Optimal Growth of Antarctic Circumpolar Waves

CHRISTOPHER M. AIKEN AND MATTHEW H. ENGLAND

Centre for Environmental Modelling and Prediction, School of Mathematics, University of New South Wales, Sydney, New South Wales, Australia

CHRISTOPHER J. C. REASON

Department of Oceanography, University of Cape Town, Cape Town, South Africa

(Manuscript received 9 August 2004, in final form 10 August 2005)

ABSTRACT

Generalized stability theory is applied to a simple dynamical model of interannual ocean–atmosphere variability in the southern midlatitudes to determine the perturbations that create the most rapid growth of energy in the system. The model is composed of a barotropic quasigeostrophic atmosphere coupled to a 1.5-layer quasigeostrophic ocean, each linearized about a zonally invariant mean state, and with atmospheric and ocean surface temperature obeying a simple heat balance. Eigenanalysis of the system reveals modes of interannual variability that resemble the so-called Antarctic Circumpolar Wave (ACW), consistent with an earlier analytical study of the system. The optimal excitation of these modes relative to an energy norm is found to be a perturbation almost entirely restricted to the ocean momentum field and is shown to resemble strongly the optimal perturbations in energy for the system. Over interannual time scales most rapid growth is seen in zonal wavenumbers 4–6, despite the fact that the least-damped eigenmodes of the system are of a lower zonal wavenumber. The rapid transient growth in energy occurs by extracting perturbation energy from the mean state through advection of the mean meridional oceanic temperature gradient. This transient growth of high-zonal-wavenumber modes dominates the model's variability when it is forced by noise that is white in space or time. A dominant low-zonal-wavenumber response, consistent with the observed and modeled ACW, occurs only when the forcing is red in space or time, with decorrelation scales greater than 3 yr or 10 000 km. It is concluded that, if the ACW is a coupled mode analogous to that supported in this simple model, then it is excited by other large-scale phenomena such as ENSO rather than by sources of higher-frequency forcing.

1. Introduction

Over the past two decades there has been a sustained effort toward observing and understanding interannual to decadal climate variability. This has been spurred to some degree by the need for a baseline against which to detect changes in the present climate. The identification of interannual and decadal modes of variability also offers the prospect of increased climate predictability, with that afforded by improved understanding of ENSO being a notable example. As such, the discovery of phase-linked interannual anomalies in a number of atmospheric and oceanic variables in the southern mid- to high latitudes, such as the Antarctic Circumpolar Wave (ACW), may have important ramifications for improving our understanding of Southern Hemisphere climate variability and assessing its predictability. In this study we focus on the ACW, although we recognize there are other important modes in the mid- to high southern latitudes, such as the Antarctic oscillation and the semiannual oscillation, that are also important in the context of climate variability studies.

The ACW was originally characterized as a set of eastward-propagating wavenumber-2 anomalies in sea surface temperature (SST), wind stress, sea level pressure (SLP), sea surface height (SSH), and sea ice extent (White and Peterson 1996; Jacobs and Mitchell 1996). SLP anomalies lead SST anomalies by approximately $\pi/4$, suggesting a coupling mechanism involving geostrophic advection of the mean SST field and a subsequent barotropic atmospheric response to surface heating. The whole pattern appears to be advected by the

Corresponding author address: Chris Aiken, Centro de Investigación en Ecosistemas de la Patagonia, Bilbao 449, Coyhaique, Chile. E-mail: aiken@maths.unsw.edu.au