

# Cyclone Nargis storm surge in Myanmar

**To the Editor** — Tropical cyclone Nargis (category 4 on the Saffir–Simpson Hurricane Scale, SSHS) made landfall on 2 May 2008, causing the worst natural disaster in Myanmar's recorded history. Official death toll estimates exceed 138,000 fatalities<sup>1</sup> making it the eighth deadliest cyclone ever recorded worldwide. Since the 1970 Bhola cyclone, which caused up to 500,000 fatalities, Nargis represents the deadliest tropical cyclone worldwide and one of the worst natural disasters, with the exceptions of the 2004 Indian Ocean tsunami and the 1976 Tangshan earthquake. The Bay of Bengal has generated seven tropical cyclones with death tolls in excess

of 100,000 striking India and Bangladesh (Supplementary Fig. 1). Damage estimates at over \$10 billion made Nargis the most destructive cyclone ever recorded in the Indian Ocean. Here we analyse the cause of the humanitarian disaster based on physical and societal observations.

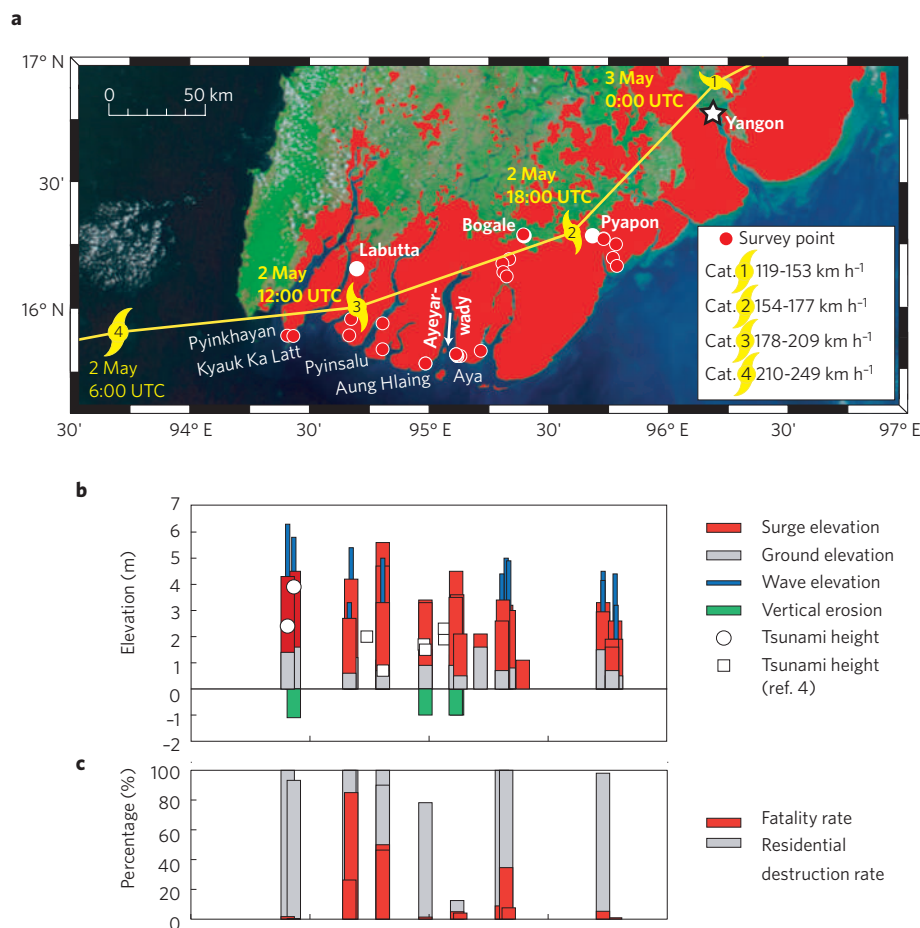
On 28 April 2008, Nargis was located near the centre of the Bay of Bengal and upgraded to a category 1 cyclone (SSHS). The tropical cyclone developed sustained winds over 210 km h<sup>-1</sup>, with gusts up to 260 km h<sup>-1</sup>, before landfall in Myanmar on 2 May as a category 4 storm (SSHS). It reached Yangon approximately 12 h later as a category 1 storm (SSHS). No previous

