Next Generation Space-borne Aquatic Sensor

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Some terminology for scoping remote sensing capabilities :

Domain	Units	Resolution	Range	
Spectral	Wavelength	$\Delta\lambda$	λ_{min}	λ_{max}
Radiometric	Radiance	ΔL	L_{min}	L_{max}
Spatial*	Length/Area	$\Delta x, \Delta y$	Coverage	
Temporal	Time	Δt	BOM	EOM

To coveral most science questions or applications in the coastal and inland aquatic habitats we need all resolution parameters ($\Delta\lambda$, ΔL, Δx, and Δt) to be small and all range parameters to be large (High resolution in all four domains has been referred to as **H4**).

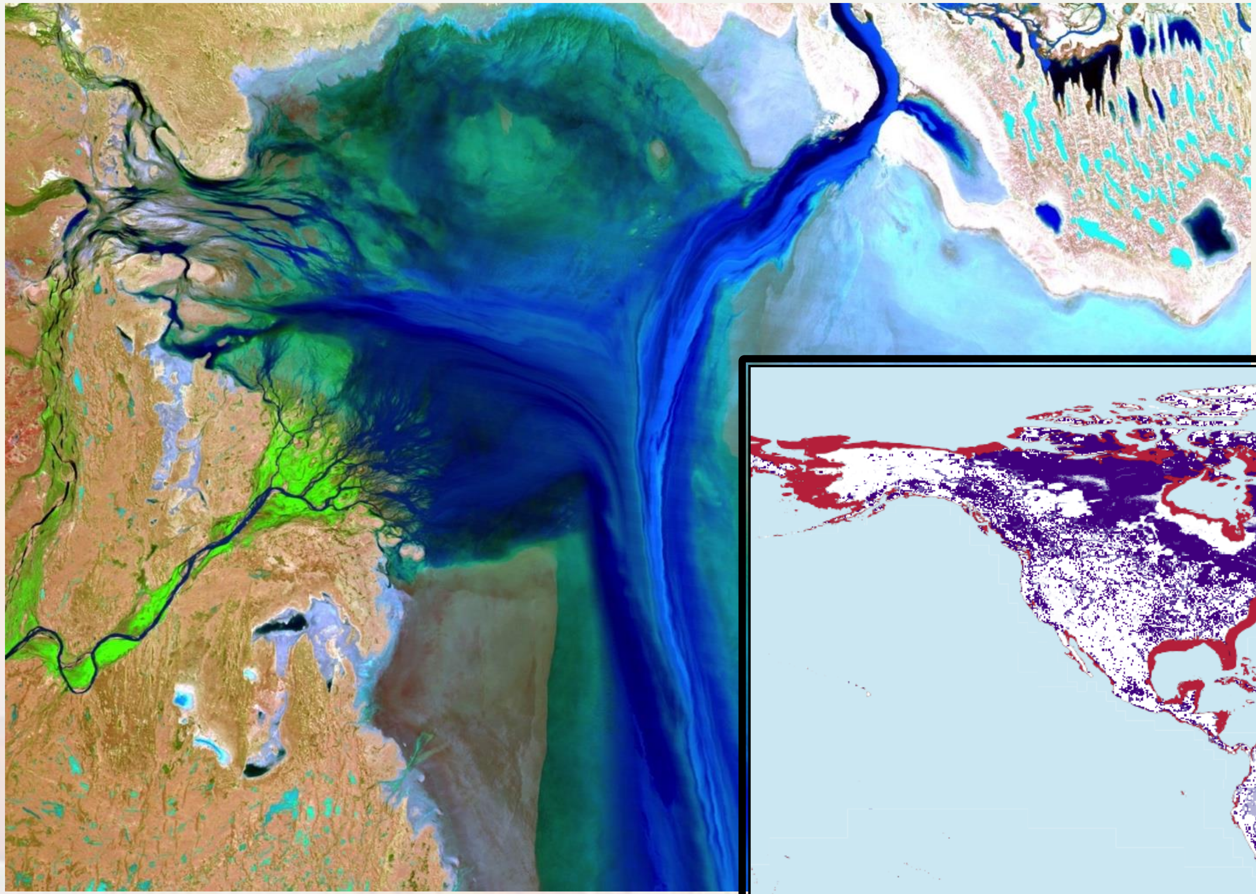
*Active remote sensing included vertical resolution (Δy) in addition to horizontal.

