Predicting El Niño Southern Oscillations and the 'spring predictability barrier'

1. INTRODUCTION

The El Niño Southern Oscillations (ENSOs) are generally known as a composite weather phenomena originating in the Pacific Ocean producing lasting teleconnections on the global climate system. The El Niño component of ENSO can be approximately considered to be an oceanic warming event which disrupts the normal Pacific circulation at irregular intervals of 2–7 years, whilst the Southern Oscillations are an inter-annual flip of the tropical sea level pressure between the western and eastern Pacific leading to the weakening and strengthening of the easterly trade winds across the ocean. To produce a conclusive theory for ENSOs one must be able to describe and understand the complete underlying mechanisms. One such hypothesis has yet to arise, however various attempts have been made to comprehend individual components and effects.

Bjerknes (1969) first theorised that a positive ocean-atmosphere feedback system would result in an El Niño event. An initial positive sea surface temperature (SST) anomaly in the eastern Pacific would reduce the east-west SST gradient which leads to the strengthening of the Walker circulation and thus the production of weaker trade winds across the equatorial Pacific. In a complete ENSO theory this positive system would be counterbalanced by a negative loop which returns the Pacific to its "normal" (pre-ENSO) state. Whilst Bjerknes' hypothesis fails to provide a negative feedback mechanism, Zebiak and Cane (1987) presented a model which demonstrated and outlined the coupling between the atmosphere and the ocean to produce an ENSO event. The atmospheric component used was a linear Gill-type model (Gill 1980) which describes the atmosphere's response to SST anomalies, and the ocean represented by a low-gravity system which is forced by the wind stress from the atmospheric constituent.

With their model they were able to replicate features observed during ENSO events such as equatorial westerly wind anomalies in the central Pacific and large SST anomalies in the eastern Pacific, on top of that they were able to predict the onset of the 1986–1987 and 1991–1992 ENSO events. Despite this success, they recognised their limited ability in simulating the real complete system as detailed comparisons with observational data would reveal discrepancies in their atmospheric and oceanic simulations. Furthermore, the short warm episodes in 1993 and 1994 would be missed in the predictions made with the Zebiak-Cane (ZC) model. This therefore requires more sophisticated models to better describe and forecast ENSO events.

2. PREDICTION LIMITATIONS WITH THE ZEBIAK-CANE MODEL

The prediction of ENSO events is particularly difficult as there are generally two types of El Niño events to account for. The first are canonical events which generally develop along the South American coast and then they propagate westwards across the Pacific, "Eastern-Pacific" events (Rasmusson and Carpenter 1982). The second type of events have warm SST mostly centred in the central Pacific which do not propagate, "Central-Pacific" events (Ashok et al. 2007). In an attempt to test whether the ZC model can predict either types of events, it was demonstrated by Duan et al. (2013) that the model tended to do well whilst simulating Eastern-Pacific (EP) events and functioned badly when portraying Central-Pacific (CP) events. This indicates that the ZC model may just contain the physics to explain EP events and that alterations would be required to additionally account for CP events.

On top of that, additional challenges for ENSO forecasting arise due to the nonlinear and complex coupling between the ocean and atmospheric systems. Within the ZC model this relationship was constrained as a result of the authors' initial assumptions and parameter choices when constructing their theory. Take for example the simulation of monthly mean SST anomalies for the atmosphere model, concessions had to be made to ensure that the analysis was not computationally costly and that accurate results would also be produced. Further experimentation would show that the amplitude and time scale of the ENSO cycles are sensitive to changes within the coupled mathematical model: an increase (or decrease) in the strength of the coupling between atmosphere and ocean would lead to increase (or decrease) in the amplitudes and periods.

It is therefore evident that the ZC model is a simplification of the real climate system and improvements must be made to provide a better fit with the observational data, for example, theoretical modifications of the individual atmospheric and oceanic components plus of their inter-relationship. Several modern ENSO oscillator theories (Table I) employ the ZC model as a basic foundation whilst making adjustments to parts of the mathematical modelling.

Theory	**Main component(s)**
The Delayed Oscillator (Battisti and Hirst 1988, Suarez and Schopf 1988)	Considers the effects of equatorially trapped oceanic wave propagation.
The Recharge Oscillator (Jin 1997)	Considers the buildup of warm water in the western Pacific as a precondition to the development of El Niño.
The Western Pacific Oscillator (Wang et al. 1999, Weisberg and Wang 1997)	Considers the role of the western Pacific and off-equatorial SST SST anomalies in the western Pacific.
The Advective-Reflective Oscillator (Picaut et al. 1997)	Considers the importance of the positive feedback of zonal currents that advect the western Pacific warm pool towards the east during El Niño.
The Unified Oscillator (Wang 2001)	Considers dynamics and thermodynamics of a coupled ocean-atmosphere system which is similar to Zebiak-Cane.

TABLE I: Various ENSO oscillator theories and their main differences from the ZC model.

The existence of multiple hypotheses highlights the intrinsic complexities of ENSO events and thus warrants further research into the predictability of ENSOs. One issue which arises within the data and models of El Niño

3. IMPROVING THE ZEBIAK-CANE MODEL

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