

CYCLONE & DROUGHT

UNIT 5

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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.

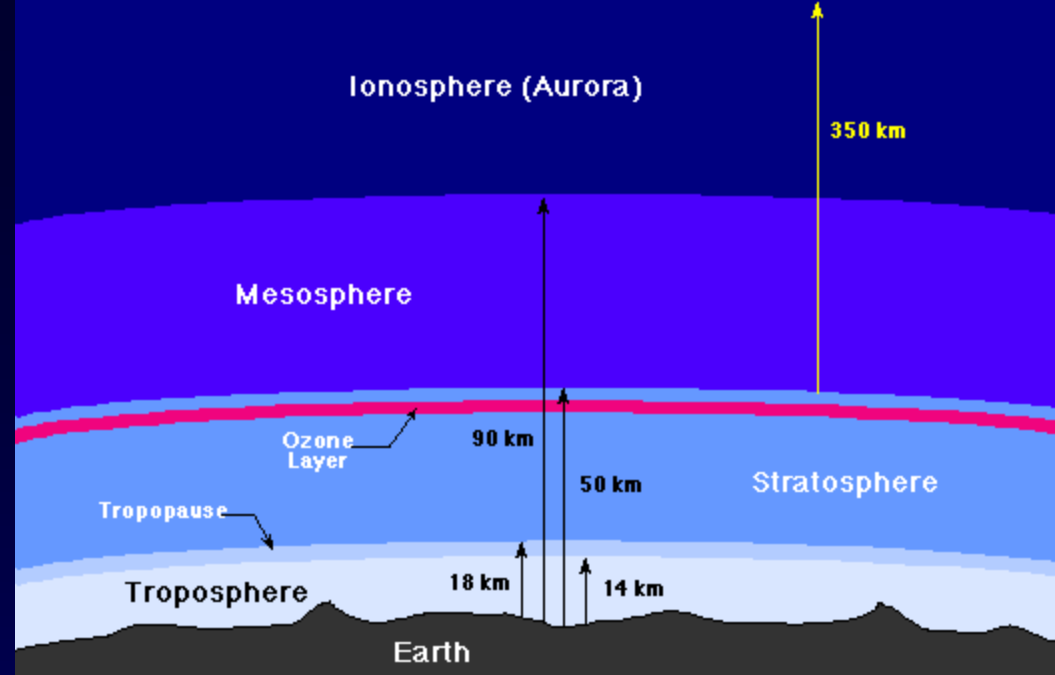
First of all, the ocean water itself must be warmer than a threshold say, 28 °C. The heat and moisture from this warm water is the source of energy for cyclones.

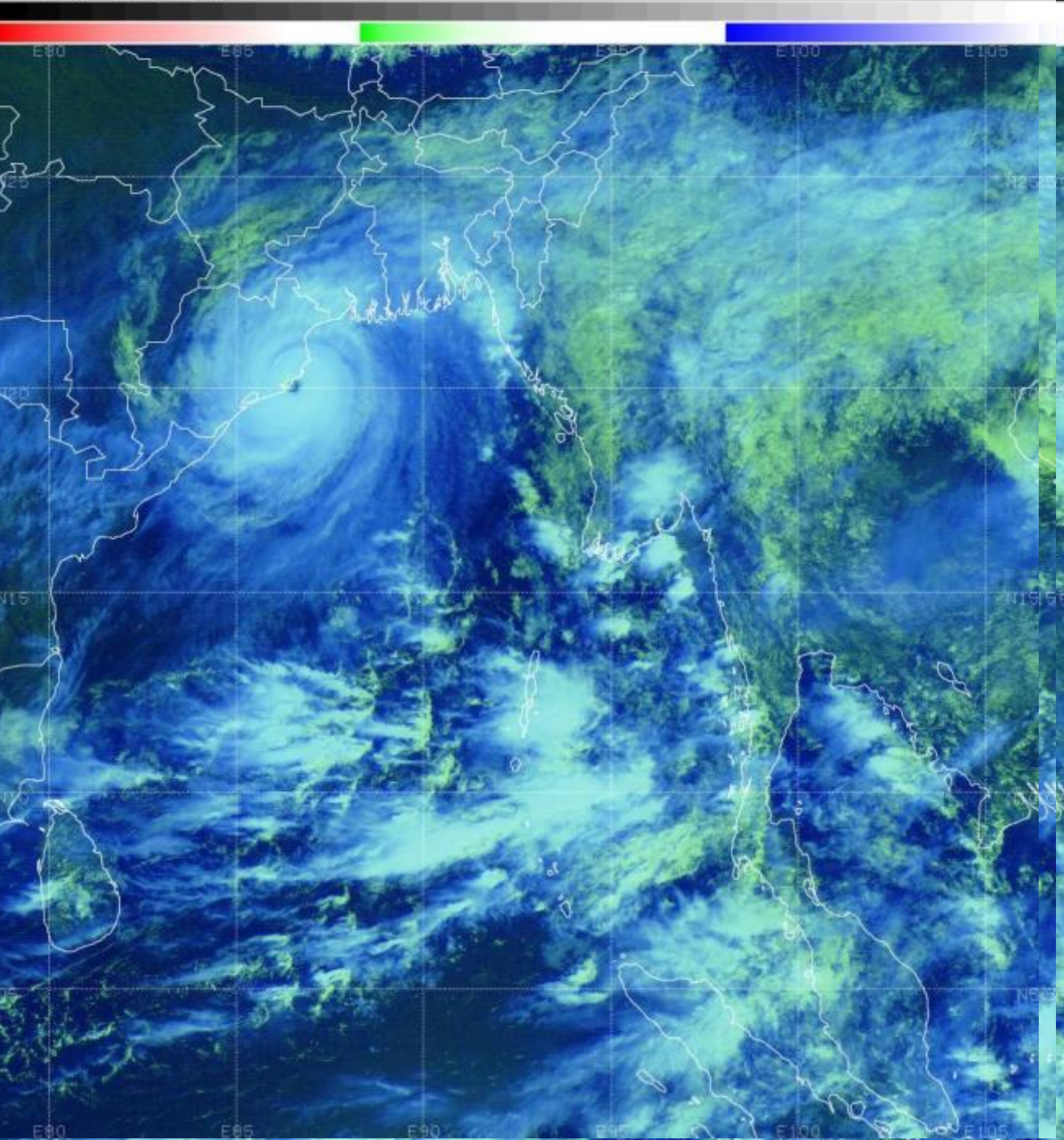
Cyclones will weaken rapidly when they travel over land or colder ocean waters — locations where their heat and/or moisture sources do not exist.

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.





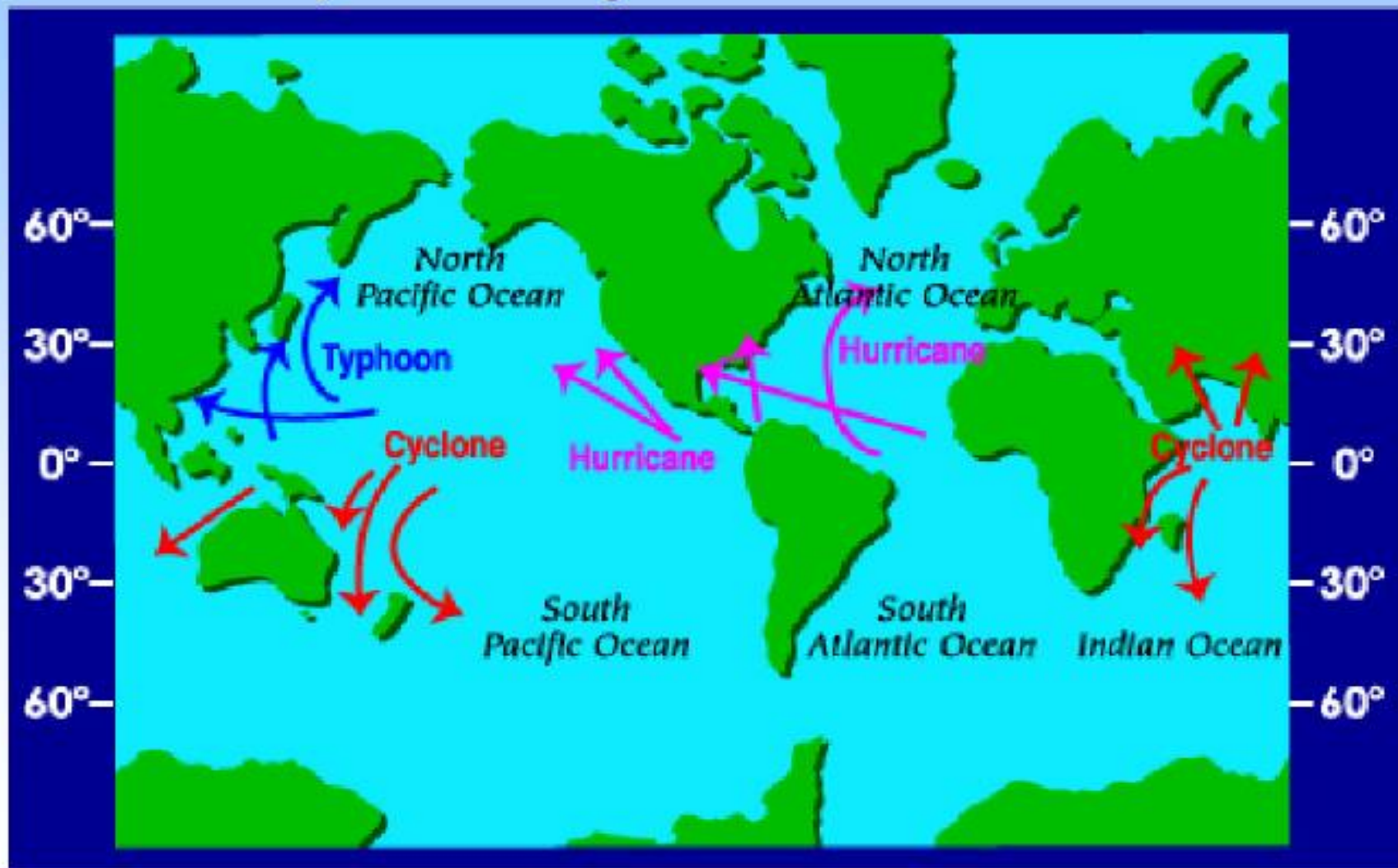
MOVEMENT OF CYCLONE

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 26.5°C.

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

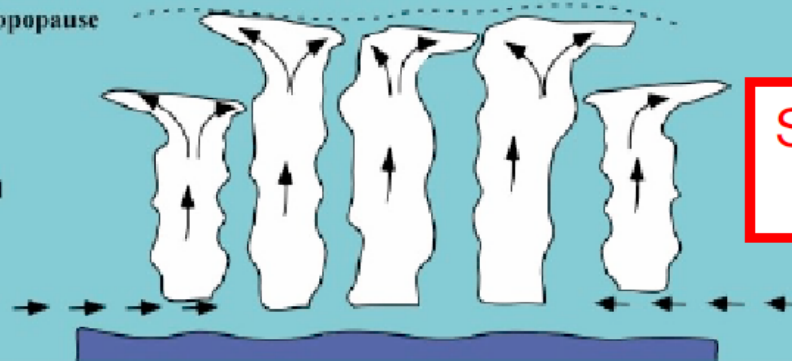
WIND: it must be blowing in the same direction and the same speed from the ocean surface right up to 9,000 meters above sea level.

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

A

Tropopause

Large scale convergence associated with ITCZ, wave, or front triggers convection.



Surface convergence and convection

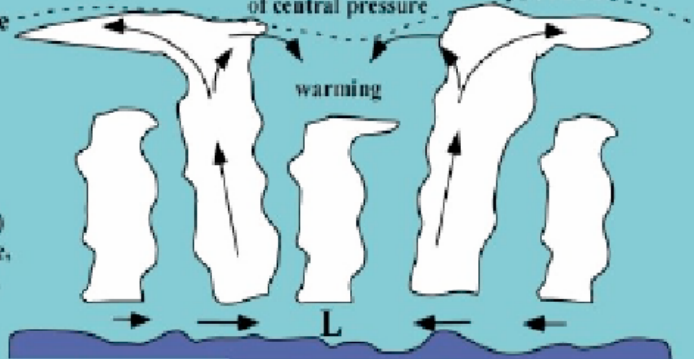
B

Tropopause

Subsidence in center of cloud cluster leads to warming and lowering of central pressure

warming

Surface winds increase, significantly increasing flux of heat and moisture (latent heat) from ocean to atmosphere, destabilizing atmosphere.



Rate of heat and moisture transfer to atmosphere greater for higher sea surface temperatures and wind speeds

Subsidence in eye and outflow

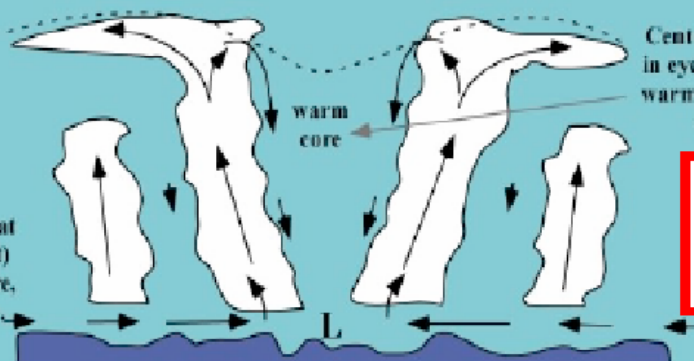
C

Tropopause

warm core

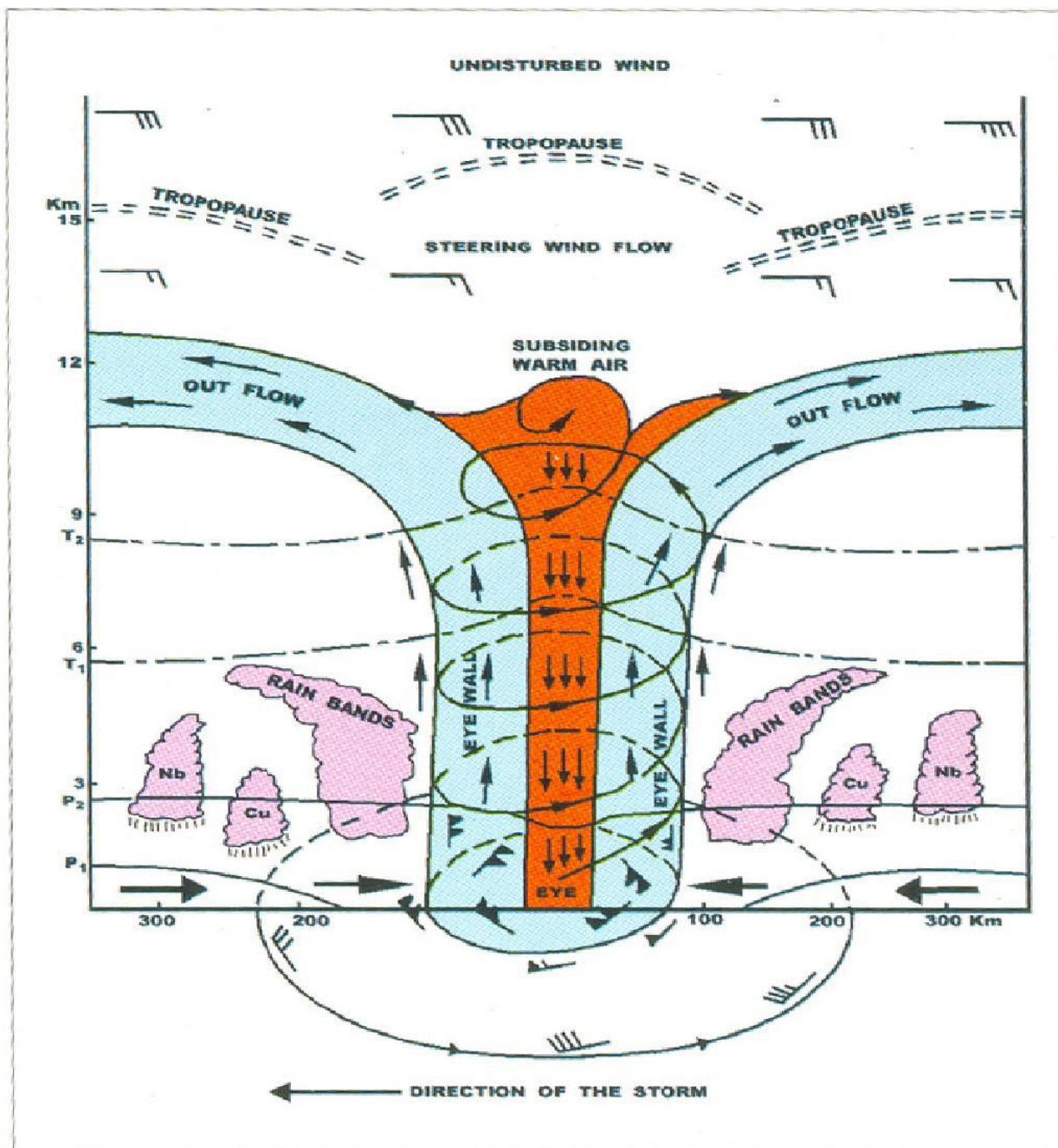
Central low pressure in eye associated with warm core created by subsidence

Strong surface winds maintain large flux of heat and moisture (latent heat) from ocean to atmosphere, destabilizing atmosphere.