A spaceborne platform is best utilized for global or synoptic observations, and tend to be designed for the broadest use.

Global observations might include:

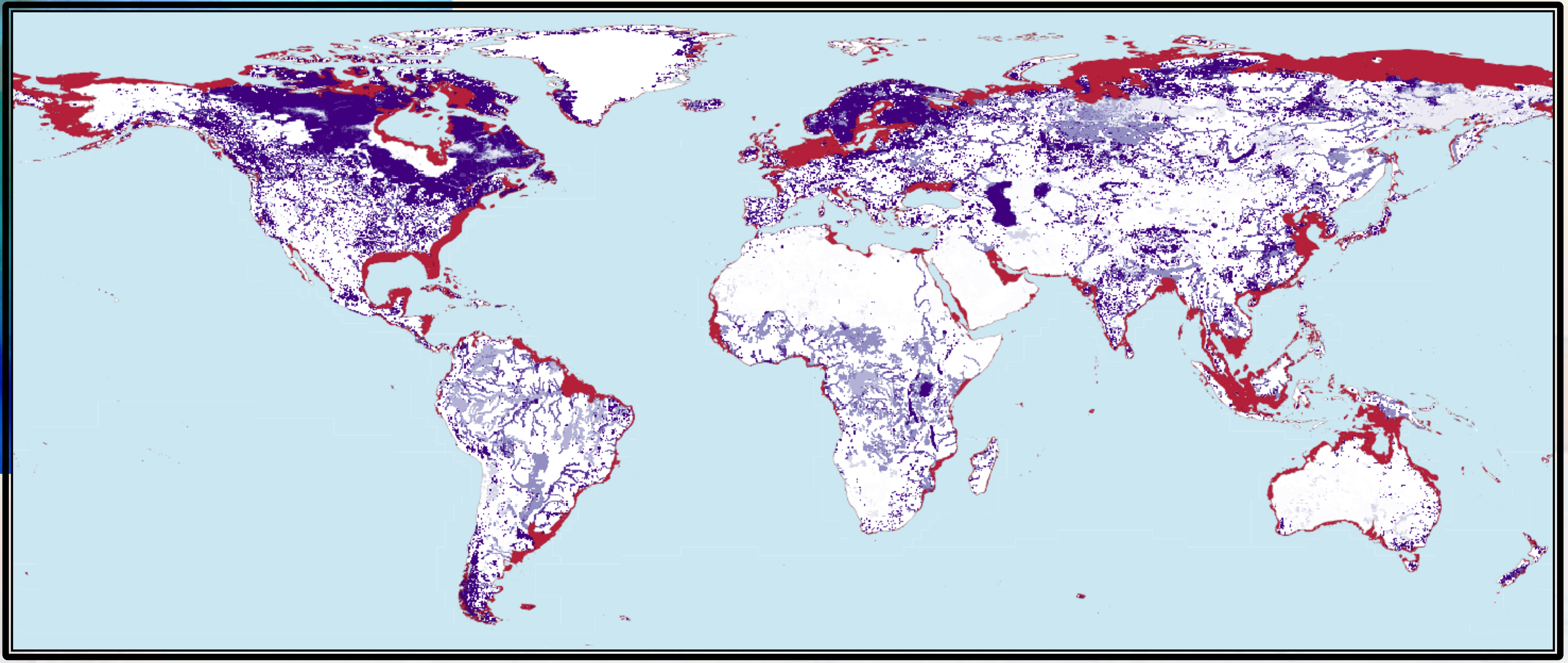
- Emergent wetlands
  - Marshes (saltwater, brackish, freshwater)
  - Woody swamps (mangrove, cypus, etc.)
- Water surface communities
  - Floating macro algae, plants
  - Microbial and oil slicks
- Water-column communities
  - Nekton (e.g., fisheries)
  - Plankton (e.g., phytoplankton)
  - Tripton (e.g., suspended sediment)
- Benthic communities
  - Submerged Aquatic Vegetation (SAV)
  - Coral reefs
  - Shellfish reefs
  - Sponges
  - Microbial mats
- Kelp forests

Coastal and inland aquatic environment is complex spatially and spectrally and found globally.



