Storm Surge Inundation in North Indian Ocean Under Climate Change Scenarios

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Loss of life due to storm surges in the North Indian Ocean (> 999)

Year	Country	Number of Deaths
1970	Bangladesh	300,000
1737	India	300,000
1876	Bangladesh	200,000
1897	Bangladesh	175,000
1991	Bangladesh	140,000
2008	Myanmar	140,000
1833	India	50,000
1864	India	50,000
1822	Bangladesh	40,000
1864	India	40,000
1942	India	40,000
1789	India	20,000
1839	India	20,000
1977	India	20,000
1965	Bangladesh	19,279
1999	India	15,000
1963	Bangladesh	11,520

Loss of life due to storm surges in the North Indian Ocean (> 999)

Year	Country	Number of Deaths
1961	Bangladesh	11,466
1985	Bangladesh	11,069
1971	India	10,000
1998	India	10,000
1960	Bangladesh	5,149
1988	Bangladesh	5,708
1972	India	5,000
1960	Bangladesh	3,000
2007	Bangladesh	3,000
1885	India	2,000
1989	Bangladesh	2,000
1996	India	2,000
1952	India	1,500
1964	India	1,000

DEATHS IN TROPICAL CYCLONES

YEAR	COUNTRIES	DEATHS
1970	Bangladesh	300,000
1737	India	300,000
1886	China	300,000
1923	Japan	250,000
1876	Bangladesh	200,000
1897	Bangladesh	175,000
1991	Bangladesh	140,000
2008	Myanmar	140,000
1833	India	50,000
1864	India	50,000
1822	Bangladesh	40,000
1780	Antilles(West Indies)	22,000
1965	Bangladesh	19,279
1999	India	15,000
1963	Bangladesh	11,520
1961	Bangladesh	11,466
1985	Bangladesh	11,069
1971	India	10,000
1977	India	10,000
1966	Cuba	7,196
1900	USA	6,000
1960	Bangladesh	5,149
1960	Japan	5,000
1972	India	5,000

- 75% events in the Bay of Bengal
- 56% of Bay events in Bangladesh
- 70% Deaths in Bangladesh

Factors Contributing to Disastrous Surge in the Bay of Bengal

- Convergence of the **Bay**
- Shallow Water
  - Large Bottom Friction
  - Retards return undercurrents
- Thickly Populated Low Lying Islands

  (Ramgati, Sandwip, Hatia, Bhola & Kutubdia)
- High Astronomical Tides
- Inlets & Estuaries

Effect of Climate Change

- The intensity (as represented by the winds) of tropical cyclones might increase in the range of 2-11% (Knutson et al.,2010)

- Coastal inundation from storm surge is computed under the following three different scenarios:

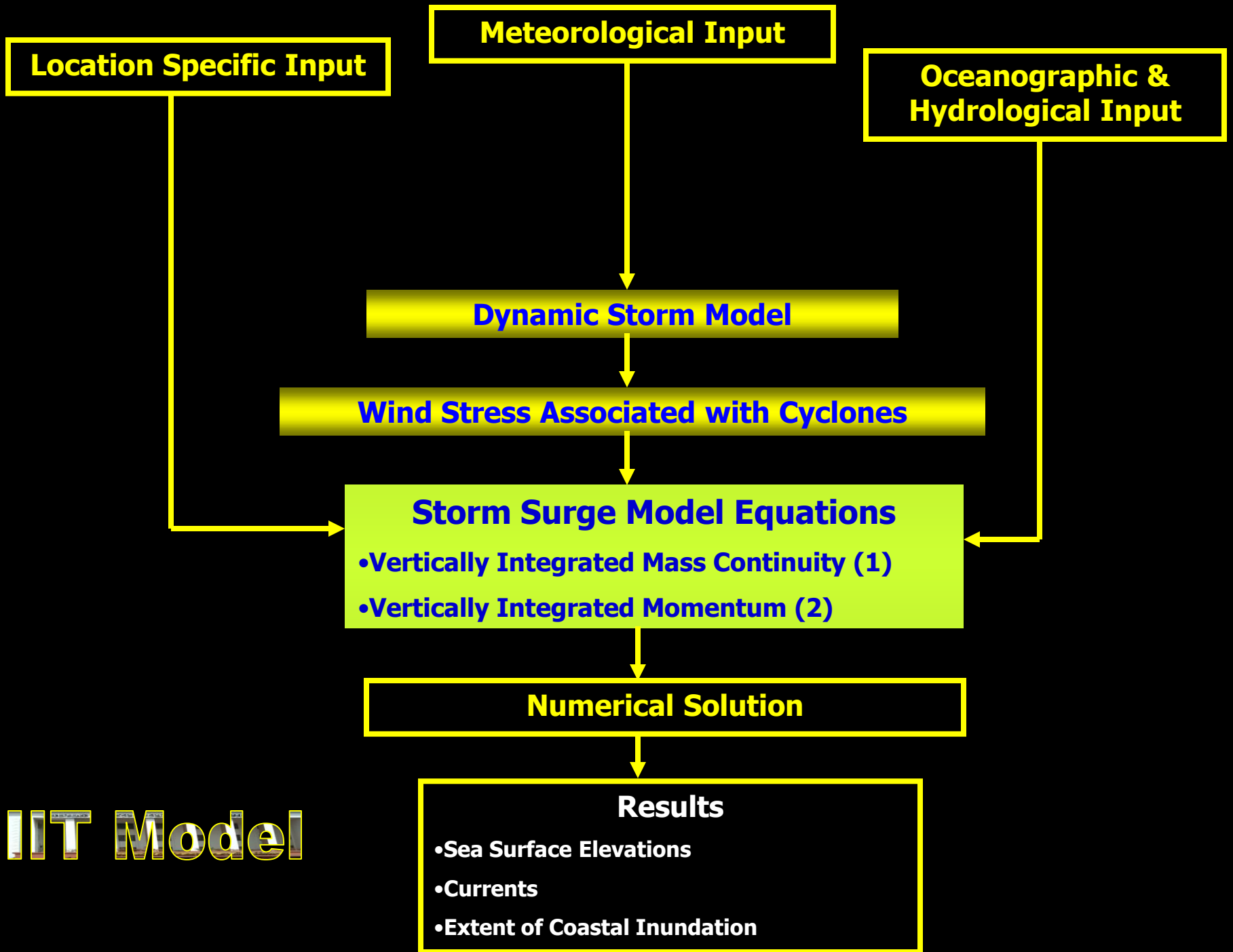
(a) no climate change,

(b) intensification of tropical cyclone by 7% which is an average value in the projected climate change range

(c) the intensification by 11% which is the extreme case

IIT Numerical Storm Surge Model

Storm Surge Prediction System


Location Specific Input
Meteorological Input
Oceanographic & Hydrological Input
Dynamic Storm Model
Wind Stress Associated with Cyclones
Storm Surge Model Equations
•Vertically Integrated Mass Continuity (1)
•Vertically Integrated Momentum (2)
Numerical Solution
Results
•Sea Surface Elevations
•Currents
•Extent of Coastal Inundation
IIT Model

Significant Feature

- Ability to investigate multiple forecast scenario in real time

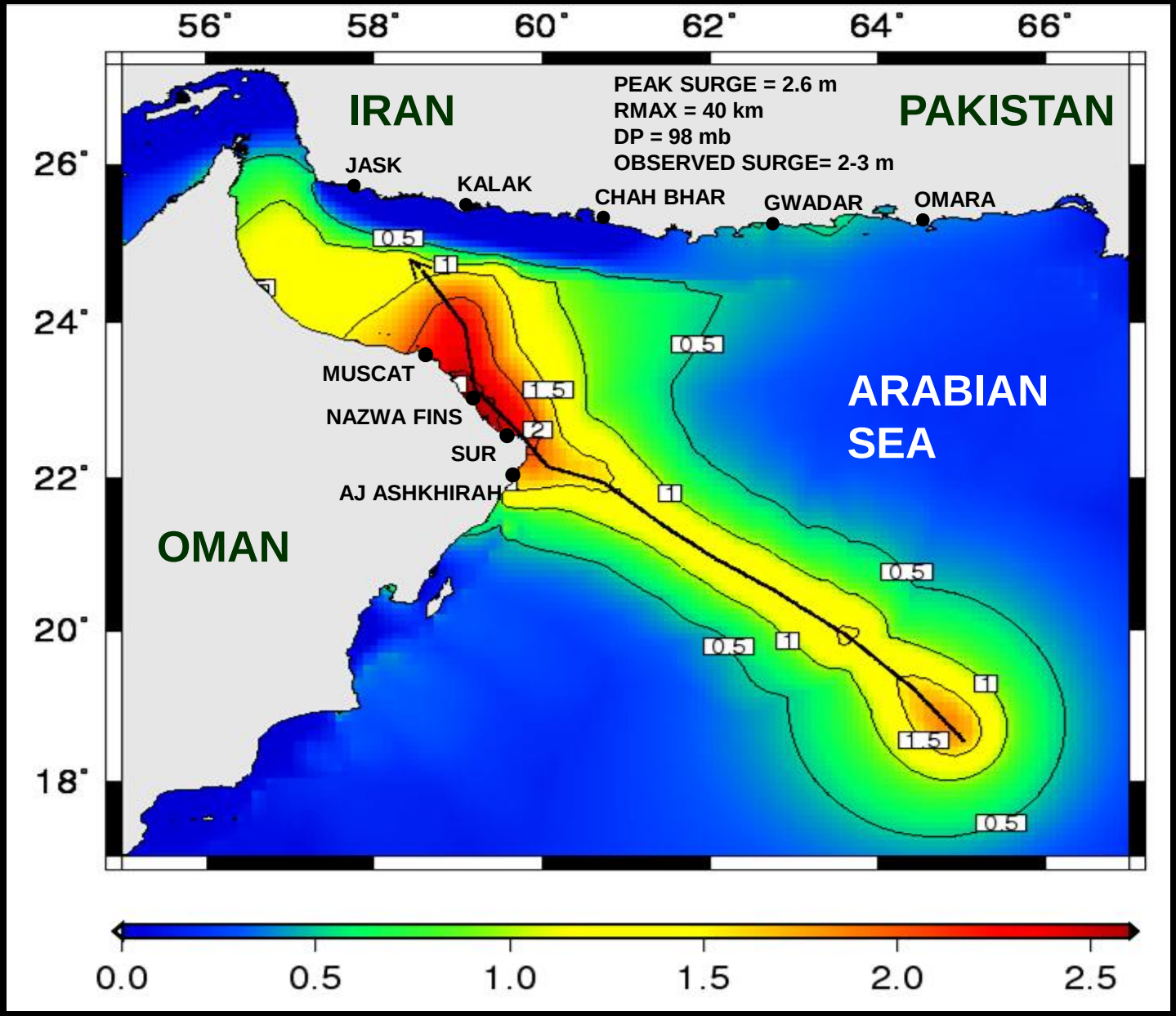
- Updates cyclone track as the cyclonic storm approaches the coast and meteorological forecast become more accurate

Highlights

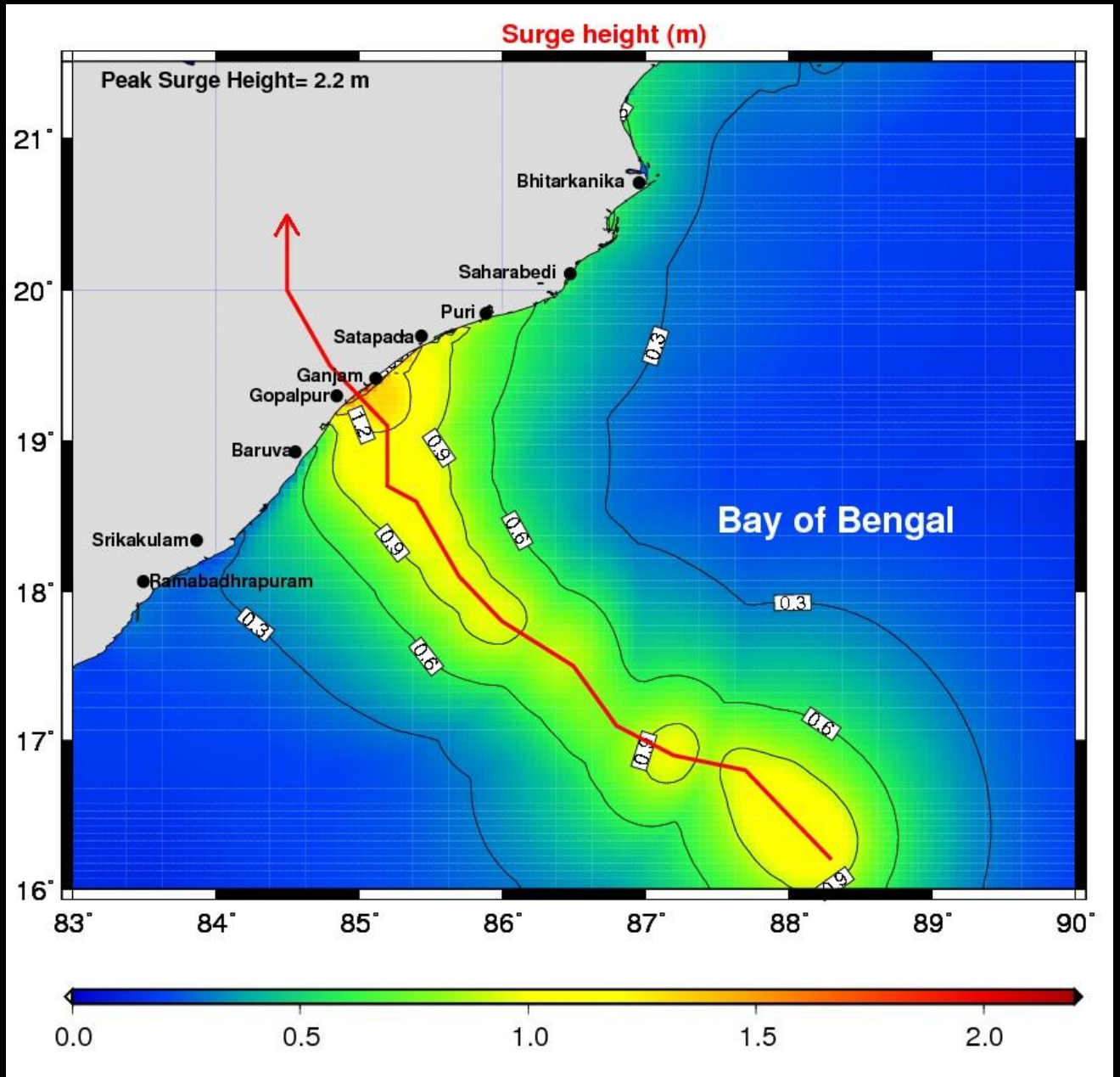
- Under the auspices of TCP/WMO the technology (IIT Model) has already been transferred to the meteorological services of **Bangladesh, Myanmar, Thailand, Sri Lanka, Pakistan & Oman** for their use

