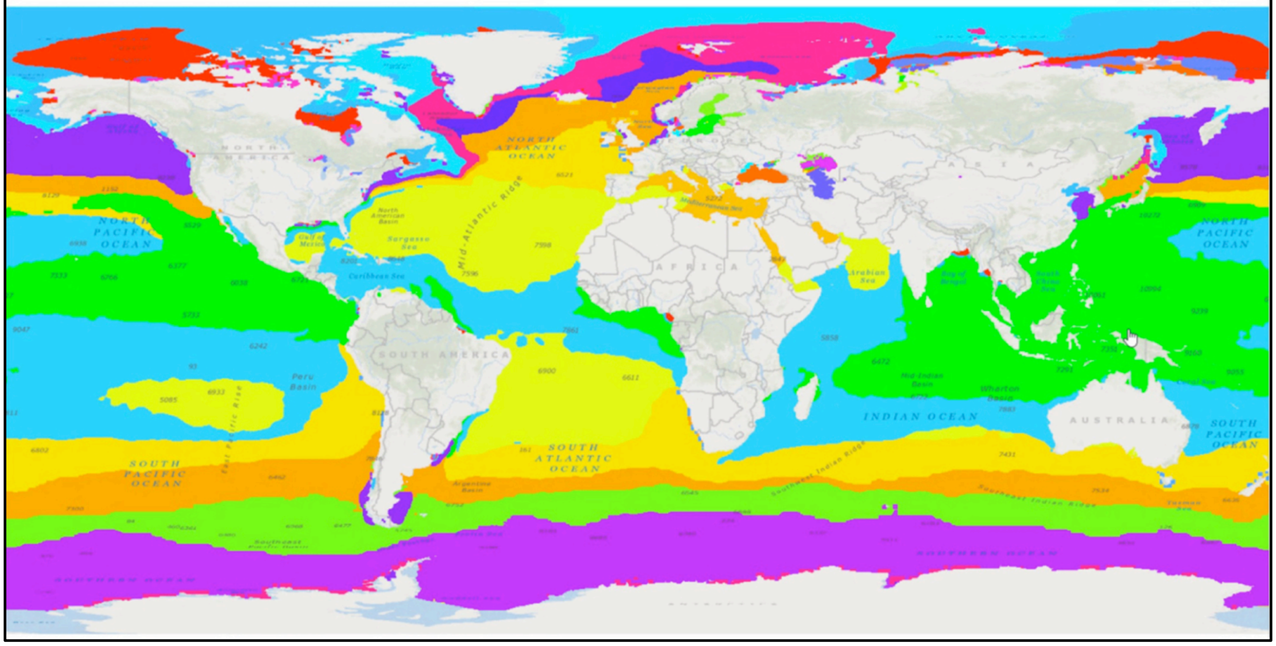
Point mesh framework

- 52,000,000 points
- ¼° by ¼° (27 x 27 km) in the horizontal; variable z depth (z thickness ranges from 5 m to 500 m)
- Data values represent the average of five “prominent decadal means”, i.e. a life of archive record
- No temporal component related to seasonality
- The point mesh lives in ArcGIS Pro

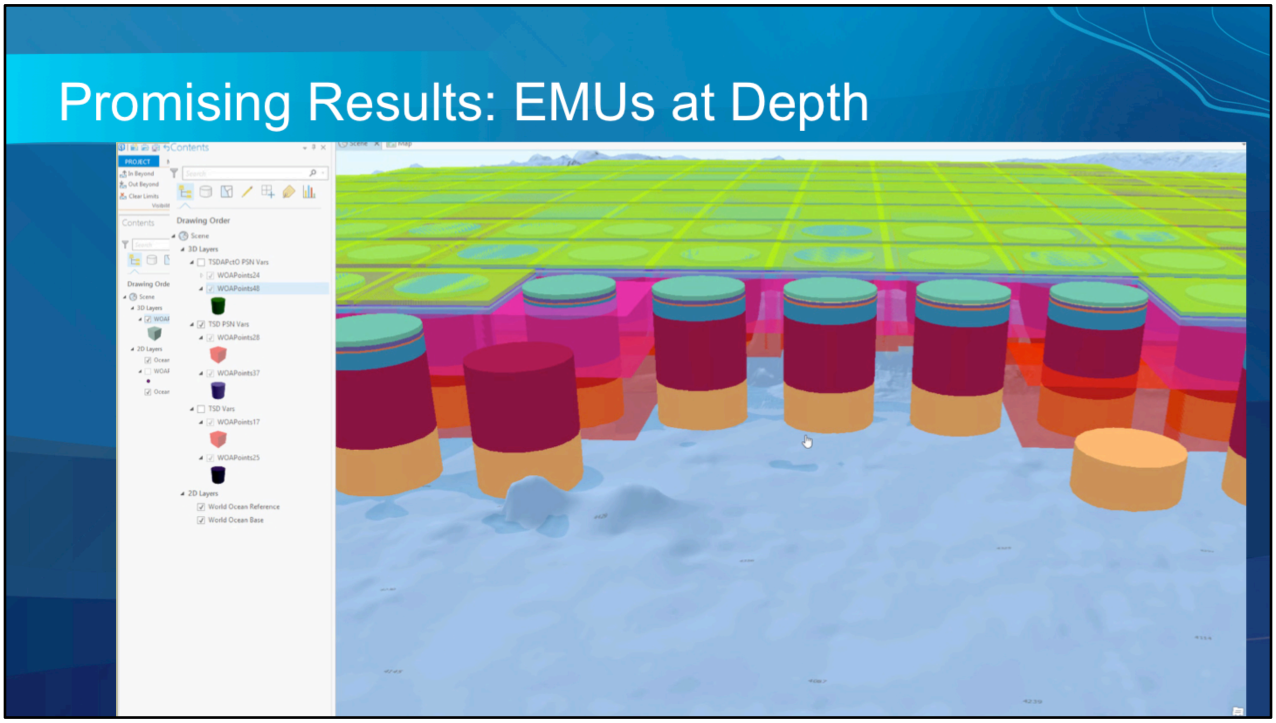
Methodological Approach

1. **Build 3-D framework** (point mesh)
2. **Attribute mesh points with 6 physical/chemical parameter values using WOA data**
3. **Statistically cluster points to identify physically distinct, relatively homogenous, pelagic volumetric regions (EMUs)**
4. **Compare/combine surface-occurring EMUs with other sea surface partitioning efforts using ocean color, etc. (e.g., Longhurst, Oliver and Andrew, MBON, Seascapes, etc.)**
5. **Compare/combine bottom-occurring EMUs with seafloor physiographic regions and features, etc. (e.g., Harris et al.)**
6. **Assess relationship between physically distinct regions and biotic distributions (e.g., OBIS Biogeographic Realms, etc.), and maybe combine to incorporate biotic dimension into the EMUs**

