7.2

THE DYNAMICS OF ENSO IN A CGCM: PRELIMINARY RESULTS

Lynette Bettio* and Kevin Walsh
The University of Melbourne, Melbourne, Australia

Scott Power
The Bureau of Meteorology Research Centre, Melbourne, Australia

1. **INTRODUCTION**

Recent coupled model studies of the ENSO cycle (e.g. Kirtman 1997, Yu and Mechoso 2001) have helped to clarify mechanisms responsible for phase transitions and growth of the ENSO cycle. The models are examined for their adherence to current paradigms of ENSO, e.g. the delayed action oscillator (Suarez and Schopf 1988, Battisti and Hirst 1989), and the recharge oscillator (Jin 1997). The variability in the tropical Pacific of the Bureau of Meteorology Research Centre (BMRC) coupled general circulation model (CGCM) is examined for its adherence to these two paradigms of ENSO.

2. **THE MODEL**

The model used in this study is a flux-adjusted version of the BMRC CGCM (Power et al. 1998), developed for the investigation of climate response to increased levels of CO_2. The atmospheric component of the model is run at a horizontal resolution of rhomboidal wave 21 with 17 sigma levels in the vertical. Further details on the atmospheric component are provided by Colman et al. (2001). The ocean component (Power et al. 1995) has 2° resolution in longitude. The meridional spacing varies from 0.5° near the equator to 5.8° near the North Pole, with 25 levels in the vertical. A hybrid vertical mixing scheme similar to that described by Chen et al. (1994) is included. Adjustments are made to the net surface heat flux, net surface freshwater flux and the short wave component of heat flux, which is allowed to penetrate into the sub-surface. The model was run for 200 years of which the last 100 are examined here.

A non flux-adjusted version of the model was examined in the ENSIP study (Latif et al. 2001). Climatological SST and its annual cycle are simulated reasonably well in the flux-adjusted model. The model shows good correspondence with the observed spatial evolution of an ENSO event and the interannual variability between events. The model shares a problem with many other CGCMs in that the cold tongue in the tropical Pacific extends too far west. The SST anomalies associated with the ENSO variability also tend to be too weak, and the model exhibits a larger biennial signal than observed (La Niña events in the model are likely to follow El Niño events, for example). The modelled variability is nevertheless El Niño-like in many respects and so it is of interest to identify the mechanisms underlying this variability.

3. **RESULTS**

One of the main paradigms used to explain ENSO is the delayed action oscillator (Schopf and Suarez 1988, Battisti and Hirst 1989). A strong feature of the delayed oscillator is the interaction of SST with the zonal wind stress. An initial westerly zonal wind stress anomaly in the central Pacific excites a downwelling Kelvin wave that propagates to the east suppressing the thermocline in this region and providing a further positive feedback between SST and windstress. Similar to Battisti and Hirst (1989), a plot of monthly zonal wind stress vs. SST (Fig.1) in the CGCM has a statistically significant positive relationship in the equatorial Pacific. A correlation between these two time series reveals a statistically strong correlation of 0.59.

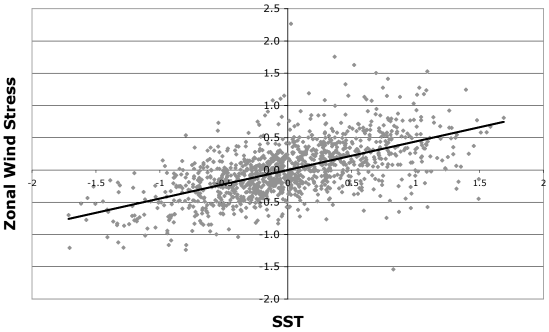

Figure 1. Plot of monthly modelled SST vs. zonal wind stress averaged over the equatorial box (2ºN-2ºS, 80º-180ºW)

The initial westerly zonal wind stress anomaly also excites slower westward propagating Rossby waves. One of the main features of the delayed oscillator paradigm is the reflection of these waves off the western boundary into equatorial Kelvin waves.

