Coastal Erosion, Salt Water Intrusion

Coastal Vulnerability

Unit 8-9

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COASTAL EROSION

COASTAL HAZARDS

(i) Storm surges (half a dozen per year)

(ii) Tsunami (one to two every century)

(iii) Coastal pollution due to industrial and domestic effluents

(iv) Coastal erosion

(v) Oil spills

(vi) Harmful algal blooms

(vii) Submarine mudslides

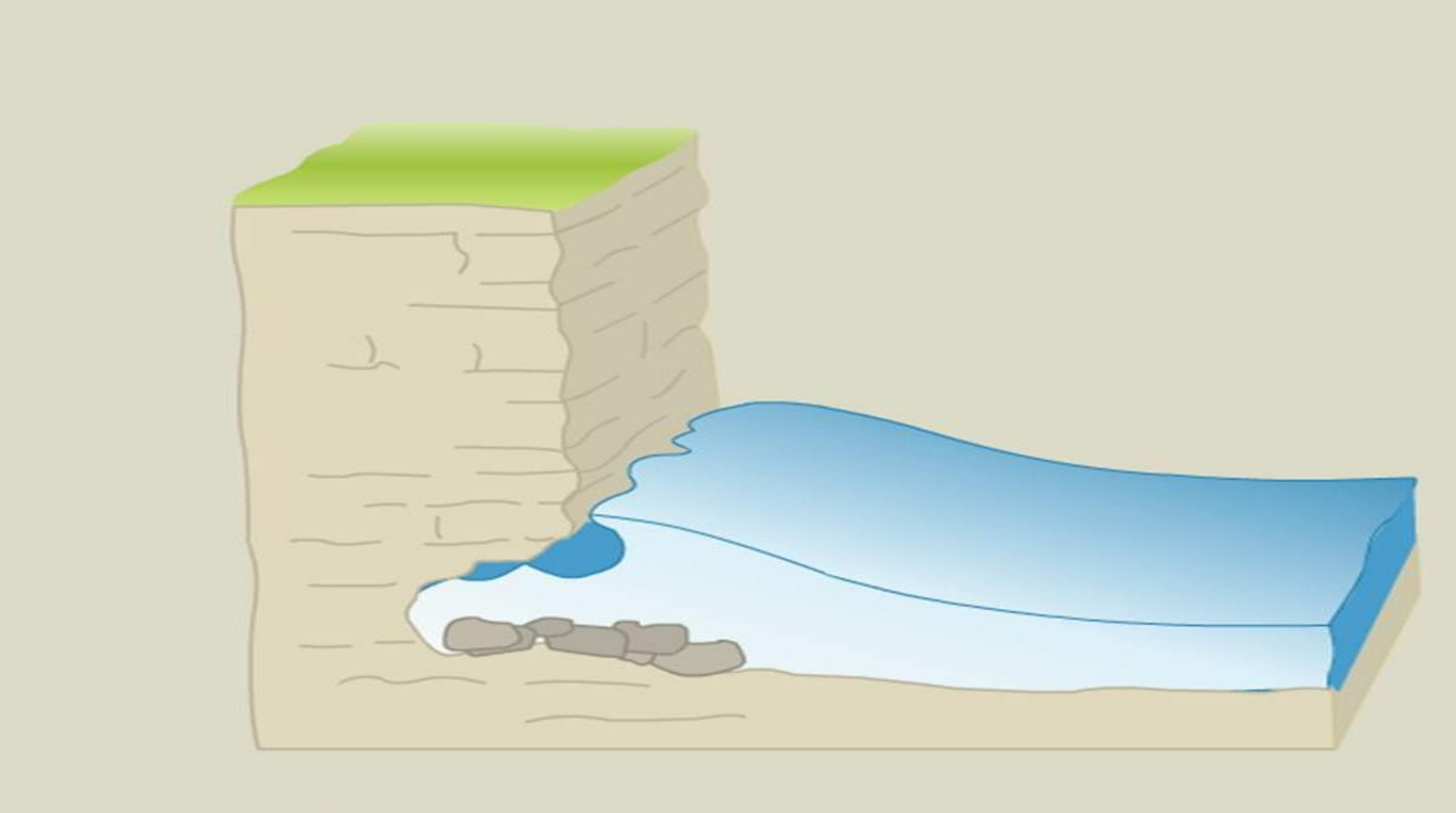
(viii) Hazards related to global climate change

COASTAL EROSION

- Coasts are subject to almost continuous change - either erode (retreat) or build seawards (accrete).

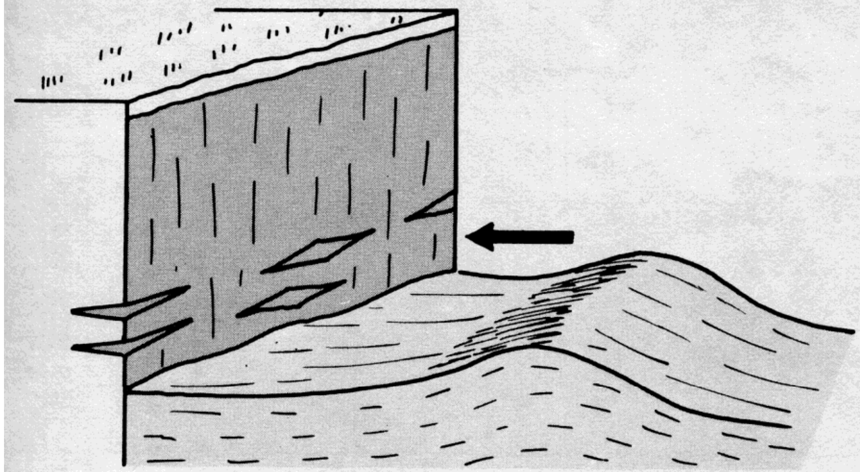
- Loss of subaerial landmass into a sea due to natural processes such as waves, winds and tides, or even due to human interference is called as coastal erosion.

There are four main forms of coastal erosion

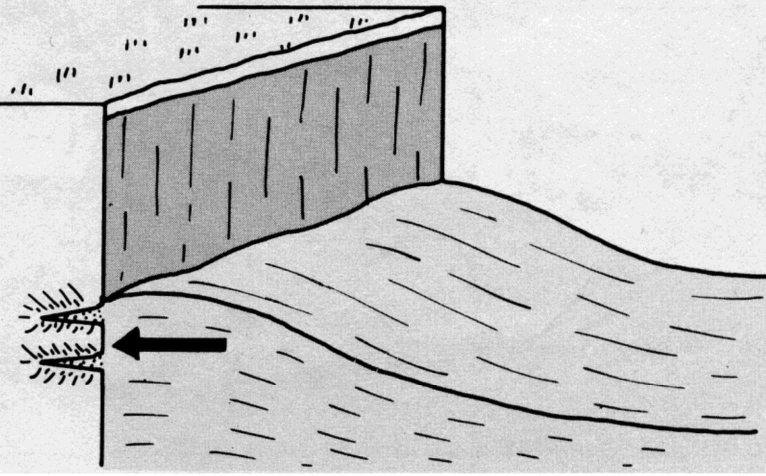


Hydraulic Action, Attrition, Abrasion, Solution

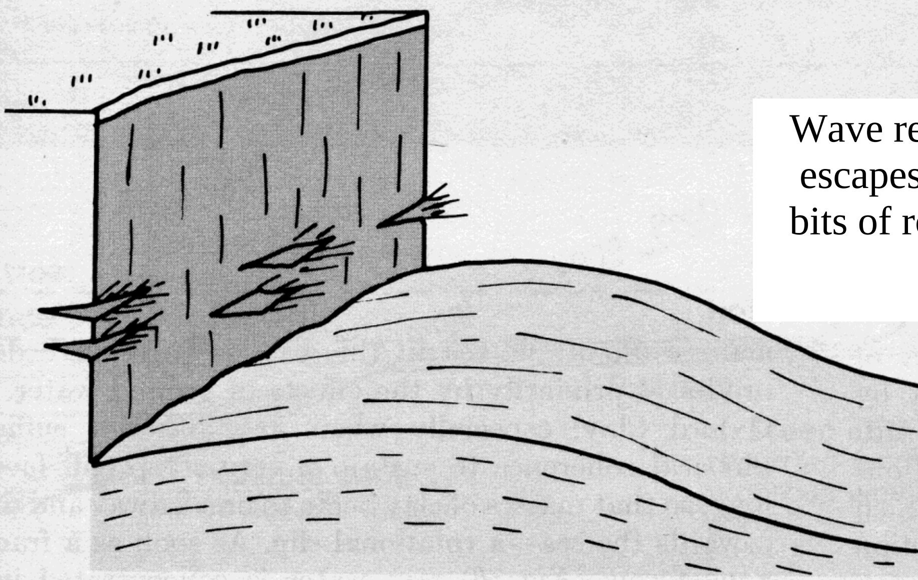
Hydraulic Action



Wave approaches the cliff. Note cracks exaggerated In size



Wave reaches the cliff & the air trapped by the wave is compressed into the crack.



Wave rebounds from the cliff & the compressed air escapes explosively, enlarging the cracks & ripping bits of rock off.

HYDRAULIC ACTION

Abrasion & Attrition (Corrasion)

Abrasion.

- The waves pick up the sediment & hurl it against the cliffs (uses the sediment as ammunition).

Attrition

- As the sediment is hurled against the cliff, bits are chipped off, the sediment gets smaller & rounder.
- Also as sediment roll against each other on a beach.

Corrosion (Solution)

- Salt & other chemicals in sea water attack & dissolve the cliffs.

Sub Aerial Processes

- The previous processes are caused by wave action & are called **CLIFF FOOT PROCESSES.**
- Sub Aerial processes are slope processes i.e weathering & mass movement, theses are called **CLIFF FACE PROCESSE**

EROSION IS CAUSED BY

- WAVES
- TIDAL STORMS
- NEAR SHORE CURRENTS
- OFFSHORE BANKS
- OFFSHORE BARS
- SAND SPIT
- TOMBOLO
- BAY
- MAN MADE STRUCTURES

TYPES OF EROSION

DUE TO WAVES

Water body obtains energy from wind, transfer across ocean and delivers
It to coastal zone

Collapse of wave near shoreline called as “wave break zone”

During winter waves will be high hence erosion more and summer less erosion

Summer swelling profile and winter storm profile to be taken into consideration

DUE TO TIDAL STORMS

Tides, low pressure and severe rainfall increase water level

Surf zone shifted towards land

Hence cause severe erosion well inside the land

Storm surges raise water level several meters accompanied by large waves
cause severe erosion

DUE TO NEAR SHORE CURRENTS

Waves breaking parallel to the shore forms seaward flowing rip currents

Waves breaking at angles produce long shore currents parallel to the shore

DUE TO OFFSHORE BANKS

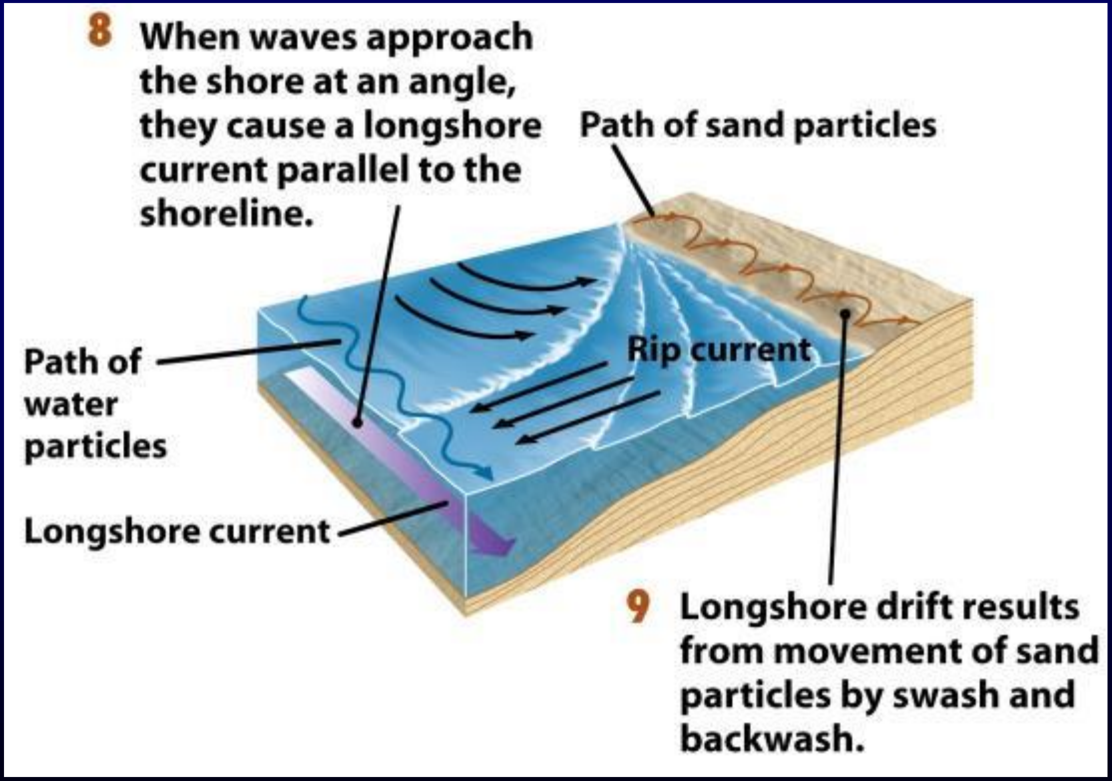
Change in the geometry of offshore banks (over period of 200 years) cause change in coastal morphology, areas once eroded show accretion and vice – versa

DUE TO OFFSHORE BARS

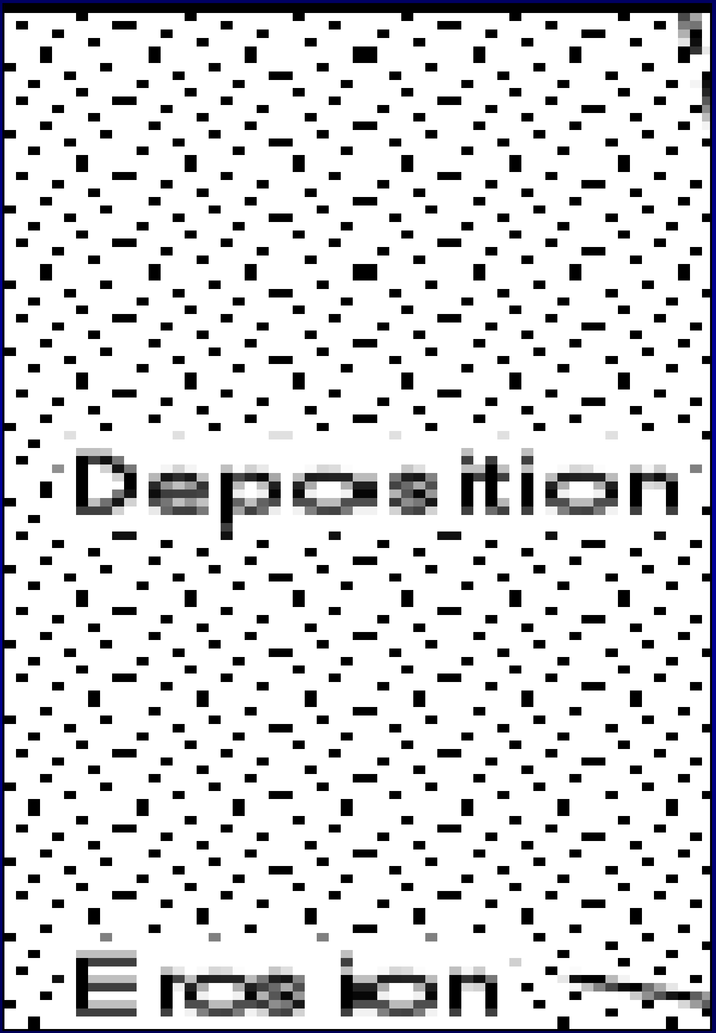
Normally found on river mouths, cause change in flow path of rivers causing Erosion on their banks

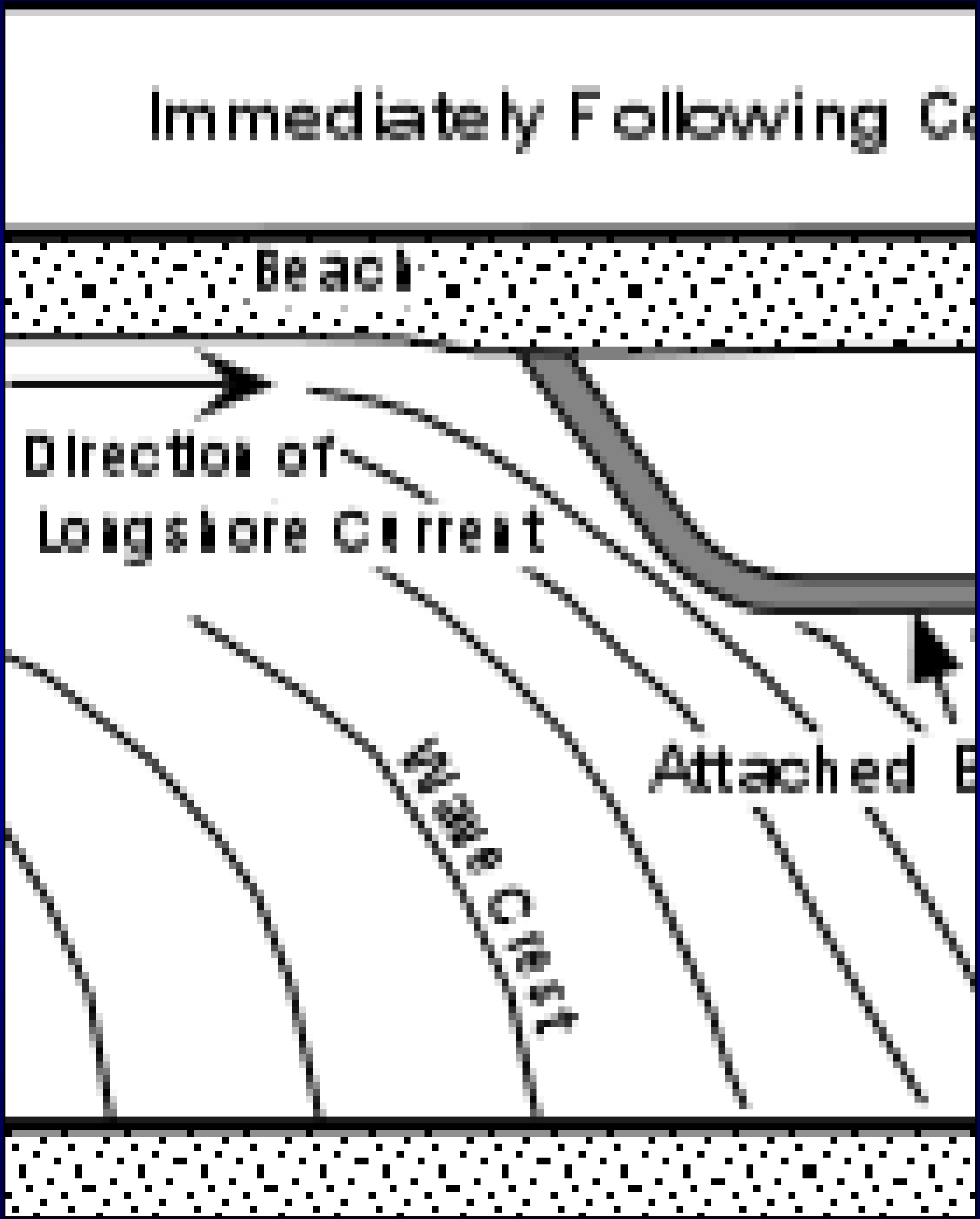
Rip currents

- When waves hit the coast and resolved into littoral currents and the seaward drifted currents such seaward drifted currents will be pushed back to the shore by wave
- This cause Rip currents



LONGSHORE CURRENTS





DUE TO SAND SPIT

Spit changes long shore currents causing accretion along spit and erosion in the updrift of the shoreline

Growth of spit cause severe erosion in the updrift

DUE TO TOMBOLO

Material that found attached between coastline and offshore

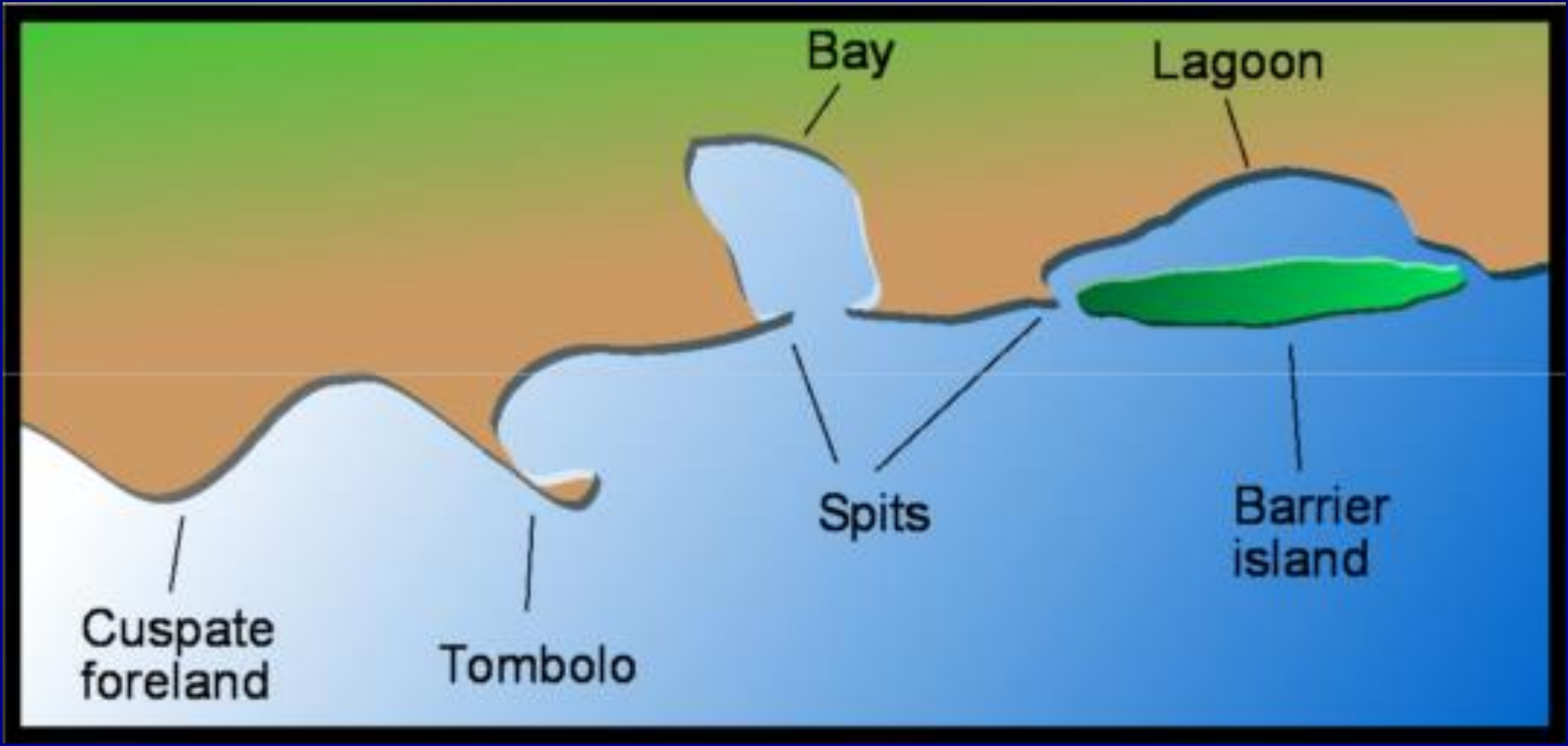
Cause littoral barriers leading to erosion in adjoining areas

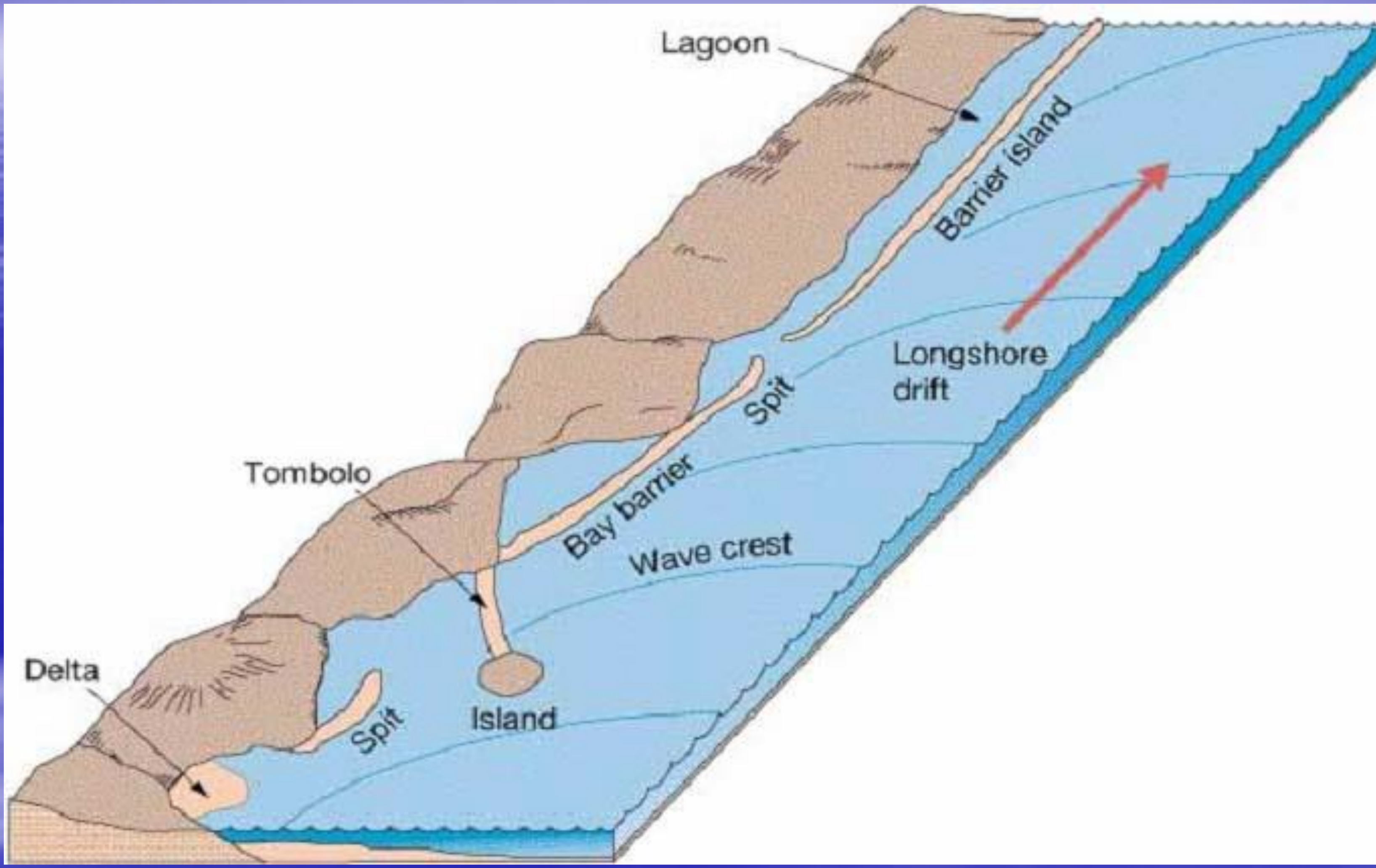
DUE TO BAY

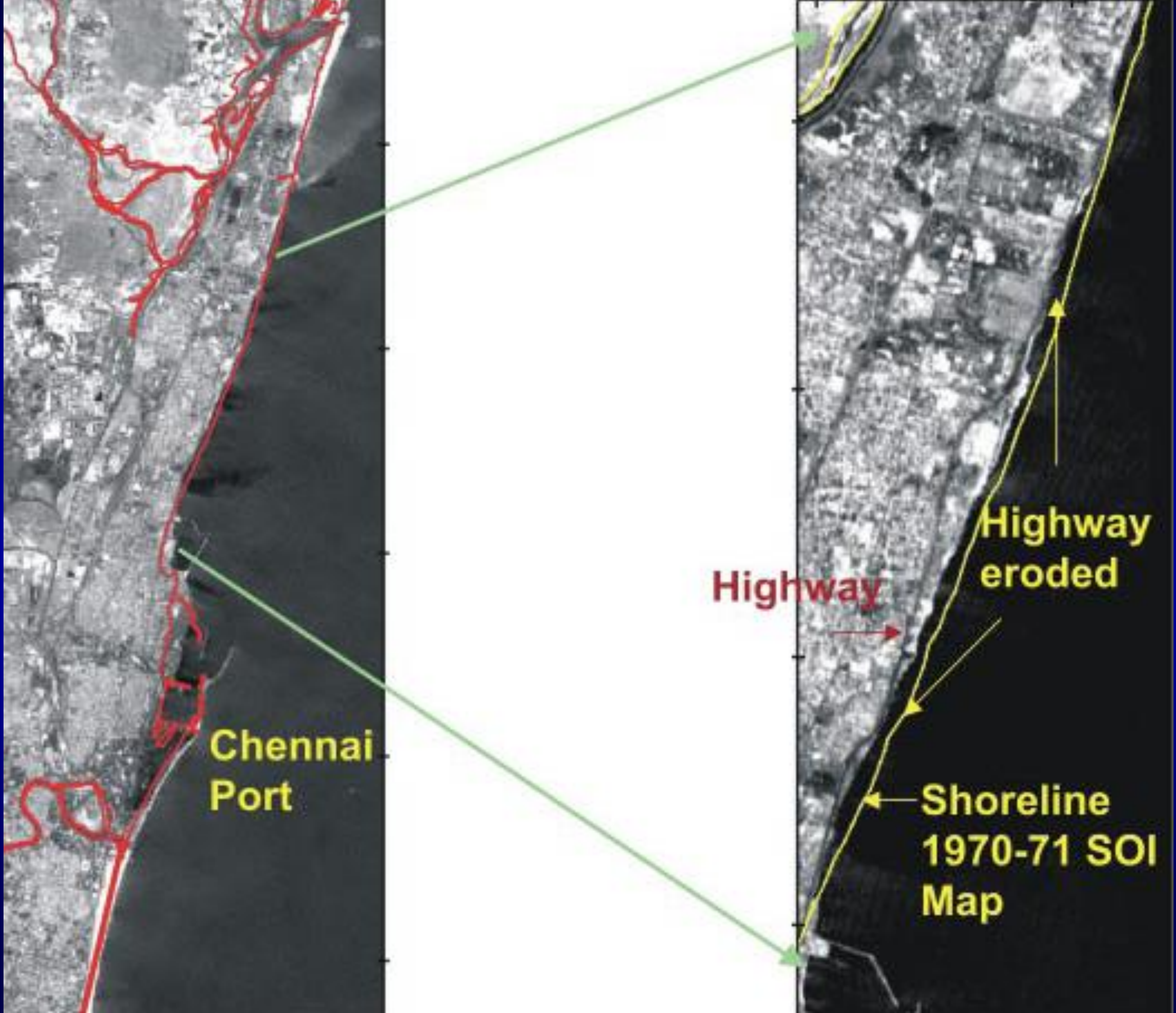
Change in wave direction cause movement of sediments within the bay

Hence accretion at one place and erosion in the other

Change in wave direction cause vice-versa effects


Bay
Lagoon
Spits
Barrier island
Cuspate foreland
Tombolo


Lagoon
Barrier island
Longshore drift
Spit
Tombolo
Bay barrier
Wave crest
Delta
Spit
Island

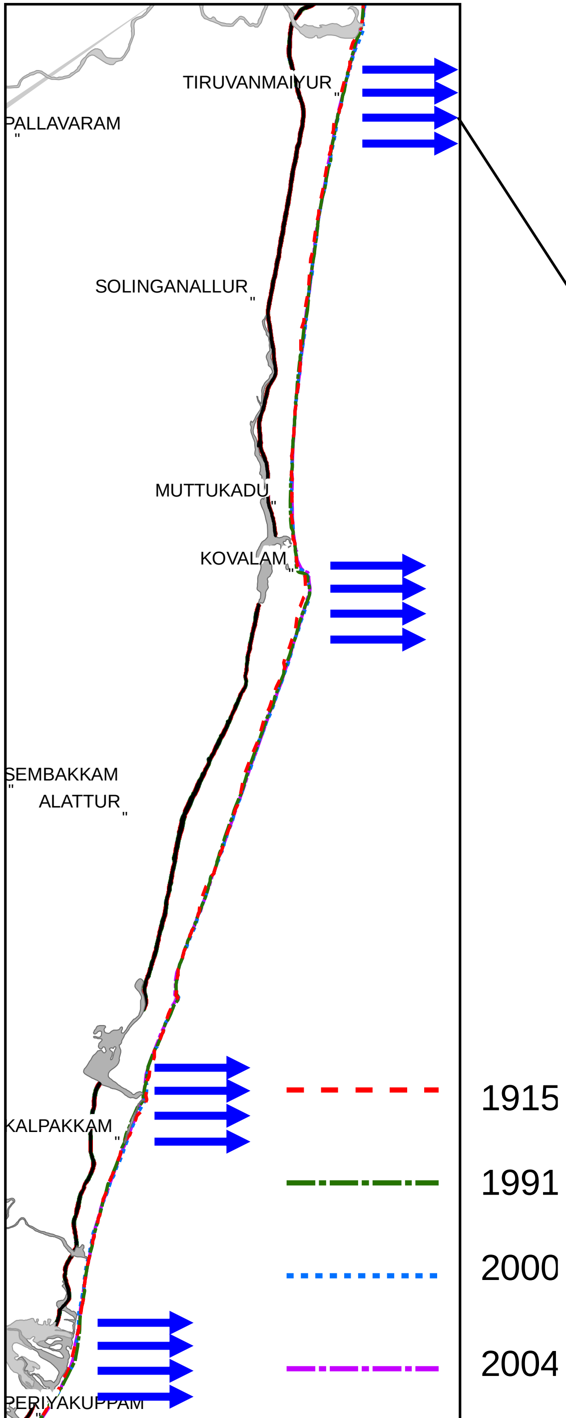

Chennai
Port
Highway
Highway
eroded
Shoreline
1970-71 SOI
Map

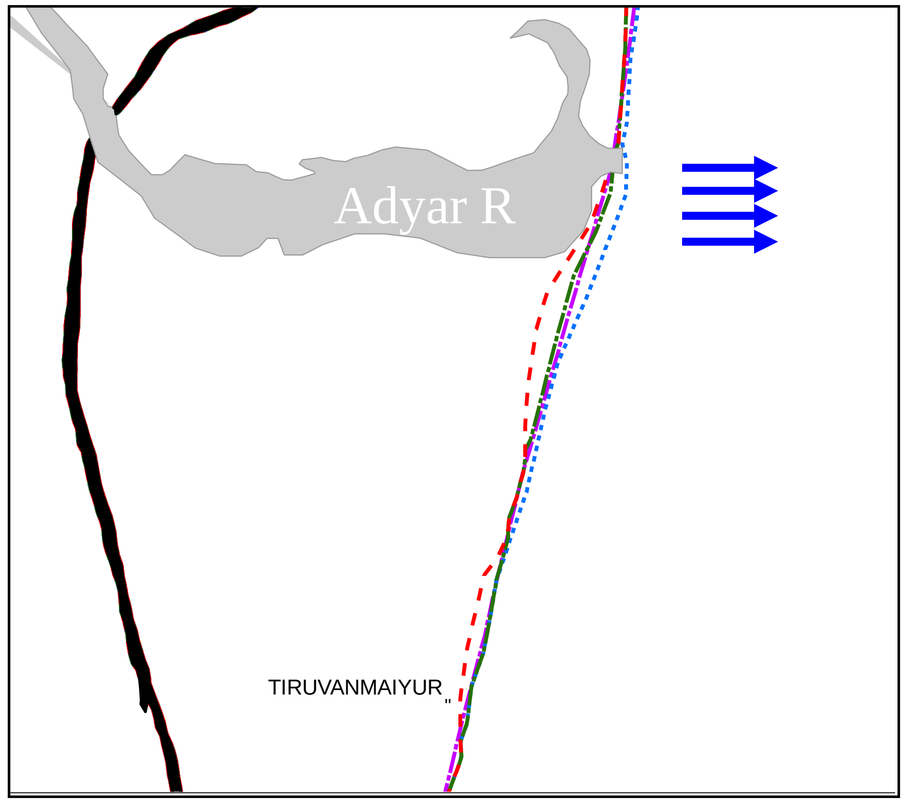
SHORELINE CHANGES

The shoreline during different periods were mapped using various data

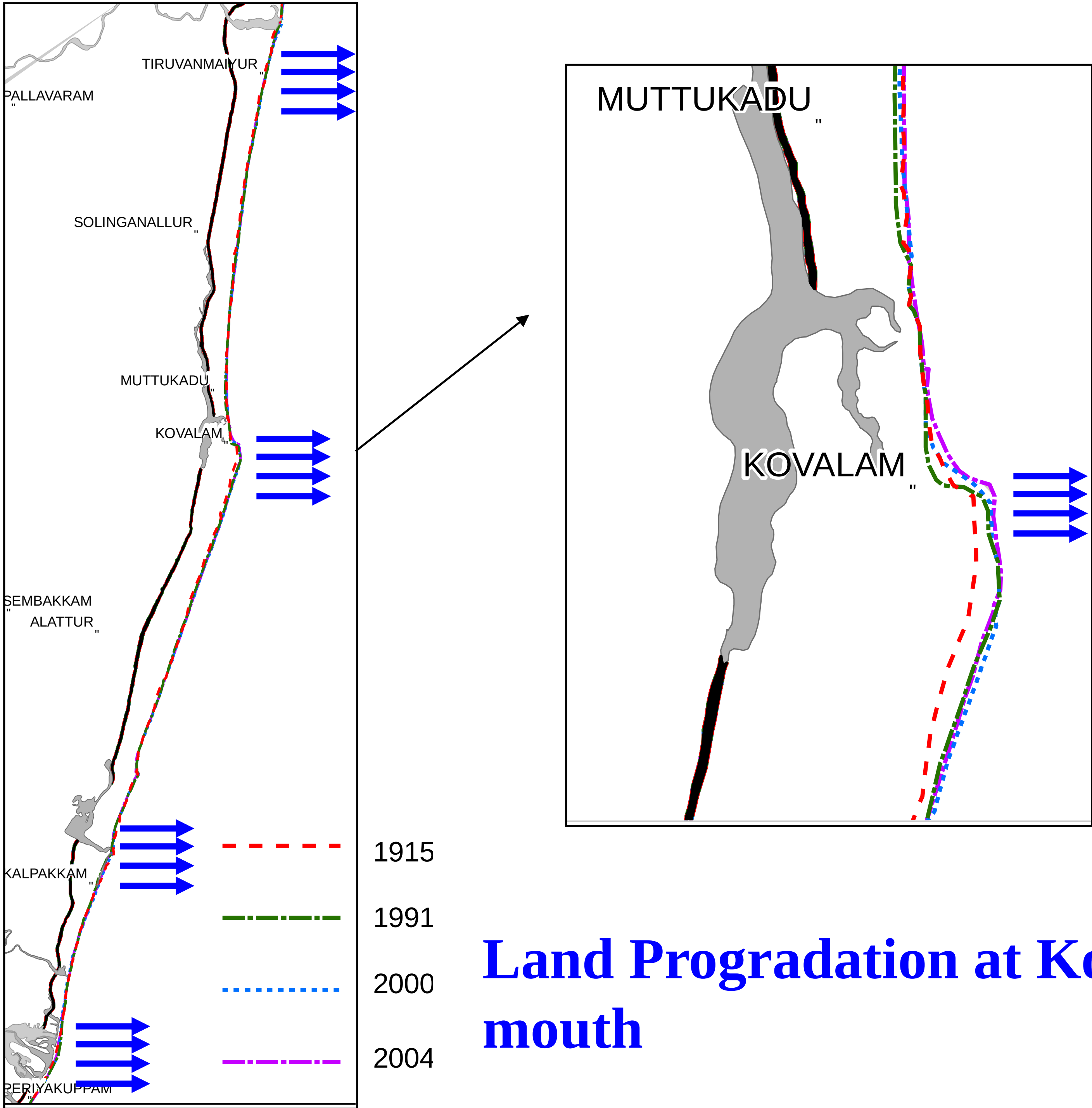
- **1915 – using old topographic sheets**
- **1991 – Using LANDSAT Thematic Mapper satellite data**
- **2000 – Using LANDSAT Enhanced Thematic Mapper data**
- **2004 – Using IRS P6 multi spectral data**

The land progradation at four areas, at Adyar river mouth, near Kovalam, Kalpakkam and Palar river mouth.

