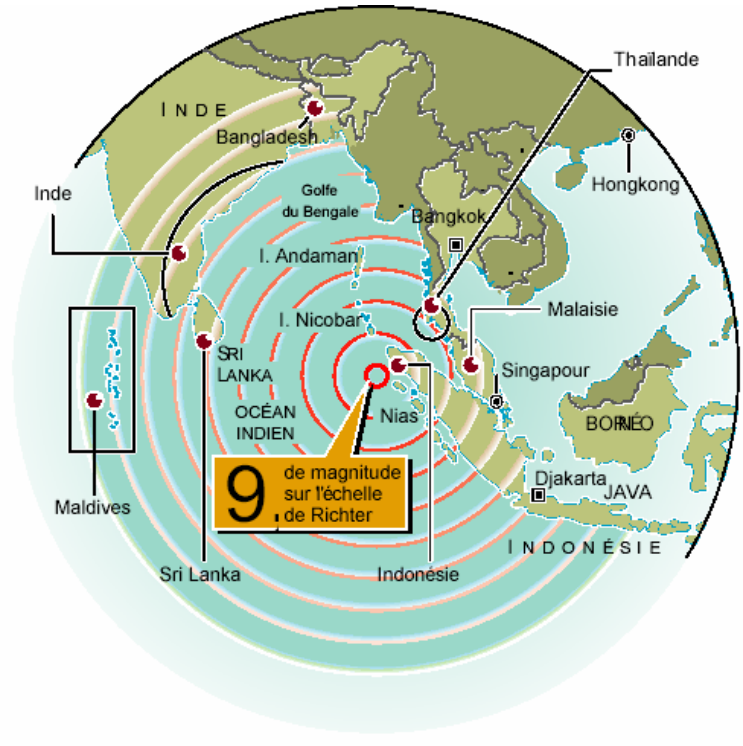
THE 2004 INDIAN OCEAN TSUNAMI

The *tsunami* that hit Asia on 26 December 2004 has killed swiftly more than 100,000 persons. Strong and fast tides swept distant populated coastlines many hours after the generating earthquake hit the north tip of Sumatra; it is amazing that a human life loss of such biblical proportions was reached in the age of world-wide satellite surveillance! The death toll is expected to rise as millions remain homeless without adequate food, water, sanitation, or medical care. The problem is exacerbated by geography, politics, and economics.

This document contains a short introduction on the mechanics of this particular *tsunami* (3 slides from *Le Monde*), NOAA's view from the sky and futile warning from the West, followed by impact photos (from *Le Monde*, *La Liberation*, the *New York Times*), and articles (from *the New York Times*) on the secondary effects of the *tsunami* on the survivors, related primarily to water scarcity and the onset of epidemics. The appendix discusses the Pacific Ocean roots of tsunamis and ends with a USGS tutorial about their formation.

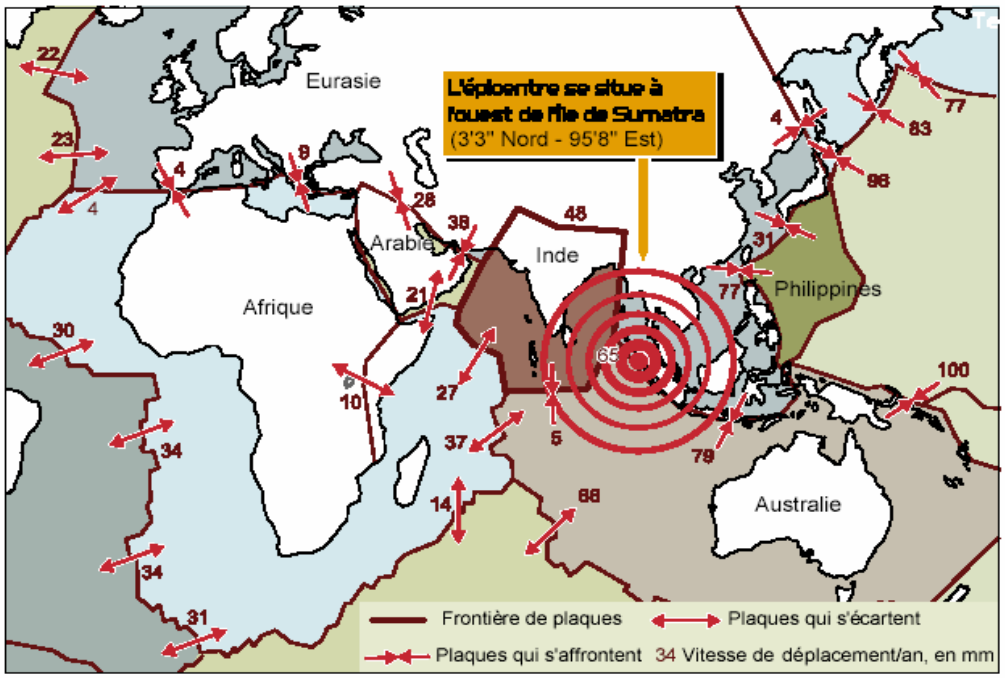
1. TSUNAMI MECHANICS




Indonésie


Sri Lanka


Thaïlande

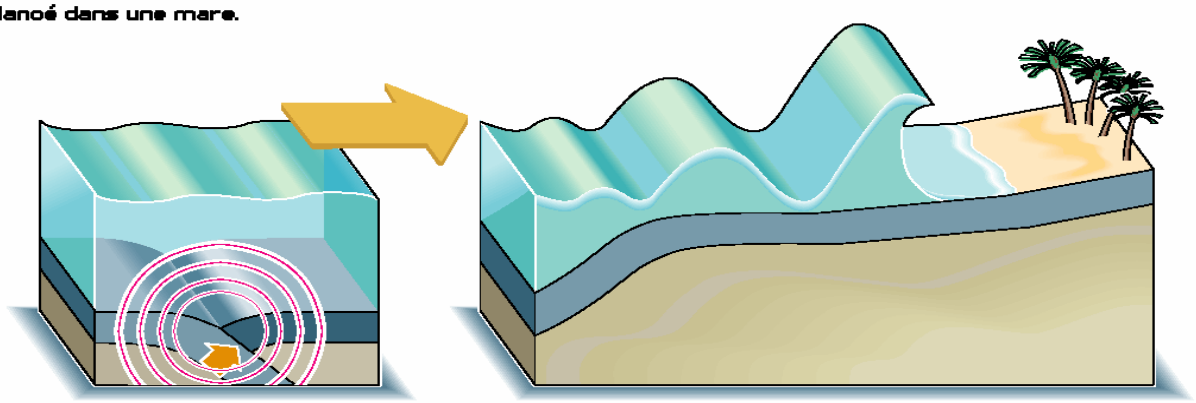


L'énergie libérée par cette puissante secousse a atteint la magnitude 9,0 sur l'échelle ouverte de Richter, une échelle qui suit une progression logarithmique, si bien qu'un séisme de magnitude 6 libère 30 fois plus d'énergie qu'un séisme de magnitude 5 et un de magnitude 7, 900 fois plus. L'énergie libérée est considérable. Ainsi, celle du séisme qui a ravagé San Francisco en 1906 (magnitude 7,9) aurait été équivalente à celle d'au moins 10 000 bombes atomiques de type Hiroshima.

Le raz de marée qui a ravagé les côtes de l'océan Indien et du golfe du Bengale est dû à l'affrontement de deux grandes plaques tectoniques dont l'une, la plaque indo-australienne, plonge à raison de 5 à 6 cm par an sous la plaque eurasienne (phénomène de subduction). D'une manière plus précise, le séisme à l'origine de cette vague géante est le fruit du réajustement d'une microplaque, la plaque de Burma, enchâssée dans cet ensemble, et qui a joué sur 1 000 km avec la plaque indo-australienne.

DE LA MER À LA CÔTE, LA PROGRESSION DU PHÉNOMÈNE

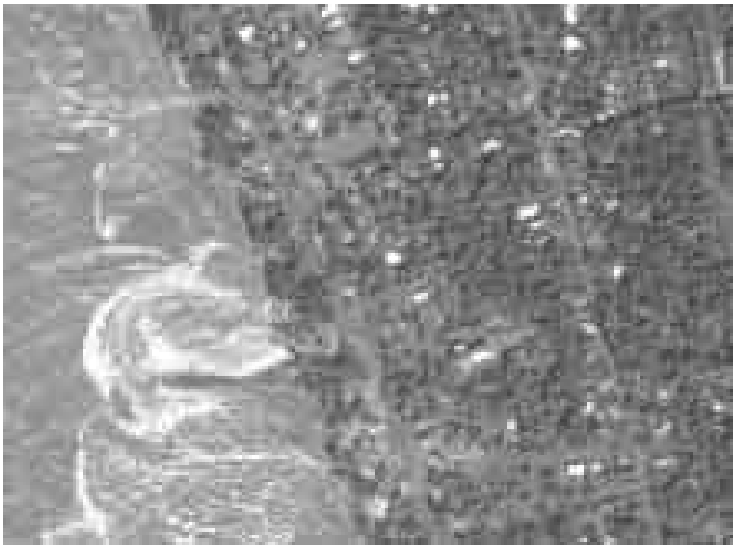
Le raz-de-marée est provoqué à l'origine par un séisme. A Sumatra, ce tremblement de terre est le fruit de l'affrontement de deux plaques tectoniques dont l'une passe sous l'autre (*subduction*). A cette occasion, un large morceau de l'écorce terrestre s'effondre et se déplace, mettant ainsi en mouvement la colonne d'eau qui est au-dessus, ce qui provoque la formation d'une série de vagues imposantes, un peu comme le fait un caillou lancé dans une mare.