Lake Eyre - Australia after floods.
[Dekker et al., 2017]

[Turpie et al., 2017]



Global distribution of coastal and inland aquatic ecosystems. Red indicates regions where water depth is less than 50 m and where land elevation is less than 50 m. Light to dark violent gives the concentration of inland wetlands, lakes, rivers and other aquatic systems. Increased darkness means greater percentage of areal coverage for inland aquatic ecosystems (UNEP-WCMC, 2005).

- Global **H4** observations would be technologically and physically difficult to achieve with a single sensor. Multiple LEO (or GEO) platforms are required for global coverage.

- Orbital platforms are limited by clouds, so suborbital and surface infrastructure should be integrated into global and regional observations.

- The spatial and spectral complexity call for global, high spatial resolution [<30m] and for passive remote sensing a spectral resolution [5 nm (+/- 3 nm) from 380 to 737 nm; 15 nm from 737 to 900 nm; 10 nm from 900 to 2500 nm] (CEOS, 2018)

- Mapping extent and distribution of sessile communities (e.g., wetlands, seagrasses, and corals) requires moderate temporal resolution (e.g., monthly measurements or better), as these geophysical characteristics tend change more slowly.

- However, changes in other habitat characteristics for sessile communities can also occur more quickly, and greater temporal resolution (e.g., weekly or better) would be needed to observe rapid change, such as
  - Effects of disturbances and precipitation events,
  - Effects of tides or diel cycles,
  - Important phases of phenology (e.g., reproductive phase), and
  - Changes in water conditions.

- Phytoplankton community and water conditions can change within hours, and highly detailed spatial distribution is sometimes less relevant.

For passive remote sensing, there is a long technological legacy for high spectral resolution imaging spectroscopy in the Earth (spaceborne and airborne) and Solar System missions.

Sentinal 1 is now providing moderate spatial resolution SAR, at low temporal resolution (ok for wetland structure, not so good for tidal processes within them).

EO-1 Hyperion provided hyperspectral imagery at 30 m spatial resolution and CHRIS/Proba continues to provide down to 17m spatial resolution. Neither makes global observations.

LEO imaging spectrometers are planned by various nations, e.g.:

- EnMap (DRL Germany) – hyperspectral, not global observations
- DESIS (DRL Germany, on ISS) – hyperspectral, not global observations
- HISUI (JAXA Japan, on ISS) – hyperspectral, not global observations
- PRISMA (Italy) – hyperspectral, not global observations
- HyspIRI/SBG (USA ?) - hyperspectral VSWIR + Thermal channels, global observations
- All have limited temporal sampling.

GEO costs grow substantially with increasing spatial resolution (decreasing Δx) and multiple platforms (3 or more) are need to provide global coverage (polar coverage still limited).

LEO is relatively cheaper to provide high spatial resolution, can easily provide global coverage with a single platform, but many platforms are needed to provide the same temporal resolution (10s or 100s) as GEO.

An alternate LEO strategy is to choose representative regions of interest and use a steerable sensor to increase temporal sampling.

It would be useful, perhaps even necessary, to integrate other very high spatial resolution multi-band imagers, suborbital hyperspectral imagers and surface assets (i.e., in situ measurements).