Promising Results: Surface-occurring EMUs

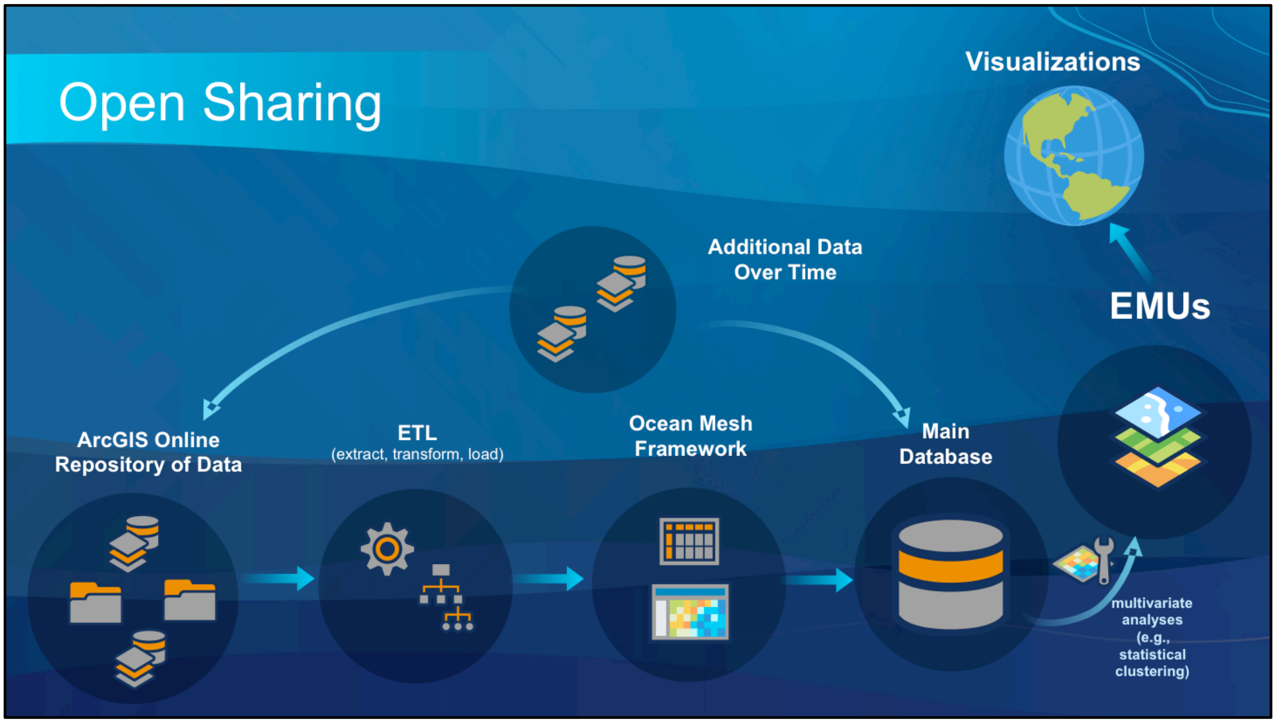


From 0 to thickness of the top unit, so around 50-100 m,planar at top, undulating at bottom of top unit; to come, thickness contours
Very much need additional parameters such as chlorophyll to tighten these up.
Again, see the work of Maria Kavanaugh et al. at Ocean Sciences 2016, https://agu.confex.com/agu/os16/meetingapp.cgi/Paper/93156



Exploring the clusters in 3D within ArcGIS Pro. (from Dec 21, 2015)
Second screen grab from ArcGIS pro shows the result of k-means statistical clustering of 6 major World Ocean Atlas variables (T, S, O2, 3 nutrients) with a pseudo-f statistical validation of the likelihood of either 28 (square) or 37 (circle) physically distinct, relatively homogeneous, volumetric regions WITHIN the water to which we can attach ecological and a host of other attributes

This will eventually be incorporated into **web scene featuring a new global elevation layer that combines topography (land elevation) and bathymetry (water depths) for use in 3D, i.e., as an elevation surface in 3D clients**. The layers and web scene will be publicly released at the end of the project.

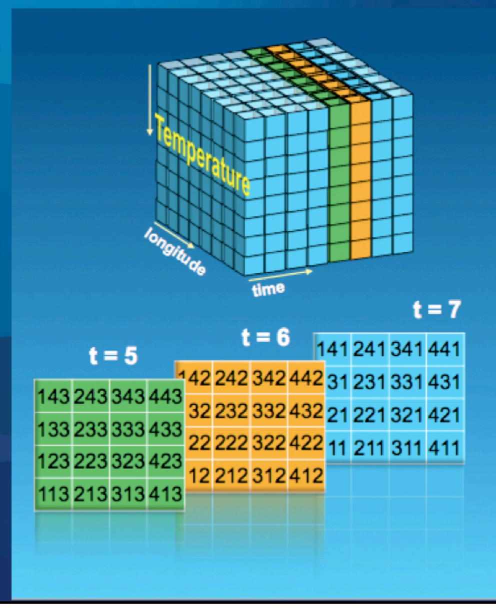


AGOL ocean data repository of objects --> ETL --> ocean data base (Voxels)
this is the file structure
X number of datasets -- > ETL --> Voxel Grid Frame (HUGELY CRITICAL, and for all the whole Earth; can lay as many pancakes on top as you want) --> Voxel/Volygon DB --> classification tool/stats/multivariate regression --> EMU --> Visualization
metadata - web maps just using rasters
maps, data for general purpose research

“Data Wrangling”

- **Unified multidimensional data model**
- **netCDF, GRIB, and HDF formats**
- **Each variable is a multidimensional array**
  - **Temperature at multiple times or depths**
  - **Salinity at multiple times or depths**
  - **Wind at multiple times**

