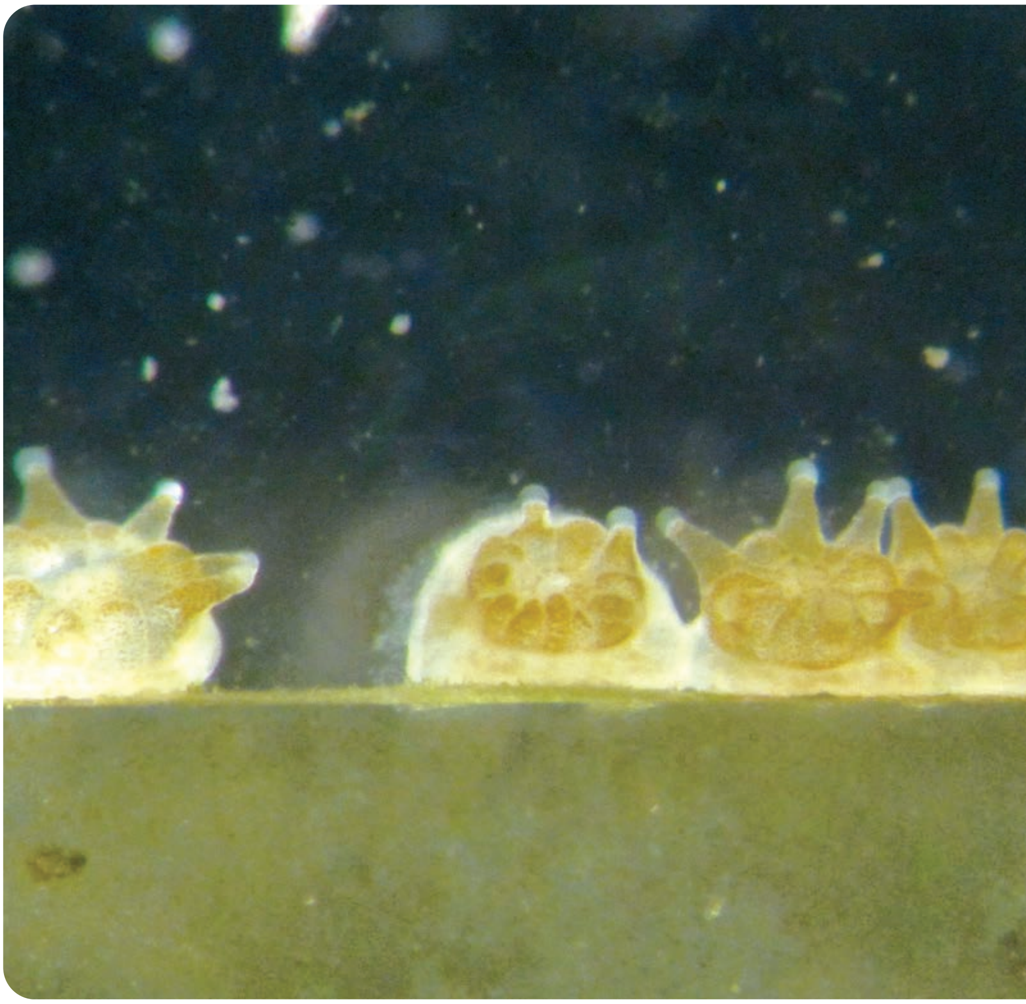
Coral reef connectivity in the southwestern Indian Ocean

Researchers at the University of Oxford have used the power of ARCHER2 to simulate how billions of coral larvae are transported by ocean currents. Understanding the connectivity of coral reefs can help conservationists to identify the most vulnerable coral reefs and develop appropriate conservation measures.

Often described as 'rainforests of the sea', coral reefs are thought to be home to almost a third of all known marine species, despite covering less than 0.1% of the ocean floor. Over 500 million people across the world also depend on coral reefs for food, tourism, and culture – representing a combined value of over $1 trillion to the global economy. Unfortunately, despite their incredible importance, coral reefs are undergoing a catastrophic decline. Whilst many reefs have already been under stress for decades from unsustainable development and fishing practices, climate change represents an existential threat due to the warming and acidification of the oceans.



