BHARATHIDASAN UNIVERSITY

Tiruchirappalli - 620 024
Tamil Nadu, India

Programme : 6 year Integrated M.Tech in Geological Technology and Geoinformatics

Course title : Marine Geology and Geoinformatics in Sea bed Exploration

Course code : MTIGT 0607

UNIT – III

Ocean resources

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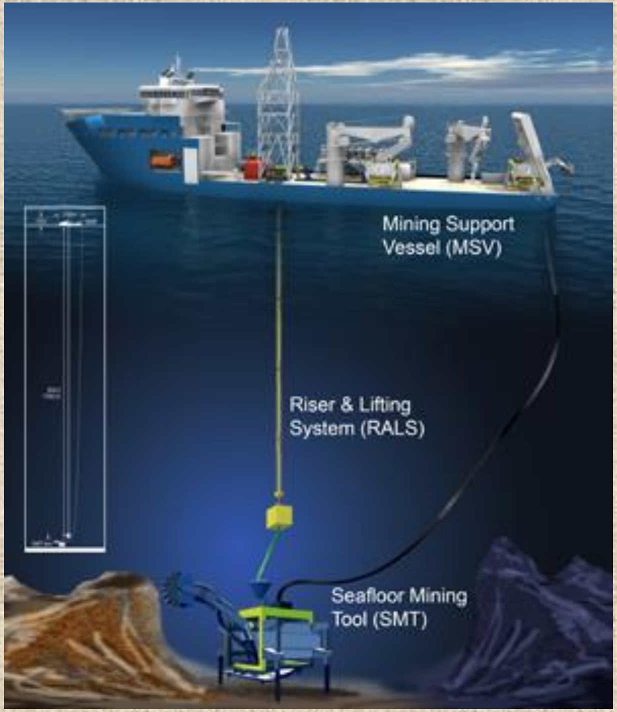
Nonliving resources of the ocean

- Desalinated seawater is a major portion of the fresh water used by many Middle Eastern countries, such as Saudi Arabia.
- As resources on land are used up and new technology makes ocean exploration and mining easier, ocean mining may increase.



Energy Resources

- Oil and gas form from the remains of living organisms.
- In the ocean, organisms are concentrated in the waters over the continental shelf.
- Oil and gas are pumped from the continental shelf of every continent but Antarctica.
- About 30% of the world's oil is pumped from deposits under the ocean floor.

Minerals and Rocks

- When rivers empty into the sea, sediments carried by the rivers drop to the bottom.
- These sediments may contain phosphorite, iron, copper, lead, gold, tin, diamonds and other minerals.

Ocean resources - Mineral Resources

Ocean mining of mineral resources has enormous economic potential. The minerals mined for resources can be classified into five groups:

- **construction material**, including sand, gravel, and other high bulk materials;
- **industrial materials** including silica sand, aragonite, phosphates, and sulfur;
- **metallic minerals in placer deposits** - gold, platinum, tin, titanium, and rare earth metals;
- **metalliferous oxides**, which contain manganese, copper, nickel, and cobalt; and
- **metalliferous sulfides**, including copper, lead, zinc, chromium, and gold.

Classification of Marine Mineral Resources

Marine mineral resources can be broadly classified into three categories, on the basis of the source of their origin.

These categories are:

- Marine mineral deposits from **terrestrial sources**;
- Marine mineral deposits from **combined terrestrial and deep ocean resources**;
- Marine minerals from **sources in ocean basins**.

Marine mineral deposits from terrestrial sources

Includes all the mineral resources that originate from the chemical and mechanical disintegration of rocks on land areas. After being disintegrated, these rock debris are eroded and transported to the oceans by rivers, where they are sorted by the wave action on the basis of their density (density of their constituent minerals). The distance to which a mineral can be transported, without any change in its state, depends upon its resistance towards the mechanical action during the transport (i.e. hardness, cleavage, density, solubility, etc).

The median distance of transport from a bedrock source to an offshore placer deposit is ~ 8 km^2. The marine minerals derived from terrestrial sources contain heavy metallic elements like Barium, Chromium, Gold, Iron, Tin, Thorium, Tungsten, Zirconium and non-metals like Diamond, Siliceous and Gravel and other rare earth elements. The significant quantities of these minerals have been detected on the shores of many countries reportedly, India, Australia and Brazil. Gold is mined, mainly from the shores of Thailand, Myanmar and Indonesia.

Marine Mineral Deposits from Combined Terrestrial and Deep Ocean Sources:

These include the marine mineral deposits that derive their origin from both the terrestrial as well as deep sea sources. Some of the significant marine mineral deposits of this type are:

- **Polymetallic or Manganese nodules**: Manganese nodules are usually found up to a depth of 5 km in the oceans on the abyssal plains. The accumulation of Manganese occurs in two ways viz. precipitates hydrogenetically from metals present in ocean water, while some of the nodules precipitate diagenetically from the metals present in pore water of the ocean sediments

- **Cobalt-rich Ferromanganese Crusts**: The precipitation of Cobalt-rich Ferromanganese crust occurs just like the Manganese nodules. These crusts are usually found on hard rock platforms like ocean ridges, abyssal hills and plateaus, etc.

- **Marine Minerals from Sources in Ocean Basins**: These deposits include those which have their origin in the ocean floor, which means these are derived from the disintegration of rocks within the ocean floor and precipitation of minerals therein. The important ones among these are:

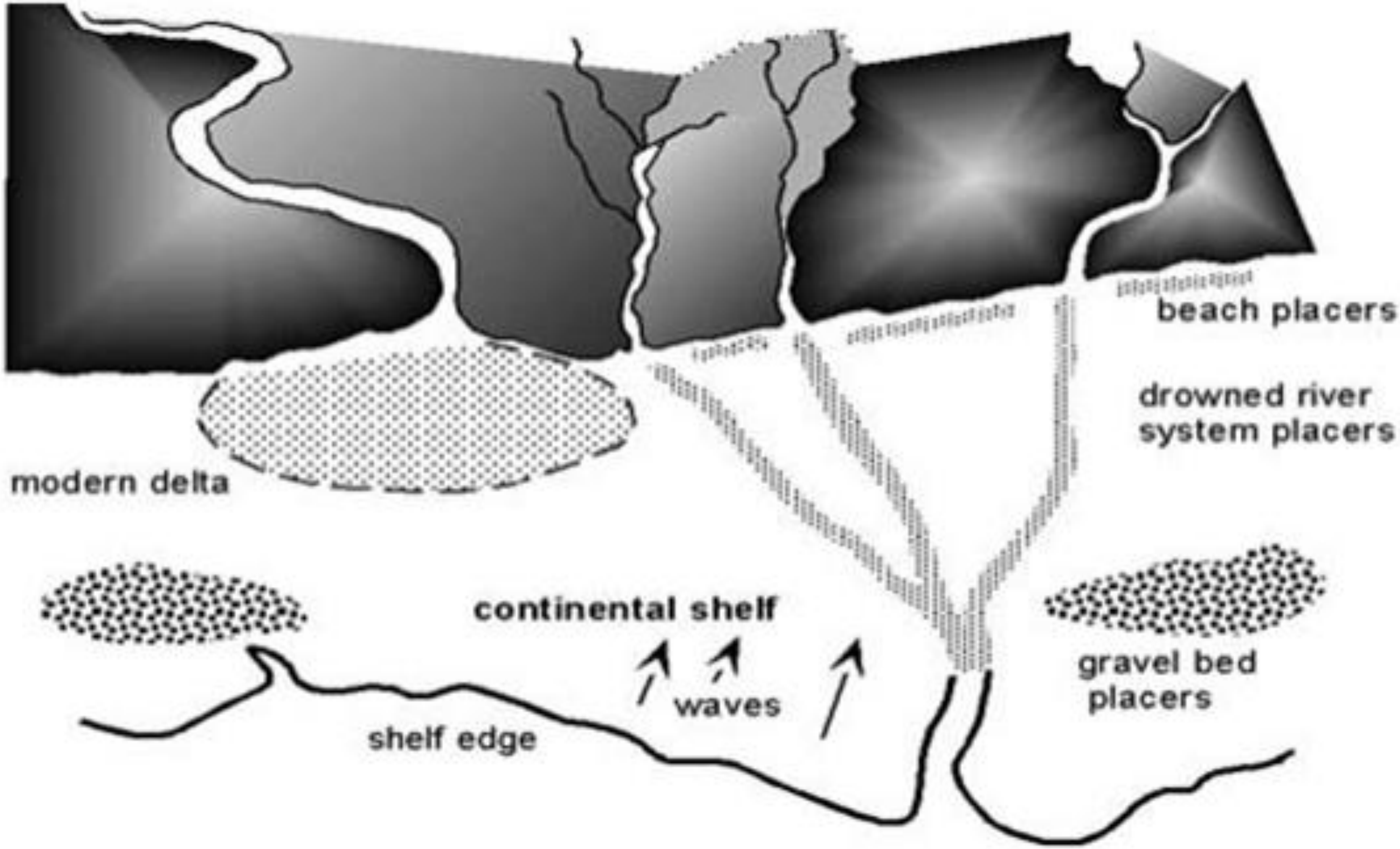
- **Metalliferous Sediments**: The first hydrothermal deposits accumulated on a fully submerged plate boundary were the Metalliferous sediments of Atlantis 2nd deep in the Red sea discovered in the year 1965. It remains the most significant mineral deposit discovered till now. The Atlantis 2nd deep is a parallelogram shaped basin which remains at a depth (water depth) of 2 km. It is 12 km long and 5 km wide. It is the largest basin that exists between the Arabian and African plates.

- **Sea-floor Massive Sulfides (SMS)**: The Sea-floor Massive Sulfides are bodies of metallic sulfides formed at and near the sea floor when submarine volcanic hot-spring fluids with temperature in between 250-350°C mix with cold seawater, typically at the depths of 1000- 3000 m.

Placer Deposits

A placer deposit is an accumulation of mineral grains concentrated primarily by sedimentary processes. When pebbles, sands, and silts are sorted by wave action or stream flow, minerals with higher specific gravity and resistance to weathering become concentrated, especially in beaches and drowned river mouths.

Placer mineral deposits are found on the continental shelf from the beaches to the outer shelf. These transported deposits may have formed in a marine environment, but have generally been emplaced while the shelf was emergent under a lower sea level. The glacial sea level lows exposed most of the shelf to subaerial processes and stream placer deposits extended across the shelf.


beach placers
drowned river system placers
modern delta
continental shelf
gravel bed placers
waves
shelf edge

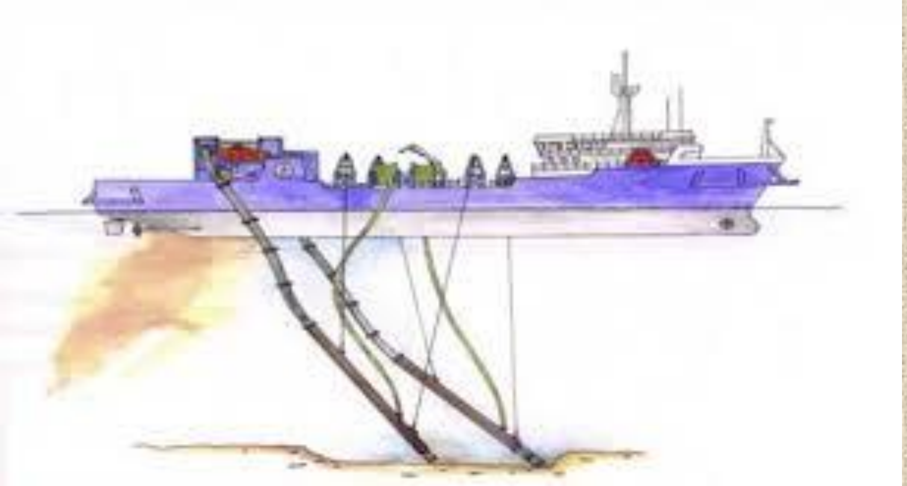
The concentration of minerals depends on the source rock, weathering, transportation and trapping by subaerial processes and subsequent reworking and modification by marine processes.

Locating potential placer resources is often less difficult than determining their exploitability, because varying littoral drift rates and directions, altering wave-energy distributions, and changing water levels contribute to regional and local variations in placer distributions.

Many mineral-bearing offshore and beach placers (diamond, gold, platinum, tin, chromite, iron sand, zircon, ilmenite, rutile, and monazite) are now mined or have been mined in the past.

Diamonds are the only gemstones presently mined offshore. World production of diamonds has grown to 100 million carats in the nineties but offshore mining produced less than 100 thousand carats in 1995.

Diamond mining from the beaches and nearshore in Southwest Africa was done from 10 to 40 meters water depth with suction and airlift dredges. Dredging for diamonds in Brazilian waters has been reported.



GIANLUIGI GUERCIA/AFP/GETTY IMAGES

95% of diamonds recovered from the sea are of "gem quality," compared to just 40-60% of diamonds from land operations

CONTINENTAL SHELF

A continental shelf is a portion of a continent that is submerged under relatively shallow water known as a shelf sea. Much of the shelves were exposed during glacial periods and interglacial periods. The shelf surrounding an island is known as an insular shelf.

The continental margin, between the continental shelf and the abyssal plain, comprises a steep continental slope followed by the flatter continental rise. Sediment from the continent above cascades down the slope and accumulates as a pile of sediment at the base of the slope, called the continental rise. Extending as far as 500 km from the slope, it consists of thick sediments deposited by turbidity currents from the shelf and slope.

Shelf Sediments

The continental shelves are covered by terrigenous sediments i.e, those derived from erosion of the continents. However, little of the sediment is from the present day rivers; some 60-70% of the sediments on the world's shelves are relict sediments, deposited during the last ice age (~115,000 - 11,700 y.B.P), when sea level was 100-120 m lower than it is now.

Sediments usually become increasingly fine with distance from the coast; sand is limited to shallow, wave-agitated waters, while silt and clays are deposited in quieter, deep water far offshore. These accumulate 15-40 cm every millennium, much faster than deep-sea pelagic sediments.

CONTINENTAL SHELF SEDIMENTS:

- ♦MAINLY TERRIGENOUS OR FROM LAND, THICKER AND COARSER THAN IN DEEP SEA
- ♦QUICKER DEPOSITION RATE THAN IN DEEP SEA

- ♦SEVERAL DIFFERNET TYPES

CLASTIC/DETRITAL

- MADE FROM BROKEN TRANSPORTED PARTICLES FROM “PREEXISTING” ROCKS AND SOILS
-CLASSED BY SIZE WHERE GRAVEL > SAND > SILT > CLAY
-UNDERGOES FINING SEAWARD SEQUENCE SO IS COARSEST NEAR SHORE

THE FOLLOWING ARE EXCEPTIONS TO THE FINING SEAWARD SEQUENCE:
AUTHIGENIC
-INORGANIC CHEMICAL PRECIPITATES THAT FORM SUCH AS PHOSPHORITES AND LIMESTONES
ORGANIC
-DEAD CORALS, MOLLUSKS, PLANKTON, ALGAE & ANIMALS RESIDUAL
-NON TRANSPORTED ROCK FRAGMENTS BROKEN OFF FROM THE BEDROCK BELOW
RELICT
-ANCIENT DEPOSITS FROM PREVIOUS CONDITIONS SUCH AS SEA LEVEL CHANGE / LOW STANDS OF SEA LEVEL DURING GLACIAL MAXIMUM. SINCE THESE SEDIMENTS ARE DERIVED FROM BROKEN TRANSPORTED PARTICLES FROM “PRE-EXISTING” ROCKS AND SOILS, THEY ARE ALSO CLASTIC / DETRITAL

Economic significance of the continental shelf

Most commercial exploitation from the sea, such as metallic-ore, non-metallic ore, and hydrocarbon extraction, takes place on the continental shelf. Sovereign rights over their continental shelves up to a depth of 100 m or to a distance where the depth of waters admitted of resource exploitation were claimed by the marine nations that signed the Convention on the Continental Shelf drawn up by the UN's International Law Commission in 1958.