**Corresponding author address*: Lynette Bettio, Earth Science Department, The University of Melbourne, Melbourne, Australia, 3010; email: lbettio@earthsci.unimelb.edu.au

Vertically Averaged Temperature (VAT) to 300m is used in this study as a proxy for heat content. Time longitude diagrams of the rate of change of anomalies of VAT on the equator (Fig. 2) show propagating west to east disturbances. Some of these disturbances are quite broad and seem to be preceded by an initial anomaly of the same sign in the western Pacific. However, strong well-defined anomalies are seen propagating east with approximate Kelvin wave speed for various modelled years (eg. Year 2140).

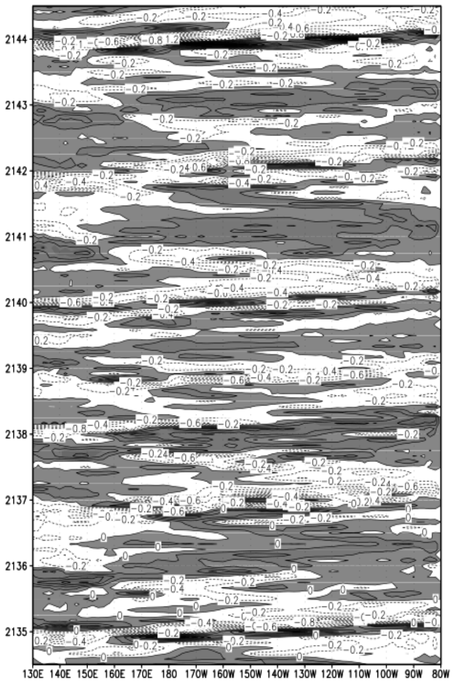

Figure 2. Time longitude diagram of modelled VAT on the equator. Positive anomalies are shaded.

The recharge oscillator theory (Jin 1997) is similar to the delayed oscillator in that it emphasises the role of heat content, or subsurface processes, in the transition between warm and cold ENSO events. But the recharge oscillator relies on the movement of heat content into and off the equator. Changes in the zonal mean thermocline depth are theorised to produce closely related changes in the zonal wind stress, zonal thermocline tilt and eastern Pacific SST.

In a recent study, Meinen and McPhaden (2000), using observations, calculated the first two Principal Components (PC) of the 20ºC isotherm depth, a proxy for thermocline depth, for which VAT is also a proxy. They argued that the first two PC spatial patterns were analogous to the zonal thermocline tilt and a zonal mean mode. Examination of the first PC spatial pattern of VAT in the model (Fig.3a), which explains 21.9% of the variance, shows a positive loading in the eastern Pacific and a negative loading in the western Pacific. This pattern can be equated to the zonal thermocline tilt just discussed. This mode is an important part of the feedback process with the usually shallow eastern Pacific thermocline now deepened and allowing the upwelling of warmer water.

The spatial pattern of the second PC of VAT is also of interest (Fig. 3b). It explains 10.4% of the variance. In this pattern, a positive loading is seen across the whole of the equatorial Pacific, with centres of negative loading to the north and south. This can be considered analogous to the zonal mean mode, a discharge and recharge of warm water in the equatorial Pacific.

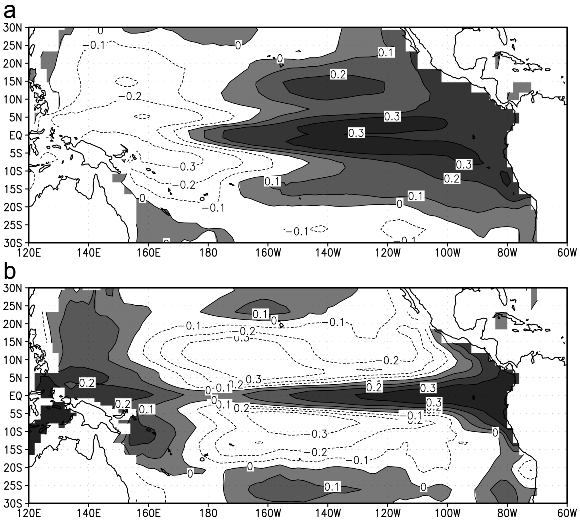

Figure 3. Spatial pattern of a) first and b) second PC of VAT. Positive loading is shaded.

