GEO SMART INDIA 2021

THEME

ADVANCING THE ROLE OF GEOSPATIAL KNOWLEDGE IN INDIAN ECONOMY

24-26 August 2021

HICC Hyderabad, India

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Geospatial Solutions for Conservation and Sustainable use of Marine Resources for Sustainable Development (SDG 14)

Role of Geospatial Technologies

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National Geospatial Chair Professor
Professor
Department of Ocean Engineering,
Indian Institute of Technology Madras

Presented at the GeoSmart India, Hyderabad on 5 December 2019

Sustainable Development Goals (SDG)

(Transforming our World: 2030 Agenda)

- A **set of goals to stimulate action** for people, planet, prosperity, peace and partnership for a sustainable development.

17 SDGs

169 Targets

Universality

(every nation and sector)

Transformation

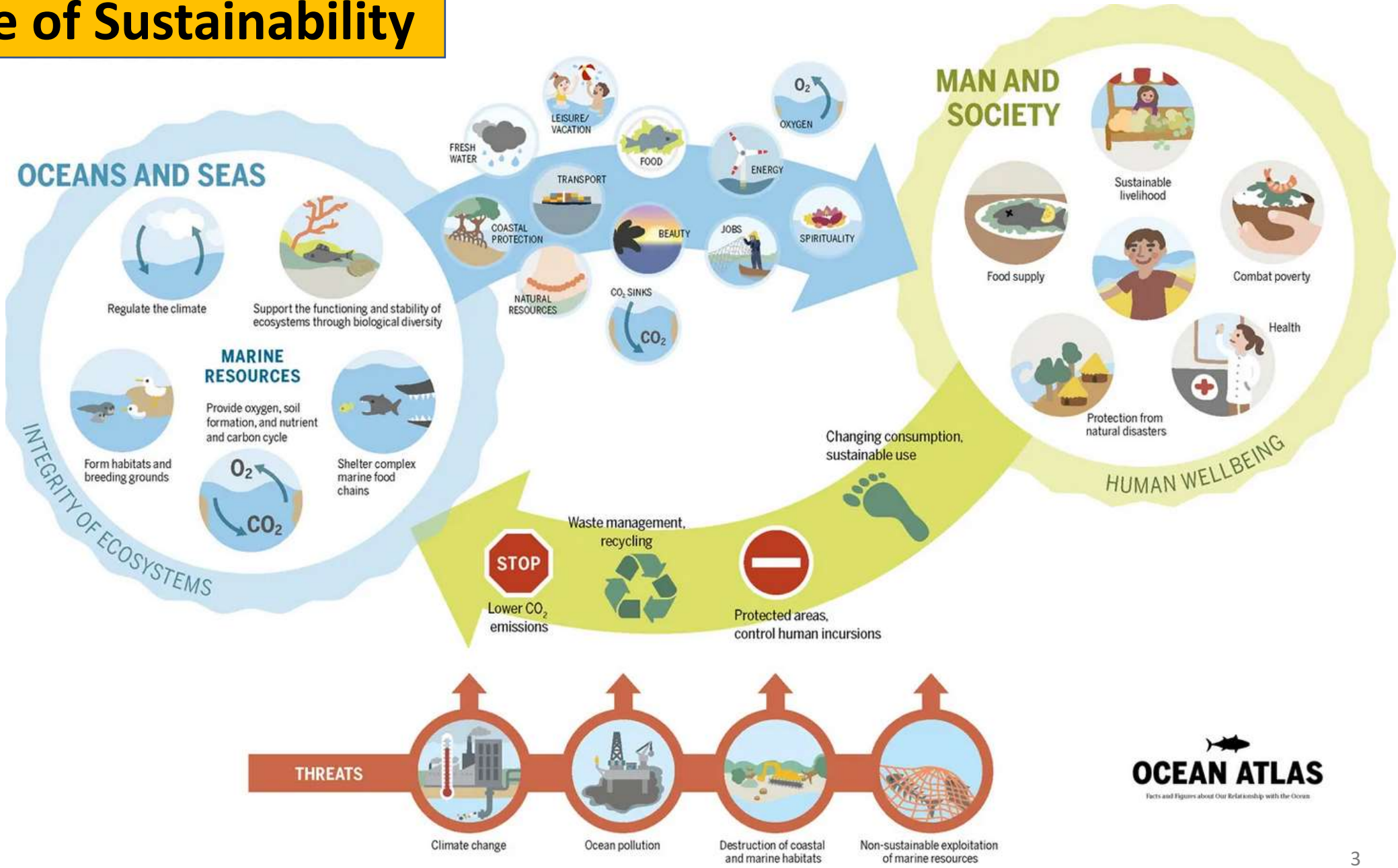
(implement into earth)

Integration

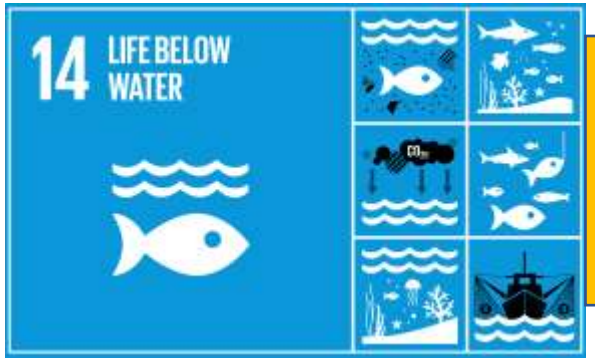
(Inter-connected)

https://www.repsol.com/en/sustainability/our-sustainability-model/our-contribution-to-the-sdgs/index.cshtml

Circle of Sustainability



https://www.nature.com/articles/s41467-018-03158-3/figures/1



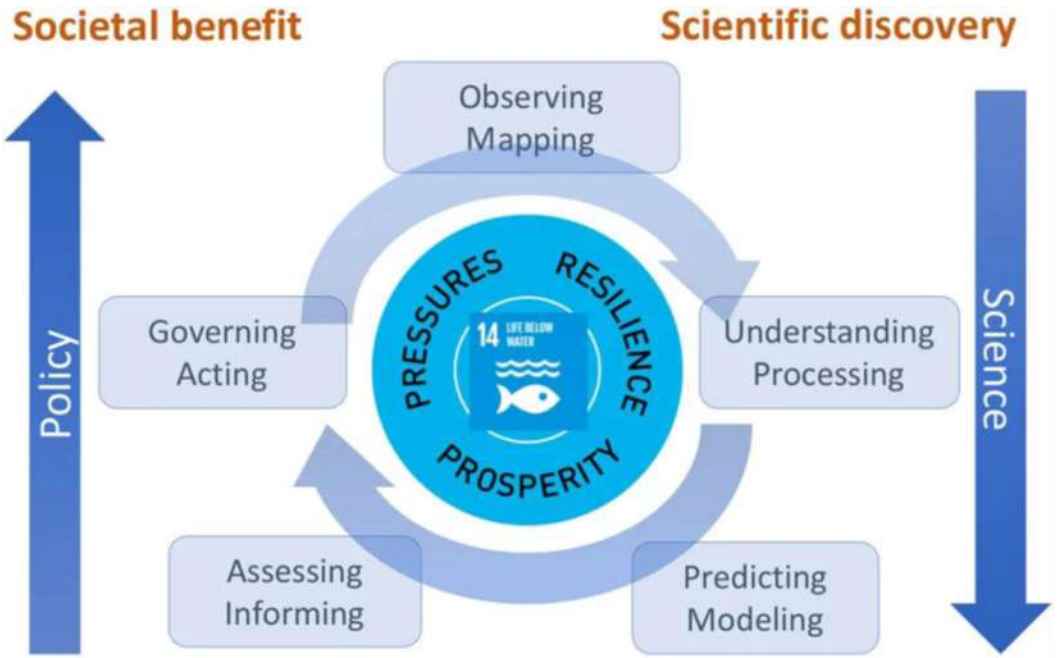
SDG-14: Conserve and sustainably use the oceans, seas and marine resources

It ensures,

- Healthy, productive, resilient and Sustainable management oceans and seas.

- The SDG-14 aims to sustainably manage and protect marine and coastal ecosystems from pollution, as well as address the impacts of ocean acidification.
- Enhancing conservation and the sustainable use of ocean resources through international law will also help mitigate some of the challenges facing our oceans.

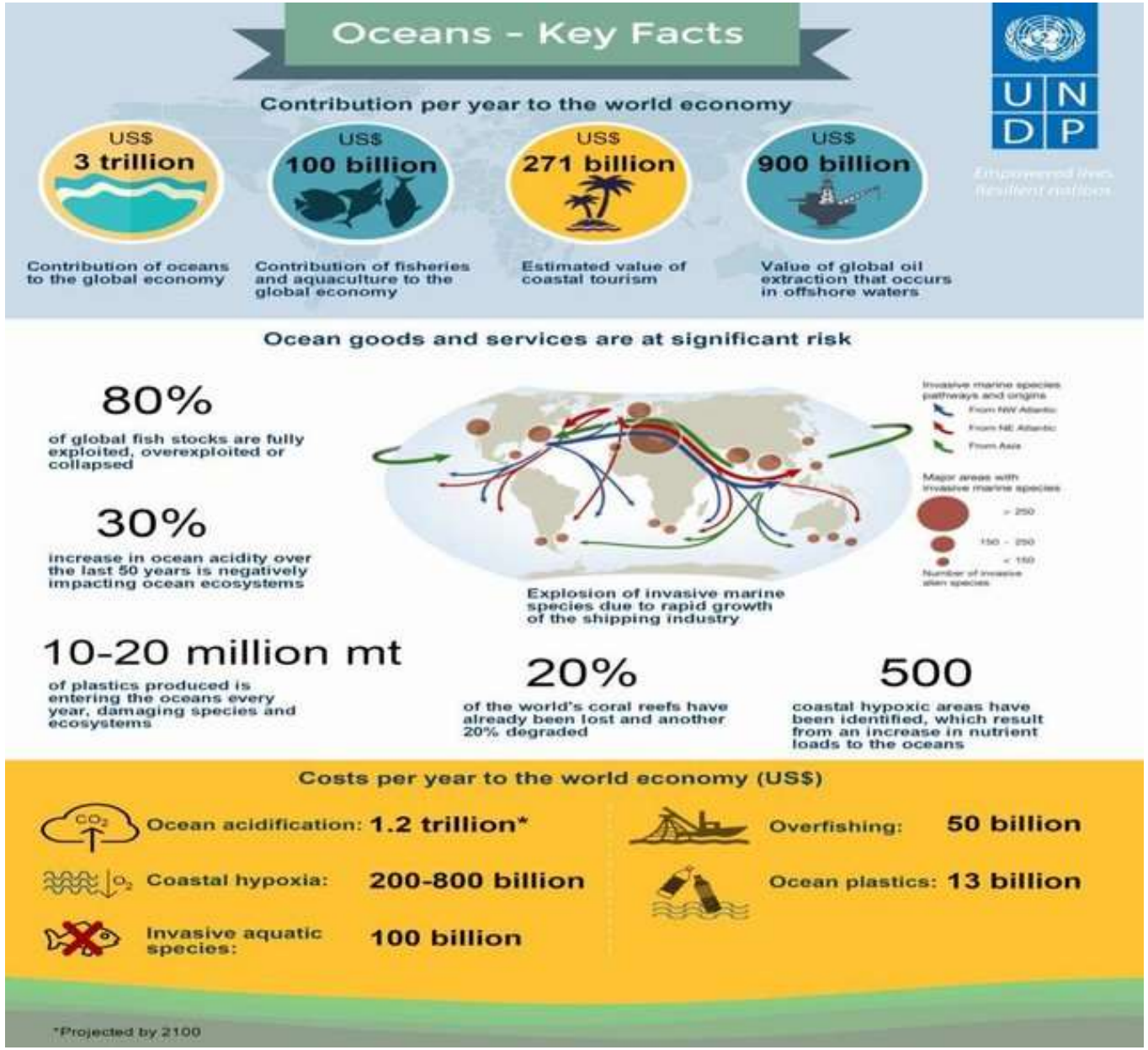
- Increased need for ocean information to meet societal needs.
- Meeting a growing range of societal demands and achieving Sustainable Development Goal 14 from the 2030 Agenda for Sustainable Development can only be fully realized if all elements of the ocean value chain are resourced adequately and **more integrated science agendas** are advanced.

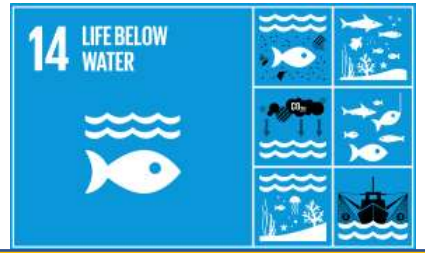


Ocean science research is key for a sustainable future

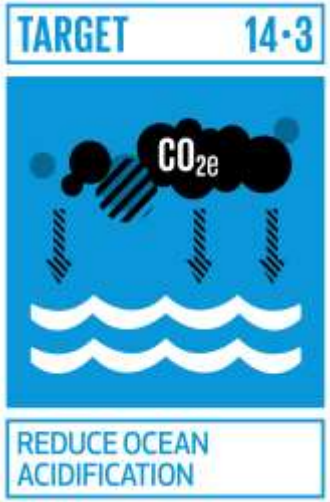
https://www.nature.com/articles/s41467-018-03158-3/figures/2

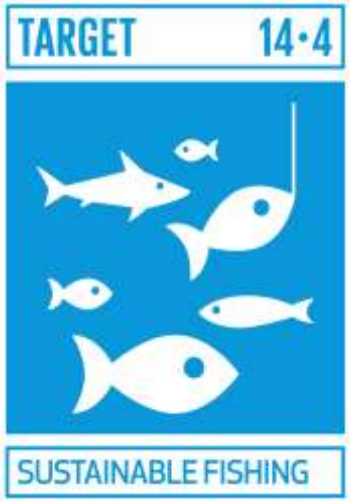
Need of SDG-14 (Life below water)

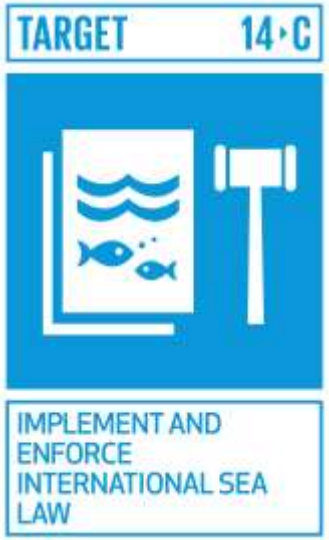




Targets in SDG-14



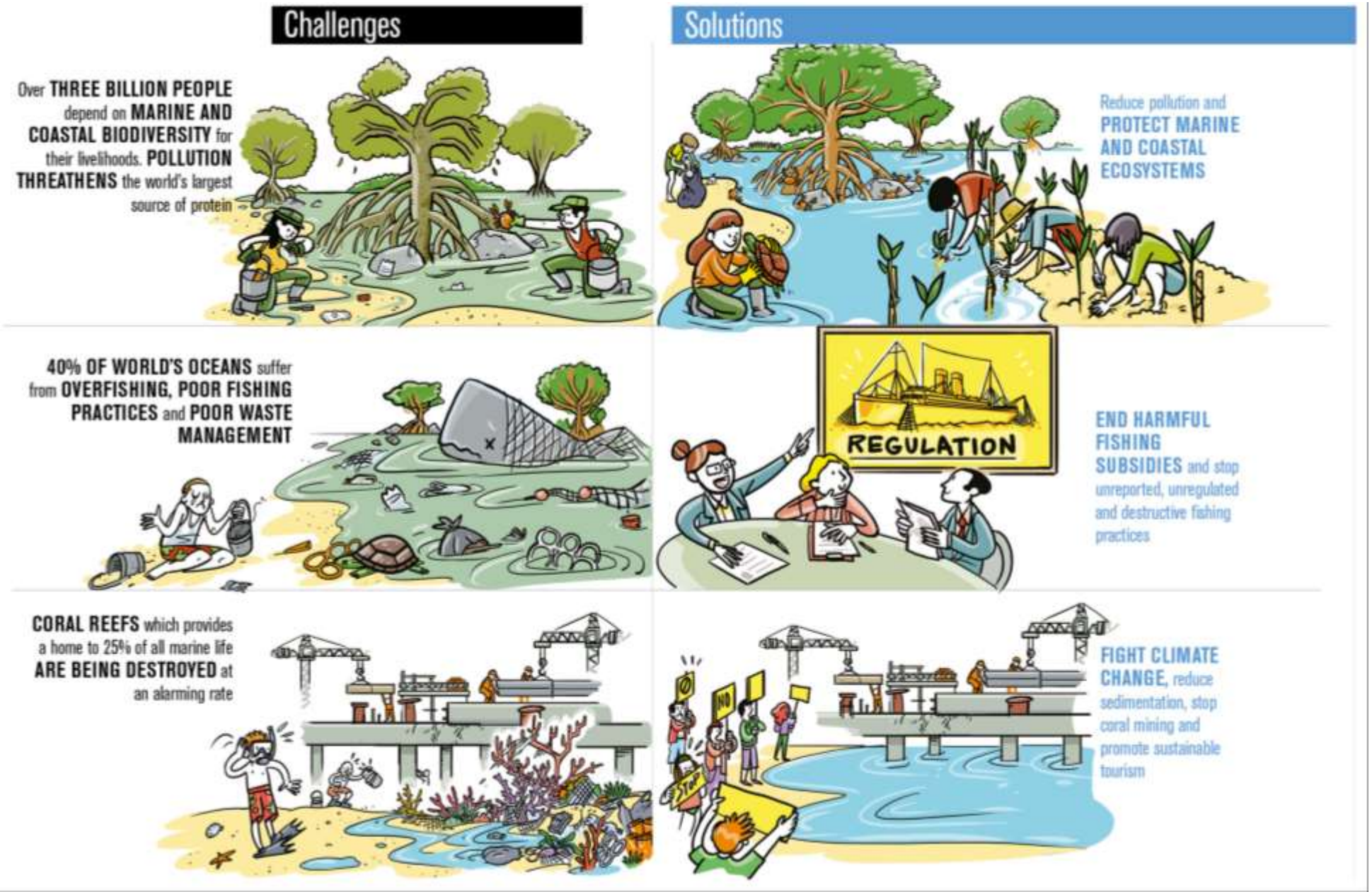




*Consistent with national and international law and based on the best available scientific information

https://sustainabledevelopment.un.org/sdg14

SDG-14: Challenges & Solutions



SDG-14: Global Initiatives

https://www.nafo.int/portals/0/Images/FIRMS/COFI2011-PosterFIRMS1-small.jpg

Northwest Atlantic Fisheries Organization

IMO
INTERNATIONAL MARITIME ORGANIZATION

UNESCO
United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

MARPOL
International Convention for the Prevention of Pollution from Ships

UNCLOS
United Nations Convention on the Law of the Sea

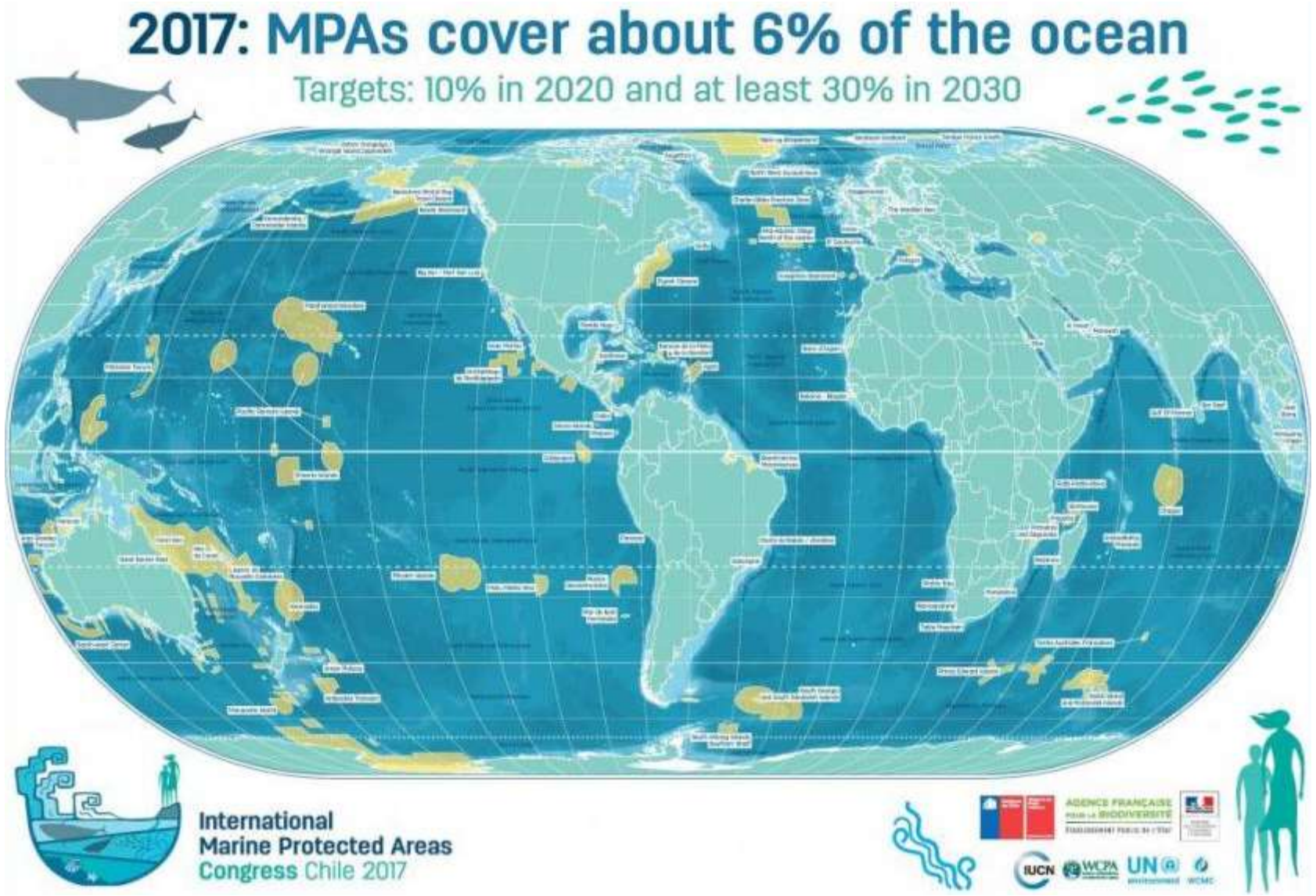
GPML
Global Partnership on Marine Litter

INTERNATIONAL WHALING COMMISSION

PROG
Partnership for Regional Ocean Governance

POLAR Code
INTERNATIONAL CODE FOR SHIPS OPERATING IN POLAR WATERS

Global Initiatives – Marine Protected Areas (MPAs)



SDG-14: Initiatives by Government and Non-Governmental Organizations around India

प्रकृतिः रक्षति रक्षिता
Nature Protects if She is Protected

Ministry of Environment, Forest & Climate Change

NITI Aayog
(National Institution for Transforming India)

NATIONAL INSTITUTE OF OCEAN TECHNOLOGY
NIOT
CHENNAI

UN environment
The Young Leaders Plastic Challenge
clean seas

National Institute of Oceanography, Goa

INCOIS

ESSO- Indian National Centre for Ocean Information Services

WORKING TOWARDS A SUSTAINABLE ENVIRONMENT
ENVIS INDIA

Wildlife Trust of India
www.wti.org.in

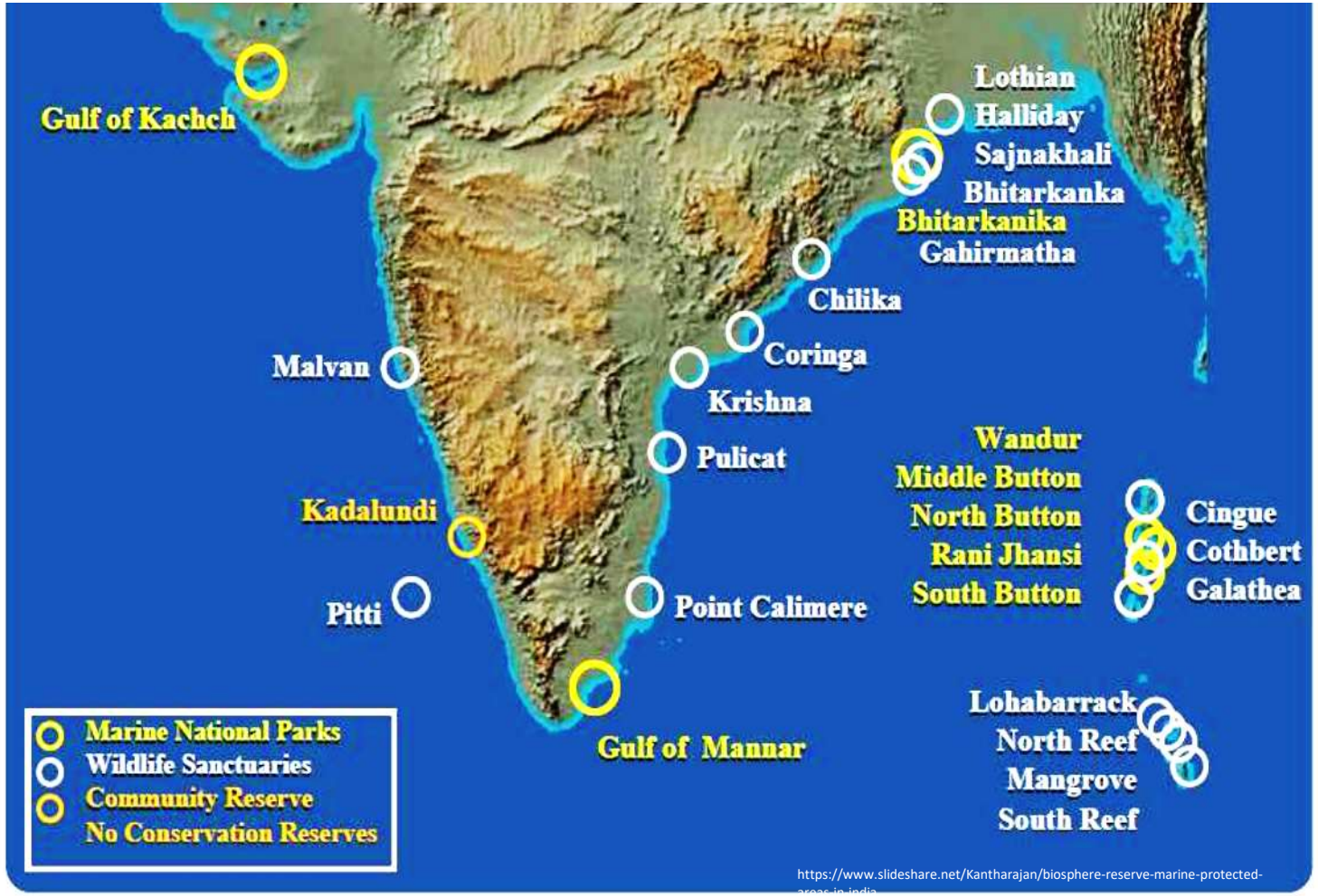
NCSCM

National Centre for Sustainable Coastal Management

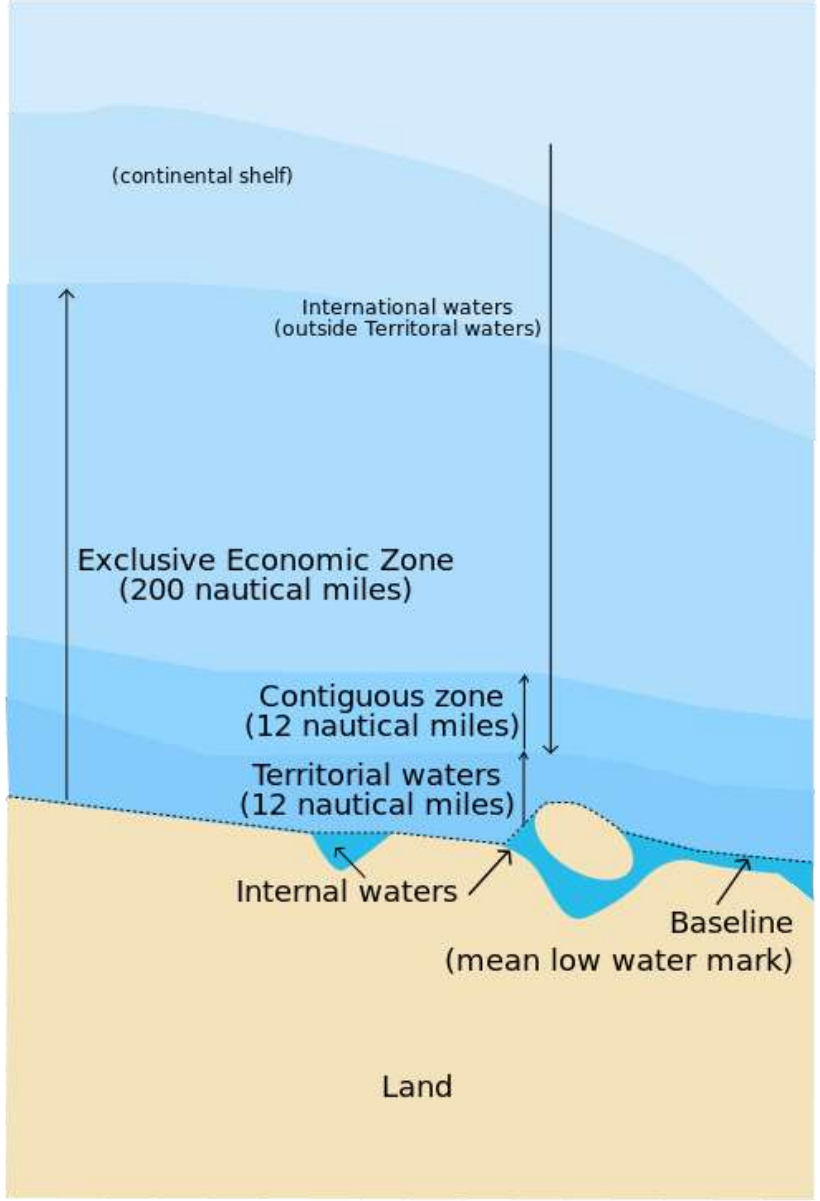
WWF

CEE
Centre for Environment Education

Marine Protected Areas (MPAs) in India



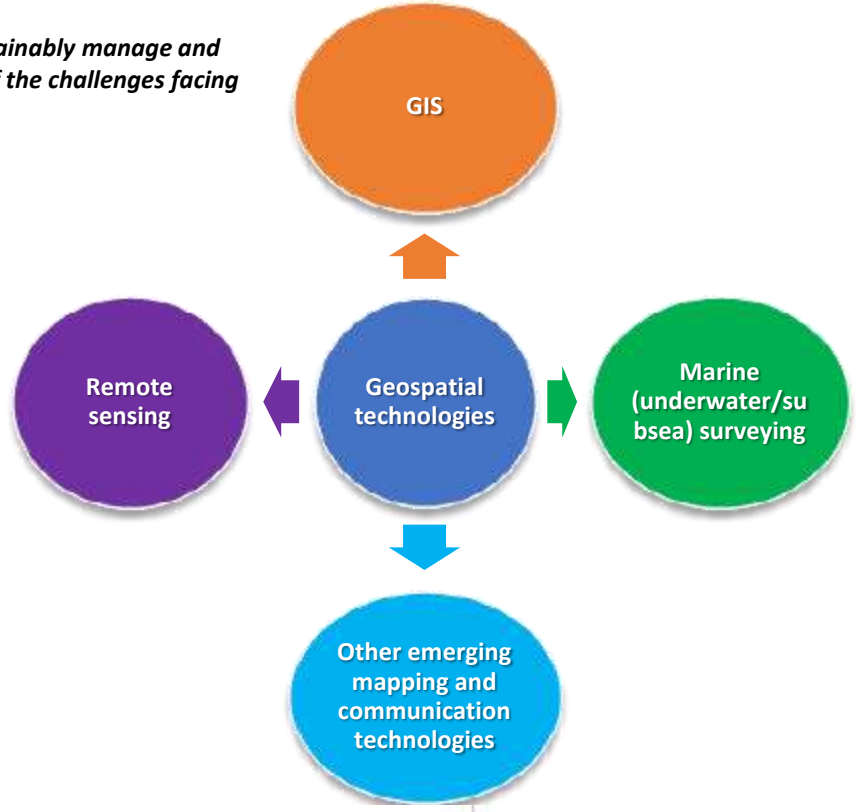
https://www.slideshare.net/Kantharajan/biosphere-reserve-marine-protected-areas-in-india



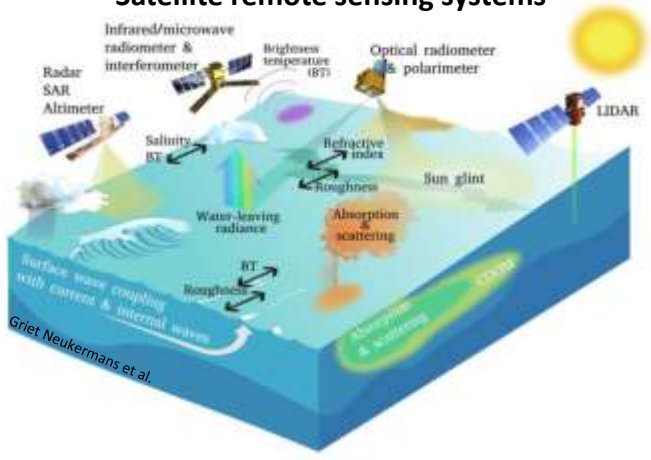
Geospatial technologies

"Marine geospatial science & technology is key for a sustainable future"

- Increased need for ocean geospatial information to meet a growing range of societal demands/needs.
- More integrated geospatial science agendas are to be advanced ***to sustainably manage and protect marine and coastal ecosystems and also help mitigate some of the challenges facing our oceans.***

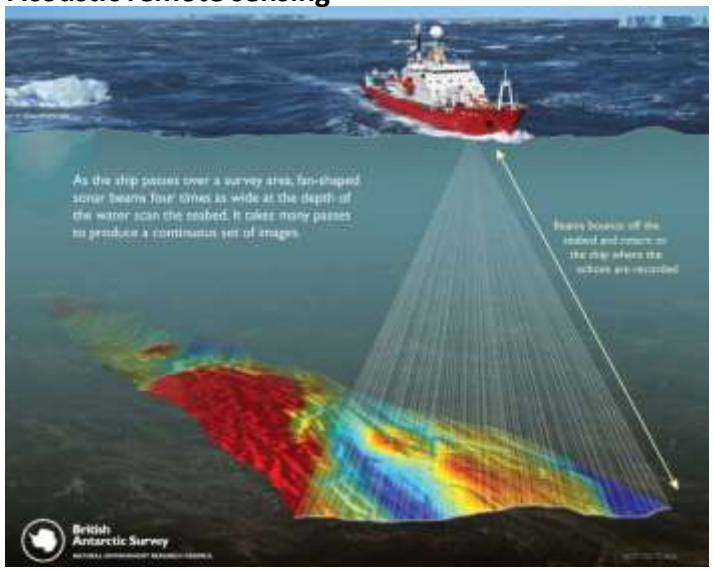


Satellite remote sensing systems

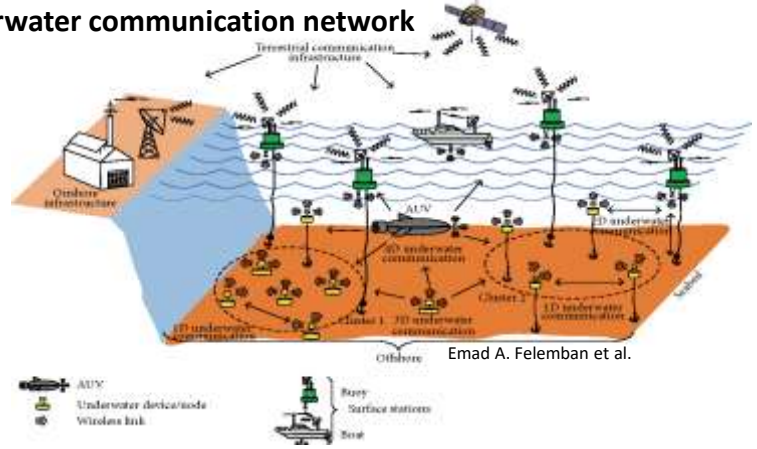


Griet Neukermans et al.

Acoustic remote sensing

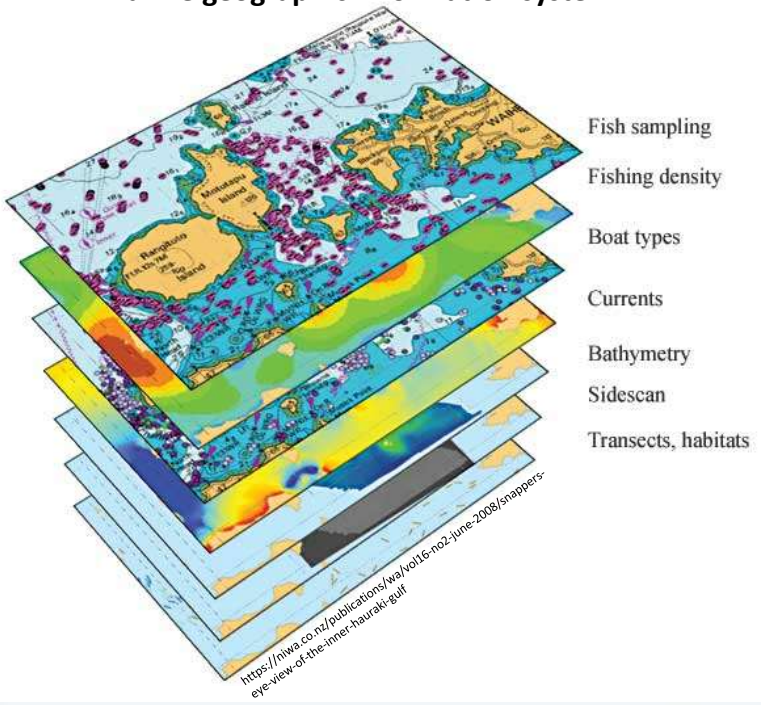


Underwater communication network



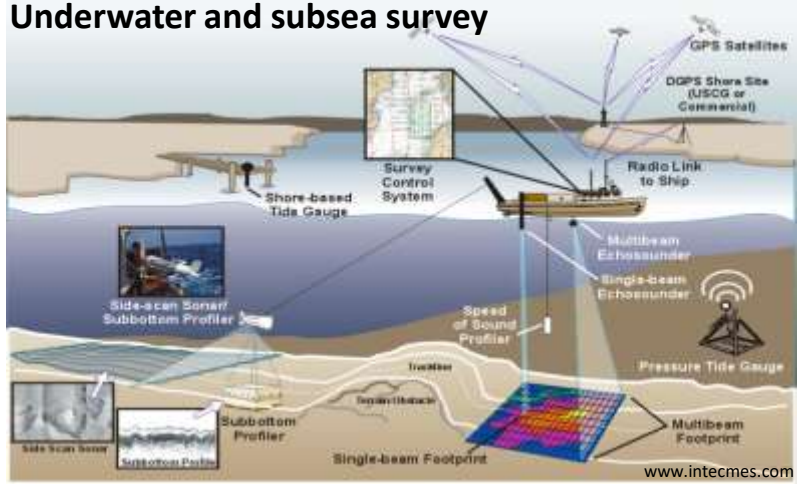
Emad A. Felemban et al.

