Ocean currents are a conveyor belt spanning the entire globe; they are transporting minerals, nutrients, organisms and other particles across vast distances. However, the full extent of the roles played by these flows is still poorly understood. Dr Rui Caldeira, Director of the Oceanic Observatory of Madeira in Portugal, and his collaborators Dr Iria Sala, Cláudio Cardoso and Maria João Lima use the latest computer modelling techniques to understand how ocean currents interact with four archipelagos in the northeast Atlantic Ocean. The team’s discoveries are shedding new light on how the region is affected by the growing problem of plastic pollution, and how similar processes are unfolding worldwide.

**Ocean currents** are a crucial aspect of the environment, taking up two thirds of our planet’s surface. Generated by factors including winds, temperature differences, and the Earth’s spin, they form colossal conveyor belts which encircle the vast regions in between continents, thereby moving minerals, nutrients, sediments, plankton to new regions across the globe. In turn, currents are the lifeblood of many ecosystems, both marine and land based, and enable the livelihoods of many millions of people. Sadly, however, they have more recently been responsible for driving the spread of discarded plastic, leaving even some of Earth’s remotest ecosystems damaged by pollution.

Despite the relevance of each of these factors, researchers still have a poor understanding of the overall dynamics of ocean currents. In the face of this challenge, the work of oceanographers is crucial to understand the role currents play in sustaining life, and how marine ecosystems are affected by human activity. In their research, Dr Rui Caldeira, Director of the Oceanic Observatory of Madeira in Portugal, and his collaborators Dr Iria Sala, Cláudio Cardoso and Maria João Lima use a branch of physics focused on a Lagrangian approach to describe the characteristics of moving fluid in the oceans. This allows them to describe the motion of individual particles by mapping their positions over time, determined by the current direction and velocity. Yet before reaching these capabilities, the researchers needed to perform an advanced set of mathematical calculations to simulate ocean currents.

**SIMULATING CURRENTS**

Through a study published in 2013, Dr Caldeira and his colleagues developed a robust method for mapping the paths of currents in the northeast Atlantic Ocean, using a computer model named the ‘Regional Oceanic Modelling System’ (ROMS). Widely used by oceanographers, ROMS enabled the team to apply Lagrangian mechanics to their oceanic flow calculations. This, in turn, allowed them to simulate the transport and dispersion of different clusters of particles over time. To test the reliability of the model’s predictions, they compared their results with satellite observations of real currents and measurements of floating arrays of sensors (“drifting buoys”), which can probe currents at varying depths.

As the team hoped, the dynamics which appeared in their model closely matched the observations and remained consistent with known circulation patterns in the northeast Atlantic. In addition, they verified the consistency of their simulations with the known distributions of several animals, including particular species of fish, lobster, eel, and sea sponge, as well as observations of drifting crude oil from the Prestige oil spill; a catastrophe which occurred off the northwest coast of Spain in 2002. Having clearly proved the reliability of ROMS in recreating the Lagrangian pathways of ocean currents, Dr Caldeira’s team could next apply their techniques to studying currents in a variety of more specific cases.

**SIEVING FOR DRIFTING PARTICLES**

The region of Macaronesia spans a large swath of the northeast Atlantic Ocean: from the Azores in the north, which lie due west of the Portuguese mainland, to Cabo Verde in the south – a nation off the coast of West Africa. In between lie the archipelagos of Madeira – where Dr Caldeira’s team is based –, considering the Canary archipelago in between. In turn, to allow them to simulate the transport and dispersion of different clusters of particles over time. To test the reliability of the model’s predictions, they compared their results with satellite observations of real currents and measurements of floating arrays of sensors (“drifting buoys”), which can probe currents at varying depths.

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**IDENTIFYING DELIVERY MECHANISMS**

Through a series of simulations, Dr Caldeira and his colleagues determined that particles reaching the Azores are mainly transported along westward-propagating corridors of swirling eddies. These corridors were likely to have broken off from the Gulf Stream: a part of the north Atlantic circulation current system which delivers warmer water from the Caribbean to Northern Europe. Furthermore, the researchers showed that these currents are stirred up by the islands in characteristic ways. This means that while the ability of the islands to capture particles is directly related to their sizes, the time they retain the particles relates to the depth of the water surrounding them – since currents are slowed down in deeper water.

In their second study, Dr Caldeira’s team again identified corridors of eddies as the main transport particles for particles arriving at the two seamount complexes. This time, however, the corridors branched off from a current flowing southward from the Azores – so that each complex was fed by a different branch of the same current. This observation not only revealed
a large-scale mechanism connecting the seamounts – which are hundreds of kilometres apart; it also indicated new mechanisms for connectivity between seamounts within the same complex.

In the Madeira-Tore complex, seamounts are generally smaller, but are more densely packed together. In the team’s simulations, this generated a ‘sticky water’ effect – where currents within the complex became slower compared with those in the surrounding open water. This improved the ability of Madeira-Tore to capture and retain particles. In contrast, the Great Meteor complex contains a lower density of larger seamounts. This generated a ‘seamount effect’ – where particle capture and retention properties are more similar to those found around islands.

UNDERSTANDING PLASTIC POLLUTION

In their latest research, Dr Caldeira’s team have built on their previous techniques to explore the impact of plastic pollution across all four archipelagos in the wider region of Macaronesia. Combining the latest datasets of ocean currents, wind, and waves using Lagrangian tools, they turned back the clock to track the motions of virtual particles intersecting the islands over a 10-year period; also accounting for the depths of the particles beneath the ocean’s surface. Their simulations revealed that the Gulf Stream was the main pathway for all of the plastic pollution intercepting each of the island groups – although Cabo Verde was less affected. As expected, particles floating on the ocean’s surface were captured by the islands on far shorter timescales than those submerged at greater depths, mainly because of the exposure of surface particles to the wind. In fact, winds blowing eastwards across the North Atlantic’s ‘garbage patch’ – a region in the middle of the North Atlantic circulation current system, where plastic tends to accumulate – are the principle mechanism driving the transport of such surface particles to the archipelagos. Particles that are exposed to the wind have the highest probability to ‘exit’ this garbage patch and intersect the archipelagos. Many particles also originated from intensive fishing industries close to all four island groups. In addition, plastic originating from the coasts of North and Central America was a common source of pollution reaching the Azores, Madeira, and the Canary Islands, while particles from the northwest African coast more readily ended up in Cabo Verde. Overall, the simulations clearly highlighted the vulnerability of each group of islands to human activities across multiple continents.

INFORMING FUTURE EFFORTS

Plastic pollution is now growing exponentially across the globe. From 50 million tons in the 1950s, levels of discarded waste grew to over 320 million tons in 2015, with between 4 and 12 million tons now being added each year according to current estimates. All of the same, the wider roles which ocean currents play in transporting and dispersing this pollution are still poorly understood, and it is still incredibly difficult for researchers to determine how specific ecosystems will be affected by it.

Although the flows and corridors affecting Macaronesia’s four archipelagos are ultimately just a small part of the global conveyor belt of ocean currents, the region’s problems with plastic pollution are being clearly reflected worldwide. In the face of this mounting crisis, calls are now growing for governments and organisations worldwide to tackle the many issues involved and to mitigate this problem.

What inspired you to conduct this research?

‘That oceanic currents and winds play in the transport of plastic pollution at a global scale. The simulations provided by Dr Caldeira’s team are crucial in understanding the extent of the problem and the mechanisms driving it. The research is also relevant to the work being done by the BIOMETORE Project, which aims to improve our understanding of marine litter affecting oceanic islands around the world.’

Maria João Lima, marine litter specialist and PhD student at the University of Algarve.