THE ENDLESS VOYAGE

"Look Out Below" Episode 114

Many of these houses have been there for decades, if not centuries, but eventually, as a result of sea level rise and storms, the shoreline is going to catch up with these structures.

So if we melt off the ice in Antarctica, all the coastlines will move inland and drown cities. They'll drown island nations. There are some whole countries that are very near sea level that will just be drowned.

The damage that's done, and the terrible wounds that are inflicted on people during the tsunamis is due in large part to the ability of the tsunami to pick up debris such as boulders, automobiles, trucks, boats—and slam that into buildings, and people as well, with tremendous force.

NARRATOR:
A CLEAR, CALM DAY ON THE OPEN OCEAN. WAVE AFTER WAVE, ONE SEEMINGLY NO DIFFERENT FROM THE NEXT, ROLLING ALONG TOWARDS AN INEVITABLE AND GENERALLY UNEXCEPTIONAL END, ON SOME DISTANCE BEACH. BUT THERE ARE TIMES, HOWEVER INFREQUENT, WHEN APPARENTLY ORDINARY WAVES CONCEAL AN UNPARALLELED CAPACITY FOR DEVASTATION, AS THE RESIDENTS OF OKUSHIRI, JAPAN DISCOVERED IN 1993.

FRANK GONZALEZ, Ph.D., National Oceanographic & Atmospheric Administration (NOAA):
In 1993, in the Sea of Japan, there was a large earthquake. Now this is an inland sea. In that inland sea was a small island—really a small resort island that was called Okushiri. At the southern end of that island was a small town called Aonae, with upwards of 4,000 residents or so, and on an exposed peninsula, perhaps 200 homes and businesses.

NARRATOR:
BUT IT WASN'T THE EARTHQUAKE ALONE THAT FOREVER CHANGED THE LIVES OF THE PEOPLE WHO LIVED IN THAT TOWN. IT WAS THE WALL OF WATER THAT FOLLOWED.

GONZALEZ:
When that tsunami occurred, within 10 minutes or so a wave probably 20 meters high—because we measured this after the fact—struck the south and east and west coast of the island and inundated Aonae, killing more than 200 people.

NARRATOR:
THE NOTION THAT SUCH A DESTRUCTIVE TORRENT OF WATER CAN BEGIN AS BARELY A RIPPLE ABOVE THE SURFACE, THOUSANDS OF MILES AWAY

FROM ITS ULTIMATE DESTINATION, WOULD SEEM TO DEFY LOGIC. BUT IN FACT, QUITE OFTEN THAT IS JUST WHAT HAPPENS.

RICK LOZINSKY, Ph.D., Fullerton College:
Tsunamis are very fast in the open ocean, where there's deep water. They can easily keep up with a commercial jetliner in terms of their speed—over 400 miles an hour. And that makes a tsunami very capable of actually crossing an ocean basin like the size of the Pacific, in—within 20, 25 hours.

ANTONY ORME, Ph.D., University of California, Los Angeles:
Now tsunami waves are such that they have exceedingly long wavelength, and because the behavior of waves is related to their length, they generally behave as shallow water waves even in the deep ocean. And the result is that in the deep ocean, they may not be observable very readily. They may be a few centimeters, perhaps a meter or so in elevation, and they may pass beneath ships with barely a recognition.

STUART WEINSTEIN, Ph.D., National Oceanic & Atmospheric Administration (NOAA):
So in fact, really, one of the best places to be, if not the best place to be during a tsunami event, is to actually be in a deep ocean. You won't even feel it.

And as the tsunami propagates, it moves the water underneath it in a current, back and forth, because it's a wave. In deep water that current is very weak because the movement is spread over several miles.

But it's when a tsunami hits shallow water that things start to change.

The same volume of water has to be squeezed into a smaller and smaller depth. So the only way to move that volume of water back and forth is to speed it up. And you can have incredible current speeds as a tsunami comes into shore.

