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Antarctic Circumpolar Wave dynamics in a simplified ocean-atmopshere coupled model

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INTRODUCTION

Using reanalysis data from the ECMWF, White and Peterson (1996, WP96) discovered a peculiar pattern of variability of the coupled ocean-atmosphere system in the Southern Ocean: the Antarctic Circumpolar Wave (ACW). We want to simulate the ACW through a simple dynamical model, and determine its basic physical mechanism. The model used is an atmospheric quasi-geostrophic tridimensional model coupled to an ocean "slab" mixed layer model. The fact that the ACW has an atmospheric and an oceanic signature (see below) suggests the existence of a coupled mode; the first goal of this work is to determine whether the ACW is really created by a coupled oscillation of the atmosphere-ocean system, or rather whether the dynamic is contained in only one of the climatic component, which then forces the other. We first present the ACW pattern and describe the model we used. Next, we present some preliminary results. We study the passive response of each climatic component to the forcing of the other to understand the origin of the coupled mechanisms which could explain the results of the coupled simulation.

THE *OBSERVED* ACW

The first description of the ACW was given by using reanalysis data from the ECMWF (ERA15). WP96 conclusion was that the ACW consists of a SLP and SST wave train of zonal wavenumber 2, travelling around Antarctica at the speed of $6-8cm.s^{-1}$ (cf figure 1,left), hence taking 8 years to complete a circle around the globe. A fundamental feature of this observed pattern is that anomalies are eastward propagating with phases locked, for example SST and SLP are in quadrature (high downstream of warm SST, figure 1,right). Different analytical theories and numerical simulations subsequent to WP96 observations were advanced to explain the ACW as a coupled oscillation in which the atmospheric and the oceanic component play different roles, Colin de Verdière and Blanc (2001), Goodman and Marshall (1999) or as a fundamentally passive response of the ocean to stochastic atmospheric forcing, Cai et al (1999).