This was partly superseded by the 1982 United Nations Convention on the Law of the Sea (UNCLOS) which created the 200 nautical miles (370 km) exclusive economic zone, plus continental shelf rights for states with physical continental shelves that extend beyond that distance.

The legal definition of a continental shelf differs significantly from the geological definition. UNCLOS states that the shelf extends to the limit of the continental margin, but no less than 200 nmi (370 km) and no more than 350 nmi (650 km) from the baseline.

1 nautical mile = 1.85 km

Deep Sea Mining

All of the minerals discussed previously have been recovered by surface mining on the shallow continental shelves or nearshore coasts. Of all the mineral resources considered as potential targets for deep-sea mining, polymetallic nodules (also commonly called **manganese nodules**) are probably the most likely commodity to be developed into a commercial operation. As well as containing commercially attractive levels of metals such as **nickel, copper, manganese and cobalt**, their occurrence on the seafloor surface presents a relatively straightforward engineering challenge in terms of their extraction when compared to some other metal deposits in the deep sea. The Polymetallic nodules were collected by the HMS Challenger in 1872 and their potential has been dreamed about ever since, but deep ocean mining of these minerals is still in its infancy. At depths between 4,000m and 6,000m, developing mining and processing technologies needed to recover the desired minerals from the nodules - nickel, copper, cobalt and manganese - require large investments.

Polymetallic nodules

Are concentrations of iron and manganese oxides, ranging from millimeters to tens of centimeters in diameter. They contain economically valuable concentrations of **nickel, copper and cobalt.** They occur mainly on the deep-seafloor. Apart from manganese and iron oxide, nickel, copper and cobalt, the nodules include trace amounts of molybdenum, platinum and other base metals.

Formation

Polymetallic nodules are rounded accretions of manganese and iron hydroxides **$Fe(OH)_2$** that cover vast areas of the seafloor, but are most abundant on abyssal plains at water depths of 4000-6500 meters. They form through the aggregation of layers of iron and manganese hydroxides around a central particle (such as a shell or small rock fragment), and range in size from a few millimeters to tens of centimeters.

Growth of these nodules is extremely slow, at a rate of millimeters per million years, and they remain on the seafloor surface, often partially buried in a thin later of sediment. The composition of nodules varies with their environment of formation, but in addition to manganese and iron, they can contain nickel, copper and cobalt in commercially attractive concentrations as well as traces of other valuable metals such as molybdenum, zirconium and REEs.

At the present time, nodules are forming at a slow rate of a one to a few tens of millimeters per million years. Their formation appears to be related to active tectonic belts such as spreading ridges and deep-ocean trenches. Nodules with high nickel and copper contents are found in some of the deep ocean basins at depth of 4000 to 5000 m.

The development and distribution of nodules are influenced by a variety of regional and local factors. These include:

a) Their size, morphology, mineralogy, age and rate of growth;

b) Bathymetry, paleo-bathymetry and seabed topography

c) Seawater composition

f) Bottom currents and paleo-currents
g) Redox potential at the sediment-water interface
h) Composition, thickness and age of underlying sediments
i) Thermal gradients in the sediment column

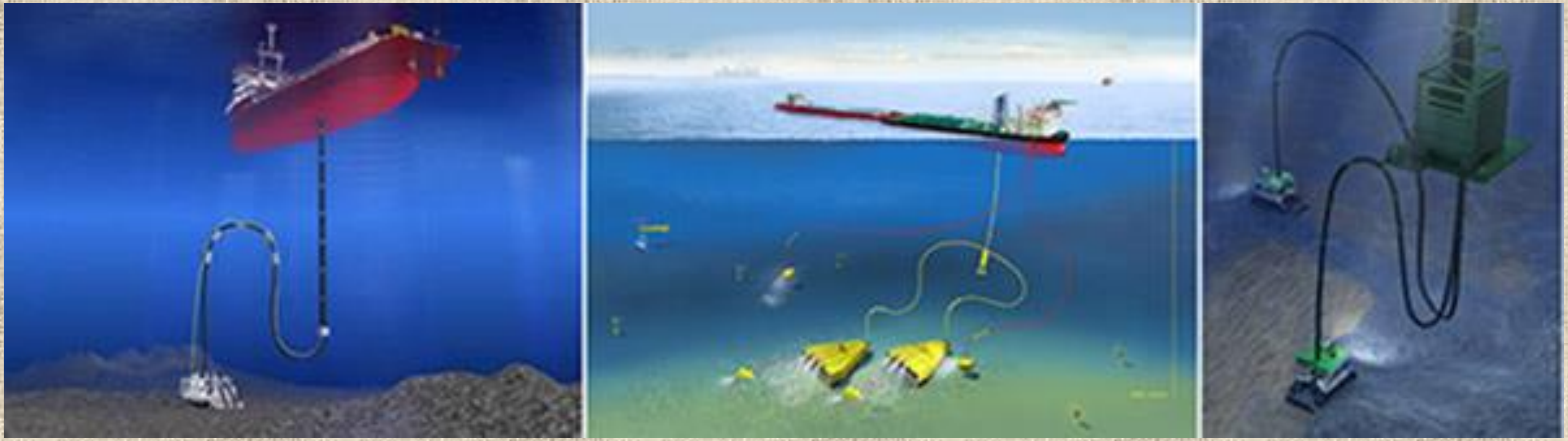
Distribution of manganese nodules

The nodules of greatest commercial interest occur in the Clarion-Clipperton Zone in the equatorial Pacific Ocean (CCZ) and in the Central Indian Ocean Basin. In the CCZ, polymetallic nodules cover 9 million km^2 with typical concentrations of 15 kg m^{-2}. The nodules contain nickel, copper, and cobalt (around 2 - 3% of the nodule weight) as well as traces of other metals such as molybdenum, Rare Earth Elements and lithium, which are important to high-tech industries. The amount of copper contained in the CCZ nodules is estimated to be about 20% of that held in global land-based reserves.

Generally, cobalt content in the manganese nodules is higher in the southern and central regions, where the nodule abundance is also higher, than in the northern region. Conversely, copper and nickel contents are higher in the northern region, where nodule abundance is lower.

The concept of polymetallic nodules as a serious commercial prospect emerged in the 1960's and 70's, leading to a rush to develop the technology to extract them. However, the industry never developed due to the cheap availability of nickel from more easily accessible land-based deposits. For current mining scenarios, the mining process is predicted to disturb about 120 km2 of seabed per year per mining operation and represents a major environmental impact. However, owing to the presence of numerous volcanic hills with a relief of about 100m the extraction of nodules will be extremely difficult.

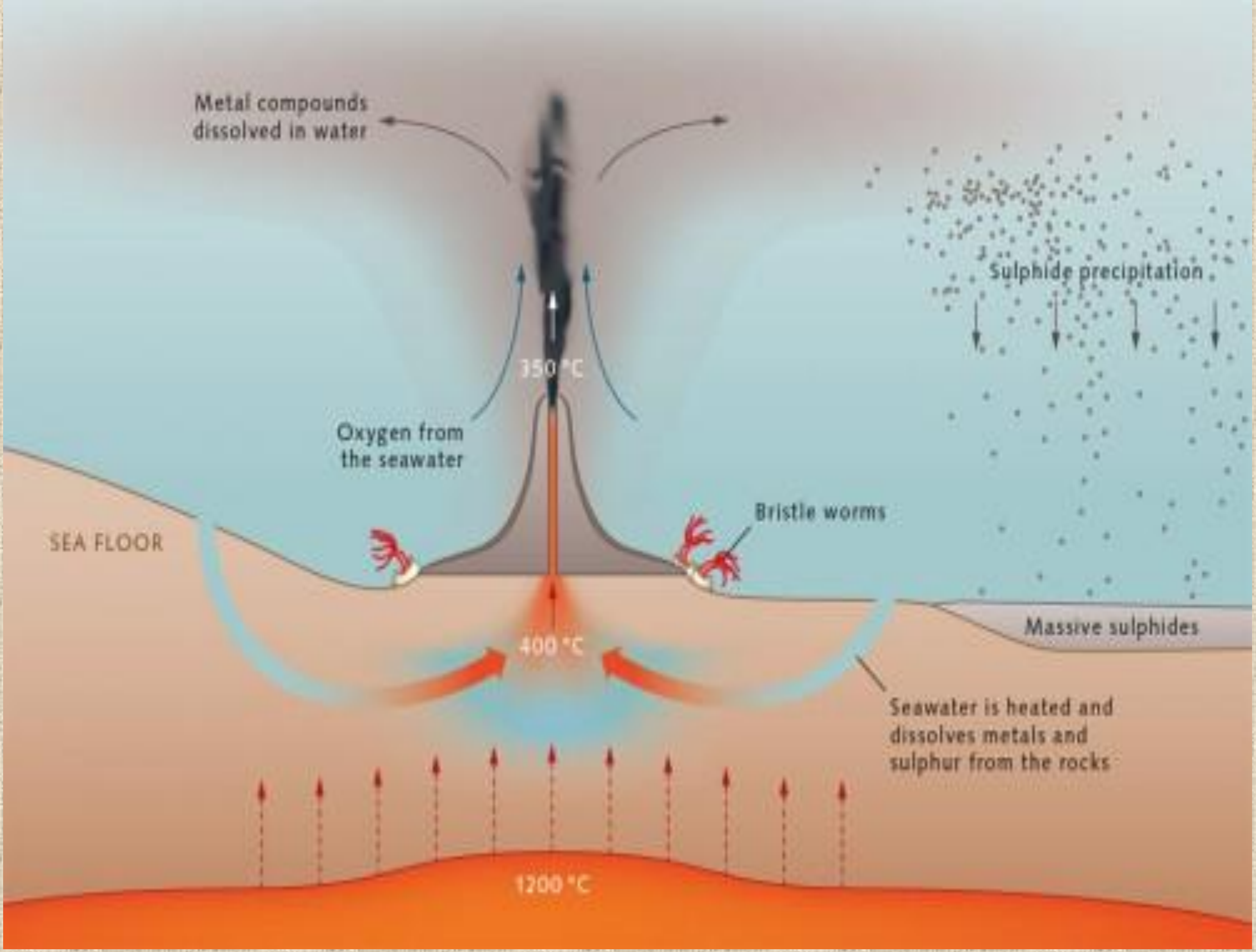
Current mining scenarios are based on a remotely-operated crawler 'harvesting' nodules from the seafloor, which are them pumped up to a production support vessel at the surface. A certain level of processing will take place aboard this vessel, with the ore then being shipped off to land for further refinement, and the particulate waste being discharged back to the seabed.



Sulfide Deposits

Beside manganese nodules, massive sulfide ore deposits, also known as Volcanogenic massive sulfides (VMS) ore deposits found in the sea. VMS are a type of metal sulfide ore deposit, mainly copper-zinc which are associated with and created by volcanic-associated hydrothermal events in submarine environments. Massive sulphides originate at hot vents in the ocean where sulphide-enriched water flows out of the sea bed. These sites of escaping hot water are called hydrothermal vents.

They are found along plate boundaries and at active undersea volcanoes, where the exchange of heat and elements between the crustal rocks and the ocean takes place due to interactions between the volcanic activity and seawater.


Metal compounds dissolved in water
Sulphide precipitation
350 °C
Oxygen from the seawater
Bristle worms
SEA FLOOR
Massive sulphides
400 °C
Seawater is heated and dissolves metals and sulphur from the rocks
1200 °C

Volcanogenic massive sulfide ore deposit at Kidd Mine, Timmins, Ontario, Canada, formed 2.7 billion years ago on an ancient seafloor.

Compositionally, VMS deposits form two broad groups:

1. Cu-Zn
2. Zn-Pb-Cu

Economically significant quantities of Au and Ag may occur in all the above lithological and compositional groups.

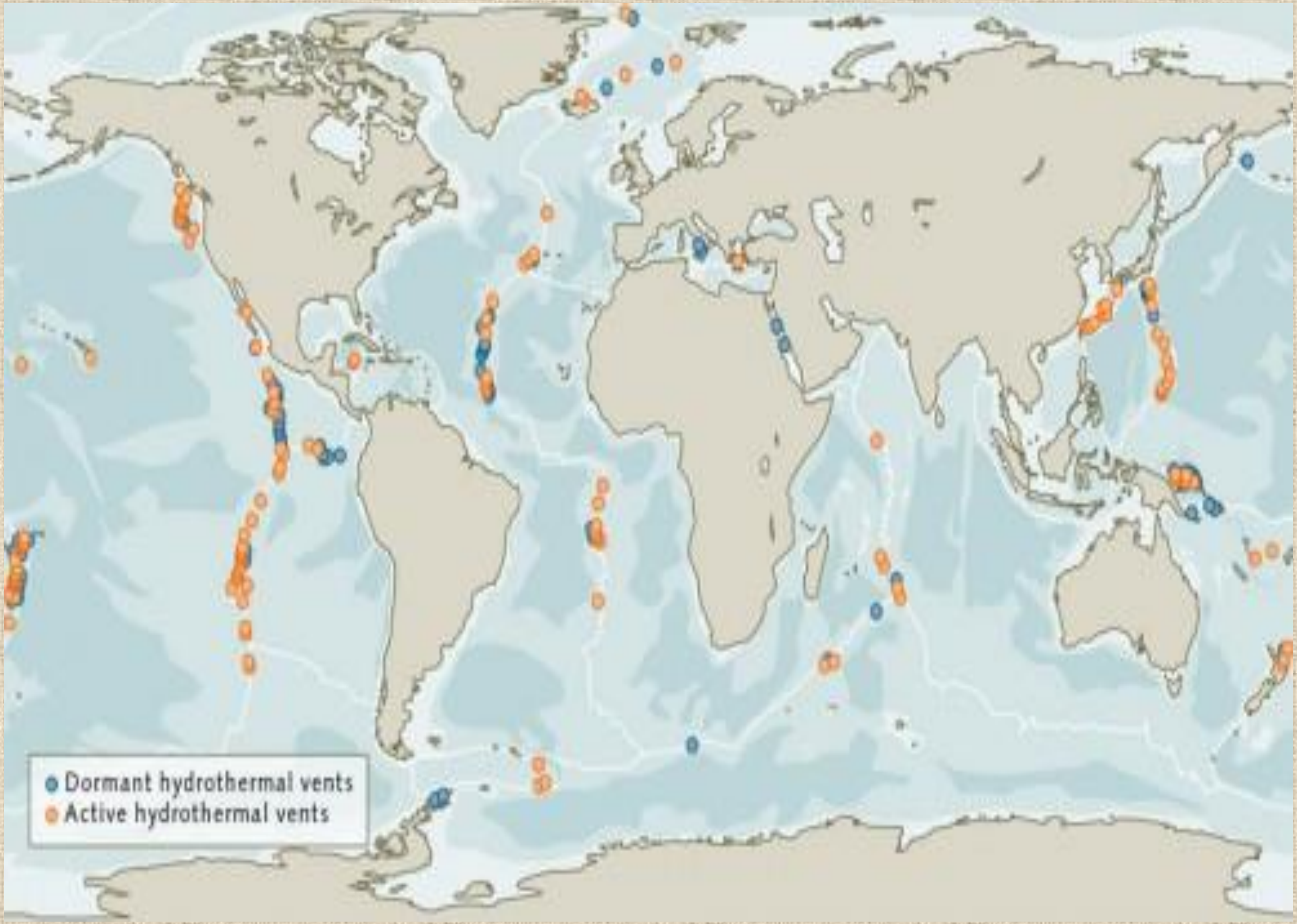
Another massive sulphide category - Pb, Zn deposits -forms in a sedimentary environment

VMS deposits tend to occur in districts. Up to two dozen deposits, might be clustered in an area of a few tens, of square kilometers. Known VMS districts are good hunting grounds for new discoveries.