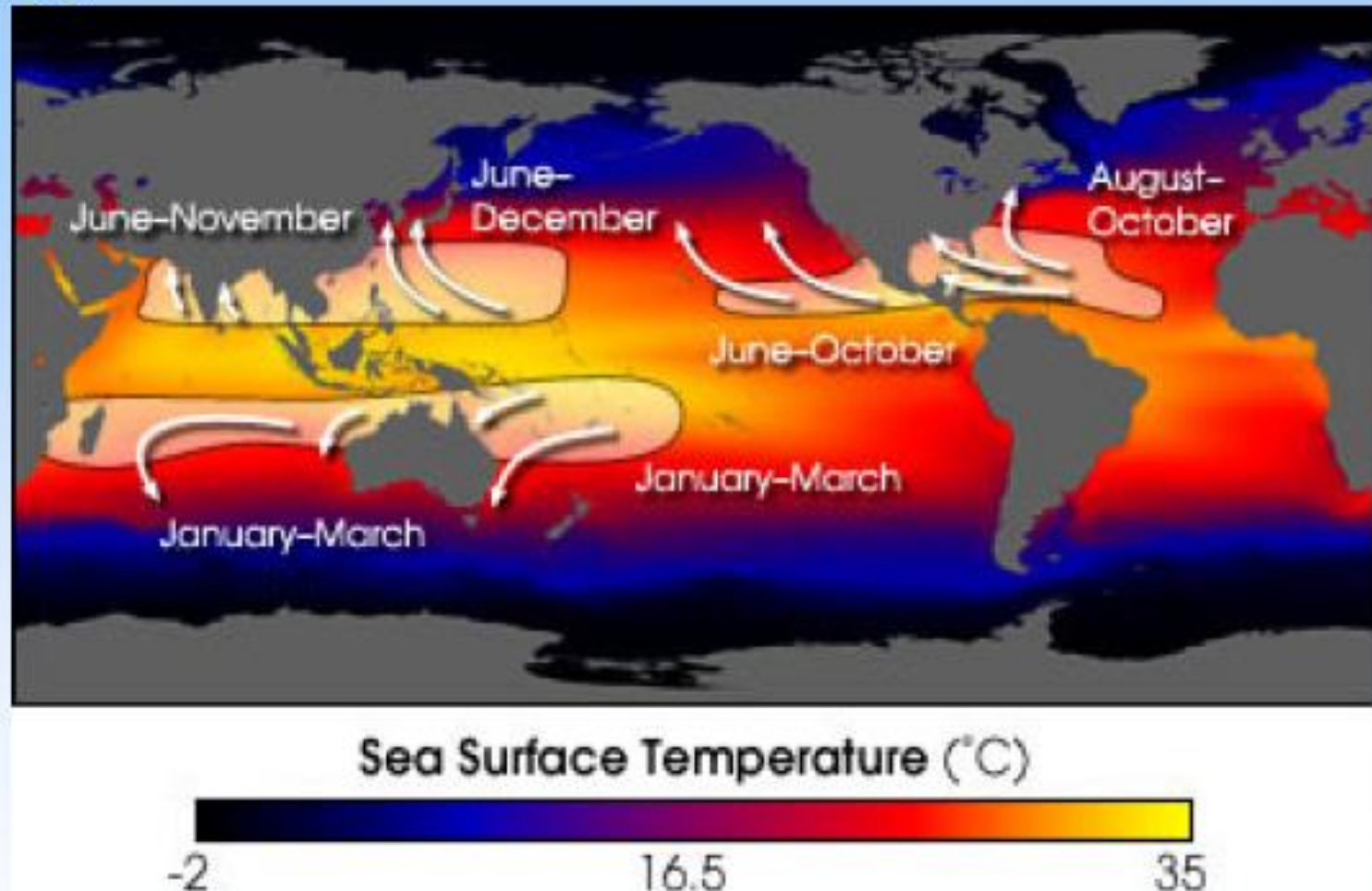


Warm water supplies heat and moisture at an increasing rate as the winds become stronger

Core warms and surface pressure lowers



Regions and seasons $T > 26.5^{\circ}\text{C}$



- 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.

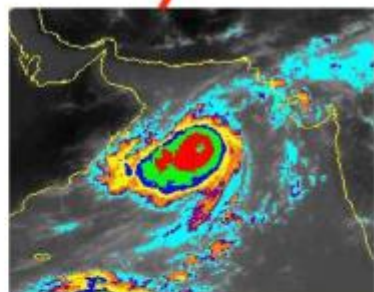


World's Deadliest Tropical Cyclones

- 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)



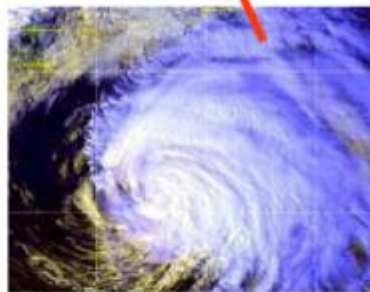
3 Super Cyclones over the Indian Ocean during the past decade



GONU

June 03-07, 2007

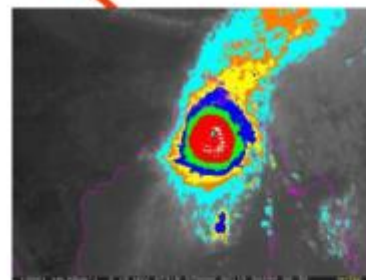
Max Wind 252 km/h



**Orissa
Super Cyclone**

Oct 26-29, 1999

Max Wind 252 km/h



SIDR

Nov 09-16, 2007

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.



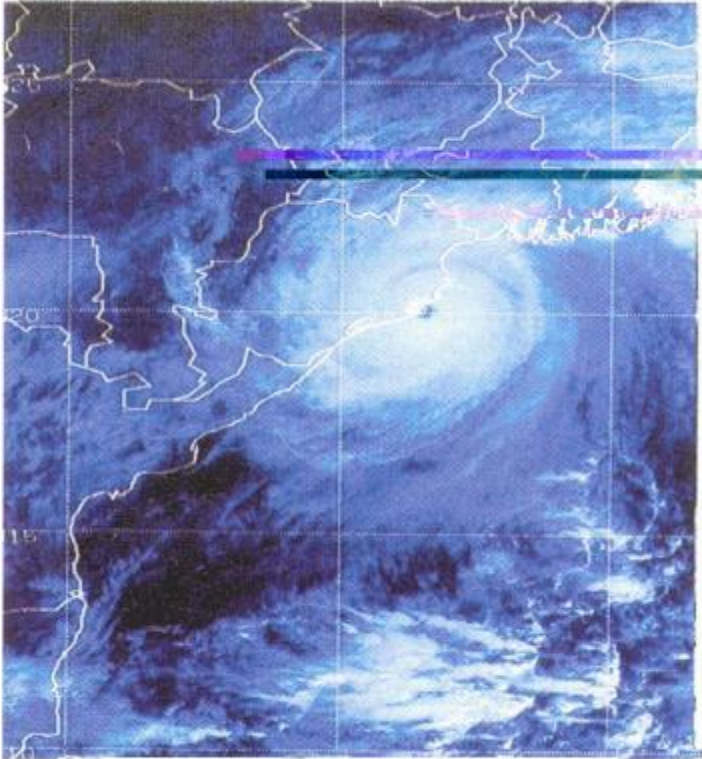
Classification of low pressure system in India

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

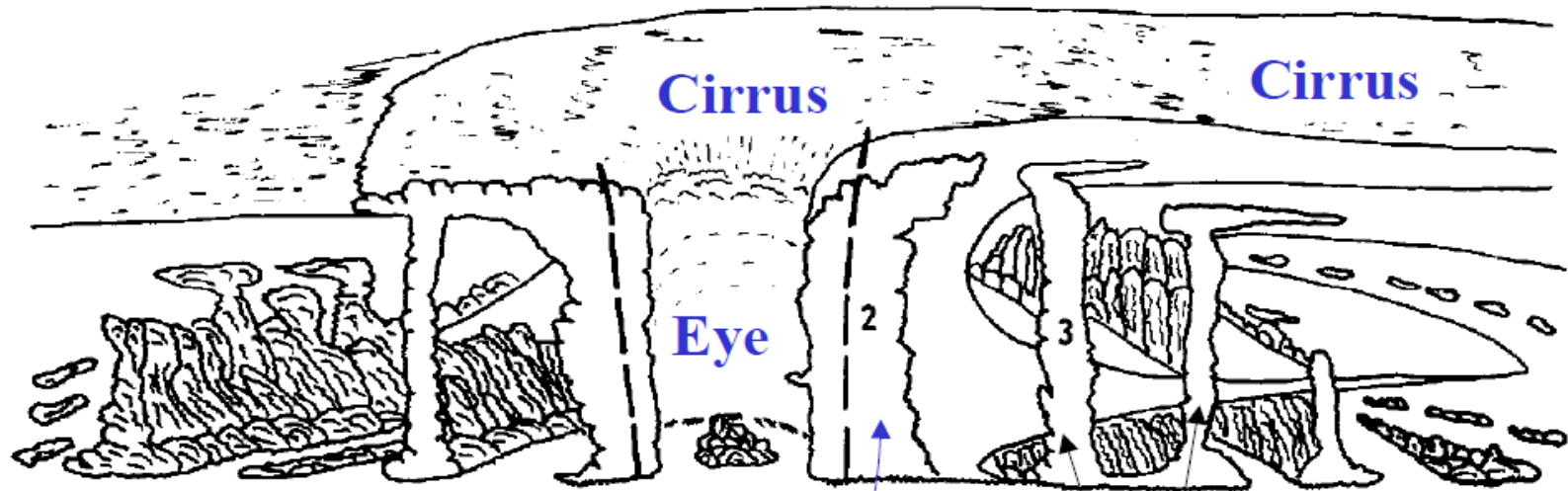
A fully developed tropical cyclone has a central cloud free region of calm winds, known as the “eye” of the cyclone with diameter varying from 10 to 50 km. Surrounding the eye is the “wall cloud region” characterised by very strong winds and torrential rains, which has the width of about 10 to 150 km.

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



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

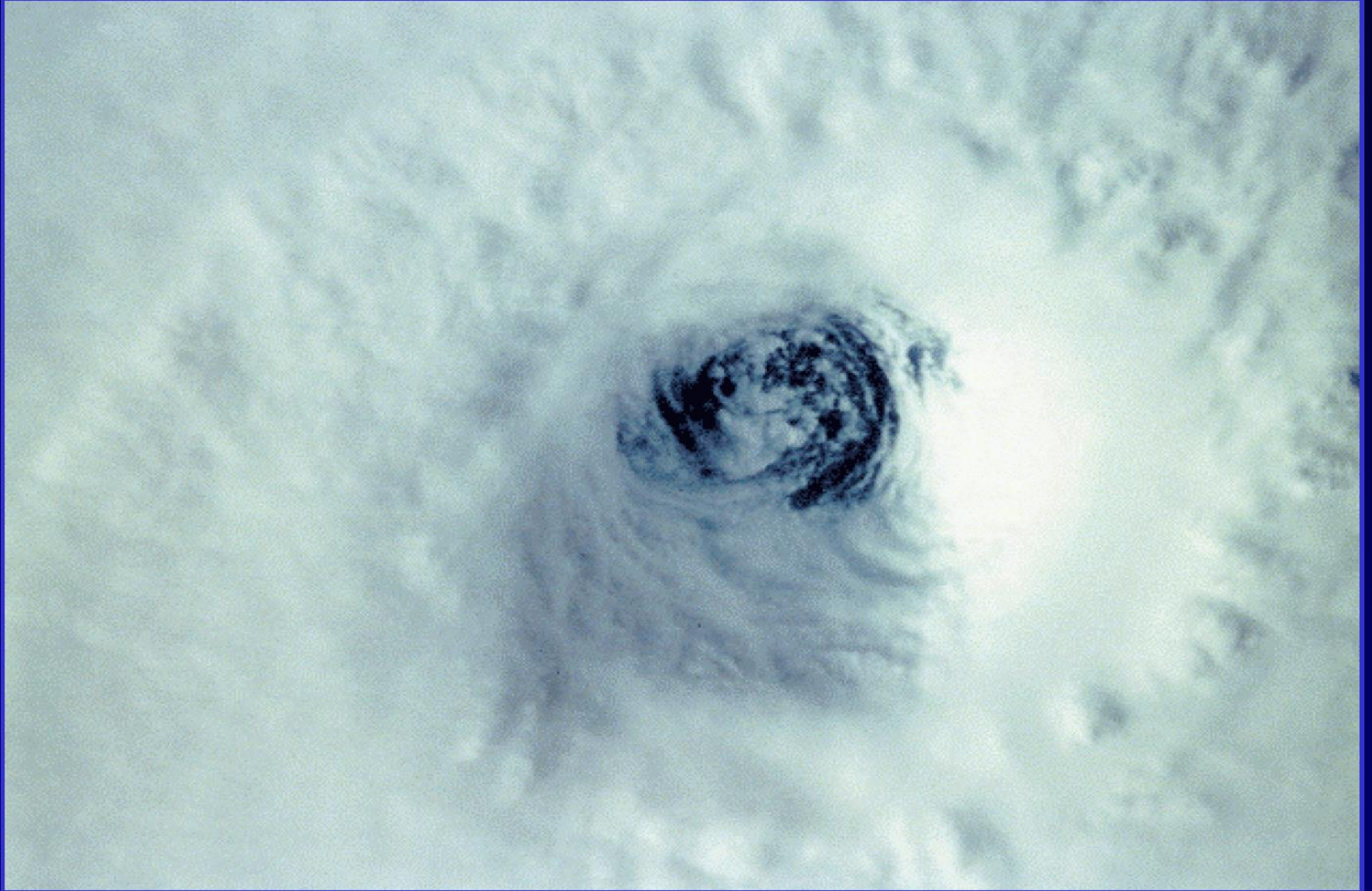
Schematic cross-section through a hurricane



Eyewall

Spiral bands

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 Machilipatnam. 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 $> 5\text{m}$)
- High risk Zone (Surge height between 3-5m)
- Moderate risk zone (Surge height between 1.5 to 3m)
- Minimal risk zone (Surge height $< 1.5\text{m}$)

The coastal areas and off-shore islands of Bengal and adjoining Bangladesh are the most storm-surge prone ($\sim 10\text{-}13\text{m}$) – VHRZ

East coast of India between Paradip and Balasore in Orissa ($\sim 5\text{-}7\text{m}$) – VHRZ

Andhra coast between Bapatla and Kakinada holding estuaries of two major rivers Krishna and Godavari ($\sim 5\text{-}7\text{m}$) – VHRZ

Tamilnadu coast between Pamban and Nagapattinam ($\sim 3\text{-}5\text{m}$) – HRZ
Gujarat along the west coast of India ($\sim 2\text{-}3\text{m}$) -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

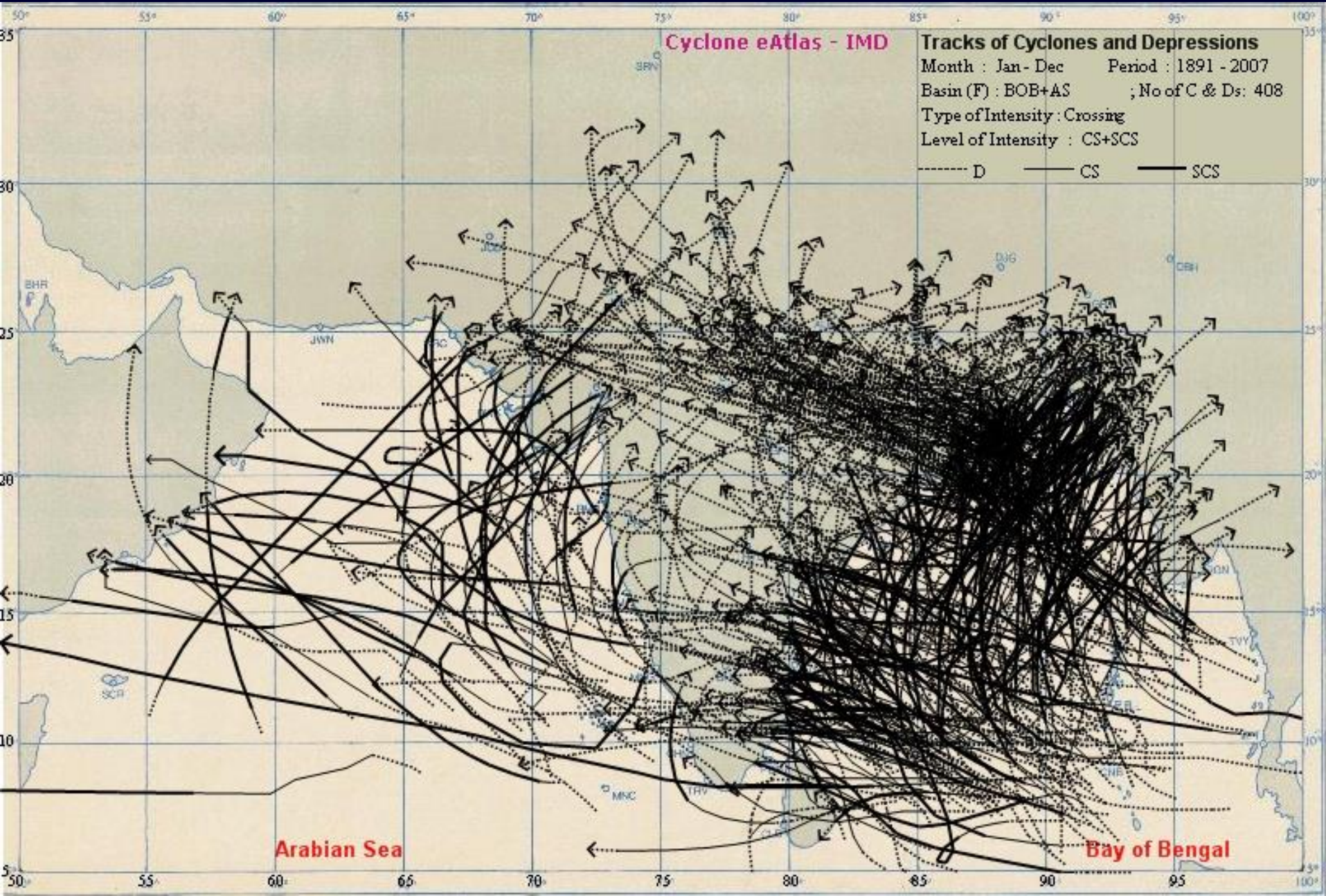
Satellite Techniques

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 at least 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

