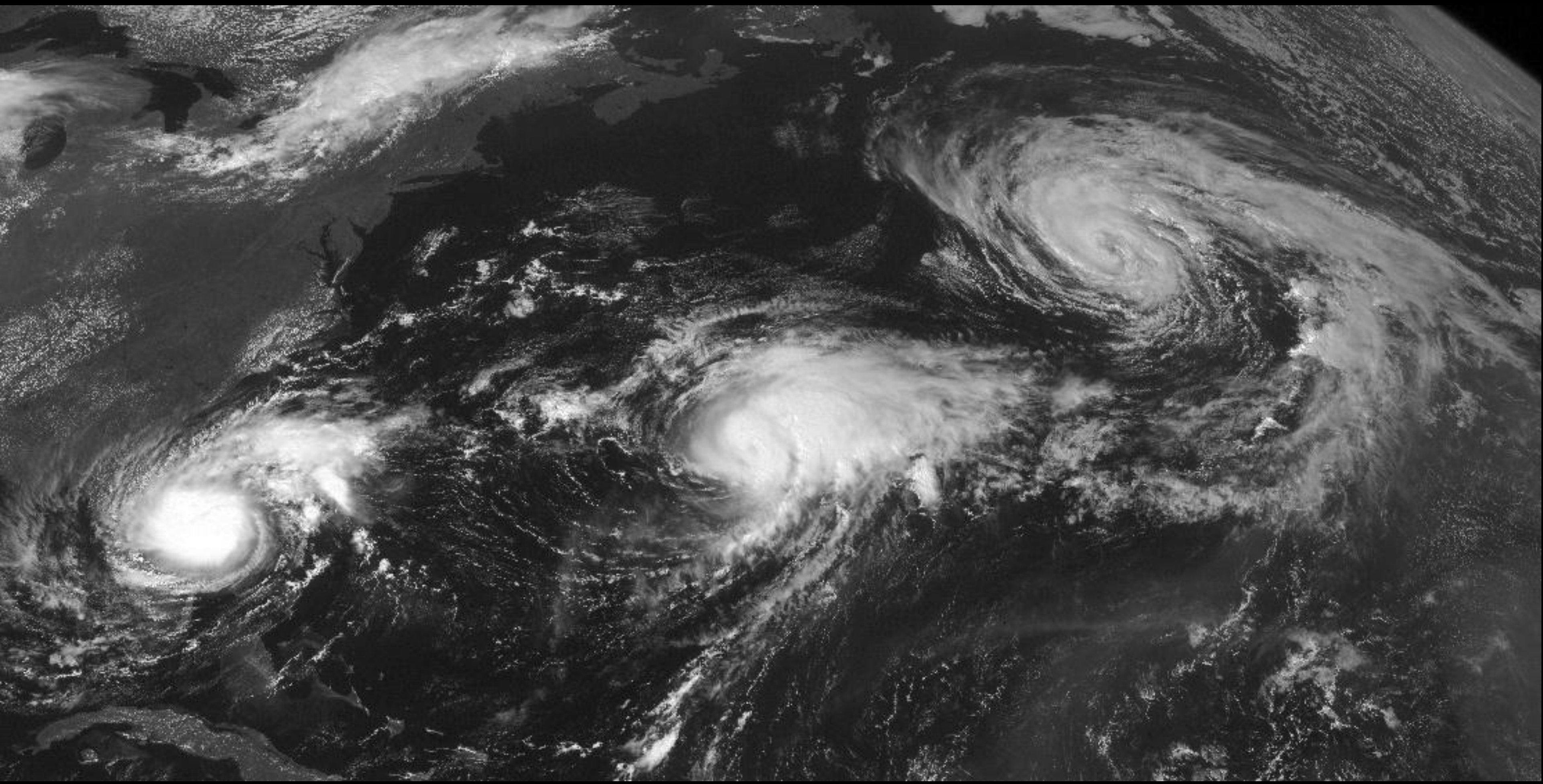
EARTH 270 – DISASTERS AND NATURAL HAZARDS (v. 2018)

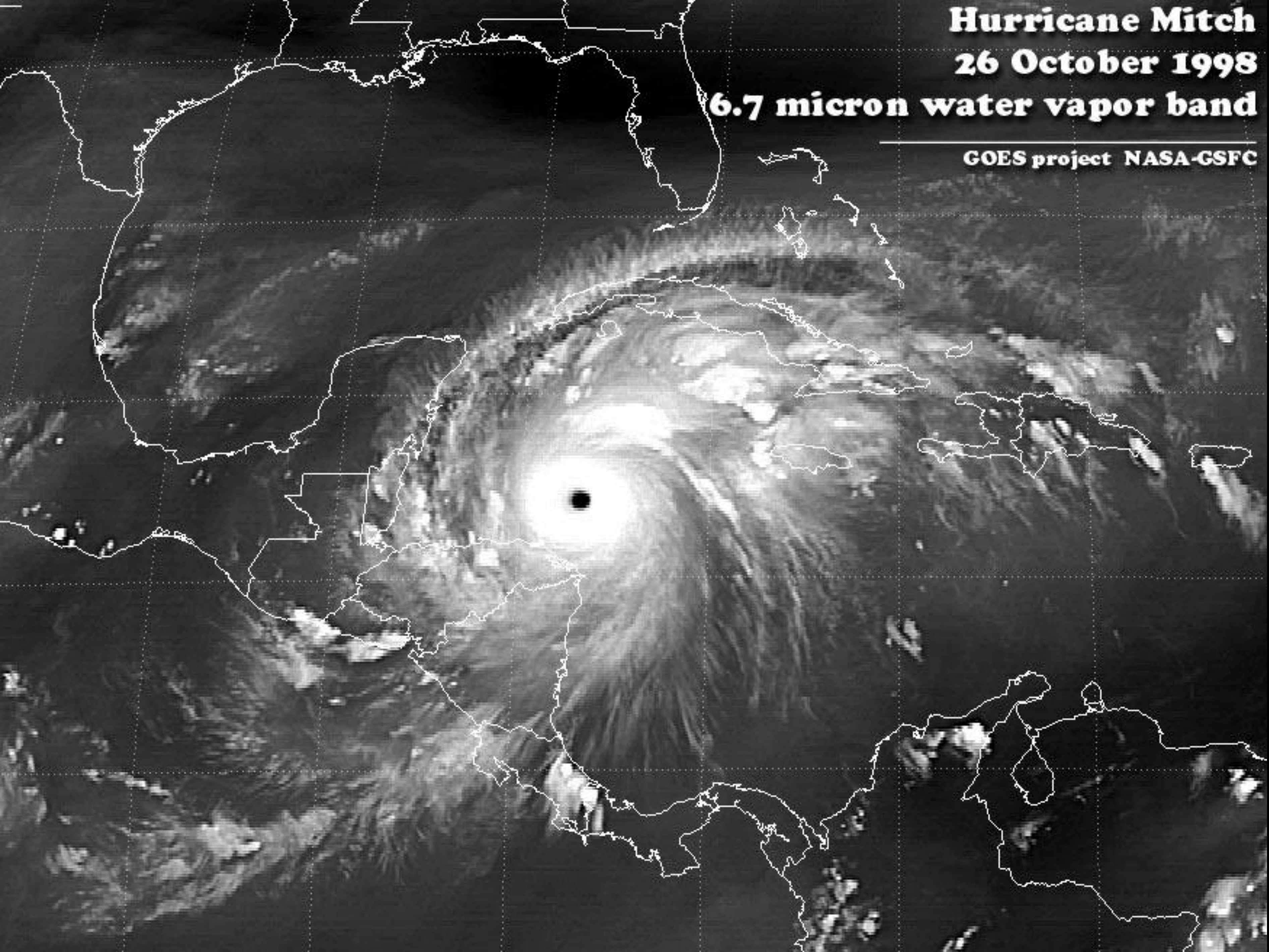

Kensennuma City, Miyagi Prefecture , Japan, March 2011

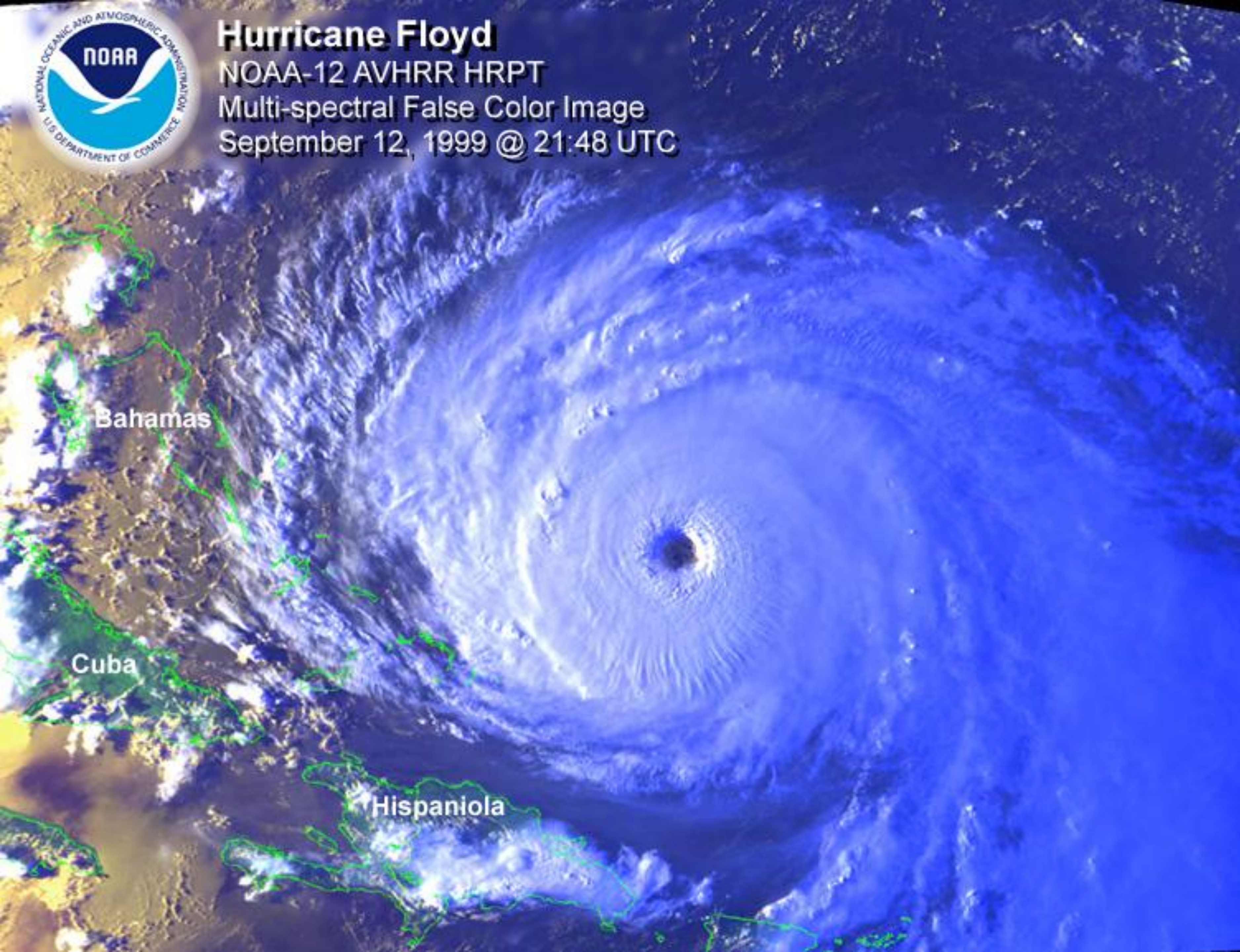
PROFESSOR S.G. EVANS, PhD, PEng (Room 303, Earth Science and Chemistry (ESC) Building)

UNIVERSITY OF WATERLOO

HURRICANES AND COASTLINE IMPACT



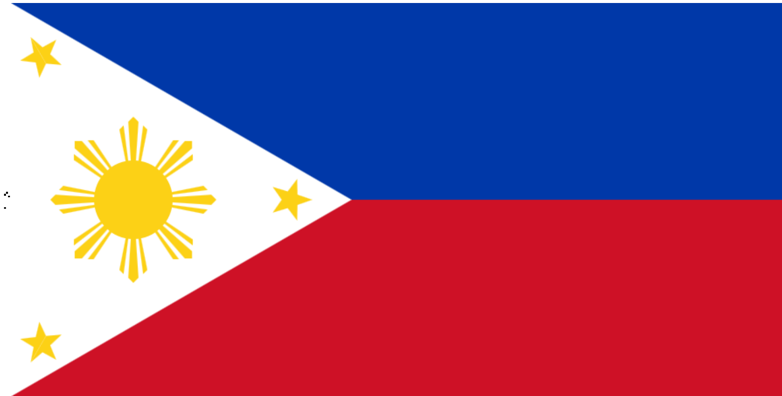

Hurricane Mitch
26 October 1998
6.7 micron water vapor band
GOES project NASA-GSFC


NOAA
Hurricane Floyd
NOAA-12 AVHRR HRPT
Multi-spectral False Color Image
September 12, 1999 @ 21:48 UTC
Bahamas
Cuba
Hispaniola

Philippines in 'national calamity'

The Philippine President Benigno Aquino declares a state of national calamity following Friday's devastating typhoon which has killed thousands of people.

- BBC reports from destroyed Cebu
- George Alagiah: Inside aid centre
- Photos before and after the storm
- Messages sent to loved ones
- In pictures: Philippines reels
- Survivors' stories



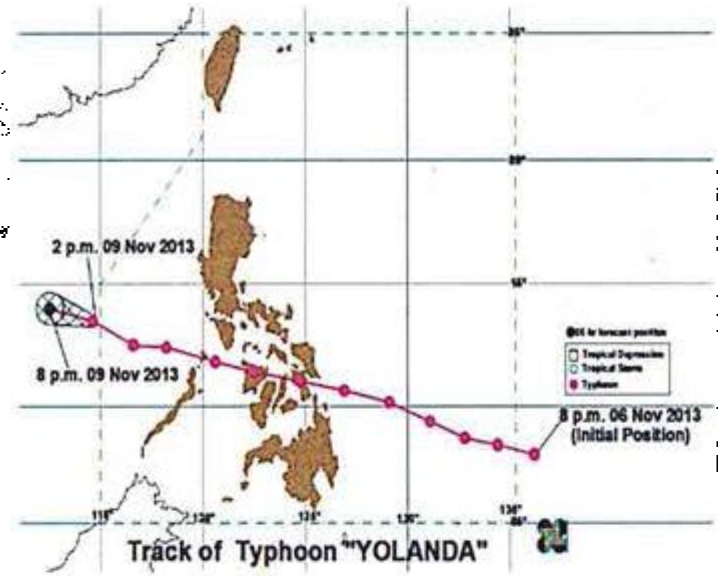
Haiyan probably the strongest tropical storm ever to make landfall

The most severe catastrophe in human terms was caused by Supertyphoon Haiyan, which tore across the southern Philippines on 7 November, with maximum wind speeds of well over 300 km/h. Shortly before that, the strongest gust was measured over the ocean at 379 km/h. The radius of the storm system amounted to around 600 km. And the eye of the tropical storm, just outside of which the wind speeds are highest, measured an exceptional 20–25 km in diameter. Haiyan was probably the strongest recorded cyclone ever to make landfall. As a result of the extreme wind force of over 300 km/h and the resultant flood wave of up to 6 m in height, many settlements like the coastal city of Tacloban were razed almost to the ground

Over 6,000 people were killed in the storm, and millions were left homeless. The harvest in this significant agricultural region, with extensive sugar cane cultivation, was largely destroyed. The overall loss totalled some US$ 10bn, equivalent to around 5% of the Philippines' annual economic output. Owing to the very low insurance penetration, the insured loss will probably only be in the mid three-digit million range.

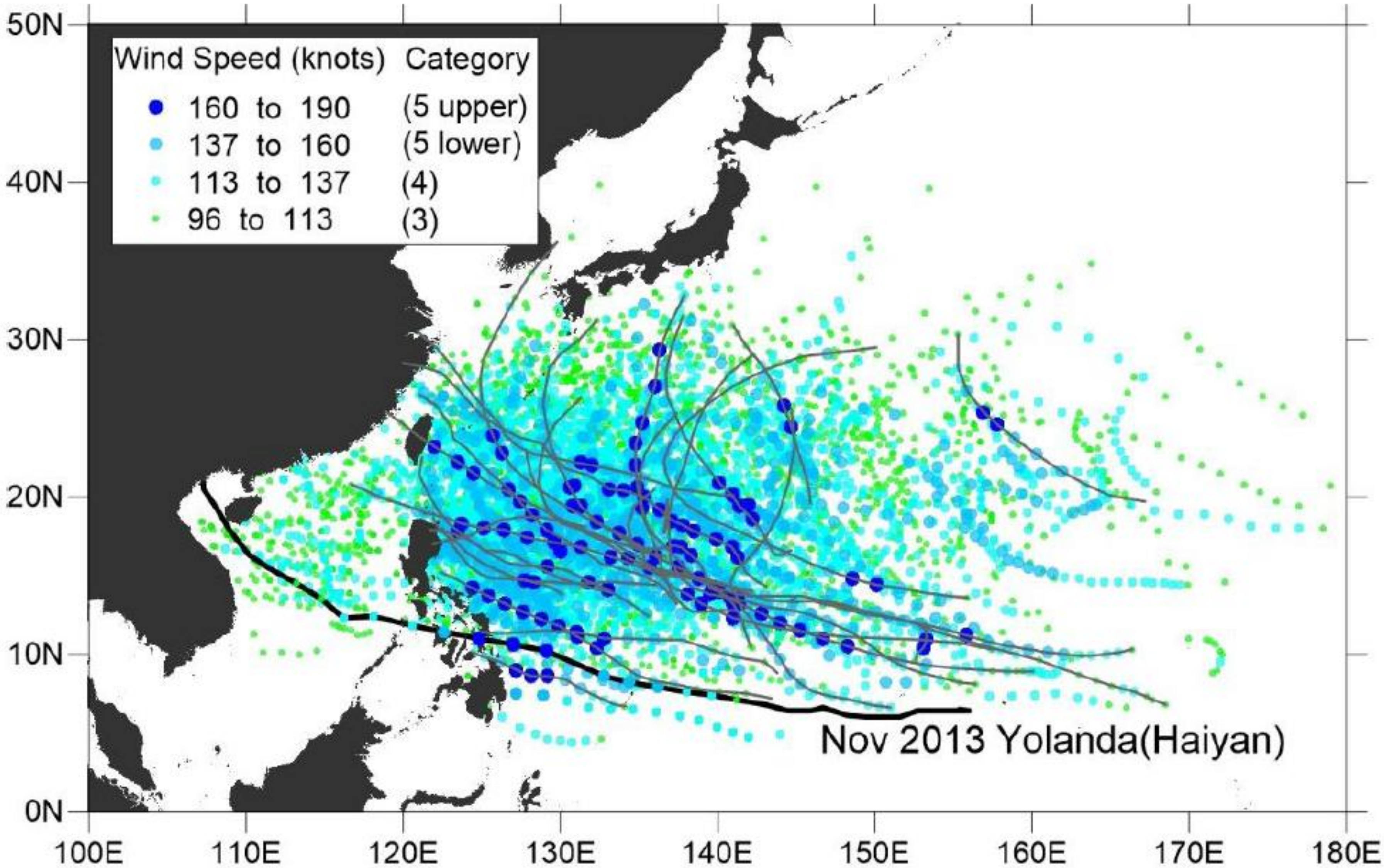
"Haiyan shows the importance of government measures in construction planning. The Philippines are the country most frequently affected by tropical cyclones", said Ludger Arnoldussen, whose responsibilities on Munich Re's Board of Management include the Asian markets. "At the same time, insurance programmes – possibly also with state backing – can help provide the people affected with quicker financial support. Studies sponsored by Munich Re have shown that insurance against natural catastrophes in emerging countries has the greatest relief effect in macroeconomic terms."

The 2013 typhoon season in the Pacific was above average in terms of activity, with 31 named storms. "The destructive power of typhoons threatens coastal regions, islands and also inland regions throughout Southeast Asia. Based on a natural cycle, our analyses predict the beginning of a phase with higher typhoon activity for the coming years", added Arnoldussen.



EUMETSAT COMPOSITE IMAGE OF TYPHOON HAIYAN IN THE PACIFIC APPROACHING THE PHILIPPINES (November 7, 2013)

SUPER TYPHOON HAIYAN (YOLANDA) 2013 : 7,329 Dead and Missing, 550,928 houses totally destroyed (as of March 14, 2014)



TYYPHOON HAIYAN AND TYPHOON TRACKS IN WESTERN PACIFIC BETWEEN 1951 and 2012

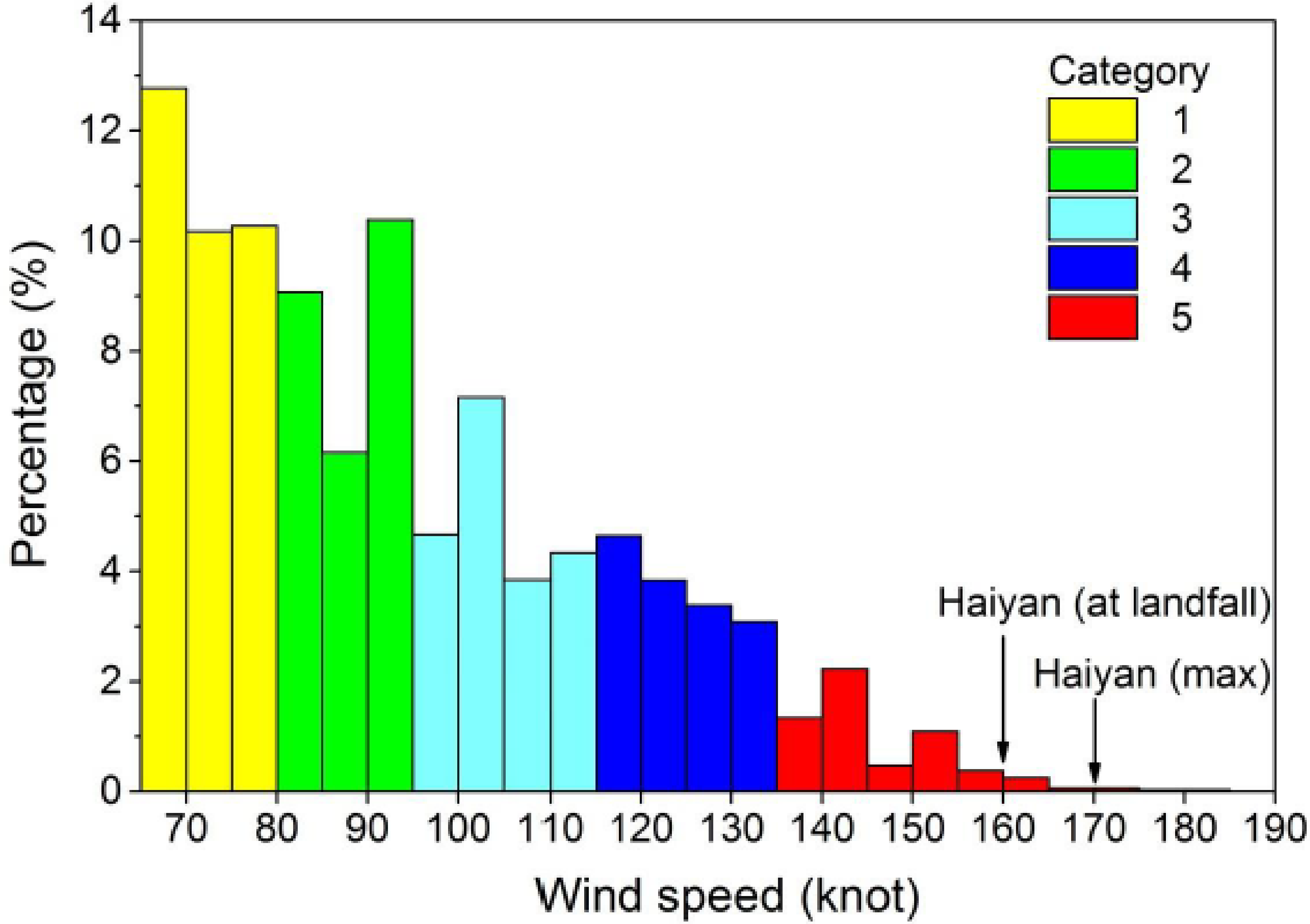


Figure 2. Historical distribution of maximum wind speeds in the Western North Pacific between 1951 and 2012, showing how Haiyan was one of the most powerful ever recorded. The figure was obtained by reanalyzing the JTWC best track data.

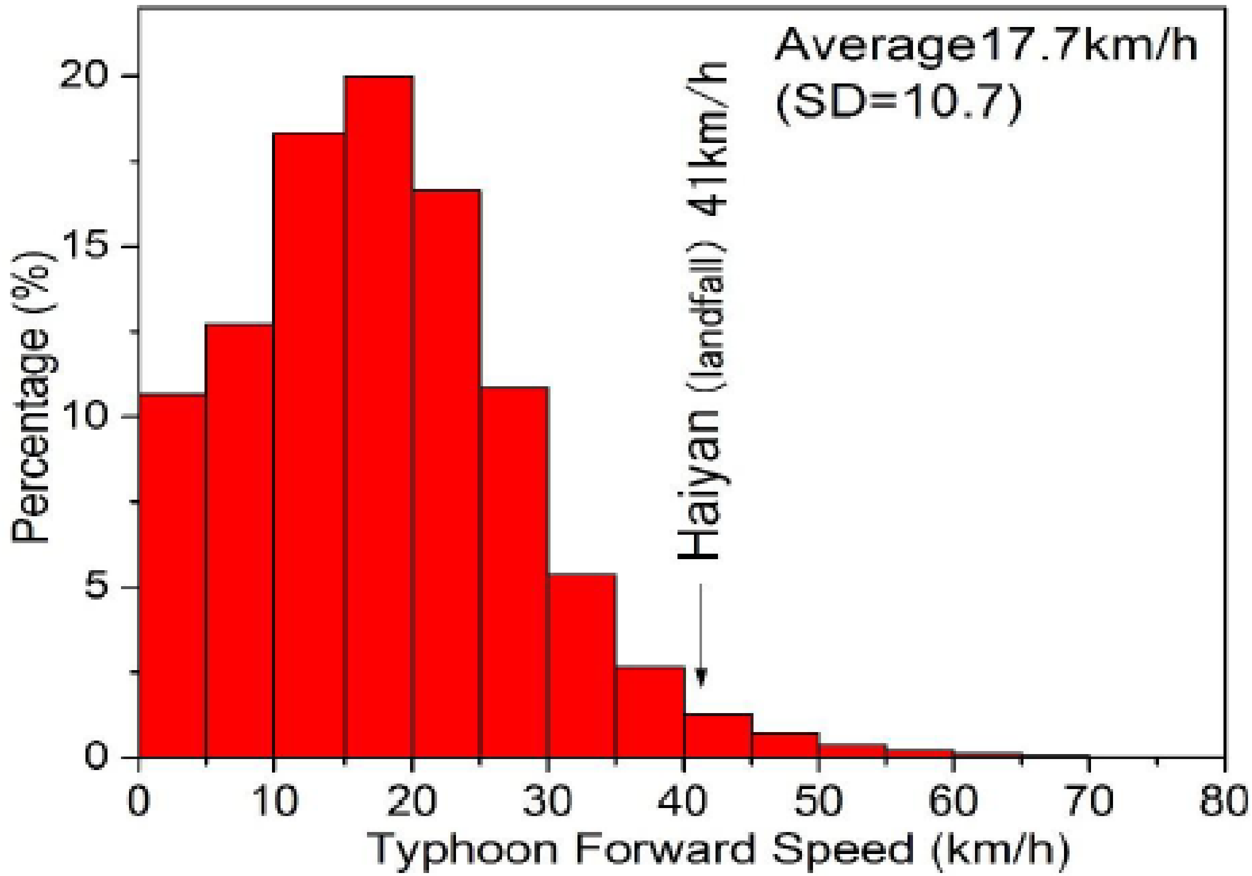


Figure 3. Historical distribution of typhoon forward speeds in the lower Western North Pacific (latitudes lower than 30°N) between 1951 and 2012. The figure was obtained by reanalyzing the JTWC best track data.


NO PARKING
03.11.2006 11:23

PASSAGE OF TYPHOON HAIYAN OVER TACLOBAN

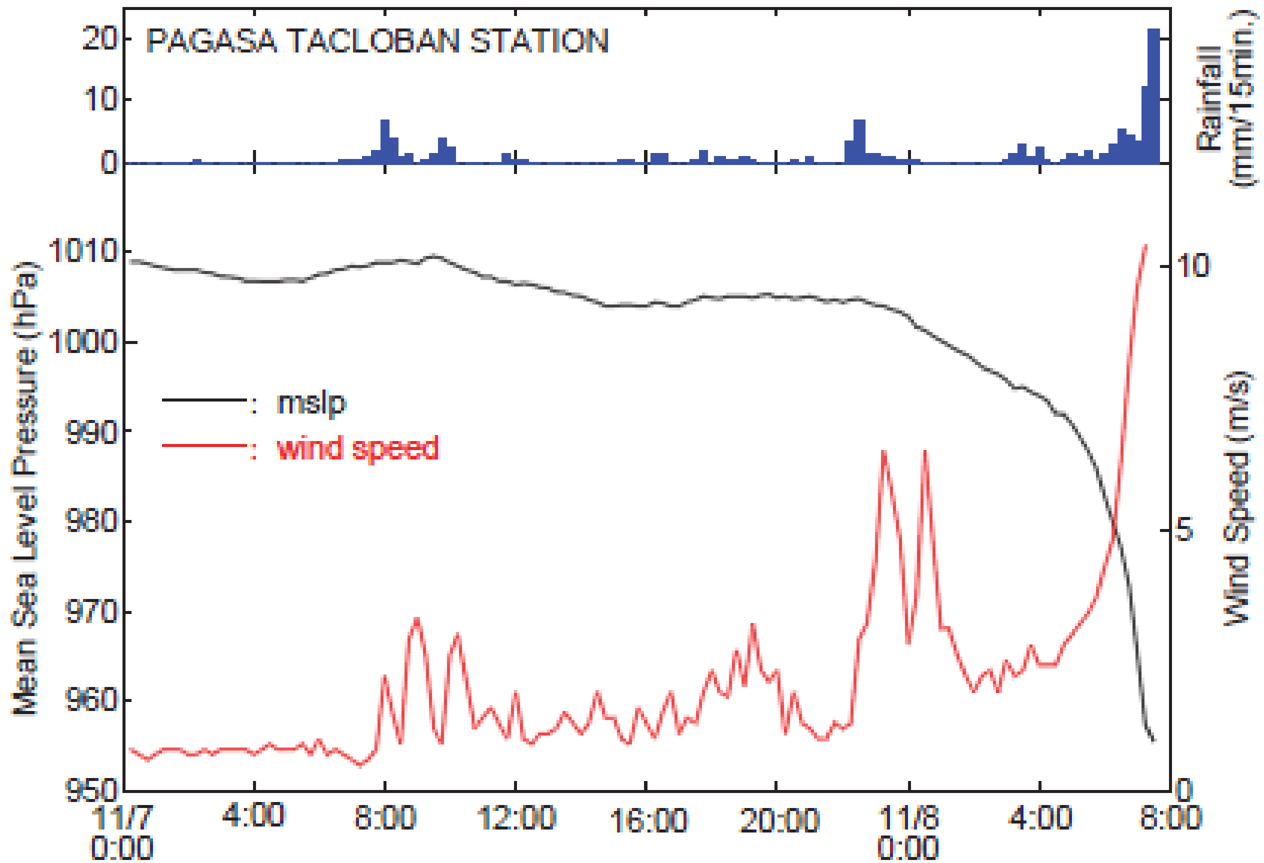


Figure 3. Time series of the wind speed and mean sea level pressure at Tacloban station, Leyte.

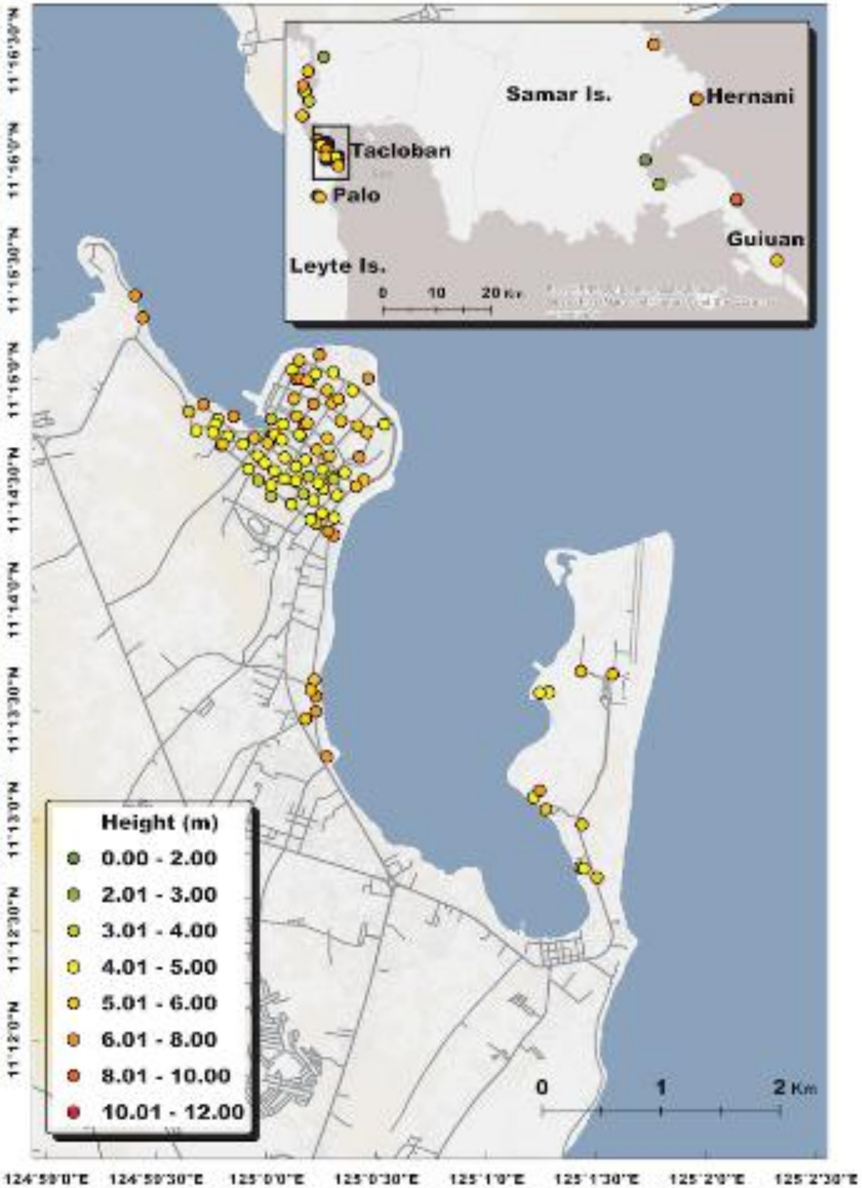


Figure 7. Storm surge inundation (Leyte Island and western Samar Island) and surface wave heights (eastern Samar Island) with respect to the local mean sea level.

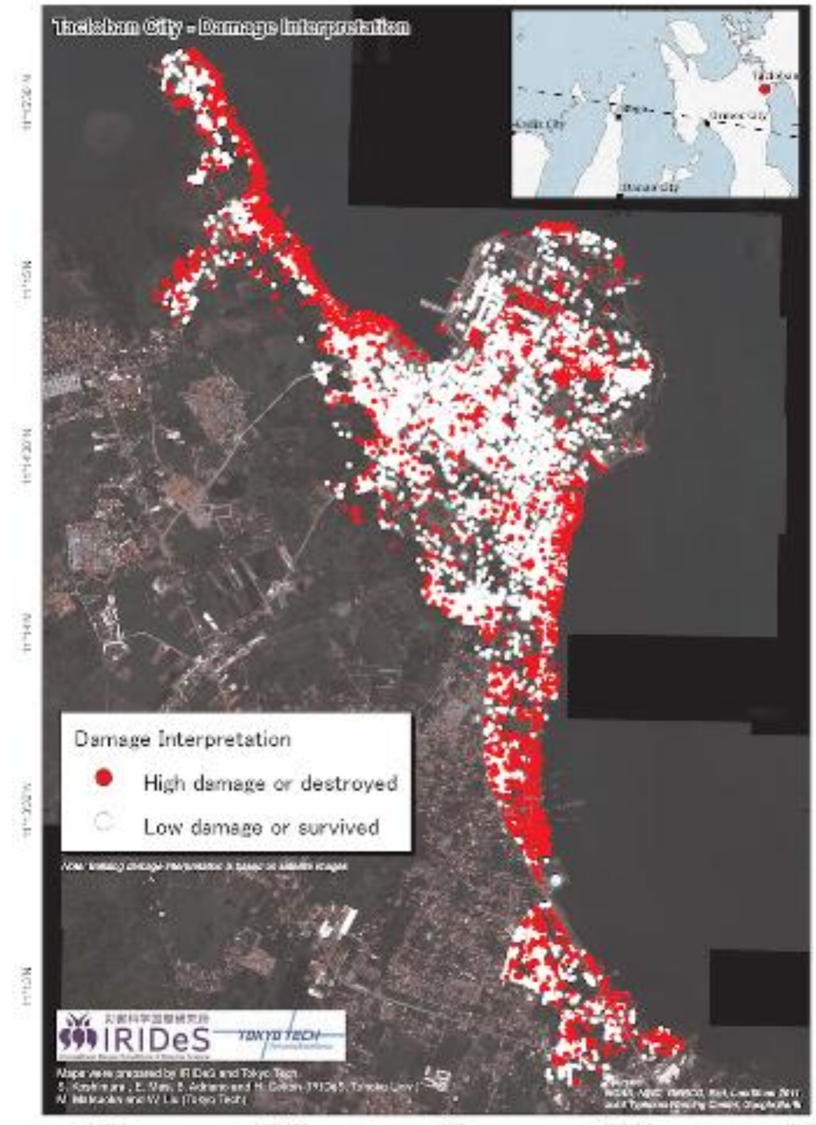


Figure 3. The results of the visual damage assessment using pre- and post-event satellite images and two classification criteria. (i) High damage or destroyed in red and (ii) low damage or survived in white.

REPEAT STORM SURGE DISASTERS OF TYPHOON HAIYAN AND ITS 1897 PREDECESSOR IN THE PHILIPPINES

BY JANNELI LEA A. SORIA, ADAM D. SWITZER, CESAR L. VILLANOY, HERMANN M. FRITZ, PRINCESS HOPE T. BILGERA, OLIVIA C. CABRERA, FERNANDO P. SIRINGAN, YVAINNE YACAT-STA. MARIA, RIOVIE D. RAMOS, AND IAN QUINO FERNANDEZ

Typhoon Haiyan's storm surge was about twice the height of the 1897 event in San Pedro Bay, but the two storm surges had similar heights on the open Pacific coast.

