THE ENDLESS VOYAGE

"Surf's Up" Episode 113

The main impact of waves that we feel as humans, or mankind, is at the shoreline, at the coast. That's where we—most of our impact of waves are going to be felt.

Well, it became clear early in World War II that amphibious landings would have to be concerned about the intensity of wave action on the beaches. If the waves were very high, you would have severe losses just from the landing operation itself.

There's been a long history in maritime history of ships rounding the cape and encountering extreme waves. And many ships have been lost at sea rounding the cape.

NARRATOR:
THE PERFECT WAVE—LONG THE HOLY GRAIL FOR SURFERS AROUND THE WORLD. OF COURSE, WAVES DO MUCH MORE THAN SIMPLY PROPEL AQUATIC THRILL-SEEKERS TO NEW HEIGHTS OF ADVENTURE. THEY SHAPE THE EDGES OF THE VERY LANDFORMS WE INHABIT, AND ARE FOR MOST PEOPLE THE ULTIMATE SYMBOL OF THE MARINE ENVIRONMENT.

ROBERT GUZA, Ph.D., Scripps Institution of Oceanography, UCSD:
The sort of ocean waves that I think most of us imagine when we hear the word "ocean wave" is a surface gravity wave, which is also known as a wind wave.

SAM IOCABELLIS, Ph.D., Scripps Institution of Oceanography, UCSD:
When I say wind waves, I'm talking about waves that were created by the wind, the force of the wind blowing over the water. Friction between the wind or the air and the water that produces the waveform.

GUZA:
Depending on the strength of the wind and how long the wind blows for and the area that the wind blows over, waves can be short, choppy ones—and by short and choppy, we might mean the wavelength is short. What do we mean by wavelength? It's the distance between two crests—the high point on waves. There's a trough, that's the bottom and a crest that's up at the top. Well, the distance between two crests is the wavelength. Suppose you sit in one location, and you just watch waves come past you. If a wave comes by every second—a crest comes by every second, it's at the period. The wave period is one second. Well, the wave period can be one second or five seconds, or 10 seconds. And the thing that determines the speed of waves, how fast the crests move, is the waveperiod and the water depth.

NARRATOR:
WHILE THE NOTION THAT MOST WAVES ARE GENERATED BY WIND BLOWING OVER THE OCEAN'S SURFACE SEEMS FAIRLY

STRAIGHTFORWARD, A WAVE’S EXACT POINT OF ORIGIN IS OFTEN MUCH LESS OBVIOUS.

IACOBELLIS:
Where the waves are formed, of course, you need wind, but these waves can move along the water surface a great distance away from where they are formed, away from the storm.

GUZA:
Just like dropping a stone into a pond, the waves radiate away from the place you dropped the stone.

So if we see waves breaking on our beach on a calm day, they were still formed by wind, but they may have moved thousands of miles away from the source.

In our summer, it’s not very windy here at all. So we don’t have very much wave generation. But in the southern hemisphere it’s windy. In fact, it’s very windy down in the southern southern ocean—40, 50, 60 south, huge storms. Those storms radiate waves, and it takes them five to seven days, but they propagate all the way from the southern ocean up to Southern California.

ROGER LUKAS, Ph.D., University of Hawaii at Manoa:
They transfer not water but energy from distant sources to other locations. So, for example, a storm off the coast of New Zealand can send energy all the way up to the coast of California, and the waves, when they actually break off the coast of California, move water in towards the beach and alter the beach environment by causing erosion, causing rip currents.

NARRATOR:
THE NOTION THAT WAVES TRANSFER ENERGY RATHER THAN WATER IS PERHAPS SOMEWHAT COUNTER-INTUITIVE, BUT WHEN WAVE MOTION IS BROKEN DOWN AND ANALYZED, THE PRINCIPLE BECOMES CLEAR.

Take a wave, say, of about two feet height, and that’s from the trough of the wave to the crest, that two feet describes the diameter of a circle that the water particles make. In a very good approximation, the particles start in one place and trace a circle and end up almost exactly where they started. Yet the waveform moves, and quite clearly we can see it move. So the waveform, which has the—contains the energy, is moving, but the water particles, although they move, they only move a very short distance and come back to where they started, except when the wave encounters shallower water and begins to break.