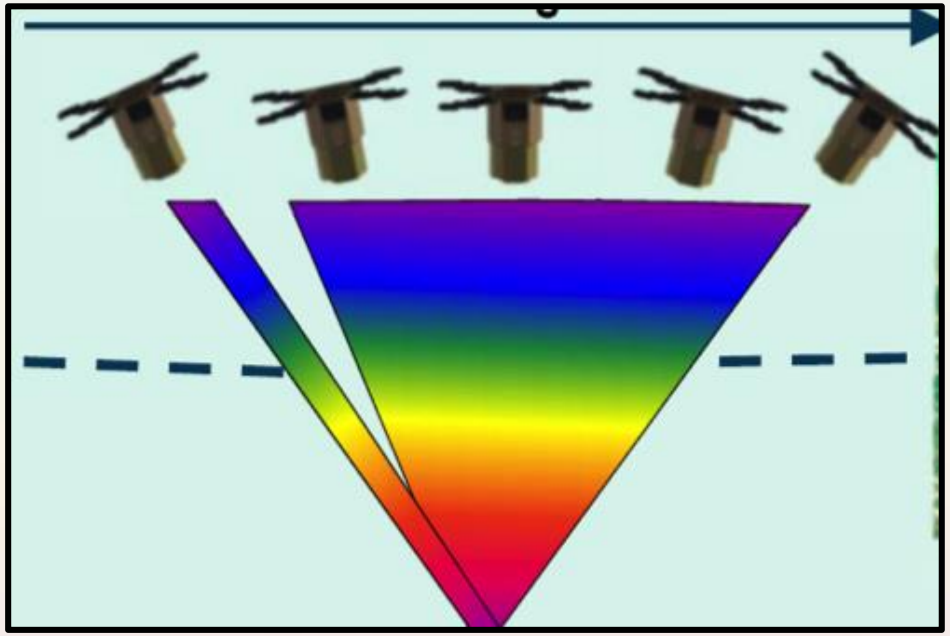
One approach is to combine both LEO and GEO:

- moderate spatial resolution GEO (100-250m) with several observations per day.
- higher resolution (<30m) LEO with 5-16 day repeats.
- both hyperspectral resolution recommended by CEOS feasibility study.

This was basically the HyspIRI / GeoCAPE model for coastal and inland aquatic passive observations.

Alternative observation technique :

- Hyperspectral 30 m spatial resolution sensor
- Sample several hundred 30x30 km areas every 3 days
- 3-day exact repeat orbit
- 1 ‘slow’ and 1 ‘fast’ scan of same target per acquisition
- Off-nadir for land vegetation
- Maximizes signal-to-noise ratio over land and over water



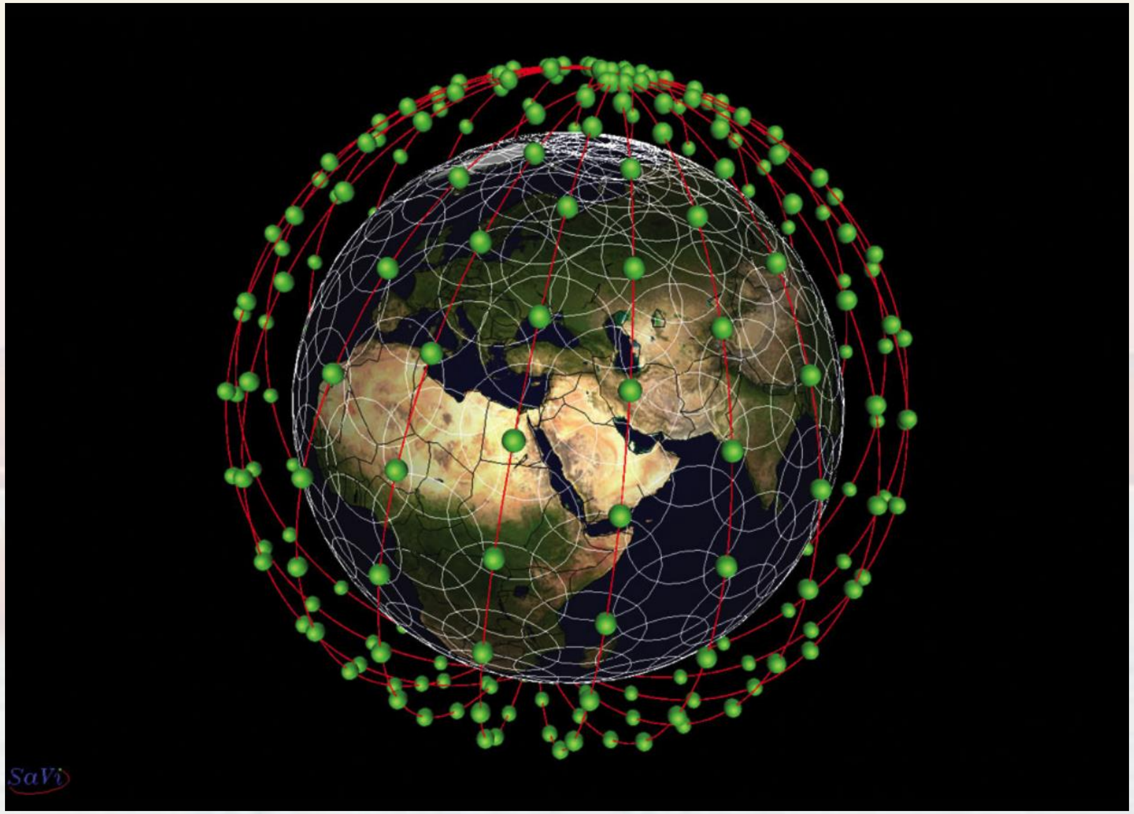
Are there regions of interest that are representative of global issues and how many are needed to understand impact of global change in coastal and inland aquatic habitats?

