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El Niño and mixed-layer processes

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Abstract

El Niño, the dominant form of interannual variability of climate, is caused by interactions between the tropical ocean and atmosphere which exchange heat and momentum. How the tropical ocean responds to atmospheric forcings depends sensitively on its mixing properties. So the nature of the El Niño depends on the oceanic mixing properties too.

The present description of mixing processes in ocean general circulation models is not fully satisfactory. Parameters are tuned to the best representation of El Niño without much regard how well they represent small scale processes or not. Even then the models have difficulties in simulating both the background state and El Niño's correctly.

We want to use ideas from atmospheric general circulation models, in particular from non-local boundary-layer model schemes, and apply them to ocean models. So far, this has been hampered by a lack of data, but we hope that recent experiments like TOGA-COARE will provide enough new information.

1. INTRODUCTION

El Niño, Spanish for the Christ child, has historically been associated with a weak, warm current appearing along the coast of Ecuador and Peru annually around Christmas, replacing the usual cold waters of the Peru current. Nowadays, the name El Niño tends to be used for a much larger scale phenomenon that occurs not annually, but every three to seven years in which the normally cold waters over the entire eastern Pacific Ocean show a dramatic warming. Also, very large anomalies in the oceanic and atmospheric circulations and in the global weather are associated with these changes in the equatorial sea surface temperature. El Niño is the dominant form of interannual variability of climate. Severe effects occur all over the world, like droughts in Australia, and reduced fishing near the coast of Peru.

At the time of this conference, it looks like that a new El Niño is about to start. One of indicators is the low pressure difference anomaly between Darwin and Tahiti over the last half year, another indicator is that the sea surface temperature (SST) around the date line is higher than normal and that this area of warm SST is moving westwards.

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2. OCEAN-ATMOSPHERE INTERACTIONS

The El Niño phenomenon (Philander, 1990) is caused by interactions between the tropical ocean and atmosphere which exchange heat and momentum. The atmosphere influences the ocean mainly through the stress exerted by the surface winds, and to a lesser extent through the heat flux and the precipation and evaporation. The ocean in turn influences the atmosphere through the sea surface temperature.

During an El Niño, weakened easterlies cause warm western Pacific water to flood over the cold eastern water and to slow down the upwelling of cold water at the coast of South America. The barrier between warm surface waters and cold deep ocean waters, the thermocline, which normally slopes upward from west to east, becomes more flat. This also contributes to the temperature rise of the waters in the east. The shift in sea surface temperature is accompanied by a shift of the major rain zone to the east. Related adjustments in the atmosphere cause a further weakening of the easterlies in the central Pacific. In this way all the coupled influences amplify each other, until eventually one can speak of a full-blown El Niño.

3. FRICTION AND MIXING IN THE TROPICS

Friction plays a more important role in the dynamics of the tropical ocean-atmosphere system than in mid-latitude systems. This is because at the equator pressure gradients can be balanced only by frictional forces, while at higher latitudes there is the possibility of a balance between the Coriolis force and the pressure force. Indeed, strong ocean currents are found along the equator. In some places, the currents have such a strong horizontal or vertical shear that mixing is much enhanced. Horizontal friction is the main limiting mechanism for equatorial currents (Crawford 1982). Vertical mixing also affects the strength of the current, but, more important, controls the shape of the thermocline (Pacanowski and Philander, 1981). In a large region in the Western Pacific, there is a deep (about 200m), mixed layer of warm water (around 30 C). The heat which can be stored in this deep warm pool plays an essental role in triggering and maintaining El Nino events. The evolution of the deep warm pool depends on mixed-layer processes.

All this has been confirmed by numerous studies, including some where KNMI was participating (M. Latif et al., 1994).

At the equator, in the Pacific, a strong eastward countercurrent, the Equatorial Undercurrent, flows below the westwards flowing surface waters. The core of this current follows approximately the thermocline. In the high-shear regions around the undercurrent, mixing is substantially enhanced. The dynamics of the undercurrent is quite sensitive to this mixing. General Circulation Models without a proper representation of the undercurrent have difficulties in making good SST simulations.

Mixing properties affect both the El Niño's, and the background mean annual cycle. In general, ocean general circulation models (OGCM's) have difficulties in reproducing both good El Niño's and a good mean annual cycle. But this is necessary if one wants to study how global climate change might affect the character of El Niño.

4. MIXING FORMULATION IN OCEAN MODELS

The present description of mixing processes in OGGM's is not fully satisfactory. The usual mixing formulation for the shear around the undercurrent (Pacanowski and Philander, 1981) is rather ad hoc and parameters are tuned to the best representation of El Niño without much regard how well they represent small scale processes. Even then the models have difficulties in simulating both the background state and El Niño's correctly. For the surface mixed layer, mixed-layer schemes of the Niiler-Kraus (1977) type often are used, but they were originally developed for mid-latitude situations, and whether they can simulate the deep warm pool in the West-Pacific and the surface waters above the undercurrent is questionable.

5. NEW MIXING SCHEMES

Models of the atmospheric boundary layer, both stable and unstable, are more versatile and seem to have reached a more advanced state of development (Holtslag and Nieuwstadt 1986). Holtslag and Moeng (1991) have found a way to parameterize countergradient heat transport in the convective boundary layer. A module based on this parameterization was made for the NCAR Community Climate Model by Holtslag and Boville (1993).

We want to apply these ideas, in particular the non-local schemes, to the oceanic boundary layer. First a 1-D model for a column of water will be made which can simulate well the detailed evolution, including day-night contrast and how the mixed layer responds to a shower. So far, testing such models has been hampered by a lack of data, but we hope to be able to do that with data from recent experiments like TOGA-COARE. Next a parameterization will be devised which is suitable for implementation in an OGCM with a resolution of the order of 15m in the first 150m, and the consequences for El Niño will be investigated.

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