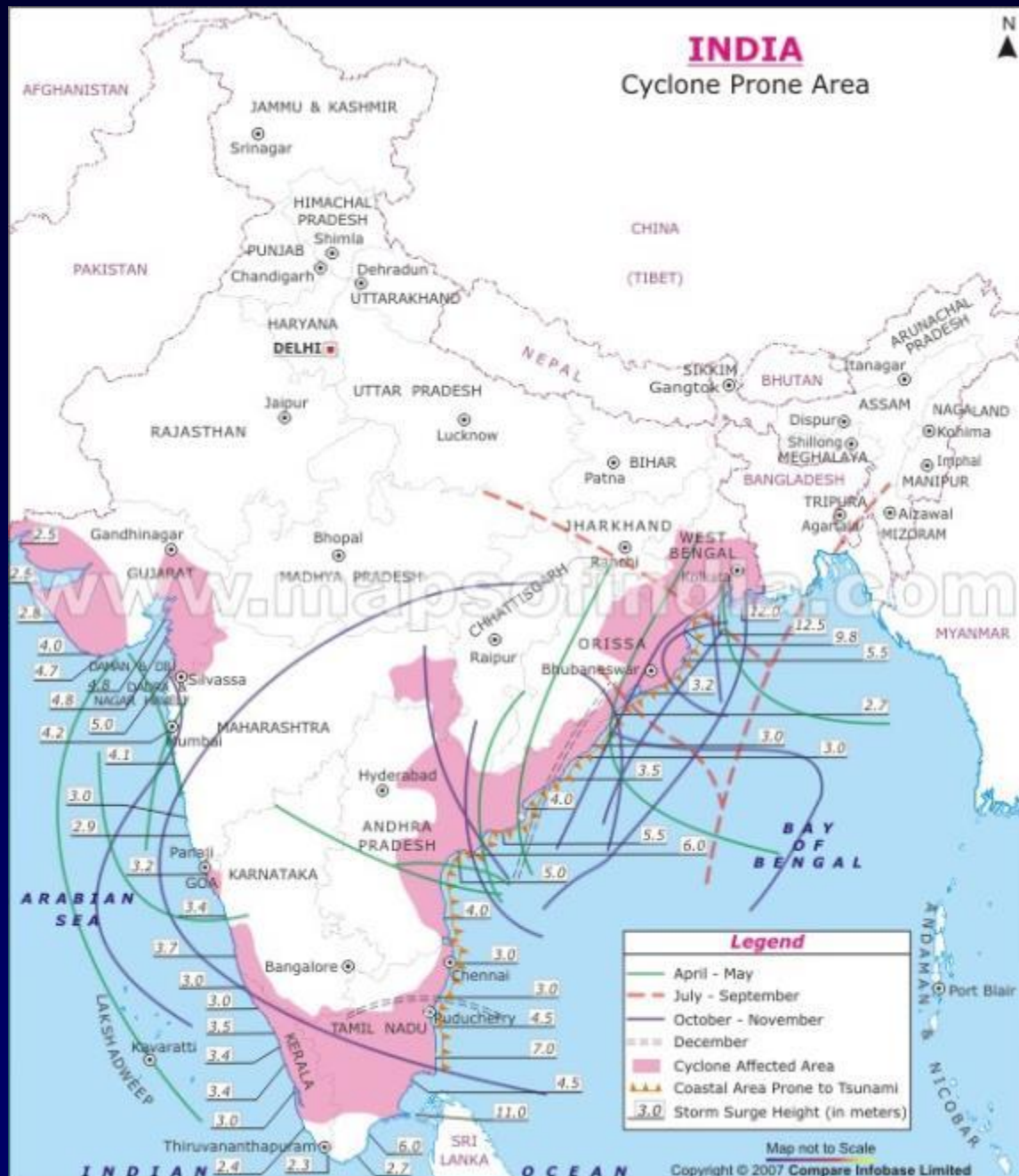
(4) Post landfall outlook

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'
<u>B'desh</u>	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'
<u>B'desh</u>	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	<u>Bul bul</u>
Sri Lanka	Priya	--	Asiri	Aa'siri	Gigum	Gi'gum	Soba	--
Thailand	Komen	Goh-men	Mora	Moh-rar	Phethai	Pay-ti	Amphan	Um-pun



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

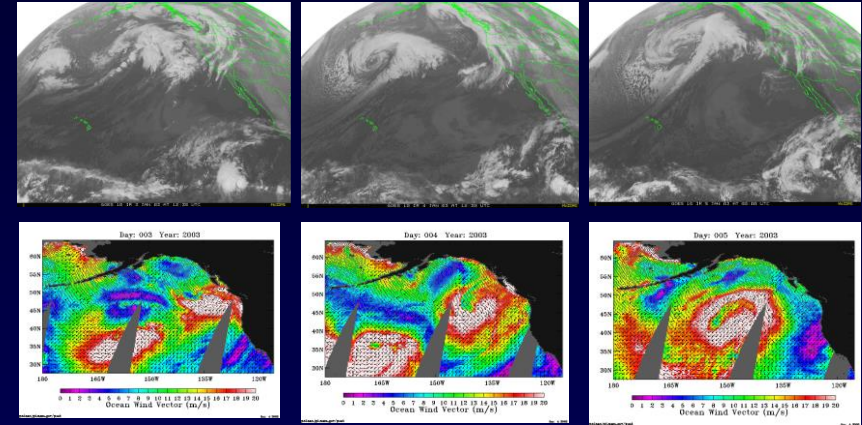
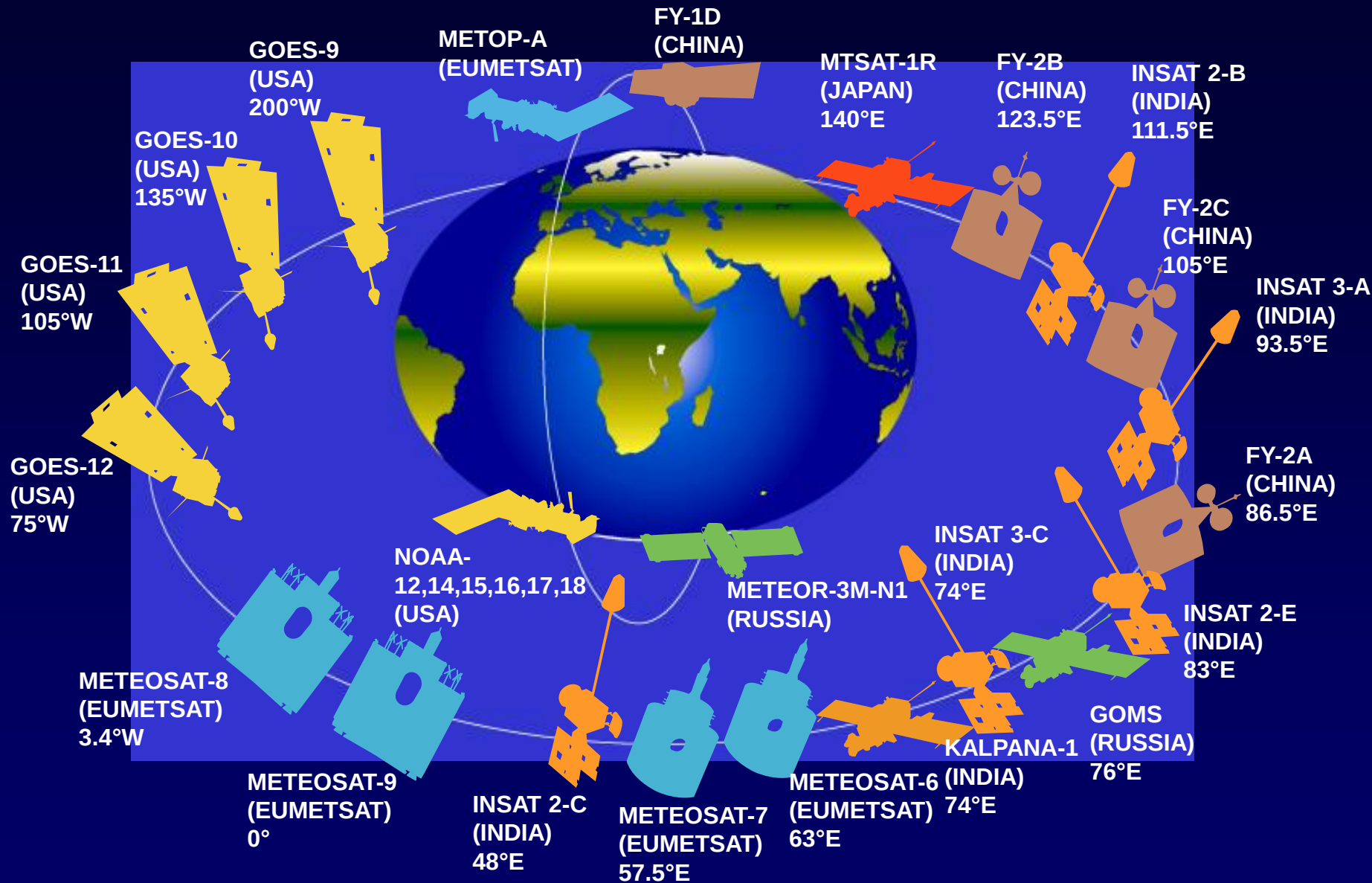


Figure 1: GOES visible (top) and QuikScat wind speed (lower) sequences collected over the North Pacific on 4-6 Jan, 2003. The visible images show the location and extent of two cyclones and the wind image provides intensity information.

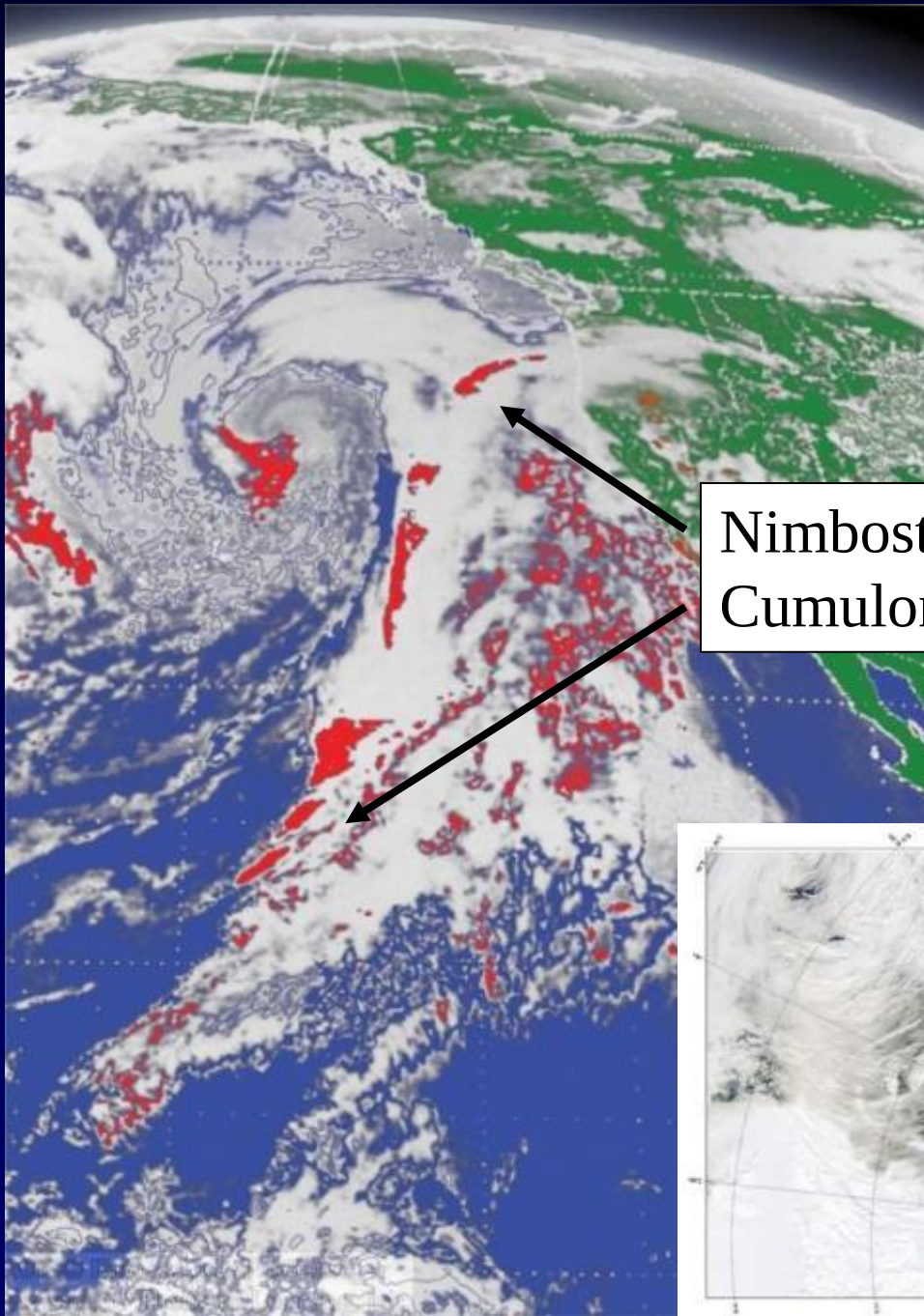
Sensor	Parameter	Spatial Resolution	Temporal freq.	Availability
GOES	Reflectance (visible). Brightness temp. (IR)	6 km	½ hr	1979 - present
AVHRR	Reflectance (visible). Brightness Temp. (IR)	4 km	6 hr (2 satellites)	1985 - present
QuikScat	Wind speed and direction	25 km	12 hrs	1999 - present
SSM/I	Brightness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

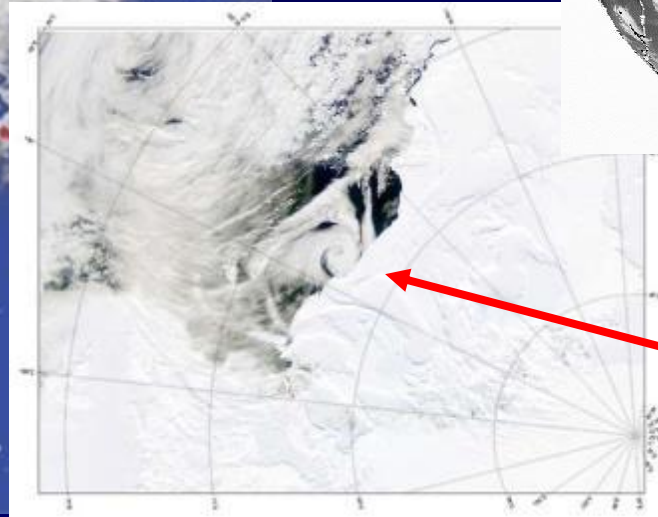
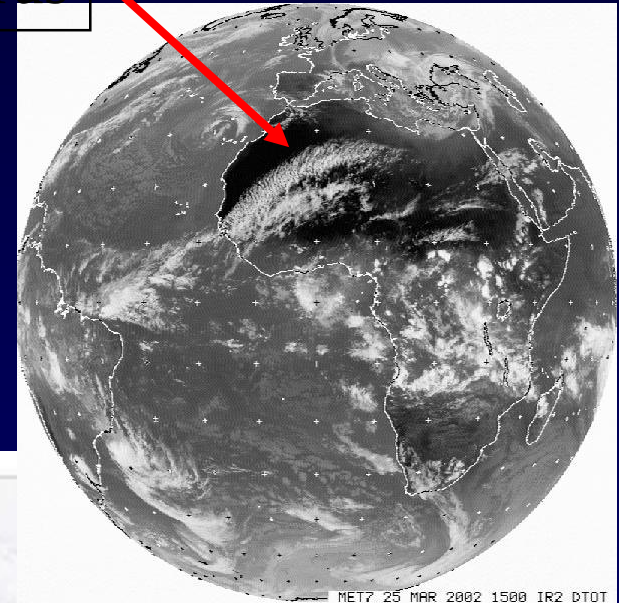