Marine geographic information system



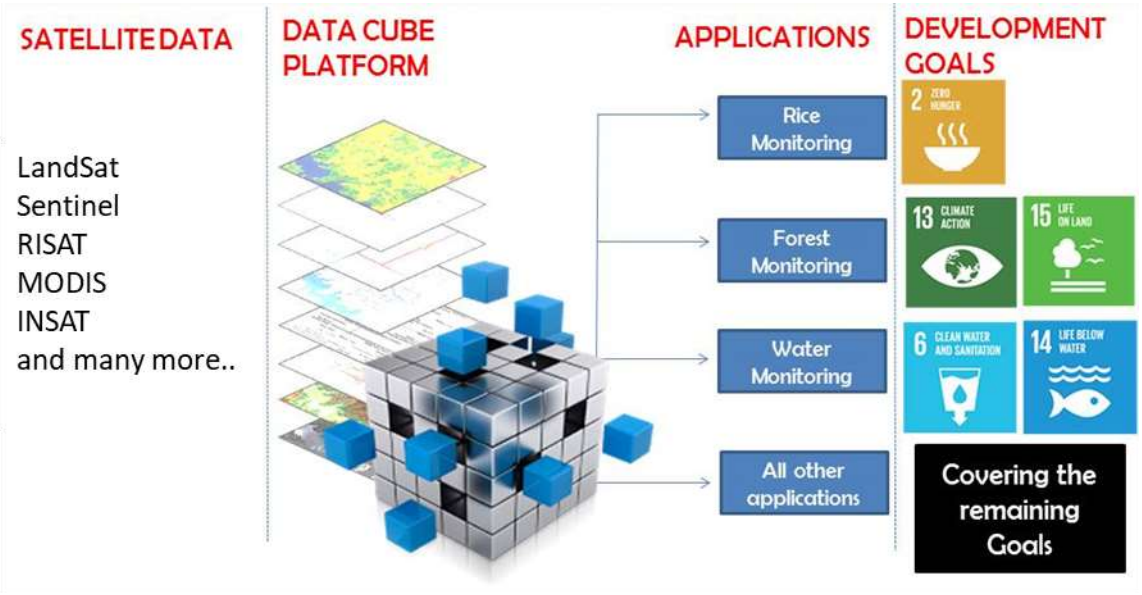
https://niwa.co.nz/publications/wa/vol16-no2-june-2008/snappers-eye-view-of-the-inner-hauraki-gulf

Underwater and subsea survey



Role of geospatial technologies in SDGs

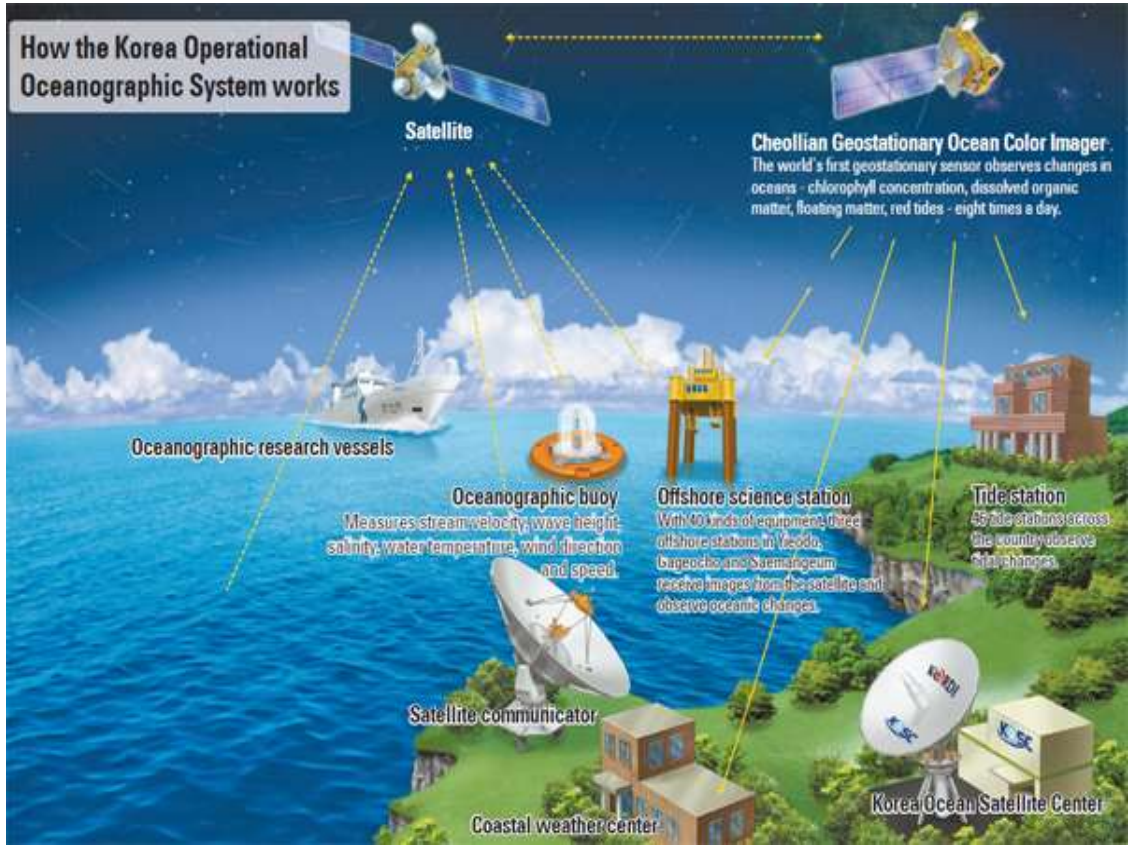
- Geospatial technologies contribute positively to a range of policy areas, including climate and weather monitoring, access to health care and education, water management, efficiency in transportation and agriculture, peacekeeping, security and humanitarian assistance.
- Widely used to implement integrated and participatory coastal zone management, including appropriate trans-boundary cooperation.
- ***Act as an interface of science and policy which strengthens the possibilities to achieve SDGs.***



https://www.earthobservations.org/documents/articles_ext/201608_unggim_geo_transforming_our_world_white_paper.pdf

Advancements in geospatial technologies around the world

Integration of Geospatial technologies for operational oceanographic system



Korean Ocean Satellite Center

Korean Ocean Satellite Center

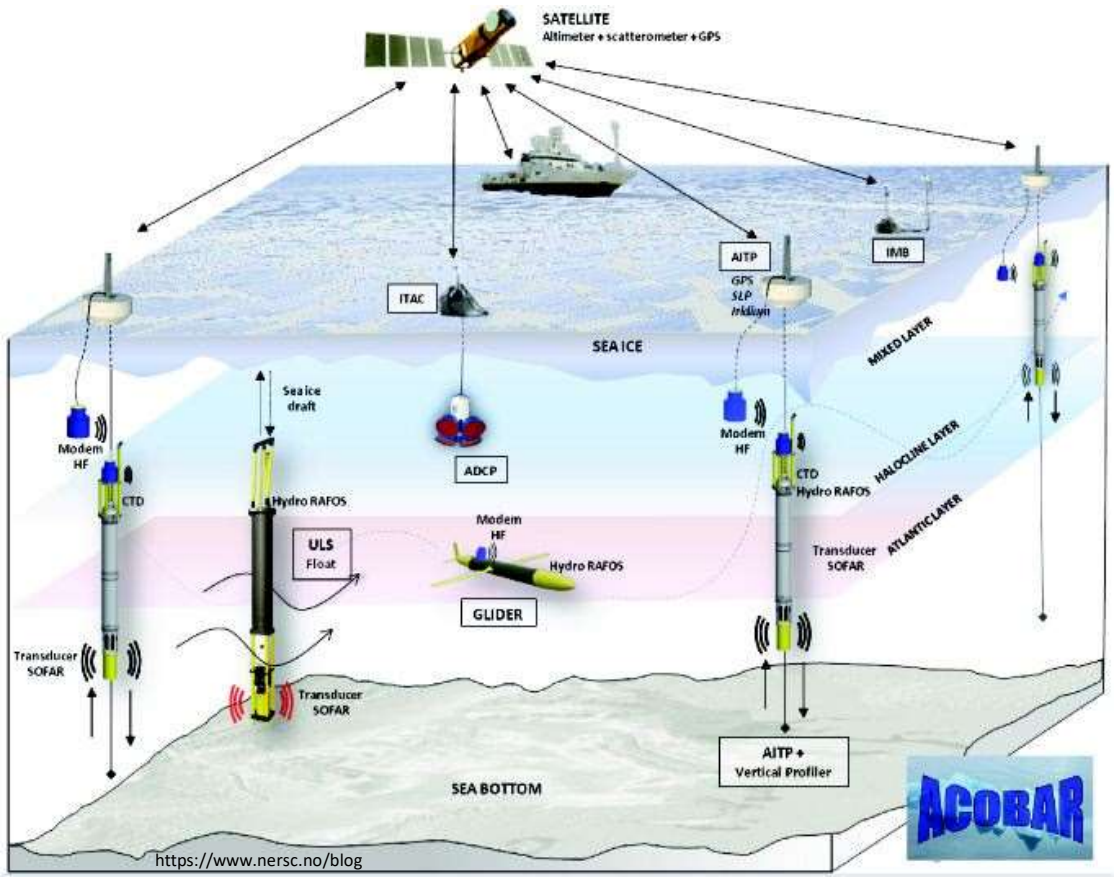
Integration of satellite remote sensing systems for ocean monitoring

Plymouth Marine Laboratory

Plymouth Marine Laboratory, UK

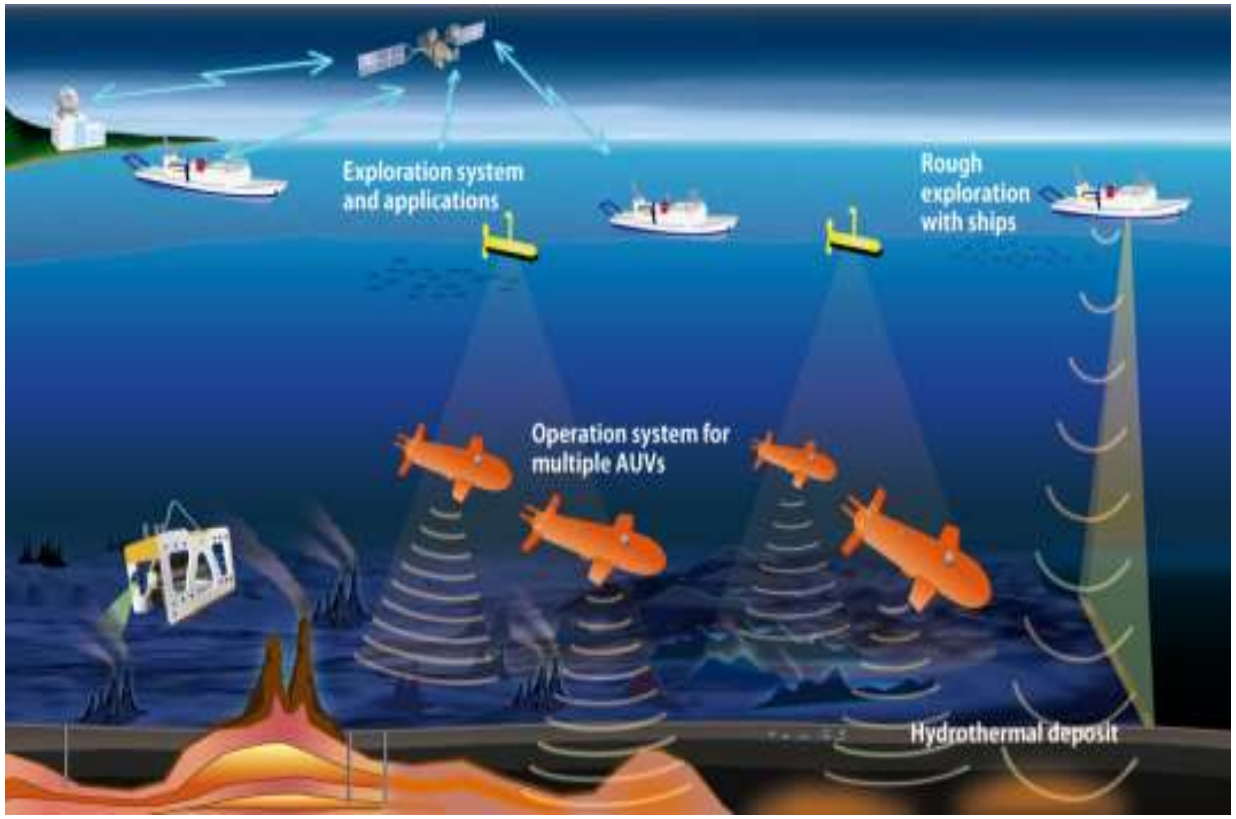
Advancements in geospatial technologies

Acoustic Technology for observing Interior of the Arctic Ocean



Nansen Environmental and Remote Sensing Center, Norway

Operational AUV systems for ocean exploration

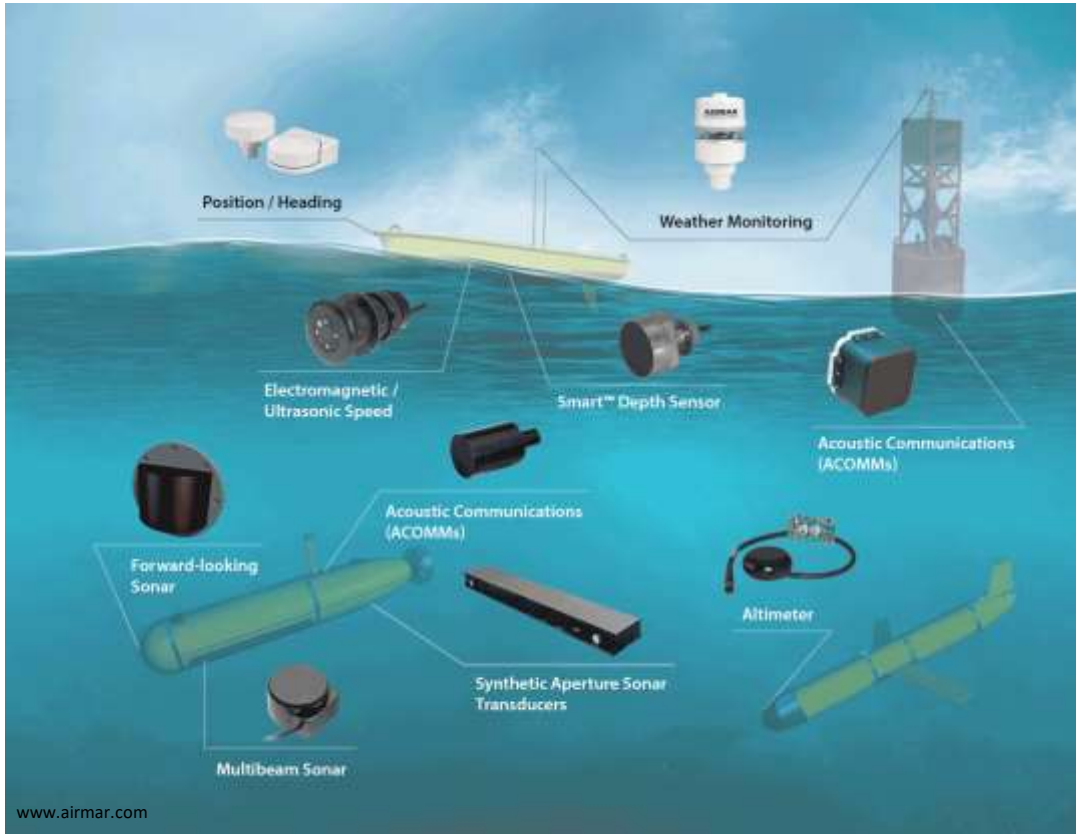


JAMSTEC- Japan Agency for Marine-Earth Science and Technology

Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

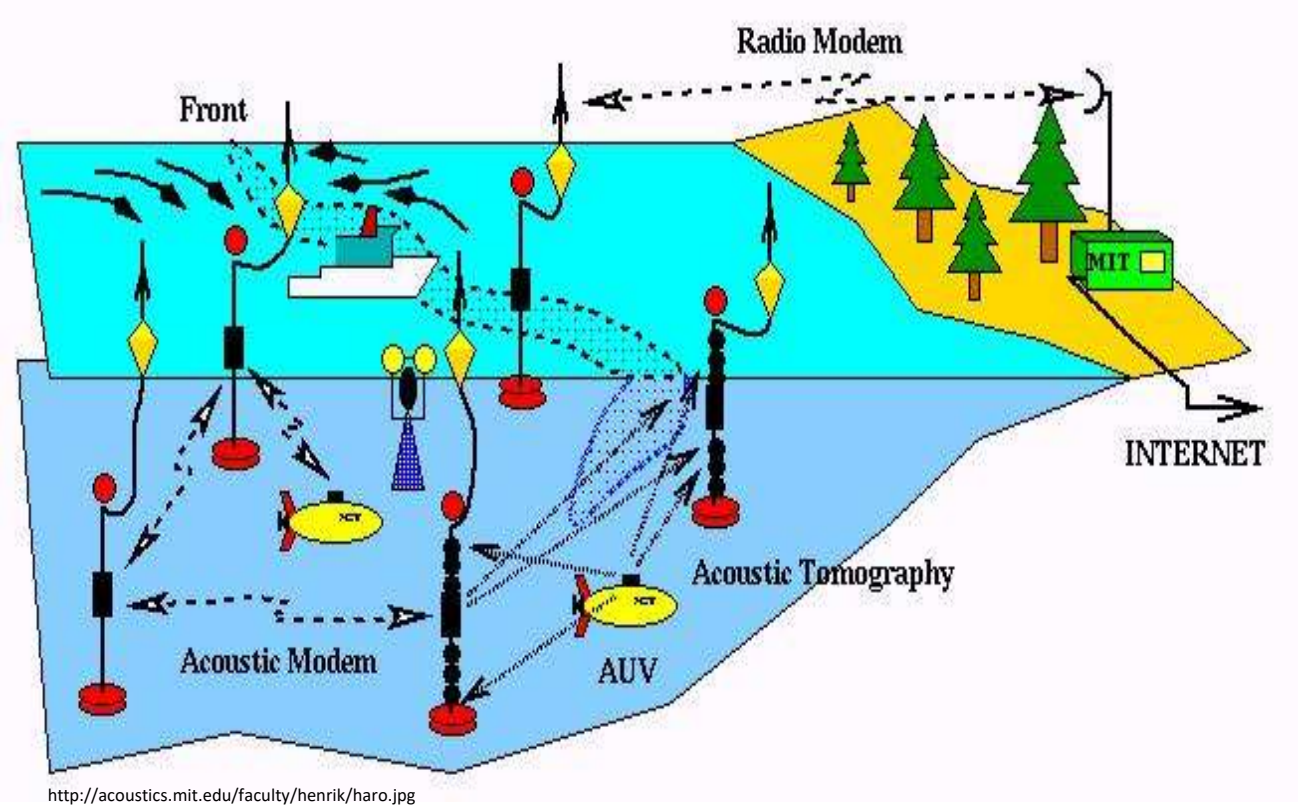
Advancements in geospatial technologies

Advanced Offshore monitoring systems



AIRMAR technology corporation, USA

Real-time, Adaptive Environmental Assessment Using Autonomous Oceanographic Sampling Networks

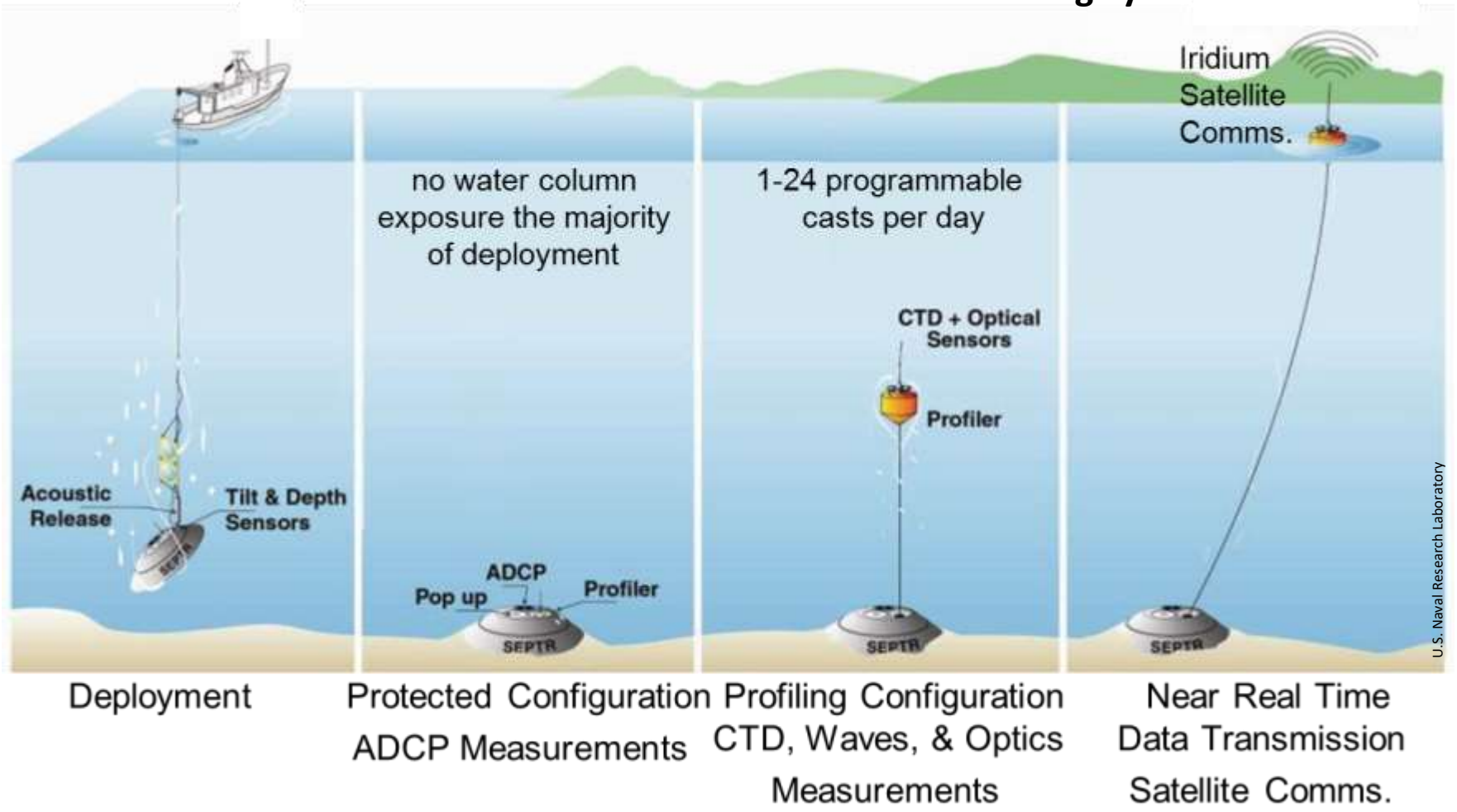


http://acoustics.mit.edu/faculty/henrik/haro.jpg

Department of Ocean Engineering, MIT, USA

Advancements in geospatial technologies

Autonomous Underwater Environmental Monitoring System



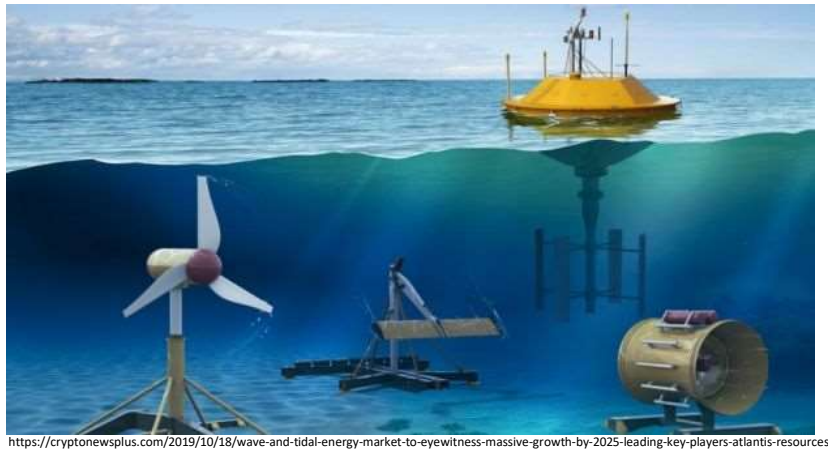
Naval Research Laboratory, USA

Marine Resources

- **Physical/Geological resources**
  - Mineral deposits, petroleum, natural gas, freshwater
- **Biological resources**
  - Plants and animals, microbes
- **Marine energy resources**
  - Energy from heat or motion of water
- **Non-extractive resources**
  - Transportation, recreation, waste disposal

https://ritefmonline.org/wp-content/uploads/2015/06/fishibg.jpg

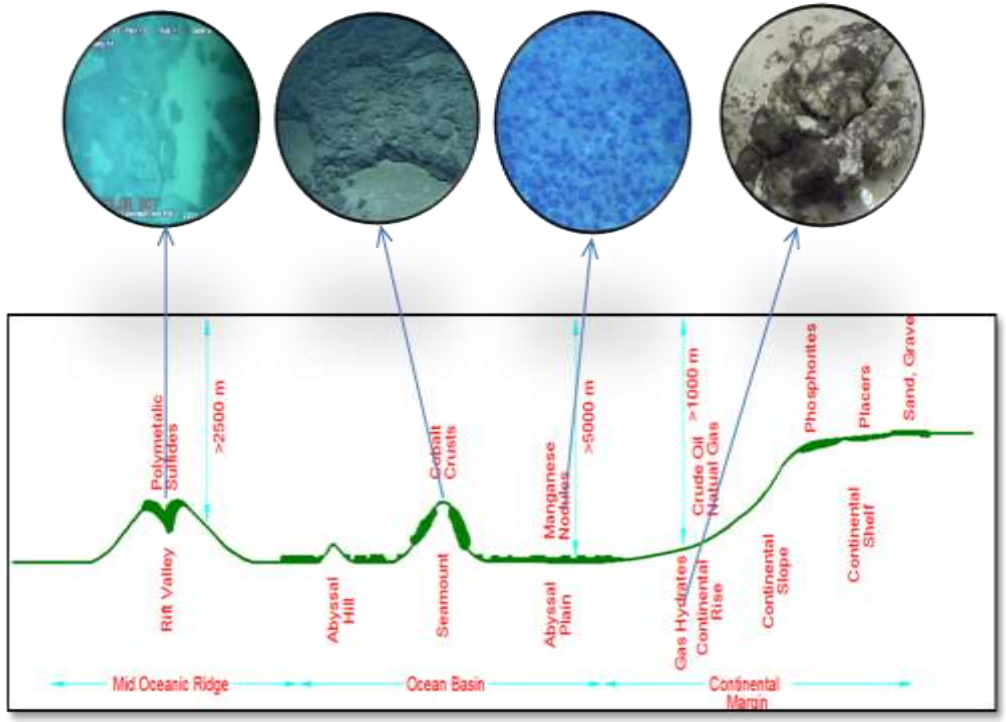
https://moneyinc.com/microbial-armor-could-be-a-solution-for-the-worlds-dying-coral-reefs/



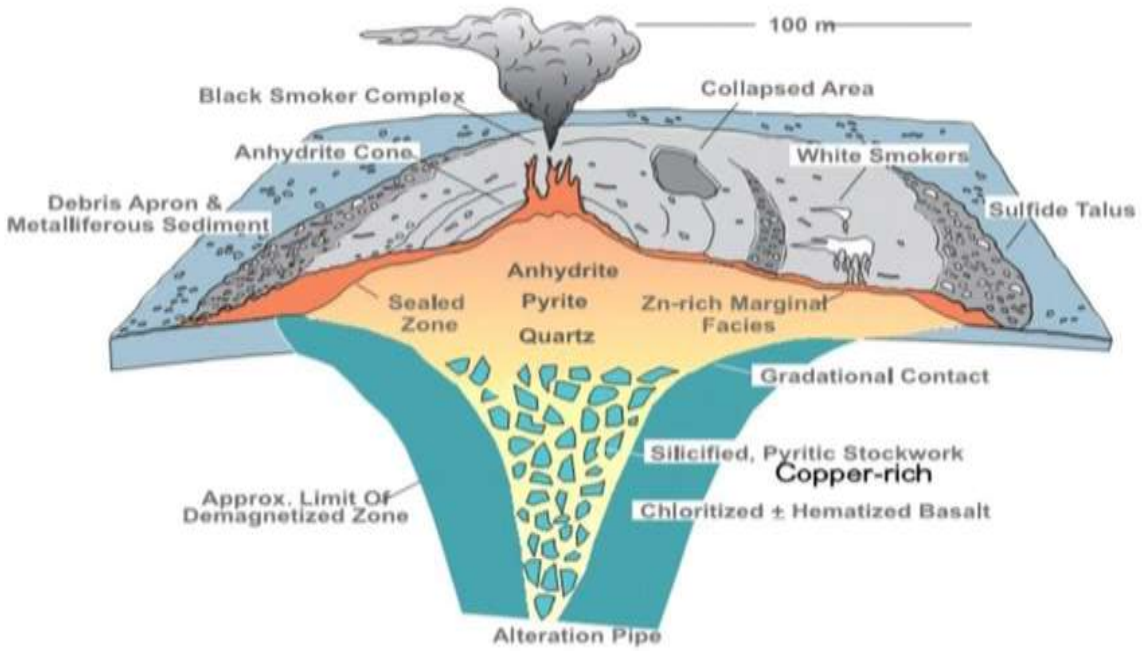
https://cryptonewsplus.com/2019/10/18/wave-and-tidal-energy-market-to-eyewitness-massive-growth-by-2025-leading-key-players-atlantis-resources-corp-aw-energy/

Marine Mineral Resources

- Marine mineral resources are found either **dissolved in the seawater** or they can be found as **deposits**.
- Classified into **five groups**:
  - Construction materials - sand, gravel, and other high bulk materials.
  - Industrial materials - silica sand, aragonite, phosphates, and sulfur.
  - Metallic minerals - gold, platinum, tin, titanium, and rare earth metals.
  - Metalliferous oxides - manganese, copper, nickel, and cobalt.
  - Metalliferous sulfides - copper, lead, zinc, chromium, and gold.

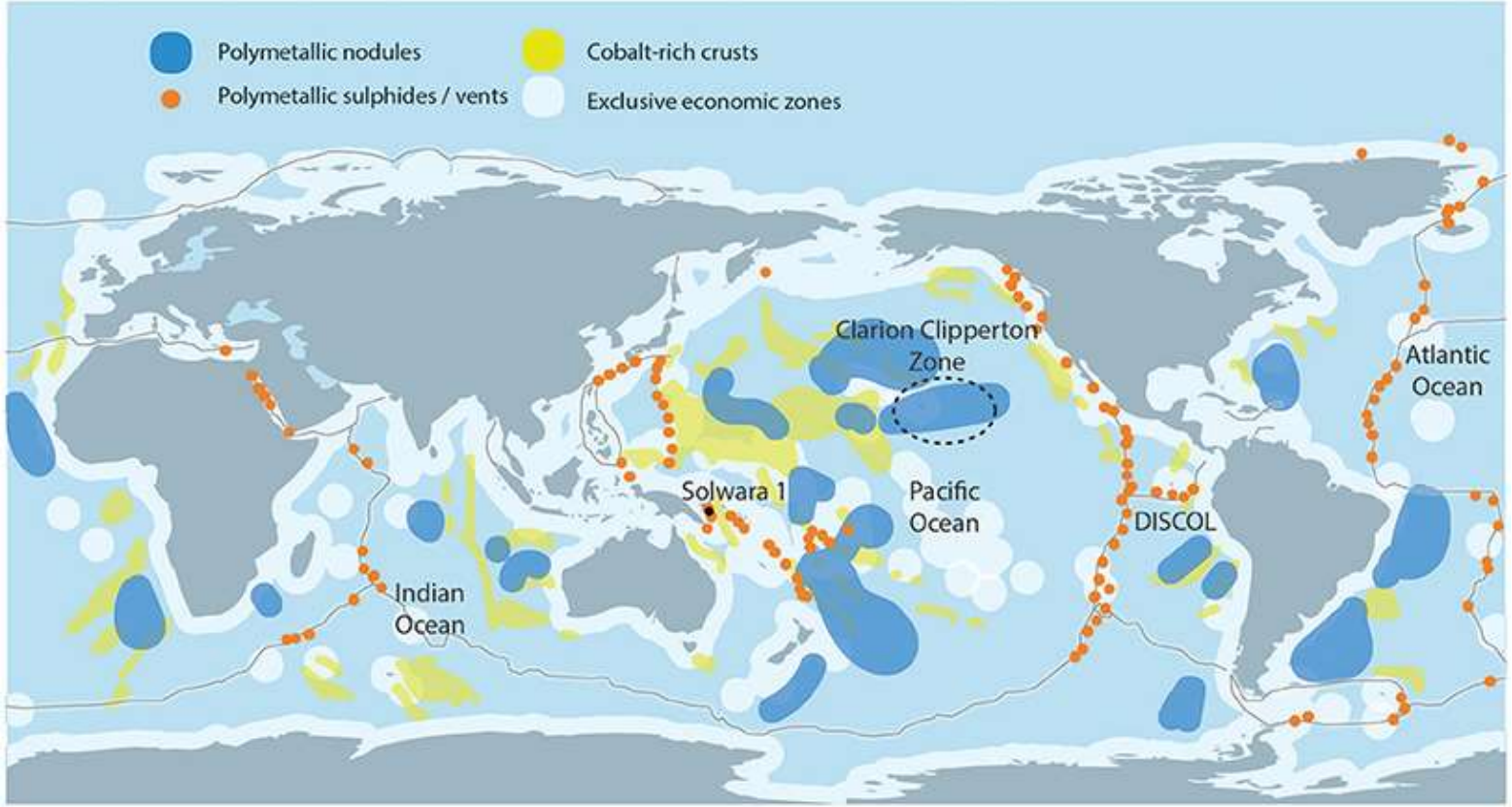


Mid Ocean Ridge Ore Deposits

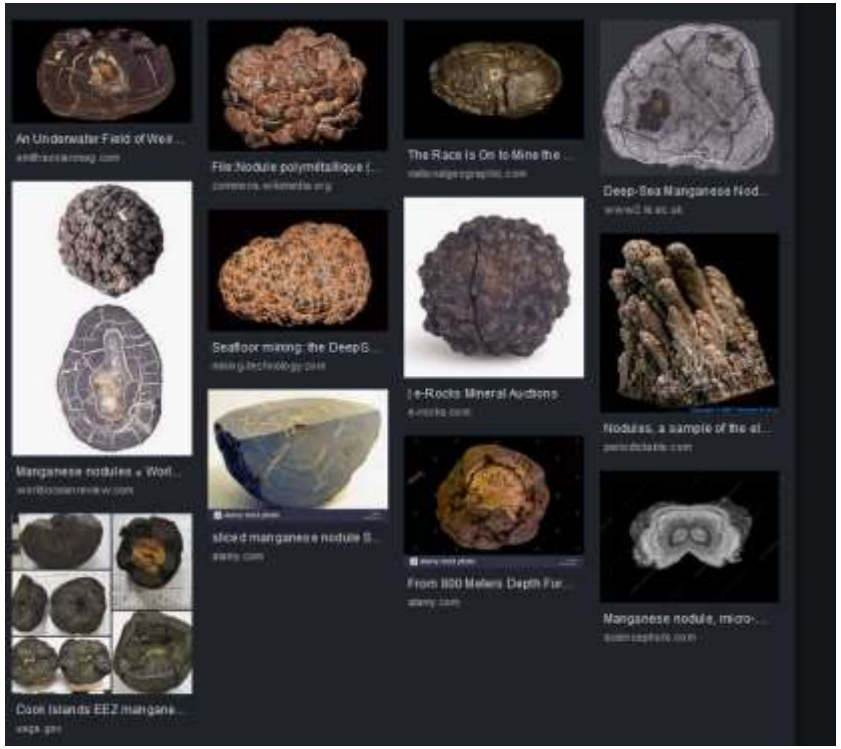


Deep Sea Minerals

- Large scale mining without permanent damage to the environment difficult.
- Highest interest area in deep sea mining.



Rising demand for minerals and metals, including for use in the technology sector, has led to a resurgence of interest in exploration of mineral resources located on the seabed

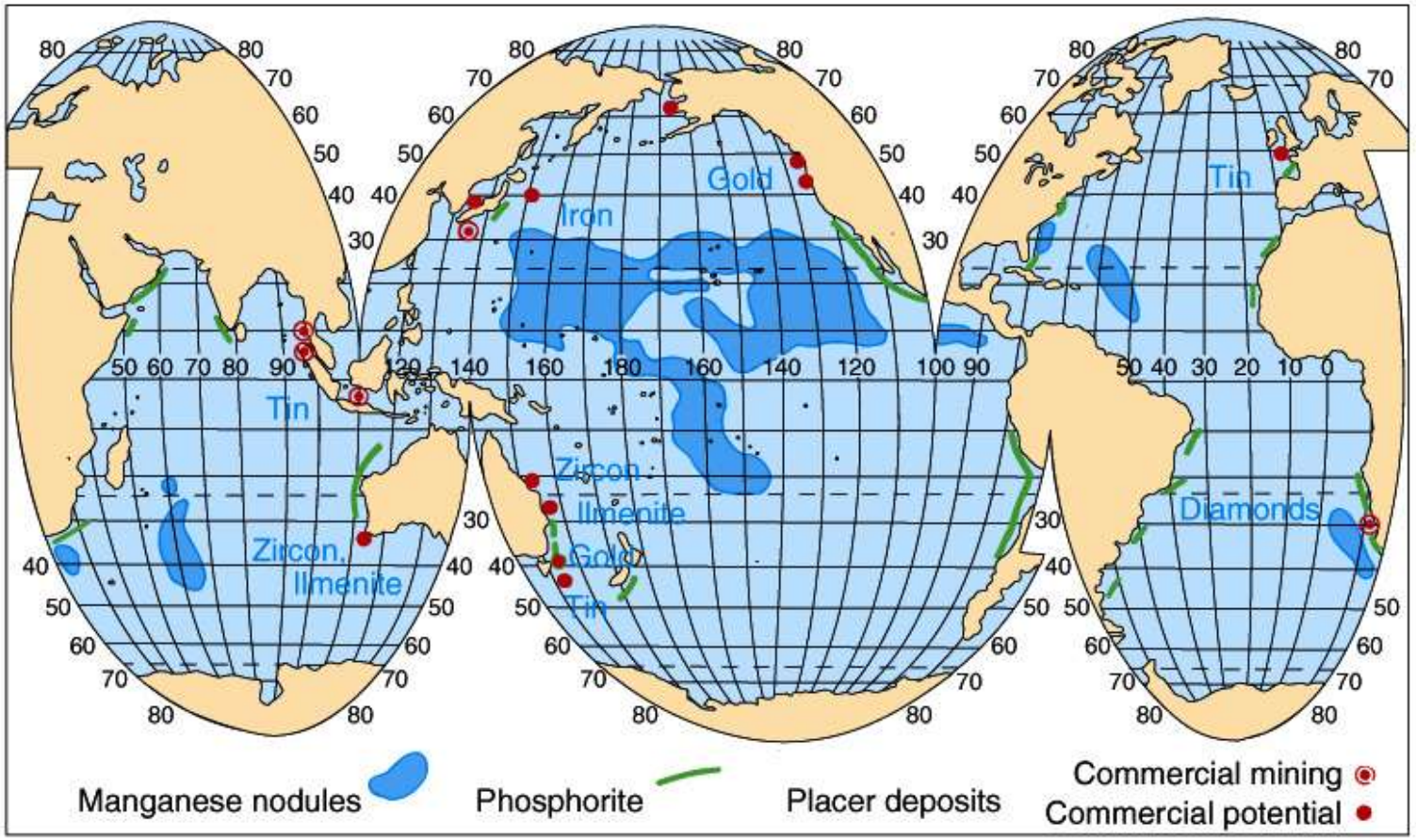


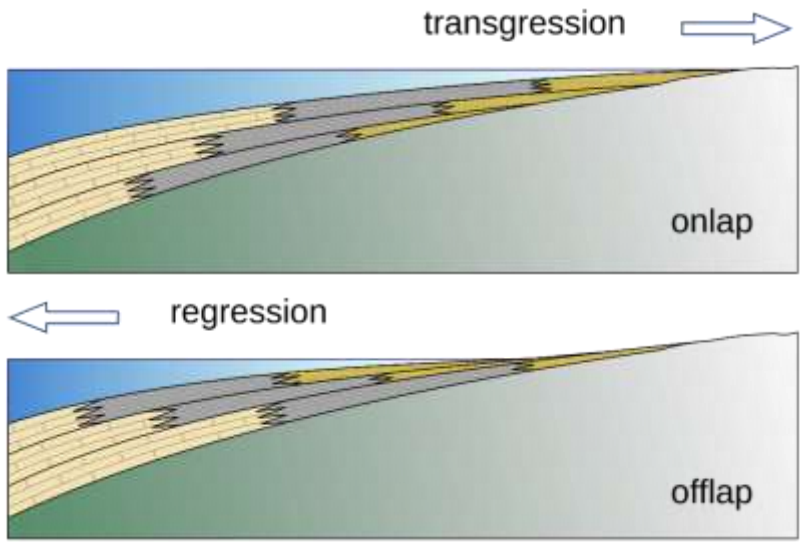
Average elemental content (dry wt. %)	Atlantic	Pacific	Indian
Manganese	15.46	19.27	15.25
Iron	23.01	11 79	13.35
Nickel	0.308	0.846	0.534
Copper	0.141	0.706	0.295
Cobalt	0.23410	0 290	0.247
Manganese/Iron	0.67	1.6	1.14

Table 1 - Average elemental concentrations for manganese nodules from different seafloor provinces (*after:* Cronan, 1977, 1980, 2000; Gross & McLeod, 1987).

