Sea surface temperature (SST) represents the ocean's interface with the atmosphere, where exchanges of heat, freshwater, and momentum regulate global climate. Even modest shifts in SSTs can trigger marine heatwaves and basin-scale climate modes, reorganising winds and rainfall from seasonal to decadal timescales and driving climate extremes worldwide. Yet the mechanisms governing SST variability across ocean basins remain unclear, particularly in the southern subtropical-midlatitude oceans.

In this talk, I first present the identification of a circumpolar wavenumber-4 climate mode in the Southern Hemisphere and examine its dynamical origin. I show how extratropical teleconnections, atmospheric Rossby wave dynamics, and upper-ocean mixed-layer processes interact to generate structured sea surface temperature patterns and associated rainfall impacts across Australia, South America, and southern Africa.

I then extend this framework to the tropical Atlantic, providing a mechanistic perspective on Atlantic Multidecadal Variability (AMV). I highlight the role of upper-ocean mixing and ocean-atmosphere coupled mechanisms in driving the growth, seasonality, and decay of tropical AMV, and discuss how biases in representing these coupled dynamics can lead to errors in simulating regional impacts, including the Indian summer monsoon. I also briefly discuss implications for understanding marine heatwaves, emphasising key challenges in representing coupled ocean-atmosphere processes.

Together, these results underscore the central role of upper-ocean dynamics and teleconnections in shaping global climate variability and highlight the importance of resolving ocean-atmosphere coupled mechanisms to improve predictability of regional climate and extremes.