- From Cyclone Season of 2009, **RSMC New Delhi** is using IIT Model for providing Storm Surge Guidance to the Countries of the Region

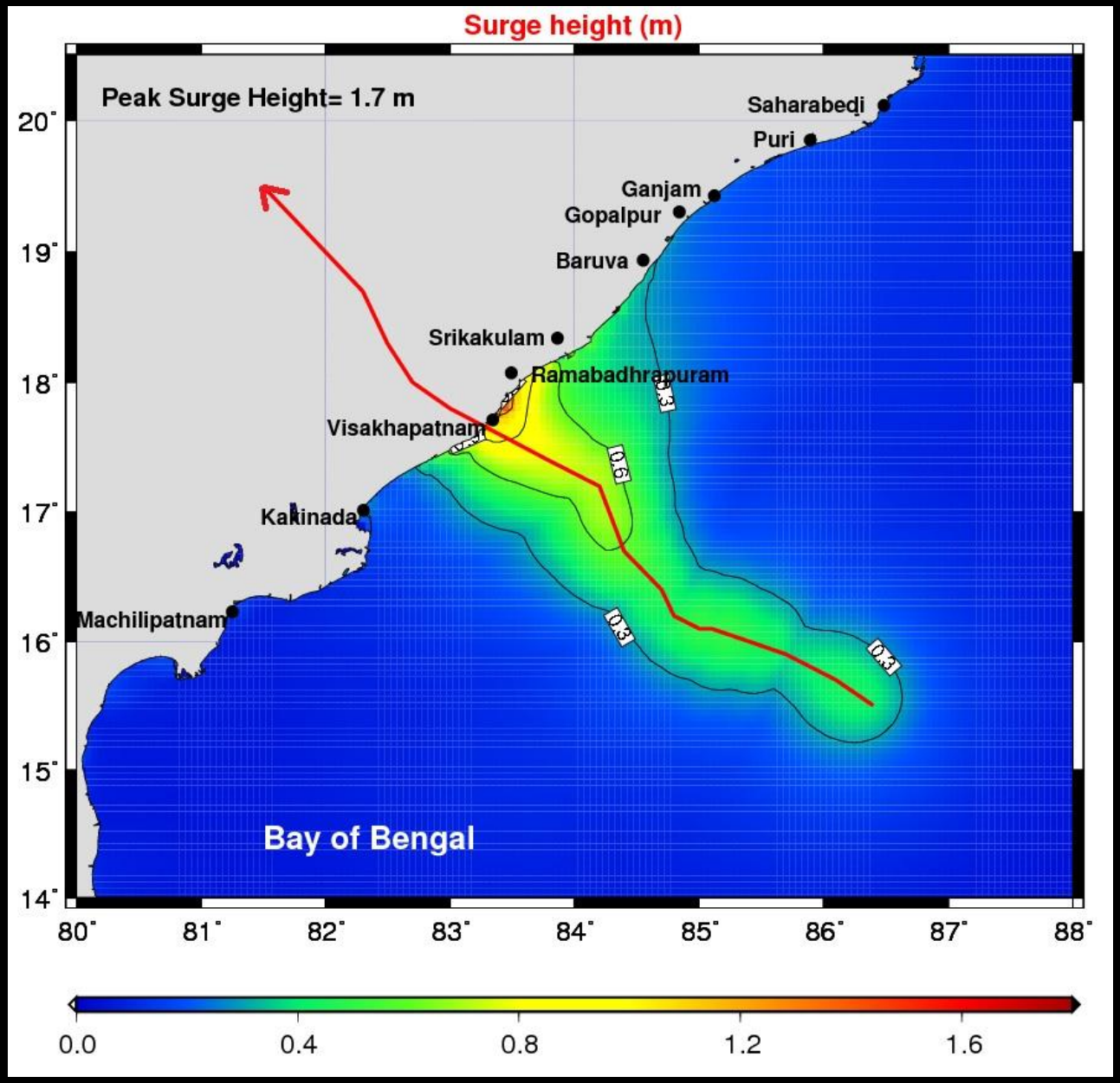
Peak Surge Envelope 2007 Gonu Cyclone



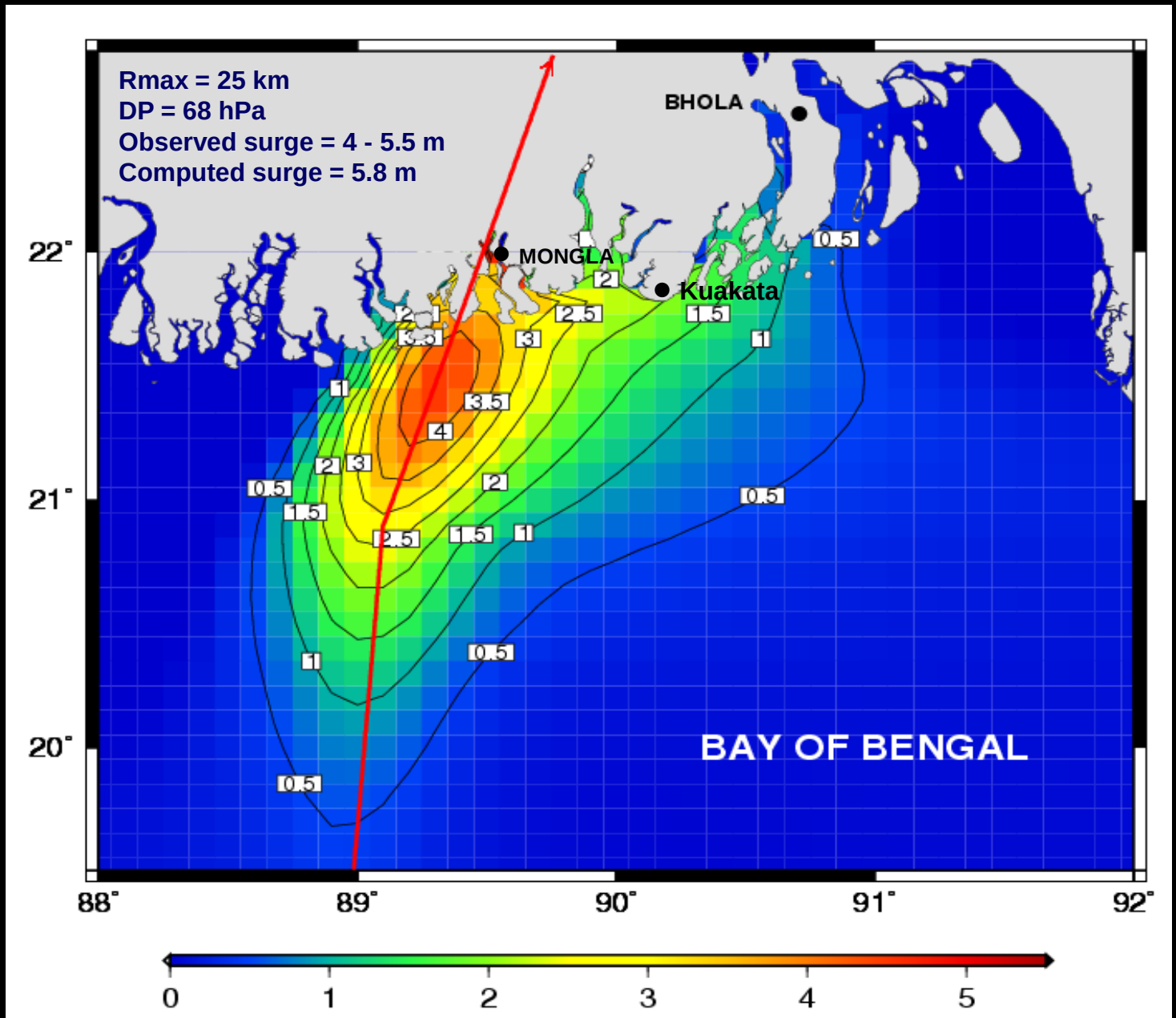
Peak Surge Envelope 2013 Phailin Cyclone



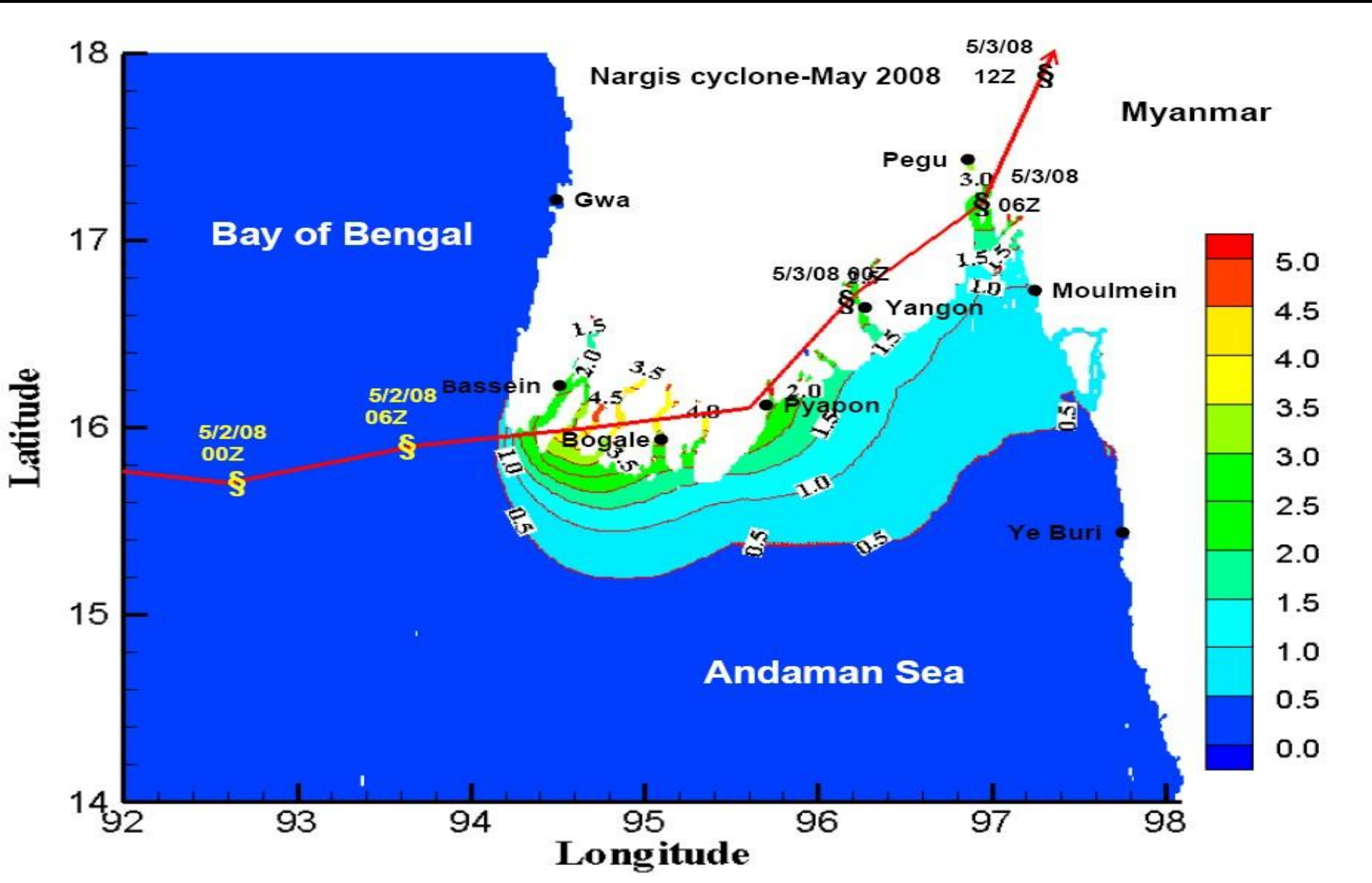
Peak Surge Envelope 2014 Hudhud Cyclone



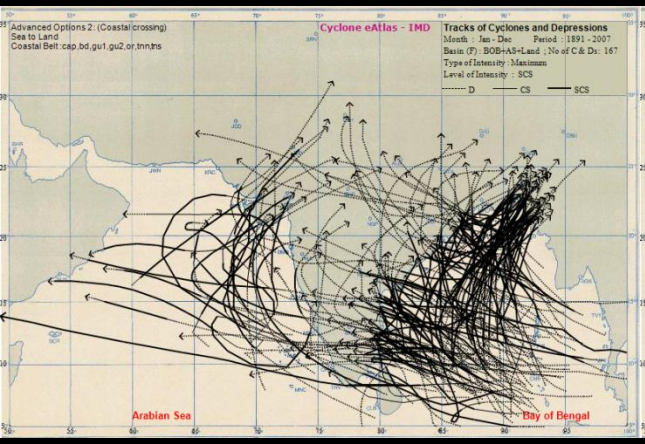
Peak Surge Envelope 2007 Bangladesh Cyclone SIDR