Identifying Clouds Satellite Imagery



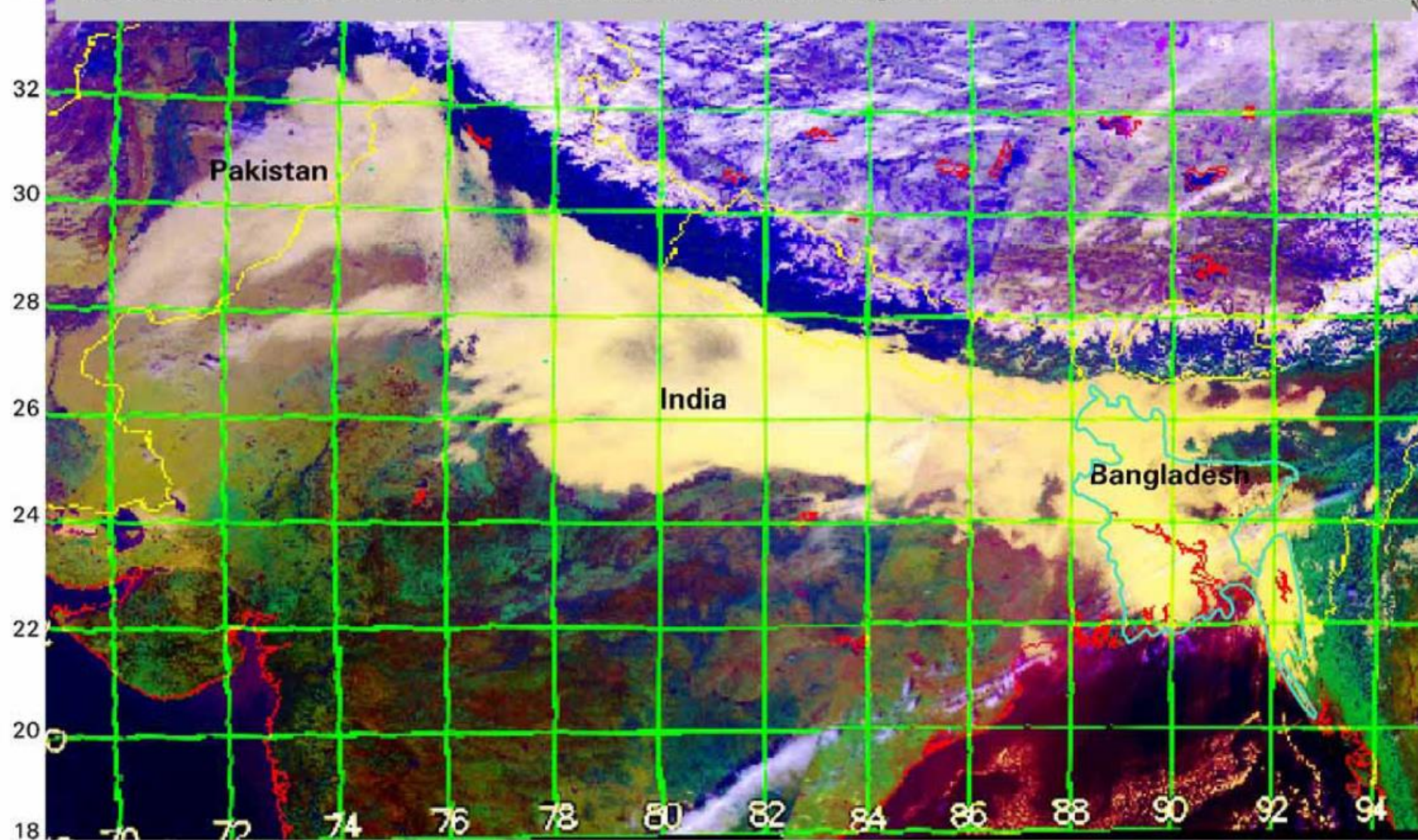
Nimbostratus
Cumulonimbus

Cirrus

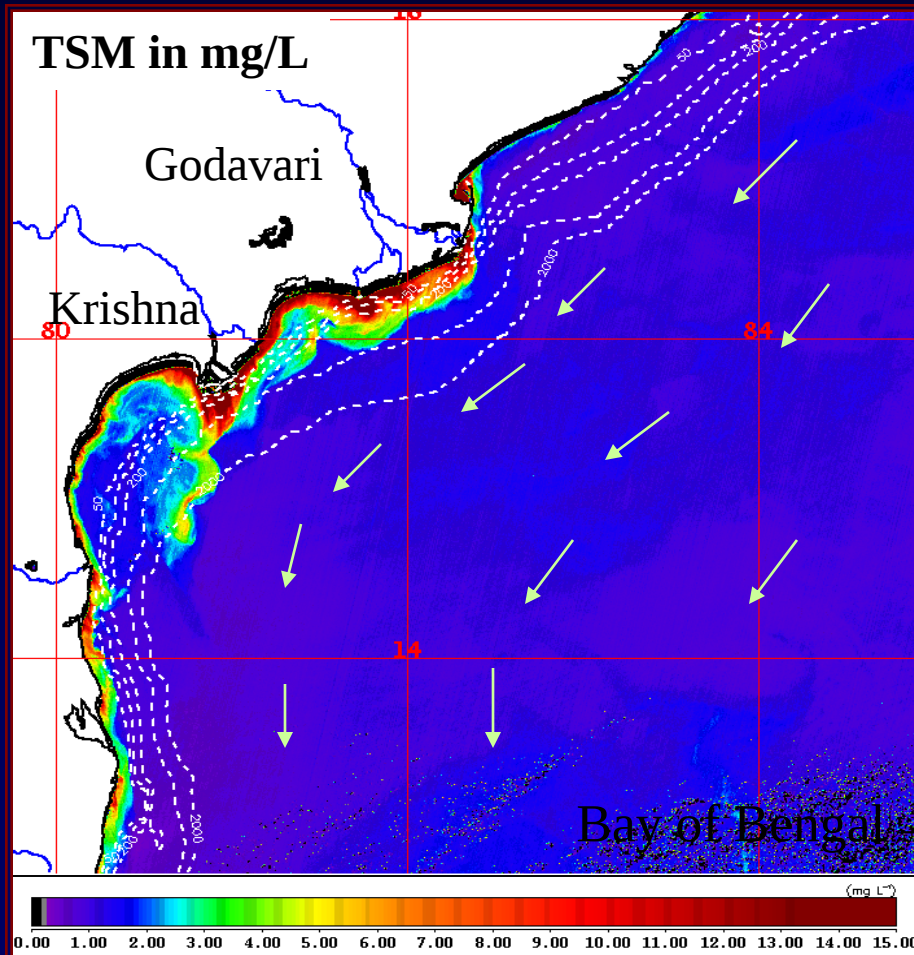


Polar Storm

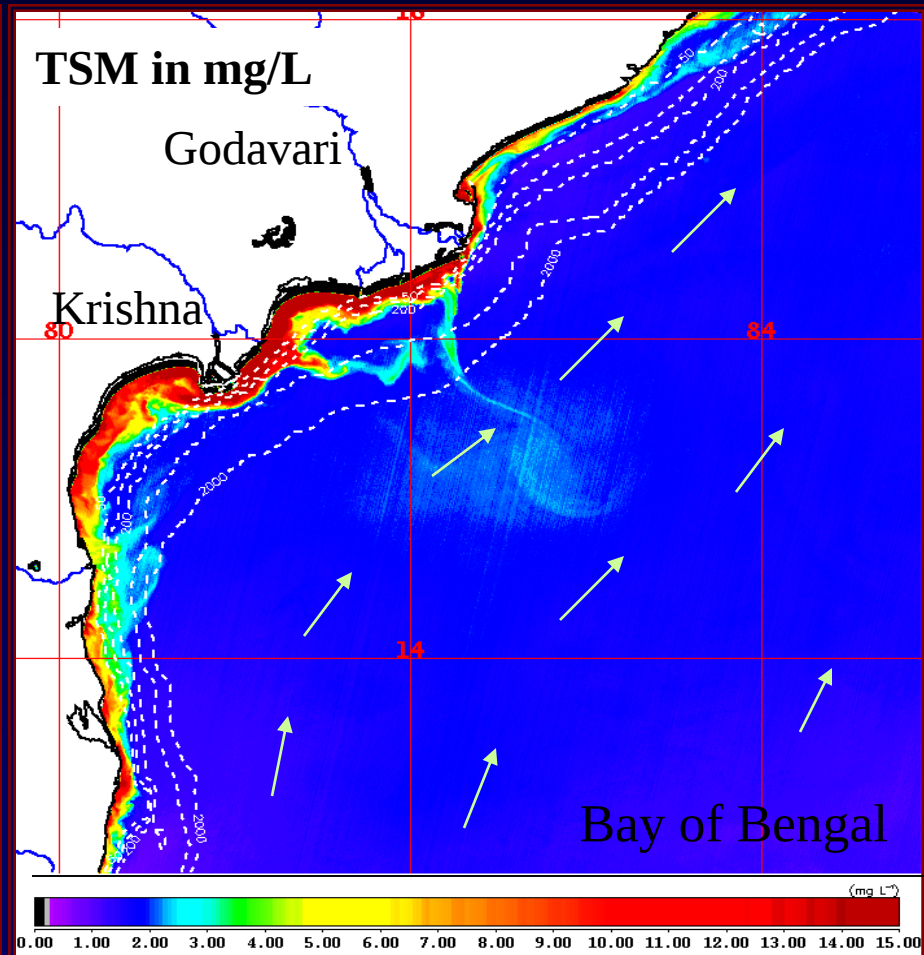
NOAA satellite picture of cold wave over Pakistan , India and Bangladesh, 3rd Jan. 2004, 10:00 & 11:45 BST



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



12 Dec 1999



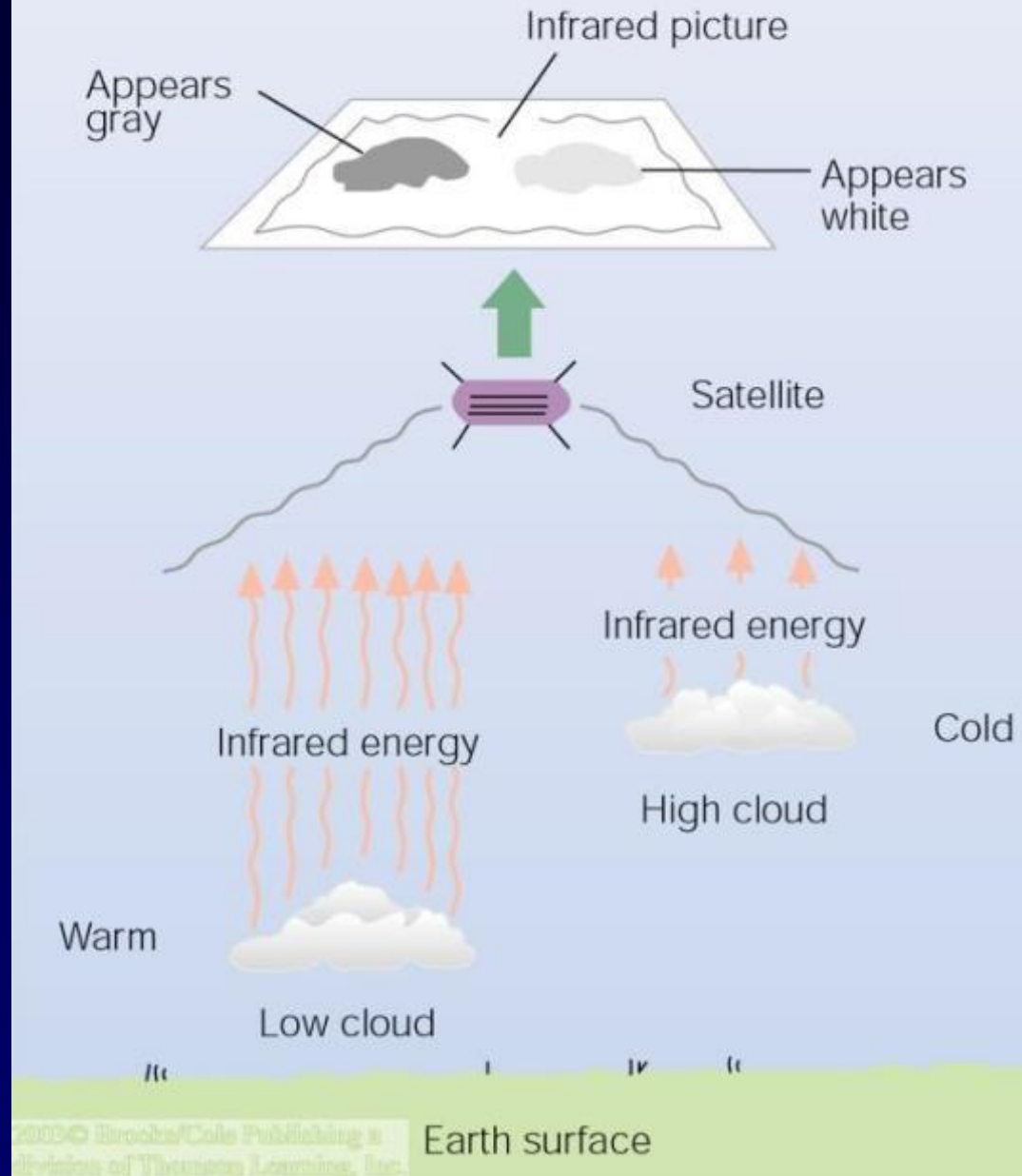
1 Mar 2000



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.

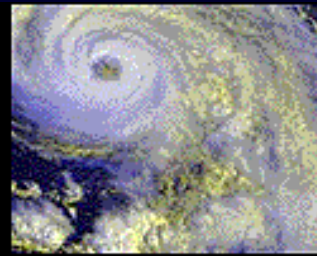
Though the water vapour imaging capability is available only on the geostationary satellite, the visible and infrared imagers are available on geostationary as well as polar orbiting satellites. The last four are currently available only on polar orbiting systems.

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, <i>etc.</i>)
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 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

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.

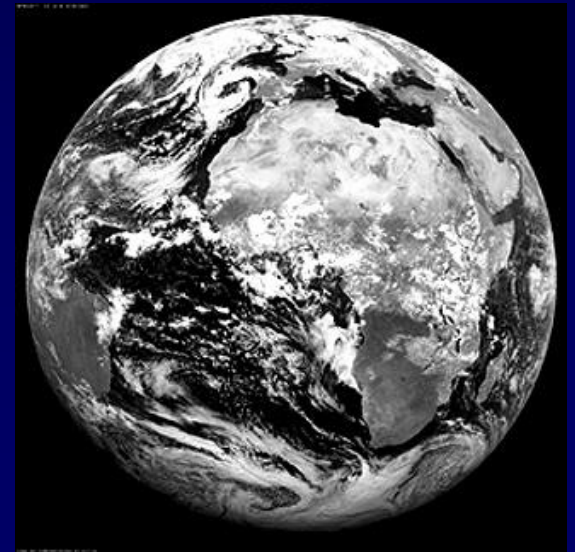
Using GOES imagery, meteorologists were able to measure the frame-to-frame movement of selected clouds at different altitudes and to obtain their wind direction and speed in order to better understand atmospheric circulation patterns.



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

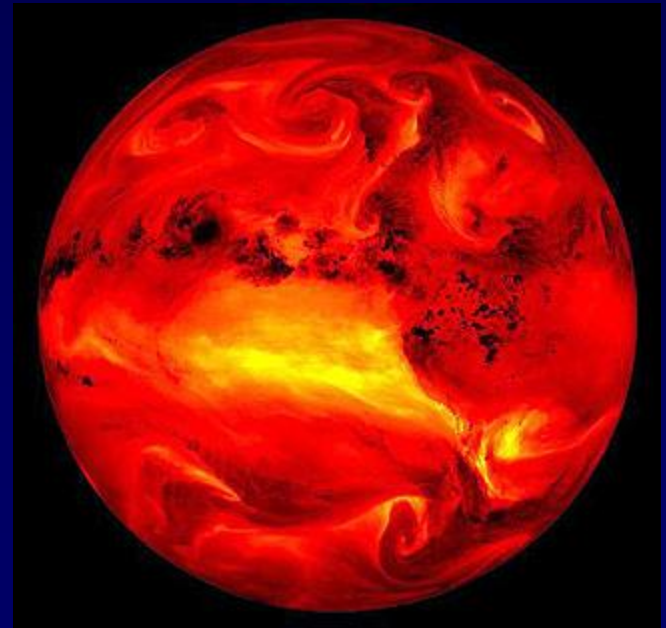
These satellites sense in three spectral bands: 0.4 - 1.1 μm , 5.7 - 7.1 μm , and 10.5 - 12.5 μm . A recent Meteosat image, showing all of Africa and most of Europe, across the South Atlantic to Brazil, was taken during the day of June 26, 2000:

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 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.

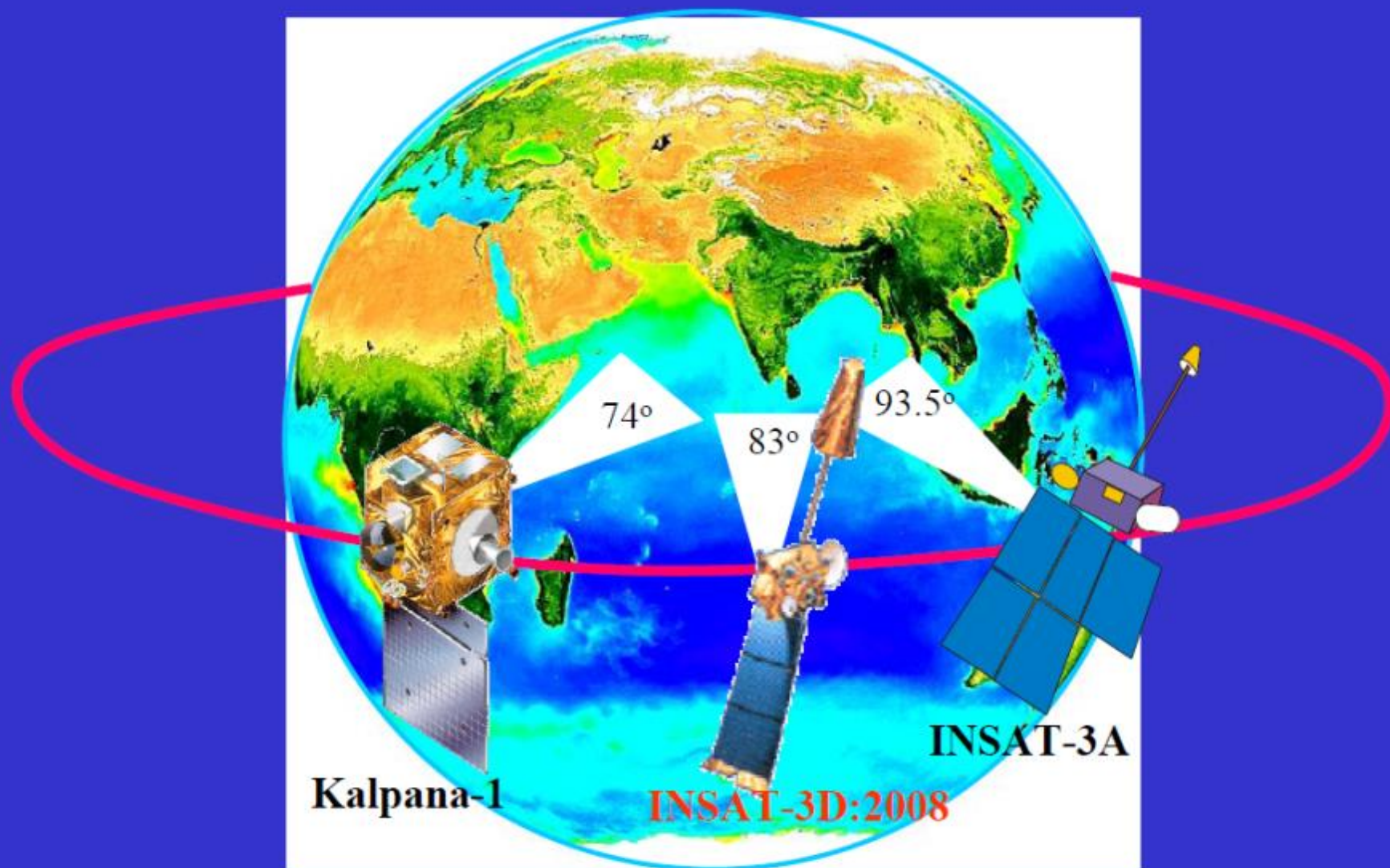


INDIAN NATIONAL SATELLITE (INSAT) FOR METEOROLOGICAL APPLICATIONS

Satellite	Launch Date	Payload	Major Applications
INSAT - 1A	April 1982	Very High Resolutions Radiometer (VHRR) Visible : 0.55-0.75 μm (Res : 2.75 km) IR : 10.5 – 12.5 μm (Res : 11 Km)	Monitoring cyclones & monsoon CMV Winds OLR Rainfall Estimation Mesoscale features
INSAT - 1B	August 1983		
INSAT - 1C	July 1988		
INSAT – 1D	June 1990		
INSAT – 2A	July 1992	Visible : 0.55-0.75 μm (Res : 2 km) IR : 10.5 – 12.5 μm (Res : 8 Km)	Flood/intense precipitation advisory Snow detection
INSAT – 2B	July 1993		
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 μm	
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)**

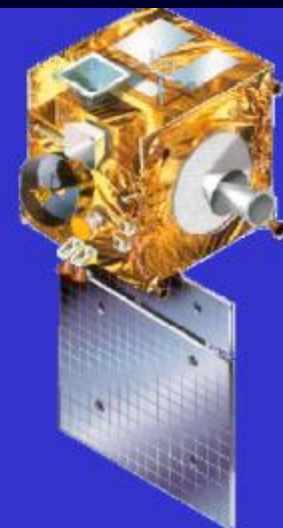
- Visible : 0.55 – 0.75
- Water vapour : 5.70 – 7.10
- Thermal Infra Red : 10.5 – 12.5