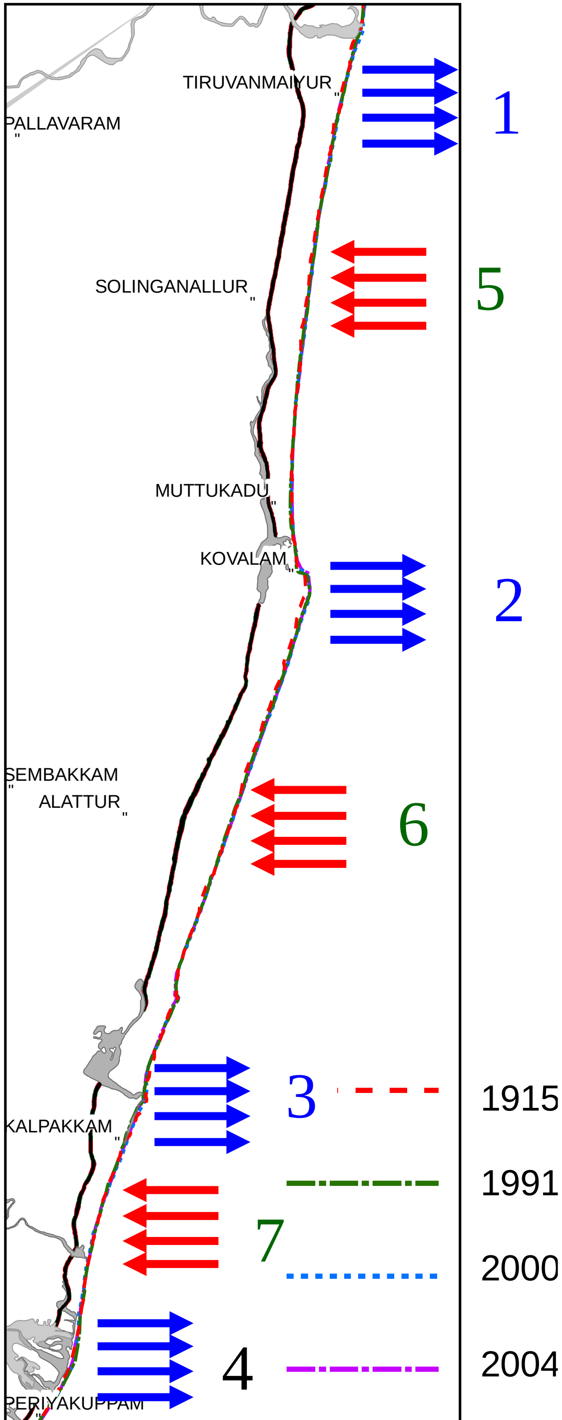




Land Progradation at Adyar R mouth



Land Progradation at Kovalam Creek mouth



The land progradation at four areas, at Adyar river mouth (1), near Kovalam (2), Kalpakkam (3) and Palar river mouth (4).

These four zones of land progradation were intervened by three zones of land loss at Solinganallur (5), Alattur (6) and north of Palar river mouth

PONDICHERRY - 1984

PONDICHERRY - 2000

EROSION DUE TO TSUNAMI NEAR NAGPATTINAM

Storm damage along the Mississippi coast from Hurricane Katrina, August 2005

DUE TO MAN MADE STRUCTURES

Harbors are developed by constructing wave breakers to form an enclosure of water body free from wave disturbance

Constructing jetties to prevent from long shore currents

MADRAS HARBOR

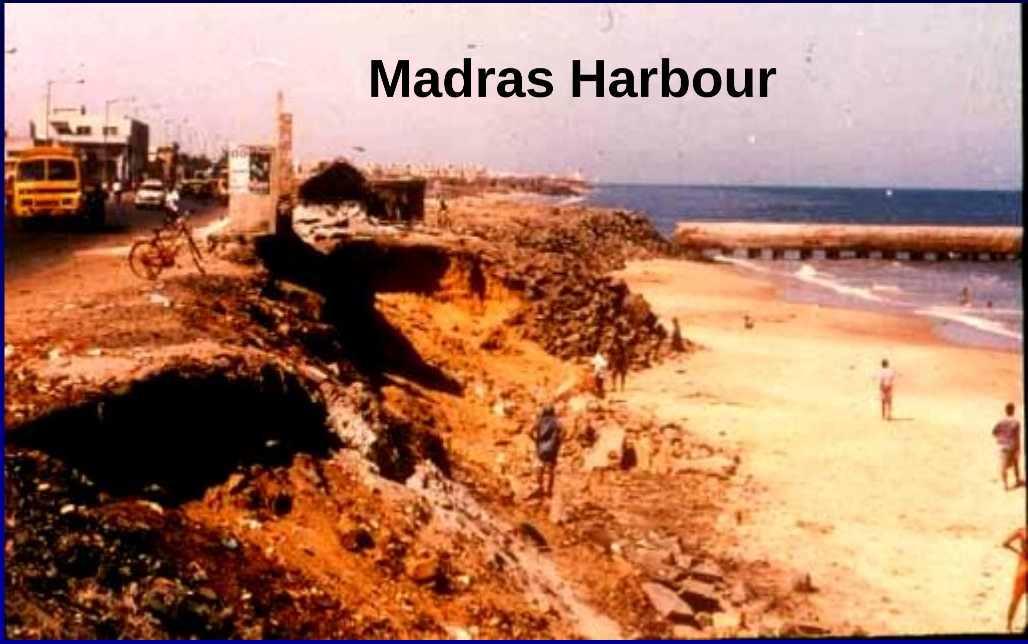
Due to construction of jetties since 1876

Accumulation of sand on the southern side results in shift of shore 10 mts/year

And severs erosion on the northern side of the harbor

MANGALORE HARBOR

Similar 500 m long jetty constructed in Mangalore cause accretion and erosion in the updrift and downdrift sides of the coast


Madras Harbour


Mahabalipuram

COASTAL PROTECTION

Usually carried out either to protect the existing beaches or to build up the Beaches lost due to erosion

- **Restoration of Beaches**
- **Protection of beaches**

RESTORATION OF BEACHES

Groynes:

Wooden, concrete and/or rock barriers or walls at right angles to the sea.
Groynes arrest littoral drift and make the shore line progress seaward till become parallel to the wave direction

(A) *Groynes on the sand-starved coast of northern New Jersey have little obvious effect on shoreline stability.*

SPACING OF GROYNES PLAYS A VITAL ROLE

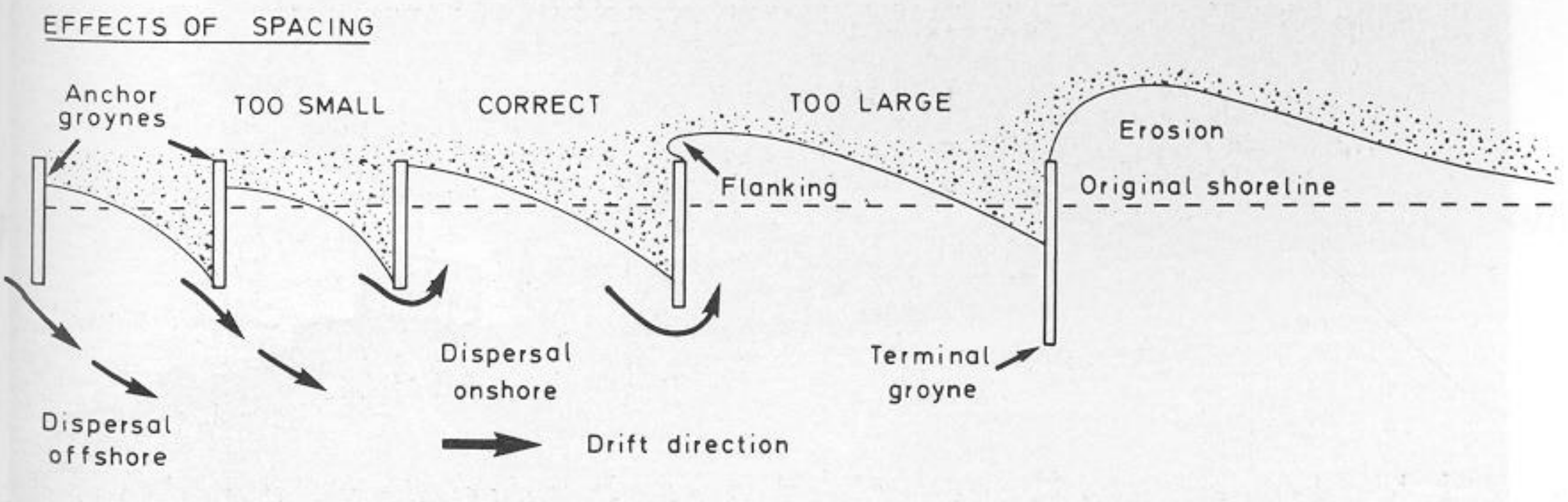


Figure 219. Of all groyne dimensions perhaps the effect of spacing is the most critical. Correct spacing is probably a function of wave parameters. Relatively small spacings encourage excessive seaward dispersal of sediment, relatively long spacings promote flanking. Terminal groynes are often responsible for downdrift erosion.

RIP RAP

Large rocks are piled or placed at the foot of cliffs, which are placed with native stones of the beach

GABIONS

Boulders and rocks are wired into mesh cages

When the seawater breaks on the gabion, the water drains through leaving sediment, losses its energy.

Gabions - wire mesh baskets filled with cobbles or crushed rock

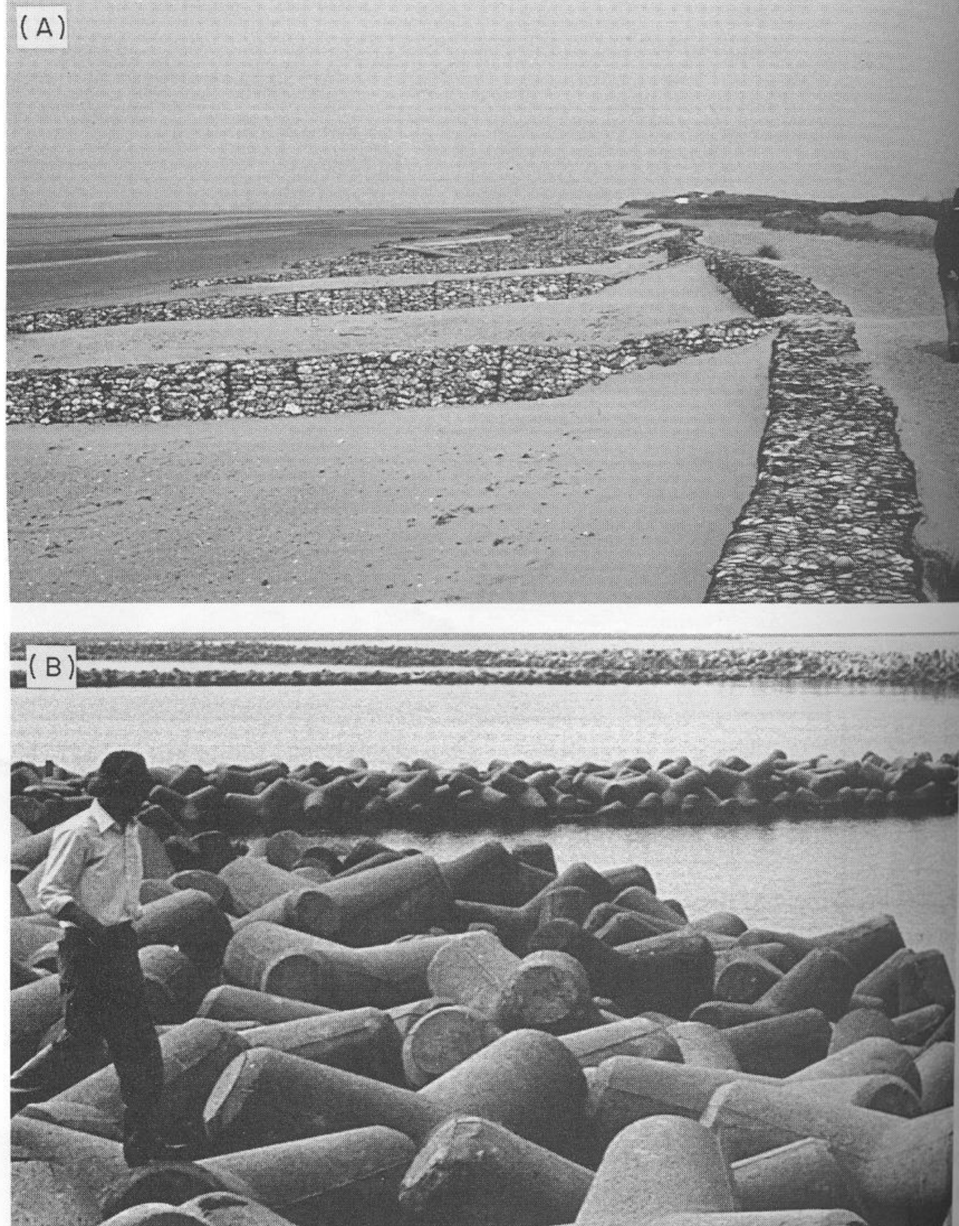


Figure 214. (A) *Wire-frame gabions employed as a groyne system on a low-energy, macro-tidal coast in Norfolk, UK.* (B) *Tetrapods are used widely to protect the shore. Their large and irregular surface area helps wave dissipation, while the "legs" interlock to produce stability.*

OFFSHORE BREAKWATER

Structures constructed parallel to the coastline in break water zone thereby reducing the magnitude of wave attack

Enormous concrete blocks and natural boulders are sunk offshore to alter wave direction and to filter the energy of waves and tides.

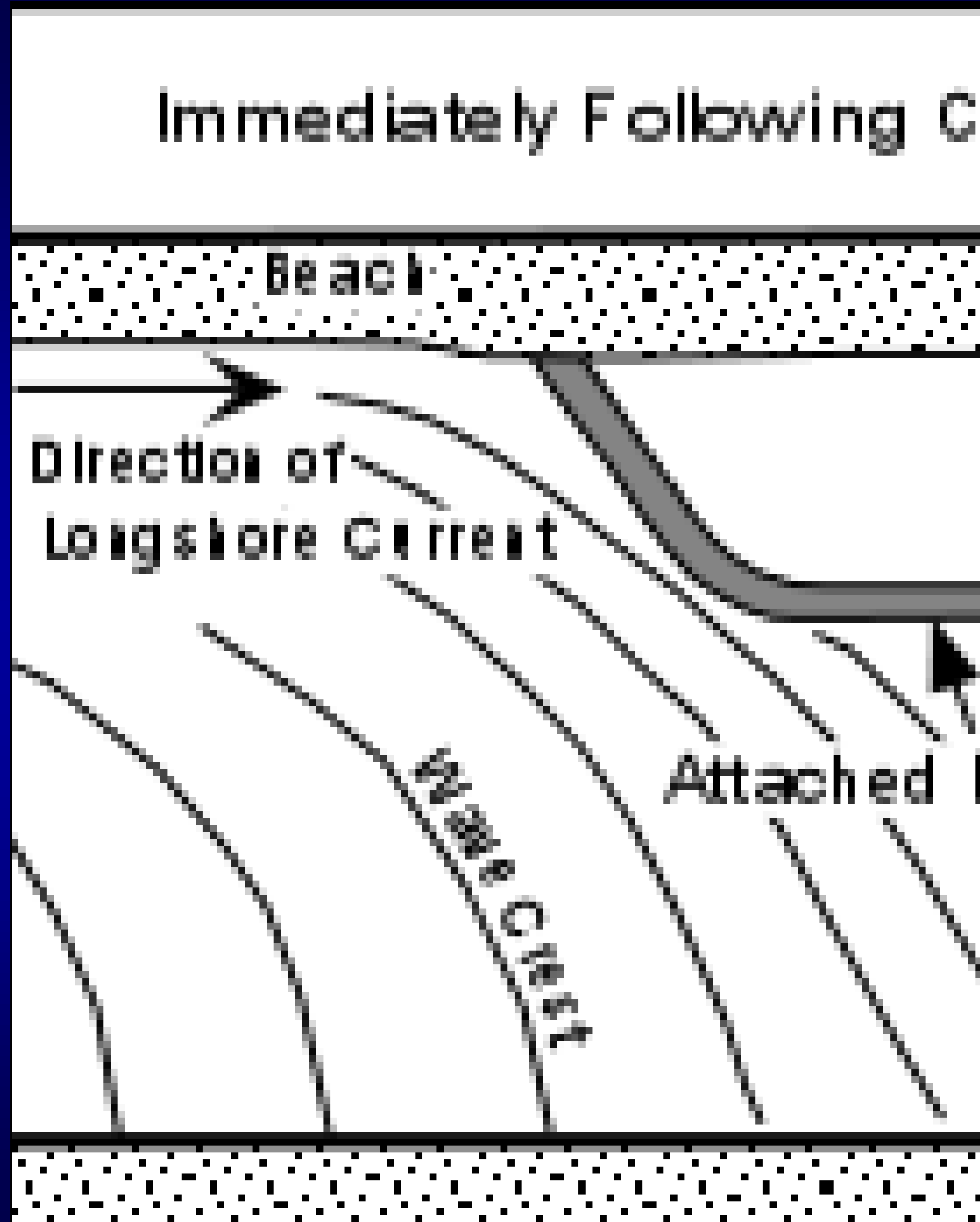
The waves brake further offshore and therefore reduce their erosive power.

This leads to wider beaches

Nearshore breakwaters

Figure 213. The vertical granite seawall at St. Malo in northern France during an onshore gale. Note the line of wooden posts aimed at reducing the direct wave forces on the wall, and the partial clapotis in the nearshore zone.

LONGSHORE CURRENTS



Offshore Break waters

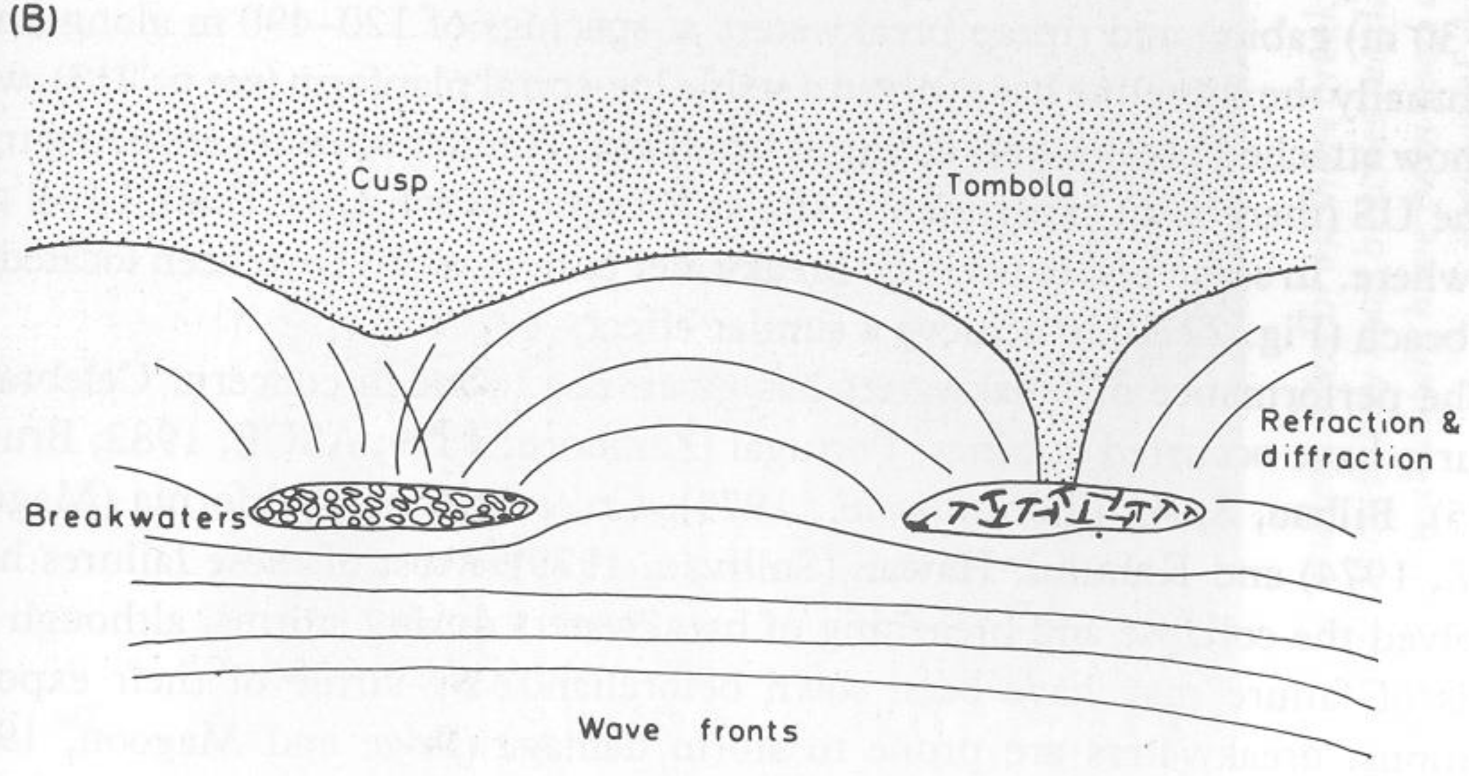


Figure 226. (A) Cross-section of an idealized rubble-mound breakwater to show the types of material that might be used in its construction. (B) Plan view of the effects of periodic offshore breakwaters, promoting wave caustics and sedimentation.

BEACH NOURISHMENT

This involves importing alien sand of the beach and piling it on top of the existing sand

The imported sand must be of a similar quality to the existing beach material so it can integrate with the natural processes occurring there, without causing any adverse effects

SAND DUNE STABILISATION

Vegetation encourages dune growth by trapping and stabilising blown sand.

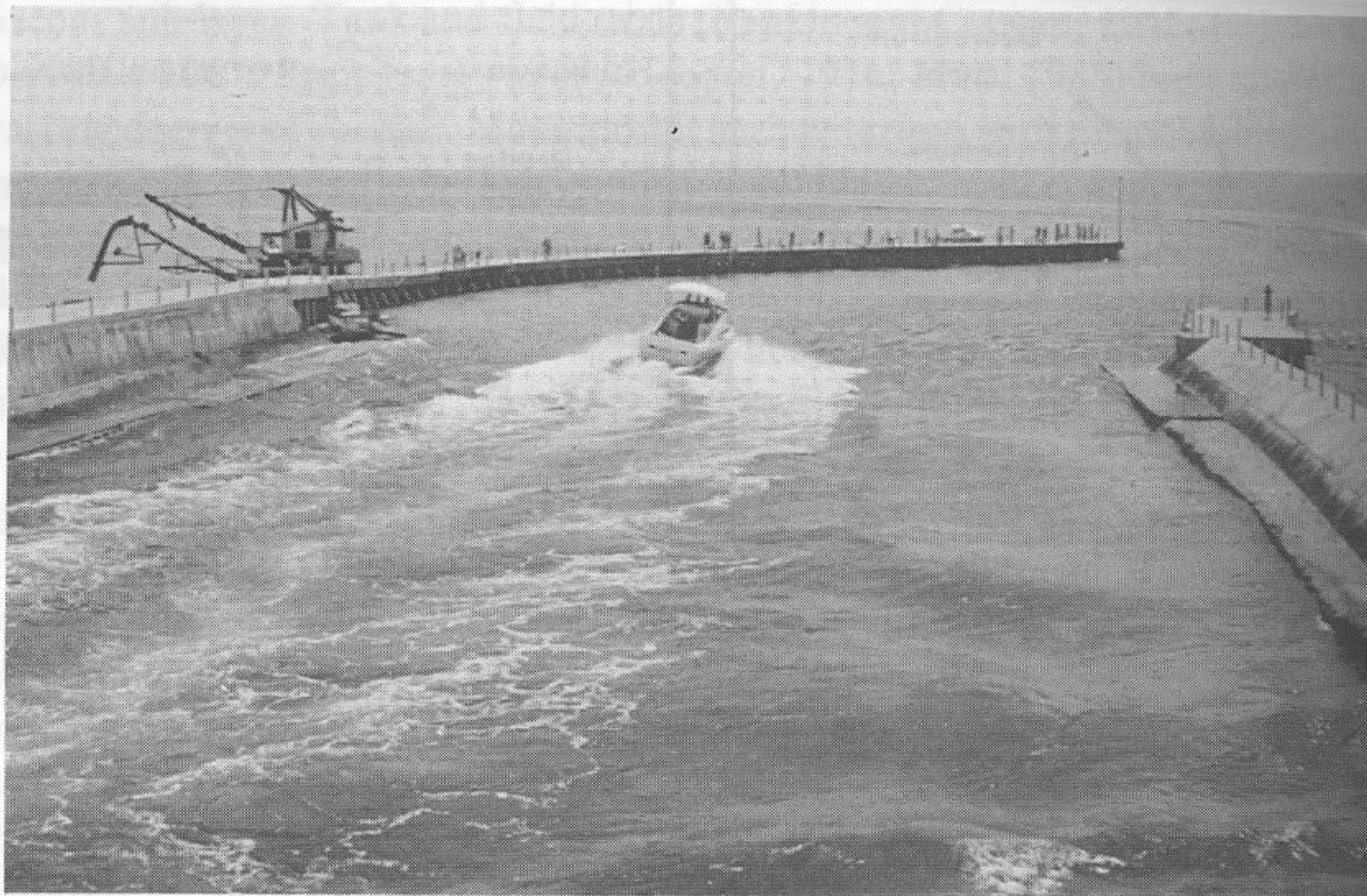


Figure 230. South Lake Worth Inlet by-passing plant in 1977. Sand from the updrift (northern side) is pumped across the inlet and redeposited on the downdrift side.

(A)

(B)

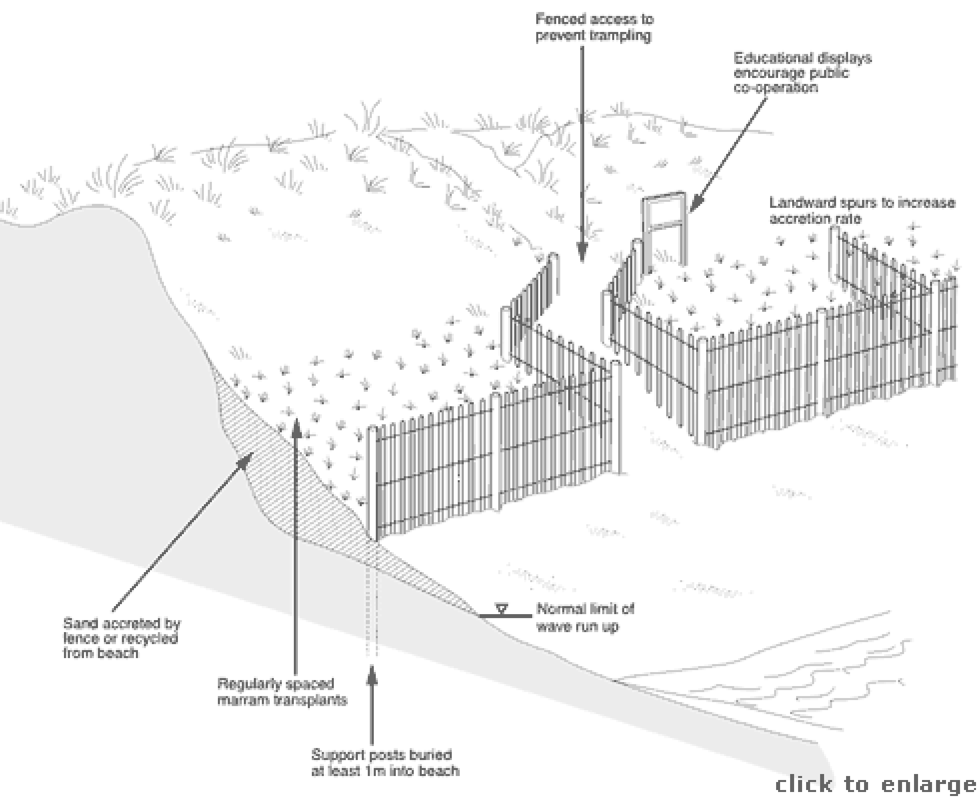
Figure 237. (A) The dumping of colliery waste onto the shore at Horden, Co. Durham has created a major depositional bulge on the coast. This colliery has now closed and dumping has ceased. (B) Sediment from Horden moves downcoast to Hartlepool, by which time it has been sorted, with the less dense coal fraction forming a commercially valuable surface placer across the beach.

Timber and geotextile

Stabilisation using grass plants.


© Pamela Gore, 1998

Fencing


Fenced access to prevent trampling
Educational displays encourage public co-operation
Landward spurs to increase accretion rate
Normal limit of wave run up
Sand accreted by fence or recycled from beach
Regularly spaced marram transplants
Support posts buried at least 1m into beach
click to enlarge

PROTECTION TO BEACHES

SEA WALL

Walls,concrete /or stone, built at base of cliff or beach.

Often curved to resist and reflect the energy of the waves back out to sea

REVETMENTS

Consist of timber slants with a possible rock infill. Waves brake against the revetments, which dissipate, greatly absorbs the energy instead of reflecting.

Seawall / bulkhead / revetments

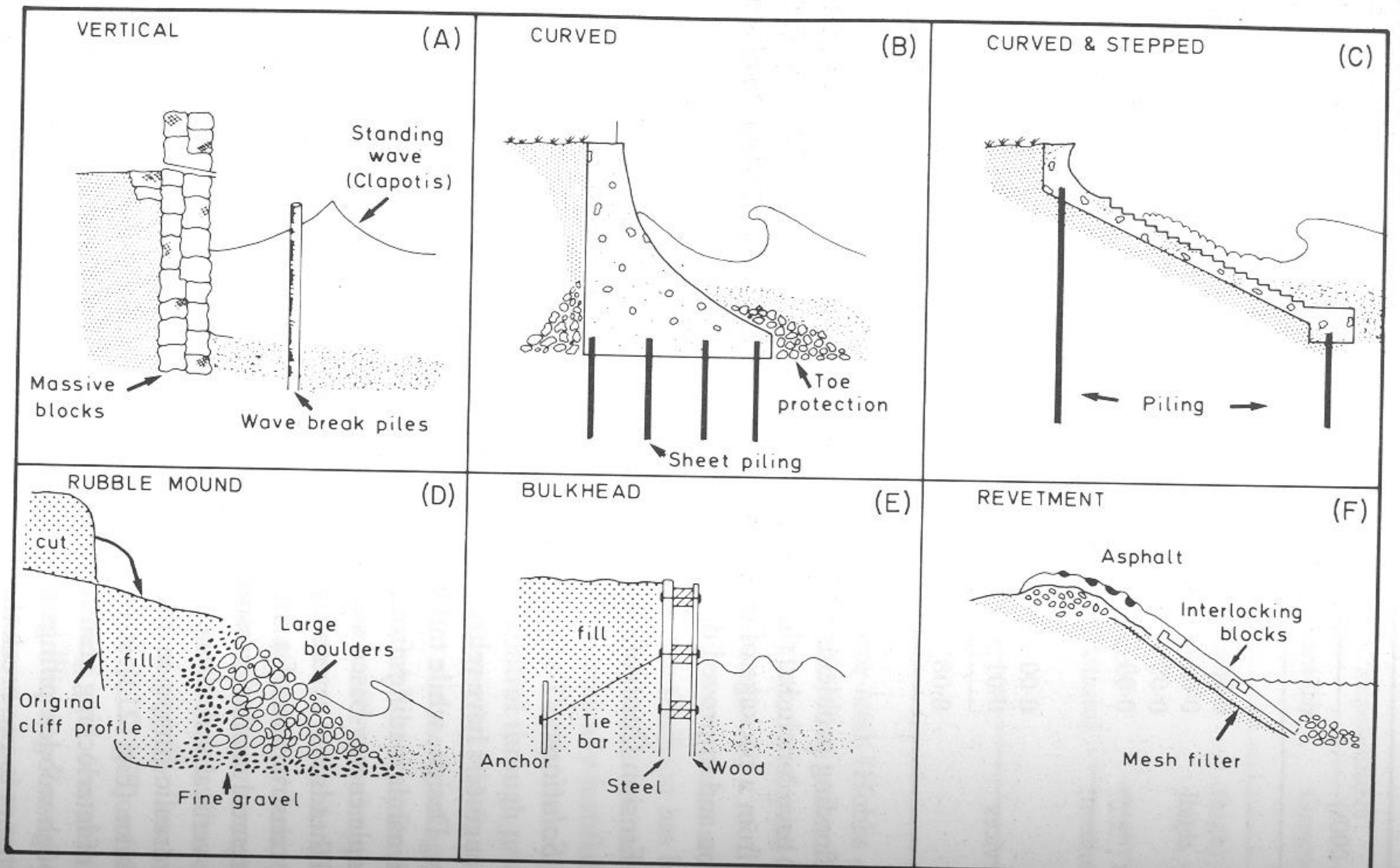
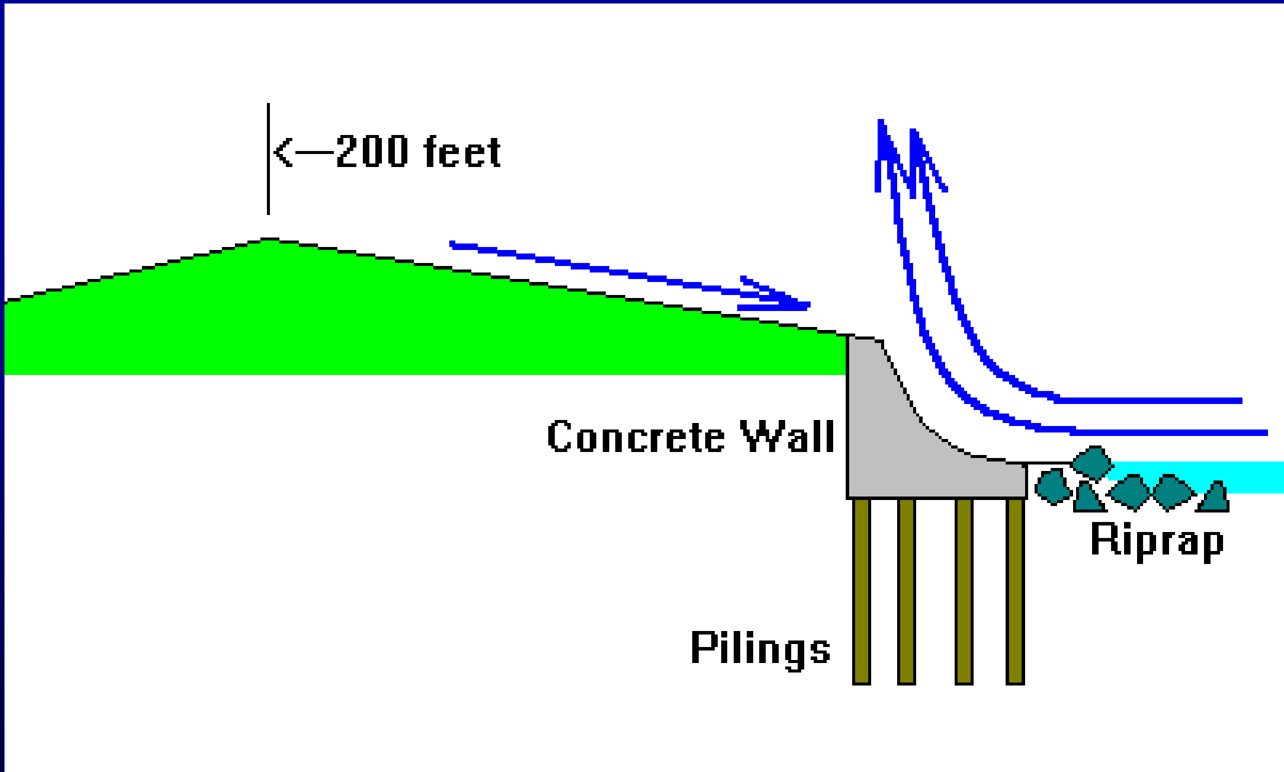


Figure 212. An energy based sequence of shore protection designs (high to low, A to F). (A) Vertical seawall constructed of resistant interlocking blocks. (B) Curved seawall with toe protection. (C) Curved and stepped wall secured by piling. (D) Rubble-mound or armouring plus regrading of the coastal slope. (E) Bulkhead of wood or steel. (F) Revetment made of armour blocks, gabions or asphalt.

Concrete and stone seawall.