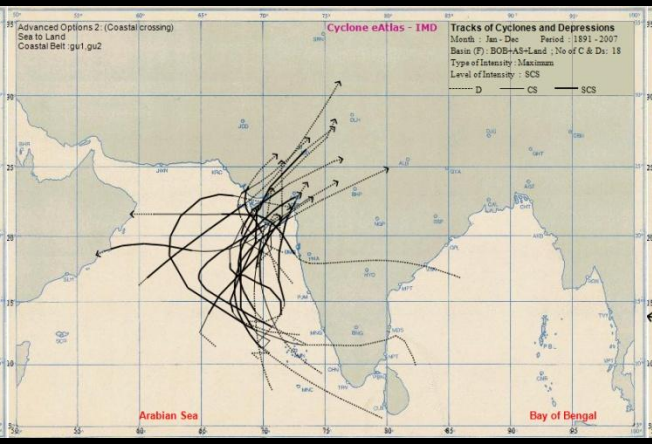
Peak Surge Envelope 2008 Myanmar Cyclone NARGIS



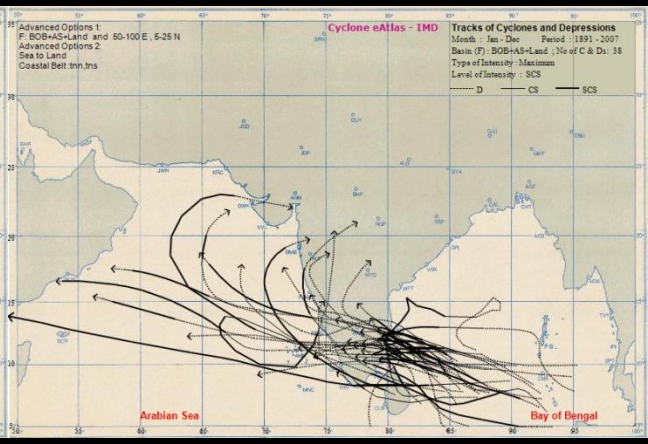
Tracks cyclones (1891-2007) used to prepare composited tracks



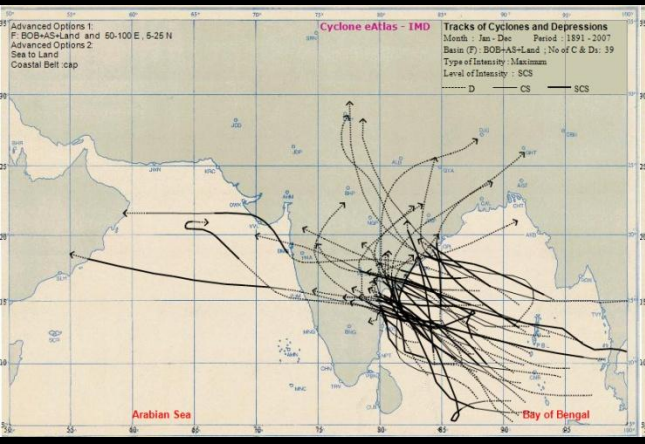
All the tracks



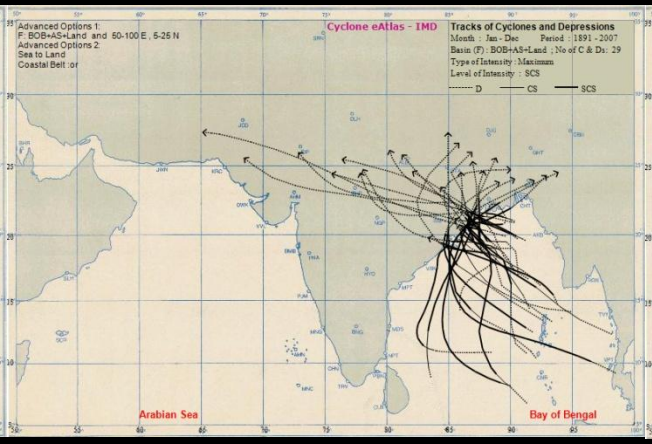
Tracks for Gujarat



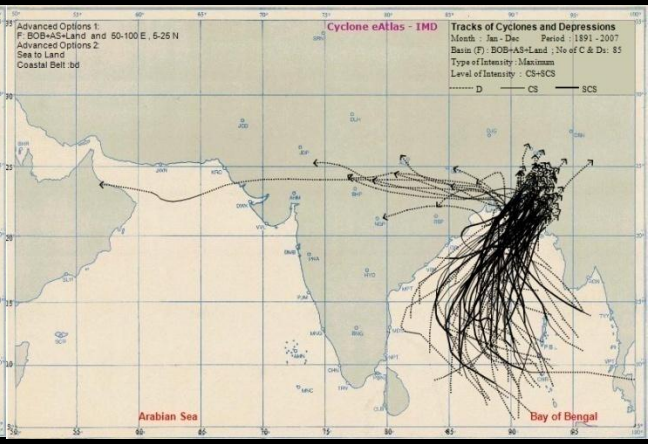
Tracks for Tamil Nadu



Tracks for Andhra Pradesh

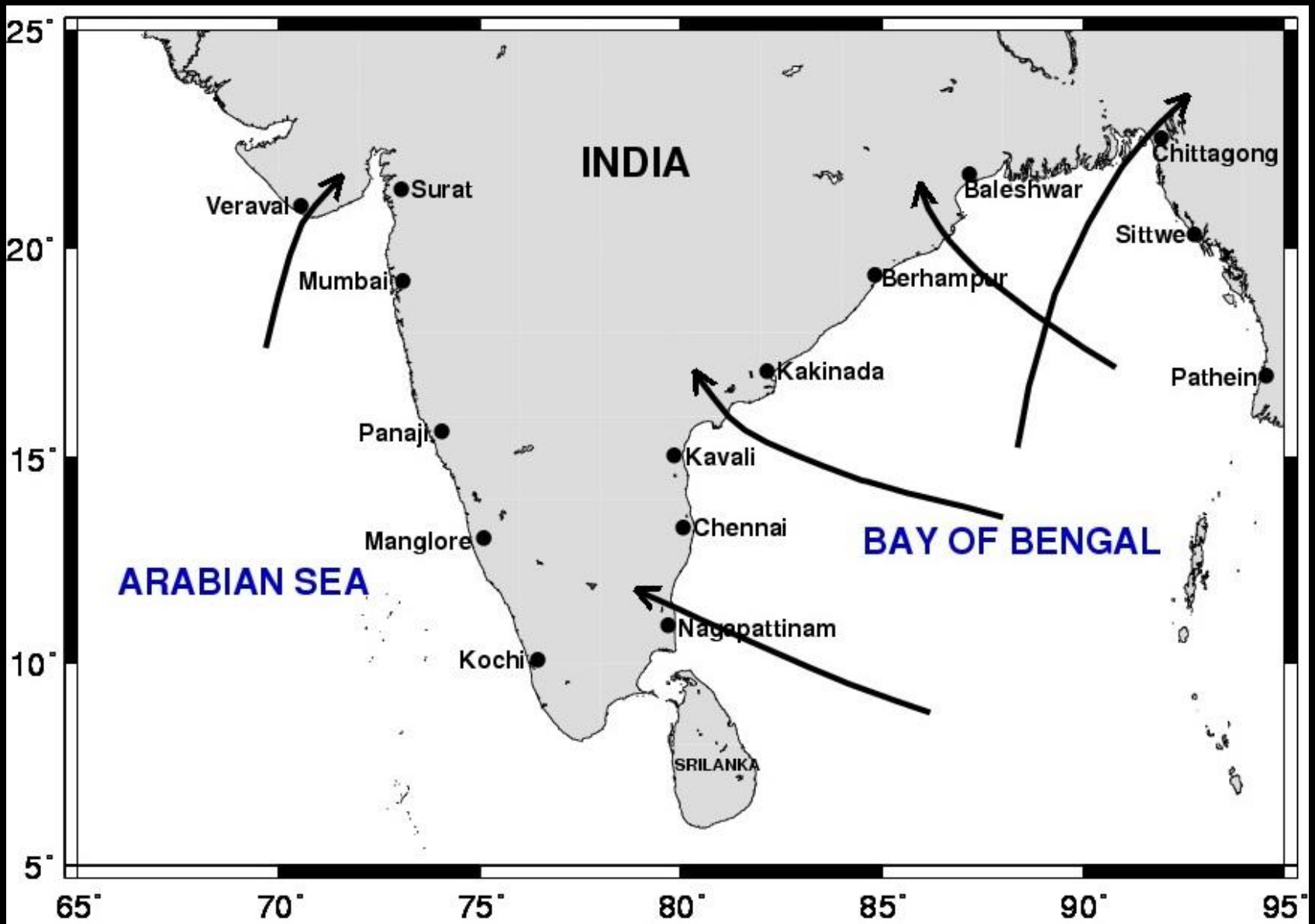


Tracks for Odisha

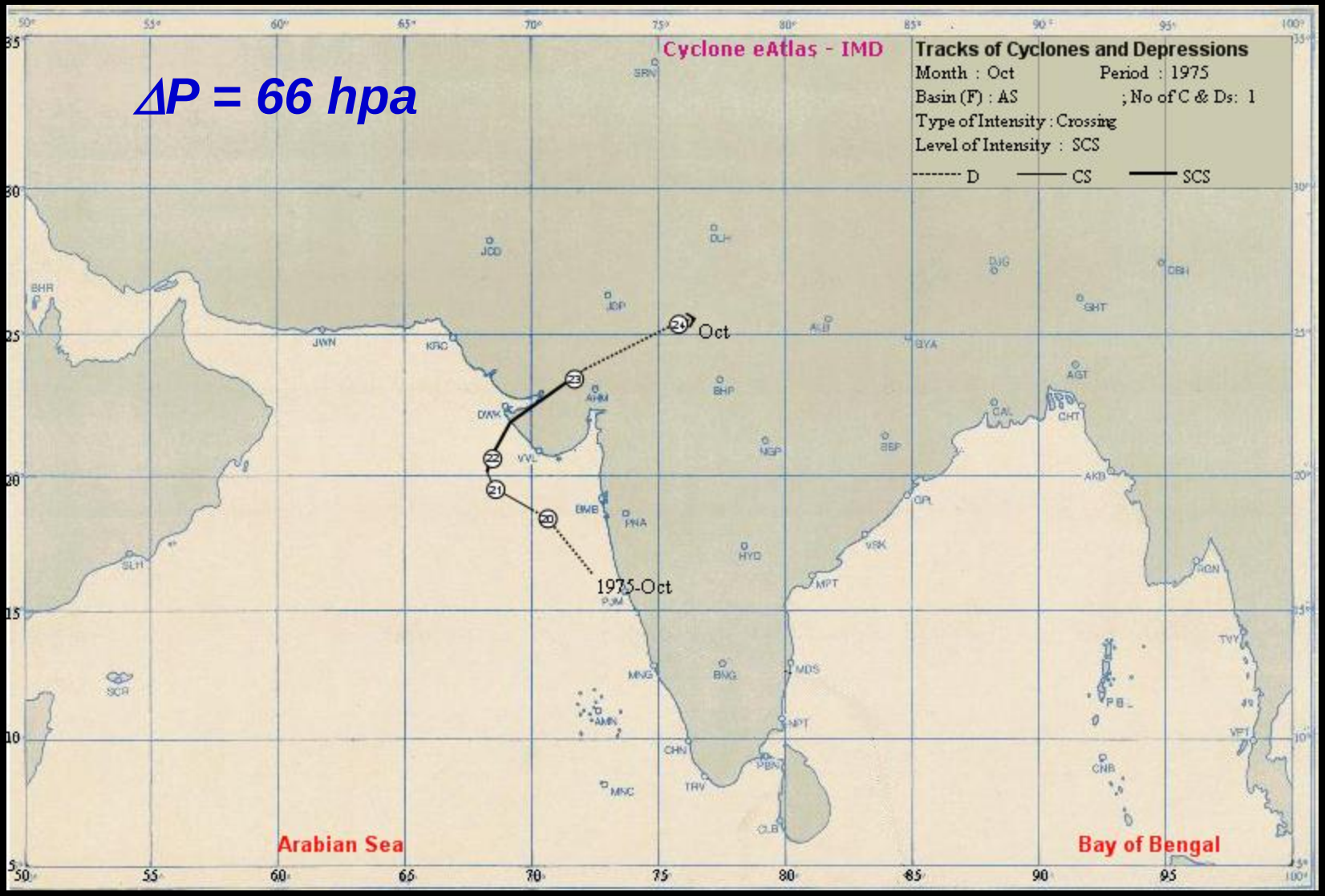


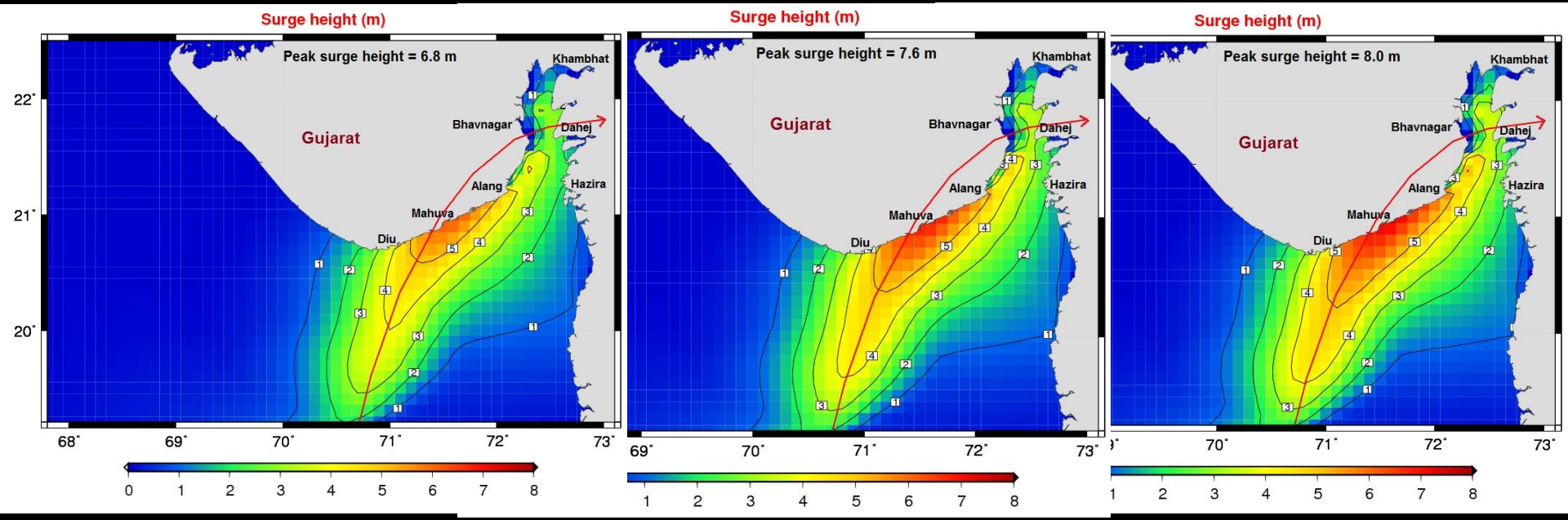
Tracks for Bangladesh

Composited storm tracks for different regions for storm surge amplitude computations