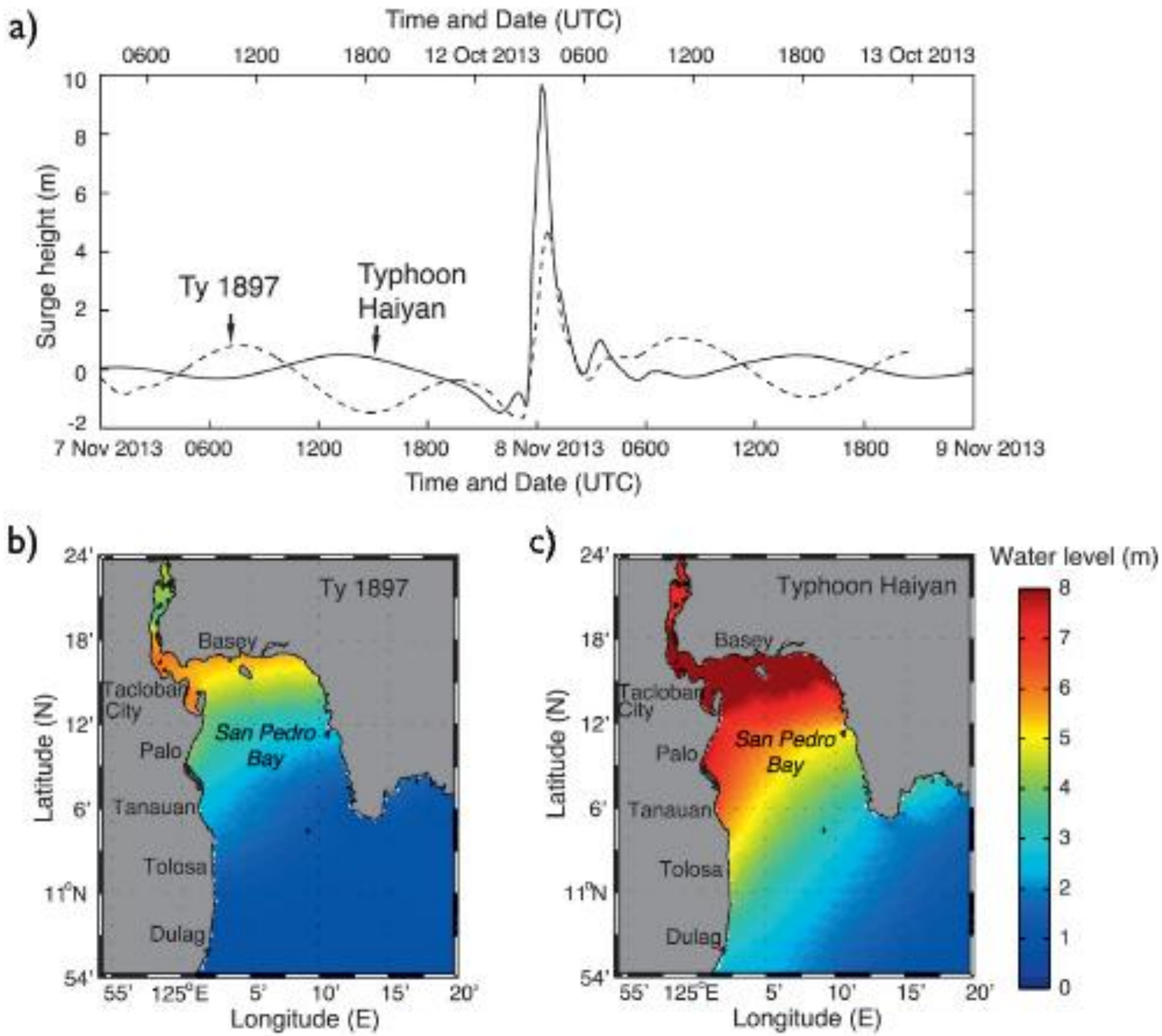


Fig. 6. Modeled surge heights comparison between Ty 1897 and Typhoon Haiyan in San Pedro Bay. (a) Graphical representation of the modeled water level at Tacloban for Ty 1897 and Typhoon Haiyan. (b) Modeled maximum surge heights in San Pedro Bay during Ty 1897. (c) Modeled maximum surge heights in San Pedro Bay during Typhoon Haiyan.

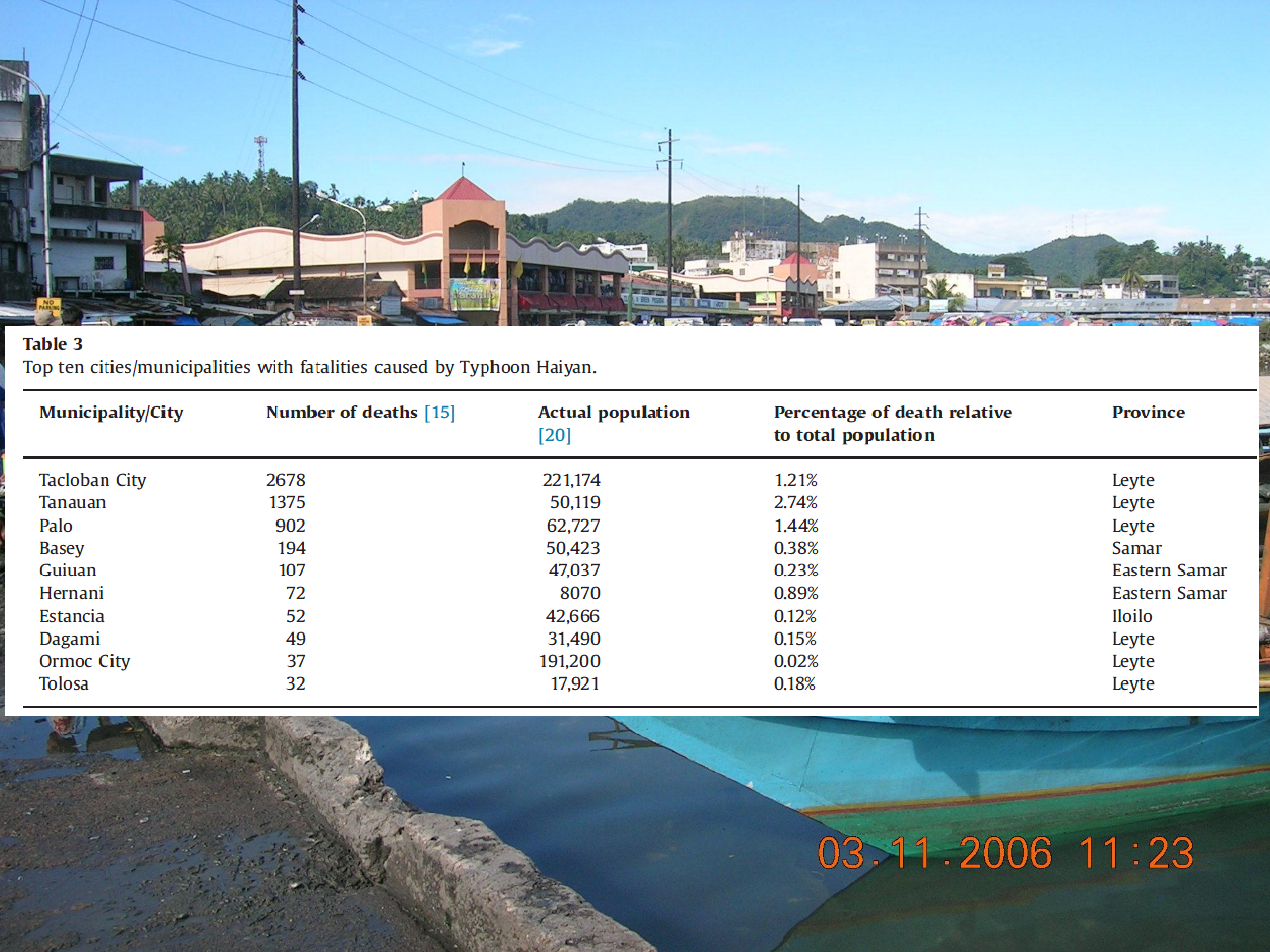


Table 3
Top ten cities/municipalities with fatalities caused by Typhoon Haiyan.

Municipality/City	Number of deaths [15]	Actual population [20]	Percentage of death relative to total population	Province
Tacloban City	2678	221,174	1.21%	Leyte
Tanauan	1375	50,119	2.74%	Leyte
Palo	902	62,727	1.44%	Leyte
Basey	194	50,423	0.38%	Samar
Guiuan	107	47,037	0.23%	Eastern Samar
Hernani	72	8070	0.89%	Eastern Samar
Estancia	52	42,666	0.12%	Iloilo
Dagami	49	31,490	0.15%	Leyte
Ormoc City	37	191,200	0.02%	Leyte
Tolosa	32	17,921	0.18%	Leyte

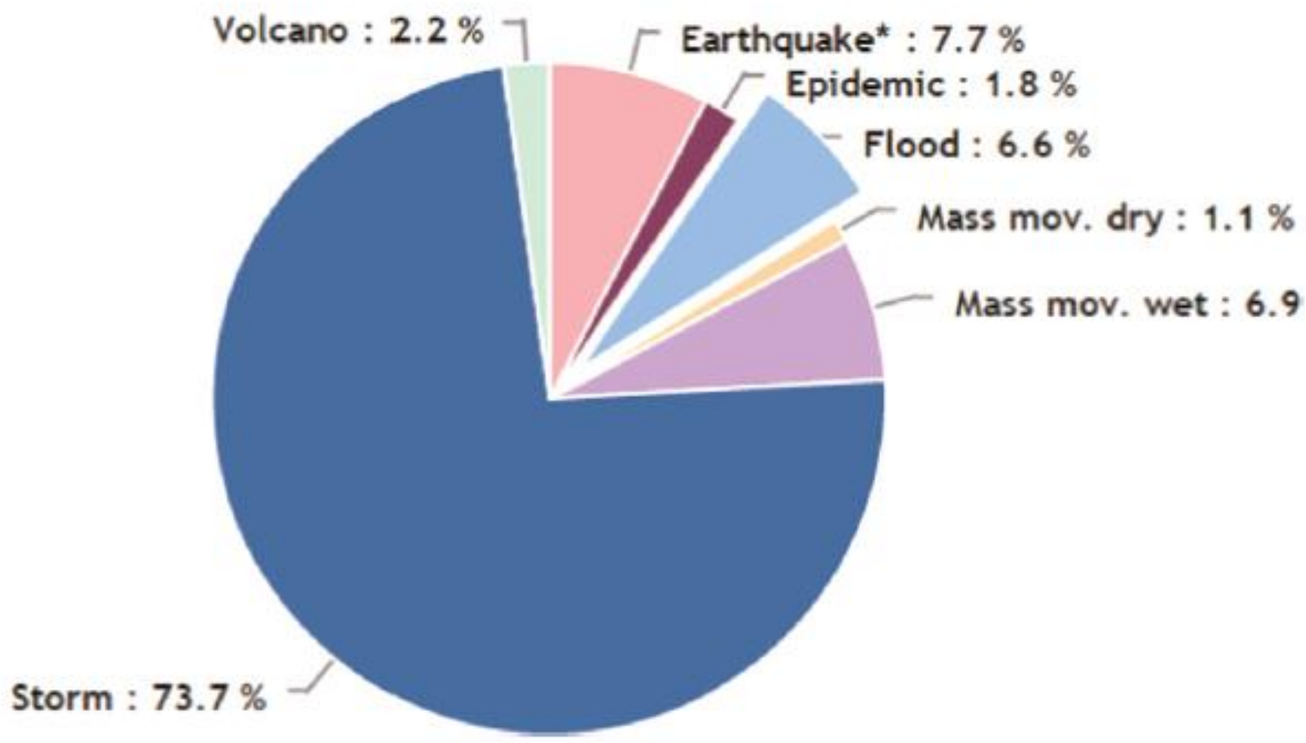
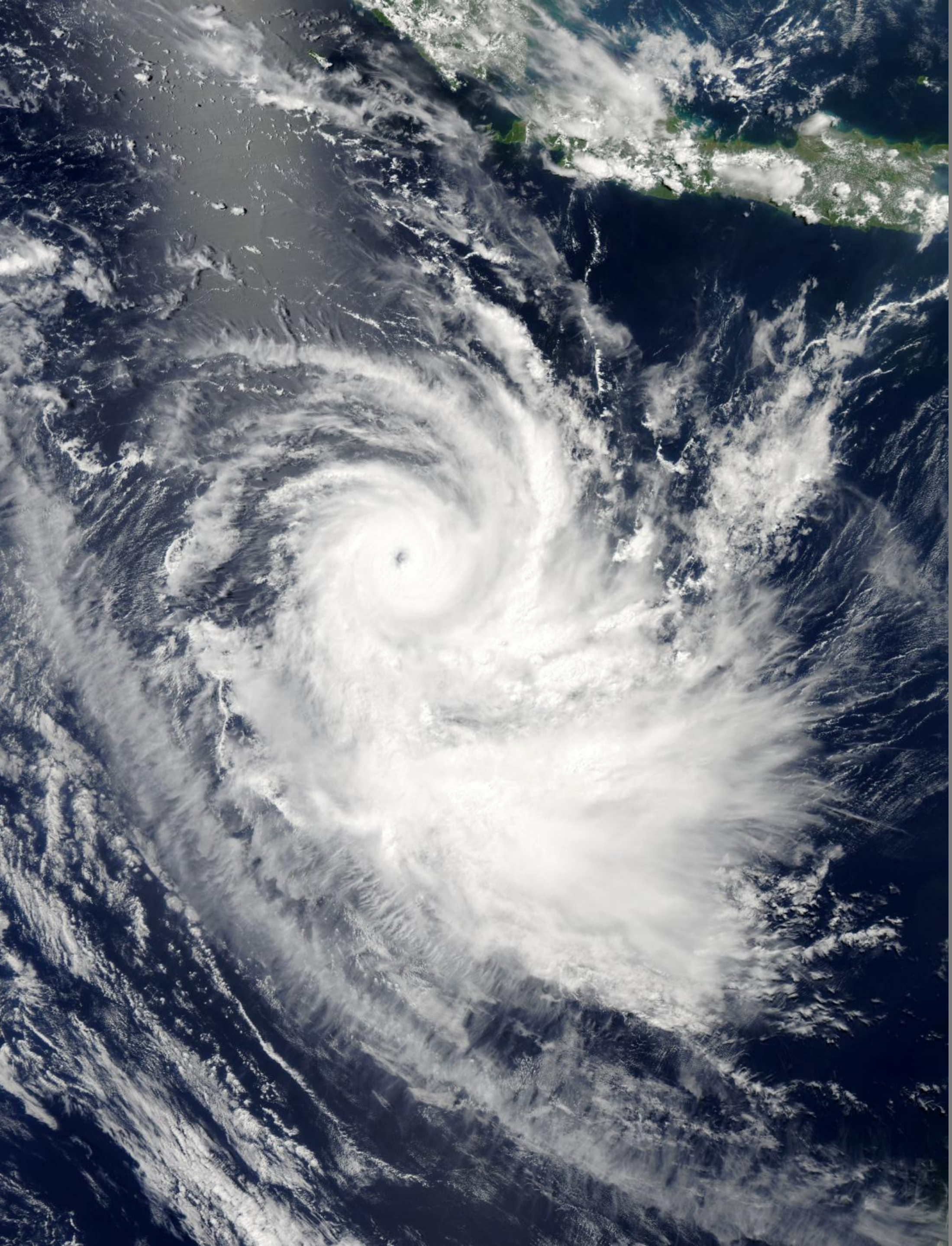
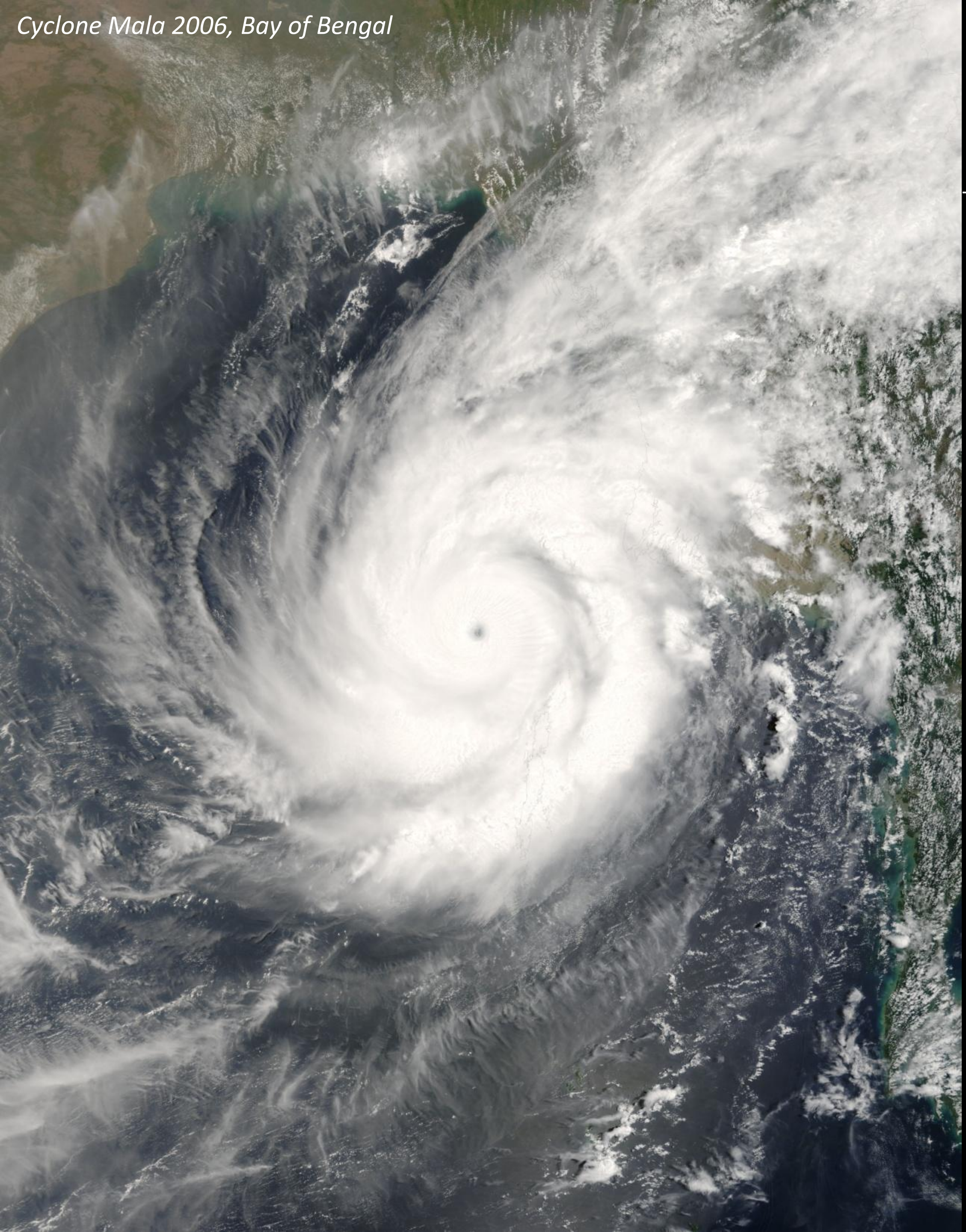


Fig. 2. Percentage of reported people killed by disaster type in the Philippines. (*Including tsunami)(Data source: EM-DAT and PreventionWeb.net).



TROPICAL CYCLONE GILLIAN, MARCH 23, 2014 – INDIAN OCEAN (winds up to 200 km/hr)



HURRICANES AND COASTAL IMPACTS

- **Hurricanes** are tropical atmospheric disturbances with maximum sustained wind speeds of 32 m/s or greater (also known as **Tropical Cyclones** and **Typhoons**); about 40-50 per year worldwide

- Intensity a function of sea temperature

- Intensity Scale is the Saffir-Simpson Scale (1-5)

- Create storm surges along coasts (in excess of 6m)

- Heavy rains cause landslides and flooding (e.g., Hurricane Mitch)

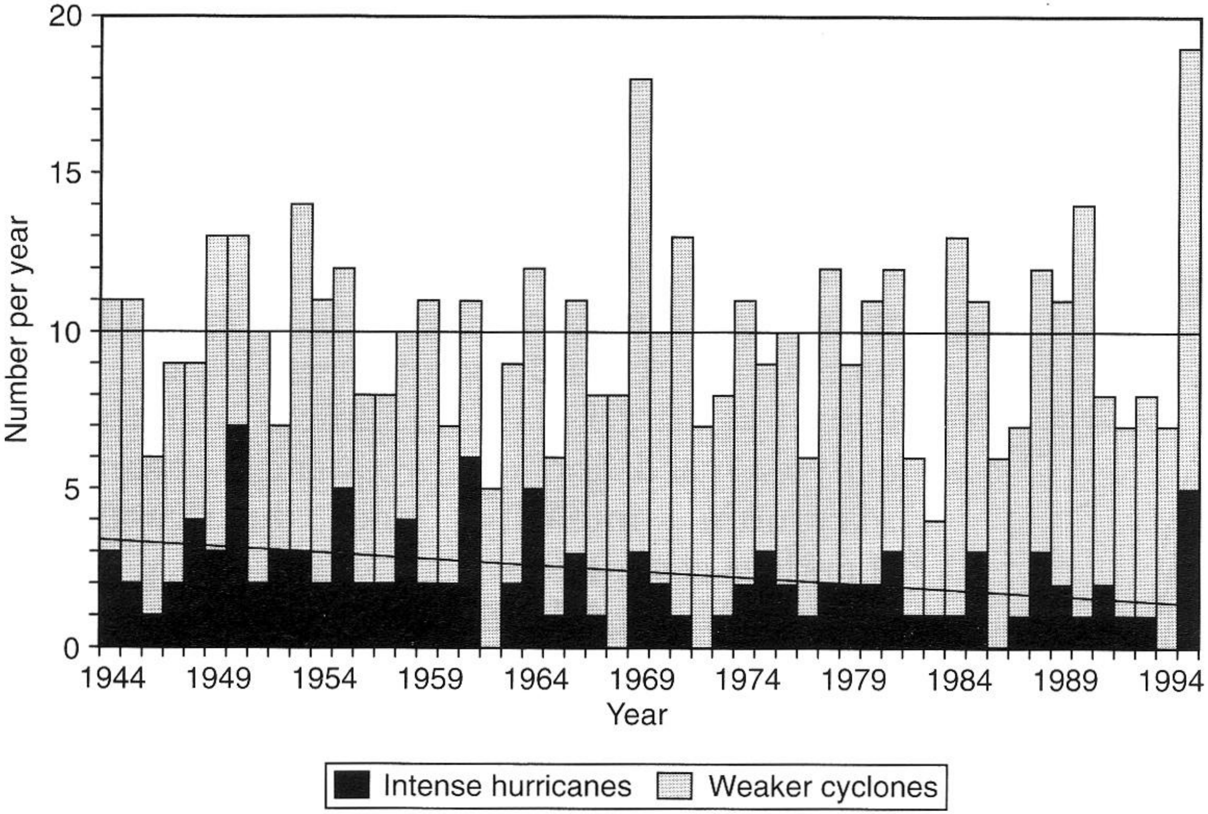
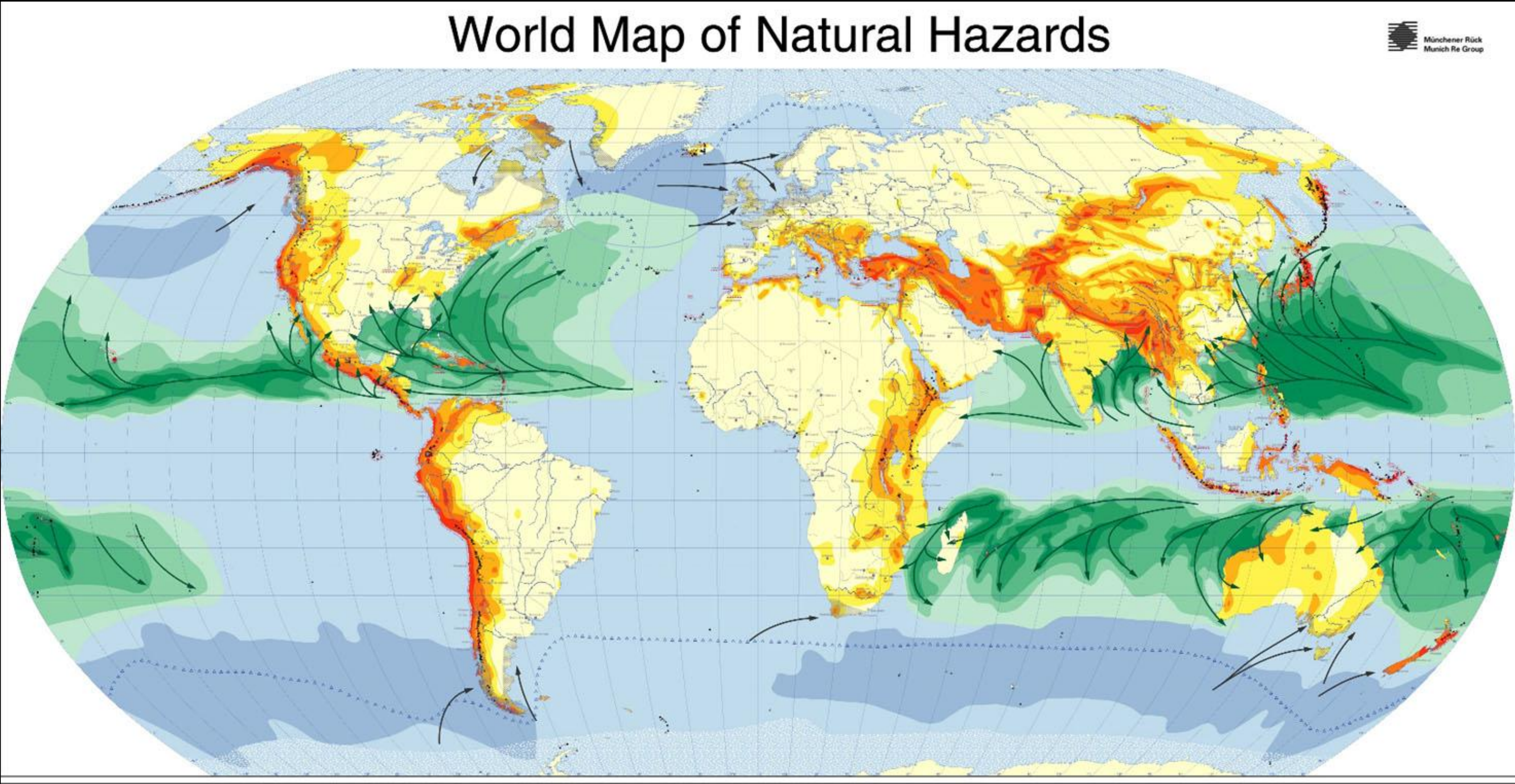


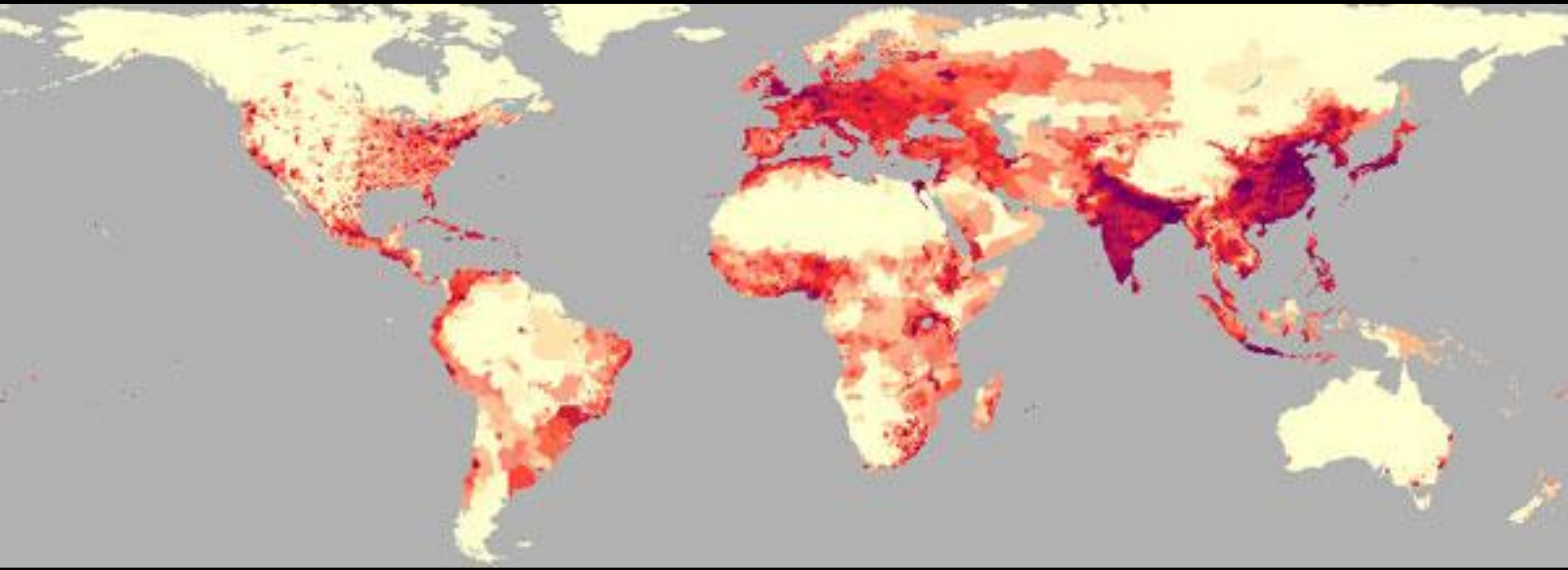
FIGURE 2.12 Annual frequency of tropical cyclones from 1944 to 1995 for the Atlantic basin. Dark bars are for major hurricanes only; light bars include all hurricanes, tropical storms and subtropical storms. Best-fit straight-line trends are also shown. (From Landsea *et al.*, 1996 with permission from the American Geophysical Union)

WORLD MAP OF NATURAL HAZARDS DEVELOPED BY THE MUNICH RE-INSURANCE COMPANY



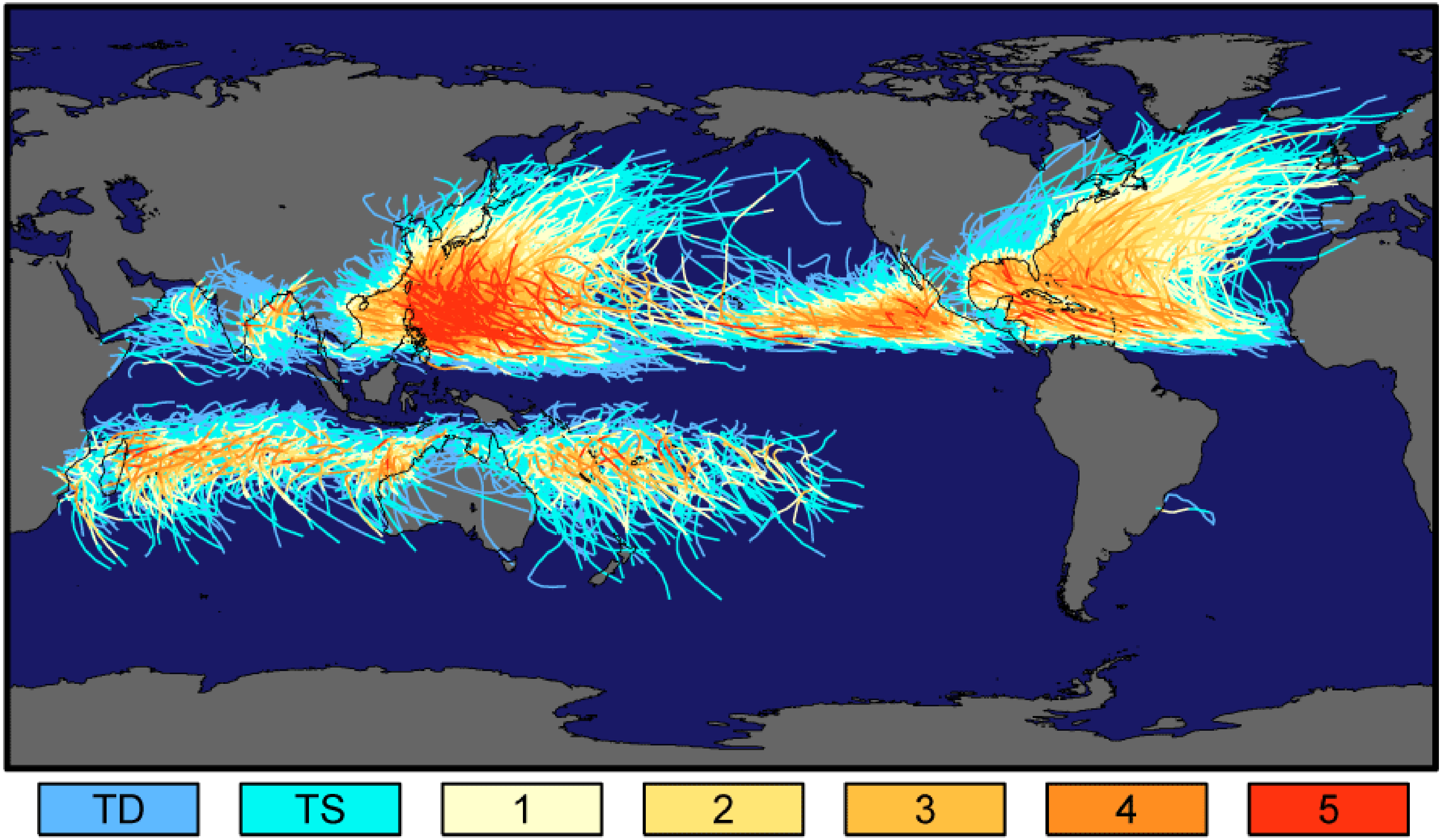
A world map of the distribution of natural hazard processes independent of human activity and distribution of population

POPULATION DENSITY OF THE WORLD (persons/sq km)



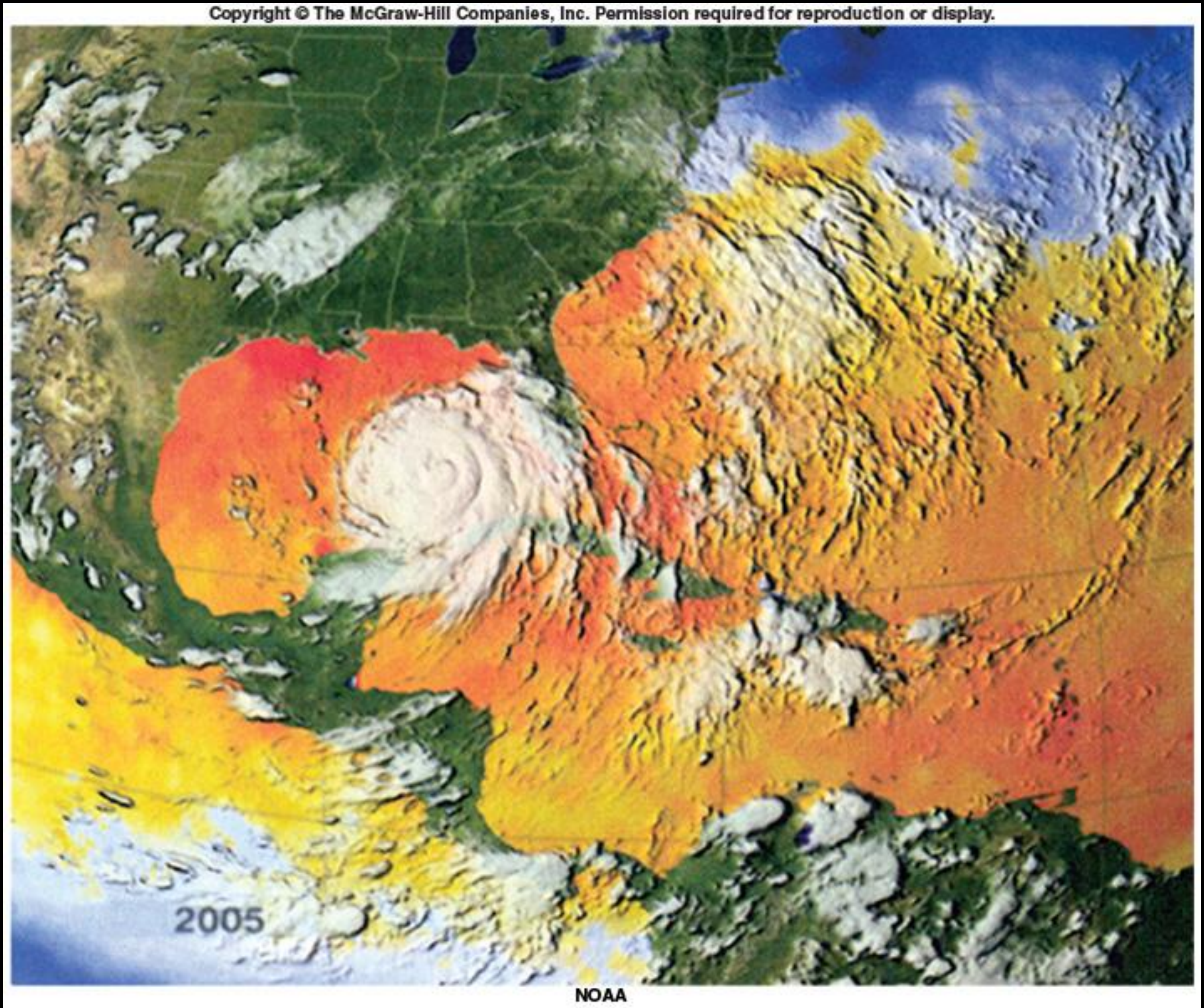
WHERE PEOPLE ARE – WHERE PEOPLE ARE NOT

Tracks and Intensity of All Tropical Storms

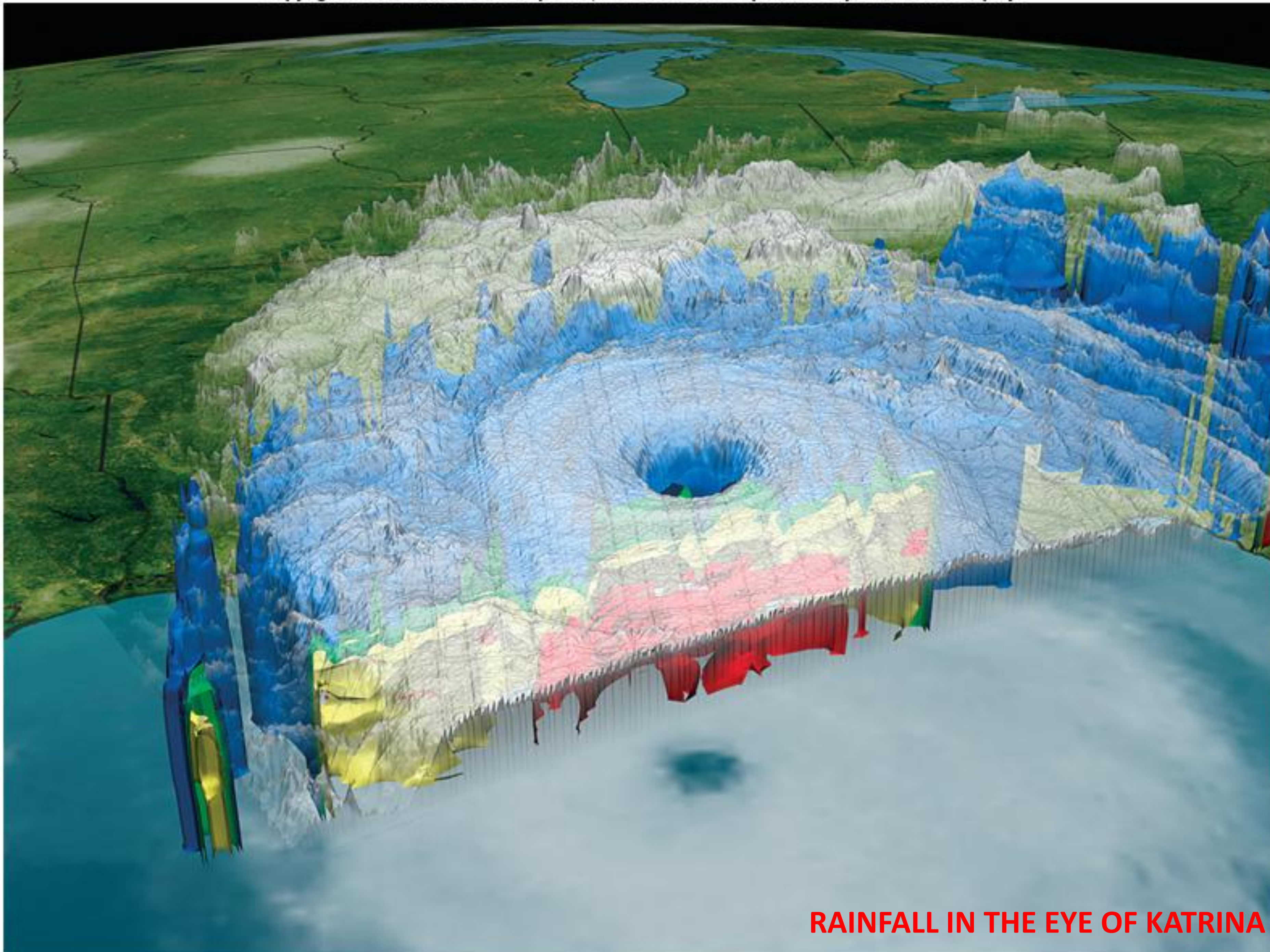


Saffir-Simpson Hurricane Intensity Scale

HURRICANES AND COASTLINES



HURRICANE KATRINA (AUG 2005) MOVING TOWARD THE HOT WATERS OF THE GULF OF MEXICO



RAINFALL IN THE EYE OF KATRINA

TABLE 13.2

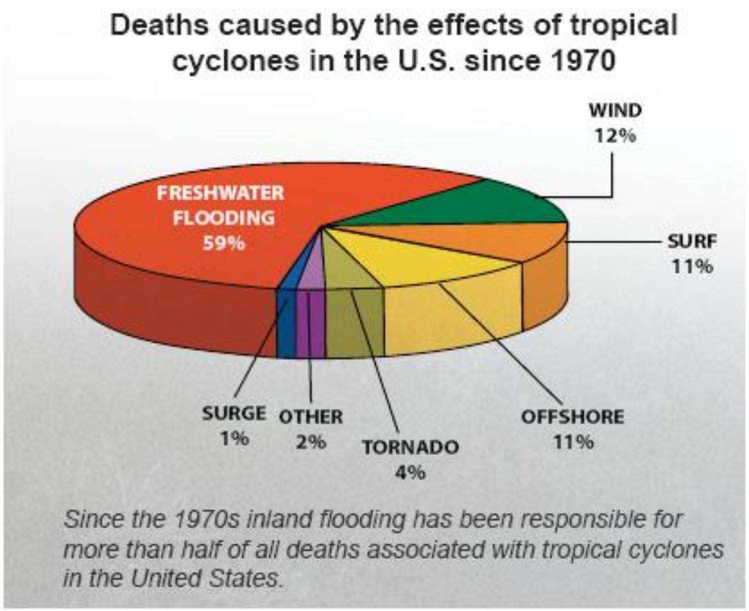
The 13 Deadliest Hurricanes in the United States Since 1990