Deposits within a specific district tend to have similar metal ratios and a fairly narrow range in composition. In any given district, deposits will tend to range in size from less than one million tons to several tens of millions of tons, with most deposits at the small end of the range and only a few large deposits.

At many hydrothermal vents around the world the sulphides have accumulated to form tall chimney-like structures on the sea floor. Water shoots out of the fissures into the sea like a fountain. More and more material is gradually deposited on the sides of the openings and the tower continues to grow. Because of their appearance, these structures are also called smokers. As the escaping water is usually black-coloured by the minerals it contains, they are also called black smokers.

The first black smokers were discovered in 1979 during an expedition to the East Pacific Rise. Hydrothermal vents have now been found in all oceans. They usually form in water depths between 1000 and 4000 metres.


● Dormant hydrothermal vents
● Active hydrothermal vents

Classes of Marine Resources

Physical resources
- Mineral deposits, petroleum, natural gas, freshwater

Biological resources
- Plants and animals, microbes

Marine energy resources
- Energy from heat or motion of water

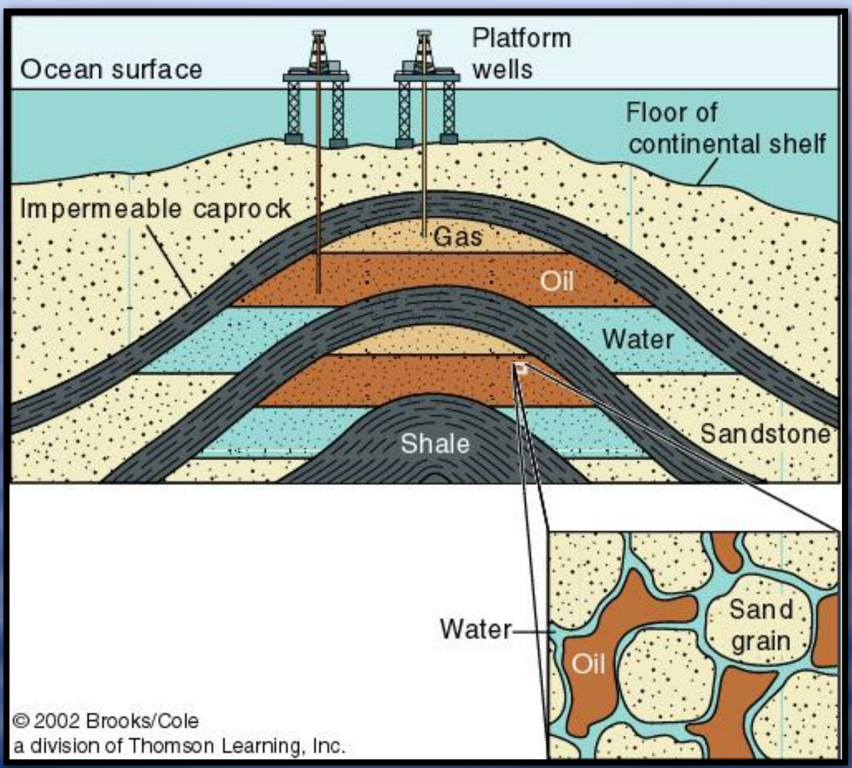
Non-extractive resources
- Transportation, recreation, waste disposal

Ocean Resources

The world is increasingly dependent on ocean resources for energy, raw materials for construction, and minerals vital to emerging communication and information technologies. Resources of high interest and value are gas hydrates, renewable kinetic energy in offshore winds, tides and currents, deposits of rare earth elements, and sand and gravel deposits for construction and beach nourishment.

USGS conducts research studies focused on geologic mapping, sampling and understanding of mineral and energy resources and studies of the geologic setting and processes to inform renewable energy development offshore.

Oil and Natural Gas



Oil and gas are often found together beneath impermeable caprock. Drilling for oil offshore requires specialized equipment and is more costly than drilling on land.

Deepwater exploration has been developed for more than 40 years since 1975; generally, its exploration history can be divided into the beginning stage (1975 - 1984), the early stage (1985 - 1995) and the rapid development stage (1996-now).

Currently, deep-water areas have become the hotspot of global oil and gas exploration, and they are also one of the most important fields of oil and gas increase in reserves and production all over the world. In 40 years, global deepwater oil and gas discoveries are mainly distributed along five deepwater basin :

(1) In deepwater basins of the Atlantic Ocean, giant discoveries of oil are mainly concentrated in Brazil, West Africa and the Gulf of Mexico, and significant discoveries of natural gas are mainly on the west coast of Norway in the northern part of the Atlantic Ocean;
(2) In deepwater basins of the East African continental margin, a group of giant gas fields hasbeen found in the Rovuma Basin and Tanzania Basin;
(3) In deepwater basins of the West Pacific Ocean, giant discoveries of oil and gas are mainly concentrated in the South China Sea and Southeast Asian waters;
(4) The deepwater basins of the Neo-Tethys Region are rich in gas, and the most important gas discoveries are mainly distributed in the northwest shelf of Australia and the eastern Mediterranean; and
(5) In deepwater basins around the Arctic Pole, major discoveries of oil and gas have been only found in deepwater areas of the Barents sea.

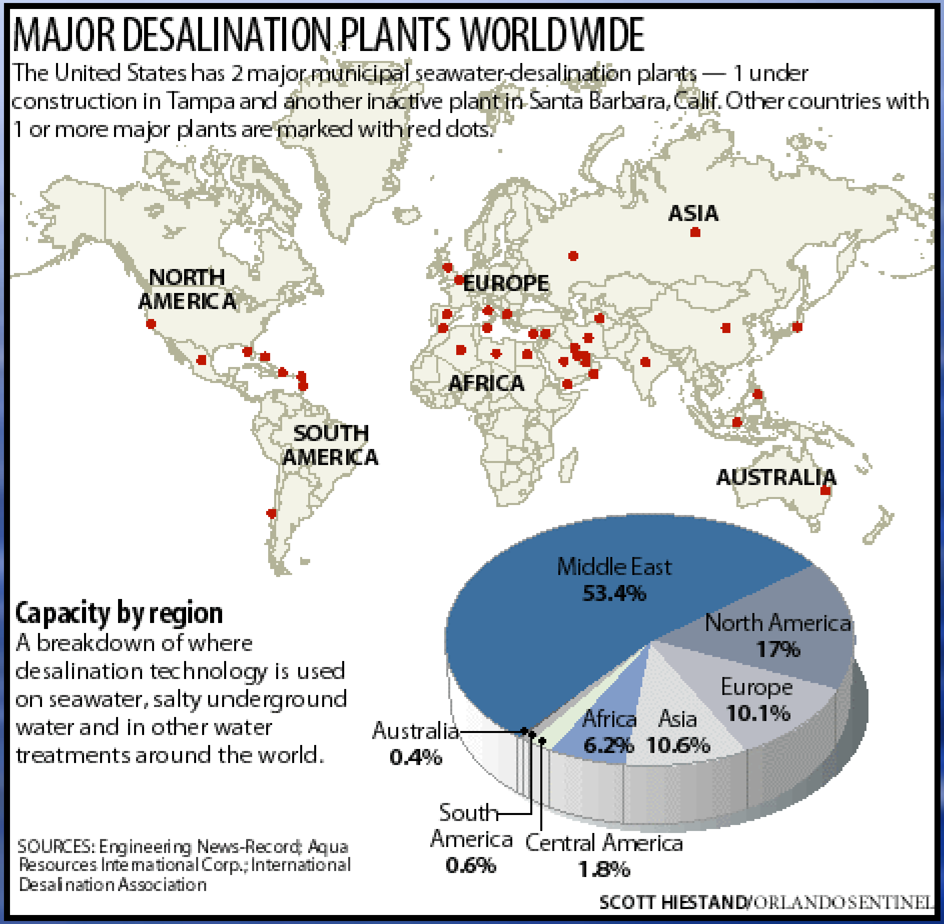
Global deepwater oil resources are mainly concentrated in the middle and south sections of the Atlantic Ocean. Deepwater gas resources are relatively widely spread and mainly distributed in the northern part of Atlantic Ocean deepwater basins, the deepwater basins of East Africa, the deepwater basins of the Neo-Tethys region and the deepwater basins around the Arctic Pole.

There will be six domains for future oil-gas exploration of global deepwater basins which are characterized by "two old and four new" domains; specifically,"two old" domains referring to the Atlantic offshore deepwater basins and offshore deepwater basins of the Neo-Tethys structural domain, where the exploration degree is relatively high, and the potential is still great. While the "four new" domains stand for pre-salt and ultra deepwater basin formations, offshore deepwater basins surrounding the North Pole area and West Pacific offshore deepwater basins and the new fields will be the main fields of deepwater oil and gas exploration


Arctic Ocean
Surround-Arctic deepwater basins
Arctic Slope Basin
Baffin Bay Basin
East Greenland Continental Shelf
Central Norway Continental Shelf
Barents Sea Basin
Kara Basin
Laptev Sea Basin
East Siberia Basin
North Sea Basin
North America
Atlantic
Europe
Asia
Neo-Tethys deepwater basins
Japanese Sea Basin
East Coast Basin
Aaiun-Tarfaya Basin
Nile Delta Basin
Bengal Basin
Gulf of Mexico Basin
deepwater
Senegal Basin
Africa
Pearl River Mouth Basin
West
Pacific
Pacific
Bay of Bengal Basin
Qiongdongnan basin
North Palawan Basin
Pacific
Niger Delta Basin
Ceara Basin
Rovuma basin
Gabon Basin
basins
Potiguar Basin
Tanzania basin
Somalia Deep-sea Basin
Zengmu Basin
Brunei-Sabah Basin
deepwater
South America
Lower Congo Basin
East Africa deepwater basins
Browse Basin
Bonaparte Basin
Sergipe-Alagoas Basin
Kwanza Basin
Namibia Basin
Espirito Santo basin
Rovuma Basin
Indian Ocean
North Carnarvon Basin
Roebuck Basin
basins
Santos Basin
Campos Basin
Australia
Western South Africa Coastal Basin
Pelotas Basin
Mozambique Basin
Gippsland Basin
Continent
Ocean
Petroliferous basin boundaries

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!



MAJOR DESALINATION PLANTS WORLDWIDE

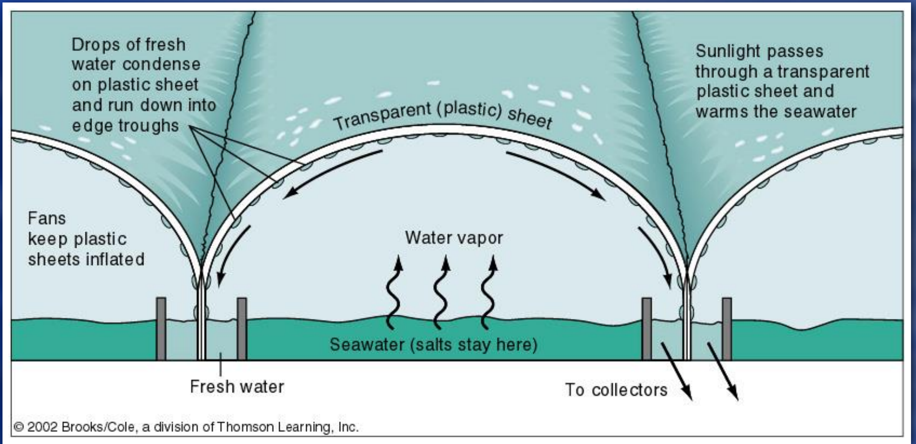
The United States has 2 major municipal seawater-desalination plants — 1 under construction in Tampa and another inactive plant in Santa Barbara, Calif. Other countries with 1 or more major plants are marked with red dots.

Capacity by region

A breakdown of where desalination technology is used on seawater, salty underground water and in other water treatments around the world.

SOURCES: Engineering News-Record; Aqua Resources International Corp.; International Desalination Association

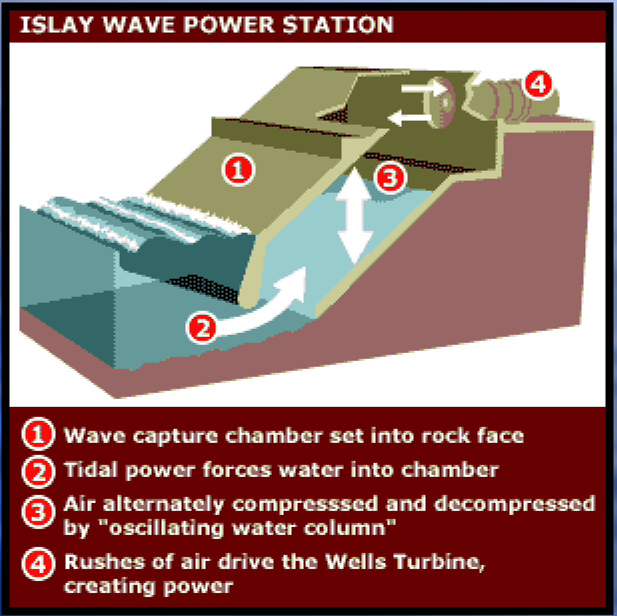
SCOTT HIESTAND/ORLANDO SENTINEL



Salts and Minerals

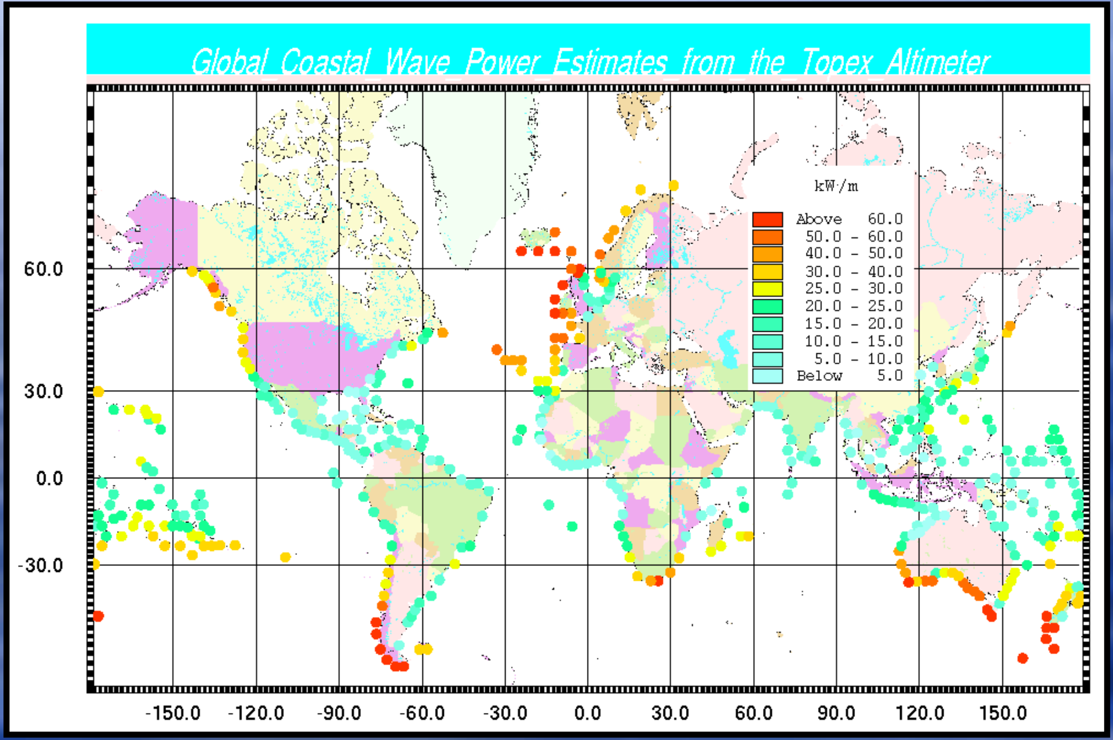
- Magnesium
- Sodium chloride
- Manganese nodules
- Phosphorite
- Metallic sulfides and muds