Placer deposits

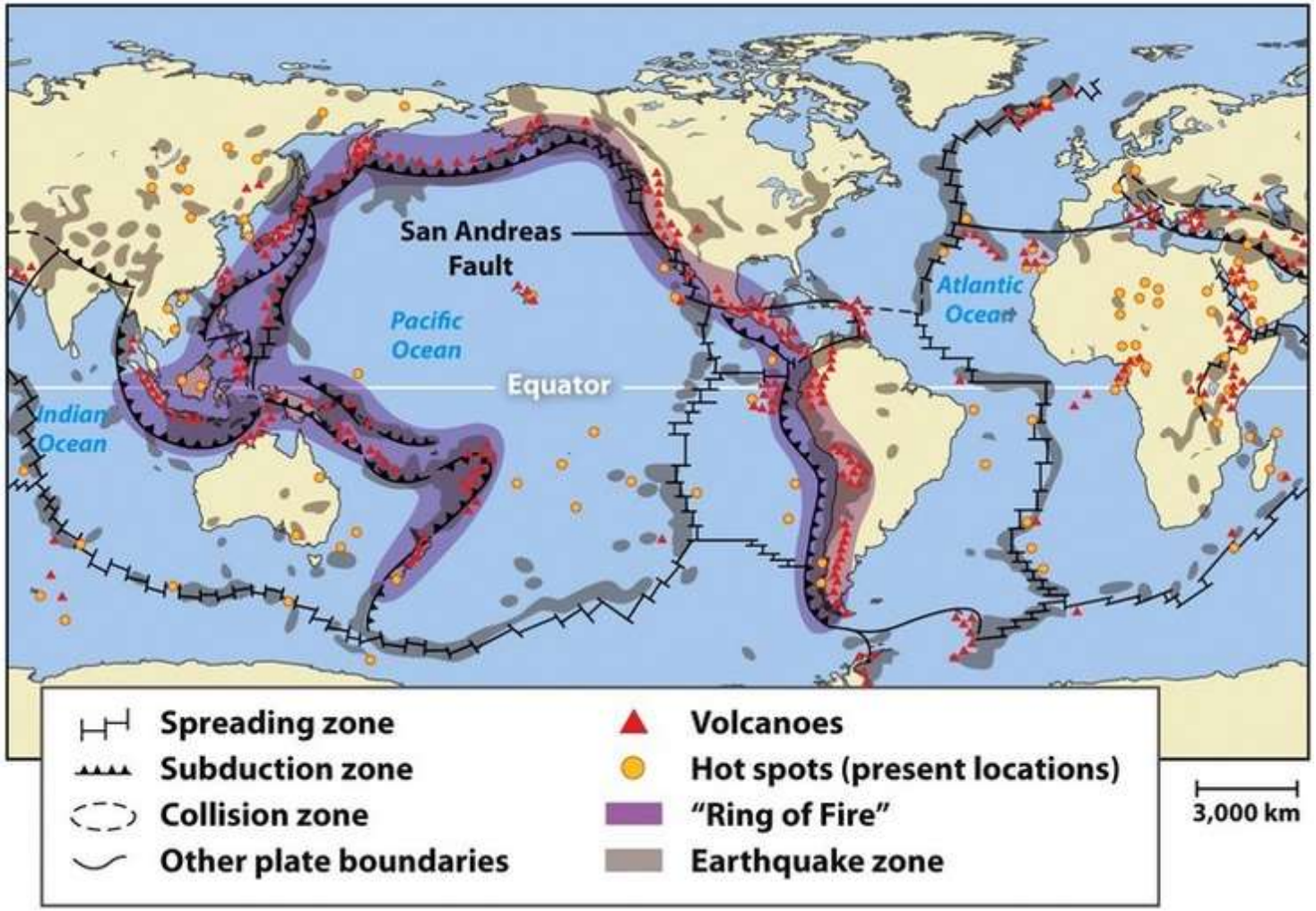
The heavy-mineral placer deposits are composed of about 85 percent opaque iron minerals, mostly magnetite, hematite, and ilmenite, and about 15 percent nonopaque minerals, mostly zircon, with minor amounts of tourmaline, rutile, garnet, sphene, hornblende, apatite, gold, cassiterite, platinum, and gemstones and traces of other minerals.
The state of Kerala is the best in India, in terms of titanium mineral placer resources - especially of ilmenite, with over 60% of contained TiO_2 in the world's leading ilmenite deposit at Chavara





Other important deposits

- There are other hard rock gold deposits other than epithermal lodes.
- There are Greenstone, volcanic massive sulphides, porphyry and Calrin trend deposits.



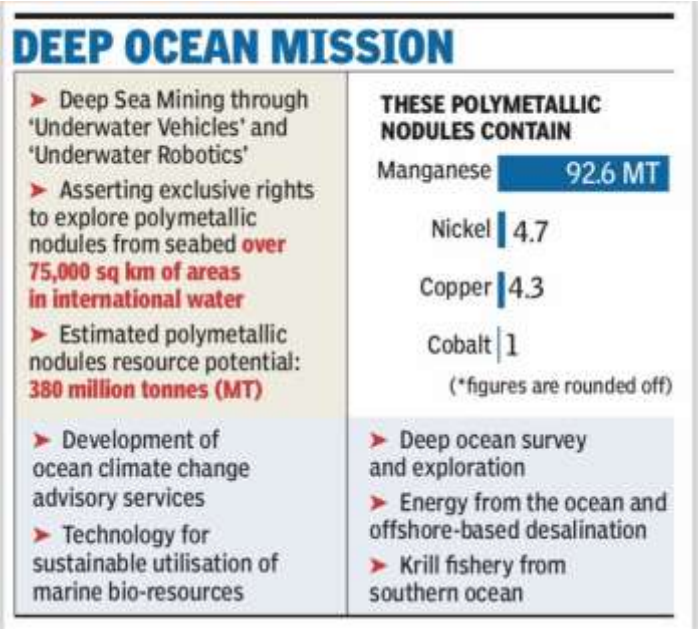
India's Deep Ocean Mission

Significance of the Mission:

- The 'Deep Ocean Mission' plan will enable India to develop capabilities **to exploit resources in the Central Indian Ocean Basin (CIOB)**.
- India has been allotted **75,000 square kilometers** in the Central Indian Ocean Basin (CIOB) by UN International Sea Bed Authority for exploration of poly-metallic nodules.
- CIOB reserves contain deposits of metals like iron, manganese, nickel and cobalt.

Potential:

- It is envisaged that 10% of recovery of that large reserve can meet the energy requirement of India for the next 100 years.
- It has been estimated that **380 million metric tonnes** of polymetallic nodules are available at the bottom of the seas in the Central Indian Ocean.



Ministry of Earth Sciences to launch 'Deep Ocean Mission'

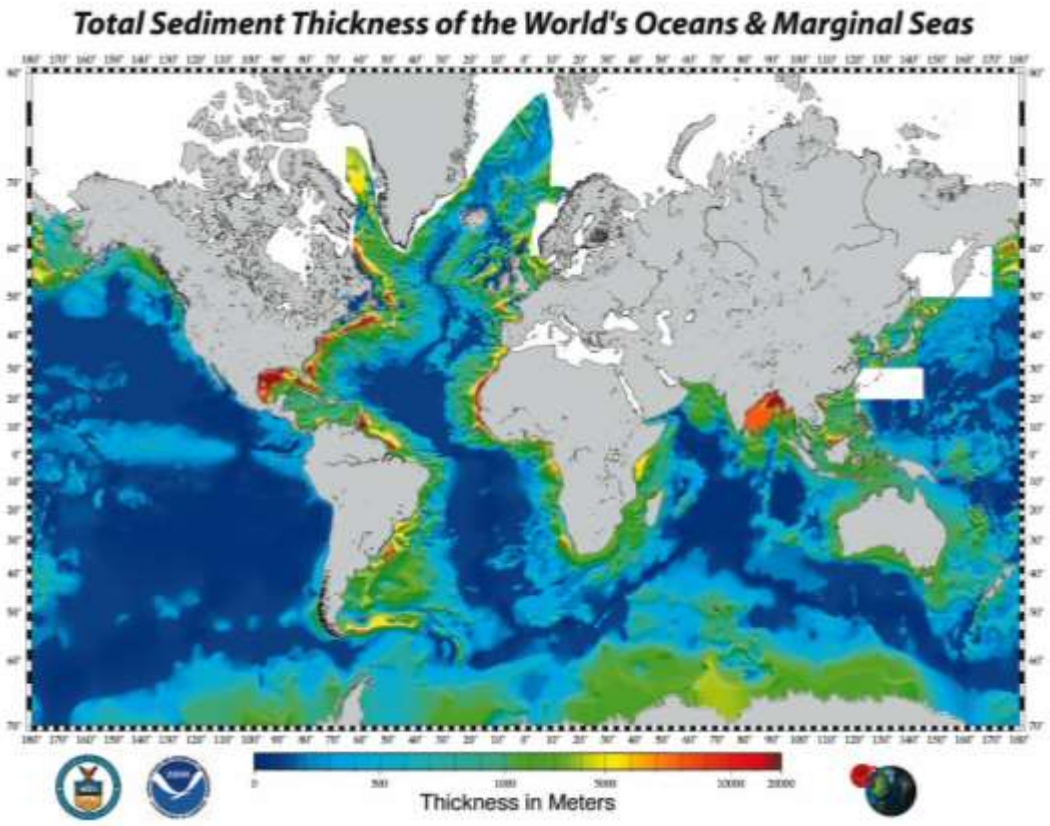
TNN | Updated: May 31, 2017, 14:29 IST

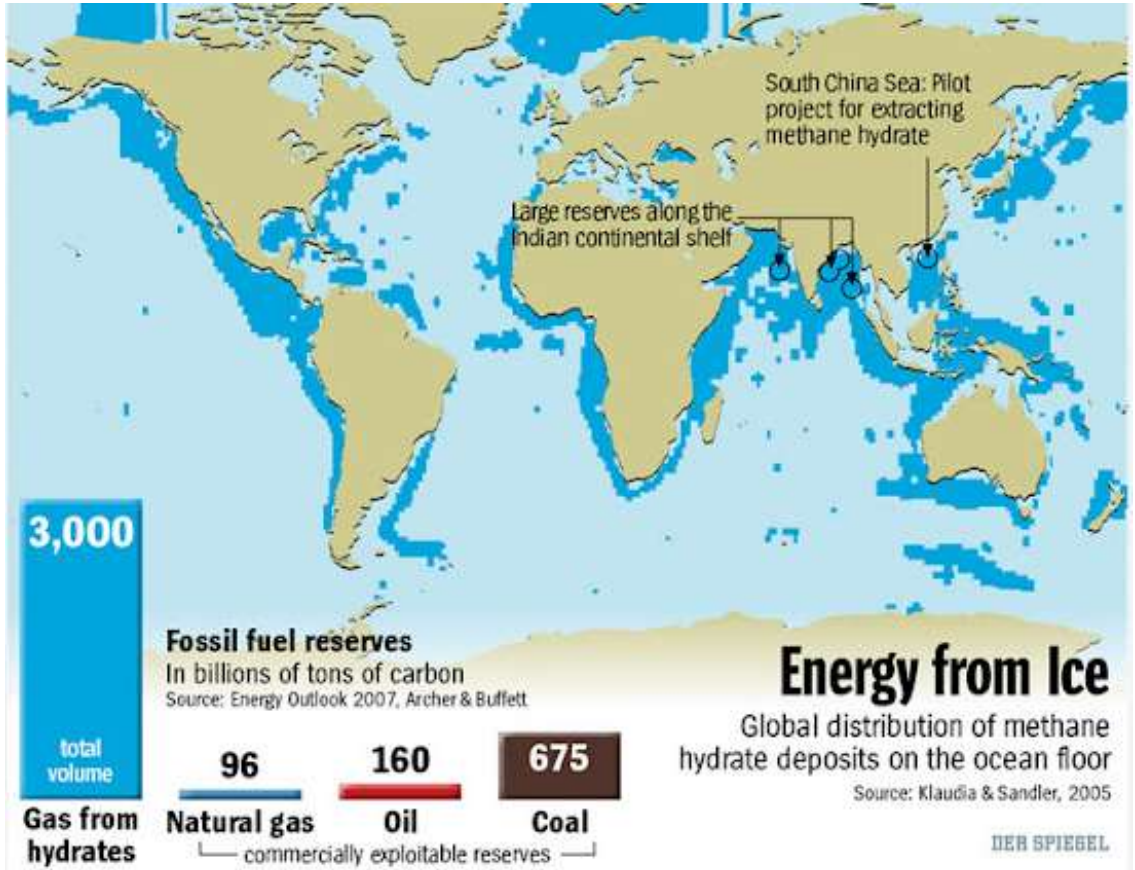
A- A+

NEW DELHI: Ministry of Earth Sciences is all set to launch 'Deep Ocean Mission' by January 2018. This will improve India's position in ocean research field.

https://timesofindia.indiatimes.com/good-governance/centre/ministry-of-earth-sciences-to-launch-deep-ocean-mission/articleshow/58922794.cms

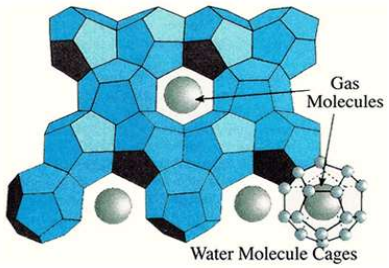
Marine petroleum resources



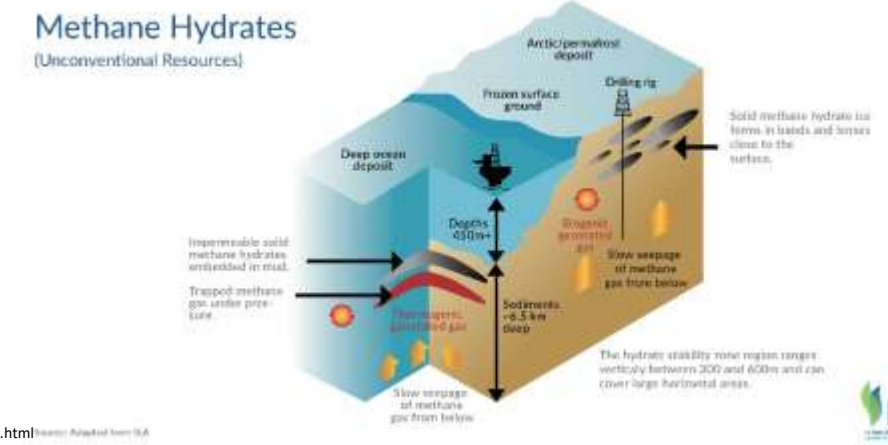


https://alfinnextlevel.wordpress.com/2016/07/09/the-age-of-petroleum-has-just-begun/

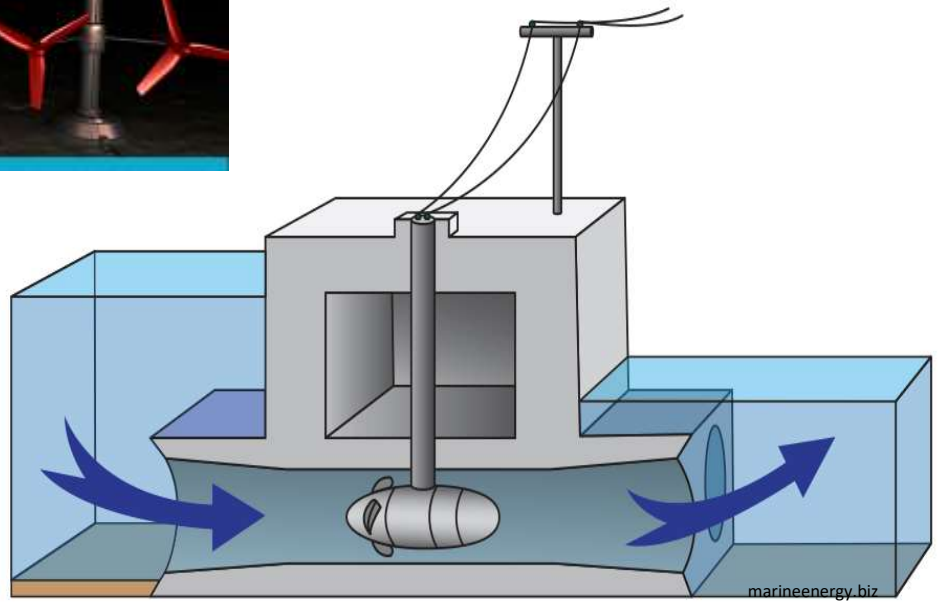
http://www.waterencyclopedia.com/Oc-Po/Petroleum-from-the-Ocean.html



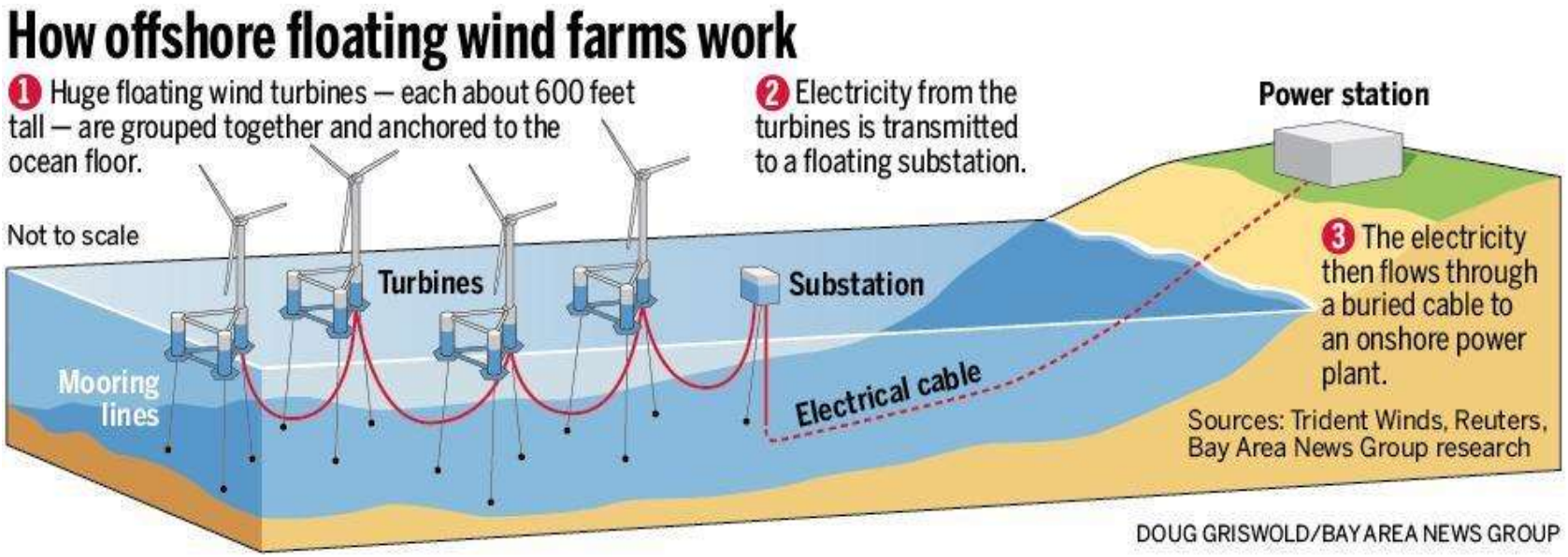
https://people.wou.edu/~courtna/Energy/Gas_Hydrates.html



Marine Energy resources – Tidal Energy

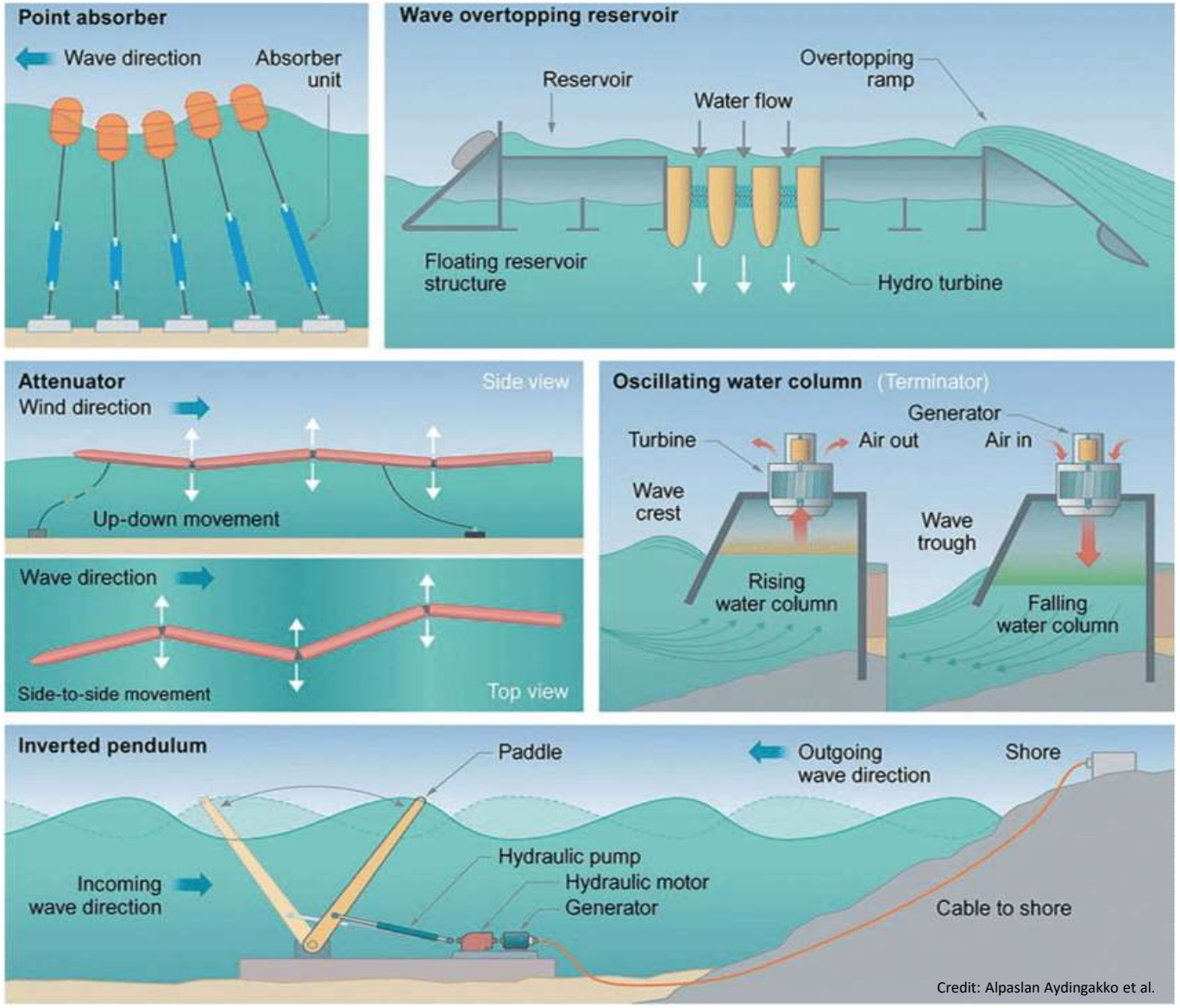


Marine Energy resources – Wind Energy



Marine Energy resources – Wave Energy

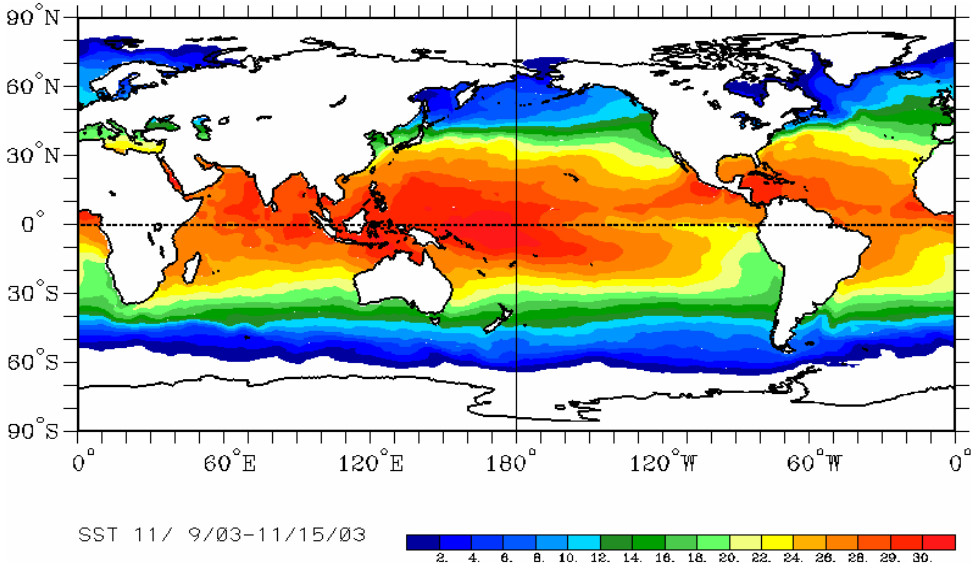
- The **Buoyant Moored** Device works by rotating about a long linkage.
- The **Hinged Contour** Device moves with the waves, the motion is resisted at the joints.
- The **Oscillating Water Column**, water works as a piston to pump air and drive a turbine to generate power.
- The **Pelamis Machine** floats on the surface of the water. The rolling motion of the waves generates electricity.
- The **Energy buoys** are anchored to the ocean floor and generating electricity by the bobbing up and down

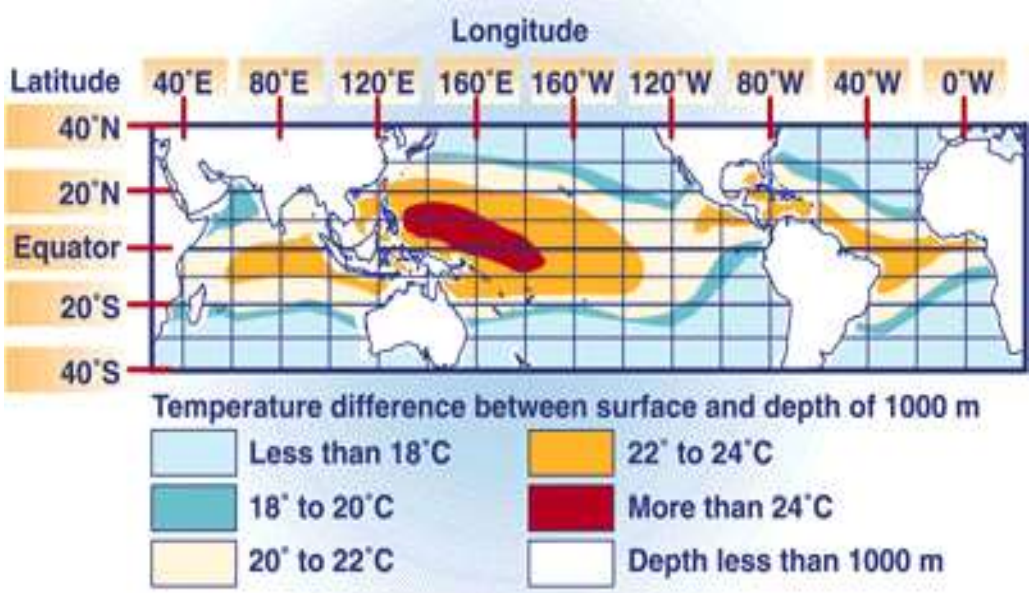


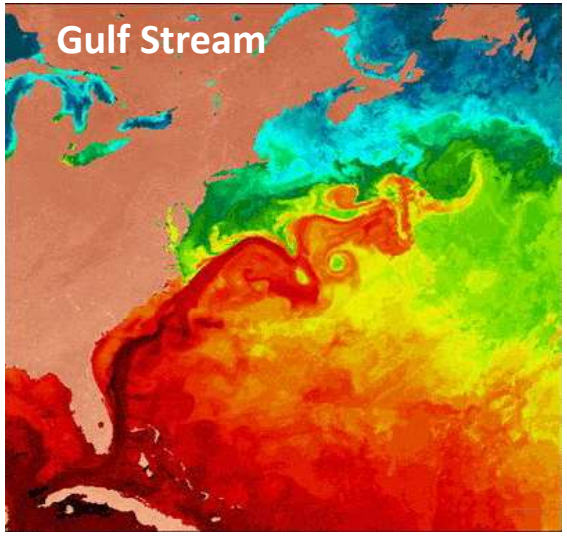
Credit: Alpaslan Aydingakko et al.

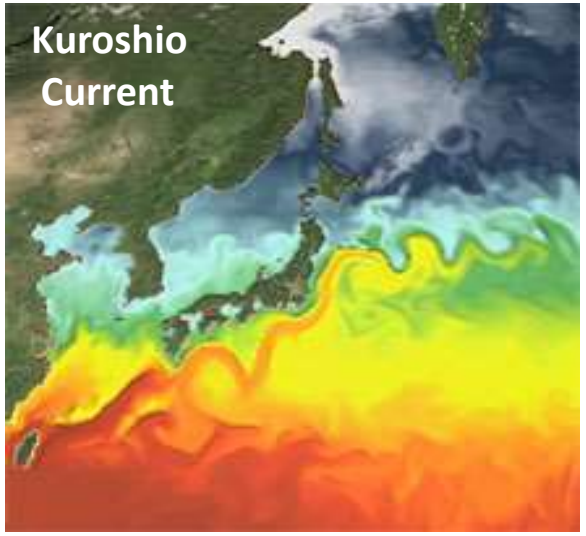
Marine Energy resources – Thermal Energy

Sea Surface Temperature (Global/regional level)









Marine resources – Fisheries/Marine foods

- Marine fisheries are **very important** to the economy and well-being of coastal communities, providing food security, job opportunities, income and livelihoods as well as traditional cultural identity.

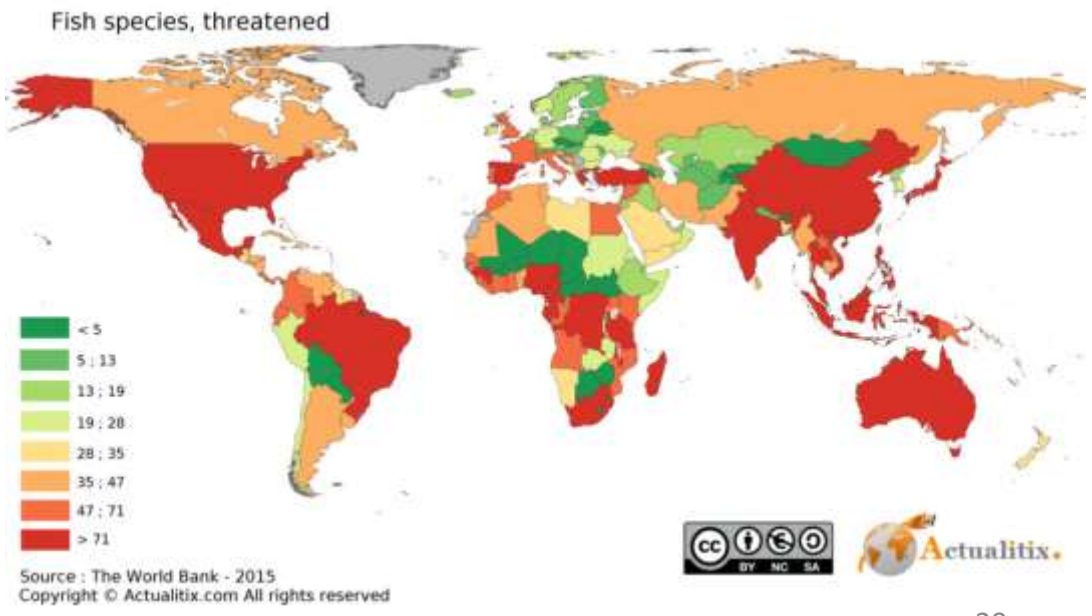
- They produced **80 million tonnes** of fish in 2009 and directly employed 34 million people in fishing operations in 2008 (FAO, 2010).

- Fish and fishery products are a vital and affordable source of high-quality protein, especially in the world's poorest nations – in 2008.

- Fish supplied **more than 3 billion people** with at least 15 percent of their average animal protein intake (FAO, 2010).

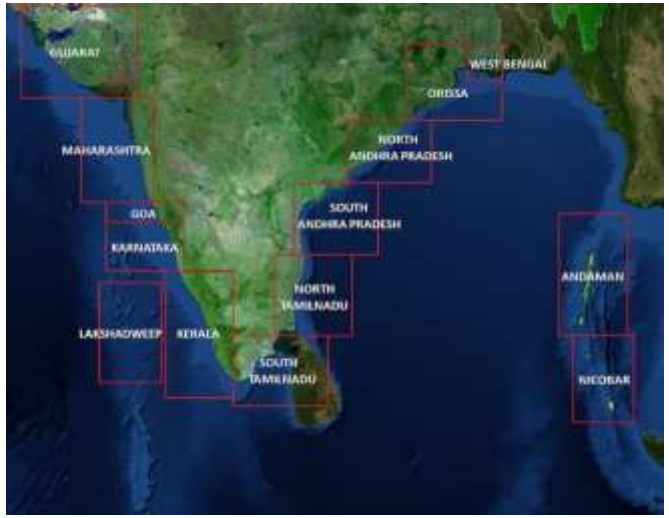
- Therefore, maintaining the long-term prosperity and sustainability of marine fisheries is not only of political and social significance but also of **economic and ecological importance**.

https://in.pinterest.com/pin/138696863500730045/?lp=true



Marine resources – Indian Fisheries/Marine foods

- Indian fisheries and aquaculture is an **important sector** of food production providing nutritional security.
- Employment to **more than 14 million people**, and contributing to agricultural exports.
- Several Species-Pelagic and Demersal Classes.
- Potential: About **3.9 MT** per annum.
- Harnessing: About 3.1 MT per annum.
- Living of **7 Million population** from 10 States and 2 Islands.
- 2.2 Million Artisanal Fishermen.
- 100,000 Motorized / Mechanized/ Deep Sea Vessels.
- 70 % Catch from West Coast.
- Shifting Fishing Grounds.
- Remaining production of 0.8 MT to come **from the EEZ**, away from the coastal areas that are already exploited.
- **Satellite-based short-term fishery forecasts** have the capability to bridge this gap as well as improve the economics of fishing operations.

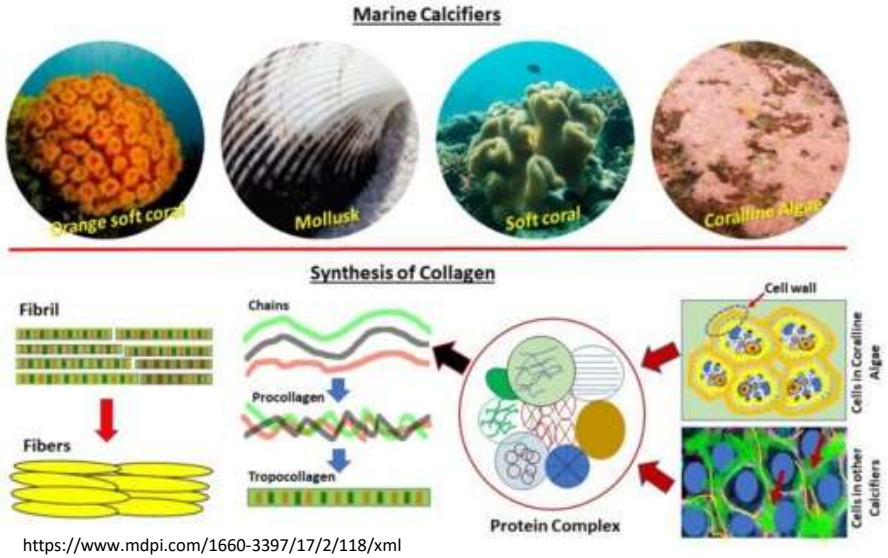


http://www.ccari.res.in/dss/images/marine/pfz1.jpg

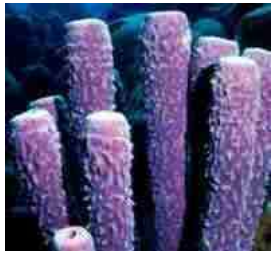
Credit: Aneesh Lotliker, INCOIS.

Marine resources – Medicines/Drugs

- 60% of prescribed drugs can be tracked back to natural products from nature – almost exclusively land-based.
- Very few marine-based medicinal drugs so far, mainly because we haven't been looking!
- New technologies e.g. **ROVs presents opportunities** for new drug discovery e.g. bacteria from hydrothermal vents.
- **Pharmaceuticals**
  - Anti-cancer compounds from sponges and pain killers from cone snails.
- **Medical research tools**
  - understanding pain reception using giant squid nerve cells.
- **Cosmetics**
  - Sea squirt extracts in face creams.
- **Nutritional supplements**
  - Omega 3's from cod liver oil.
- **Enzymes**
  - 'Anti-freeze' enzymes from ice fish to reduce frost damage in tomato plants.



https://www.mdpi.com/1660-3397/17/2/118/xml

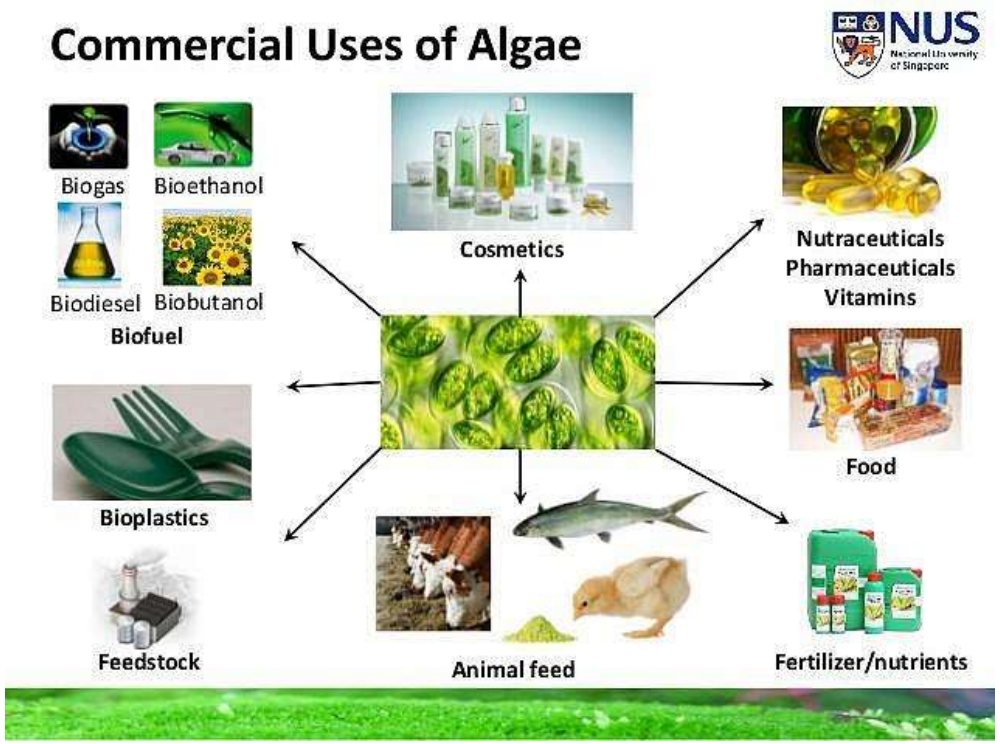


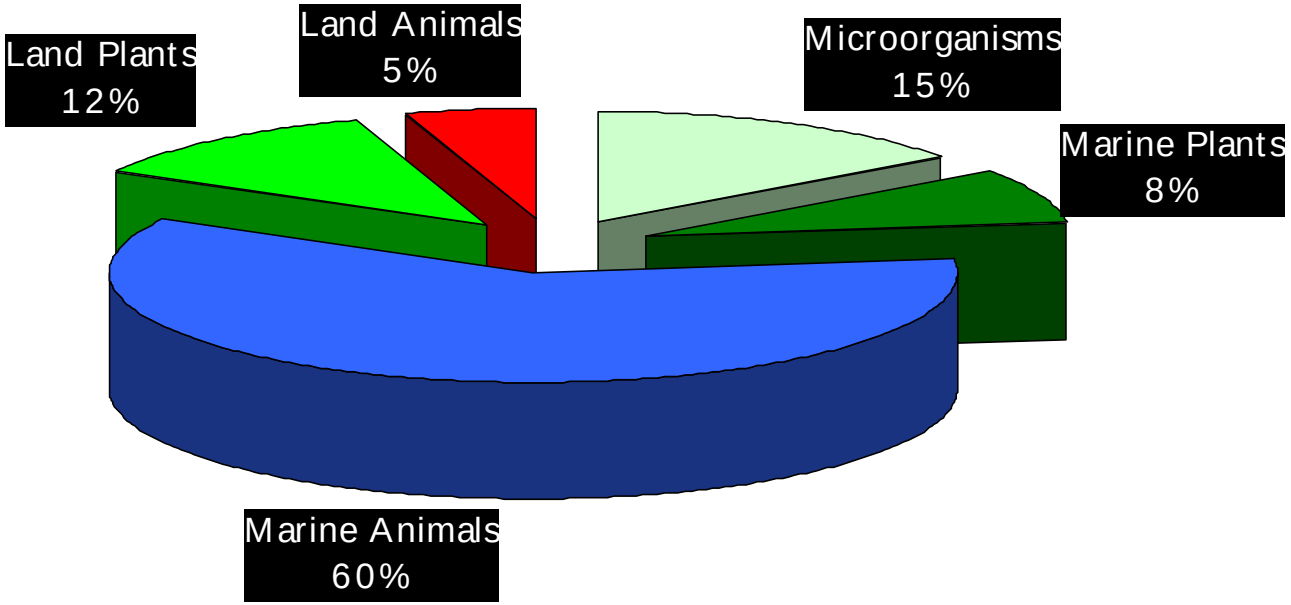
https://www.slideshare.net/VarshaSrivastav/recent-advances-in-marine-drugs

Marine resources – Medicines/Drugs

Results of DNA screening for '**bio-active**' compounds show marine animals come out on **top as potential sources** of medicinal drugs for the future.