When	Where	Number of Deaths
8 September 1900	Galveston, Texas	8,000
mid-September 1928	South Florida—Lake Okeechobee	2,500
29 August 2005	New Orleans, LA/Mississippi	1,836
mid-September 1919	Florida Keys/Corpus Christi, Texas	600
21 September 1938	New England, especially Rhode Island	600
2 September 1935	Florida Keys	408
27 June 1957	Hurricane Audrey—Morgan City, LA	390
14–15 September 1944	East Coast—Virginia to Massachusetts	390
mid-September 1926	Miami, Florida/Alabama	372
21 September 1909	Grand Isle, Louisiana	350
17 August 1915	Galveston, Texas	275
29 September 1915	New Orleans, Louisiana	275
17–18 August 1969	Hurricane Camille—Mississippi	256

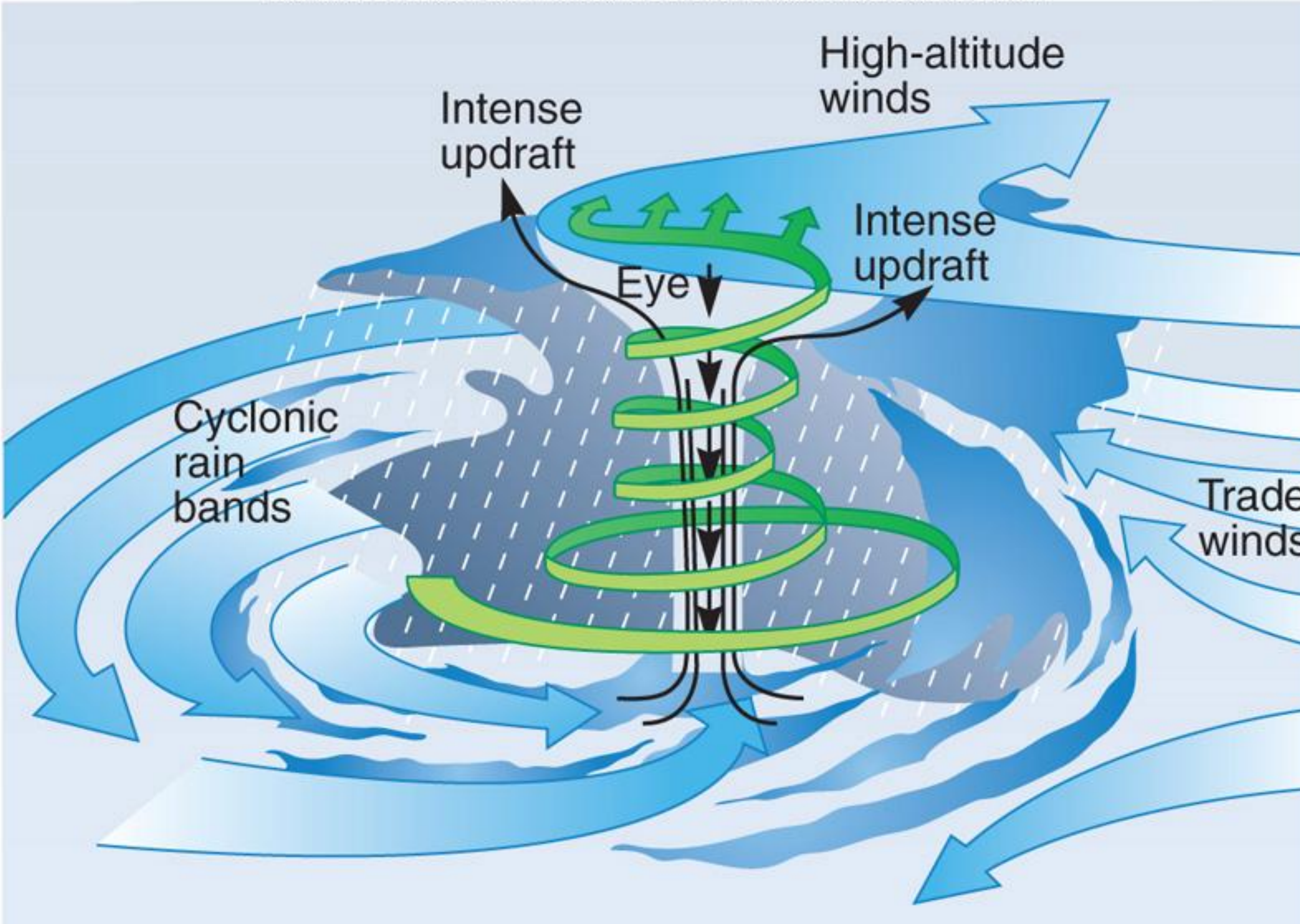
TABLE 13.9

US Hurricane Deaths, 1970–99

Inland flooding	59%
Wind	12
Storm surge	12
Offshore	11
Tornado	4
Other	2
	100%



Source: Tropical Cyclones & Inland Flooding (2001), NOAA.



US Department of Commerce, 1971

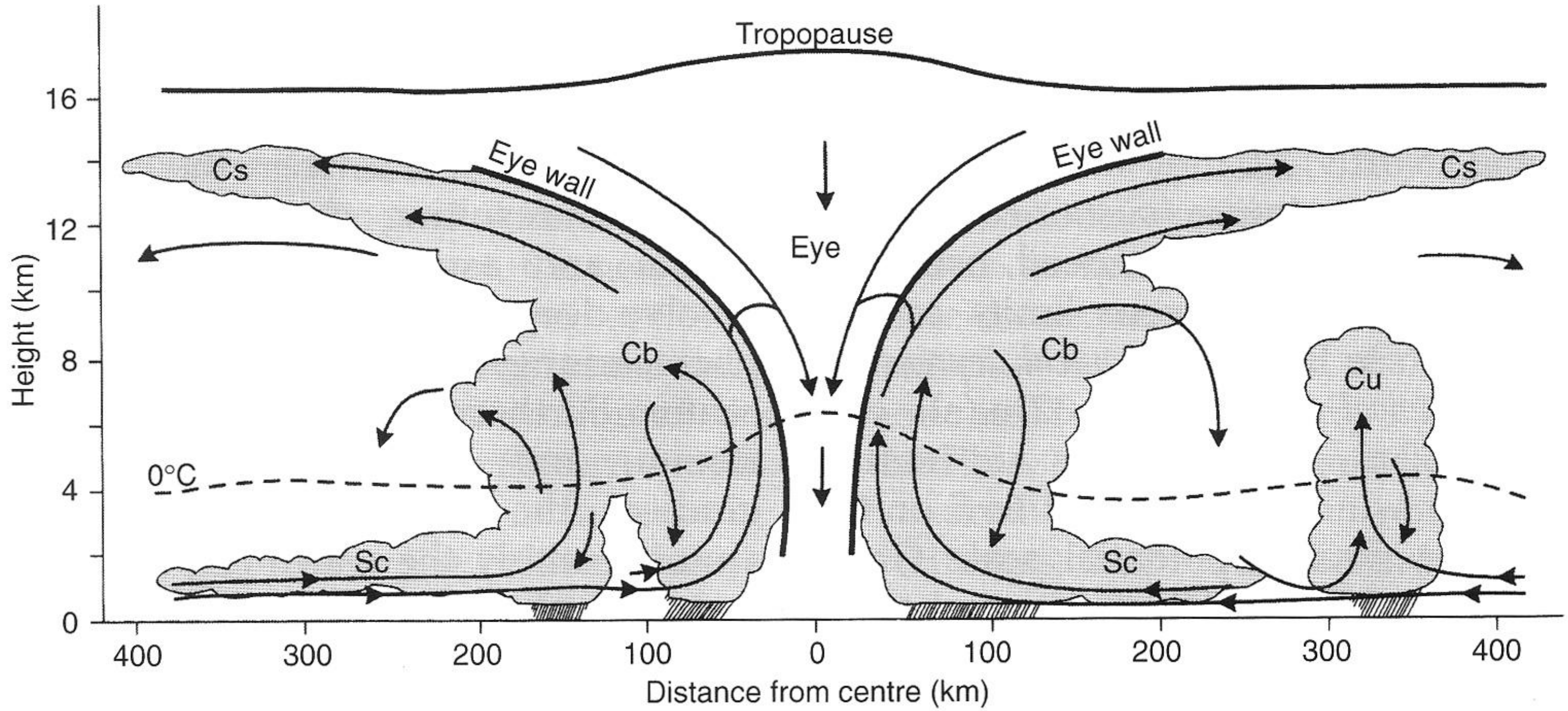


FIGURE 2.9 Schematic representation of the vertical structure of a mature hurricane, with arrows representing the air flows involved. (Reproduced from *Atmospheric Processes and Systems* by Russell D. Thompson, 1998 with permission from Routledge)

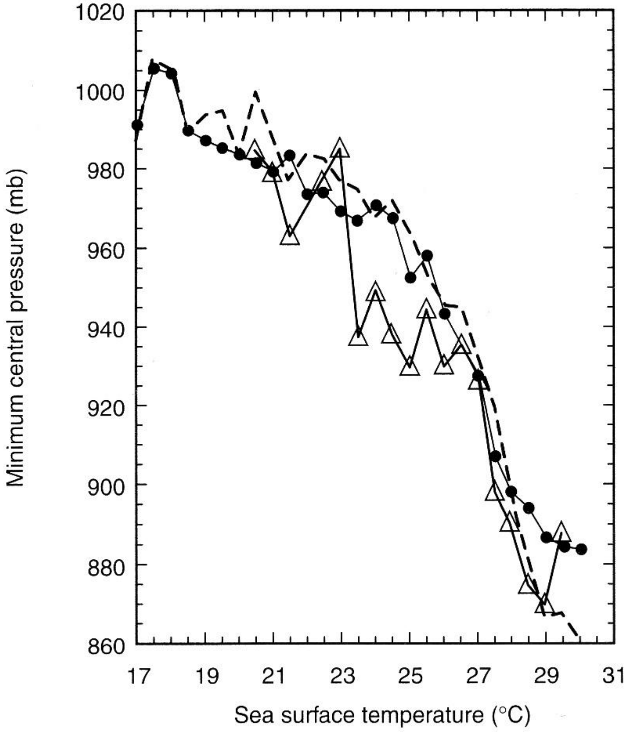
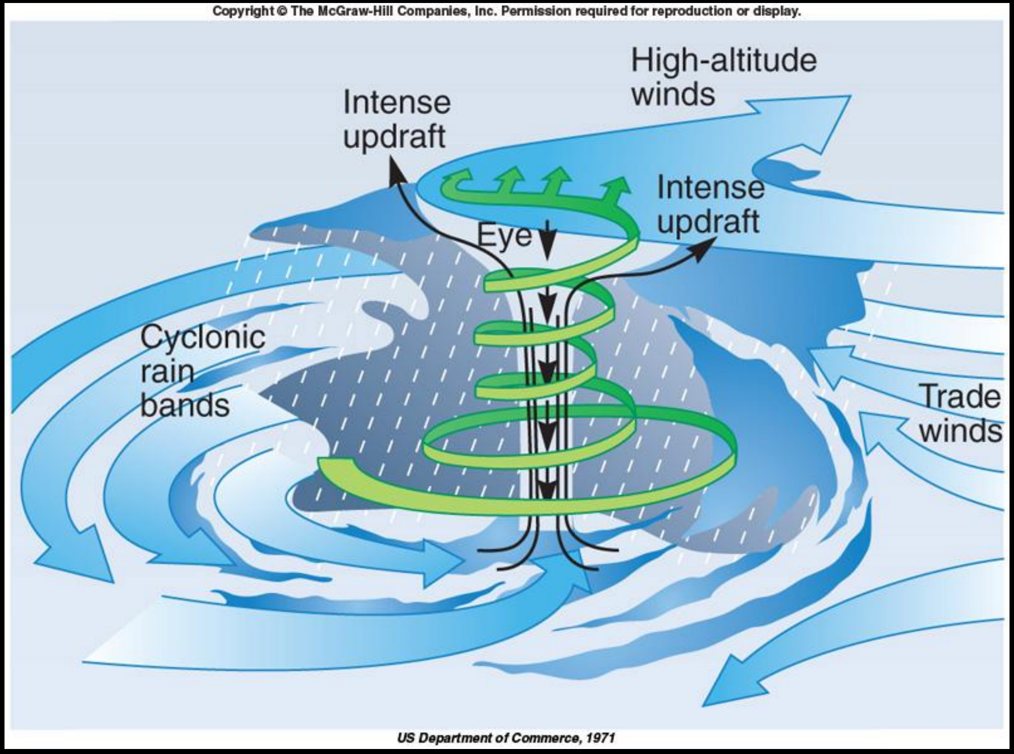


FIGURE 2.11 Hurricane maximum potential intensity (MPI, shown as minimum central pressure), as a function of sea surface temperature (SST), for the North Atlantic, north-west Pacific and Australian/south-west Pacific basins combined. Observed maximum storm intensities are compared with MPIs calculated using the thermodynamic models of Emanuel (1986, 1991) and Holland (1997). Below 26°C, the observed values are an overestimate of the MPI because the hurricanes originally formed in warmer waters. (Reproduced from Tonkin *et al.*, 2000 with permission from the American Meteorological Society)

- WARM TROPICAL OCEAN SURFACE (MUST BE AT LEAST 26-27°C)
- CONVECTION
- REMOVAL OF WARMED AIR AT ALTITUDE
- VERY MOIST AIR IN THE TROPOSPHERE
- SPIN RESULTS FROM CENTRIFUGAL FORCE (CORIOLIS FORCE)
- HAS TO HAVE A KICK-START (PRE-EXISTING CYCLONIC ACTIVITY, SPIN-UP)
- HURRICANES TRAVEL WITH THE REGIONAL WINDS (ca. 10m/s)



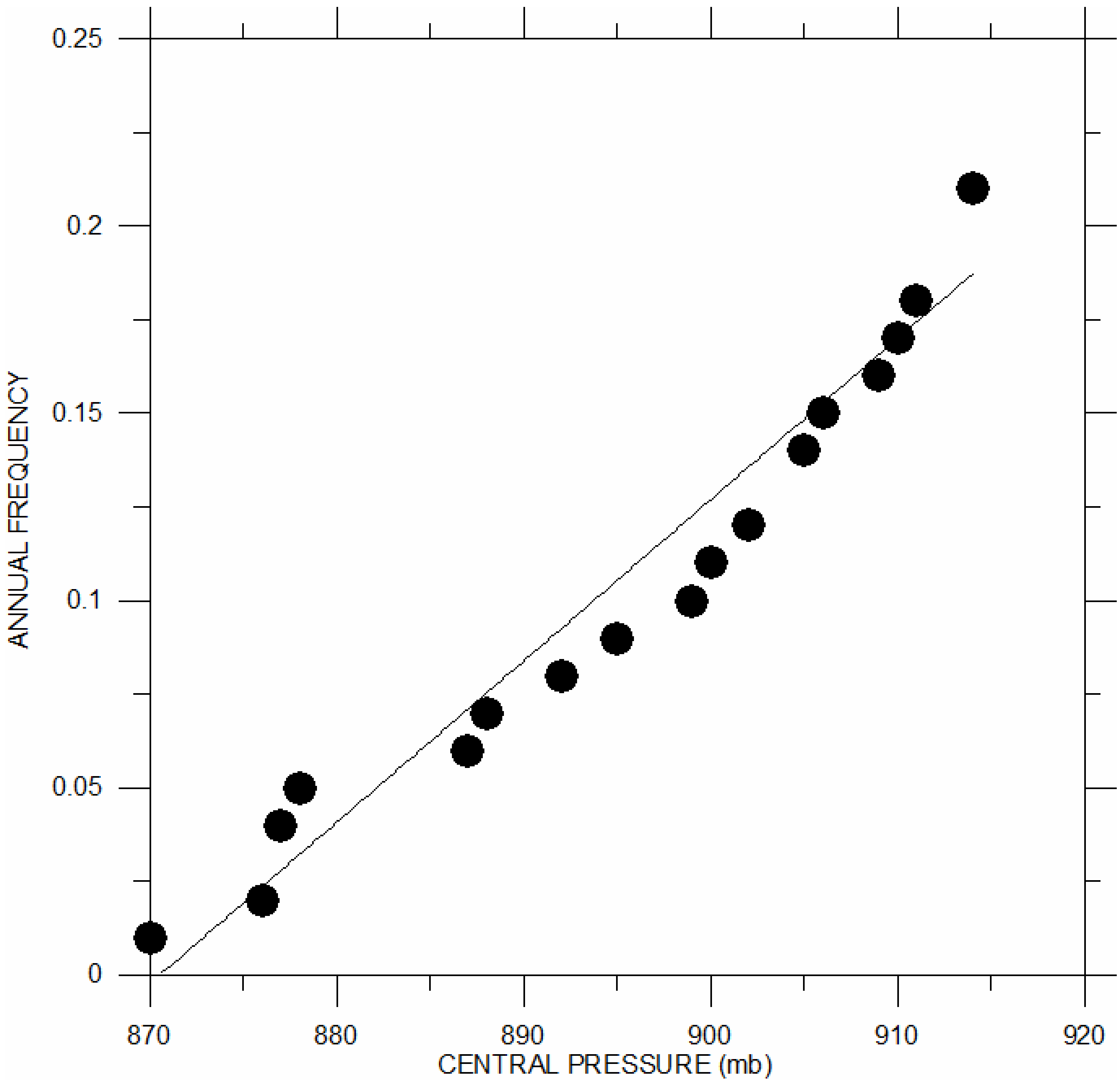
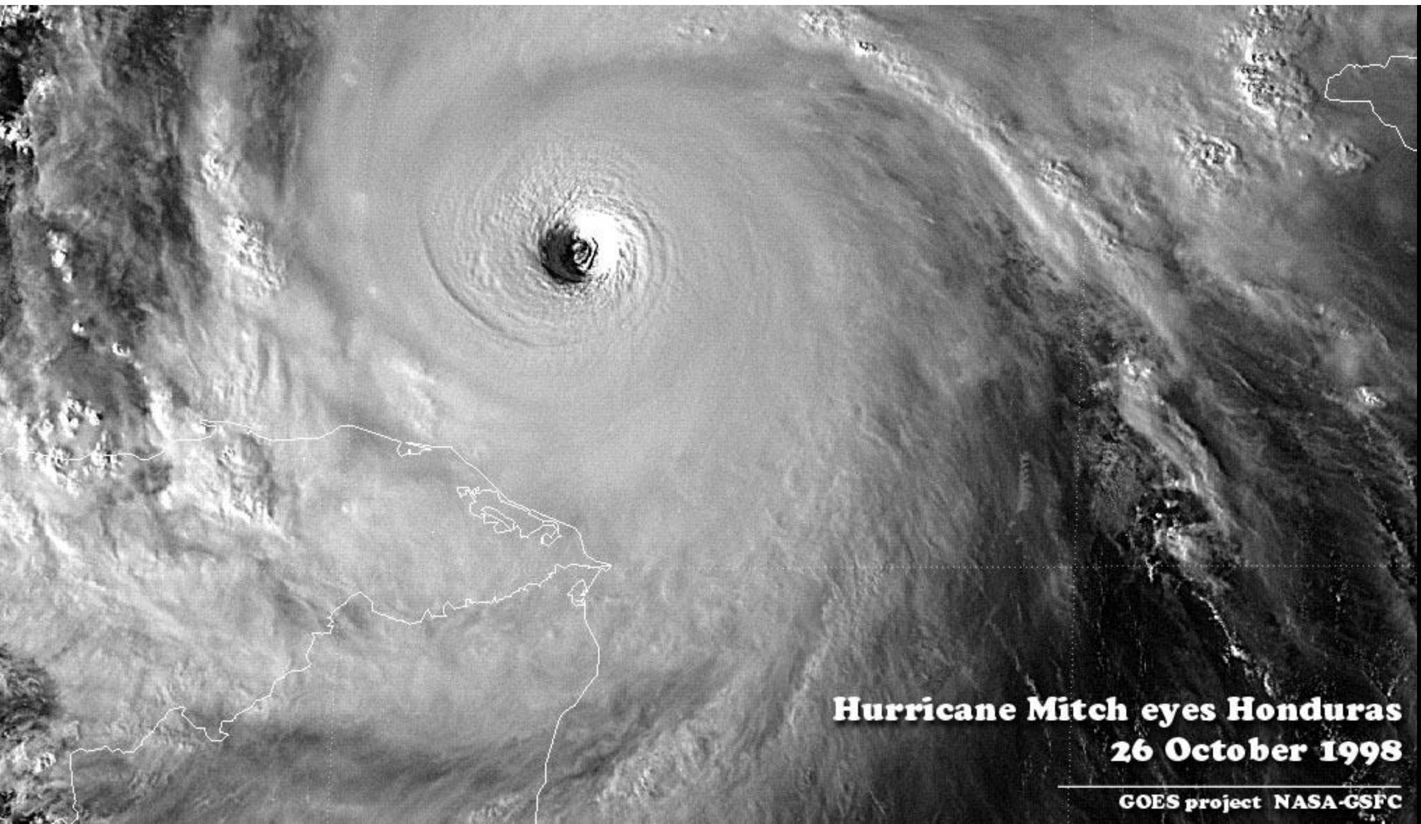

0.25
0.2
0.15
0.1
0.05
0
ANNUAL FREQUENCY
870
880
890
900
910
920
CENTRAL PRESSURE (mb)

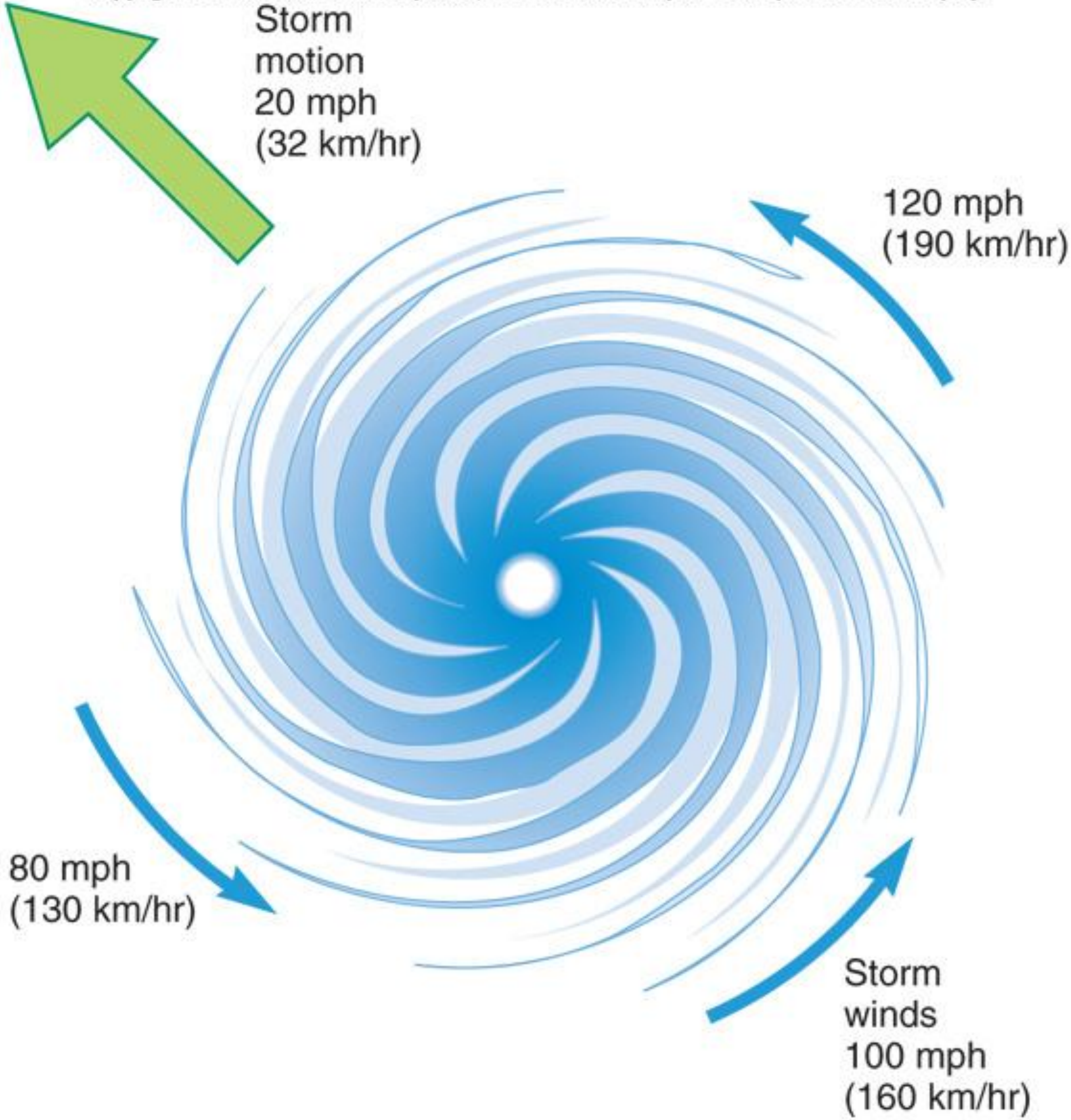
TABLE 2.1 The Saffir–Simpson scale for hurricanes

Category	Damage	Central pressure (mb)	V (m/s)	Surge (m)
1	Minimal	≥ 980	33–42	1.0–1.5
2	Moderate	965–979	43–49	1.5–2.5
3	Extensive	945–964	50–58	2.5–4.0
4	Extreme	920–944	59–69	4.0–5.5
5	Catastrophic	< 920	> 69	> 5.5

V is the maximum (1-minute average) surface (10 m) wind speed. The storm surge limits are converted from feet and given to the nearest 0.5 m.



SAFFIR-SIMPSON INTENSITY SCALE FOR HURRICANES


Storm
motion
20 mph
(32 km/hr)
120 mph
(190 km/hr)
80 mph
(130 km/hr)
Storm
winds
100 mph
(160 km/hr)

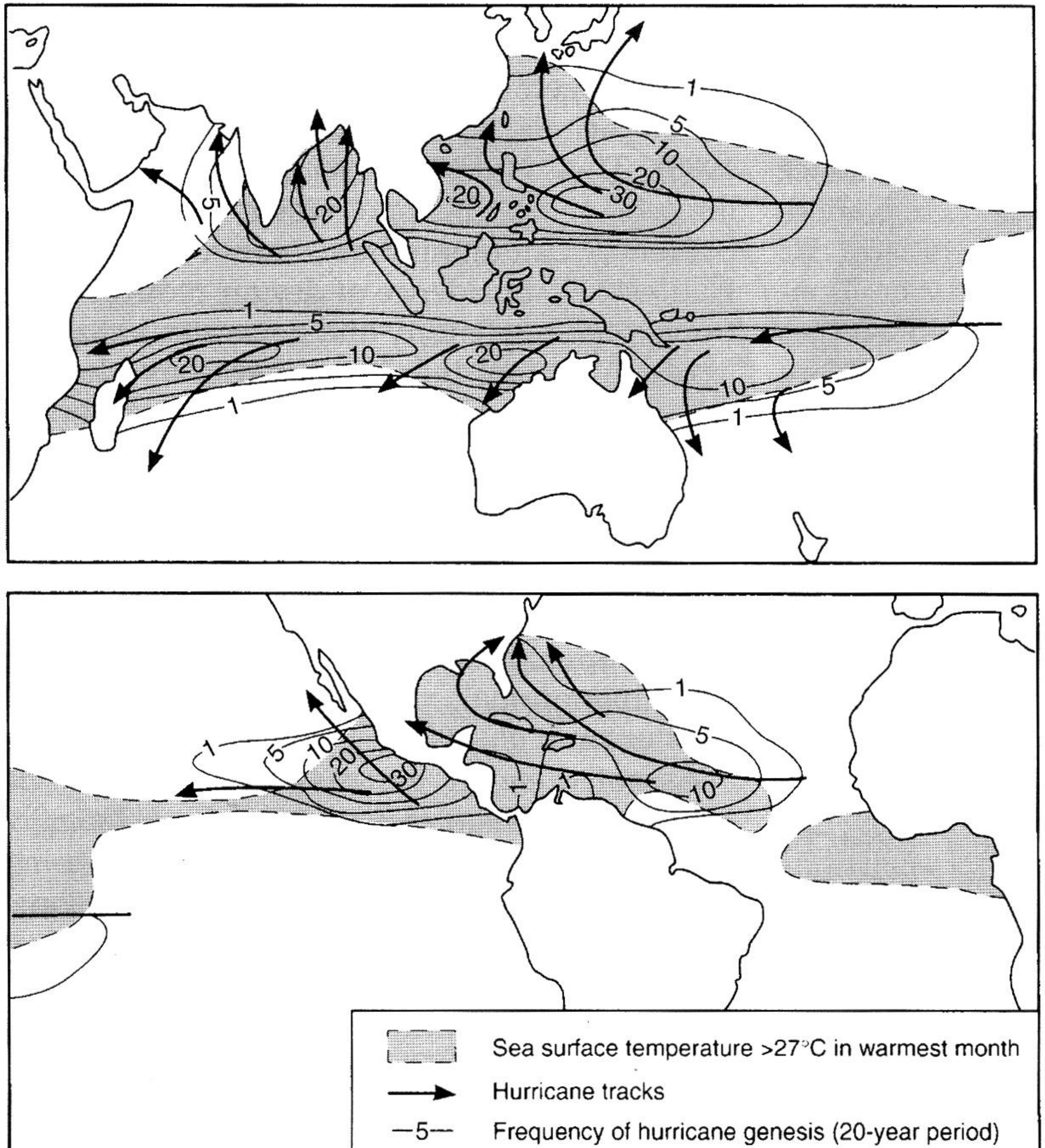
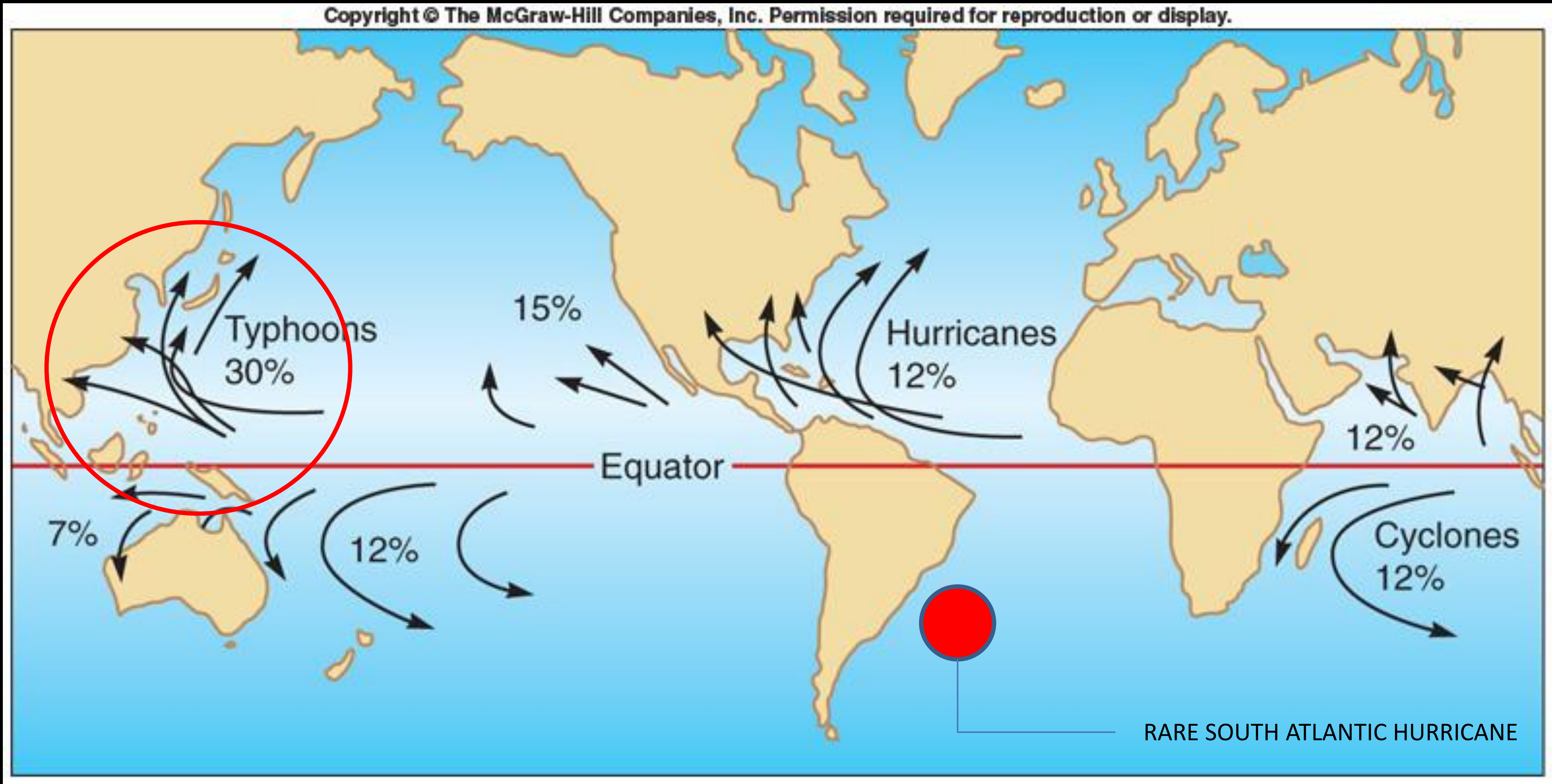
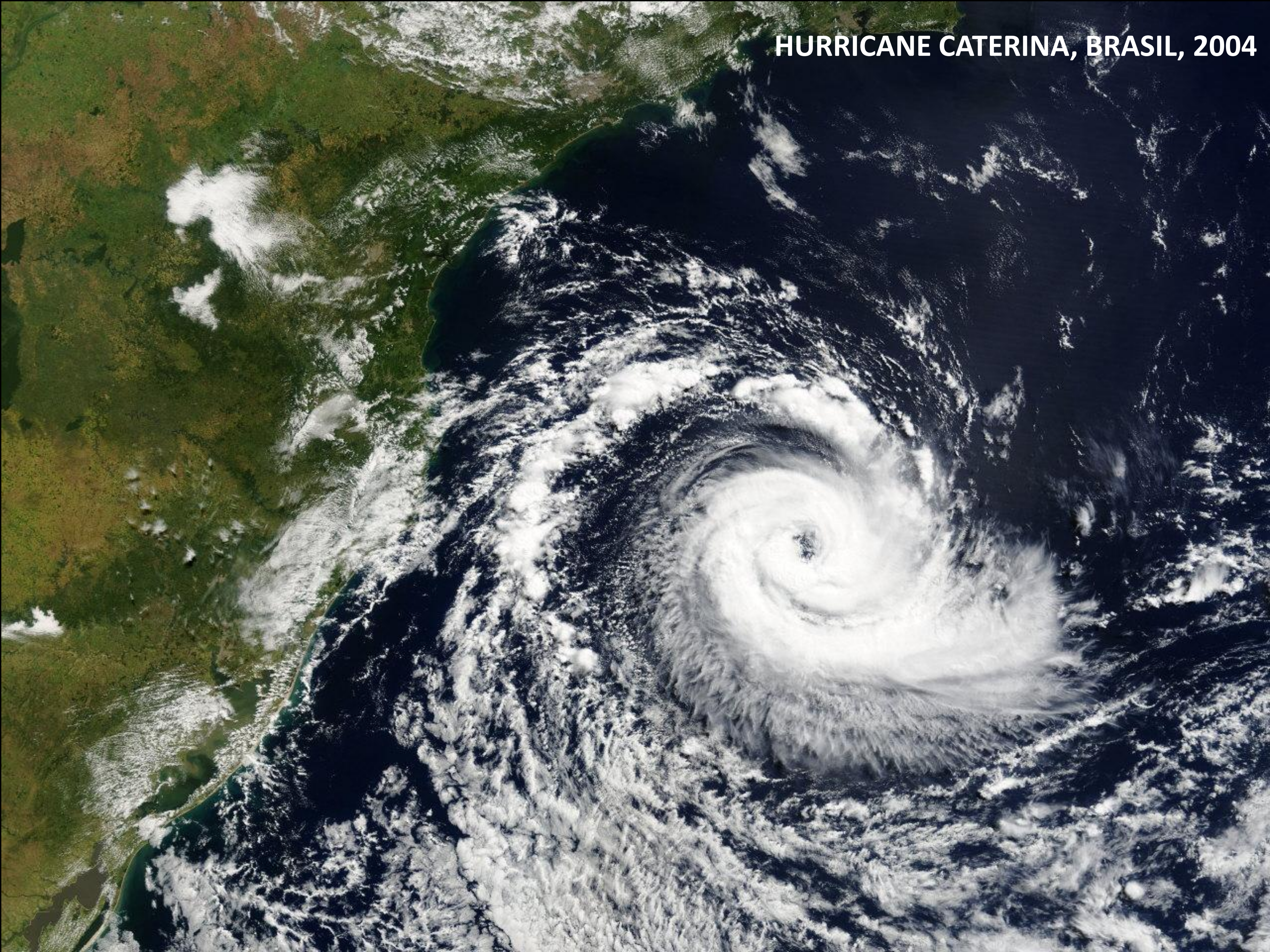