- **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





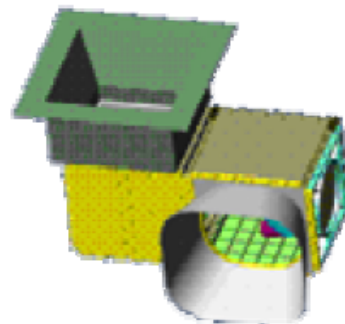
INSAT - 3D



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

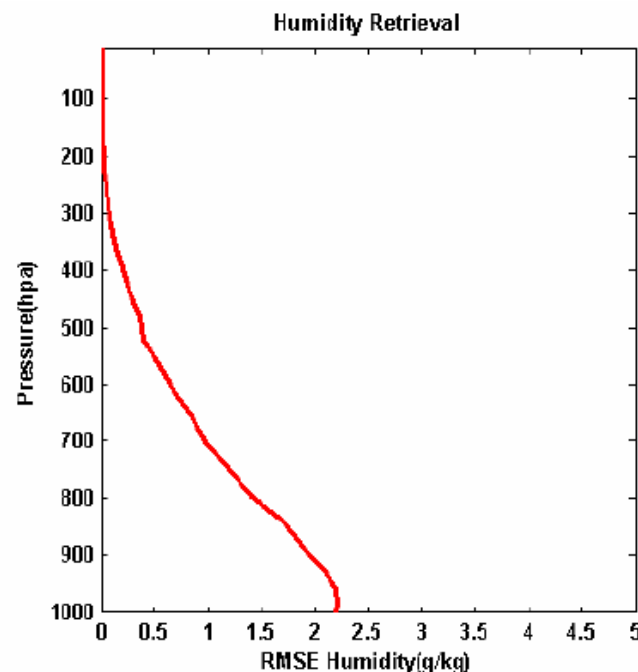
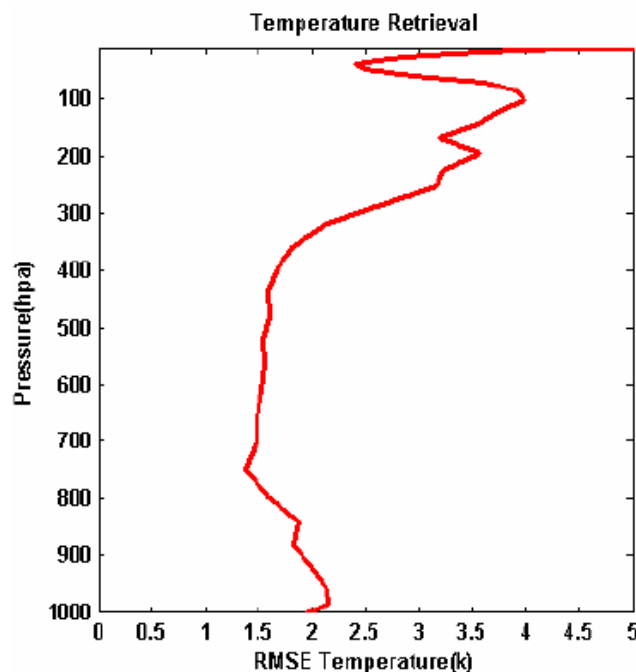
Channel No.	Central Wavelength in um	Principal absorbing constituents
1	14.71	CO-2 band
2	14.37	CO-2 band
3	14.06	CO-2 band
4	13.96	CO-2 band
5	13.37	CO-2 band
6	12.66	water vapor
7	12.02	water vapor
8	11.03	window
9	9.71	ozone
10	7.43	water vapor
11	7.02	water vapor
12	6.51	water vapor
13	4.57	N-2 0
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

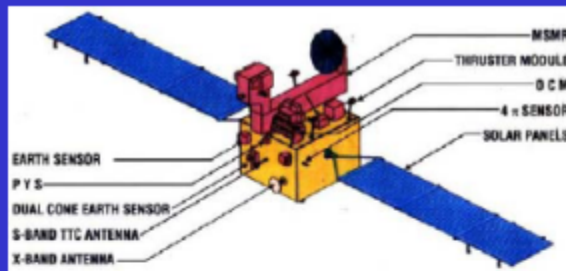
- Tropical regions have high water vapour content
- Effective Channels Simulated for tropical atmosphere
- Regression Retrieval for temperature and humidity profile
 - Training dataset : SeeBor (SSEC/UW)
 - RT Model : PLOD Fast RT model



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

IRS-P4

Oceansat-1



OCM

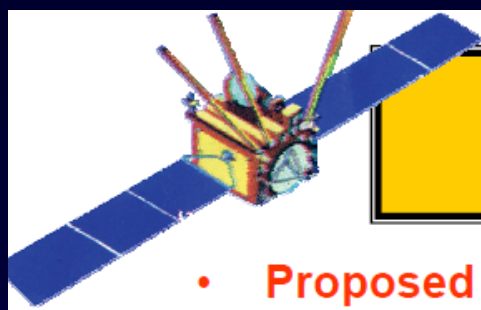
Specifications

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

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

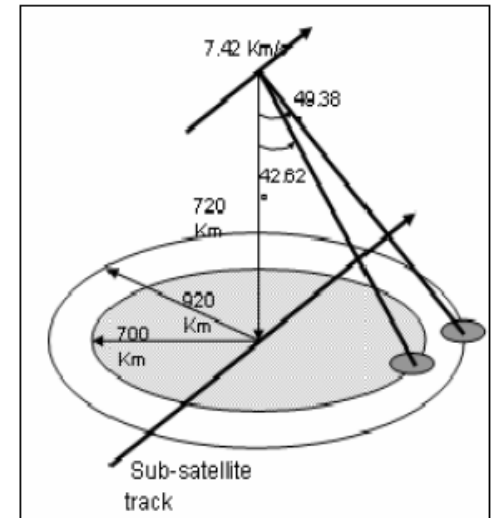
• Applications:

- 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	HH	VV
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 Geometry



EGHA-TROPQUES

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	19.99ointended:20o
Apoapsis	865 km (537 mi) intended:867
Periapsis	864 km (537 mi) intended: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

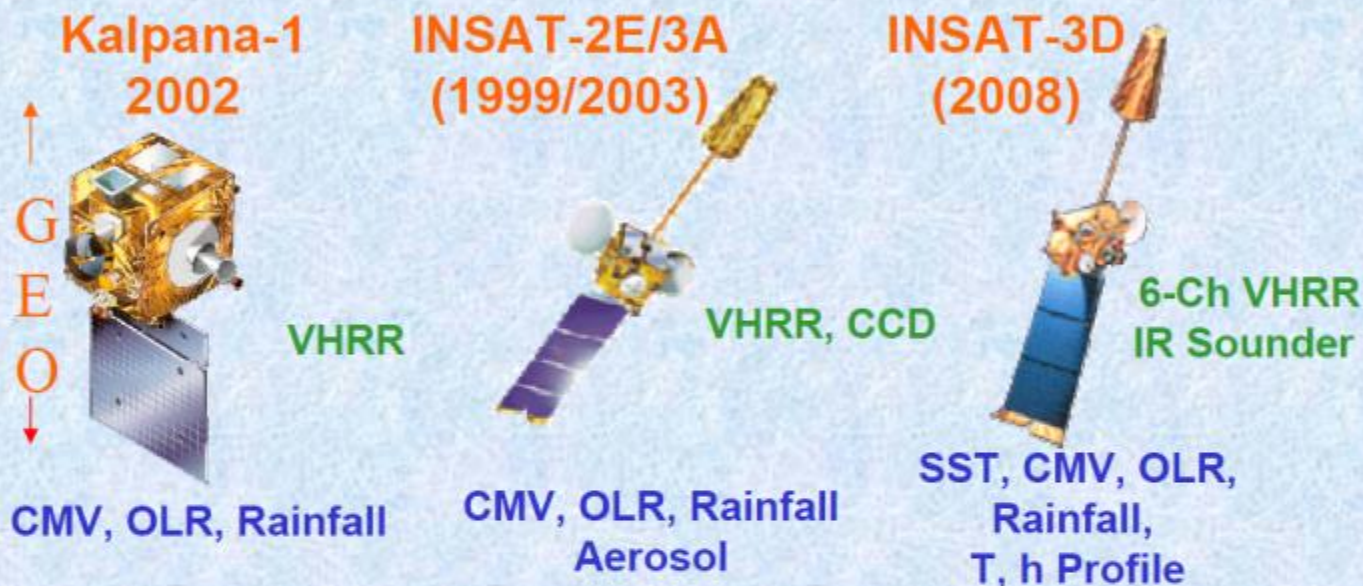
- **INSAT 3D Repeat (~ 2012)**
- **Follow-up of INSAT-3D**
 - **Defining Stage**
 - **Very High resolution Radiometer**
 - **Sounder – more channels**
 - Different channel simulations using hyperspectral Sounder observation (Metop-IASI/ Aqua-AIRS)
 - Sensitivity study with different central wavenumber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

... contd

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



- INSAT-3D R
- Geo-HR
(~2012)

- Follow-up
(~2015)



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.

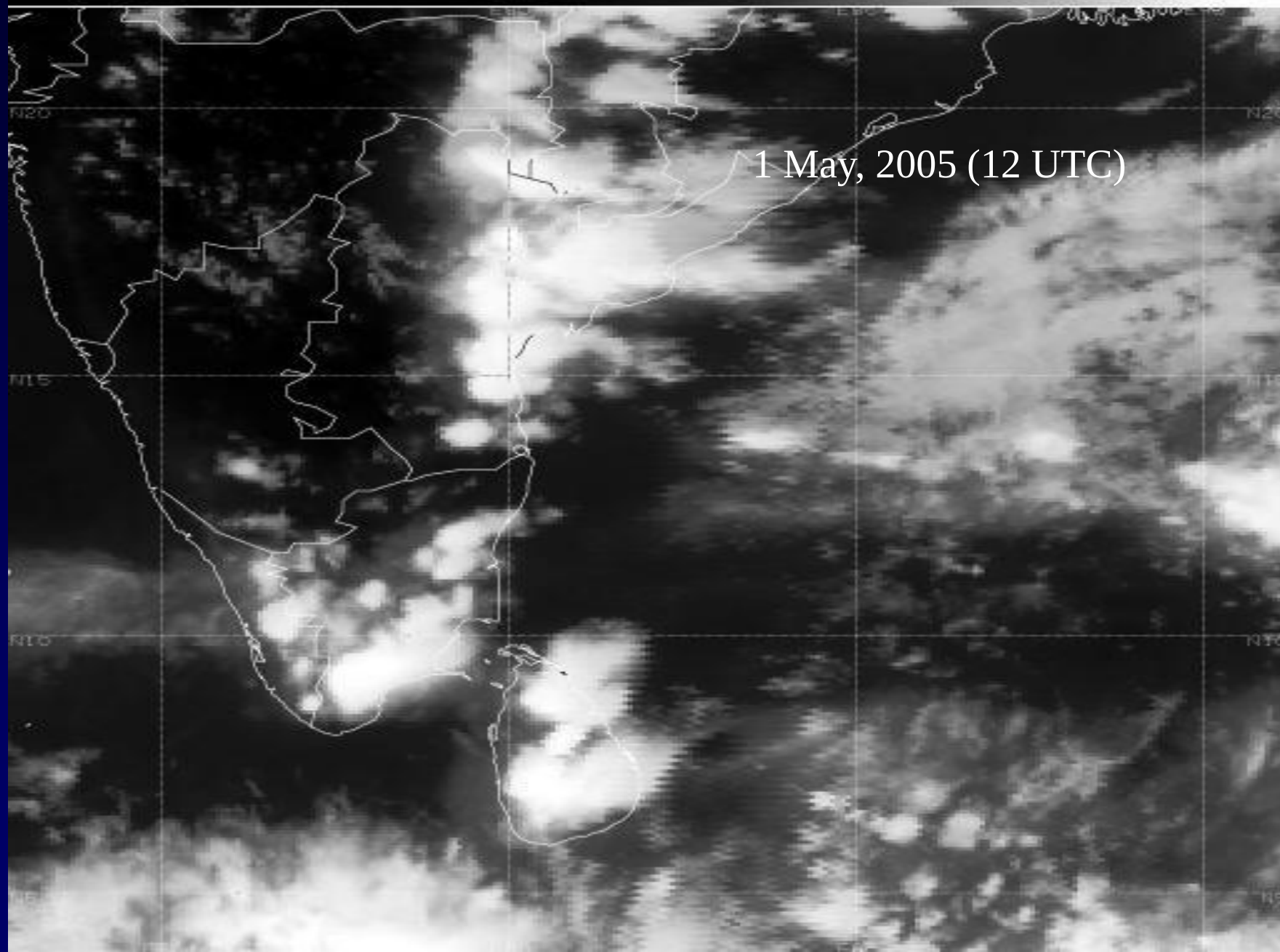
During the last few years a number of polar and geostationary satellites carrying a sophisticated array of instruments making measurements in the various regions of electromagnetic spectrum have provided valuable quantitative information about the cyclones.

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.



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

- 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



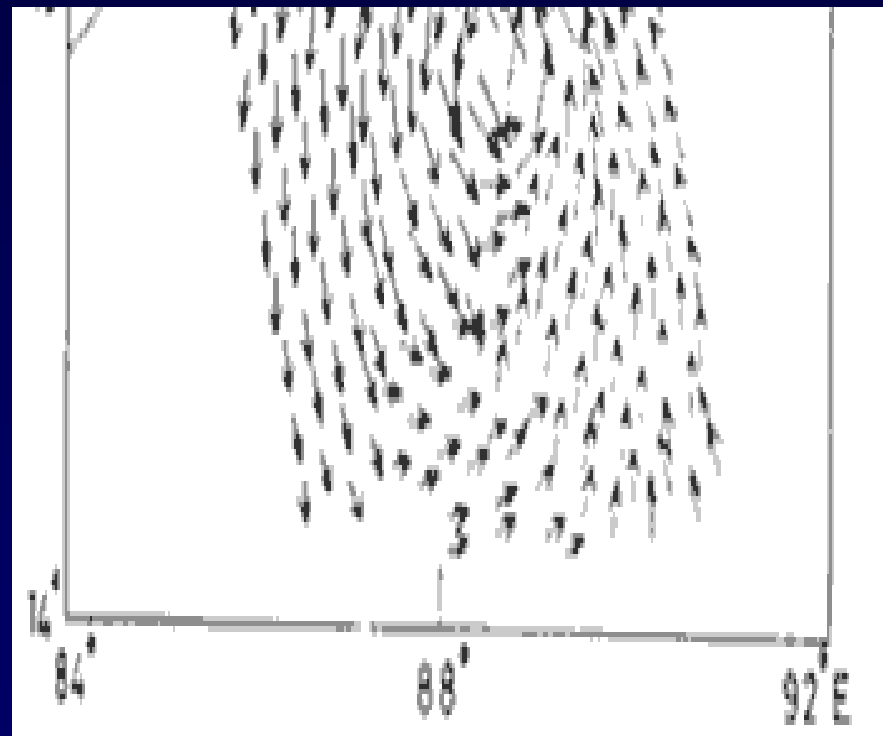
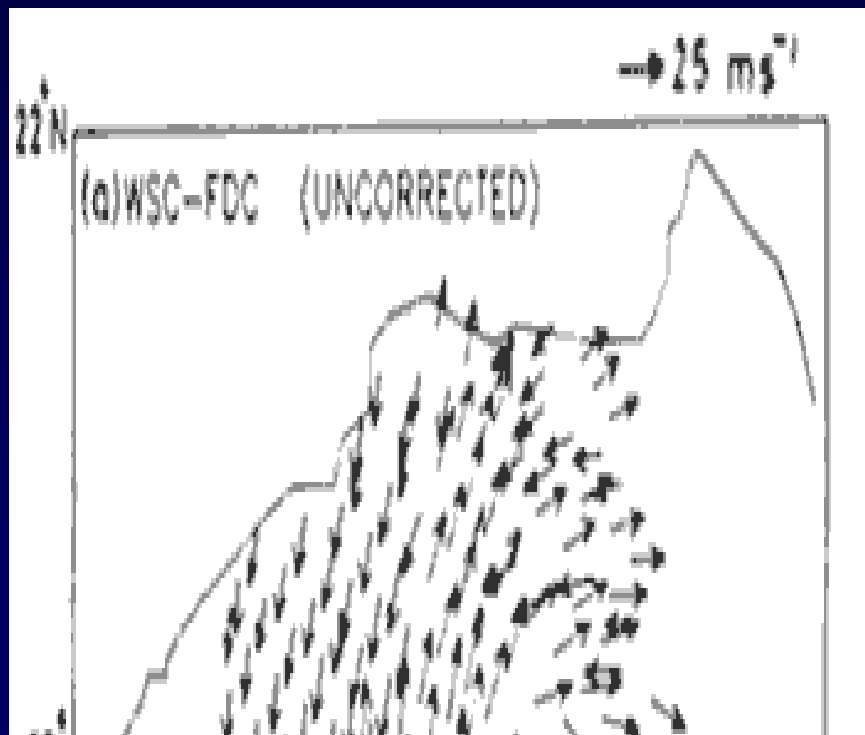
The following products are available in Oceansat-2 and Megha-Tropiques (polar orbiting satellites)

- 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).

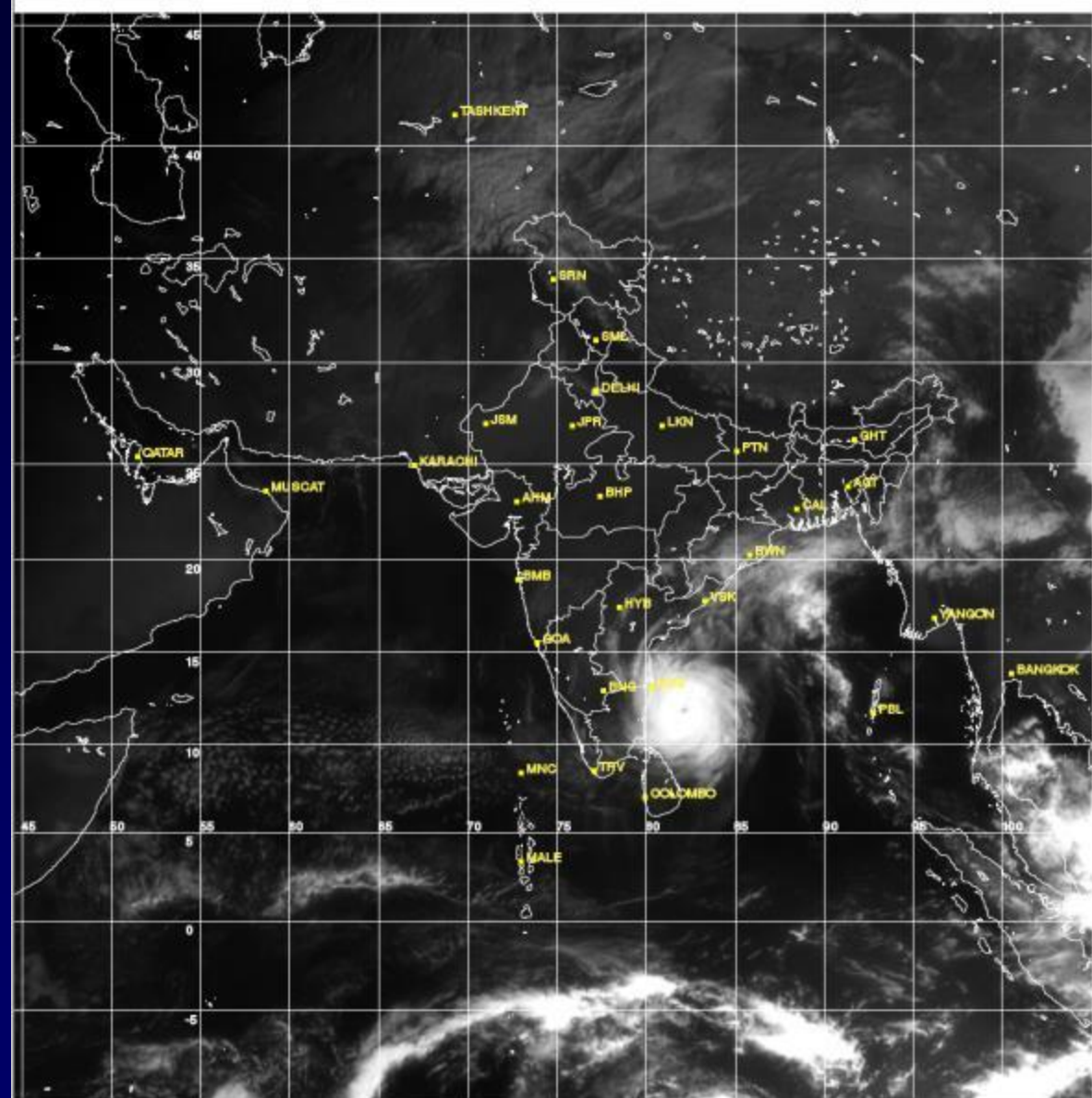
The **Special Sensor microwave/Imager** onboard the US Defense Meteorological Satellite Program (DNSP) provide measurements of reflected and emitted microwave radiation at frequencies 19.4, 22.2, 37.0 and 85.5 GHz. All these channels are dual polarized except the 22.2 GHz which provides polarizaion only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



THANE CYCLONE

VIS Linear Stretch 1.0%



The very severe cyclonic storm **THANE** over southwest Bay of Bengal moved west-southwestward and lay centered at 0530 hrs IST of today, the 29th December 2011 near latitude 12.3°N and longitude 83.0°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 30th 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. °N/ long. °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.