"the potential is enormous… "

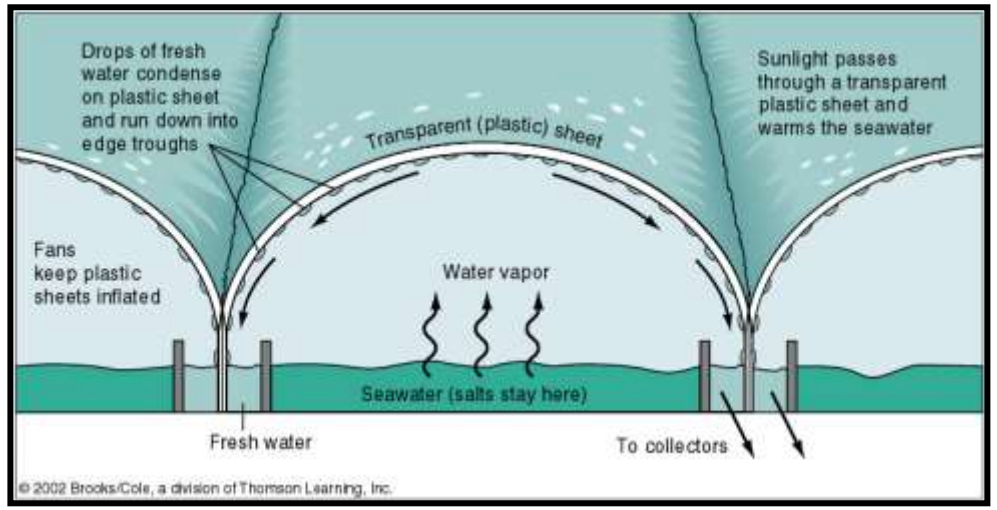


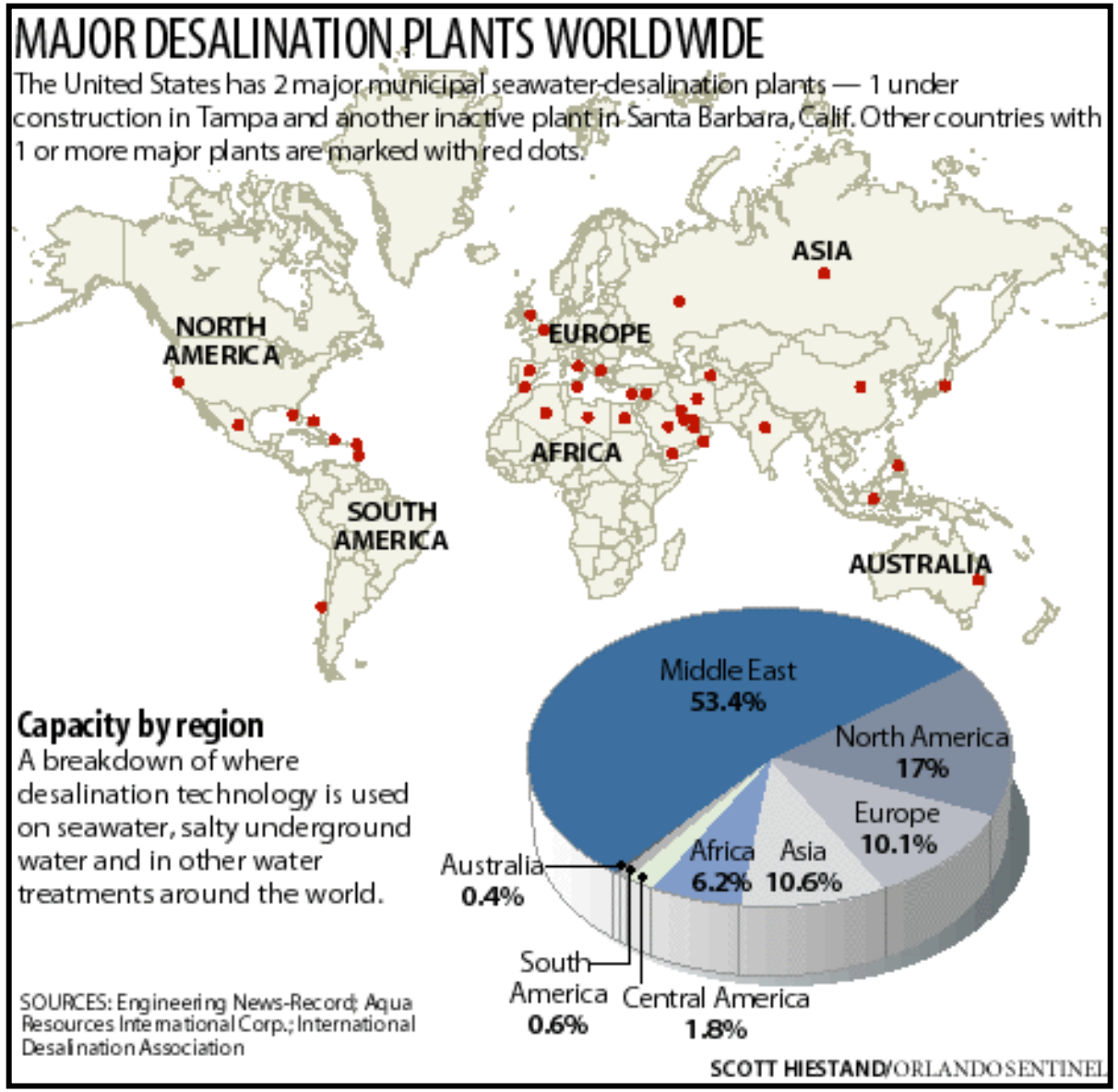


https://www.slideshare.net/VarshaSrivastav/recent-advances-in-marine-drugs

Fresh Water

- Only 0.071% of Earth's water is liquid, fresh, and available at the surface for humans.
- More than 1500 desalination plants worldwide.
- 3.5 billion gallons/day, and rising!





Action areas in marine environment

Threats to ocean

- Pollution / water quality degradation
- Eutrophication, Coastal hypoxia
- Harmful algal blooms
- Dredging and turbidity plume
- Marine micro-macro-plastics
- Ocean acidification, Coral bleaching
- Degradation of wetland/mangrove ecosystem
- Coastal aquaculture development and impacts
- Coastal erosion, sediment transportation and deposition
- Sea level rise, Tsunami, Storm surge
- Coastal land subsidence, Coastal flooding / Inundation
- Deep sea mining and ocean vulnerability
- Thermal plume contamination in coastal zones

https://sdgcompass.org/wp-content/uploads/2016/04/Goal_14.pdf

Promote ocean sustainability, innovative solutions that reduce/ mitigate detrimental impacts to marine environments .

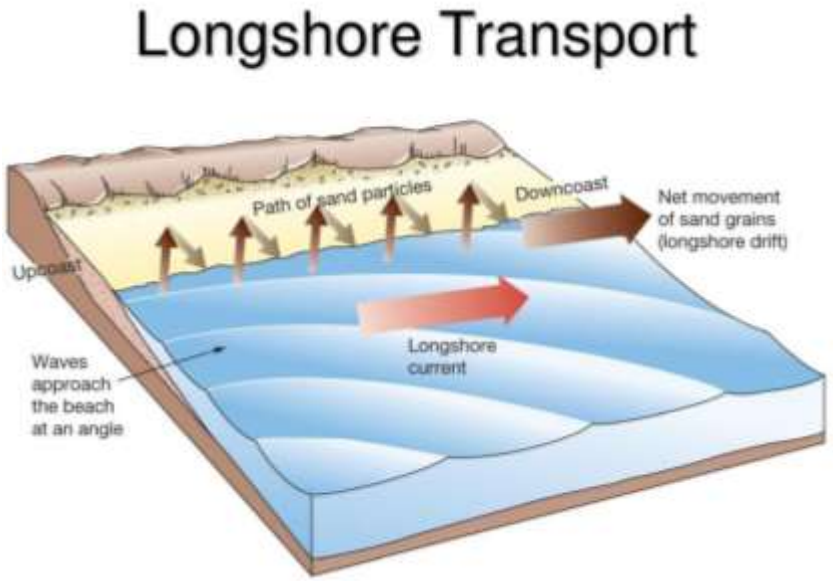
Vulnerabilities in marine and coastal environment

Coastal Erosion

Erosion is destructive waves wearing away the coast.

- **Abrasion**
- **Attrition**
- **Hydraulic Action**
- **Solution**

Sediment Transport



Movement of material along the shore by wave.

- **Swash**
- **Backwash**

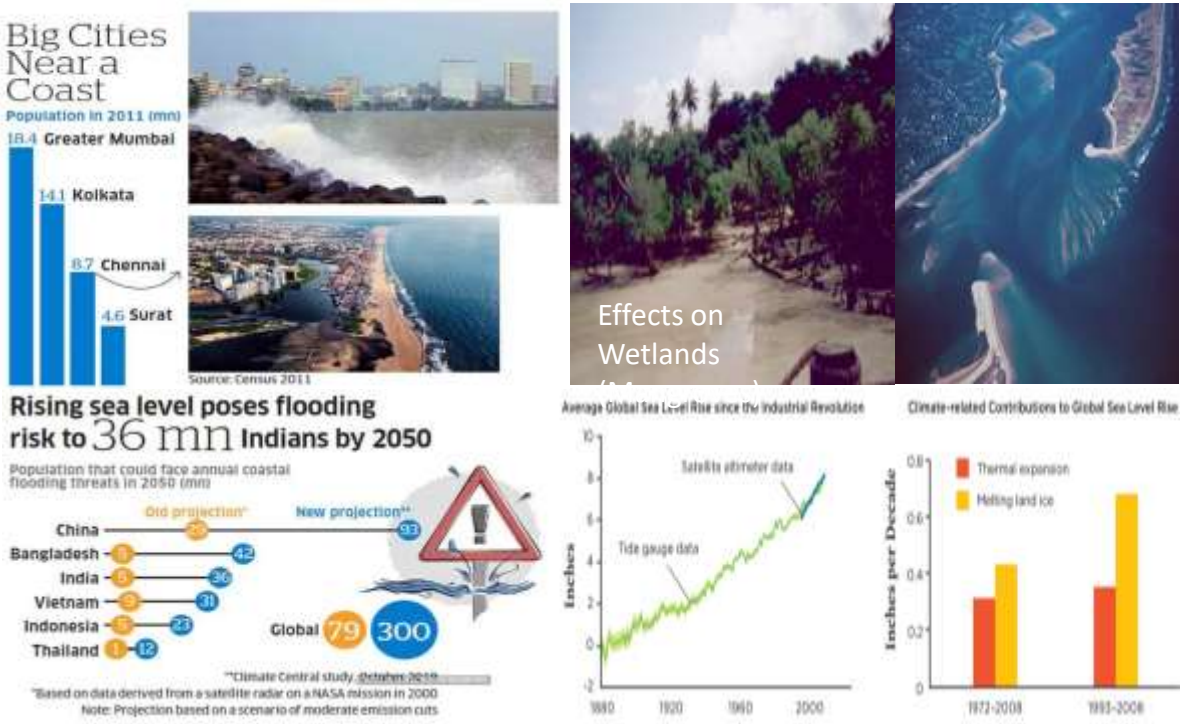
Sediment Deposition

Dropping of material due to a fall in energy resulting in depositional landforms.

- Beaches, Spits, Tombolo,
- Sand bars, Barrier islands, Barrier beaches,
- Cuspate forelands and Sand dunes.

Vulnerabilities in marine and coastal environment

Sea Level Rise



- Loss of wetland/buffer zones
- Loss of fishing/hunting
- cultural impacts- loss of historic lands

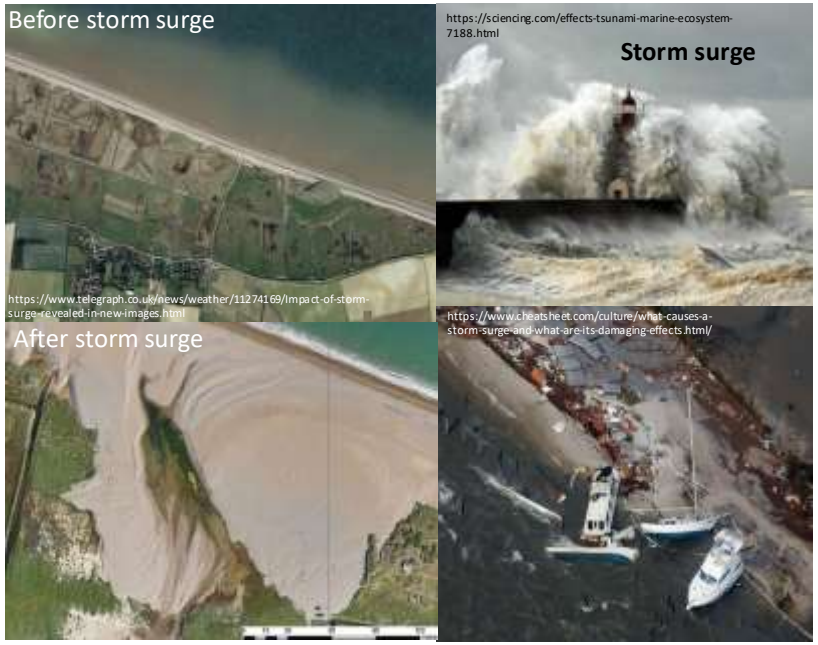
Tsunami

http://static.howstuffworks.com/gif/tsunami-formation.gif

- Tsunamis are long-wavelength waves generally **generated by submarine earthquakes**.
- **Deep-Ocean Assessment and Reporting of Tsunamis** (DART) uses unique **pressure recorders** that sit on the ocean bottom.

Vulnerabilities in marine and coastal environment

Storm surge



A rising of the sea as a result of wind and atmospheric pressure changes – typically a low pressure weather system associated with a tropical cyclone

- Storm surge travels several km inland destroying everything in its path (poorly constructed buildings are so easily swept away).
- Salt water contaminates soil – country relies on agriculture- subsistence life style. Leaves many people to lose their livelihood.

Coastal Flooding

A flood is an overflow of water that submerges land that is usually dry.

- Floods have large social consequences for communities and individuals.
- As most people are well aware, the immediate impacts of flooding include,
  - loss of human life, damage to property, destruction of crops,
  - loss of livestock, and deterioration of health conditions owing to waterborne diseases.

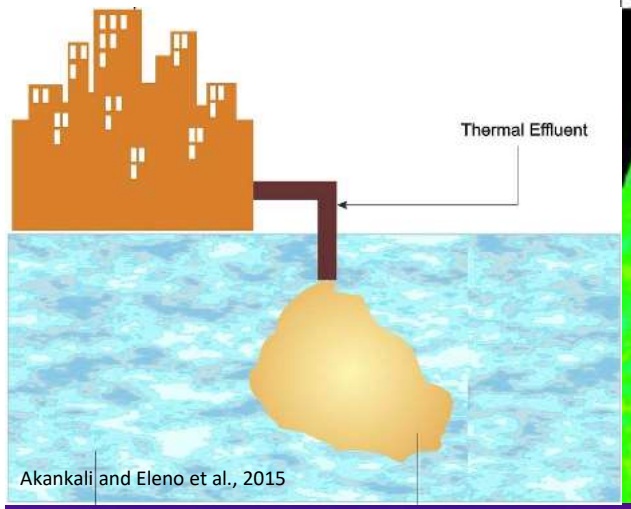
Inundation

An overflow; a flood; a rising and spreading of water over grounds; and to the state of being inundated; flooding.

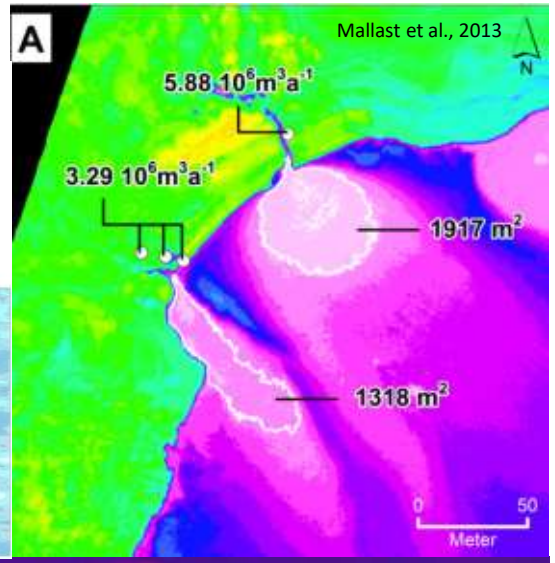
- Economic hardship due to a temporary decline in tourism, rebuilding costs
- food shortages leading to price increases is a common after-effect of severe flooding.

Vulnerabilities in marine and coastal environment

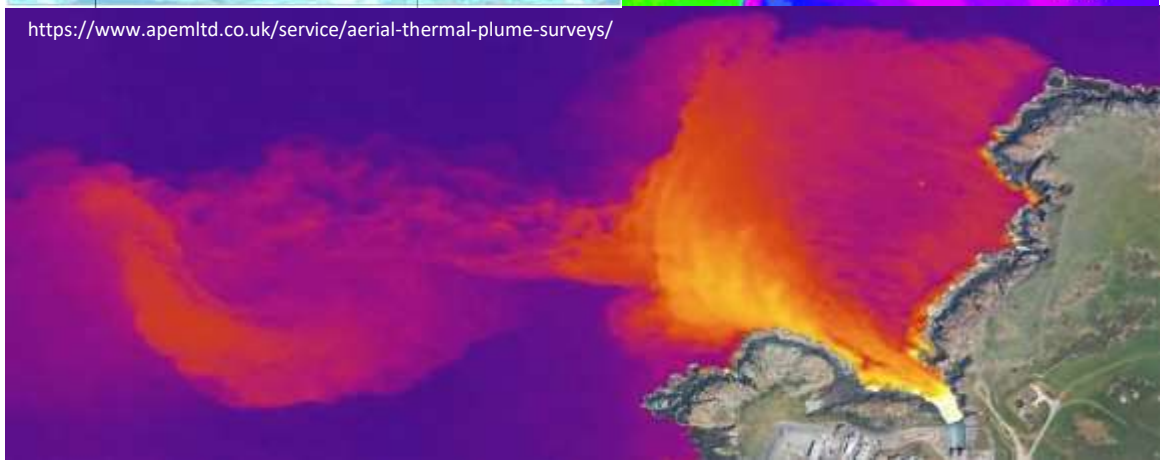
Thermal plume contamination in coastal zones



Akankali and Eleno et al., 2015



Mallast et al., 2013



https://www.apemltd.co.uk/service/aerial-thermal-plume-surveys/

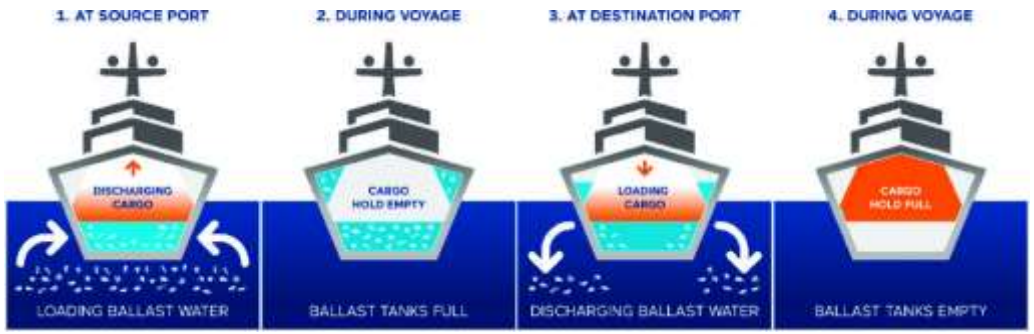
- Harmful effects on many of aquatic organisms because of too sensitive to the changes in their ecosystem.
- Heat flux distribution may deplete the dissolved oxygen content both at surface and subsurface water columns.
- The elevated water temperature often tends to produce a physiologically and ecologically stressful environment.
- High thermal exposure significantly alters the biological, physical (e.g. salinity) and chemical systems of a water body.
- Induce changes in physiological and genetic state of marine habitats.

Vulnerabilities in marine and coastal environment

Oil Spills

- Oil spills can have devastating effects.
- While being toxic to marine life, polycyclic aromatic hydrocarbons (PAHs), the components in crude oil, are very difficult to clean up, and last for years in the sediment and marine environment.

Invasive species



- Invasive species facilitate the spread of new diseases, introduce new genetic material, alter underwater seascapes and jeopardize the ability of native species to obtain food.

Sundarbans (Shela River) Oil Spill on 9 December 2014, Bangladesh

39

Vulnerabilities in marine and coastal environment

Dredging

Operation of removing material from underwater by a floating plant called a dredger

- Effect on overall water quality
- Excavation of sediments
- Increase in suspended sediment concentrations.
- Possible release of organic matter, nutrients and / or contaminants

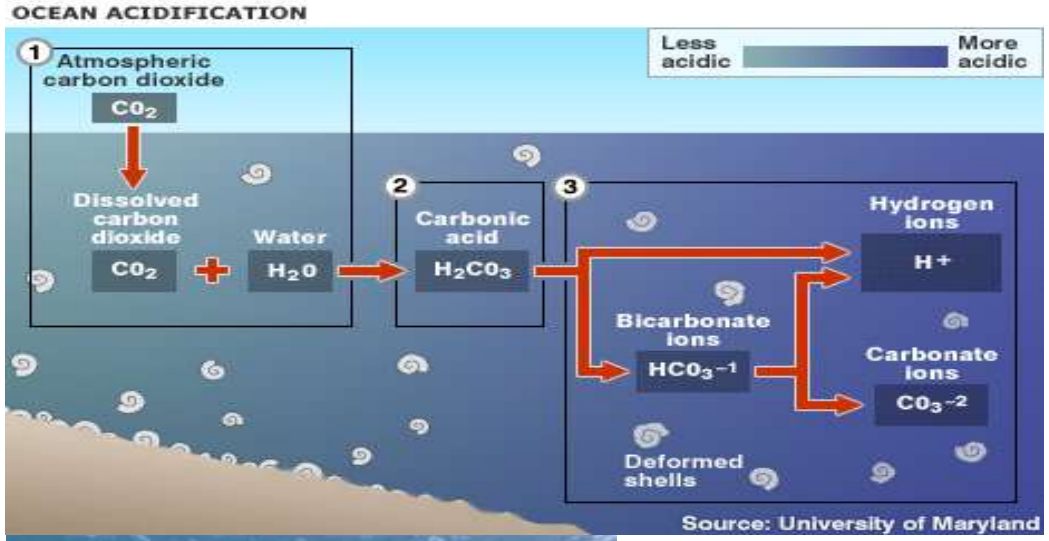
Deep Sea Mining

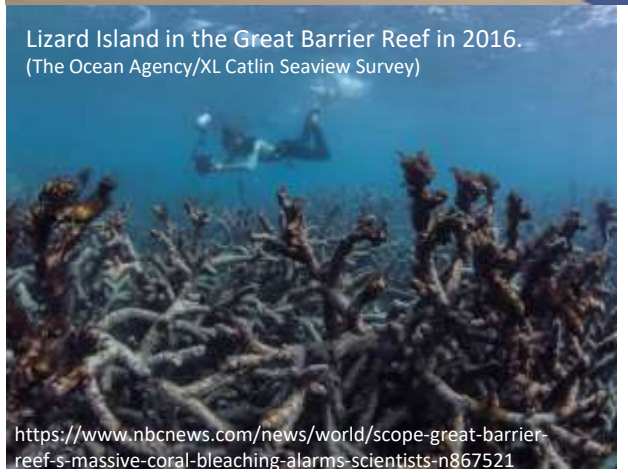
Marine plastics

Almost 90% of all floating materials in the ocean are plastic Marine debris, especially plastic, kills more than one million seabirds and 100,000 mammals and sea turtles every year. Aquatic life can be threatened through **entanglement, suffocation, and ingestion**.

Vulnerabilities in marine and coastal environment

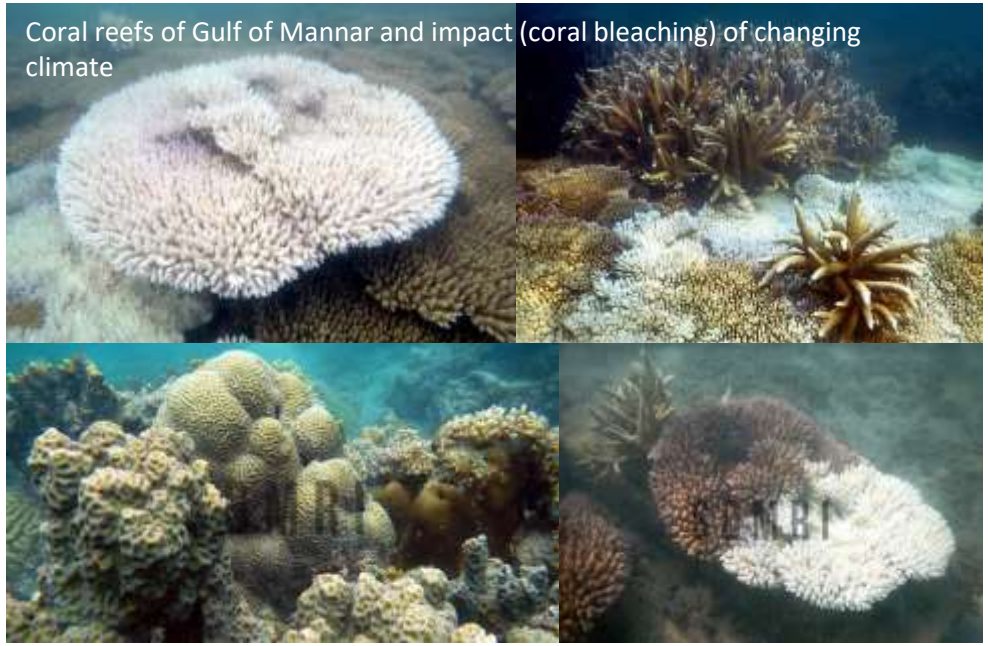
Ocean Acidification




Lizard Island in the Great Barrier Reef in 2016.
(The Ocean Agency/XL Catlin Seaview Survey)
https://www.nbcnews.com/news/world/scope-great-barrier-reef-s-massive-coral-bleaching-alarms-scientists-n867521

The oceans are normally a natural carbon sink, absorbing carbon dioxide from the atmosphere.
Because the levels of atmospheric carbon dioxide are increasing, the oceans are becoming more acidic.
Increase of H+ ions lowers the pH of seawater.

Coral Bleaching


Coral reefs of Gulf of Mannar and impact (coral bleaching) of changing climate

When corals are stressed by changes in conditions such as **temperature, light, or nutrients,** they expel the symbiotic algae living in their tissues, causing them to turn completely white.

Importance of Corals:

- Coral reefs are the tropical rainforests of the sea
- Reefs provide a barrier to prevent erosion and protect from storms and floods.
- Home to thousands of different species of fish.

Vulnerabilities in marine and coastal environment

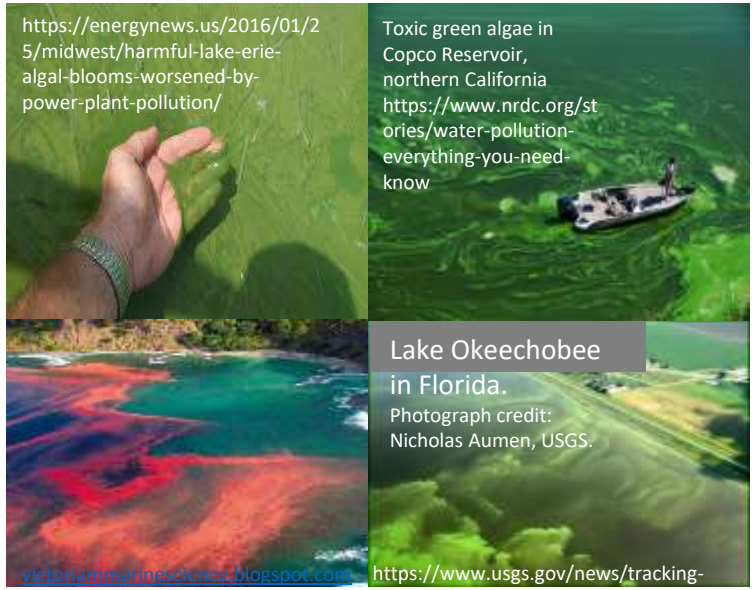
Water Quality Degradation

Coastal water is a critical habitat for many marine species.

80 % ocean pollution marine pollution) originates on land—whether along the coast or far inland.

- disappearance of biodiversity
- bacterial or viral diseases

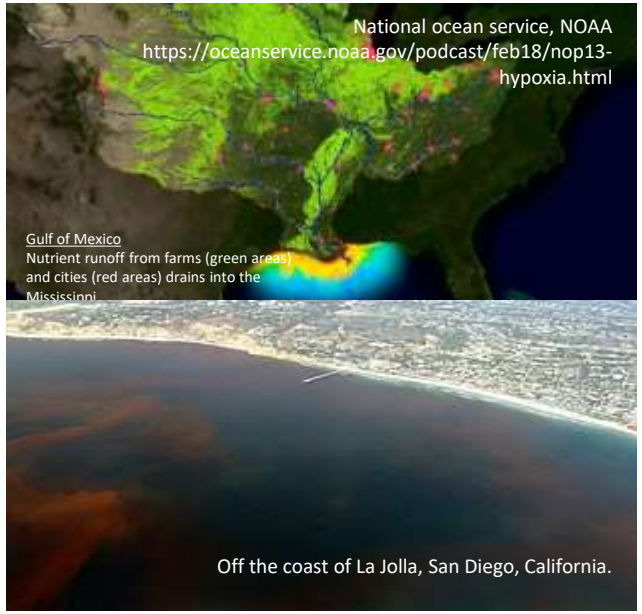
Harmful Algal Blooms (HABs)



An algal bloom is a rapid increase in the population of algae in an aquatic system.

- Odors or discoloration of water
- Affects Aquaculture industries
- Massive fish kills
- Hamper the operation of Thermal Power Plants & Desalination plants.

Coastal Hypoxia



"Low-oxygen areas in the world's oceans and large lakes, caused by "excessive nutrient pollution from human activities coupled with other factors that deplete the oxygen required to support most marine life in bottom and near-bottom water. "

Coastal Hypoxia-Dead zone

Vulnerabilities in marine and coastal environment

Eutrophication

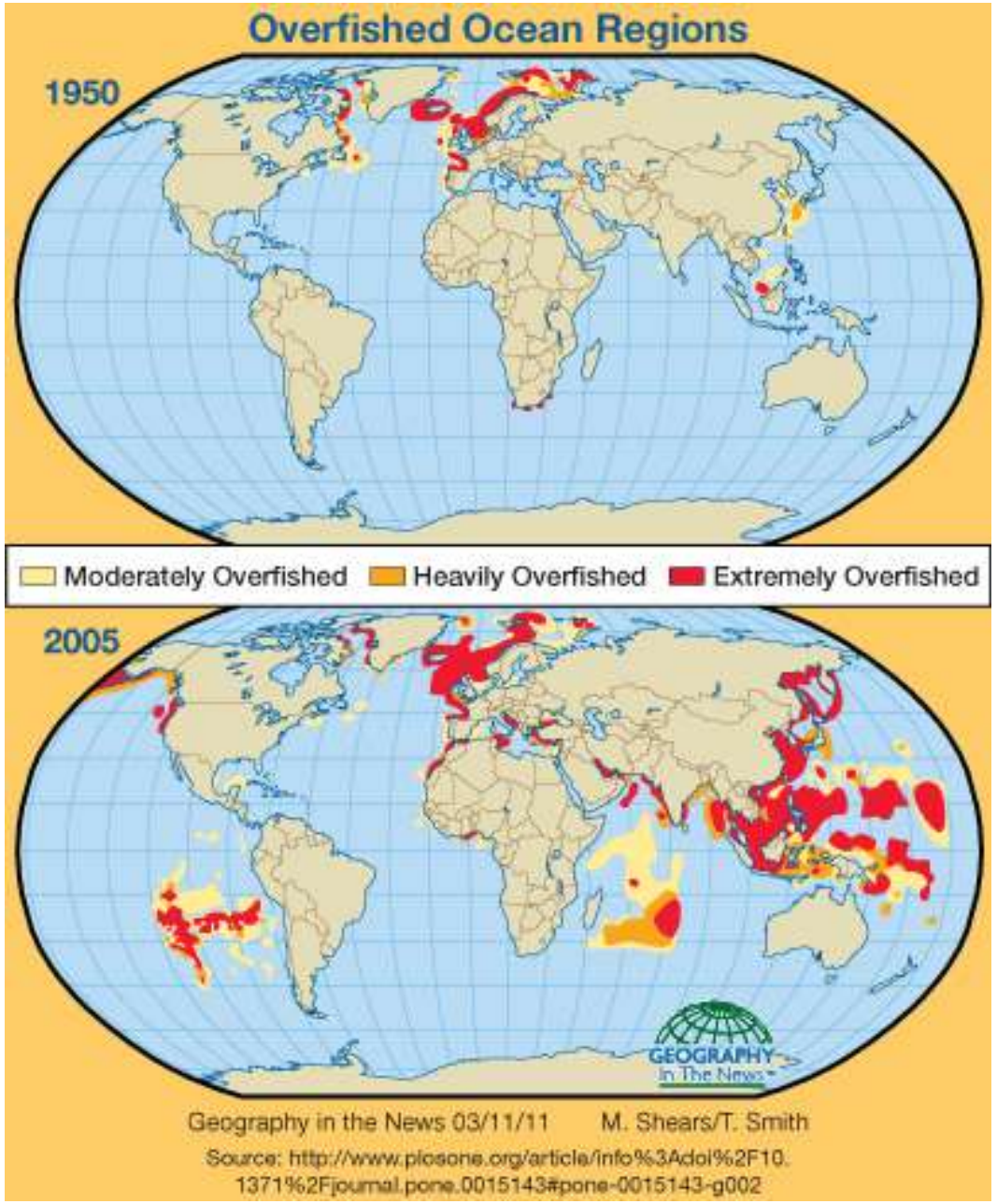
- An increase in chemical nutrients (nitrogen or phosphorus), results in an increase in the ecosystem's primary productivity (excessive plant growth and decay).
- This effects including lack of oxygen and severe reductions in water quality, fish, and other animal populations.
- An excess of oxygen depleting chemicals in the water can lead to hypoxia and the creation of a dead zone.

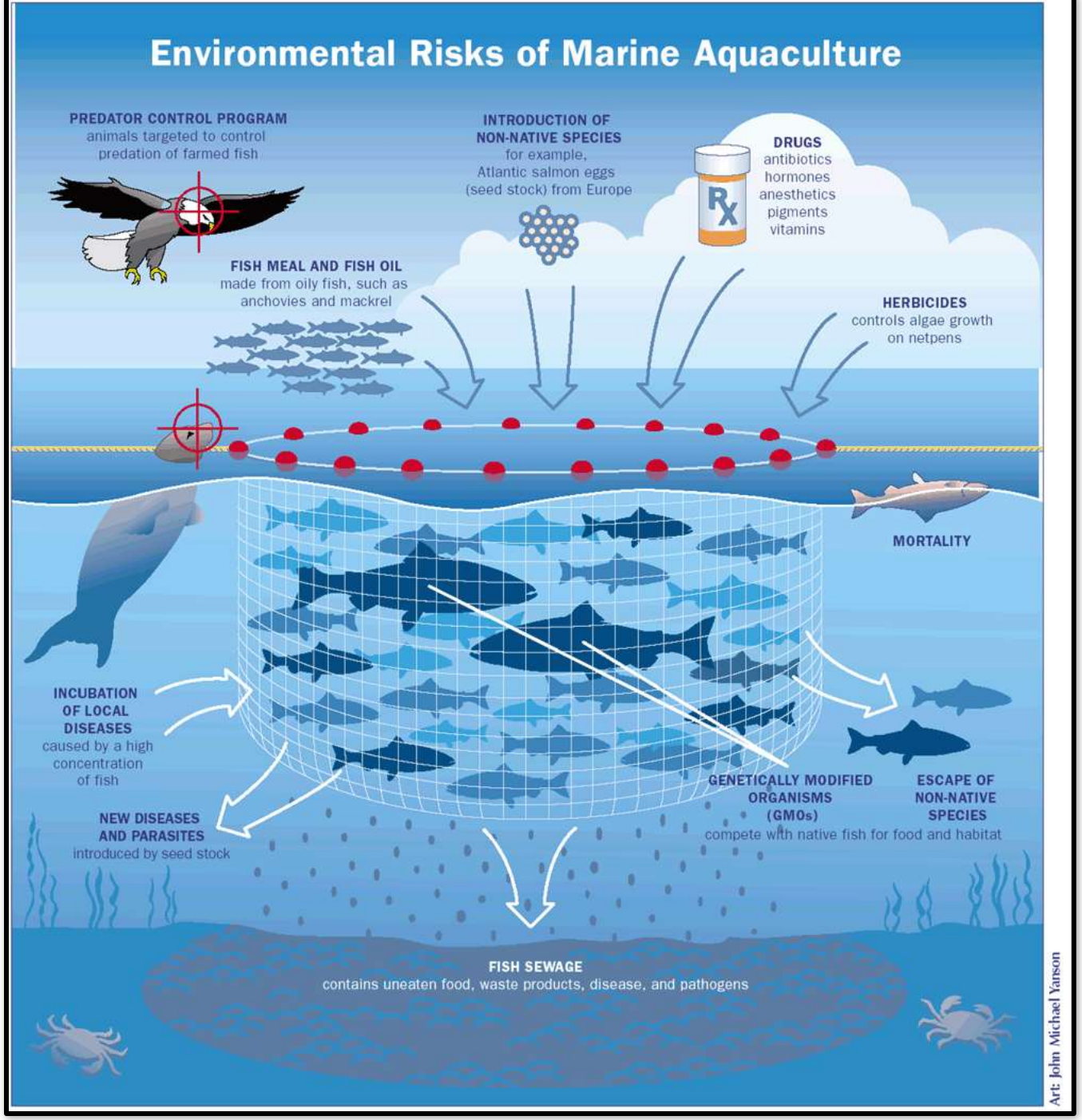
Mangrove degradation

- This benefit is long-term and requires no maintenance.
- The 1999 super typhoon, Orissa, killed over 10,000 people in India drowning many with its powerful storm surge. This number could have been lower if the mangroves had been retained.
- Widespread destruction of mangroves (Bahamas, Australia) has resulted in the loss of some of the worlds most diverse ecosystems.