Most Intense Cyclone that hit the Gujarat Coast of India





ΔP = 66 hpa

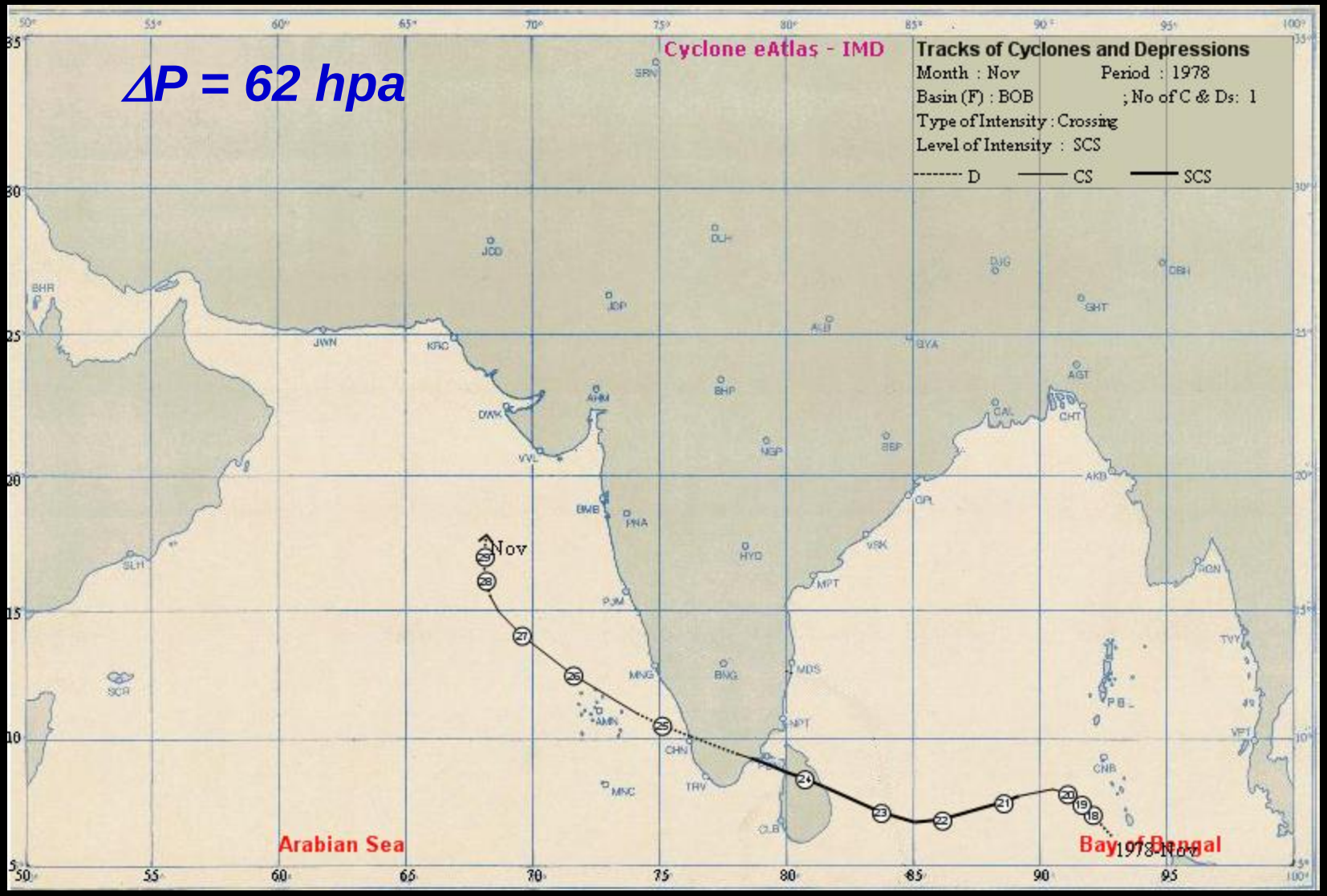
No Climate Change

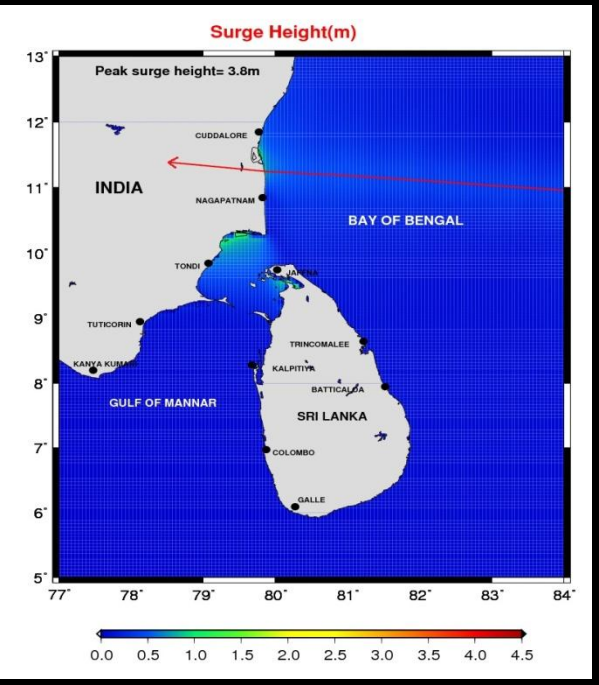
7% increase in winds

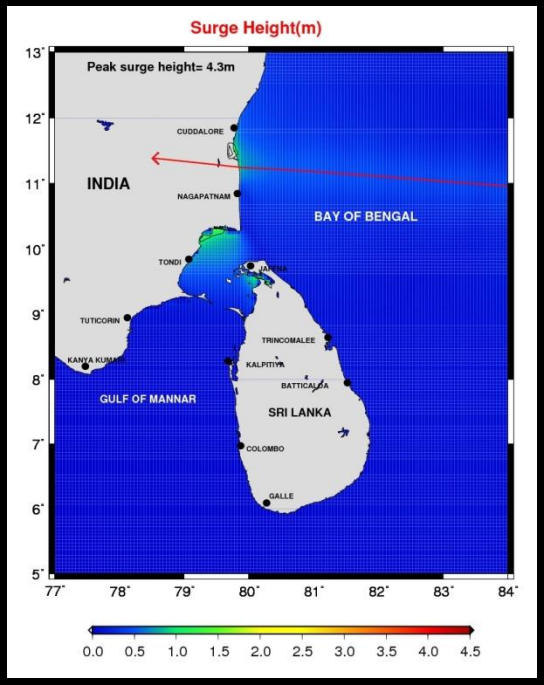
11% increase in winds

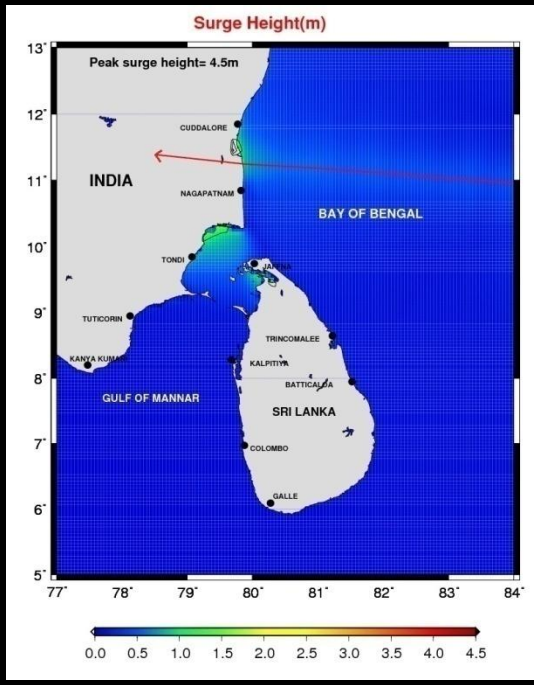
Storm Surge amplitudes for Gujarat coast of India