ROCK REVENMENTS

Rock faced concrete revetment

Sand bags

COASTAL VULNERABILITY MAPPING

Table 1. Summary of coastal vulnerability indices, their geographical application and th
variables needed to implement them

Index	Geographical application	Variables considered	Reference
Coastal vulnerability index (CVI)	USA	Relief, rock types, landform, relative sea-level change, shoreline displacement, tidal range and maximum wave height	Gornitz and Kanciruk (1989), Gornitz (1991), Gornitz et al. (1991)
Coastal vulnerability index (CVI)	USA	Geomorphology, shoreline erosion and accretion, coastal slope, relative sea-level change, mean wave height and mean tidal range	Thieler and Hammer-Klose (2000) and numerous other USGS reports
Social vulnerability index (SoVI)	USA	Principal components analysis of Census-derived social data	Boruff et al. (2005)
Coastal social vulnerability score (CSoVI)	USA	Combination of CVI and SoVI	Boruff et al. (2005)
Sensitivity index (SI)	Canada	Relief, rock type, landform, sea-level change, shoreline displacement, tidal range and maximum wave height	Shaw et al. (1998)
Erosion hazard index	Canada	As SI, plus exposure, storm surge water level, slope	Forbes et al. (2003)
Risk matrix	South Africa	Location, infrastructure (economic value), hazard	Hughes and Brundrit (1992)
Sustainable capacity index (SCI)	South Pacific	Vulnerability and resilience of natural, cultural, institutional, infrastructural, economic and human factors	Yamada et al. (1995)
Sensitivity index	Ireland	Shoreface slope, coastal features, coastal structures, access, land use	Carter (1990)
Vulnerability index	UK	Disturbance event frequency, relaxation (recovery) time	Pethick and Crooks (2000)

Ranking of coastal vulnerability index variables

(Thieler and Hammar-Klose, 2000)

	Ranking of coastal vulnerability index				
	Very low	Low	Moderate	High	Very high
VARIABLE	1	2	3	4	5
Geomorphology	Rocky, cliffed coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Alluvial plains	Cobble beaches Estuary Lagoon	Barrier beaches Sand Beaches Salt marsh Mud flats Deltas Mangrove Coral reefs
Coastal Slope (%)	> 1.9	1.3 – 1.9	0.9 – 1.3	0.6 –0.9	< .6
Relative sea-level change (mm/yr)	< -1.21	-1.21 – 0.1	0.1 – 1.24	1.24 –1.36	> 1.36
Shoreline erosion/ accretion (m/yr)	>2.0 Accretion	1.0 –2.0	-1.0 – +1.0 Stable	-1.1– -2.0	< - 2.0 Erosion
Mean tide range (m)	> 6.0	4.1 – 6.0	2.0 – 4.0	1.0 –1.9	< 1.0
Mean wave height (m)	<1.1	1.1 – 2.0	2.0 – 2.25	2.25 –2.60	>2.60

$$CVI = \sqrt{((a*b*c*d*e*f)/6)}$$

Table 3. *Physical variables used to create the coastal physical vulnerability index (CVI).**

Variable	Measurement	Source
Mean tidal range	Meters	Tide gauges
Coastal slope	Percent	Topography, bathymetry
Rate of relative sea-level rise	Δ mean water elevation	Tide gauges
Shoreline erosion and accretion rates	Meters/year	Coastal Erosion Information System (CEIS)
Mean wave height	Meters	Wave Information Study (WIS)
Geomorphology (erodability)	Ordinal value	Geology, topography

* Based on data from Thieler and Hammer-Klose (1999, 2000a, 2000b).

Table 3. Ranking of coastal vulnerability index (CVI) variables for the Illawarra coast, NSW, Australia, adapted from the coastal risk classes of Gornitz (1991)

Category	**Very low**	**Low**	**Moderate**	**High**	**Very High**
VARIABLE	**1**	**2**	**3**	**4**	**5**
a1. Dune height (m)	≥ 30.1	20.1 - 30.0	10.1 - 20.0	5.1 - 10.0	0 – 5.0
a2. Barrier types	Transgressive	Prograded	Stationary	Receded	Mainland beach
a3. Beach types	Dissipative (D) Longshore bar trough (LBT)	Rhythmic bar beach (RBB)	Transverse bar rip (TBR)	Low tide terrace (LTT)	Reflective (R)
a4. Relative sea-level change (mm/yr)	≤ -1.1 Land rising	- 1.0 - 0.99	1.0 - 2.0 Eustatic rise	2.1 - 4.0	≥ 4.1 Land sinking
a5. Shoreline erosion/accretion (m/yr)	≥ + 2.1 accretion	1.0 - 2.0 Stable	-1.0 - + 1.0 Erosion	-1.1 - -2.0 erosion	≤-2.1 Erosion
a6. Mean tidal range (m)	≤ 0.99 Microtidal	1.0 - 1.9 Microtidal	2.0 - 4.0 Mesotidal	4.1 - 6.0 Mesotidal	≥ 6.1 Macrotidal
a7. Mean wave height (m)	0 - 2.9	3.0 - 4.9	5.0 - 5.9	6.0 - 6.9	≥ 7.0

RESULTS

Barrier types were classified based on knowledge of depositional environments and histories (Thom et al., 1978).

Five types of barriers were recognised; episodic transgressive, prograded, stationary, receded and mainland beach barriers.

Episodic transgressive dune barriers can be attributed to locally high rates of sand supply at the downdrift terminus of a littoral drift system, implying an abundant sand supply

Prograded barriers are typically characterised by multiple beach ridges (e.g. Moruya and Seven Mile Beaches).

Stationary barriers are generally narrower, characterised by dominantly vertical rather than lateral growth. They are recognised on the basis of the absence of significant morphological evidence of progradation

Receded barriers are thin marine sand deposits that overlie estuarine or back-barrier sediments which outcrop on the shoreface.

Mainland beach barriers are an end-member of the barrier types that comprise thin veneers of beach mantling a pre-Holocene erosional substrate (Roy et al., 1994).

Beach types **– A series of beach types (also called states as a beach may vary from one type to another over time) have been described by Short (1993, 1999). The 6 types are: Dissipative (D), Longshore Bar and Trough (LBT), Rhythmic Bar and Beach (RBB), Transverse Bar and Rip (TBR), Low Tide Terrace (LTT) and Reflective (R) beaches.**

Dissipative beaches have wide surf zones with shore parallel bars and channels with an abundant median to fine sand. An example is the northern part of Seven Mile beach. They tend to be relatively stable systems with low frequency of shoreline displacement events and spatially continuous, parallel, back-beach foredune scarps.

Intermediate beaches occupy states between the fully dissipative and reflective. They are characterized by rip circulation, crescentic-transverse bars and megacusps. Examples are Stanwell Park, Coledale, Bulli, Perkins, Warilla, mid Seven Mile and Moruya Beaches.

Reflective beaches are characterized by barless surfzone and steep, narrow, cusped or bermed beach. Fishermans Beach is an example, although not included in this study.

SALTWATER INTRUSION

Salt water intrusion

Mass transport of saline waters into zones previously occupied by fresher water is defined as salt water intrusion (stewart 1999).

Sea water mixing with fresh water in coastal aquifer

Intrusion of sea water into the coastal aquifer system – may be considered as a type of environmental pollution due to human activities or/and to physical factors.

Salt Water Intrusion….

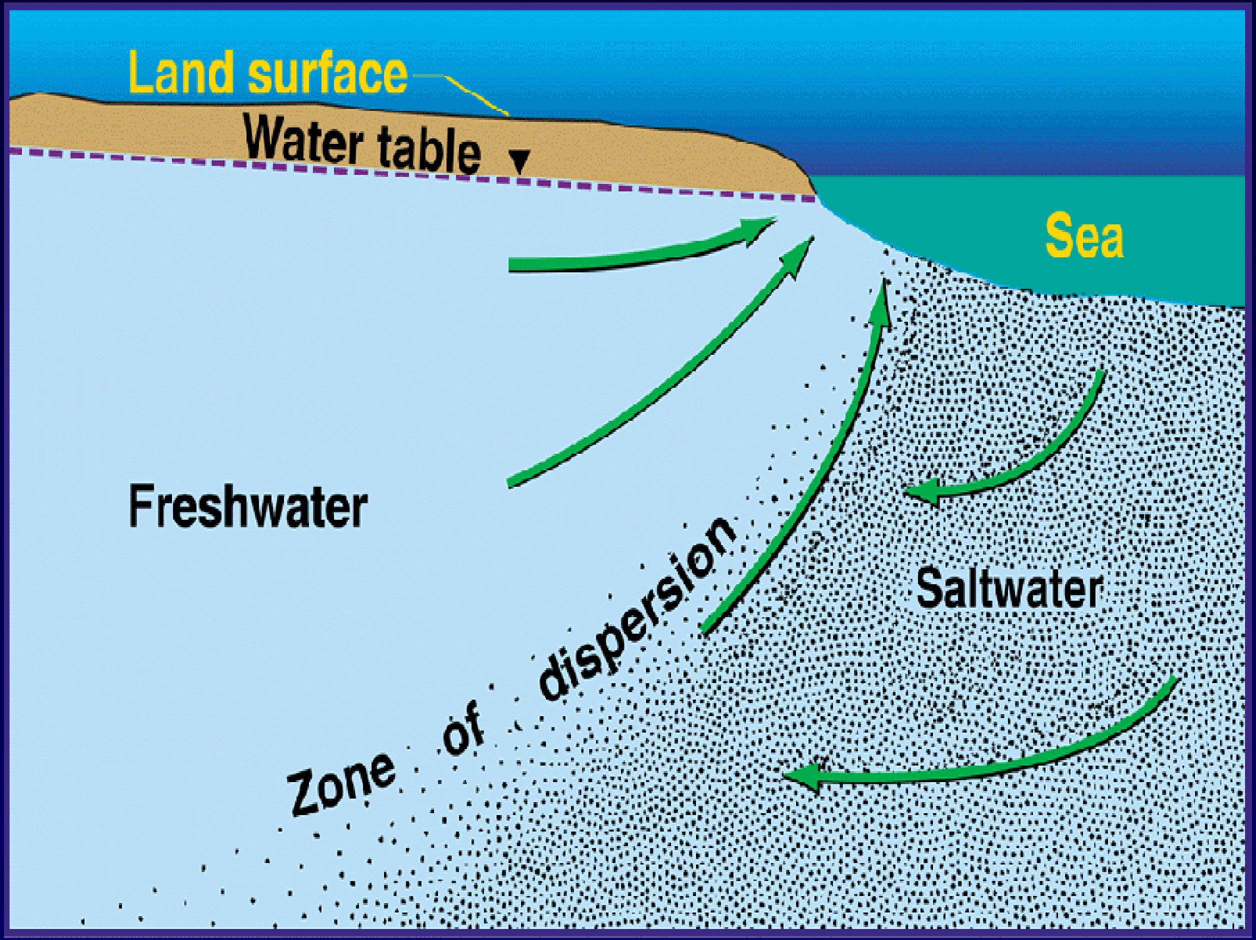
- The problem of saltwater intrusion was recognized as early as the 19th century,

- Because saltwater has high concentrations of total dissolved solids and certain inorganic constituents, it is unfit for human consumption and many other anthropogenic uses.

- The encroachment of saline water into freshwater aquifers most often is caused by over-pumping from coastal wells.

- Saltwater intrusion is a particularly acute problem in an island setting.

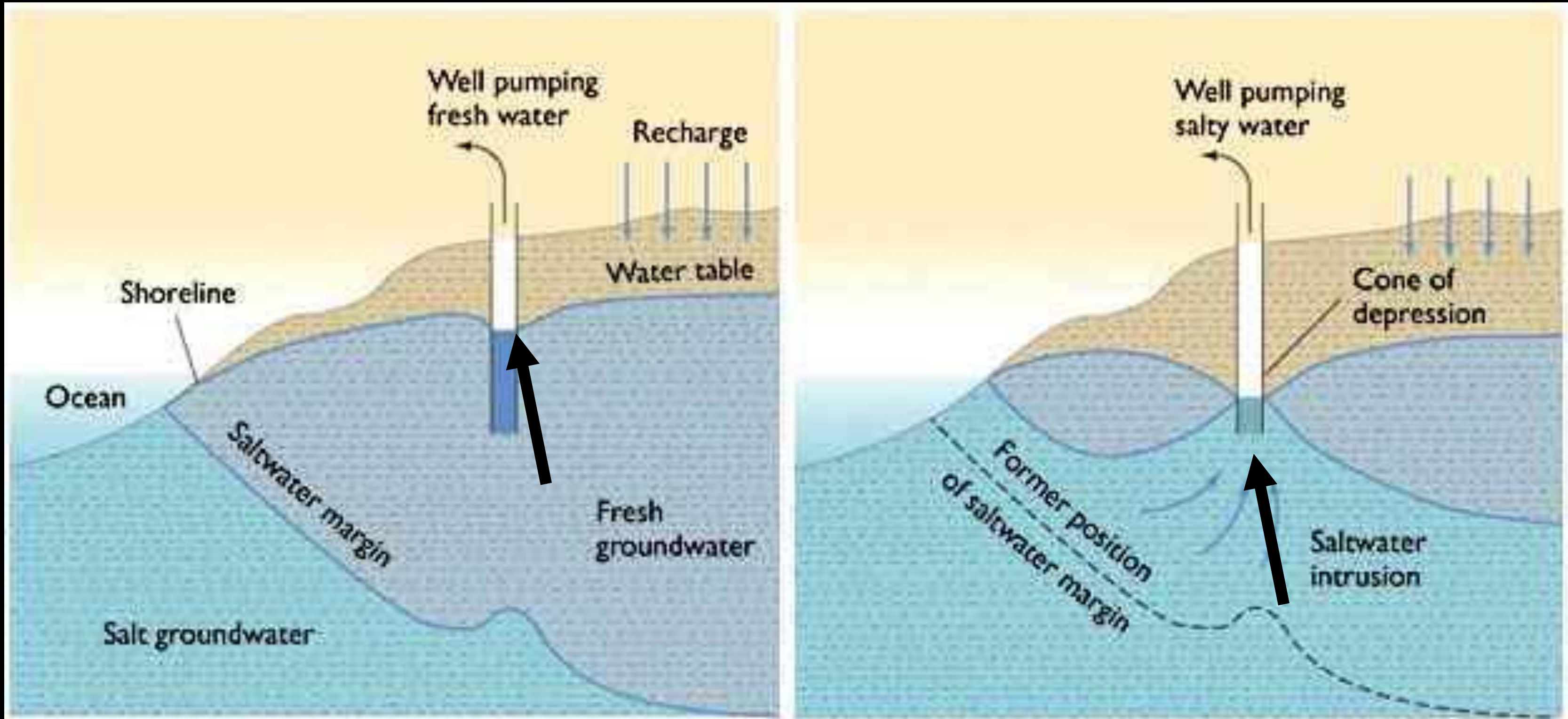
Conceptual Model of Saltwater Intrusion (*Cooper*, 1964)



Saltwater circulates from the sea to the transition zone.

Induced by mixing processes at the transition zone, saltwater then flows back to the sea.

Salt Water Intrusion



(a) Before extensive pumping (b) After extensive pumping by many wells

Pumping causes a cone of depression and draws the salt water upwards into the well

Reasons for salt water intrusion

- Rapid decline in rain fall along coastal zone
- High groundwater extraction / over use of gw along coastal aquifers
- Low natural recharge rate along coastal aquifers
- Drainage of irrigation water along coastal aquifer zones
- Construction of coastal roads and their drainage systems
- Unorganized drainage conditions in riverine, delta or estuarine areas
- Alluvial landscapes and natural sedimentation which determine the nutrient and energy flows in coastal areas are increasingly reduced
- Degradation of coastal wet lands through aquaculture forms, forest degradation, settlement construction, etc.

- Tidal wave action
- Fractures and faults extending from land to ocean could act both as leaky aquifer and path ways for salt water intrusion
- Permeable rock types or stratigraphy and their thickness along coast
- Existing folded structures along coast
- Sea level rise due to increase in temperature and subsequent melting of ice in the polar regions

Presence of salinity in coastal aquifers can be detected by

(a) Geophysical methods

- Resistivity method

(b) Geochemical investigations

- Chemical composition of groundwater
- Isotope studies (age of water to identify the source of salinity)

Mapping of salt water intruded areas

Conducting geophysical resistivity survey – gridwise along coast

Use of remote sensing in preparation of geomorphology, landuse/cover, soil, drainage and slope maps

Collection of field data such as groundwater level, hydrogeochemistty, etc.

Use of GIS in thematic data integration

GEOPHYSICAL MAPPING OF SALTWATER INTRUSION IN EVERGLADES NATIONAL PARK

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Keywords: saltwater intrusion, airborne geophysics, borehole geophysics, electromagnetics, time-domain electromagnetic, induction logs, specific conductance, water quality, monitoring wells

1. ABSTRACT

The mapping of saltwater intrusion in coastal aquifers has traditionally relied upon observation wells and collection of water samples. This approach may miss important hydrologic features related to saltwater intrusion in areas where access is difficult and wells are widely spaced, such as the Everglades. To map saltwater intrusion in Everglades National Park, a different approach has been used. We have relied heavily on helicopter electromagnetic (HEM) measurements to map lateral variations of electrical resistivity, which are directly related to water quality. The HEM data are inverted to provide a three-dimensional resistivity model of the subsurface. Borehole geophysical and water quality measurements made in a selected set of observations wells are used to determine the relation between formation resistivity and specific conductance of pore water. Applying this relation to the 3-D HEM resistivity model produces an estimated water-quality model. This model provides constraints for variable density, ground-water models of the area. Time-domain electromagnetic (TEM) soundings have also be used to map saltwater intrusion. Because of the high density of HEM sampling (a measurement point every 10 meters along flight lines) models with a cell size of 100 meters on a side are possible, revealing features which could not be recognized from either the TEM or the observation wells alone. The very detailed resistivity maps show the extent of saltwater intrusion and the effect of former and present canals and roadbeds. The HEM survey provides a means of quickly obtaining a synoptic picture of saltwater intrusion, which also serves as a baseline for monitoring the effects of Everglades restoration activities.

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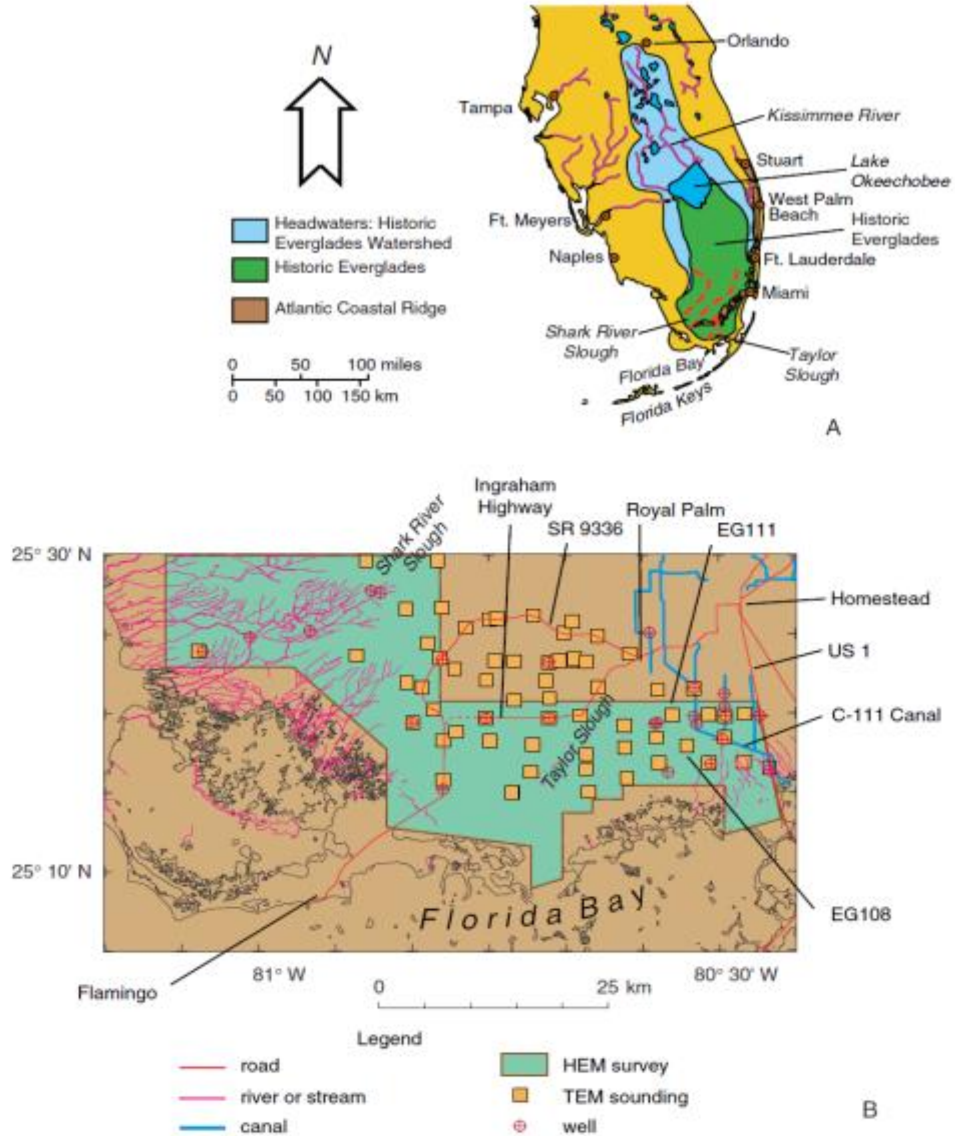

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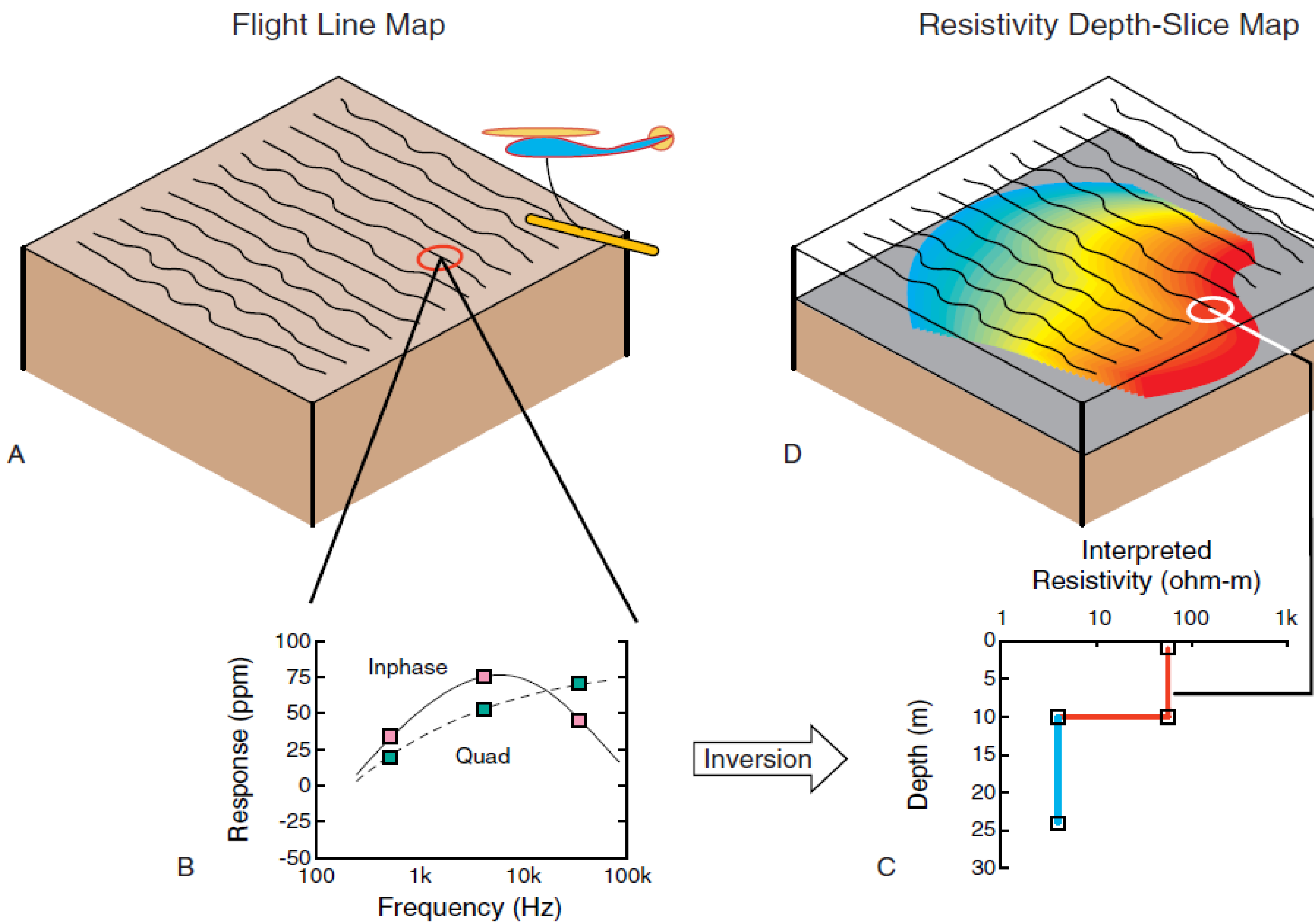

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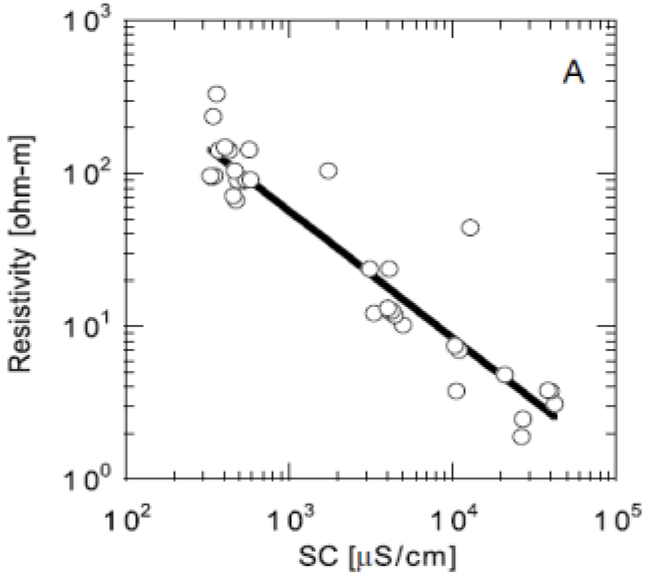

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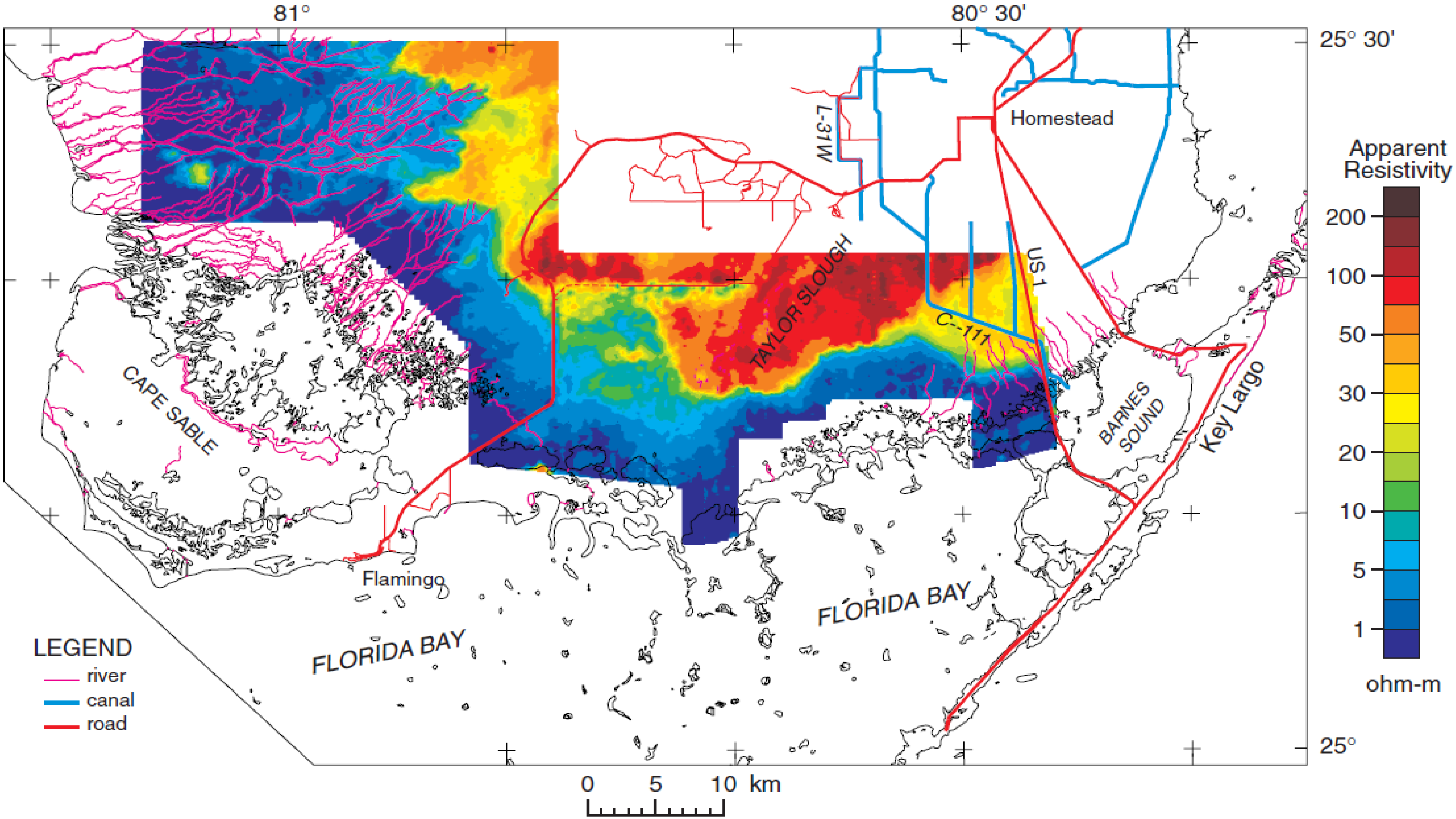

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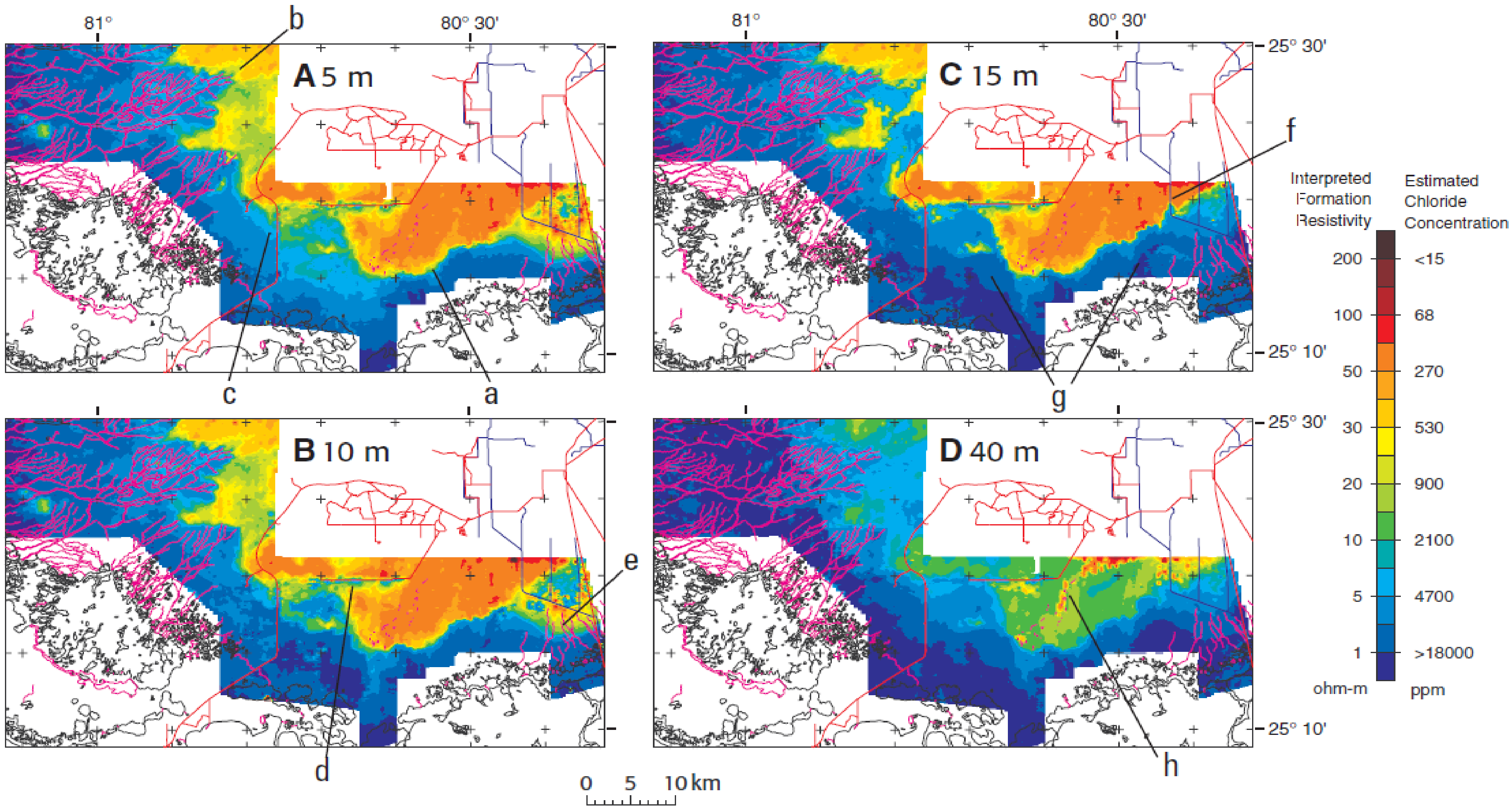

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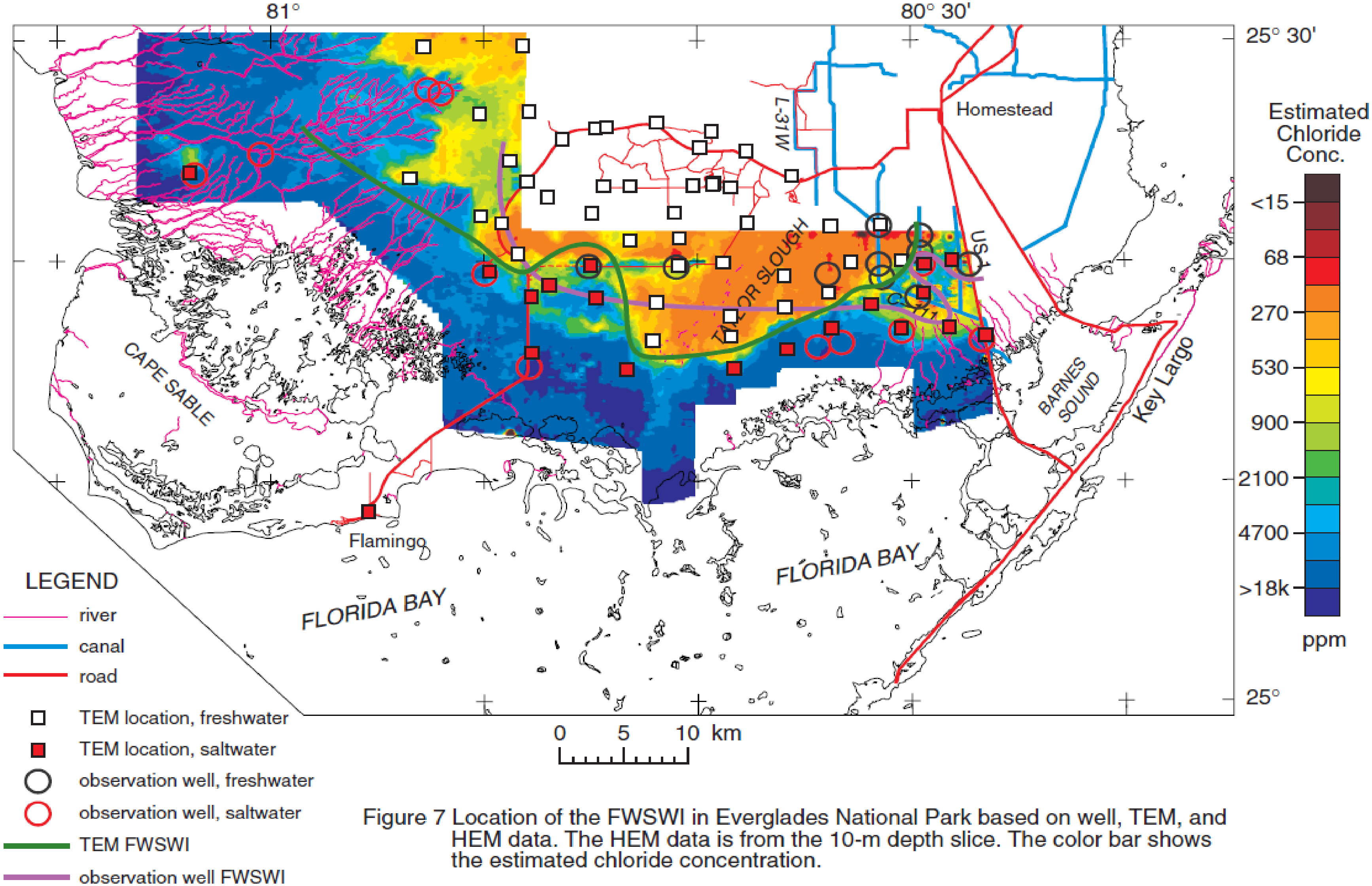

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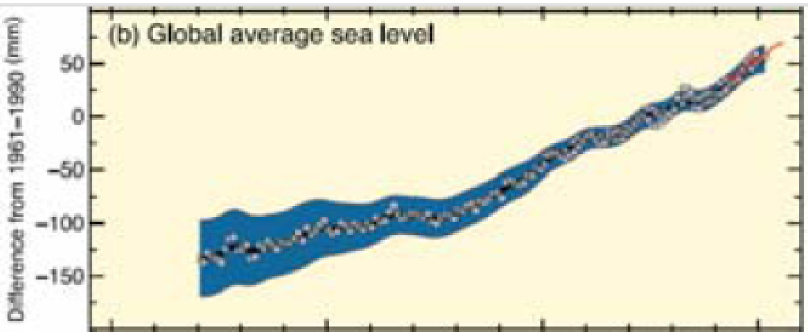