As it starts approaching shore and the depth of water starts to decrease, the bottom of the wave actually starts dragging on the surface, and this causes the wave to slow down.

So the waves in the rear are moving faster than the waves in front. So what you have is kind of an accordion effect. They shrink or shorten the actual length of these waves. And so that also creates, if you will, a kind of a piling up effect.

And as a wave starts to slow down, it'll go from like 400 miles an hour down to highway speeds, like 50, 60 miles an hour. Well, with that energy being slowed down, the wave will start to build up, because it's trying to conserve energy. And because they're slowing up, they'll start to bunch up, and these, particularly in harbors that have a funneling effect, they narrow. It focuses all that energy to one place, and that could cause a wave that's out in the open water to be maybe a bump of about two feet in height, to grow to heights up to 100 feet when it hits some of these special coastal areas.

The wave height increases so that, in fact, you have a shallow water waveform that rears up, and can move on shore with enormous speed and with great devastation.

They can have a long run-up, where they can go inland for several hundred feet, maybe up to almost a half a mile, depending on how flat the land is that they're moving over. And they don't just come in as one single wave. There's a train of waves that's following them. So over a period of time like eight, 10, 15 minutes, the water just gradually gets deeper and deeper. So it's just not one wave moving. It's like a temporary change of sea level that's moving in and then moves back out. So it's very, very damaging. Knocks buildings down, bridges out, anybody in the way gets swept inland and then out in the sea again. So it's just a horrifying experience for anyone that's caught in it.

NARRATOR:
MANY PEOPLE MISTAKENLY USE THE TERM TIDAL WAVE TO DESCRIBE ONE OF THESE EVENTS, INSTEAD OF TSUNAMI, WHICH LITERALLY MEANS "HARBOR WAVE." IN FACT, TSUNAMIS HAVE NOTHING TO DO WITH THE RISE AND FALL OF THE TIDES.

LOZINSKY:
Tidal waves are associated with the gravitational pull of the moon and the sun on the earth, causing bulges within the ocean, and this is not a tsunami.

Tsunamis are actually very special ocean waves that are triggered by vertical—uplift of the ocean floor. And this creates a disturbance on the surface as a wave or a series of waves that can propagate out in all directions, very similar, but to a much smaller degree or scale, as you would throw a pebble into the water and watch the ripples move away.

LAURA KONG, Ph.D., National Oceanic & Atmospheric Administration (NOAA):
Tsunamis also have nothing to do with surf waves, or wind-generated waves. In particular, tsunamis are what's called shallow water waves, which means that their wavelength is much longer than the depth of water. In contrast, surf waves might have wave periods of, say, tens of minutes and wavelengths of several hundred meters. Tsunamis, on the other hand, would have wave periods of maybe several minutes to maybe a couple of hours, and wavelengths of several hundred kilometers to much more.

The other characteristic is that tsunamis are fundamentally different in that the energy of a tsunami extends from the surface of the water all the way down. That is, the entire water column is energized by the tsunami. Whereas for example, wind-generated waves, the energy is mostly just contained in the upper two or three feet. The fundamental difference between that kind of a wave and a tsunami is that in a tsunami, because the energy's contained over the entire water column, it's really the entire water column that's moving. So you can't duck a tsunami wave. Okay, so if you were to try to duck a tsunami wave, or dive into the tsunami wave, the only thing that would happen is that the tsunami wave would pick you up and carry you inward. It would not pass over you.

NARRATOR:
UNLIKE WIND WAVES, WHICH AS THEIR NAME SUGGESTS, ARE GENERATED PRIMARILY BY THE WIND, TSUNAMIS ARE USUALLY THE PRODUCT OF A TECTONIC EVENT.

ORME:
Tsunamis are generated by—normally by under water disturbances associated with earthquakes, submarine volcanic eruptions or submarine landslides. Sometimes they may be caused by coastal landslides and coastal features on land, but sufficient to generate a wave or a wave train.