En pleine mer, cette vague géante se déplace à des vitesses comprises entre 500 et 800 km/h. Elle est en général suivi de plusieurs autres vagues – des répliques – tout aussi meurtrières

En eau peu profonde, à l'approche des côtes, cette vague perd en vitesse mais gagne en amplitude et forme un mur d'eau qui peut dépasser 30 mètres de hauteur.

2. VIEW FROM "ABOVE"



This QuickBird satellite image of the southwestern coast of Sri Lanka, just south of Colombo in a resort area called Kalutara, was made shortly after the moment of tsunami impact, at 10.20 a.m. local time on Sunday, slightly less than four hours after the earthquake. The tsunami took an hour to reach the coast of Indonesia and two Indian islands, another hour to hit Thailand and Sri Lanka and a full six hours to reach Africa. That provided ample time for many of the victims to have been warned of its approach and to have taken action to get to higher ground and save themselves.

BUT THE WARNING NETWORK WAS NOT THERE….(the following is from NOAA's site)

Dec. 29, 2004 — NOAA scientists at the Pacific Tsunami Warning Center in Hawaii went to work within minutes of getting a seismic signal that an earthquake occurred off the west coast of Northern Sumatra, Indonesia. NOAA issued a bulletin indicating no threat of a tsunami to Hawaii, the West Coast of North America or to other coasts in the Pacific Basin—the area served by the existing tsunami warning system established by the Pacific rim countries and operated by NOAA in Hawaii.

NOAA scientists then began an effort to notify countries about the possibility that a tsunami may have been triggered by the massive 9.0 undersea earthquake. The Pacific Basin tsunami warning system did not detect a tsunami in the Indian Ocean since there are no buoys in place there. Even without a way to detect whether a tsunami had formed in the Indian Ocean, NOAA officials tried to get the message out to other nations not a part of its Pacific warning system to alert them of the possibility of a tsunami. However, the tsunami raced across the ocean at speeds up to 500 mph. Below is the timeline of agency's actions once the undersea earthquake was detected by the NOAA Pacific Tsunami Warning Center in Hawaii.

(All times listed below are Hawaii Standard Time or HST.)

At 2:59 p.m. Hawaii Standard Time (HST) on Christmas Day a large earthquake occurred in the Indian Ocean near Sumatra, Indonesia.

At 3:07 p.m. the resulting seismic signals received at the NOAA Pacific Tsunami Warning Center (PTWC) from stations in Australia triggered an alarm that alerted watchstanders.

At 3:10 p.m. PTWC issued a message to other observatories in the Pacific with its preliminary earthquake parameters.

At 3:14 p.m. PTWC issued a bulletin providing information on the earthquake and stating there was no tsunami threat to the Pacific nations that participate in the Tsunami Warning System in the Pacific (ITSU). These member nations are part of the UNESCO Intergovernmental Oceanographic Commission (IOC) and the International Coordination Group for the Tsunami Warning System in the Pacific (ICG/ITSU). India, Sri Lanka and the Maldives are not part of the Pacific system.

At 4:04 p.m. PTWC issued bulletin No. 2 revising the earthquake magnitude to 8.5. That bulletin stated no tsunami threat to the Pacific but identified the possibility of a tsunami near the epicenter. No additional information regarding the formation of a tsunami was available.

At approximately 4:30 p.m. HST PTWC attempted to contact the Australia Met Service with no luck but were successful in contacting Australia Emergency Management. They confirmed they were aware of the earthquake.

At approximately 5:30 p.m. Internet newswire reports of casualties in Sri Lanka provided PTWC with the first indications of the existence of a destructive tsunami. Indications are that the tsunami had already struck the entire area by this time, although we have not been able to obtain arrival times.

At approximately 5:45 p.m., armed with knowledge of a tsunami, PTWC contacted the U.S. Pacific Command (PACOM) in Hawaii.

At approximately 5:45 p.m., PTWC received a call from a Sri Lanka Navy Commander inquiring about the potential for further tsunami waves from aftershocks.

At approximately 6:00 p.m. the U.S. Ambassador in Sri Lanka called PTWC to set up a notification system in case of big aftershock. He said they would contact Sri Lanka Prime Minister's office for such notifications.

Continuing news reports gave increasing and more widespread casualties.

At approximately 7:25 p.m. the first reading from the Australian National Tidal Center gauge at Cocos Island west of Australia gave a reading of 0.5m crest-to-trough.

At 7:25 p.m. the Harvard University Seismology Department reported its preliminary Centroid Moment Tensor solution that indicated a magnitude of 8.9.

At approximately 7:45 p.m. PTWC contacted the Australia Bureau of Meteorology and advised them about the increased earthquake magnitude and the 0.5m reading at Cocos Island, as well as the possibility of a destructive tsunami impact on Australia's west coasts.

At approximately 8:00 p.m. PTWC re-contacted PACOM to advise of increased earthquake magnitude and potential for further tsunami impacts in the western Indian Ocean.

At approximately 8:15 p.m. Australia Bureau of Met called PTWC to advise they had issued an alert to their west coast.

At approximately 8:20 p.m. NOAA National Weather Service Pacific Region director contacted PTWC to report PACOM said no tsunami was observed at Diego Garcia in the Pacific.

At approximately 10:15 p.m. PTWC spoke with U.S. State Department Operations and advised them about the potential threat to Madagascar and Africa. They set up a conference call with the U.S. embassies at Madagascar and Mauritius, and PTWC advised them of the situation.

At 5:36 a.m. on December 27 PTWC issued a third Tsunami Information Bulletin for this event informing the Pacific that small sea level fluctuations from the Indian Ocean tsunami were being observed in the Pacific, probably from energy that wrapped around south of Australia.

The Pacific Warning System

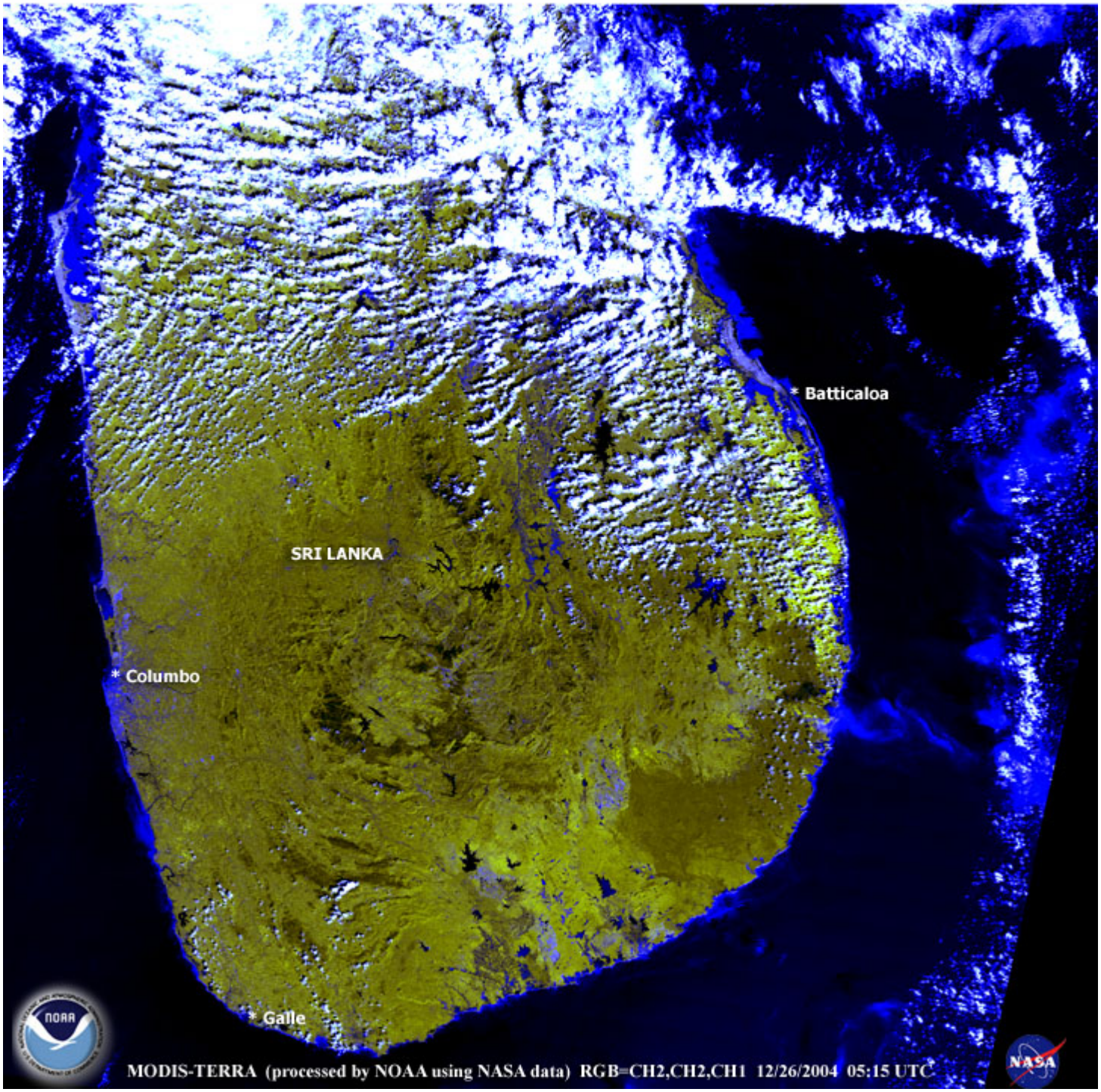
Pacific warning network is comprised of (1) hundreds of seismic stations worldwide; (2) coastal tide gauges and sophisticated Deep-ocean Assessment and Reporting of Tsunamis (DART) buoys in the Pacific Basin capable of detecting a centimeter's difference in ocean height.