Ghyben-Herzberg principle (based on hydrostatic equilibrium):
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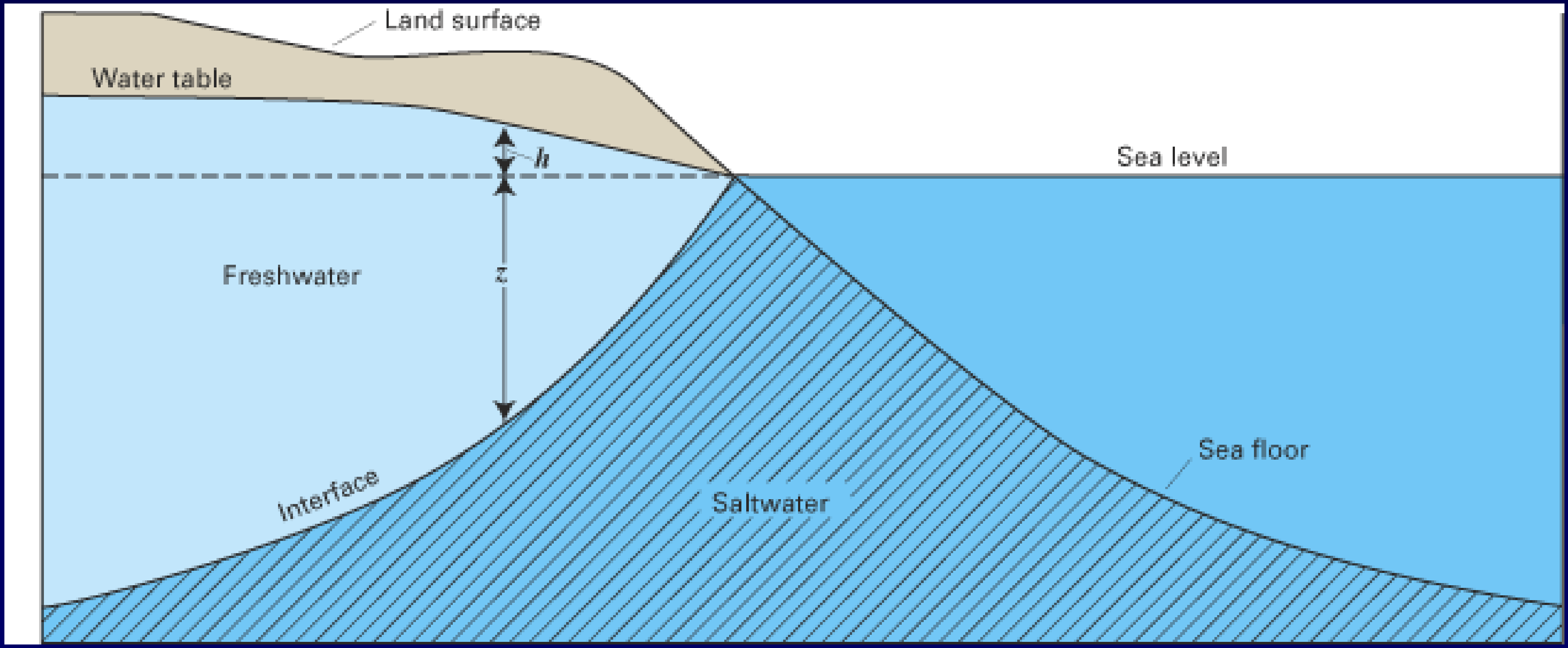

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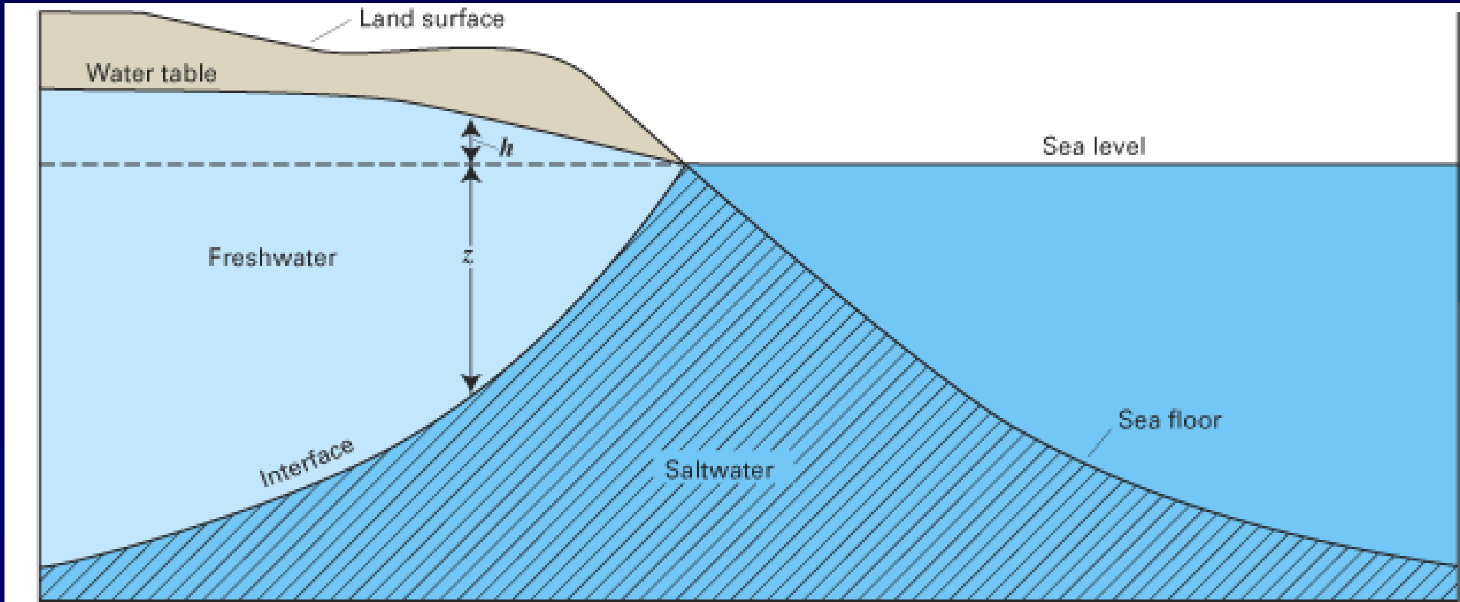

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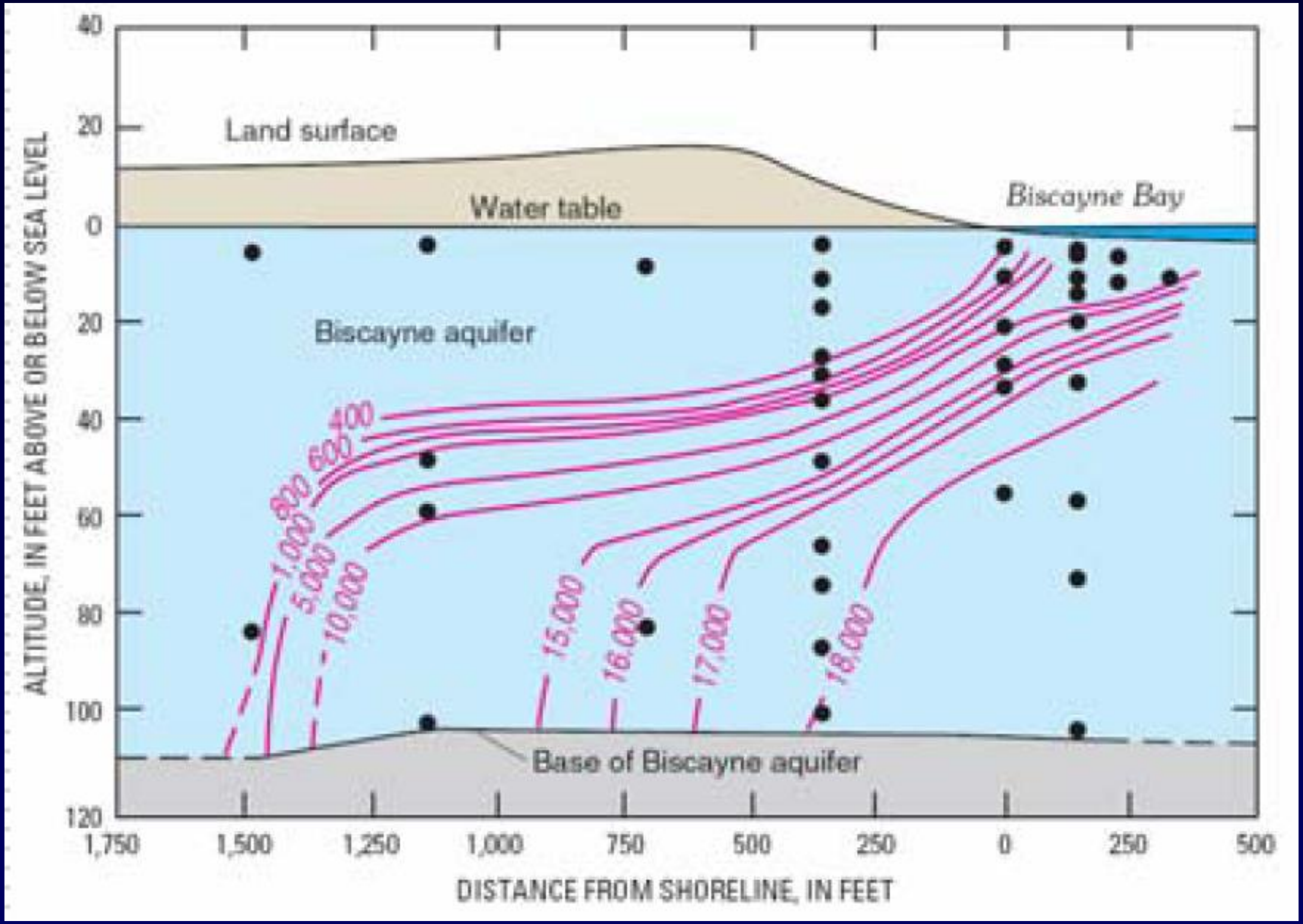

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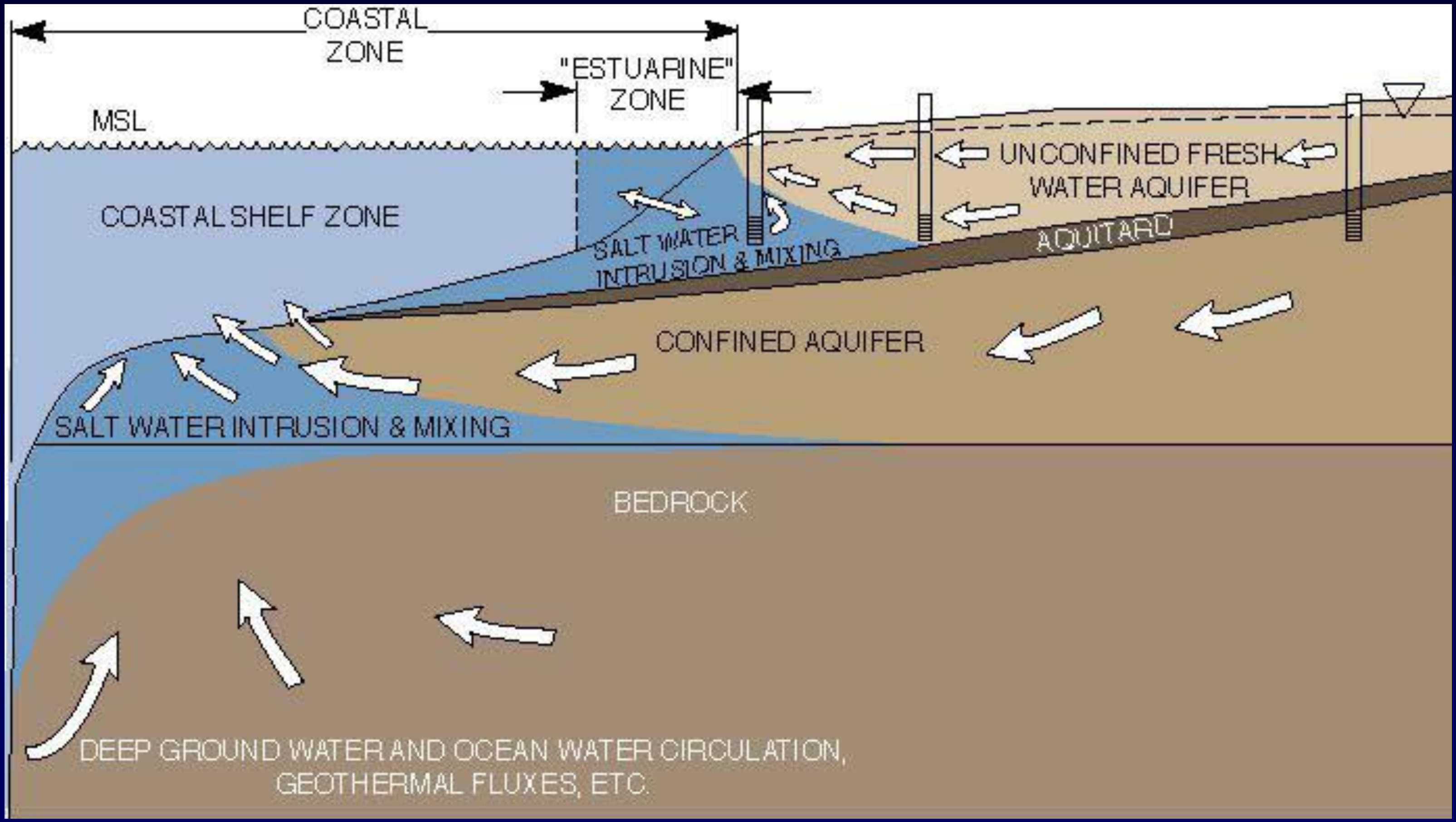

- SGD is driven by hydraulic gradient in the coastal aquifer
- Oceanic forces can induce tidal pumping and waves
- Mixing of the two can significantly impact the fluid chemistry of the ecosystem

Quantity and Quality of Groundwater in Coastal Ecosystems

The encroachment of saline water into a coastal aquifer is modulated by submarine groundwater discharge.

Coastal ecosystems undergo degradation from anthropogenic causes, including population growth and urbanization, pollution (untreated human waste, toxic waste), eutrophication (enhanced nutrient loading from agriculatural run-off, sewage and burning of fossil fuels).

Unlike surface discharge, there is a scarcity of data on the magnitude of SGD and its role as a source of dissolved solids, nutrients and contaminants.

VULNERABILITY EVALUATION by GALDIT METHOD

Groundwater occurrence (aquifer type; unconfined, confined or leaky confined)

Aquifer hydraulic conductivity

Depth to water level above the sea

Distance from the shore (distance inland perpendicular from shoreline)

Impact of existing status of sea water intrusion in the area and

Thickness of the aquifer.

Table 1 - Summary of GALDIT parameter weights, rates, and ranges

Parameters	G (Groundwater occurrence/ aquifer type)	A /Aquifer conductivity) (m/day)	L (Groundwater levels above mean sea level) (m)	D (Distance from coast) (m)	I (impact of existing intrusion) (epm)	T (Aquifer thickness) (m)
Weights→ Rates ↓	1	3	4	2	1	2
1		0.0 - 4.0	> 2.0	>1000	$Cl/HCO_3+CO_3<1.5$	<1.0
2		>4.0 - 12.0	>1.75 - 2.0	>800- 1000		>1.0-2.0
3			>1.50 - 1.75	>700 - 800		>2.0-3.0
4		>12.0 - 28.0	>1.25 - 1.50	>600 - 700		>3.0-4.0
5			>1.00 - 1.25	>500 - 600	$Cl/HCO_3+CO_3>1.5-2$	>4.0-5.0
6		>28.0 - 41.0	>0.75 - 1.00	>400 - 500		>5.0-6.0
7			>0.50 - 0.75	>300 - 400		>6.0-7.0
8	Leaky confined	>41.0 - 81.0	>0.25 -0.50	>200 - 300		>7.0-8.0
9	Unconfined		>0.00 - 0.25	>100 - 200		>8.0-10.0
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Serial no	Total GALDIT score	Vulnerability class
1	>90	Highly vulnerable
2	>60–90	Vulnerable
3	>30–60	Moderately vulnerable
4	<30	Not vulnerable

Most popular models for seawater intrusion

- SUTRA
- SEAWAT
- HST3D
- FEFLOW

Recently released **Visual MODFLOW Pro 4.1** now integrates SEAWAT-2000 to solve variable density flow problems, such as seawater intrusion modeling projects.

MEASURES

1. Potable water development – conservation of coastal wet lands

2. Ground water recharge

Water spreading (spreading surplus water into large tanks and ponds)

Injection method by injecting water into aquifer system (Adequate care on the water quality has to be taken)

Construction of percolation ponds and check dams to allow percolation.

Areas of artificial recharge should be based on the intensity of the problems, the course of action should follow.

Identifying the coastal aquifers and demarking the area for development and vulnerable areas needing immediate remedies

Collection of hydrogeological, hydrological, land use, water use and ecological data

Applying management technique and monitoring

SALTWATER INTRUSION

Salt water intrusion

Mass transport of saline waters into zones previously occupied by fresher water is defined as salt water intrusion (stewart 1999).

Sea water mixing with fresh water in coastal aquifer

Intrusion of sea water into the coastal aquifer system – may be considered as a type of environmental pollution due to human activities or/and to physical factors.

Salt Water Intrusion….

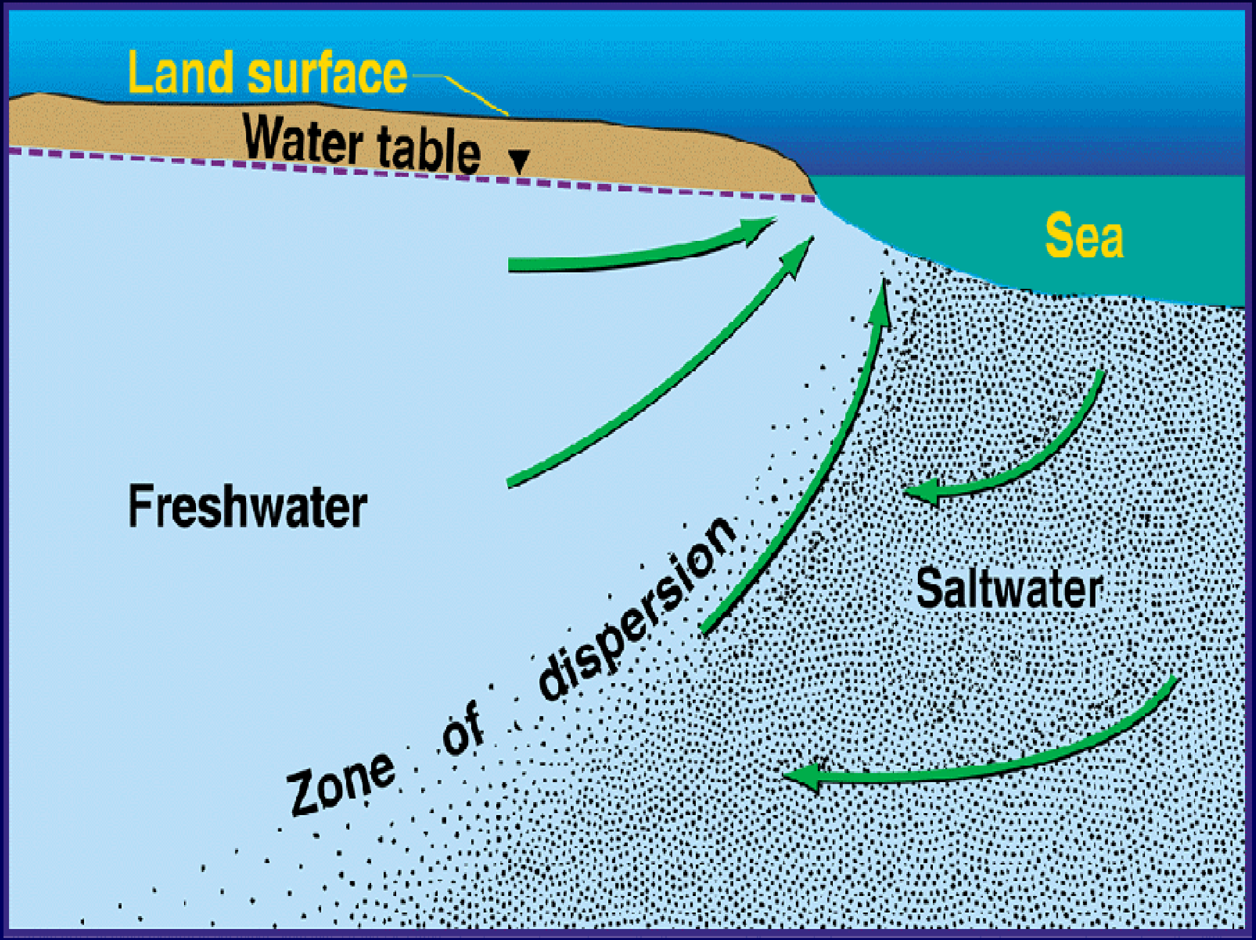
- The problem of saltwater intrusion was recognized as early as the 19th century,

- Because saltwater has high concentrations of total dissolved solids and certain inorganic constituents, it is unfit for human consumption and many other anthropogenic uses.

- The encroachment of saline water into freshwater aquifers most often is caused by over-pumping from coastal wells.

- Saltwater intrusion is a particularly acute problem in an island setting.

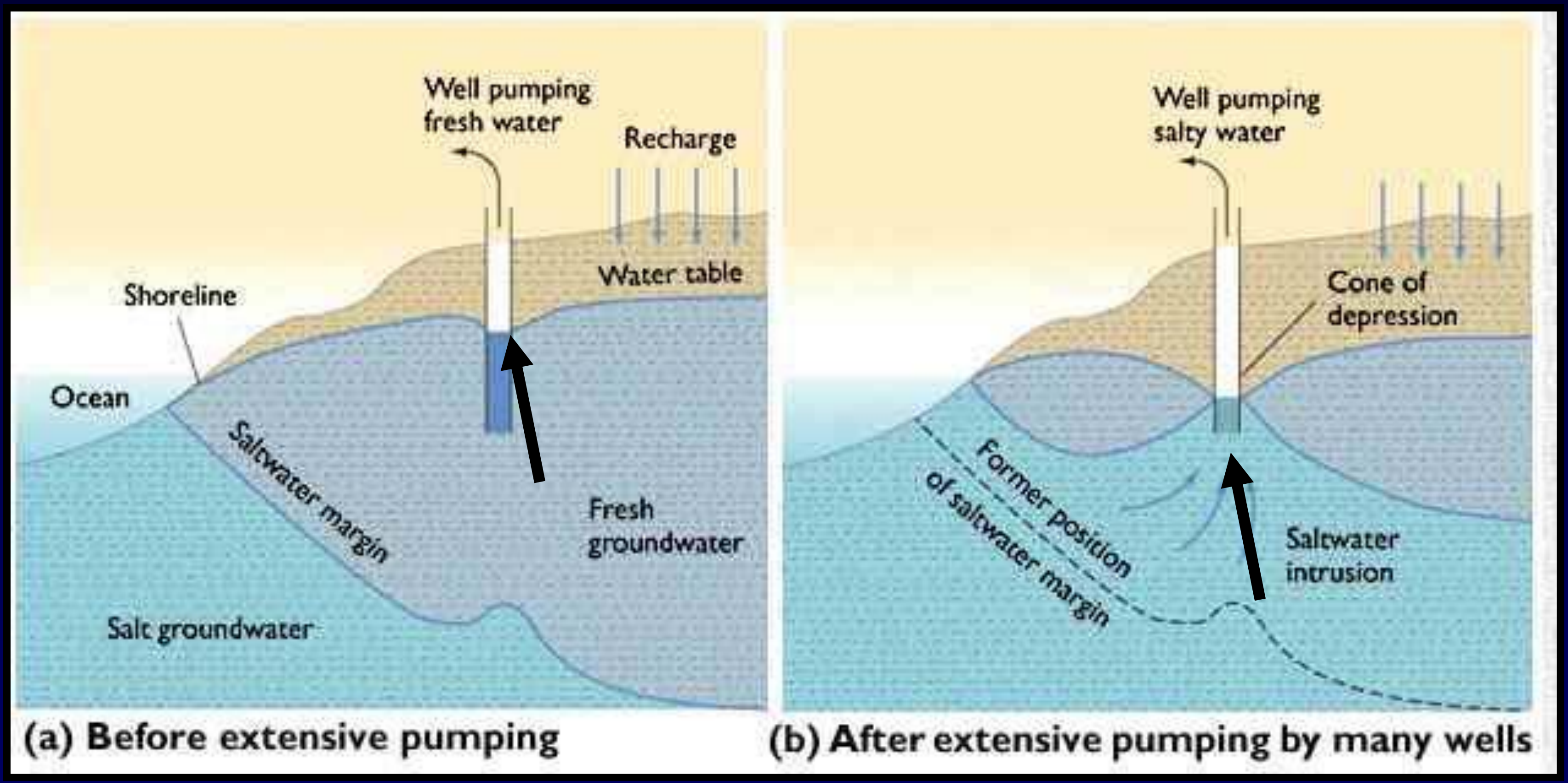
Conceptual Model of Saltwater Intrusion (*Cooper*, 1964)



Saltwater circulates from the sea to the transition zone.

Induced by mixing processes at the transition zone, saltwater then flows back to the sea.

Salt Water Intrusion



Pumping causes a cone of depression and draws the salt water upwards into the well

Reasons for salt water intrusion

- **Rapid decline in rain fall along coastal zone**
- **High groundwater extraction / over use of gw along coastal aquifers**
- **Low natural recharge rate along coastal aquifers**
- **Drainage of irrigation water along coastal aquifer zones**
- **Construction of coastal roads and their drainage systems**
- **Unorganized drainage conditions in riverine, delta or estuarine areas**
- **Alluvial landscapes and natural sedimentation which determine the nutrient and energy flows in coastal areas are increasingly reduced**
- **Degradation of coastal wet lands through aquaculture forms, forest degradation, settlement construction, etc.**

- **Tidal wave action**
- **Fractures and faults extending from land to ocean could act both as leaky aquifer and path ways for salt water intrusion**
- **Permeable rock types or stratigraphy and their thickness along coast**
- **Existing folded structures along coast**
- **Sea level rise due to increase in temperature and subsequent melting of ice in the polar regions**

Presence of salinity in coastal aquifers can be detected by

(a) Geophysical methods

- Resistivity method

(b) Geochemical investigations

- Chemical composition of groundwater
- Isotope studies (age of water to identify the source of salinity)

Mapping of salt water intruded areas

Conducting geophysical resistivity survey – gridwise along coast

Use of remote sensing in preparation of geomorphology, landuse/cover, soil, drainage and slope maps

Collection of field data such as groundwater level, hydrogeochemistty, etc.

Use of GIS in thematic data integration

GEOPHYSICAL MAPPING OF SALTWATER INTRUSION IN EVERGLADES NATIONAL PARK

David V. Fitterman
Maria Deszcz-Pan

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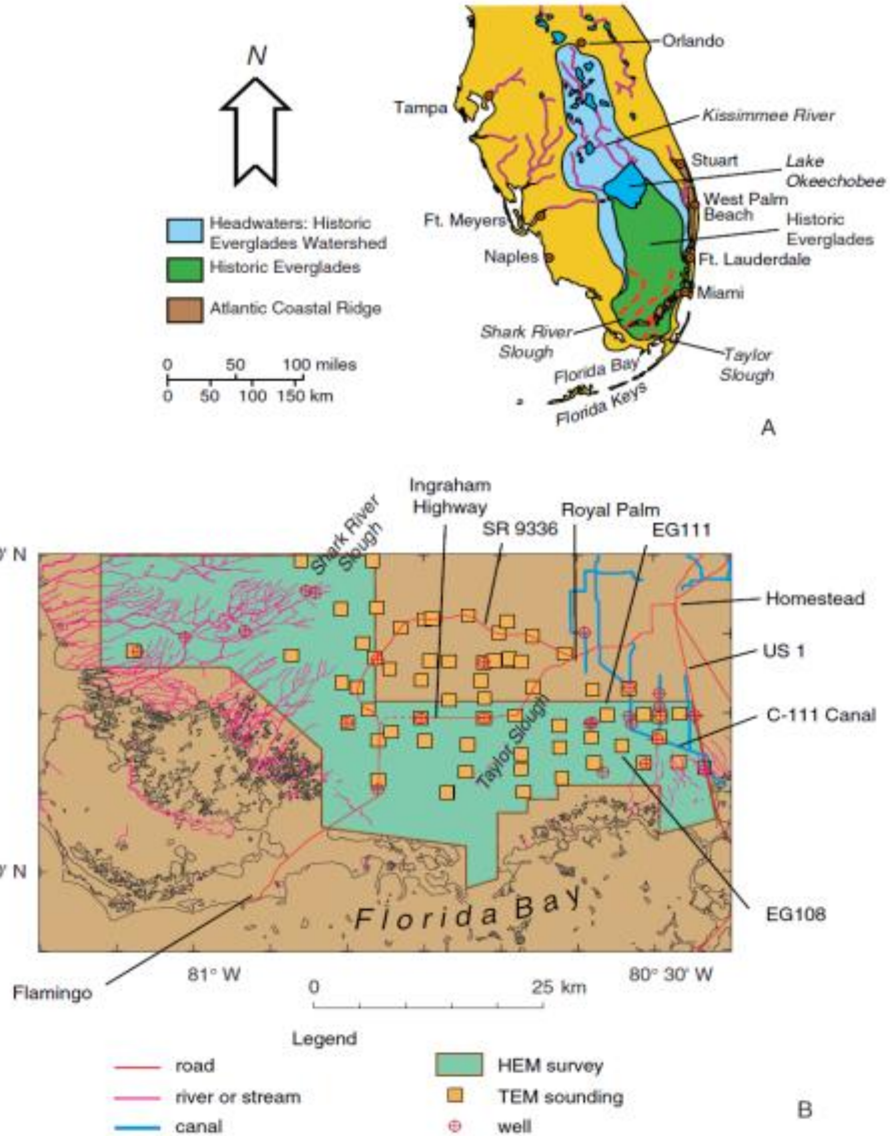

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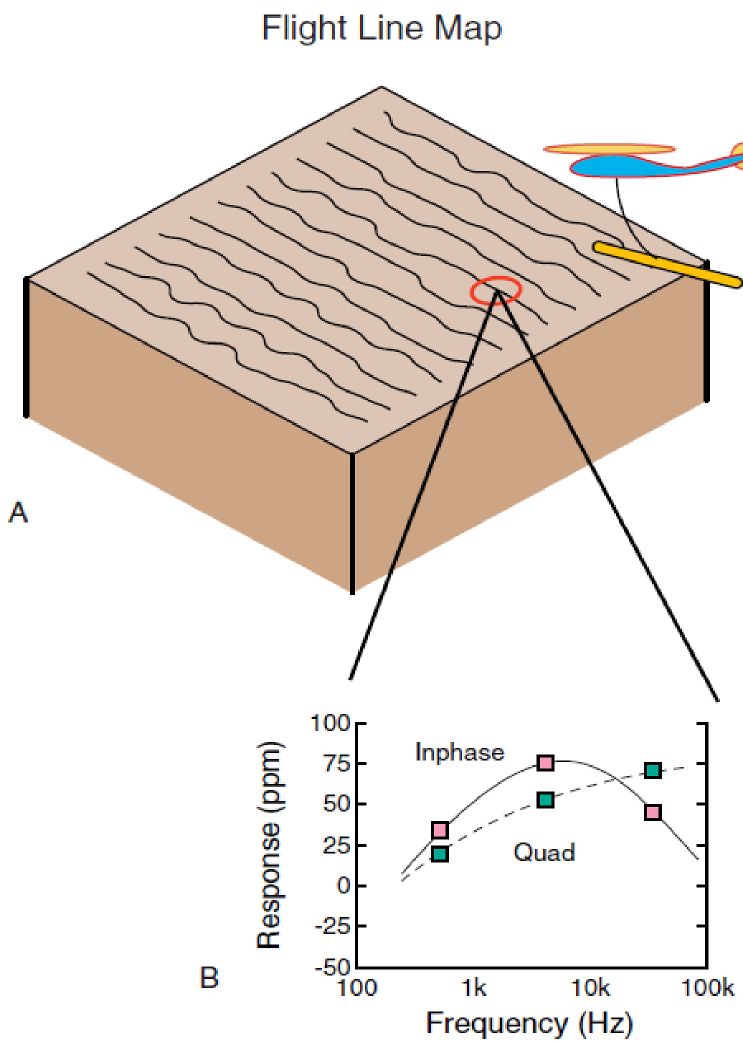

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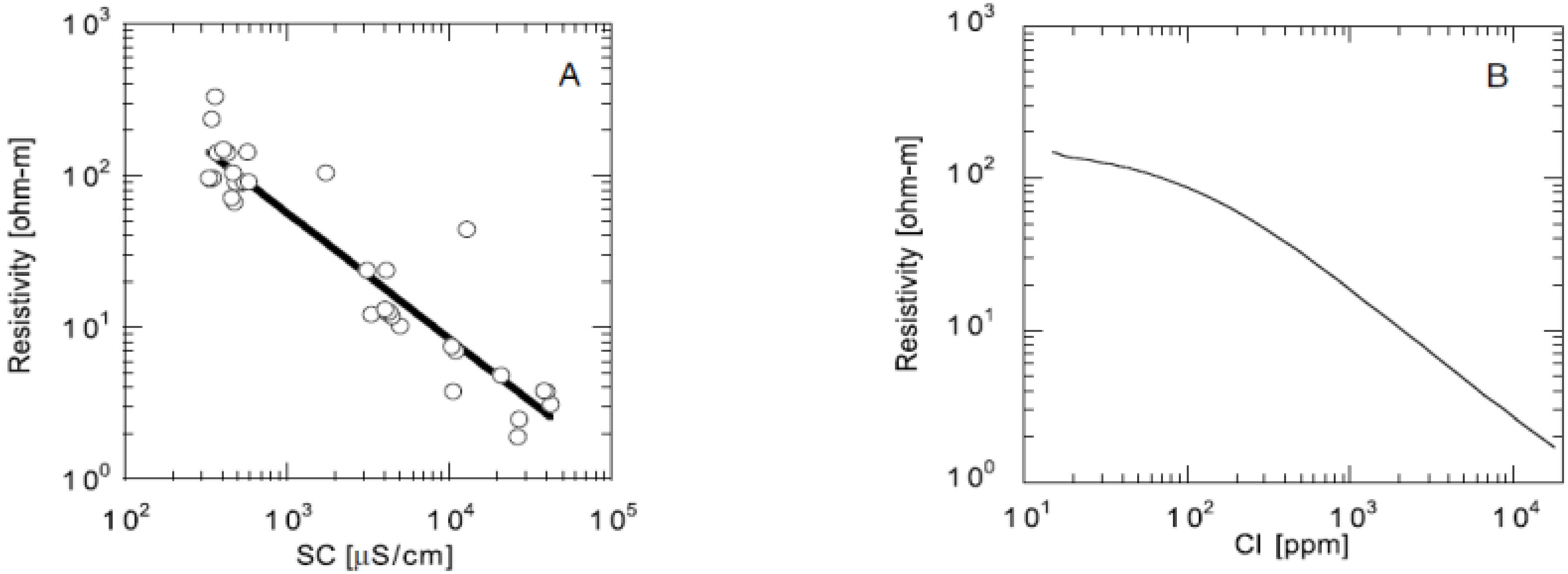

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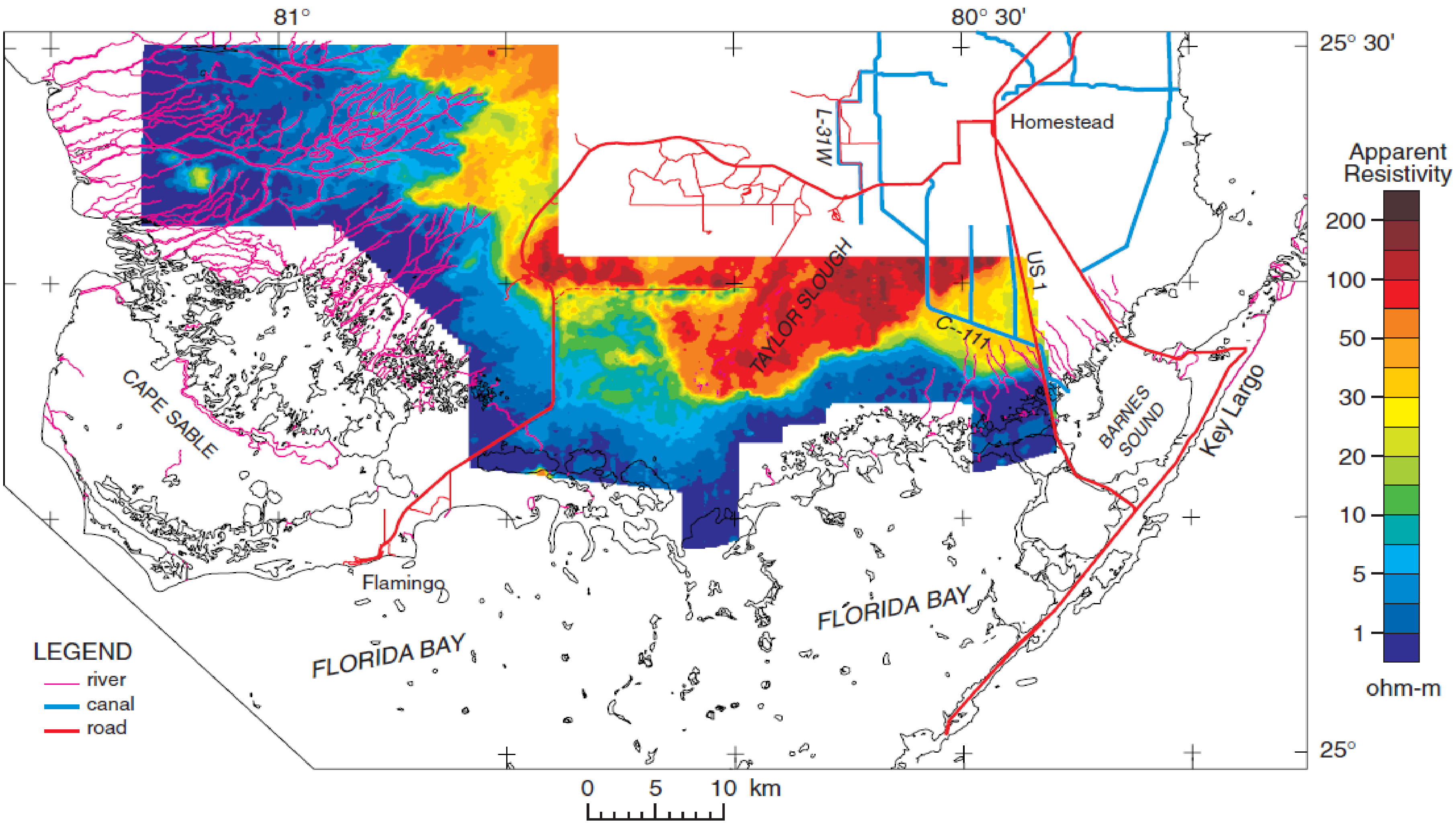