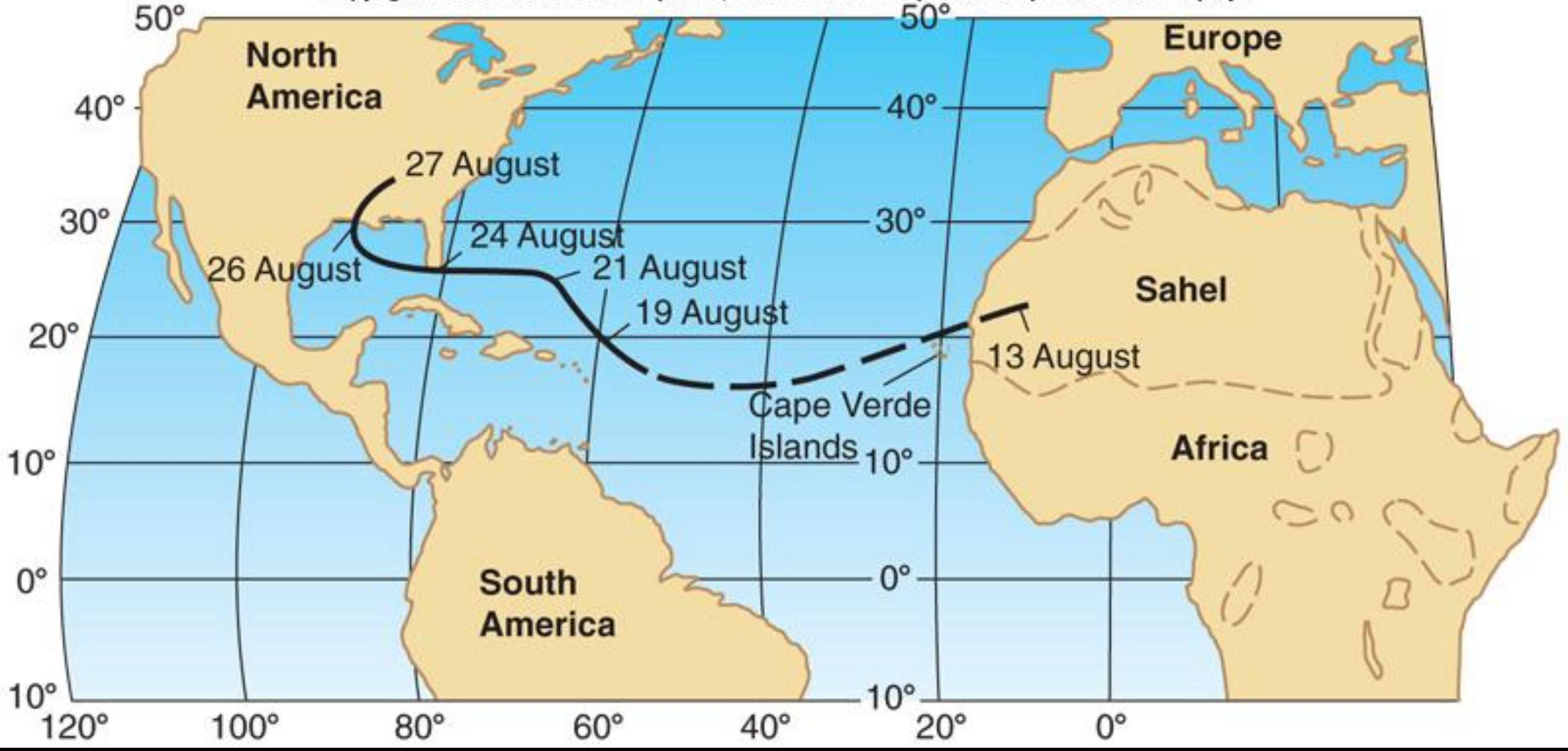
FIGURE 2.10 Contours of hurricane genesis frequency (in a 20-year period), showing the main formation basins. The main hurricane tracks, and areas that are warmer than 27°C in their warmest month, are also shown. (Reproduced from *Atmospheric Processes and Systems* by Russell D. Thompson, 1998 with permission from Routledge)

HURRICANES, TYPHOONS AND TROPICAL CYCLONES

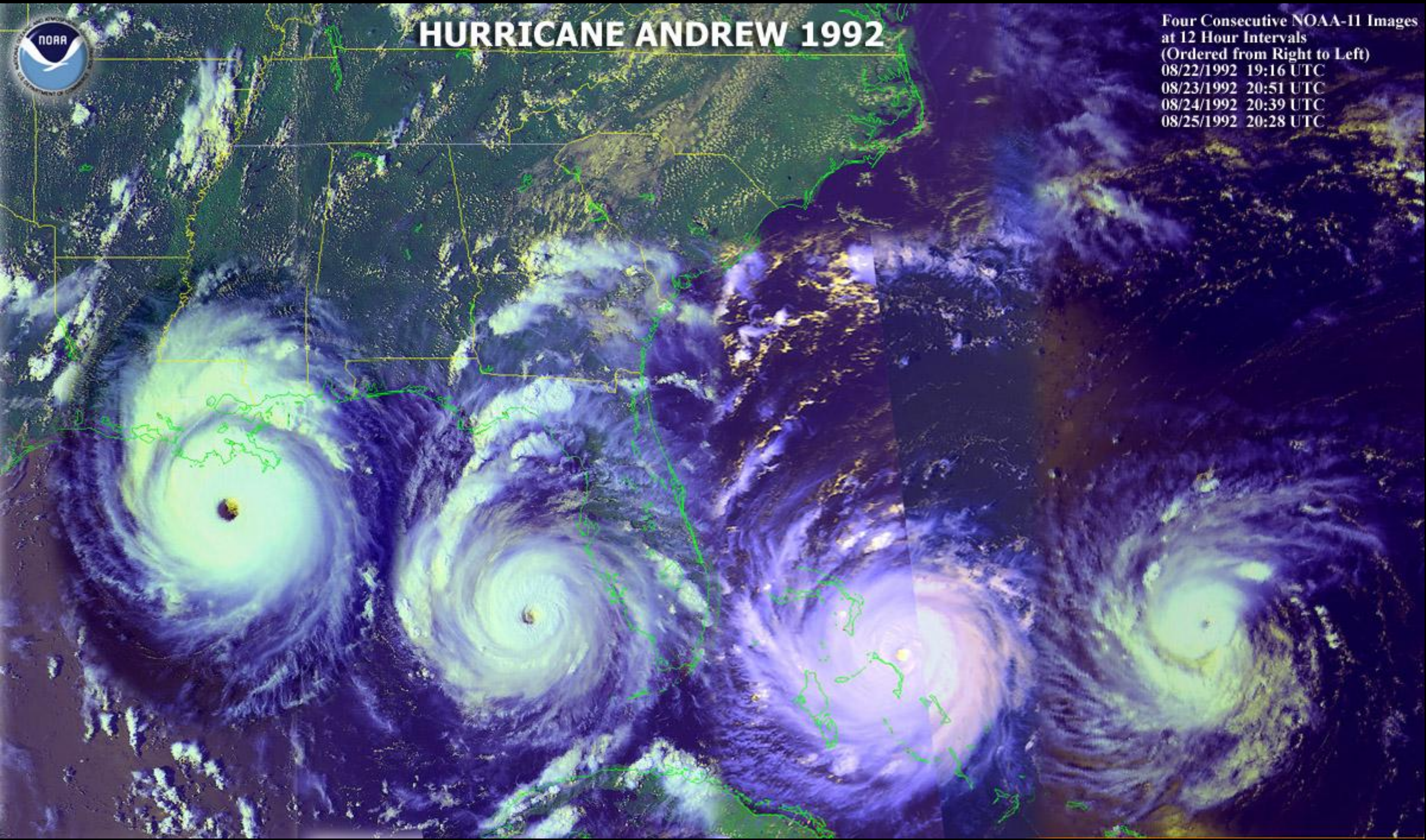


http://www.aoml.noaa.gov/hrd/tcfaq/G6.html


HURRICANE CATERINA, BRASIL, 2004



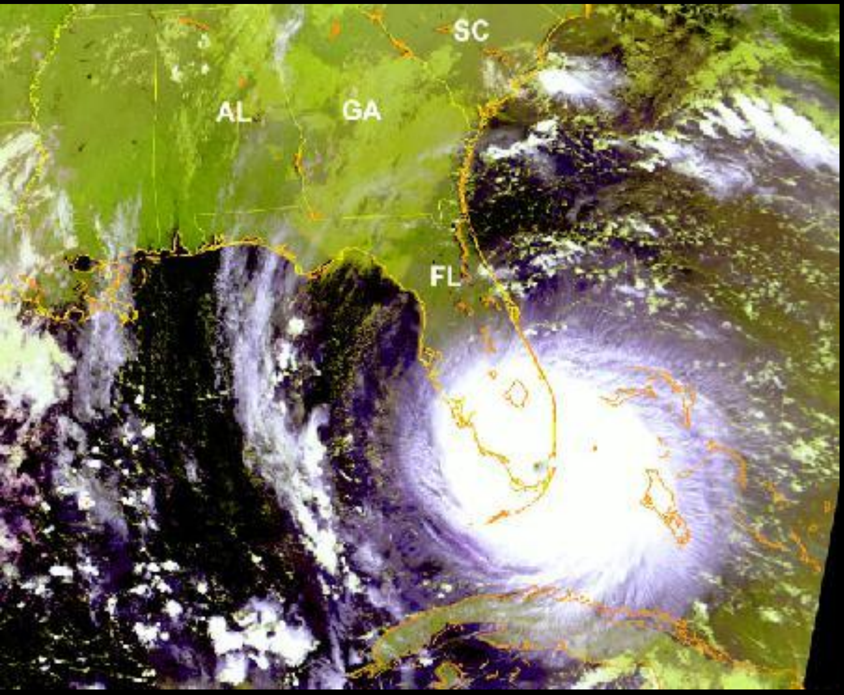
HURRICANE ANDREW AUGUST 1992

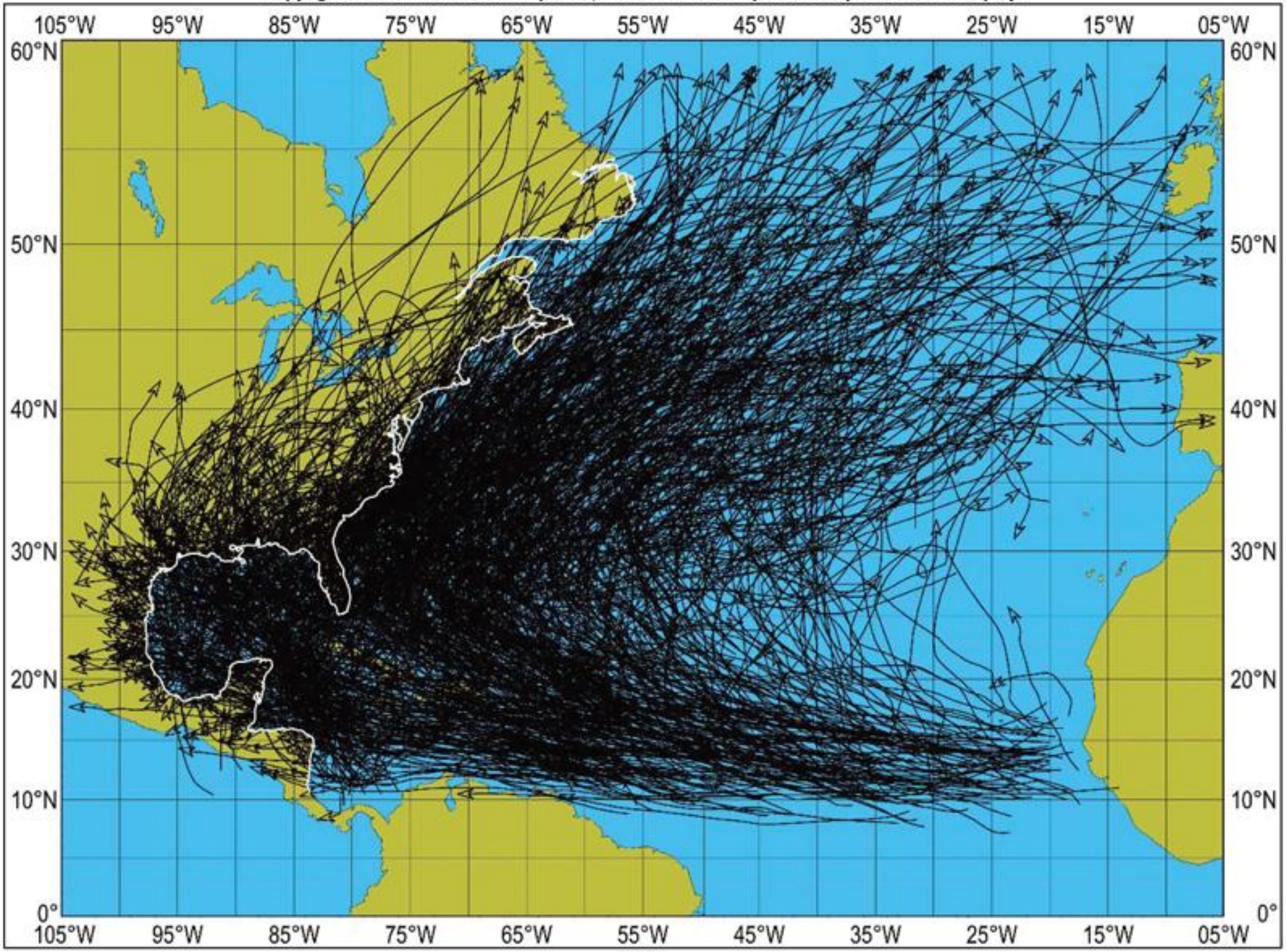


THE PATH OF HURRICANE ANDREW ACROSS THE ATLANTIC, AUGUST 22-25 1992

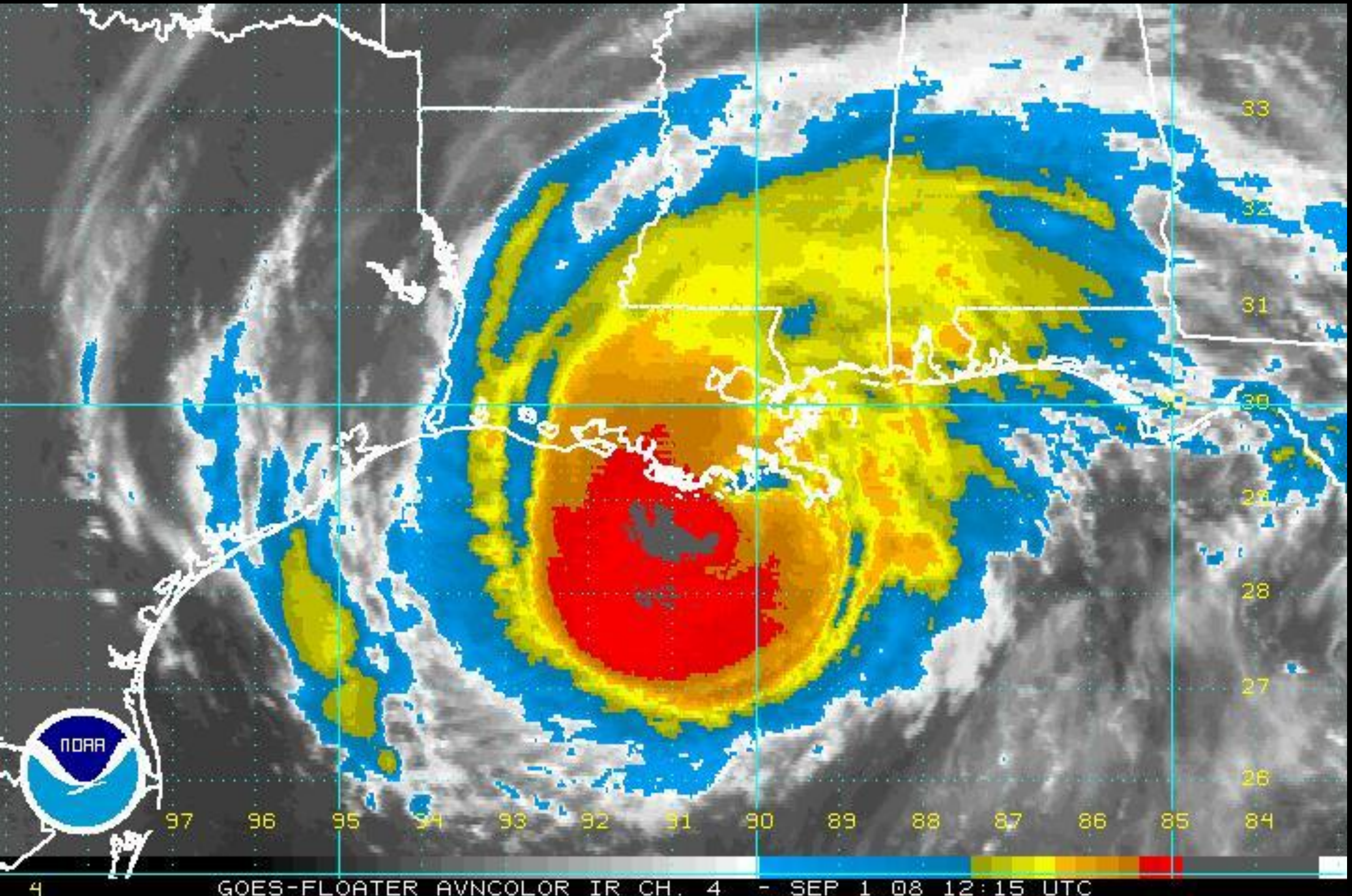
HURRICANE ANDREW – 1992

$44 B of damage (second only to Katrina); Category 5 affected Florida




105°W
95°W
85°W
75°W
65°W
55°W
45°W
35°W
25°W
15°W
05°W
60°N
50°N
40°N
30°N
20°N
10°N
0°
NOAA

SOME ERRATIC PATHS OF HURRICANES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NOAA
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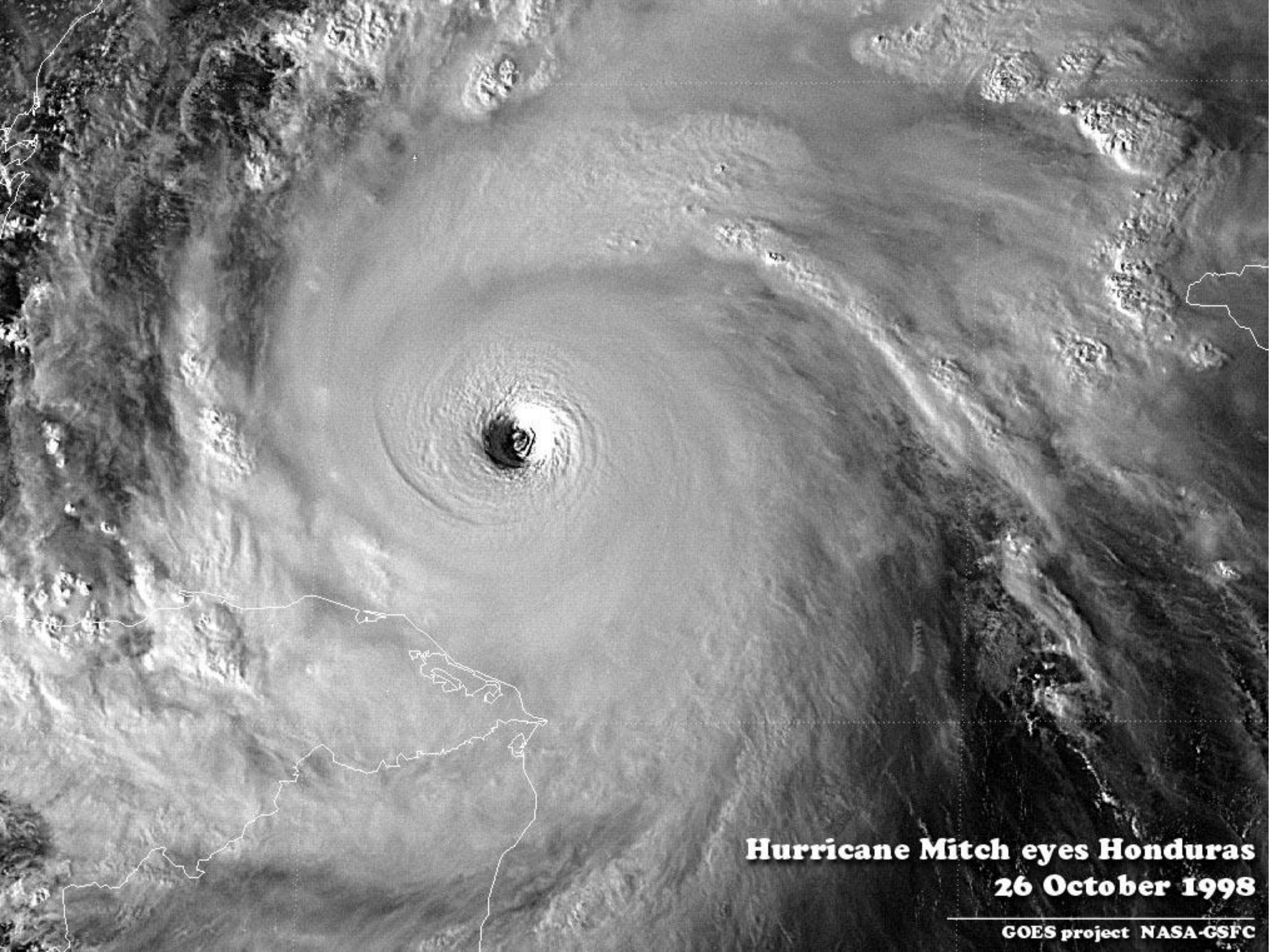
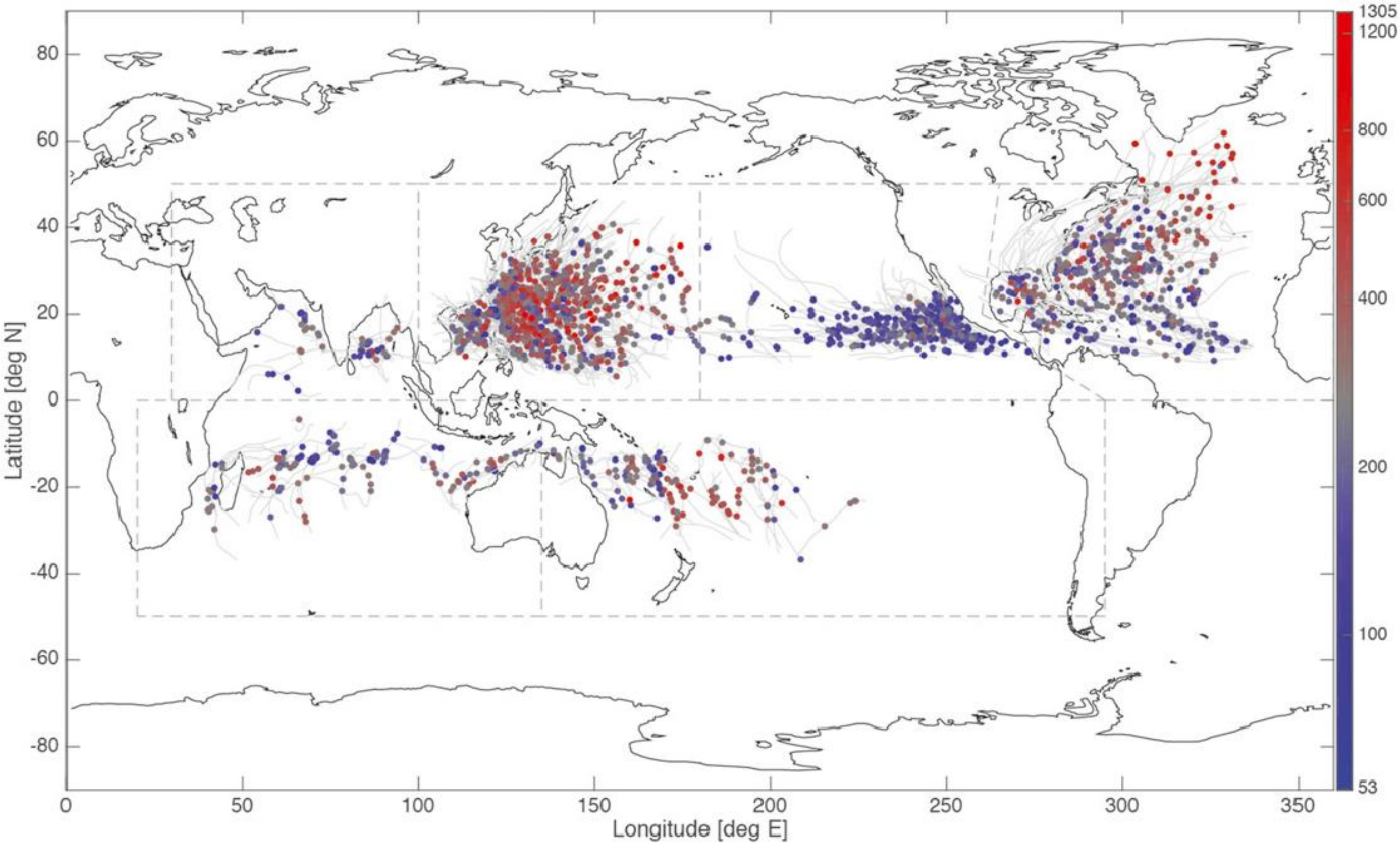
GOES-FLOATER AVNCOLOR IR CH. 4 - SEP 1 08 12:15 UTC


Hurricane Mitch eyes Honduras
26 October 1998
GOES project NASA-GSFC



STORM SIZE (MEASURED AS RADIUS) 1999-2009 AS REPORTED BY CHAVAS et al. (2016)

NATURE CLIMATE CHANGE DOI: 10.1038/NCLIMATE1410

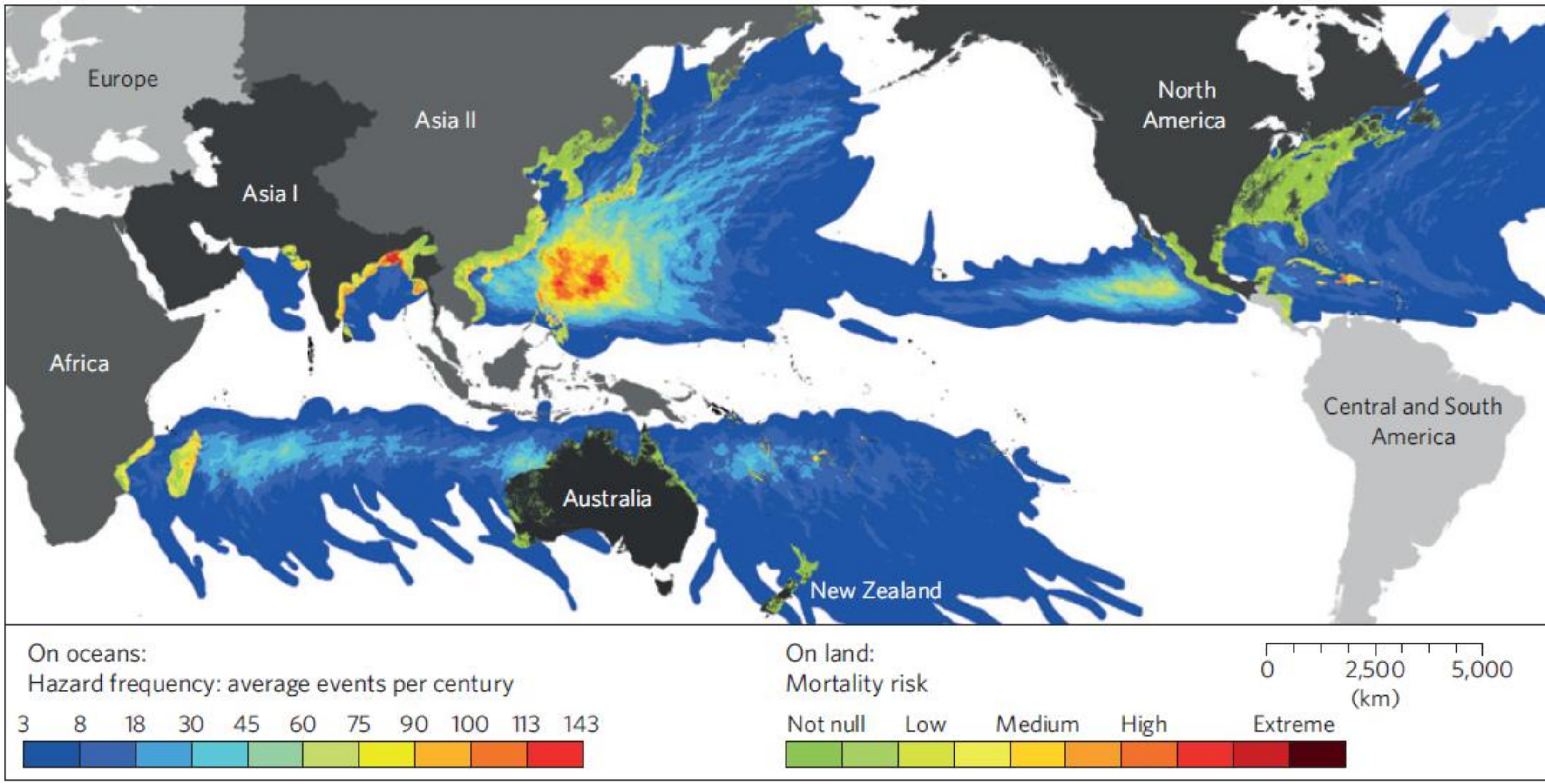


Figure 1 | Map showing distribution of hazard frequency and mortality risk from TCs for the year 2010. Estimates are applied to all pixels on a geographic grid. Mortality risk is categorized from low to extreme.

Peduzzi et al. 2012 *Global trends in tropical cyclone risk*

nature climate change

ARTICLES

PUBLISHED ONLINE: 12 FEBRUARY 2012 | DOI:10.1038/NCLIMATE1410

Global trends in tropical cyclone risk

P. Peduzzi[1,2]*, B. Chatenoux[1,3], H. Dao[1,4], A. De Bono[1,3], C. Herold[1,3], J. Kossin[5], F. Mouton[6] and O. Nordbeck[1]

The impact of tropical cyclones on humans depends on the number of people exposed and their vulnerability, as well as the frequency and intensity of storms. How will the cumulative effects of climate change, demography and vulnerability affect risk? Conventionally, reports assessing tropical cyclone risk trends are based on reported losses, but these figures are biased by improvements to information access. Here we present a new methodology based on thousands of physically observed events and related contextual parameters. We show that mortality risk depends on tropical cyclone intensity, exposure, levels of poverty and governance. Despite the projected reduction in the frequency of tropical cyclones, projected increases in both demographic pressure and tropical cyclone intensity over the next 20 years can be expected to greatly increase the number of people exposed per year and exacerbate disaster risk, despite potential progression in development and governance.

TROPICAL CYCLONE – GENERATED STORM SURGES

Reviews of Geophysics

REVIEW ARTICLE
10.1002/2014RG000477

2015

Key Points:
- Identify global storm surge data sources
- Identify global storm surge observations
- Identify global storm surge impacts

Correspondence to:
H. F. Needham

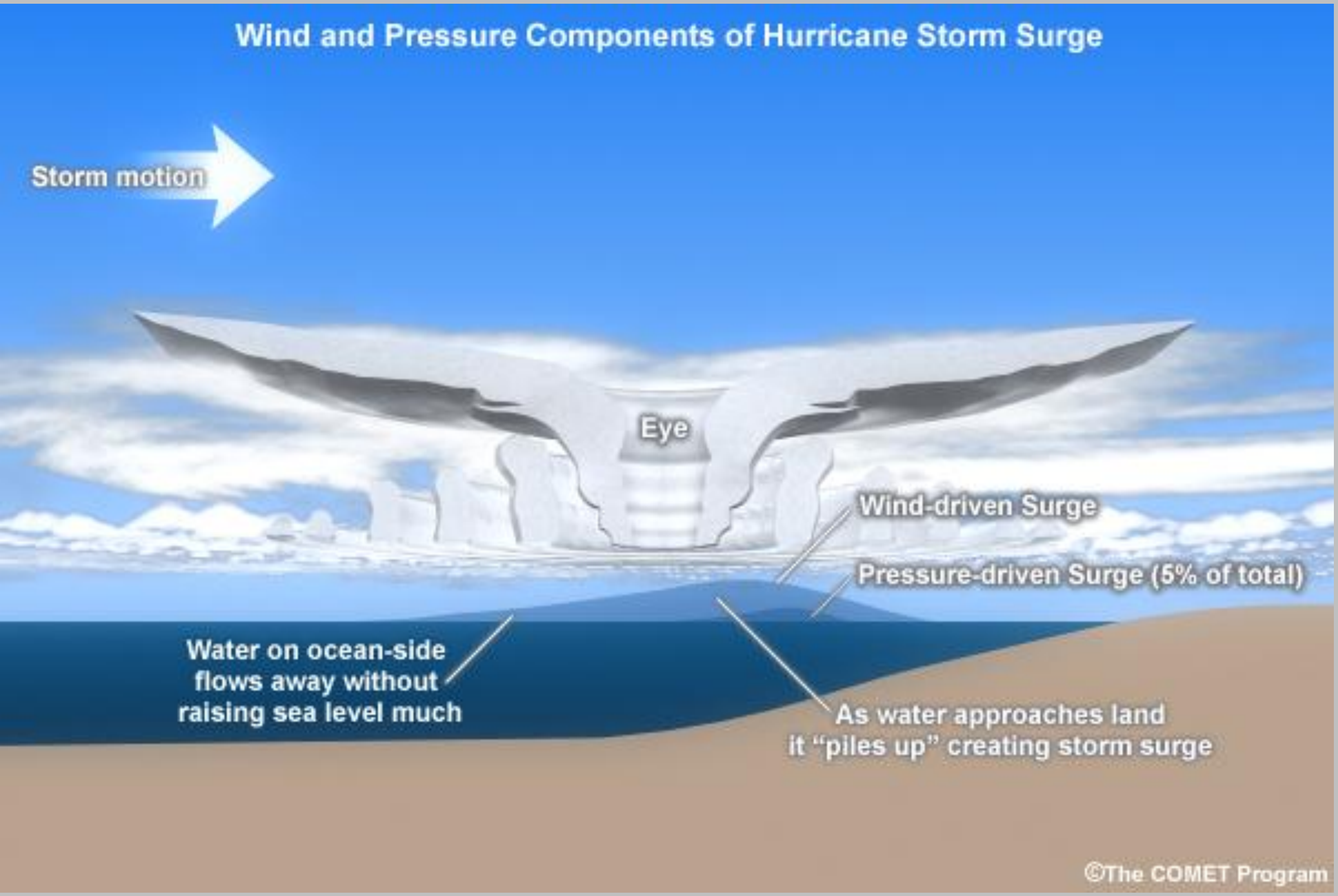
A review of tropical cyclone-generated storm surges: Global data sources, observations, and impacts

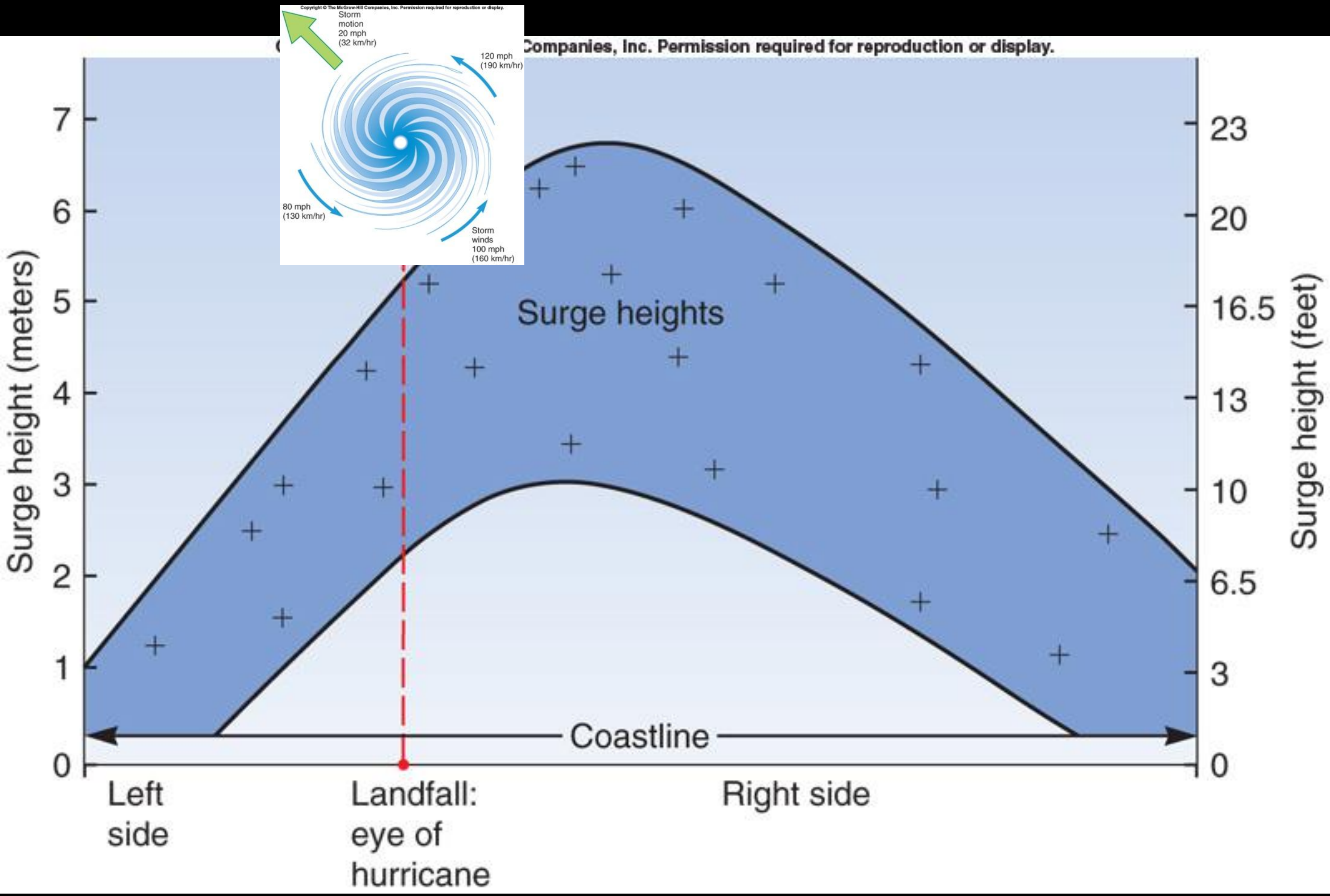
Hal F. Needham[1], Barry D. Keim[2], and David Sathiaraj[3]

[1]Southern Climate Impacts Planning Program, Louisiana State University, Baton Rouge, Louisiana, USA, [2]Department of Geography and Anthropology, Louisiana State University, Baton Rouge, Louisiana, USA, [3]NOAA/Southern Regional Climate Center, Louisiana State University, Baton Rouge, Louisiana, USA

Key aspects of TC-generated storm surges – a) among the most deadly and costly global catastrophes, b) for example, 1970 Cyclone Bhola generated a 9.1 m storm surge that killed approximately 300,000 people in Bangladesh, c) killed as many as 2.6 M people in last 200 years, d) average of around 13,000 deaths per year. e) about 250 M people who live below the maximum storm surge level in tropical areas are vulnerable to storm surge inundation every year.

