EL NINO SIMULATIONS WITH THE CANE AND ZEBIAK's MODEL AND OBSERVATIONS: THE NEED FOR BOTH HYDROGRAPHY AND ALTIMETRY

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1. INTRODUCTION

The Cane and Zebiak's model (Zebiak and Cane, 1987), further referenced as CZ model, is currently used for routine diagnosis and prediction of ENSO fluctuations (see Climate Diagnostics Bulletins). The beauty of this model is its simplicity. This model or similar versions of it have been widely used and analyzed (e.g. Battisti 1988, Goswami and Shukla 1993).

Satellite altimetry provides a unique opportunity to observe synoptic events such as El Niño-La Niña oscillations (e.g Cheney and Miller, 1988). More recently, TOPEX&Poseidon started to provide sea level variations with an unprecedented accuracy. Thanks to the TOGA program, ***in situ*** observations were regularly gathered in order to monitor the tropical Pacific ocean in the upper 400m. Indeed TOPEX and TAO data have been compared and agree very well (Busalacchi et al, 1994).

We illustrate here how both these data sets are complementary and needed when one wants to try and improve the skill of the Cane and Zebiak's model in simulating El Niño events. We performed a detailed comparison between simulations and observations, using various data in the oceanic or the atmospheric fields. The altimetric, hydrographic, SST, wind, solar radiation, latent heat and cloud convection data that we used, are described in (Perigaud and Dewitte, 1.995) and in (Dewitte and Perigaud, 1995). These two latter studies are further named as PD95 and DP95.

The CZ model is first run in an uncoupled context, meaning that the ocean model is driven by observed winds and simulates SST anomalies which are used to drive the atmospheric model. By comparing model and data (see PD95) or by introducing data in the CZ model (see DP95), we were led to revisit the model parametrization of the oceanic temperature at 50m. We examine here the behaviour of the CZ model with the new parametrization in an uncoupled or a coupled mode.

2. RUNS WHERE THE OCEAN MODEL IS DRIVEN BY THE FSU WINDS

In this section, the CZ model is run in an uncoupled mode, starting from rest in 1964. This run is called CR for “control run”. We concentrate on the period 1980-1994. In PD95, we have seen that over this period, the CR simulates the three El Nino events in 1982-83, 1986-87 and 1991-92, but it never simulates cold SST nor easterlies. This is illustrated in (Figure 1). Forcing the atmospheric model with the observed SST (see DP95), shows that the CZ model does not simulate easterlies because of the oceanic model component, not because of the atmospheric one.

Comparing observed and simulated budgets of the various terms involved in the SST equation (see DP95), allows to determine the source of inadequacy in the ocean. The CZ model does not simulate cold events because the net anomalous upwelling term is almost nul. There are two terms of vertical advection (see equation Al 1 in Zebiak and Cane, 1987). One corresponds to the anomalous upwelling of mean temperature vertical