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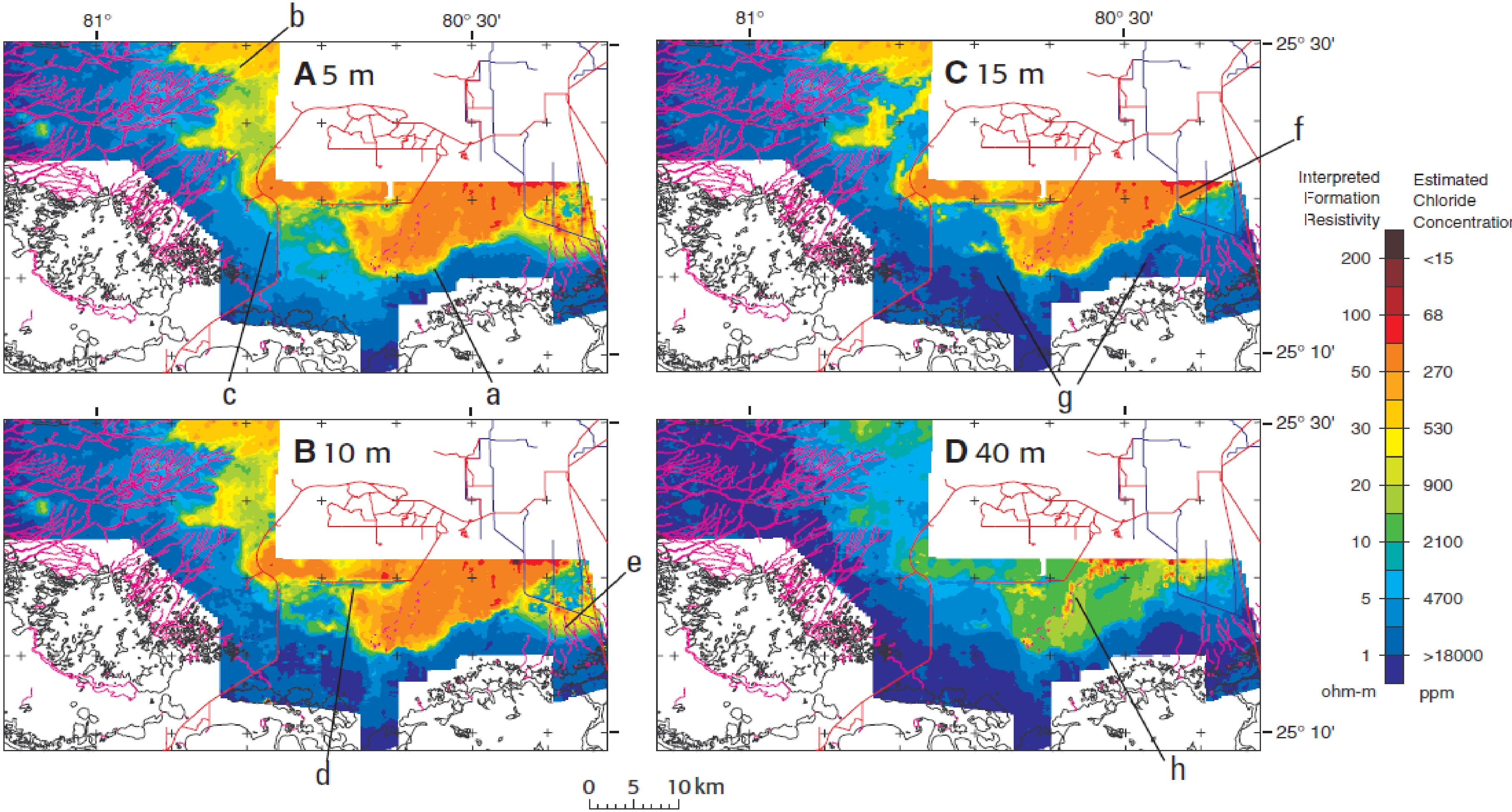

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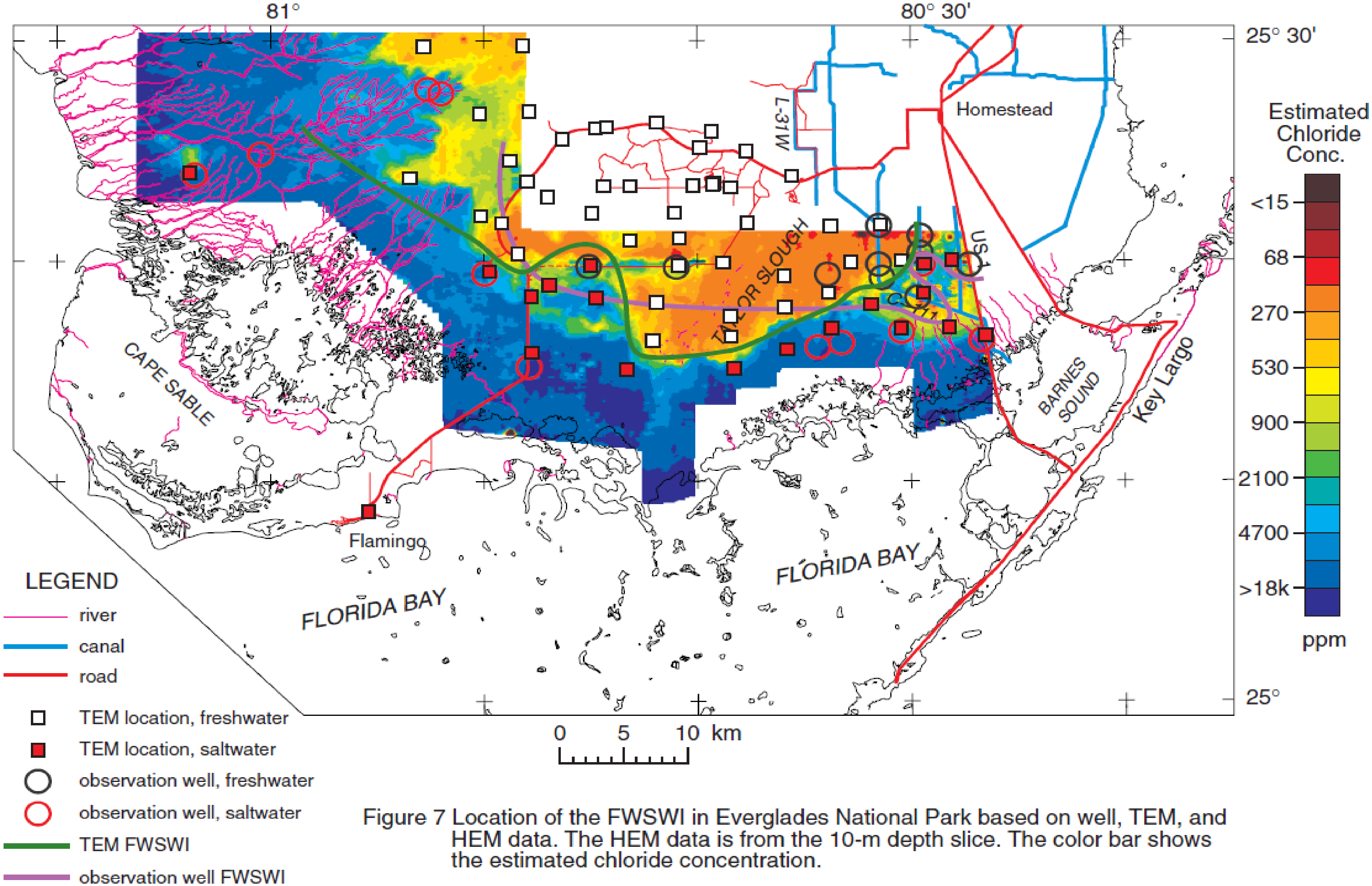

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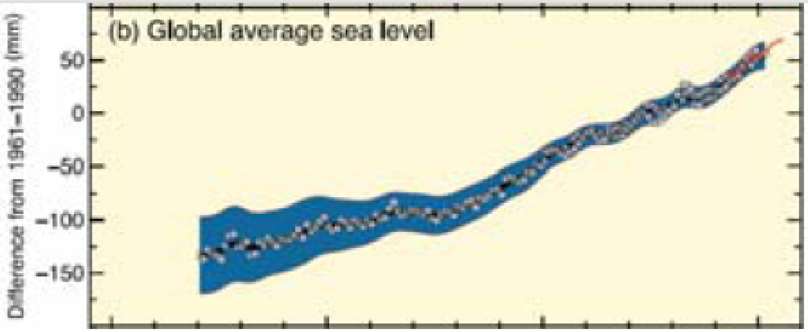

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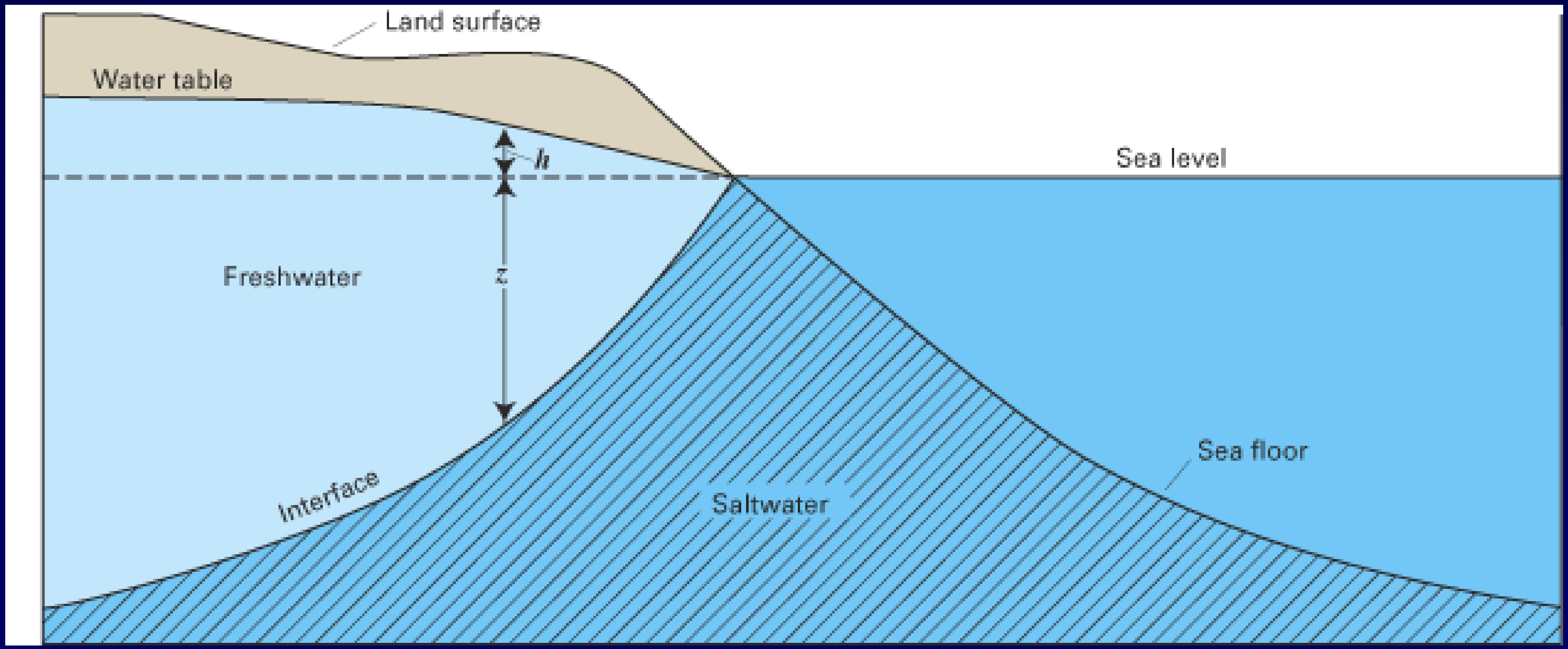

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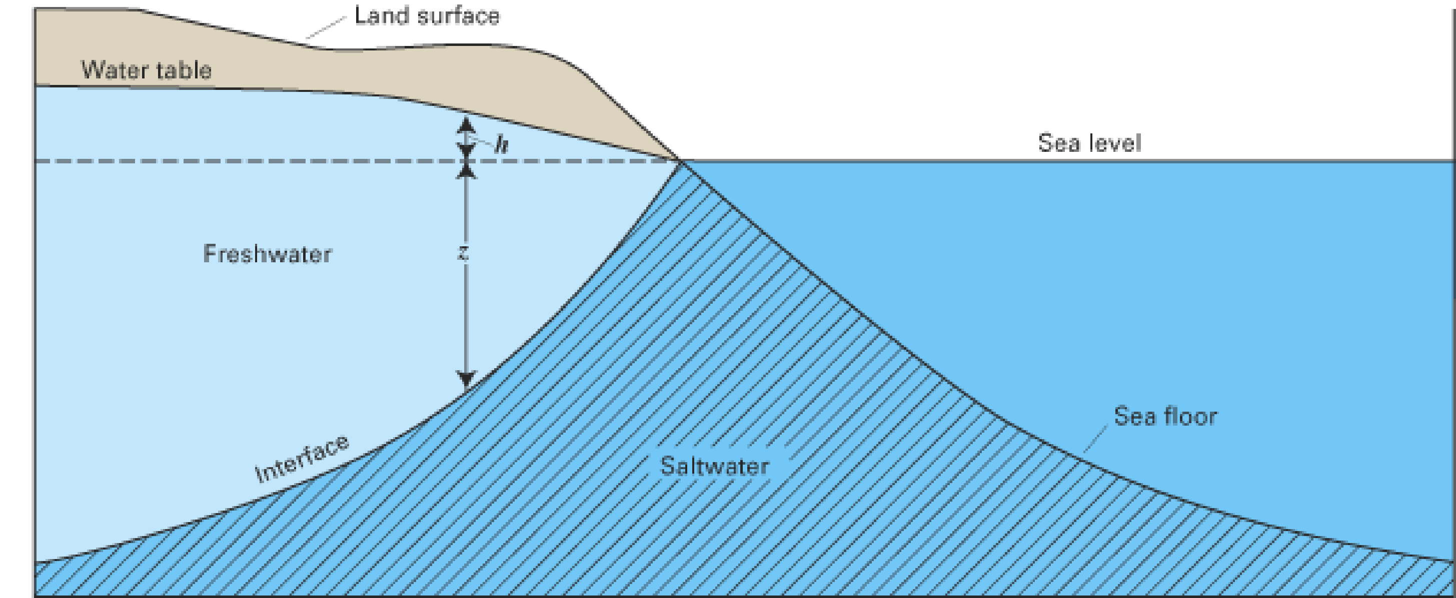

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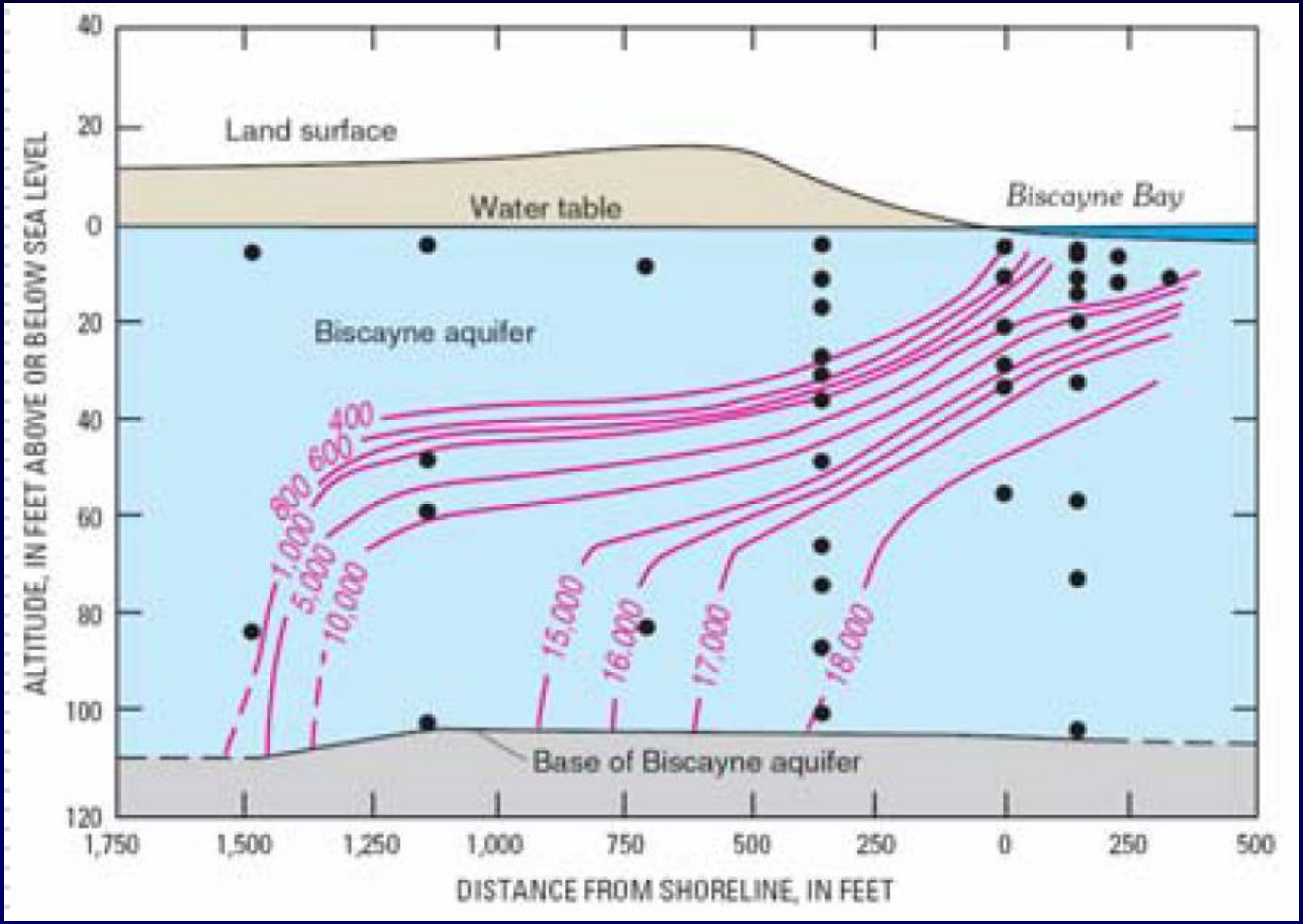

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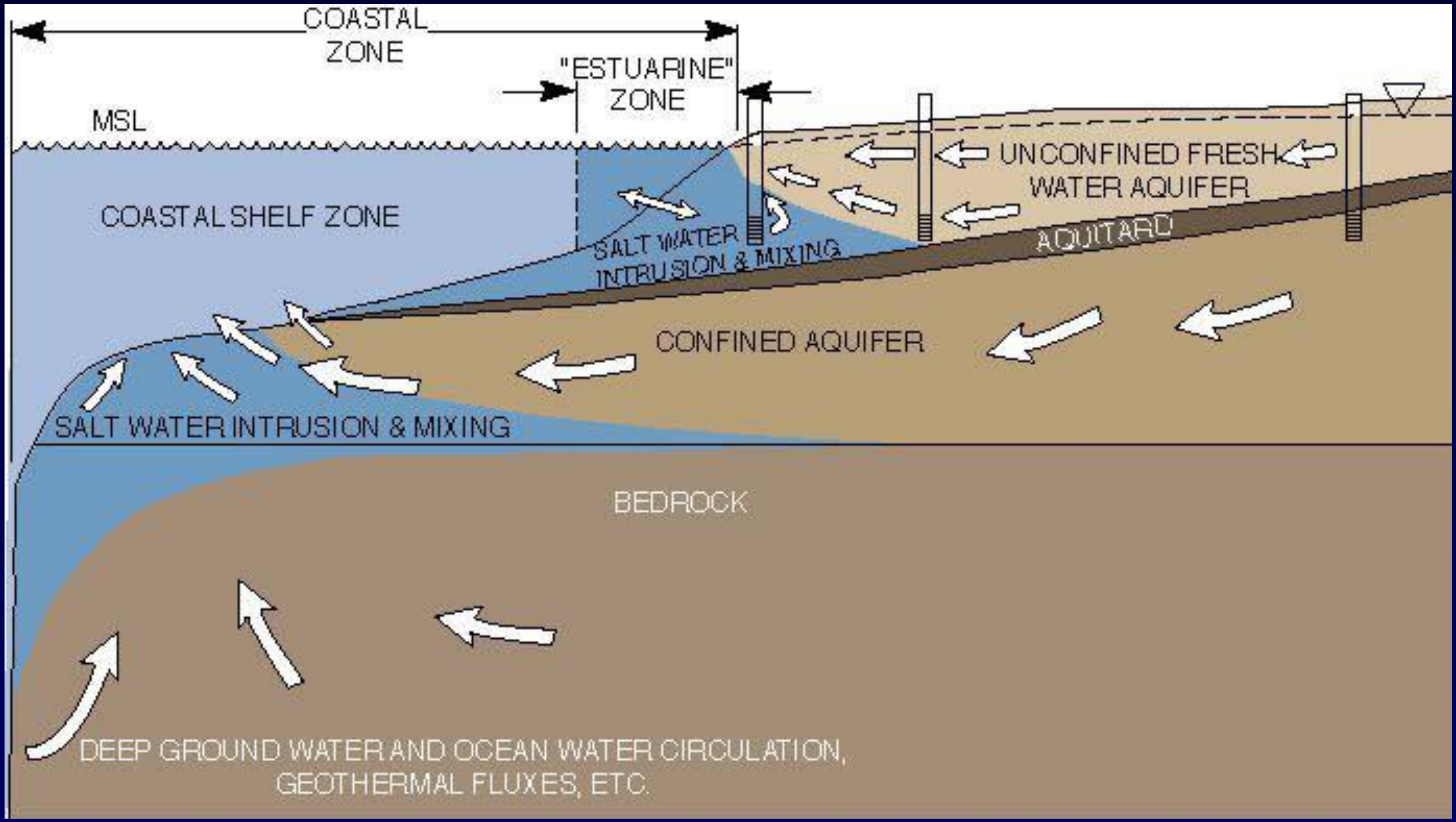

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4	<30	Not vulnerable

Most popular models for seawater intrusion

- SUTRA
- SEAWAT
- HST3D
- FEFLOW

Recently released **Visual MODFLOW Pro 4.1** now integrates SEAWAT-2000 to solve variable density flow problems, such as seawater intrusion modeling projects.

MEASURES

1. **Potable water development – conservation of coastal wet lands**

2. **Ground water recharge**

Water spreading (spreading surplus water into large tanks and ponds)

Injection method by injecting water into aquifer system (Adequate care on the water quality has to be taken)

Construction of percolation ponds and check dams to allow percolation.

Areas of artificial recharge should be based on the intensity of the problems, the course of action should follow.

Identifying the coastal aquifers and demarking the area for development and vulnerable areas needing immediate remedies

Collection of hydrogeological, hydrological, land use, water use and ecological data

Applying management technique and monitoring

CYCLONES

The word cyclone has been derived from Greek word ‘cyclos’ which means ‘coiling of a snake’. The word cyclone was coined by Heary Piddington who worked as a Rapporteur in Kolkata during British rule. The terms "hurricane" and "typhoon" are region specific names for a strong "tropical cyclone". Tropical cyclones are called “Hurricanes” over the Atlantic Ocean and “Typhoons” over the Pacific Ocean.

A cyclone is a low pressure area in the atmosphere in which winds spiral upward. A cyclone can cover an area as large as half of the United States. All cyclones are characterized by:

(1) low pressure at the centre, and

(2) winds spiraling toward the center.

The direction of the spiral is unique because in the northern hemisphere the winds blow counter-clockwise and in the southern hemisphere they blow clockwise.

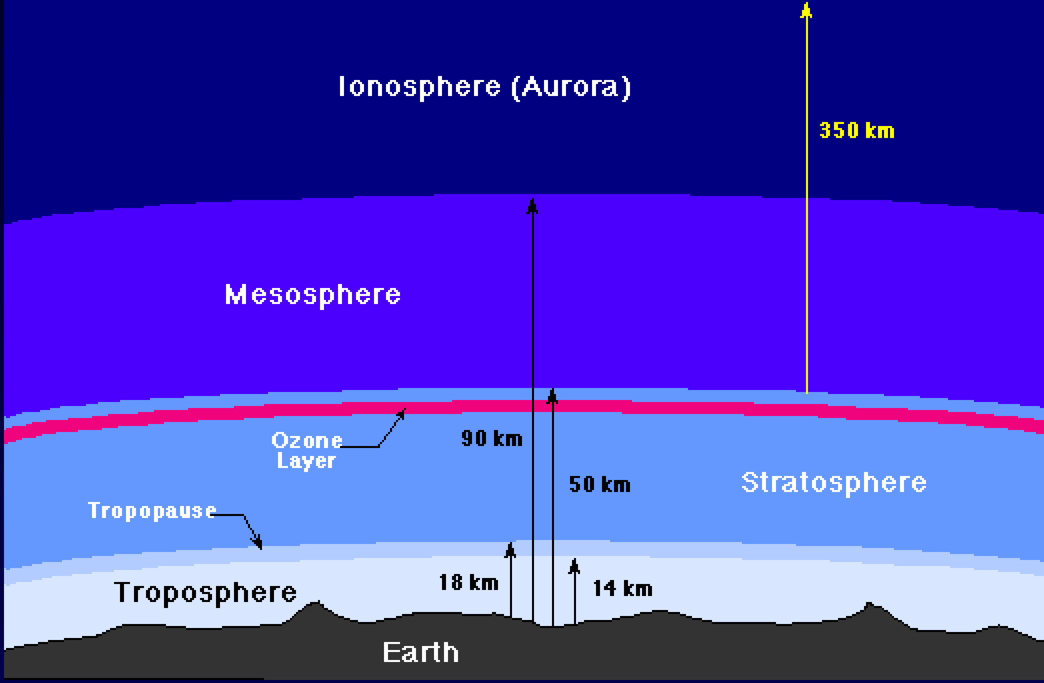
First of all, the ocean water itself must be warmer than a threshold say, 28 °C. The heat and moisture from this warm water is the source of energy for cyclones.

Cyclones will weaken rapidly when they travel over land or colder ocean waters — locations where their heat and/or moisture sources do not exist.

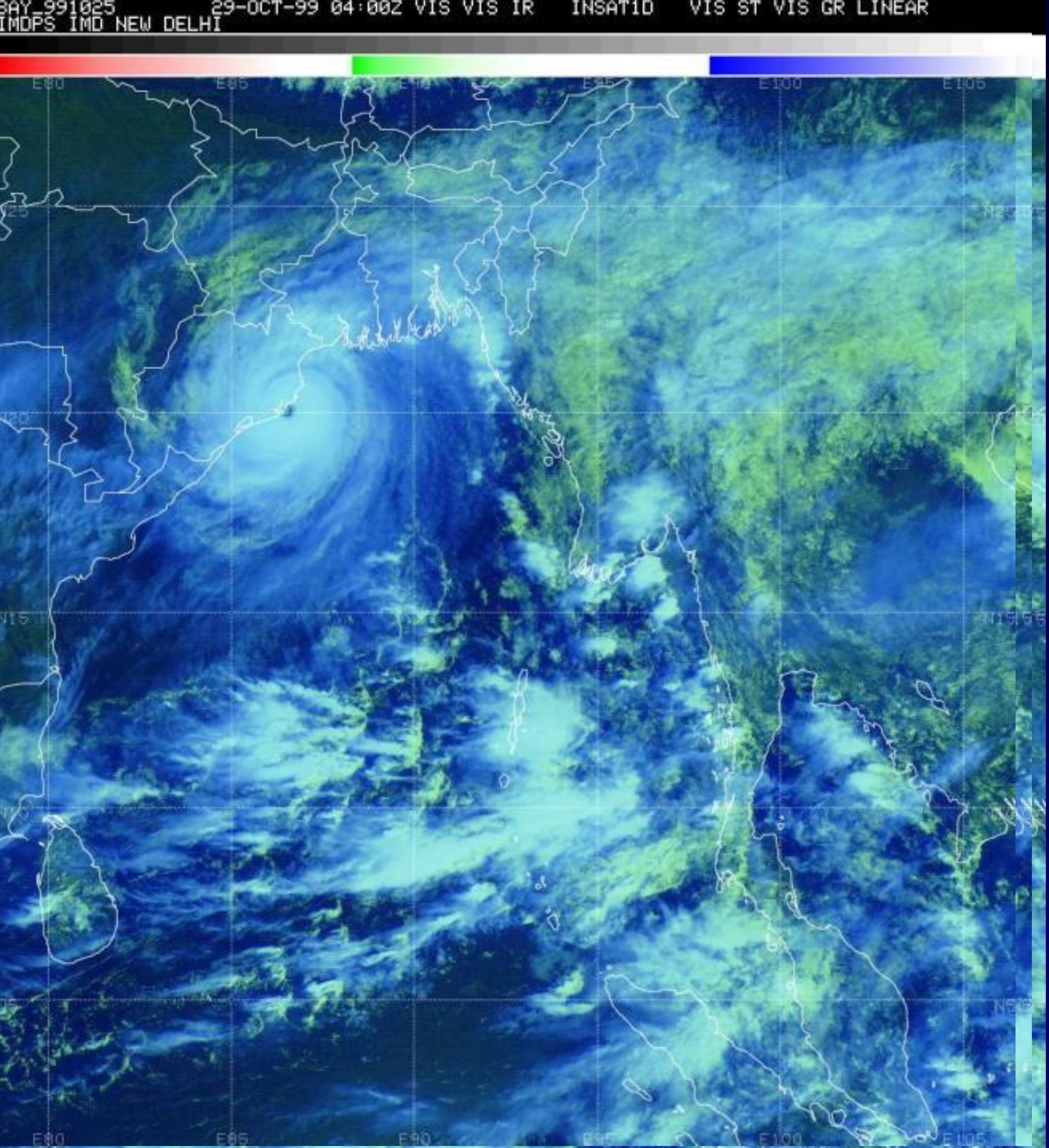
High relative humidities in the lower and middle troposphere are also required for cyclone development.

These high humidities reduce the amount of evaporation in clouds and maximizes the latent heat released because there is more precipitation

The vertical wind shear in a tropical cyclone's environment is also important. Wind shear is defined as the amount of change in the wind's direction or speed with increasing altitude. When the wind shear is weak, the storms that are part of the cyclone grow vertically, and the latent heat from condensation is released into the air directly above the storm, aiding in development. When there is stronger wind shear, the storms become more slanted and the latent heat release is dispersed over a much larger area.



Ionosphere (Aurora)
350 km
Mesosphere
Ozone Layer
90 km
50 km
Stratosphere
Tropopause
Troposphere
18 km
14 km
Earth



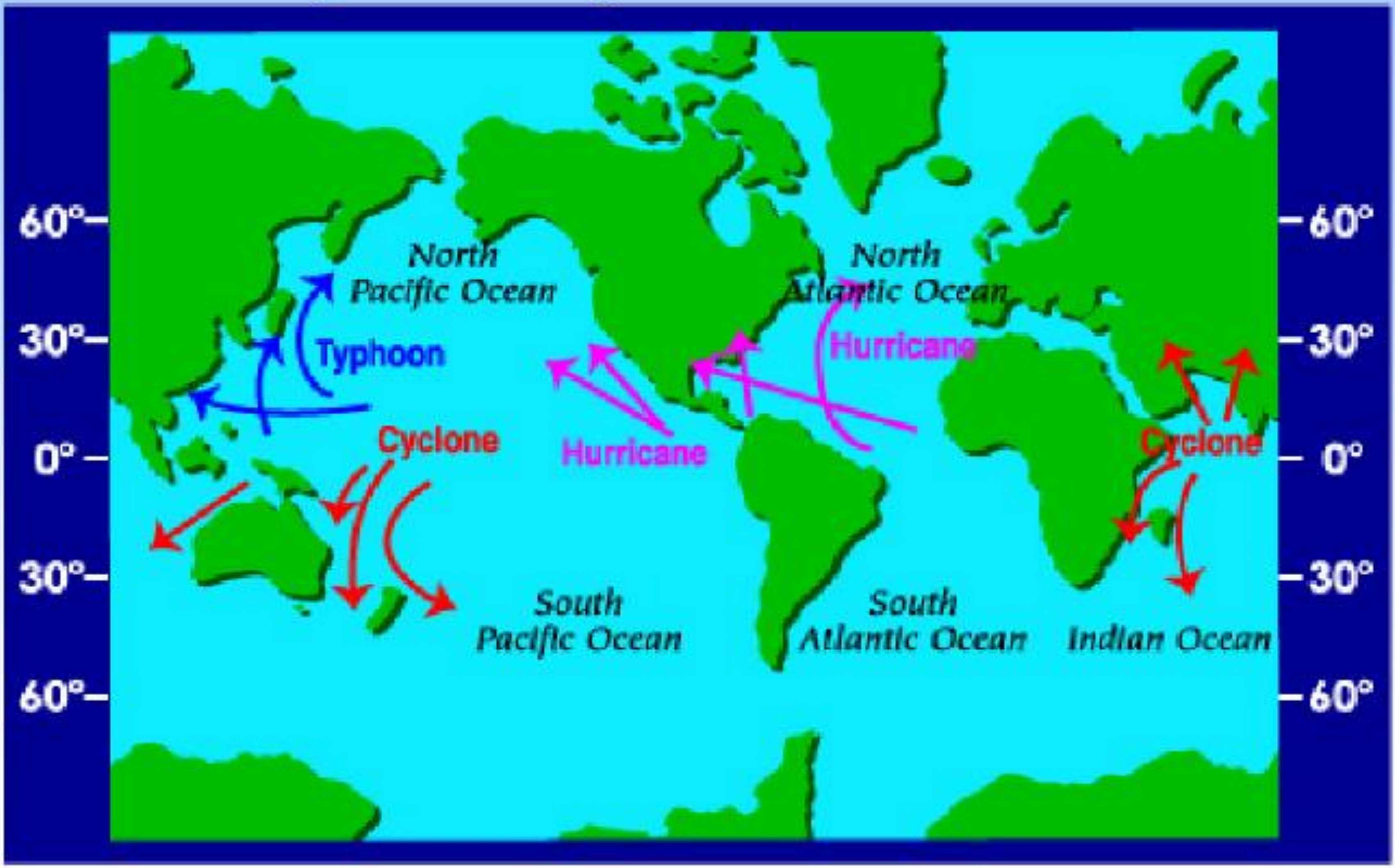
MOVEMENT OF CYCLONE

Cyclones are characterized as tornadoes, hurricanes and typhoons. A tornado is a smaller kind of cyclone. When a cyclone forms over tropical waters in the North Atlantic or eastern North Pacific oceans and has winds of 119 km/hr or more it is called a Hurricane. If the cyclone forms in the western Pacific with winds of 119 km/hr or more it is called a Typhoon.

All of these storms are generally accompanied by high winds, heavy rains, severe thunder, and lightening. In the north Indian Ocean they are simply called as tropical cyclones

A tropical cyclone is a rotational low pressure system in tropics when the central pressure falls by 5 to 6 hPa from the surrounding and maximum sustained wind speed reaches 34 knots (about 62 kmph). It is a vast violent whirl of 150 to 800 km, spiraling around a centre and progressing along the surface of the sea at a rate of 300 to 500 km a day.

Tropical Cyclone locations



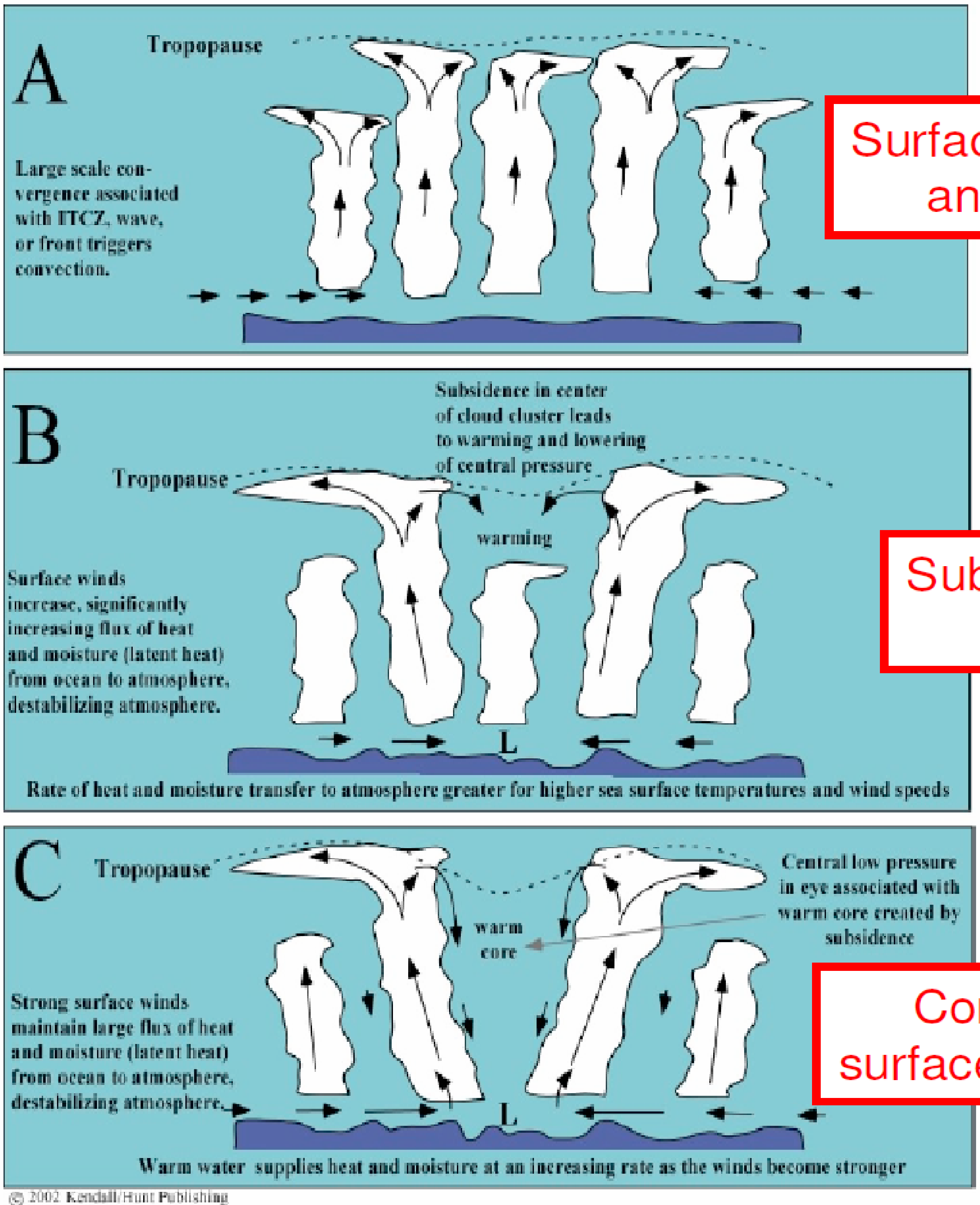
Conditions for Tropical Cyclone Formation

They form only over oceanic regions with sea-surface temperatures (SSTs) are greater than 26.5oC.

They do not form within 5 degrees of the equator due to the negligible Coriolis Force there

WIND: it must be blowing in the same direction and the same speed from the ocean surface right up to 9,000 meters above sea level.