- **Can store many variables (measures) in one file**

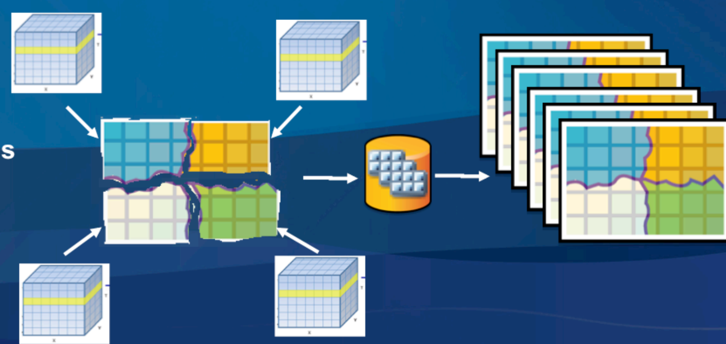


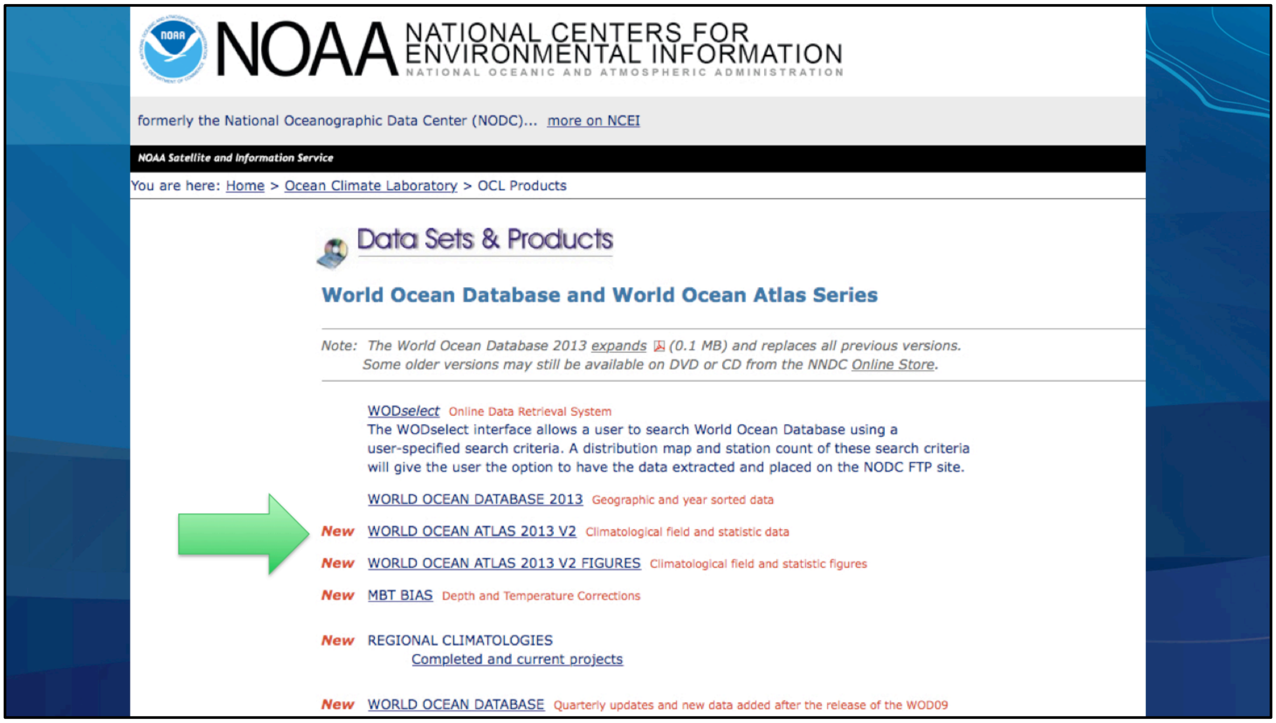
“Data Wrangling”

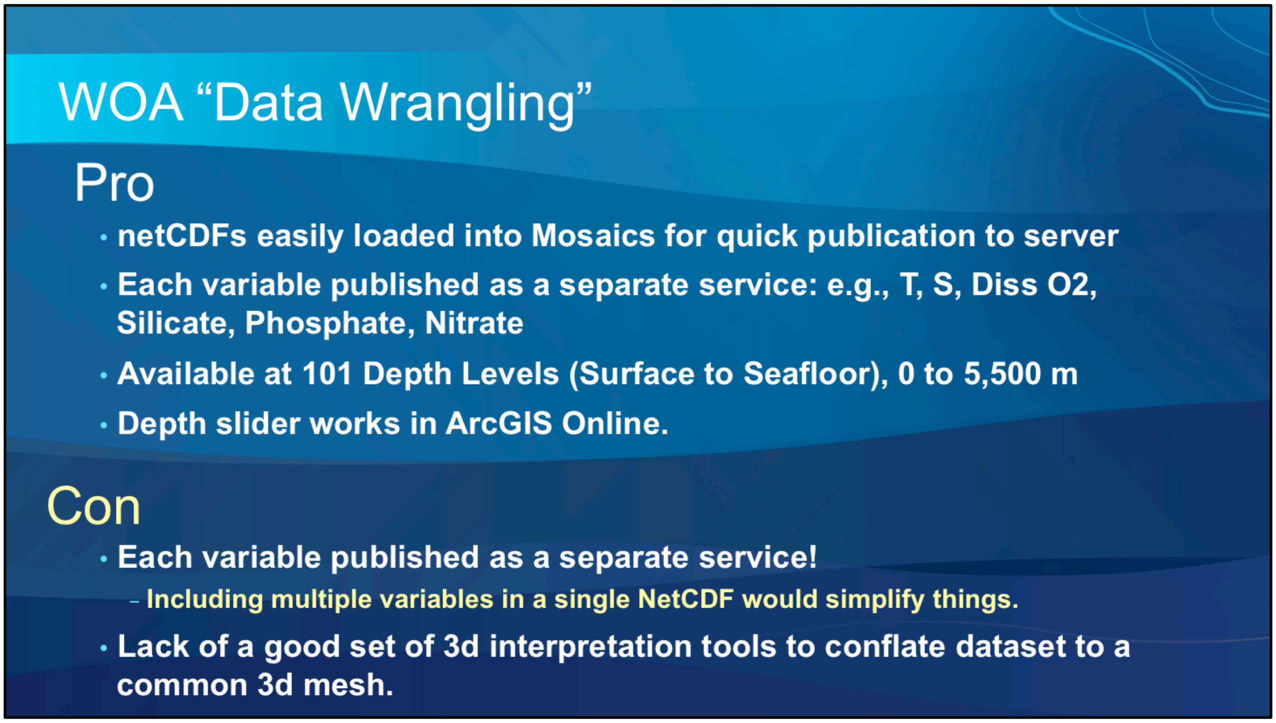
Multidimensional Mosaic Dataset

Aggregate data spatial, time and vertical dimension

- Add multiple variables
- Add from multiple files
- Normalize time dimension
- Normalize vertical dimensions




NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
formerly the National Oceanographic Data Center (NODC)... more on NCEI
NOAA Satellite and Information Service
You are here: Home > Ocean Climate Laboratory > OCL Products
Data Sets & Products
World Ocean Database and World Ocean Atlas Series
Note: The World Ocean Database 2013 expands (0.1 MB) and replaces all previous versions.
Some older versions may still be available on DVD or CD from the NNDC Online Store.
WODselect Online Data Retrieval System
The WODselect interface allows a user to search World Ocean Database using a user-specified search criteria. A distribution map and station count of these search criteria will give the user the option to have the data extracted and placed on the NODC FTP site.
WORLD OCEAN DATABASE 2013 Geographic and year sorted data
New WORLD OCEAN ATLAS 2013 V2 Climatological field and statistic data
New WORLD OCEAN ATLAS 2013 V2 FIGURES Climatological field and statistic figures
New MBT BIAS Depth and Temperature Corrections
New REGIONAL CLIMATOLOGIES
Completed and current projects
New WORLD OCEAN DATABASE Quarterly updates and new data added after the release of the WOD09

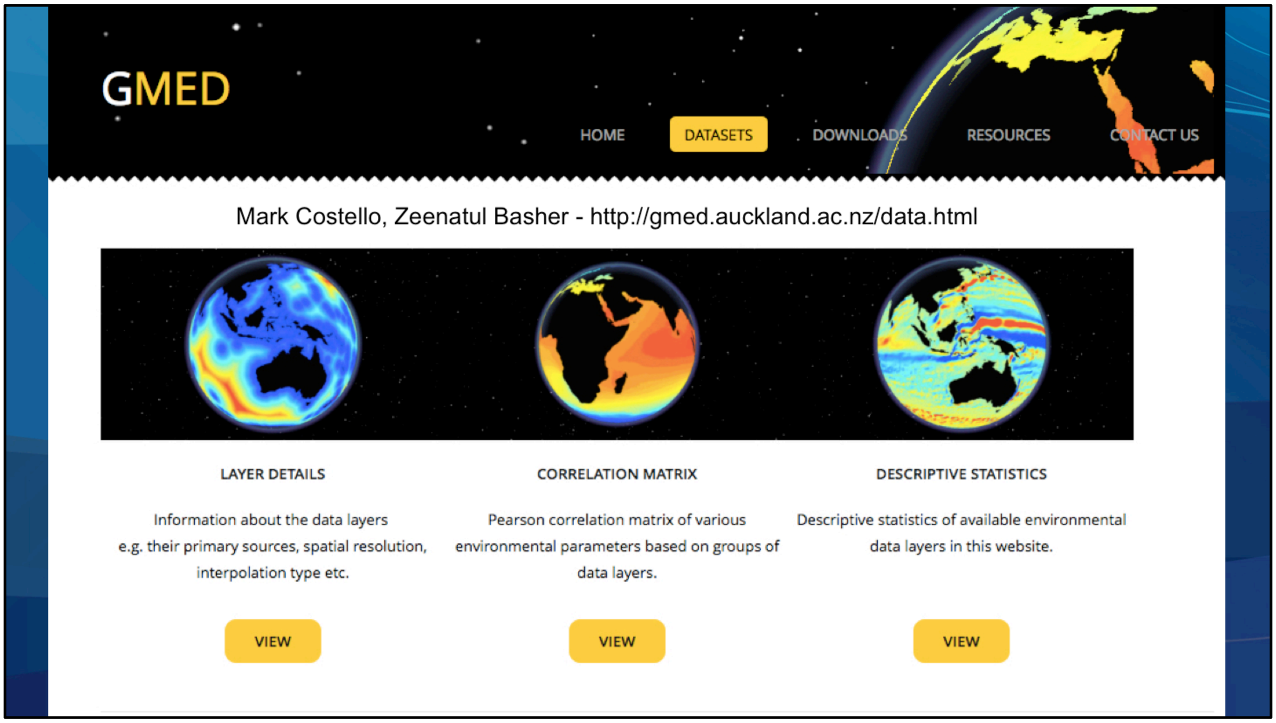


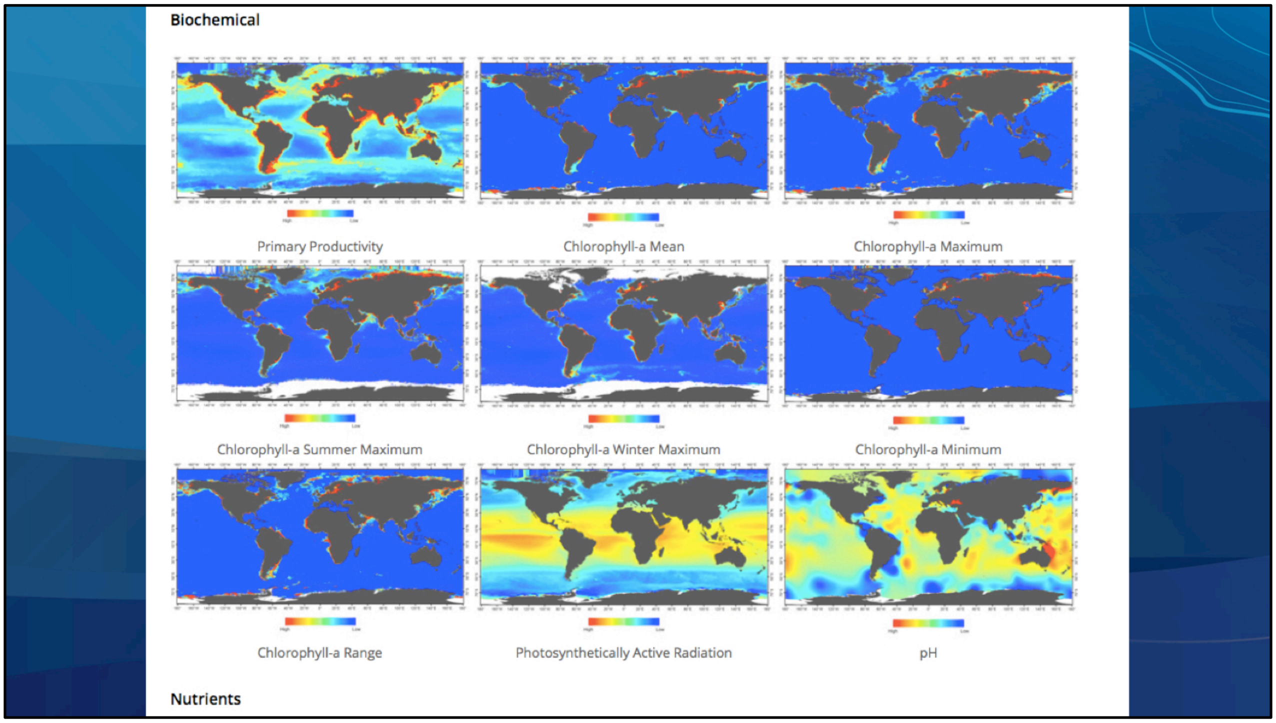
NOAA provides 8 oceanographic variables available in NetCDF format through the World Ocean Atlas. This data is multi-dimensional in nature (X,Y,Z,variable). For our project we focused on the “Objectively analyzed climatologies”. Objectively analyzed climatologies are the objectively interpolated mean fields for oceanographic variables at standard depth levels for the World Ocean.