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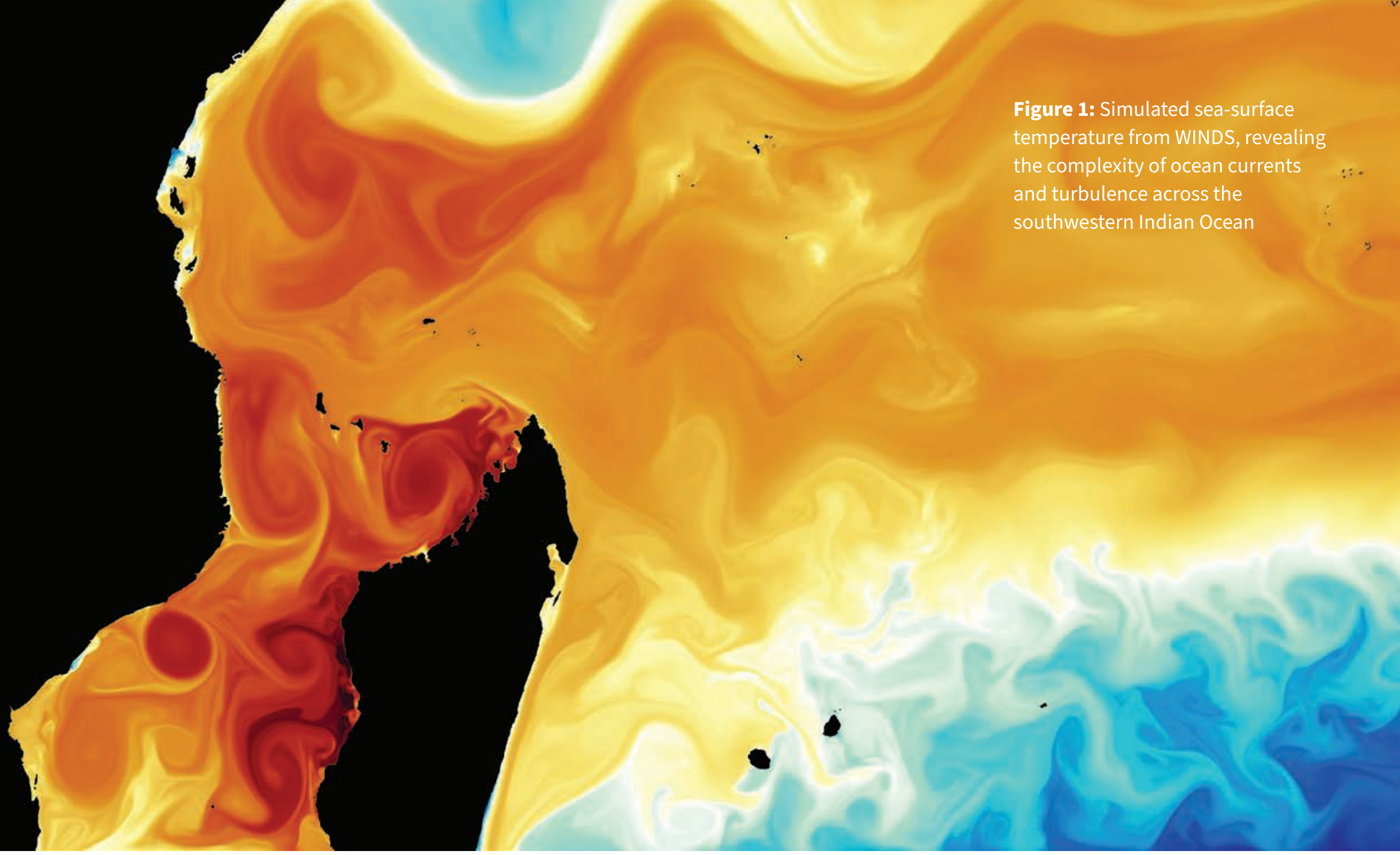

Figure 1: Simulated sea-surface temperature from WINDS, revealing the complexity of ocean currents and turbulence across the southwestern Indian Ocean

Because corals are cemented to the ocean floor, we often think of individual reefs as isolated ecosystems. However, baby corals, known as coral larvae, are able to float freely in the water column and can be swept over enormous distances by powerful ocean currents.