Most Intense Cyclone that hit the Tamil Nadu Coast of India









ΔP = 62 hpa

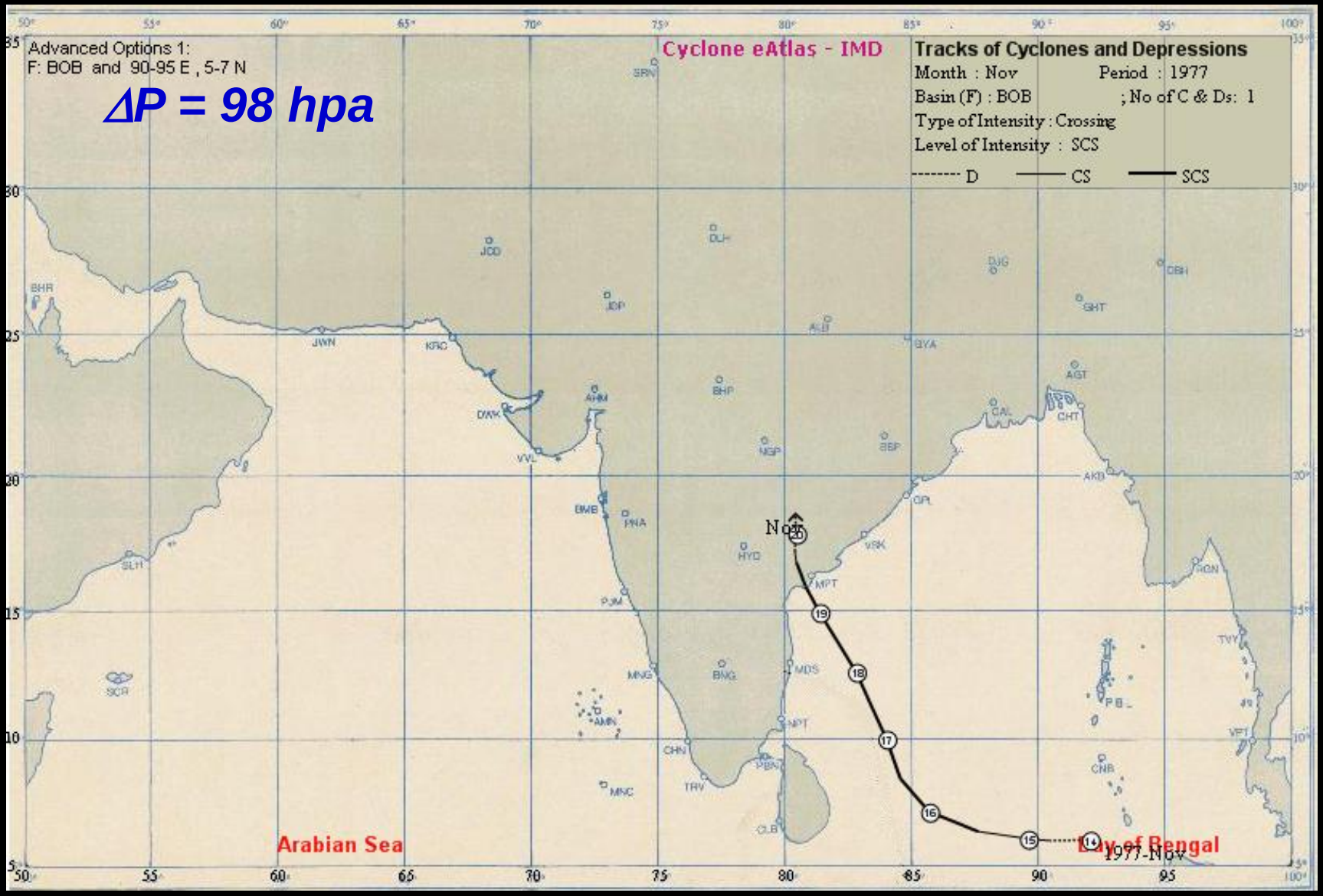
No Climate Change

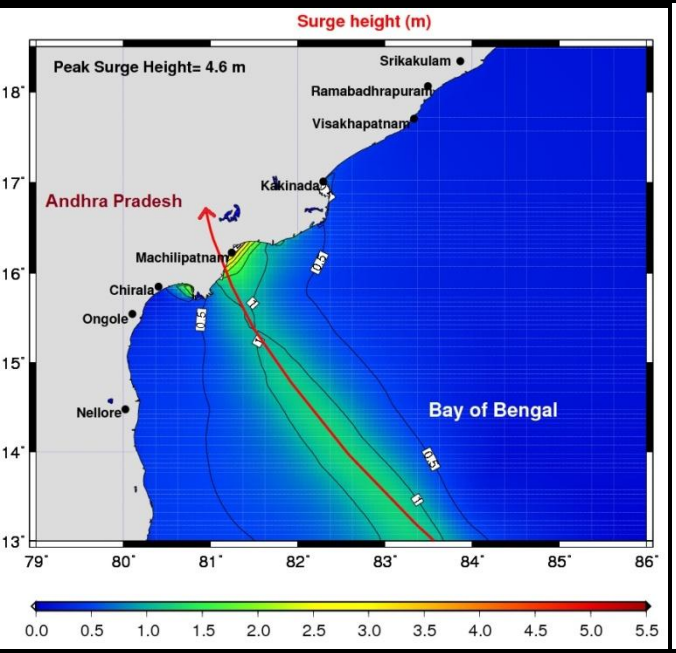
7% increase in winds

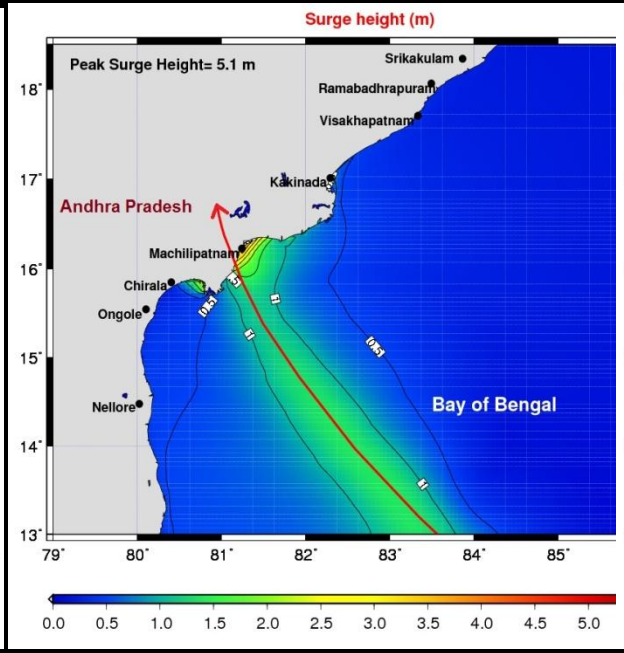
11% increase in wind

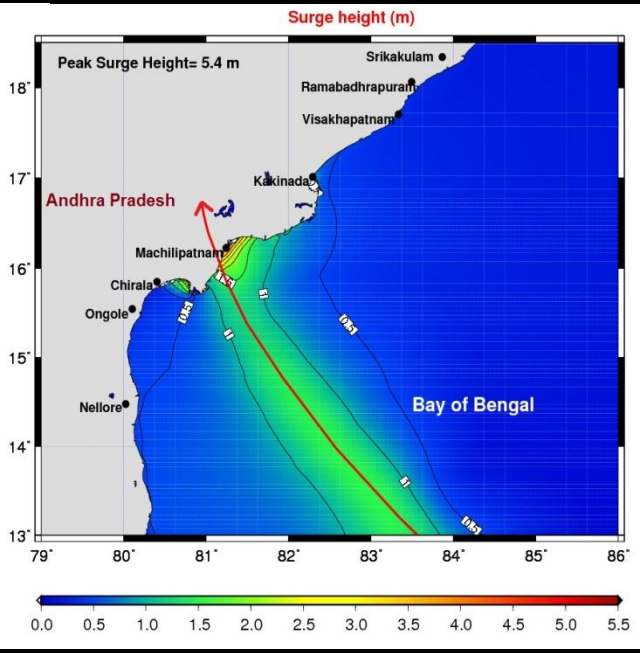
Storm Surge amplitudes for Tamil Nadu coast of India

Most Intense Cyclone that hit the Andhra Pradesh Coast of India









ΔP = 98 hpa

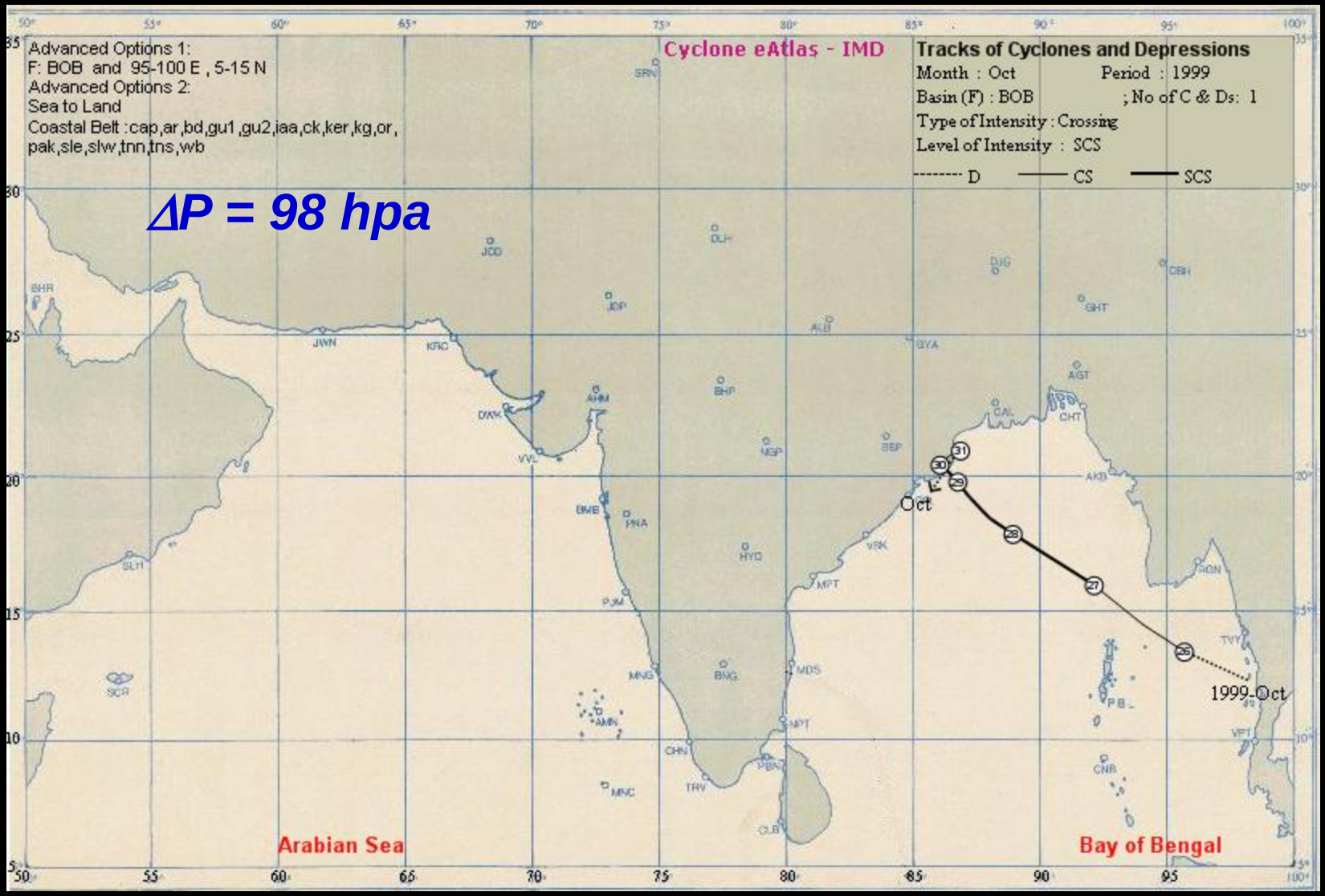
No Climate Change

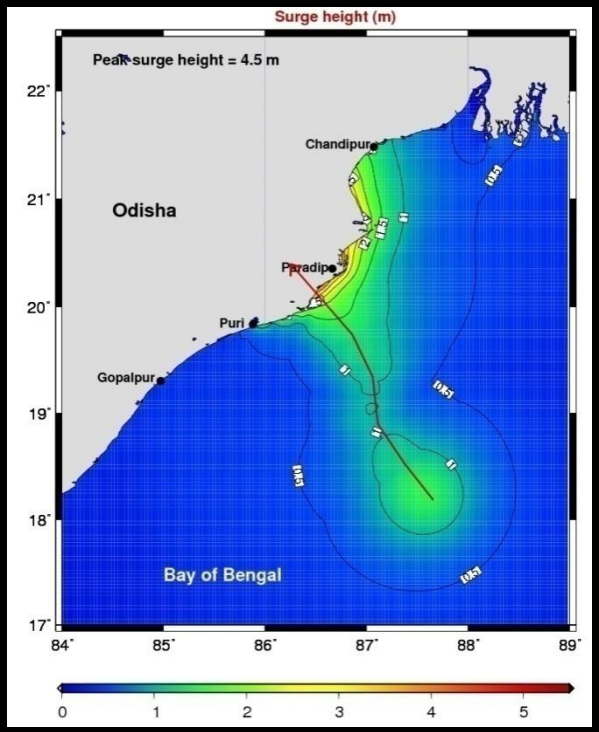
7% increase in winds

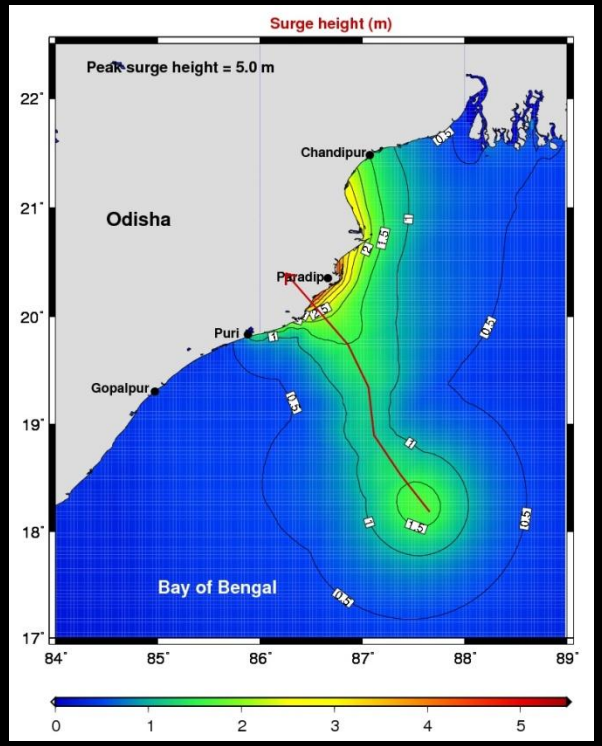
11% increase in winds

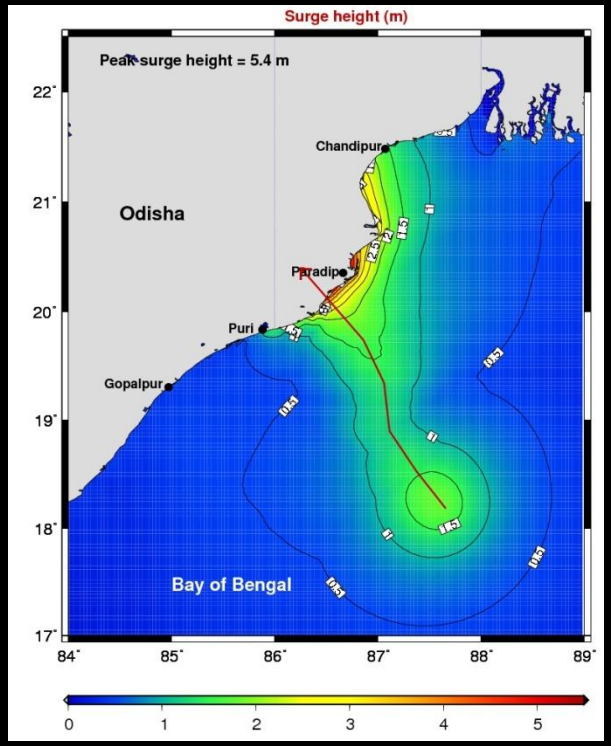
Storm Surge amplitudes for Andhra Pradesh coast of India