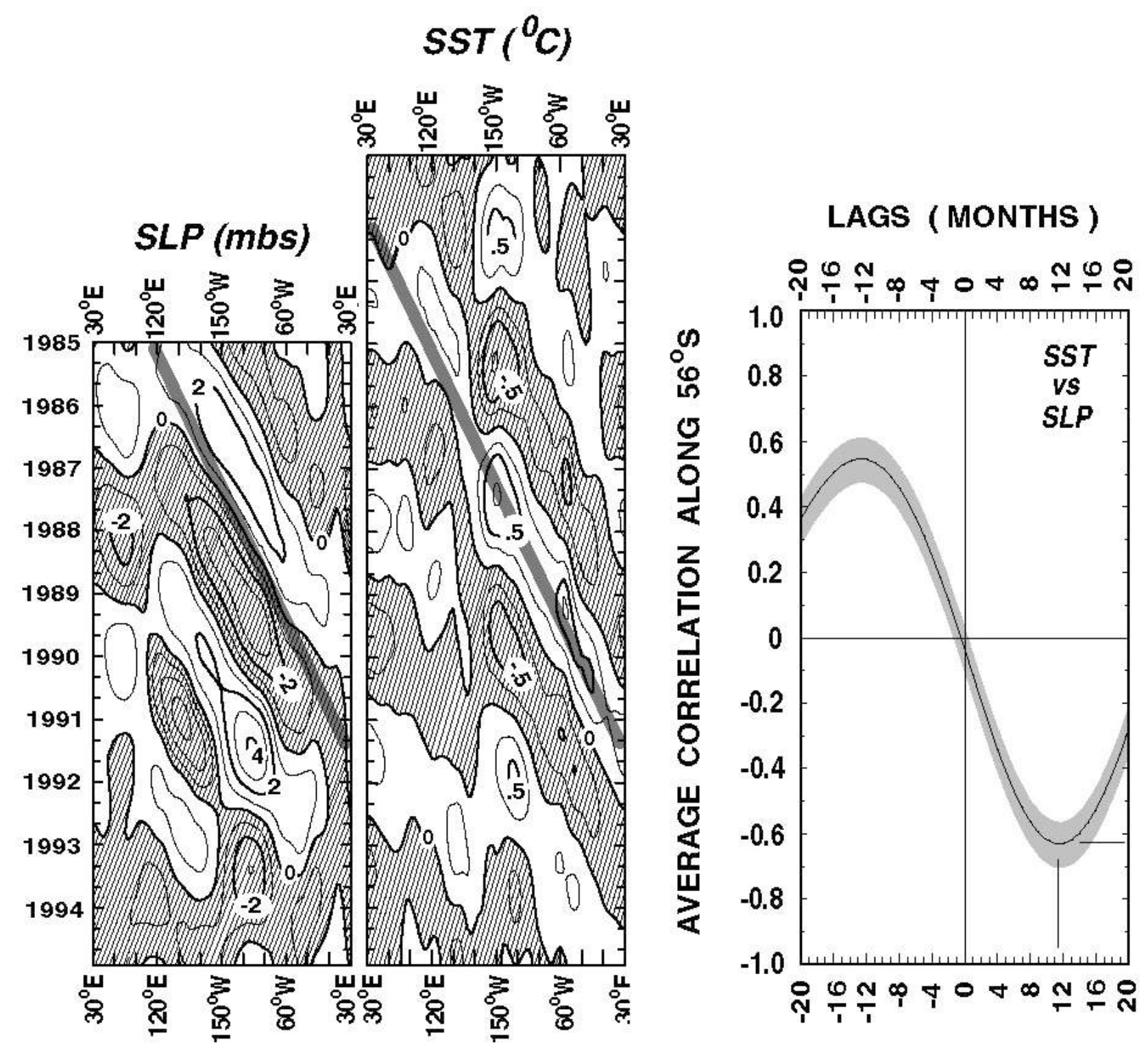


FIGURE 1: Left: SLP and SST Hovmoller diagram from the ECMWF ERA15 dataset. Right: zonal mean cross-correlation between SST and SLP. White and Peterson (1996)

THE QG MODEL

We used the T21 atmospheric spectral model of Marshall and Molteni (1993) where the quasi-geostrophic potential vorticity equation:

$$\frac{Dq}{Dt} = S + \kappa(F) - D \tag{1}$$

is solved on the sphere and discretized at 3 vertical levels: 200, 500 and 800mb. We coupled this atmospheric model to the ocean through surface heat flux -SHF- which induces PV sources (κ) at 500 and 800mb. SHF is given by the bulk formulae:

$$F = \rho_a C_D c_{pa}(1+1/B)|\underline{U}_s|(SST - T_s) \tag{2}$$

where $B = 0.5$ is the Bowen ratio, $|\underline{U}_s|$ the surface wind intensity and T_s is the atmospheric surface temperature.
The ocean model consists of a mixed layer of constant depth whose temperature equation reads:

$$\frac{\partial SST}{\partial t} = -J(\psi_g, SST) - \underline{U_E}.\underline{\nabla}SST - \frac{F}{C_{po}} - D + S_{sst} \tag{3}$$

where C_{po} is the heat capacity of the water column, D is a linear dissipation term and S_{SST} is a source term. The coupled model was integrated with truncature "T21" for the atmosphere and with a resolution of roughly 5 degrees for the ocean. S and S_{sst} are source terms which insures that mean states are the imposed climatology.

RESULT 1 → Passive Ocean

We performed an integration of 1000 years in which the atmospheric part of the model forces the ocean but only feels a constant SST in return. Observation of Hovmoller diagrams of SST along the 55^oS latitude (figure 2) exhibits SST of absolute amplitude $0.2K$ propagating eastward and having approximately a zonal mode 2. Despite a strong interdecadal modulation, when anomalies can be observed, they have a 10 years period and can be followed for 1 to 2 or 3 revolutions around the globe. Even if evidences of propagative anomalies in the atmosphere are less clear, time lagged crosscorrelations between SST and atmospheric variables are strong at all longitudes. This is due to a propagative atmospheric component which is phase locked to the SST. Figure 3 shows in dashed lines zonal mean of crosscorrelation of SST versus several variables. We observe high geopotential height, downward heat flux and positive SAT leading a positive SST by 4 to 6 months. This is caused by high air temperature creating the heat fluxes that create in turn the SST anomaly. We see an oceanic response which is compatible with WP96 and is entirely organised by the atmospheric dynamics.