Data Summary:
Format: NetCDF files

Easily loaded into a Mosaic Dataset and able to be published to server quickly.
Each variable published as a separate service.
Total of 8 services (Temperature, Salinity, Dissolved Oxygen, Percent Oxygen Saturation, Apparent Oxygen Utilization, Silicate, Phosphate, and Nitrate)
Available at 101 Depth Levels (Surface to Seafloor) 0m to 5,500m
Depth slider works in ArcGIS Online.

Including multiple variables in a single NetCDF would simplify things.
Lack of a good set of 3d interpretation tools to conflate dataset to a common 3d mesh.

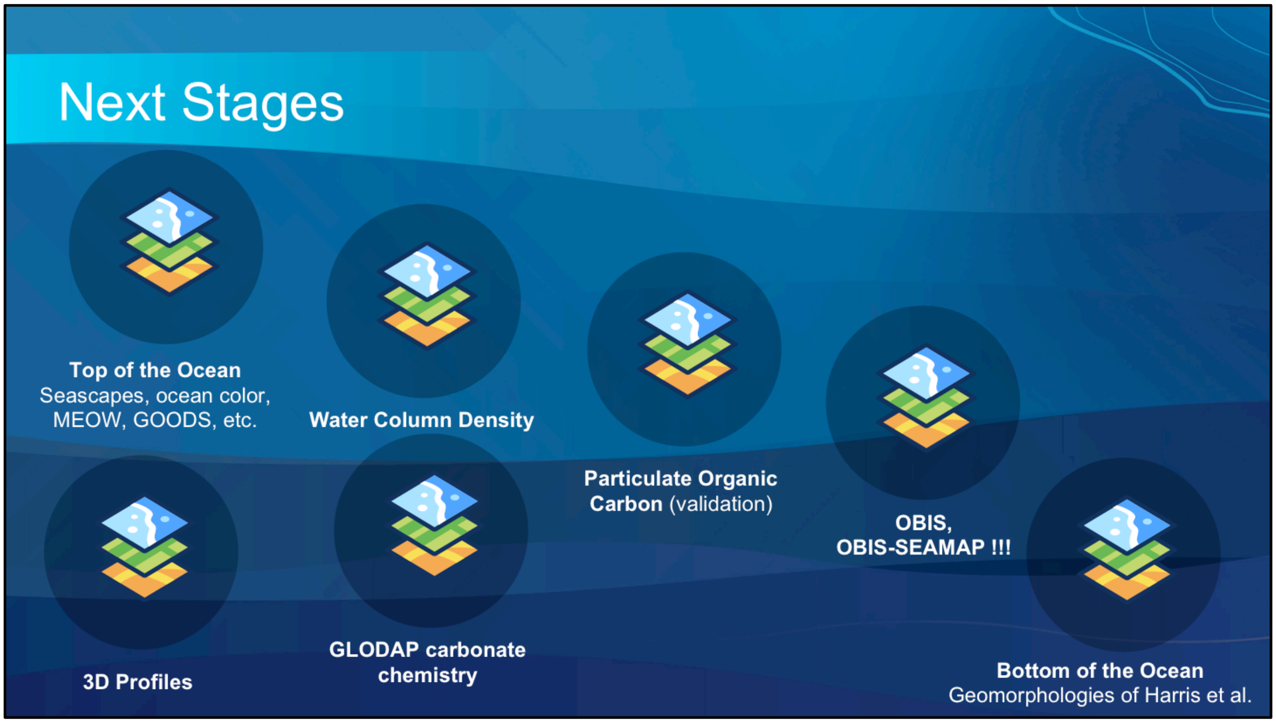

GMED
HOME
DATASETS
DOWNLOADS
RESOURCES
CONTACT US
Mark Costello, Zeenatul Basher - http://gmed.auckland.ac.nz/data.html
LAYER DETAILS
Information about the data layers e.g. their primary sources, spatial resolution, interpolation type etc.
VIEW
CORRELATION MATRIX
Pearson correlation matrix of various environmental parameters based on groups of data layers.
VIEW
DESCRIPTIVE STATISTICS
Descriptive statistics of available environmental data layers in this website.
VIEW


Biochemical
Primary Productivity
Chlorophyll-a Mean
Chlorophyll-a Maximum
Chlorophyll-a Summer Maximum
Chlorophyll-a Winter Maximum
Chlorophyll-a Minimum
Chlorophyll-a Range
Photosynthetically Active Radiation
pH
Nutrients

GMED
GMED hosts a suite of more than 41 environmental layers and supporting metadata available for download. The site is well organized and the information can be found easily.
Data Summary:
Format: asc files
Pixel Type: 32bit float

Each dataset reviewed to validate no data values,
Differences in units (pixel values) – using values that are optimized for performance then applying raster functions, etc.
**Able to use LERC compression now for better performance on scientific data.
41 individual rasters would be added to mosaic datasets for publishing. 41 separate services.