LOZINSKY:
Probably the most famous occurred in 1883, when Krakatoa erupted. It created a large tsunami over 100 feet high, or a series of them, that crashed on o the shoreline of Java that killed over 30,000 people.

NARRATOR:
WHILE TSUNAMIS CAN RESULT FROM ANY NUMBER OF TECTONIC EVENTS, PACIFIC BASIN EARTHQUAKES ARE FREQUENTLY THE DRIVING FORCE.

This is an area that is a hotbed for large earthquakes that can generate tsunamis, that can generate landslides, which create tsunamis and also because of the tremendous friction that's generated when these plates rub up against each other.

WEINSTEIN:
It's no accident the largest earthquakes recorded in modern history would come from the Pacific basin. You know, the 1960 Chilean earthquake, the 1964 Anchorage earthquake, there's the Kamchatka earthquake in '57—that's one of the top five in terms of the energy release. So the Pacific is very special.

NARRATOR:
ANOTHER REASON FOR THE GREATER FREQUENCY OF TSUNAMI EVENTS IN THE PACIFIC IS COASTAL TOPOGRAPHY.

LOZINSKY:
There are some coastal areas that are much more susceptible to generating the larger wave fronts—places like Hilo, Hawaii or Crescent City, California, where we've seen some large tsunamis that hit. Again, they have areas where the ocean water gradually shallows out, and so there's more time for the wave to slow down and to start building up. In areas where the coastline is very deep and then suddenly comes online, the wave doesn't have enough time to really drag and slow down and to bunch up and build.

NARRATOR:
IN 1948, TWO YEARS AFTER HILO, HAWAII, WAS HIT BY A TSUNAMI THAT KILLED OVER 150 PEOPLE, THE PACIFIC TSUNAMI WARNING SYSTEM WAS ESTABLISHED.

RICHARD LOZINSKY, Ph.D., Fullerton College:
This was a tsunami that was generated by an earthquake in Alaska, and many geologists, oceanographers felt that we can set up certain kind of monitoring systems, based on earthquakes, to tell when a tsunami has been generated from these earthquakes, and give people warning that they can evacuate. So that's really what prompted it. We now have the tsunami center located in Hawaii, but they've also centered another one out of Alaska.

STUART WEINSTEIN, Ph.D., National Oceanic & Atmospheric Administration (NOAA):
And the Alaska Tsunami Warning Center has responsibility for Alaska and the Aleutian Islands and the west coast United States. And we cooperate with them. We exchange data, and for large earthquakes in the Pacific, then we coordinate, you know? We compare locations. We compare estimates of the earthquake magnitude. And then when we send out messages, you know, we will have the same information in our messages because of this kind of coordination. The greatest success of the tsunami warning system actually occurred back in the 50s, in the '52, the '57 tsunamis. I think the '52 tsunami was generated in Kamchatka and the '57 tsunami was another Aleutian event. These were very destructive tsunamis and nobody was killed. So it did cause a lot of damage, but it would have caused a lot of death had there been no tsunami warning system.

NARRATOR:
IN THE MID 1990s, FOLLOWING A SMALL TSUNAMI GENERATED BY A NORTHERN CALIFORNIA EARTHQUAKE, NOAA, THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, ESTABLISHED THE NATIONAL TSUNAMI HAZARD MITIGATION PROGRAM.

FRANK GONZALEZ, Ph.D., National Oceanic & Atmospheric Administration (NOAA):
The program itself is divided into three major efforts aimed at reducing the hazards due to tsunamis. The first one is called hazard assessment, and that basically just means you look at a community, and try to estimate what the hazard is to that community. And the technology that's brought to bear on that, besides good common sense—you know, do they have a history of tsunamis there? But to get a good, quantitative assessment, the technology that's brought to bear is the use of computer models—numerical simulations—to produce "what if" scenarios.