HURRICANE STORM SURGE

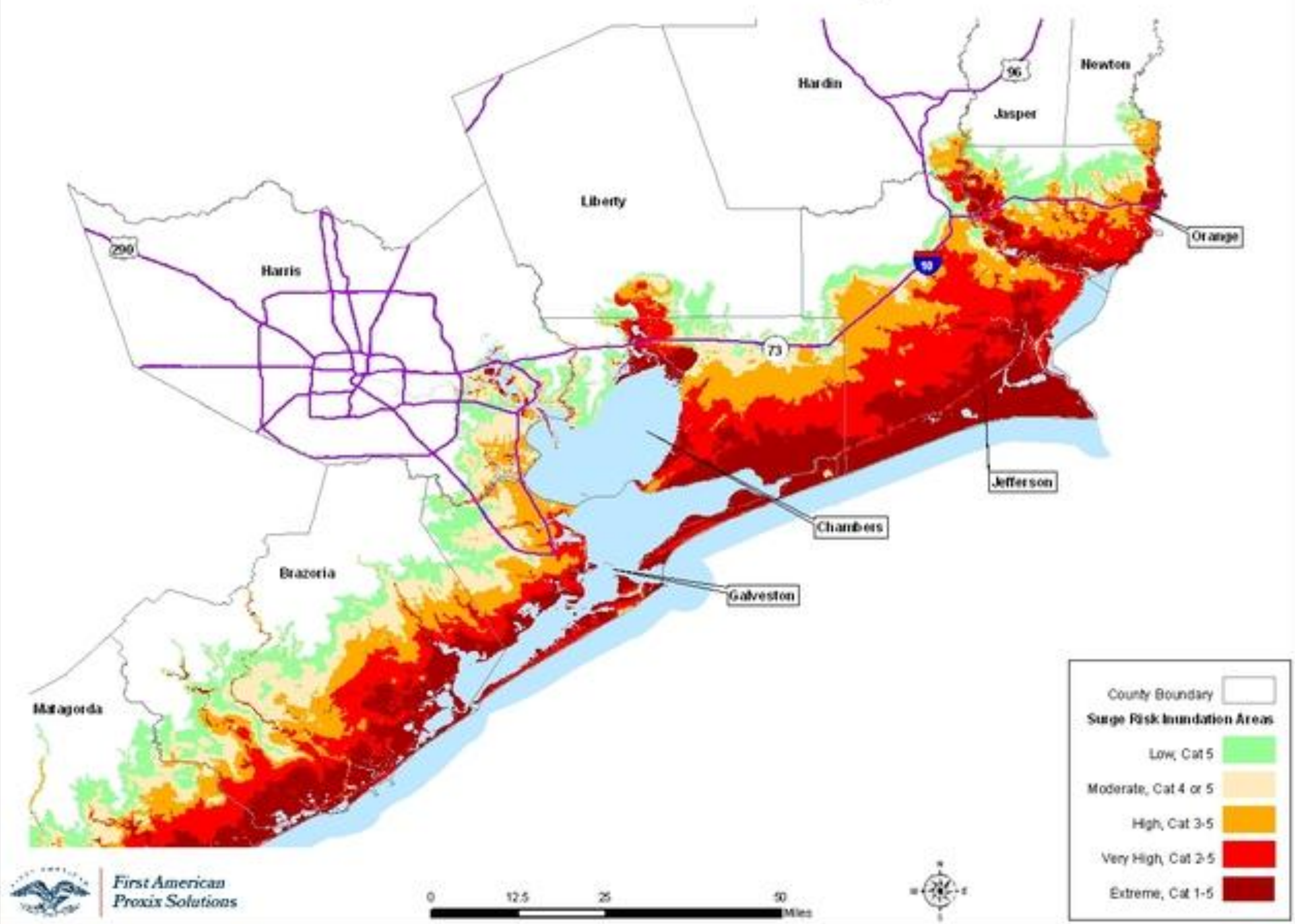




STORM SURGE HEIGHT

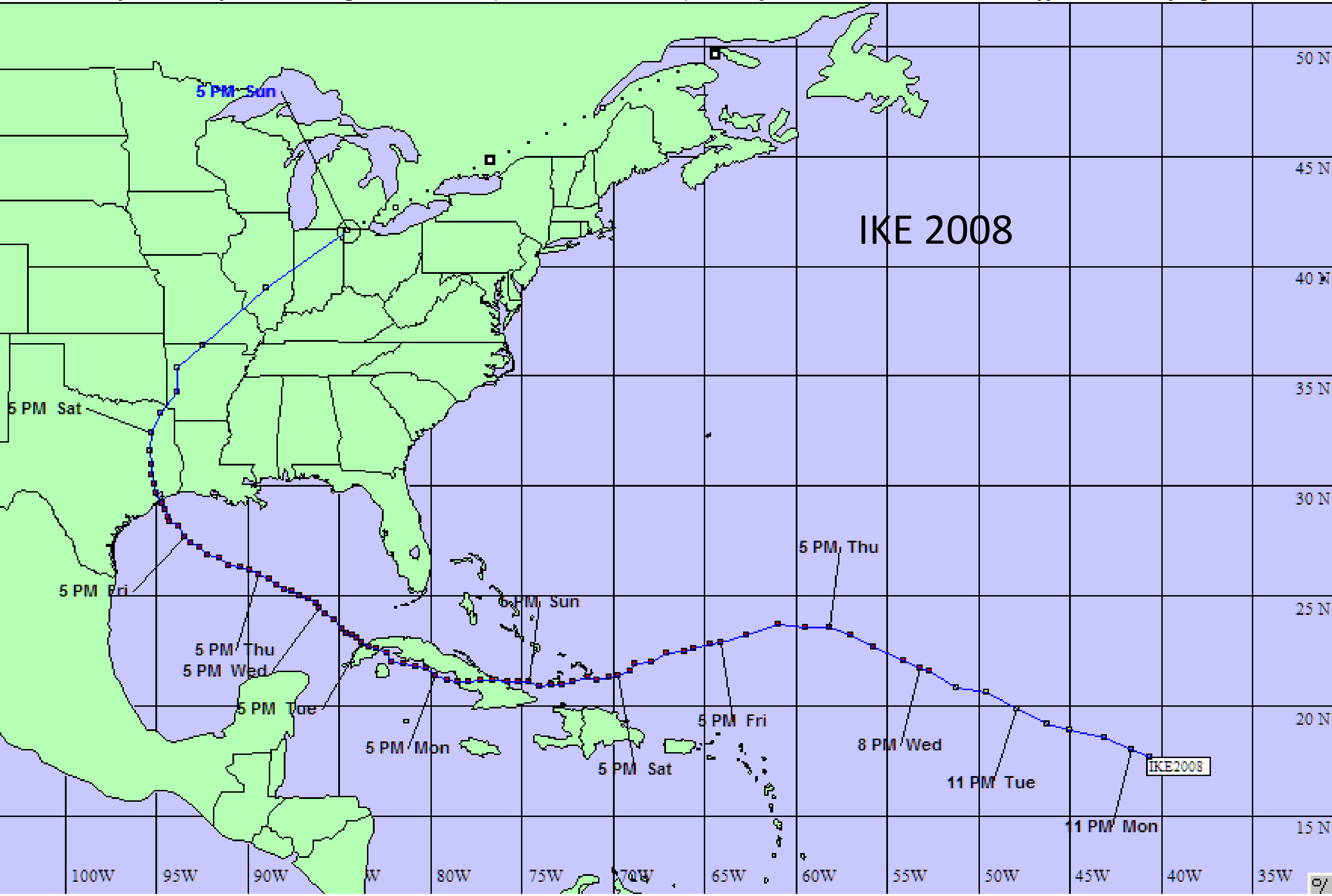
STORM SURGE DAMAGE, HURRICANE HUGO, 1989

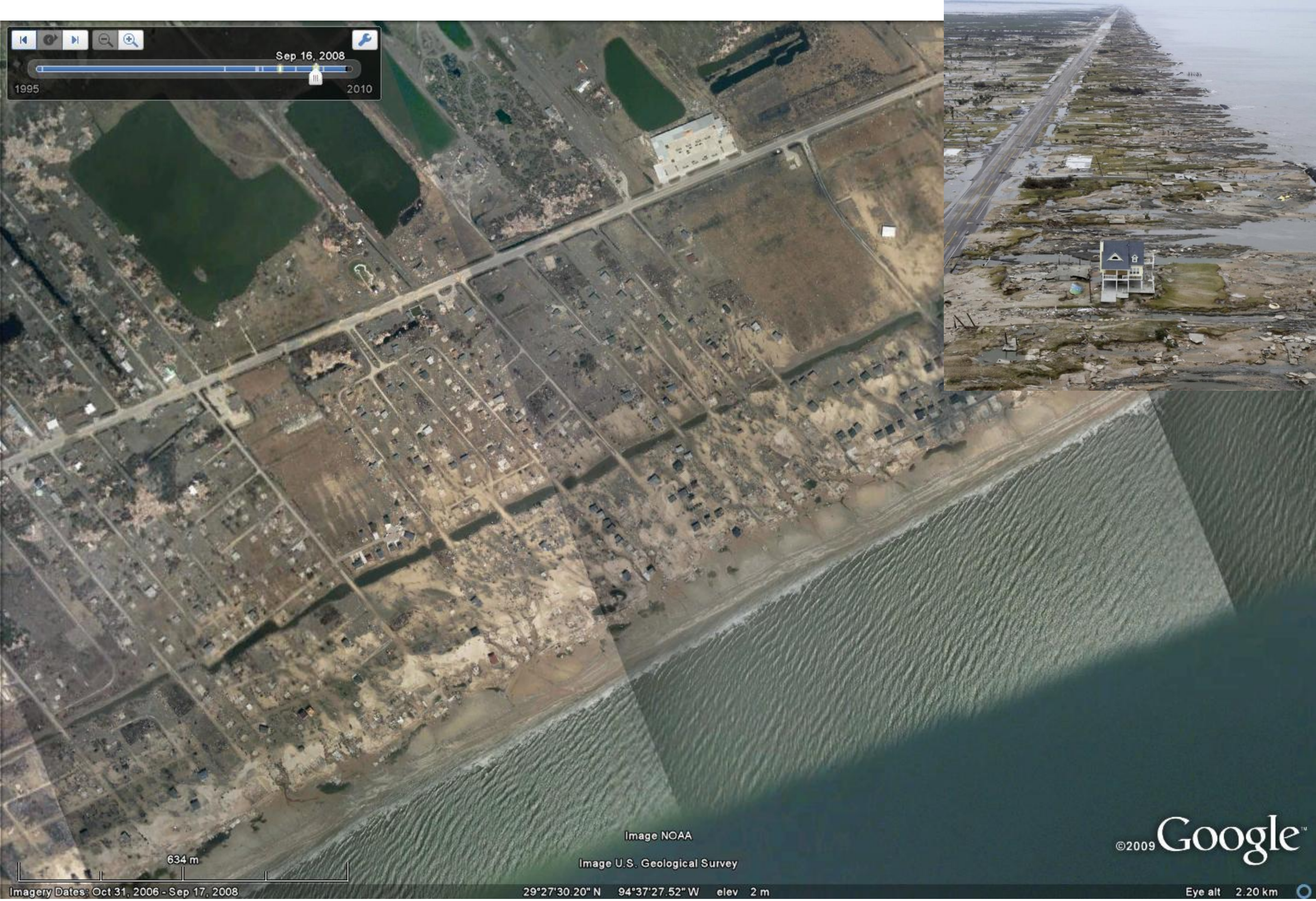
Houston Area Hurricane Storm Surge Potential



IKE # 55 NHC Past(solid) and Forecast(dots) Track >34Kt(39mph) >50Kt(58mph) >64kt(74mph)

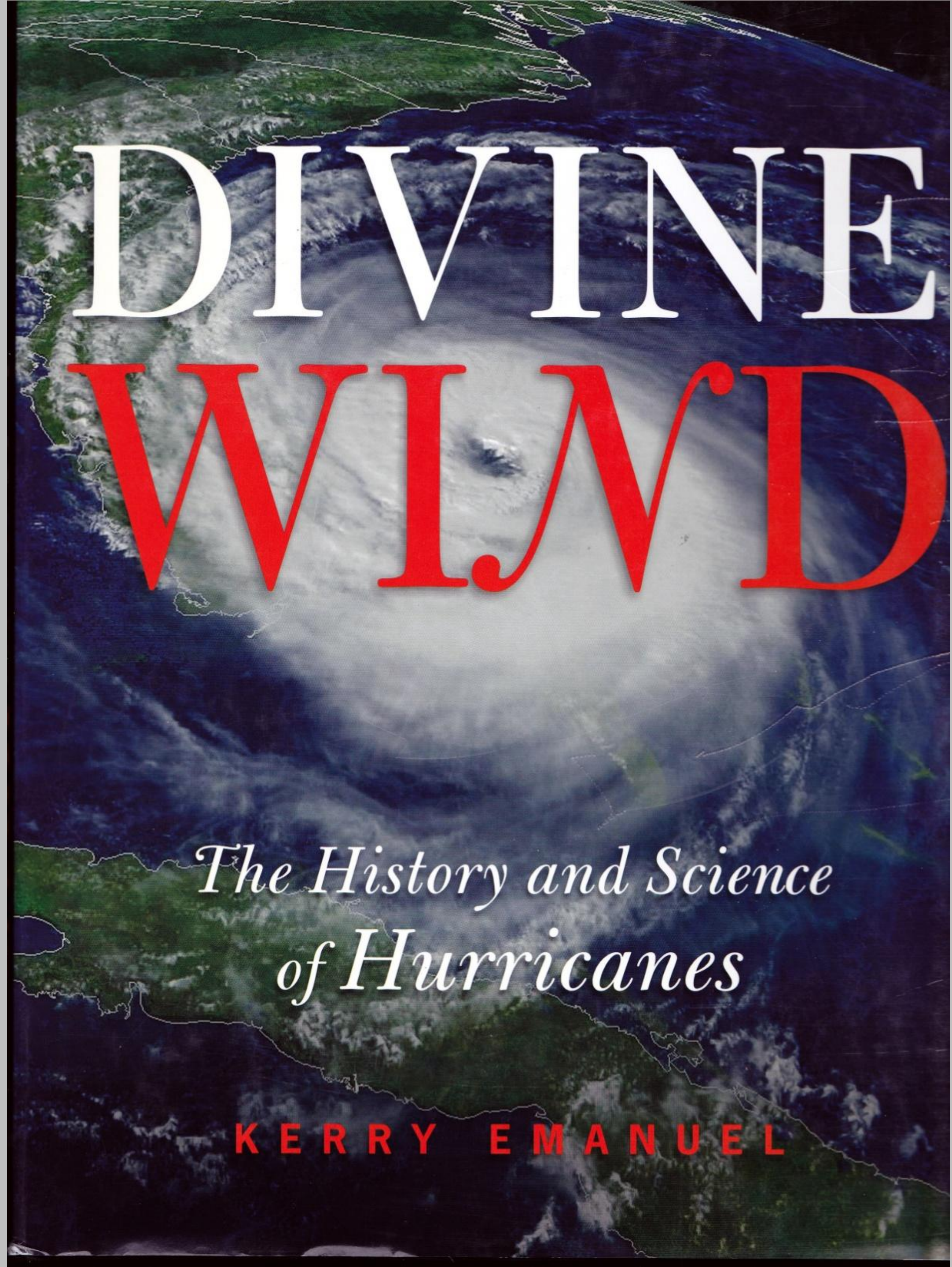
National Hurricane Center Disclaimer: 'Wind Range Contours show the maximum extent of winds expected in each quadrant. Users are cautioned that winds vary greatly within each quadrant. For quadrants extending over land and water, over-water values are used, which may make the extent of inland wind radii appear unrealistically large'



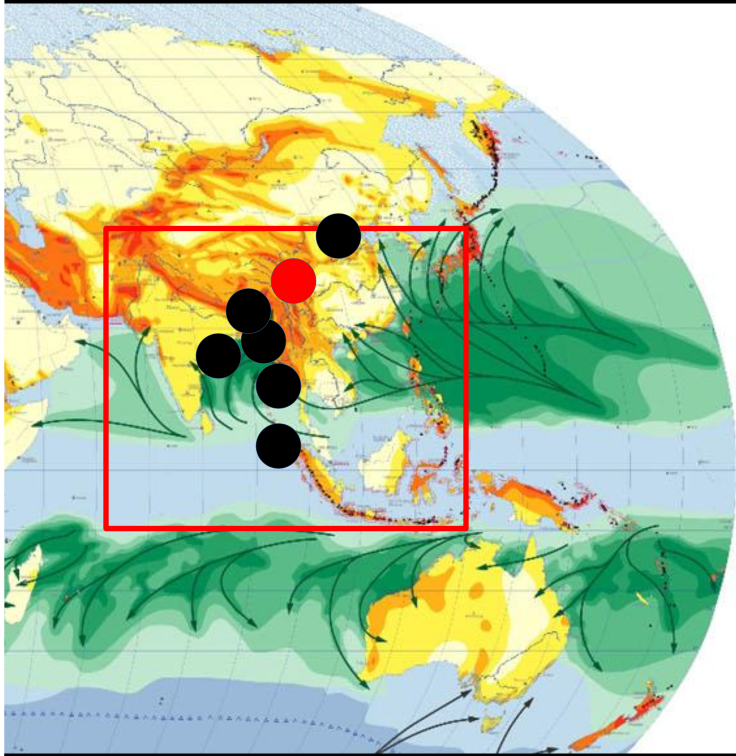


DAMAGE ON TEXAS COAST DUE TO HURRICANE IKE, SEPTEMBER 2008

HURRICANE IKE DAMAGE, GALVESTON ISLAND, TEXAS, SEPTEMBER 2008


DIVINE
WIND
The History and Science
of Hurricanes
KERRY EMANUEL

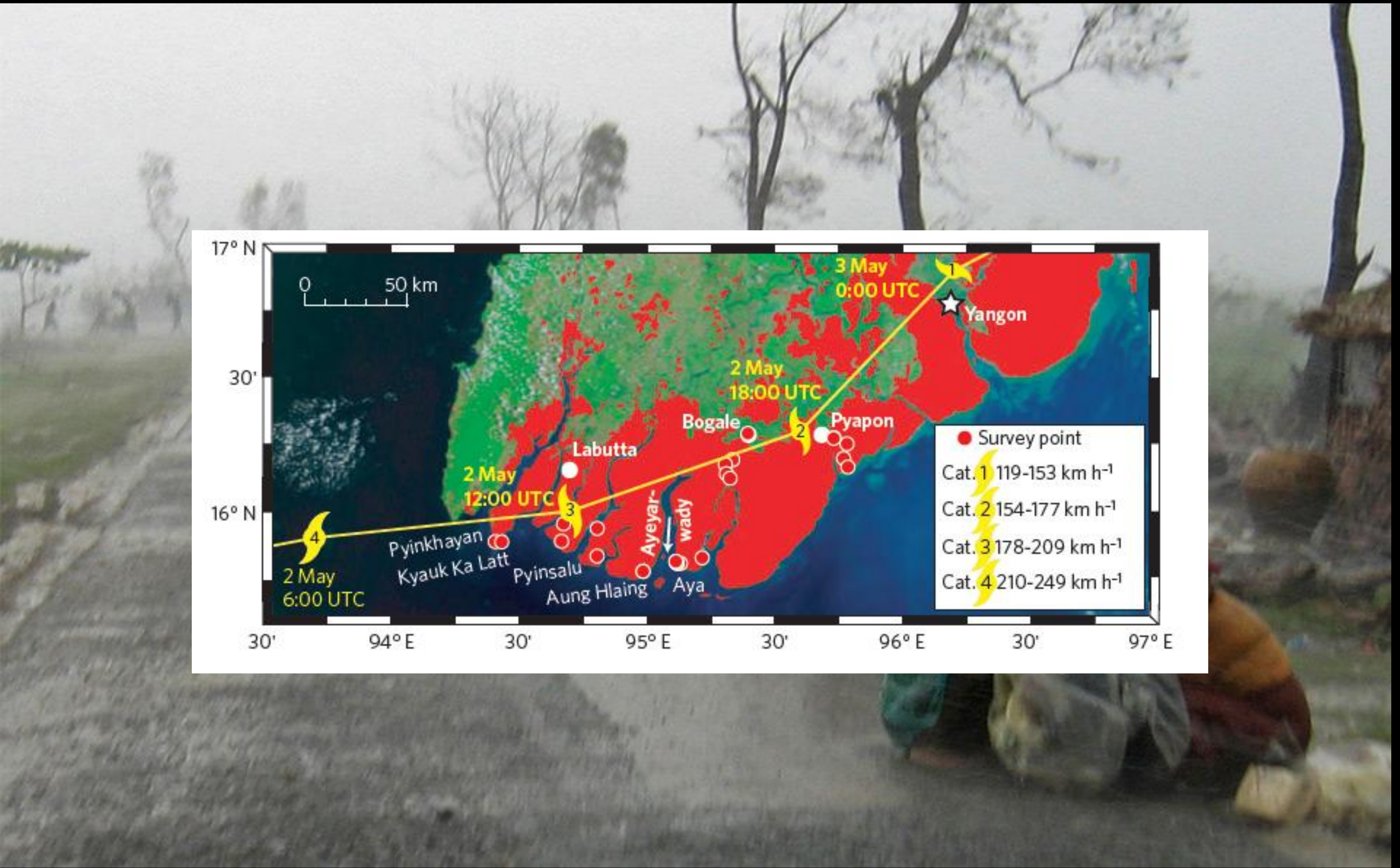
Cyclone Nargis, Irrawaddy Delta, May 2008



	DATE	HAZARD	COUNTRY	DEATHS
1	1970/11/14	Hurricane (Cyclone Bhola)	Bangladesh	400,000
2	1976/07/28	Earthquake (Tangshan Earthquake)	China	255,000
3	2004/12/26	Earthquake & Tsunami	South Asia	246,000
4	1991/04/30	Hurricane (Cyclone Gorky)	Bangladesh	140,000
5	2008/05/2-5	Hurricane (Cyclone Nargis)	Myanmar	134,500

GLOBAL DISASTERS WITH HIGHEST DEATH TOLLS SINCE 1970

CYCLONE NARGIS 2008



17° N
30'
16° N
0 50 km
3 May
0:00 UTC
Yangon
2 May
18:00 UTC
Bogale
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12:00 UTC
2 May
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Pyinkhayan
Kyauk Ka Latt
Pyinsalu
Aung Hlaing
Ayeyar-
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Aya
1
2
3
4
Survey point
Cat. 1 119-153 km h-1
Cat. 2 154-177 km h-1
Cat. 3 178-209 km h-1
Cat. 4 210-249 km h-1
30'
94° E
30'
95° E
30'
96° E
30'
97° E

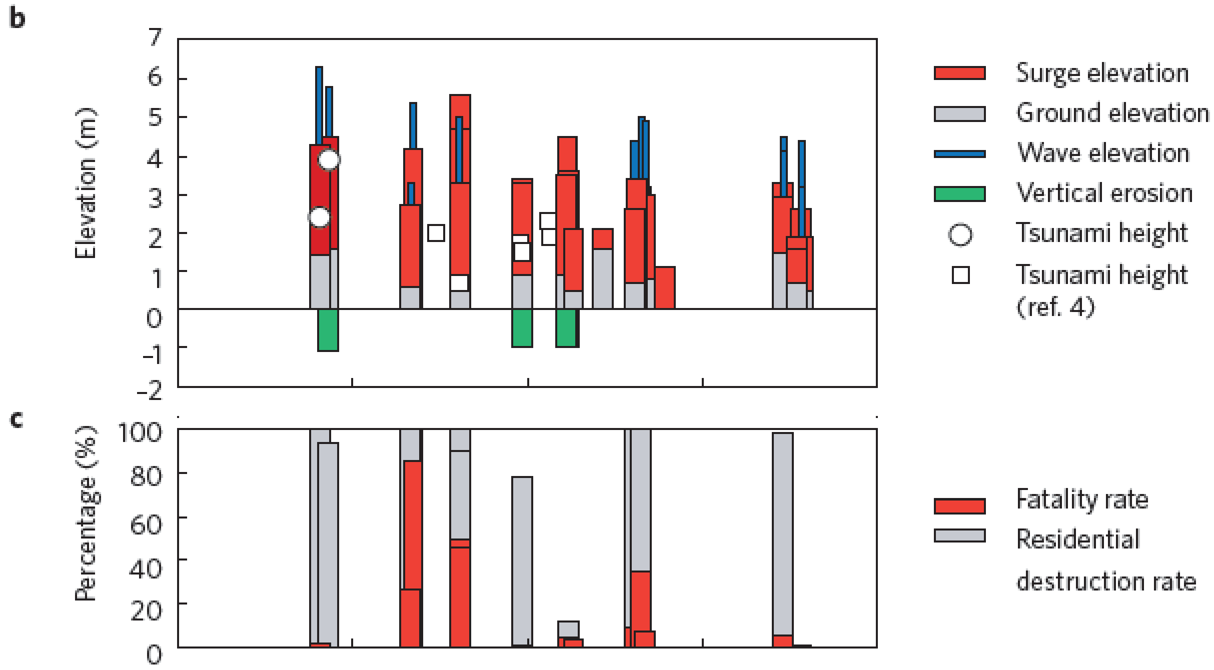


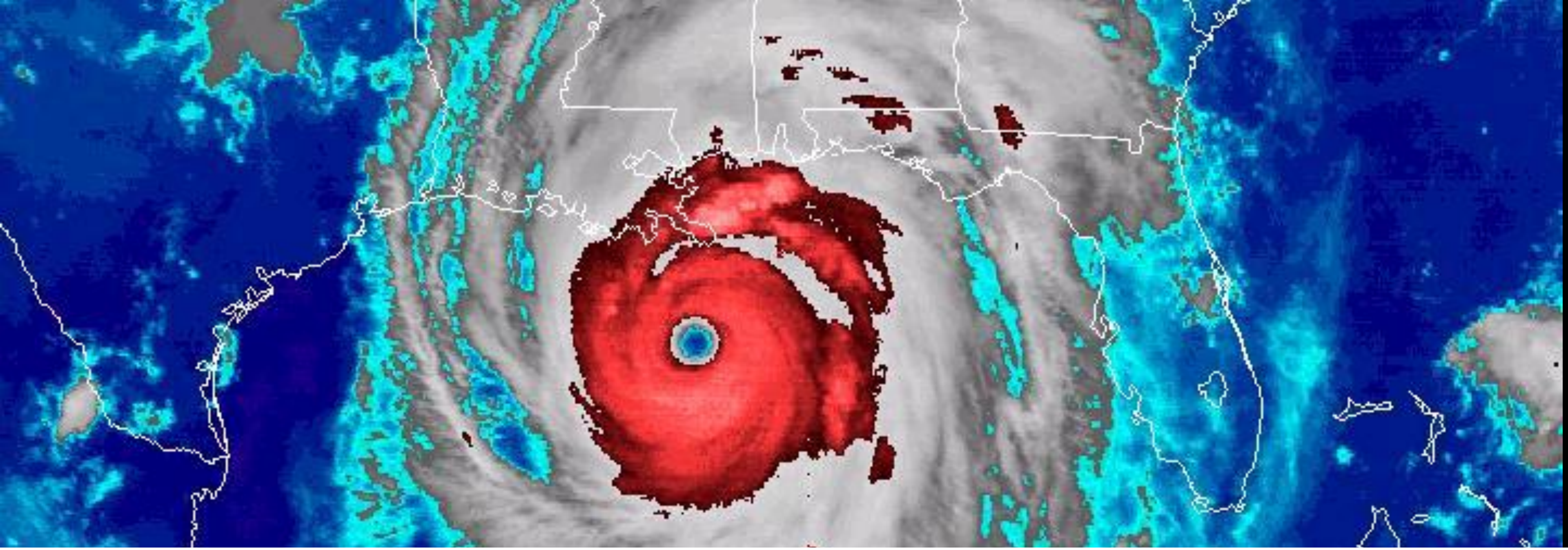
Figure 1 | Field observations of the cyclone Nargis storm surge in Myanmar, which made landfall on 2 May 2008. **a**, NASA MODIS Rapid Response imagery with a UNOSAT flood overlay (in red) modified based on ground reconnaissance; storm track and categories are shown in yellow. **b**, Measured storm-surge and storm-wave heights for the region between 94 and 96° E, compared with the 2004 Indian Ocean tsunami heights (see Supplementary Table 1). **c**, Recorded mortality and residential destruction rates in the region between 94 and 96° E (see Supplementary Table 2). Measurement accuracies: ±0.1 m for vertical measurements and ±0.3 m for wave-height estimates.

Climate impacts overwhelming - UN

Global warming is likely to have a "severe, pervasive and irreversible" impact, the UN warns after a comprehensive assessment. 1033

- 'Profound' climate change report
- Diving in acid oceans
- Climate report: Key findings
- Reaction to report
- A food crisis in Japan?
- Risk of flooding

BBC News, March 31, 2014

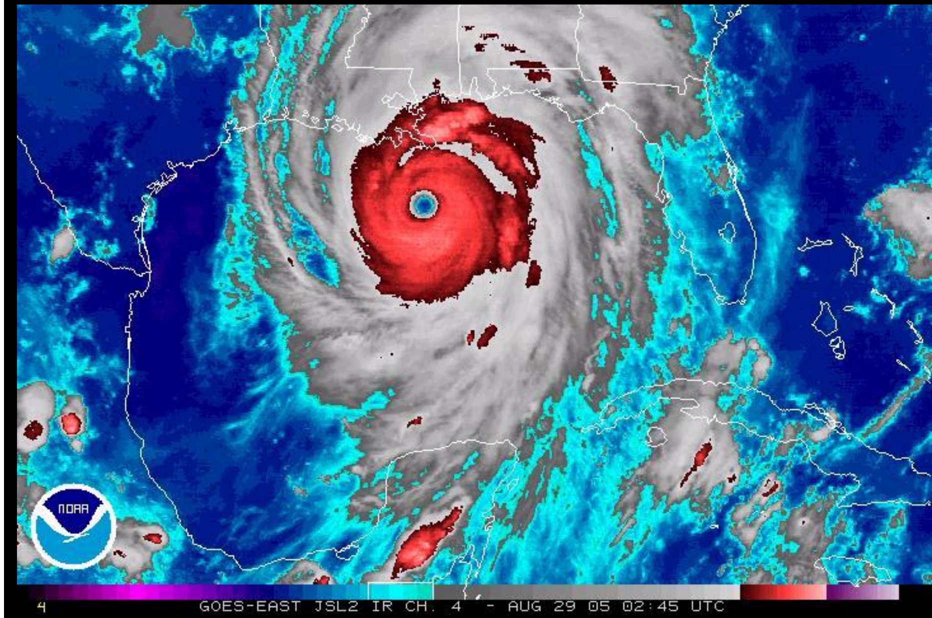


HURRICANES AND GLOBAL WARMING

BY R. A. PIELKE JR., C. LANDSEA, M. MAYFIELD, J. LAVER, AND R. PASCH

An interdisciplinary team of researchers survey the peer-reviewed literature to assess the relationships between global warming, hurricanes, and hurricane impacts.

CONCLUSIONS. To summarize, claims of linkages between global warming and hurricane impacts are premature for three reasons. First, no connection has been established between greenhouse gas emissions and the observed behavior of hurricanes (Houghton et al. 2001; Walsh 2004). Emanuel (2005) is suggestive of such a connection, but is by no means definitive. In the future, such a connection may be established [e.g., in the case of the observations of Emanuel (2005) or the projections of Knutson and Tuleya (2004)] or made in the context of other metrics of tropical cyclone intensity and duration that remain to be closely examined. Second, the peer-reviewed literature reflects that a scientific consensus exists that any future changes in hurricane intensities will likely be small in the context of observed variability (Knutson and Tuleya 2004; Henderson-Sellers et al. 1998), while the scientific problem of tropical cyclogenesis is so far from being solved that little can be said about possible changes in frequency. And third, under the assumptions of the IPCC, expected future damages to society of its projected changes in the behavior of hurricanes are dwarfed by the influence of its own projections of growing wealth and population (Pielke et al. 2000).



Climate impacts overwhelming - UN

Global warming is likely to have a "severe, pervasive and irreversible" impact, the UN warns after a comprehensive assessment. 1033

'Profound' climate change report

Diving in acid oceans

Climate report: Key findings

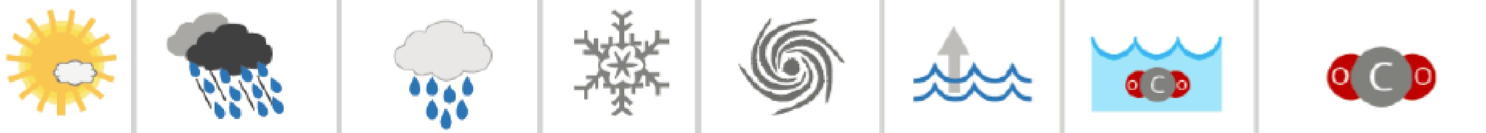
Reaction to report

A food crisis in Japan?

Risk of flooding

Climate change: Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.' The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Climate-related drivers of impacts

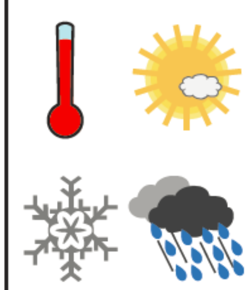


Warming trend	Extreme temperature	Drying trend	Extreme precipitation	Precipitation	Snow cover	Damaging cyclone	Sea level	Ocean acidification	Carbon dioxide fertilization

Asia

Key risk	Adaptation issues & prospects	Climatic drivers
Increased riverine, coastal, and urban flooding leading to widespread damage to infrastructure, livelihoods, and settlements in Asia (*medium confidence*) [24.4]	• Exposure reduction via structural and non-structural measures, effective land-use planning, and selective relocation • Reduction in the vulnerability of lifeline infrastructure and services (e.g., water, energy, waste management, food, biomass, mobility, local ecosystems, telecommunications) • Construction of monitoring and early warning systems; measures to identify exposed areas, assist vulnerable areas and households, and diversify livelihoods • Economic diversification	

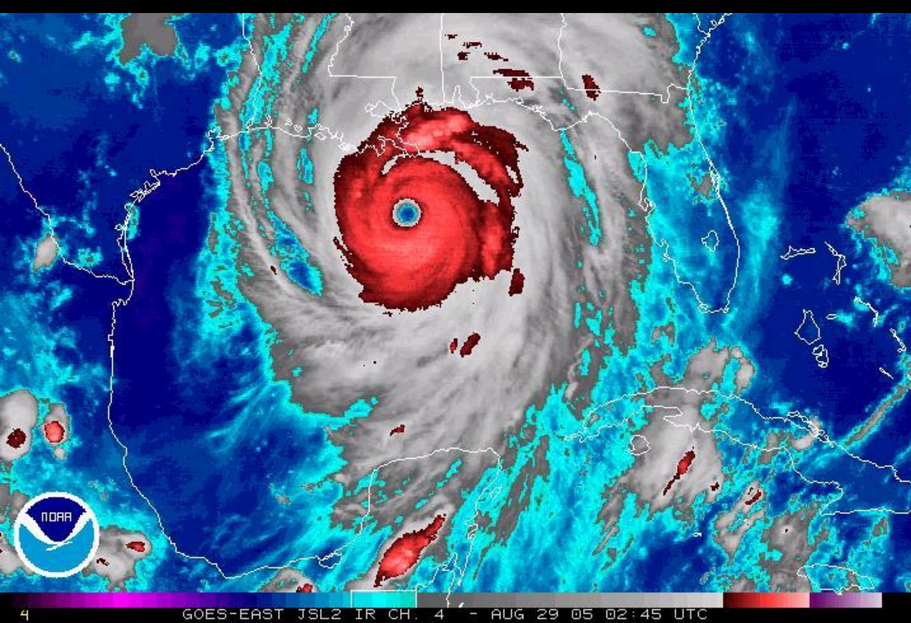
Central and South America

Key risk	Adaptation issues & prospects	Climatic drivers
Water availability in semi-arid and glacier-melt-dependent regions and Central America; flooding and landslides in urban and rural areas due to extreme precipitation (*high confidence*) [27.3]	• Integrated water resource management • Urban and rural flood management (including infrastructure), early warning systems, better weather and runoff forecasts, and infectious disease control	

Tropical cyclones and climate change

Thomas R. Knutson[1*], John L. McBride[2], Johnny Chan[3], Kerry Emanuel[4], Greg Holland[5], Chris Landsea[6], Isaac Held[1], James P. Kossin[7], A. K. Srivastava[8] and Masato Sugi[9]

Whether the characteristics of tropical cyclones have changed or will change in a warming climate — and if so, how — has been the subject of considerable investigation, often with conflicting results. Large amplitude fluctuations in the frequency and intensity of tropical cyclones greatly complicate both the detection of long-term trends and their attribution to rising levels of atmospheric greenhouse gases. Trend detection is further impeded by substantial limitations in the availability and quality of global historical records of tropical cyclones. Therefore, it remains uncertain whether past changes in tropical cyclone activity have exceeded the variability expected from natural causes. However, future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100. Existing modelling studies also consistently project decreases in the globally averaged frequency of tropical cyclones, by 6–34%. Balanced against this, higher resolution modelling studies typically project substantial increases in the frequency of the most intense cyclones, and increases of the order of 20% in the precipitation rate within 100 km of the storm centre. For all cyclone parameters, projected changes for individual basins show large variations between different modelling studies.



nature geoscience

Box 1 | Summary of detection, attribution and projection assessments. [from Knutson et al.]

