

## **Research Statement – Jaclyn Brown**

I am an oceanographer and applied mathematician, interested in the general circulation of the ocean, especially in its relation to climate and global climate change, and large-scale interactions between the ocean and the atmosphere. My research so far has been focused mainly on problems related to phenomena in the Pacific and Indian Oceans, including the structure of ocean circulation in the Pacific, the dynamics of El Niño-Southern Oscillation (ENSO), and the physics behind the Indian Ocean Dipole Mode. One of the projects I am currently working on concerns fundamental mechanisms by which wind energy is dissipated in the ocean.

My research is driven by trying to understand climate and climate change, particularly as we begin to experience record breaking phenomenon such as drought and heat waves, possibly related to global warming. To understand the physical mechanisms behind climate and climate change, we must first understand what the key oceanic features are, how they operate in the real world and how they appear in models. Studies of past climate are also helpful as they offer insight to different climate regimes and interactions, possibly ones we may experience again in the future. At this stage, coupled models predict the same climatic features but for different reasons. Until we determine exactly how climate should evolve in present day and how it has in the past, it is difficult to understand how it will behave in the future.

### ***Ocean Circulation in the Pacific.***

My PhD research concentrated on the circulation and nonlinear feedbacks in the equatorial Pacific Ocean. More recently I have begun to explore the tropical – subtropical interactions in the Pacific, with a particular focus on how the subtropics can affect ENSO.

The eastern equatorial Pacific has high levels of ocean variability, especially associated with Tropical Instability Waves (TIWs). Extensive observations suggest that these waves are extremely important for ocean dynamics; however, many climate models still do not resolve these and other fine-scale features of ocean circulation with the accuracy needed. In my PhD research, I used a high-resolution ocean model to demonstrate that the flow structure in this region is much more complex than previously thought. The approach of my Ph.D. work was to study the flow on instantaneous density layers which allowed me to establish some new features of the equatorial flow such as a fine-scale near-surface southward cross-equatorial flow and previously unknown behaviour of the equatorial meridional cells that lie within 5° of the equator (Brown and Godfrey 2006a).

In addition to flow pathways, I analysed the zonal momentum equation on these instantaneous density layers (Brown and Godfrey 2006b). It is frequently assumed that the dominant dynamical balance in the equatorial Pacific ocean is a linear balance between the windstress and zonal pressure gradient. I demonstrated that nonlinearity becomes important along the equator in the eastern part of the Pacific and along 2-4° N where Tropical Instability Waves are particularly active.

In Brown and Godfrey 2006c, we explored the mean, depth integrated Pacific equatorial currents which can be understood in terms of the balance between the curl of the windstress and the curl of the nonlinear advection. Extending our previous work, we took in to consideration the time varying component of the flow and explored the interactions between the windstress and nonlinearity that produce seasonal variations in the flow, including the Spring Time Surge in the Equatorial Undercurrent and water crossing the strong potential vorticity barrier in the vicinity of the equator.

Tropical climate does not exist in isolation to the rest of the globe. The water that upwells in the eastern equatorial Pacific originates from the subtropics. Therefore subtle long term changes to the subduction in this region and pathway to the equator may have significant effects on the properties of the water when it upwells at the equator. One question that I am about to begin exploring is how a water parcel changes temperature from when it subducts with a temperature of around 14°C to when it upwells with a temperature of around 21°C in the eastern Pacific cold tongue. Does this warming occur in western boundary currents, or during recirculations within the equatorial undercurrent? Once we have established this we will look at how changes to features such as windstress alter this pathway and hence final temperature at the equator.

### ***Energy Dissipation in the Ocean***

A fundamental problem of ocean dynamics is how the energy supplied to the ocean by the wind is dissipated. Wind variations modify the slope of the isopycnals and hence the Available Potential Energy (APE) associated with the slope of the isopycnals. It is still unclear how quickly and by which mechanisms the anomalous APE is dissipated. The tropical Pacific Ocean is an interesting case for energy analysis as here the winds vary annually and interannually.

In particular, I am studying this energy balance as it is relevant to the tropical ocean and ENSO. We have been using ocean-only models to quantify the energy being put into the ocean and how much is being stored as potential energy in the thermocline. We have also been able to measure the dissipation rates of the energy on ENSO time scales.

Studies have shown that coupled models represent ENSO in fundamentally very different ways. For example, some models have a large signal in the seasonal cycle and small for interannual variability while others have the reverse. We are investigating these differences by studying the ways coupled models dissipate energy. Preliminary results show that coupled models are inconsistent, some dissipating more energy than others. Do models with higher coupling parameters need stronger dissipation? Are models dissipating energy through the same physical mechanisms? It is important to resolve this issue of model disparity. We cannot conclusively determine what will happen to climatic events such as ENSO under global warming unless we are sure we understand it in the present day.