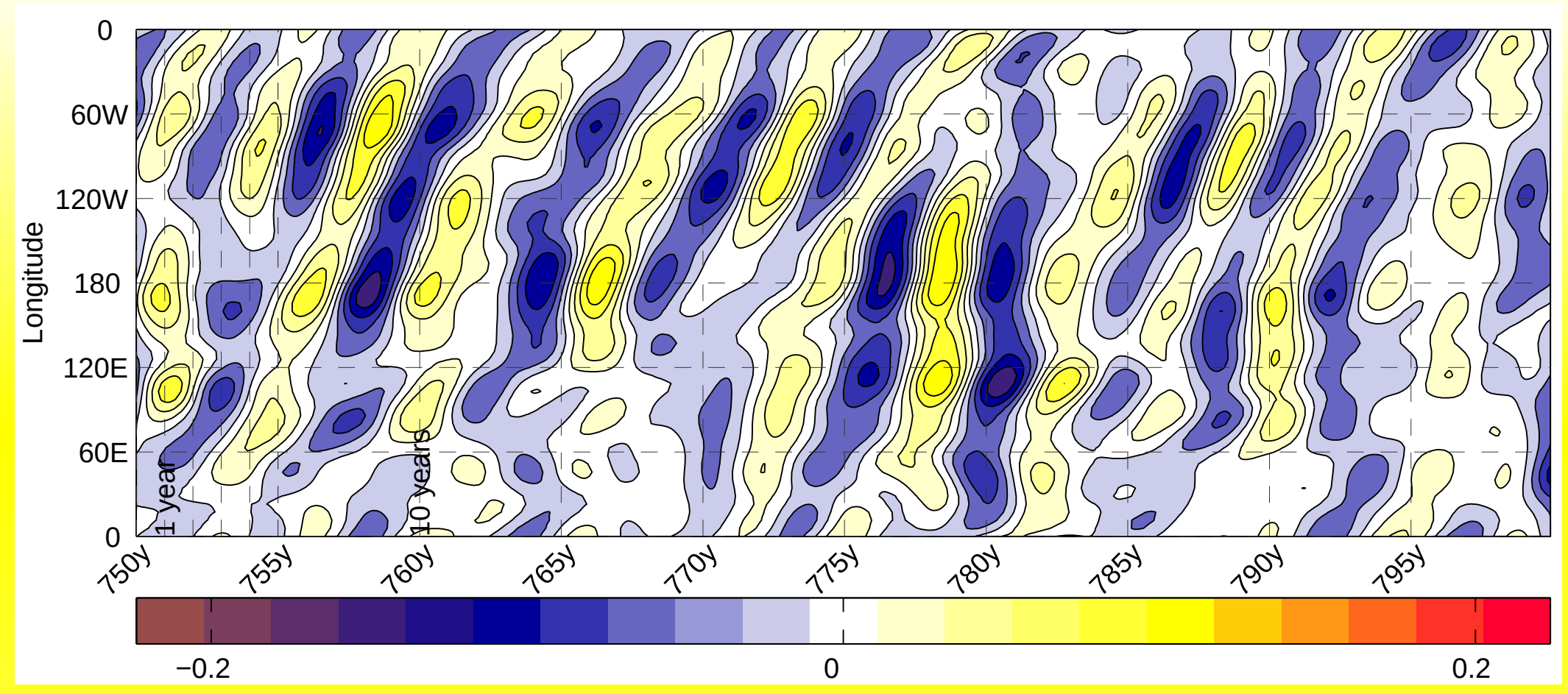


FIGURE 2: Hovmoller diagram of SST anamolies along 55^oS for the ocean forced simulation.