Detection and attribution

It remains uncertain whether past changes in any tropical cyclone activity (frequency, intensity, rainfall, and so on) exceed the variability expected through natural causes, after accounting for changes over time in observing capabilities.

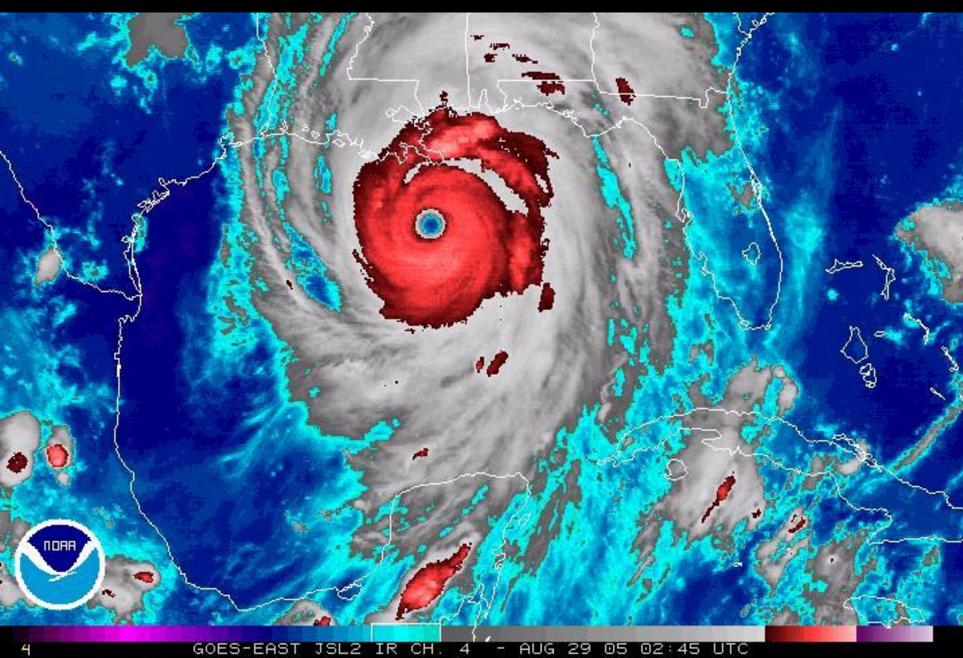
Tropical cyclone projections

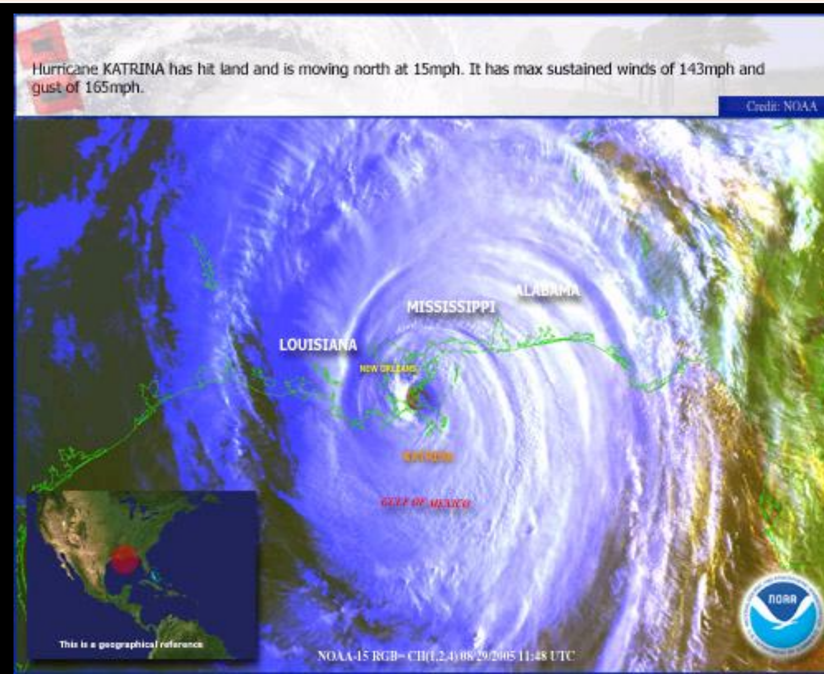
Frequency. It is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged owing to greenhouse warming. We have very low confidence in projected changes in individual basins. Current models project changes ranging from −6 to −34% globally, and up to ±50% or more in individual basins by the late twenty-first century.

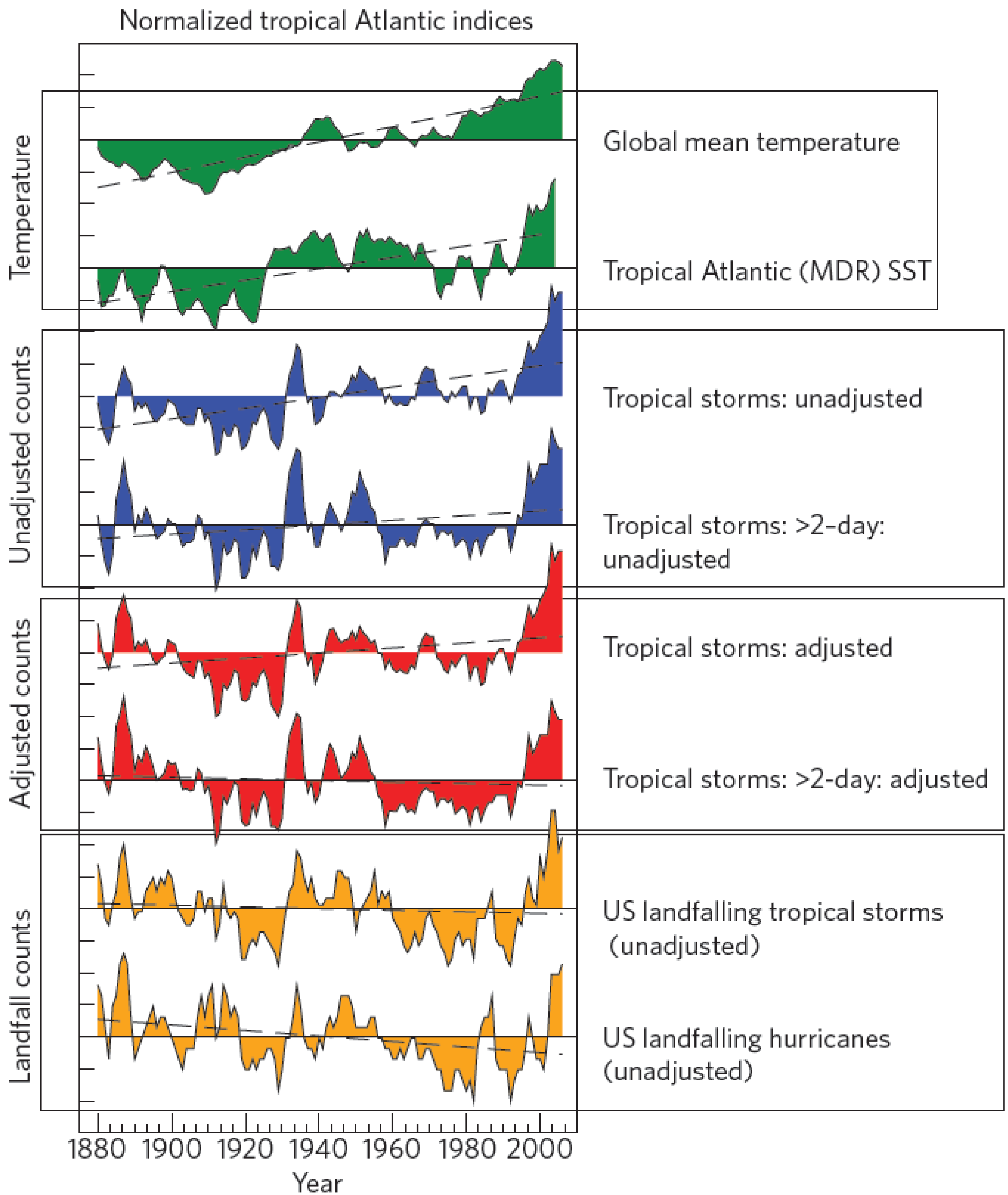
Intensity. Some increase in the mean maximum wind speed of tropical cyclones is likely (+2 to +11% globally) with projected twenty-first-century warming, although increases may not occur in all tropical regions. The frequency of the most intense (rare/high-impact) storms will more likely than not increase by a substantially larger percentage in some basins.

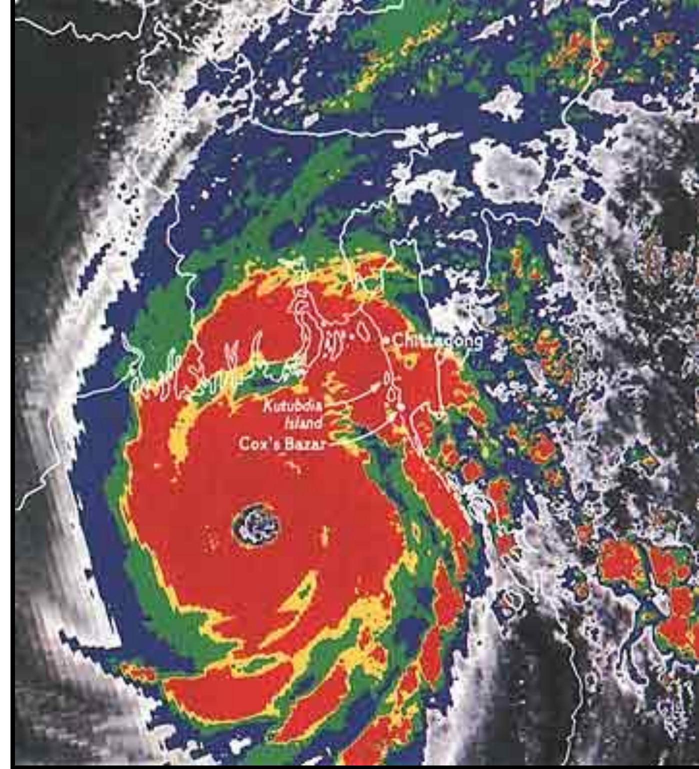
Rainfall. Rainfall rates are likely to increase. The projected magnitude is on the order of +20% within 100 km of the tropical cyclone centre.

Genesis, tracks, duration and surge flooding. We have low confidence in projected changes in tropical cyclone genesis-location, tracks, duration and areas of impact. Existing model projections do not show dramatic large-scale changes in these features. The vulnerability of coastal regions to storm-surge flooding is expected to increase with future sea-level rise and coastal development, although this vulnerability will also depend on future storm characteristics.









(from Knutson et al.)

Hurricanes and rising global temperatures

Greg J. Holland[1]
Earth Systems Laboratory, National Center for Atmospheric Research, Boulder, CO 80301

Theoretical and modeling assessments consistently point toward an increase in hurricane intensity with global warming (1–3). For the North Atlantic, the annual number of the most intense hurricanes has been predicted to increase by more than 50% for each 1-°C increase in surface temperatures (2, 4). However, there is no consensus on whether current hurricanes have responded to the substantial global warming that has already occurred (2, 3); some studies find a substantial increase in intense systems (5–7) whereas others find none (8, 9). This presents a conundrum: if we cannot find a current signal, how can we interpret, or even accept, the future projections?

A major issue has been the heterogeneity of most of the available hurricane data, which contain inherent trends in observing and analysis methodologies that are difficult to isolate. This masks any real trends and has generated substantial debate on how to interpret information that may appear to have substantial inherent contradictions.

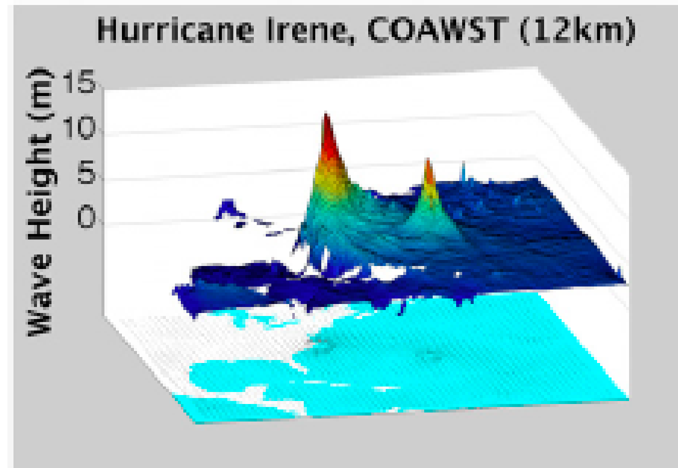


Fig. 1. Wind (*Lower*) with overlaid 3D depiction of the near-coastal ocean wave fields associated with Hurricane Irene (left peak), with a second peak over the open ocean driven by Hurricane Katia. COAWST, Coupled-Ocean-Atmosphere-Wave-Sediment-Transport modeling system. (Fields provided by Brian Bonnlander.)

termine almost all the damage that has been observed (11). The surge index provides a physical integration of these factors and this may prove to be its most valuable aspect.

Grinsted et al. (10) show that the index

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Holland (2012) Proceedings National Academy of Sciences

Increasing destructiveness of tropical cyclones over the past 30 years

Kerry Emanuel[1]

Theory[1] and modelling[2] predict that hurricane intensity should increase with increasing global mean temperatures, but work on the detection of trends in hurricane activity has focused mostly on their frequency[3,4] and shows no trend. Here I define an index of the potential destructiveness of hurricanes based on the total dissipation of power, integrated over the lifetime of the cyclone, and show that this index has increased markedly since the mid-1970s. This trend is due to both longer storm lifetimes and greater storm intensities. I find that the record of net hurricane power dissipation is highly correlated with tropical sea surface temperature, reflecting well-documented climate signals, including multi-decadal oscillations in the North Atlantic and North Pacific, and global warming. My results suggest that future warming may lead to an upward trend in tropical cyclone destructive potential, and—taking into account an increasing coastal population—a substantial increase in hurricane-related losses in the twenty-first century.

more controversial, with little guidance from existing theory. Global climate model predictions of the influence of global warming on storm frequency are highly inconsistent, and there is no detectable trend in the global annual frequency of tropical cyclones in historical tropical cyclone data.

Although the frequency of tropical cyclones is an important scientific issue, it is not by itself an optimal measure of tropical cyclone threat. The actual monetary loss in wind storms rises roughly as the cube of the wind speed[14] as does the total power dissipation (PD; ref. 15), which, integrated over the surface area affected by a storm and over its lifetime is given by:

$$\mathrm{PD} = 2\pi \int_0^{\tau} \int_0^{r_0} C_{\mathrm{D}} \rho |\mathbf{V}|^3 r \, \mathrm{d}r \, \mathrm{d}t \qquad (1)$$

where C_{D} is the surface drag coefficient, ρ is the surface air density, $|\mathbf{V}|$ is the magnitude of the surface wind, and the integral is over radius to an outer storm limit given by r_0 and over τ, the lifetime of

ARTICLE

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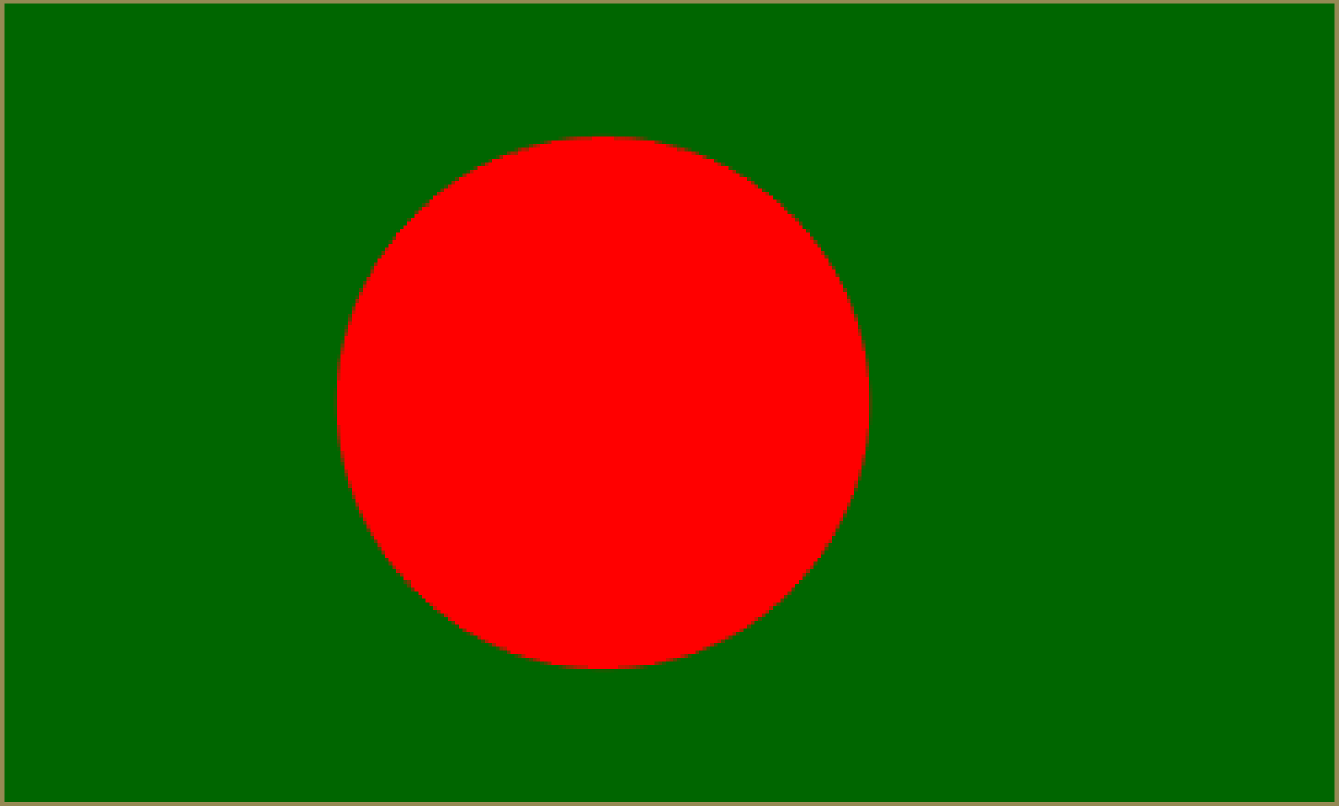
OPEN

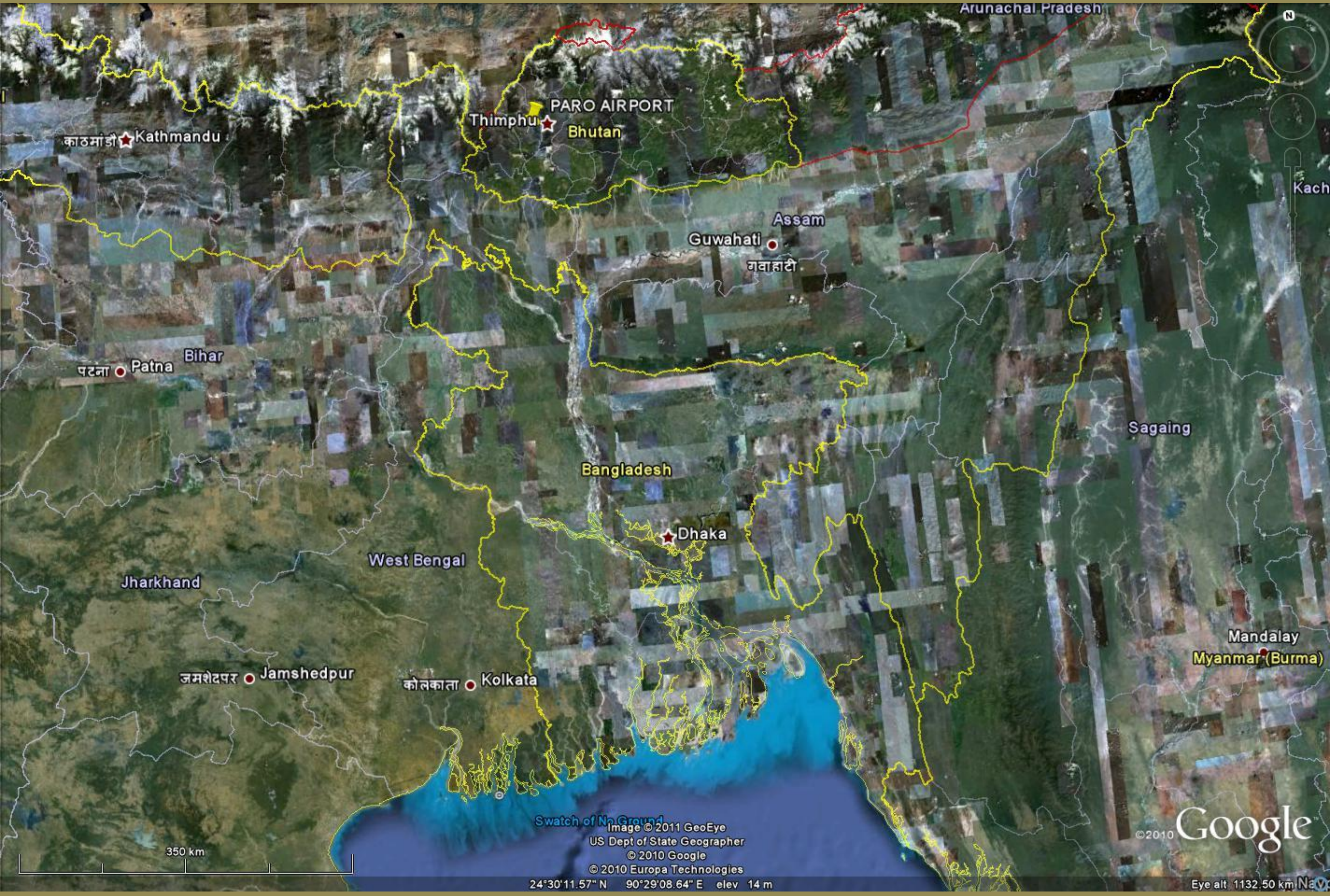
Recent decrease in typhoon destructive potential and global warming implications

I-I Lin[1] & Johnny C.L. Chan[2]

Typhoons (tropical cyclones) severely impact the half-billion population of the Asian Pacific. Intriguingly, during the recent decade, typhoon destructive potential (Power Dissipation Index, PDI) has decreased considerably (by ~35%). This decrease, paradoxically, has occurred despite the increase in typhoon intensity and ocean warming. Using the method proposed by Emanuel (in 2007), we show that the stronger negative contributions from typhoon frequency and duration, decrease to cancel the positive contribution from the increasing intensity, controlling the PDI. Examining the typhoons' environmental conditions, we find that although the ocean condition became more favourable (warming) in the recent decade, the atmospheric condition 'worsened' at the same time. The 'worsened' atmospheric condition appears to effectively overpower the 'better' ocean conditions to suppress PDI. This stronger negative contribution from reduced typhoon frequency over the increased intensity is also present under the global warming scenario, based on analysis of the simulated typhoon data from high-resolution modelling.

DISASTERS AND NATURAL HAZARDS – THE CASE OF BANGLADESH



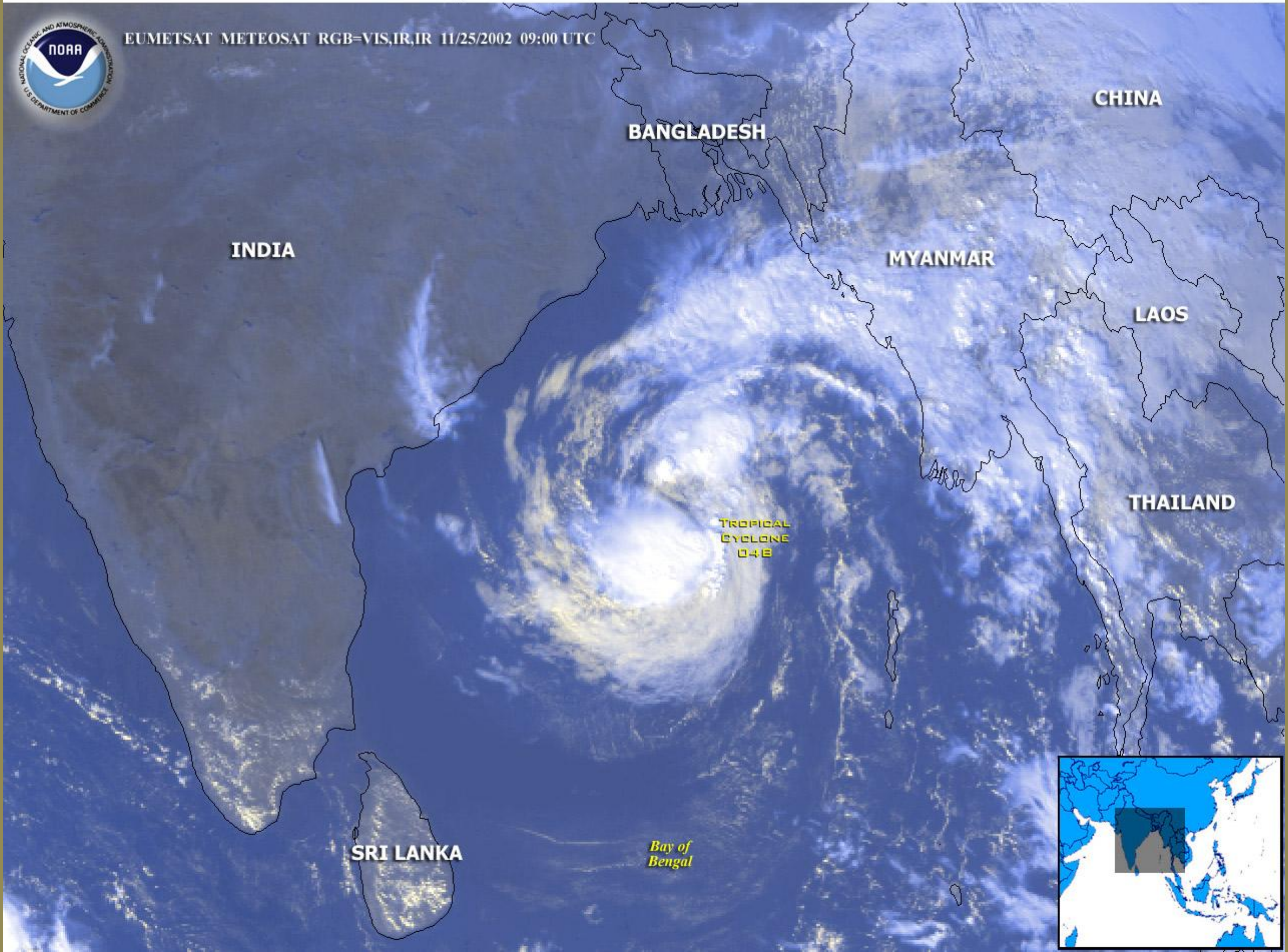


Arunachal Pradesh
PARO AIRPORT
Thimphu
Bhutan
काठमांडौ Kathmandu
Kach
Assam
Guwahati
गवाहाटी
Bihar
पटना Patna
Sagaing
Bangladesh
Dhaka
West Bengal
Jharkhand
Mandalay
Myanmar (Burma)
जमशेदपर Jamshedpur
कोलकाता Kolkata
Swatch of No Ground
Image © 2011 GeoEye
US Dept of State Geographer
© 2010 Google
© 2010 Europa Technologies
©2010 Google
350 km
24°30'11.57" N 90°29'08.64" E elev 14 m
Eye alt 1132.50 km

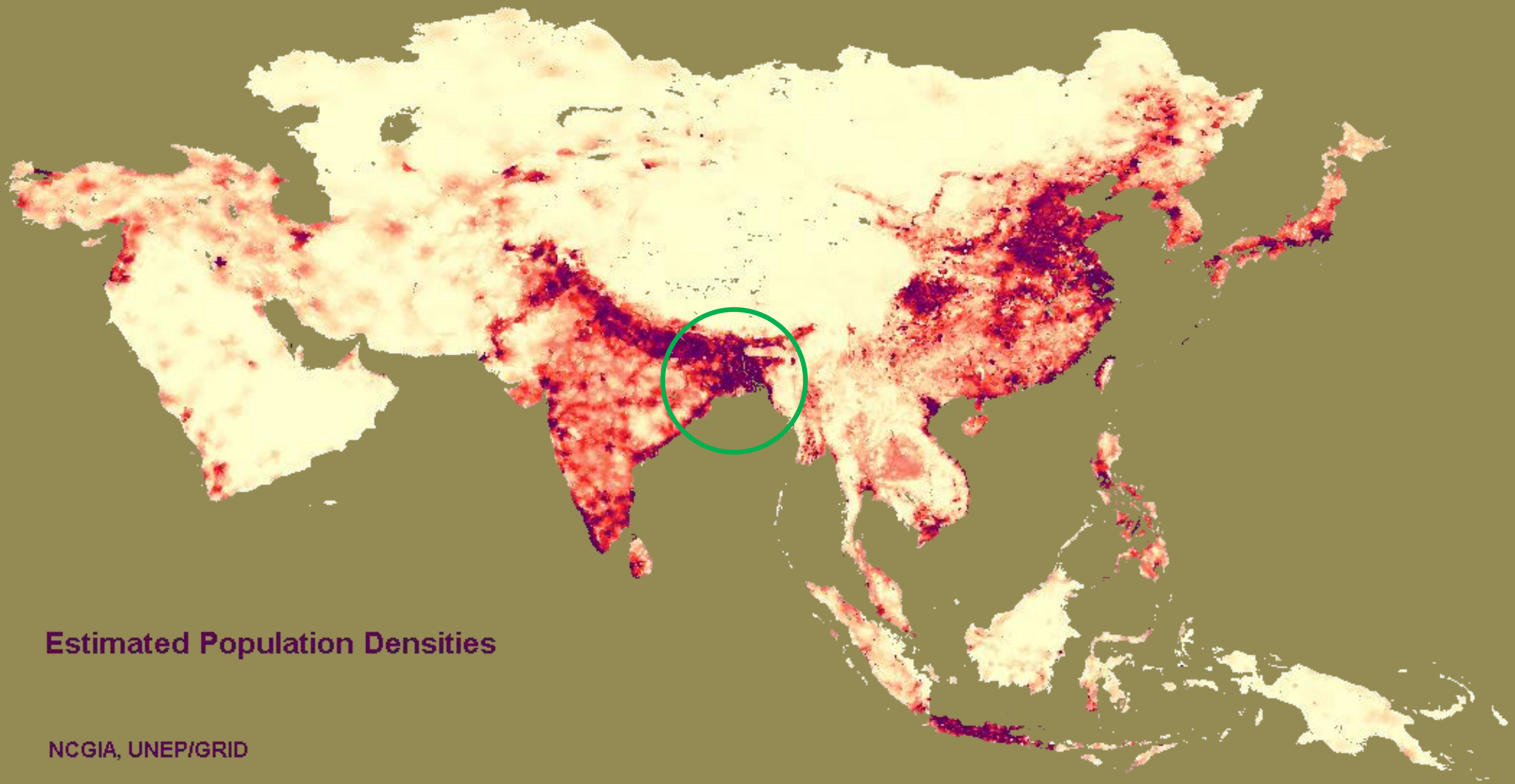
1. STORM SURGES CAUSED BY TROPICAL CYCLONES
2. RIVER FLOODING (Ganges and Brahmaputra)
3. TORNADOES
4. LANDSLIDES

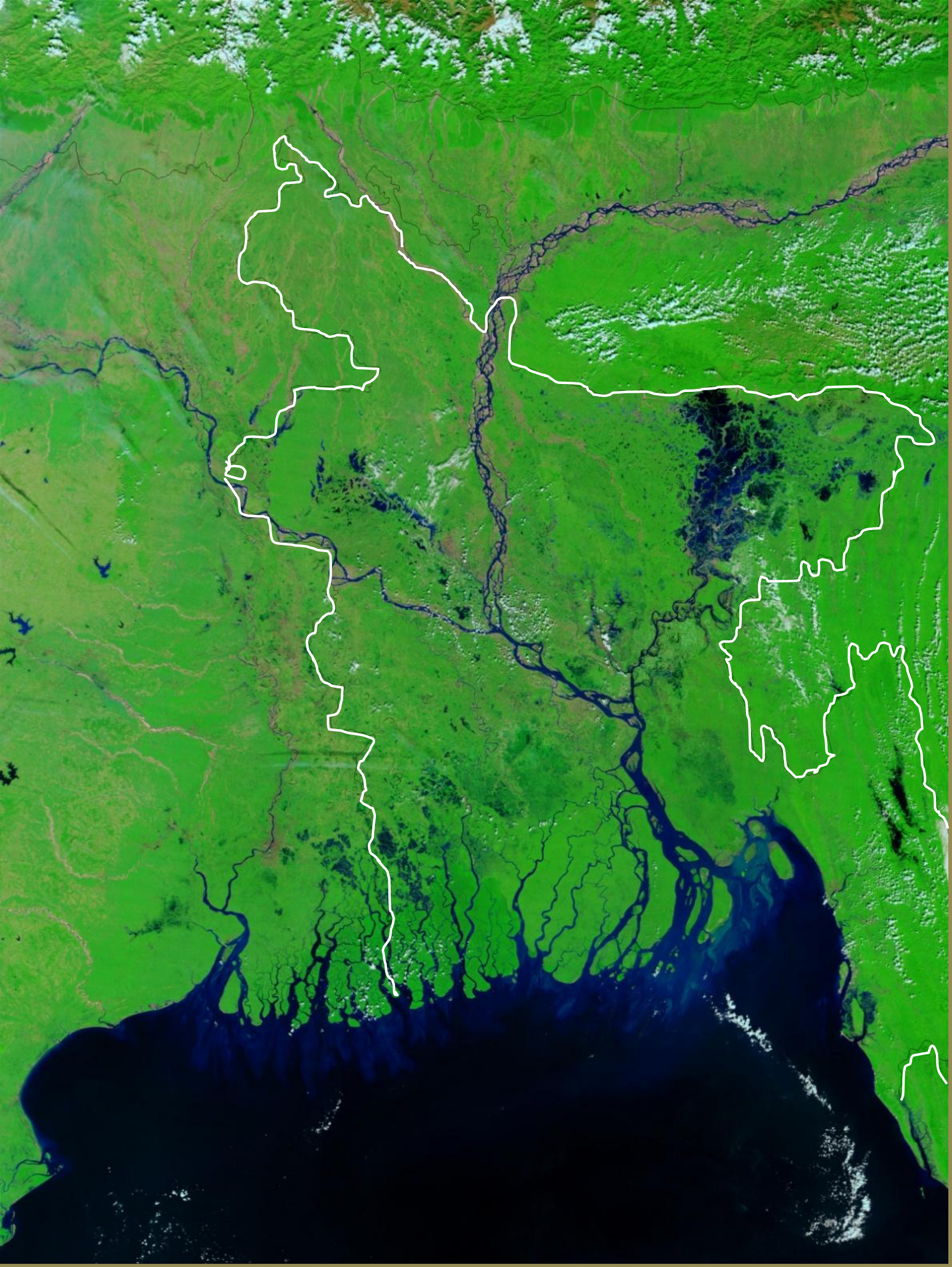
Tropical Cyclone 04B was located over the Bay of Bengal near 15.2N 87.4E at 12:00 UTC. The storm has been moving westward at 5 knots with maximum sustained winds estimated at 35 knots, gusts to 45 knots.