Marine Energy – Wave Motion



ISLAY WAVE POWER STATION

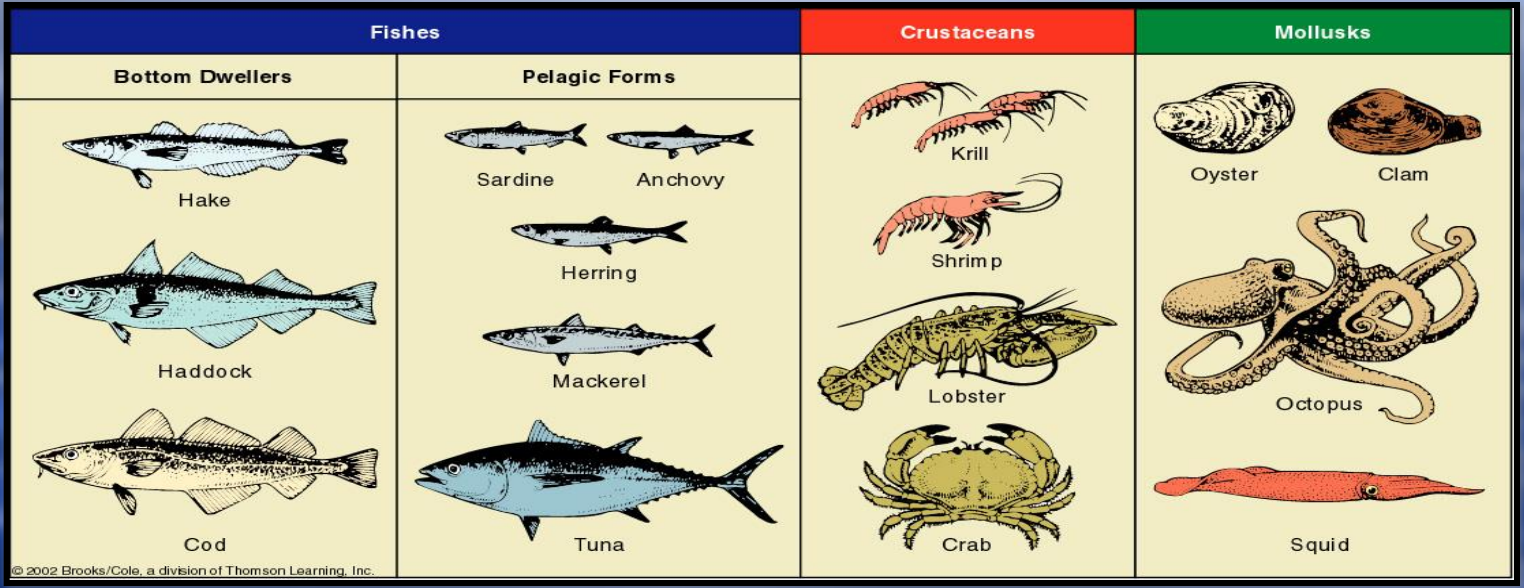
① Wave capture chamber set into rock face
② Tidal power forces water into chamber
③ Air alternately compresssed and decompressed by "oscillating water column"
④ Rushes of air drive the Wells Turbine, creating power



Global Coastal Wave Power Estimates from the Topex Altimeter

Energy generated by waves (Dr Brekken) and tides

Biological Resources



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Major types of commercially harvested fishes, crustaceans, and mollusks

The Coasts

A Fragile Ecosystem

High biological productivity, wealth of species and genetic diversity and fluvial discharge

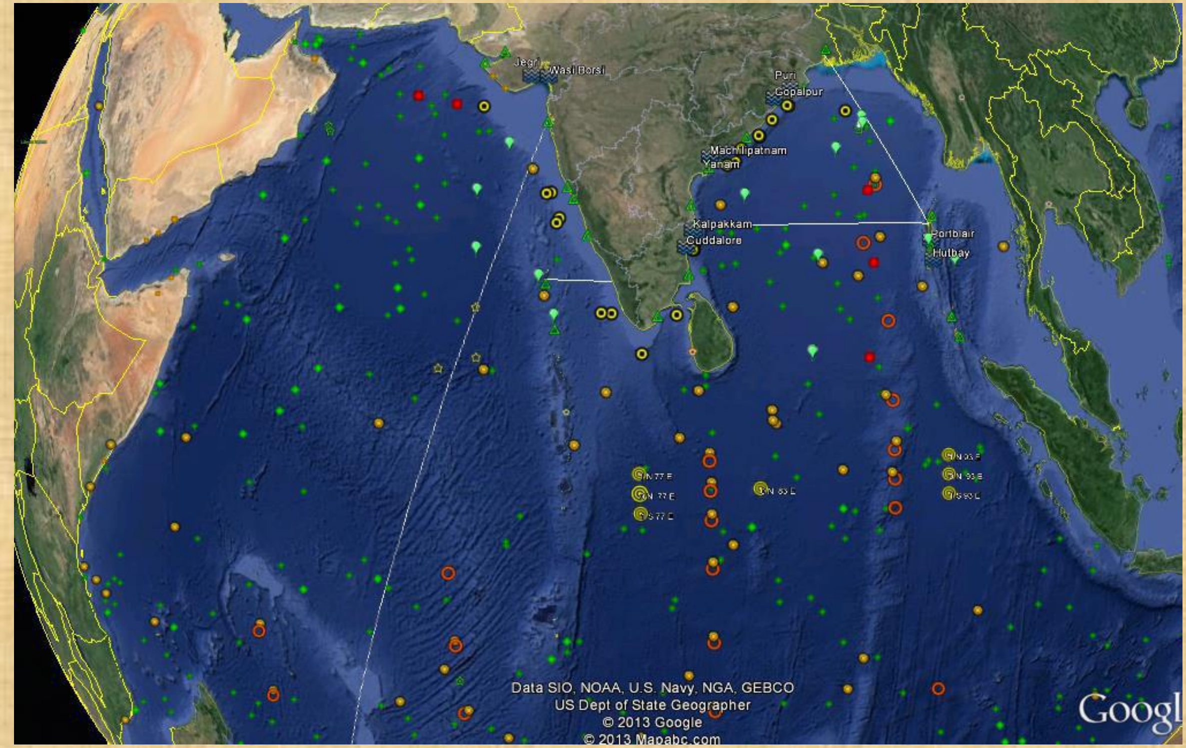
High rates of population growth, development of industries, trade and commerce (60 % of human population, 2/3 of the world's large cities)

Degradation of ecosystems, diminishing living resources and deteriorating water quality

Episodic events, cyclones, floods, tsunami, etc

In-situ Observation Systems

Observations are important for understanding the vast expanse of our Oceans



In-situ Observation Systems by India

Developments in 20th Century:

- Acoustic Sounding for Bathymetry
- Instruments for measuring T & S
- Instruments for monitoring for Deep Currents
- Global Experiments (IIOE, TOGA, WOCE)

TOGA (Tropical Ocean and Global Atmosphere) Program; World Ocean Circulation Experiment (WOCE)

Last Decade: Argo, Moorings, Acoustic Doppler Current Profiler (ADCP), drifters, The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA buoys), Current meter moorings, Expendable Bathythermograph (XBT), CODAR, Tsunami buoys, wave rider buoys, Tide Gauges etc.

Limitations of in-situ observation systems:

- Point observations
- Limited spatial & temporal resolutions
- High Cost
- Sensor Degradation
- Inability to maintain systems at desired locations
- Geo-political considerations

Coastal wetlands, estuaries, and coral reefs represent highly productive and critical habitats for a wide variety of plants, fish, shellfish, and other wildlife. Wetlands also provide flood protection, protection from storm and wave damage, water quality improvement through filtering of agricultural and industrial waste, and recharge of aquifers. After years of degradation due to dredge and fill operations, impoundments, urban development, subsidence/erosion, toxic pollutants, and eutrophication, wetlands and estuaries are finally receiving public attention and protection.

In addition to immediate impacts due to anthropogenic activities, global warming and sea-level rise (SLR) will have serious long-term consequences for coastal ecosystems, such as wetlands and coral reefs. The rate of SLR around the world has increased over the past century to an average of about 3 mm a year, as a result of melting glaciers and the expansion of ocean water as it warms. The Intergovernmental Panel on Climate Change estimates that the rate of SLR will accelerate in the future, with an upper range of SLR of 0.59 m by 2100. Based on the observed acceleration of SLR, some scientists are estimating a SLR of more than a meter by 2100

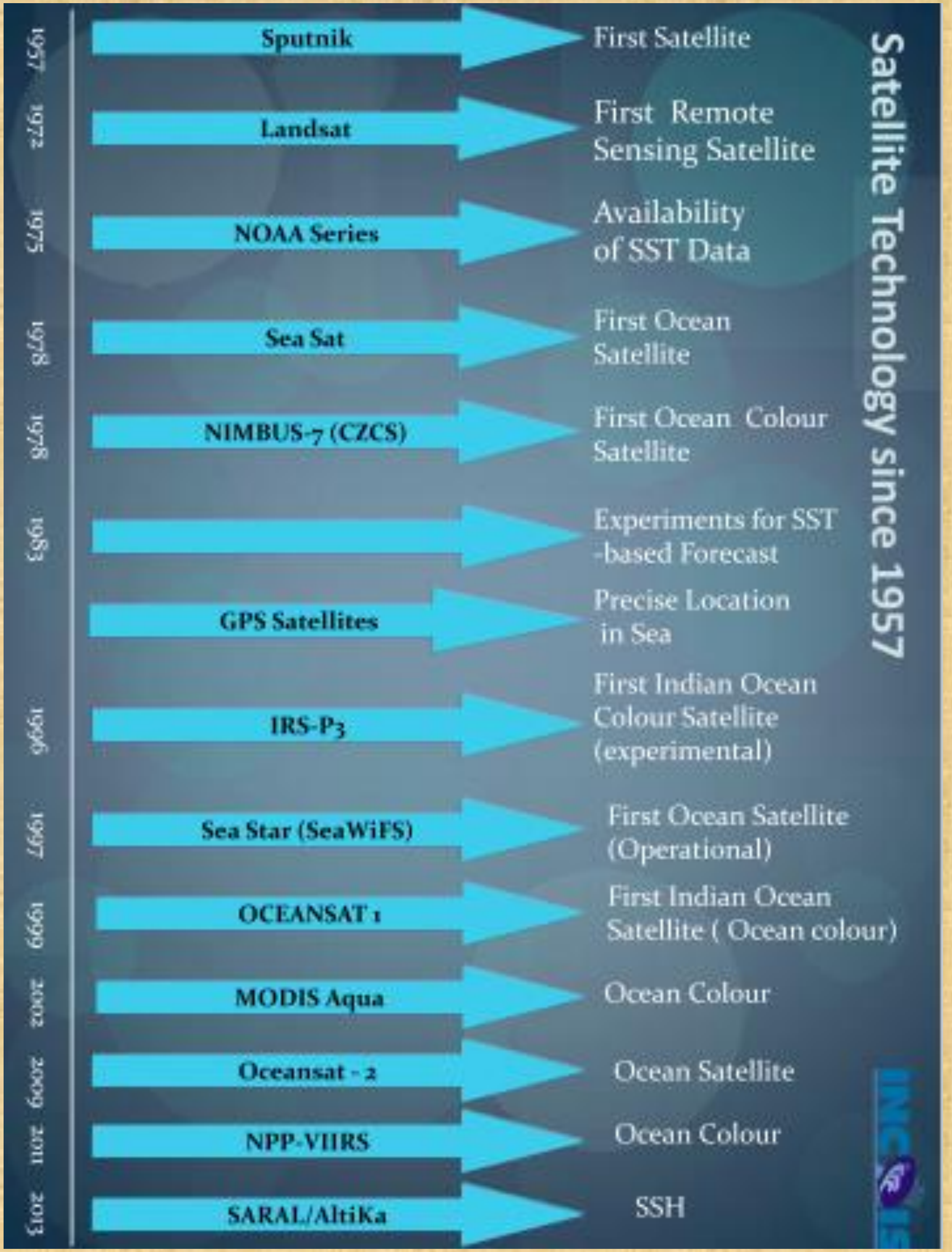
This substantial SLR and more frequent storms predicted for the next 100 years will impact coastal wetlands, beach erosion control strategies, salinity of estuaries and aquifers, coastal drainage systems, and coastal economic development.

Coastal areas such as barrier islands, beaches, and wetlands are highly sensitive to sea-level changes. Rising seas will intensify coastal flooding and increase the erosion of beaches, bluffs, and wetlands, as well as threaten jetties, piers, seawalls, harbors, and waterfront property. Along barrier islands, the erosion of beachfront property by flooding water will be severe, leading to greater probability of over wash during storm surges. Rapid SLR can cause segmentation of barrier islands or disintegration of wetlands, especially if the sediment supply cannot keep up with the SLR.

Furthermore, as the ocean surface water warms, stronger storms are predicted for the coasts of the Atlantic and the Gulf of Mexico. A major hurricane can devastate a wetland.

