THE ENDLESS VOYAGE

“Deep Connections” Episode 112

Early on it was thought that the deep ocean was stagnant, and there were no currents at the deep ocean. But we now know that strong currents exist throughout the ocean’s depths.

We see almost an ancient history of climate in some of the old water masses which are moving through the system.

The beautiful aspect of measuring ocean topography—it is a surface signature of deep ocean change.

NARRATOR:
FOR THE ANCIENT MARINERS WHO FIRST VENTURED INTO THE ATLANTIC AT GIBRALTAR, IT WAS APPARENT THAT THIS GREAT OCEAN WAS MORE THAN JUST A STAGNANT MASS OF STANDING WATER, THAT, IN FACT, IT FLOWED SOUTHWARD, ALMOST LIKE AN IMMENSE RIVER, POWERFUL ENOUGH TO DRIVE SAILING SHIPS OFF COURSE. TODAY, OCEANOGRAPHERS RECOGNIZE THAT CURRENTS PLAY A VITAL ROLE THROUGHOUT THE MARINE ENVIRONMENT, TRANSPORTING WATER, HEAT, AND NUTRIENTS TO EVERY CORNER OF THE WORLD OCEAN.

DAVID PIERCE, Ph.D., Scripps Institution of Oceanography, UCSD:
There’s a number of factors that influence both the surface ocean currents and the deep ocean currents. On the surface, you have the wind blowing. Obviously, you don’t have that on the deep ocean. But on the deep ocean, you have friction against the bottom, which you don’t have on the surface. Now, in both cases the Coriolis Effect—which is the way that things tend to go to the right in the northern hemisphere and if you push on them—that influences both the surface and the deep currents.

STEPHEN RISER, Ph.D., University of Washington:
Once you get below the surface, it’s clear that the primary driving mechanism is probably not the wind anymore. Below the upper few hundred meters, the primary driving mechanism is the difference in temperature, the difference in salinity between various parts of the ocean, which again set up differences in pressure which cause flows to be—to occur.

NARRATOR:
THE FLOW OF OCEAN CURRENTS FOLLOWS PREDICTABLE PATTERNS GOVERNED BY A VARIETY OF PHYSICAL FACTORS. FOR SURFACE CURRENTS, WHICH INCLUDE WATER FLOWING HORIZONTALLY IN THE UPPER 400 METERS OF THE OCEAN, WIND IS THE PRIMARY DRIVING FORCE. FOR DEEP OCEAN CURRENTS, THE MOST IMPORTANT FORCE IS

GRAVITY. COLD, SALTY, DENSE WATER SINKS TOWARD THE OCEAN BOTTOM.

PETER RHINES, Ph.D., University of Washington:
The deep circulation of the ocean is a complex pattern of arteries and mixing events which is connecting these very few sites of sinking—the far northern Atlantic and the rim of Antarctica—connecting them with topographically determined pathways which can be very, very long. And there are small basins in between where water can re-circulate for many years before going on to the next basin. It's a problem of hallways and chambers, if you like, with the deep circulation taking thousands of years to complete one circuit. Now, going back to the North Atlantic—the sort of rabbit hole down through which much of this global overturning circulation proceeds—we have to look even a little bit further north into the Arctic, because the Sub-Polar Seas—Labrador Sea and the Nordic Seas, between Greenland and Europe—are intermediate basins. And then one quickly encounters the Arctic basin itself, which is partially ice covered. And in these cold regions, where there's so many possibilities to transform water into very dense cold, and possibly salty water, we have a great opportunity for producing deep circulation, for producing the sinking that we see.

NARRATOR:
THE MOVEMENT OF WATER DUE TO DIFFERENCES IN DENSITY IS CALLED THERMOHALINE CIRCULATION. THIS PROCESS IS RESPONSIBLE FOR NOT ONLY THE VERTICAL MOVEMENT OF OCEAN WATER, BUT FOR THE CIRCULATION OF THE GLOBAL OCEAN AS A WHOLE.

PETER WEBSTER, Ph.D., University of Colorado, Boulder:
Generally, the most saline in the water is, the denser it is. The colder the water is the more dense it is. And so these form what are called thermohaline—thermo meaning temperature, and haline meaning the amount of salt-circulations. And that is changed by the amount of heating or cooling a particular ocean column has.