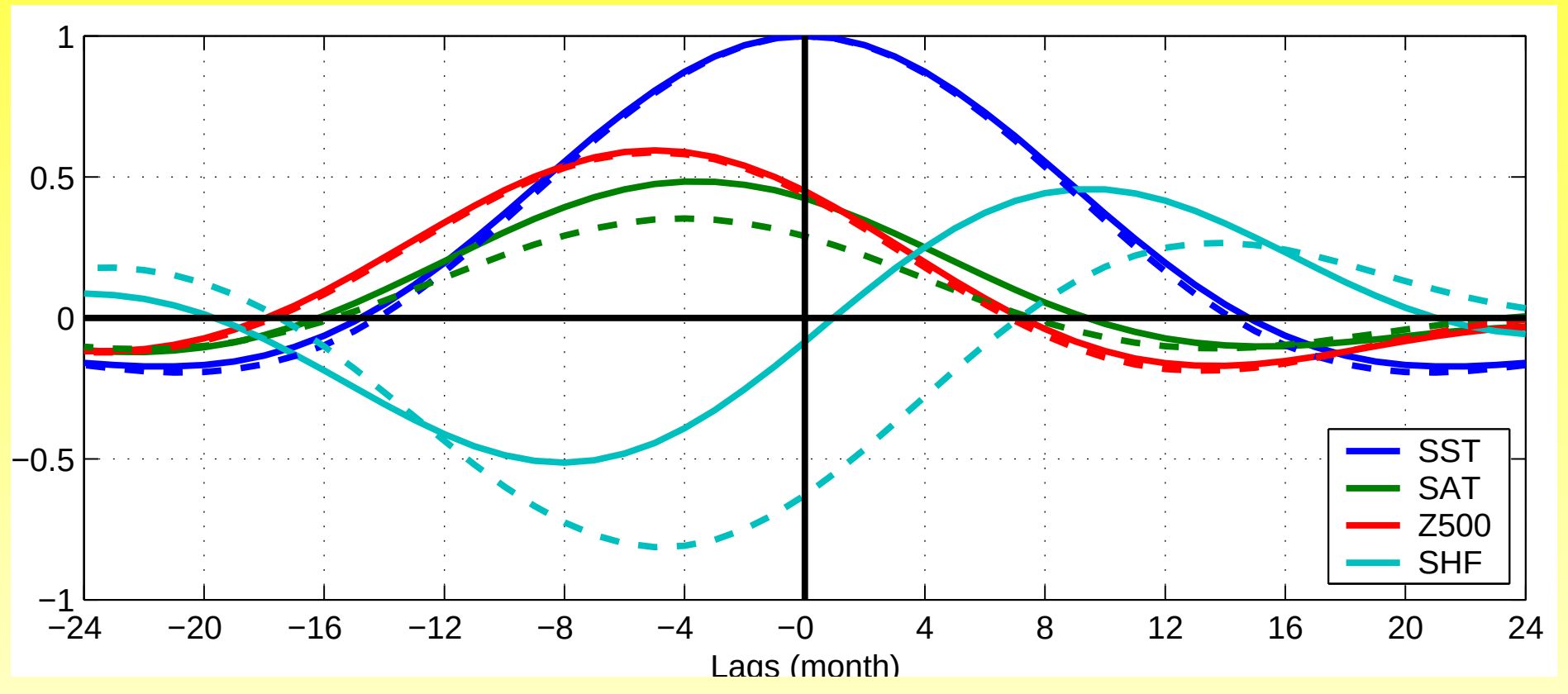


FIGURE 3: Zonal mean of time lagged crosscorrelation along 55^oS for ocean forced (dashed lines) and coupled (plain lines) simulations between SST and itself (heavy blue), SAT (green), Z500 (red) and SHF (light blue).

RESULT 2 → Passive Atmosphere

We analyse here the atmospheric response to standing and propagating prescribed SSTa of several patterns. Figure 4 shows results for a standing wavetrain of SSTa with a zonal mode 2 and 1K amplitude. This anomaly provides a 15m geopotential height anomaly at 500mb, extending 60^o eastward and a bottom layer temperature anomaly of roughly $1K$, 40^o eastward. Although weak these responses are significant at 99% confidence level. Figure 5 confirms these observations when the wavetrain propagates eastward. What we can see is that a large positive crosscorrelation develops between warm SSTa and high pressure at 500mb and warm atmospheric temperature, respectively 60^o and 40^o eastwards of the SSTa. These observations are robust to all the SSTa pattern we used, even if some zonal modulation in the eastward shift was observed. This can be probably explained by a local influence of the Antarctic Oscillation.