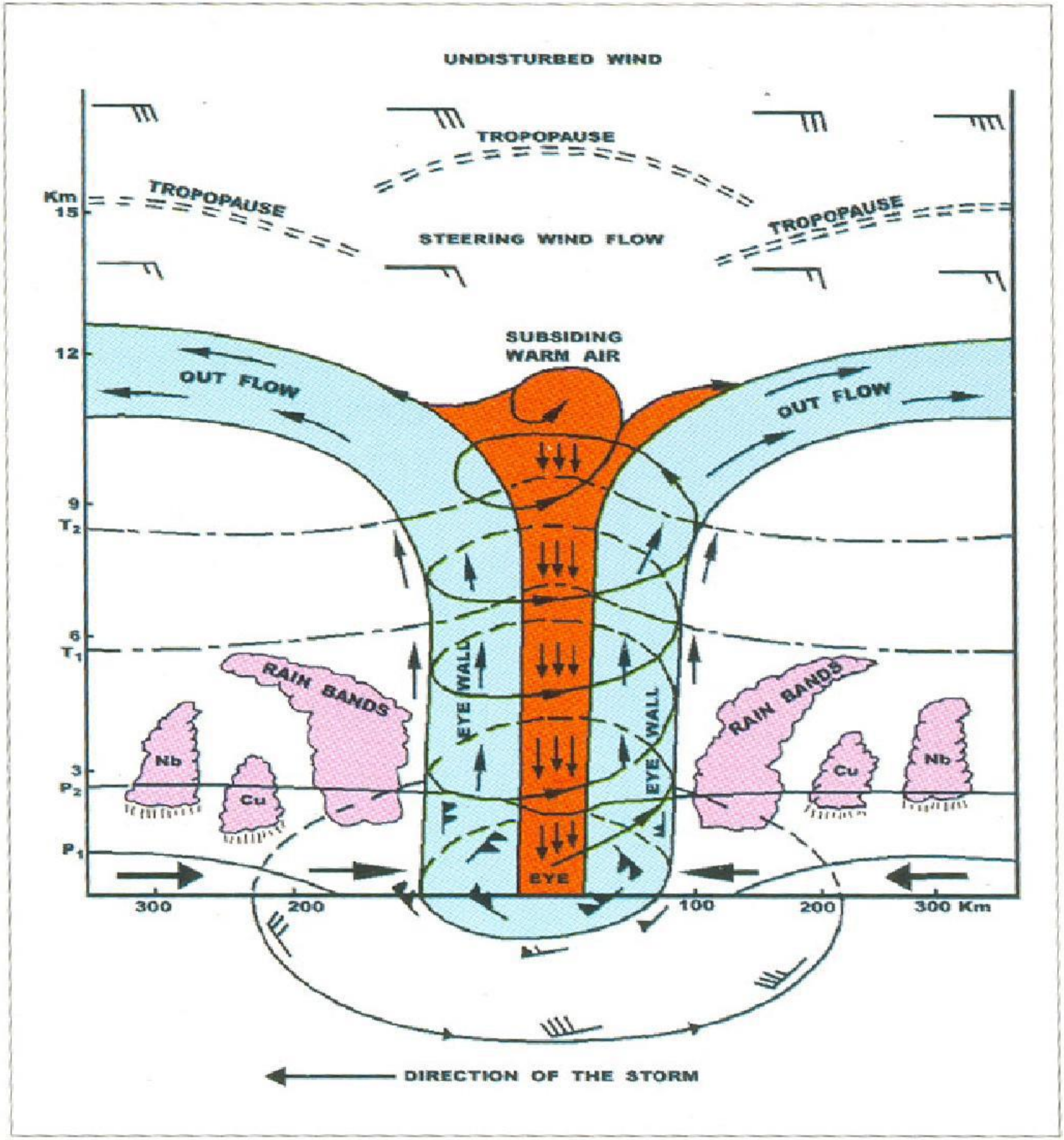
A Tropical Cyclone should be at least 500 km from the equator in order to form. This is because the hurricane needs the Coriolis Force to be able to spin like this picture



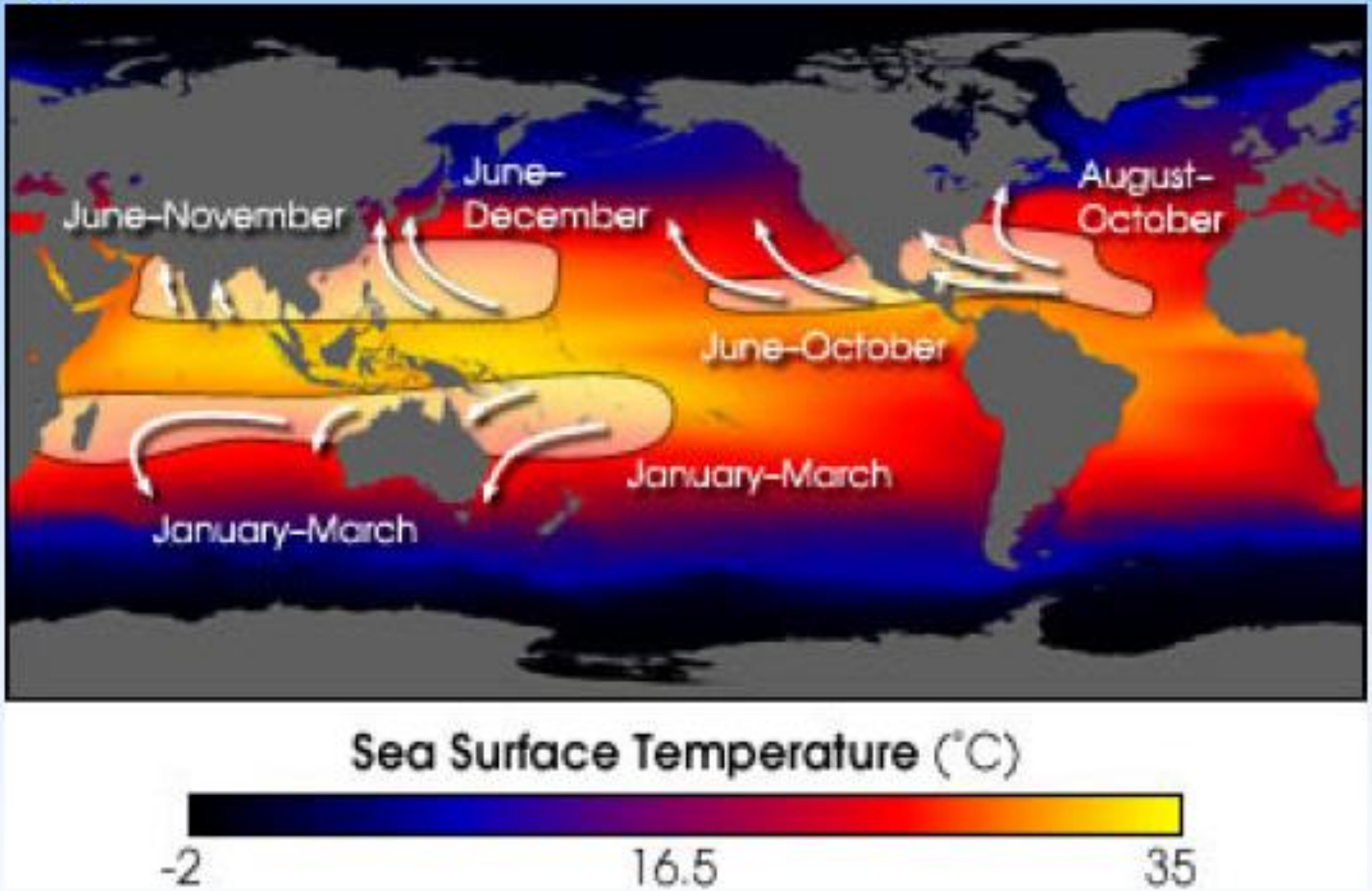
Surface convergence and convection

Subsidence in eye and outflow

Core warms and surface pressure lowers


UNDISTURBED WIND
TROPOPAUSE
Km
15
TROPOPAUSE
TROPOPAUSE
STEERING WIND FLOW
SUBSIDING WARM AIR
12
OUT FLOW
OUT FLOW
9
T2
6
T1
RAIN BANDS
RAIN BANDS
EYE WALL
EYE WALL
3
P2
Nb
Cu
Nb
Cu
P1
EYE
300
200
100
200
300 Km
DIRECTION OF THE STORM

Regions and seasons T>26.5oC



- Orange/yellow regions - tropics between June and December

World’s Deadliest Tropical Cyclones

- Of the 20 deadliest tropical cyclones, 14 have occurred in South Asia (India, Bangladesh).

- The deadliest was the great Bhola Cyclone which hit Bangladesh in 1970 resulting in app. 500,000 deaths.

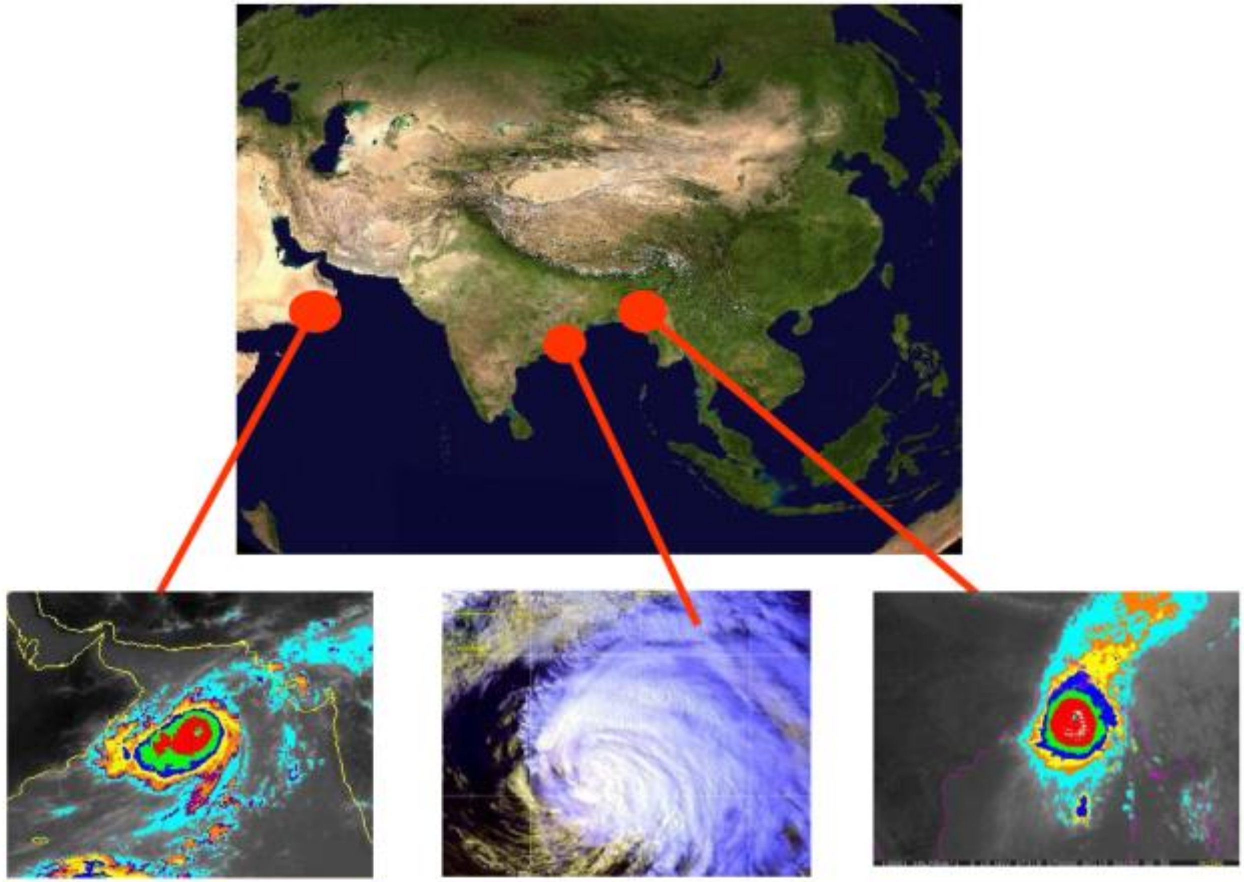
World's Deadliest Tropical Cyclones

- The deadliest storm in the Atlantic Basin occurred in 1780. (22,000 deaths)

- Deadliest US storm was the Galveston Hurricane in 1900 which killed app. 8,000 people.

- Of the 10 deadliest storms in the US, only 1 has occurred since 1957 (Katrina - 1900 dead)

3 Super Cyclones over the Indian Ocean during the past decade

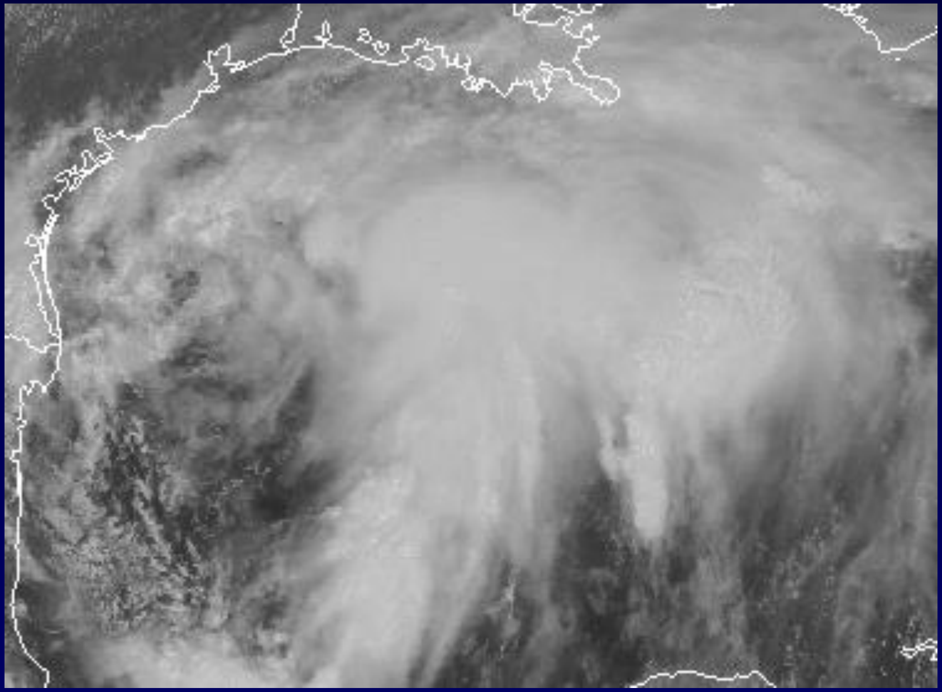


GONU	**Orissa Super Cyclone**	**SIDR**
June 03-07, 2007	Oct 26-29, 1999	Nov 09-16, 2007
Max Wind 252 km/h	Max Wind 252 km/h	Max Wind 250 km/h

Life Cycle

- A tropical depression is designated when the first appearance of a lowered pressure and organized circulation in the center of the thunderstorm complex occurs.

- Winds near the center are constantly between 20 (37 kph) and 34 knots (23 - 39 mph).



Life Cycle

- Once a tropical depression has intensified to the point where its maximum sustained winds are between 35 (63 kph)-64 knots (39-73 mph), it becomes a tropical storm. It is at this time that it is assigned a name.

- Tropical Storm Fay (2008)

- Note that you can see some banding and

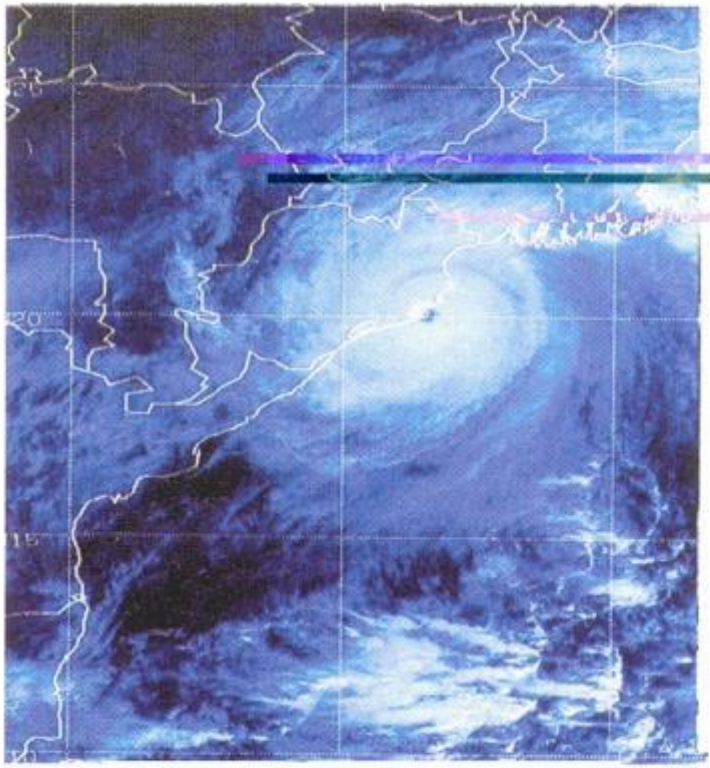
Life Cycle

- As surface pressures continue to drop, a tropical storm becomes a cyclone when sustained wind speeds reach 64 knots (74 mph or 120 kph). A pronounced rotation develops around the central core.
- Large bands of clouds and precipitation spiral from the eye wall and are thusly called spiral rain bands.

Classification of low pressure system in India

System	Pressure deficient hPa	Associated wind speed Knots (Kmph)
Low pressure area	1.0	<17(<32)
Depression	1.0- 3.0	17-27 (32–50)
Deep Depression	3.0 - 4.5	28-33 (51–59)
Cyclonic Storm	4.5- 8.5	34-47 (60-90)
Severe Cyclonic Storm (SCS)	8.5-15.5	48-63 (90-119)
Very Severe Cyclonic Storm	15.5-65.6	64-119 (119-220)
Super Cyclonic Storm	>65.6	>119(>220)

structure of a tropical cyclone

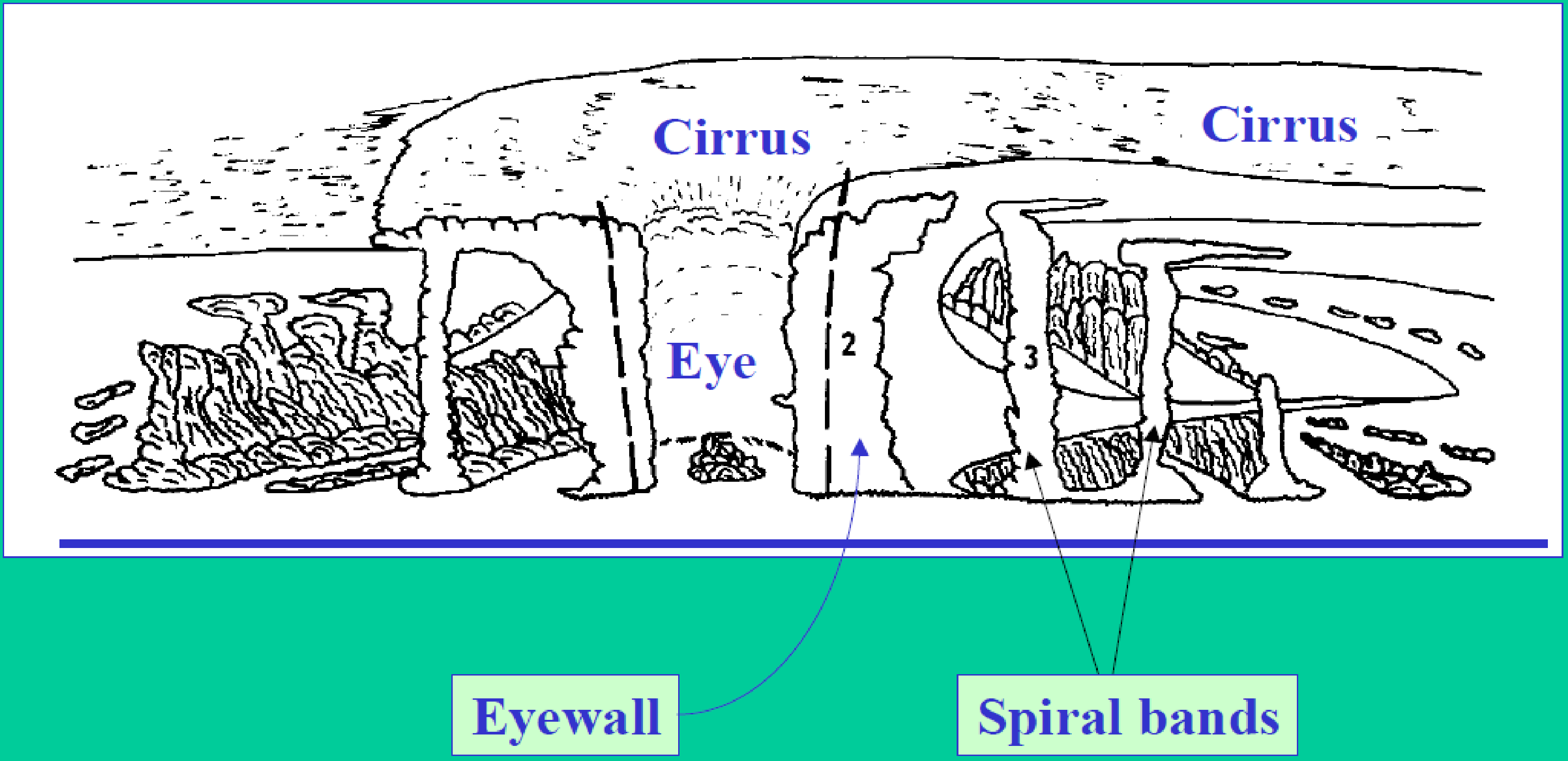


Satellite picture (29 Oct., 0930 IST) of 1999 Orissa Super Cyclone

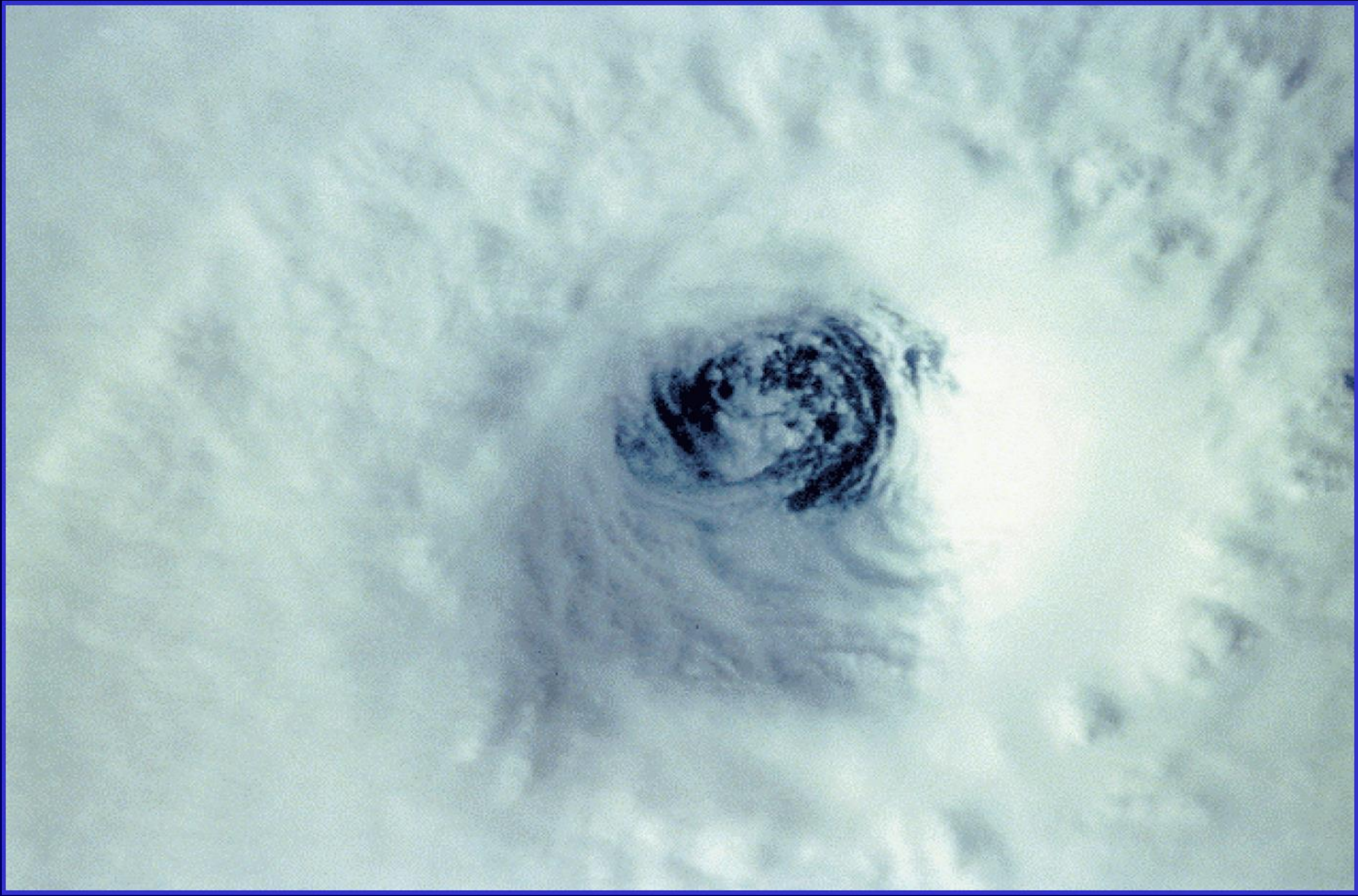
A fully developed tropical cyclone has a central cloud free region of calm winds, known as the "eye" of the cyclone with diameter varying from 10 to 50 km. Surrounding the eye is the "wall cloud region" characterised by very strong winds and torrential rains, which has the width of about 10 to 150 km.

The winds over this region rotate around the centre and resemble the "coils of a snake". Wind speed fall off gradually away from this core region. There may be one or more spiral branch in a cyclone where higher rainfall occurs. The vertical extent of the cyclone is about 15 km. The INSAT imagery of Orissa Super cyclone on 29th October, 1999 is shown in the figure

Schematic cross-section through a hurricane



Close up photograph of the eye



Monitoring of Tropical Cyclones

IMD has a well-established and time-tested organization for monitoring and forecasting tropical cyclones. A good network of meteorological observatories (both surface and upper air) is operated by IMD, covering the entire coastline and islands.

The conventional observations are supplemented by observational data from automatic weather stations (AWS), radar and satellite systems. INSAT imagery obtained at hourly intervals during cyclone situations has proved to be immensely useful in monitoring the development and movement of cyclones.

A network of conventional Cyclone Detection Radars (CDRs) has been established at Kolkata, Paradip, Visakhapatnam, Machilipatnam, Chennai and Karaikal along the east coast and Goa, Cochin, Mumbai and Bhuj along the west coast.

These conventional radars are being phased out and replaced by Doppler Weather Radars (DWRs). DWR have already been installed and made operational at Chennai, Kolkata, Visakhapatnam and Machlipatnam. An indigenously developed DWR Radar by Indian Space Research Organisation (ISRO) has been installed at Sriharikota.

It is proposed to replace all the conventional radars by DWRs during the next 3-4 years.

The dangers associated with cyclonic storms are generally three fold.

- Very heavy rains causing floods.
- Strong wind.
- Storm surge.

The rainfall associated with a storm vary from storm to storm even with the same intensity. Record rainfall in a cyclonic storm has been as low as trace to as high as 250 cms.

It has been found that the intensity of rainfall is about 85 cms/day within a radius of 50 kms and about 35 cms/day between 50 to 100 kms from the centre of the storm. Precipitation of about 50 cm/day is quite common with a cyclonic storms This phenomenal rain can cause flash flood.

The strong wind speed associated with a cyclonic storm. (60-90 kmph) can result into some damage to kutcha houses and tree branches likely to break off. Winds of a severe Cyclonic storm (90-120 kmph) can cause uprooting of trees, damage to pucca houses and disruption of communications.

The wind associated with a very severe Cyclonic storm and super cyclonic storm can uproot big trees, cause wide spread damages to houses and installations and total disruption of communications. The maximum wind speed associated with a very severe Cyclonic storm that hit Indian coast in the past 100 years was 260 kmph in Oct., 1999 (Paradeep Super cyclone).

The severest destructive feature of a tropical storm is the storm surge popularly called tidal waves. The costal areas are subjected to storm surge and is accentuated if the landfall time coincides with that of high tides.

This is again more if the sea bed is shallow. Storm surge as high as 15 to 20 ft. may occur. This storm tide inundates low lying coastal areas which has far reaching consequences apart from flooding. The fertility of land is lost due to inundation by saline water for a few years to come.

Disaster potential due to cyclones is due to high storm surges occurring at the time of landfall. The storm surges are by far the greatest killers in a cyclone. as sea water inundates low lying areas of the coastal regions causing heavy floods, erosion of beaches and embankments, damage to vegetation and reducing soil fertility.

Flooding due to storm surges pollute drinking water sources resulting in shortage of drinking water and causing out-break of epidemics, mostly water borne diseases Very strong winds (Gales) may cause uprooting of trees, damage to dwellings, overhead installations, communication lines etc., resulting in loss of life and property. Past records show that very heavy loss of life due to tropical cyclones have occurred in the coastal areas surrounding the Bay of Bengal. Cyclones are also often accompanied by very intense & heavy precipitation (exceeding 40-50 cm in a day or about 10cm or more per hour in some places)

vulnerability our coastline from the point of view of storm surge potential, Entire Indian coast can be categorized into 4 zones

- Very high risk zones (Surge height > 5m)
- High risk Zone (Surge height between 3-5m)
- Moderate risk zone (Surge height between 1.5 to 3m)
- Minimal risk zone (Surge height < 1.5m)

The coastal areas and off-shore islands of Bengal and adjoining Bangladesh are the most storm-surge prone (~ 10-13m) – VHRZ

East coast of India between Paradip and Balasore in Orissa (~ 5-7m) – VHRZ

Andhra coast between Bapatla and Kakinada holding estuaries of two major rivers Krishna and Godavari (~ 5-7m) – VHRZ

Tamilnadu coast between Pamban and Nagapattinam (~ 3-5m) – HRZ
Gujarat along the west coast of India (~ 2-3m) -MRZ

The damage potential of a deep depression (28 – 33 knots)

Structures: Minor damage to loose/ unsecured structures
Communication & power:

Road/Rail: Some breaches in Kutcha road due to flooding

Agriculture: Minor damage to Banana trees and near coastal agriculture due to salt spray. Damage to ripe paddy crops

Marine Interests: Very rough seas. Sea waves about 4-6 m high.

Coastal Zone: Minor damage to Kutcha embankments

Overall Damage Category: Minor

Suggested Actions: Fishermen advised not to venture into sea

The damage potential of a cyclonic storm (34-47 knots or 62 to 87 kmph)

Structures: Damage to thatched huts

Communication and power: Minor damage to power and communication lines due to breaking of tree branches.

Road/Rail: Major damage to Kutcha and minor damage to Pucca roads.

Agriculture: Some damage to paddy crops, Banana, Papaya trees and orchards.

Marine Interests: High to very high sea waves about 6-9 m high.

Coastal Zone: Sea water inundation in low lying areas after erosion of Kutcha embankments

Overall Damage Category: Minor to Moderate

Suggested Actions: Fishermen advised not to venture into sea

The damage potential of a severe cyclonic storm 48-63 Knots (88-117 Kmph)

Structures: Major damage to thatched houses / huts. Roof tops may blow off. Unattached metal sheets may fly.

Communication and power: Minor damage to power and communication lines.

Road/Rail: Major damage to Kutcha and some damage to Pucca roads. Flooding of escape routes.

Agriculture: Breaking of tree branches, uprooting of large avenue trees.

Moderate damage to Banana and Papaya trees: Large dead limbs blown from trees.

Marine Interests: Phenomenal seas with wave height 9-14 m. Movement in motor boats unsafe.

Coastal Zone: Major damage to coastal crops. Storm surge upto 1.5m (area specific) causing damage to embankments/ salt pans. Inundation upto 5 Km in specific areas.

Overall Damage Category: Moderate

Suggested Actions: Fishermen advised not to venture into sea. Coastal hutment dwellers advised to move to safer places. Other people in the affected areas to remain indoors.

The damage potential of a very severe cyclonic storm (64-90 Knots or 118-167 Kmph)

Structures: Total destruction of thatched houses/ extensive damage to Kutcha houses. Some damage to Pucca houses. Potential threat from flying objects.

Communication and power: Bending/ uprooting of power and communication poles.

Road/Rail: Major damage to Kutcha and Pucca roads. Flooding of escape routes. Minor disruption of railways, overhead power lines and signaling systems.

Agriculture: Widespread damage to standing crops plantations, orchards, falling of green coconuts and tearing of palm fronds Blowing down bushy trees like mango.

Marine Interests: Phenomenal seas with wave heights more than 14m. Visibility severely affected. Movement in motor boats and small ships unsafe.

Coastal Zone: Storm surge up to 2 m, Inundation up to 10 Km in specific areas. Small boats, country crafts may get detached from moorings.

Overall Damage Category: Large

Suggested Actions: Fishermen not to venture into sea. Evacuation from coastal areas needs to be mobilized. People advised to remain indoors. Judicious regulation of rail and road traffic needed.

The damage potential of a very severe cyclonic storm (91-119 Knots or 168-221 Kmph)

Structures: Extensive damage to all types Kutcha houses, some damage to old badly managed Pucca structures. Potential threat from flying objects.

Communication and power: Extensive uprooting of power and communication poles.

Road/Rail: Disruption of rail / road link at several places.

Agriculture: Extensive damage to standing crops plantations, orchards. Blowing down of Palm and Coconut trees. Uprooting of large bushy trees.

Marine Interests: Phenomenal seas with wave heights more than 14m. Movement in motor boats and small ships not advisable.

Coastal Zone: Storm surge up to 2 – 5 m, Inundation may extend up to 10-15 Km over specific areas. Large boats and ships may get torn from their moorings, country crafts may get detached from moorings

Overall Damage Category: Extensive

Suggested Actions: Fishermen not to venture into sea. Evacuation from coastal areas essential. Diversion / suspension of rail traffic may be required.

The damage potential of a super cyclonic storm 120 Knots (222 Kmph) & above

Structures: Extensive damage to non-concrete residential and industrial building. Structural damage to concrete structures. Air full of large projectiles.
Communication and power: Uprooting of power and communication poles. Total disruption of communication and power supply.
Road/Rail: Extensive damage to Kutcha roads and some damage to poorly repaired pucca roads. Large scale submerging of coastal roads due to flooding and sea water inundation. Total disruption of railway and road traffic due to major damages to bridges, signals and railway tracks. Washing away of rail / road links at several places.
Agriculture: Total destruction of standing crops / orchards, uprooting of large trees and blowing away of palm and coconut crowns, stripping of tree barks.
Marine Interests: Phenomenal seas with wave heights more than 14m. All shipping activity unsafe.
Coastal Zone: Extensive damage to port installations. Storm surge more than 5m, Inundation up to 40 Km in specific areas and extensive beach erosion. All ships torn from their moorings. Flooding of escape routes.
Overall Damage Category: Catastrophic
Suggested Actions: Fishermen not to venture into sea. Large scale evacuations needed. Total stoppage of rail and road traffic needed in vulnerable areas

Various Techniques are available for Track Prediction of the storm as mentioned below:

Methods based on climatology, persistence and both Climatology & Persistence (CLIPER)

Synoptic Techniques – Empirical Techniques

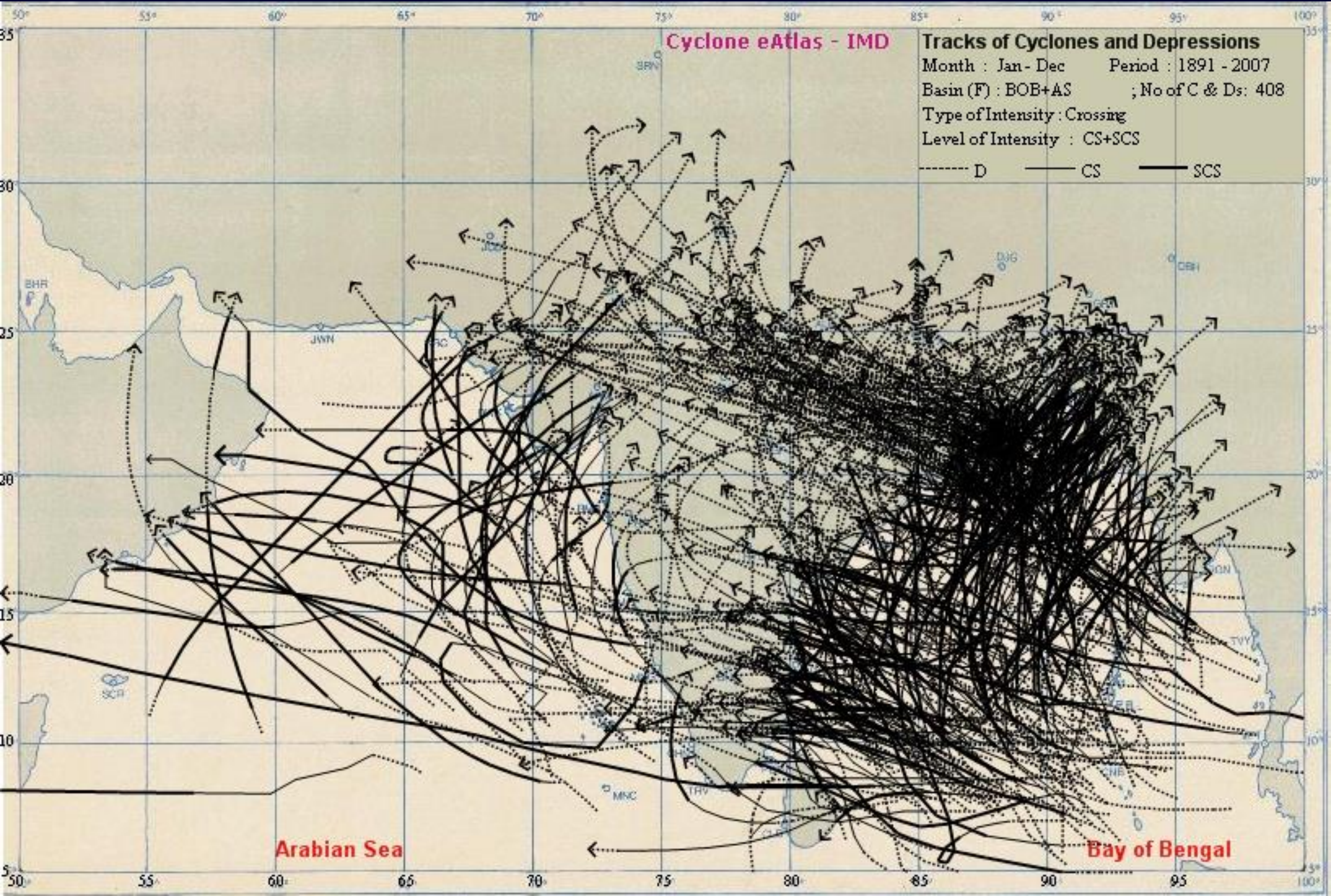
Satellite Techniques

Statistical Techniques using climatology, persistence and synoptic

Analogue Techniques

Numerical weather prediction models

The tracks of the cyclonic storms over north India ocean during 1891-2007 are shown below:



4-stage warning system for Tropical Cyclones

(1) Pre-Cyclone Watch

Issued when a depression forms over the Bay of Bengal irrespective of its distance from the coast and is likely to affect Indian coast in future. The pre-cyclone watch is issued by the name of Director General of Meteorology and is issued at least 72 hours in advance of the commencement of adverse weather. It is issued at least once a day

(2) Cyclone Alert

Issued atleast 48 hours before the commencement of the bad weather when the cyclone is located beyond 500 Km from the coast. It is issued every three hours.