With the wide variety of remote sensing systems available, choosing the proper data source for observing land cover and coastal waters can be challenging. Characteristics often used to describe and compare these analogue and digital systems are grouped into four different types of resolution: spatial, spectral, radiometric, and temporal. Spatial resolution is a measure of sharpness or fineness of spatial detail. It determines the

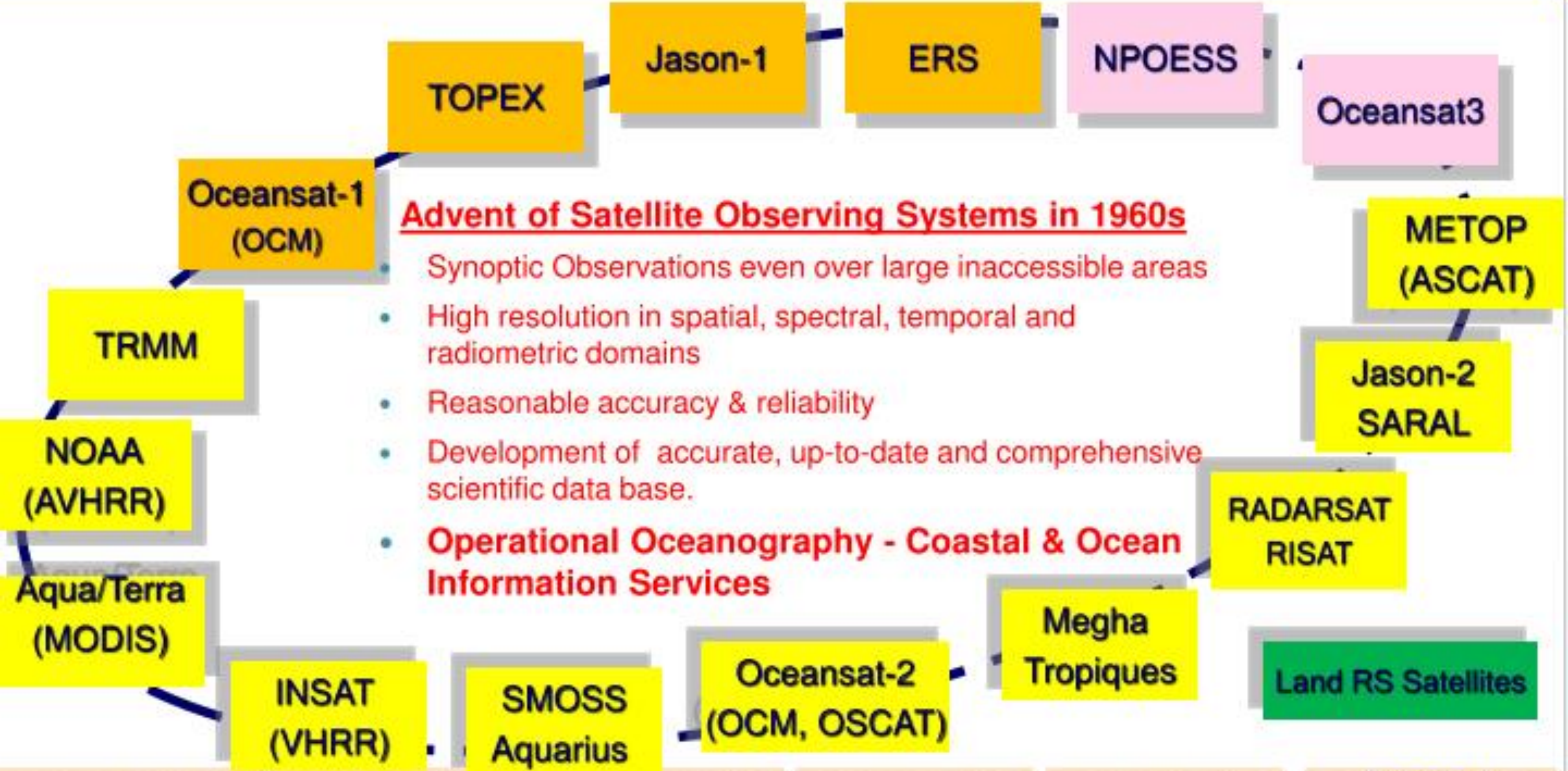
The MODIS on NASA’s Terra satellite captured this image on September 26, 2008, thirteen days after Hurricane Ike came ashore. The brown areas in the image are the result of a massive storm surge that Ike pushed far inland over Texas and Louisiana causing a major marsh dieback.



Satellite Technology since 1957

1957	Sputnik	First Satellite
1972	Landsat	First Remote Sensing Satellite
1975	NOAA Series	Availability of SST Data
1978	Sea Sat	First Ocean Satellite
1978	NIMBUS-7 (CZCS)	First Ocean Colour Satellite
1983		Experiments for SST -based Forecast
	GPS Satellites	Precise Location in Sea
1996	IRS-P3	First Indian Ocean Colour Satellite (experimental)
1997	Sea Star (SeaWiFS)	First Ocean Satellite (Operational)
1999	OCEANSAT 1	First Indian Ocean Satellite (Ocean colour)
2002	MODIS Aqua	Ocean Colour
2009	Oceansat - 2	Ocean Satellite
2011	NPP-VIIRS	Ocean Colour
2013	SARAL/AltiKa	SSH

Remote Sensing Observations – Some Recent Missions



INSAT (VHRR)

Aqua/Terra (MODIS)

NOAA (AVHRR)

TRMM

Oceansat-1 (OCM)

TOPEX

Jason-1

ERS

NPOESS

Oceansat3

METOP (ASCAT)

Jason-2 SARAL

RADARSAT RISAT

Megha Tropiques

Oceansat-2 (OCM, OSCAT)

SMOSS Aquarius

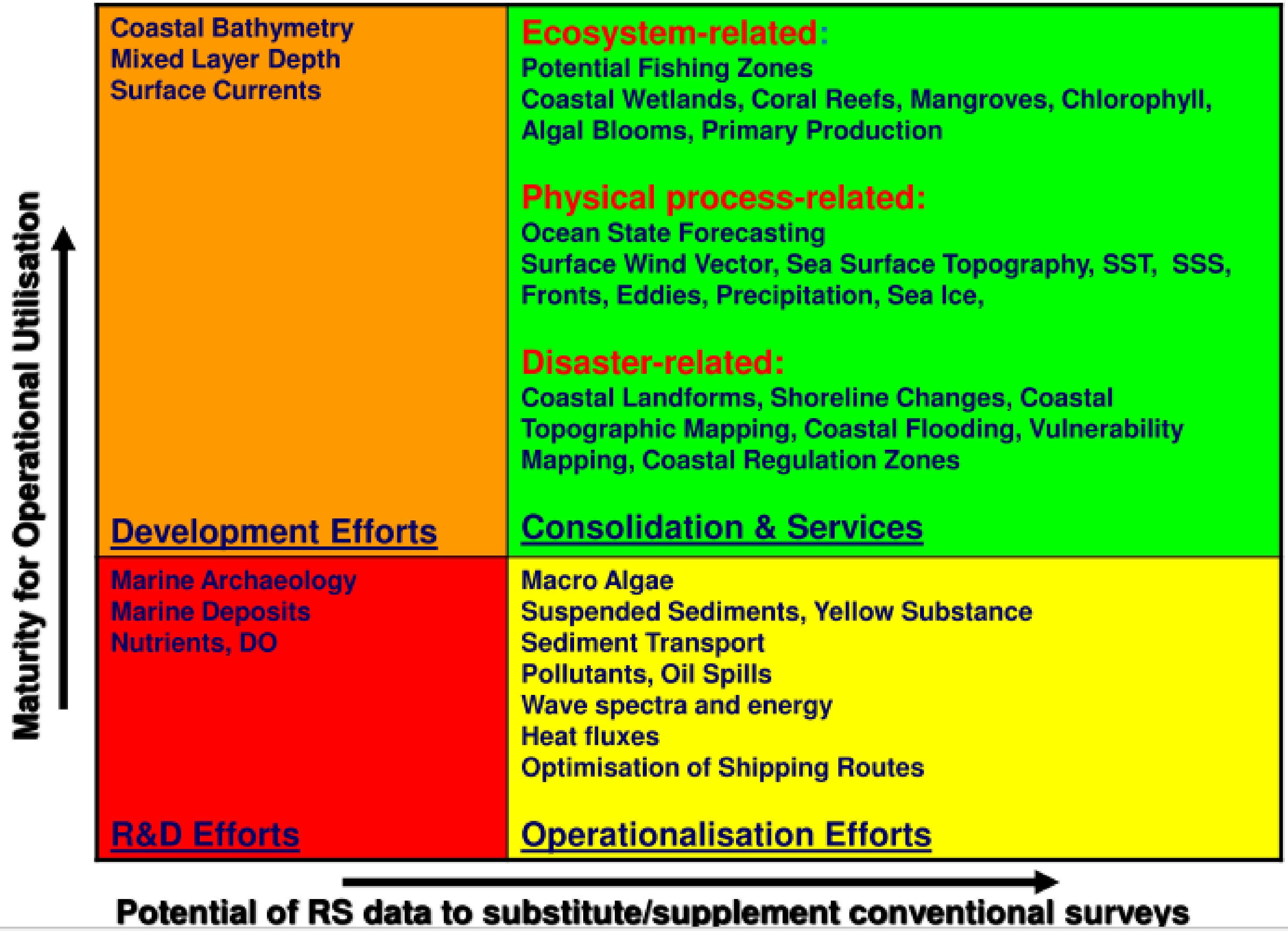
Land RS Satellites

Advent of Satellite Observing Systems in 1960s

- Synoptic Observations even over large inaccessible areas
- High resolution in spatial, spectral, temporal and radiometric domains
- Reasonable accuracy & reliability
- Development of accurate, up-to-date and comprehensive scientific data base.
- **Operational Oceanography - Coastal & Ocean Information Services**

Radiometer (VIS, IR)	Radiometer (MW)	Altimeter (MW)	Scatterometer (MW)	SAR (MW)	Imaging Radiometer (MW)
•Ocean Colour •SST •Coastal Processes	•Wind Speed •SST •Sea Ice Extent	•Wave Ht. •Sea Level •Sea Ice	•Surface Wind Vector	•Wave Spectrum •Sea Mounts	• SSS

Operational Ocean & Coastal Services from RS Data



Maturity for Operational Utilisation

Coastal Bathymetry
Mixed Layer Depth
Surface Currents

Development Efforts

Ecosystem-related:
Potential Fishing Zones
Coastal Wetlands, Coral Reefs, Mangroves, Chlorophyll, Algal Blooms, Primary Production

Physical process-related:
Ocean State Forecasting
Surface Wind Vector, Sea Surface Topography, SST, SSS, Fronts, Eddies, Precipitation, Sea Ice,

Disaster-related:
Coastal Landforms, Shoreline Changes, Coastal Topographic Mapping, Coastal Flooding, Vulnerability Mapping, Coastal Regulation Zones

Consolidation & Services

Marine Archaeology
Marine Deposits
Nutrients, DO

R&D Efforts

Macro Algae
Suspended Sediments, Yellow Substance
Sediment Transport
Pollutants, Oil Spills
Wave spectra and energy
Heat fluxes
Optimisation of Shipping Routes

Operationalisation Efforts

Potential of RS data to substitute/supplement conventional surveys

ESSO-INCOIS: Institutional Mechanism for Operational Oceanography

Remote Sensing for Fisheries

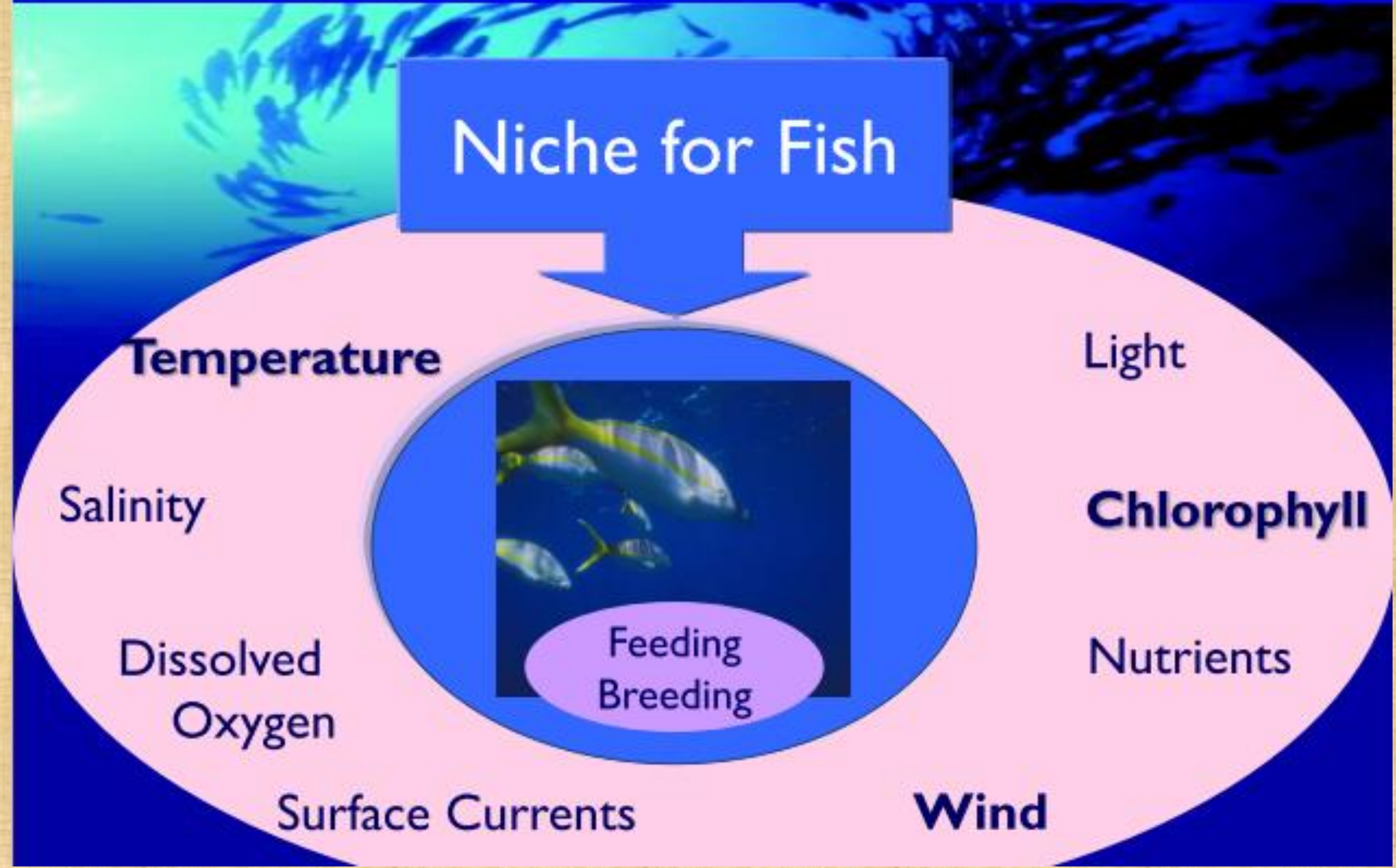
Fish schools cannot be seen directly from satellite altitudes; Indirect methods are used.

Fish have certain physiological, metabolic and respiratory requirements which govern their continued presence in certain areas or habitats for survival.

It is well known that the Fishes are known to react to changes in the surrounding environment and migrate to areas where favorable conditions in terms of seawater temperature, salinity, dissolved oxygen levels, etc., exist.

Sea Surface Temperature (SST) - indicative of the physical environment, and Chlorophyll a -indicator of food availability are easily monitored through Satellites.