Overexploitation of fishing resources

- Fish production
- Potential world fishery about 100 to 120 million metric tons
- Overfished areas
  - Intended catch and bycatch



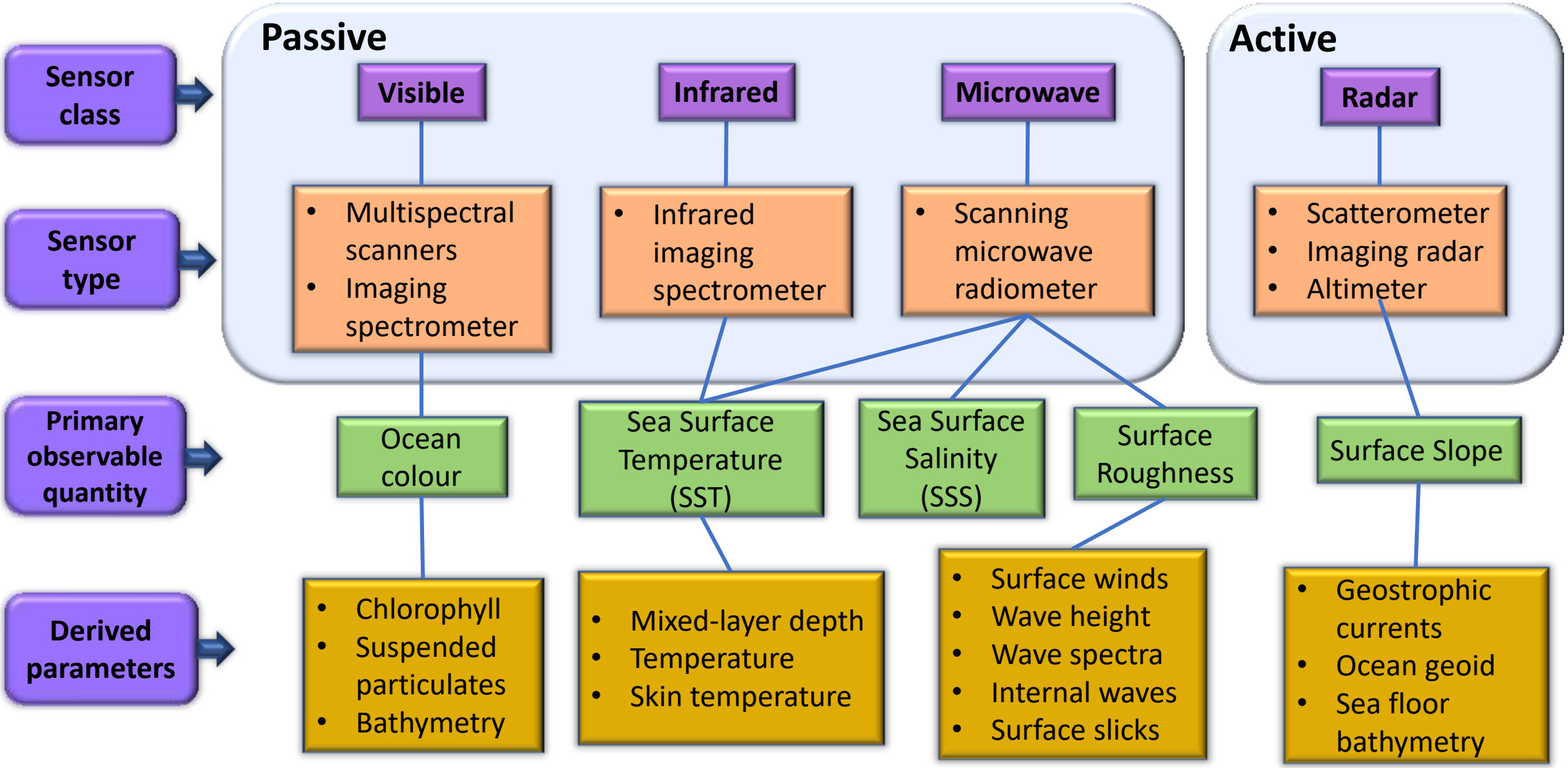


Potential Harmful Impacts of Mariculture

- Escape of non-native species
- Herbicides
- Disease tolerance and spread
- Nutrient enrichment -> eutrophication

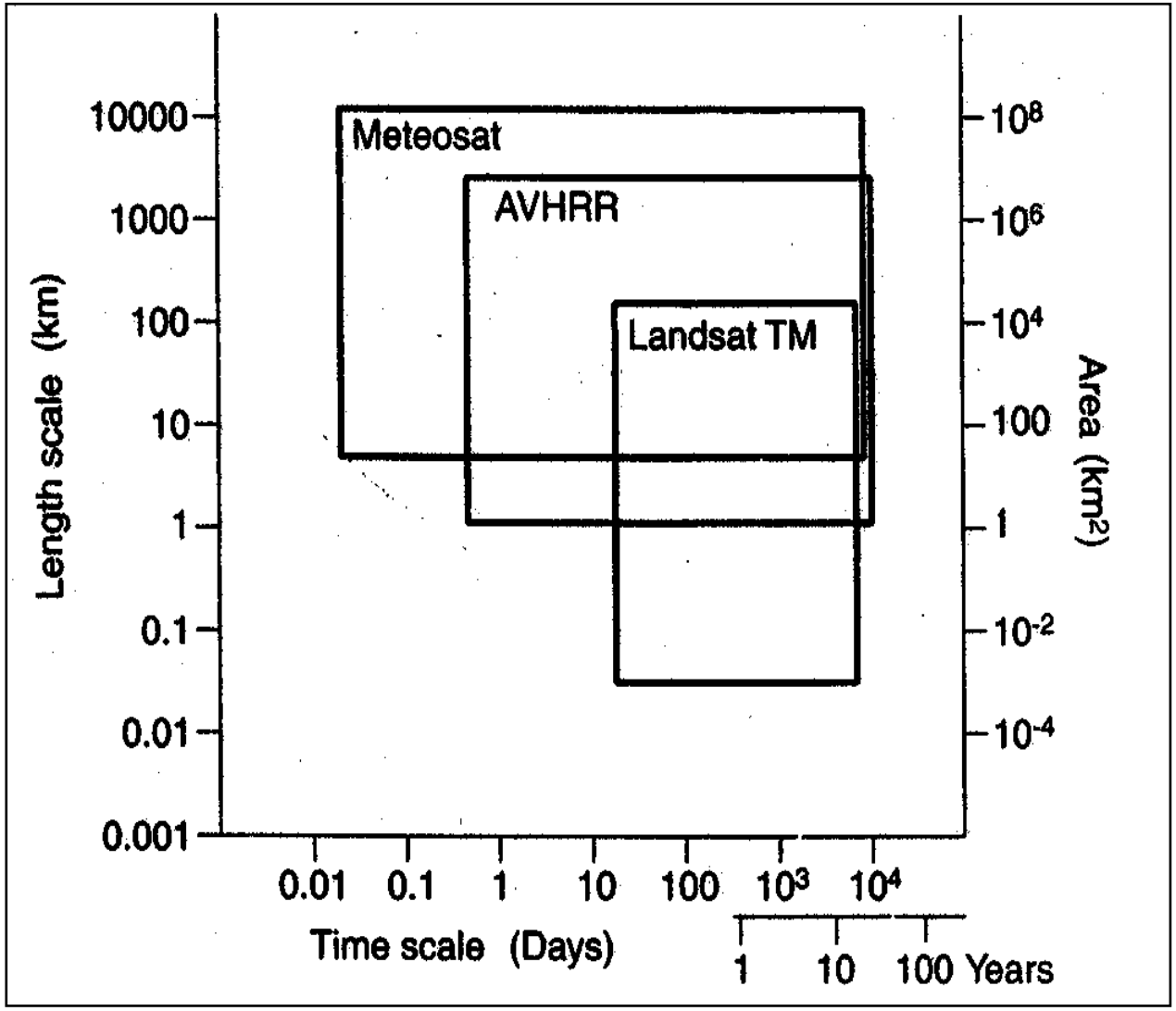
Marine geospatial solutions for vulnerability assessment

Ocean satellite sensors and their applicability



Space-Time Sampling Characteristics of Remotely Sensed Data

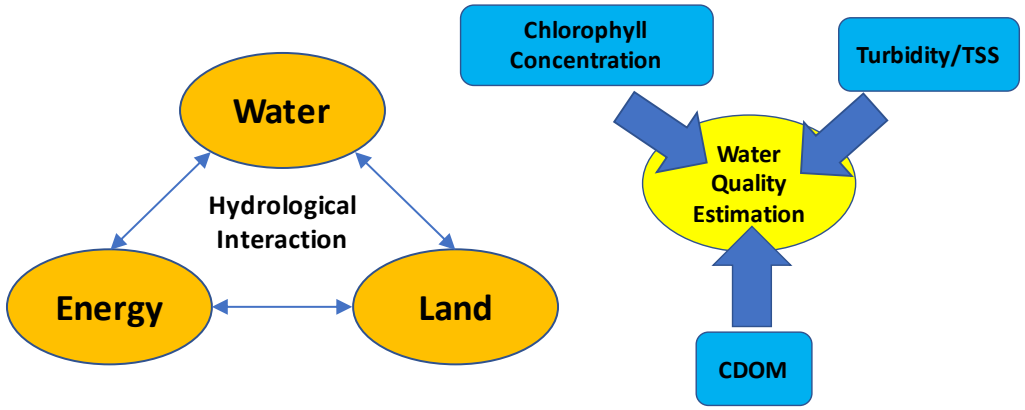
- An inverse relationship between the spatial and temporal resolution that can practically be achieved.
- Three classes of visible or IR sensors are used to illustrate the breadth of scales that are achieved.
- The vertical axis represents a logarithmic length scale and the horizontal axis represents a logarithmic time scale.
- The **lower boundary** of the region allocated to a particular sensor represents the smallest spatial scale that can be detected by the sensor (e.g., **its spatial resolution**).
- Similarly the **left-hand boundary** represents the shortest time interval over which variations in the ocean can be detected (**i.e., the temporal sampling resolution**).
- The **top boundary** for each sensor represents the largest **extent of spatial coverage** that can be obtained for a near-instantaneous view.
- The **right hand boundary** represents the span of available data, and depends on the **lifetime** over which useful data have been collected.



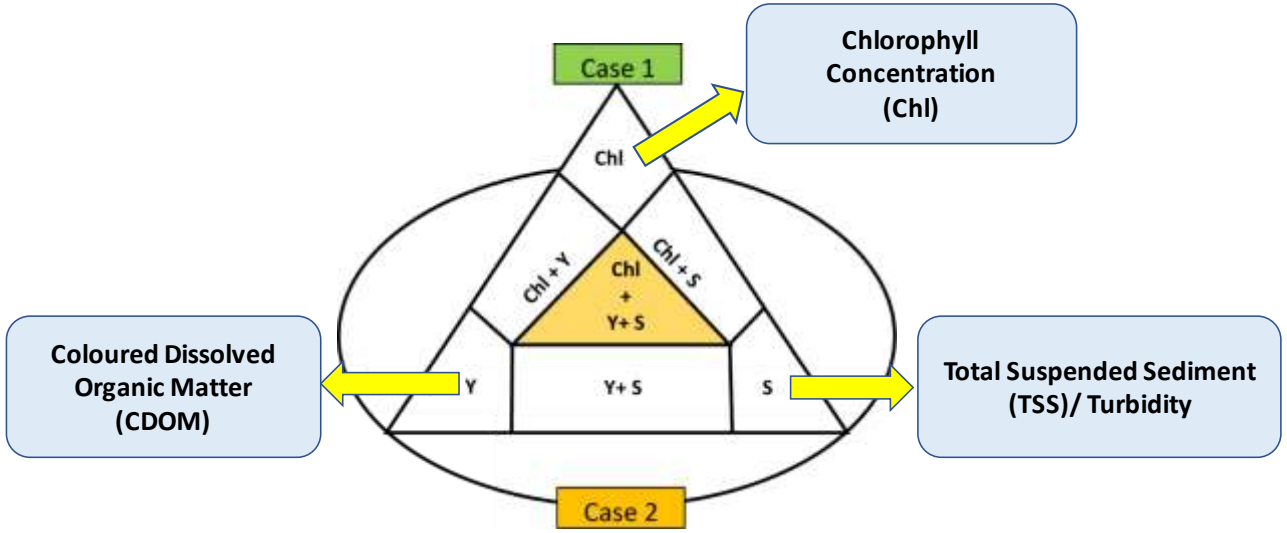
Credit: Dr. Young-Heon Jo

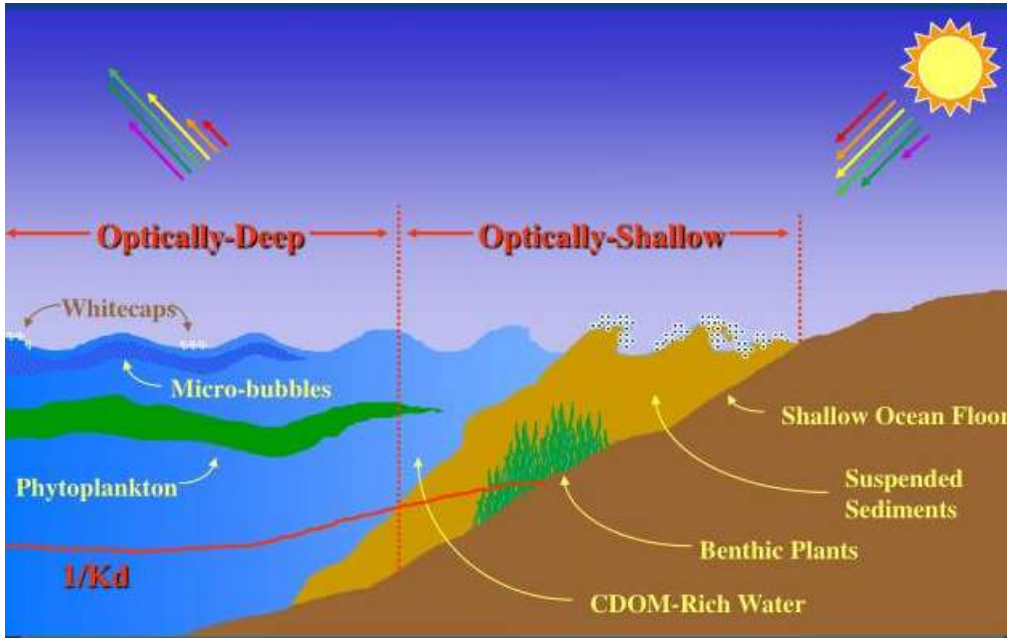
Water quality modelling and assessment in coastal and inland zones

- A multi-component approach can be used to accurately predict the water quality status of inland and coastal waters
- Dynamic coastal process occurring at land-sea interface such as coastal erosion, fresh water inundation and sediment transport, movement of particulate matter due to current drift
- Environmental and illumination conditions play a crucial role and significantly influence concentration of water quality variables

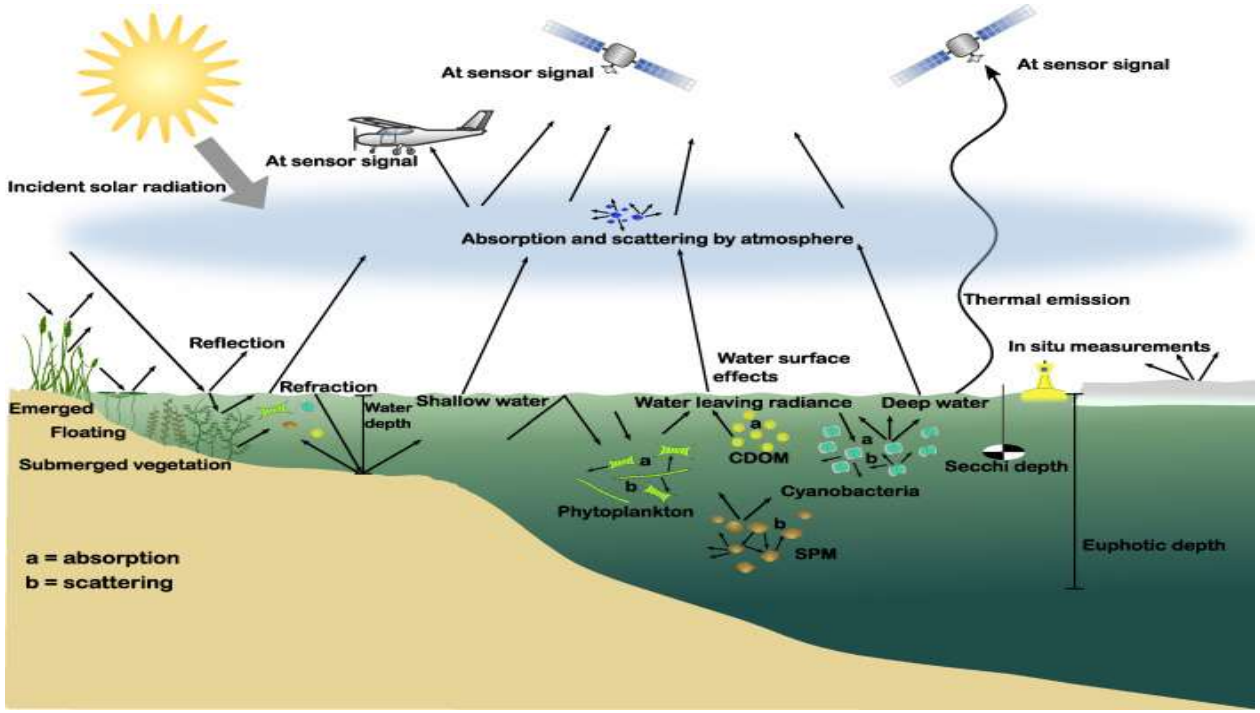


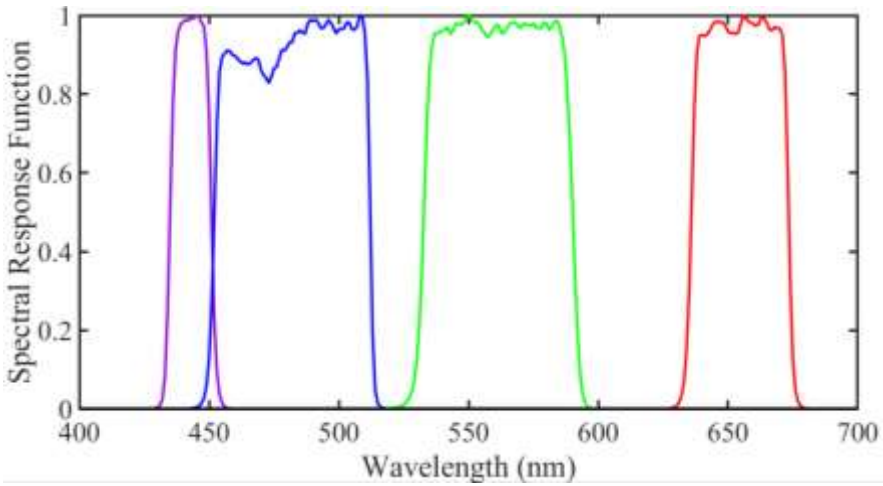
Identification of Water Quality product

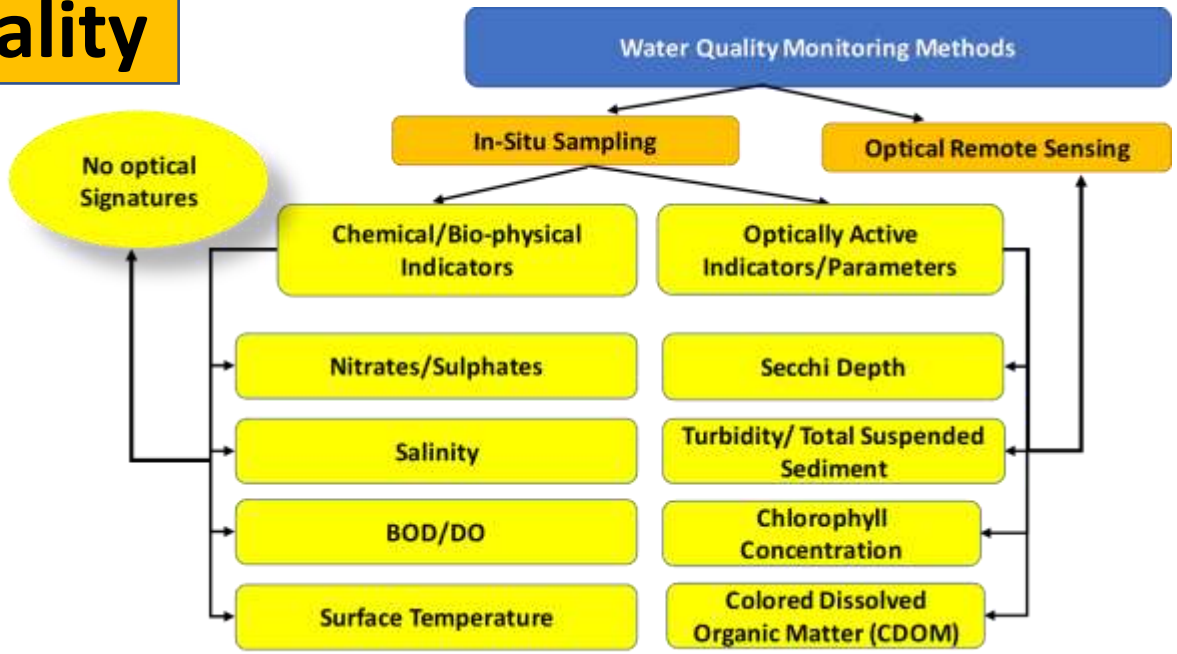




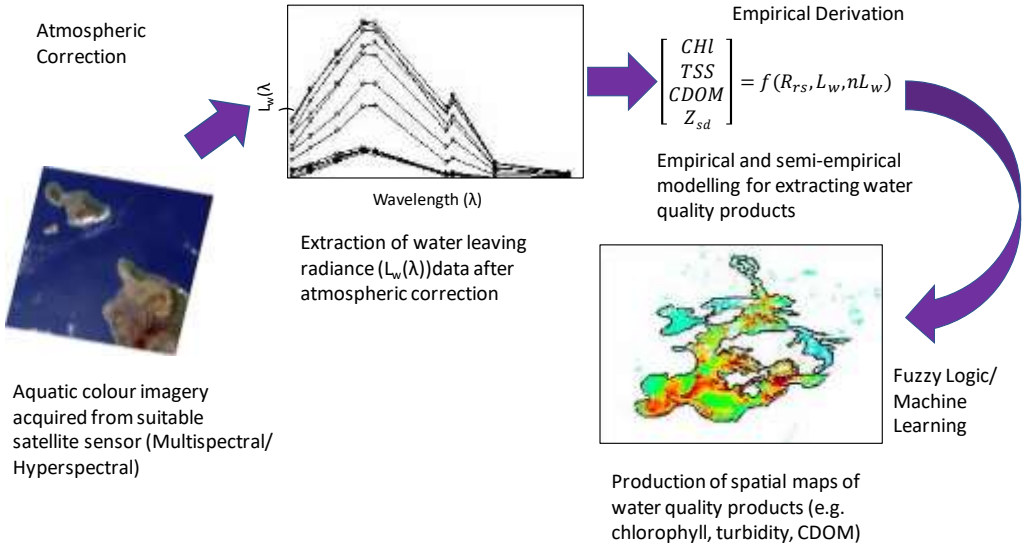
Optical Remote Sensing of Water Quality





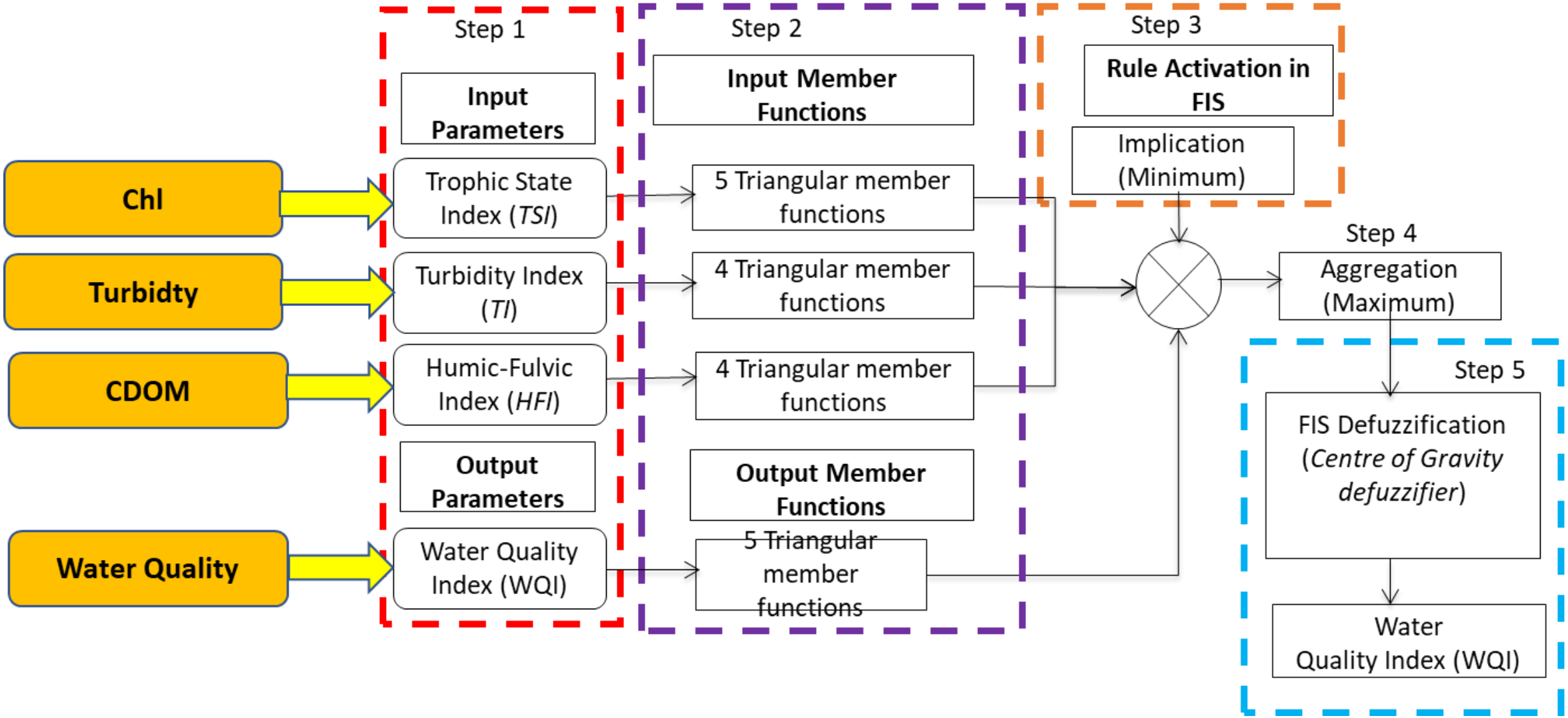


Optical assessment

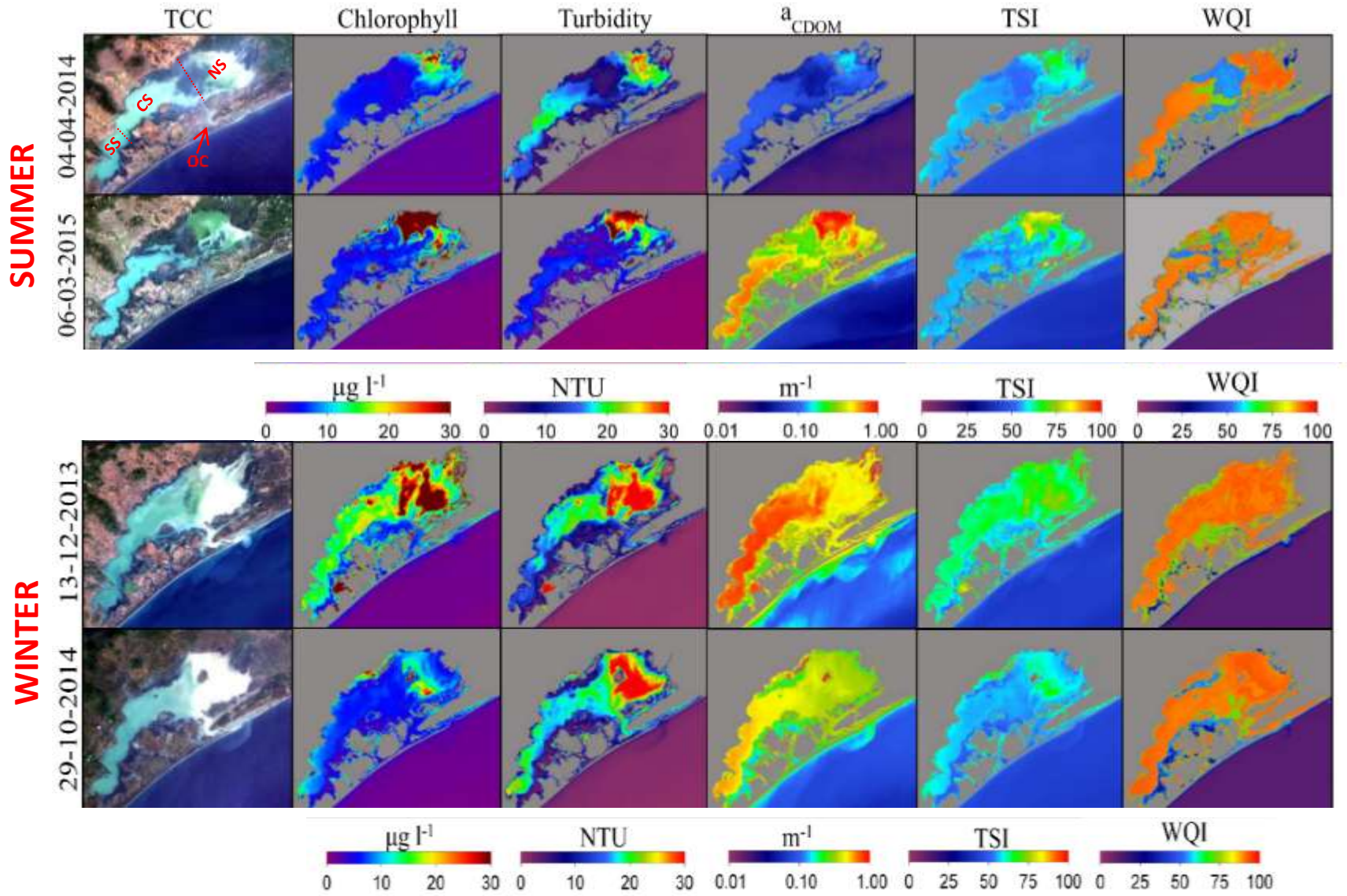


Mainframe structure for developing WQI

Schematic flowchart of WQI



Application of TSI and WQI model to Chilika Lake for winter months



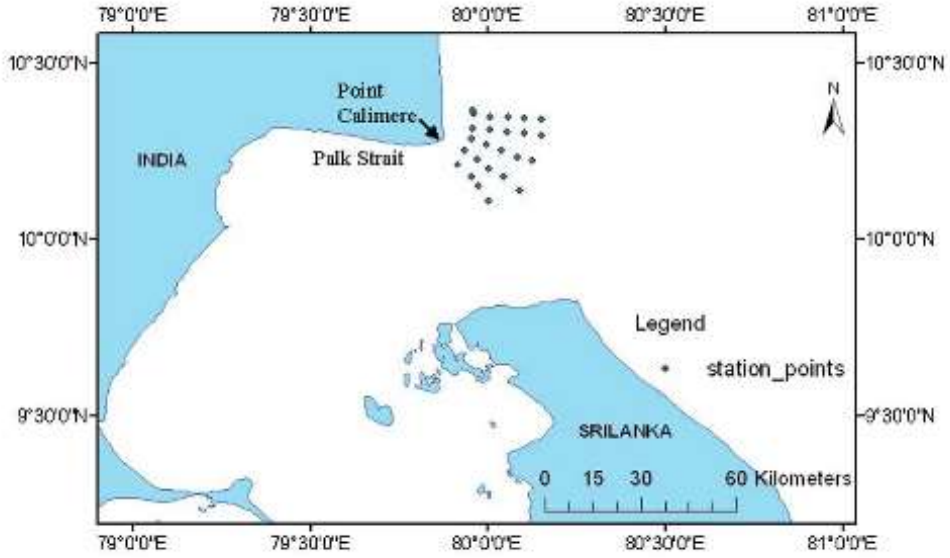
- TSI and WQI values were governed primarily by the hydrological changes driven by the presence or absence of strong river inputs, tidal incursions in different sectors of the lake, and longshore drift along the coast
- These parameters are greatly influenced by the local changes in hydrological, geomorphological and land-use (such as anthropogenic and human interferences) conditions which govern the variation of the water quality conditions in inland and coastal waters.

K. Anuj and P. Shanmugam, 2018. Assessment of trophic state and water quality of coastal-inland lakes based on Fuzzy Inference System. Journal of Great Lakes.

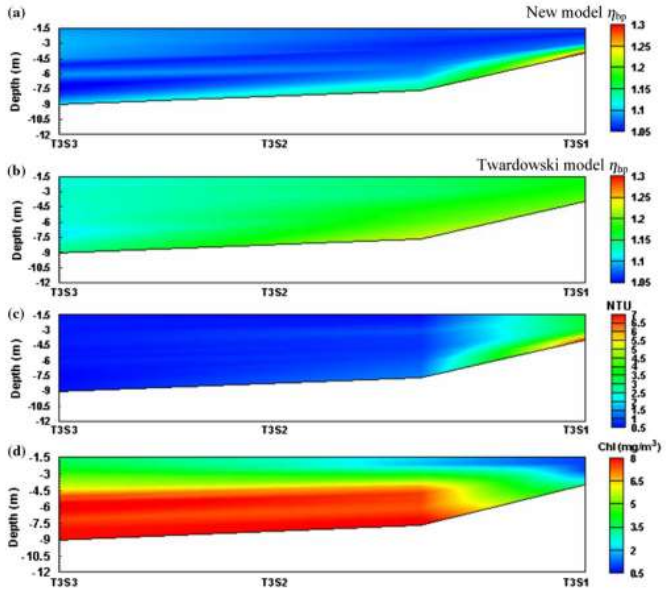
Bulk particulate refractive index estimation in Coastal Oceanic Waters

- This study becomes useful for retrieving Bulk refractive index (η_p) to better characterize the different particle assemblages (phytoplankton, detrital and inorganic) occurring in these dynamic coastal waters.
- Bulk refractive index (η_p) of particle assemblages is modelled by solving Mie theory inversion equations combined with various IOP parameterizations

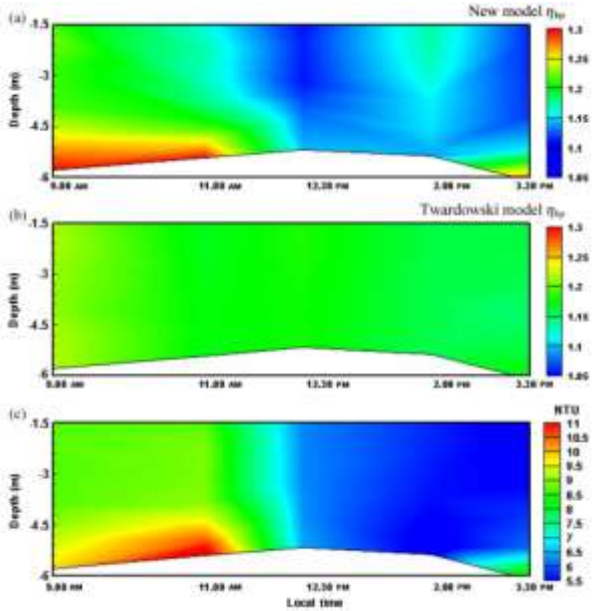
Density of particulates has significant role in modeling **the refraction characteristics of particles**



Location map of in-situ data points



η_p vertical profiles from shore to offshore in Off Point Calimere (OPC) waters



Time series η_p profile of OPC waters from New and Twardowski et al 2001 model.

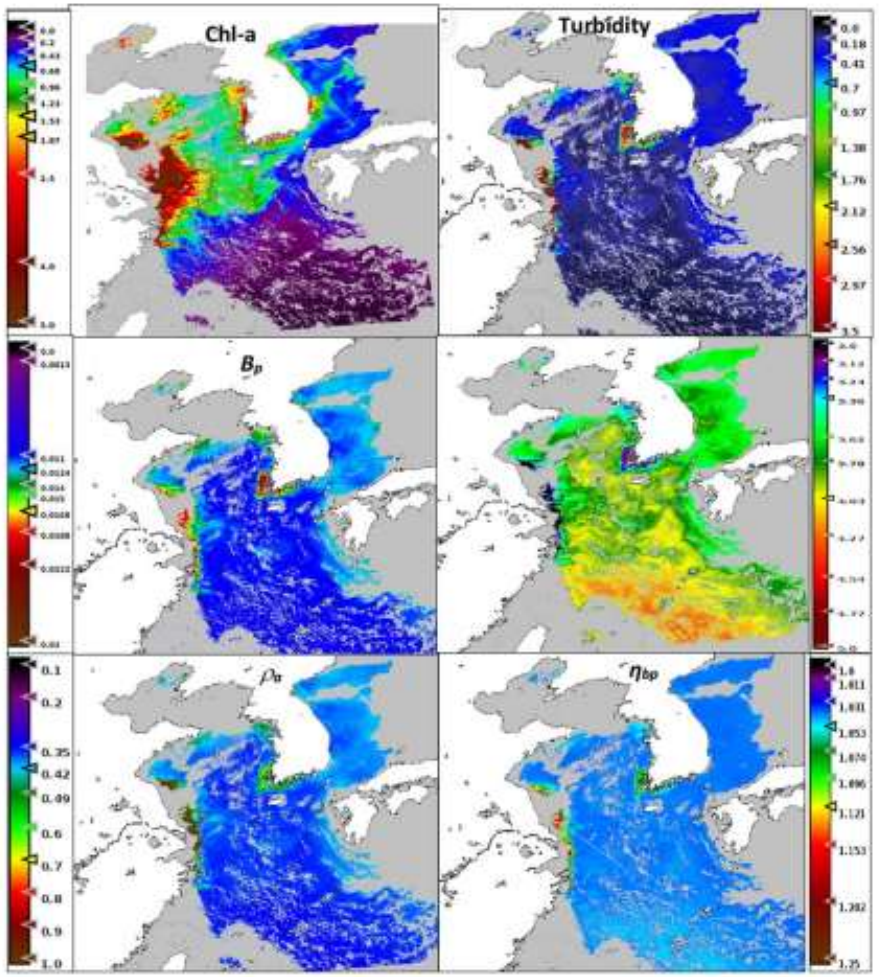
Nasiha, H. J., Shanmugam, P., & Hariharasudhan, V. G. (2014). A new inversion model to estimate bulk refractive index of particles in coastal oceanic waters: Implications for remote sensing. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 7*(7), 3069-3083.

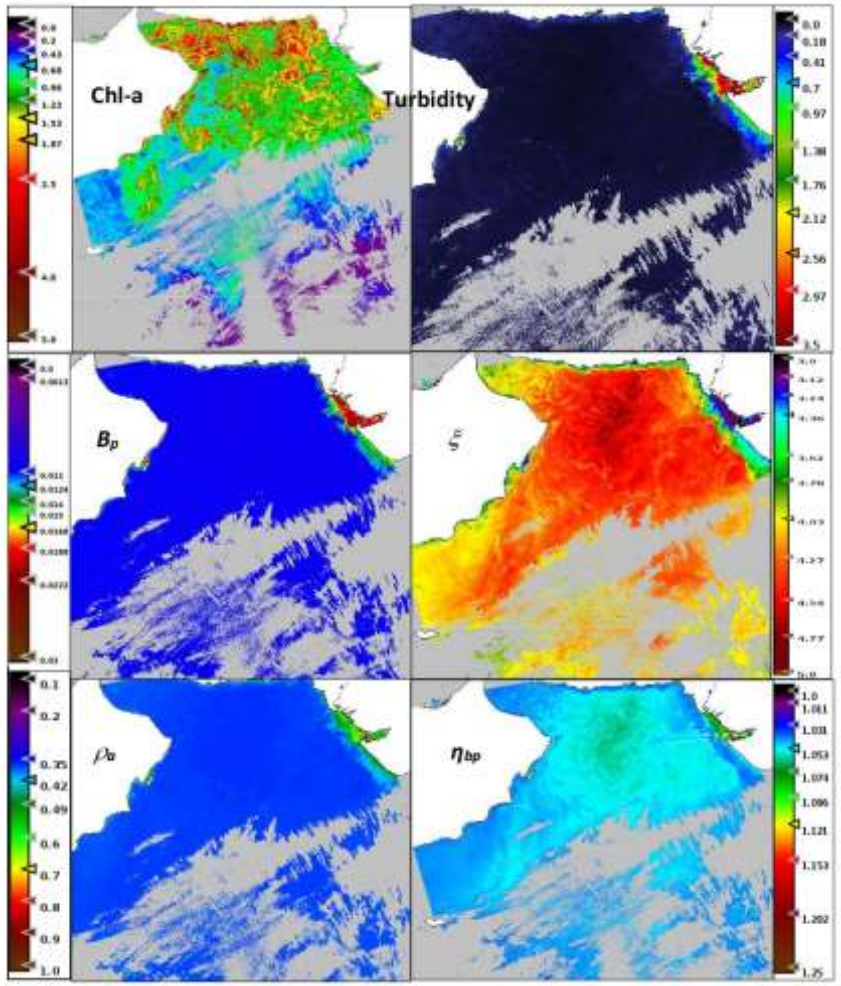
Satellite remote sensing of bulk particulate refractive index

February 18, 2010

August 13, 2013

East China Sea (including Yangtze river plume), Yellow Sea and Korean Southwest Sea





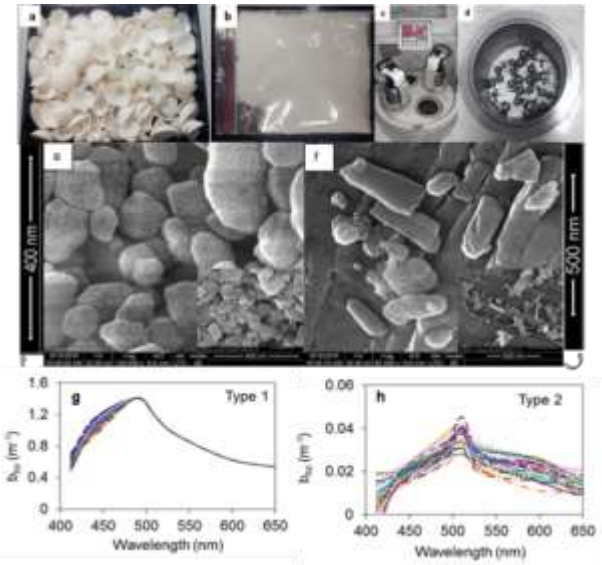
Arabian Sea

Maps of the ABI-chlorophyll (Chl-a), turbidity, particulate backscattering ratio (Bp), PSD slope (ξ), apparent density (ρa), and bulk refractive index of particles (ηbp) derived from the MODIS-Aqua satellite data.