tropical cyclone track included in the International Best Track Record for Climate Stewardship database<sup>2</sup> has made a direct landfall in Myanmar's Ayeyarwady river delta at an untypically low latitude near 16° N. In 2006, a similar tropical cyclone (Mala, category 4, SSHS) made landfall in Myanmar at 17.6° N causing only 22 deaths after a well executed evacuation effort, and the 2004 Indian Ocean tsunami, which affected Myanmar's Andaman coast, resulted in only 71 fatalities.

Three months after cyclone Nargis, access was granted to the hardest-hit Ayeyarwady delta for the 9–23 August 2008 storm-surge reconnaissance, which surveyed coastal and inland villages encompassing the Bogale and Ayeyarwady rivers. The boat and helicopter survey spanned 150 km parallel to the cyclone track between Pyapon and Pyinkhayan, encompassing the 20 hardest-hit settlements such as Pyinsalu. High-water marks, overland flow depths and inundation distances were recorded based on established protocol<sup>3</sup> (Fig. 1). The Nargis high-water marks surpassed the 2004 Indian Ocean tsunami run-up at corresponding locations<sup>4</sup> and the storm surge peaked at over 5 m in the landfall area. In most areas, roughly 2-m-high storm waves were superimposed on surge levels. Inundation distances reached 50 km inland from the nearest coastline, based on flooding direction. The Nargis high-water measurements are comparable to observations in Louisiana's Mississippi delta after Hurricane Katrina<sup>5</sup>. Both Nargis and Katrina affected major river deltas as both tracks crossed river mouths.

Ephemeral coastal erosion, and vegetation and infrastructure damage were documented. More than 1 m of vertical erosion and 100 m of land loss were measured at various coastal locations from the landfall area to the Ayeyarwady river mouth (Supplementary Fig. 2). Drinking water wells were flooded with saltwater, scoured and left stranded in the surf zone. A golden Buddhist stupa, originally built on dry land, pierced the water surface 150 m offshore from Aya. Deforestation for charcoal and rice paddies as primary land-use had left few primary growth mangroves, which may have provided some wave attenuation<sup>6</sup> within 30 km of the coast (Supplementary Fig. 3).

Catastrophic peak fatality rates exceeded 80% in the hardest-hit villages. The fatality



**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:  $\pm 0.1$  m for vertical measurements and  $\pm 0.3$  m for wave-height estimates.

rates in the initial landfall area were surprisingly low because of spontaneous self-evacuation facilitated by nearby high ground. All interviewed eyewitnesses ignored warnings owing to lack of cyclone awareness and evacuation plans, absence of high ground or shelters, and no indigenous knowledge of comparable previous storm-surge flooding in the Ayeyarwady river delta. Residents surprised by the deadly flooding struggled with capsizing small boats and canoes, while some 'floaters' survived by tying themselves to a tree. In sharp contrast, the residents of the Gwa coastline, frequently struck by cyclones such as Mala, are aware of cyclone hazards and have evacuation plans. Gwa is located 150 km north of the Nargis landfall area and has high ground nearby facilitating evacuation.

The field survey in the aftermath of cyclone Nargis provides ephemeral storm-surge data that is critically important for

numerical model validation, which is widely absent for historical events in the Bay of Bengal. The inundation penetrated 50 km inland inhibiting last-minute evacuations owing to the lack of high ground at most locations. Unfortunately, the widely deforested, low-lying and densely populated Ayeyarwady delta with its poor housing construction remains extremely vulnerable to future storm-surge flooding, potential sea-level rise or tsunami. Coastal protection in the Bay of Bengal must be approached with community-based education and awareness programs suited for a multi-hazard perspective<sup>7,8</sup>.