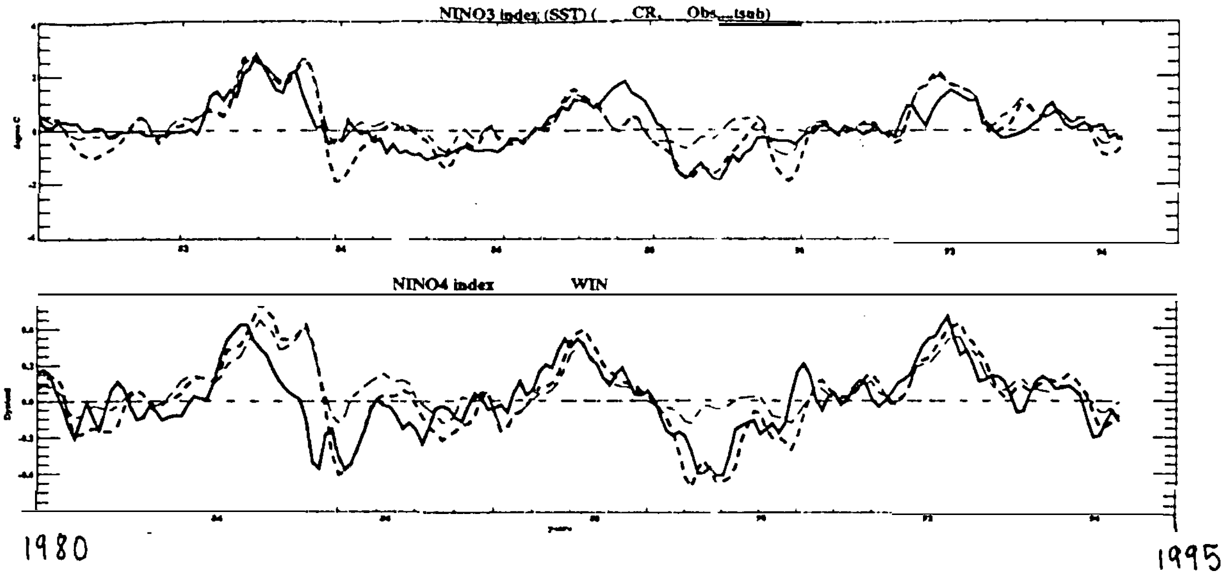

Figure 1: Time series of zonal wind-stress averaged over Nino4 and of SST anomalies averaged over Nino3. The plain line corresponds to Reynods and FSU observations, the thin dashed line to the control run (CR) and the thick dashed line to the model run with the new parametrization Tsub.

gradient, and the other one to the climatologic upwelling of anomalous temperature gradient. The CZ model simulates two terms of equal strength which are anticorrelated, whereas the observed budget indicates a dominant role of the anomalous upwelling of mean vertical gradient. In the CZ model, the anomalous temperature gradient is parametrized by assuming that the temperature at 50m, called Tsub, is a function of thermocline depth (see equation A13 in Zebiak and Cane, 1987).

The hydrographic profiles allow to determine how Tsub varies as a function of oceanic heat content in the upper 400m. This latter quantity is a measure of the thermocline depth (we also used the depth of the 20°C isotherm to check the validity of this approximation). The XBT profiles indicate a Tsub anomaly as strong for cold events as for warm events. The parametrization in the CZ model assumes a Tsub anomaly which is very small in case of thermocline upwelling. Based on the XBT data, we determined a new parametrization which allows to recover the observed Tsub anomaly pretty well (see DP95). The CZ model run with this new parametrization is then pretty successful in simulating realistic SST anomalies and easterlies during cold events (_Figure 1).

It is then worth examining more closely the SST budgets. Along the equator, the meridional advection terms are small. Using altimetry, we derived zonal current anomalies (ZCA) by projecting the observed sea level on the Kelvin and first Rossby modes and we validated the results with drifters and current-meter moorings (see PD95). Based on the comparison between the simulated ZCA and the ones derived from altimetry (see PD95), we found that the model simulates too much reflection at the eastern boundary. Based on data, the low-frequency changes of zonal advection are positively correlated to the changes of SST.

Let us compare the Lagrangian derivative of SST (local changes plus the zonal, meridional and vertical advection terms) with the damping term αT assumed in the model over the central Pacific and over the eastern Pacific. In reality, the Lagrangian Derivative over a closed domain is measuring the heat input across the surface. Along the equator, the contribution of the meridional" exhanges is very small. Based on observations (FSU winds, Reynolds SST, ZCA derived from Geosat and Tsub derived from XBT), we find that the Lagrangian derivative cannot fully be balanced by the