The deep circulation of the world ocean, where the wind really has a limited effect, the thermohaline circulation there is the whole story, really. And you can think about at the poles, where you're cooling the surface water enough in some places that you can actually make it sink all the way to the bottom to be convectively unstable. Or you can make it dense not by cooling but by, from sea ice, extracting the salt or adding the salt, you can make the surface water very dense—it can sink—and this can set up a deep circulation that can be felt throughout the entire world ocean.

It's sometimes thought about as a conveyor belt, which moves carrying warm surface waters to the Polar Regions. The water sinks in the Polar Regions, slides around at very deep parts of the world ocean, and then eventually rises back to the surface and soaks up heat, completing the circuit. And the whole circuit can take centuries or maybe even a thousand years for a water parcel to circulate through this whole thermohaline circulation.

RAYMOND W. SCHMITT JR., Ph.D., Woods Hold Oceanographic Institution:
The thermohaline circulation—its structure, the patterns—really depends on the distribution of continents and the distribution of ocean currents. And one of the things we are certain must have happened in the distant past—when the arrangement of continents on the surface of the earth was very different—the thermohaline circulation had to be very different. And we think that in the future it could change and cause abrupt climate change for the U.S. and Europe.

In terms of long-term climate change, the thermohaline circulation gives the climate system enormous memory. It carries with it the characteristics of the climate at the time of its formation, and that might change as you go from a glacial period to an inter-glacial period. You'll still have remnants of the memory circulating through the deep ocean circulation of that previous climate state. And some people feel that this thermohaline circulation, which tends to move through all the ocean basins, eventually resurfacing in the southern Atlantic Ocean, can be very, very important in terms of determining rapid climate change.

RHINES:
If sufficient warming occurs at high latitudes to melt ice, and if more precipitation lands on the oceans at high latitude, you'll create a super layer, of very buoyant, fresh water, which will float out, and it's been known to happen, as at the terminus of the last ice age. This super layer of buoyant water can insulate the ocean from the atmosphere and basically shut down the overturning and sinking circulations for a time—probably not forever, but possibly for a hundred years. And the changes in circulation would be more dramatic than one can imagine, really, whether or not it would freeze Europe, because it would prevent the oceanic heat from being carried northward by the circulation, that is one prediction. I think that's overly dramatic, however, major changes in the lives of people living in the north would be inevitable.

NARRATOR:
GIVEN THE DYNAMIC AND COMPLEX LINK BETWEEN DEEP OCEAN CIRCULATION AND GLOBAL CLIMATE, THE NEED TO LEARN MORE ABOUT OCEAN CURRENTS IS CLEAR.

One thing I was really surprised to find out in my studies of the ocean was that it's kind of like layers of an onion, which is before I thought that, you know, water was just water—it was all very homogenous, had no particular differences—but what actually is the case in the oceans is there's these stacked layers of different kinds of water. And what we mean by different kinds of water, which are sometimes called "water masses," is a body of water that has one particular temperature and salinity. And the reason temperature and salinity are important is because together, those determine the density of the water mass, and the density determines where vertically the water goes.

Water masses are a lot like air masses in the atmosphere. And we think of a big weather change when we get cold, dry Canadian air in the winter, or warm, tropical air from the

Gulf of Mexico in the summer. These are familiar to the average person. Well, something very similar happens in the ocean.

Water masses are similar to air masses, except they have a much longer lifetime scale. And so they keep their characteristics for centuries.

PIERCE:
So, if you were just to go off, say, the coast of the United States and look down in the water column, you would see these interleaving, different water masses. Now these water masses may have come from very far away. The ones near the bottom may have come from off Greenland, they may have come from Antarctica, and slid very slowly around the bottom of the world ocean. So, the water masses carry these properties for huge distances, and preserve their temperature and salinity as they travel.

Different places in the ocean have different temperature and salinity characteristics. For example, the water exiting the Mediterranean into the North Atlantic is very high in salinity. The water in the Northwest Pacific, off of Russia, off of the Bering Sea, is very low in salinity. So, we know why that happens in these places, but then these water, these particular pieces of water don't just sit there off of Russia or off of the Mediterranean, they are carried around the ocean and retain their properties. Slowly they mix in with the background, but for a very long time, decades sometimes, they retain their properties and one can use these high salinity or low salinity properties to try to guess where this water mass came from and what—how long it might have taken for the circulation to bring it there.