DROUGHT

Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (G.Hagman 1984).

Droughts have no universal definition. As drought definitions are region specific, reflecting differences in climatic characteristics as well as incorporating different physical, biological and socio-economic variables, it is usually difficult to transfer definitions derived for one region to another

However some of the common definitions for drought

The Director of Common Wealth Bureau of Meteorology in 1965 suggested a broad definition of drought as “severe water shortage”.

Definition given by Palmer states that “Drought is an interval of time, generally of the order of months or years in duration, during which the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply (Palmer, 1965)

According to Mc Mohan and Diaz Arena (1982), “Drought is a period of abnormally dry weather sufficiently for the lack of precipitation to cause a serious hydrological imbalance and carries connotations of a moisture deficiency with respect to man’s usage of water

By studying the above definitions it can be understood that drought is mainly concerned with the shortage of water which in turn affects availability of food and fodder thereby leading to displacement and loss to economies as a whole.

Droughts can be classified in four major categories:

- ❖ Meteorological drought
- ❖ Hydrological drought
- ❖ Agricultural drought
- ❖ Socio-economic drought

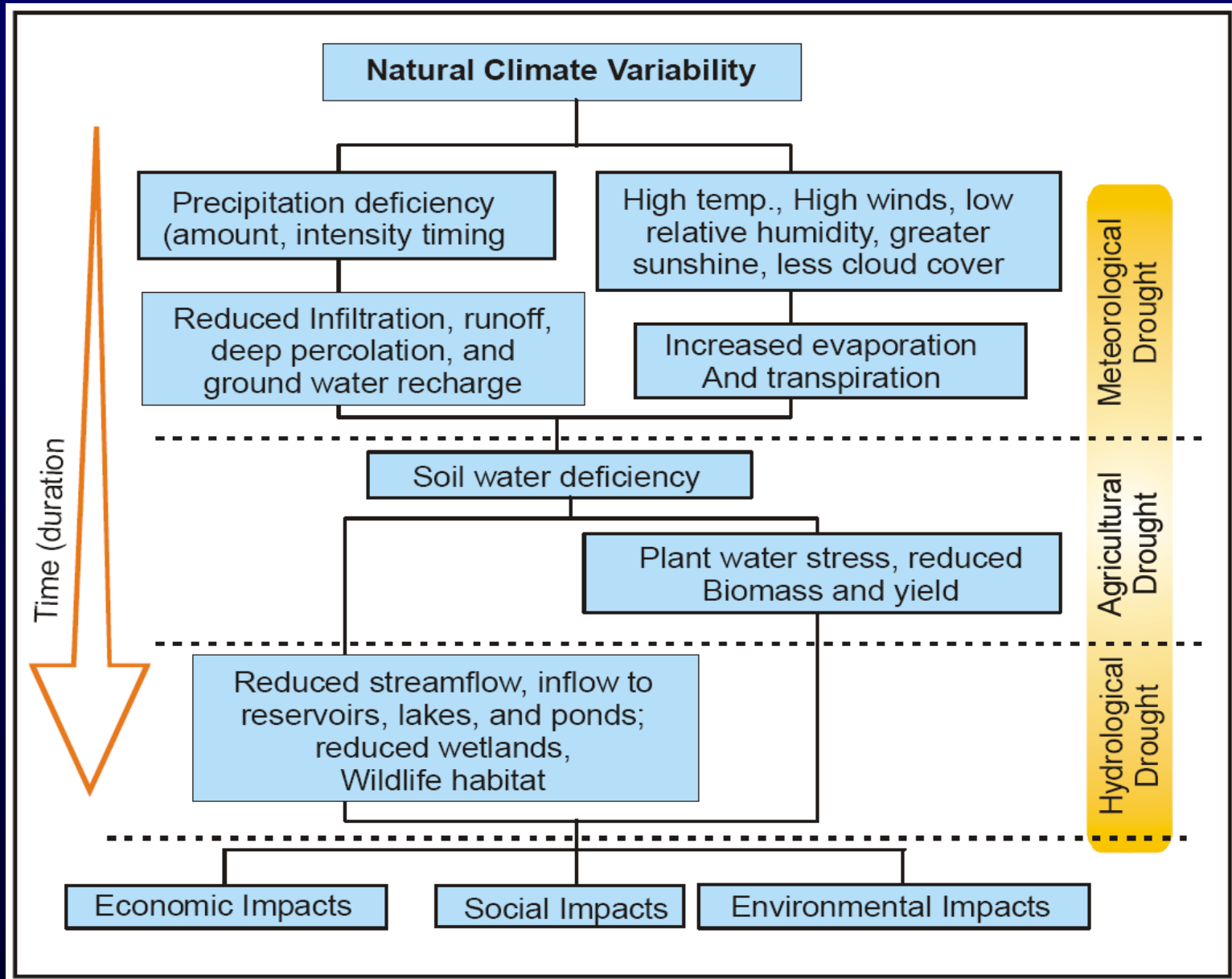
Meteorological drought: it simply implies rainfall deficiency where the precipitation is reduced by more than 25% from normal in any given area. These are region specific, since deficiency of precipitation is highly variable from region to region.

Hydrological drought: these are associated with the deficiency of water on surface or subsurface due to shortfall in precipitation. Although all droughts have their origination from deficiency in precipitation, hydrological drought is mainly concerned about how this deficiency affects components of the hydrological system such as soil moisture, stream flow, ground water and reservoir levels etc

Agricultural drought: this links various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual potential evapotranspiration, soil, soil water deficits, and reduced ground water or reservoir levels. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, and its stage of growth and the physical and biological properties of the soil.

Socio-economic drought: it is associated with the demand and supply aspect of economic goods together with elements of meteorological, hydrological and agricultural drought. This type of drought mainly occurs when the demand for an economic good exceeds its supply due to weather related shortfall in water supply

A relationship between the meteorological, agricultural and hydrological droughts



Economic impacts

Many economic impacts occur in agriculture and related sectors, including forestry and fisheries, because of the dependence of these sectors on surface and subsurface water supplies.

In addition to obvious losses in yields in crop and livestock production, drought is associated with increases in insect infestations, plant disease, and wind erosion. Droughts also bring increased problems with insects and diseases to forests and reduce growth.

The incidence of forest fires increases substantially during extended droughts, which in turn places both human and wildlife populations at higher levels of risk.

Environmental Impacts

Environmental losses are the result of

- ❖ Damages to plant and animal species, wildlife habitat, and air and water quality
- ❖ Forest and range fires
- ❖ Degradation of landscape quality;
- ❖ Loss of biodiversity and
- ❖ Soil erosion

Social Impacts

- ❖ Social impacts involve public safety, health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief.
- ❖ Population migration is a significant problem in many countries, often stimulated by a greater supply of food and water elsewhere.
- ❖ Migration is usually to urban areas within the stressed area, or to regions outside the drought area. Migration may even be to adjacent countries.
- ❖ The drought migrants place increasing pressure on the social infrastructure of the urban areas, leading to increased poverty and social unrest.

History of droughts in India and Gujarat

Agriculture in India is often seen as a gamble on summer monsoon rainfall. Summer monsoon rains constitute the greatest climatic resource of the Indian subcontinent as these rains support not only the country's agriculture and food production but substantially contribute to power generation (H.P.Das 2000).

Thus success or failure of the crops and economy are intimately linked with prospects of good or bad monsoon

The Indian subcontinent is predominantly characterized by a tropical monsoon climate, where climatic regimes are governed by the differences in rainfall, rather than temperatures.

There are two monsoon systems operating in the region- the southwest or summer monsoon and the northeast or the winter monsoon.

The summer monsoon accounts for 70 to 90 percent of the annual rainfall over major parts of South Asia (Krishnamurthy and Shukla, 2000).

There is a large variability in the monsoon rainfall on both space and time scales.

some part of the country or the other almost every year during the monsoon period (June-September).

The drought of 1987 was one of the worst in the century. The monsoon rainfall was normal only in 14 out of 35 meteorological sub-divisions in the country. The overall deficiency in rainfall was 19% as compared to 26% in 1918 and 25% in 1972 being worst years.

Agricultural operations were adversely affected in 43% (58.6 million ha) of cropped area in 263 districts in 15 States and 6 Union Territories.

In the two worst affected states of Rajasthan and Gujarat, the rainfall was less than 50% from normal.

In these states, the drought of 1987 was the third or fourth in succession resulting in distress to an unprecedented level. Gujarat is one such state where drought occurs with unfailing regularity

1901- 1910	1911- 1920	1921- 1930	1931- 1940	1941- 1950	1951- 1960	1961- 1970	1971- 1980	1981- 1990	1991- 2000
Gujarat state									
1901	1911	1923	1931	1942	1951	1962	1972	1982	1991
1904	1915	1924	1936	1948	1952	1963	1973	1985	1993
1905	1918	1925	1938		1955	1965	1974	1986	1995
	1920	1927	1939		1957	1966		1987	1998
		1929	1940		1960	1968		1990	1999
									2000
All India									
1901	1911			1941	1951	1965	1972	1982	
1904	1918					1966	1974	1987	
1905	1920					1968	1979		

Table 1-1 All India and Gujarat state Drought Years

(Source: Gore and Ponkshe, 2004)

The monsoon of 2000 was the 13th consecutive normal monsoon considering country as a whole, but on a regional basis, this was the third consecutive drought year in areas covered by the states of Rajasthan, Gujarat and Andhra Pradesh

In 1999, as many as 98 out of a total of 225 blocks in the state received less than 50% of the season's expected rainfall. In 1999, Gujarat faced the worst drought of the past 100 years. Some 7,500 villages spread over 145 blocks in 15 districts were severely affected. The state has been hit by the worst drought in 100 years. More than 25 million people living in 9,000 villages of 17 of the 25 districts have been hit.

Almost all water sources have dried up; there is no food for the people and no fodder for over 7 million cattle. The water table in drought affected Saurashtra, Kutch and northern Gujarat is said to be falling by 10-15 feet each year (Bavadam 2001).

Drought risk evaluation

Risk assessment involves evaluation of the significance of a risk, either quantitatively or qualitatively.

Risk assessment/evaluation according to Kates and Kasperson (1983) comprises of three steps:

- Identification of hazards, which may cause disasters.
- Estimation of risks arising out of such events and
- Estimation of losses

Meteorological drought indices and drought detection

Drought indices have been developed as a means to measure drought. A drought index assimilates thousands of data on rainfall, snow pack, stream flow and other water-supply indicators into a comprehensible picture.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms.

Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), and Surface Water Supply Index (SWSI).

Palmer Drought Severity Index (PDSI)

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply (Palmer,1965).

The Palmer Drought Severity Index (PDSI) is to provide standardized measurements of moisture conditions so that comparison could be made between locations and between months.

The PDSI is a meteorological drought index that is responsive to abnormal weather conditions either on dry or abnormally wet side.

The index was specifically designed to treat the drought problem in semiarid and sub humid climates; with palmer himself cautioning that extrapolation beyond these conditions may lead to unrealistic results.

Crop Moisture Index (CMI).

Three years after the introduction of his drought index, Palmer (1968) introduced a new drought index based on weekly mean temperature and precipitation known as Crop Moisture Index (CMI). It was specifically designed as an agricultural drought index

It measures both evapotranspiration deficits (drought) and excessive wetness (more than enough precipitation to meet evapotranspiration demand and recharge the soil).

CMI is designed to monitor short-term moisture conditions affecting a developing crop; therefore CMI is not a good long-term drought-monitoring tool.

Standardized Precipitation Index (SPI)

Tom Mckee, Nolan Doesken and John Kleist of the Colorado Climate Centre formulated the SPI in

The purpose is to assign a single numeric value to the precipitation that can be compared across

SPI Values	
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

Table 2-1 Standardised Precipitation Index

Surface Water Supply Index (SWSI)

Shafer and Dezman (1982) to complement the Palmer Index for moisture conditions developed the Surface Water Supply Index (SWSI).

This index compliments the Palmer index for moisture condition.

It is dependent on the season; SWSI is computed with only snowpack, precipitation, and reservoir storage in the winter. During the summer months, stream flow replaces snowpack as a component within the SWSI equation.

Satellite based drought indices for drought characterization

Drought indicators assimilate information on rainfall, stored soil moisture or water supply but do not express much local spatial detail. Also, drought indices calculated at one location is only valid for single location. Thus, a major drawback of climate based drought indicators is their lack of spatial detail as well as they are dependent on data collected at weather stations which sometimes are sparsely

Satellite derived drought indicators calculated from satellite-derived surface parameters have been widely used to study droughts. Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), and Temperature Condition Index (TCI) are some of the extensively used vegetation indices.

Normalized Difference Vegetation Index (NDVI)

Tucker first suggested NDVI in 1979 as an index of vegetation health and density

NDVI is defined as: **$NDVI = (NIR - RED) / (NIR + RED)$**

Where, NIR and RED are the reflectance in the near infrared and red bands.

NDVI is a good indicator of green biomass, leaf area index, and patterns of production (Thenkabail and Gamage et al. 2004, Wang and Wang et al. 2004).

NDVI is the most commonly used vegetation index. It varies from +1 to -1. Since climate is one of the most important factors affecting vegetation condition, **AVHRR-NDVI** data have been used to evaluate climatic and environmental changes at regional and global scales

It can be used not only for accurate description of continental land cover, vegetation classification and vegetation strength but is also effective for monitoring rainfall and drought, estimating net primary production of vegetation, crop growth conditions and crop yields, detecting weather impacts and other events important for agriculture, ecology and economics (Singh & Roy et al. 2003).

NDVI has been used successfully to identify stressed and damaged crops and pastures but only in homogenous terrain. In more heterogeneous terrain regions their interpretation becomes more difficult (Vogt et al. 1998; Singh et al. 2003).

Many studies in the Sahel Zone (Tucker et al 2005), Argentina (Sullivan et al. 1998), South Africa (Unganani & Kogan, 2004) and Mediterranean (Vogt et al., 1998), and Senegal (Li. et al., 2004) indicate meaningful direct relationships between NDVI derived from NOAA AVHRR satellites, rainfall and vegetation cover and biomass.

Vegetation Condition Index (VCI)

It was first suggested by Kogan (1997) (Thenkabail et al.2004; Vogt et al. 1998).

VCI is an indicator of the status of the vegetation cover as a function of the NDVI minimum and maxima encountered for a given ecosystem over many years.

VCI is defined as:

$$VCI_j = (NDVI_j - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) * 100$$

Where, $NDVI_{max}$ $NDVI_{min}$ is calculated from long-term record for a particular month and j is the index of the current month. The condition of the ground vegetation presented by VCI is measured in percent.

The VCI values between 50% to 100% indicate optimal or above normal conditions whereas VCI values close to zero percent reflects an extreme dry month.

VCI has been used by (Kogan and Unganani) for estimation of corn yield in South Africa; drought detection in Argentina (Sullivan et al 1998); drought monitoring over India (Singh et al.2002); monitoring droughts in the southern Great Plains, USA (Wan et al.2004); drought detection and monitoring in the Mediterranean region (Vogt et al.2000) and drought assessment and monitoring in Southwest Asia (Thenkabail et al. 2004).

These studies suggest that VCI captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas. Also, VCI values indicate how much the vegetation has advanced or deteriorated in response to weather.

It was concluded from the above studies that VCI has provided an assessment of spatial characteristics of drought, as well as its duration and severity and were in good agreement with precipitation patterns.

Temperature Condition Index (TCI)

TCI was also suggested by Kogan (1997), (Thenkabail et al. 2004). It was developed to reflect vegetation response to temperature i.e. higher the temperature the more extreme the drought.