Most Intense Cyclone that hit the Odisha Coast of India









ΔP = 98 hpa

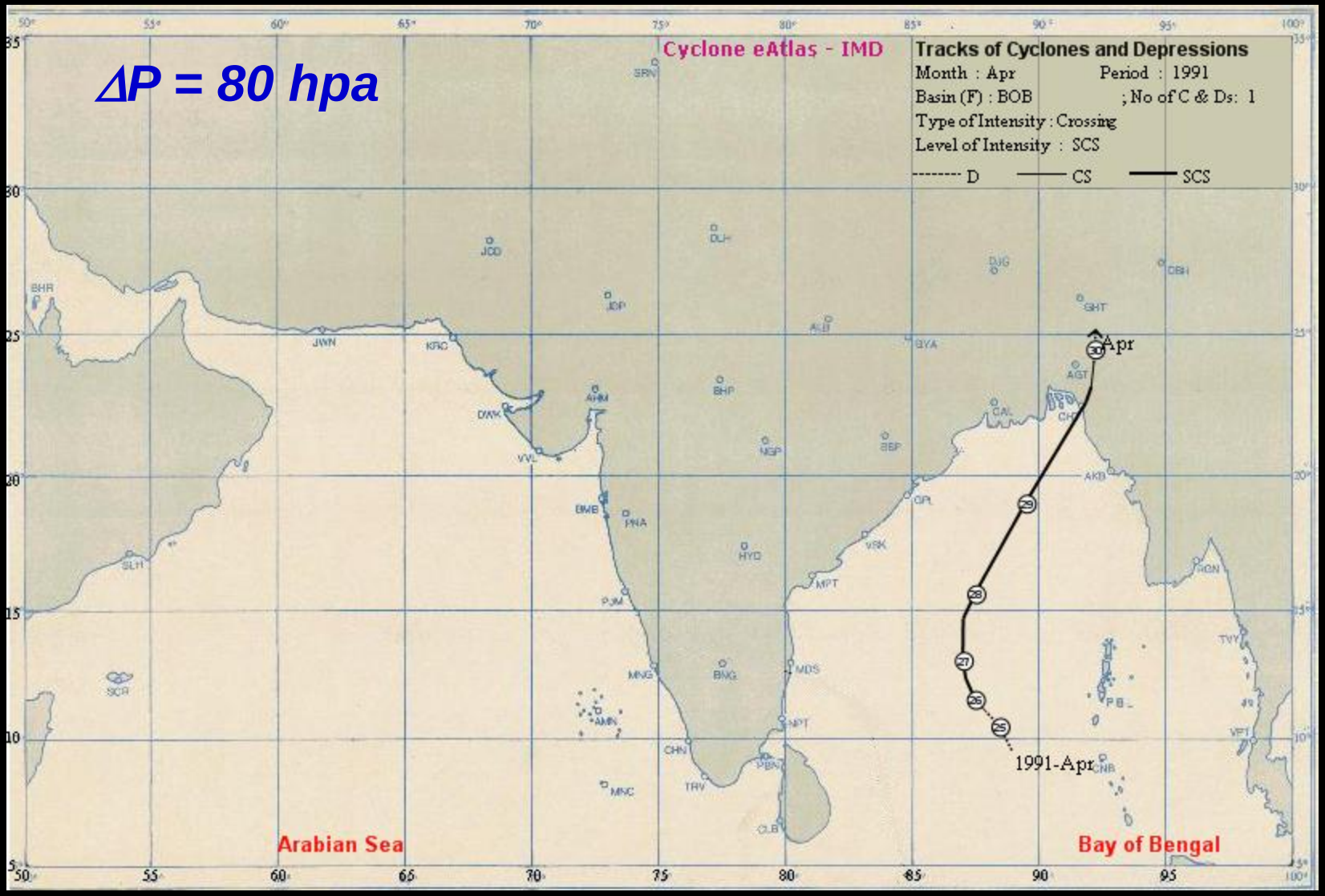
No Climate Change

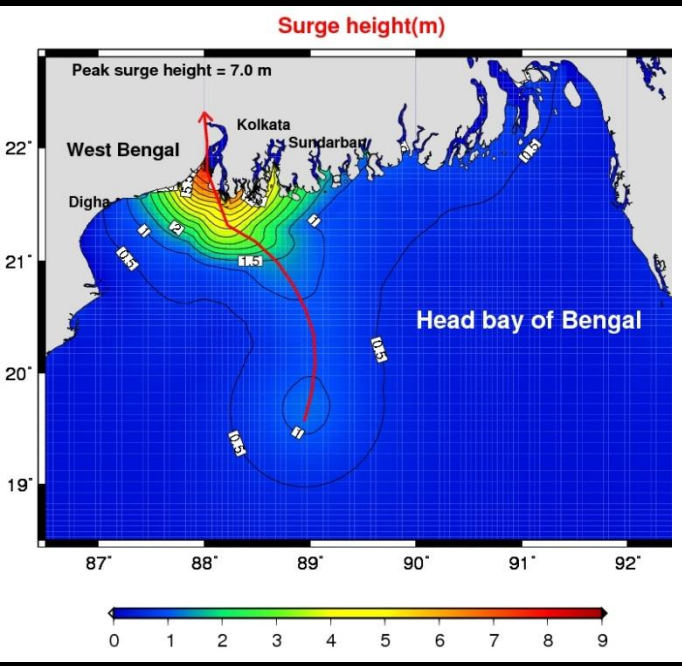
7% increase in winds

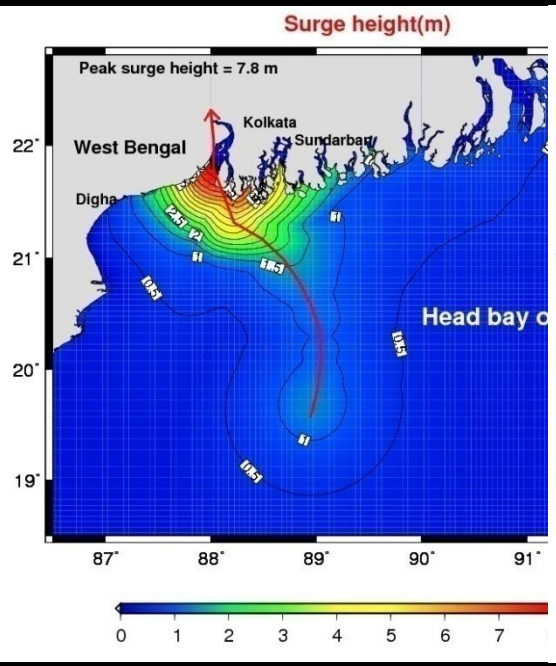
11% increase in winds

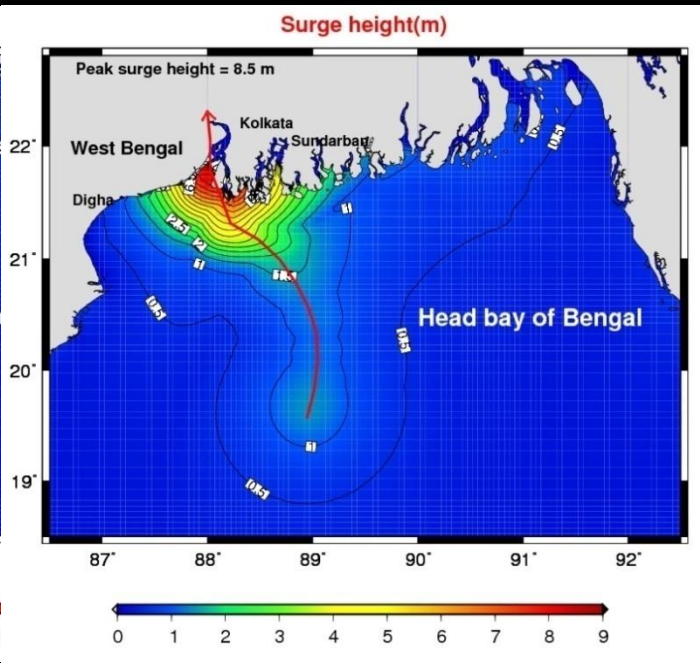
Storm Surge amplitudes for Odisha coast of India

Most Intense Cyclone that hit the Bangla & Bangladesh Coast









ΔP = 80 hpa
No Climate Change

7% increase in winds

11% increase in winds

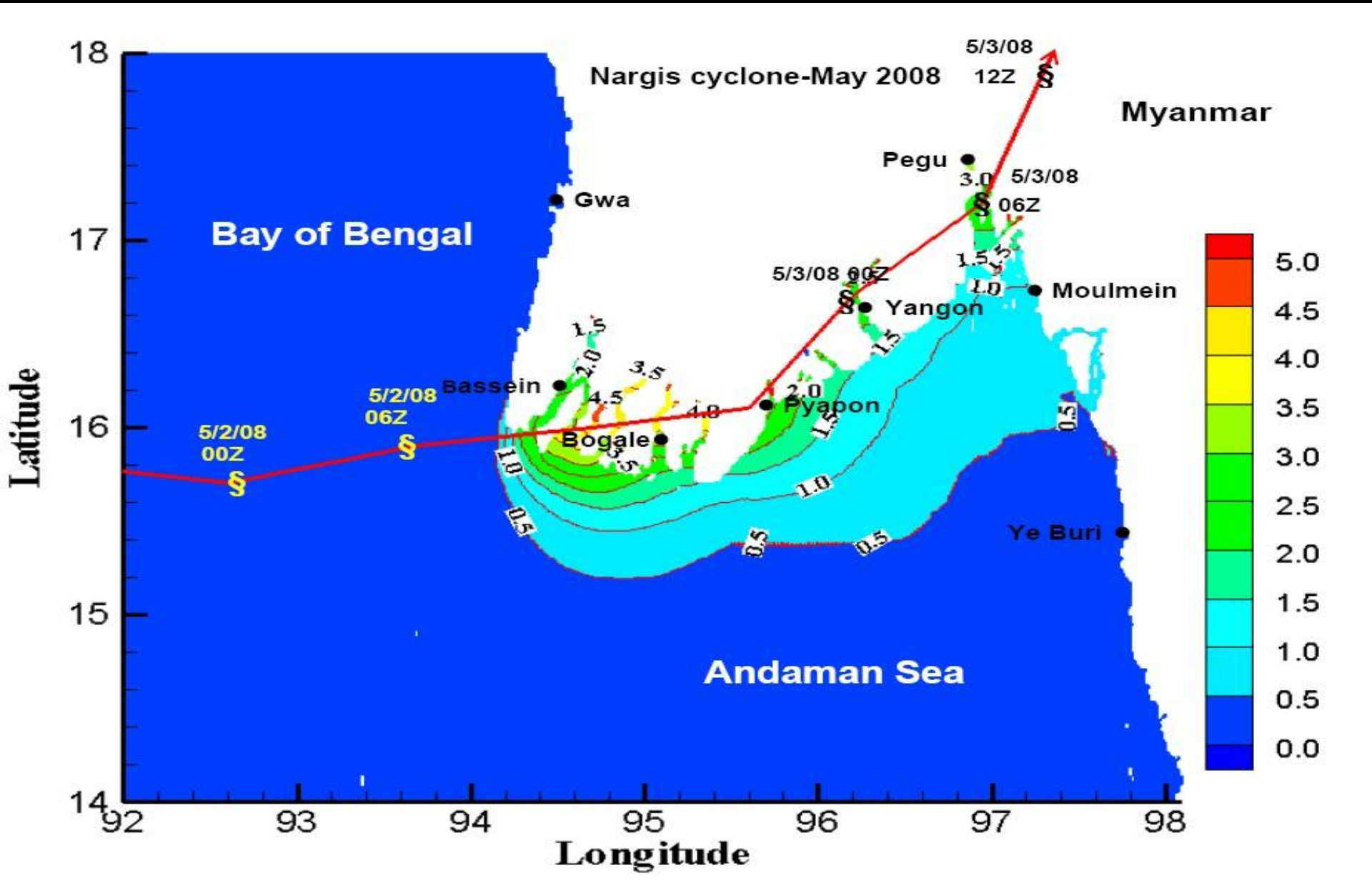
Storm Surge amplitudes for Head Bay

Maximum storm surge amplitudes (m) for different regions and different climate change scenarios

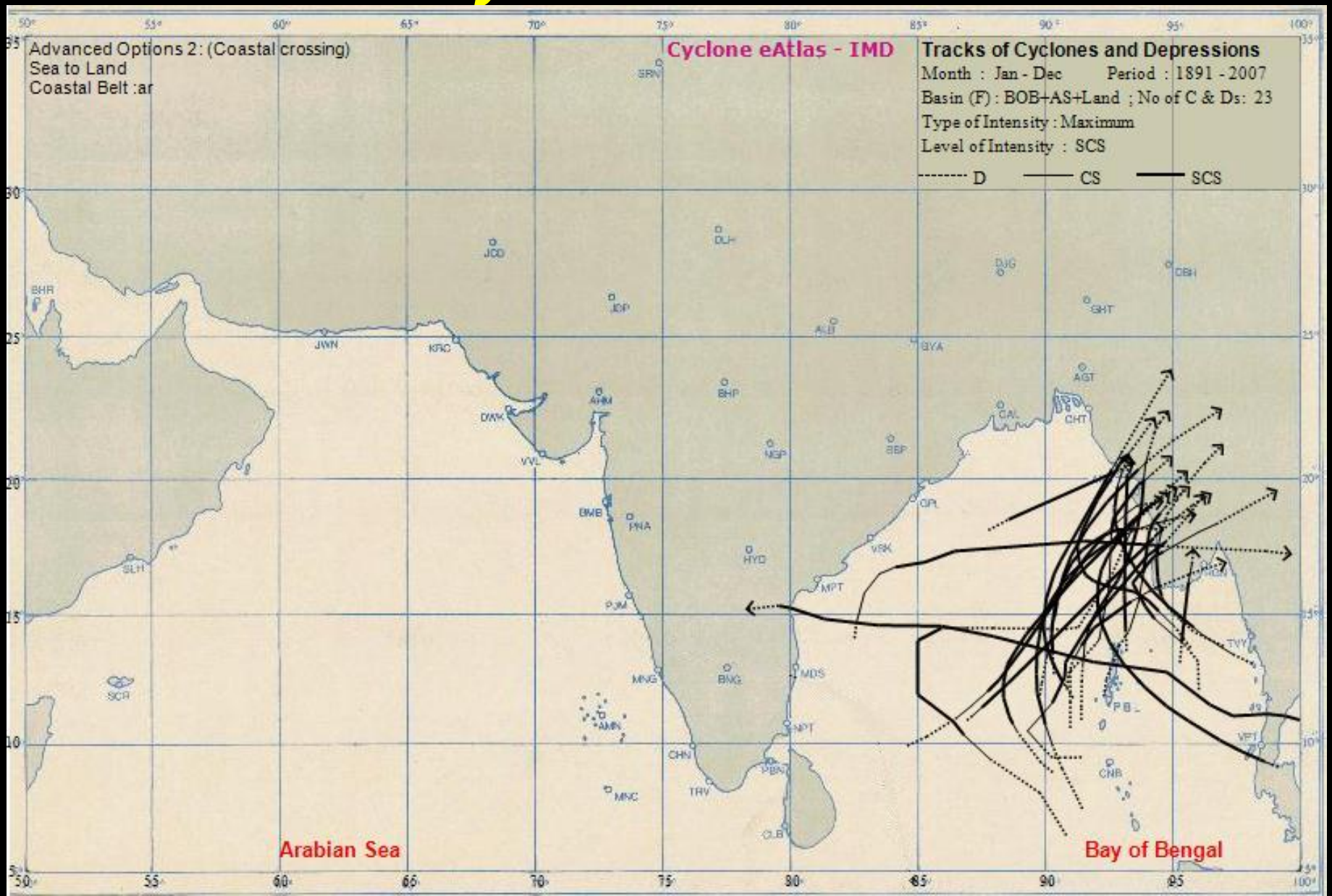
Regions	Amplitude (m) No Climate Change	Amplitude (m) 7% Intensification	Amplitude (m) 11% Intensification
Gujarat	6.8	7.6 (11.8 % increase)	8.0 (17.6% increase)
Tamil Nadu	3.8	4.3 (13.2 % increase)	4.5 (18.4% increase)
Andhra Pradesh	4.6	5.1 (10.9% increase)	5.4 (17.4% increase)
Odisha	4.5	5.0 (11.1% increase)	5.8 (28.8% increase)
Head Bay	7.0	7.8 (11.4% increase)	8.5 (18.8% increase)