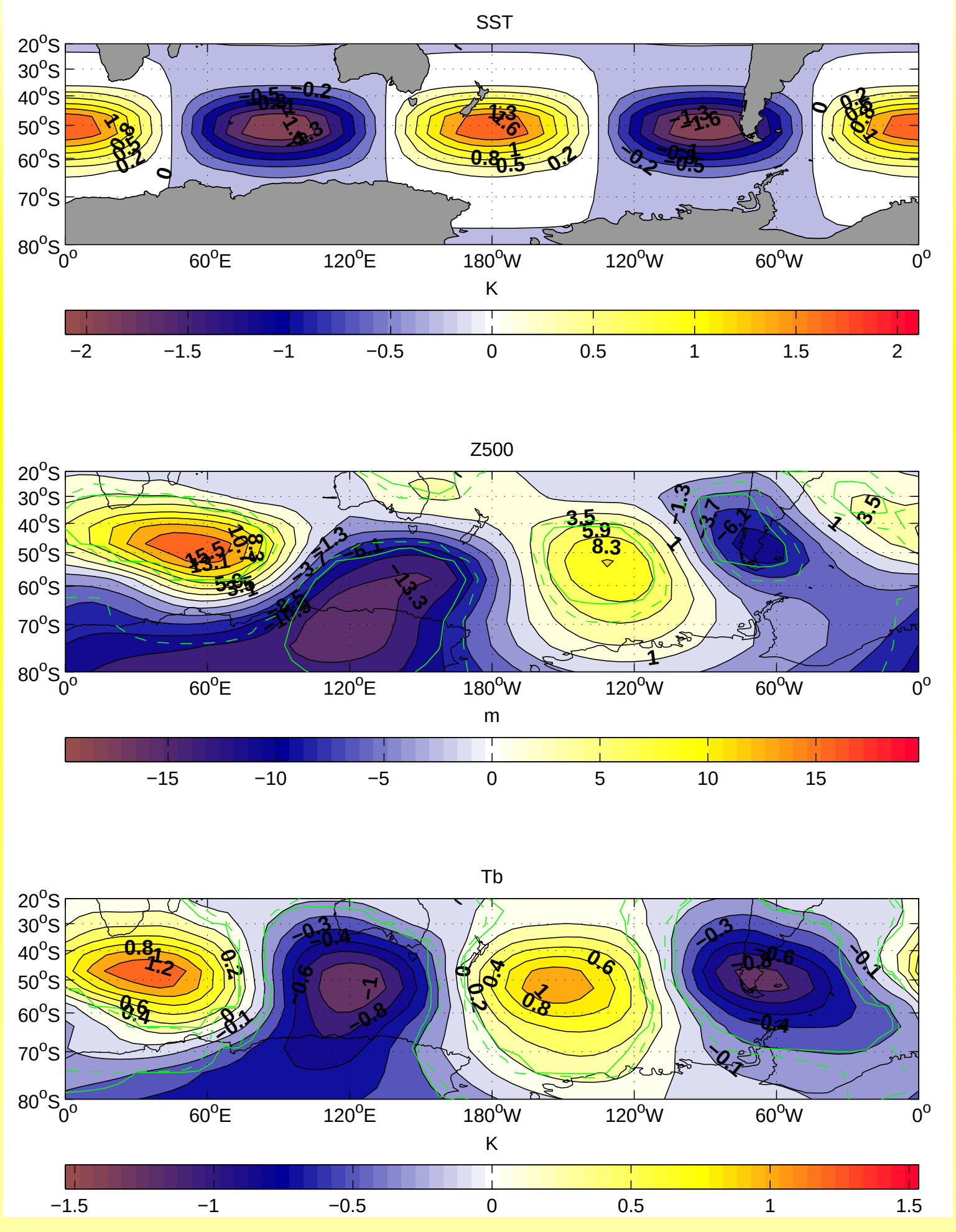


FIGURE 4: Differences between mean fields from positive and negative anomalies simulations with a 1K SSTa wavetrain of zonal mode 2 centered on 52^oS. Upper SST field, lower Z500 and T650 fields. Green lines indicates 99% (plain) and 95% (dashed) significance level.