Remote Sensing for Fisheries



Niche for Fish

Feeding
Breeding

Temperature

Salinity

Dissolved Oxygen

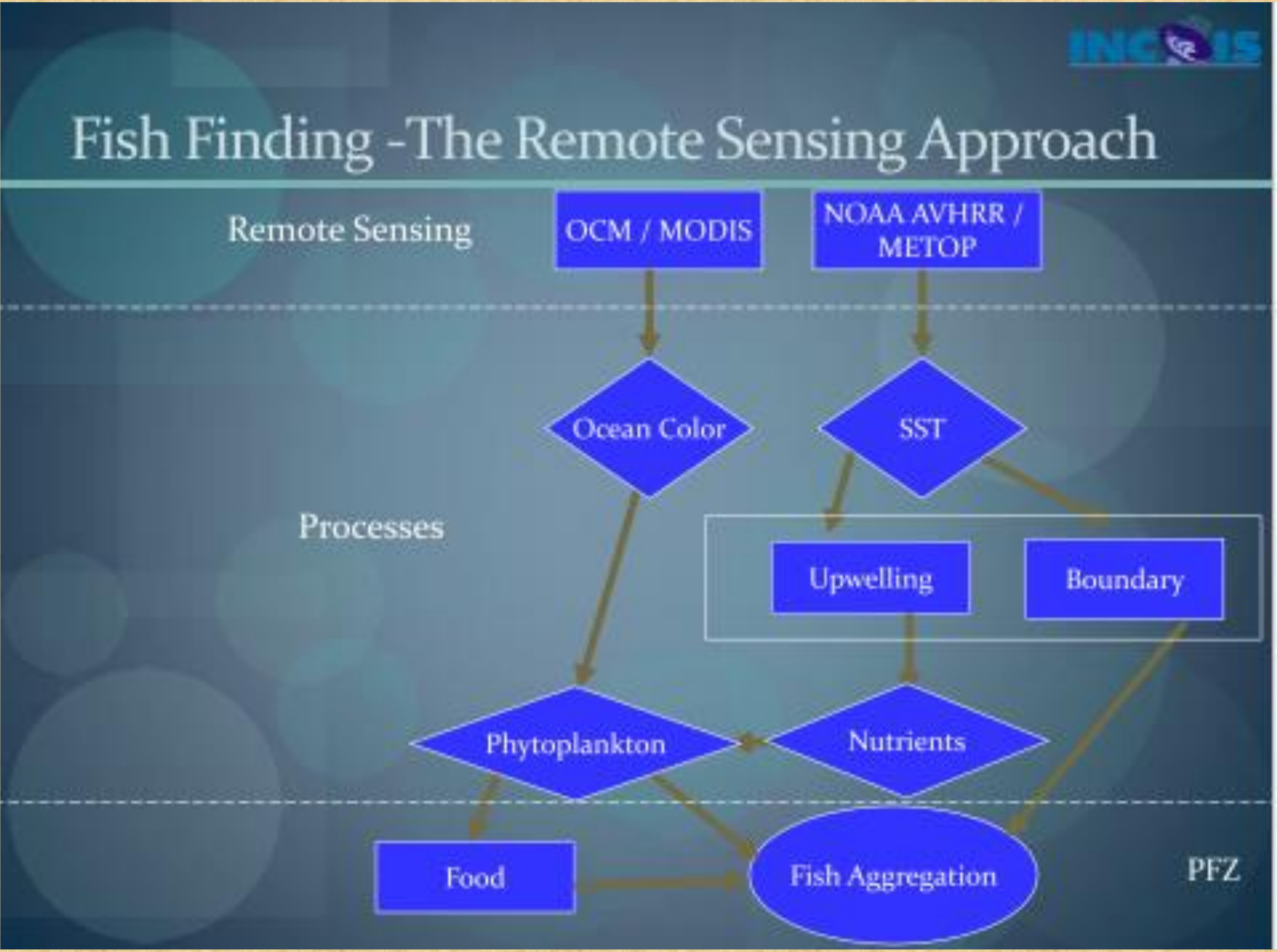
Surface Currents

Light

Chlorophyll

Nutrients

Wind



Fish Finding -The Remote Sensing Approach

Remote Sensing

OCM / MODIS

NOAA AVHRR / METOP

Ocean Color

SST

Processes

Upwelling

Boundary

Phytoplankton

Nutrients

Food

Fish Aggregation

PFZ

Food Chain

Primary producers Phytoplankton

Primary consumers

Secondary consumers

Higher trophic level
e.g. Fishes

Phytoplankton is an index of Primary productivity

Technologies Adopted

Remote Sensing

- Real time acquisition of SST and Chlorophyll parameters through satellites

Image Processing

- Processing and manipulation of acquired satellite images in near-real time

Geographic Information System (GIS) and GPS

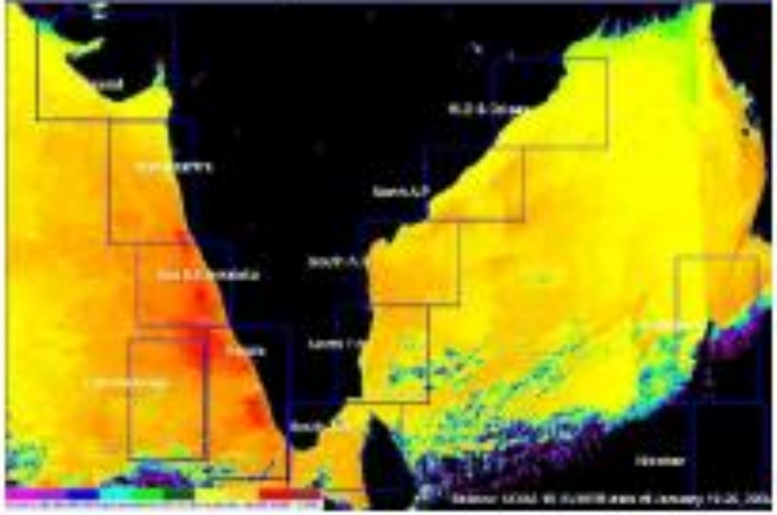
- Generation of digital databases, preparation of maps, location, etc.

Information and Communication Technology

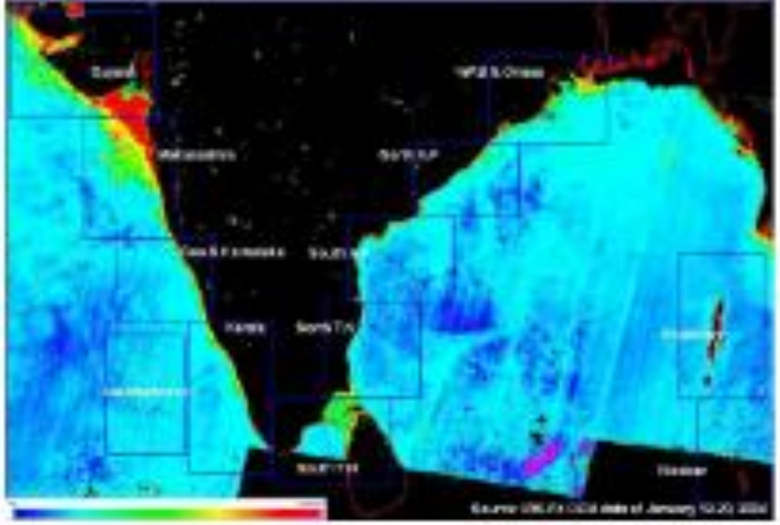
- ✓ Dissemination of the information with the state-of-the art technologies available.

SST and Chlorophyll Images

- Image Processing techniques for
  - Geometric correction
  - Filtering
  - Geo-coding

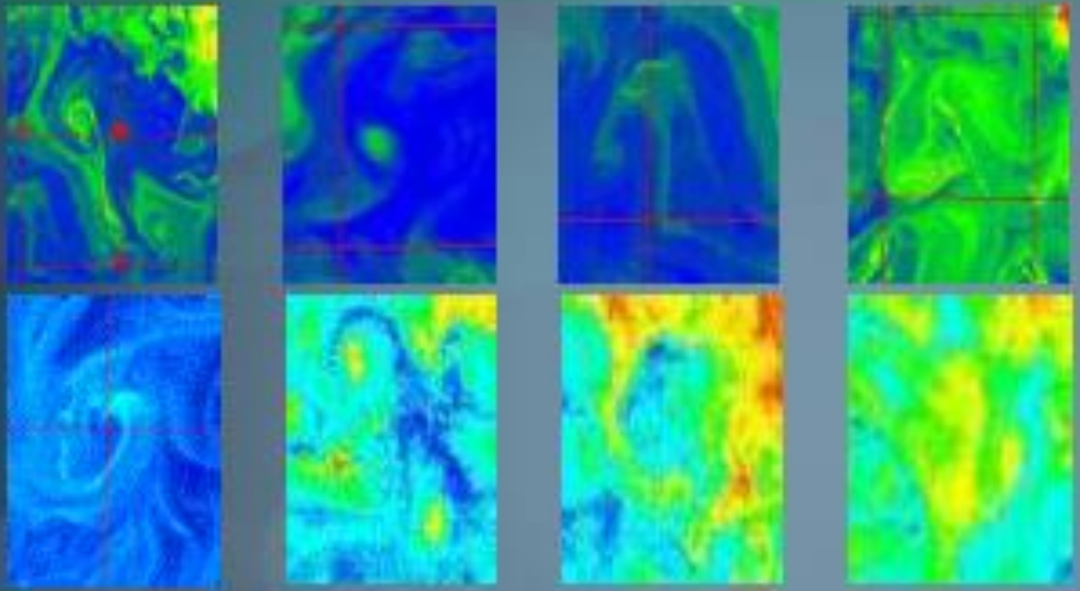


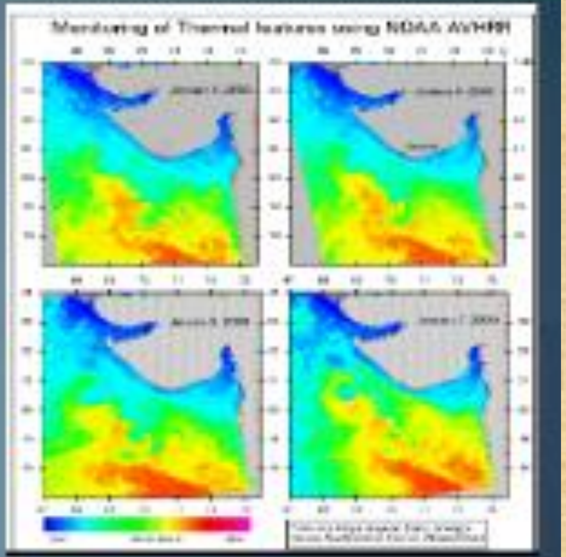
Sample Image of SST



Sample Image of Chlorophyll

Potential Fishing Zones – The Keys





Eddies, Rings, Meanders
Tongue/Mushroom features
Upwelling ,Thermal Fronts

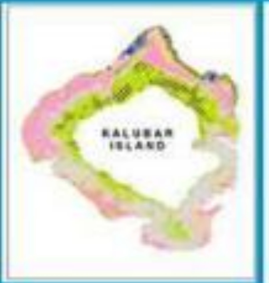
Integrated PFZ (SST + Chlorophyll) Methodology

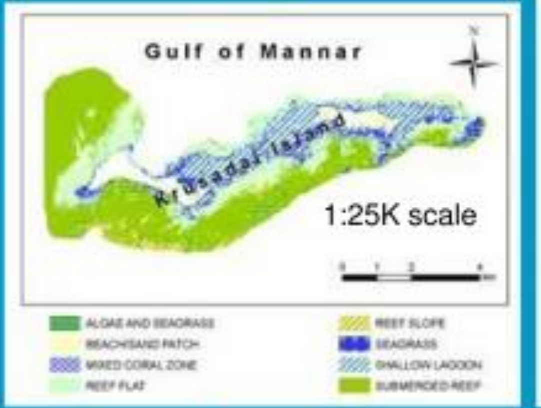
Daily operational forecasts from INCOIS using real-time satellite data (non-monsoon, non-ban season)