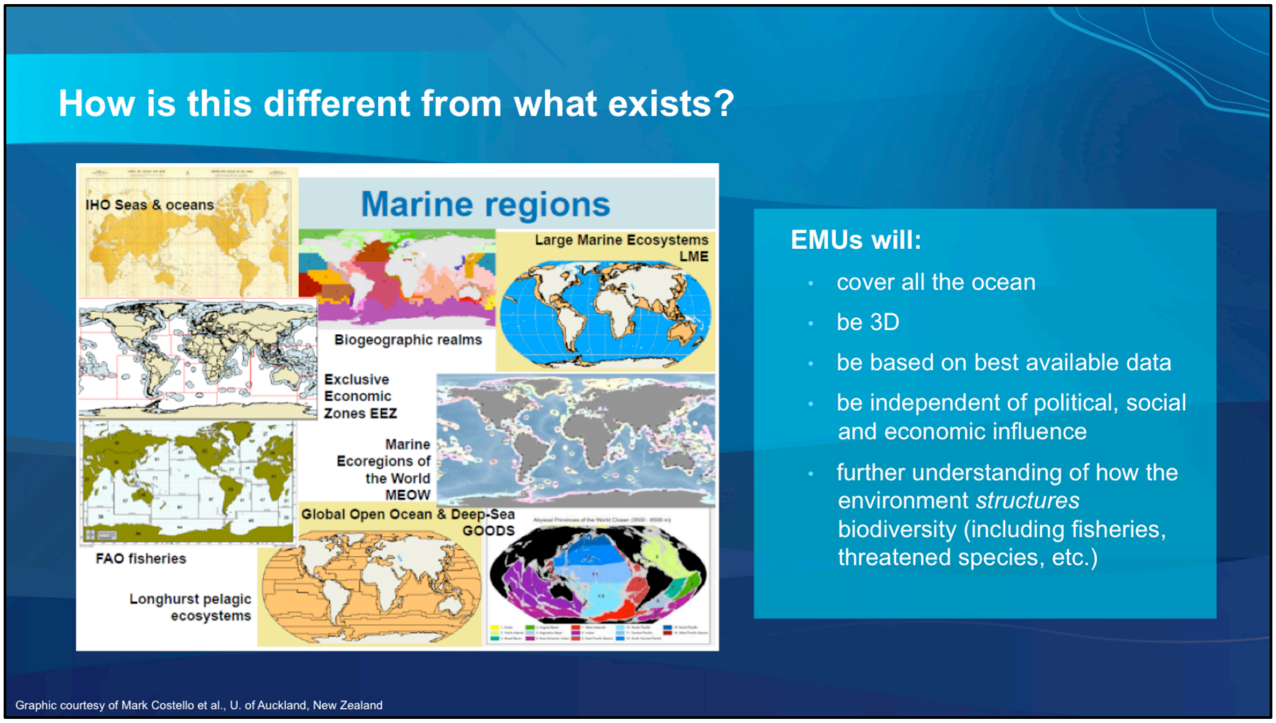
***Would be ideal to develop a consistent land/water mask.
Overall lack of a consistent land water boundary is a big deal.



Regarding seascapes/ocean color see the work of Maria Kavanaugh et al. and Muller-Karger at Ocean Sciences 2016:
A Hierarchical and Dynamic Seascape Framework for Scaling and Comparing Ocean Biodiversity Observations, https://agu.confex.com/agu/os16/meetingapp.cgi/Paper/93156
National Marine Sanctuaries as Sentinel Sites for a Demonstration Marine Biodiversity Observation Network (MBON), https://agu.confex.com/agu/os16/meetingapp.cgi/Paper/88458

Maria has also surmised that POC may be useful more as a **validation** of the clustering rather than as input (POC data are scattered, hard to obtain from Lutz or to compile from NASA, hard to recalculate for entire global water column)

Logo by Esri’s Sean Breyer



We are also aware of the work of Anne Fontaine, Rodolphe Devillers et al. in determining which taxonomic groups to choose for marine ecological units. We've read their 2015 paper in Diversity & Distributions and added Rodolphe to the team.

What will it contain?

Sea surface

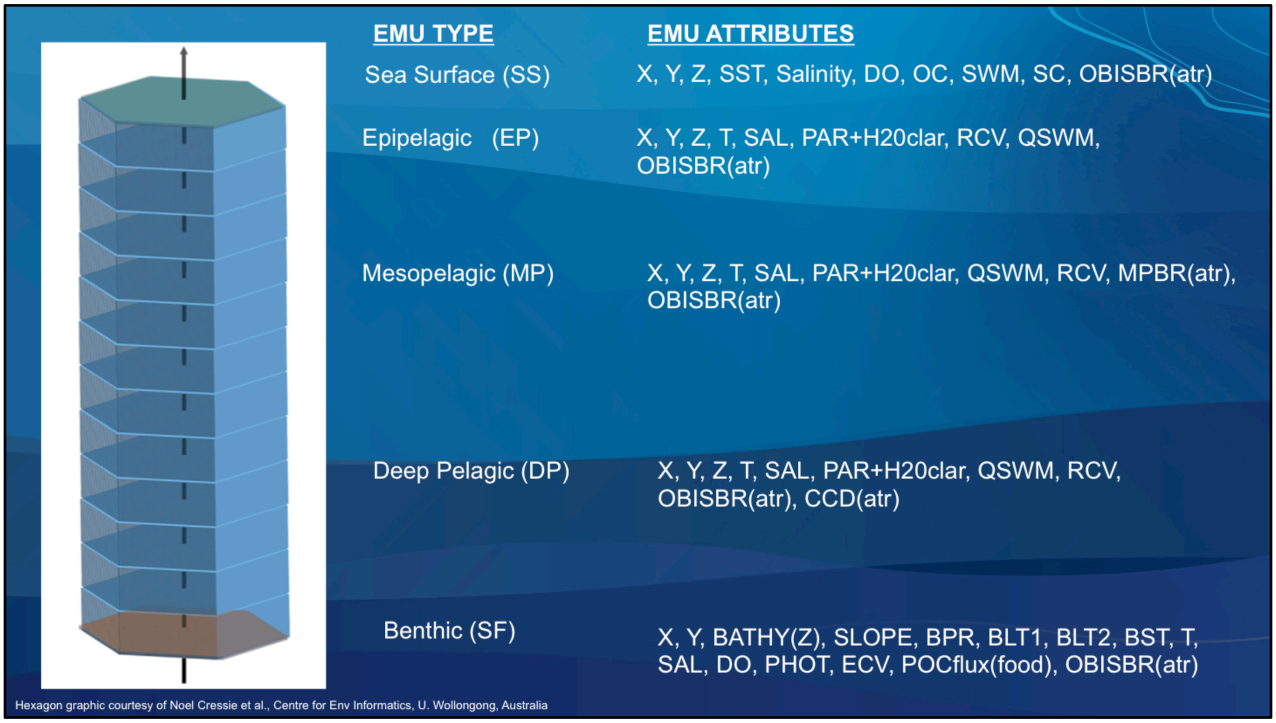
Epipelagic (photic)