TCI is based on brightness temperature and represents the deviation of the current month's value from the recorded maximum. TCI is defined as:

$$TCI_j = (BT_{max} - BT_j) / (BT_{max} - BT_{min}) * 100$$

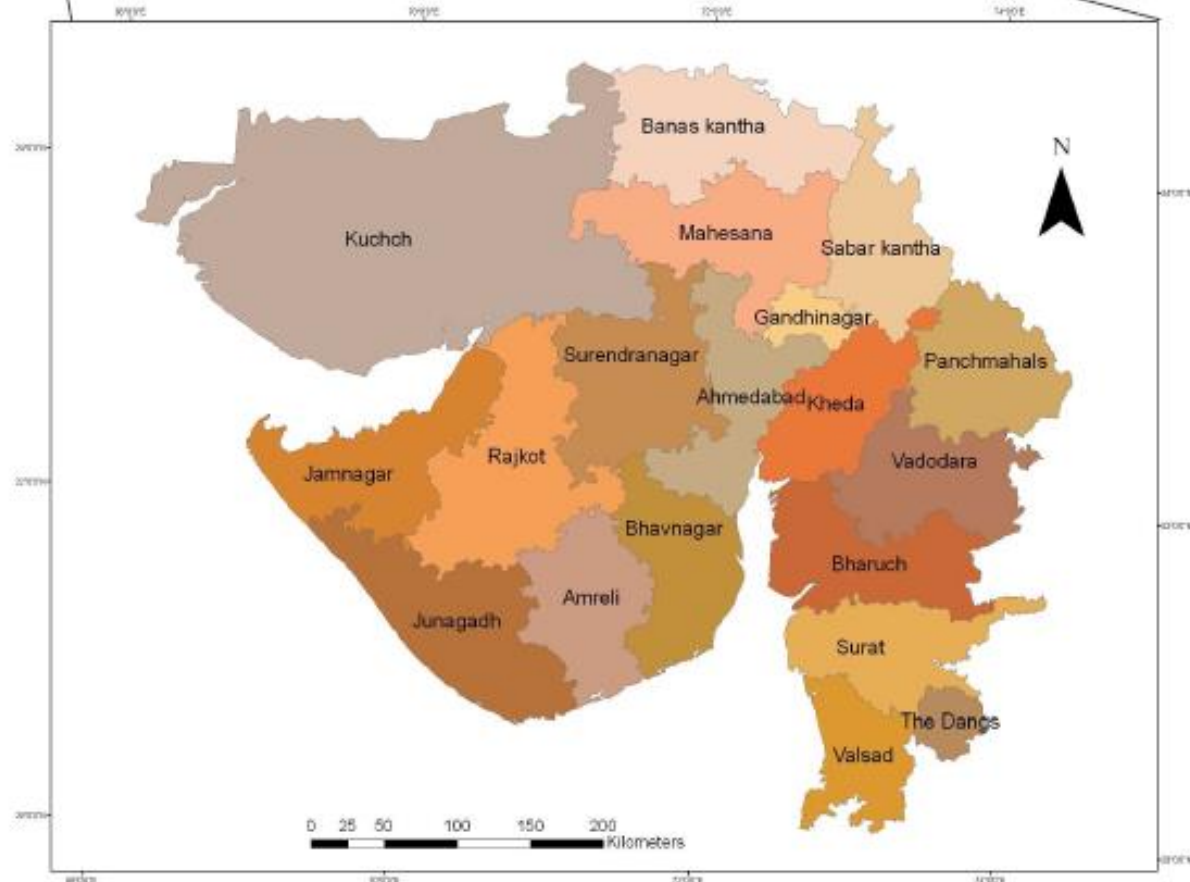
Where BT is brightness temperature. Maximum and minimum BT values are calculated from the long-term record of remote sensing images for a particular period j

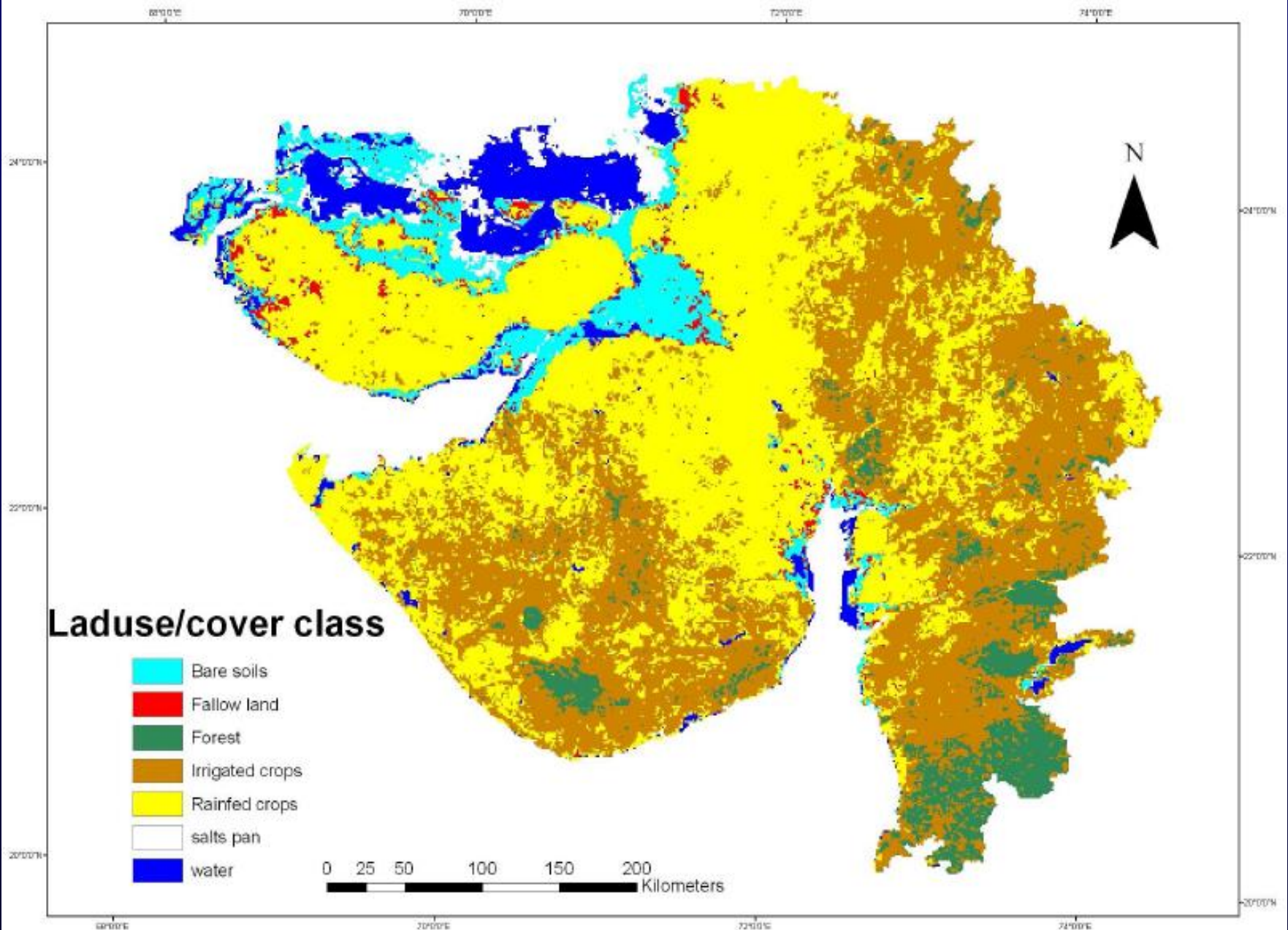
Low TCI values indicate very hot weather.

TCI has been used for drought monitoring in the USA, China, Zimbabwe and the Former Soviet Union.

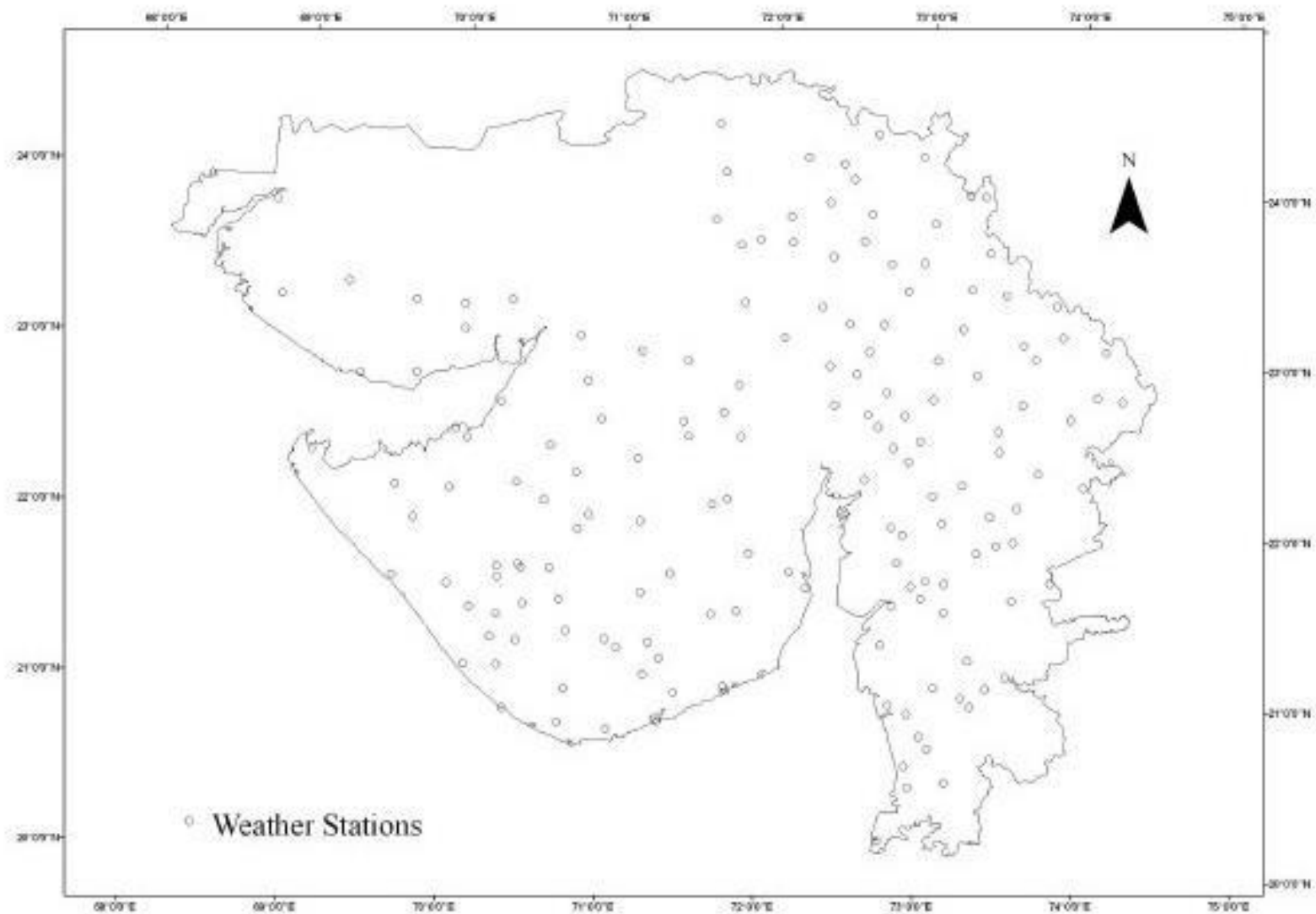
A study in Argentina for drought detection revealed that TCI was useful to assess the spatial characteristics, the duration and severity of droughts, and were in good agreement in precipitation patterns (Seiler et al.1998).

TCI has been related to recent regional scale drought patterns in South Africa (Kogan, 1998).



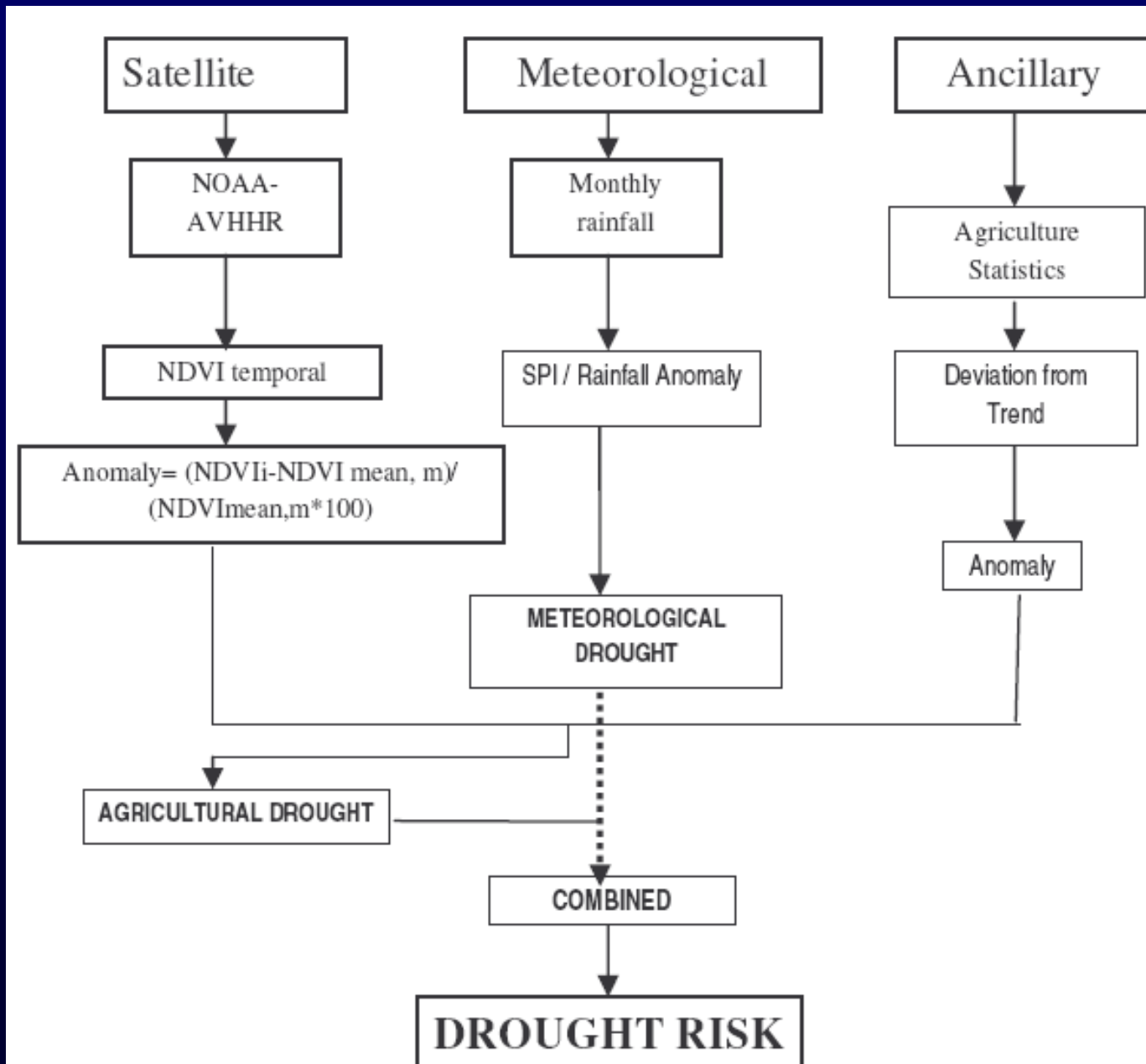


Generalised Landuse/cover map of Gujarat



Location of 164 weather stations in Gujarat

METHODOLOGY



RAINFALL vs NDVI (1981-2000)

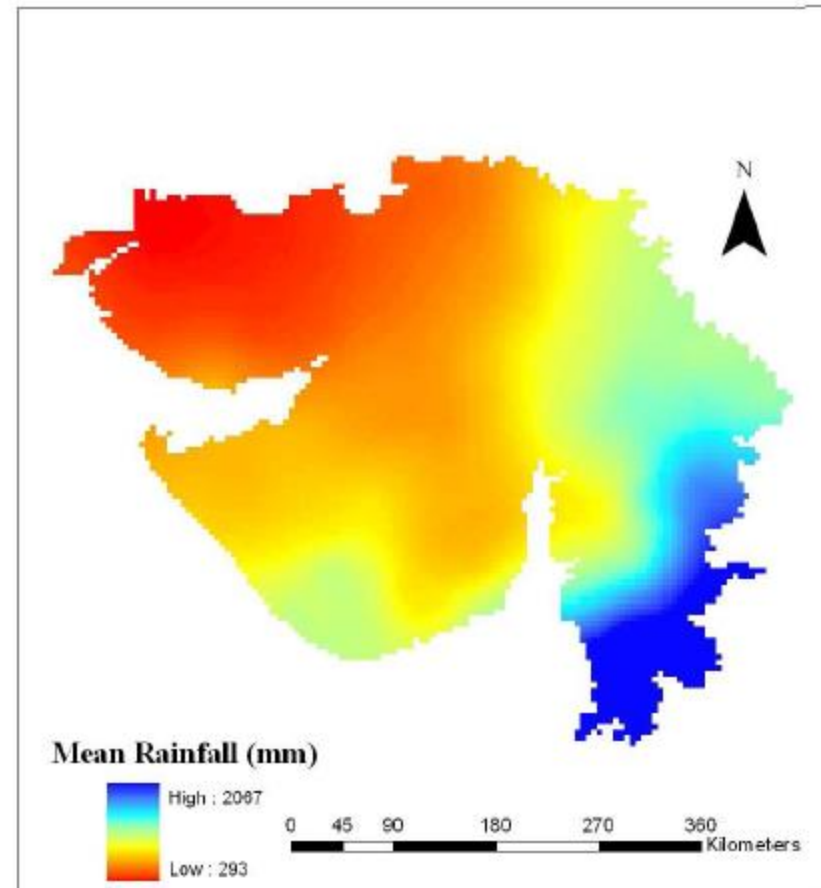
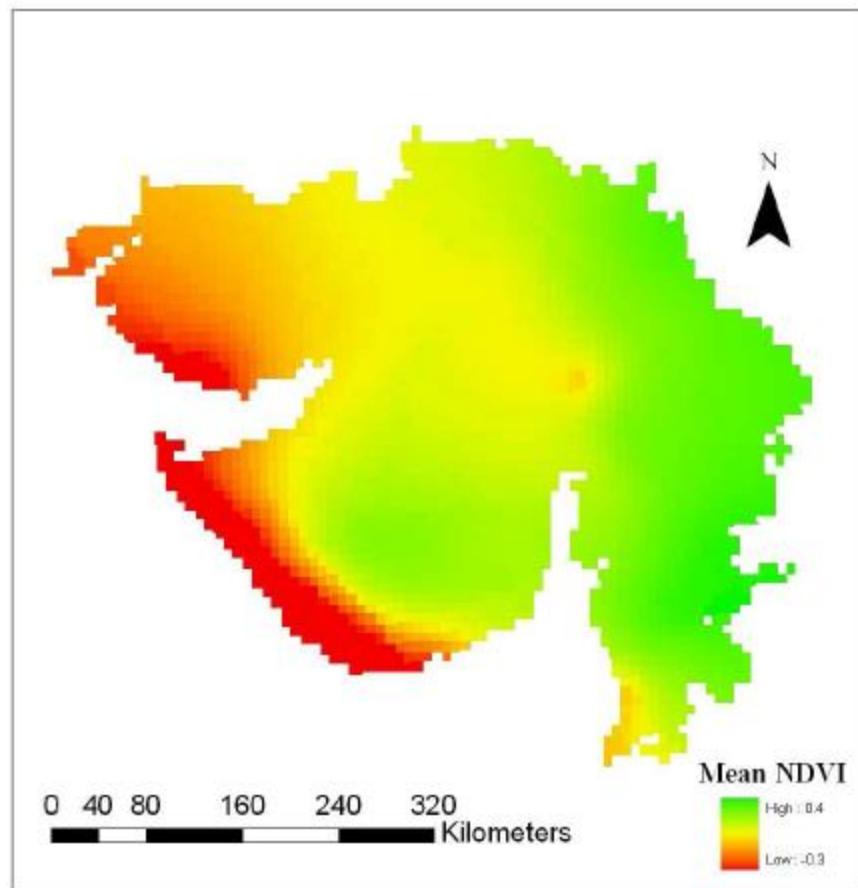


Figure 5-2 Average rainfall and Average NDVI (1981-2000)