The transport of coral larvae between reefs therefore represents a complex web of connectivity, where resilient reefs may provide the final lifeline for those undergoing severe destruction. Observing the connectivity between coral reefs is challenging, however, because coral larvae are less than a millimetre in size and can travel hundreds of kilometres. Alternatively, we can use supercomputers to simulate ocean currents at high resolution, and predict the dispersal of billions of virtual larvae, and therefore coral reef connectivity. By observing coral larvae in a simulated ocean, we can prioritise conservation efforts to sites that are disproportionally important for regional reef resilience, and also identify reefs that are particularly vulnerable (e.g. those that are poorly connected).

Research carried out at the University of Oxford targets the southwestern Indian Ocean, home to over 15,000 km^2 of coral reefs. The researchers firstly ran state-of-the-art ocean simulations for the region, providing 28 years of surface current predictions for Seychelles and the wider tropical southwestern Indian Ocean (the Western Indian Ocean Simulation, WINDS – Figure 1). Through the use of the ARCHER2 supercomputing facility, these simulations achieved a 400% improvement in terms of resolution when compared to the previous best ocean current product available for the region. These simulations are now freely available for all through the British Oceanographic Data Centre. This dataset will not only be vital for coral reef management across the southwestern Indian Ocean, but will also be valuable for assessing many other environmental problems, such as marine plastic pollution.

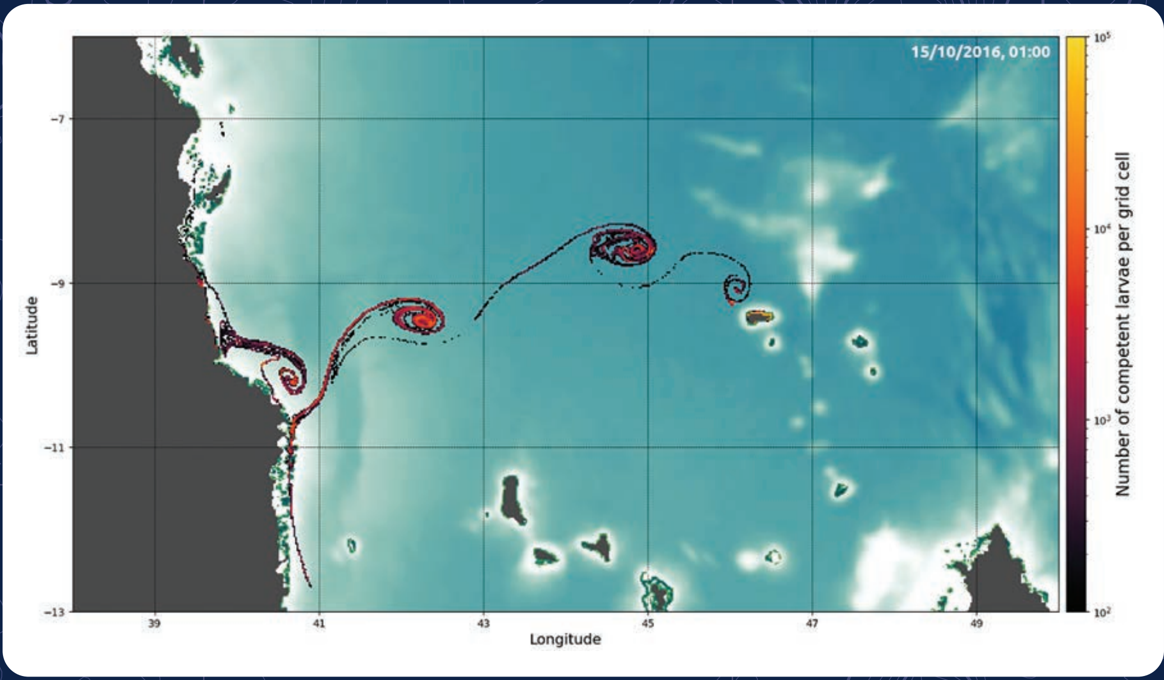

Figure 2: Virtual coral larvae streaming off Aldabra Atoll (Seychelles) and drifting towards the reefs of Mozambique and Tanzania, simulated using ocean currents from WINDS