So, regionally, we have great variations in the production of water masses. When they get into the ocean interior, they stratify upon—one upon the other and they get carried by the general ocean circulation. So the actual pattern of water masses can be very complex from ocean basin to ocean basin.

NARRATOR:
OCEANOGRAPHERS STUDY THE FORMATION AND MOVEMENT OF WATER MASSES FOR A NUMBER OF REASONS.

Understanding how water masses form and move around has a lot of implications. It's really the movement of warm water masses that carry heat, say, to the northern Atlantic, and release it to moderate the climate of Europe. Once the heat is released, those cold waters sink and move around the ocean. So, the movement of heat through the ocean is really another way of saying you're looking at the movement of water masses.

KATHERINE BARBEAU, Ph.D., Scripps Institution of Oceanography, UCSD:
The implications are huge in terms of global climate, because the circulation of water masses—that's a major factor in the movement of heat around the earth's surface, and in the movement of chemicals for phytoplankton growth.

DAVID PIERCE, Ph.D., Scripps Institution of Oceanography, UCSD:
Now, another aspect of this is that different water masses have different temperatures, and strong changes in temperature, which are called the thermocline, have implications for where some fish live in the ocean. The fish care about what temperature of the water they live at.

NARRATOR:
TRACKING TEMPERATURE VARIATION IS ONE WAY OCEANOGRAPHERS ARE ABLE TO CHART THE MOVEMENT OF INDIVIDUAL WATER MASSES, BUT THERE ARE MANY OTHERS. COLLECTIVELY, THESE ARE KNOWN AS TRACERS.

KENNETH COALE, Ph.D., Moss Landing Marine Laboratories, CSU:
A tracer is usually a property or a substance that can be used to help elucidate a process occurring in the oceans. Now what does that mean? Well, that means that we can use temperature, for instance, to trace currents around the oceans. That's a useful—that's a useful tracer. We can use salinity to trace certain water masses also around the oceans.

STEVEN EMERSON, Ph.D., University of Washington:
Salinity and temperature together control the density. So, by making measurements of salinity, we determine the density of the water and, even more importantly the salinity of a water mass tells you where it came from. For example, if we were in an area of the ocean where the evaporation exceeded precipitation at the surface, that would be an area where the salinity is high, because there's a lot of evaporation—the water is going off into the atmosphere, leaving the salt behind—the salinity becomes high. That water sinks then, and goes into the ocean, and you can follow that water mass for thousands and thousands of kilometers through the oceans, and tag it because of its salinity.

But there are other kinds of tracers that are very useful for tracing ocean processes and, although it's kind of an irony, the refrigerants from refrigerators, the CFCs, have been useful tracers of water movement, because we know the history of their introduction into the atmosphere. We know that around 1930, they started producing C11 refrigerant, and we know that it has a specific chemical compound.

STEPHEN RISER, Ph.D., University of Washington:
And if you see chlorofluorocarbon in the deep sea, you know that that must have gotten there within the last 30 or 40 years, and it gives you some idea of knowing what is the invasion rates of surface gases of any kind of gas into the deep sea. It may take 30 or 40 years to do that. That's an example of the kind of things you can do with tracers.

COALE:
So, CFCs have been useful tracers of atmospheric exchange and deep water formation. There are other kinds of isotopes that have been useful tracers. Some of the isotopes that have been the most useful tracers also, ironically, have been produced by man's activity.

WILLIAM JENKINS, Ph.D., Woods Hole Oceanographic Institution:
In the 1950s and the 1960s, we did some atmospheric nuclear weapons tests, and these produced radioactive elements that have entered the oceans. Now, clearly, the Test Ban Treaties were executed because of concerns about the impact of this radioactivity on our environment, and that's certainly fair, but the presence of these radioactive elements in the oceans and how they're being moved around is actually very important, not because there's any significant effect on the environment, because they're in such trace amounts, but because we can actually see them moving around. These are called transient tracers, because they're changing in time and they're being redistributed in time. And the opportunity to observe these tracers moving through the system is an extremely important thing because it allows us to clock these processes.