However, it is important to note that without similar gauges and buoys in the Indian Ocean PTWC officers were not in a position to detect a tsunami there.

Furthermore, the development of the Global Earth Observing System of Systems (GEOSS) led by the United States, Japan, South Africa and the European Commission—with 53 nations currently participating at the ministerial level—should help fill the sensor gap for other regions of the world. Two key focus areas of the GEOSS initiative are addressing "reducing loss of life and property due to disasters" and "monitoring our oceans."

This Moderate Resolution Imaging Spectroradiometer (MODIS) image was processed from 250 meter resolution data taken by NASA's Terra Satellite at 11:15 AM local time December 26, 2004, reportedly about an hour after the tsunami generated by an earthquake in Indonesia struck the coast.

CREDIT: NOAA/NASA



December 31, 2004

GAUGING DISASTER

How Scientists and Victims Watched Helplessly

Agence France-Presse

Tourists try to rush to safety before the tsunami hit the Hat Rai Lay Beach in Thailand. The water had receded before the deadly wave struck.

By ANDREW C. REVKIN

It was 7 p.m. Seattle time on Dec. 25 when Vasily V. Titov raced to his office, sat down at his computer and prepared to simulate an earthquake and tsunami that was already sweeping across the Indian Ocean.

He started from a blank screen and with the muted hope that just maybe he could warn officials across the globe about the magnitude of what was unfolding. But the obstacles were numerous.

Two hours had already passed since the quake, and there was no established model of what a tsunami might do in the Indian Ocean. Ninety percent of tsunamis occur in the Pacific, and that was where most research had been done.

Dr. Titov, a mathematician who works for a government marine laboratory, began to assemble his digital tools on his computer's hard drive: a three-dimensional map of the Indian Ocean seafloor and the seismic data showing the force, breadth and direction of the earthquake's punch to the sea.

As he set to work, Sumatra's shores were already a soup of human flotsam. Thailand to the east was awash. The pulse of energy transferred from seabed to water, traveling at jetliner speed, was already most of the way across the Bay of Bengal and approaching unsuspecting villagers and tourists, fishermen and bathers, from the eight-foot-high coral strands of the Maldives to the teeming shores of Sri Lanka and eastern India.

In the end, Dr. Titov could not get ahead of that wave with his numbers. He could not help avert the wreckage and death. But alone in his office, following his computer model of the real tsunami, he began to understand, as few others in the world did at that moment, that this was no local disaster.

With an eerie time lag, his data would reveal the dimensions of the catastrophe that was unfolding across eight brutal hours on Sunday, one that stole tens of thousands of lives and remade the coasts of the Asian subcontinent.

For those on the shores of the affected countries, the reckoning with the tsunami's power came all but out of the blue, and cost them their lives. It began near a corner of the island of Sumatra, and ended 3,000 miles away on the East African shore.

For the scientists in Hawaii, at the planet's main tsunami center, who managed to send out one of the rare formal warnings, there was intense frustration. They had useful information; they were trained to get word out; but they were stymied by limitations, including a lack of telephone numbers for counterparts in other countries.

For Colleen McGinn, a disaster relief worker in Melbourne, Australia, the developing crisis would send her off on an aid mission that she could not have comprehended and that United Nations officials have projected to be the greatest relief effort ever mounted.

For others like Phil Cummins, an Australian seismologist, what was happening made all too much sense. He had grasped the dangers a year earlier, and in 2004 had delivered a Powerpoint presentation to tsunami experts in Japan and Hawaii.

"It really seems strange now to see the title," Dr. Cummins recalled yesterday. "Tsunami in the Indian Ocean - Why should we care?"

Hawaii: Helpless Warners

He wore two beepers, in case one failed. Both chirped.

It was a languorous Christmas afternoon, with his girlfriend away and nothing to do, and Barry Hirshorn, 48, was asleep. As a geophysicist, he was used to having his rest interrupted. Almost daily, earthquakes announced themselves somewhere, usually modest nuisances, and off went his pagers.

It was just after 3 p.m. in Honolulu, nearly halfway around the globe from where the earth was trembling. Mr. Hirshorn worked at the Pacific Tsunami Warning Center, a

stubby cinderblock structure set in a weedy plain in Ewa Beach. He was one of five staff scientists entrusted with the big task of alerting Pacific countries and the United States military to deadly tsunamis.

"I knew it wasn't tiny," he said. "Probably over a 6." The messages on his beepers indicated alerts from two far-apart seismic monitoring stations, meaning the quake had power.

Shrugging into a shirt, he hopped onto his "duty bike," and pedaled the several hundred yards to the center, operated by the National Oceanic and Atmospheric Administration.

Stuart Weinstein, 43, was already at a terminal in the windowless operations room, staring at the thick blue seismic lines that signaled an "event." "This is a big earthquake," he recalled thinking. "Maybe a 7."

Dr. Weinstein began pinpointing the location. Sliding into the seat beside him, Mr. Hirshorn waited to calculate the magnitude. Within minutes, they concluded it was a quake of 8.0 magnitude.

More data arrived, and they reworked their calculations. But they stayed with 8.0.

At 3:14 p.m., 15 minutes after the earthquake struck, they issued a routine bulletin announcing an event off Sumatra with a magnitude of 8.0. It added, "There is no tsunami warning or watch in effect." This referred to the Pacific.

The bulletin alerted perhaps 26 countries, including Indonesia and Thailand, though it did not go to other coastal areas of the Indian Ocean, for they were not part of any warning system.

Next, the men tackled a slower but more precise means to measure an earthquake, using waves that pierce the earth's mantle rather than simply the initial waves. They got an 8.5, a marked difference in possible threat. "Uh oh," Dr. Weinstein said.

It was 3:45 and time to call the boss: Dr. Charles McCreery stood in a friend's living room a few miles away, delivering a gift after a brunch at his sister-in-law's. His 4-year-old twin daughters were hoping that he would soon assemble their new bicycles.

Dr. McCreery, 54, said a fresh bulletin should go out, reporting the higher magnitude and mentioning the chance of a tsunami near the epicenter. But he and his colleagues doubted that an 8.5 quake would unleash a far-ranging "teletsunami" that could traverse an ocean and wipe out villages.

Once the second bulletin left, at 4:04 p.m., there was little more that their machines could confide, unless tsunamis crossed the Indian Ocean and entered the Pacific. They had no sea monitors in the Indian Ocean.

Dr. Weinstein scrolled the Internet. They tuned in CNN on television. Only in the same way that most of the world learned, from news reports, did the three men come to see the ghastly reality, the widening tsunami paths and the lethal coastal destruction.

A wire dispatch at 5:30 told them that Sri Lanka had been pounded. Their spirits drooped. "More are going to die," Mr. Hirshorn said.

Their instinct was to somehow tell more, to warn the region that it would continue, to reach people who could clear beaches. But how? Mr. Hirshorn recalled a tsunami expert he knew in Australia, called and got an answering machine. He left a message. Someone phoned the International Tsunami Information Center, asking if they knew people in the stricken region. The center simply had no contacts in this distant world.

At 7:25, an e-mail message from Harvard's seismology group reckoned the earthquake at 8.9. Now they understood why such a monster tsunami had been unleashed.

They continued to scramble to reach countries that could still escape death, but they were reaching into a void. Around 10:15 p.m., they did speak to the United States embassies in Mauritius and Madagascar, which promised to warn Somalia and Kenya, not yet hit, but it is unclear what came of this.

Their day ended, engulfed in gloom. "Part of me said I wish it had occurred in the Pacific, because we could have saved an awful lot of people," Dr. Weinstein said. "We felt terrible that we couldn't get the messages to where they were most needed."

