Ocean Extras: Overturning Circulation and the Rapid Array

Val we've got a lovely rotating globe here with lots of data on it. Why are the oceans all these different colours?

Well this is sea surface temperature from satellites. And the red is the hottest part. So you can see here, up near the equator, it's 25, 30 degrees. And down here in the Southern ocean near the Ice Age, it's warm 2 maybe 3 degrees.

So it's a huge variation.

Yes, it's a huge variation. And you can actually see the surface circulation of the ocean currents in this map. So if you look here, you've got the Agulhas current coming down. That's a warm current that transports heat away from the equator. And here, we got the Benguela current which is a cold current that takes cool water towards the equator.

And it's the same again, here with the Brazil current coming down taking warm water towards high latitudes. And this is same up in the Northern hemisphere, which is on the top so you can't see it here.

So one of the very important things here is that it's not just that the Earth is mostly taking in heat in the equator and giving it away at the poles. It's moving it around the planet. And so that's why you can see the currents because as warm water moves into areas of colder water, you can see where it is.

And the circulation forms these huge gyres in all the oceans, there's five all together. But there's another part because the ocean is 3D. It's 5,500 metres or deeper in some places. And the water actually sinks in high latitudes.

When we're talking about ocean circulation, it matters because the oceans are not just what's happening at the surface, there's a huge three dimensional structure, the water is moving around this dynamic system.

That's right. And that's how the ocean transports heats to high latitudes from the equator. You have the water sinks in the North Atlantic and down here in the Southern ocean.

So we've just got the Atlantic coming-- so this is one of the best examples of it. So if we wait for it to come around and stop it about here--

So warm water is pulled up towards the North, which we can't see where it sinks between Iceland, Norway, and Greenland. It sinks down. At the bottom of the sea floor, it goes back towards the equator. And here, it's the same again as the ice forms, which you can see down here. The brine is excluded from the ice. That's very heavy, very dense and it sinks to the sea floor. And flows towards the equator right along the bottom.

So this is one big type of circulation. The thermohaline circulation.

So that overturning is what is transports the heat and makes Britain warm, basically. And one of the things that is really important for our climate is that we know how that heat transport can continue in the future with climate change, for example. So we try to measure it.

And we can't easily measure that from satellite until very recently. But we have an array across the Atlantic at 26 degrees North called the rapid array. And that's been there since 2004. And it measures sea ocean currents from right at the top all the way down to the bottom.

So you've got a line just above here at 26 degrees, an array going this way.

Goes from Florida to Morocco. and it meshes the water that flows northward in the surface ocean and then the water that comes back in the deep ocean. And surface and deep ocean are separated from each other with the thermocline where the temperatures changes very quickly. And that prevents mixing the two.

So anything that is transported into the deep ocean by the sinking at high latitudes, takes hundreds of years to come back. And that's other important role that the circulation has in the climate system. It actually takes carbon dioxide from the atmosphere into the deep ocean. And once there, it's stored away for hundreds of years.

So this engine here in the North Atlantic, it has two halves. It has the surface waters which are flowing northwards. It has the deeper water which are flowing southwards. So you might think a satellite could only learn about the top half of that engine.

Yes.

But that's not quite true, is it?

No. With altimetry, which measures the sea surface height, we can actually calculate the overall currents. We can also calculate that flow in the surface layer and the flow at depth from satellites. We actually, even before the new techniques for measuring the whole overturning from satellites, we used from the rapid data, we used the wind measurements from satellites to calculate the flow in the surface layer. And then we used all the data from the moorings across the Atlantic to calculate the rest of the flow.

So there's several complicated components to this, the gyre which is going around it's the overturning circulation, which is going around this way. And this is all being monitored not just in the deep ocean, but also using satellite data. And that's what's helping pull the whole picture together.

Yes, you need both the measurements. All the way down to the sea floor from instruments on board buoys, and you need the satellites to get the broad overview and to see how the surface circulation works.

And what we benefit from is the surface circulation. But what pulls that far enough North to be useful for us is the overturning circulation. And in order to know what's going to happen, we need to know how both of those are changing.

So describe to me, briefly, the rapid array. You've got this line across the Atlantic Ocean. What happens at each point on that line?

The line is actually not quite a line. Most of the measurements are made in the West and the East and around the mid-Atlantic ridge. And then we can extrapolate between them to get the rest of the measurements. And from the-- they've got current metres.

So each point, there's something that's hanging down.

Yes, there's the buoy that it doesn't quite come up to the surface because if you're up at the surface, you tend to get fished. And you get caught in nets and there are all sorts of issues with going all the way to the surface, which is why we use satellites for the surface flow.

But the moorings go all the way to the sea floor. And the tallest of those moorings is so huge that if you imagine you being as tall as the mooring, then the Eiffel Tower would come up to a little bit on your shoe.

So the ocean is gigantically deep and these lines these, moorings--

They go all the way down.

Go through all the depths of the ocean. And then the satellites help for the last little bit of what's actually happening at the surface. And so you're monitoring, not quite in three dimensions, but you've got a slice through the ocean.

We've got a slice.

And you can watch this overturning.

And Eleanor, my colleague Eleanor, she's going to tell you how we actually can combine that with satellite data to get information about the overturning somewhere else, as well.

