BANGKOK—At 10:42 p.m. on Sunday, 24 July, a strong undersea earthquake rattled the Nicobar Islands, 660 kilometers west of Thailand. Minutes after the 7.3-magnitude quake struck, Thailand’s National Disaster Warning Center (NDWC) swung into action. Director Plodprasop Suraswadi appeared on national television to issue the country’s first-ever tsunami watch: If the quake generated a tsunami, he warned, the wave would hit the resort island of Phuket at 12:12 a.m.

The advisory, broadcast on all Thai channels, was not an evacuation order. But with memories of the devastating 26 December 2004 Indian Ocean tsunami still fresh, hundreds of people on Phuket and along the Andaman Sea coast of the Malay Peninsula grabbed what they could and fled to higher ground. A crucial piece of data came in just before midnight: Off the Similan Islands, 50 kilometers from the Andaman coast, a tide gauge measuring sea level had barely bobbed. There would be no tsunami. Suraswadi took to the airwaves to sound the all clear.

If the NDWC had been operational last year, thousands of lives might have been spared. The Indian Ocean tsunami killed 5396 people in Thailand; another 2951 people are still listed as missing. Warnings could have saved countless lives elsewhere. Some 230,000 people died in a dozen nations, including 168,000 in Indonesia’s Aceh province at the tip of the island of Sumatra.

The lesson in ill-preparedness has sparked a mad dash to create a tsunami warning system for the Indian Ocean. As the first anniversary of the disaster approaches, an alarm network is beginning to emerge—a loose web of deep ocean sensors, tide gauges, and seismic stations operated by individual countries, along with mechanisms for sharing data and disseminating public warnings. Last month, for example, Indonesia, the country deemed most vulnerable to the next big Indian Ocean tsunami, deployed two sea-floor pressure sensors and associated buoys, the vanguard of a 10-sensor network. “We want to show the world that we are ready,” says Jan Sopaheluwakan, deputy chair of earth sciences at the Indonesian Institute of Sciences in Jakarta.

By establishing warning centers, Thailand and other countries have begun to fill a lethal void. They will issue tsunami advisories more often, and in most instances the resulting wave will be puny or nonexistent—ratcheting up anxiety and prompting people to flee the seaside needlessly. “People are going to have to be understanding about this,” says NDWC’s Cherdsk Virapat, director of Thailand’s International Ocean Institute in Bangkok.

Asleep at the wheel
The Indian Ocean tsunami last December caught governments woefully off-guard. The trigger was a monster earthquake at a magnitude of 9.3, centered west of Aceh, on the northwestern tip of Sumatra. The quake struck at 7:59 a.m. Indonesia time, and within 40 minutes a wave, the first of three destructive moving mounds of seawater, had inundated the city of Banda Aceh. Nearly 2 hours after the earthquake, the first wave barreled into Phuket and neighboring seaside provinces of Thailand. It was a Sunday morning; most government offices were closed. Staff in a meteorological office in northern Thailand saw the seismic report but had no idea that a tsunami might be imminent, says Virapat. “Every year, someone would ask, ‘What should we do if there is a tsunami?’ ” The possibility seemed remote, he says.

Minutes later, the Nicobar Islands, including an Indian Air Force base at Car Nicobar, were pummeled. It took another 90 minutes for the tsunami to travel across the Bay of Bengal. But no one sounded the alarm, and the waves claimed 15,000 in India and 31,000 in Sri Lanka.
Stunned by the realization that the human toll need not have been so high, representatives of Indian Ocean nations met in Bangkok last January to begin planning for a tsunami alert system. Discussions bogged down over who would host a regional warning center. By then it was clear that each country would establish its own center, although the Inter-governmental Oceanographic Commission of UNESCO was invited to coordinate an Indian Ocean Tsunami Warning and Mitigation System, the subject of an IOC meeting next week in Hyderabad, India. It is expected to cost $200 million to bring the system online over the next few years.

IOC is counting on five nations—Australia, India, Indonesia, Malaysia, and Thailand—to cover the entire Indian Ocean, with other nations enhancing the coverage. “No single nation can protect itself or provide protection to others alone,” says IOC executive secretary Patricio Bernal. Real-time data will stream into one or more “sub-regional centers,” he says, where it will be rapidly processed and fed back to national warning centers, which would decide on their own whether to issue tsunami advisories to their citizens. India continues to resist sharing real-time seismic and tidal data, out of concern that certain information could compromise its nuclear weapons program (see sidebar, p. 1604). Nevertheless, a basic Indian Ocean—wide system is expected to be in place by July 2006, says physical oceanographer William Erb, head of IOC’s office in West Perth, Australia. More advanced assets, such as the deep-ocean tsunameters, will come later.

A hazardous way ahead

As governments gear up to cope with the next tsunami, scientists have pieced together a vivid picture of the shattered Sunda fault off the island of Sumatra—and an idea of what could be in store for the region.

