Available online at www.sciencedirect.com
SCIENCE DIRECT®
Dynamics of Atmospheres and Oceans
39 (2005) 153–173
dynamics of atmospheres and oceans
www.elsevier.com/locate/dynatmoce

Laboratory simulations of coastally trapped waves with rotation, topography and stratification

Peter G. Baines[a,*], Don L. Boyer[b], Bin Xie[b]

[a] *Department of Civil and Environmental Engineering, University of Melbourne, Victoria 3010, Australia*
[b] *Environmental Fluid Dynamics Program, Department of Mechanical and Aerospace Engineering, Arizona State University, Tempe, AZ, USA*

Received 25 February 2004; received in revised form 12 December 2004; accepted 17 December 2004

Abstract

We describe observations of the generation and propagation of coastally trapped waves in the laboratory and their comparison with theory, over a range of values of several experimental parameters. The topography and stratification used consisted of a sloping continental shelf and vertical continental slope with three-layer stratification that could be approximated by an extended version of the Gill and Clarke model [Gill, A.E., Clarke, A., 1974. Wind-induced upwelling, coastal currents and sea level changes. Deep Sea Res. 21, 325–345]. The latter was modified to accommodate a central mixed layer, curved geometry, and friction on the shelf. This configuration represents coastal geometry with large Burger number. The experiments were successful in realizing coastally trapped waves that were consistent with the theoretical expectations. However, the waves propagated more slowly, and for narrow shelves were damped more rapidly than predicted by the theory. The first was attributed to: (i) the effect of stratification on fluid on the shelf, reducing the topographic Rossby wave effect; (ii) the parameterization of the viscosity. The second difference was attributed to the mechanism of generation: the paddle used did not always generate sinusoidal waves, and the subsequent dispersion resulted in a net loss of amplitude.

Keywords: Topography; Amplitude; Coastal

* Corresponding author.
E-mail address: p.baines@civenv.unimelb.edu.au (P.G. Baines).

0377-0265/$ – see front matter
doi:10.1016/j.dynatmoce.2004.12.003

1. Introduction

It is well established that in coastal waters, wind and tidal forcing at subinertial frequencies can generate waves that propagate along the continental slopes and shelves of the world's coastlines as coastal-trapped waves (CTWs). Among the earliest observations of CTWs were those of Hamon (1962, 1963, 1966) in which he analyzed data taken during June 1957 to December 1958 along both the eastern and western Australian coasts. Hamon's interpretation of the data as being of the nature of CTWs was supported by an analysis by Robinson (1964). The phase speed of these waves is in a direction with the coast on the right (left), facing downstream, in the northern (southern) hemisphere.

CTWs generated by alongshore wind stresses due to storms, for example, have typical periods ranging from days to weeks. Reviews by Allen (1980) and Brink (1991, 1998a) have described the observational evidence for the existence of CTWs, and the linear theory that describes their generation and propagation. The ubiquity of these waves is demonstrated by observations of them in the following regions: the eastern coast of Australia (Freeland et al., 1986; Church and Freeland, 1987), the east coast of North America (Noble and Butman, 1979; Yankovsky and Garvine, 1998), the Oregon and Washington coasts (Battisti and Hickey, 1984; Chapman, 1987), the Peru coast (Smith, 1978; Enfield et al., 1987; Clarke and Ahmed, 1999) and the West Florida shelf (Mitchum and Clarke, 1986). Poleward of 30° latitude, they may also be generated by the interaction of diurnal tides with topographic features such as the Strait of Juan de Fuca (Crawford and Thomson, 1984; Flather, 1988) and the Gulf of Maine (Daifuku and Beardsley, 1983). CTWs may also arise from the equatorial wave guide where this intersects a west coast coastline, producing waves with long periods ranging from several days to months and even years (Brink, 1998b).

The linear theory for the propagation of CTWs for the case of a stably stratified background fluid and a continental shelf-slope topographic profile independent of the alongshore coordinate is well developed (e.g., Huthnance, 1978; Brink, 1991). The dependent variables to be determined are the velocity components (u, v, w) and the perturbation pressure and density functions (p and ρ); the independent variables are the rectangular Cartesian coordinates (x, y, z) in the off-shore, along-shore (with the coast on the left) and vertically upward directions, respectively, and the time t. Solutions for free CTWs are obtained by assuming solutions of the form $p = \exp[i(\omega t + ky)]F(x, z)$, where ω is the frequency of the disturbance and k the along-shore wavenumber. Thus, for a given wavenumber k, the problem is reduced to an eigenvalue problem for $F(x, z)$ and ω. The modal structures can be found via resonance iteration (Wang and Mooers, 1976; Brink, 1982; Brink and Chapman, 1987), or inverse iteration (Huthnance, 1978).

CTWs may take a variety of different forms. For example, the dimensionless governing equations lead to the introduction of the Burger number defined as $Bu = (NH/fL)^2$, where H is the fluid depth, N the buoyancy frequency, f the Coriolis parameter and L the cross-shelf characteristic length scale. The Burger number can be interpreted as the ratio of the internal radius of deformation to the horizontal length scale, and its value characterizes the type of CTWs that may occur. When Bu is small, the waves resemble barotropic topographic Rossby waves (known as continental shelf waves), but when Bu is large they more resemble internal Kelvin waves (Huthnance, 1978). When kL is large, they resemble bottom edge waves of the form described by Rhines (1970).