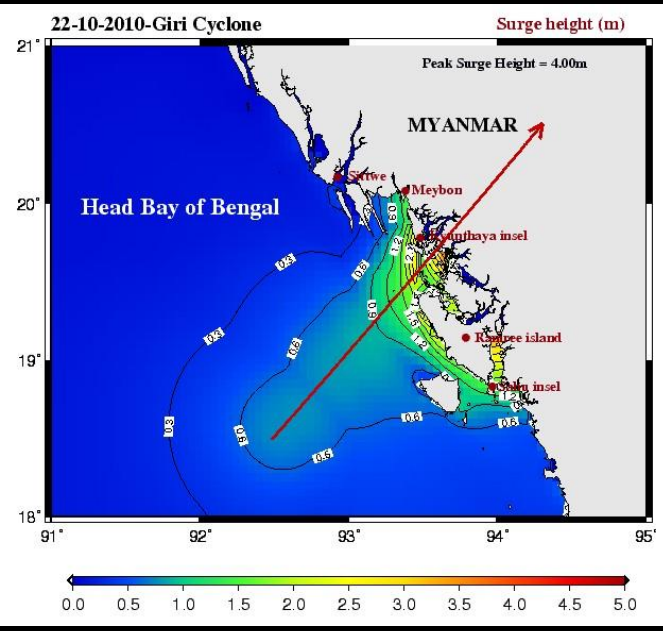
Storm Surge Inundation in Rekhine & Deltaic Coast of Myanmar Under Climate Change Scenarios

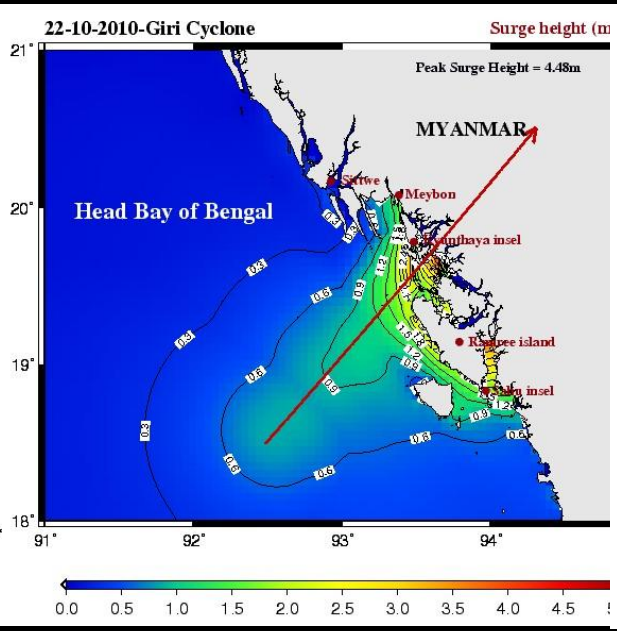
Peak Surge Envelope 2008 Myanmar Cyclone NARGIS

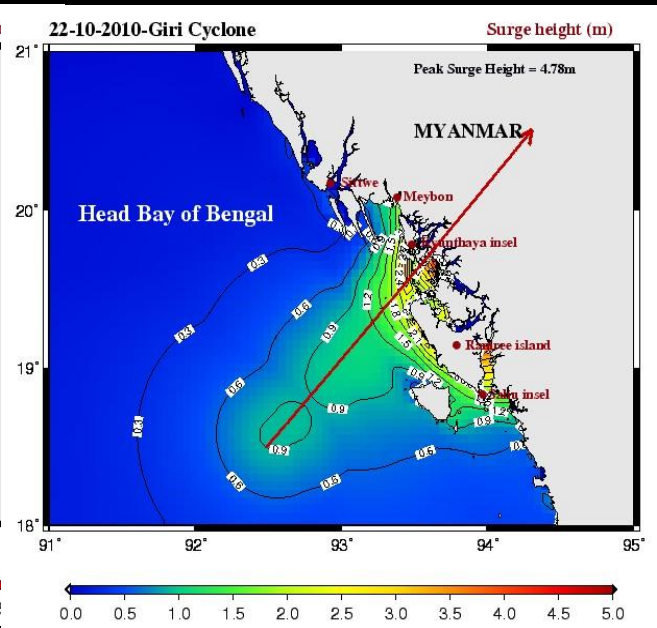


Tracks cyclones (1891-2007) hitting Myanmar Coast







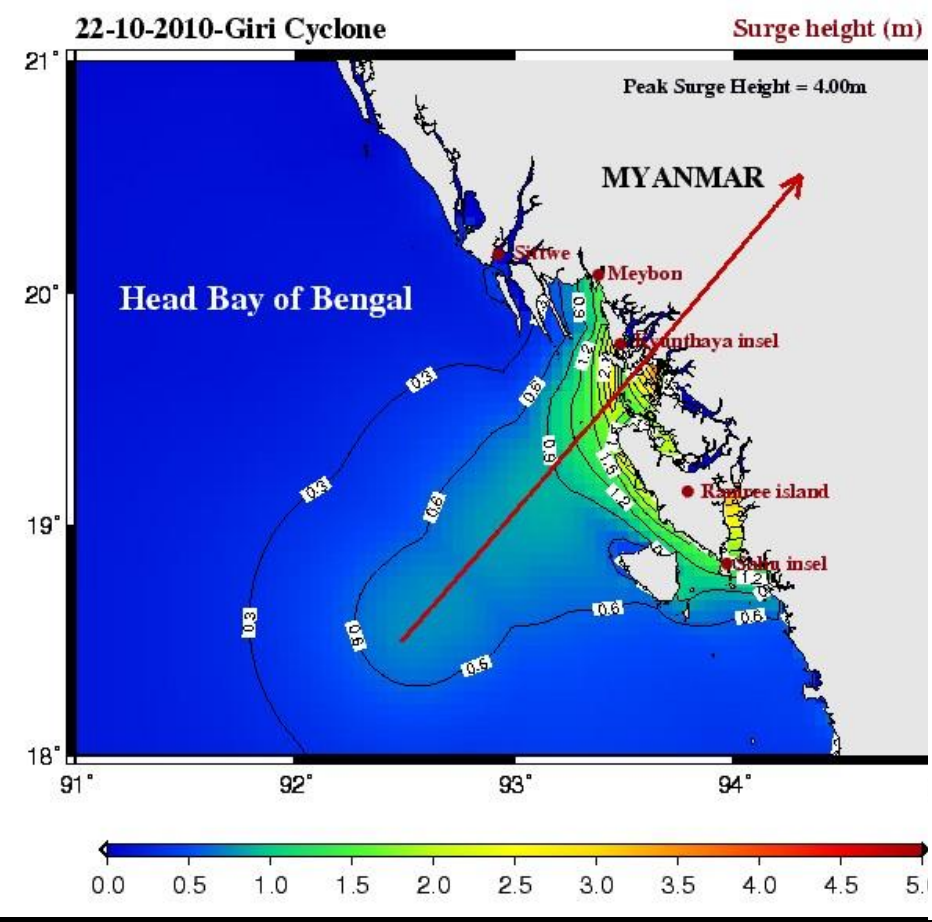


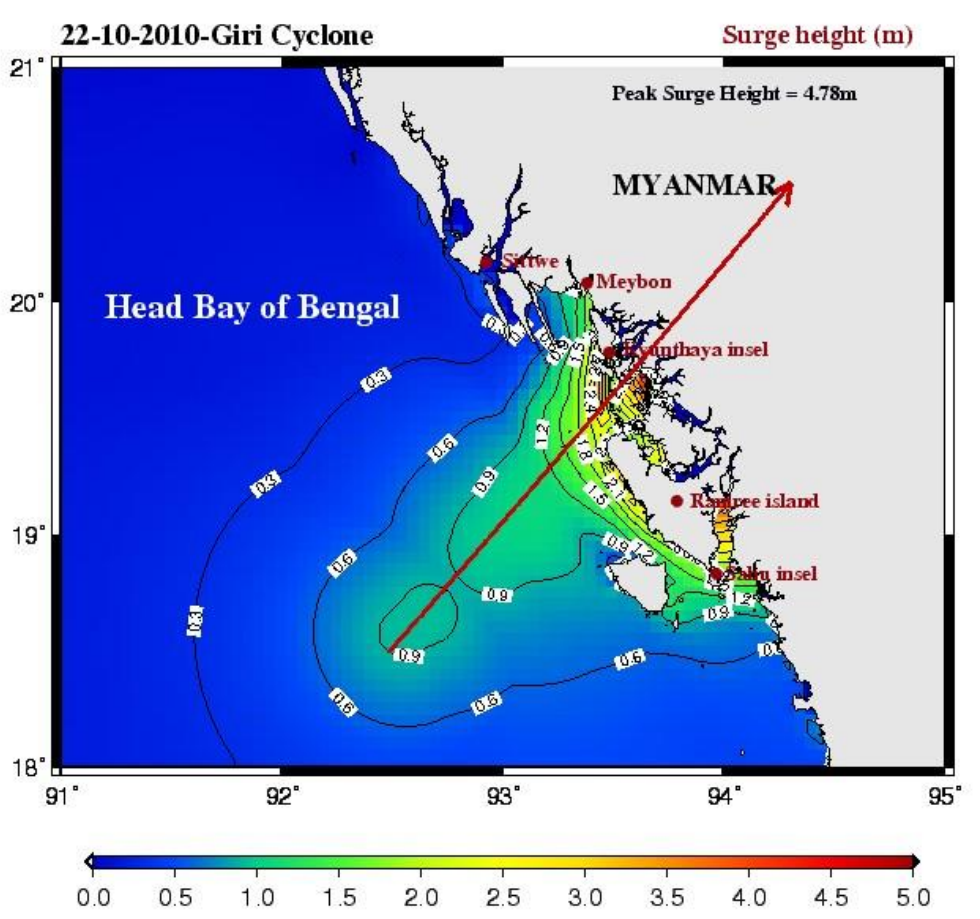
ΔP = 52 hpa

7% increase in winds

11% increase in winds

Storm Surge amplitudes for Northern most coast of Myanmar

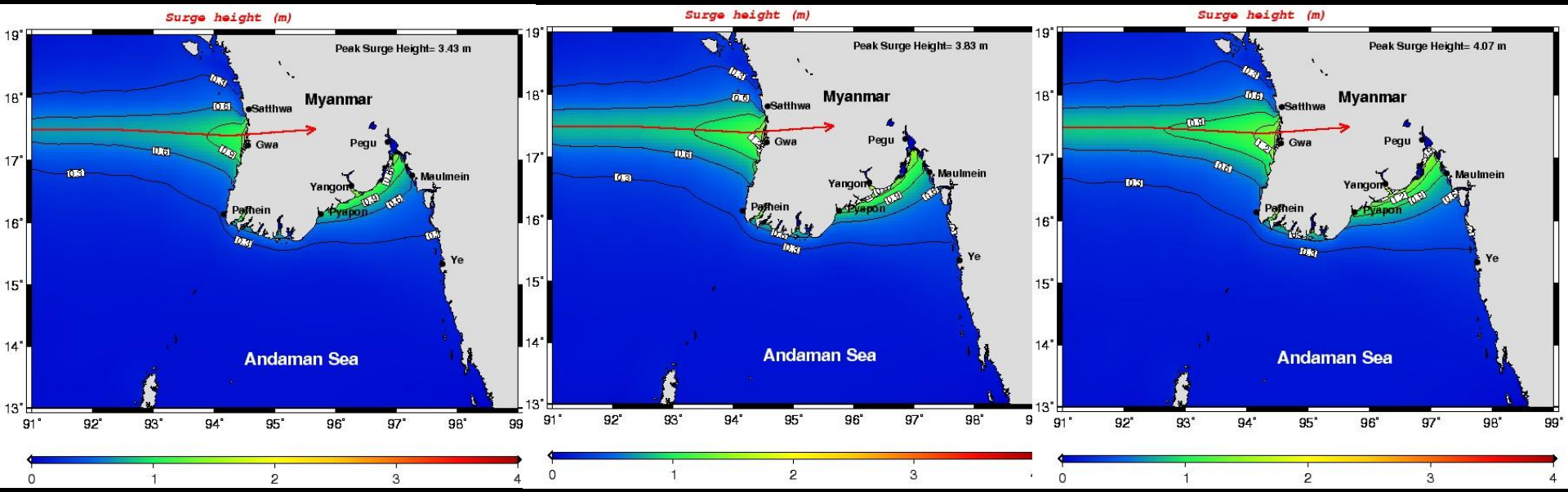




Without climate change
ΔP = 52 hpa

11% increase in winds

A comparison of extent of coastal stretch of the Northern most coast of Myanmar affected by Storm Surge with & without climate change projection