CREDIT: NOAA

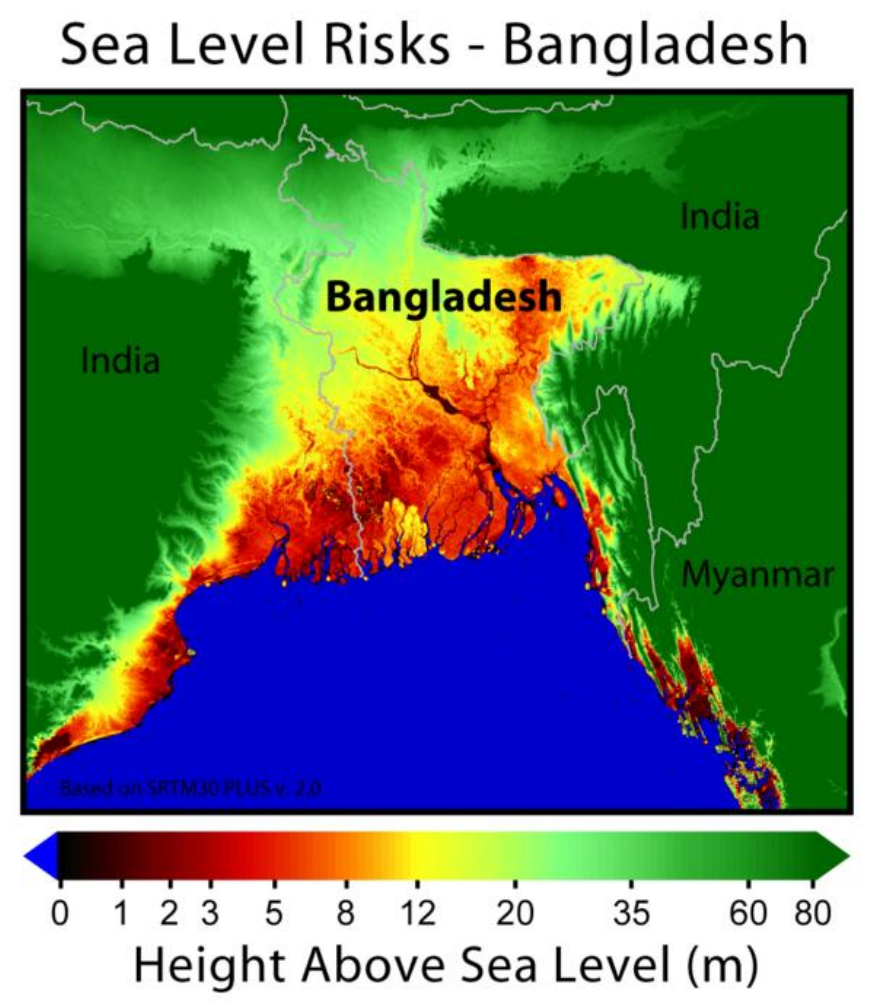


POPULATION DENSITY OF ASIA : LOCATION OF BANGLADESH





PHYSICAL SETTING OF BANGLADESH



BANGLADESH , NETHERLANDS AND ONTARIO ; PHYSICAL AND DEMOGRAPHIC COMPARISONS

AREA

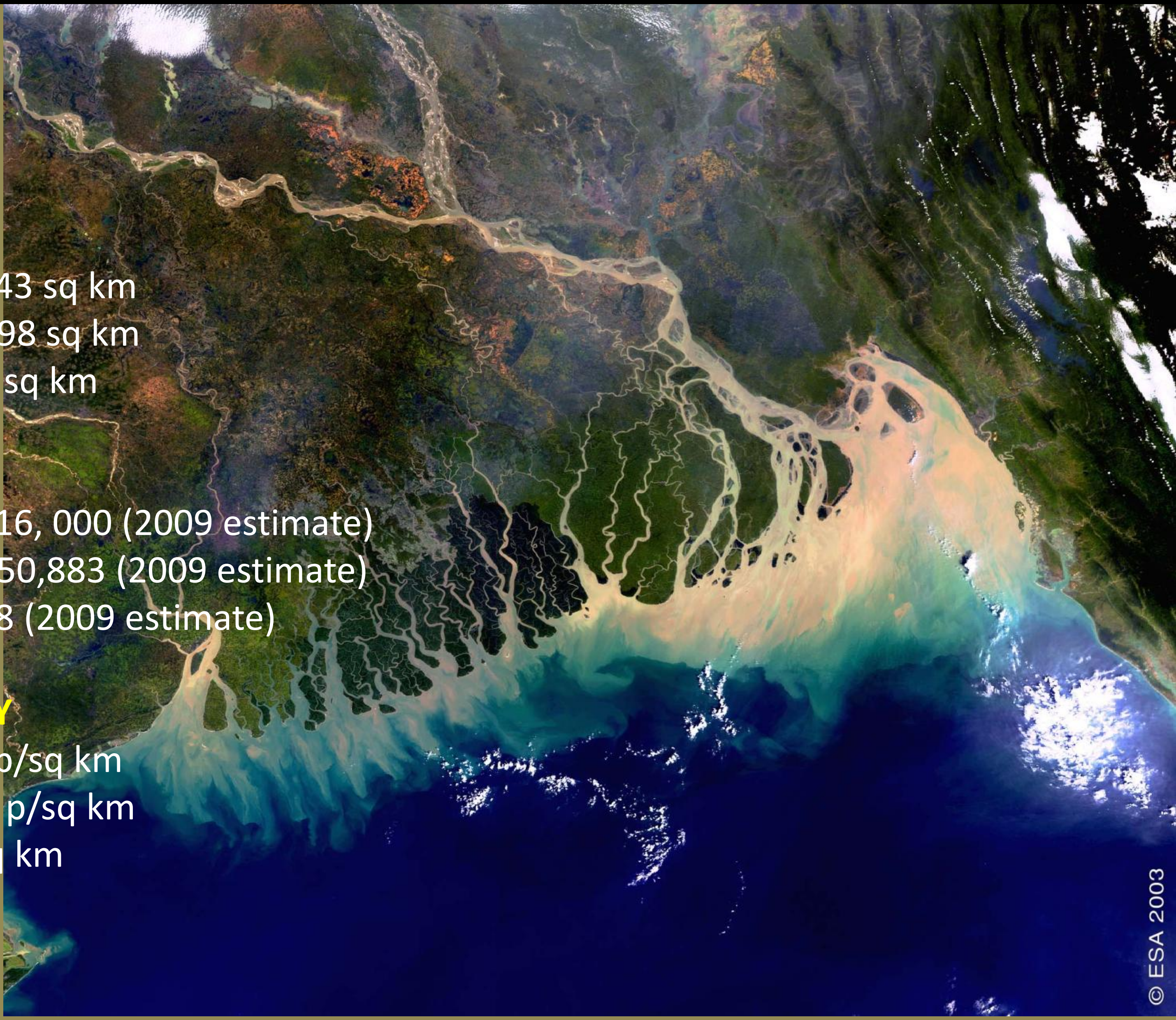
NETHERLANDS – 41,543 sq km
BANGLADESH – 143.998 sq km
ONTARIO – 1,076,395 sq km

POPULATION

NETHERLANDS – 16,716, 000 (2009 estimate)
BANGLADESH – 156,050,883 (2009 estimate)
ONTARIO – 13,014,018 (2009 estimate)

POPULATION DENSITY

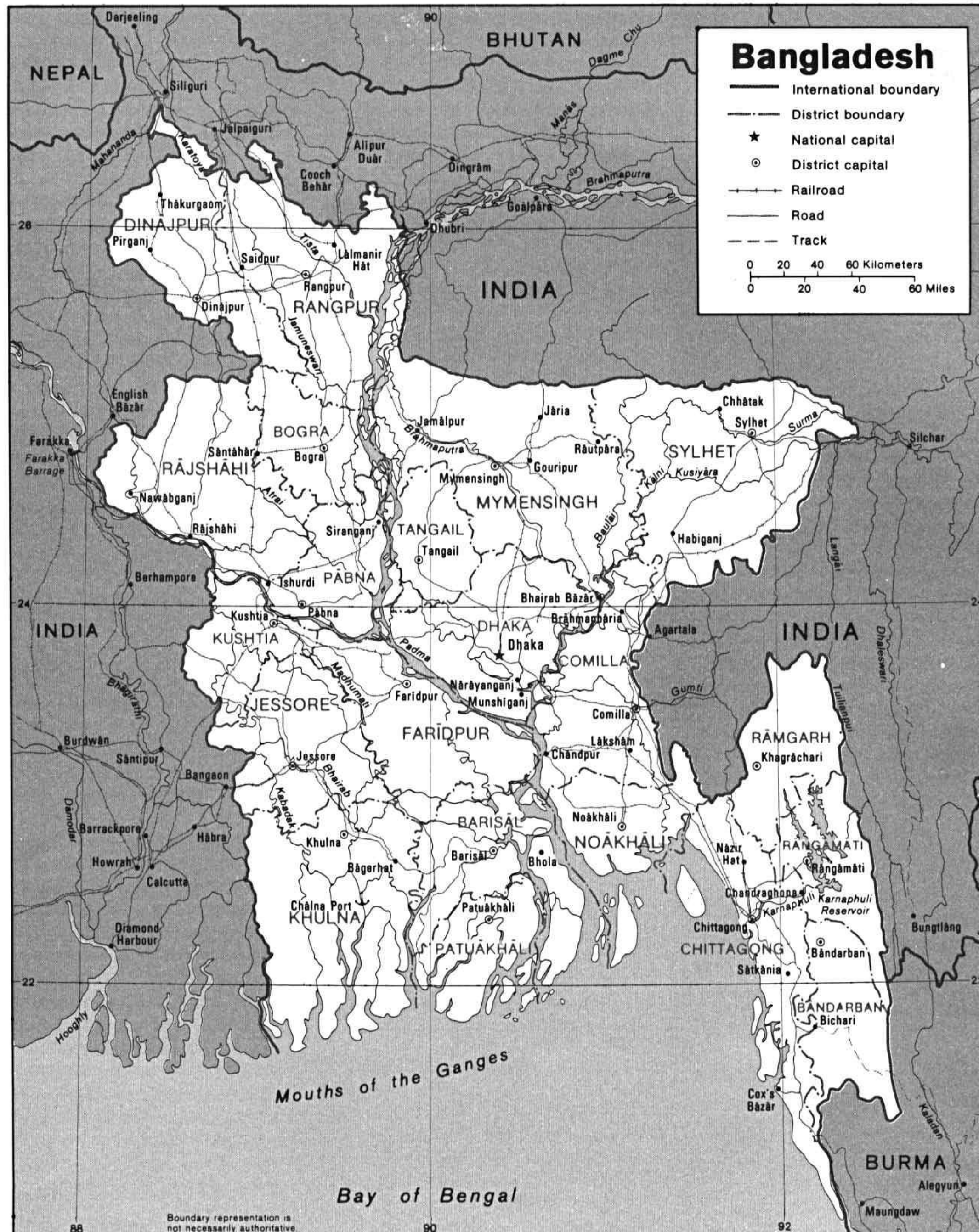
NETHERLANDS – 402 p/sq km
BANGLADESH – 1,084 p/sq km
ONTARIO – 12.09 p/sq km

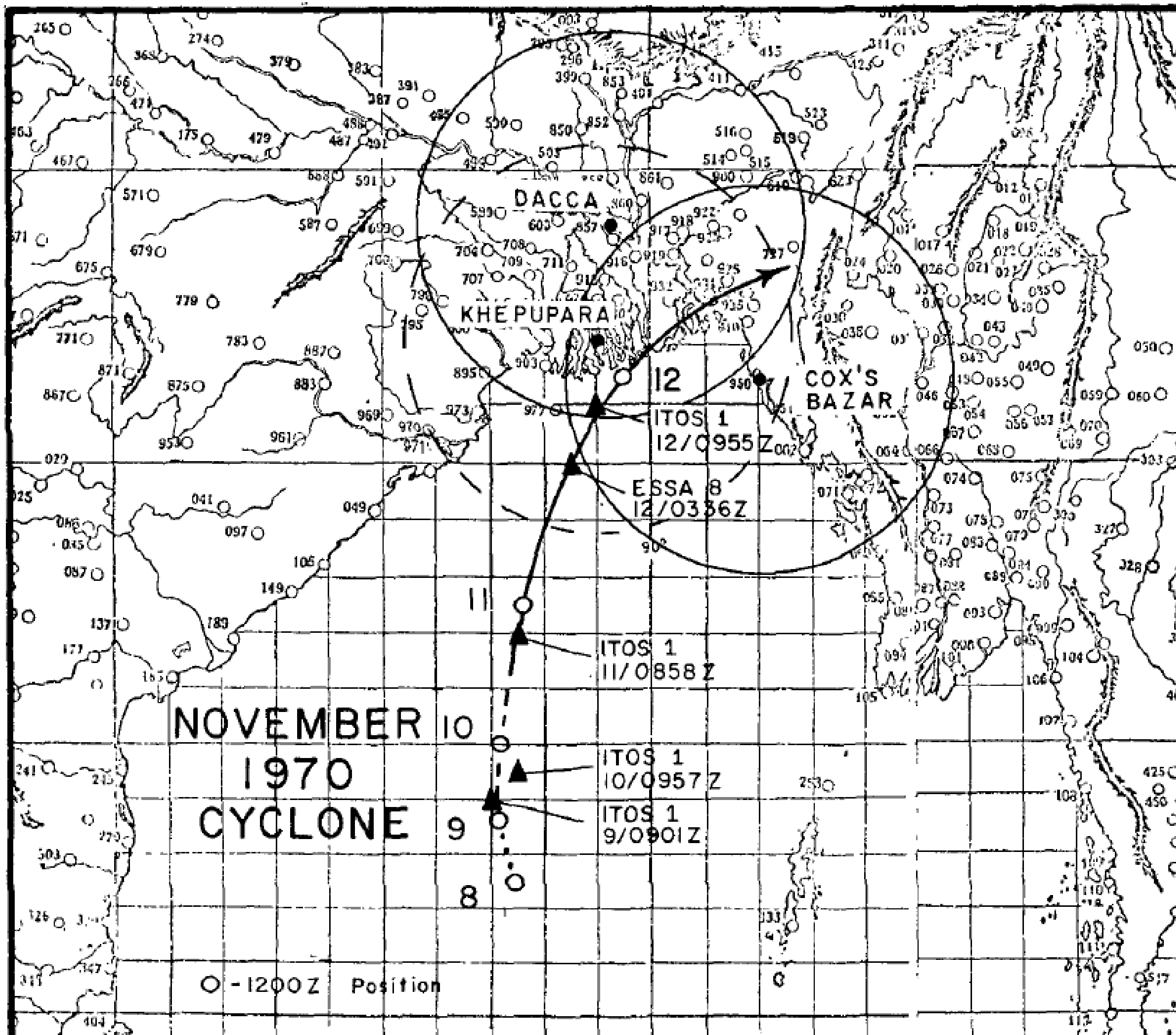


Deadly Surges in the Bay of Bengal: Dynamics and Storm-tide Tables

DURING the 1960s alone about 400,000 people died in the exceptionally high tides which swept in along the low lying northern coast of the Bay of Bengal under the force of tropical cyclones. Over half of these lives were lost in the single surge caused by the storm of November 1970[1]. Such loss of life can be prevented only by depopulation of the area, construction of permanent defences, or by prediction of and protection against individual storms. The latter involves the identification and survey of a severe cyclone, forecast of the development and course of the storm, prediction of the sea level response, warning of danger, and protection of the survivors. We have

Cyclone Bhola 1970; 400,00 deaths

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KHEPUPARA
COX'S BAZAR
12
ITOS 1
12/0955Z
ESSA 8
12/0336Z
11
ITOS 1
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1970
CYCLONE 9
ITOS 1
10/0957Z
ITOS 1
9/0901Z
8
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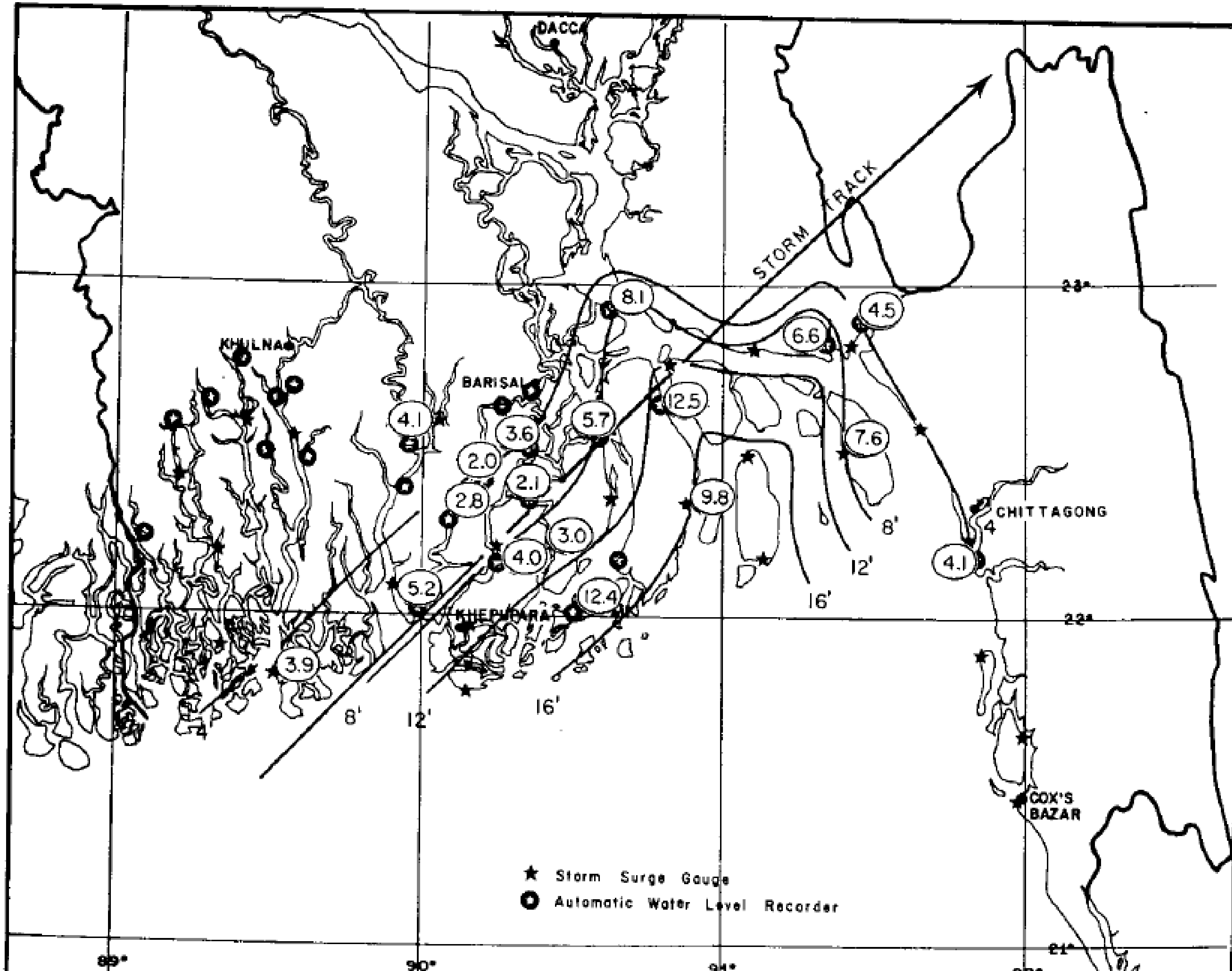

DACCA
STORM TRACK
KHULNA
BARISAL
KHEPUPARA
CHITTAGONG
COX'S BAZAR
8.1
4.5
6.6
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2.1
2.8
9.8
3.0
4.0
5.2
12.4
4.1
3.9
8'
12'
16'
4
23°
22°
21°
89°
90°
91°
92°
★ Storm Surge Gauge
● Automatic Water Level Recorder

THE EFFECT OF STATE OF TIDE ON STORM SURGE HEIGHT

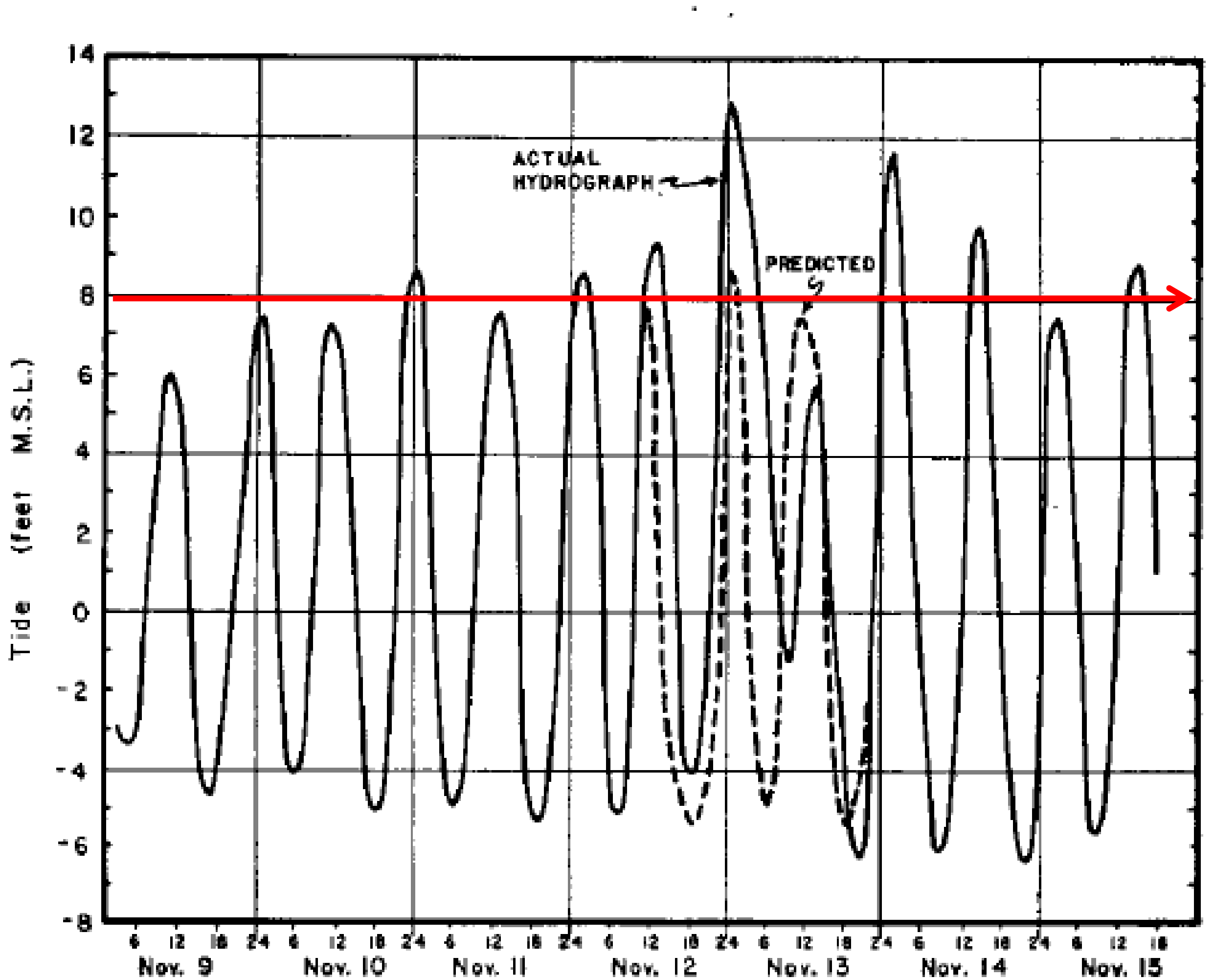
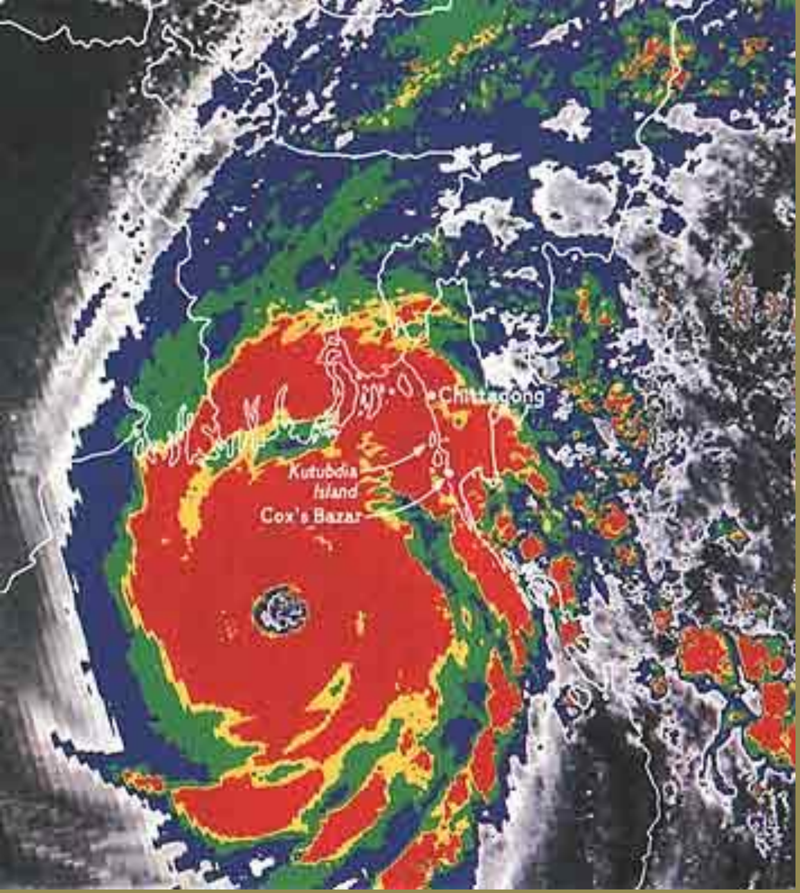
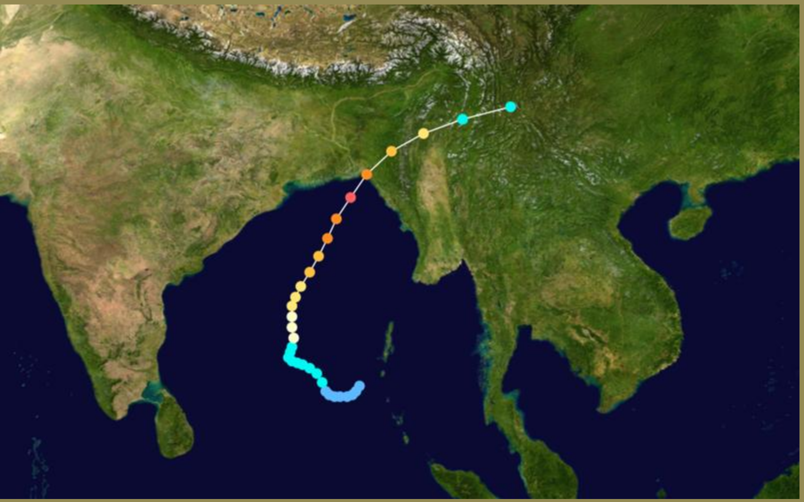


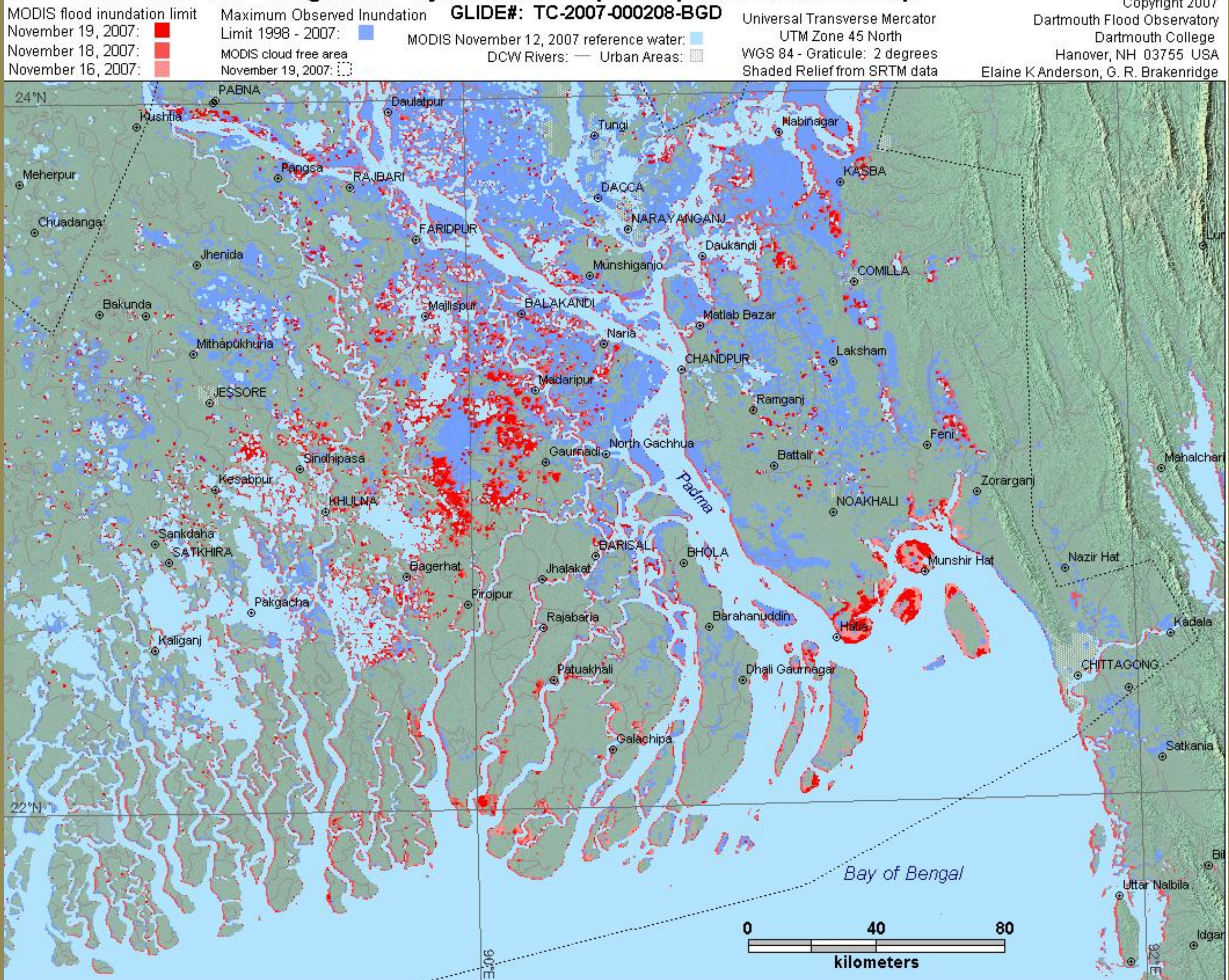
FIG. 4. Water level record from a coastal gage outside Chittagong harbor. The dashed line is the predicted trace.

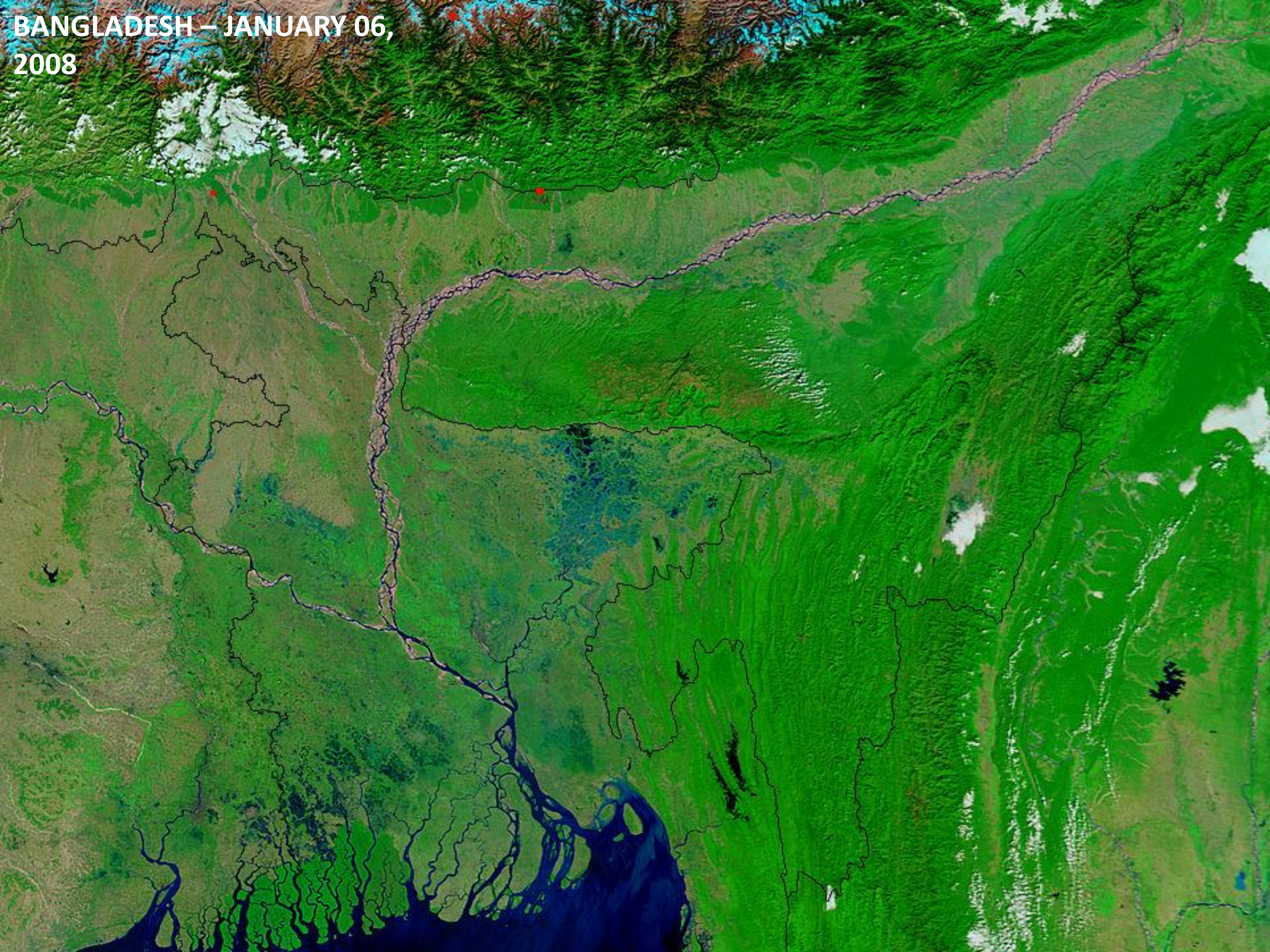


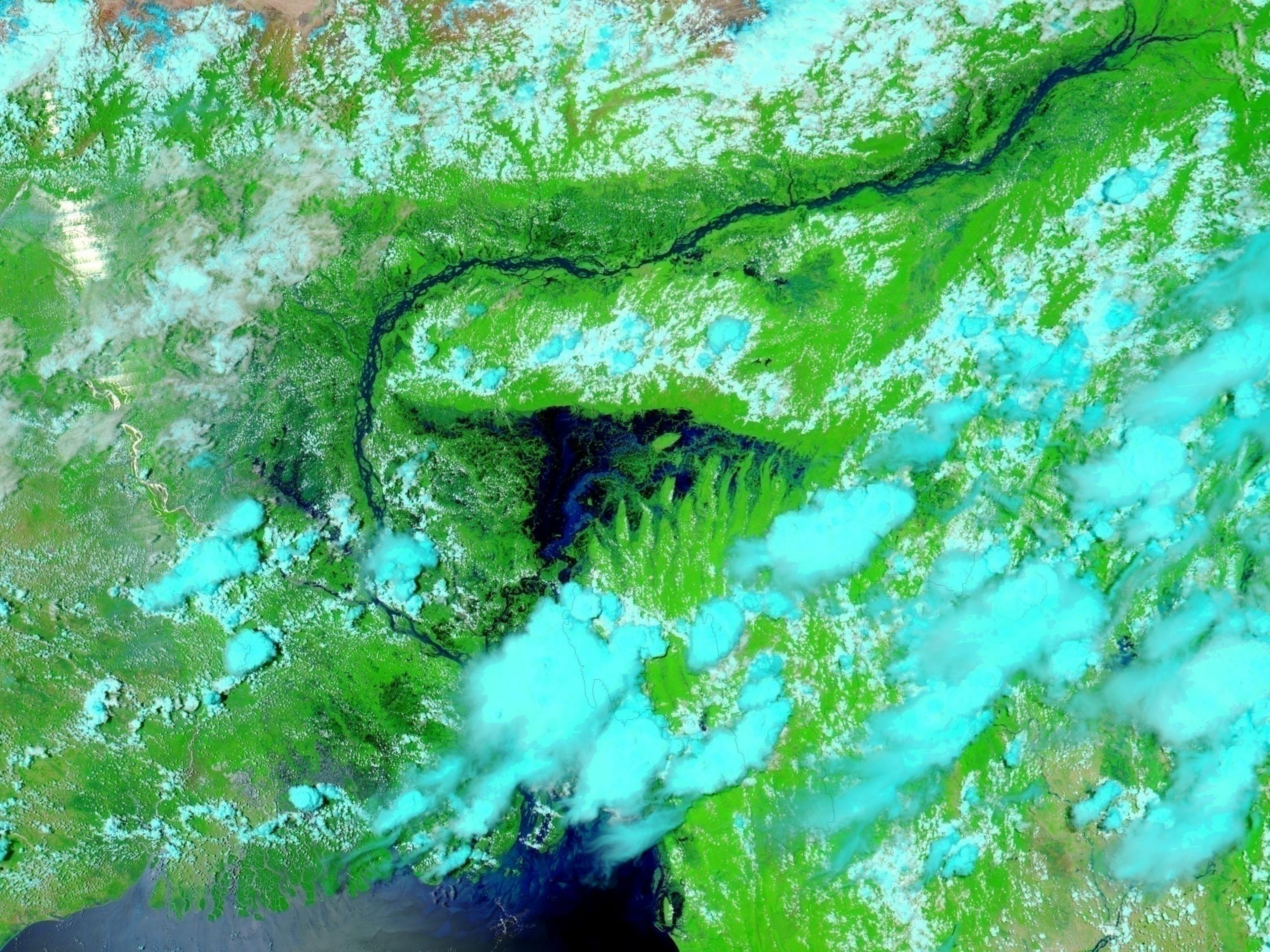


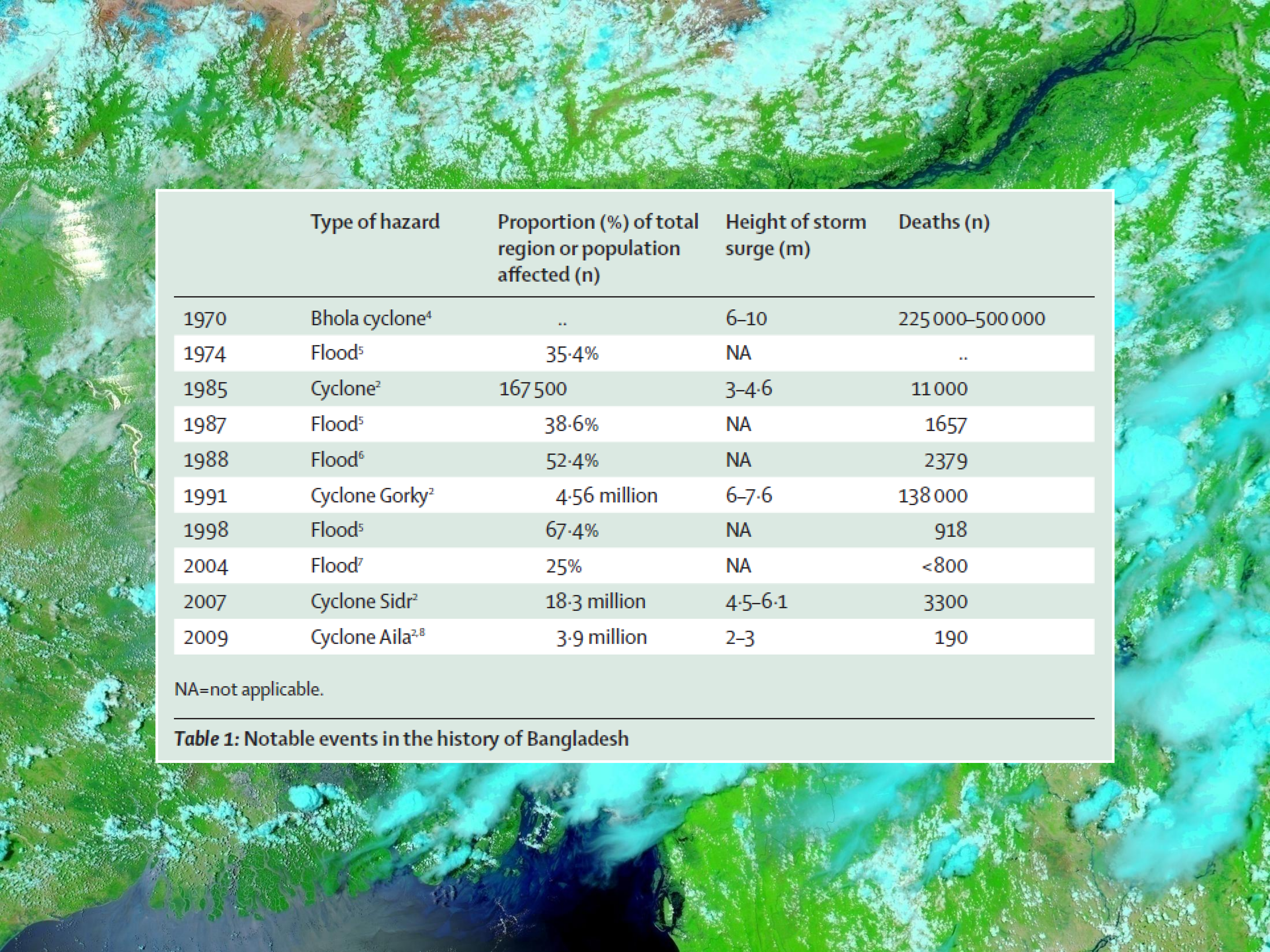
1991 Cyclone Bangla (aka Gorky); 140,000 deaths

DFO Event # 2007- 219 - Bangladesh - Cyclone Sidr - Rapid Response Inundation Map




BANGLADESH – JANUARY 06, 2008



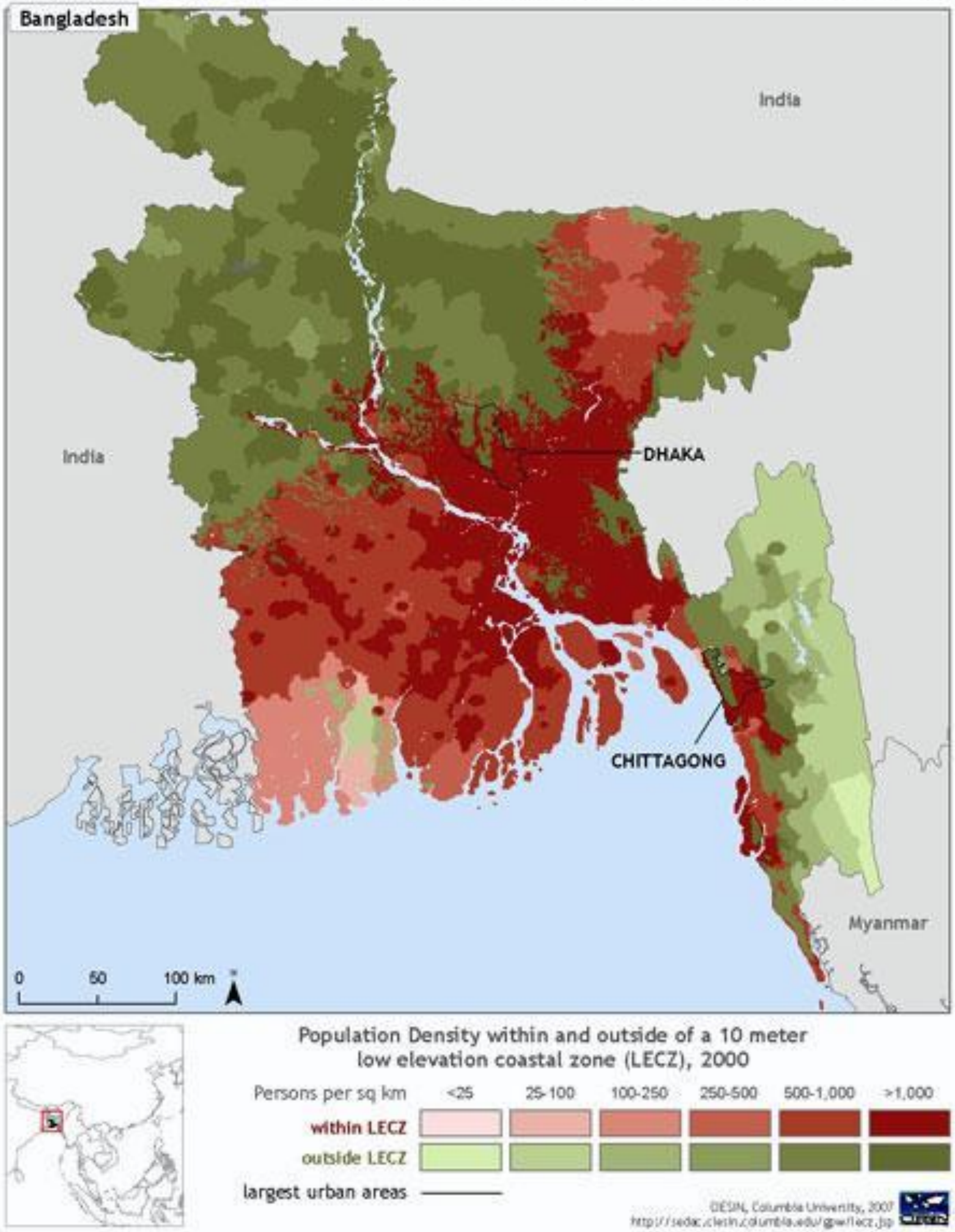


	Type of hazard	Proportion (%) of total region or population affected (n)	Height of storm surge (m)	Deaths (n)
1970	Bhola cyclone[4]	..	6–10	225 000–500 000
1974	Flood[5]	35·4%	NA	..
1985	Cyclone[2]	167 500	3–4·6	11 000
1987	Flood[5]	38·6%	NA	1657
1988	Flood[6]	52·4%	NA	2379
1991	Cyclone Gorky[2]	4·56 million	6–7·6	138 000
1998	Flood[5]	67·4%	NA	918
2004	Flood[7]	25%	NA	<800
2007	Cyclone Sidr[2]	18·3 million	4·5–6·1	3300
2009	Cyclone Aila[2,8]	3·9 million	2–3	190

NA=not applicable.