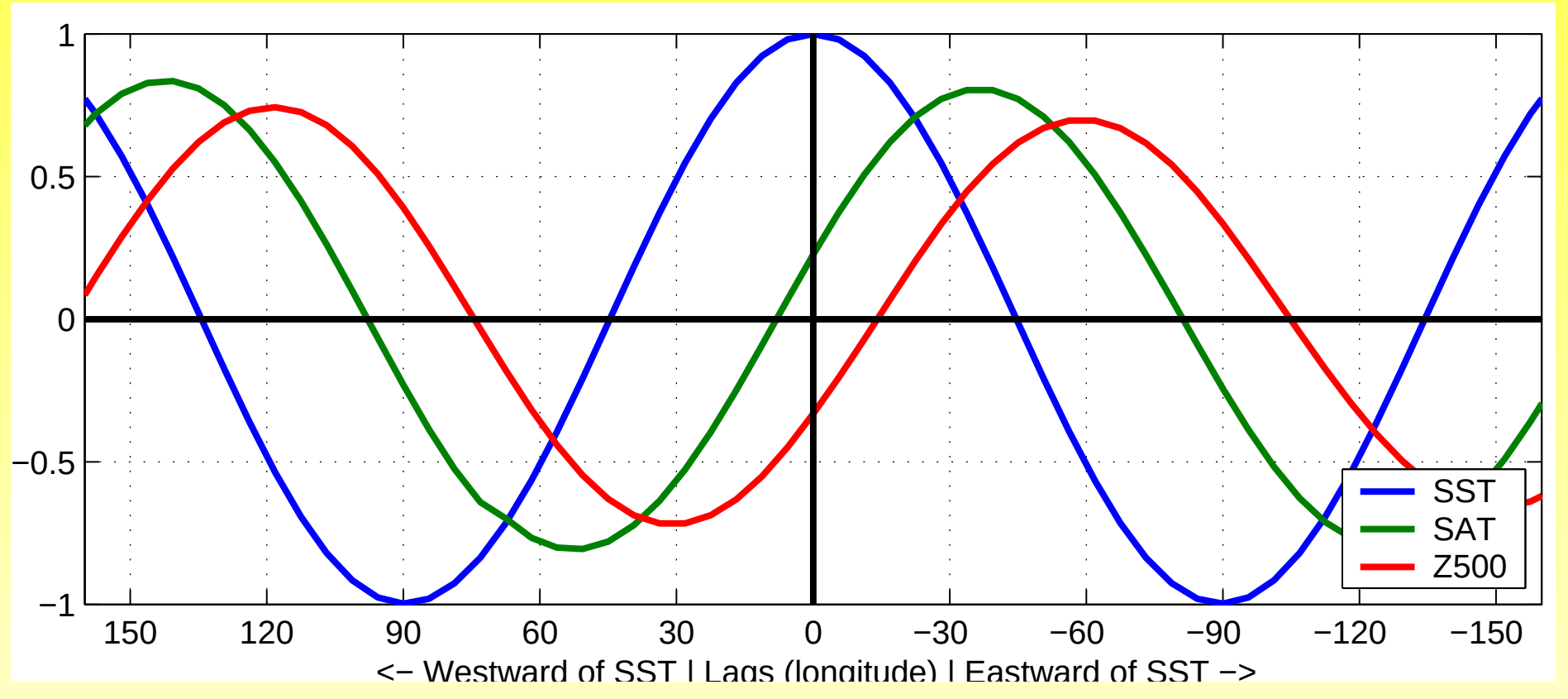


FIGURE 5: Average on composites of space lagged crosscorrelation along 55^oS for the passive atmosphere simulation between SST and itself (heavy blue), SAT (green), Z500 (red).

RESULT 3 → Coupled Ocean-Atmosphere

We performed a fully coupled integration of 1000 years. As in the passive-ocean simulation, Hovmoller diagrams show a SST wavetrain of zonal mode 2 propagating eastwards and taking 8 to 9 years to encircle the globe, but the amplitudes have doubled (0.3 to 0.4^oK), so that the coupling enhances the oceanic response. Figure 3 shows in plain lines the lagged crosscorrelation between SST and SAT, Z500 and SHF. The coupling signature can be seen in the increase of correlation with the SAT and in the quadrature phase relation with the SHF. In the passive ocean simulation downward heat flux led SST by 4 months, in the coupled simulation downward SHF leads SST by 8 months and upward SHF lags SST by 8 months. Moreover, the unfiltered SST autocorrelation decrease (a proxy for SST life time) indicates that SST anomalies in the coupled simulation persist longer than in the passive-ocean simulation (figure 6). All these observations indicate that positive feedbacks from the ocean to the atmosphere exist.

