Prediction limitations with ENSO models 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 AND 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 propagate westwards across the Pacific, "Eastern-Pacific" events (Rasmusson and Carpenter 1982). The second type of events have non-propagating warm SST concentrated mostly in the central Pacific, "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 reproducing 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 other events.

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 researchers' initial assumptions and parameter choices when constructing their theory. For example with the simulation of monthly mean SST anomalies in the atmosphere model, concessions had to be made to ensure accurate results could be produced whilst the analysis not being computationally costly. Further experimentation would exhibit that the amplitude and time scale of the ENSO cycles would be sensitive to changes within the coupled mathematical model: an increase (or decrease) in the strength of the coupling between the 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. Theoretical modifications of the individual atmospheric and oceanic components plus of their inter-relationship would be key in developing the theory further. Several modern ENSO oscillator theories (Table I) employ the ZC model as a basic foundation whilst making adjustments to parts of the mathematical modelling thus improving their ability to explain and account for various ENSO effects.

Theory	**Main components**
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.

Changes to the ZC model are not limited to just the atmospheric and oceanic components, as a response to the model failing to agree with observations from 1992 to 1995, Qian and Wang (1997) introduced planetary scale Hadley and Walker cells which improved the prediction of equatorial eastern Pacific SST anomalies for 1970–1971 and in 1992–1995.

However further shortfalls exist within the modelling for ENSOs which limits their accuracy and applicability. In particular, there is a limitation found in many models known as the "spring predictability barrier" (SPB) where the seasonal predictions for

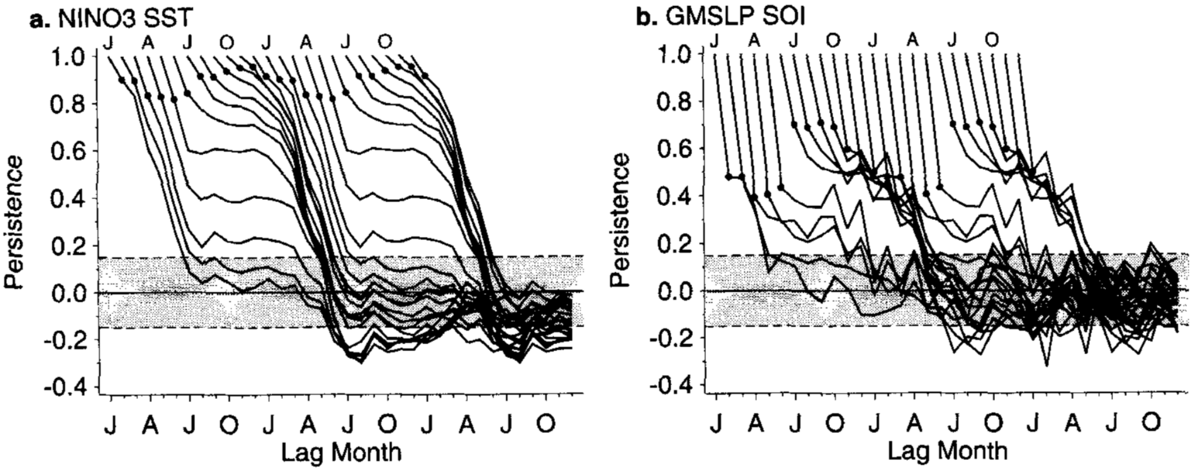

FIG. 1: Data showing persistence between different months of the year (Torrence and Webster 1998). (a) Persistence of NINO3 surface sea temperature (SST) with each curve shifted to line up with the starting month on the top axis (JAJO=January, April, July, October), and the corresponding lag month on the lower axis. The black dots show the lag-1 persistence, and all twelve curves for one year were repeated for clarity. (b) Same analysis applied but for the GMSLP Southern Oscillation Index (SOI).