Mesopelagic

Deep Sea

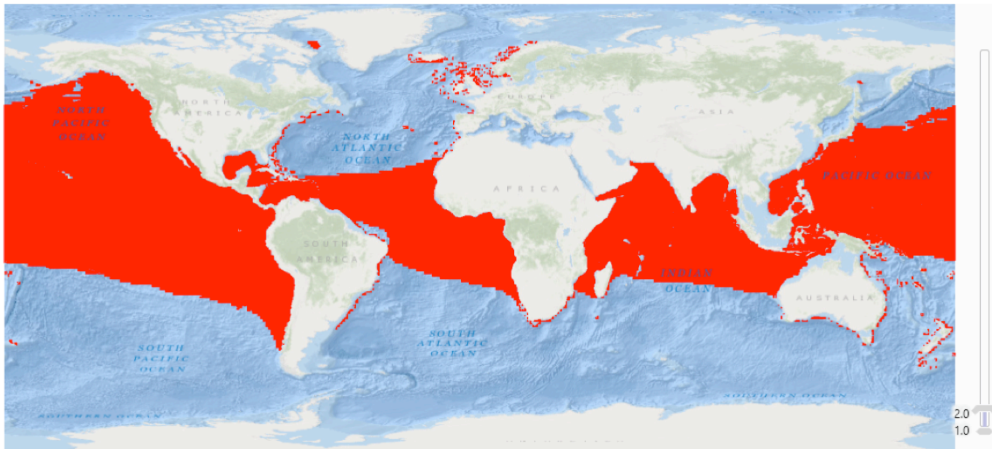
Seabed

- X, Y, Z coordinates
- Ocean color (chlorophyll, productivity)
- Temperature (annual average)
- Major freshwater inputs
- Salinity
- Ice cover
- Tidal height
- Wave height
- Current velocity (including max on seabed)
- Particulate Organic Carbon
- Diffuse attenuation coefficient and/or Photosynthetic Active Radiation
- Aragonite
- Geomorphology
- Coral reefs, mangroves



¼ degree (27 km) x ¼ degree (27 km) with data-driven slices in the z
SST = sea surface temperature; SAL = salinity; DO = dissolved oxygen; OC = ocean color; SWM = surface water mass, SC = surface current; OBISBR = Ocean Biogeographic Information System biogeographic region; atr(as an attribute)
T = temperature; PAR+H2Oclar = photosynthetically available radiation + water clarity; RCV = regional current velocity; QSWM = quasi-stationary water mass; MPBR = mesopelagic biogeographic region
CCD = carbonate compensation depth
SLOPE = slope; BPR = benthic physiographic region; BLT = benthic landform type; BST = bottom sediment type; PHOT = photons/light; ECV = episodic current velocity; POCflux = particulate organic carbon flux (food)

Cluster 1

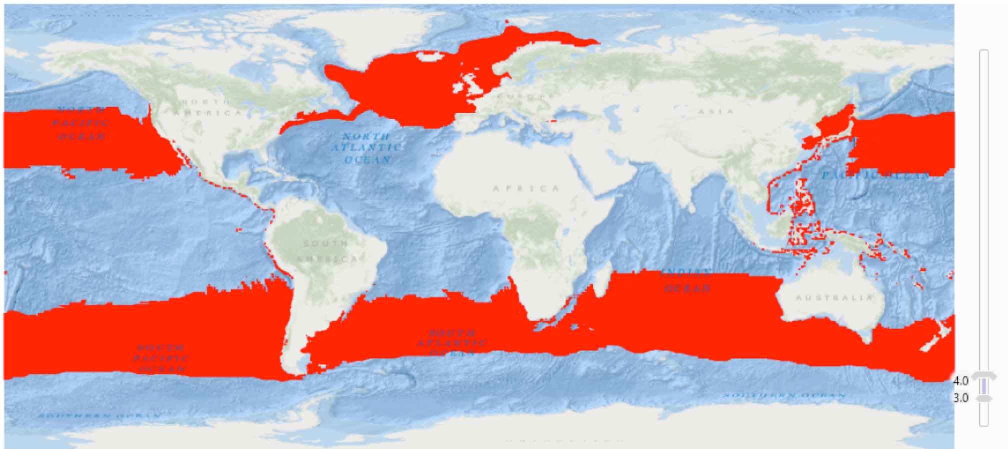


Thickness	
Min	5
Mean	467.165
Max	4225
Std	293.266

Temperature	Min	-0.434	Dissolved O2	Min	0.149	Percent O2 Saturation	Min	2.291	Phosphate	Min	0.956
	Mean	7.947		Mean	2.002		Mean	29.635		Mean	2.374
	Max	23.707		Max	3.517		Max	48.761		Max	3.348
	Std	2.108		Std	0.789		Std	11.028		Std	0.230
Salinity	Min	33.431	Apparent O2			Nitrate	Min	15.620	Silicate	Min	5.269
	Mean	34.568	Utilization	Min	3.239		Mean	32.559		Mean	46.248
	Max	36.822		Mean	4.675		Max	41.897		Max	101.331
	Std	0.359		Max	6.802		Std	2.423		Std	17.423
				Std	0.596						

Subsequent clustering of the entire global water column yielded the 24 mutually exclusive clusters, representing a 3D partitioning of the water column into 24 global EMUs. The global geographic (x and y dimensions) extent of each of the 24 clusters and their physico-chemical characteristics are presented as a series of maps. These global maps of the clusters represent the maximum global horizontal dimensions of the cluster, but do not include a consideration of depth. Many of the clusters are large, with global distributions (e.g., **Clusters 1, 3, 17**), while others are small and localized (e.g., Clusters 2, 10, 22).