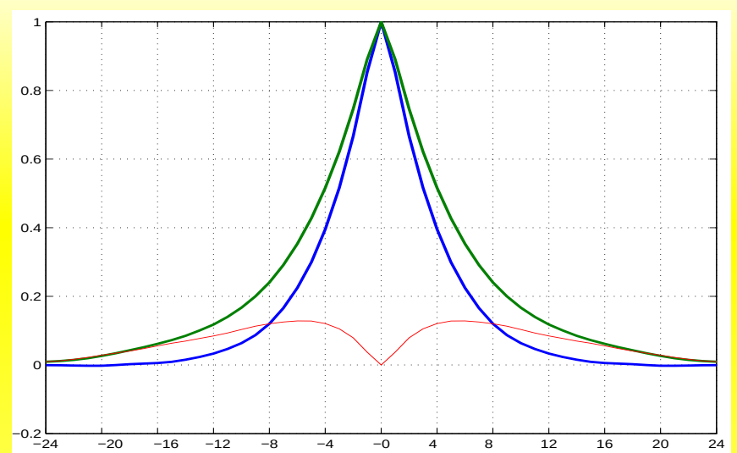
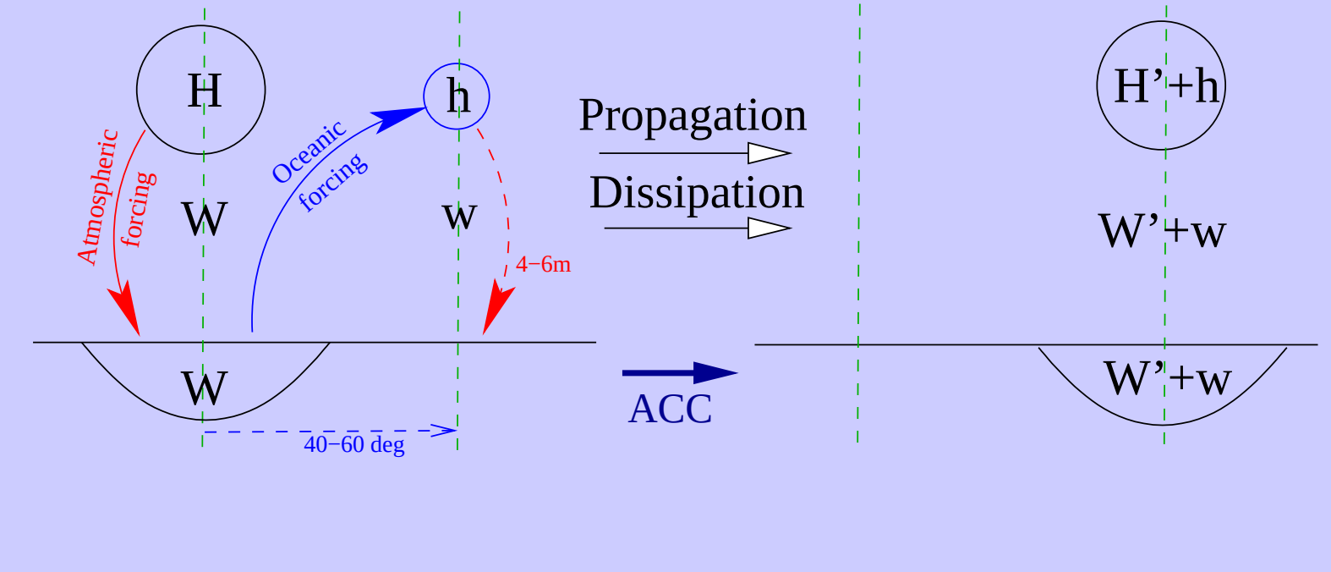


FIGURE 6: Lagged autocorrelation of SST for coupled model (green) and ocean-forced model (blue) with doubled SHF. Difference between coupled and forced ocean in red.

CONCLUSION



Comparing results from the passive ocean and passive atmosphere simulations, the possibility of a positive feedback emerges to explain the increase of SST life time and amplitude in the coupled simulation. Moreover, the SST propagation speed in the coupled simulation seems to be higher than in the passive-ocean one, indicating that the mecanism proposed may contribute to both SST propagation speed and persistence.

Bibliography

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