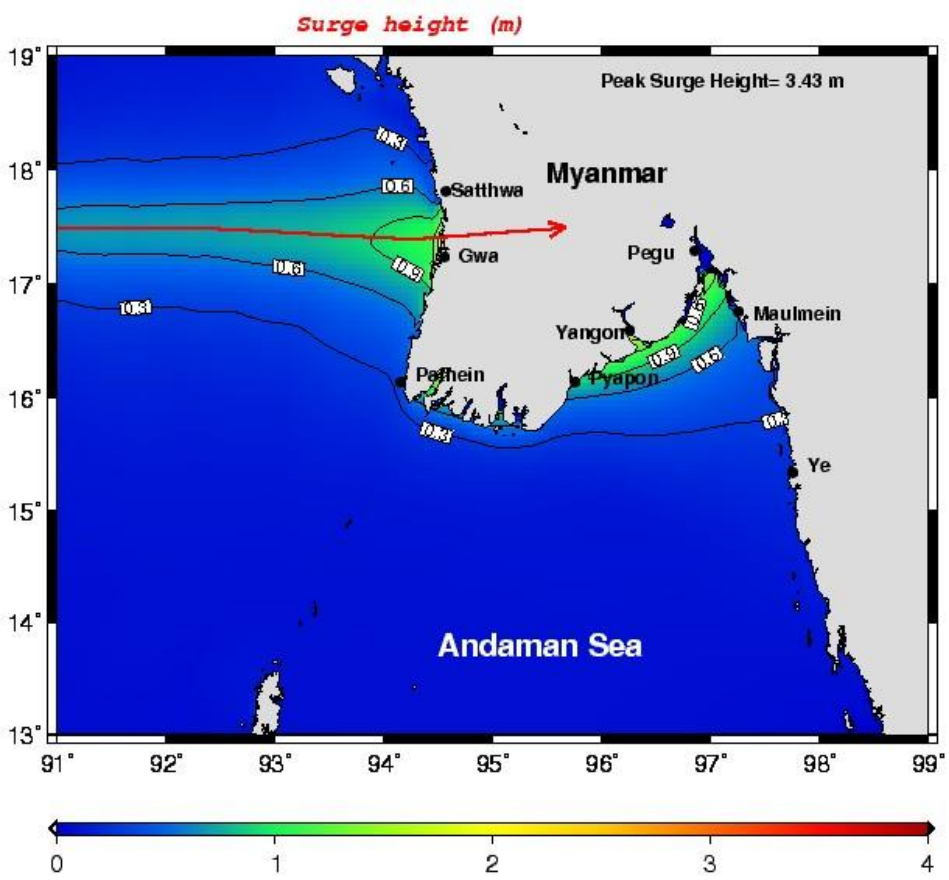


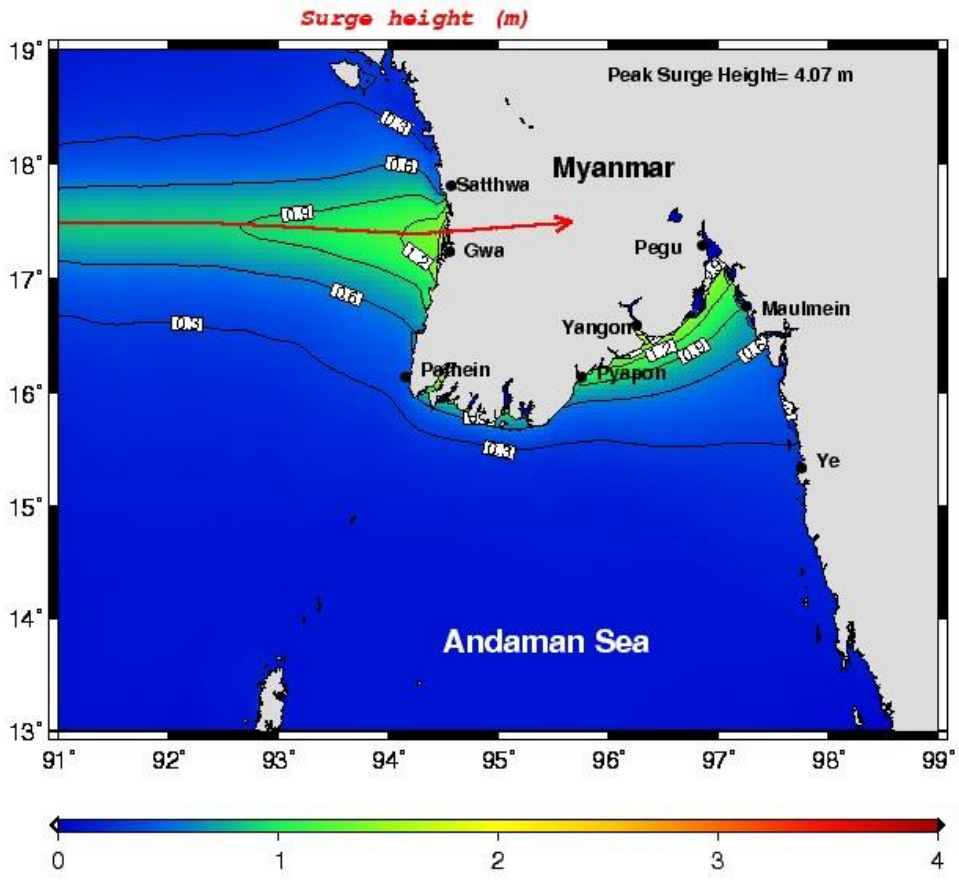
ΔP = 52 hpa

7% increase in winds

11% increase in winds

Storm Surge amplitudes for Central Rekhine coast of Myanmar

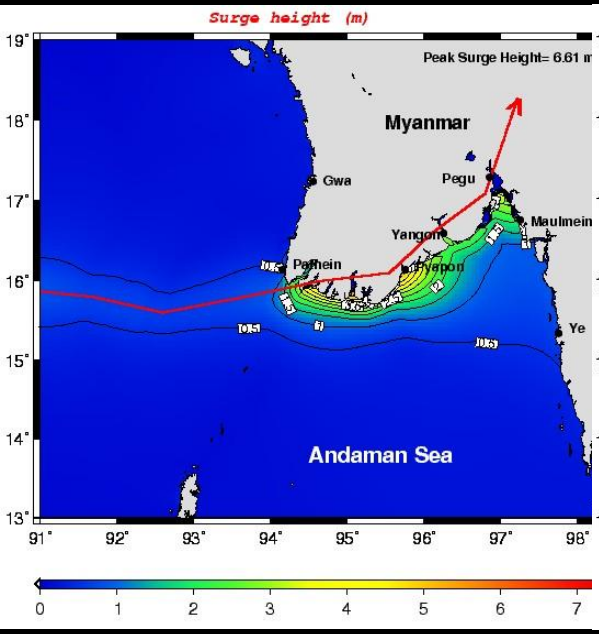


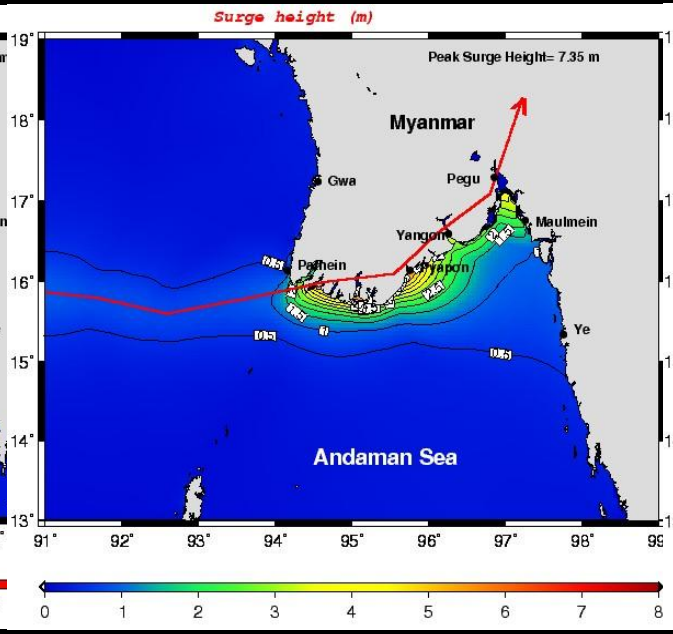


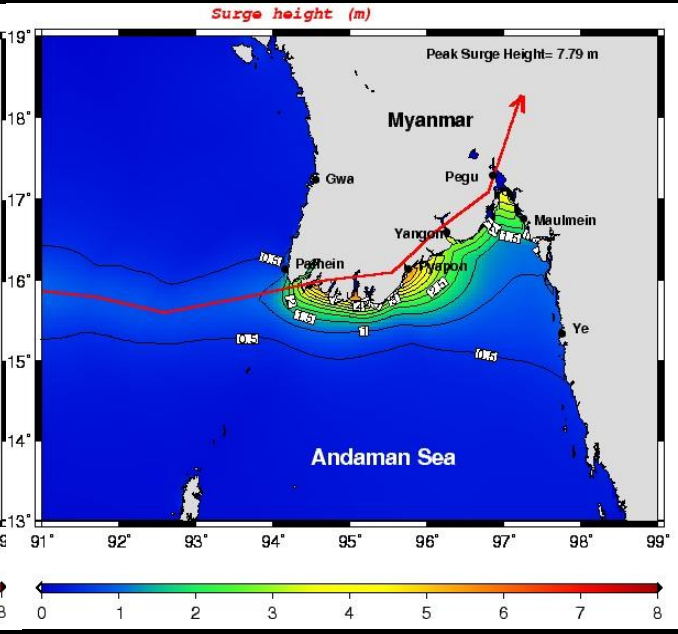
Without climate change
ΔP = 52 hpa

11% increase in winds

A comparison of extent of coastal stretch of the Central Rekhine coast of Myanmar affected by Storm Surge with & without climate change projection





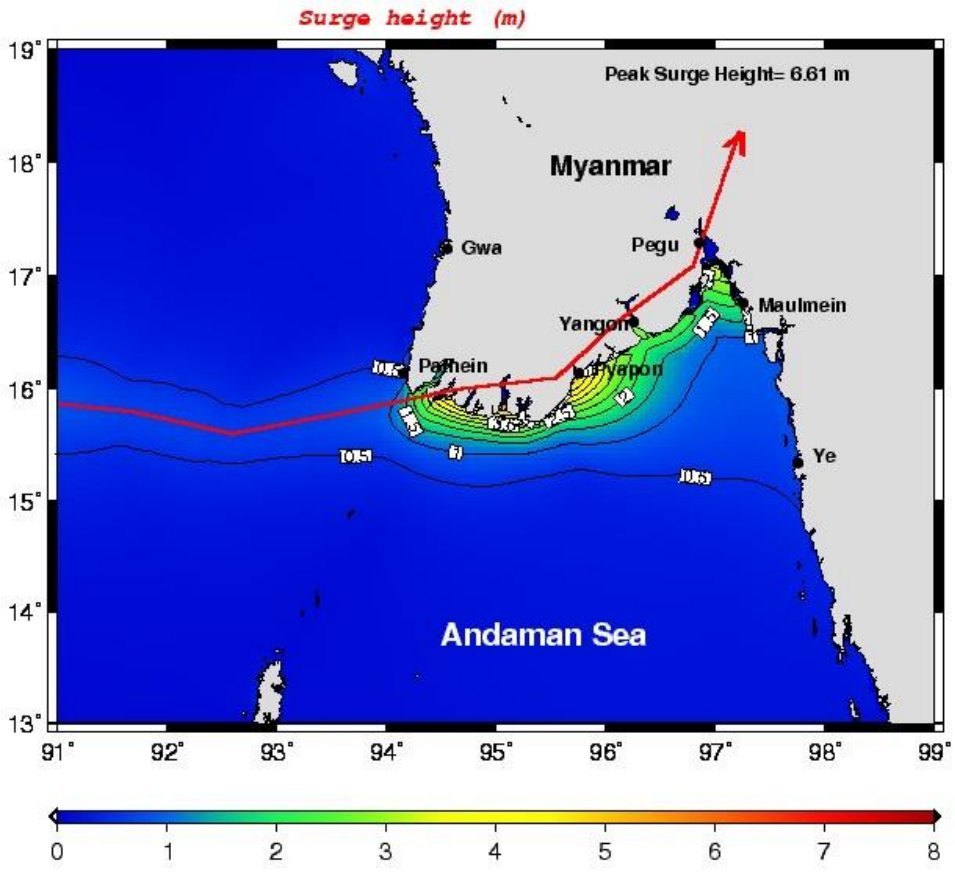


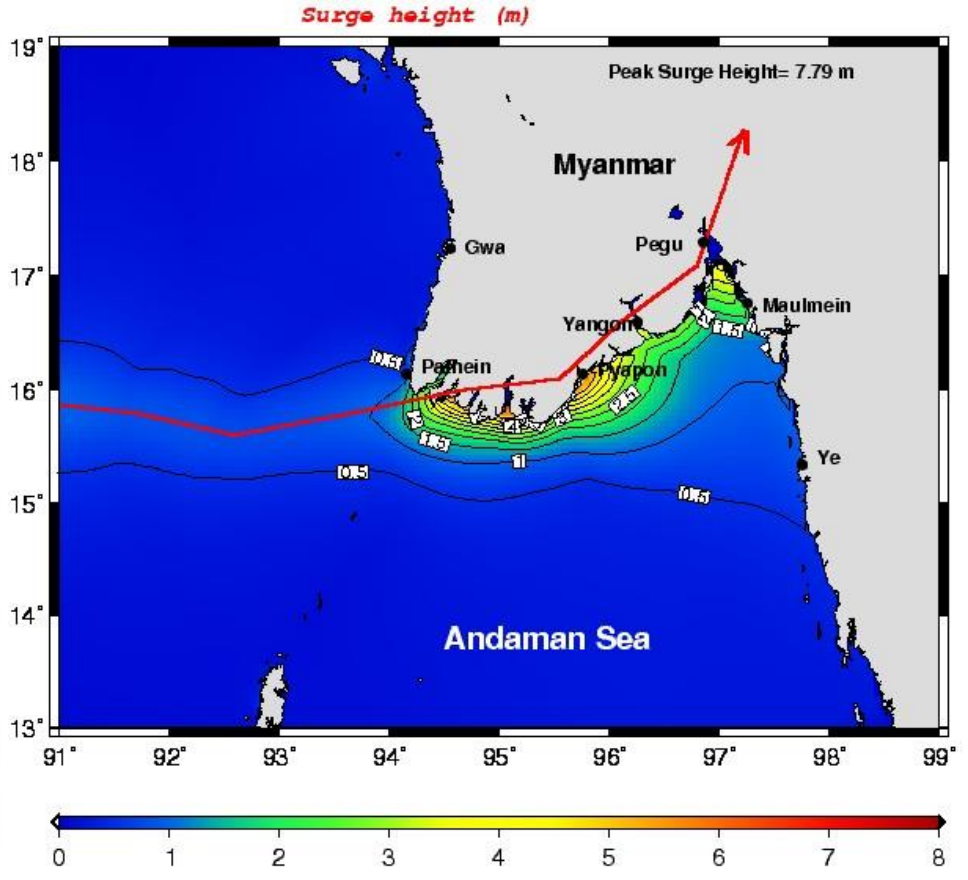
ΔP = 52 hpa

7% increase in winds

11% increase in winds

Storm Surge amplitudes for Deltaic coast of Myanmar





Without climate change
ΔP = 52 hpa

11% increase in winds

A comparison of extent of coastal stretch of the Deltaic coast of Myanmar affected by Storm Surge with & without climate change projection

Maximum storm surge amplitudes (m) for different regions and different climate change scenarios

Regions	Amplitude (m) No Climate Change	Amplitude (m) 7% Intensification	Amplitude (m) 11% Intensification
Northern most Rekhine	4.0	4.5 (12.5 % increase)	4.8 (20% increase)
Rekhine Central	3.4	3.8 (11.8 % increase)	4.1 (20.6% increase)
Deltaic Coast	6.6	7.4 (12% increase)	7.8 (18% increase)

THANK YOU for Attention