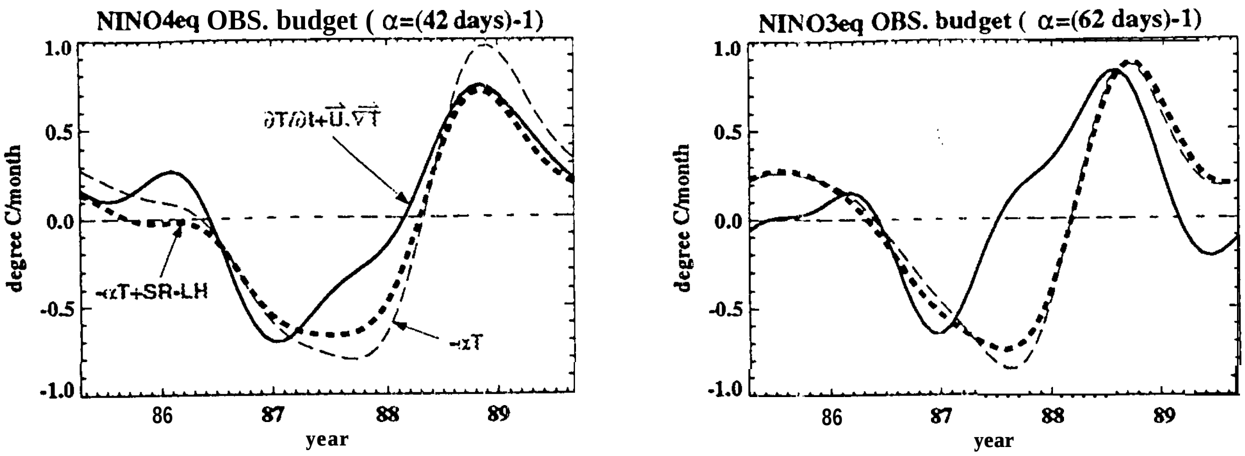

Figure 2: Time series of SST change budgets in Degree per month averaged over Nino4 and Nino3 along the equator. The plain line corresponds to the sum: $\delta T/\delta t + u\, \delta T/\delta x + w\, \delta T/\delta z$ and the thick dashed line to the damping term aT.

damping term αT, especially over the eastern Pacific (Figure 2). These two curves differ in amplitude and phase. We chose the value of the damping term so that the rms difference be the smallest. Nevertheless, the phase lag cannot be compensated and the difference can reach 0.8°C/month, e.g. 40W/m^2 over 50m. We found in DP95 that the lag over the central Pacific can partly be explained by the surface heat flux budget. The solar radiation and latent heat flux anomalies are both quite different from the anomalous field αT, with a maximum amplitude in the central Pacific. Adding air-sea flux budget in the CZ model allows to reduce the misfit in the central Pacific. The unbalance in the eastern Pacific is more difficult to interpret. The four terms of zonal advection and vertical advection have all similar amplitudes and are phase lagged. It is possible that the relative weights of zonal advection versus vertical advection is not adequate. There are quantities in the model which we could not validate with data. In particular, we did not validate the parameter γ, nor the prescribed climatologic fields (see Zebiak and Cane, 1987).

3. COUPLED RUNS

The CZ model is hereafter run in a coupled mode over 45 years, starting from the initial conditions of the CR in January 1980. In the standard coupled run, we verify that the Nino3 SST index oscillates at a frequency close to 4 years. The model with the new Tsub parametrization simulates an index which oscillates at a higher frequency which is close to 2 years (Figure 3).

The interpretation of this result is not straightforward, As explained in Jin and Neelin (1993), there are "fast propagating" modes and "slow propagating" modes, the fast ones being due to the purely dynamic modes. The new parametrization gives a stronger role to the thermocline displacements in the Tsub changes. The idea that this drives the model closer to the fast dynamic modes is not a valid explanation. Increasing the Tsub sensitivity to thermocline changes actually reduces the impact of thermocline on SST