(3) Cyclone Warning

Issued at least 24 hours before the commencement of the bad weather when the cyclone is located within 500 Km from the coast. Information about time /place of landfall are indicated in the bulletin. Confidence in estimation increases as the cyclone comes closer to the coast

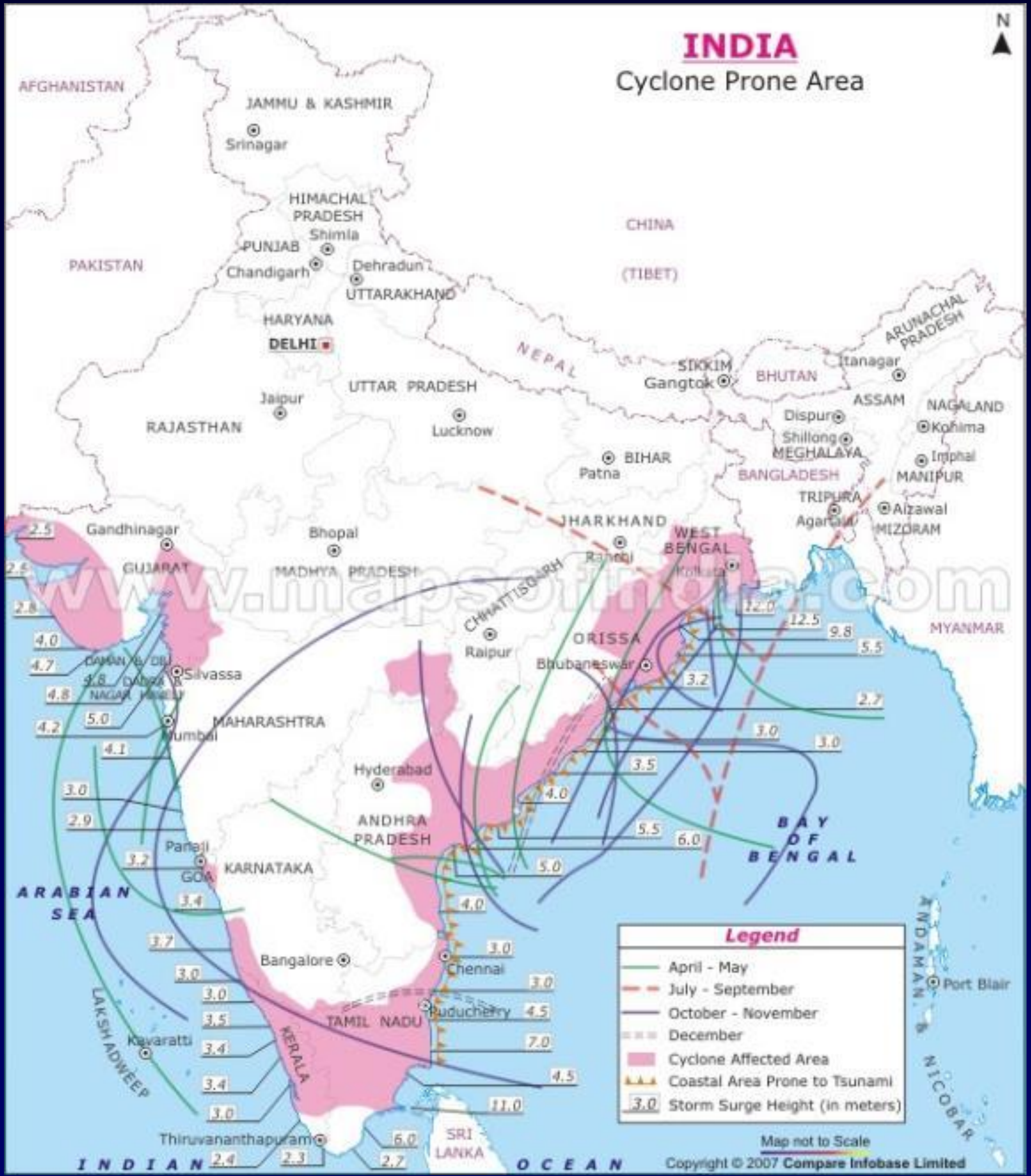
(4) Post landfall outlook

It is issued 12 hours before the cyclone landfall, when the cyclone is located within 200 Km from the coast. More accurate & specific information about time /place of landfall and associated bad weather indicated in the bulletin. In addition, the interior distraction is likely to be affected due to the cyclone are warned in this bulletin.

Table.1 : Table for naming tropical cyclones for the Bay of Bengal and Arabian Sea

Panel Member	Column one		Column two		Column three		Column four	
	Names	Pron'	Names	Pron'	Names	Pron'	Names	Pron'
B'desh	Onil	Onil	Ogni	Og-ni	Nisha	Ni-sha	Giri	Gi-ri
India	Agni	Ag'ni	Akash	Aakaa'sh	Bijli	Bij'li	Jal	Jal
Maldives	Hibaru	--	Gonu	--	Aila	--	Keila	--
Myanmar	Pyarr	Pyarr	Yemyin	Ye-myin	Phyan	Phyan	Thane	Thane
Oman	Baaz	Ba-az	Sidr	Sidr'	Ward	War'd	Murjan	Mur'jaan
Pakistan	Fanoos	Fanoos	Nargis	Nar gis	Laila	Lai la	Nilam	Ni lam
Sri Lanka	Mala	--	Rashmi	Rash'mi	Bandu	--	Mahasen	--
Thailand	Mukda	Muuk-dar	Khai Muk	Ki-muuk	Phet	Pet	Phailin	Pi-lin

Panel Member	Column five		Column six		Column seven		Column eight	
	Names	Pron’	Names	Pron’	Names	Pron’	Names	Pron’
B’desh	Helen	Helen	Chapala	Cho-po-la	Ockhi	Ok-khi	Fani	Foni
India	Lehar	Le’har	Megh	Me’gh	Sagar	Saa’gar	Vayu	Vaa’yu
Maldives	Madi	--	Roanu	--	Mekunu	--	Hikaa	--
Myanmar	Nanauk	Na-nauk	Kyant	Kyant	Daye	Da-ye	Kyarr	Kyarr
Oman	Hudhud	Hud’hud	Nada	N’nada	Luban	L’luban	Maha	M’maha
Pakistan	Nilofar	Ni lofar	Vardah	Var dah	Titli	Titli	Bulbul	Bul bul
Sri Lanka	Priya	--	Asiri	Aa’siri	Gigum	Gi’gum	Soba	--
Thailand	Komen	Goh-men	Mora	Moh-rar	Phethai	Pay-ti	Amphan	Um-pun



INDIA
Cyclone Prone Area
N
AFGHANISTAN
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
PUNJAB
Chandigarh
Dehradun
UTTARAKHAND
PAKISTAN
CHINA
(TIBET)
HARYANA
DELHI
NEPAL
SIKKIM
Gangtok
BHUTAN
ARUNACHAL PRADESH
Itanagar
ASSAM
Dispur
NAGALAND
Kohima
Shillong
MEGHALAYA
Imphal
MANIPUR
UTTAR PRADESH
Lucknow
Jaipur
RAJASTHAN
BIHAR
Patna
BANGLADESH
TRIPURA
Agartala
Aizawal
MIZORAM
JHARKHAND
Ranchi
WEST BENGAL
Kolkata
Gandhinagar
GUJARAT
Bhopal
MADHYA PRADESH
CHHATTISGARH
Raipur
ORISSA
Bhubaneswar
MYANMAR
DAMAN & DIU
DADRA & NAGAR HAVELI
Silvassa
MAHARASHTRA
Mumbai
Hyderabad
ANDHRA PRADESH
Panaji
GOA
KARNATAKA
ARABIAN SEA
BAY OF BENGAL
Bangalore
Chennai
Puducherry
TAMIL NADU
KERALA
Kavaratti
LAKSHADWEEP
Thiruvananthapuram
SRI LANKA
INDIAN OCEAN
ANDAMAN
Port Blair
NICOBAR
2.5
2.5
2.8
4.0
4.7
4.8
4.8
5.0
4.2
4.1
3.0
2.9
3.2
3.4
3.7
3.0
3.0
3.5
3.4
3.4
3.0
2.4
2.3
6.0
2.7
12.0
12.5
9.8
5.5
3.2
2.7
3.0
3.0
3.5
4.0
5.5
6.0
5.0
4.0
3.0
3.0
4.5
7.0
4.5
11.0
Legend
April - May
July - September
October - November
December
Cyclone Affected Area
Coastal Area Prone to Tsunami
3.0 Storm Surge Height (in meters)
Map not to Scale
Copyright © 2007 Compare Infobase Limited
www.mapsofindia.com

Remote Sensors for Cyclone Detection

- GOES – visible cloud formation
- NOAA-AVHRR – cloud-free surface temperature or top of the atmosphere temperature
- QuikSCAT – surface wind speed and direction
- AMSR-E surface temperature

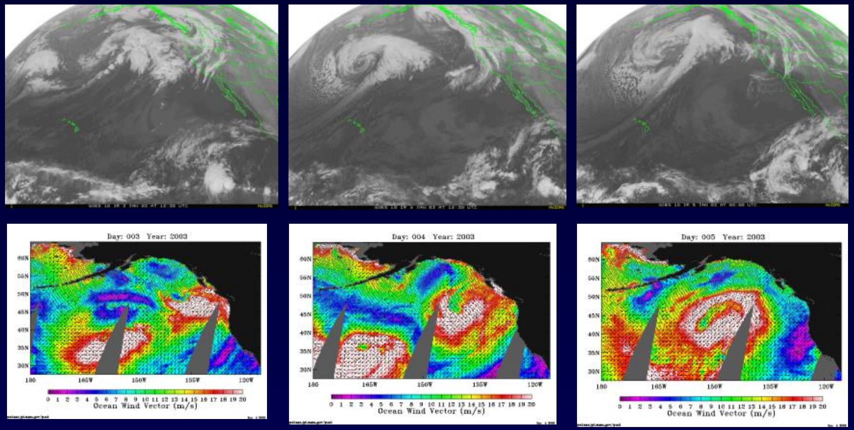
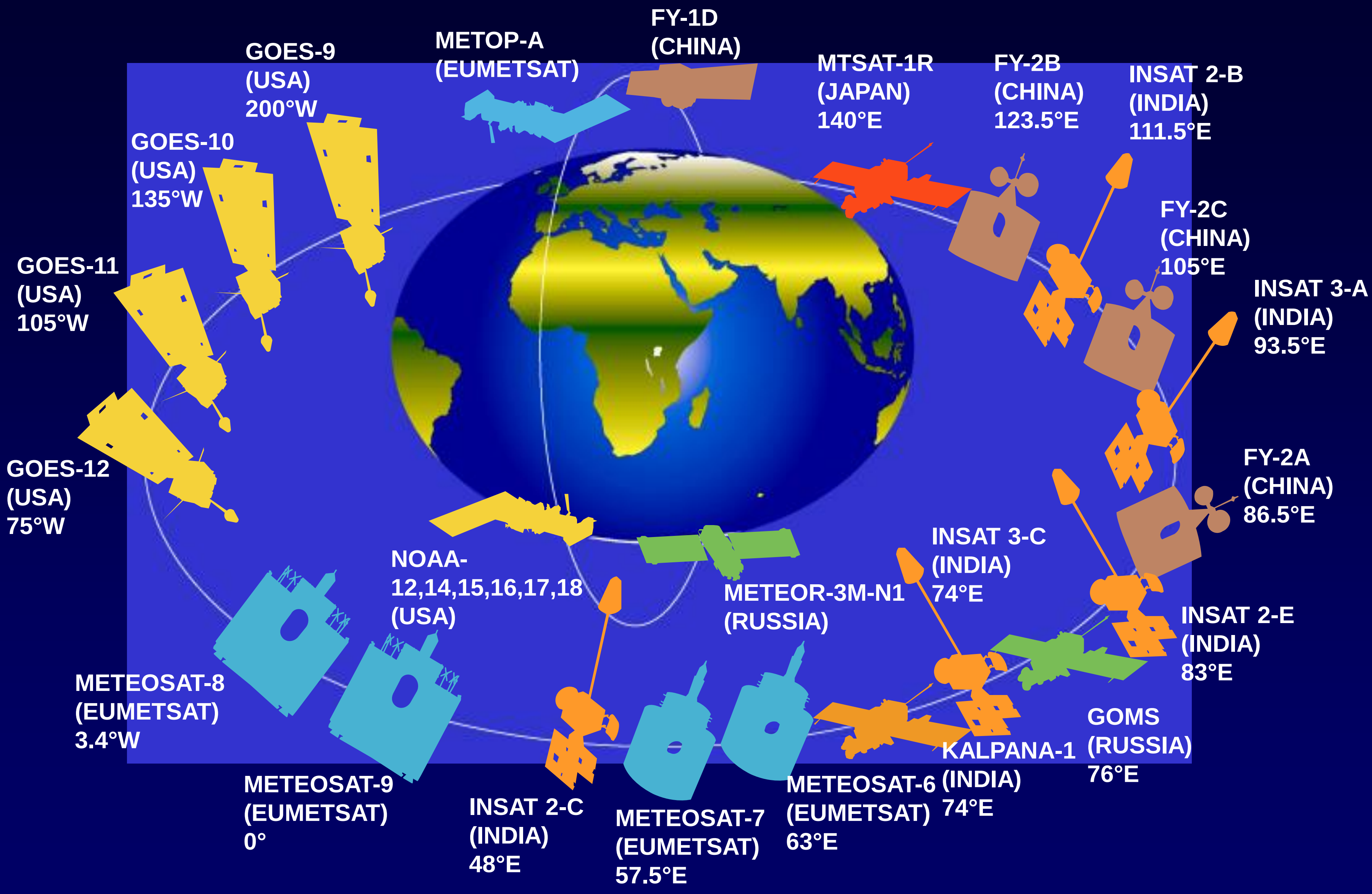


Figure 1: **GOES visible (top) and QuikScat wind speed (lower) sequences collected over the North Pacific on 4-6 Jan, 2003. The visible images show the location and extent of two cyclones and the wind image provides intensity information.**

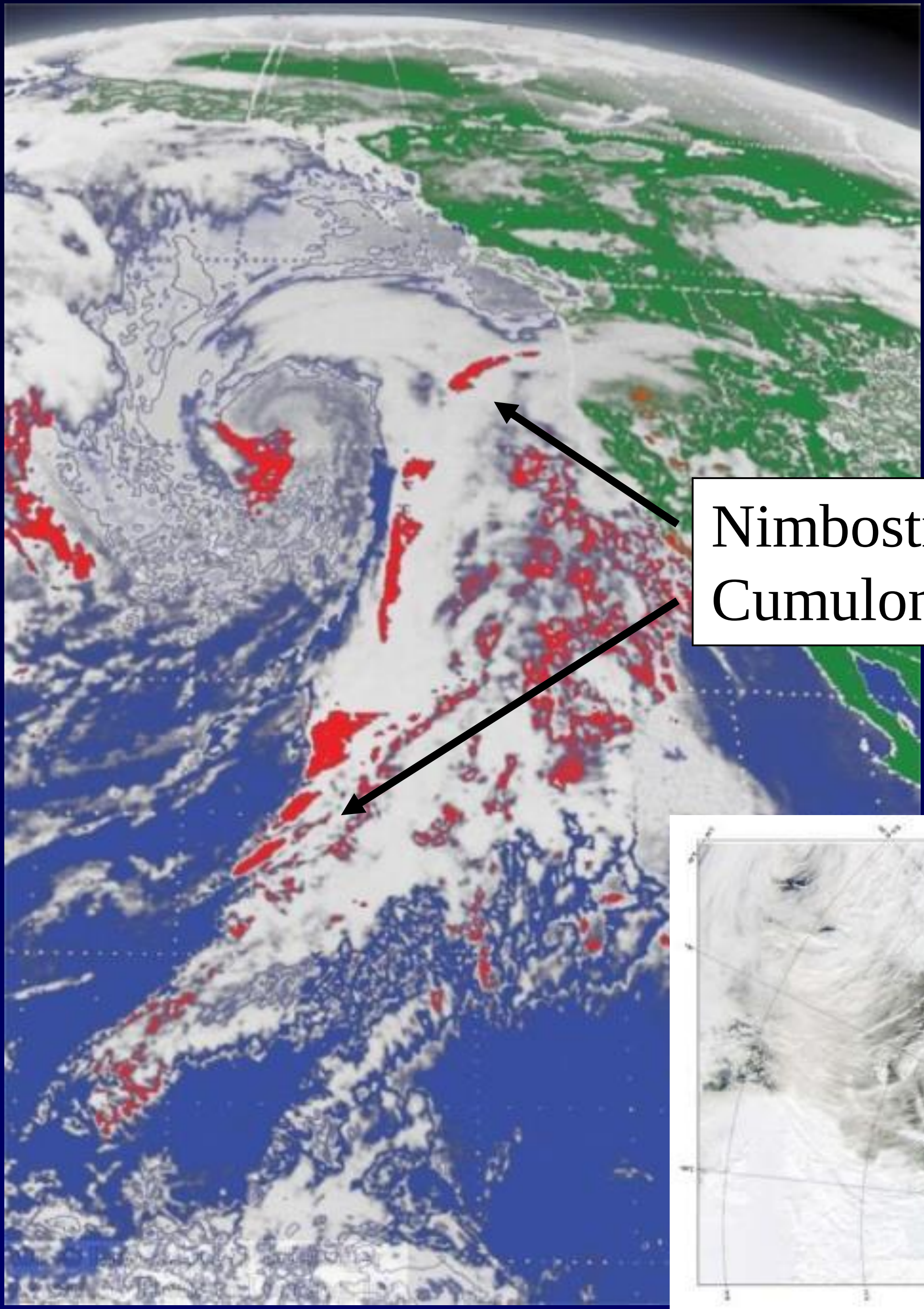
Sensor	Parameter	Spatial Resolution	Temporal freq.	Availability
GOES	Reflectance (visible), Brightness temp. (IR)	6 km	½ hr	1979 - present
AVHRR	Reflectance (visible), Brightness Temp. (IR)	4 km	6 hr (2 satellites)	1985 - present
QuikScat	Wind speed and direction	25 km	12 hrs	1999 - present
SSMI	Brightness Temp, wind speed	25 km	12 hrs	1987 - present
AMSR-E	Brightness Temp, wind speed	25 km	12 hrs	1987 - present

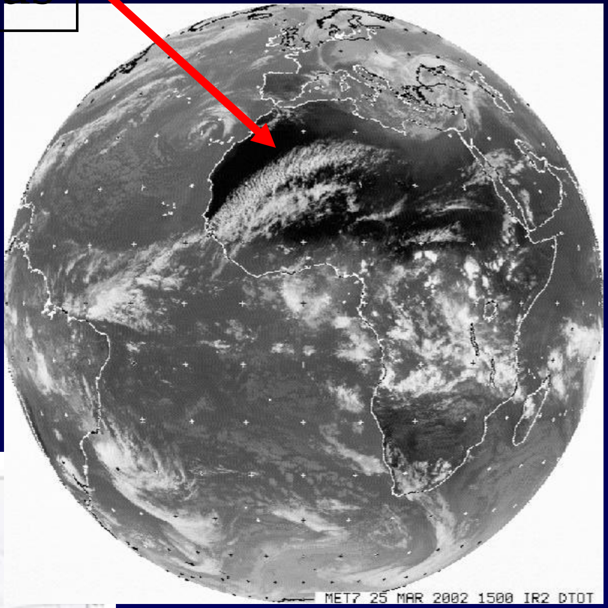
Table 1: Satellite sensor system, the parameters they measure and resolution, and GLYDER goals for multisensor co-registration and fusion

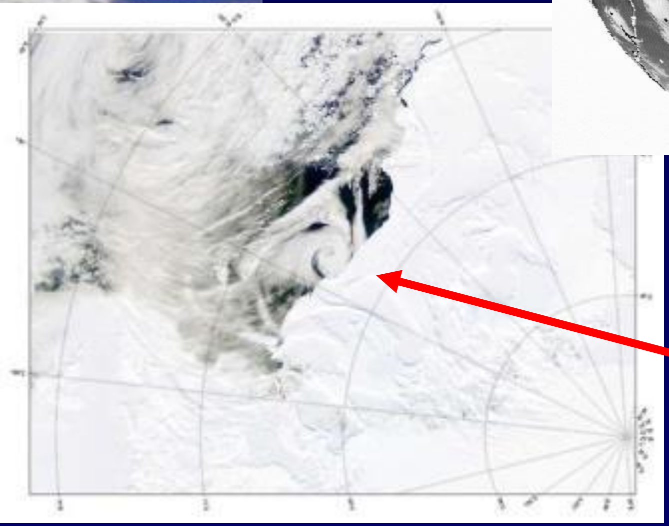
Constellation of Meteorological Satellites

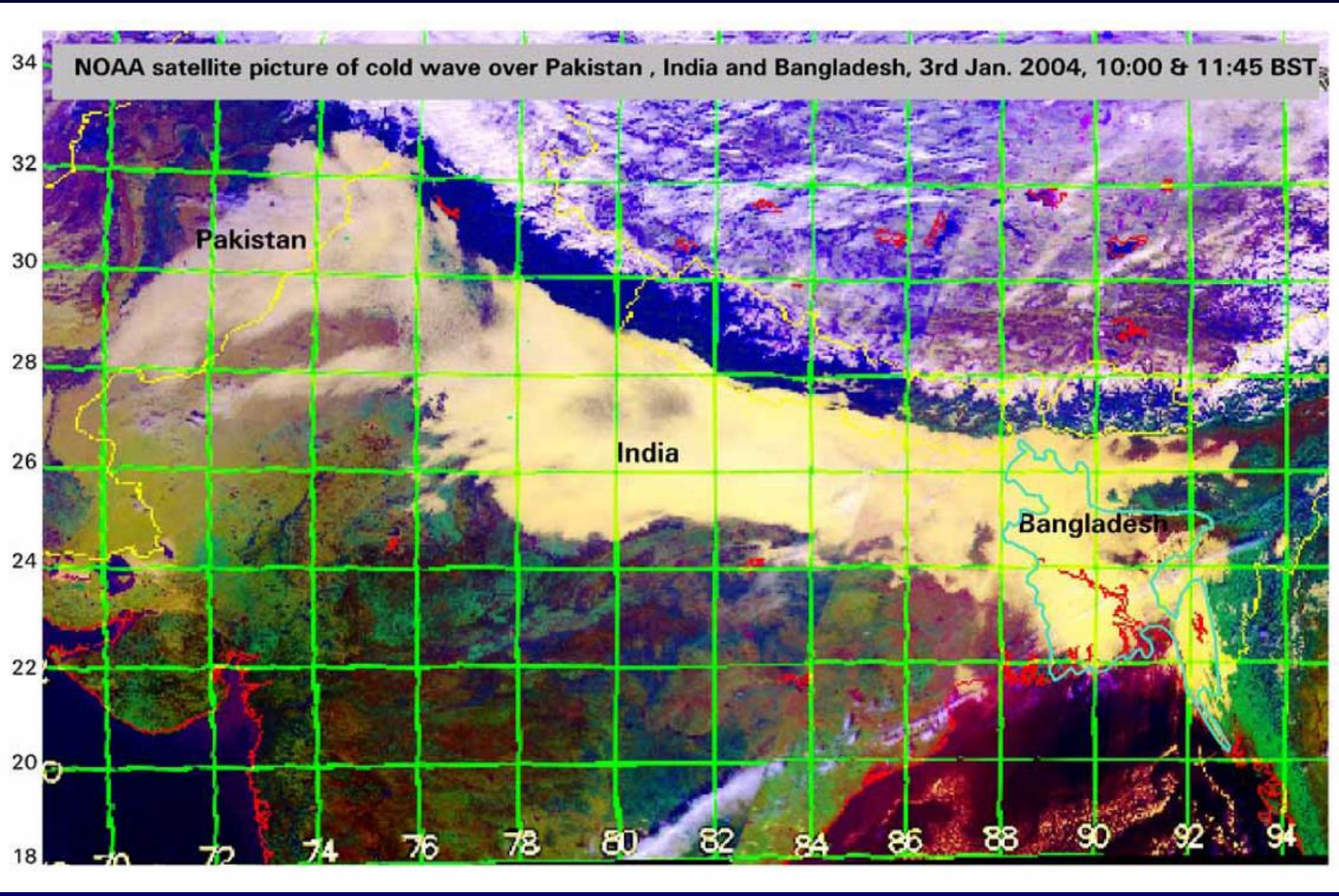


Identifying Clouds Satellite Imagery








NOAA satellite picture of cold wave over Pakistan , India and Bangladesh, 3rd Jan. 2004, 10:00 & 11:45 BST
Pakistan
India
Bangladesh
34
32
30
28
26
24
22
20
18
72
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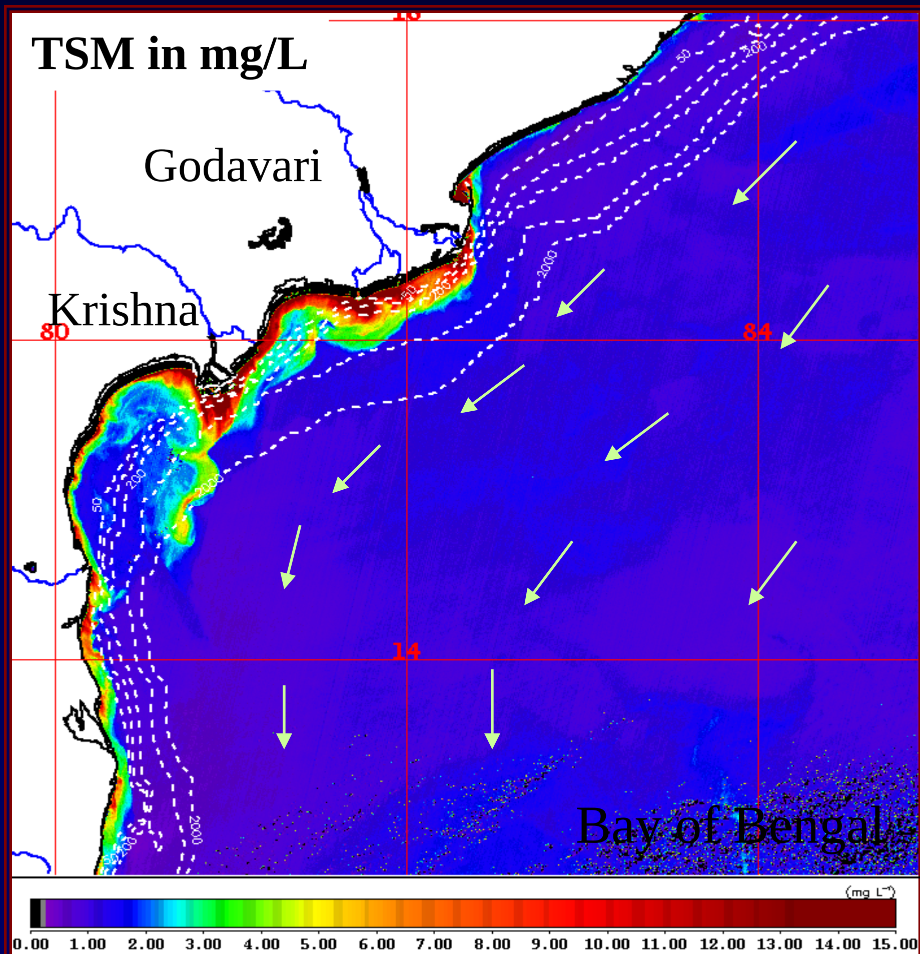
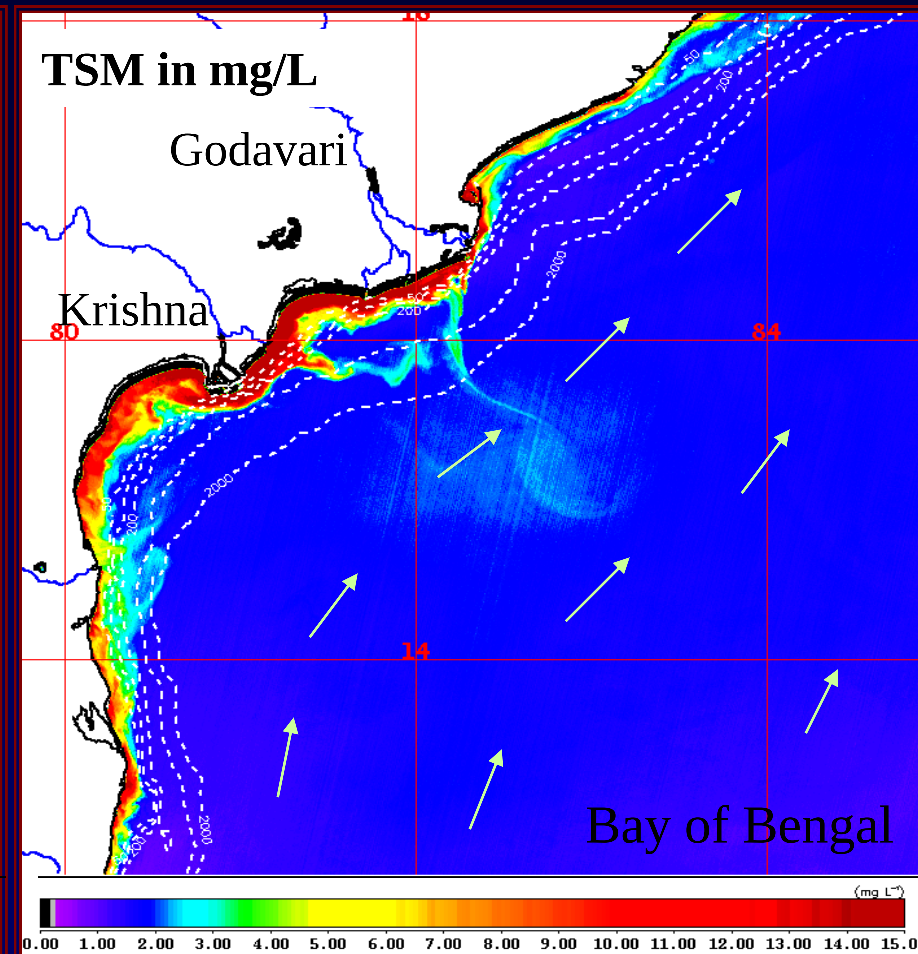
94

Coastal Circulation & Plume Dynamics using OCM Sediment images in Krishna-Godavari Delta, Bay of Bengal



12 Dec 1999



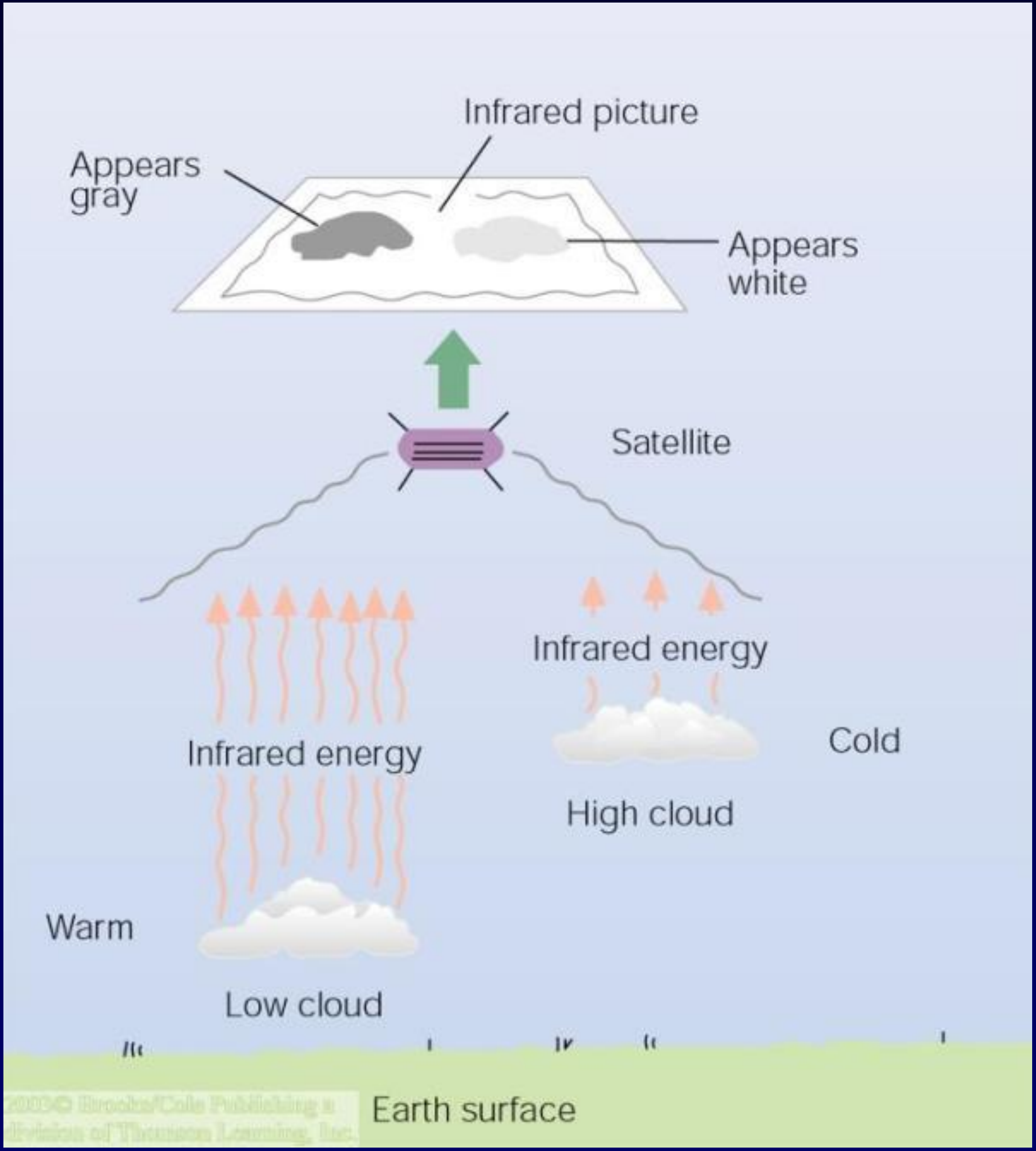
1 Mar 2000

N

What the Satellite Sees…

Infrared
Thermal
Temperature

Brightness
Visible



METEOROLOGICAL SATELLITES / PAYLOADS

During the last few years a number of polar and geostationary satellites carrying a sophisticated array of instruments making measurements in the various regions of electromagnetic spectrum have provided valuable quantitative information about the cyclones.

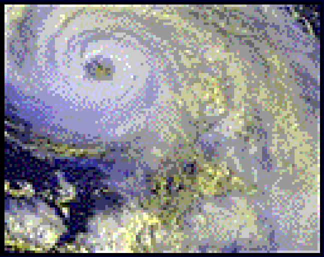
Currently several operational meteorological satellites are providing global and regional observations. Six different types of satellite systems currently in use are : 1) Visible/ Infrared / Water Vapour Imagers, 2) Infrared Sounders, 3) Microwave Imagers, 4) Microwave Sounders, 5) Scatterometers and 6) Radar Altimeters.

Though the water vapour imaging capability is available only on the geostationary satellite, the visible and infrared imagers are available on geostationary as well as polar orbiting satellites. The last four are currently available only on polar orbiting systems.

Table 2. *Spaceborne ocean sensing techniques.*

Color scanner	Ocean color (chlorophyll concentration, suspended sediment, attenuation coefficient)
Infrared radiometer	Sea surface temperature (surface temperature, current patterns)
Synthetic Aperture Radar	Short surface waves (swell, internal waves, oil slicks, *etc.*)
Altimeter	Topography and roughness of sea surface (sea level, currents, wave height)
Scatterometer	Amplitude of short surface waves (surface wind velocity, roughness)
Microwave radiometer	Microwave brightness temperature (salinity, surface temperature, water vapor, soil moisture)

The GOES Program
Geostationary Operational Environmental Satellite



International Geostationary Meteorological Satellites

The GOES program grew out of the successful use of geostationary weather satellites with the experimental SMS -1 & -2. Like many weather satellites, GOES was developed and launched by NASA, but once operational GOES was turned over to NOAA for day-to-day administration.

The provision of timely global weather information, including advance warning of developing storms, is the primary function of the GOES. GOES imagery is commonly featured on many TV weather reports across the United States and the world.

The GOES satellite system has remained an essential cornerstone of weather observations and forecasting for 25 years.

GOES 1978-1987

GOES-4 made the first vertical temperature and moisture measurements from synchronous orbit. From these cross-sections, the altitudes and temperatures of clouds were determined and a three-dimensional picture of their distribution was drawn for more accurate weather prediction.

Using GOES imagery, meteorologists were able to measure the frame-to-frame movement of selected clouds at different altitudes and to obtain their wind direction and speed in order to better understand atmospheric circulation patterns.

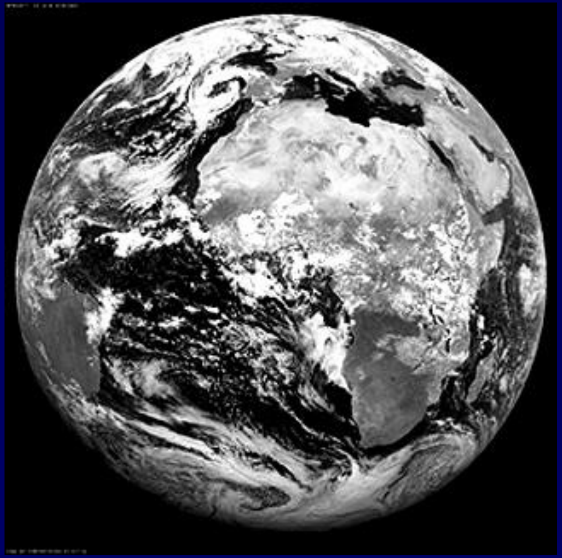
GOES missions

1968 - 1977
GOES-1
GOES-2
1978 - 1987
GOES-3
GOES-4
GOES-5
GOES-6
GOES-G
GOES-7
1988 - 1997
GOES-8
GOES-9
GOES-10

The European Space Agency (ESA) began a geosynchronous satellite program (EurMetSat) in 1977 with Meteosat-1. they have placed six Meteosats in orbit.

These satellites sense in three spectral bands: 0.4 - 1.1 µm, 5.7 - 7.1 µm, and 10.5 - 12.5 µm. A recent Meteosat image, showing all of Africa and most of Europe, across the South Atlantic to Brazil, was taken during the day of June 26, 2000:

A recent Meteosat image, showing all of Africa and most of Europe, across the South Atlantic to Brazil, was taken during the day of June 26, 2000:



The prime sensor used now for many years on U.S. Metsats is AVHRR

The AVHRR has five channels, whose characteristics are:

Band Number	Wavelengths (µm)	Main Uses
1	0.58-0.68	Day clouds; snow; ice
2	0.725-1.10	Surface water; snow; ice
3	3.55-3.93	Fires; clouds at night
4	10.30-11.30	Day/nite cloud & surface temperatures and mapping
5	11.50-12.50	Same as 4; water vapor

AVHRR has flown on NOAA's polar-orbiting satellites, starting with TIROS-N, and is still very much in use today (GOES series). The ground resolution at nadir for this instrument, for a field of view of 1.4 milliradians (producing a swath width of 2,400 km [1,491 mi]), when flown at 830 km (516 mi) is 1,100 m (3,608 ft).