The researchers then simulated the dispersal of coral larvae using a sophisticated biological model combined with their ocean current predictions (Figure 2), requiring them to generate tens of billions of virtual coral larvae, with each larva keeping track of many biological parameters. This was only made possible by running large numbers of simulations in parallel on ARCHER2. This has allowed them to comprehensively map the connectivity between the many coral reefs in the southwestern Indian Ocean for a range of coral species (Figure 3). These datasets make it straightforward for marine spatial planners and conservationists to assess the vulnerability of the reefs they are responsible for, and prioritise conservation measures. The researchers are developing an interactive online platform which will allow anybody to access and analyse these connectivity predictions, which will considerably improve access to this research for marine practitioners in the southwestern Indian Ocean. Finally, they are now directly comparing their simulations to genetic estimates of coral reef connectivity (Figure 4), which will provide novel insights into the physical versus biological drivers of connectivity, a major knowledge gap.

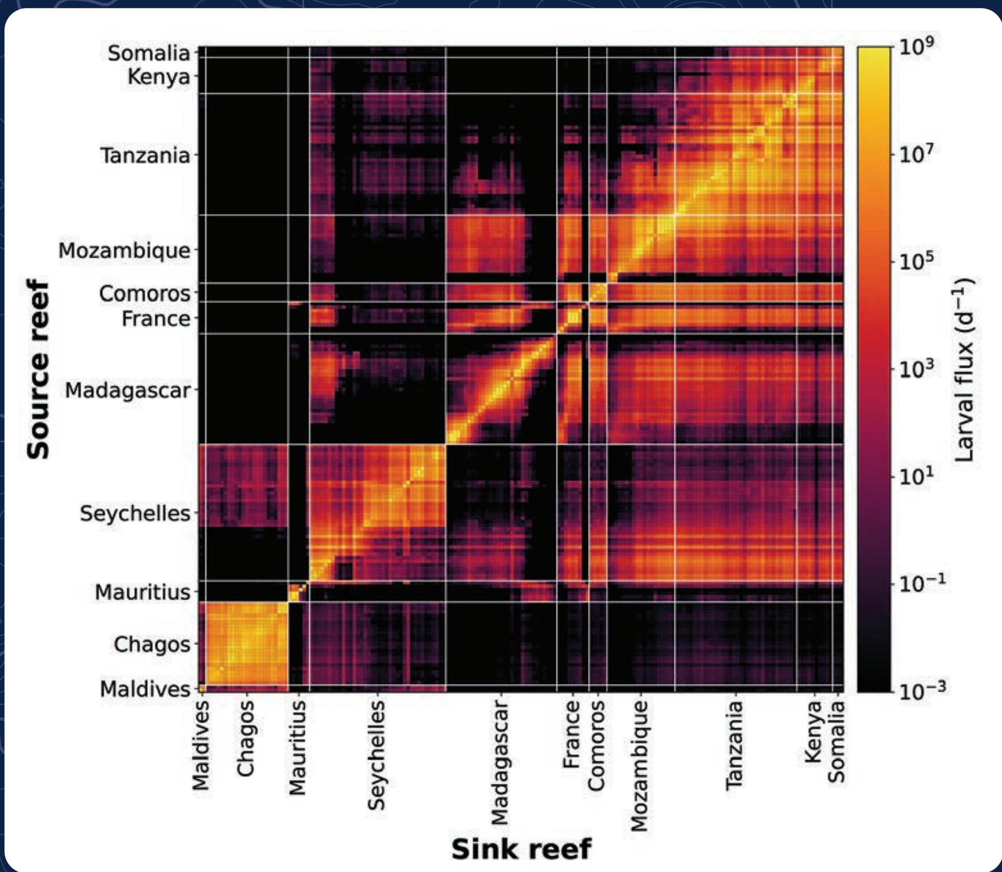

Figure 3: Coral reef connectivity across the southwestern Indian Ocean, based on biophysical simulations using WINDS. Brighter colours represent stronger connections between source (parent) reefs (vertical axis), and sink (daughter) reefs (horizontal axis). Quantifying coral reef connectivity allows the identification of reefs which supply the wider region with larvae and which therefore may play a vital role in maintaining regional reef resilience (e.g. Seychelles and Tanzania), and reefs that may be more weakly connected and therefore less resilient to environmental change.