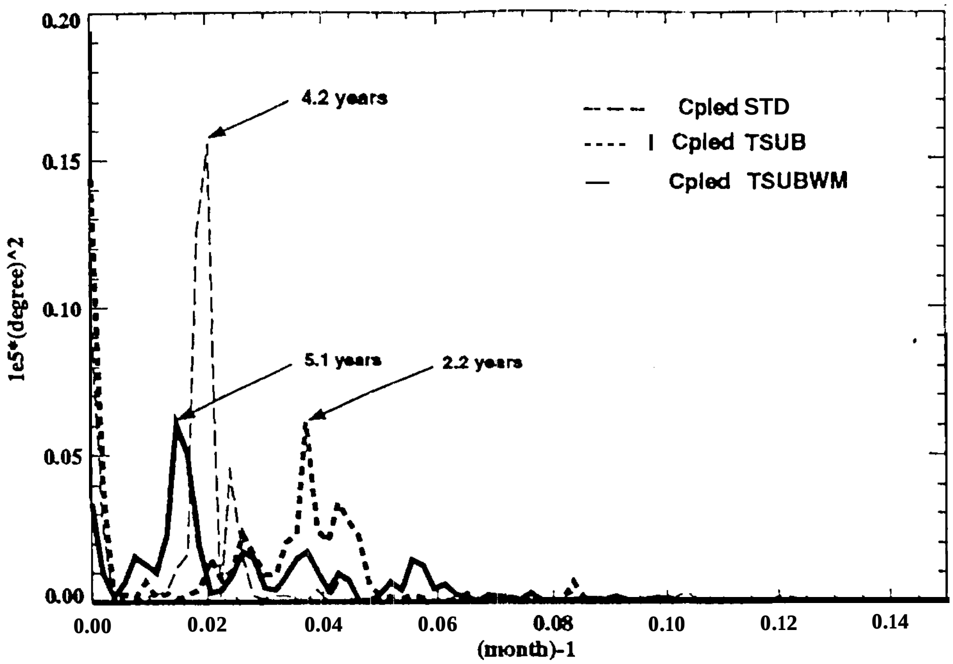

Figure 3: Energy spectrum of the Nino3 'SST index as a function of frequency in month^{-1}. The thin dashed line corresponds to the standard coupled" run (CPD.STD), the thick dashed line to the coupled run with the new parametrization Tsub (CPD.Tsub) and the plain line to the coupled run with new Tsub and reduced climatologic upwelling (CPD.TsubWM).

changes. 'With the new parametrization, it is the anomalous upwelling which plays a stronger role in the SST changes, compared to the role of the climatologic upwelling of anomalous temperature gradient. We found that the anomalous upwelling is dominated by the variations of the Ekman meridional component, i.e. the wind. So the 2 year peak of the model with the new parametrization corresponds to a coupled response of the model. It cannot be interpreted in an uncoupled context.

All these results depend on the climatologic fields which are prescribed in the model. Observations tell us that the tropical Pacific ocean has been undergoing decadal trends. The XBT data indicate that the oceanic heat content in the 10°S-10°N band in the Pacific has increased regularly since 1980. Converted into thermocline depth, the trend is of the order of 20m over 14 years. This observed trend is certainly due to various complex mechanisms involving off-equatorial processes that we do not discuss here. It is possible that this trend is linked to a weaker mean upwelling rate than what we had 10 years ago. So let us run the coupled model with the new parametrization, but with a climatologic upwelling rate reduced by 10%. Indeed this value is close to the one used in Mantua and Battisti (1995). Then, the Nino3 index oscillates within 3 and 7 years (Figure 3).

4. CONCLUSION

The CZ model run in its "uncoupled mode" over 1980-1993 simulates fairly well the observed warm SST and westerlies during El Niño events, but not the observed cold SST, nor the easterlies during La Niña 1988. The XBT data show that this is because the temperature of the ocean at 50m is not adequately parametrized as a function of thermocline depth variation in the model. The vertical profiles of temperature observed with XBT allow to determine a parametrization which is more realistic. With this new parametrization, the model is successful to simulate the cold SST anomalies and the easterlies over 1980-1993.

Then 45-year long runs were performed with the model in its coupled mode. With the new parametrization, the simulated Nino3 index is not oscillating with a 4 year peak, but with a 2 year peak. The XBT data show that the oceanic heat content in the tropical Pacific has been increasing over the last decade. This may correspond to an upwelling rate at the equator which is weaker today than 10 years ago. By prescribing a slightly weaker climatologic rate of upwelling, the coupled model with the new parametrization simulates a Nino3 index oscill sting between 3 and 7 years.

In this study, the XBT data have been extremely useful to derive the new parametrization, because these data provide subsurface information, Altimetric data have been useful to derive zonal current anomalies in the equatorial wave guide. This is possible thanks to their synoptic and dense coverage. Indeed dense XBT as the TOGA-TAO network allows to derive accurate thermocline depth and zonal current anomalies as Topex&Poseidon. We also show that based on the decadal trend observed with XBT in the equatorial Pacific ocean, the coupled simulations are highly sensitive to the prescribed climatology in the equatorial ocean. Long-time series of accurate altimetry such as TOPEX&Poseidon are needed to examine the large scale meridional sea level variations, which are probably linked to the decadal trends in the equatorial ocean.

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