Japan: Looking On

The seismograph at the Matsushiro Seismological Observatory, about 110 miles northwest of Tokyo, is buried inside a mountain tunnel. The tunnel had first been created as an alternative headquarters for the country's imperial military during the final years of the war in the Pacific, and scientists saw it had advantages for recording as precisely as possible tremors in the earth: protection from the effects of temperature and wind.

"Our job is to identify the epicenter and the size of earthquakes all over the world," said Masashi Kobayashi, an official at the observatory. "There are many observatories recording the earthquakes in the vicinity of Japan, but this observatory is the only one in Japan for observing the earthquakes of the world."

And Mr. Kobayashi said he did not mistake the significance of what got recorded deep inside the mountain on Sunday.

"I got surprised," he said.

The recording showed an earthquake with a magnitude of 8.

"In the vicinity of Japan," he said, "that size is recorded only once in several years to 10 years."

Mr. Kobayashi said he had calculated the location, as well as the magnitude of the quake. "I reported it is west of Sumatra island, including the latitude and longitude," he said.

And with that, he said, he realized something else.

"When I found it was in the ocean," he said, "I thought the first thing to worry about was a tsunami."

There has been over the last several days, as the death count from the earthquake and tsunami has steadily climbed to more than 100,000, much discussion of whether enough was done by scientists and government officials around the world to relay word of the possible peril millions of people suddenly faced.

There have been accounts in newspapers of officials in Indonesia and Thailand and Malaysia struggling to comprehend the threat and get out warnings. All agree that, whatever people's intentions or capabilities, no sufficient warnings were transmitted that might have limited the toll at some of the hardest-hit places.

What Mr. Kobayashi did with his information, and concern, is not entirely clear. In an interview, he said he had made his reports to headquarters. It is not clear what, if anything, his superiors did.

Asked directly if he thought his reports led to any movement toward issuing a warning about a tsunami, Mr. Kobayashi said, "My job is to decide the size and the location of the earthquake epicenter, so it is beyond my job to answer that question."

Indonesia: First Losses

As deputy mayor of Banda Aceh, Aceh Province's most bustling town, Muhammad Kadir was about the closest thing the townspeople had to an alarm bell when the tsunami hit Indonesia.

Elected to office as an elder statesman of sorts, the 76-year-old Mr. Kadir had hurried Sunday morning to a seaside market at the tip of the island of Sumatra for emergency supplies after the initial earthquake struck. It was at the market, a few minutes later, that he said he had looked far out to sea and noticed something strange: the waterline was dipping off to the sides and rising furiously in the middle.

"The water separated, then it attacked," he said. "I've never even seen anything like it in the movies. I couldn't imagine anything like it."

After spotting the raging waters, Mr. Kadir raced through the town banging on doors and shouting into a local mosque. "I told people the water was getting higher and higher - get out," he recounted.

His mad dash was the closest many people on Sumatra would come to an early warning system. Before the waves subsided, more than 43,000 people in the Aceh region alone - many of them women and children unable to resist the violent waters - would perish.

"The water was coming too hard, too fast," Azwar Muhammad, a local resident, said. "This was God's destiny."

As a separate set of mammoth waves hurtled across the Indian Ocean in the opposite direction, due west, Amir Khan, a strapping 30-year-old off-duty police officer, relaxed in his home in the town of Kalmunai on the east coast of Sri Lanka.

Mr. Khan, like every other local government official, was enjoying a day off and completely oblivious to the walls of water surging toward Sri Lanka when he heard what sounded like a low-flying helicopter. Some in Kalmunai remember the ocean's abruptly changing colors from green to a dark, menacing black, as if it were filled with oil. Others remember the water turning white with foam. All recall the first wave's shape: a 10- to 12-foot-tall wall of water.

Mr. Khan shouted, "Run! Run!" to his parents and siblings and bolted out of his house, sprinting as fast as his strong, young legs would carry him. His 68-year-old father and 50-year-old mother stayed in the house. As water engulfed them, they grabbed onto a ceiling beam and were able to survive.

His three sisters-in-law were less lucky. Two ran but drowned in the water. A third remained in the house and drowned as well.

Three subsequent waves, each larger and more powerful than the last, obliterated the neighborhood and reached 700 yards inland. The waves ripped sturdy, one-story brick homes off their foundations, snapping four-inch-thick brick walls into small chunks. It picked up cars and swept them hundreds of yards inland. It reached the rooftops off one-story buildings, ripping off gutters as it surged passed.

Kalandar Umma, a 60-year-old grandmother, was found clinging to the upper branches of a tree. She had no memory of the waves or how she got there. Nineteen members of her family died, including one son, five granddaughters and two grandsons, including an 18-month-old boy.

Local officials, unsure what had happened, ordered people to go to high ground. Groups of stunned municipal employees, schoolteachers and retirees began searching for bodies. In the first day alone, 1,824 bodies were recovered and buried behind a local

mosque. Local government officials quickly lost control of the process, with families burying relatives as soon as they discovered them.

Advance notice of the wave's approach would have saved thousands of lives, according to officials and residents. Baheera Sahariban, a waiflike 25-year-old mother, said she had easily been able to carry her 18-month-old son to safety from her house, which sits only 15 yards from the ocean. The reason: a warning.

"Someone helped me," Ms. Sahariban said, as she gently cradled her son. "Someone said, 'Run away.' "

Australia: A Call to Aid

At 6 p.m. Sunday in Melbourne, Colleen McGinn was having tea in her backyard patio with a man she had met recently in an emergency first aid class. It was a year to the day that Oxfam, the relief organization that Ms. McGinn worked for, had gotten the call about an earthquake in Iran that would kill 26,000.

Today, it was again Boxing Day, a national holiday in Australia, and it was her turn to be on call. She knew anything could happen. She hoped nothing would. But she kept her cellphone near. Then the phone rang.

"I hate to bother you," the caller said. It was Marlene McIntyre, one of the bosses at Oxfam, who also happened to be her friend. "But there has been an earthquake."

"Very funny, Marlene," Ms. McGinn said, chuckling. "Merry Christmas to you, too."

"No, this is real," Ms. McIntyre said. "There has been an earthquake and a tsunami. Sri Lanka was hit, we were hearing."

It was six hours after an undersea earthquake off the Indonesian island of Sumatra had set off one of the worst natural disasters in recent decades. Ms. McGinn, who was born in Indonesia but raised in Athens, Ohio, had worked previously in Sierra Leone, the Balkans and Afghanistan, dealing with war victims and refugees.

Those were man-made disasters. This would be different. This was nature, and the marathon of tackling people's misery had just begun.

"I need a ride," she told her friend, instantly enlisting the young man, a potential date, into a relief aide. Off they went, on his motorcycle, along the beachside highway, driving as the sun set to the nearby home of her boss at Oxfam, Chris Stewart. The global Oxfam emergency response machine needed to be put into motion. It was up to these two women to start the engine. Now.

Out came the emergency contact list, and the chain of calls began: East Asia regional manager, South Asia regional manager, the agency executive director. The list went on.

But even while they were working the phones, the news coming from the television and Internet started to turn darker and darker.

The would-be date turned into a decent assistant.

"We need a better map," she told him. "We need another map."

The telephone calls continued for hours, fueled by pizza and coffee that was ordered. Day had become night. But as darkness fell, what had at first appeared to be a probably deadly, but at least isolated incident - impacting perhaps just Indonesia and Sri Lanka at first - was turning into a incomprehensible catastrophe.

"This is unbelievable," Ms. McGinn said, pausing to look up at the television. "All the countries in the Indian Ocean have been hit. This is massive. Oh my God."

Across the world, in New York, there was a similar growing sense of dread.

Jan Egeland, the United Nations' emergency relief coordinator and under secretary for humanitarian affairs, is a 46-year-old Norwegian whose boyish looks and shock of chestnut hair falling across his forehead would become familiar to millions of television viewers around the world as he reported on the global relief effort.

He had been lying in bed in the midtown Manhattan apartment where he lives with his wife and two daughters when his telephone rang at 7 a.m. New York time, bringing him the first word of tsunami. Mr. Egeland and his colleagues at the United Nations offices in Geneva sent emergency relief teams to the Maldives, Sir Lanka and Indonesia, the first countries to request help, right away and began to consider additional countries as they learned more about the geographical extent of the damage. Teams would soon be added for India, Thailand and Malaysia.

"We were not even close to understanding the true enormity of it," he said. "The initial indication was that a few hundred were affected."

Ms. McGinn and Ms. Stewart would wrap up their initial round of calls sometime before midnight in Melbourne. Monday would be another day of telephone calls, as work was now under way by different Oxfam offices to prepare an IL-76 cargo plane, packed with 27 tons of emergency supplies that would soon take off for Sri Lanka and Indonesia. Water tanks, pumps and taps to set up emergency drinking water would all be included, as would latrine slabs to build emergency bathrooms.

Ms. McGinn would soon be boarding a plane herself to fly to Sri Lanka, leaving Melbourne on Tuesday, for the trip across Asia to the dead zone. Her father had been in Indonesia at the moment of the earthquake, although not near the affected part of the country. Still, she had not heard from him.

It was not long after she landed at the airport in Colombo, Sri Lanka, that it was clear what that phone call on a gorgeous day after Christmas had spelled: fields of misery and devastation unlike any she had ever seen.