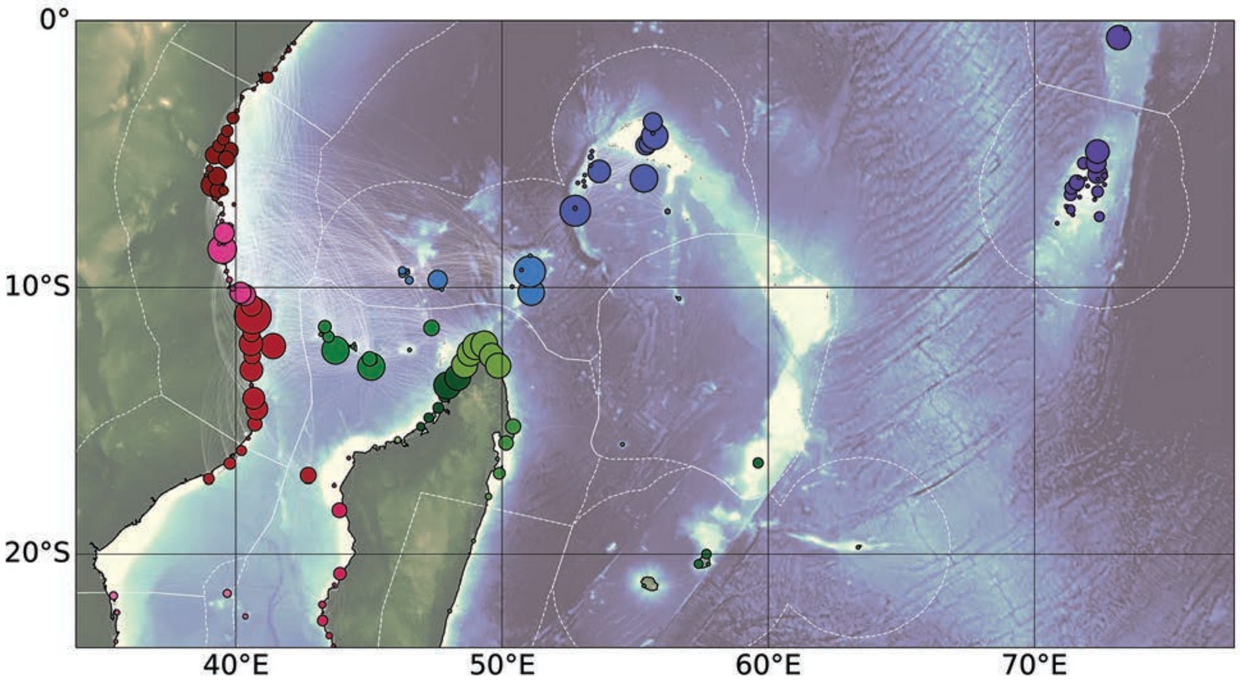

Figure 4: Predicted reef clusters (colours) based on simulated gene flow between reefs. Sets of points with similar colours represent reefs which the simulation predicts should have strong gene flow between them. For example, this simulation suggests that there should be three major clusters of well-connected reefs: (i) East Africa, (ii) Northern Madagascar and the Comoro islands, and (iii) Seychelles and the Chagos Archipelago. These predictions can be compared to coral genetic surveys to understand the biological and physical drivers of reef connectivity.

In conclusion, this research represents a major contribution towards coral reef conservation (amongst other applications) in the southwestern Indian Ocean, acts as a step towards tackling UN sustainable development goals 1, 2, 13 and 14[1], and supports the United Kingdom's international development goals. This research was only possible thanks to the computational power of ARCHER2.

Reference:

Multidecadal and climatological surface current simulations for the southwestern Indian Ocean at 1⁄50° resolution:
https://doi.org/10.5194/gmd-16-1163-2023

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[1] https://sdgs.un.org/goals

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About ARCHER2

Archer2 is the UK's National Supercomputing Service, a world class advanced computing resource for UK researchers. ARCHER2 is provided by UKRI, EPCC, HPE and the University of Edinburgh. ARCHER2 is the latest in a series of National Supercomputing Services provided to UK researchers.