ENSOs made during or before boreal spring (March–May) have much lower skill than those made at other times of the year (Torrence and Webster 1998). This barrier can be evidenced in oceanic circulation models (Latif and Graham 1992), in dynamical-statistical models (Balmaseda et al. 1994), and in coupled ocean-atmosphere models (Goswami and Shukla 1991, Xue et al. 1994). To better predict ENSO events, this barrier therefore must be understood and accounted for within climate modelling.

3. EVIDENCE FOR THE SPRING PREDICTABILITY BARRIER

Examinations of the autocorrelation and persistence for ENSO data sets provides one method for identifying the predictability barrier without the need to explore complex theoretical models (Torrence and Webster 1998).

Autocorrelation is the correlation of a data set with a version of it self which has been shifted in time by a certain lag. Trenberth (1976) analysed monthly sea level pressures across the Pacific Ocean to conclude that the SST and Southern Oscillation Index (SOI) both have high degrees of autocorrelations which agree with the general observation that ENSO events normally persist for several months. This allows for a forecast of "persistence" across several months where the prediction hinges on the starting month of the initial persistence forecast.

Persistence is another form of analysis which makes use of correlation, however, it looks at the fixed-phase correlation between different months within a single time series (Troup 1965). Contrasting with autocorrelation which is independent of the starting month, persistence allows for the observation of any seasonal changes in the correlation between one month and the next. Analysis by Torrence and Webster (1998) of NINO3 SST and GMSLP SOI data shows that persistence has distinct structure which is phase locked to an annual cycle (Fig. 1). Regardless of starting month, the persistence shows that there is a rapid decline in the March–April–May period which is the manifestation

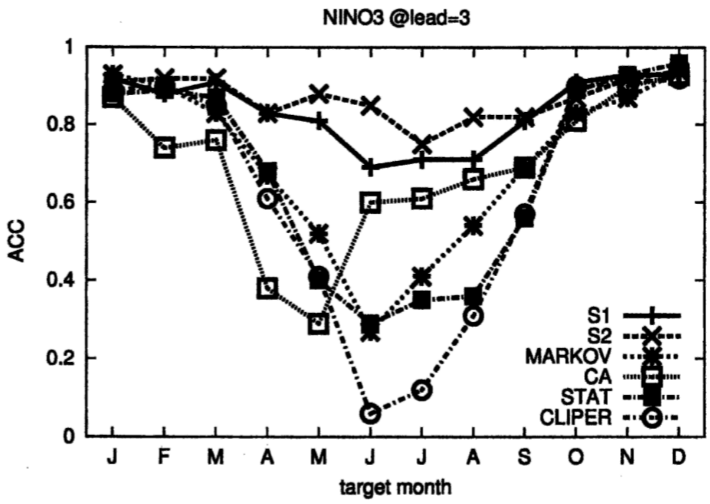

FIG. 2: Plot of the anomaly correlation coefficients of six dynamical and statistical models (S1, S2, MARKOV, CA, STAT, CLIPER) against the months of the year. This demonstrates the skill in predicting monthly Niño-3 index with a lead time of +3 months (Jan van Oldenborgh et al. 2005).

of the spring predictability barrier.

With the SPB apparent from observational data, it would be logical to consider where the barrier occurs in theoretical modelling. As discussed previously, the SPB can arise in dynamical and statistical models where these frameworks often have origins in seasonal forecasting. They couple the dynamics of the atmosphere, ocean and land, thus making them potentially highly applicable in ENSO forecasting. Jan van Oldenborgh et al. (2005) explores the research performed by the European Centre for Medium-Range Weather Forecasts (ECMWF) to test this possibility. Through adapting six dynamical and statistical models from ECMWF, they concluded that whilst in their analysis the spring predictability barrier could occur at different times, there is still high skill in the prediction of ENSO events outside the barrier period (Fig. 2).

Alternative studies which

4. OVERCOMING THE SPRING PREDICTABILITY BARRIER

To surpass the spring predictability barrier

5. CONCLUSIONS

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