The December quake’s 1300-kilometer-long offshore rupture sent shock waves southward beneath the sea floor, prompting seismologists to warn that the section of fault adjacent to Sumatra could be the next to fail. No one knew how close to failure that segment was, but geophysicists John McCloskey, Suleyman Nalbant, and Sandy Steacy of the University of Ulster in Coleraine, Northern Ireland, warned in the 17 March issue of Nature that the fault had not broken since 1861. That was enough time to build up energy for a sizable earthquake. On 28 March, it struck at a hefty magnitude 8.7.

As in December, the region was unprepared. The U.S. National Oceanic and Atmospheric Administration’s (NOAA’s) Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, registered the earthquake 8 minutes after it occurred and issued a tsunami bulletin 11 minutes later. Without any deep ocean sensors or tide gauges off Indonesia, “it took hours to determine if, in fact, [the earthquake had] created a tsunami,” notes David Johnson, director of NOAA’s National Weather Service. The bang ended with a whimper: The wave recorded at Cocos Island was just 23 centimeters. The tsunami was trivial in large part because the quake had heaved the sea floor upward beneath islands and surrounding shallow waters, not in deep waters where motions can spawn massive waves (Science, 15 April, p. 341).

Now the Ulster group, joined by paleoseismologist Kerry Sieh of the California Institute of Technology in Pasadena, is warning that the risk is moving southward. The next section of fault down the line—from 1°S to 5°S, offshore of the Sumatran city of Padang—could well be poised for disaster. This segment last failed in 1833; the accumulated stress could drive a quake larger than magnitude 8.5. A subsequent tsunami would threaten a million people along 500 kilometers of low-lying Indonesian coast.

New findings underscore the risk. Earlier this week, at the fall meeting of the American Geophysical Union (AGU) in San Francisco, California, the Ulster group, with colleagues at the National Institute of Geophysics and Volcanology in Rome, reported preliminary computer simulations of possible south Sumatra tsunamis. They first modeled a range of possible earthquakes of magnitude 8.0 to 9.0 and then used the resulting sea-floor movement to drive a model of tsunami wave generation. Initial results show that the coast from Padang south could be devastated.

Elsewhere around the Indian Ocean, the tsunami risk from a massive quake off Padang is relatively low. The new simulations suggest that farther from Sumatra, most wave energy would be dissipated in the vast emptiness of the ocean. Here, the fault bends along the southward-facing Indonesian archipelago in a way that a far-traveling tsunami would be directed away from December’s hard-hit targets: Thailand, India, and Sri Lanka.

Other stretches of the deep-sea Sunda fault are less worrisome. At the AGU meeting, seismologists Emile Okal and Seth Stein
of Northwestern University in Evanston, Illinois, reported that, based on the behavior of similar faults around the Pacific, the continuation of the fault to the south off the Indonesian island of Java is not likely to generate a devastating magnitude-9 quake. And to the north of last December’s break, the fault hasn’t even produced magnitude 7s. “Our guess would be you’re not going to have big, thrusting earthquakes there” of the sort that generate a tsunami, says Stein. Instead of the tectonic plate thrusting down into the mantle and shoving up the sea floor to generate a tsunami, he says, to the north the plates probably slide by each other San Andreas-style, without triggering tsunamis.

**Round-the-clock surveillance**

With south Sumatra identified as the area of high tsunami risk, experts are hoping to get a better fix on how far inland tsunamis of various sizes would run, while devising evacuation plans and reinforcing infrastructure. The models have “spurred us to get to work,” says Jose Borrero of the Tsunami Research Center at the University of Southern California (USC) in Los Angeles, who charted the ebb and flow of last December’s tsunami based on his field surveys and satellite imagery (*Science*, 10 June, p. 1596). His team is now modeling inundation scenarios in the Padang region.

Indonesia is taking the threat seriously. Padang’s vulnerability is “bitter news” for the local population, says Sopaheluwakan. “To prevent Padang from becoming the next disaster,” he says, the government is working with local authorities to develop a comprehensive evacuation plan. If an earthquake of magnitude 6 or larger occurs in the Sunda Trench, an immediate evacuation order will be broadcast for any coastal area that a wave would strike within 30 minutes of the quake, Sopaheluwakan says.

Indonesia won’t rely solely on seismic signals in making a call on a tsunami. Last month, scientists deployed the first two sea-floor sensors of the German Indonesian Tsunami Early Warning System. The devices, whose development was spearheaded by the National Research Centre for Geosciences in Potsdam and the Leibniz Institute of Marine Sciences in Kiel, measure sea-floor vibrations and pressure changes in the water column. Data are transmitted by acoustic modem to a buoy linked by satellite to Jakarta. The system is designed to alert Jakarta within tens of seconds of an oncoming tsunami.