Mapping and Monitoring of Coral Reefs

Highly Diverse & Valuable Ecosystems on Earth

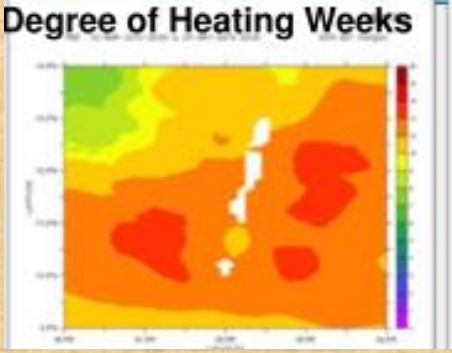
Study Sites → Mapping → Atlas





Data Source

LISS-III, PAN, LISS-IV


Degree of Heating Weeks

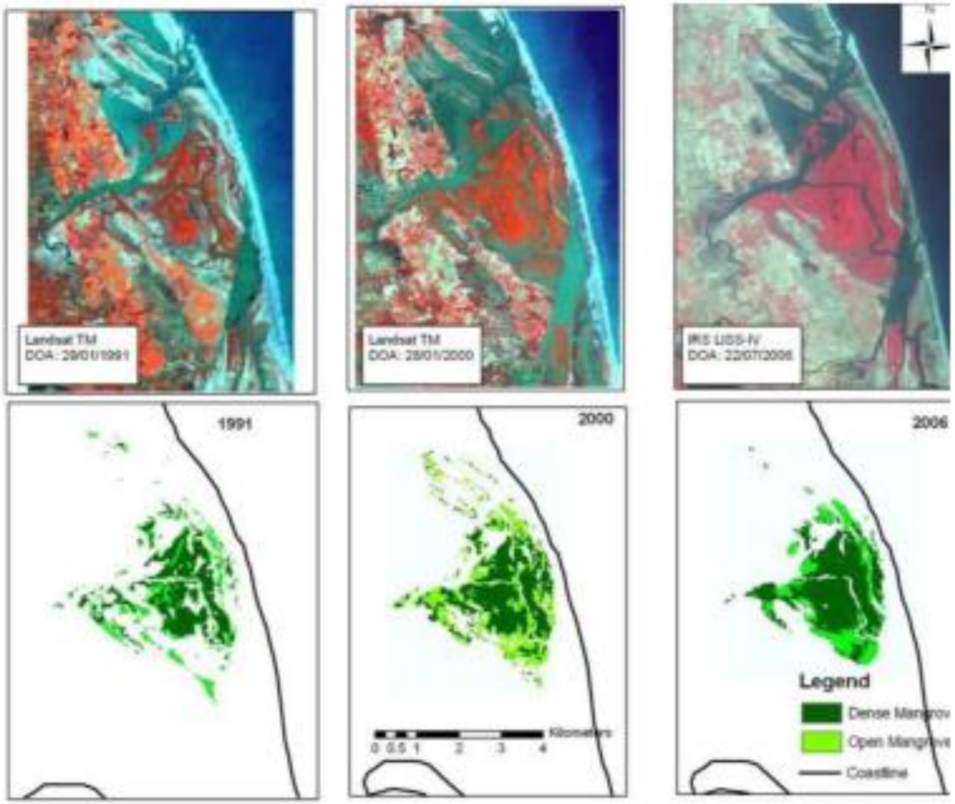

SST Climatology


HotSpot Time Series

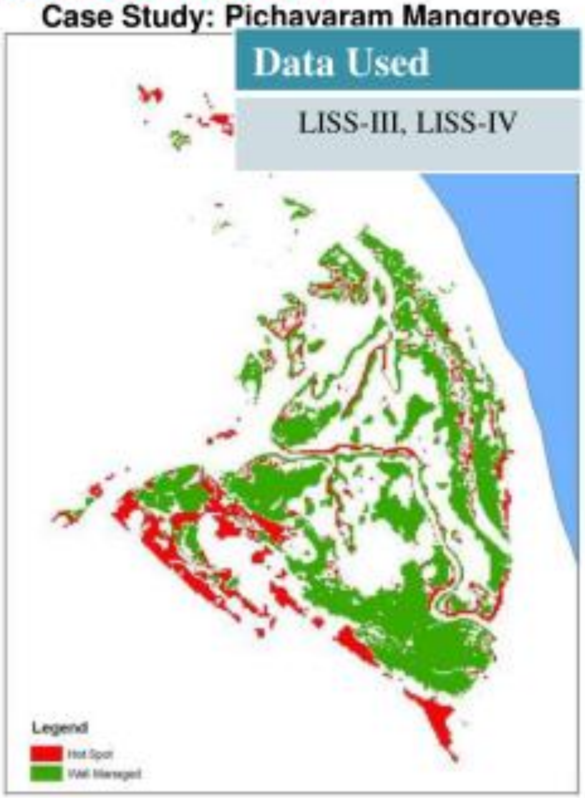

2010 Bleaching

Mapping and Monitoring of Mangroves

Coastal Protection, Fisheries, Plant Products, Tourism



Case Study: Pichavaram Mangroves

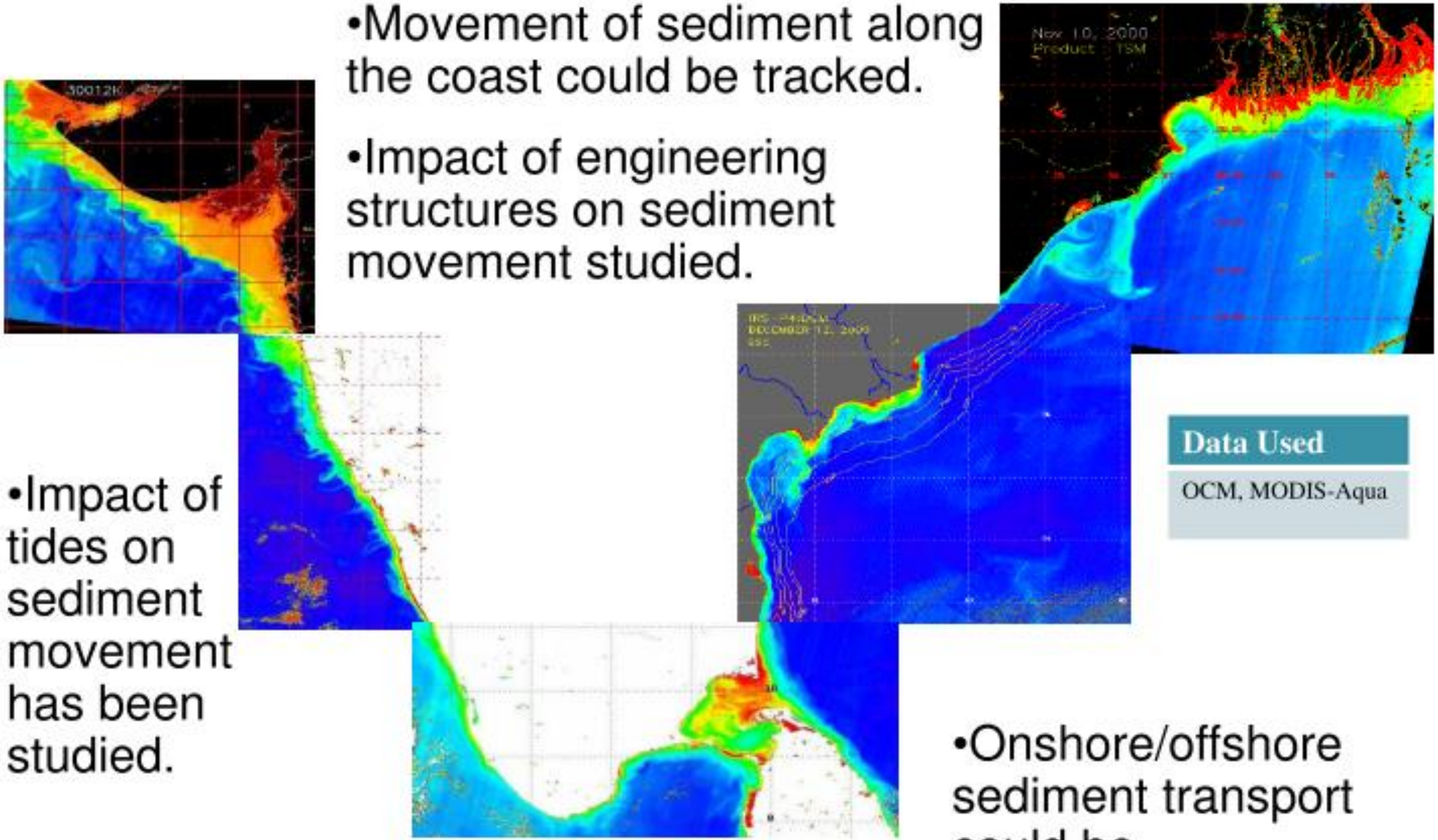


Data Used

LISS-III, LISS-IV

Mapping and Monitoring of Coastal Sediments

- Movement of sediment along the coast could be tracked.
- Impact of engineering structures on sediment movement studied.



- Impact of tides on sediment movement has been studied.

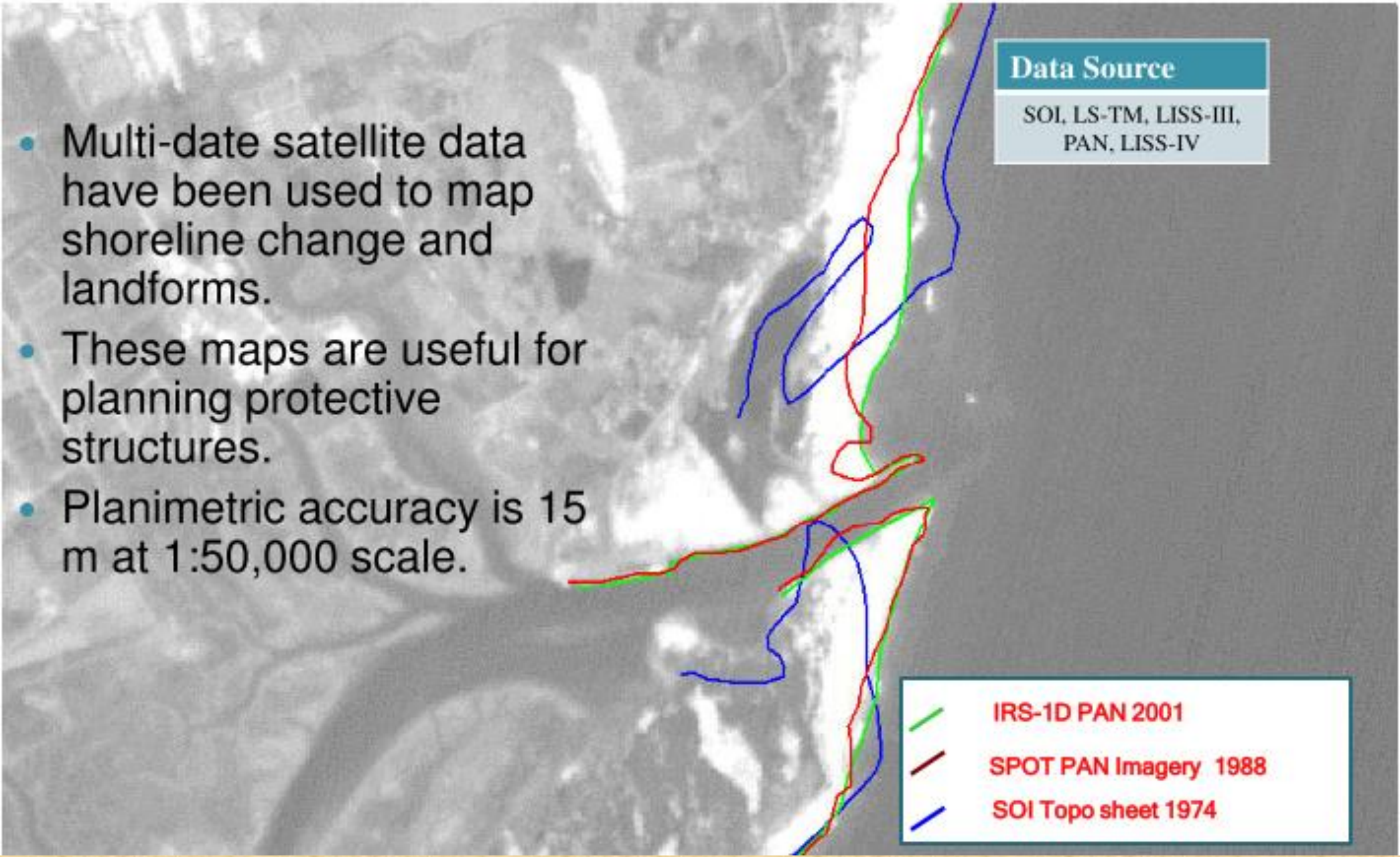
Data Used

OCM, MODIS-Aqua

- Onshore/offshore sediment transport could be

Mapping and Monitoring of Shoreline Changes

- Multi-date satellite data have been used to map shoreline change and landforms.
- These maps are useful for planning protective structures.
- Planimetric accuracy is 15 m at 1:50,000 scale.



Data Source

SOI, LS-TM, LISS-III, PAN, LISS-IV

Mapping of Coastal Vulnerability to Future Sea-level Rise

"Vulnerability is an internal risk factor of the subject or system that is exposed to a hazard and corresponds to its intrinsic predisposition to be affected, or to be susceptible to damage"

Methodology

Input Parameters

Geological
- Shoreline Change Rate
- Coastal Slope
- Coastal Regional Elevations
- Coastal Geomorphology

Physical
- Sea Level Change Rate
- Mean Significant Wave Height
- Tide Range

Analysis

Risk Rating

$CVI = \sqrt{[(a*b*c*d*e*f*g)/7]}$

Where,
a = Shoreline change rate (m/y)
b = Coastal slope (degree)
c = Coastal regional elevation (m)
d = Coastal geomorphology
e = Sea level change rate (mm/y)
f = Significant wave height (m)
g = Tide range (m)

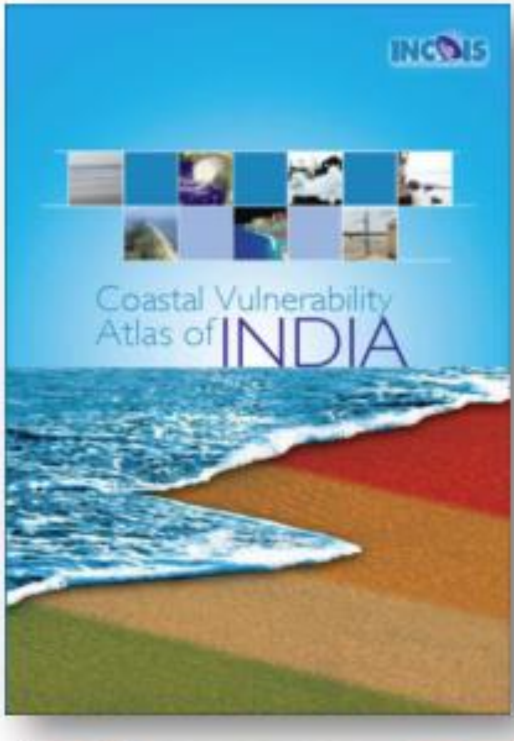
Output

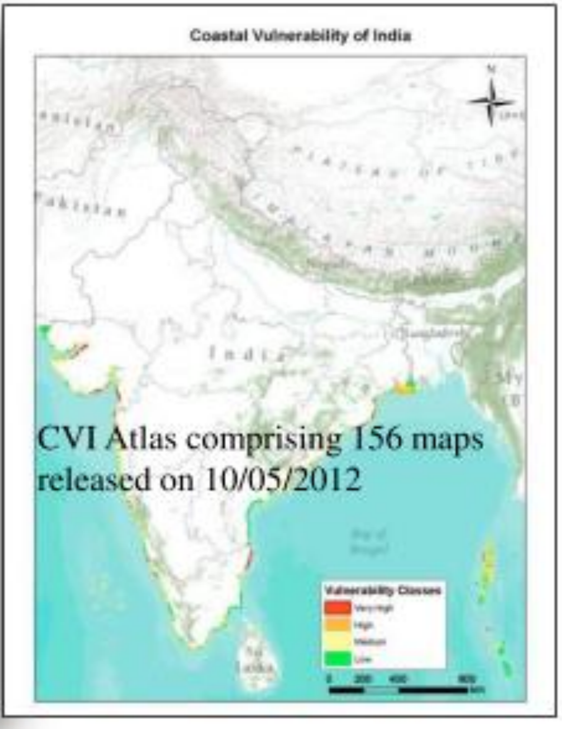
CVI Maps

Coastal Vulnerability Atlas

Data Used

Parameter	Data
Geomorphology	IRS LISS-IV
Slope	GEBCO
Elevation	SRTM
Tidal Range	Astronomical tides
Shoreline Change Rate	Landsat data (1972-2000)
Historical Sea Level	PSMSL data from GLOSS
Significant Wave Height	Simulated data from Mike model