Cluster 3



Thickness	
Min	5
Mean	277.624
Max	3800
Std	209.972

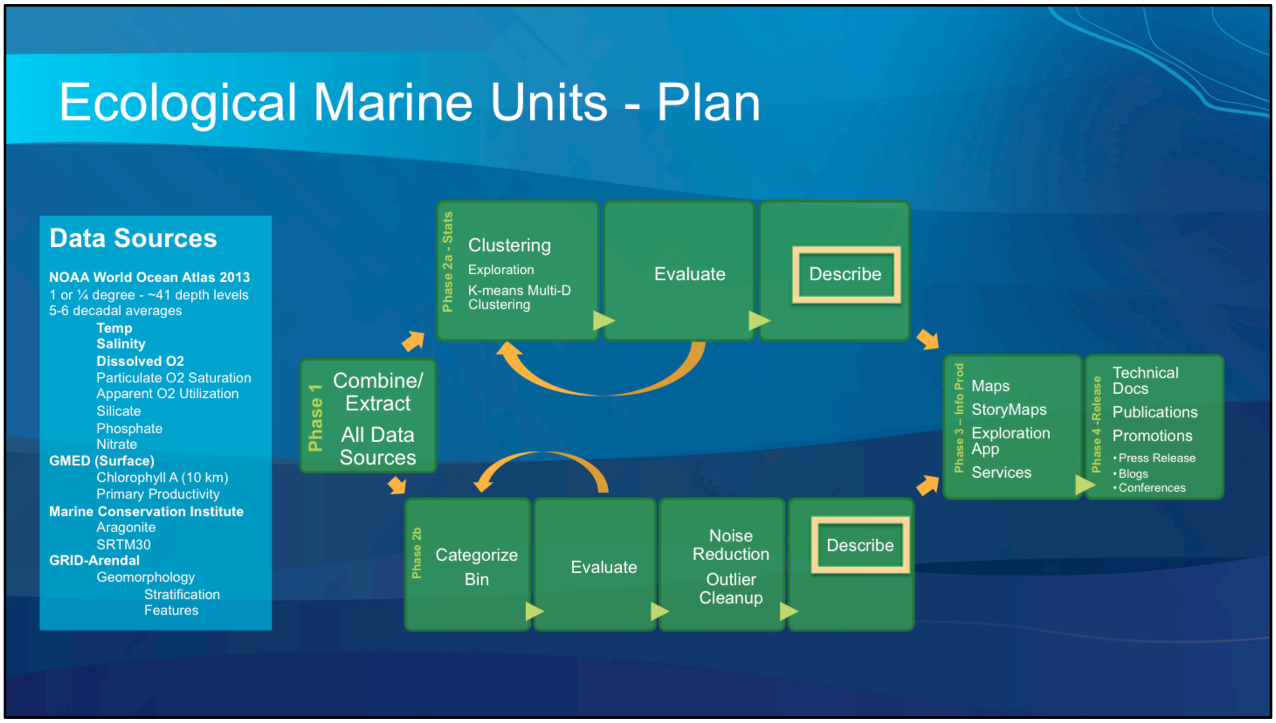
Temperature	Min	2.780
	Mean	11.018
	Max	19.654
	Std	2.794
Salinity	Min	32.261
	Mean	34.606
	Max	35.777
	Std	0.511

Dissolved O2	Min	4.342
	Mean	5.704
	Max	7.875
	Std	0.681
Apparent O2 Utilization	Min	-0.379
	Mean	0.541
	Max	1.793
	Std	0.390

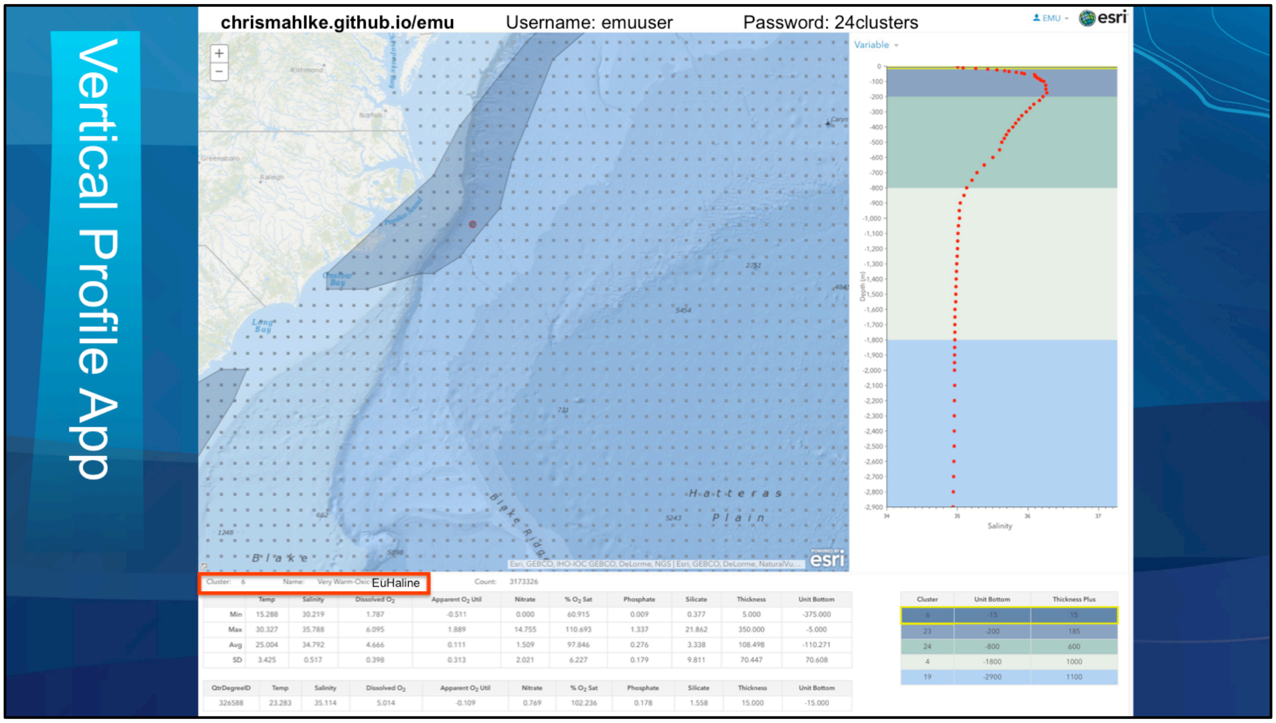
Percent O2 Saturation	Min	73.042
	Mean	91.255
	Max	105.747
	Std	6.509
Nitrate	Min	0.257
	Mean	10.819
	Max	23.972
	Std	3.969

Phosphate	Min	0.106
	Mean	0.859
	Max	1.769
	Std	0.252
Silicate	Min	0.000
	Mean	6.021
	Max	39.976
	Std	3.521

Subsequent clustering of the entire global water column yielded the 24 mutually exclusive clusters, representing a 3D partitioning of the water column into 24 global EMUs. The global geographic (x and y dimensions) extent of each of the 24 clusters and their physico-chemical characteristics are presented as a series of maps. These global maps of the clusters represent the maximum global horizontal dimensions of the cluster, but do not include a consideration of depth. Many of the clusters are large, with global distributions (e.g., **Clusters 1, 3, 17**), while others are small and localized (e.g., Clusters 2, 10, 22).



Focus on DESCRIBING. Can we begin to name the clusters in a way similar to our combinations of Bioclimate, Landform, and Lithology and Land Cover (e.g., Warm Wet Plains Metamorphic Rock Mostly Deciduous Forest)?



Exploring the clusters in 2D within EMU prototype Vertical Profile App, Salinity, Cluster 6 at top of water column