(Muller-Karger et al., 2018)

Alternative observation technique :

A constellation of many small satellites in LEO, combining passive and active remote sensing.

This approach would achieve H4 characteristics globally, but reliable application is probably too expensive… for now.



(SpaceRef Business 2014, Boeing)

http://spaceref.biz/company/will-google-build-a-satellite-constellation.html

Remote Sensing Activities:
Spaceborne Imaging Spectrometers

ISS Orbital Pattern

Sensor	Orbit	Global?	>1µm?	Status
HICO	ISS	No	No	Off
CHRIS/Proba	Polar	No	No	Working
Hyperion	Polar	No	Yes	Off
EnMap	Polar	No	No	<5 years
DESIS	ISS	No	No	<5 years
HISUI	ISS	No	No	<5 years
PRISMA	Polar	No	No	<5 years
COCI	Polar	Yes	No	Unknown
PACE^{+}	Polar	Yes	Yes	5 years
GeoCAPE	GEO	No	No	Cancelled
HyspIRI/SBG	Polar	Yes	Yes	5-10 years
Landsat 10	Polar	Yes	Yes	~10 years

Remote Sensing Activities:
Airborne Campaigns and Feasibility Studies

Sensor	Activity	Sensors	Subject of Study
ABC LOBO	Study	AVIRIS, PRISM	S. FL Watershed
CORAL	Campaign	PRISM	Coral Reefs
HyperMAQ	Study	?	Coastal/Inland Waters
HyspIRI APC: CA	Campaigns	AVIRIS-C	Coastal/Inland Waters
HyspIRI APC: HI	Campaigns	AVIRIS-C (+PRISM?)	Coral Reefs (MOBY)
C-HARRIER 	Instrument	2 Line Spectrometers	Coastal/Inland Waters
AirShrimp	Instrument	Line Spectrometer	Coastal Waters
Great Lakes AC	Campaigns	Imaging Spectrometer	Inland Water Quality
GLiHT	Campaigns	Imaging Spectrometer	S. FL Mangroves
air-LUSI	Instrument	Spectrograph	Moon (Reference)

THANK YOU

REMOTE SENSING AS AN OBSERVATIONAL TOOL

The Challenge

- Rapid global degradation calls for urgent observation for assessment and monitoring of aquatic habitats.
- Large-scale observation of aquatic habitats is hampered by the inability to routinely observe ecosystem processes *in situ* with sufficient temporal, spatial and spectral resolution.
- There is large uncertainty in knowledge of areal extent and distribution of many types of aquatic habitats.

A Solution

- Imaging spectrometers on airborne or spaceborne platforms can provide large-scale observations to varying degrees of spatial, spectral, radiometric and temporal resolution.
- Measurements of habitat extent and spatial distribution, and observing changes in these quantities, can be done through the detection of the spectral signatures of foundation species and their structures.