NARRATOR:
IN MOST CASES, WAVES NEVER TOUCH BOTTOM UNTIL THEY REACH THE END OF WHAT IS OFTEN A LENGTHY JOURNEY.

GUZA:
Eventually, they're going to hit a continent, and what happens to the wave is, it proceeds into shallower water until the depth is approximately equal to a wavelength.

IACOBELLIS:
And eventually will feel the bottom to such an extent that it slows down, and the top part of the wave doesn't slow down, so it breaks. If it's typical of a long period wave, it kind of comes up on a relatively smooth way, and it kind of percolates down through the sand if there's a sandy beach, or cobbles if it's a cobble beach, and kind of goes back out to the ocean, kind of a relatively slow, peaceful progression. If it's in the middle of a storm when you have lots of short period waves beating on the beach, a lot of times that's kind of—you get the swash back and forth and doesn't percolate down, but it takes the beach with it as it's moving back. So that can also lead to rip tides, rip currents, different long shore currents along the beach.

ANTONY ORME, Ph.D., University of California, Los Angeles:
Rip currents are high velocity components to the seaward return flow that may have velocities of one, two or three meters per second. These are very, very swift currents. They actually penetrate back through the breaker zone, often at intermediate depths, sometimes along the bottom and eventually, they dissipate beyond the breaker zone. They're obviously a problem for swimmers. If you get caught in a rip current, it's easier said than done, but one of the things that you might well do is not struggle too much, but simply let the rip current take you out through the breaker zone. And, of course, it usually disperses beyond the breakers, then you swim to the side and you can swim back in. But that's all right for the bold swimmer. It's not so good if your little child is in the surf zone. Obviously, one must be very alert to the presence of rip current.

NARRATOR:
AS WITH RIP CURRENTS, NEARLY ALL OF THE EFFECTS OF WIND WAVE ENERGY ARE FELT ALONG THE SHORELINE.

IACOBELLIS:
Occasionally you get a large wave hitting the coastline. But one wave won't really hurt the coastline too much, as far as the beaches are concerned. It's usually large amounts of waves over a long period of time that will erode a beach. Now that we're building homes closer and closer to the beach, we've got to take into consideration the actions of the waves and how that erodes beaches.

GUZA:
For as long as there's been waves and sandy beaches, sand has moved by waves from one place on the beach to another. And this can lead to rotations in the coast. One part of the coast will build out and another part will erode. So it actually changes the orientation of the coast. And this is not in itself bad. It's a completely natural process, just as a flood is a completely natural process. For humans it can be a substantial problem, because we may have established houses on a particular stretch of coast, and the homeowners object to becoming underwater.

NARRATOR:
AS IMPORTANT AS WAVES BREAKING ON THE SHORELINE MAY BE, THEIR IMPACT CAN ALSO BE FELT OUT IN THE OPEN OCEAN.

IACOBELLIS:
A little further out to sea, we’re building oil rigs. Occasionally we get huge waves out there, and we want to make sure that what we’re doing is safe for the environment, of course, and for the people who work on these structures. Ships in the middle of the ocean, they have to encounter waves at all times. Most of the time a decently built ship won’t have any problems, but there are occurrences of rogue waves, and larger seas during a storm. We’re pretty good at predicting storms these days, so we know we can tell ships if they have radio communication, avoid these areas. But rogue waves tend to kind of show up unannounced and they’re very hard to predict.

What’s usually meant by a rogue wave is a wave that is much larger than other large waves. Maybe the average wave height is 10 foot and one wave is 30 foot. That might be called a rogue wave.

Rogue waves are really just another way of talking about statistically extreme waves. And these are the very highest waves that are observed. And there’s a number of causes.

They’re usually in an area of active storm or where waves are being formed in seas as opposed to a swell. That’s not always the case, but that’s generally the case. And in seas, we have waves of different period, different wavelengths, all combining and all moving in different directions. You can imagine at times the interference—you get constructive interference of several waves together, that might create a very large wave. And it’s all a statistical process, like a happenstance, and sometimes when everything happens together, you get a large wave.