After the crew on the *Sonne*, a German research ship, positioned the first sensor and buoy on the Sunda Trench southwest of Padang on 20 November, they made a port call in Padang. If a tsunami were heading there, the area would be tough to evacuate. “Only three streets lead out of the city to higher ground. On a normal day, those three streets are usually full to overflowing with traffic,” expedition scientist Ernst Flüh, a geophysicist at the Leibniz institute, noted in a Web log on the *Deutsche Welle* Web site. Locals he met were placing high hopes in the German sensors. “Over and over again we had to explain that one or two buoys do not make an early warning system,” he wrote.

The second buoy and sensor set was deployed northwest of Padang on 24 November. The system won’t be operational until another eight are installed over the next 2 years. They will run in a line off the coast from Banda Aceh to Bali, each separated by at most 200 kilometers. The German government is footing the system’s €45 million bill.

A network of deep ocean tsunami buoys operated by other countries will monitor the rest of the Indian Ocean. The U.S.-made Deep-Ocean Assessment and Reporting of

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**Pallava Bagla**

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**A Dead Spot for the Tsunami Network?**

**New Delhi**—The budding regional tsunami warning system in the Indian Ocean may get little useful information from one key partner: India. The Indian government insists it will not release seismic recordings in real time, because if it were to resume nuclear testing, the detailed seismic signatures would immediately be broadcast to the world. Officials have also told *Science* they will not share online tide-gauge data, out of concern that such information could aid an aggressor attempting an invasion by sea. Delays in pinpointing an earthquake’s location or confirming wave propagation could delay a tsunami warning.

India’s status as data holdout contrasts with its commitment to creating the region’s most ambitious warning center for tsunamis and cyclone-generated storm surges. Under a $30 million plan, India will increase the number of its tide gauges fivefold and more than triple its seismic stations from 51 to 170. The first of 17 new broadband seismic stations came online at Port Blair, capital of the Andaman and Nicobar Islands, last May. And India plans to deploy up to 12 tsunami systems—Deep-Ocean Assessment and Reporting of Tsunamis (DART) buoys and sea-floor sensors that detect pressure changes in the water column—although it is not expected to share these readings in real time either. Data will feed into a nerve center in Hyderabad, planned to be operating by September 2007.

Indian scientists predict that the new tools, coupled with inundation models under development at the National Institute of Oceanography in Goa, should reduce the time required to assess tsunami risk after an earthquake from 40 minutes to 10. To minimize false alarms, Indian officials say that a tsunami warning will be issued after a major quake only if a significant pressure increase is registered by a DART, once these are in place in the Bay of Bengal, the Arabian Sea, and the southern Indian Ocean.

India’s reluctance to share data could come back to haunt it. India has refused to hook up its vaunted array of seismometers to the Global Seismographic Network, 128 stations that record tremors and listen for signatures of nuclear detonations to help verify compliance with the Comprehensive Test Ban Treaty, which India has not joined. The seismic network is crucial to quickly pinpointing a quake’s magnitude and location—and for analyzing tsunami threats.

Some Indian officials acknowledge a risk. “Our existing policy of not sharing online seismic data has to change,” says Valangiman Subramanian Ramamurthy, a nuclear scientist and secretary of the Department of Science and Technology. He says India is reassessing its relationship with international networks, and India may agree to divulge data on earthquakes greater than 5 on the Richter scale in “near-real time.” That would help, but near–real time equates to a roughly 40-minute lag as Indian experts process data before releasing it.

Earlier this year, some tsunami experts were highly critical of India’s policy (*Science*, 28 January, p. 503). But concerns have been eased by ongoing efforts to bolster seismic stations elsewhere in the region and by the prospect of DARTs managed by other countries. “I am less pessimistic now,” says Costas Synolakis of the University of Southern California in Los Angeles. “India’s [seismic] recordings are not as essential for early warning, particularly for sources ‘far’ from India,” he says. Maybe not—if a killer wave doesn’t come before the rest of the Indian Ocean states bring their new instrumentation on line.

**Sharper hearing.** India has fired up its first new broadband seismometer, in Port Blair.
Tsunamis tsunameters—each a buoy and an associated bottom pressure sensor—already serve as sentinels for the PTWC in Hawaii. It’s the only such device that’s been “tried and tested,” notes IOC’s Erb. At a price tag of $250,000 per buoy and a design life of 1 year, the network won’t come cheap, nor will it come quickly: The U.S. factory that produces the buoys was inundated by Hurricane Katrina, so production is lagging, and fish for gene variations, or alleles, that may underlie susceptibility to PTSD. A team led by geneticist Veraputh Prapanhophoj of Thailand’s Department of Mental Health will target about 20 genes by zeroing in on DNA markers called single-nucleotide polymorphisms. His group will also take a second tack, trawling for genetic signals in a whole-genome association study of a few hundred individuals.

Experts suspect that several genes are involved in susceptibility to PTSD, considering the constellation and variability of symptoms, some of which overlap with those of anxiety disorder and depression. Preliminary results are due in late 2006. Yale’s Joel Gelernter, for one, has high expectations. “There’s a very good chance” that the study will pinpoint more candidate PTSD genes, he says. —R.S.