Chapter 7

THE DYNAMICS AND PHYSICS OF ENSO

Dancing on equatorial waves.
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In chapter 1, the El Niño /Southern Oscillation (ENSO) phenomenon was introduced as an interannual climate variation in the Tropical Pacific. Sea surface temperature (SST) anomalies of up to a few degrees occur in the eastern part of the Pacific (El Niño /La Niña) and are accompanied by a weakening and strengthening of the trade winds (Southern Oscillation). ENSO is the most prominent example of interannual variability in the climate system. Because it evolves on relatively short time scales, it is one of the best studied climate phenomena, both observational and theoretical. ENSO is caused by processes both in the tropical ocean and atmosphere with a central role for the SST. The observed spatial structures involved, their temporal development and the relationship between the oceanic and atmospheric variables are now fairly well known (Rasmusson and Carpenter, 1982; Wallace *et al.*, 1998). A historical overview of key research leading to this knowledge is given in Philander (1990) and Wallace *et al.* (1998).

In this chapter, focus is on the dynamical understanding of El Niño which has been obtained over the past decades through mechanistic studies with intermediate complexity coupled ocean-atmosphere models (ICMs). Because bifurcation analysis has not been performed on a hierarchy of models such as that for the ocean circulation, this chapter has a slightly different setup than the previous two chapters. We will mainly focus on one class of ICMs and dynamical systems methods will help interpret its solutions.

The chapter starts with a short description of the phenomena under study in section 7.1, which ends with the central questions posed. Modeling of the equatorial ocean is subject of section 7.2 where the relevant equatorial waves and adjustment processes are discussed. In section 7.3, the physics of coupled processes between the equatorial ocean and atmosphere is addressed while simultaneously the additional ingredients for an ICM are introduced. An overview of results of the first ICM, which was able to successfully simulate ENSO-like behavior (Zebiak and Cane, 1987) is given in section 7.4. In the next section 7.5, the development is sketched towards a conceptual framework, the delayed oscillator, to understand the results in this ICM. It is here that a dynamical systems approach turns out to be useful. The involvement of coupled processes in the annual-mean state and its consequences for ENSO are subject of section 7.6 and 7.7, while the interaction of the seasonal cycle and ENSO is dealt with in section 7.8. In the section 7.9, ENSO variability is addressed in a broader context together with an overview of results from Coupled General Circulation Models (CGCMs). A synthesis of the results in this chapter follows in section 7.10.

7.1. Basic Phenomena

The spatial and temporal structures of the annual-mean state, the seasonal cycle and of ENSO are described below, but only those features which easily relate to those computed from the ICMs introduced later on. Hence, this description has a very limited scope and other sources should be consulted (for example Philander (1990), Horel (1982) and Wallace *et al.* (1998)) for a more complete view of the phenomena involved.