First, as she approached the seaside community of Batticaloa, it was simply the crowds of people standing outside schools and other government buildings, which had been transformed into shelters. Then it was roads clogged with emergency vehicles and trucks. And then it was a stretch of coastline where there was such utter chaos it was unclear how and where the work should begin.

Boats sitting upturned on land, far from the shore. A major bridge had been lifted off its supports, twisted and then thrown like a toy. Whole swaths where houses once stood were now flat, wide-open land, the ground strewn with debris. People milled around, eyes glazed over with fear and despair. To top it all, this was the rainy season, so it was pouring.

"I never seen anything like this," Ms. McGinn said.

The only option was to begin work, unloading trucks that had arrived with relief supplies, everything from clothes and instant noodles to soap. It was quite a distance she had traveled from that lazy evening sipping tea on the patio in Melbourne.

California: A Scientist Explains

As soon as Kerry Sieh, an earthquake expert at California Institute of Technology in Pasadena, heard the reports on Sunday of the earthquake and tsunamis in the Indian Ocean, he knew exactly what had happened.

He was preparing for his next trip to Sumatra, the island hardest hit by the tsunami. He had spent a decade there and on nearby islands, cutting slices out of coral heads with a chainsaw to read traces of past seismic upheavals, and to look for hints about future quakes.

Most of his colleagues who study undersea earthquakes were focused on even more violent fault lines closer to the developed world, those off Japan and the Pacific Northwest and the island arc of the Aleutians in the far North Pacific.

Like them, Dr. Sieh was consumed with what he could learn about the dynamics of the earthquake factories called subduction zones. But the archives he mined existed only in the coral off Sumatra. "It's tucked away in a corner of the world that just doesn't have much scientific traffic," he said.

In the calcium carbonate coral layers, he could read the seafloor's history. Deformations of the layers showed when the seabed beneath had been shoved upward, plunged down or tilted.

So the mechanism of the earthquake that had just occurred was familiar. The offshore plate of rock underlying the Indian Ocean normally slides relentlessly under Indonesia, like the disappearing belt on an airport walkway, descending into the earth's mantle to be consumed and recycled.

In places, this process was smooth. The junction between that ever-shifting India plate and the plate under Southeast Asia was "greased," he said. But there were places where it was stuck.

In 1797, 1833, 1861 and now again long stretches that were stuck sprang free. In each case, the rock had built up tension in the intervening decades, as the greased sections continued to shift, leaving the stuck part behind, just as an archer's bow flexes when drawn.

At some point, the force is too great. Friction is overcome. The stuck section gets to catch up, in seconds making up for a century of lagging behind, and if the plate is moving up or down, that energy is transferred pistonlike to the incompressible water above.

The energy unleashed in a 9.0 quake, as this one would ultimately come to measure, is roughly the amount that would be unleashed if it were possible to create a bomb made of 32 billion tons of TNT and set it off.

As the news media calls began flooding in, Dr. Sieh began to recount the mechanism he knew so well. It would be two days and nights before he would have time to turn on a television and witness the consequences of the upheaval. It was likely that a fresh distortion would be etched in the corals. It was certain that a region and people he had grown to love had been ripped asunder.

Australia: International Inertia

The possibility of tsunamis arising in the Indian Ocean had not completely escaped international attention. During the 1990's, an obscure United Nations group, the International Coordination Group for the Tsunami Warning System in the Pacific, periodically considered the extension of tsunami alert systems to parts of the globe outside the Pacific, including the Caribbean and Indian Ocean.

At a meeting of the group in Lima, Peru, in September 1997, for example, its members had considered proposals to expand the network to the Indian Ocean, particularly because of Indonesia's tectonic activity. Nothing concrete happened.

Among the scientists who kept up a restrained but insistent pressure was Dr. Phil Cummins, a seismologist with Australia's geosciences agency. He continued to gather and present evidence that an Indian Ocean tsunami was inevitable, although unpredictable in terms of timing, and posed a grave threat to many countries. He met with no ill will, but with considerable inertia, he said.

"Just look at the name," he said. "The international body designed to coordinate international tsunami-related activity is mandated as a Pacific entity."

Dr. Cummins cited details from dusty records kept by the Dutch colonists in Indonesia and from Dr. Sieh's coral studies that great 19th-century earthquakes in the 1,200-mile arc of faults west of Sumatra had generated destructive ocean-spanning waves.

He made his case in October 2003, at a meeting of the international tsunami group in Wellington, New Zealand, when he pushed for formal expansion of the international network into the Indian Ocean.

The group rebuffed him, saying, in the stiff language of meeting minutes, that any such expansion could occur only if an overarching governing body dealing in global oceanographic issues formally redefined its "terms of reference."

In the meantime, it voted to establish "a sessional working group to prepare a recommendation to establish an intersessional working group that will study the establishment of a regional warning system for the Southwest Pacific and Indian Ocean."

Dr. Cummins prepared a position paper at that meeting laying out his arguments. He used a computer model similar to that used by Dr. Titov in Seattle to study how tsunamis spread from the great Sumatran quake of 1833.

He simulated the quake in a mathematical simulacrum of the ocean, and simulated waves radiated until they struck as far north as eastern India and all around western Australia. The Sumatran shore east of the fault was devastated, and a directional pulse of energy, resulting in higher waves, splayed westward like a shotgun blast.

At the time, the images of those reconstructed virtual waves must have seemed like yet another computer analysis, predicting yet another potential disaster that might or might not occur in this, or the next century.

Now, the reconstructions, so similar to what happened last Sunday, carry a disturbing weight.

Kenya: A Last Victim

Capt. Twalib Hamisi was sitting in his office at the Port Authority in Mombasa, Kenya, when word of the curious water first reached him. A staffer had phoned to report unusual movements in the main port there.

"The tide was supposed to be falling, but it was rising," Mr. Hamisi, the harbor master, recalled. "I went to the water, and we saw it moving really fast. I thought a pipe might be broken in the port."

It was about 1 p.m. Sunday, and he decided to call other ports in Malindi and Lamu, where workers reported similar water movements. "It was like seeing the sun setting in the east," he said. "The tide was crazy. The water wasn't following the rules."

Then, Mr. Hamisi said, the minister of foreign affairs phoned to report the heavy damage in Asia.

After realizing the direction the waves were headed, Mr. Hamisi called the Port Authority director. "I said: 'We have a problem. We have to institute our emergency plan.' "

The emergency plan was intended for things like oil spills or fires, not tsunamis. But it was all they had. The police were informed to evacuate beaches. The news media were called to spread the word. The local authorities were mobilized up and down the coast. Radio messages were sent to commercial fishing vessels and ships. For the wooden dhows that are so common in Kenya and that lack radio communication, the looming danger was spread by word of mouth.

At Jomo Kenyatta Beach in Mombasa, there were thousands of people packed on the sand. The police made announcements at first, and then armed riot policemen moved in to relocate people away from the water.

"It was Sunday, so the beaches were full of holiday makers," Mr. Hamisi said.

At Hemingway's Resort in Watamu, a plush seaside hotel, employees who heard of the storm on television began working the phones. They called the Port Authority, but the person who answered the phone there did not seem overly alarmed. They called the Kenyan Navy, where someone agreed to investigate. They tried to track down a British professor who someone said was an expert on the wave patterns off the Kenyan coast.

Frustrated and fearful, Hemingway's staff began evacuating guests to a parking lot half a mile from the coast.

Further north, Mabeya Mogaka, the district commissioner in Malindi, was spreading word of the dangerous seas as well. "I ran out and told people not to panic but to be aware," he said.

The beaches were virtually deserted, he said. But not everybody got the message that danger was near. There were still people swimming when the waves began to churn with more force.

One of them was Samuel Njoroge, 20, a mechanic from Nairobi who was in the water with his uncle and was swimming for the first time. He was about 10 feet from the sand when the waves became rough. His relatives describe what happened next: Samuel was pulled under. His uncle grabbed him but was also pulled under. Eventually, Italian tourists who were swimming nearby got both men to shore.

But Samuel had already taken in too much water. More than seven hours after the tsunami hit land in Indonesia, some 3,000 miles away, Samuel became Kenya's only confirmed storm-related death.

"We are in shock," said Peter Mwanji, a relative who visited the mortuary on Thursday to claim Samuel Njoroge's body. "We are still trying to understand how this storm could have taken him. He was so excited to see the ocean and to swim in it. He was so happy. Then he was gone."

Seattle: A Final Picture

Back in Seattle, around the time that the beaches of East Africa were being swept by the great pulse of waves, Dr. Titov was close to finishing his fresh-minted model for simulating Indian Ocean tsunamis.

He hit enter on his terminal keyboard, and the computer began calculating numbers.

As the real tsunami was spending its last destructive power, his virtual tsunami began. It burst out like a shotgun blast from the epicenter of the quake, focused due west from the fault line.

By 4:28 a.m. Sunday morning, the simulation had run its course, and Dr. Titov posted his work on the Web and stumbled home, knowing, but still not knowing since he had seen no news, what had happened.