#### References

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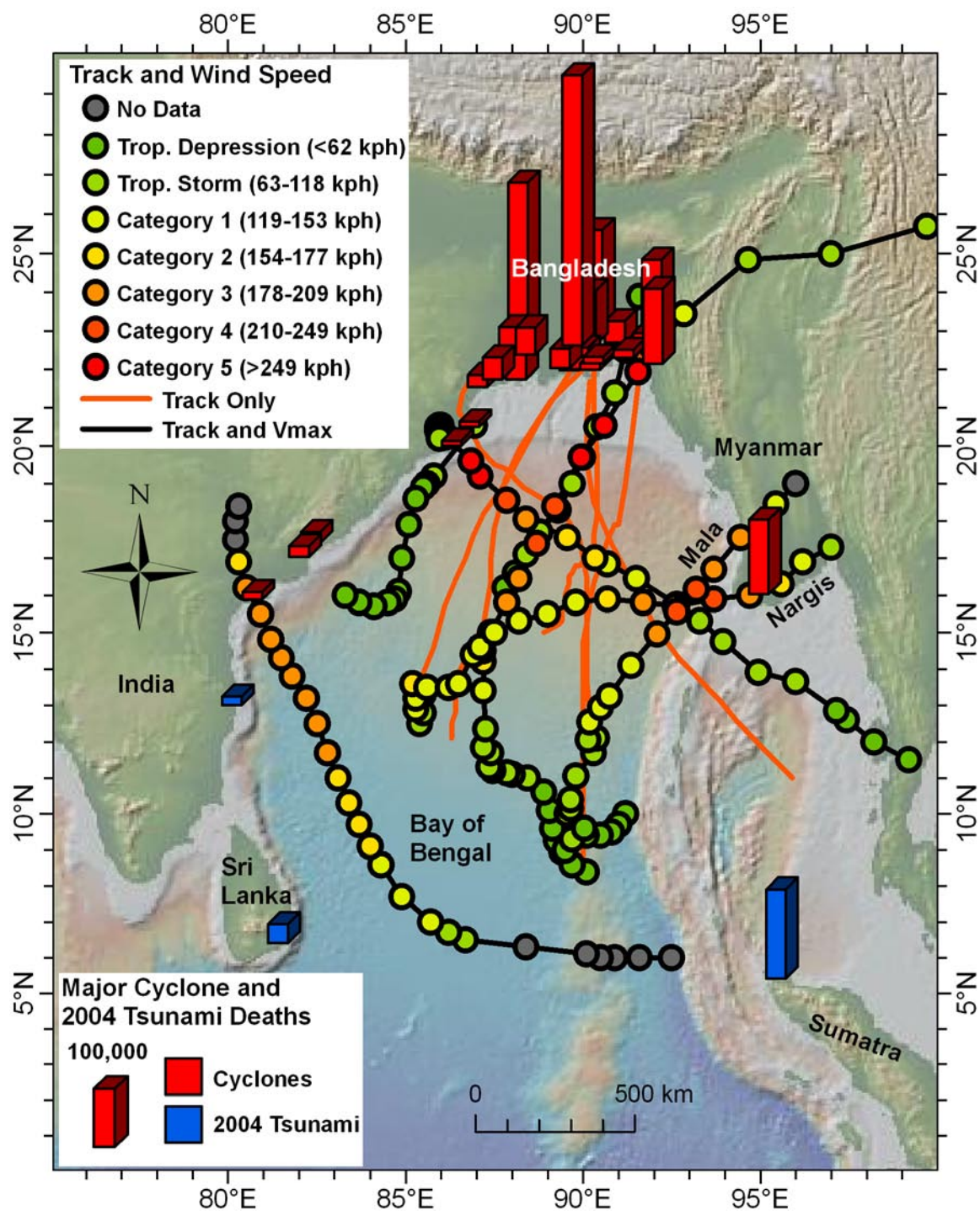
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Supplementary Information to accompany