NARRATOR:
THE SECOND COMPONENT OF NOAA'S TSUNAMI PROGRAM DEALS WITH HAZARD MITIGATION. IT CONSISTS OF BOTH STATE AND NATIONAL PARTNERS, INCLUDING FEMA, THE FEDERAL EMERGENCY MANAGEMENT AGENCY, WHICH IS RESPONSIBLE FOR REDUCING THE LOSS OF LIFE THAT

RESULTS FROM ALL NATURAL DISASTERS, INCLUDING TSUNAMIS. AMONG THE MORE IMPORTANT TOOLS USED IN THE HAZARD MITIGATION PHASE ARE INUNDATION MAPS.

WEINSTEIN:
Inundation maps are constructed on the basis of past historical tsunami information. They're constructed using the results of some numerical modeling. And that information is put together, and these inundation maps are generated, and they basically indicate the areas that are at most risk from a tsunami.

This information is then handed over to emergency managers in a state. Those emergency managers can generate what are called hazard mitigation products from that scientific information. A good example is an evacuation map—what routes should people take away from dangerous areas? What are the safe places that they can gather? Where is food and clothing stashed? They can also use these maps and the evacuation maps to mount educational and outreach programs, which are very, very important.

And in Hawaii, the inundation zones are actually published in the phonebooks. So there's really no excuse for a local resident not to know what to do in the event of a watch warning. So that is the value of these inundation maps—they basically tell us which areas need to be evacuated.

NARRATOR:
HAZARD MITIGATION ALSO TAKES THE FORM OF BUILDING CODES IN JAPAN AND HAWAII THAT HAD BEEN REVISED WITH TSUNAMIS IN MIND.

WEINSTEIN:
For example, many of the newer structures in Hawaii—for example, hotels that are built near the ocean front—they have a special feature in that they're designed such that the water can actually flow through the first two or three floors, and therefore reduces the load on the building. So that's one way to mitigate property damage is by being clever about your design.

NARRATOR:
FINALLY, THE THIRD ELEMENT OF NOAA'S PROGRAM IS THE WARNING SYSTEM THAT PROVIDES NOTIFICATION IN ADVANCE OF A SUSPECTED TSUNAMI.

GONZALEZ:
As soon as an earthquake occurs, warning centers begin to monitor tide gauges along the coast, and also the deep ocean gauges that we call "DART."

LAURA KONG, Ph.D., National Oceanic & Atmospheric Administration (NOAA):
And they're primarily deep ocean tsunami sensors or deep ocean water pressure sensors. And what these buoys do is there is a sensor at the bottom of the ocean, and they are sensitive enough to measure changes in basically water pressure, but what it translates to

is changes in wave height at the bottom of the ocean. And they're what we call triggered, so that if there is a tsunami wave of greater than a certain height, the buoy will say, "I better report this" and via satellite it would send its transmission to the go satellite, which I believe it goes through Wallop's Island on the east coast, and it actually comes back to the warning centers in real time. And based on whether they see a tsunami on those buoys, that would be another way to confirm whether a tsunami has occurred or not.

NARRATOR:
TSUNAMIS MAY BE THE MOST DRAMATIC EXAMPLE OF WHAT A RISING WALL OF WATER CAN DO. BUT THERE'S ANOTHER WAY IN WHICH WATER ON THE RISE CAN HAVE AN IMPACT, ONE THAT OCCURS MUCH MORE SLOWLY, BUT THAT ULTIMATELY MAY BE FAR MORE SIGNIFICANT THAN AN ISOLATED TSUNAMI EVENT.

CHIP FLETCHER, Ph.D., University of Hawaii at Manoa:
Today, we do know that sea level is rising. It's rising on the order of 1.8 to 2 millimeters per year. That is a higher rate of rise than has been experienced over the last century or two. There are projections based on computer models of global warming in the future that sea level will not only continue to rise, but that it will accelerate its rate of rise, and that we have actually put enough heat into the oceans and into the atmosphere that we're currently committed to a sea level rise on the order of several centuries.