Like everyone else, he became transfixed by television images of heaving seas and devastation, with one difference, he said: "It feels like I have already seen it."

Reporting for this article was contributed by Eric Lipton in Washington, Eric Lichtblau in Indonesia,Marc Lacey in Kenya, N. R. Kleinfeld in New York, David Rohde in Sri Lanka,Yasuko Kamiizumi in Japanand Michele Kayal in Hawaii.

2. THE ENVIRONMENTAL IMPACT

Banda Aceh, Sumatra, Indonesia ("Ground Zero")

Sri Lanka

Andaman Isles (India)

3. IMPACT ON HUMANS

3.1 Water Is Key to Averting Epidemics Along Coasts

By LAWRENCE K. ALTMAN and DENISE GRADY

Published: December 30, 2004


Darren Whiteside/Reuters
Bodies near Banda Aceh, Indonesia. Since Sunday's tsunamis, experts are worried about diarrheal diseases.

Tens of thousands of tsunami survivors are at risk from diseases spread by dirty water, mosquitoes and crowding, and the best medicine is large quantities of clean water, officials of the World Health Organization said yesterday.

While no epidemics have been confirmed in the vast coastal areas devastated by the tsunamis on Sunday, the officials said they were most worried about diarrheal diseases - cholera, typhoid fever and shigellosis - as well as liver diseases like hepatitis A and E. Those diseases are caused by bacteria or viruses in contaminated drinking water or food, in sewage and among people who lack clean water to wash their hands.

Health organizations like the W.H.O. and Unicef recommend that each person be given about five gallons of clean water a day. Dr. David Nabarro, the director of crisis operations for the W.H.O., said in a telephone interview from its headquarters in Geneva that water shortages had already occurred in the Maldives and Sri Lanka, and that tanker trucks would be needed to provide clean water.

In addition, water-purifying tablets are being rushed into the affected countries, along with medicines to treat the dehydration that can result from diarrhea.

Another hazard to drinking water is contamination of wells by salt water from the tsunamis. Martin Dawes, a regional spokesman for Unicef in Colombo, Sri Lanka, estimated that 1,000 drinking-water wells in the country's hard-hit eastern region had been contaminated and would have to be pumped out.

"At the moment," he said, "the water people don't have the right kind of pumps to rescue the wells." He added that his agency was seeking pumps or money to buy them.

Mr. Dawes said Unicef had also bought about 20 million gallons of drinking water in 1,500-gallon barrels, enough for 100,000 people, and was expecting them to be delivered to the affected areas on Thursday.

Dr. Nabarro also said there had been unconfirmed reports of measles in Sri Lanka. "That does give me cause for concern, because we would have expected a pretty high level of coverage by immunization in Sri Lanka," he said. The disease is caused by a virus that spreads through the air when patients cough, particularly in overcrowded conditions like shelters set up for people whose homes were destroyed.

Although influenza can also spread rapidly in such conditions, the areas hit by the tsunamis have not reported flu outbreaks, and are unlikely to experience them, officials said.

Among the diarrheal diseases, cholera, typhoid and shigellosis are caused by bacteria. In cholera, the bacterium produces a toxin that causes severe fluid loss and can kill quickly, and the key to treating it is to replace fluids. Typhoid can also be fatal and requires antibiotic treatment. Shigellosis causes severe dysentery but usually goes away in about a week.

Dr. Nabarro said relief workers would provide antibiotics to treat these infections, but he said the health organization recommended against using the drugs prophylactically, to prevent illness. Widespread use of the drugs in healthy people would contribute to the emergence of bacteria resistant to antibiotics.

Hepatitis A and E, caused by viruses, infect the liver and can cause jaundice, fever and abdominal discomfort. Hepatitis A usually causes a mild illness, but can become disabling. Hepatitis E can be fatal in pregnant women.

Dr. Pino Annunziata, a member of the W.H.O. emergency team, said that within a few weeks, there could also be increases in mosquito-borne diseases like malaria and dengue fever, unless insecticide-spraying starts immediately.

3.2 Amid Chaos, Sri Lankans Are Struggling to Survive

By SETH MYDANS

Published: December 30, 2004

NILAVELI, Sri Lanka, Dec. 29 - His home gone, his family shivering and hungry, everything he owned swept out to sea, Velu Kannan wandered down a lonely road on Wednesday looking for a pen.

Stagnant salt water lay in the fields around him, reflecting a gray sky. In his hands he carried a piece of cardboard he had found among the debris.

"I need somebody to help me write 'Refugee Camp,' " he said. "All the cars drive past us. Nobody knows we are here."

Mr. Kannan and his family fled their fishing village when it was destroyed on Sunday and took refuge with 10 other families on a hillside where they hoped to be safe if giant waves crashed in again from the sea. Now he needed to survive.

All along the shoreline here in Trincomalee district on the hard-hit eastern coast of Sri Lanka, small groups have found shelter in schools, temples, vacant buildings or makeshift tents, kept alive by small donations from private convoys of trucks and vans.

"What we need is clothes," said Wasantakumari Sridhar, 35, who was camped by the side of the road under a tarpaulin with two other women, three men and nine children. "Our homes have become mud. Everything we had is gone."

Not far down the road, in the shelter of a half-built gasoline station, Pasida Muhamad said: "We only want food and milk. We are not asking for everything. But our babies have no milk to drink."

The death toll in Sri Lanka continued to climb Wednesday past 22,000 as more bodies were pulled from debris or floated ashore with the tides, to be quickly buried. At the same time, a new potential disaster approached as up to two million people remained homeless without adequate food, water, sanitation and medical care.

Some, like the families along the road here in Nilaveli, were receiving small handouts. Others, like the villagers north of the broken bridge at Kuchchaveli or farther south on the sand bars near Batticaloa, remained beyond the reach of aid.

"It's a mess," said Patrick Walder, who heads the office of the International Committee of the Red Cross here in Trincomalee. "The problem is disorganization. There are many

agencies and they are not coordinated. The government is not coordinating. Some of the district offices are wiped out so we have nothing to work with."

Private banks are running out of money, he said. Fuel and medicine are running short. There is an immediate need for the basics of food and shelter. If disease begins to spread, as many people fear, medical care will become urgent.

In the initial division of labor, he said, the government is responsible for food distribution; standard emergency stockpiles will soon run out. The government has also begun chlorinating contaminated wells. Large areas must have electric power restored. Scores of bridges need to be rebuilt.

Red Cross agencies will provide survival kits that include sleeping mats, plastic sheeting, plates, cups, buckets, cooking pans, soap, washing powder and sheets. The first trucks of supplies began heading here from the capital, Colombo, on Wednesday.

"The question is, are there enough supplies to meet the demand?" said John Punter, another official with the International Committee for the Red Cross. "Are there a million plastic buckets in Sri Lanka?"

Soon, planeloads of aid will start arriving in Colombo from abroad, he said. "The first thing is, where do you start? It's everywhere. It's the whole country. And not only is it one country, it's six or seven countries over a massive area."

Sri Lanka's challenges - from survival to subsistence to the avoidance of epidemics- are only the beginning. In this poor country of 20 million people, as many as a million or more now have no way to earn a living.

"What we need is boats," said the men sheltering on the hillside with Mr. Kannan. Like most of these coastal refugees, they were fishermen and like most of them, their boats, nets and motors were swallowed by the ocean that once fed them.

Once the world has spent millions of dollars on aid to the victims here and around the region, it is hard to know how these penniless fishermen will find the means to support their families again.

In Trincomalee, which was sheltered in a cove from the worst of the inundation, scores of fishermen have pulled their boats out of the harbor for safety and they now line the narrow streets like parked cars.

As a measure of the national trauma here, the disaster caused by an undersea earthquake measuring a 9.0 magnitude is now being referred to on television as "9.0, 2004." Radio stations have begun reading out the names of the missing, just as desperate families in America posted photographs of the missing after the attacks of Sept. 11, 2001.

Some people are raising the hope of a silver lining - that this calamity will help bring together the Tamil and Sinhalese sides that fought nearly 20 years of civil war until a fragile cease-fire was declared in 2002.

Mr. Walder of the Red Cross said the Tamil rebels have been "quite well organized" in bringing relief to areas they control. The aid group associated with them, the Tamil Rehabilitation Organization, has been cooperating well with the government, he said.

In Trincomalee, Sunday's natural disaster struck an area that had been torn apart by fighting for years. Along the Nilaveli road, buildings knocked askew by the ocean stand side by side with the rubble of buildings destroyed by war.

The turbulent waves robbed a nearby military base of its weapons just as Tamil raiders had done in the past and scattered buried land mines back into areas that had been cleared since the cease-fire.

On the grounds of the ruined Nilaveli Hotel, cars hung from trees along with bits of clothing, a dead goat and a head of cabbage.

Foam hissed up the quiet beach and the ocean stretched to the horizon, placid and glittering, almost smug after this demonstration of its power.

3.3 Frayed Nerves and Aftershocks Create Panic in Southern Asia

By JANE PERLEZ
and AMY WALDMAN

AKARTA, Indonesia, Friday, Dec. 31 - Survivors lasted a fourth day on Thursday without food, water or medical supplies as nations and aid agencies struggled to bring together the world's largest relief effort and the tally from the week's devastation surged to close to 120,000.