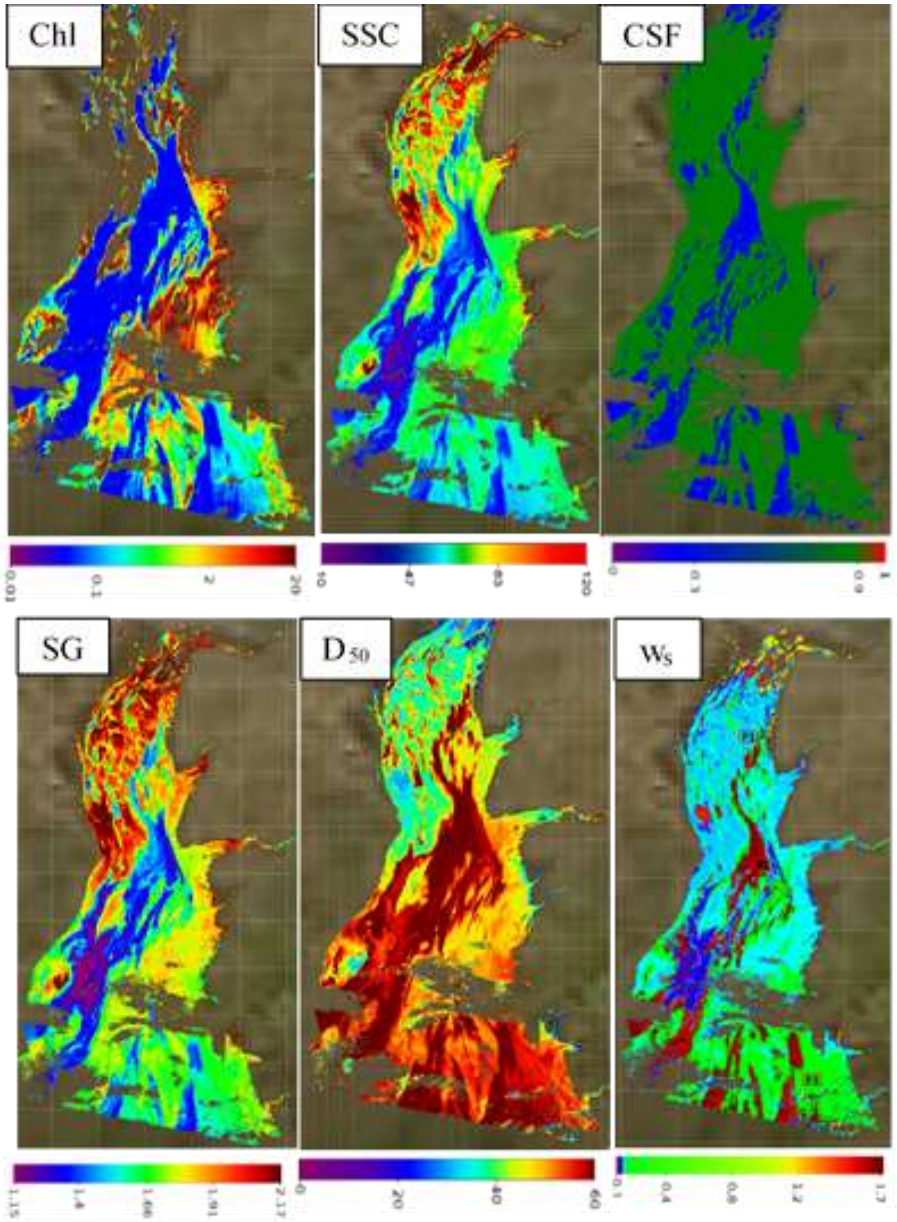
Nasiha, H. J., & Shanmugam, P. (2015). Estimating the bulk refractive index and related particulate properties of natural waters from remote-sensing data. *IEEE Journal of Selected Topics In Applied Earth Observations and Remote Sensing, 8(11)*, 5324-5335.

Satellite remote sensing of sediment settling velocity

- Sediment settling velocity of spherical and non-spherical particles is modelled by combining physical, optical and hydrodynamic properties based on in-situ measurements
- **Spectral light backscattering measurements** of settling particles in a water tank were made showing a distinct optical feature with a peak shifting from 470-490 nm to 500-520 nm for particle populations from spherical to flaky grains.



- Large in situ measurement data of the remote sensing reflectance (R_{rs}), and other IOPs were used in this study to establish remote sensing algorithms
- Particulate median diameter, specific gravity and shape parameter had been derived from satellite R_{rs} and settling velocity was found

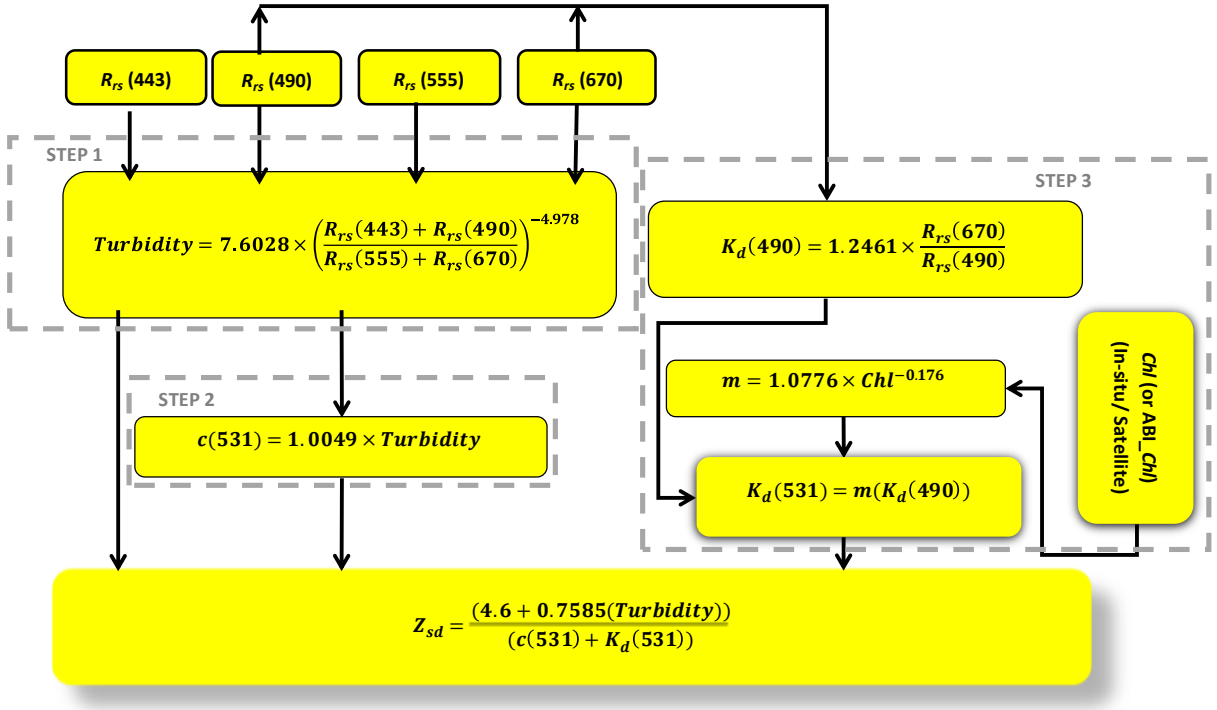


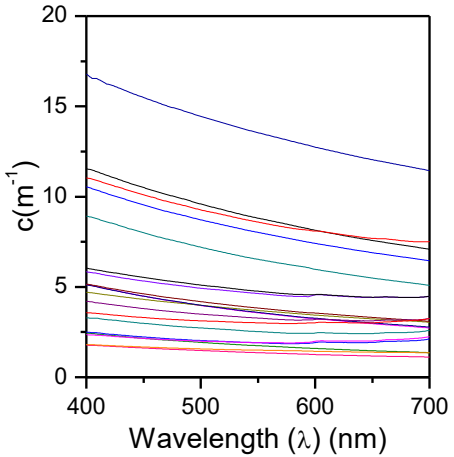
Maps of sediment settling velocity (w_s) (mm s^{-1}) and other derived model parameters from the Landsat 8 imagery over Gulf of Cambay on 03 May 2016

Nasiha, H. J., & Shanmugam, P. (2018). Estimation of settling velocity of sediment particles in estuarine and coastal waters. *Estuarine, Coastal and Shelf Science*, 203, 59-71.

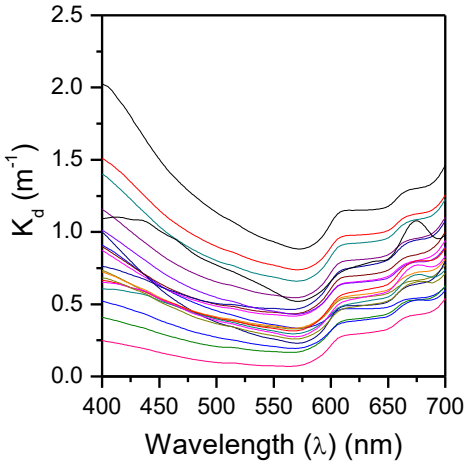
Underwater visibility algorithm for coastal and inland waters

- Accurate estimation of water clarity in coastal regions is highly desired search and recovery operations, dredging and water quality monitoring
- optical relationships obtained for the selected wavelengths (i.e. 520, 530 and 540 nm) exhibit an inverse relationship between Secchi depth (Z_{sd}) and the length attenuation coefficient

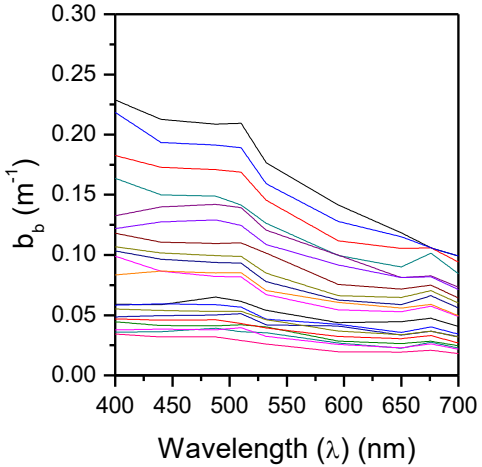




Beam attenuation coefficient



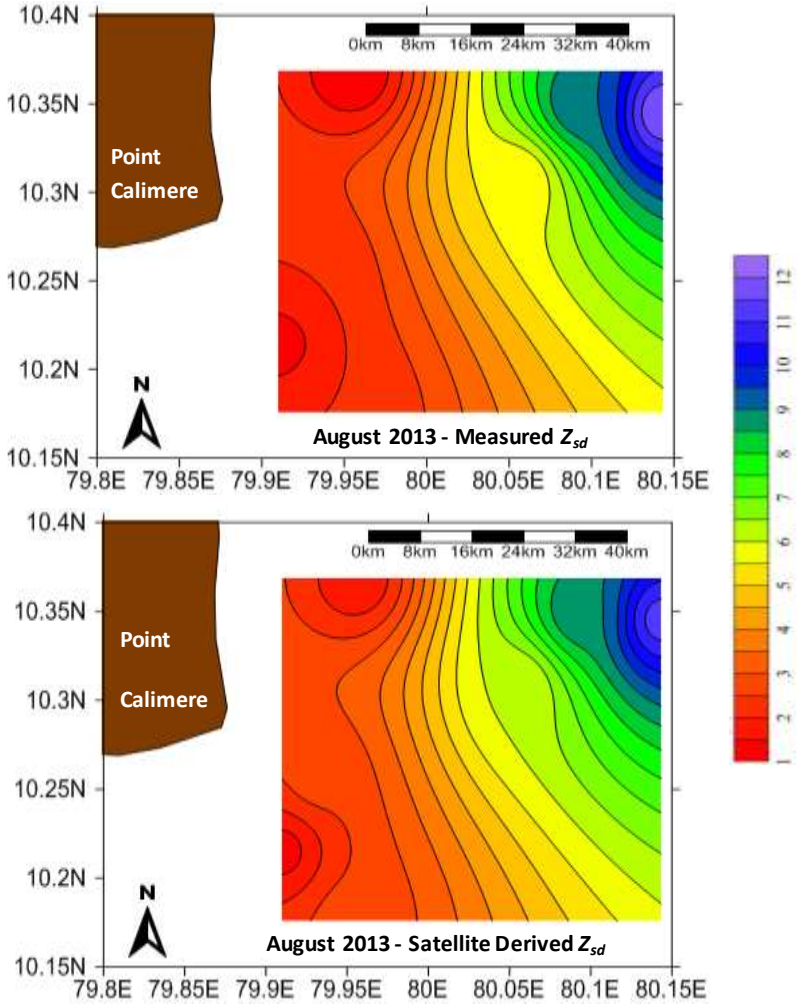
Vertical diffuse attenuation coefficient



Backscattering coefficient

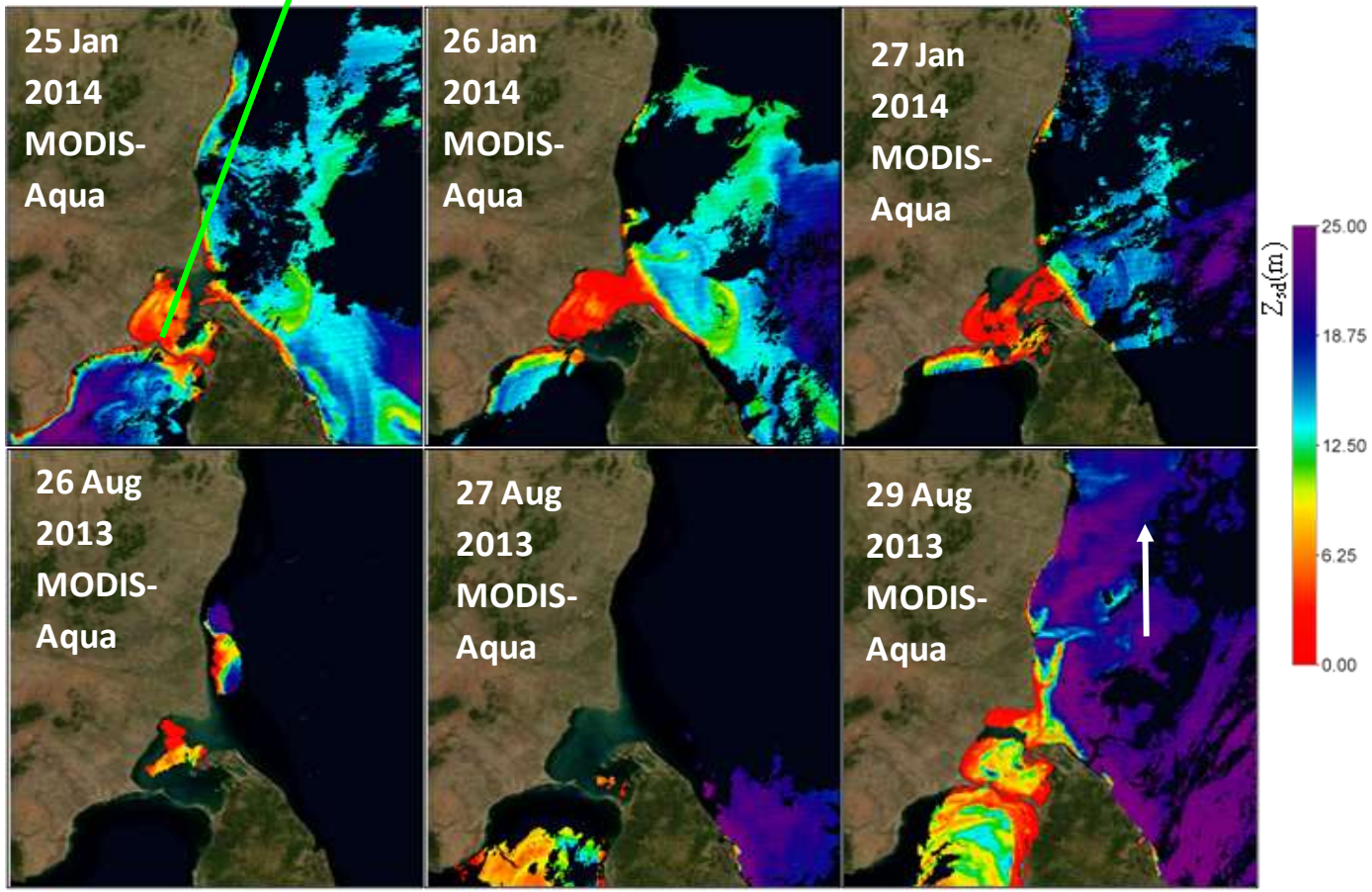
Kulshreshtha, A. and Shanmugam, P., 2015. An optical method to assess water clarity in coastal waters. *Environmental monitoring and assessment*, *187*(12), p.742.

Underwater visibility algorithm for coastal and inland waters



Contour plots of MODIS-Aqua-derived Z_{sd} in coastal waters off Point Calimere

The high sedimentation near coast, occurs due to the entrapment of fluvial discharge and re-suspended sediments and sediment dynamics lowers Z_{sd}



Water transparency map depicting the remotely derived Z_{sd} using the present algorithm

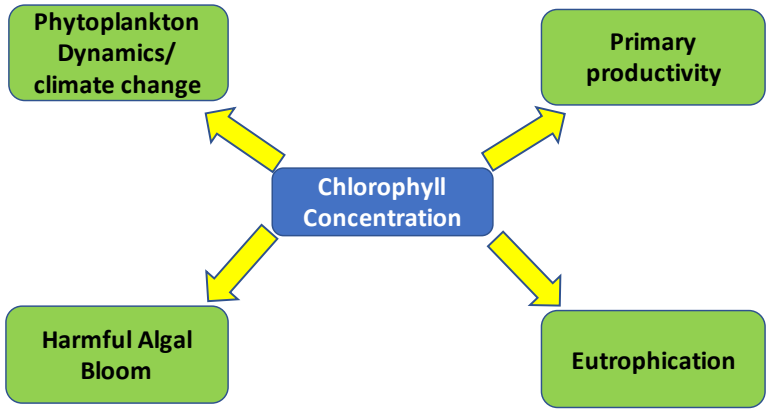
Kulshreshtha, A. and Shanmugam, P., 2017. Estimation of underwater visibility in coastal and inland waters using remote sensing data. *Environmental monitoring and assessment*, *189*(4), p.199.

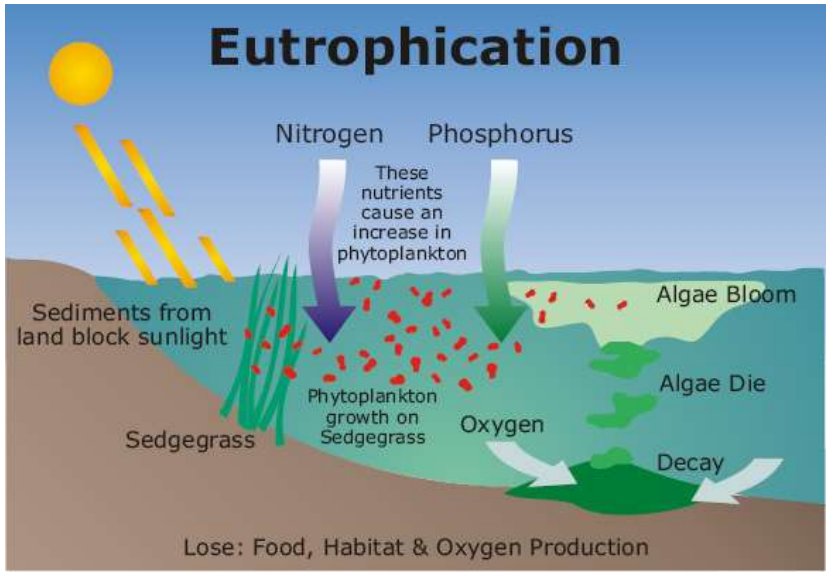
Chlorophyll Concentration

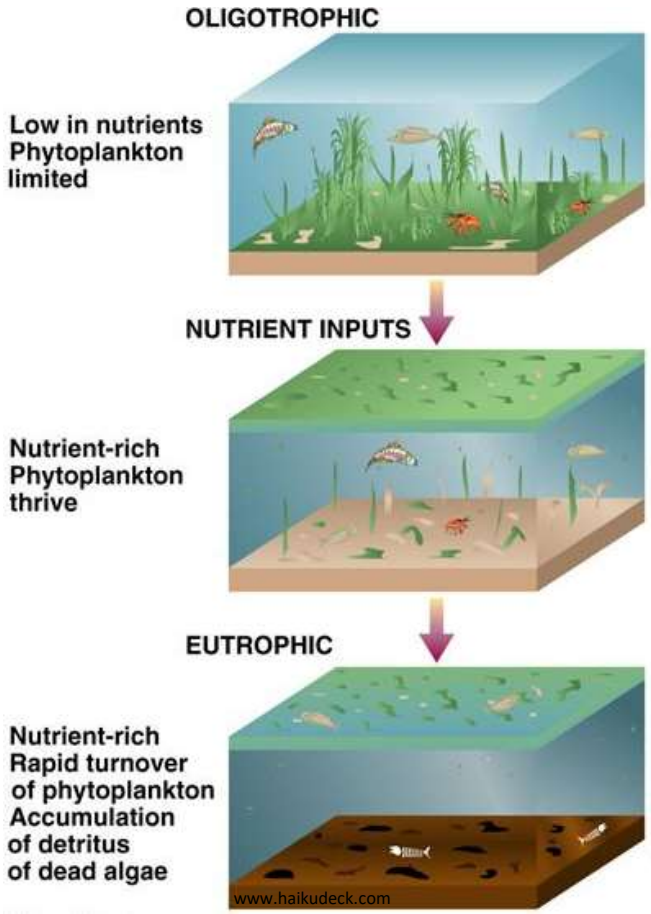
- Represents phytoplankton biomass and a surrogate indicator of primary productivity
- Higher consumption of nutrient leads to higher chlorophyll concentration
- Estimation of chlorophyll in turbid and productive waters is more complicates, due to presence of additional components such as suspended sediments, detritus, and coloured dissolved organic matter (CDOM).

Primary productivity (PP) = Synthesis of organic matter by autotrophs

- Designing the predictive scale o estimate eutrophication in inland and coastal waters





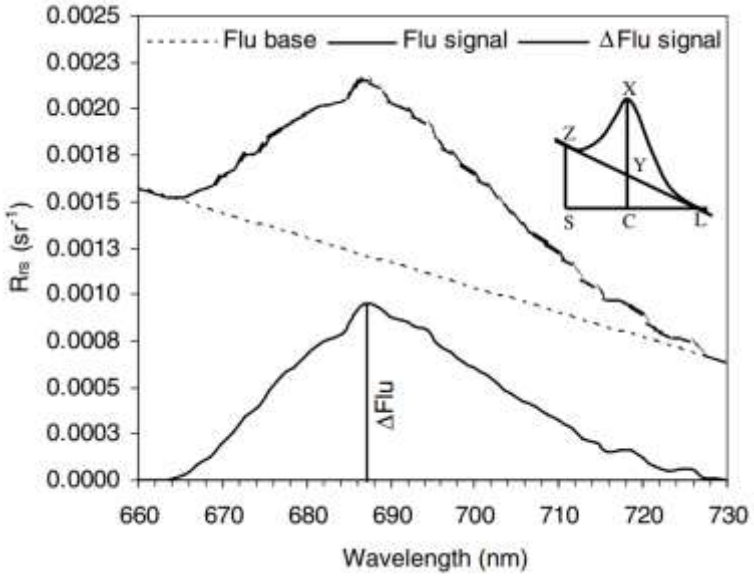


Fluorescence algorithms to estimate phytoplankton pigment concentrations in optically complex coastal waters

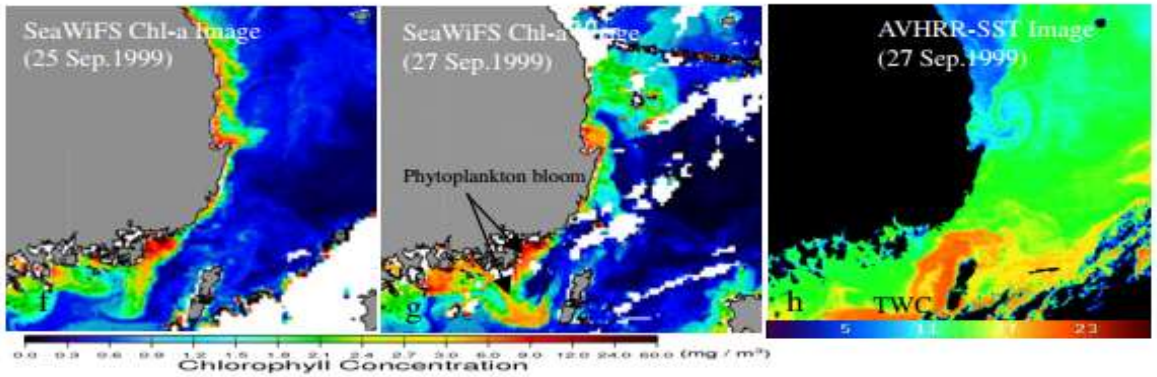
- Fluorescence-based algorithms tended to reproduce *in situ* Chl-a concentrations (from 0.1 to 82 mg m^{-3}), whereas standard spectral ratios algorithms gave inconsistent estimates.

- The peak around **683–685 nm wavelength** in their radiance or reflectance measurements was indeed found to be closely correlated to the *in situ* Chl-a concentrations, representing an important complement to remotely estimate phytoplankton pigment concentrations in natural water bodies.

- These algorithms are simplistic in their nature by neglecting the complex algal physiological and irradiance effects on fluorescence and are based on the following parameters:
  (1) the height of the fluorescence peak (also referred to as the **fluorescence line height**–FLH) at 681 and 688 nm (ΔFlu), and
  (2) the area delimited by the **ΔFlu curve** (ΔFlu*(*area*)*).



Schematic representation of the fluorescence line height (ΔFlu) estimation using the R_{rs} spectrum.

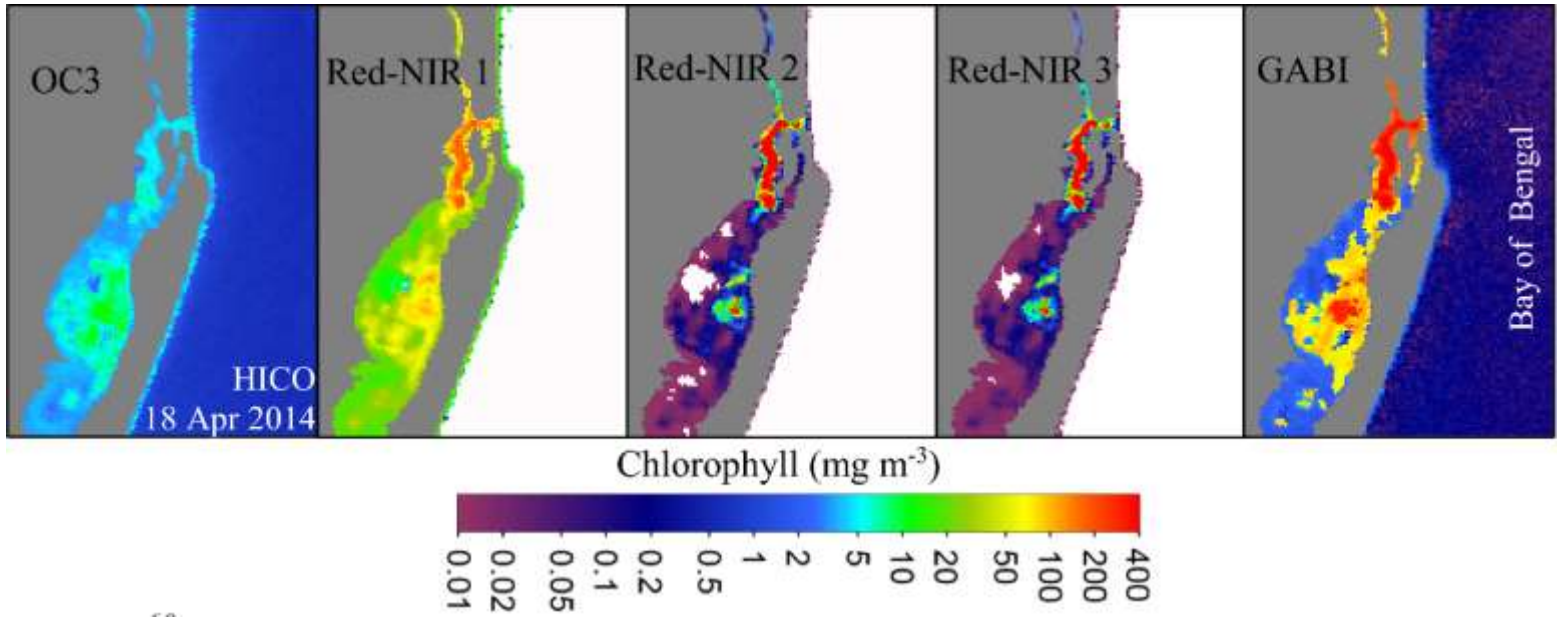


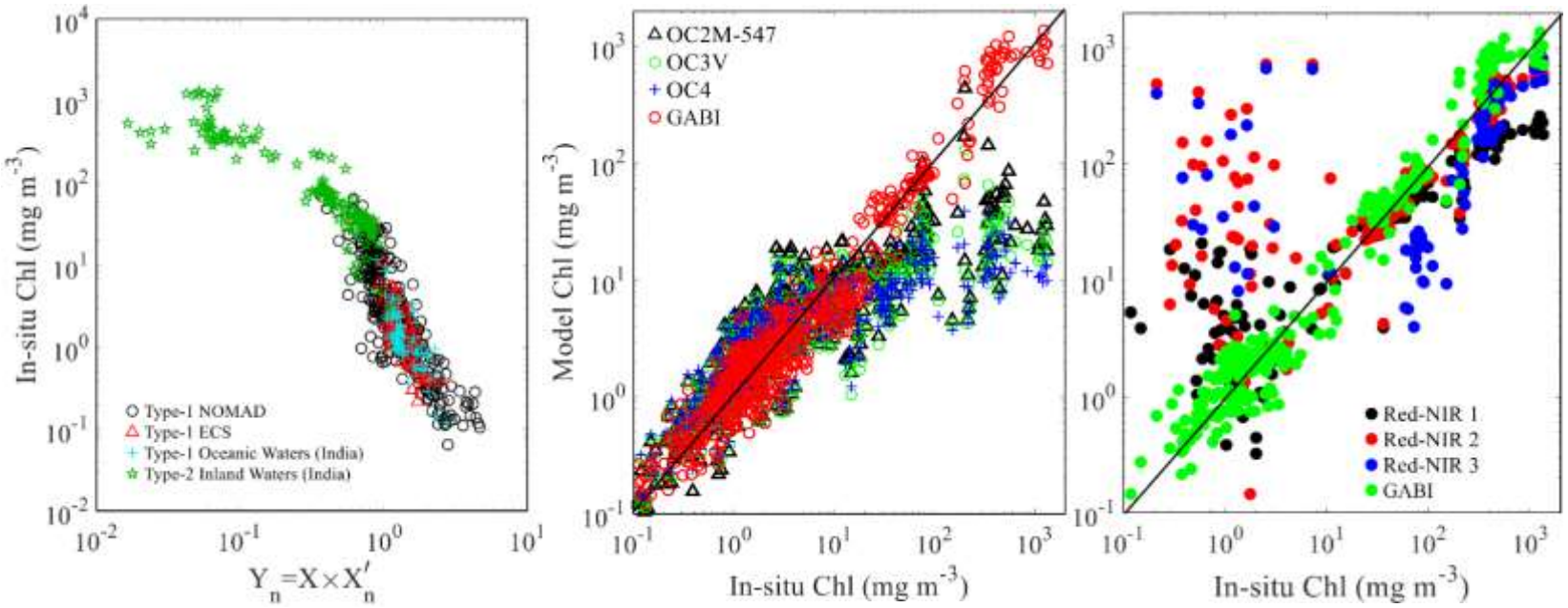
SeaWiFS Chl-a images and Sea surface temperature from a NOAA AVHRR image

Ahn, Yu-Hwan, and Palanisamy Shanmugam. "Derivation and analysis of the fluorescence algorithms to estimate phytoplankton pigment concentrations in optically complex coastal waters." *Journal of Optics A: Pure and Applied Optics* 9.4 (2007): 352.

Generalized Algal Bloom Index

- The conventional blue-green ratio algorithms break down in moderate to highly turbid productive waters.
- The influence of CDOM and SS on the nLw signal in the wavelength range 670–710 nm is generally overwhelmed by the chlorophyll pigment content in highly productive waters.
- This shift of red-NIR peak provides an alternate mean to estimate Chl concentration in turbid productive waters, however, enhanced backscattering intensity in sediment-laden waters could increase the background signal which could lead to erroneous Chl values.
- nL_w data to calibrate GABI must be collected preferably from an above-water platform, because of high signal attenuation across the water-air interface.



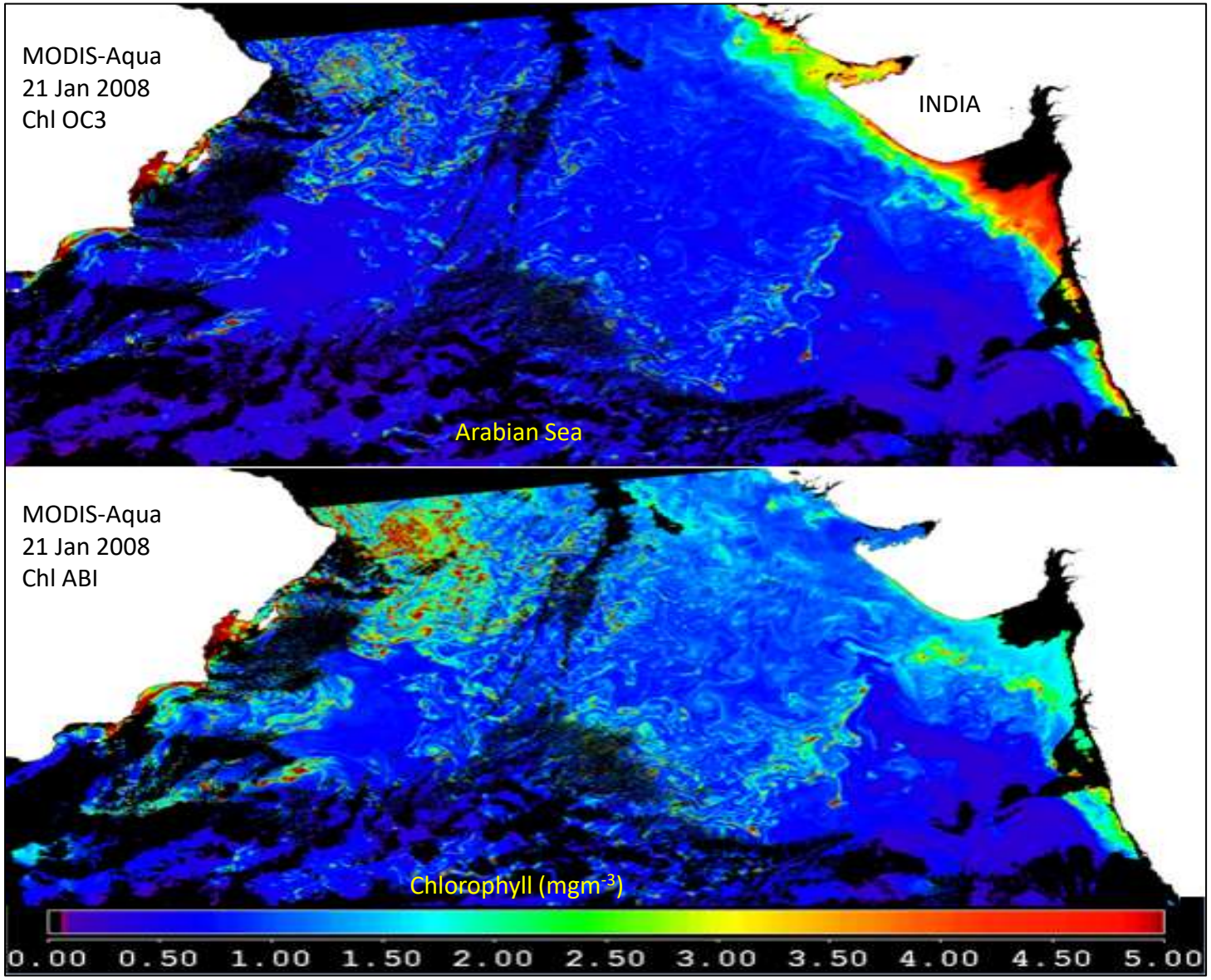


Shanmugam, P., He, X., Singh, R.K. and Varunan, T., 2018. A modern robust approach to remotely estimate chlorophyll in coastal and inland zones. *Advances in Space Research*, *61*(10), pp.2491-2509.

Bio-optical algorithm for the remote sensing of algal blooms in complex ocean waters

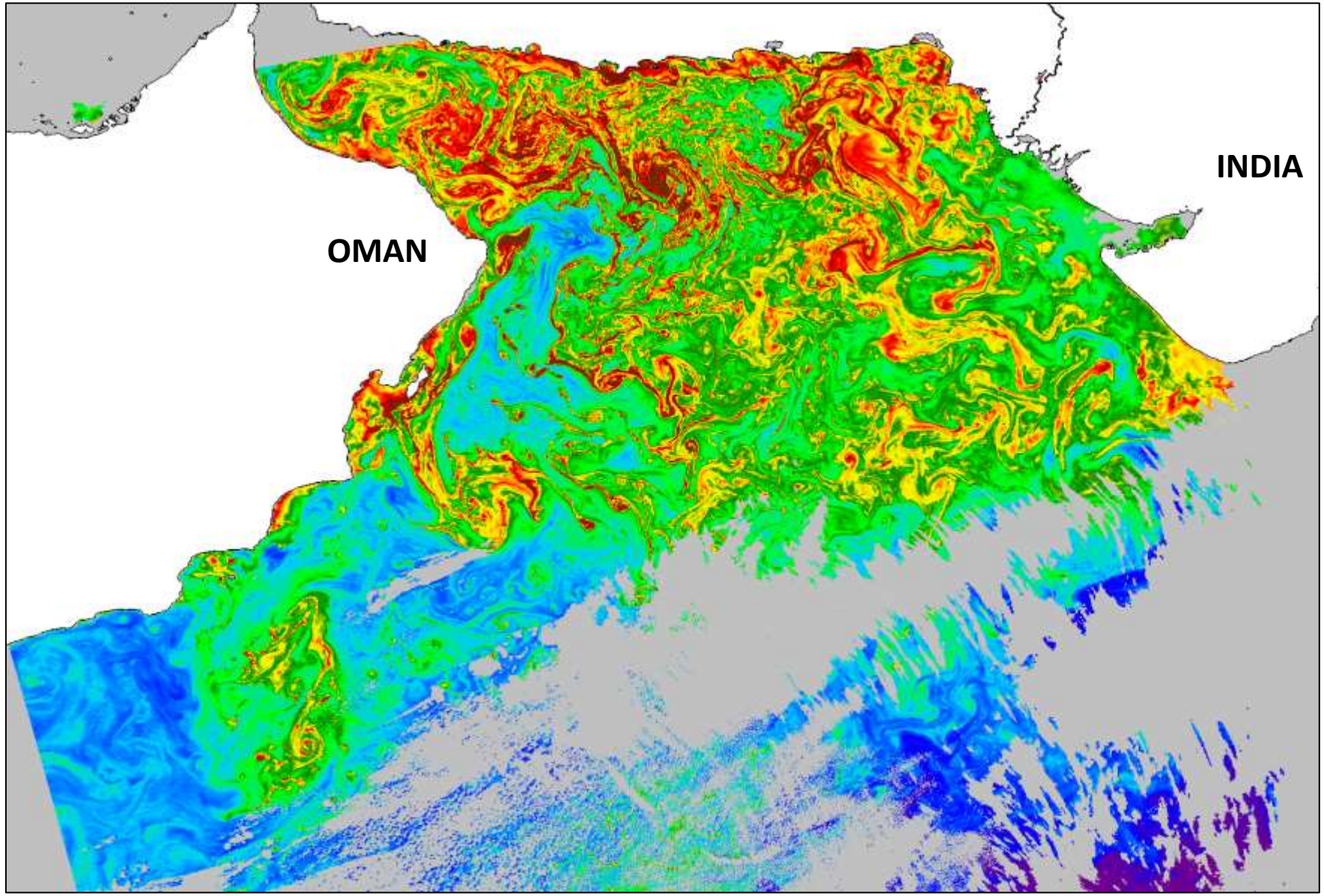
Algal Bloom Index

- Accurate assessments of Chl concentration is achieved for detection and mapping of algal blooms from satellite data in optically complex waters.
- The presence of suspended sediments and dissolved substances can interfere with phytoplankton signal and thus confound conventional band ratio algorithms.
- Chl has a strong, inverse relationship with the reflectance at 443 nm and a much weaker, positive relationship at 555 nm.
- OC3 algorithm has significant errors in optically complex waters, although yielding relatively consistent results in clear waters.