NARRATOR:
WHILE RISE IN SEA LEVEL OF TWO MILLIMETERS ANNUALLY MAY NOT SOUND ESPECIALLY WORRISOME, IF SUCH A TREND CONTINUES, THE RESULTS COULD EVENTUALLY BE QUITE SERIOUS.

The effect of rising sea level, or change in sea level on a shoreline, would be the first order to either flood or withdraw from the shoreline. It's interesting to note that there are enough shorelines in the world that are currently on the cusp, if you will, between emerging and submerging that future projections for sea level rise may cause a number of shorelines to go from formerly emerging to, in the near future, submerging.

TANYA ATWATER, Ph.D., University of California, Santa Barbara:
One thing that a lot of people don't realize is that the coast is a very arbitrary thing. When we think about continents and oceans, we think the beach is the difference, but it's not. For a geologist, the edge of the continent is the continental shelf. That's where you go from thick crust to thin crust. And it just depends how much water is in the ocean right now, that is, whether some is saved in ice in glaciers or other things. It just depends on how much water there is in the ocean, how much it laps over the top of the continent.

REINHARD FLICK, Ph.D., Scripps Institution of Oceanography, UCSD:
And this is especially true over very long periods of time—that is, periods of time longer than hundreds of years, into the length of thousands of years or tens of thousands of years. Over those kinds of geological time periods of thousands of years to tens of

thousands of years, the rise and fall of sea level is the most important factor in determining the location of the shoreline.

NARRATOR:
GIVEN CURRENT POPULATION TRENDS IN THE UNITED STATES, SHORELINE LOCATION IS A SIGNIFICANT ISSUE.

FLETCHER:
On the order of 80% of the U.S. population lives in coastal counties, and since World War II there's been a national migration away from the interior of the United States out towards the coastlines. We have a national, indeed it's a global problem, with the development of our shorelines in a way that's not really compatible with coastal processes. This takes two forms: one is that we are building expensive infrastructure—sewage delivery systems, highways—and we are also building our homes and cities in the pathway of very high energy, dangerous marine processes, such as hurricanes, tsunamis, and those that are not quite so life-threatening such as erosion—passive coastal erosion that takes place. And, of course, future sea level rise.

NARRATOR:
THE PRECISE ROLE THAT GLOBAL WARMING PLAYS IN DETERMINING SEA LEVEL IS A SUBJECT OF CONSIDERABLE CONTROVERSY, BUT MANY SCIENTISTS BELIEVE THERE IS A CLEAR LINK.

MICHAEL FOSTER, Ph.D., Moss Landing Marine Laboratories, CSU:
That heating of the atmosphere and the ocean is going to contribute to the melting of glaciers and ice packs, and, in fact, that is being very well-documented almost on a daily basis in science magazines. The loss of glaciers, retreats of glaciers, in many parts of the world. The ultimate result of that is exactly what happened in the Pleistocene, when it was a warm period in the earth's history. Those melt—well, that water goes into the ocean and sea level rises as a result. There's a surprising amount of water stored in glaciers around the earth. And so sea level will rise. That has immediate consequences for anybody that has oceanfront property. It'll be underwater. The amount of the rise is a bit uncertain, but certainly it's going to be maybe on the order of tens of feet. It's going to have huge consequences for some nations in which much of their country is just slightly above sea level—large parts of Indonesia, for instance.

LEE-LUENG FU, Ph.D., Jet Propulsion Laboratory:
So a slight change of the sea level can erode beaches and a large amount of the sea level change, for instance, one meter of sea level change probably can displace tens of millions of people in places like Bangladesh.

ROSS HEATH, Ph.D., University of Washington:
The period we're in now is warmer than it's been for over a hundred thousand years. So people who ask about global warming, for example, can look at the geologic record and say, you know, "No, this isn't just a normal variation that, you know, occurs every few thousand years. This hasn't happened before for a very long time."