### ***Predictability of ENSO, Decadal climate variability and climate change***

My fascination with ENSO began with my undergraduate honours project on ENSO, the Madden Julian Oscillation (MJO) and Westerly Wind Bursts (WWBs). The goal of reliable and timely ENSO forecasting however is much more complex. An important feature is the recharge-discharge oscillator. Prior to an El Niño the ocean needs to be in a 'recharged' state, that is, a deeper than average thermocline. This is a necessary, but not sufficient condition for an El Niño to occur and the ocean can remain in this state for a number of years.

A further complication in ENSO forecasting is the changing background state due to multi-decadal variability and global warming. Along with ENSO features such as the Pacific subtropical cells, many other climatic features changed in the late 1970s. It is very difficult to determine whether these changes are part of a multi-decadal variability that will 'switch back' in the near future, or if it is part of a more permanent change due to global warming. Either way, the manner in which ENSO events develop has been altered since the late 1970s meaning that statistically we cannot use previous ENSO events to understand and predict present day ones.

Around 1980 observational data significantly increased. Some of the background changes at this time may be due to the fact that we are able to measure the climate more accurately post 1980. It is difficult however to separate out these effects from the climate shift in the late 1970s.

I am about to submit a paper related to these issues, based on sea level reconstructions which extend back to 1950. The length of the data set allows us to explore the recharge-discharge theory prior to 1980. My results show very different oscillation characteristics prior to this time. It is, however, difficult to determine to what extent this change is attributable to the ocean dynamics and to what it is due to the introduction of new extensive observational data.

## ***The Indian Ocean and the Indian Ocean Dipole Mode (IODM)***

The IODM is still a contentious feature of tropical climate research. The equatorial Indian Ocean is unique in that it does not have a cool upwelling tongue in the east, due to the open boundary of the Indonesian Throughflow. It is also a relatively unstudied ocean with a limited number of observations as compared to the Pacific and Atlantic Oceans. In the beginning of my graduate studies I approached the IODM in terms of a simple intermediate complexity model (results were presented at an Indian Ocean Conference in Japan 2001). We found that nonlinearity was important to these flows, making a linear intermediate model inadequate to analyse the IODM. We then explored the nonlinearity in the better understood Pacific Ocean in an attempt to extend our results to the Indian Ocean.

My analysis in the Pacific for both the zonal momentum equation and the nonlinear feedbacks highlighted the importance of these features in understanding ocean and climate state. At a later stage I intend to return to study the Indian Ocean using the tools I developed when studying the Pacific.

## ***Paleoclimate***

Our understanding of climate tends to be limited by the structure of today's climate. By looking to the past we can explore alternate climate states. This allows us to understand key relationships in the ocean such as mean temperatures and heat fluxes. It also allows us to understand the climate state we may be entering under global warming.

Three million years ago, the earth's climate was a few degrees warmer than that of today while the atmospheric concentration of carbon dioxide was at a comparable level. Furthermore, the proxy data suggest that the equatorial Pacific had a much weaker zonal sea surface temperature gradient than at present. This temperature pattern would suggest stronger, or more prolonged El Niño events, often referred to as a permanent El Niño.

Modelling a state of significantly reduced zonal SST gradient in the Pacific remains a challenge. It may be that models are tuned to today's climate and therefore unable to simulate such extreme climate states. Alternatively we may not yet have found the right combination of boundary conditions and forcing terms to allow this state to exist. Ultimately this is a coupled problem that requires an understanding of both the ocean and the atmosphere and the coupled feedbacks between the two.

In my new project discussed above on tropical/subtropical interactions in the Pacific Ocean, I hope to address this issue further. By only looking at the ocean we will experiment with different wind regimes, and temperature and salinity boundary conditions to see how we can warm the eastern Pacific cold tongue to a state more like a permanent El Niño. We believe that this is an important contribution towards helping understand the atmosphere-ocean interactions needed for a permanent El Niño like state.

### ***Summary***

I grew up in a rural Australian town preoccupied with declining rainfall. I saw first hand the hardships related to an unpredictable climate. It wasn't until I went to University to study mathematics that I discovered I could actually do something to try to address these issues. Even though we cannot control the climate, if we can predict it, we can prepare for it. The drive behind my research is to improve our understanding of climate, particularly as global warming takes hold and directs us into a new, unknown climate regime.

In order to have confidence in the forward projections of climate change in the Australian region we need to be confident that the coupled models that we use are able to represent El Niño not only in today's climate but also in the altered background states of the future. My research interests encompass two broad avenues for attacking this issue, namely

- (i) the dynamical analysis of ocean models to explore differences between the ways models achieve their outcomes, and
- (ii) exploring past climates for clues as to whether our present models contain the necessary physics so that past climates can be simulated.

This type of work needs to be done globally in order to increase our confidence in climate predictions, but it especially needs to be done in the Australian context as our primary industries are strongly modulated by climate variability.