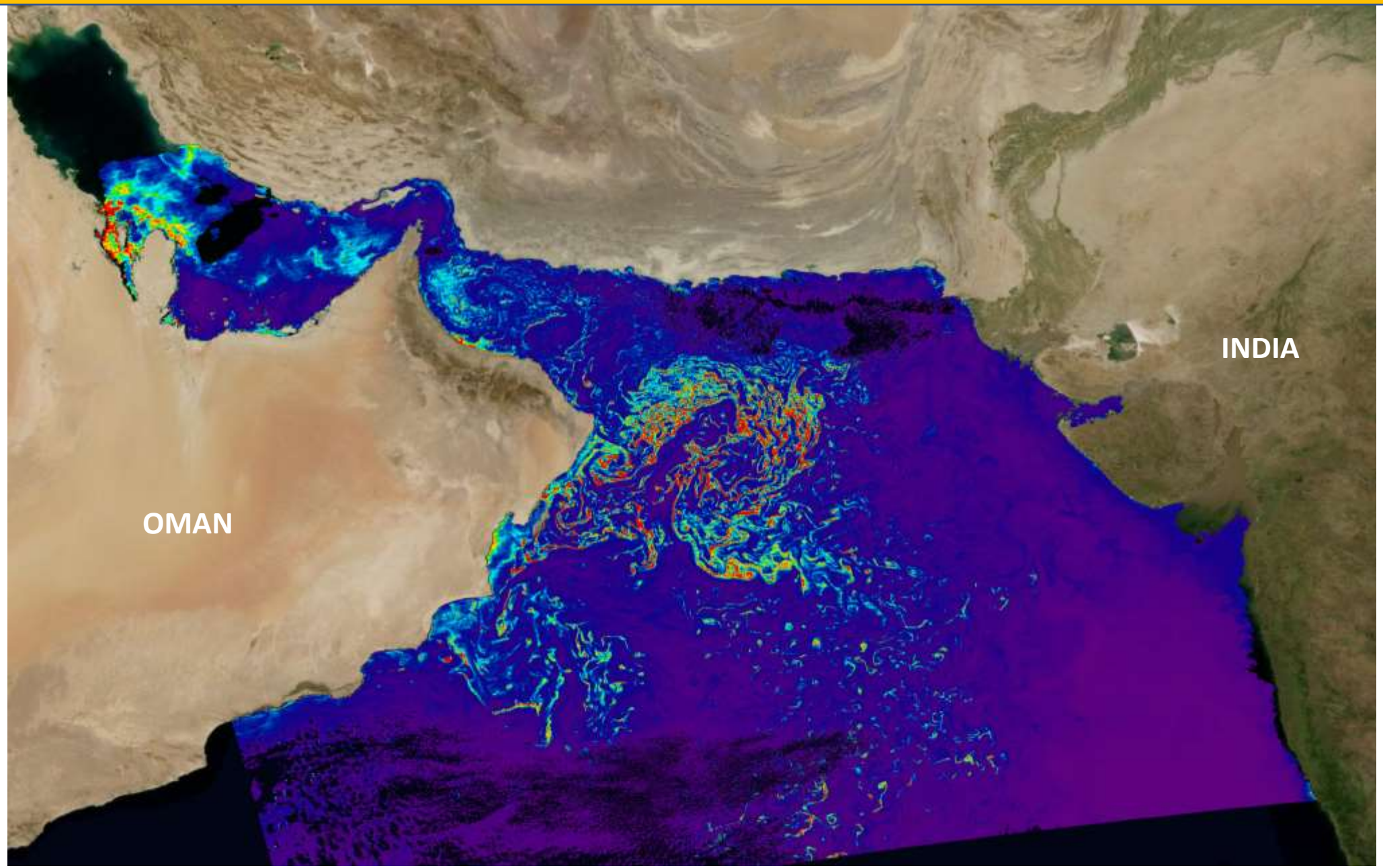
Shanmugam (2011). A new bio-optical algorithm for the remote sensing of algal blooms in complex ocean waters. *Journal of Geophysical Research: Oceans*, *116*(C4).

Arabian Sea turns to be the biologically productive region in response to climate change



Shanmugam (2011)

Arabian Sea turns to be the biologically productive region in response to climate change

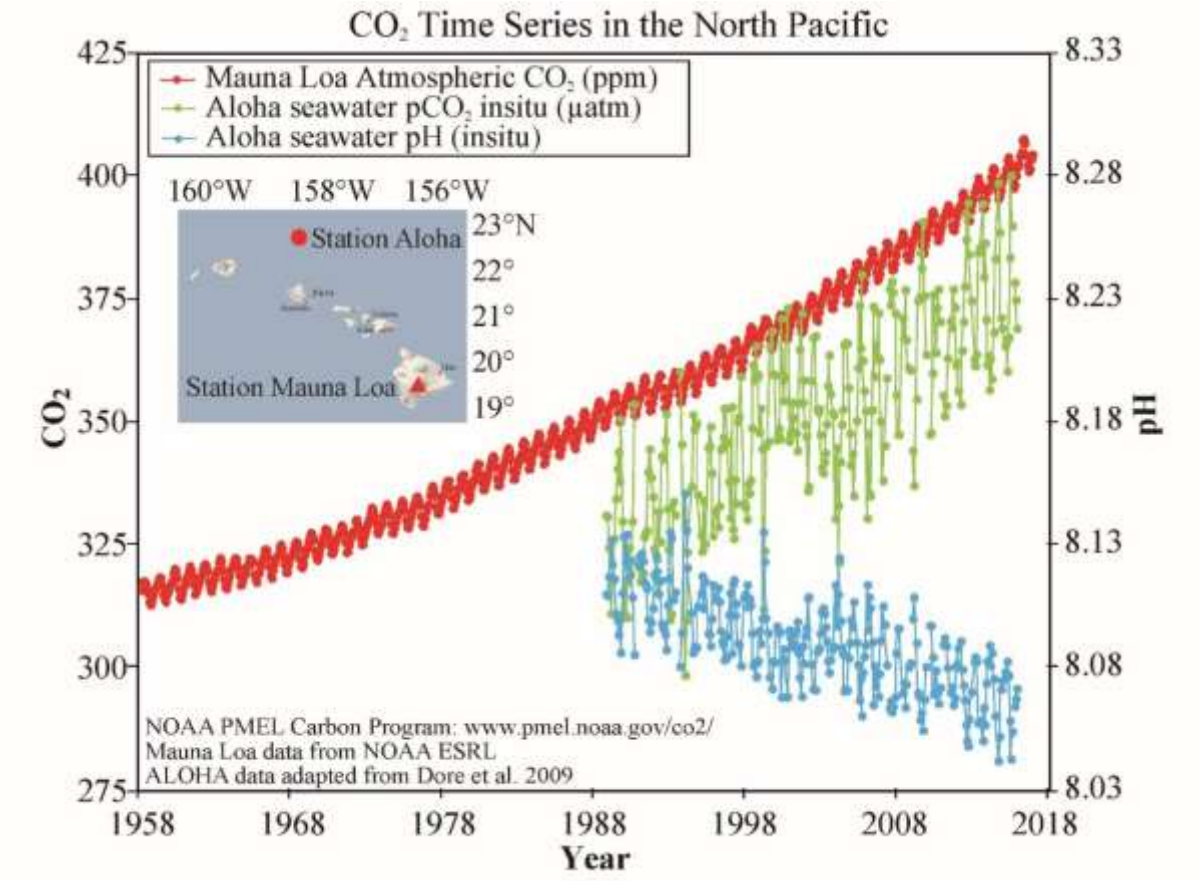


Shanmugam (2011)

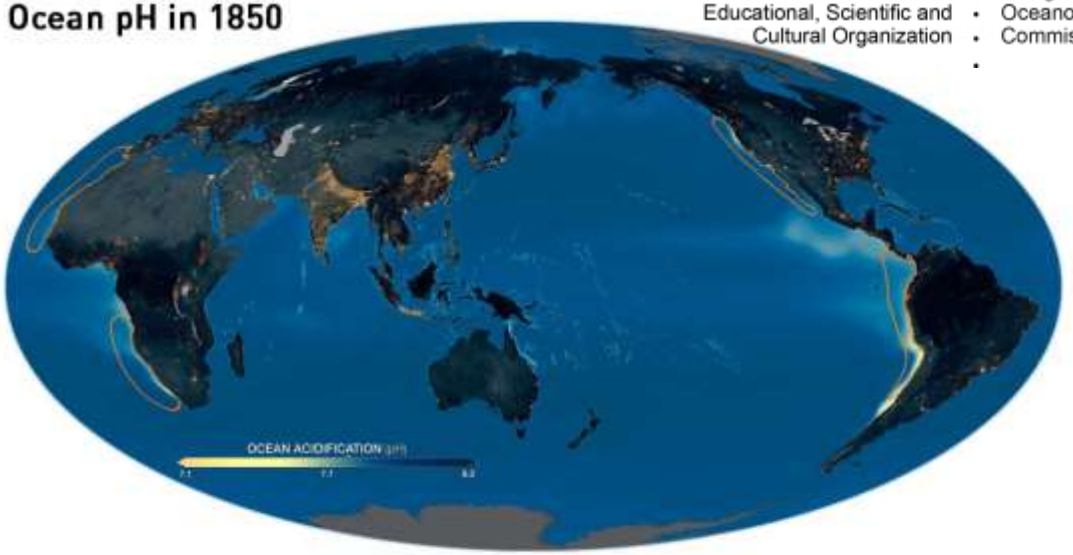
Ocean Acidification

United Nations Educational, Scientific and Cultural Organization

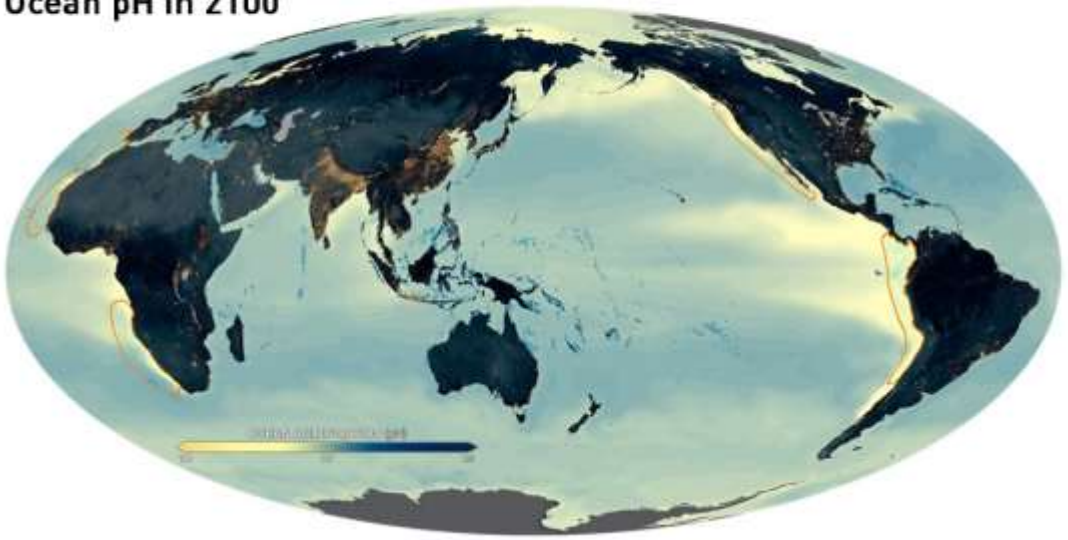
Intergovernmental Oceanographic Commission



Ocean pH in 1850

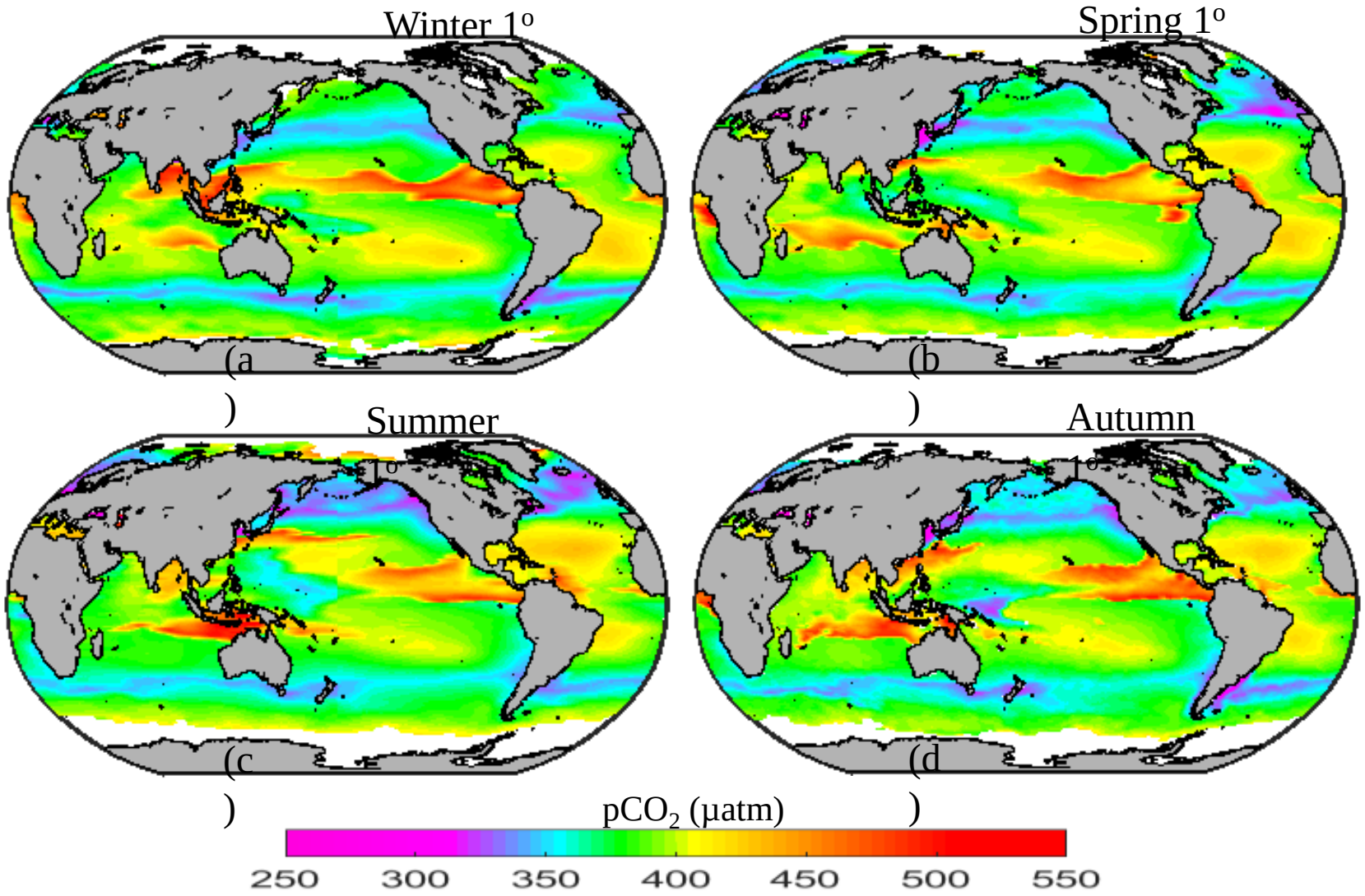


Ocean pH in 2100



pCO_2 distribution in global oceanic waters

Global maps of pCO_2 distribution for (a) Winter (January-March), (b) Spring (April-June), (c) Summer (July-September), and (d) Autumn (October-December) in 2014

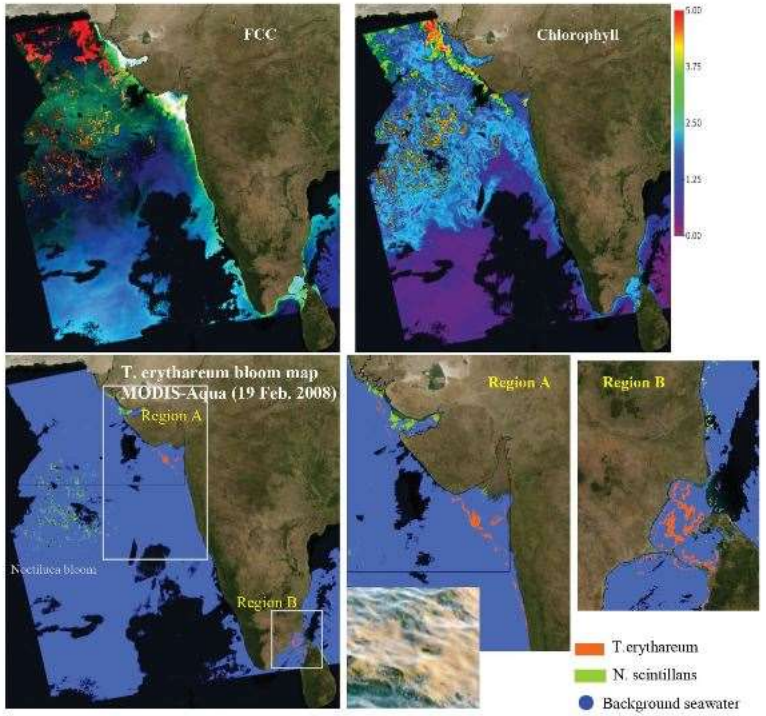


Vamsi Krishna and Shanmugam (2019)

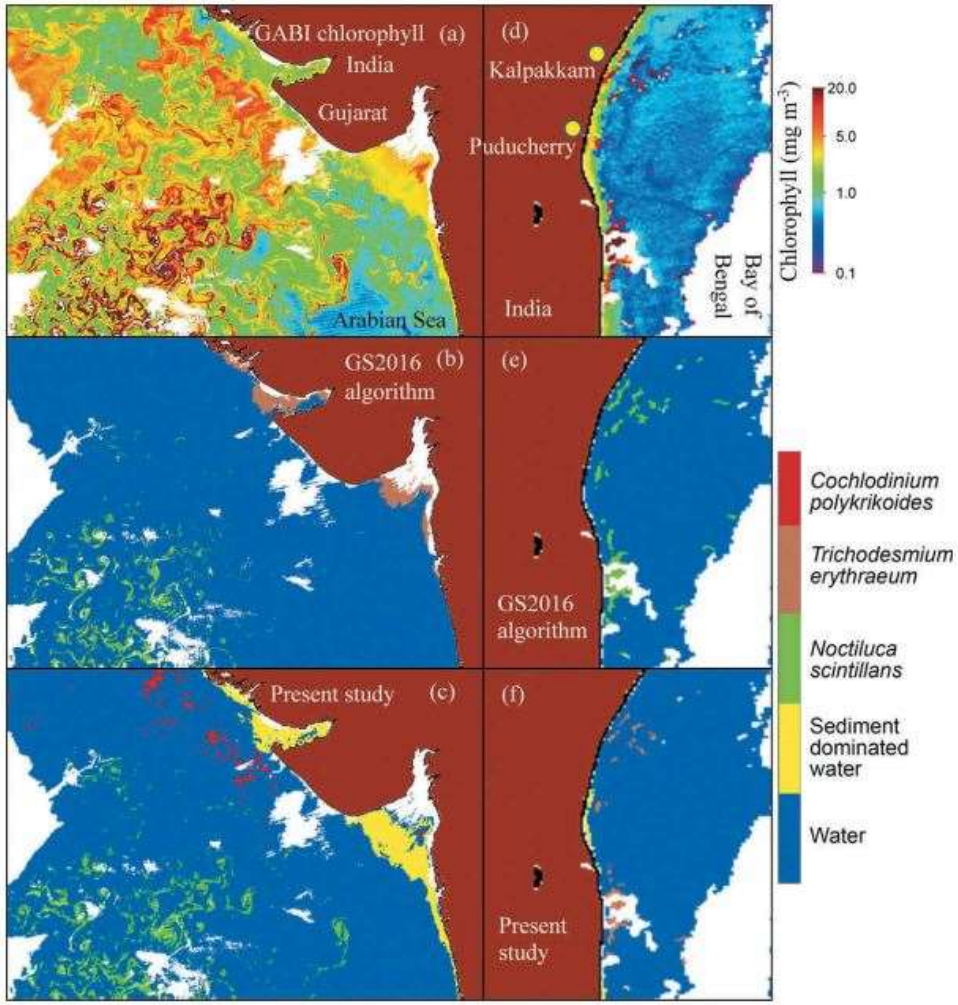
Classification of algal bloom species from remote sensing data

- Detection capabilities of **causative algal bloom species based on remote sensing data are greatly limited** because of the difficulties in interpreting the composite reflectance signal from different water features and types.
- Three major algal blooms focused here include Noctiluca scintillans/miliaris, Trichodesmium erythraeum, and Cochlodinium polykrikoides, which are recurring events in coastal and oceanic waters around India.
- An **extreme gradient boosted decision tree (XGBoost) model** is chosen to improve the prediction accuracy by prevention of overfitting.
- This **increases the scalability** of the model on several unseen test data.

Singular Value Decomposition algorithm



XG Boost algorithm

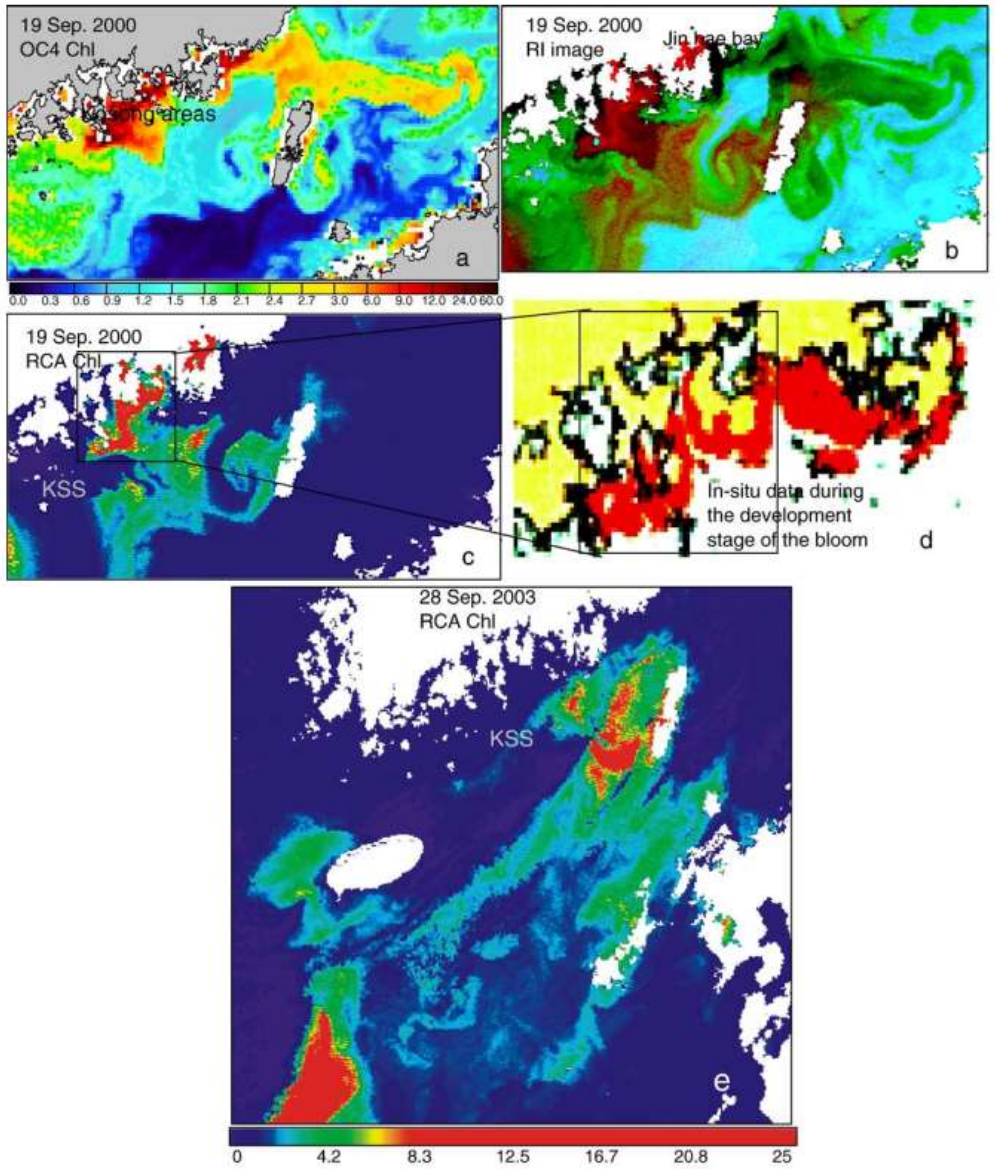


- This model was trained using 1.5 million samples and resulted in a classification **accuracy of over 98%.**
- When the results were validated using forty thousand random samples from the known blooms, an **overall accuracy more than 96.8%** was achieved.

Jayesh Ganpat Ghatkar, Rakesh Kumar Singh & Palanisamy Shanmugam (2019) Classification of algal bloom species from remote sensing data using an extreme gradient boosted decision tree model, International Journal of Remote Sensing, 40:24, 9412-9438.

Remote sensing of Harmful Algal Blooms

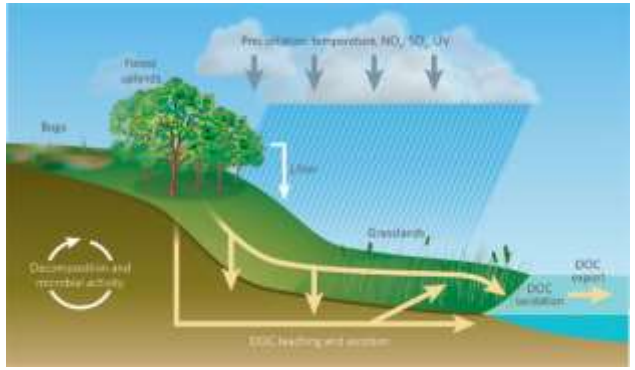
- Coastal regions throughout the world have experienced incidences of algal blooms, which are harmful or otherwise toxic because of their potential threat to humans as well as marine organisms.
- It is therefore very essential to detect, monitor and forecast their development and movement using currently available remote sensing technology because traditional ship-based field sampling and analysis are very limited in both space and temporal frequency.
- A new index called **Red tide Index (RI)** was developed for correct identification of HABs from satellite ocean color measurements in optically complex Case-2 water environments off the Korean and Chinese coasts.
- In order to quantify the HABs in terms of chlorophyll (Chl), an empirical relationship is established between the RI and in-situ Chl in surface waters from about 0.4–71 mg m^{-3}, which yields a **Red tide index Chlorophyll Algorithm (RCA)** based on an exponential function with correlation coefficient R^2=0.92.



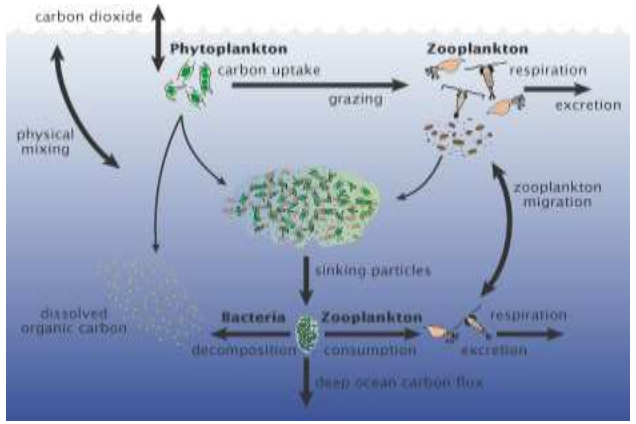
(a–d) Comparison of red tide detection by SAC-OC4 and SSMM-RI algorithms applied to SeaWiFS image of 19 September 2000 in the Korean South Sea.

Ahn, Yu-Hwan, and Palanisamy Shanmugam. "Detecting the red tide algal blooms from satellite ocean color observations in optically complex Northeast-Asia Coastal waters." *Remote Sensing of Environment* 103.4 (2006): 419-437.

CDOM retrieval – exponential model



Bauer and Bianchi (2011), Roulet & Moore (2006)

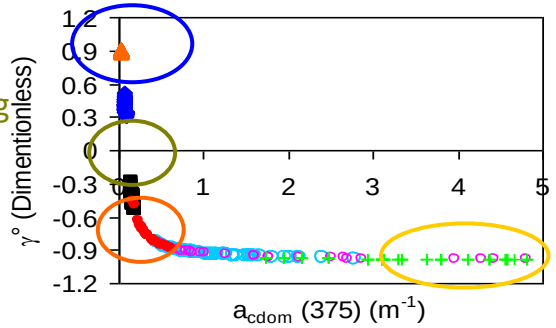


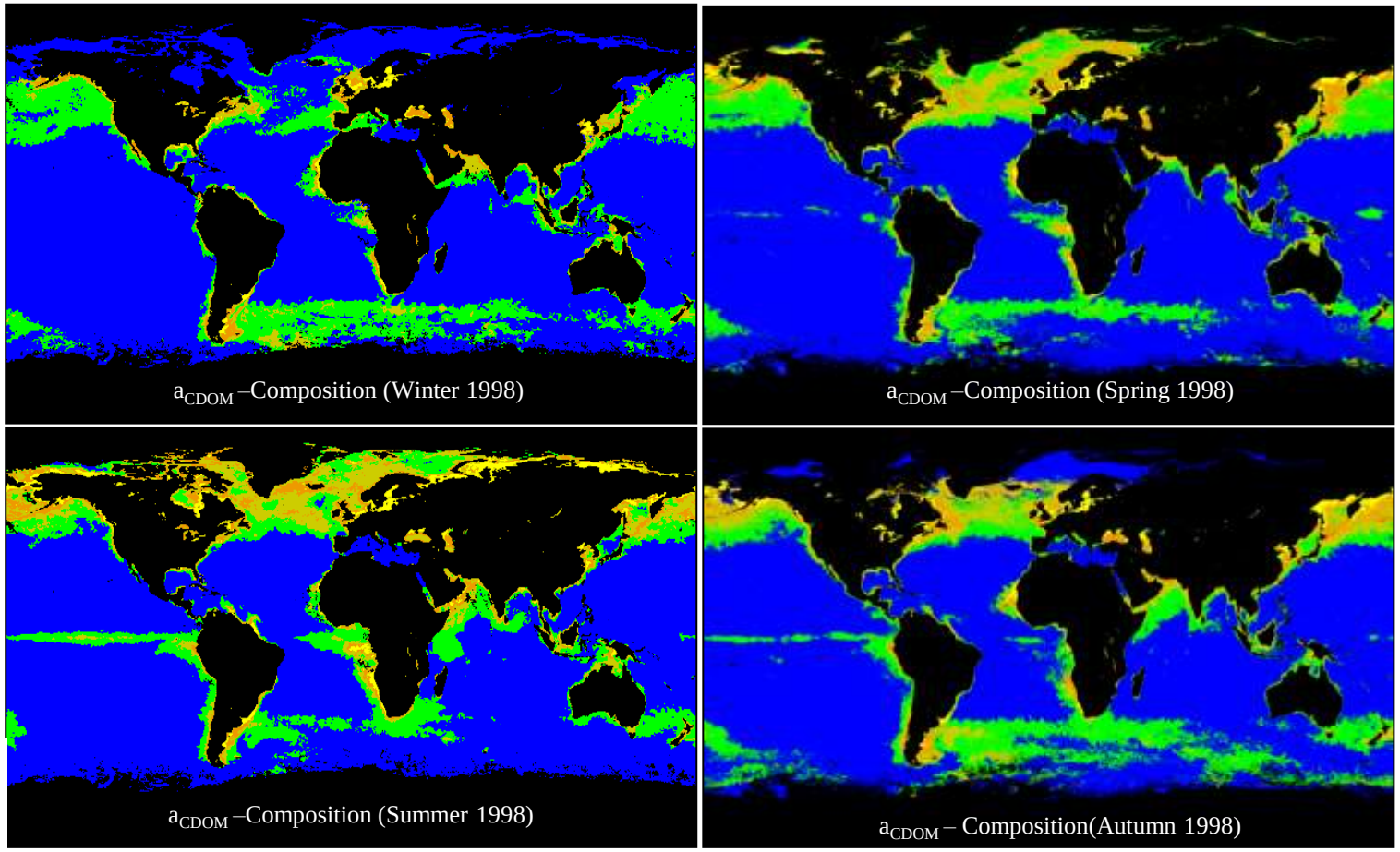
Clear oceanic waters

Coastal-Oceanic mixing waters

Turbid coastal waters

Dark/chocolate color waters





Spatial distribution of CDOM in the Global Oceans

Shanmugam, P., 2011. New models for retrieving and partitioning the colored dissolved organic matter in the global ocean: Implications for remote sensing. Remote Sensing of Environment, 115(6), pp.1501-1521.

Acoustic models – remote sensing application

Sound attenuation ($\alpha = \alpha_w + \alpha_v + \alpha_s$)

1. Sea water (α_w), function {frequency (38 k Hz), salinity, temperature and depth (1 m)}

(i) magnesium sulfate,

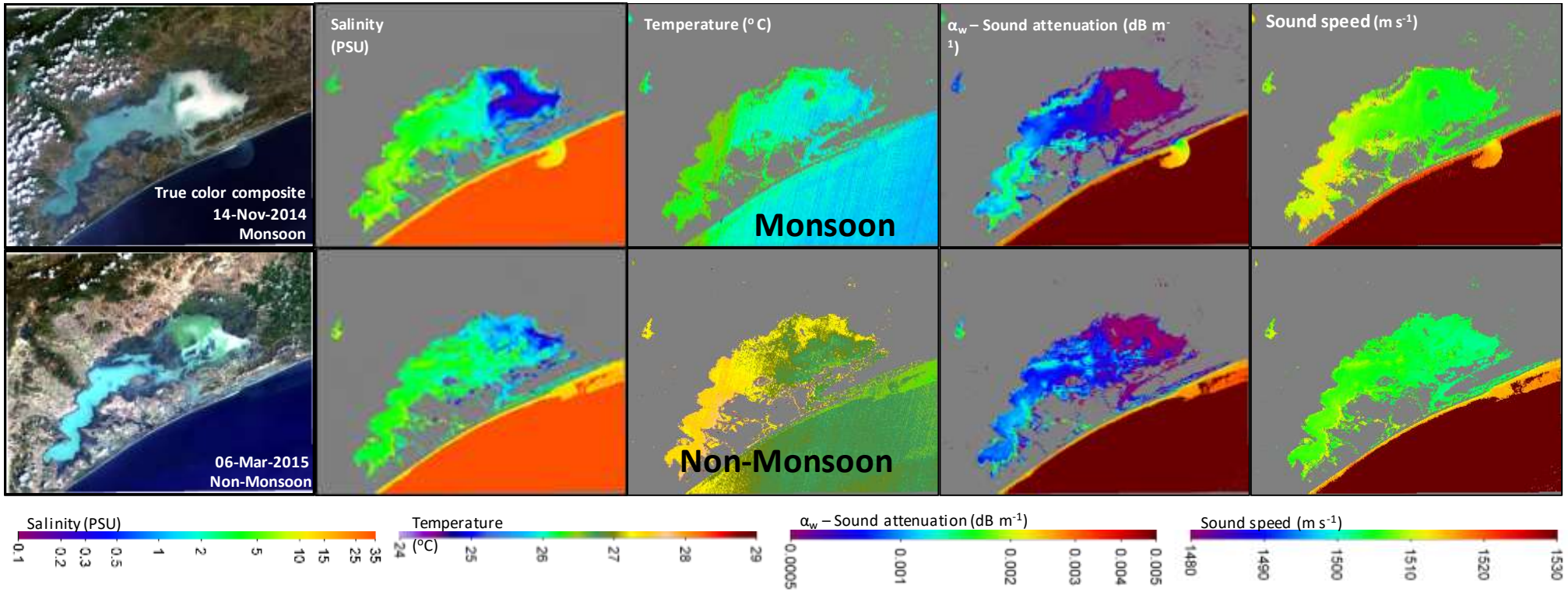
(ii) boric acid and

(iii) seawater

2. **Suspended sediments**

(i) **Viscous absorption (α_v)**, function {SS concentration, density of water, density of sediment particle (here quartz, 2650 kg m^{-3}), angular frequency}

(ii) **Scattering (α_s)** (very small and can be negligible)



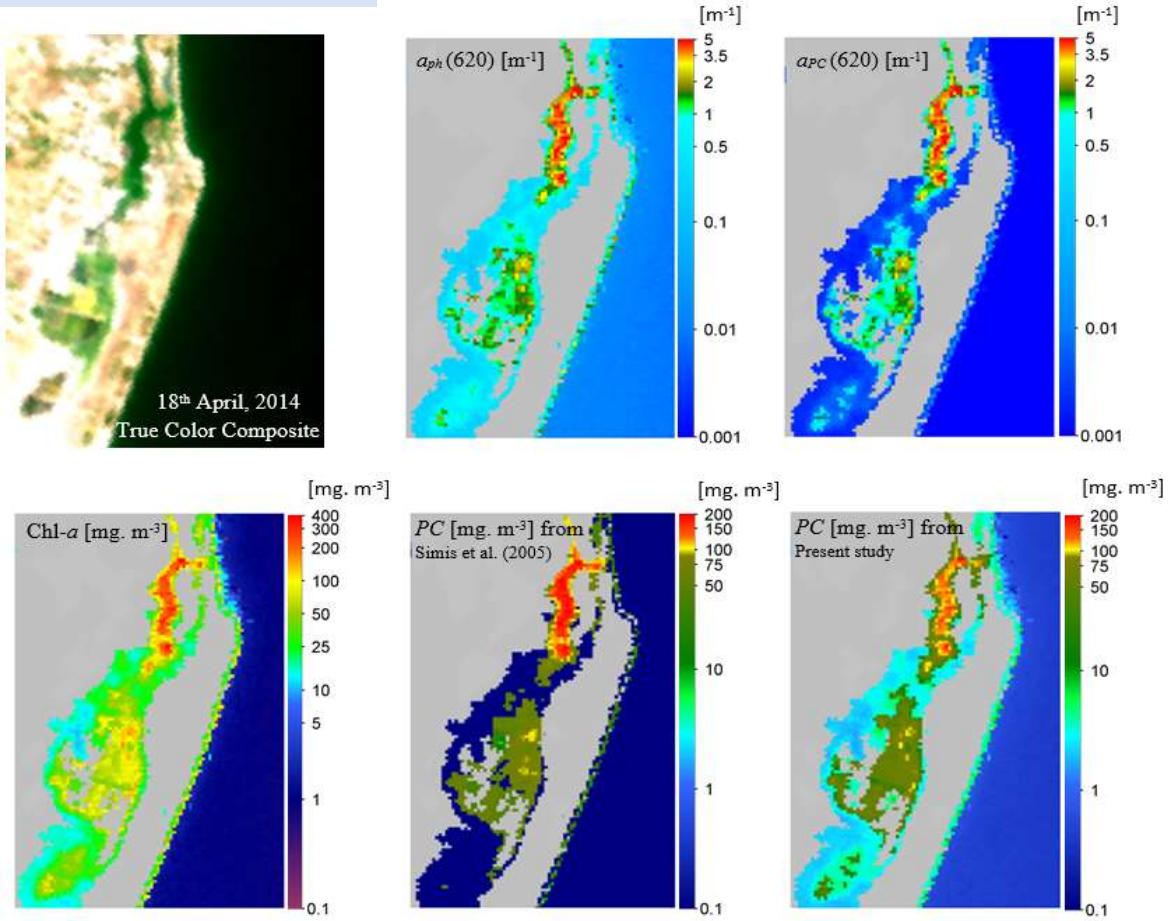
Dynamic changes in physical and acoustic properties

Varunan, T. and Shanmugam, P., 2018. Use of Landsat 8 data for characterizing dynamic changes in physical and acoustical properties of coastal lagoon and estuarine waters. Advances in Space Research, 62(9), pp.2393-2417

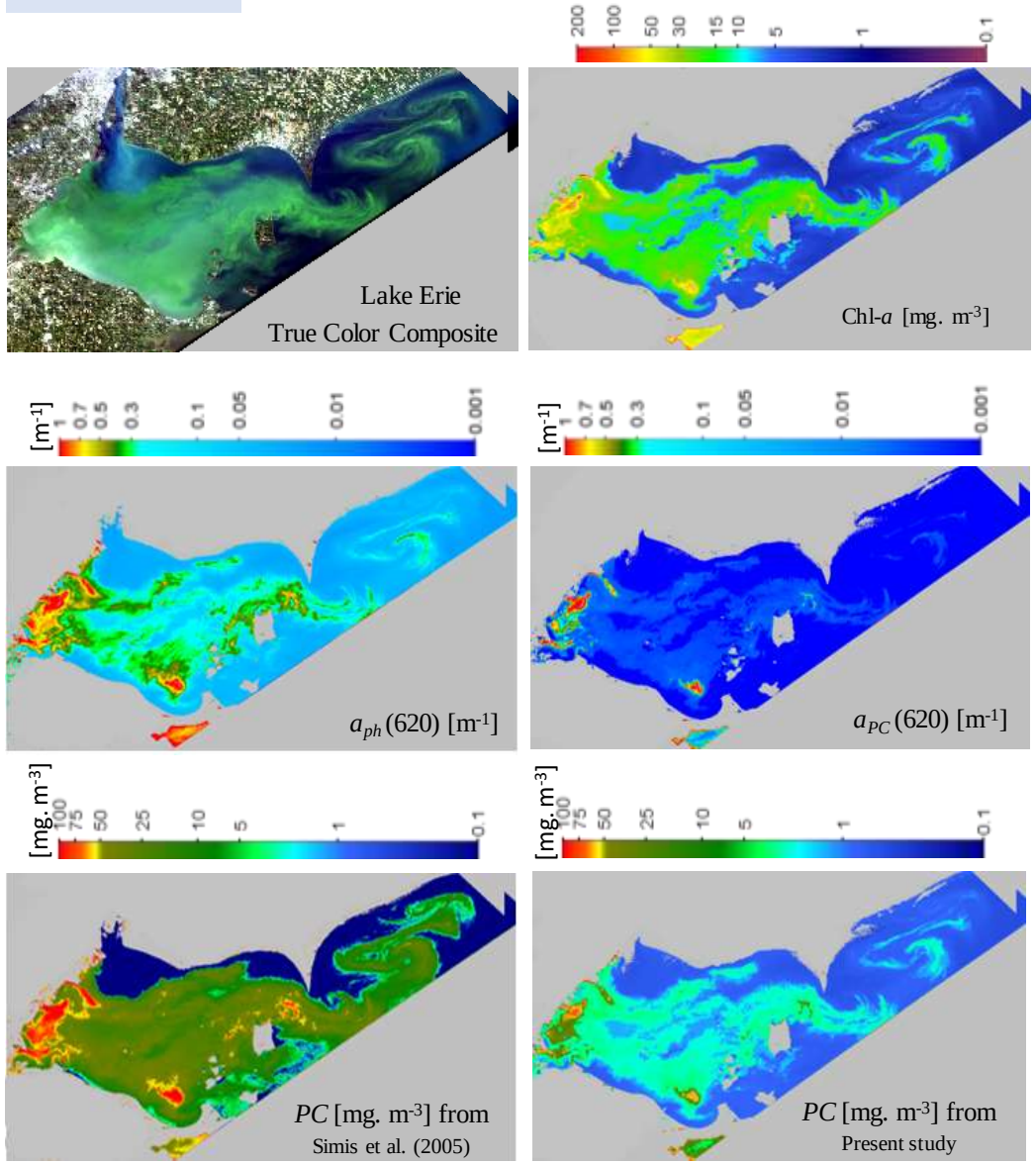
Phycocyanin concentration

- The PC concentration is estimated as a function of absorption by Phycocyanin at 620 nm using power law.