NARRATOR:
SCIENTISTS, PUBLIC OFFICIALS AND OTHERS CONTINUE TO DEBATE THE ROLE OF GLOBAL WARMING, AS WELL AS THE DEGREE TO WHICH HUMAN ACTIVITIES MAY CONTRIBUTE TO THIS PROCESS. WHAT IS WIDELY AGREED UPON, THOUGH, IS THAT HOWEVER IT OCCURS, A SIGNIFICANT RISE IN LONG-TERM SEA LEVEL MAY EVENTUALLY HAVE DIRE CONSEQUENCES. AND WHAT MAKES SEA LEVEL RISE EVEN MORE OMINOUS IS THAT IT DOESN'T TAKE PLACE IN A VACUUM—ITS IMPACT CAN BE COMPOUNDED BY ACCOMPANYING TECTONIC ACTIVITY.

ERIC TERRILL, Ph.D., Scripps Institution of Oceanography, UCSD:
One of the things to bear mind is many parts of the coastline are geologically active. So, in fact, you can have the actual land surface rising or lowering because of geological processes. The end result is the same.

JAMES O'CONNELL, Woods Hole Oceanographic Institution:
In many areas around the globe, eustatic sea level is rising worldwide at approximately four to six inches every 100 years. As it rises, it inundates the land mass and moves the shoreline landward. But to consider where the shore will end up, you better take the land mass movements into it as well. For example, in Massachusetts the land mass is sinking. And it's sinking approximately twice as fast as the worldwide sea level is rising.

NARRATOR:
FURTHER SOUTH ALONG THE EASTERN SEABOARD, SEA LEVEL RISE IS BEING ACCELERATED BY GEOLOGIC REACTIONS TO AN ANCIENT CONTINENTAL GLACIER THAT WAS AT ONE TIME LOCATED IN THE CAPE COD AND LONG ISLAND AREAS.

CHIP FLETCHER, Ph.D., University of Hawaii at Manoa:
And that's because directly in front of the ice sheet there was a bulge in the crust, an upward bulge in the crust due to the weight of the ice pushing down under the northeast states. Now that the ice has been removed, that bulge is deflating and so the land is actually tectonically, or glacial-isostatically going down, while modern sea level is going up.

NARRATOR:
GIVEN THE OBVIOUS IMPORTANCE OF MONITORING LONG-TERM SEA LEVEL CHANGE, SCIENTISTS HAVE DEVOTED CONSIDERABLE RESOURCES TO COMPARING CURRENT LEVELS TO THOSE OF THE PAST. BUT THAT HASN'T ALWAYS BEEN EASY.

FLICK:
One of the big problems in trying to sort out trends in past sea level changes—global sea level changes—has been the inability to measure sea level at lots of places over the ocean. Almost all of the sea level measurements that we rely on to talk about global

change, you know, global sea level increases, come from the tide gauge networks that are located on coastlines and on a very few mid-ocean islands, like Hawaii, for example. The fact that we can now make ocean elevation change measurements from satellites is a very big deal, because we can cover the entire ocean. This has not only benefits for the long-term change in sea level, but also for relatively short-term changes in sea level. For example, those associated with El Niño, and these important fluctuations in weather patterns and climate-related variability due to changes like El Niño, and tropical effects that have sea level signatures.

NARRATOR:
AS WE WITNESS THE ONGOING IMPACT OF DYNAMIC EVENTS AND PROCESSES LIKE TSUNAMIS AND SEA LEVEL FLUCTUATION, ONE POINT IS UNMISTAKABLE—THE SAME OCEAN THAT PROVIDES US WITH FOOD AND MODERATES OUR CLIMATE CAN AND OFTEN DOES DRAMATICALLY ALTER THE VERY FACE OF THIS PLANET IN WAYS THAT EXCEED ANYTHING WE CAN EVEN IMAGINE.

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