LUKAS:
Out in the real ocean, you don’t have just a simple one wave running along. You have a superposition of many waves. And waves can add together transiently just for a brief period of time in one location in such a way that they can be extremely high. Another way that you can get an extreme wave is when waves encounter an opposing current.

ROBERT GUZA, Ph.D., Scripps Institution of Oceanography, UCSD:
This can happen at the outflow of large rivers like the Columbia River, and can create extremely dangerous situations. The waves can’t propagate their energy upstream against the current. Something has to happen to that wave energy, it can’t get upstream. The waves buck up and they lose their energy by breaking.

These things occur for example, in the Agulhas Current, offshore of South Africa, and these waves have actually broken ships apart.

SAM IACOBELLIS, Ph.D., Scripps Institution of Oceanography, UCSD:
The Agulhas Current occurs right on a continental shelf which is a very steep and very drastic change in depth. And we think that these waves interacting with the depth and the current can really concentrate wave energy, and so that's an area where ships are warned to beware.

LUKAS:
Another source is in thunderstorms out at sea. You can have extremely large rainfalls and heavy downdrafts of air that when they hit the sea surface, they spread sideways, and these gust fronts can have winds which are 60, 70, 80 miles an hour, and these generate waves. The largest wave which has been accurately measured is 112 feet, and this was measured, I believe, in the 1930s from a U.S. Navy ship in the North Pacific.

NARRATOR:
WIND WAVES THAT BREAK ON SHORE MAY BE THE MOST FAMILIAR VARIETY OF OCEAN WAVE. AND ROGUE WAVES THAT REACH IMMENSE HEIGHTS MAY BE THE MOST DRAMATIC. BUT THERE ARE OTHER WAVES, WHICH MOST OF US NEVER SEE, THAT CAN BE OF EXTRAORDINARY IMPORTANCE. THEY ARE KNOWN AS INTERNAL WAVES.

IACOBELLIS:
Wind waves that we're most familiar with are the ones that travel on the surface of the water and the atmosphere. And for scientific purposes, for physics, the atmosphere is a fluid. It just has a much different density than the water. I mean, 1,000 times lighter. Internal waves form between two different fluids of different density, much like surface waves, but in the internal waves, the two fluids are both water. Typically, we have the water on top is less dense, and then you might have more dense water underneath, and in between that is what we call a thermocline or a stratification region. And internal waves will travel along this region of quickly changing density, much like wind waves will travel on the surface.

Internal waves are important because, when they break, you don't see them because they're not at the surface. They're at the boundary between white fluid and dense fluid. And their amplitudes can be very large, 50 meters from the crest of an internal wave to the trough. 50 meters, 150 feet, that's large indeed. And they break similar to the way that surface waves you see break. That is, they steepen up and then they roll up. Well, what they do when they roll up is mix the ocean. And the internal waves are probably very important in mixing the ocean and transferring energy from the wind or solar into mixing in the ocean, at least in the upper parts of the ocean. And internal waves can propagate horizontally, vertically—they're much more complicated than the sorts of surface gravity waves that we see.

NARRATOR:
CLEARLY, WAVES INFLUENCE PLANET EARTH IN MANY DIFFERENT WAYS—ALTERING THE COASTAL LANDSCAPE, CHALLENGING MARINERS, AND ACTIVELY PARTICIPATING IN THE GLOBAL CLIMATE SYSTEM. FOR

ALL THESE REASONS, OCEANOGRAPHERS HAVE LONG RECOGNIZED THE IMPORTANCE OF GAINING A GREATER UNDERSTANDING OF THIS VERY DYNAMIC ASPECT OF THE MARINE ENVIRONMENT, BUT INTEREST INTENSIFIED FOR STILL ANOTHER REASON IN THE EARLY TO MID 1940s.

GUZA:
Surf zone wave and currents really became of national interest during the Second World War, and this was because the U.S. and our allies were involved in amphibious landings, for example, D-Day. And questions of how large the waves were and where they would be large and where they would be small were questions that hundreds of thousands of lives hinged on.