Muttukadu Lagoon



Lake Erie



Varunan, T. and Shanmugam, P., 2017. An optical tool for quantitative assessment of phycocyanin pigment concentration in cyanobacterial blooms within inland and marine environments. Journal of Great Lakes Research, 43(1), pp.32-49.

Real time Flood Forecasting

Pluvial flooding

- When rainfall intensity /amounts exceed the capacity of existing storm water or combined sewerage pipes.

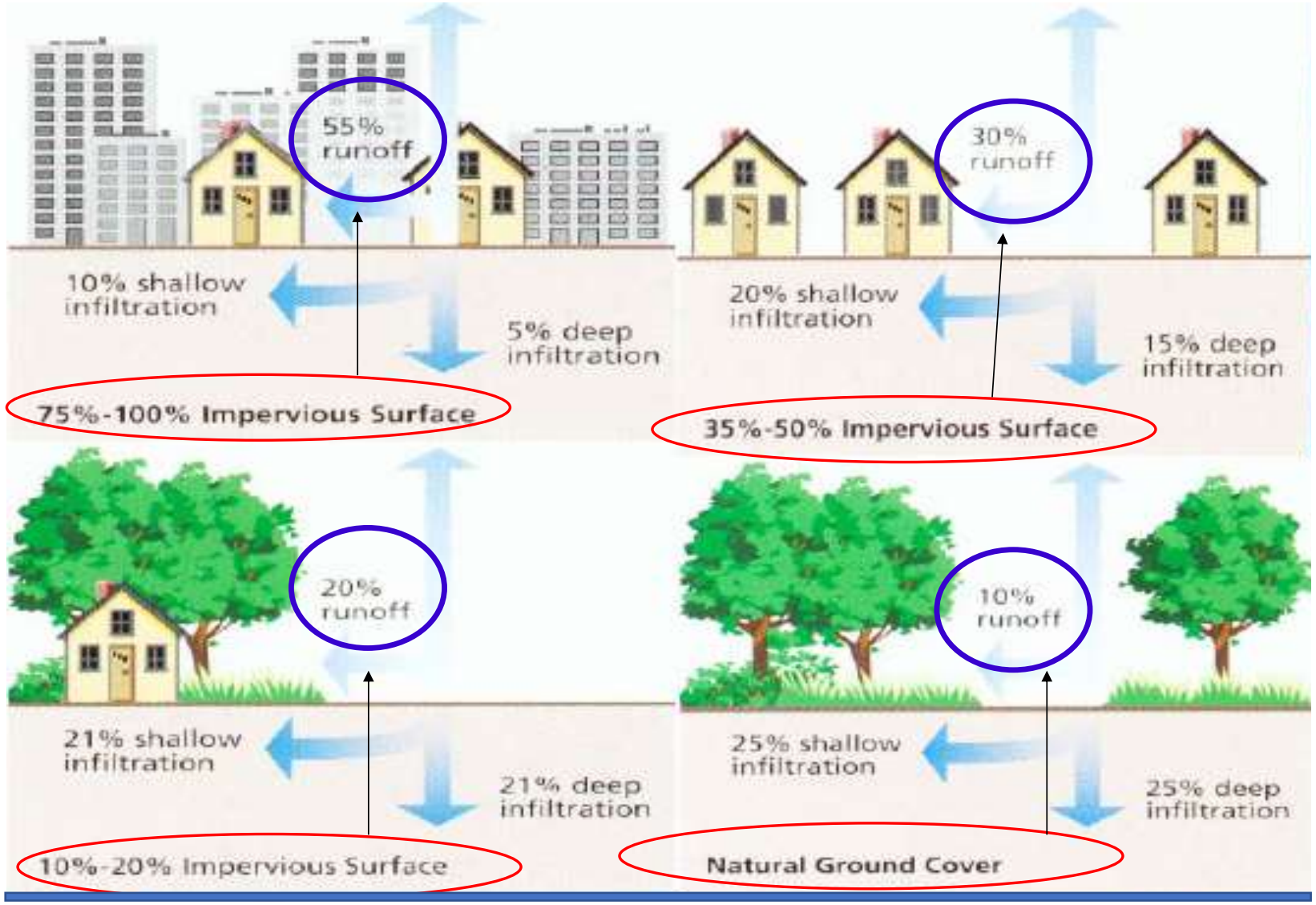
Fluvial flooding

- When the river channel cannot pass high flood flows.

Tidal flooding

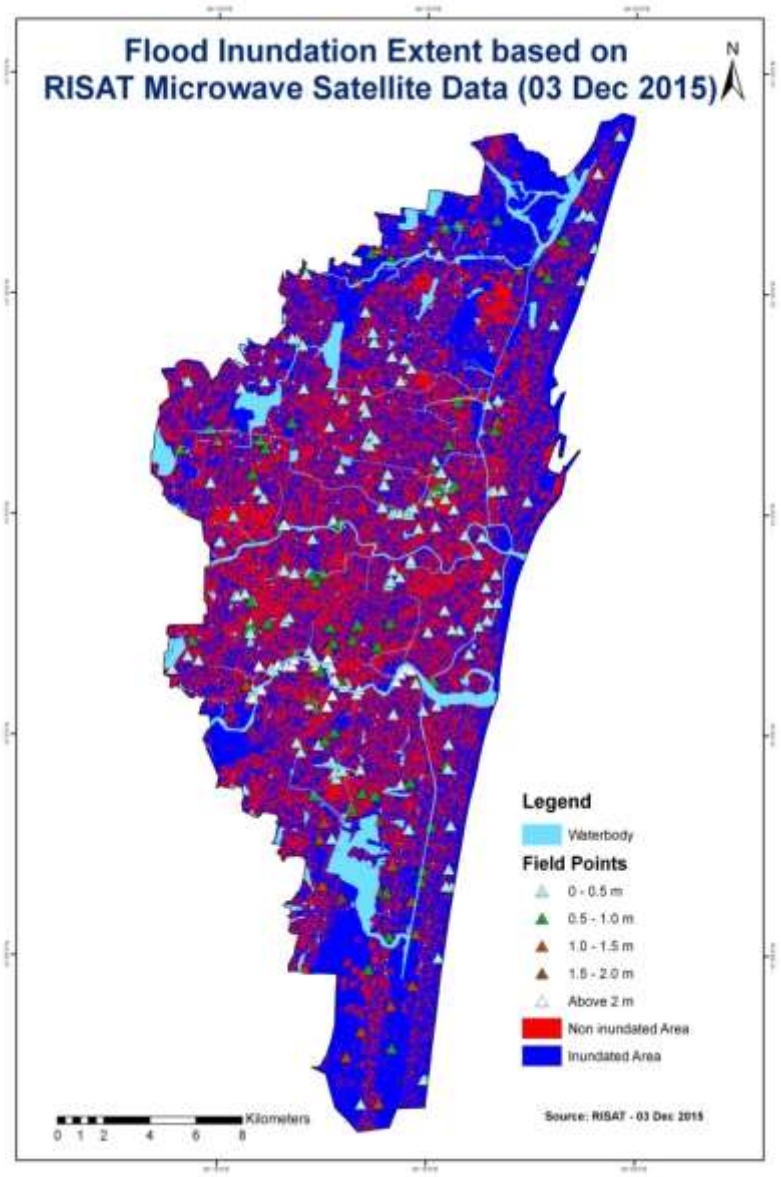
- Higher sea level (i.e. Worst combination of High Tide + Storm Surge).

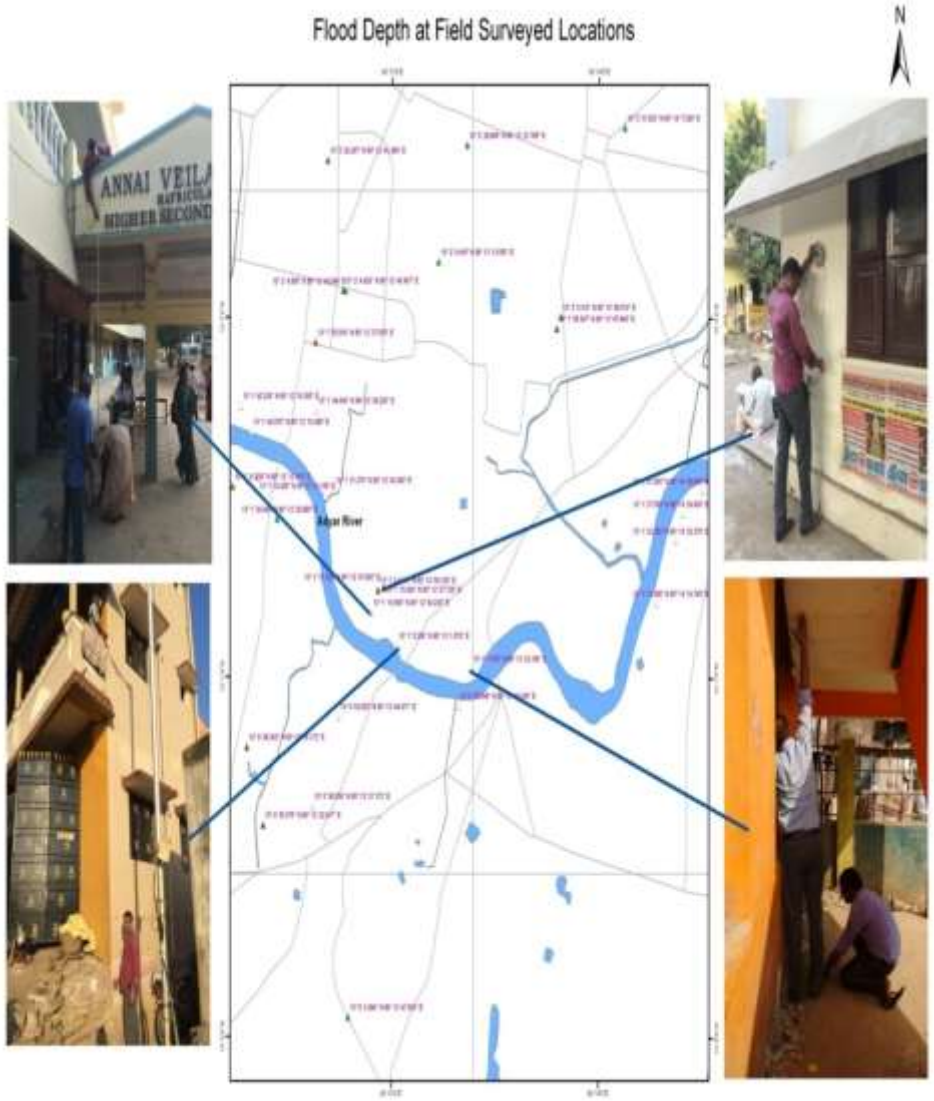
URBAN FLOODING – IMPERVIOUSNESS VERUS RUNOFF



Credit: Dr. D. Thirumalaivasan, IRS, Chennai.

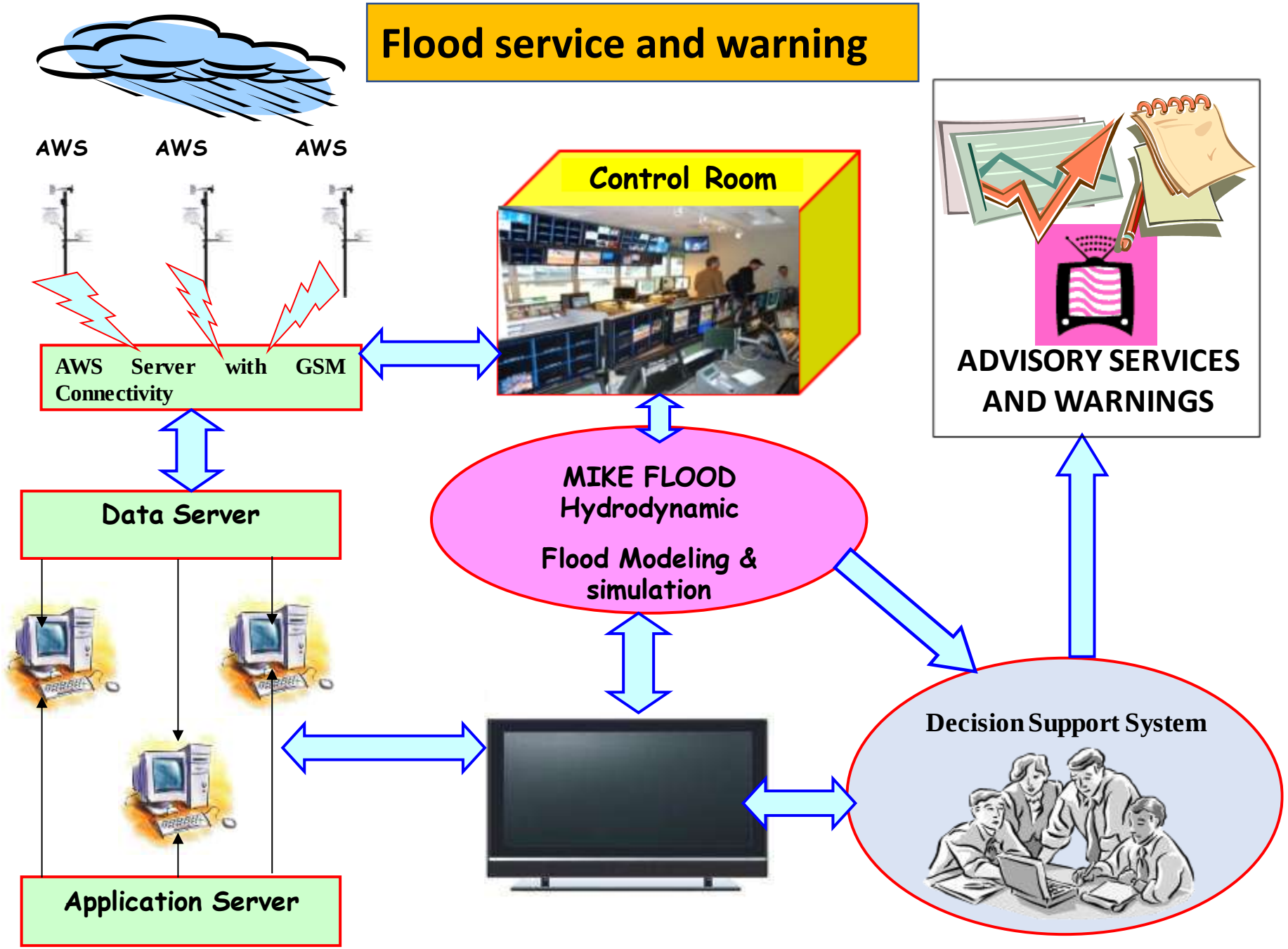
Mapping of flood inundation (Dec 2015 event) area using RISAT microwave satellite data and flood depth by field measurement – Chennai





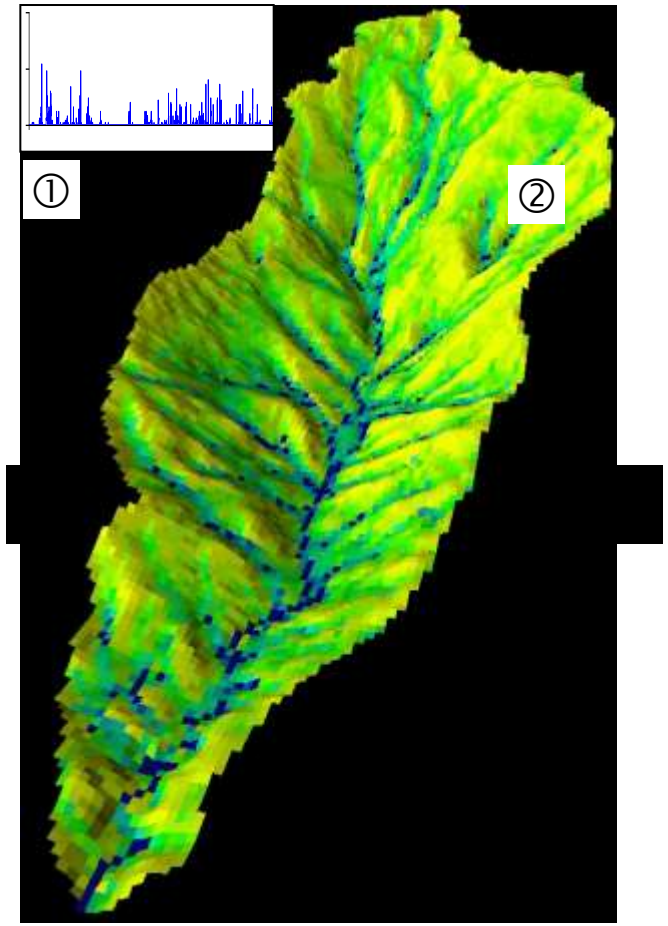
Credit: Dr. D. Thirumalaivasan, IRS, Chennai.

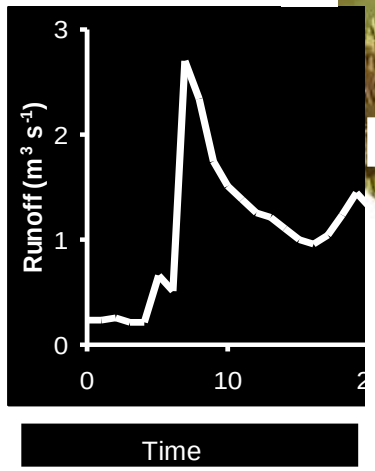
Flood service and warning



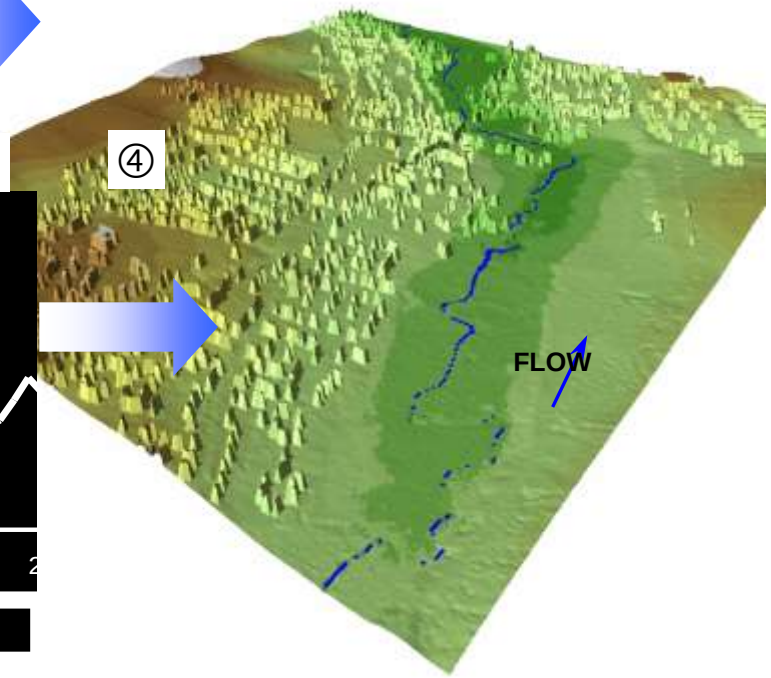
Credit: Dr. D. Thirumalaivasan, IRS, Chennai.

Continuous Simulation of Flood Hazards





Floodplain Hydraulics

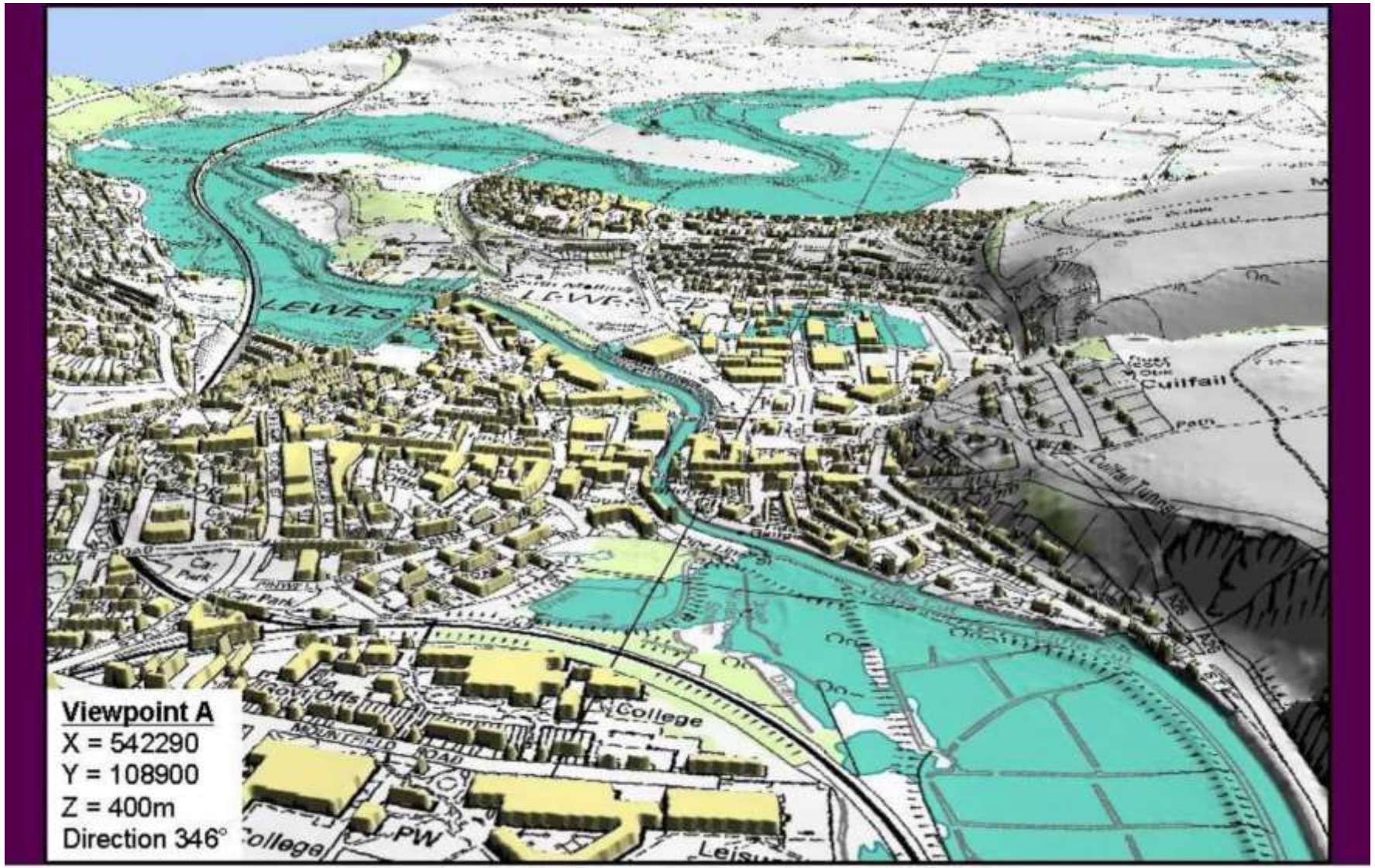


END-TO-END MODELLING

① Stochastic Rainfall Simulation
② Rainfall-Runoff Modelling
③ T-period Event Modelling
④ Floodplain Inundation Modelling

Credit: Dr. D. Thirumalaivasan, IRS, Chennai.

Scenario 1: Fluvial 1 in 2 year, Tidal 1 in 200 year

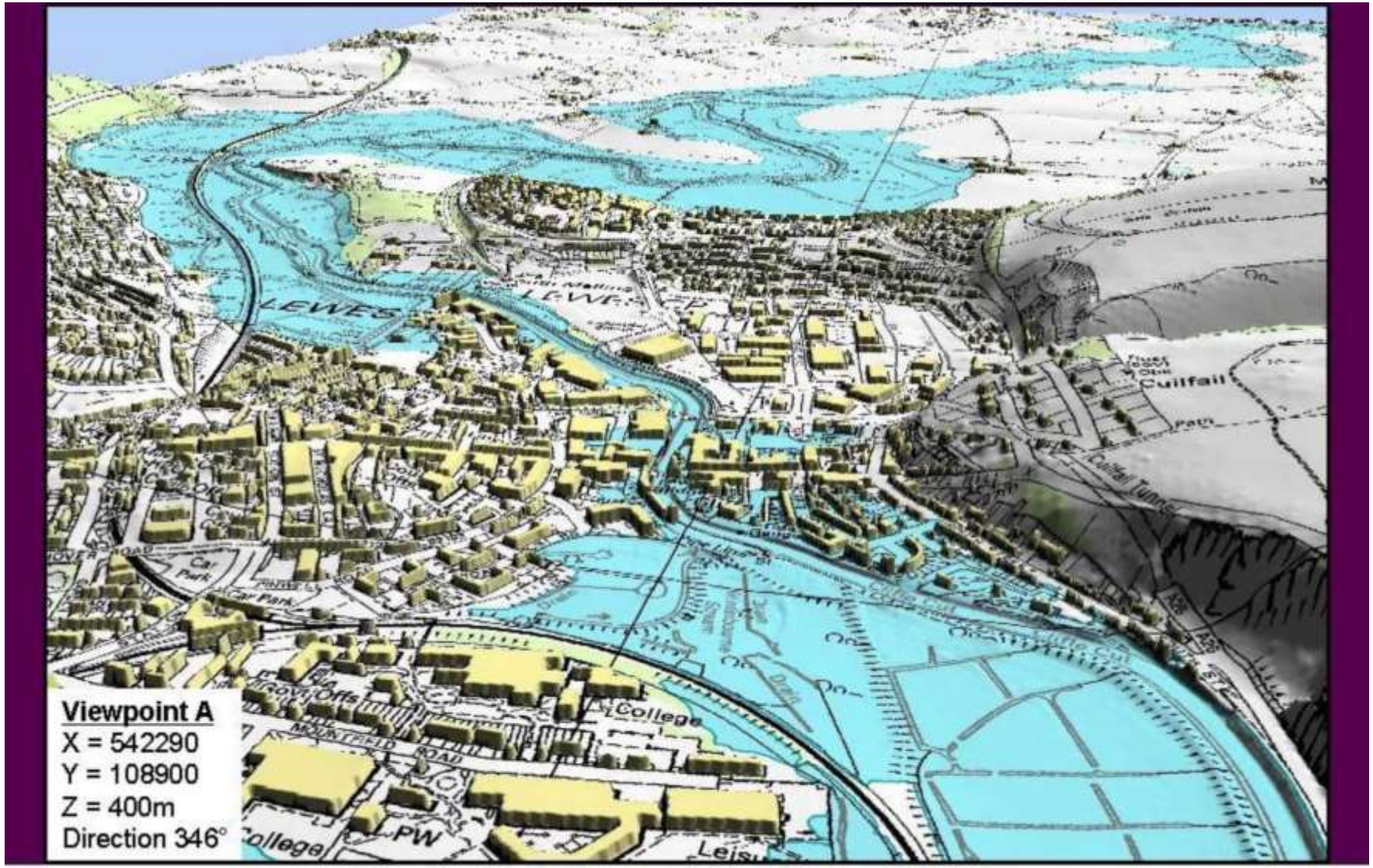


Geomatics Group

Integrated spatial data

Credit: Dr. D. Thirumalaivasan, IRS, Chennai.

Scenario 2: Fluvial 1 in 2 year, Tidal 1 in 200 year, Plus Climate Change



Geomatics Group

Integrated spatial data

Credit: Dr. D. Thirumalaivasan, IRS, Chennai.

Coastal & Marine protection related Acts by Indian Government

- The Constitution of India: **Article 297** of the Constitution of India deals with the protection of marine resources.
- **Maritime Zone Act, 1976 -** The Territorial Waters, Continental Shelf, Exclusive Economic Zone and Other.
- Wildlife (Protection) Act, 1972 and Marine Protected Areas (MPAs).
- Biological Diversity Act, 2002 and MPAs.
- Coastal Regulation Zone Notification, 2019.
- **Merchant Shipping Act, 1954** - Provisions for control of pollution arising from ships & offshore oil production - Coast guard empowered for surveillance of oil pollution in areas including EEZ - Administration by Min. of Surface Transport.
- **Coast Guard Act, 1972** - to protect and conserve the marine environment in the high seas - Coast guard empowered for surveillance of oil pollution in areas including EEZ.
- **Water Act, 1974** Amendment - deals with land based sources of water pollution - jurisdiction of 5km - enforcement Central and State pollution control boards - administration by Min. of Environment and Forest.
- **Environment Protection Act 1986** - Umbrella act for all Environmental related issues in the country - Prescribes discharge standards - administration by Min. of Environ. and Forest.

Role of various government organizations in SDG-14

- **Ministry of Environment and Forest & Climate Change -** prevention and control of marine pollution from land based sources.

- **Ministry of Earth Sciences -** monitoring of marine pollution all over the sea.

- **Ministry of Surface Transport -** prevention and control of oil pollution from ships and offshore oil platforms and ports.

- **Ministry of Petroleum and Natural Gas -** monitoring and combating of oil pollution in and around offshore platforms and coastal refineries.

- **Ministry of Defence -** combating of oil pollution all over the sea except in port limits, oil platforms and refineries.

In summary

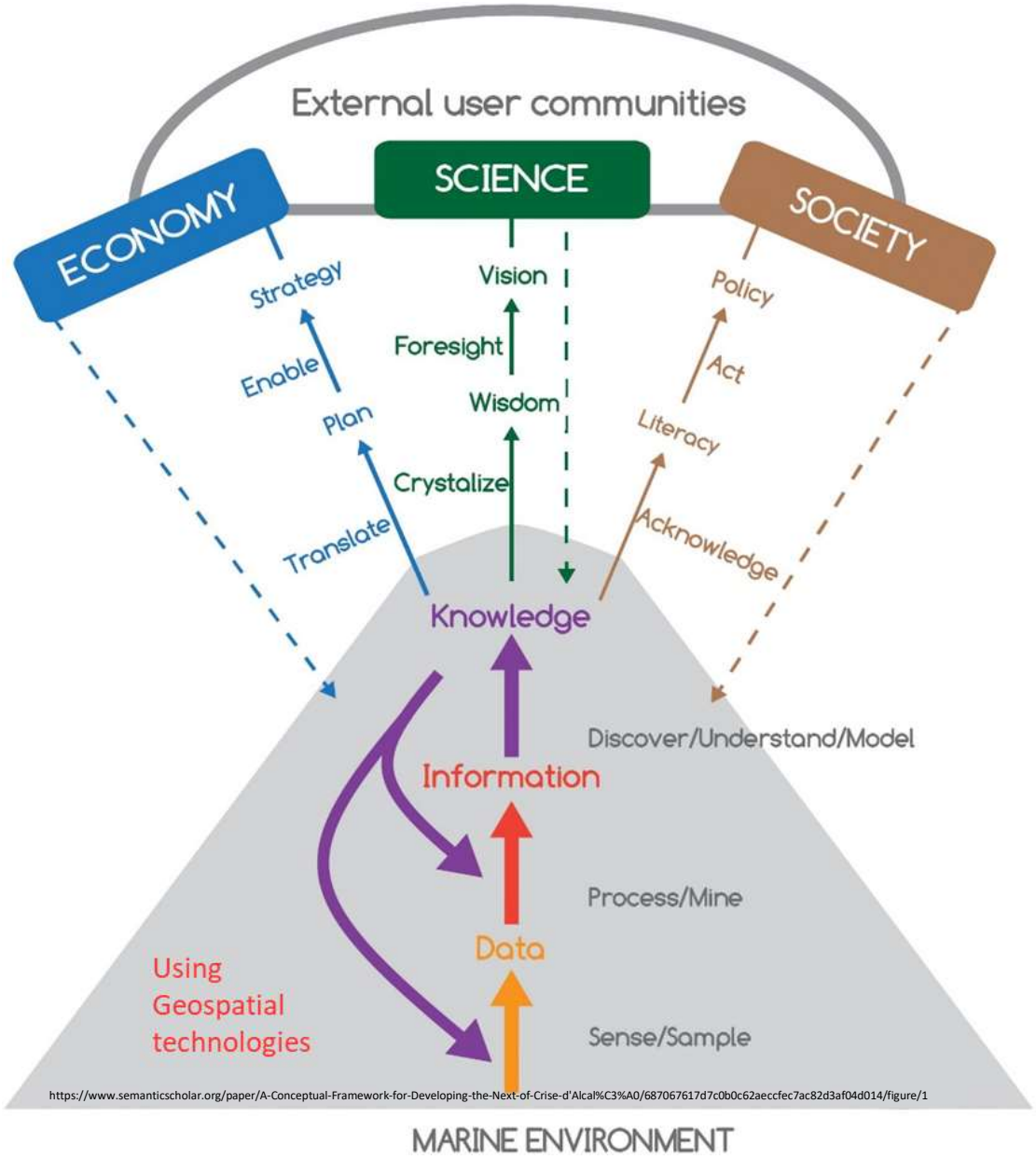
- Laws and policies are established for the protection of marine resources, but there is a need to further strengthen out efforts to properly implement these polices across the states.

- The effort is also necessary to focus on creating awareness among the common people by arranging various conventions, conferences and declarations so that conservation and preservation of marine resources can be possible for present and future generations.

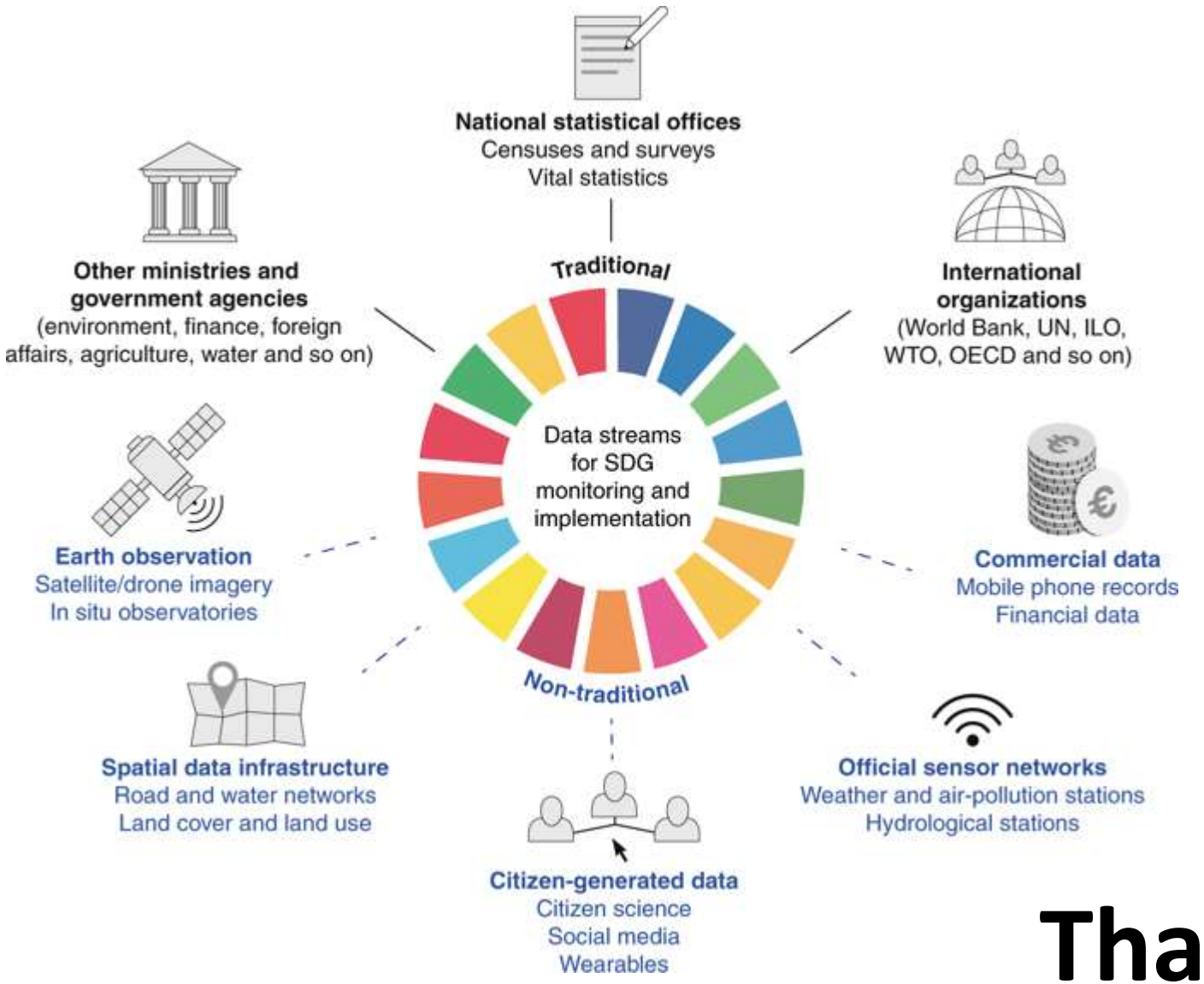
- Marine geospatial technologies are inevitable for the management and conservation of coastal/marine resources and address various forms of vulnerabilities associated with the coastal/marine ecosystem.

- It also provides an interface of science and policy which strengthens the possibilities to achieve SDGs

- To achieve the SDGs, it is thus necessary to advance the marine geospatial science and technology.



https://www.semanticscholar.org/paper/A-Conceptual-Framework-for-Developing-the-Next-of-Crise-d'Alcal%C3%A0/687067617d7c0b0c62aeccfec7ac82d3af04d014/figure/1



Thank you

Fritz, S., See, L., Carlson, T. *et al.* Citizen science and the United Nations Sustainable Development Goals. *Nat Sustain* **2,** 922–930 (2019)