**Cyclone Nargis storm surge in Myanmar**

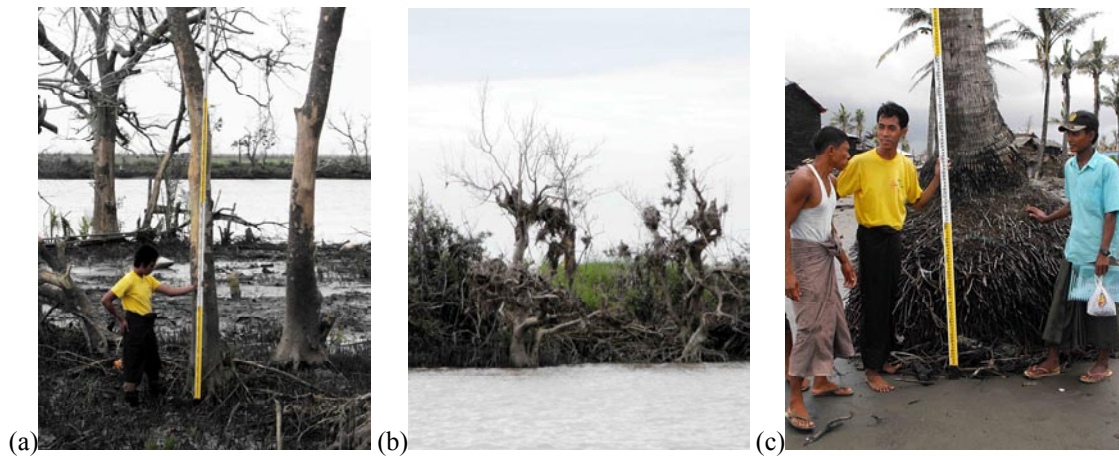
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This section contains Supplementary Figures 1-3 and Supplementary Tables 1 and 2.



Supplementary Fig 1. Fatalities from major cyclone events (> 10,000 deaths) from 1584 up to Nargis compiled from the Emergency Events Database (EM-DAT) and other sources (see refs. S1-S3) with storm track and wind speed (from the Joint Typhoon Warning Center and IBTrACS) compared against 2004 Indian Ocean tsunami deaths (ref. S1). Additional cyclone track: 2006 Cyclone Mala with 22 deaths in Myanmar.





Supplementary Fig. 2. Field survey: (a) bark damage and (b) rafted debris in trees as high water marks at Pyinsalu; (c) vertical erosion on palm tree roots at Aung Hlaing.



Supplementary Fig. 3. Coastal erosion: (a) Drinking water wells scoured in surf zone at Aya; (b) Golden Buddhist Stupa built on land piercing the water surface offshore highlighting 150m land loss. Land use: (c) Deforestation of mangroves for use as charcoal and rice paddies; (d) Secondary growth mangroves with cyclone damage in a forestry reserve.

Supplementary Table 1. Summary of physical survey after Cyclone Nargis. Vertical survey natures are classified as: TB = tree bark, MI = mudline inside, MO = mudline outside, RD = rafted debris, DT = damage trimline, WL = wrackline, EW = eye witness.