The human toll in Indonesia jumped overnight after health ministry officials said that nearly 28,000 more dead had been uncovered in Sumatra, near the epicenter of Sunday's enormous undersea quake. Large parts of the island's northernmost province, Aceh, remain inaccessible and as many as 20,000 more people are feared dead in the area.

The tally in Aceh, which contains nearly all of Indonesia's dead, made the province the hardest hit of any place in a disaster felt as far away as Africa.

The government said it had begun dropping instant noodles and medicine to those still stranded amid cliffs on Aceh's western coast, but even in the cities, like the provincial capital, Banda Aceh, relief of any kind was still lacking and frustrations were growing.

"For four days now we haven't gotten any help," said Dasrizal Nyakna, 38, a leader of a group of some 35 volunteers who crammed into a truck and drove more than 24 hours up the coast to lend a hand, lugging boxes packed with clothing and food.

"People are still suffering," he said. "They're still waiting, and we need more help, much more help." He lost his wife and two children on Sunday when the tsunami swept over Aceh Province,

The toll from the devastation that swept through nearly a dozen Asian nations jumped to close to 120,000 on Thursday, as Indonesia said at least 80,000 people had been killed here alone.

The delivery of water and food to survivors in the worst-hit areas of the province of Aceh remained stymied by lack of fuel and trucks, red tape, and in many cases a lack of personnel, including drivers and medics, many of whom are presumed dead.

The threat of cholera and typhoid, and the stench of decay, had become so severe that people burned bloated bodies exposed to the tropical sun since Sunday in the city of Banda Aceh. A board of Indonesian Muslim clerics said they were considering giving

official permission for the burning of bodies, a practice forbidden by Islam except in emergency situations.

In Nagappattinam, India, frayed nerves and a slight aftershock created widespread panic throughout southern Asia on Thursday, as the Indian government issued a warning of another tsunami along India's southern coast. In India and Sri Lanka, many fled the beaches in fear of more deadly waves, muddling the relief effort and bringing the recovery of bodies in many areas to a temporary halt.

Three aftershocks that measured just above 5 on the Richter scale ultimately led officials in India to issue what amounted to a false alarm. The government's overreaction reflected the sensitivity of Indian officials to criticism that they should have given notice of the tsunami to coastal villages, which in many cases were hit two or three hours after the earthquake on Sunday that devastated much of southern Asia.

The warning came a day after world leaders, including President Bush, promised long-range help to Asian countries as impatience with the pace of relief efforts rose along with the estimated toll from the week's disaster.

Prime Minister Silvio Berlusconi of Italy called on Thursday for an emergency meeting of the Group of Eight to discuss options for aid and debt reduction in response to what he called "the worst cataclysm of the modern era," according to the Reuters news agency.

The Bush administration announced that Secretary of State Colin L. Powell and Gov. Jeb Bush of Florida would visit the affected areas around the Indian Ocean this weekend. The White House said that Mr. Bush, the president's brother, had been selected for the trip because he has had experience dealing with natural disasters in Florida.

Three United States Navy ships, part of an expeditionary strike group en route to Iraq from San Diego with more than 2,000 marines, were expected to near the Straits of Malacca today and could be diverted to Aceh, an American military official said.

The ships are carrying about a dozen heavy-lift helicopters, and full surgical hospitals, he said. "These amphibious ships bring significant help to the relief effort if the decision is made to deploy them," the official said. The marines were needed in Iraq prior to the January elections, and whether they would be sent to the disaster area in Indonesia was a "political" decision that would be made in the next 24 hours, he said Thursday.

The first American assistance arrived on a military C-130 cargo plane on Thursday in Medan, a city south of Aceh, carrying food and water.

Also on board was a small group of American soldiers sent to assess how the far bigger supplies and equipment en route by American naval ships would be distributed. But the soldiers were not expected to get on the ground in Aceh until sometime today, an American official said.

In all, the United States military was preparing a "very extensive" relief effort for the Indian Ocean countries in the arc from India to Sri Lanka, to Thailand and down to Indonesia, the military official said. It was likely to end up rivaling the assistance given by the American military to Bangladesh in 1991 when more than 130,000 people were killed by a major cyclone.

In Washington, two influential Republican lawmakers said today they would introduce legislation in the new Congress for a sizable aid package.

"I think there will be very decisive action early on," said Senator Richard G. Lugar of Indiana, the chairman of the Senate Foreign Relations Committee. Mr. Lugar, speaking on CNN, said he had drawn up a resolution anticipating "very generous appropriations."

Mr. Lugar's House counterpart, Representative Henry J. Hyde of Illinois, said he too is drafting legislation for action early in the new year. "The challenges of coping with suffering on this magnitude are almost unfathomable, and we will act," Mr. Hyde said in a statement issued by the House Committee on International Relations, which he heads.

Mr. Hyde said a Congressional delegation led by Representative Jim Leach, Republican of Iowa, would visit Thailand and Sri Lanka next week, and that the group's findings would be important in shaping the aid legislation. Mr. Leach is chairman of the Subcommittee on East Asia and the Pacific.

Mr. Powell visited the embassies of Thailand and Sri Lanka to offer condolences on behalf of President Bush and the American people and to promise that "we will stand with them in solidarity and do everything we can to assist in this time of tragedy," as he put it outside the Sri Lankan Embassy.

Meanwhile, Secretary General Kofi Annan cut short his vacation to return to New York to oversee the United Nations' relief effort, one of the largest in the organization's history.

Today, Mr. Annan told reporters that world governments had donated $500 million thus far to help disaster victims.

The Australian government, which is coordinating its relief efforts with the United States, said Thursday it had sent four C-130 Hercules transport aircraft and a Boeing 707 carrying medical supplies, generators, shelter and water purification to Aceh. In addition, the government said, a navy ship with helicopters will leave Australia today but will not arrive in Aceh until Jan. 13.

At Meulaboh, a town of about 120,000 on the west coast of Aceh, about one-third of the population perished in the succession of waves that swamped the town on Sunday, Indonesian officials said.

An Indonesian soldier, Capt. Bachtiar, who is a member of the military command at Meulaboh, told Agence France-Presse that seven successive waves from the tsunami hit the town, about 90 miles from the epicenter of the under-sea earthquake.

He described how he had been pinned under a rock and had given up hope of living. "I had already accepted my fate," the captain said. "My entire body was aching and I felt there was no longer any hope. But suddenly my leg managed to loosen itself." A wave then threw him safely onto a treetop.

A British conservationist, Mike Griffiths, who flew over Meulaboh on Wednesday in a light aircraft said he could see thirsty and hungry survivors walking around dazed. "The picture that comes to me is of old photos you see of Hiroshima," Mr. Griffiths said. "There is nothing just a few odd buildings."

An Indonesian military ship sent to the town to deliver supplies on Wednesday could not dock, and had to leave, according to an Indonesian report.

The Indonesian president, Susilo Bambang Yudhoyono, who visited Banda Aceh briefly the day after the earthquake, will return Saturday, his aides said. He plans to make a special effort to fly to Meulaboh to stress the needs there, they said.

But criticism of the Indonesian government's efforts by Indonesians mounted Thursday. The minister of trade, Mari Pangestu, acknowledged the slow pace of relief that left people in the city of Banda Aceh begging for food and drinking water.

She said the government had a system but that lack of transport and lack of fuel in the disaster area had kept assistance parked at the airports at Medan and Banda Aceh from being delivered.

In many cases, bulldozers and other heavy equipment needed to dispose of the piled up bodies and to clear debris had survived Sunday's destruction but remained useless because there were no drivers. The drivers were either presumed dead or had gone searching for family members, said Dino Djalal, an adviser to President Yudhoyono, who visited the disaster area.

One of Indonesia's most popular Muslim preachers, Abdullah Gynastyar, visited Banda Aceh on Thursday, and said the situation was so devastating that Indonesians should forgo celebrating on New Year's Eve. He pressed President Yudhoyono to publicly cancel celebrations. "Someone who dances while his brothers suffer is evil," Mr. Gynastyar said.

Several Indonesian transport aircraft flew sorties to drop food, mostly dried noodles, on Thursday. But an American official said that Indonesia's helicopter fleet, which should be able to make food drops, appeared to be grounded with technical problems.

The extent of the red tape was dramatized when the United Nations Children's Fund announced Thursday that enough aid to help 200,000 people, including medical supplies, soap, plastic sheets and tarpaulins, had landed at Jakarta airport far from the disaster scene. The aid had to await customs clearance today before it could be moved north, Unicef said.

The tsunami warning on Thursday by the Indian government created panic and confusion throughout India, halting the passage of relief trucks into the Nagappattinam district, where 4,332 people have been confirmed dead, and the continuing effort to recover bodies was halted.

Near the village of Akkarapatti, boats thrown up by the sea during the tsunami had blocked the roads and delayed the recovery of bodies. The warning caused officials to abandon plans to use giant rollers to clear the way.