WALTER MUNK, Ph.D., Scripps Institution of Oceanography, UCSD:
You wanted to pick days when the waves were relatively low, just as you want to pick weather which is favorable. There had not been any serious attempt of predicting waves prior to the war. And I was involved together with the then Director of Scripps, Harald Sverdrup, in attempting to work out a method of predicting waves. Surface waves are caused by winds, period. And so it's a question of starting out with knowing the size of existing storms, how intense they were, how large the area was, in which the direction the wind blew, to calculate—estimate—how high the waves would be would be generated. And then finally, you have to know something about the configuration of the landing beaches to calculate how the incoming waves would be transformed by shallow water.

Obviously, a landing craft that is flipped upside down in the surf zone is going to be a disaster in terms of not fulfilling their mission. And it was the U.S. Navy that actually started some of the research. Most of the research in the United Starts was started on surf zone waves and currents—was started during the Second World War as part of trying to better plan amphibious landings.

You know that the wave climate on a certain beach is such that your ability to land is fair in the month of June and poor in the month of November. That's a statistical statement, and you do your strategy on that basis.

Ocean waves have a climate similar to the way that continental locations have a weather climate.

ROGER LUKAS, Ph.D., University of Hawaii at Manoa:
Wave climatology is really something about the statistical nature of the waves that are encountered say, at a coastline, and how those statistics change over the seasons. And we all know that in the wintertime that we have winter storms, we tend to see large surf and very stormy conditions. And during the summer, it's generally a lot more calm. Now, the east coast and the west coast have very different wave climatologies, and principally because the winter storms move from west to east. So, that means they're approaching the west coast and they're leaving the east coast. And because waves are moving towards the west coast, the effect of fetch, or the distance over which waves are generated, is very long in the north Pacific. And so you get much larger waves typically on the west

coast in higher latitudes than you do on the east coast. That's not to say that the east coast doesn't see some big waves during a northeaster, for example. But generally speaking, the west coast has larger surf. So, depending on the strength of the wind and the size of the water body, it basically determines your wave climate. Just like in South Dakota, they have blistering hot summers and really frigid winters, in some locations the waves die down to virtually nothing in the summer, and then in the winter, the waves can come up to very large heights. So it can be very seasonal, depending on the seasonality of the winds.

NARRATOR:
BY FACTORING IN THE WAVE CLIMATE OF THE FRENCH COAST, ALLIED COMMANDERS WERE ABLE TO MAKE AN EDUCATED GUESS ABOUT THE BEST TIME TO SCHEDULE AN AMPHIBIOUS INVASION.

You don't plan to have a major amphibious operation, say, in November, on that beach. Then you give yourself enough leeway that you can wait a few days, and pick your precise day of landing on the basis of weather prediction. And that prediction cannot be done better than possibly a week in advance. In Normandy, for example, the waves were predicted to be unfavorable on the day of landing. The landing was postponed for one full day for that reason, with great concern about loss of security. Then, on the next day, the conditions were somewhat more favorable, but still not good, and General Eisenhower made the decision that the loss of another day would almost surely give away security, and decided to come in in spite of the fact that the situation was not favorable. But in the estimate of people who did the prediction, it was possible. And that worked out to be the correct prediction.

NARRATOR:
WHILE THE STAKES SURROUNDING WAVE PREDICTION MAY NEVER BE AS HIGH AS THEY WERE IN FRANCE, IN JUNE OF 1944, OCEANOGRAPHERS SINCE THAT TIME HAVE CARRIED ON THE EFFORT TO MONITOR AND BETTER PREDICT WAVE PROCESSES. ALONG THE WAY, THEY'VE DEVELOPED A NUMBER OF HIGHLY INNOVATIVE TECHNIQUES AND DEVICES.