#	Location	Latitude [°N]	Longitude [°E]	Date	Local Time [UTC+6:30]	Nargis Vertical Survey Data				2004 Tsunami	
						Surge [m]	Wave [m]	Nature	Erosion [m]	Height [m]	Nature
1	Thaukkya	16.19516	95.76763	12-Aug-2008	13:27	1.90		TB, EW			
2	Thaukkya	16.19517	95.76821	12-Aug-2008	13:34	1.60		MI, EW			
3	Gway Gone	16.16275	95.78517	12-Aug-2008	14:21	1.90	1.3	MI, EW			
4	Lae Ein Dan	16.25017	95.78088	12-Aug-2008	16:13	2.60	1.8	TB, EW			
5	Nauk Pyan Toe	16.27390	95.73006	12-Aug-2008	17:08	2.95	1.2	MO, EW			
6	Nauk Pyan Toe	16.27131	95.73076	12-Aug-2008	17:23	3.30	1.2	TB, EW			
7	Bogale	16.28894	95.39317	14-Aug-2008	8:57	1.10		WL, EW			
8	Kyar Chaung	16.19118	95.33466	14-Aug-2008	10:52	3.00	1.9	MO, EW			
9	Tae Tae Ku	16.17357	95.30560	14-Aug-2008	11:52	2.60	1.8	TB, EW			
10	Along Kyondon River	16.13791	95.31047	14-Aug-2008	12:50	3.40		RD			
11	Hteik Chaung	16.12244	95.32365	14-Aug-2008	13:36	3.20	1.8	TB, EW			
12	Kadon Kani	15.82248	95.21595	15-Aug-2008	7:13	2.10		MO, EW			
13	Ohn Pin Su	15.80148	95.13107	15-Aug-2008	8:32	2.10		TB, EW	-1.0		
14	Aya	15.80085	95.11753	15-Aug-2008	9:53						
15	Aya	15.80113	95.11799	15-Aug-2008	10:00	3.60		TB, EW			
16	Aya	15.80548	95.11373	15-Aug-2008	10:20	4.50		DT, EW			
17	Aya	15.80885	95.11195	15-Aug-2008	10:35	3.50		EW			
18	Aya	15.80899	95.11187	15-Aug-2008	10:46				-1.0		
19	Aung Hlaing	15.77123	94.98468	15-Aug-2008	13:30	3.30		TB, EW	-1.0		
20	Aung Hlaing	15.77098	94.98461	15-Aug-2008	13:53	3.40		MO, EW			
21	Pyinsalu	15.82900	94.80557	16-Aug-2008	6:39	4.70		TB, EW			
22	Pyinsalu	15.82900	94.80557	16-Aug-2008	6:39	5.60		TB, EW			
23	Ye Gyaw Wa	15.93291	94.80584	16-Aug-2008	9:12	3.30	1.7	TB, EW			
24	Mi Chaung Ai	15.88404	94.66521	16-Aug-2008	12:16	2.70	0.6	TB, EW			
25	Dae Yae Phyu	15.95060	94.67308	16-Aug-2008	13:38	4.20	1.2	TB, EW			
26	Ze Thauang	15.88307	94.40648	17-Aug-2008	12:29	4.30	2.0	EW		2.4	EW
27	Kyauk Ka Latt	15.88185	94.43219	17-Aug-2008	13:57	4.50	1.3	DT, EW	-1.1	3.9	EW

Supplementary Table 2. Summary of societal survey after Cyclone Nargis.

#	Location	Nargis Fatality Survey			Residential Destruction Rate (%)
		Fatalities	Population	Rate (%)	
1	Thaukkyia				
2	Thaukkyia				
3	Gway Gone				
4	Lae Ein Dan	12	1320	0.9	
5	Nauk Pyan Toe	116	2178	5.3	98
6	Nauk Pyan Toe				
7	Bogale				
8	Kyar Chaung	41	542	7.6	
9	Tae Tae Ku	21	236	8.9	100
10	Along Kyondon River				
11	Hteik Chaung	173	500	34.6	100
12	Kadon Kani	5	20000	0.0	
13	Ohn Pin Su	26	634	4.1	
14	Aya				
15	Aya	500	10000	5.0	13
16	Aya				
17	Aya				
18	Aya				
19	Aung Hlaing	28	1999	1.4	78
20	Aung Hlaing				
21	Pyinsalu	700	1510	46.4	90
22	Pyinsalu				
23	Ye Gyaw Wa	500	1000	50.0	100
24	Mi Chaung Ai	400	1520	26.3	100
25	Dae Yae Phyu	1700	2000	85.0	100
26	Ze Thauung	2	117	1.7	100
27	Kyauk Ka Latt	5	2000	0.3	93

### Supplementary References

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# After the storm

Hermann M. Fritz and colleagues travelled by cargo boat through the Ayeyarwady delta in Myanmar to document the damage after cyclone Nargis.