Now Val told us a little bit about the rapid array which sits at a certain latitude measuring the depths of the water but you are looking at this overturning circulation using satellites. How could you do that?

So we use the observations from the in situ array and those tell us what the actual circulation is doing. And then we took just the information about how fast the water was moving and compared it to what sea level anomalies looked like across the North Atlantic.

And by doing that, we actually found that on certain time scales, longer than an annual time scale, we could recover the variability of the transports as measured by the in situ observations.

The message here then is that even though all of this water movement is obviously going on beneath the surface, it has a signature on the surface. And that's what the satellite can measure.

That's right. That's right. So even though the circulation that we're interested in is this top 1,000 metres, the sea surface height is actually responding to that. So the things that are driving the circulation are happening 1,000 metres deep or deeper. But the sea surface height mirrors what's happening subsurface. And so you can use that to look at the transport variability.

And that's because all these tiny flows underneath, even if they only make a tiny difference at each individual depth, that adds up by the time you get to the sea surface. And what sort of data-- how do you use the satellite measurements to compare with in situ measurements and what's the comparison?

So the in situ measurements are telling us the density of the water so its temperature, salinity, and pressure. And we can use that actually to add up those contributions to changes in sea level. And what the satellite is actually telling us is just what the sea level anomaly is.

So if we compare the in situ observations that tell us what it should be at an individual point, to sort of this spatial view from space of what the sea level looks like over a region, if we find a good relationship, it means that we have the chance to replace one with the other. And turn that back into a transport estimate.

And you had some data that showed the comparison between the satellite measurements and the in situ measurements.

That's right. And it worked better than expected. So this is now a time series that shows, in red, the strength of the transport over the last 10 years. So since 2004 to present, and what we saw over this 10 year period, was a relatively high strength of the overturning circulation. And we measure this in sphere drops which are a million cubic metres per second.

So we had 20 million cubic metres a second going northward and also coming southward. And then since then, sort of dipped off. And then, what's shown behind this in black is actually the same signal but constructed from sea level anomaly as well as the surface winds that Val also talked about.

So that's the satellite data.

And that's also from the satellite data. But the part that I was talking about here is actually the top 1,000 metre transports that we're replacing with sea level anomaly. So those two things combined, along with the strength of the Gulf Stream, to give us this time series of the overturning circulation. And over the time period where we have the in situ observations, the agreement is very good.

So when they were high, they were both high. When they had this dip, they both dipped. And so on. And so what this means is that actually we can use this 10 year period to extend our knowledge back in time because the sea level anomaly, the satellite is available since or the satellite systems are available since 1993. so we can extend back in time. And we can also look a little broader in space. So we're no longer limited to looking just at 26 North where we have the in situ observations.

So the deal here is that you could do very detailed checks on what the satellites are telling you from 2004 onwards. But because that match, you can have confidence in earlier satellite data.

We have some confidence. We believe the satellite data. The thing that we don't know quite as well is whether or not the relationship between the satellite data and the in situ transports was stationary in time. Whether the relationship was the same back then as it is now.

If it was, then I would say we do have confidence that the strength of the overturning looks something like this back in time.

So there's a little variation in the system and you're capturing it using these two systems together.

That's right, yes.

And what does this have to say about the spatial, because obviously, this is one line along the North Atlantic, but there's quite a lot of the rest of the North Atlantic.

That's right. So here we've used one location in the Atlantic to estimate the transports. But we can actually look at the spatial pattern and how that compares to this one location. That's shown here. And so this is a spatial pattern of the relationship between sea level anomaly in the in situ transports.

So again, we've got Europe here and Africa down there. Canada and North America going down here. And here's the Atlantic Ocean in the middle.

Yes. And so 26 North, this location where we have the in situ observations, is this line in red. And the location that has the best relationship with the transports is somewhere off in the West and localised to 26 North. But the spatial pattern where that relationship is good, actually extends beyond the single latitude.

So the idea is that you have confidence in the match between the satellite data and your array here, but that same region where you have similar matching extends up and so the satellite data might also be useful in different parts of the ocean.

If that relationship is the same. And we don't yet have evidence that it really is the same. But if it is the same, then what it's telling us is that what the ocean is doing at 26 North, it's doing across the whole subtropical gyre so that the measurement we make with the in situ observations at one location, is actually telling us about a larger spatial pattern in the ocean.

And this is a new thing. This is recent work that's a new way of using satellite data to get at something very important.

Yes. It is very recent. We did have this expectation that it could work but previous attempts to compare the transports, the in situ transports to a satellite hadn't worked before. And so some of that was due to noise from small scale eddies in the ocean.

And also, a strong seasonal cycle that was in the sea level anomaly but not in situ transports. But now in this new way that we've looked at it and because we have the in situ observations to train up the relationship between the satellite data and the in situ estimates, the true estimates of the transports, then we can actually say something more about the ocean circulation.

And then, of course, because you have satellite data for the whole ocean, you've got potentially lots of interesting things to look at.

That's right. So we're just now starting to look at other latitudes. There are some in situ observations at 41 North and at 16 North. And so we're hoping to use this to broaden our view of the ocean circulation.