The GOES-8 sounder has a visible band and 18 thermal bands, which are sensitive to temperature variations related to CO2, ozone, and water vapor at different atmospheric levels.

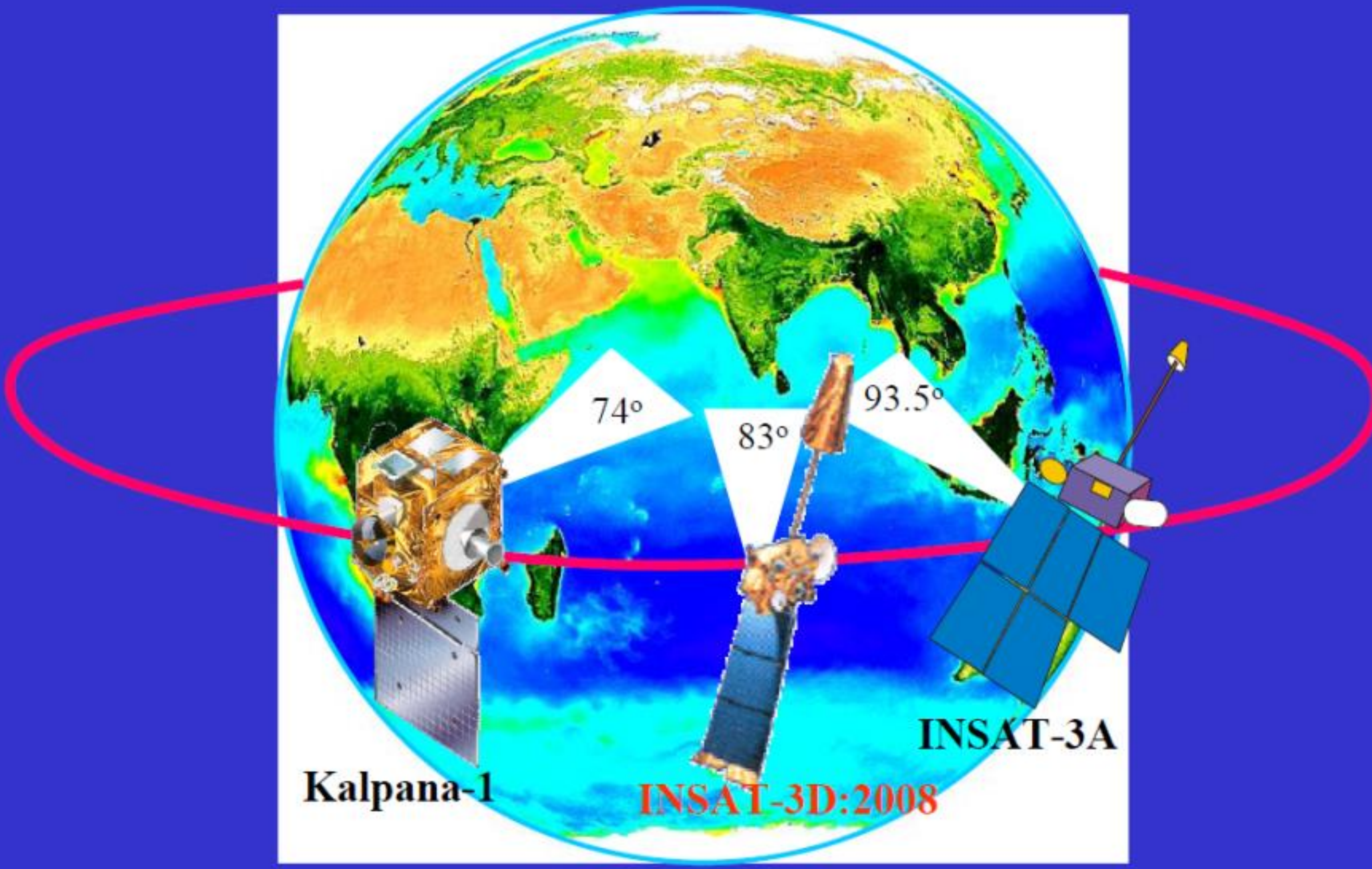
Unusual color composites can be made from different channel images. Colorized rendition of the 6.7 μm channel image from GOES-8, which is sensitive to water vapor distribution, highlighting a big U.S. storm on March 20, 1994.

INDIAN NATIONAL SATELLITE (INSAT) FOR METEOROLOGICAL APPLICATIONS

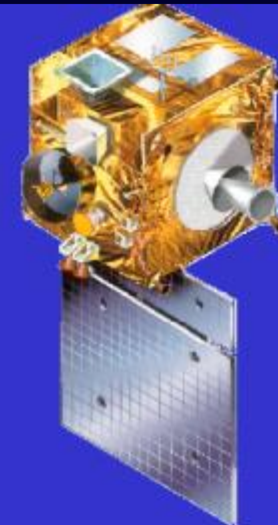
Satellite	Launch Date	Payload	Major Applications
INSAT - 1A	April 1982	Very High Resolutions Radiometer (VHRR)	
INSAT - 1B	August 1983	Visible : 0.55-0.75 µm (Res : 2.75 km)	Monitoring cyclones & monsoon
INSAT - 1C	July 1988	IR : 10.5 – 12.5 µm (Res : 11 Km)	CMV Winds
INSAT – 1D	June 1990		OLR
INSAT – 2A	July 1992	Visible : 0.55-0.75 µm (Res : 2 km)	Rainfall Estimation
INSAT – 2B	July 1993	IR : 10.5 – 12.5 µm (Res : 8 Km	Mesoscale features
INSAT – 2E	April 1999	VHRR: As in 2B + WV Band: 5.7 -7.1 µm CCD: Band: 0.62 – 0.68 µm 0.77 – 0.86 µm 1.55 – 1.69 um	Flood/intense precipitation advisory Snow detection
KALPANA	September 2002	VHRR as in INSAT – 2E	
INSAT – 3A	April 2003	VHRR & CCD as in INSAT – 2E	

Total : 9 (Since 1982)

Current Indian Geostationary Meteorological Satellites



INSAT-3A & Kalpana-1



Location : INSAT 3A : 93.5°E
Kalpana-1 : 74°E

Payload : (i) VHRR & CCD camera in INSAT 3A
(ii) VHRR in Kalpana-1

- VHRR Bands (μm)
  - Visible : 0.55 – 0.75
  - Water vapour : 5.70 – 7.10
  - Thermal Infra Red : 10.5 – 12.5
- Resolution (km) : 2 X 2 for Visible
  8 X 8 for TIR and WV
- CCD Camera Bands (μm)
  - Visible : 0.62 – 0.68
  - Near Infra Red : 0.77 – 0.86
  - Short Wave Infra Red : 1.55 – 1.69
- Resolution (km) : 1 X 1 for all bands

INSAT - 3D

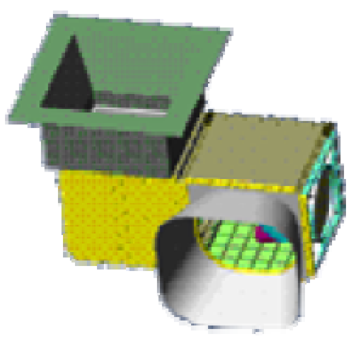
Improved Understanding of Mesoscale Systems

6 Channel IMAGER

- Spectral Bands (µm)

Visible	: 0.55 - 0.75
Short Wave Infra Red	: 1.55 - 1.70
Mid Wave Infra Red	: 3.80 – 4.00
Water Vapour	: 6.50 - 7.10
Thermal Infra Red – 1	: 10.30 - 11.30
Thermal Infra Red – 2	: 11.50 - 12.50

- Resolution : 1 km for VIS, SWIR
4 km for MIR, TIR
8 km for WV



19 Channel SOUNDER

- Spectral Bands (µm)

Short Wave Infra Red	:	Six bands
Mid Wave Infra Red	:	Five Bands
Long Wave Infra Red	:	Seven Bands
Visible	:	One Band

- Resolution (km) : 10 X 10 for all bands
- No of simultaneous sounding per band : Four

NINETEEN CHANNEL ATMOSPHERIC SOUNDER

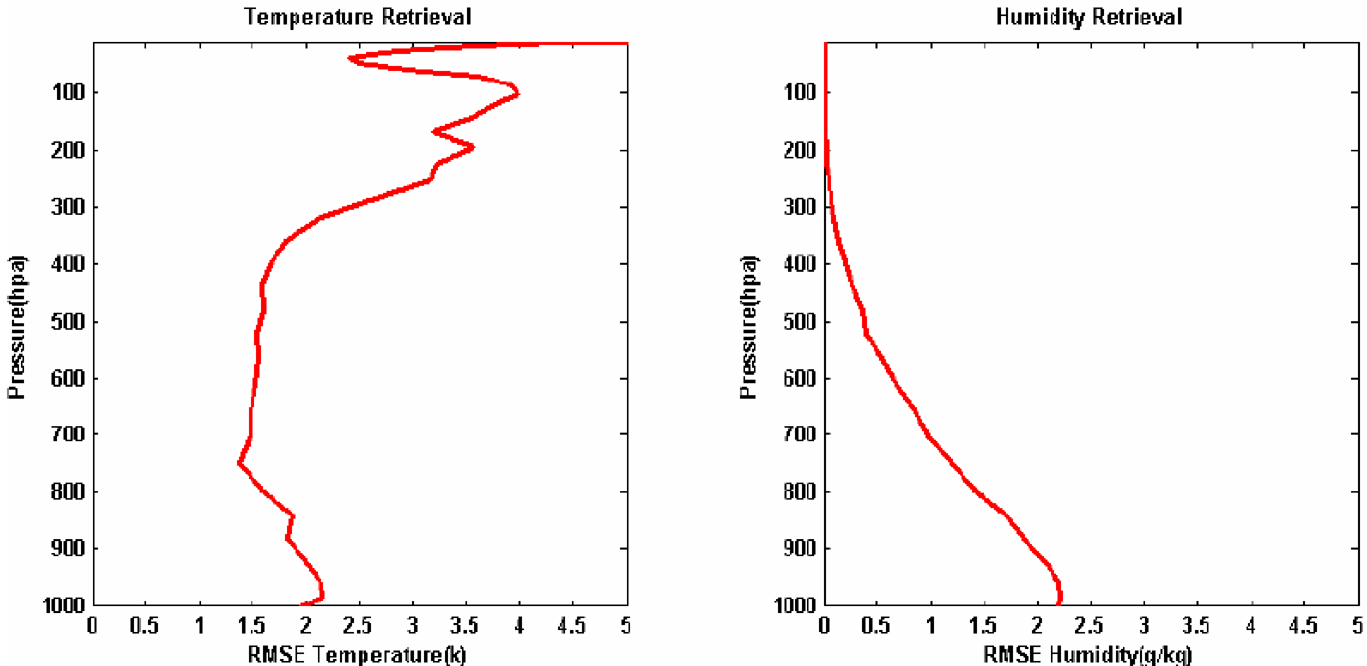
A-19 channels atmospheric sounder for derivation of vertical temperature and moisture profiles with a resolution of 10 km at Sub-Satellite

Channel No.	Central Wavelength in um	Principal absorbing constituents
1	14.71	CO-2 band
2	14.37	CO-2 band
3	14.06	CO-2 band
4	13.96	CO-2 band
5	13.37	CO-2 band
6	12.66	water vapor
7	12.02	water vapor
8	11.03	window
9	9.71	ozone
10	7.43	water vapor
11	7.02	water vapor
12	6.51	water vapor
13	4.57	N-2 0
14	4.52	N-2 0
15	4.45	CO-2
16	4.13	CO-2
17	3.98	window
18	3.74	window
19	0.69	vis

Only Sounder in Geostationary orbit, after GOES

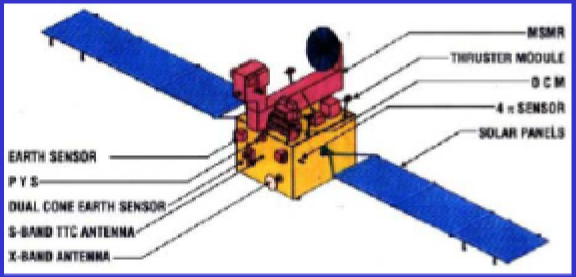
INSAT-3D Sounder Simulation Studies

- Tropical regions have high water vapour content
- Effective Channels Simulated for tropical atmosphere
- Regression Retrieval for temperature and humidity profile
  - Training dataset : SeeBor (SSEC/UW)
  - RT Model : PLOD Fast RT model



RMSE of Temperature and humidity profiles from INSAT-3D Sounder simulated radiances using non-linear regression (for Indian region)

IRS-P4
Oceansat-1



Specifications

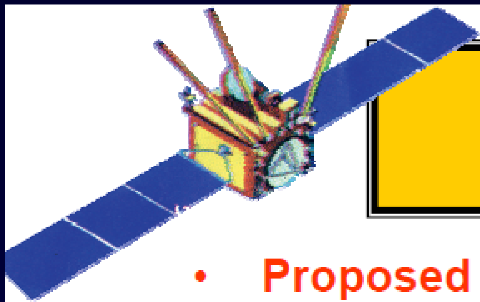
Altitude	720 Km
Swath	1360 Km
Repetivity	2 days
Orbit inclination	98
Launch	May 26, 1999
Sensors	MSMR & OCM

MSMR

Weight	65 Kg
Frequency	6.6, 10.6, 18 and 21 GHz
Polarization	V & H
Spatial Resolution	40 to 120 Km
Temperature Resolution	1 K
Parameters	: WS,WV,SST,CLW,Rain

OCM

Sensor	OCM - 1
Resolution (km)	0.360
Swath(km)	1420
Repeativity(days)	2
Equatorial crossing (hrs)	12:00
Spectral bands (nm)	412±10 443±10 490±10 510±10 555±10 670±10 765±20 865±20
Radiometric quantisation	12
SNR	~350



Oceansat -II

- ## Proposed Instruments:
  - Scatterometer Ku band
  - Ocean Colour Monitor
    - Instead of 660-680 nm in OS-I it has 610-630 nm
  - Radio Occultation (ROSA)

Launched on
23 September 2009

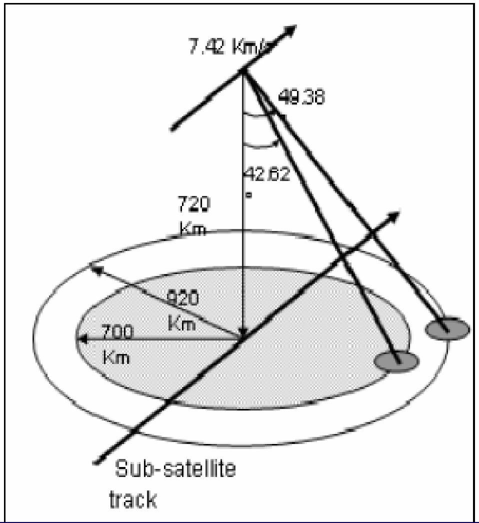
- **Announcement of Opportunity**
  - Last Date : March 31, 2008
  - Available in www.isro.gov.in

- ## Applications:
  - Sea State Forecast: Waves, Circulation and MLD
  - Monsoon and Cyclone Forecast – Medium and Extended Range
  - Antarctic Sea Ice
  - Fisheries and Primary productivity estimation
  - Detection and monitoring of Phytoplankton blooms
  - Sediment dynamics

Scatterometer Specifications

Parameter	Inner Beam	Outer Beam
Attitude	720 km	
Frequency	13.515 GHz	
PRF	200 Hz	
Wind speed range	4 to 24 m / sec.	
Wind speed accuracy	Better than 20 % (rms)	
Wind direction accuracy	20° (rms)	
Polarization	H H	V V
Swath	1400 km	1840 km
Elevation angle	42.62°	49.38°
Incidence angle	48.90°	57.60°
Footprint	26 X 46 km	31 X 65 km
Scanning rate	20.5 rpm	

Scatterometer Observational Geometr



EGHA-TROPIQUES	
Operator	ISRO / CNES
Major contractors	ISRO
Mission type	Meteorological Research Satellite
Satellite of	Earth
Launch date	12 October 2011,Sriharikota Andhra Pradesh, India
Launch vehicle	PSLV-CA
Mission duration	3 years (minimal)
COSPAR ID	2011-058A
Homepage	Official website
Mass	1,000 kg (2,205 lb)
Orbital elements	
Eccentricity	near circular
Inclination	19.99ointented:20o
Apoapsis	865 km (537 mi) intented:867
Periapsis	864 km (537 mi) intented:865
Orbital period	101.93 minutes

Megha-Tropiques is a satellite mission to study the water cycle in the tropical atmosphere in the context of climate change[1] A collaborative effort between Indian Space Research Organisation (ISRO) and French Centre National d'Etudes Spatiales (CNES), Megha-Tropiques was successfully deployed into orbit by a PSLV rocket in October 2011.

Future Geostationary Satellites

- INSAT 3D Repeat (~ 2012)
- Follow-up of INSAT-3D
  - Defining Stage
  - Very High resolution Radiometer
  - Sounder – more channels
    - Different channel simulations using hyperspectral Sounder observation (Metop-IASI/ Aqua-AIRS)
    - Sensitivity study with different central wavenumber and bandwidth to arrive at suitable number of sounder channels for profile retrieval over Indian region.

… contd

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Future Geostationary Satellites

- Geo – HR (~2012) [name yet to be frozen]
- Visible – 50 m
- 3 Channel IR – 1.5 Km
- Visible and SWIR Hyper-spectral – 500 m
  - 50 – 60 channels in VIS
  - 50 – 60 channels in SWIR
- For general remote sensing and can also be used for meteorological purpose

Indian Missions for Weather & Climate Studies : Current & Future

GEO

Kalpana-1
2002

VHRR

CMV, OLR, Rainfall

INSAT-2E/3A
(1999/2003)

VHRR, CCD

CMV, OLR, Rainfall
Aerosol

INSAT-3D
(2008)

6-Ch VHRR
IR Sounder

SST, CMV, OLR,
Rainfall,
T, h Profile

- INSAT-3D R
- Geo-HR

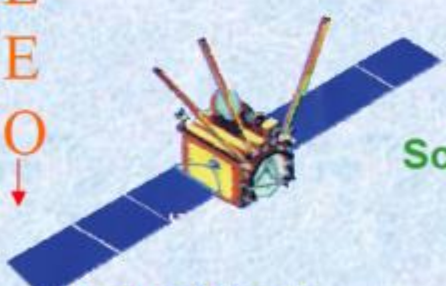
(~2012)

- Follow-up

(~2015)

LEO

OCEANSAT–1/2
(1999/2008)



MSMR,
OCM,
Scatterometer
ROSA

Vector Winds
Aerosol, TWV

SARAL
(2009)

Altimeter

SSH,Waves, Winds

MEGHA-TROPIQUES
(2009)

MW Imager,
WV Sounder
ScaRaB
IGOR(GPS)

SS Wind, TWV, Rainfall
T, h Profile,
Radiation Budget

The INSAT system which is the primary satellite for weather surveillance in this part of the globe. It is a multipurpose geostationary satellite that caters to the requirements of Meteorology and Communication. It carries a met payload called Very High Resolution Radiometer (VHRR) that enables us to have visible, infrared and now even water vapour images.

INSAT applications programme started with the launch of INSAT-1 series of satellites in early 1980s. INSAT-2 series that followed was designed based on user feedback. INSAT-2A and 2B launched in 1992 and 1993 carried VHRR payload with improved resolution of 2 km in visible and 8 km in thermal band. The imaging capability included three modes, viz. full frame, normal mode and sector mode of 5 minutes for rapid coverage of severe weather systems.

INSAT-2E launched in 1999 carried an advanced VHRR payload operating in three channels – visible (2 km), thermal and water vapour (8 km). The water vapour channel is capable of giving water vapour distribution and flow patterns in the middle troposphere.

Besides this, INSAT-2E also carried a CCD camera with 3 channels – visible, near infrared and short wave infrared with 1 km resolution to map the vegetation cover.

A geostationary meteorological satellite (METSAT) system devoted totally to meteorology was launched in 2002. It has been renamed as Kalpana-1 and is currently the operational satellite system being used by IMD.

INSAT-3A has been launched in April 2003 and carries identical payloads as in INSAT-2E. INSAT- 3D planned for future will also carry atmospheric sounder for temperature and water vapour profiles and split thermal channels for accurate sea surface temperature retrieval.

Data from INSAT satellites are being used to retrieve a number of quantitative products. INSAT imagery is being used very exhaustively to provide support for synoptic analysis and weather forecasting.

Recent observational studies using extensive satellite data to supplement conventional surface and upper air data have revealed the structure of tropical cyclones.

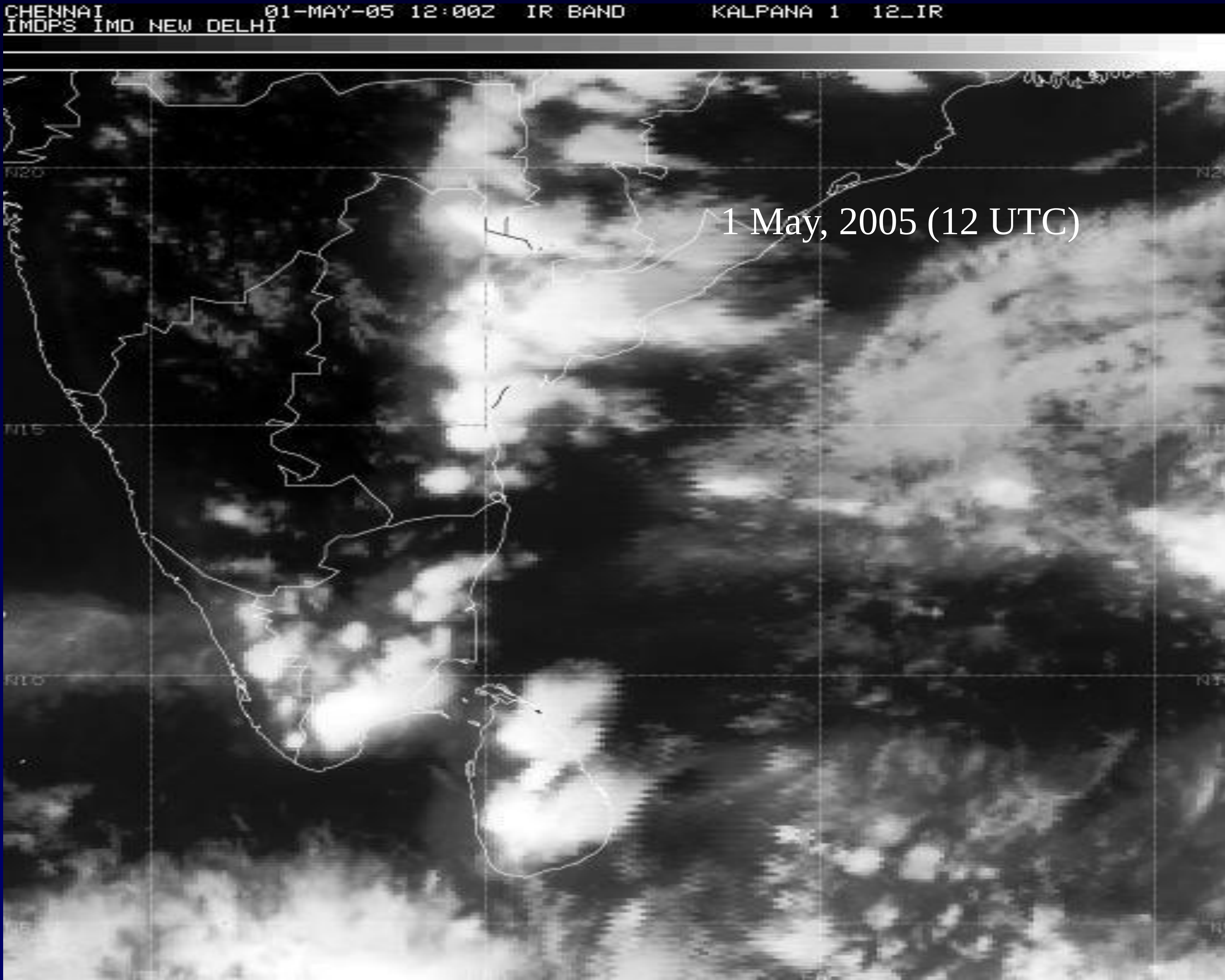
During the last few years a number of polar and geostationary satellites carrying a sophisticated array of instruments making measurements in the various regions of electromagnetic spectrum have provided valuable quantitative information about the cyclones.

Geostationary satellite INSAT with a Very High Resolution Radiometer (VHRR) onboard provides visible and infrared pictures once in 30 minutes. These are operationally used for locating the centre of the cyclone as well as to estimate the current intensity of the storm.

NOAA series of satellites with a sounder facilitates the retrieval of atmospheric temperature profile even in the cloudy conditions.

Unprecedented views of surface wind fields in tropical cyclone are now provided by the 5.3 GHz scatterometer on the ERS-1 satellite.

Similarly SSM/I observations from DMSP satellite provide information on the convection and instantaneous rain rate in the cyclones.


CHENNAI 01-MAY-05 12:00Z IR BAND KALPANA 1 12_IR
IMDPS IMD NEW DELHI
1 May, 2005 (12 UTC)
N20
N15
N10

India's Polar Satellite Launch Vehicle, PSLV-C14, in its 16th Mission launched 958 kg Oceansat-2 and six nano-satellites into a 720 km. intended Sun Synchronous Polar Orbit (SSPO) on September 23, 2009.Oceansat-2 mission is meant to provide continuity of operational services for IRS-P4 OCM data users and also targets to meet new applications requirement in Oceanography and Meteorology.

This satellite would carry three payloads, Ocean Color Monitor (OCM) with eight spectral bands from the visible to near infrared (0.4-0.9 microns), Ku band Scatterometer and Radio Occultation Sounder for Atmosphere(ROSA).

The installation of Polar orbiting NOAA/MODIS /Metop ground receiving and processing systems at New Delhi , Chennai and Guawahati will provide the following Products for <u>each pass for use in conventional forecasting and NWP:</u>

- Temperature , humidity , Ozone and pressure profiles
- Total Ozone
- Sea Surface Temperatures
- Vegetation Index
- Precipitable water and stability indices
- Images in all channels of NOAA/MODIS and Metop satellites
- Aerosol Products
- Cloud Top Temperatures and pressure
- Fog
- surface emissivity

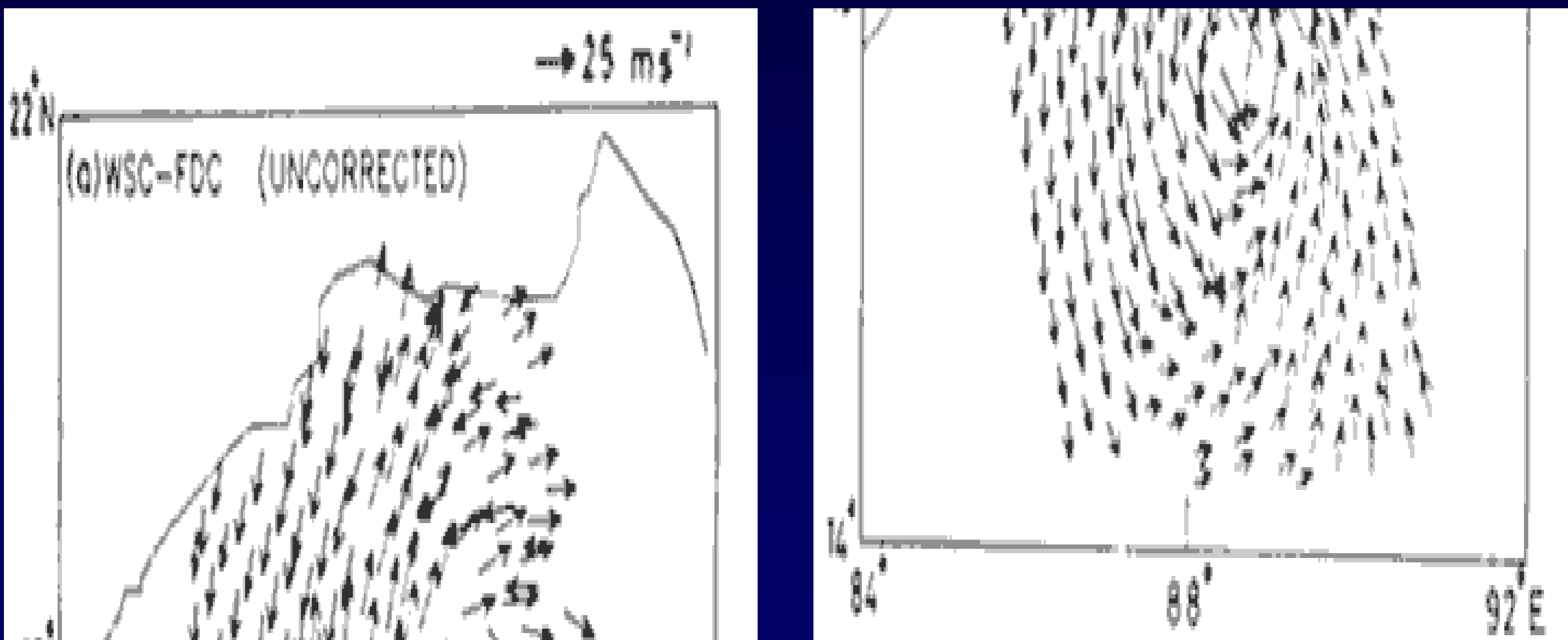
The following products are available in Oceansat-2 <u>and Megha-Tropiques (polar orbiting satellites)</u>

- Sea Surface winds from scatterometer
- Vertical profile of Humidity
- Top of Atmosphere Radiative flux
- Rain over oceans
- Integrated water vapour
- Liquid water in clouds
- Convective rain areas over land and sea
- Ice at cloud tops
- Vertical profiles of radio refractive temperatures derived from Radio-Occultation method

Surface wind observations using ERS-1 Satellite

European Remote Sensing Satellite (ERS-1) launched in 1991, with an onboard 5.3 GHz Scatterometer, provides surface wind fields.

A number of cyclones in the Indian region since 1991 with ERS-1 coverage have been analysed to study different aspects of cyclones particularly the evolution of rotating winds.



ERS-1 Scatterometer derived Surface wind field over the Bay of Bengal cyclone on November 19, 1992.

Warm core observations of tropical cyclones using NOAA microwave data

Kidder et al (1978) and Velden and Smith (1983) have documented the existence of an upper level warm core in tropical cyclones.

This warm temperature anomaly is the result of latent heat being released in the convective regions of the storm

Passive microwave data from NOAA satellites have the ability to penetrate cloudy regions associated with tropical cyclones and delineate the thermal anomalies that exist.

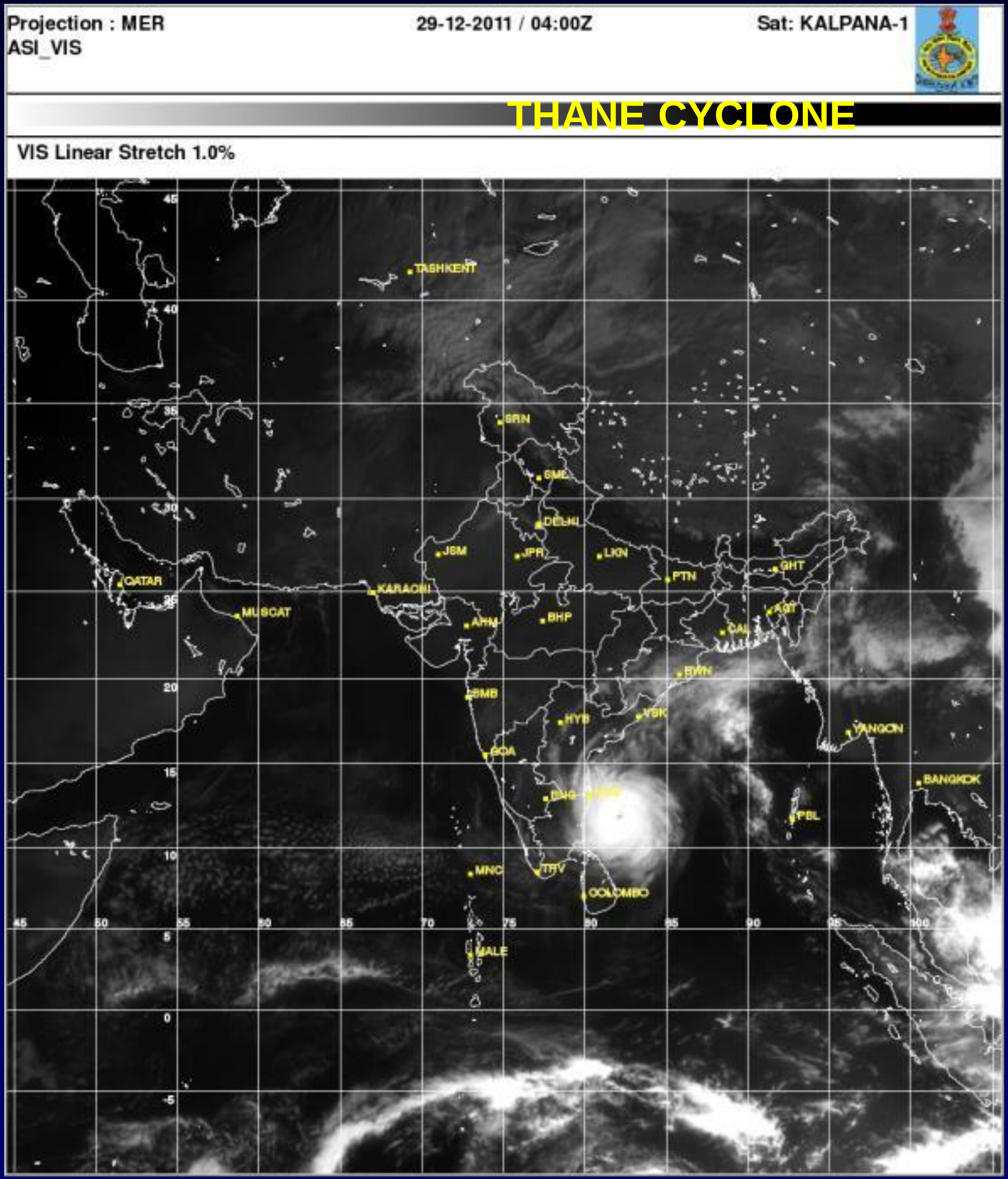
NOAA series of satellites carry a TIROS Operational Vertical Sounder (TOVS) onboard, which includes a Microwave Sounding Unit (MSU), MSU operates in the oxygen absorption bands at 50.31, 53.73, 54.96 and 57.05 GHz and enables derivation of atmospheric temperature profiles

Precipitation characteristics of tropical cyclones from SSM/I

The interaction and maintenance of a mature tropical cyclone is dependent on the amount and distribution of rain within the inner core region of the tropical cyclone (Weatherford, 1987).

The Special Sensor microwave/Imager onboard the US Defense Meteorological Satellite Program (DNSP) provide measurements of reflected and emitted microwave radiation at frequencies 19.4, 22.2, 37.0 and 85.5 GHz. All these channels are dual polarized except the 22.2 GHz which provides polarizaion only in the vertical.

Adler et al (1993), Alliss et al (1992) have documented the SSM/I observations related to hurricanes. Their results indicate that SSM/I measurements can identify rain areas.



The very severe cyclonic storm **THANE** over southwest Bay of Bengal moved west-southwestward and lay centered at 0530 hrs IST of today, the 29^{th} December 2011 near latitude 12.3^{0}N and longitude 83.0^{0}E, about 300 km east-southeast of Chennai (Tamilnadu) and 480 km north-northeast of Trincomalee (Sri Lanka). The system is likely to move westwards and cross north Tamil Nadu coast between Nagapattinam and Chennai, close to Puducherry around morning of 30^{th}December 2011. However, as the cyclonic storm will come further close to coast, there is probability of slight weakening before landfall.

Date/Time(IST)	Position (lat. ^{0}N/ long. ^{0}E)	Sustained maximum surface wind speed (kmph)	Intensity
29-12-2011/0530	12.3/83.0	120-130 gusting to 145	Very Severe Cyclonic Storm
29-12-2011/1130	12.0/82.3	120-130 gusting to 145	Very Severe Cyclonic Storm
29-12-2011/1730	12.0/81.5	110-120 gusting to 135	Severe Cyclonic Storm
29-12-2011/2330	12.0/80.7	110-120 gusting to 135	Severe Cyclonic Storm
30-12-2011/0530	12.0/80.0	100-110 gusting to 125	Severe Cyclonic Storm
30-12-2011/1730	12.0/78.6	65-75 gusting to 85	Cyclonic Storm
31-12-2011/0530	12.0/77.2	55-65 gusting to 75	Deep Depression
31-12-2011/1730	12.0/75.8	45-55 gusting to 65	Depression

Under the influence of this system, rainfall at most places with isolated heavy rainfall is likely over north Tamil Nadu & Puducherry and south coastal Andhra Pradesh from today morning, the 29th December 2011 onwards. The intensity of rainfall would increase with heavy to very heavy falls at a few places and isolated extremely heavy falls (25cm or more) from today evening onwards and extend to Rayalseema and north interior Tamil Nadu.

Squally winds speed reaching 45-55 kmph likely to commence along and off north Tamil Nadu, Puducherry and south Andhra Pradesh coasts from today morning The wind speed will increase gradually from today night onwards becoming 100-110 kmph gusting to 125 kmph along and off north Tamilnadu and south Andhra Pradesh coast at the time of landfall.
Storm surge of about 1 meter height above the astronomical tide would inundate the low lying areas of Chennai and Tiruvallur, Kanchipuram & Villupuram districts of north Tamil Nadu at the time of landfall.

Sea condition will be high to very high around the system centre. Sea condition will be high to very high along and off north Tamil Nadu, Puducherry and south Andhra Pradesh coasts from today night onwards.

Fishermen along north Tamil Nadu, Puducherry & south Andhra Pradesh coasts are advised not to venture into sea. Those who are out at sea are advised to return to the coast.

Damage expected (over north coastal Tamil Nadu and south coastal Andhra Pradesh)**:** Extensive damage to thatched roof and huts. Minor damage to power and communication line due to uprooting of large avenue trees. Flooding of escape routes.

Action suggested (over north coastal Tamil Nadu and south coastal Andhra Pradesh)**:** Total suspension of fishing operations. Coastal hutment dwellers to be moved to safer place. People in affected areas to remain indoors.
The next bulletin will be issued at 1130 hrs IST of today the 29th December, 2011.