Examination of the time series of the first two PCs reveals modes of a similar amplitude and broad phase, indeed a spectral analysis performed reveals an approximate two-year period for both PC1 and PC2 (not shown). It was found that with PC2 cross-correlated with PC1 there was a peak of .5 with PC1 lagging PC2 by five months compared to .77 at nine months lag found by Meinen and McPhaden (2000).

4. CONCLUSION

The BMRC CGCM is seen to display some mechanisms of theoretical paradigms of ENSO phase change and growth. Wave reflection off the western boundary, a feature of the delayed action oscillator, is present in the model. Also present is the relationship between the zonal mean of VAT and the zonal thermocline tilt as described by the recharge oscillator. A more detailed analysis of the mechanisms underlying the ENSO variability in the model and the role of these and other paradigms, e.g. the SST mode (Neelin 1991), is currently underway.

Further work would include a study of the links between ENSO in the model and Australian precipitation. Wu et al. (2002), studying ENSO in the BMRC CGCM, found that spatial patterns of precipitation were simulated reasonably well in the Australian region during an El Niño event. A greater understanding of the dynamics of ENSO in the model would enable a clearer understanding of the links between ENSO and Australian precipitation.

REFERENCES

Battisti, D. and A. Hirst, 1989: Interannual variability in a tropical ocean-atmosphere model: Influence of the basic state, ocean geometry and non-linearity. *J Atmos. Sci.*, **20**, 1113-1129.

Chen, D., L. M. Rothstein and A. J. Busalacchi, 1994: A hybrid vertical mixing scheme and its application to tropical ocean models. *J. Phys. Oceanogr.*, **24**, 2156-2179.

Colman, R.A., 2001: Climate feedbacks in a general circulation model incorporating prognostic clouds. *Clim. Dyn.* **18**, 103-122.

Jin, F.-F., 1997: An equatorial ocean recharge paradigm for ENSO. Part I: Conceptual model. *J Atmos. Sci.,* **54**, 811-829.

Kirtman, B., 1997: Oceanic Rossby wave dynamics and the ENSO period in a coupled model. *J. Climate*, **10**, 1690-1704.

Latif, M. and Co-authors 2001: ENSIP: The El Niño simulation intercomparison project. *Climate Dyn.*, **18**, 255-276.

Meinen, C. S. and M. J. McPhaden, 2000: Observations of warm water volume changes in the equatorial Pacific and their relationship to El Niño and La Niña. *J Climate,* **14**, 391-402.

Neelin, J. D., 1991: The slow sea surface temperature mode and the fast wave limit: analytic theory for tropical interannual oscillations and experiments in a hybrid coupled model. *J. Atmos. Sci.*, **48**, 584-606.

Power, S., F. Tseitkin, R. Colman and A. Sulaiman, 1998: A coupled general circulation model for seasonal prediction and climate change research. *BMRC Res. Rep.*, **66**, 52 pp.

Power, S.B. et al., 1995: On a global version of the GFDL MOM for ENSO studies. BMRC Tech. Rep.18 pp.

Suarez, M. J. and P. S. Schopf, 1988:A delayed action oscillator for ENSO. *J Atmos Sci.,* **45**, 3283-3287.

Wu, Z.-J., R. Colman, S. Power, X. Wang and B. McAvaney, 2002: The El Nino Southern Oscillation Response in BMRC Coupled CGCM, *BMRC Res. Rep.,* **91**, 23 pp

Yu, J.-Y., and C. Mechoso, 1998: A coupled atmosphere-ocean GCM study of the ENSO cycle. *J. Climate*, **14**, 2329-2350.