"Everybody gets into a panic situation," said Shantha Sheela Nair, an official coordinating relief work in the district. "If we get a warning of tsunami again, we are hampered at every step." The warning, from the Ministry of Home Affairs, was sent out by loudspeaker in coastal villages, where the search for bodies is still under way.

In Gharamganbadi, gloved men searching for the remains of their wives and children in the rubble of their homes just steps from the sea began arguing over whether to abandon their work and move away from the water whose swell suddenly seemed to take on an ominous cast when the warning arrived.

Reluctantly, they left.

In another town, Velankanni, the site of a religious shrine where about 1,300 bodies have been recovered so far, the announcement by the police on Thursday morning that people should move at least three kilometers inland sent hundreds running through the ravaged lanes of the town.

The stench of rotting bodies continued to rise from the beaches of the most affected villages. Government agencies have moved enough machines and manpower to dig out bodies that remain stranded in the sand and debris, but the work stalled in Nagappattinam because of the tsunami warnings.

The tsunami alert was issued following reports that several aftershocks had pushed up the water level, an official at the emergency control room of India's Home Ministry said, according to news agencies.

A 5.7 magnitude underwater quake was recorded at 5:18 a.m. local time northwest of Sumatra, Indonesia, near the epicenter of the original earthquake. That quake registered 9.0, meaning it was 30,000 times more energetic than the aftershock. Other quakes were felt in Thailand and Myanmar.

"We have issued an alert; there could be a wave attack in the next one hour," said Veera Shanmuga Mani, the top administrator in Nagappattinam.

As police sirens blared on beaches here in Tamil Nadu, where most of India's tsunami deaths occurred, thousands streamed inland on foot or crammed any vehicle they could find, looking for higher ground. Some shouted: "Waves are coming! Waves are coming!" The police ordered hundreds of vehicles carrying relief supplies not to enter Nagappattinam. Similar warnings were issued for Kerala, a southern state, and for the Andaman and Nicobar Islands.

Later, as it became clear the government had overreacted to the aftershocks, officials appealed for calm.

"There is no reason to panic," an official in the back of a jeep said through a megaphone in the Andaman and Nicobar Islands. "You can go back to your jobs or your home, wherever you please. There is no imminent danger."

In Sri Lanka, the military told residents of coastal areas not to panic, but the government advised them to move to higher ground as a precaution. The advice and the Indian alert, heard on radio in coastal Sri Lanka, prompted thousands of Sri Lankans to panic and flee inland, Reuters reported. At a lagoon near Arugam Bay on the island's eastern coast, local residents jumped off a naval ship ferrying aid and waded to the beaches.

In Thailand, tsunami sirens in the south sent people dashing from beaches, but only small waves followed.

Jane Perlez reported from Jakarta, Indonesia, for this article, Amy Waldman and Hari Kumar contributed from Nagappattinam, India, Warren Hoge contributed from the United Nations and Steven R. Weisman and David Stout contributed from Washington.

APPENDIX

津波

Tsunami

is a Japanese word meaning "harbor wave." The term “tidal wave” is a misnomer, although it expresses its effect correctly. A tsunami is a wave or series of waves that are generated in a body of water by a sudden disturbance that displaces water. They are typically caused by earthquakes and landslides in coastal regions. Volcanic eruptions, nuclear explosions, and even impact of meteorites, asteroids, and comets from outer space can generate a tsunami. 80% of tsunamis occur in the Pacific Ocean.

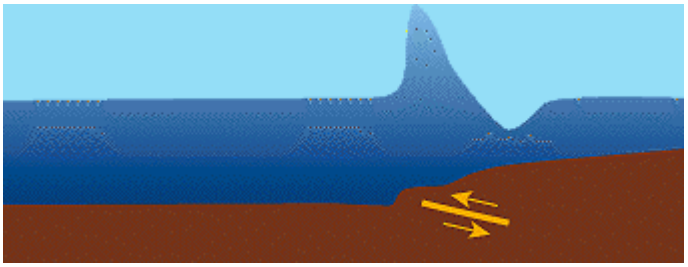
The photo below shows people run from an approaching tsunami in Hilo, Hawai'i, on 1 April 1946; note the wave just left of the man's head in right center of image.

DOCUMENT UPDATED ON 31 December 2004 CST

USGS science for a changing world

Western Region Coastal & Marine Geology

Life of a Tsunami



Panel 1--Initiation: Earthquakes are commonly associated with ground shaking that is a result of elastic waves traveling through the solid earth. However, near the source of submarine earthquakes, the seafloor is "permanently" uplifted and down-dropped, pushing the entire water column up and down.

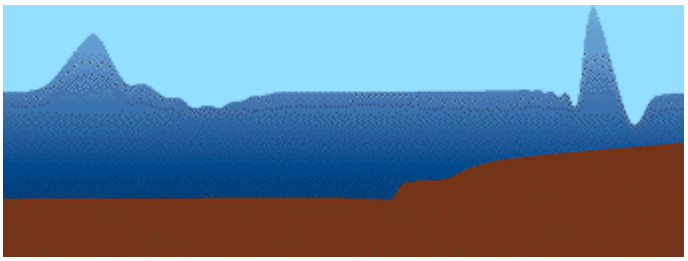
The potential energy that results from pushing water above mean sea level is then transferred to horizontal propagation of the tsunami wave (kinetic energy). For the case shown above, the earthquake rupture occurred at the base of the continental slope in relatively deep water. Situations can also arise where the earthquake rupture occurs beneath the continental shelf in much shallower water.

Note: In the figure the waves are greatly exaggerated compared to water depth! In the open ocean, the waves are at most, several meters high spread over many tens to hundreds of kilometers in length.

Panel 2--Split: Within several minutes of the earthquake, the initial tsunami (Panel 1) is split into a tsunami that travels out to the deep ocean (distant tsunami) and another tsunami

that travels towards the nearby coast (local tsunami).

The height above mean sea level of the two oppositely traveling tsunamis is approximately half that of the original tsunami (Panel 1). (This is somewhat modified in three dimensions, but the same idea holds.) The speed at which both tsunamis travel varies as the square root of the water depth. Therefore the deep-ocean tsunami travels faster than the local tsunami near shore.



Panel 3--Amplification: Several things happen as the local tsunami travels over the continental slope. Most obvious is that the amplitude increases. In addition, the wavelength decreases. This results in steepening of the leading wave--an important control of wave runup at the coast (next panel). Note also that the deep ocean tsunami has traveled much farther than the local tsunami because of the higher propagation speed. As the deep ocean tsunami approaches a distant shore, amplification and shortening of the wave will occur, just as with the local tsunami shown above.

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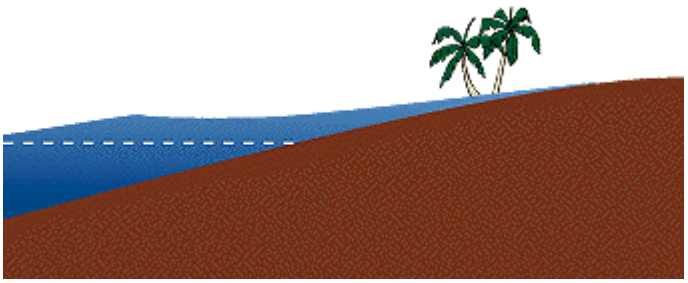
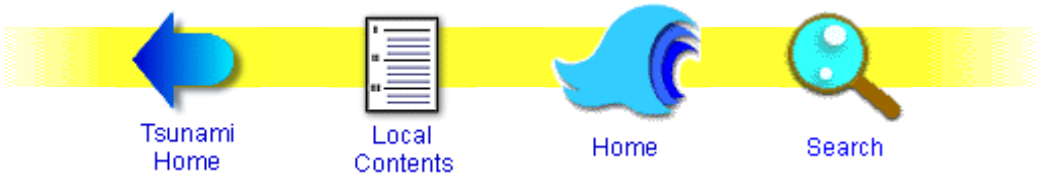


Panel 4--Runup: As the tsunami wave travels from the deep-water, continental slope region to the near-shore region, tsunami runup occurs. Runup is a

measurement of the height of the water onshore observed above a reference sea level.

Contrary to many artistic images of tsunamis, most tsunamis do not result in giant breaking waves (like normal surf waves at the beach that curl over as they approach shore). Rather, they come in much like very strong and very fast tides (i.e., a rapid, local rise in sea level). Much of the damage inflicted by tsunamis is caused by strong currents and floating debris. The small number of tsunamis that do break often form vertical walls of turbulent water called bores. Tsunamis will often travel much farther inland than normal waves.

Do tsunamis stop once on land? After runup, part of the tsunami energy is reflected back to the open ocean. In addition, a tsunami can generate a particular type of wave called edge waves that travel back-and forth, parallel to shore. These effects result in many arrivals of the tsunami at a particular point on the coast rather than a single wave suggested by Panel 3. Because of the complicated behavior of tsunami waves near the coast, the first runup of a tsunami is often not the largest, emphasizing the importance of not returning to a beach several hours after a tsunami hits. For more information on tsunami preparedness, see tsunami links.



http://walrus.wr.usgs.gov/tsunami/basics.html
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