## ■ What was the objective of the work?

On 2 May 2008, cyclone Nargis hit the Ayeyarwady delta in Myanmar, resulting in the worst natural disaster the country has seen. In the following weeks, there was a complete lack of reliable information on the impact of the storm, as neither international media nor relief organizations had direct access to the region. Three months after the event we were granted access to the area. The aim of our project was to document the extent of flooding and damage in the delta.

## ■ How did you choose fieldwork locations?

The itinerary and field survey locations were pre-planned based on unofficial damage reports provided by volunteers from local non-government organizations in Myanmar, physical-storm and cyclone-track data, satellite imagery, numerical model benchmark requirements and experience gained surveying other coastal megadisasters, including the Indian Ocean tsunami and Hurricane Katrina. However, we had to modify the plan several times along the way owing to complicated logistics such as the scale of post-disaster fieldwork, limited resources and the political situation in Myanmar.

## ■ What sorts of data were you after?

We were after perishable data — such as infrastructure damage before repair and reconstruction — which would otherwise be lost forever. In the flood zone we searched for water marks on buildings, scars on trees and rafted debris to determine maximum water surface elevation. We measured the distance from the nearest beach or waterway to the high water marks, to see how far the water had come in. We used exposed tree roots, land loss and eyewitness accounts to determine the degree of ephemeral coastal erosion.

## ■ Did you encounter any difficulties?

On arrival in Yangon, the initial disaster relief period was officially terminated by the Myanmar government, and all UN



Coastal erosion and land loss at Aya near the Ayeyarwady estuary, Myanmar. At the top left you can see the golden Buddhist stupa — originally built on dry land — piercing the water surface 150 m offshore.

helicopters and aid flights were grounded indefinitely. We were on the passenger list of the first cancelled flight. Thus, we were forced to travel on a small cargo boat, which limited our access to rivers, waterways and coastal waters. However, although this approach was extremely slow and arduous, the old boat provided full independence between checkpoints, and flexibility in terms of which villages to survey.

## ■ Did you have any encounters with dangerous animals?

There was great concern about the dangerous snakes and saltwater crocodiles roaming in the Ayeyarwady delta. We avoided surveying several destroyed villages near an abandoned and empty crocodile farm. However, daily encounters with snakes were unavoidable — given that Myanmar has the highest rate of poisonous snakebites in the world, this was always unnerving. For example, while cruising through mangroves our local colleagues suddenly jumped back and pointed towards a massive several-metre-long snake that had launched into the waterway and was crossing at an unbelievable speed in front of the bow — it was little comfort when it disappeared into the mangroves. One time, while interviewing a survivor next to a rice paddy, a snake attacked a nearby frog, which tried to defend itself

by inflation. One of the survivors looked at the scene, commented “that’s nature” and continued explaining how he survived cyclone Nargis by tying himself to the tree next to him and bouncing in the waves all night long.

## ■ Any low points?

A week of visiting one destroyed village after another and speaking to eyewitnesses who had just lost their entire families drained everyone’s spirits towards the end of the survey. Drinking tea made from boiled water out of flooded rice paddies and eating pure rice meals, combined with nights in makeshift stick huts, mosquitoes and continuous monsoon rain did not aid in raising moral.

## ■ What was the highlight of the trip?

The discovery of a centuries-old golden Buddhist stupa piercing the milk coloured coastal waters offshore Aya was the highlight. For once the monsoon clouds opened and the bright sunlight appeared to put a spotlight on the scene. The stupa had originally been built on dry land, but it now marks the largest documented coastal erosion due to storm-surge flooding.

*This is the Backstory to the work by Hermann M. Fritz and colleagues, published on page 448 of this issue.*