Table 1: Notable events in the history of Bangladesh

Population Density within and outside of a 10m Low Elevation Costal Zone



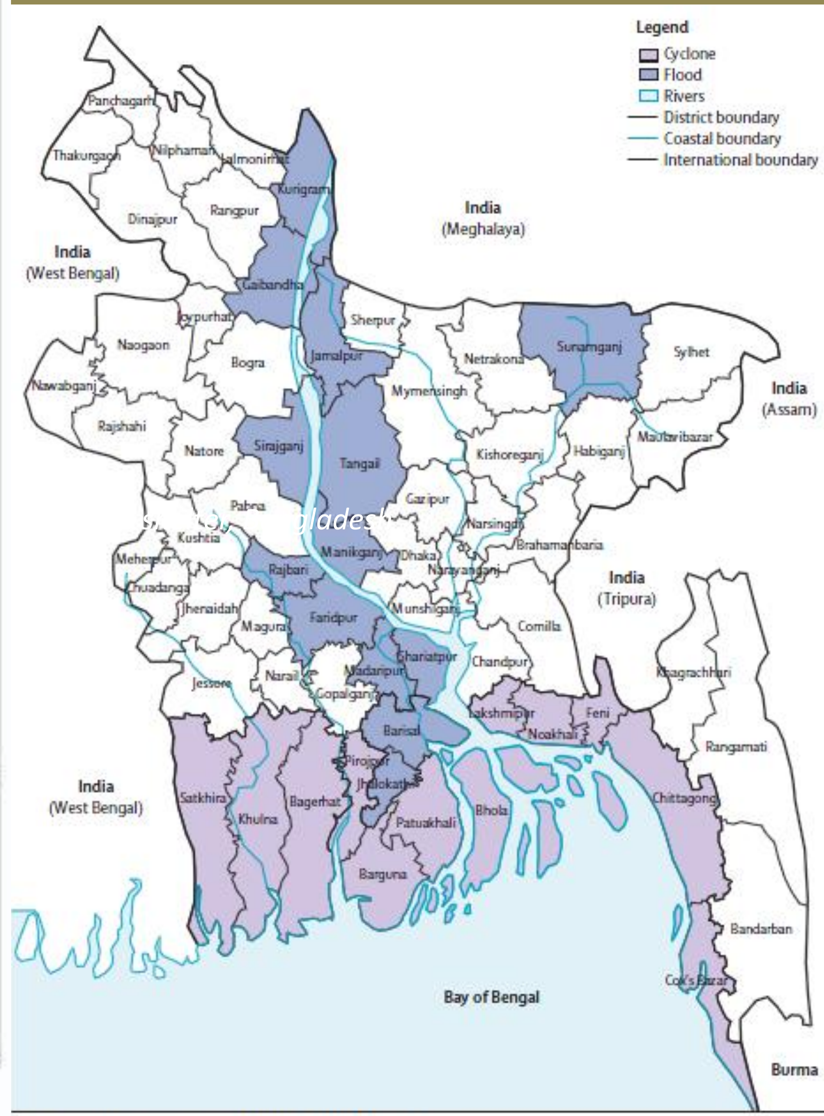
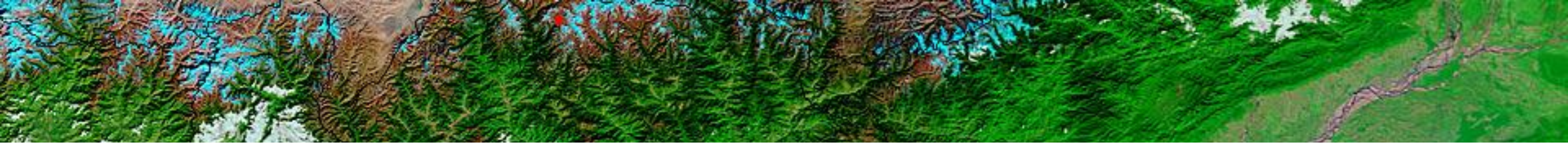


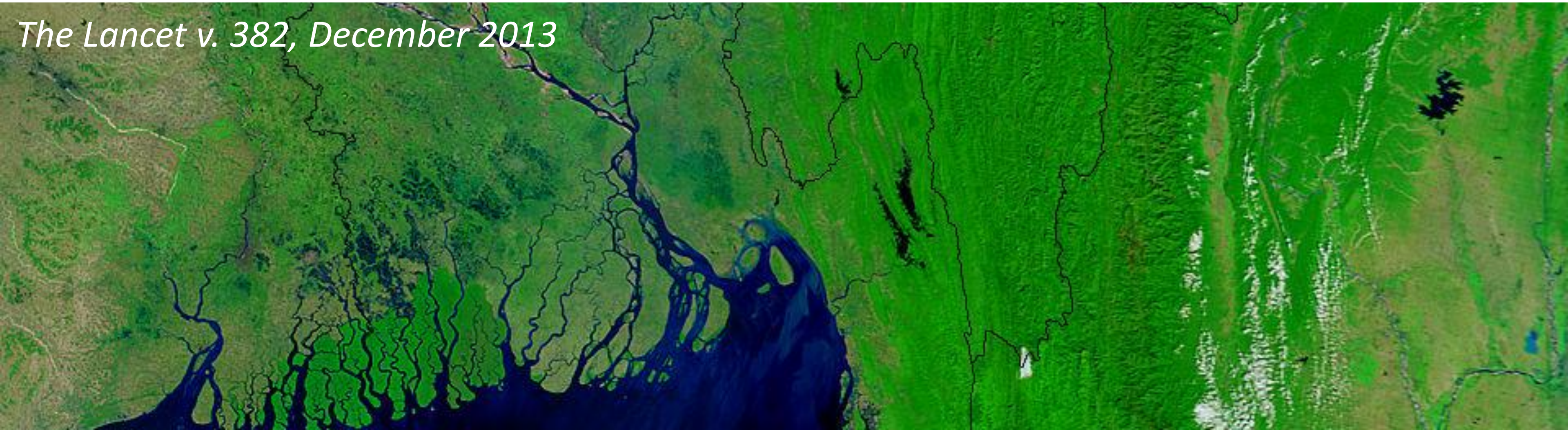
Figure: Disaster-prone regions of Bangladesh, by district[1]



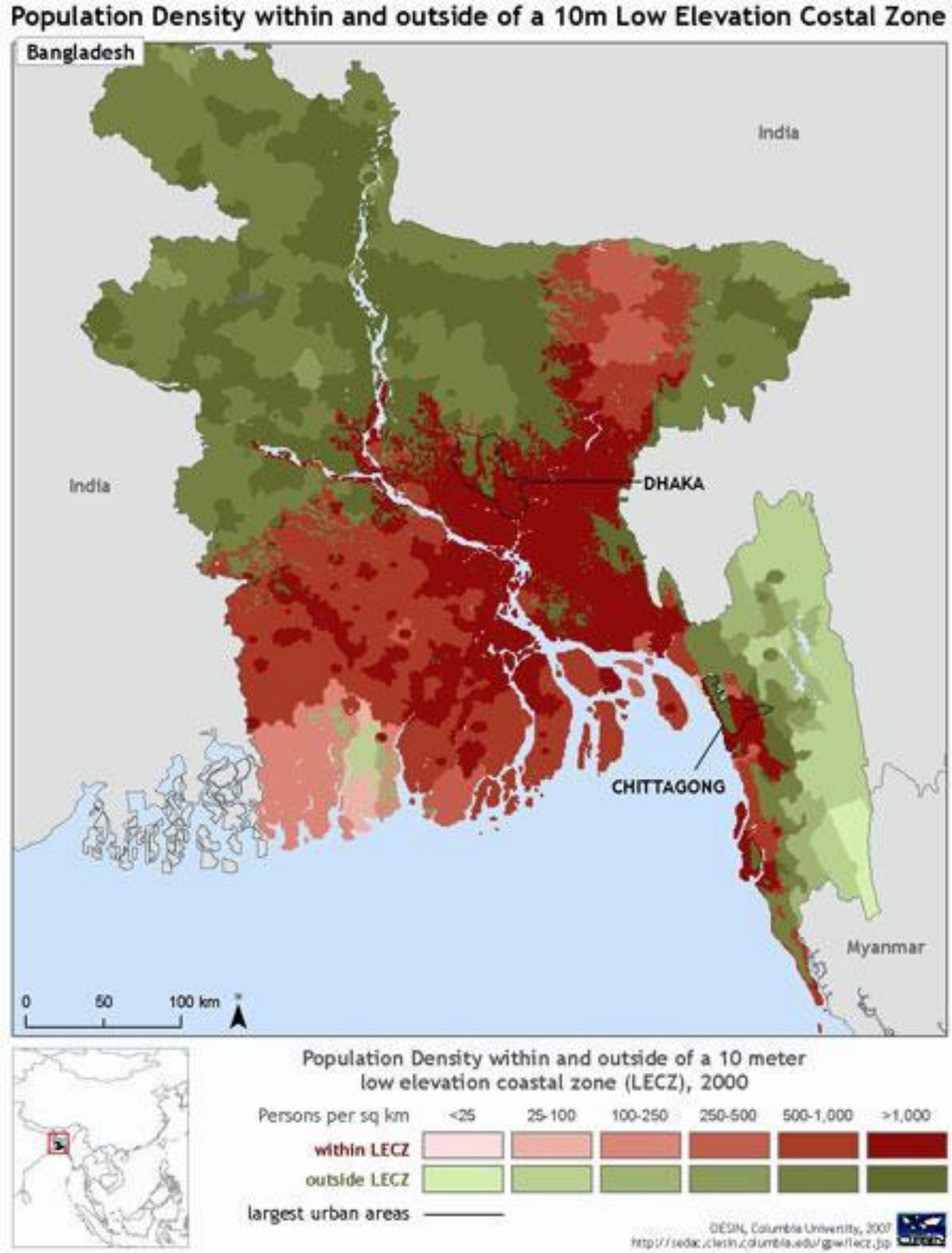
Reducing the health effect of natural hazards in Bangladesh

Richard A Cash, Shantana R Halder, Mushtuq Husain, Md Sirajul Islam, Fuad H Mallick, Maria A May, Mahmudur Rahman, M Aminur Rahman

Bangladesh, with a population of 151 million people, is a country that is particularly prone to natural disasters: 26% o the population are affected by cyclones and 70% live in flood-prone regions. Mortality and morbidity from these events have fallen substantially in the past 50 years, partly because of improvements in disaster management Thousands of cyclone shelters have been built and government and civil society have mobilised strategies to provide early warning and respond quickly. Increasingly, flood and cyclone interventions have leveraged community resilience and general activities for poverty reduction have integrated disaster management. Furthermore, overall population health has improved greatly on the basis of successful public health activities, which has helped to mitigate the effec of natural disasters. Challenges to the maintenance and reduction of the effect of cyclones and floods include rapic urbanisation and the growing effect of global warming. Although the effects of earthquakes are unknown, some efforts to prepare for this type of event are underway.

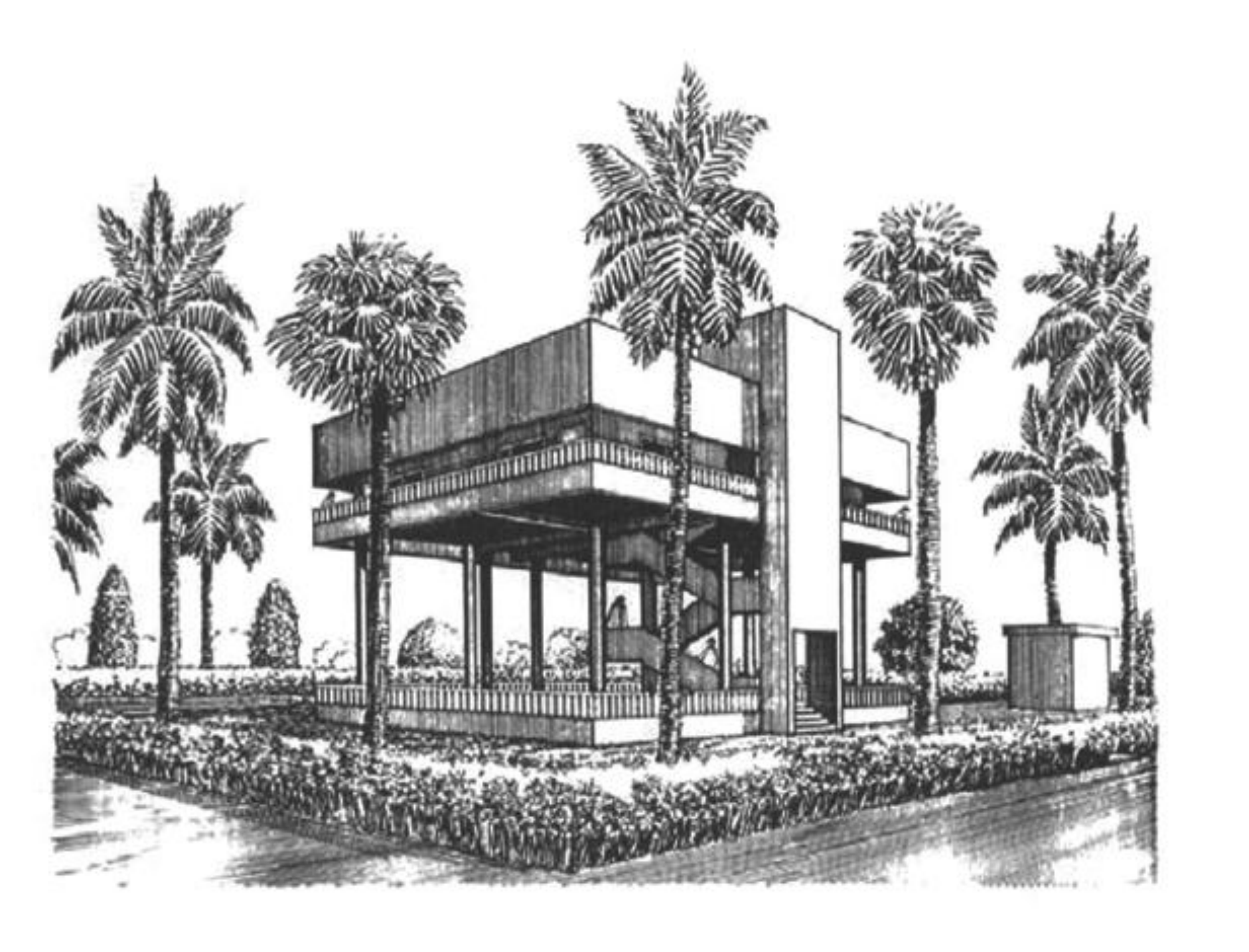


The Lancet v. 382, December 2013



Cyclone shelter, Bangladesh

Fertile soils, intensive agriculture, dense population dst



Architectural drawing of cyclone shelter, Bangladesh

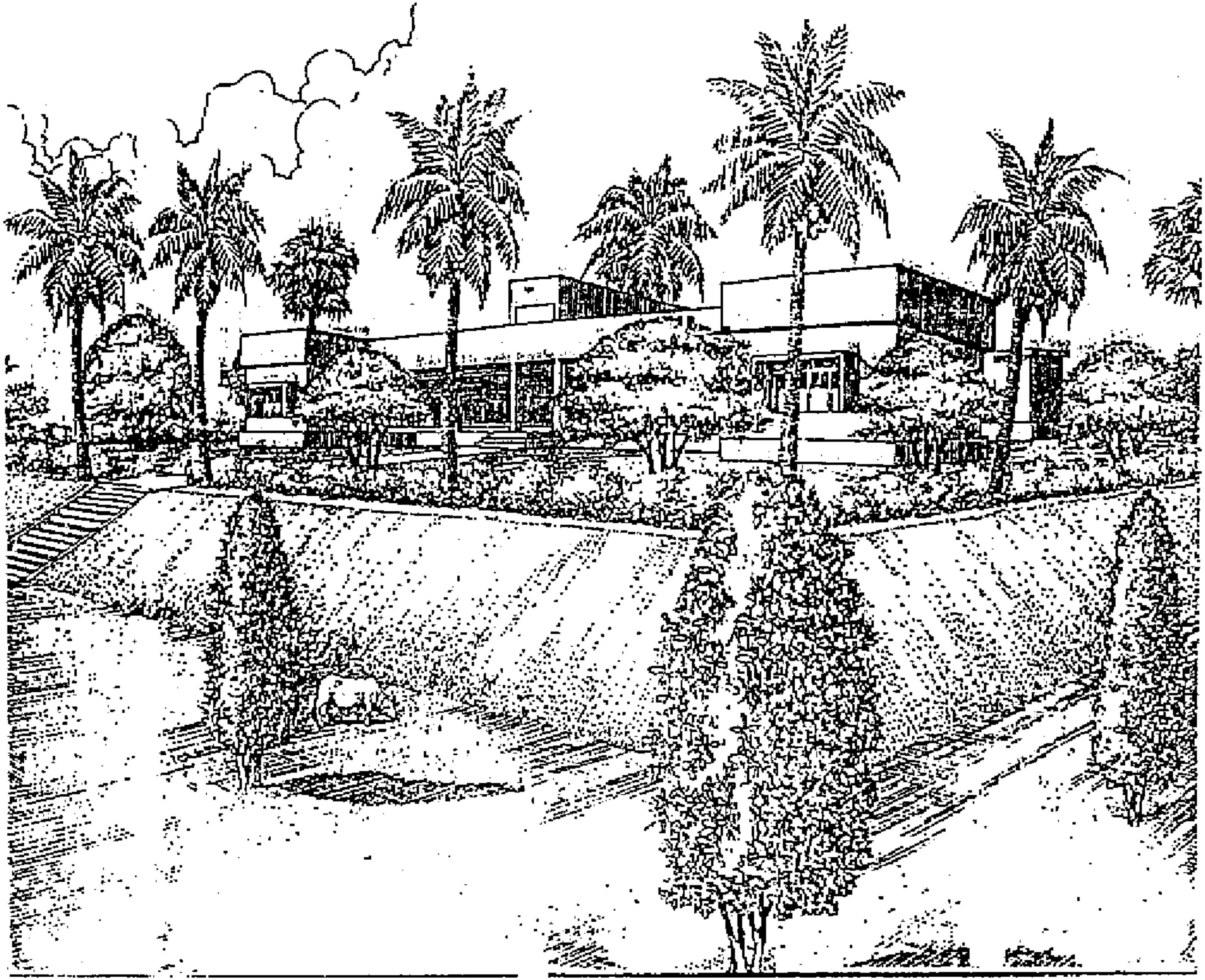


Figure 2. Typical Multipurpose Cyclone Shelter on a *Killa*

CYCLONE SHELTERS IN BANGLADESH – EFFECTIVE MITIGATION AGAINST STORM SURGE HAZARD

Panel 2: Innovations in the design of cyclone shelters

The greatest issue with the first generation of shelters was the poor maintenance, which often rendered facilities unusable. Despite evidence showing that evacuation to a cyclone shelter greatly reduces mortality, many people chose to remain in their homes. A new design was needed that retained functionality and was attractive to local households. The new strategy for cyclone shelters insures that they have various uses, such as for schools, government buildings, or community centres. The space is maintained because it is important for daily use, and families are aware of where to seek shelter during a storm. Some families still remain at home because they refuse to abandon their livestock, often their most important asset. In the past few years, designs for multipurpose cyclone shelters with provisions for cattle and livestock have been piloted. The decision to scale up will require difficult choices. One cow needs 2·4–3 m^2 of space—the same amount needed for two to four people, and some of the designs are fairly costly to construct.[19]

Additionally, architects have begun to think about how to construct houses and infrastructure that are more likely to withstand cyclones, terming the concept Disaster Resilient Habitat (DHR).[19] The largest DRH project to date is in Shyamnagar, a region destroyed by Cyclone Aila in 2009. Efforts were taken to combine the building skills of the community with technical knowledge from architects and engineers. The house owners voluntarily participated in the design, construction, and management processes. 43 houses and a school were built with a reinforced concrete frame at the base. Although high winds might blow away weak parts of the house, the basic structure will remain, allowing for faster reconstruction. From a cost perspective, this strategy seems to be similar or favourable to cyclone shelters.

	Flood	Cyclone
Frequency	Seasonal	Seasonal
Average advance notice	Predictable	Restricted
Duration of event	Days or weeks	Hours
Moments of high risk	Slowly rising waters	Storm surge
Potential long-term effects	Damage to constructed facilities, river erosion, salinity, damage to water supply, livelihood damage	Damage to constructed facilities, infrastructure, waterlogging
Preparation	Embankments, shelters, and elevated homesteads	Two-storey shelters and raising of awareness to seek shelter
Readiness	Evacuation to nearby high ground, flood shelters when appropriate, supplying of water and food, and movement of assets to higher ground	Evacuation to nearby shelters
Response	Rehabilitation of water sources, provision of food support and agricultural resources (several months of assistance, particularly for food, might be needed)	Provision of water and food in the immediate aftermath, and of cash, work, or materials to rebuild houses

Table 2: Characteristics and responses to floods versus cyclones

Disaster Resilient Habitat, Bangladesh

An Alternative Comprehensive Approach to Disaster Risk Reduction and Climate Change Adaptation

THE SALIENT FEATURES

Structural Safety: cyclone resilient structural design, based on 100 years tidal surge and 215 KM/per hour wind safety measures, saline proof structure etc.

Adaptation Interventions: renewable energy, rain water harvesting, etc.

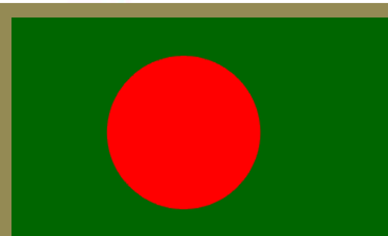
Social Protection: children's school program, health care etc.

Sustainable Livelihood: common grazing land, mini-dairy farm, aquaculture ponds, fishery supports, common production centre etc.

Early Warning: community warning, dissemination by and through volunteers, and telecommunication transmission

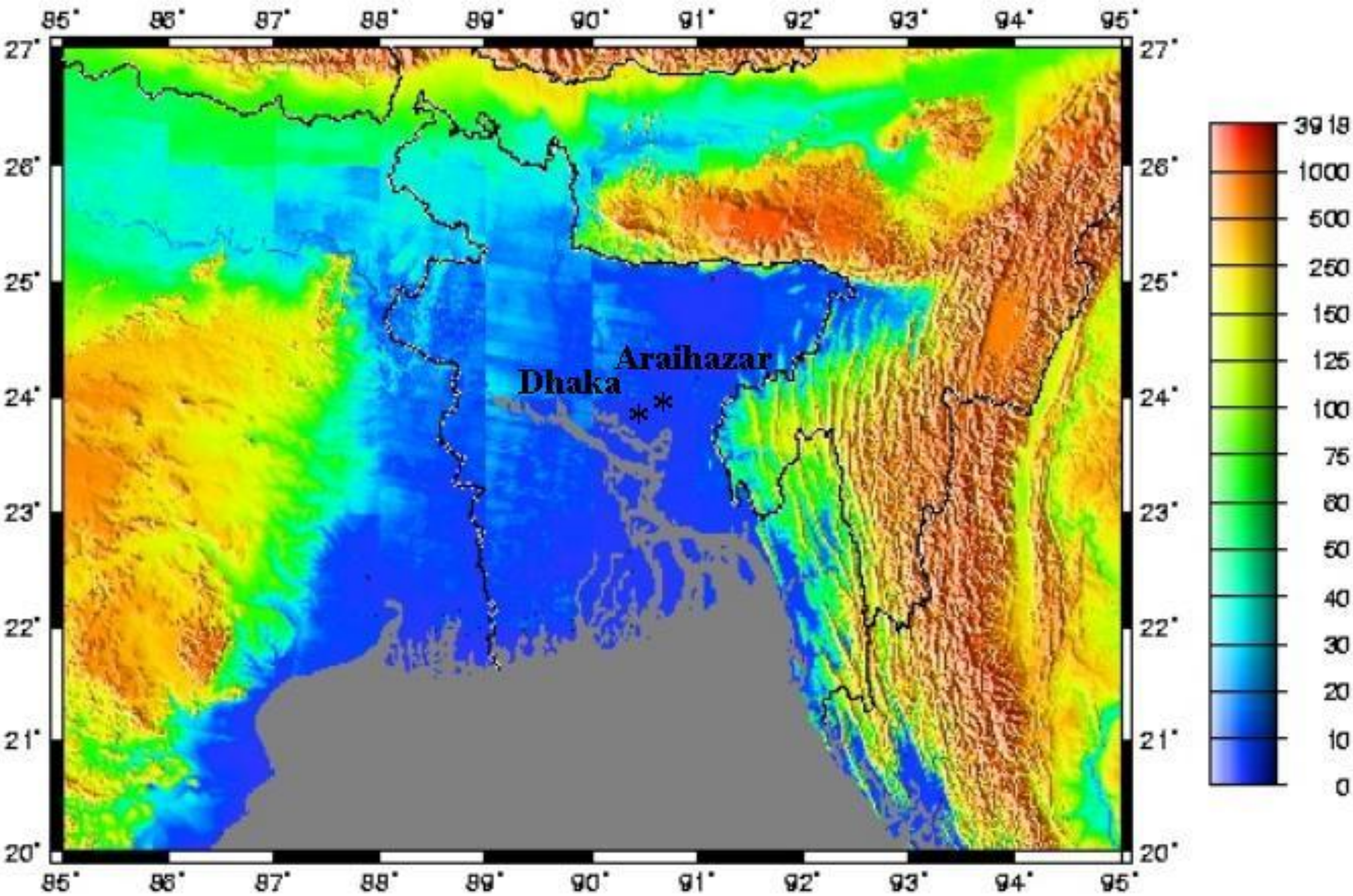
Natural Ecosystem: wind breaking tree plantation sustainable land and water management.

Community-managed: to be self-governed by local committees.

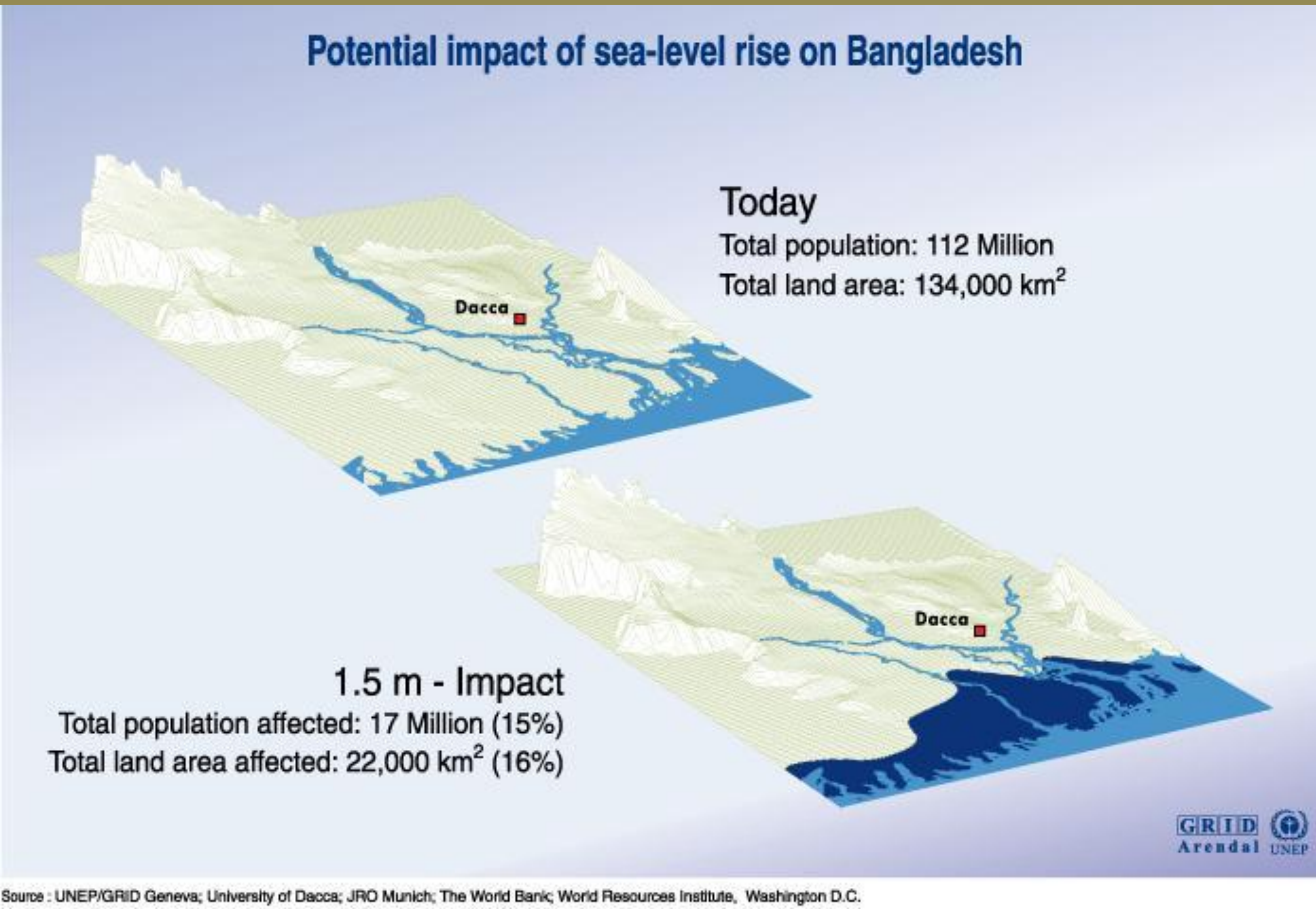


Key messages

- In Bangladesh, the health consequences of floods and cyclones have reduced substantially in the past 40 years
- With improvements in the health of the population through such interventions as high levels of immunisation, knowledge, and use of oral rehydration therapy, and with increased distribution of health care and low-cost drugs, the health effect of natural disasters can be mitigated
- Political commitment, activities of non-governmental organisations, and community mobilisation contribute to Bangladesh's ability to respond to natural hazards
- Data for risks associated with morbidity and mortality from natural disasters should be obtained as soon after the event as possible to inform planners what needs to be done to mitigate the effect of the next natural disaster
- Improvements in preparedness, both before and after disasters, are a continuing process, especially as knowledge and technology improves
- Urbanisation and climate change create new challenges, and earthquakes remain an unaddressed threat

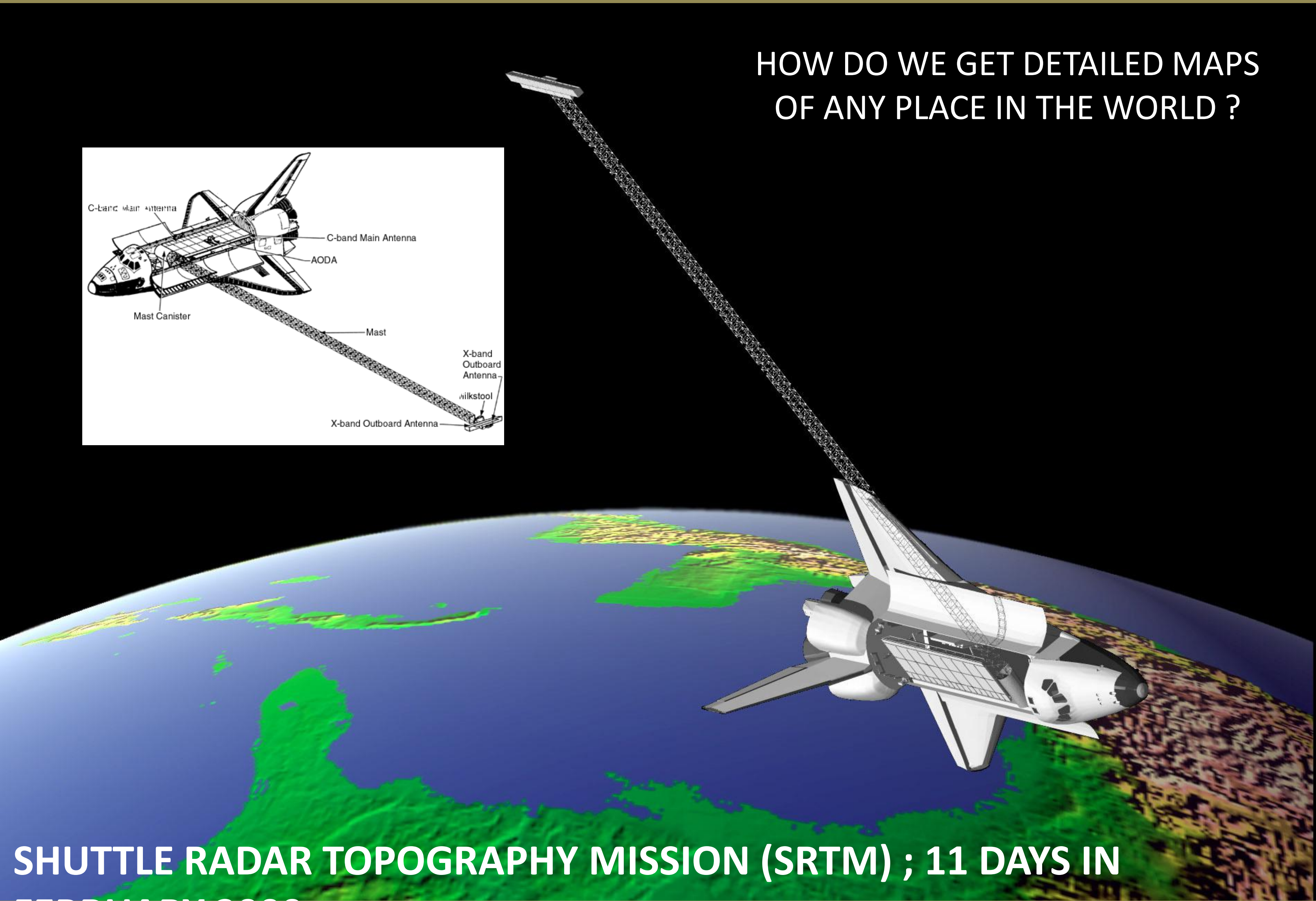


Source: M. Steckler, LDEO, based on GTOPO30 digital elevation model (USGS EROS Data Center).



Use of digital terrain models to forecast impact of seal level rise

HOW DO WE GET DETAILED MAPS OF ANY PLACE IN THE WORLD ?



SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM) ; 11 DAYS IN FEBRUARY 2000