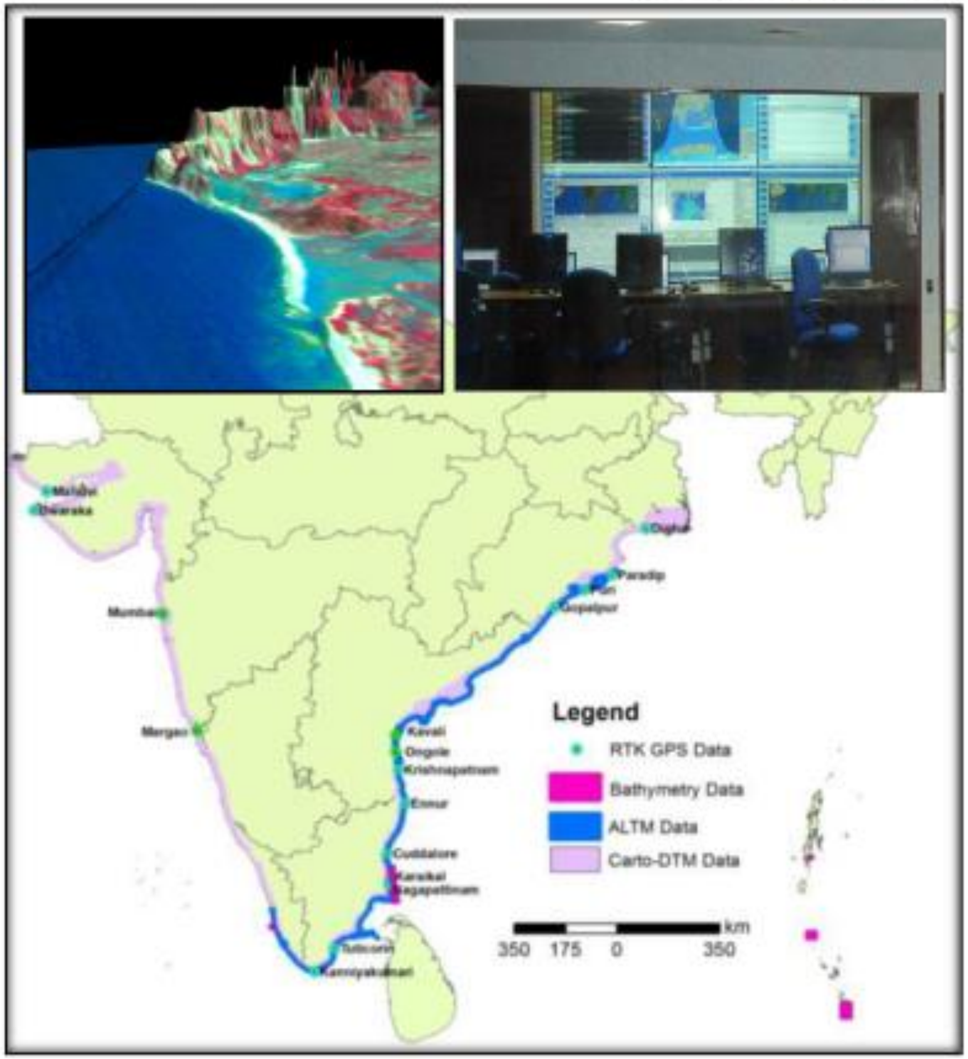


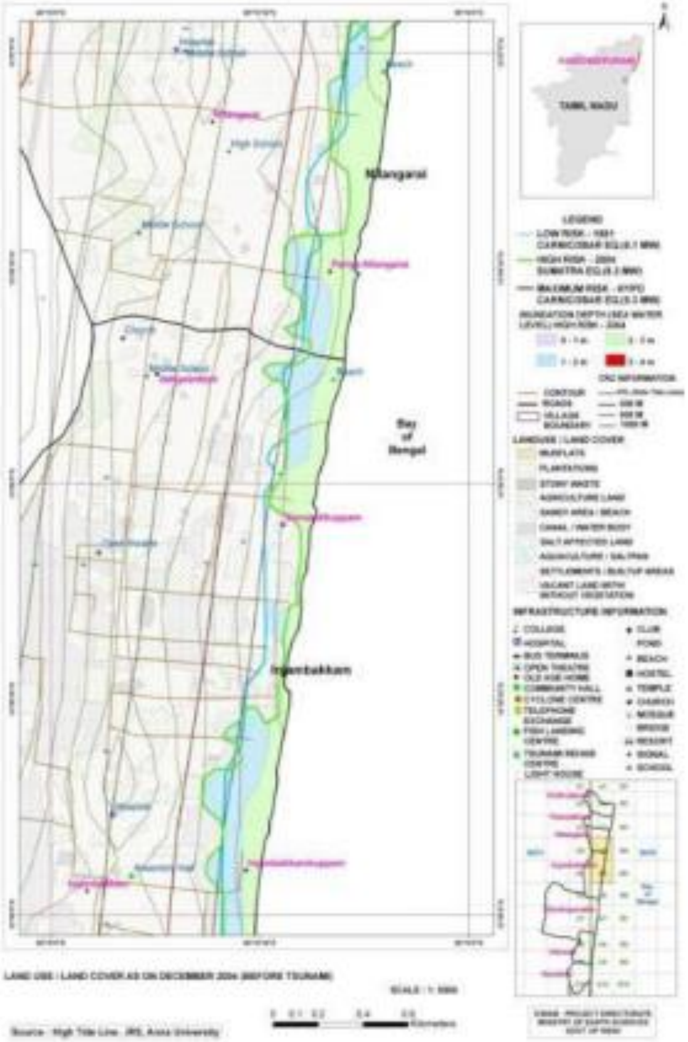
CVI Atlas comprising 156 maps released on 10/05/2012

www.incois.gov.in

Mapping of Coastal Vulnerability to Tsunamis

Topographic Data Used



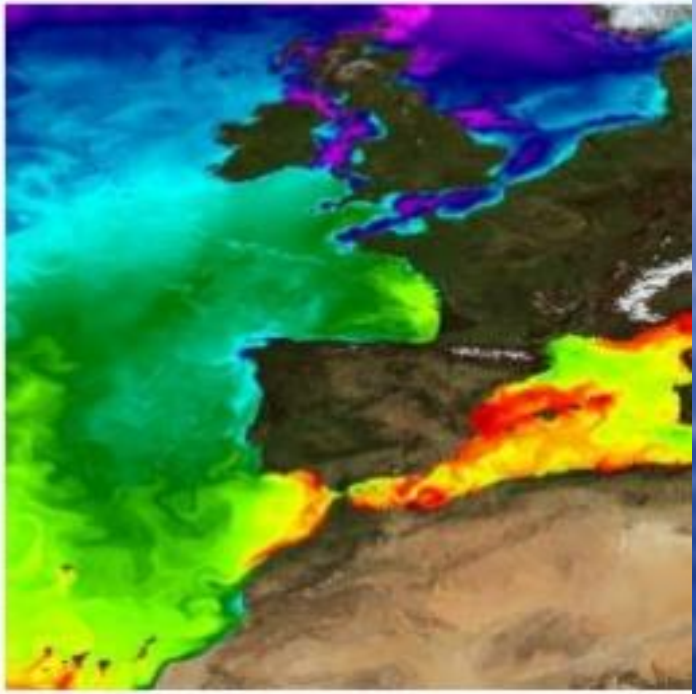


Indian Tsunami Early Warning Centre is located at ESSO-INCIS

Why measure sea surface temperature?

- Sea surface temperature (SST) is the temperature of the ocean near the surface. Knowing the temperature of this part of the ocean is absolutely essential for many reasons. For oceanographers, meteorologists and climatologists, it is one of the signs/results of the exchange of energy between the ocean and the atmosphere. For marine biologists, it is the parameter that determines the development of different biological organisms. For fishermen, important temperature variations as seen on a map (thermal fronts) indicate prolific fishing zones.
- Meteorological phenomena such as El Niño or tropical hurricanes/cyclones are the direct consequences of specific temperature variations at the sea-surface.
- Sea surface temperature varies between -1,8°C, temperature at which sea water freezes, and +30°C near/below the Equator.

How SST is measured

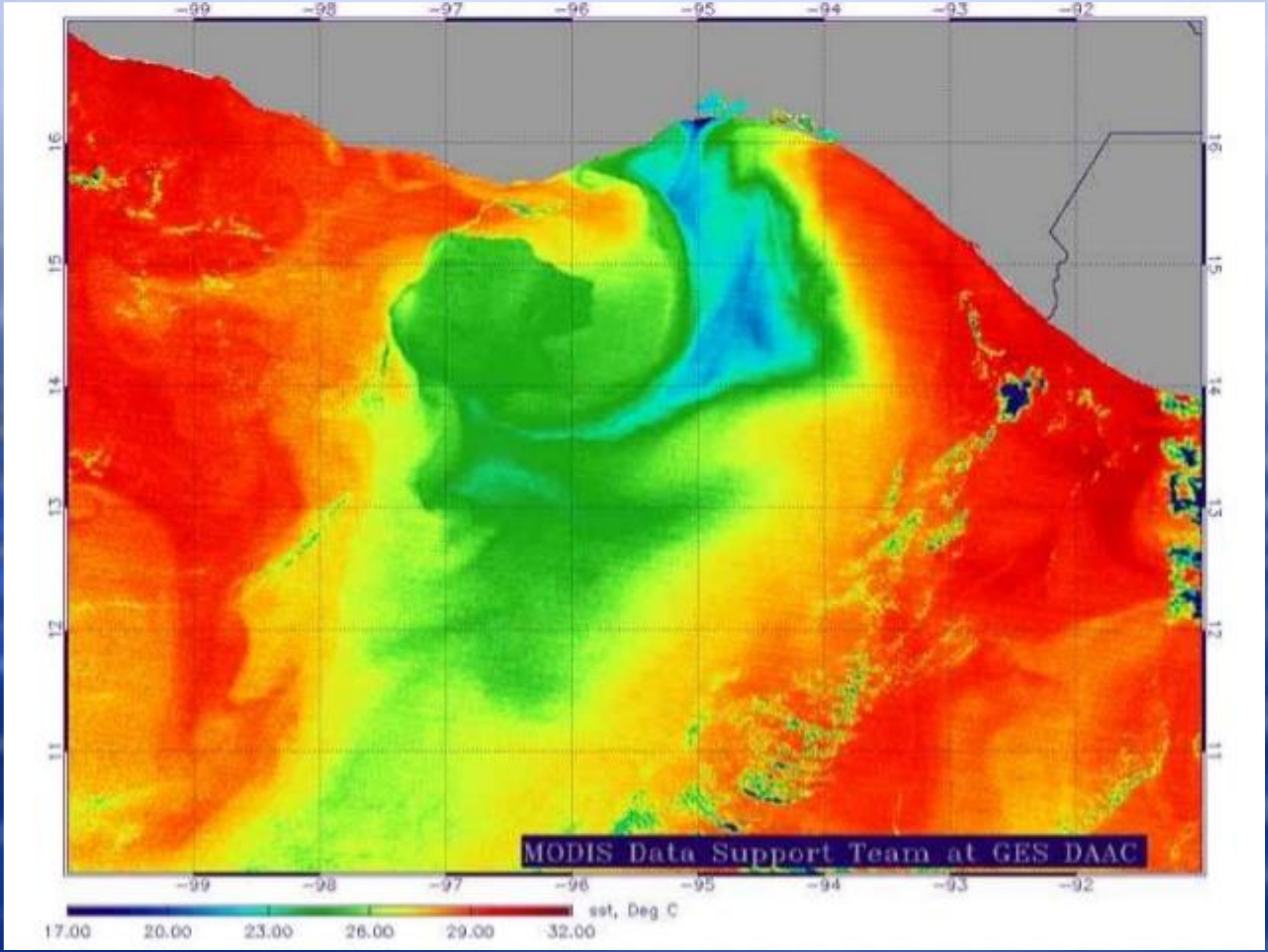


- **By satellite**
  - Infrared radiometers
  - Microwave radiometers

  In-situ techniques
  - Ships of opportunity
  - Drifting buoys
  - Argo profiling floats
  - Moored buoys
- **Numerical models**
  Numerical atmospheric or oceanic models are also capable of calculating sea surface temperature. Models are calibrated by comparing the sea surface temperature produced by the model with that measured by different sensors.

Which Satellite Instruments are used for monitoring SST ?

- MODIS (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) andAqua (EOS PM) satellites.
- Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon.
- Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. These data improve our understanding of global dynamics and processes occurring in the oceans, and in the lower atmosphere. MODIS is playing a vital role to predict global change accurately.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MODIS Data Support Team at GES DAAC
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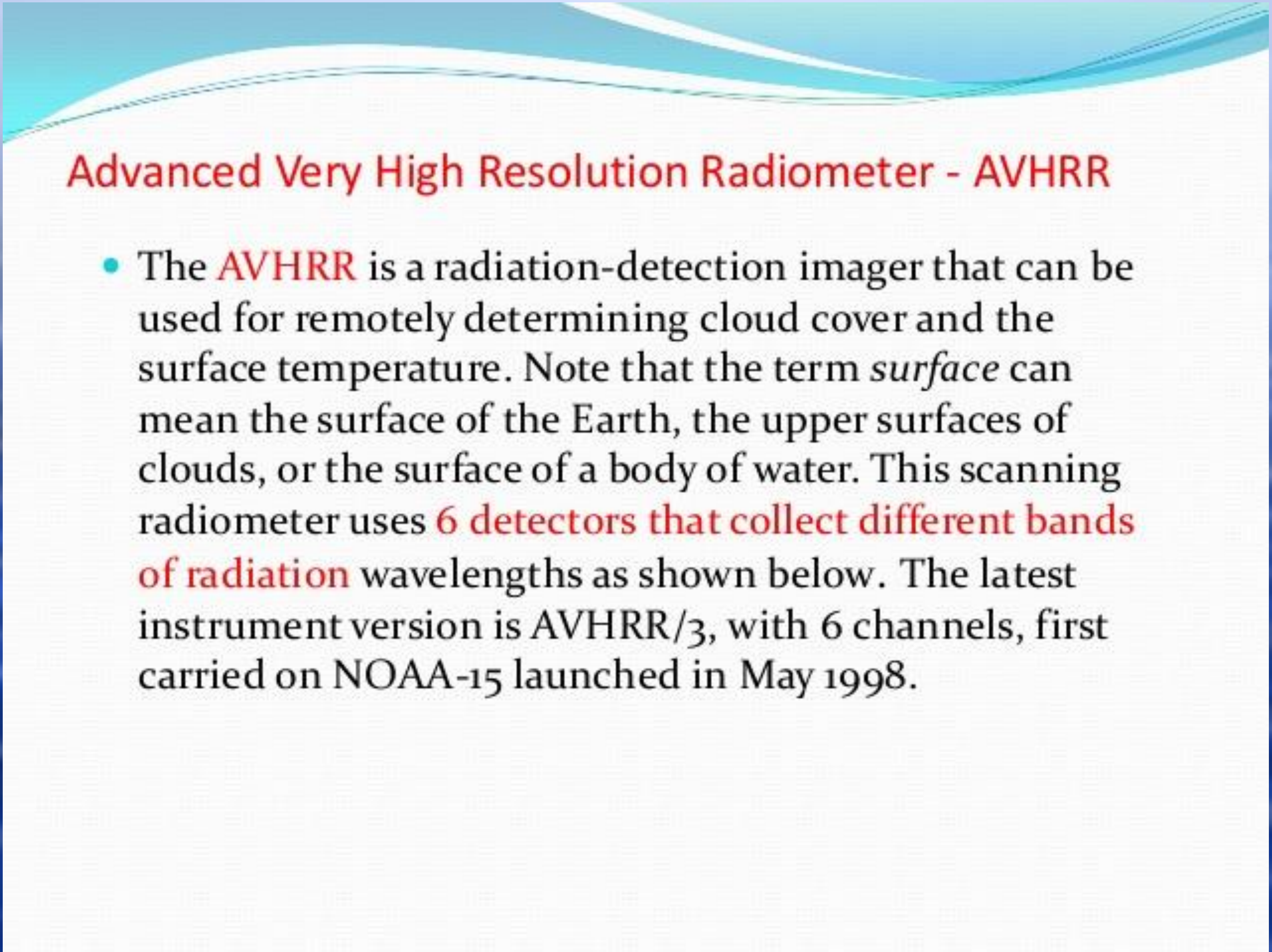

Advanced Very High Resolution Radiometer - AVHRR

- The AVHRR is a radiation-detection imager that can be used for remotely determining cloud cover and the surface temperature. Note that the term *surface* can mean the surface of the Earth, the upper surfaces of clouds, or the surface of a body of water. This scanning radiometer uses 6 detectors that collect different bands of radiation wavelengths as shown below. The latest instrument version is AVHRR/3, with 6 channels, first carried on NOAA-15 launched in May 1998.