GUZA:
There's a device called the pressure sensor, and it's mounted on the seafloor and it functionally weighs the amount of water that is on top of the sensor. If there's no waves, then that weight of water just stays the same over time. It doesn't change because it's the same amount of water, but as waves go past, it gets higher—the water columns—so the pressure goes up and then goes down. So it's a way of knowing what's going on at the surface without having something sticking up through the surface. There are wave height gauges. These are electric gauges that can tell how much of them is wet and how much of them is dry. So as the water goes up and down, it goes up and down the pole. The difficulty with surface-piercing gauges is with large, energetic waves in the surf zone, not much stands up for long. So many of the successful instruments that are used in the surf

zone can be mounted on the seafloor, pegged to the bottom on a pipe with a low profile, so they don't get hit by floating logs, surfers, or whatever else is out there.

NARRATOR:
AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY, THE COASTAL DATA INFORMATION PROGRAM UTILIZES FLOATING WAVE BUOYS THAT REPORT ON WAVE CONDITIONS UP AND DOWN THE COAST OF CALIFORNIA, AS WELL AS PARTS OF OREGON AND WASHINGTON. THE GOAL IS TO CREATE A MONITORING SYSTEM SIMILAR TO THAT USED FOR TERRESTRIAL METEOROLOGY.

ROBERT GUZA, Ph.D., Scripps Institution of Oceanography, UCSD:
These buoys measure wave height, wave direction, and they have onboard data loggers and transmitters. The data is transmitted from the offshore buoys back to shore, gobbled up by computers, and it's all gathered here at Scripps. And every half hour, CDIP program gathers data from buoys and then puts out on the Internet what the wave heights are at those locations. This is used for a variety of purposes, including what parts of a harbor entrance might be not a good idea on a particular day because the waves are too large.

NARRATOR:
AMONG THE VARIOUS INSTRUMENTS USED BY OCEANOGRAPHERS WHO STUDY WAVES ARE SATELLITE ALTIMETERS.

LUKAS:
And we can use that information to improve our models of how waves are generated and how they propagate around the globe. We're interested in wave breaking—not just in the coastal environment, but out in the open ocean, because when a wave breaks, that energy's turned into turbulence, which mixes things, and we want to understand that source of turbulence. Another area which is very important for societal applications, has to do with the generation of coastal currents and the dispersal of pollutants. Sometimes, for example, you spill oil, it'll cause the waves to stop breaking. But to the extent that, say, a chemical spill doesn't alter the wave breaking, the wave breaking mixes the chemical down. In the coastal environment, it's the most important area because the currents which transport the pollutants, you'd like to predict those currents, and they depend very strongly not just on the local winds, not just on the local waves, but also on the remote swells.

NARRATOR:
IN ADDITION TO THEIR ROLE IN LOCAL POLLUTION EPISODES, WAVES ALSO CONTRIBUTE TO GLOBAL ENVIRONMENTAL CONDITIONS.

LUKAS:
And what we are able to do is to actually relate the turbulence that we measure in the top three meters of the ocean to the wave environment. And so we're working to try and improve a model, a theoretical model, which relates that turbulence to the waves. And

this is important because it’s an additional source of mixing energy besides the direct force of the winds or the sheering of currents, which help to bring nutrients from the deeper part of the ocean back up into the surface layer so that plants can grow—phytoplankton. And this, of course, is the grass of the ocean, if you will, the primary production.

NARRATOR:
AS OCEANOGRAPHERS WHO STUDY WAVES LOOK TO THE FUTURE, THEIR GOAL IS TO BETTER UNDERSTAND THE FULL RANGE OF WAVE PROCESSES IN AS MANY LOCATIONS AS POSSIBLE.

A substantial amount of the research that’s been done on surf zone waves and circulation has been done in locations that were chosen for their simplicity—no big holes in the beach, no sea walls, no jetties sticking out. And that’s because one has to understand the simple before one can understand the complex. And I think that we’ve made a lot of progress as a community in understanding simple, idealized situations. I believe that the challenge is now to move from those simple, idealized situations into much more common, complex situations in order to really understand what’s happening on the range of beaches that we have, as opposed to a few carefully selected for their simplicity sights. So it’s moving from the ideal to the real. And part of that is to be able to better use the kind of wave information and circulation information on beaches to address problems, regional sand management, beach nourishment, questions of practical application to society. I think the scientists do have something to input into improving those processes. And I think that that’s some of the challenge we’re at now. Use what we’ve learned optimally.

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