NARRATOR:
IN ADDITION TO LOOKING AT TRACERS LIKE TEMPERATURE, SALINITY AND THE POLLUTANTS THAT RESULT FROM HUMAN ACTIVITY, OCEANOGRAPHERS ALSO PAY CLOSE ATTENTION TO SHELLS AND OTHER REMAINS OF MARINE ANIMALS THAT LIVED IN THE PAST.

JENKINS:
There's two sort of major thrusts that one can see for that kind of process. Corals, for example, are banded just like trees are. There's annual rings that are formed that you can actually count back in time. And so you can use these corals as a tree ring record, if you will, of things that have gone on in the past. And there are certain isotopes and elements that you can use to treat as proxy records of processes that are going on in the past.

LIHINI ALUWIHARE, Ph.D., Scripps Institution of Oceanography, UCSD:
So things like coral and foraminifera, which are organisms that live in surface and deep waters—these organisms secrete calcite shells, and when they do that, they deposit certain elements in the same ratios as they are in seawater. So, at a given time when these shells are deposited, it provides a snapshot of the chemistry of the seawater at the time that the shells were secreted.

PETER BREWER, Ph.D., Monterey Bay Aquarium Research Institute:
The shells of marine animals are very powerful recorders of geochemical events which occur—that are occurring today and have occurred in the past.

ALUWIHARE:
For example, you can measure the ratio of oxygen 18 to oxygen 16 isotopes in a calcium carbonate of foraminifera and corals, and this is done very widely to look at changes in the salinity and, therefore, the temperature of the water at the time these organisms were living. So, you use oxygen 18 isotopes within these shells as a tracer for glacial-interglacial variations in temperature.

NARRATOR:
WHILE THE UTILITY OF SPECIFIC TRACERS VARIES ACCORDING TO THE CIRCUMSTANCE, TRACERS AS A GROUP PROVIDE A RICH SOURCE OF CRITICAL INFORMATION ABOUT OCEAN CIRCULATION.

The deep ocean has a mean circulation time scale of about 500 years. It takes about 250 years for water which enters surface waters of the Arctic Ocean to traverse through the Atlantic and reach the Antarctic. The mixing time for the Pacific Ocean is rather longer. And so on a time scale of a few decades, we can see tongues of these chemically-changed water masses moving along. So, it tells us how fast deep ocean currents move, and how they move around oceanographic boundaries like ridges, they confine to the west side or the east side of ocean basins and so on. There are excellent models of the physical motions of the ocean, and the tracers, of course, display those very beautifully, and they're a powerful tool for ocean scientists.

STEVE EMERSON:
So, by learning from these tracers how the ocean circulates, we learn a lot about the carbon cycle of the globe, the carbon cycle of the ocean and of the atmosphere and the ocean together, so that we can ultimately learn about the climate—that is how—where the carbon is going to go, and how much warmer the earth will get in the future. So, we study this circulation—we study the density of the sea, we study the salinity of the sea, we study these tracers of water motion—so that we can understand how the climate works, how the carbon cycle works. And this is not just a curiosity. It's something that we have to know, because we are making a big enough impact now on the environment that we have to manage it, and so we try very hard to understand these things, like how the ocean circulates.

NARRATOR:
TRACERS HAVE PROVEN IMMENSELY USEFUL AS TOOLS WITH WHICH TO MONITOR AND ANALYZE OCEAN CIRCULATION, BUT TRACERS ALONE ARE NOT ENOUGH. THE SHEER SIZE OF THE WORLD OCEAN PRESENTS SCIENTISTS LIKE STEPHEN RISER AT THE UNIVERSITY OF WASHINGTON WITH AN ON-GOING CHALLENGE.

I'm part of a very ambitious program—I think it's ambitious, I hope we can do it—to try to create the first prototype ocean observing system, global ocean observing system. The idea is that we have a technology called profiling floats. These were developed originally by two very well known oceanographers, Russ Davis and Doug Webb, about 20 years ago. And now we've added more sensors to them, and the idea is to put out 3,000 or so of these in the world ocean so that we will have the oceanic analog of weather balloons—an atmospheric observing system—we'll have the oceanic analog of that, with something like an observation every 300 kilometers, every 500 miles or so, throughout the whole world ocean, from pole to pole, everywhere.