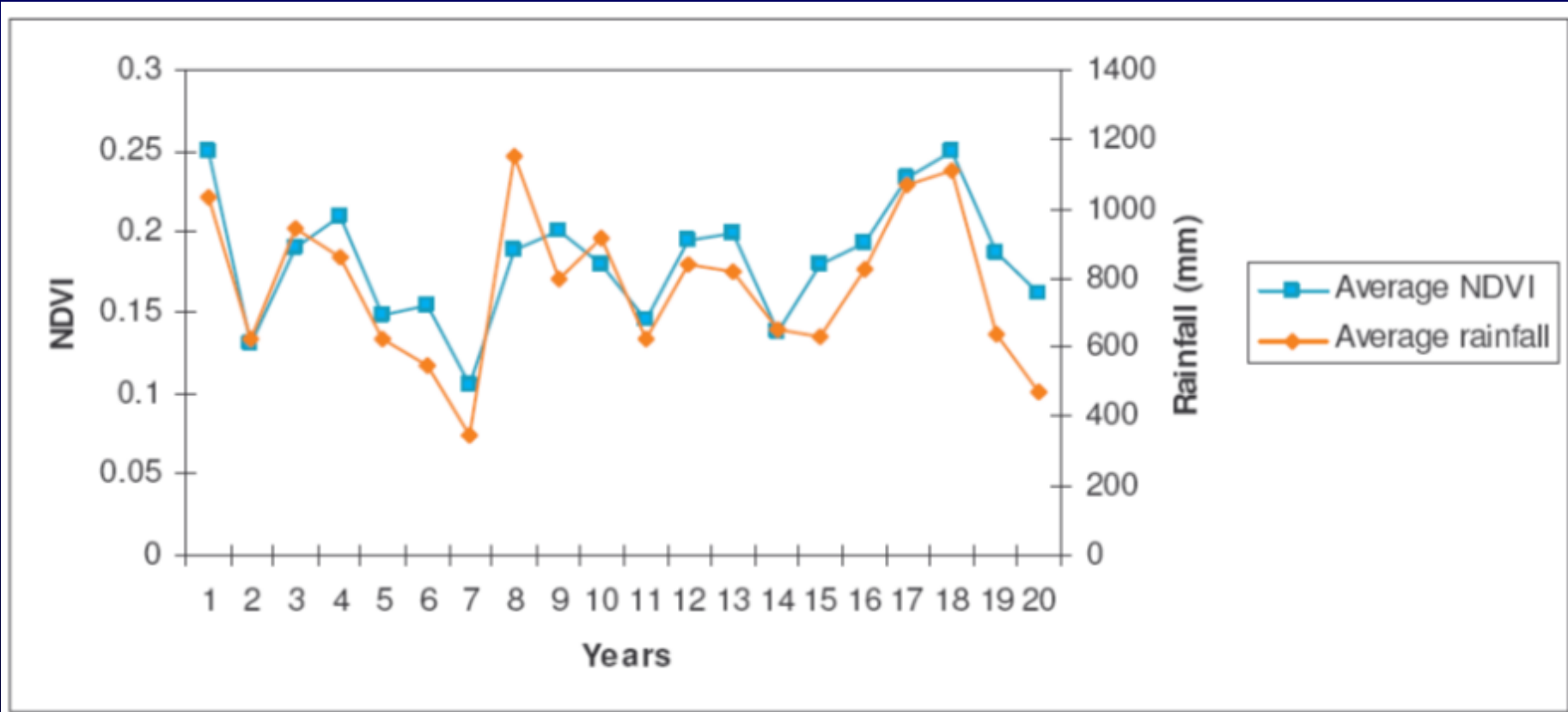
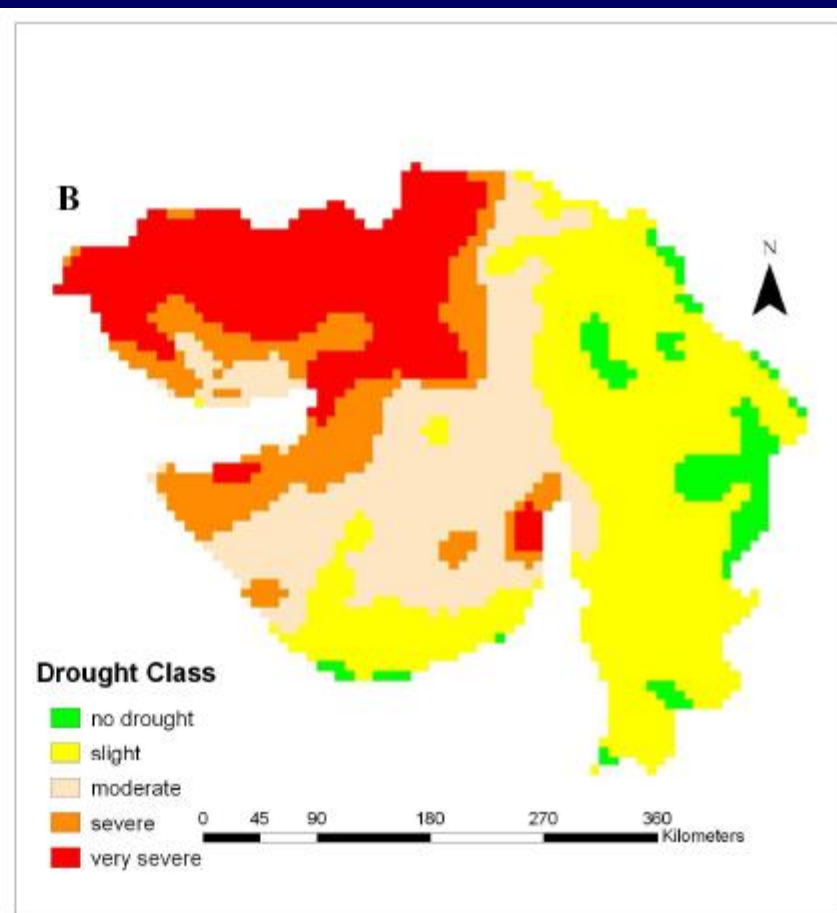
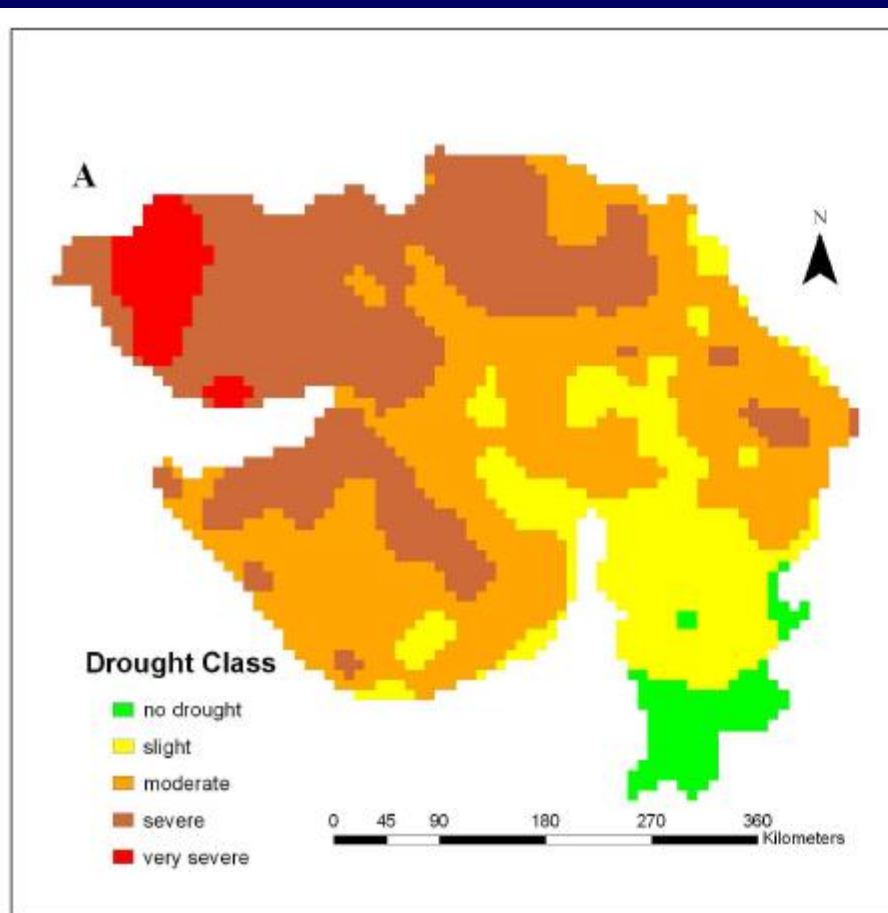


Figure 5-3 Temporal trends of NDVI and Rainfall (1981-2000)



(A) Meteorological Drought Risk and (B) Agriculture Drought Risk

Figure 5-18 Meteorological & Agriculture drought risk

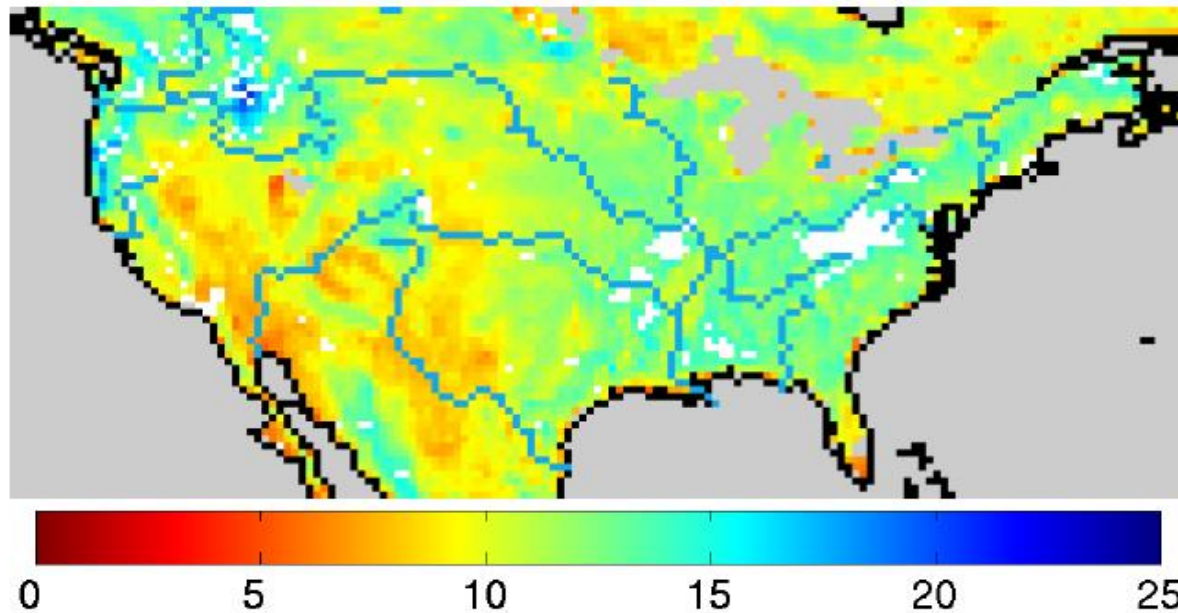


Figure 1. AMSR-E monthly averaged soil moisture (volumetric %) for August 2002 showing dry conditions over the western U.S.

Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E)

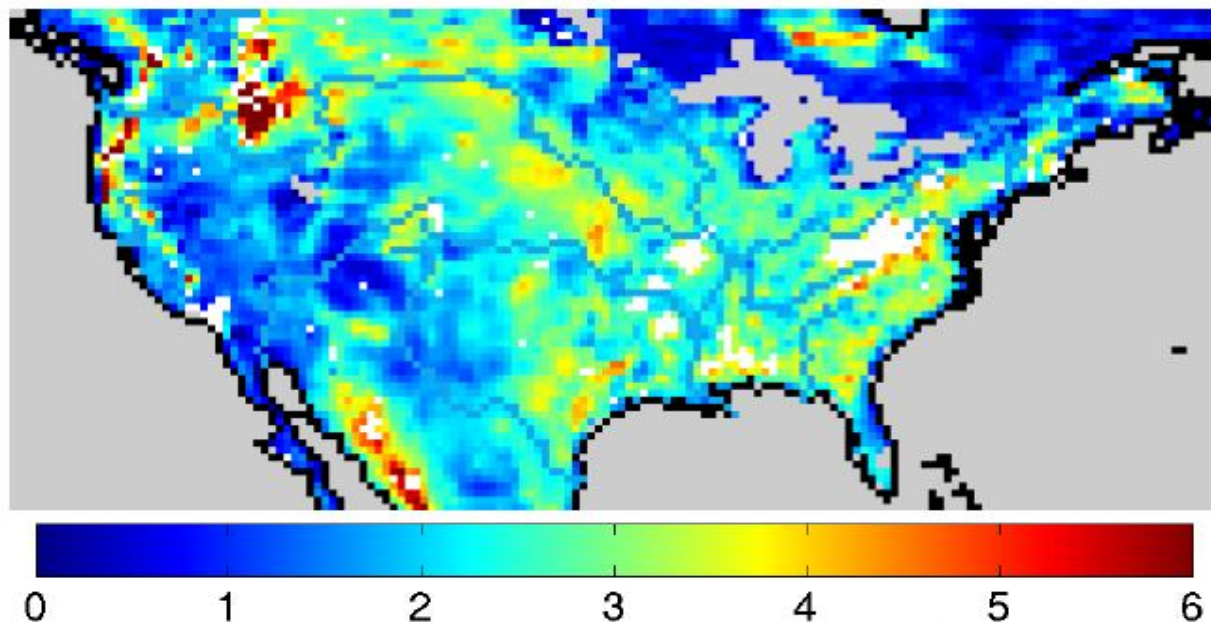
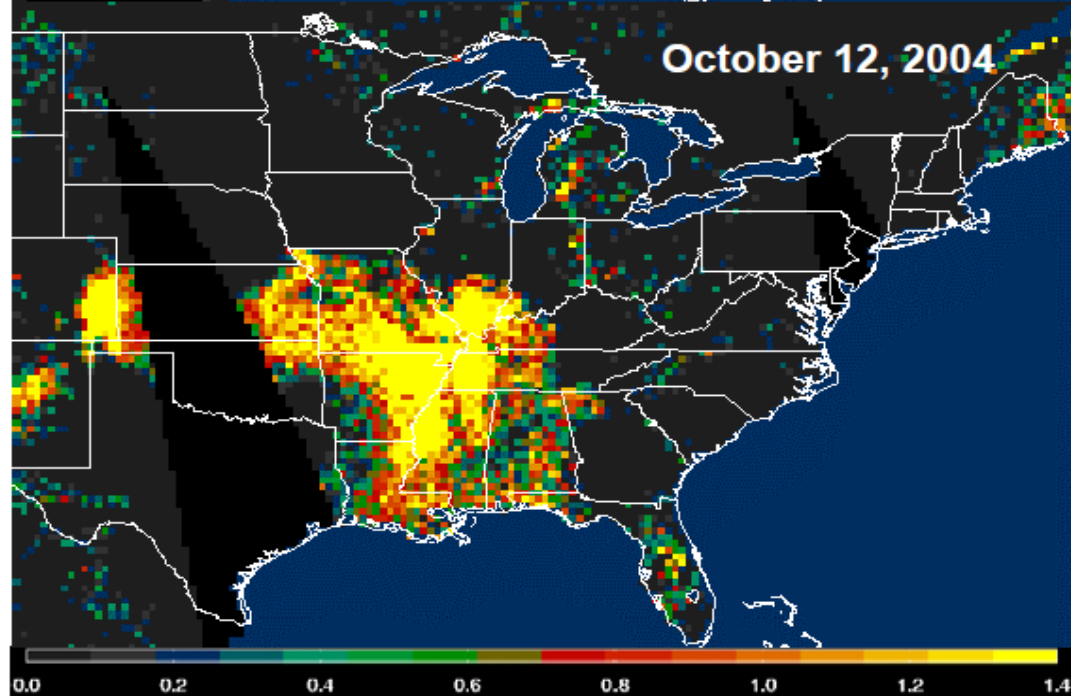
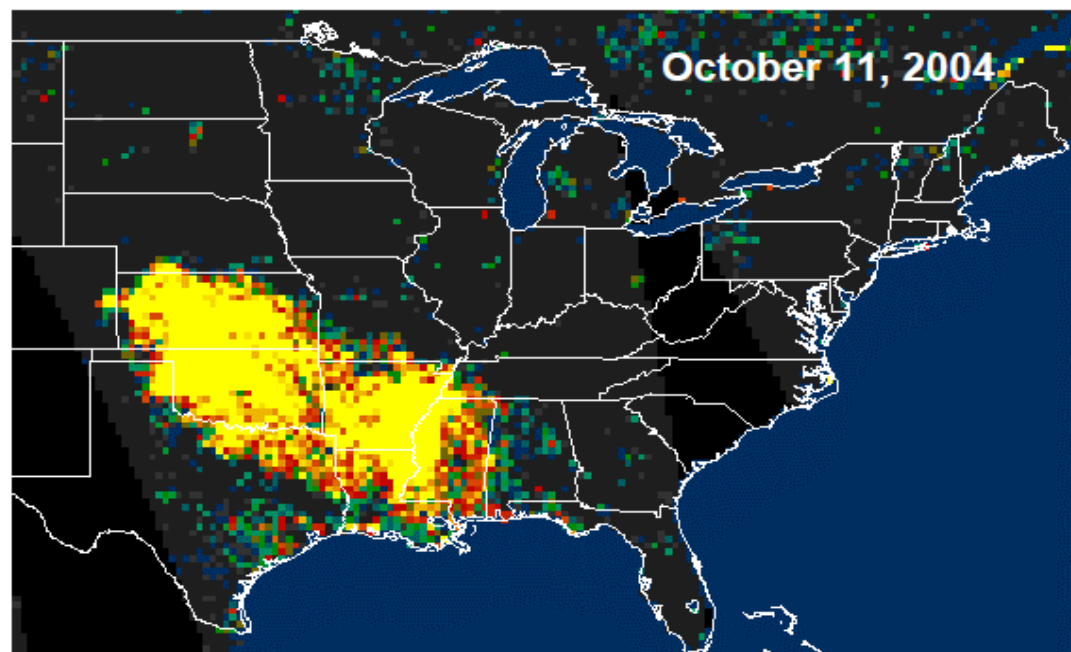


Figure 2. AMSR-E monthly averaged vegetation water content ($\text{kg}\cdot\text{m}^{-2}$) for August 2002 showing moist vegetation over the eastern U.S.



*QSCAT daily maps of
surface water increase
due to precipitation*

the SeaWinds
scatterometer
aboard the
QuikSCAT satellite
(QSCAT).

Global scenario on Remote Sensing use for Drought

The normalised difference vegetation index (NDVI) and temperature condition index (TCI) derived from the satellite data are accepted world-wide for regional monitoring.

The ongoing program on Africa Real-Time Environmental Monitoring using Imaging Satellites (ARTEMIS) is operational at FAO and uses METEOSAT rainfall estimates and AVHRR NDVI values for Africa.

The USDA/NOAA Joint Agricultural Weather Facility (JAWF) uses Global OLR anomaly maps, rainfall map, vegetation and temperature condition maps from GOES, METEOSAT, GMS and NOAA satellites.

Canada issues weekly crop condition reports based on NOAA AVHRR based NDVI along with agro meteorological statistics

National Remote Sensing Agency, Department of Space issues biweekly drought bulletin and monthly reports at smaller administrative units for India under National Agricultural Drought Assessment and Monitoring System (NADAMS) which uses NOAA AVHRR and IRS WiFS based NDVI with ground based weather reports.