NARRATOR:
THE PROFILING FLOATS THEMSELVES, WHICH ARE FREE-FLOATING, CAN COLLECT DATA FROM THE OCEAN SURFACE TO A DEPTH OF ABOUT 2,000 METERS. ALTHOUGH NOT PROPELLED BY ANYTHING, THEY ARE ABLE TO RISE AND FALL BY CHANGING THEIR DENSITY. WHEN THEY REACH THE SURFACE, THEY CAN TRANSMIT DATA THEY'VE COLLECTED TO A SATELLITE.

RISER:
Once you have this, one can begin to make maps of the ocean circulation, temperature, salinity, velocity, every five or 10 days. And one can be able to map the ocean flow the same way we map the atmospheric flow. There are obviously climate implications to this to the extent the ocean and the atmosphere interact. If you maintain a system like this for a number of years, you can begin to see changes in the ocean climate the same way now people are beginning to see changes in the atmospheric climate. But there are more applied kind of uses, too. Eventually, people will use this in fishery studies. They will use it in pollution studies. They will use it to try to optimize the paths that container ships go in world ocean. One has to couple these kinds of observations with a good model in order for this to work the same way that the atmospheric observing system is coupled to computer models. But that's all being developed at the same time by other groups.

NARRATOR:
AT WOODS HOLE OCEANOGRAPHIC INSTITUTION, A PROJECT IS UNDERWAY TO STUDY OCEAN MIXING AT THE BOTTOM OF THE OCEAN. WOODS HOLE SCIENTISTS REALIZED EARLY ON THAT THIS EFFORT WOULD REQUIRE THE FABRICATION OF A VERY UNIQUE INSTRUMENT.

RAYMOND SCHMITT JR., Ph.D., Woods Hole Oceanographic Institution:
We had to make it a very large instrument because we have very sensitive sensors to measure turbulence on centimeter scales in the deep ocean. It had to go to the bottom of the ocean because we had this suspicion that there were special things going on in the deep ocean that had never been observed. And we had to make it tough to withstand the rigors of work in the rough ocean. We had to make it large and robust, able to withstand a little rough handling on a ship in rough seas. So we built this special instrument. It's a freefall profiler—it means it has no attachment to the ship when it's deployed.

NARRATOR:
THIS FREEFALL PROFILER, ALSO KNOWN AS A HIGH RESOLUTION PROFILER, OR H.R.P., IS EQUIPPED WITH WEIGHTS THAT IT RELEASES WHEN IT REACHES A DEPTH THAT'S BEEN PREPROGRAMMED ACCORDING TO PRESSURE. DATA GATHERED BY AN ONBOARD COMPUTER PROVIDES A DENSITY PROFILE EXTENDING FROM THE SURFACE OF THE OCEAN TO THE VERY BOTTOM.

SCHMITT:
And what we've found is that very smooth bottoms, which characterize what we call abyssal plains over much of the ocean bottom, tend to have very little turbulence above them. But when we approach an area of rough ocean bottom, such as the mid-Atlantic ridge, we find there's a great enhancement of turbulence, and this turbulence is associated with internal waves generated by the tides that are flowing over the mid-ocean ridges. So, this has been a new revelation that's come out in the past few years, that there is this intense turbulence in the deep ocean that had never been observed before. From the patterns of a distribution of this mixing, we have inferred new insight into the circulation of the deep ocean, because mixing must be maintained by circulation, and from looking at the patterns of change in mixing rate as a function of distance and depth, we can infer new circulation patterns never before observed.

NARRATOR:
WHETHER STUDYING THE PROCESSES OF WORK IN THE UPPER 2,000 METERS ACROSS THE WORLD OCEAN, OR EXPLORING OCEAN MIXING AT THE GREATEST DEPTHS IMAGINABLE, SCIENTISTS HOPE TO GAIN A BETTER UNDERSTANDING OF THE FORCES THAT DRIVE OCEAN CURRENTS, AND ULTIMATELY SHAPE THE VERY FABRIC OF THE MARINE ENVIRONMENT.

Once you have the same kind of predictive capability that you have in the atmosphere, then we're going to move beyond purely physical models here. People will start to make biological models, fisheries models, all kinds of other things that this kind of knowledge can be used for. Those turn out to be very difficult. Making a physical model is very difficult, but making some of these other things is even tougher. So we have to cross the physical bridge first, but once we do, ecological models, biological models—I think those things will ultimately be the most important thing to come out of this research, things that have a direct impact on people's daily lives.

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