Abstract View

Volume 14, Issue 6 (June 1984)

Journal of Physical Oceanography
Article: pp. 1032–1046 | Abstract | PDF (999K)

Boundary-Forced Nonlinear Planetary Radiation

Paola Malanotte-Rizzoli

Department of Earth, Atmospheric and Planetary Sciences. Massachusetts Institute of Technology, Cambridge, MA 02139

(Manuscript received October 21, 1983, in final form March 13, 1984)

DOI: 10.1175/1520-0485(1984)014<1032:BFNPR>2.0.CO;2

ABSTRACT

In recent years there has been renewed interest in the Gulf Stream system and its interaction with the mesoscale oceanic eddy field. An important question, not yet adequately addressed, concern the possible generation mechanisms of the mesoscale eddy field and, in general, the problem of radiation of mesoscale energy from a meandering current. This problem has been investigated in a variety of studies, the basic result of which is that, in the quiescent ocean, the far field can transmit energy radiated by a meandering northern current only if the latter has a westward phase speed. All the proposed models are, however, linear. Nonlinear effects may be expected to modify the above results, as indicated by numerical experiments carried out with fully nonlinear models.

In the present study, the question is addressed in the context of a fully nonlinear but simple model, the quasi-geostrophic equivalent barotropic potential velocity equation in a zonal channel over variable relief. The meandering current is idealized as a moving northern boundary. First, the case of free nonlinear Rossby wave radiation is studied. Solutions are found in both the weak and high-amplitude limit. The latter solutions are symmetric monopoles with closed recirculation regions, strongly similar to the ring shapes observed to be shed by the Gulf Stream.

In the boundary-forced case, the weakly nonlinear problem is thoroughly analyzed and boundary-forced, equilibrium nonlinear solutions are found. The basic effects of nonlinearity can be summarized as follows:

1) Nonlinearity allows for the production of nonlinear radiation in the interior field through a resonance mechanism. The resonant, equilibrium-forced solutions obey a forced Korteweg-de Vries (KdV) equation and admit, for a specific choice of the forcing, two equilibrium amplitudes.

2) Allowing for a slow time modulation of the northern boundary wave, the resonant interior response obeys the time-dependent KdV equation. Numerical experiments show that an initial condition corresponding to the steady equilibrium solution previously found evolves with soliton production in the region affected by the forcing. Thus, the interior response undergoes, on a long time scale, a nonlinear deterministic cascade process leading to nonlinear radiation of shorter wavelength.

3) In the limit of high nonlinearity, and for long-wave radiation, it can be shown analytically that the cross-channel structure of the interior field is very different from the structure allowed by the corresponding linear model. In the linear case, over an essentially northward-sloping relief, an eastward-moving boundary excites a response which, at best, has an oscillatory nature only in some interior, limited region, while exponentially decaying near the northern boundary. Conversely, in the highly nonlinear case the resonant response is oscillatory, i.e., radiating near the northern boundary. For sufficiently high nonlinearity, the excited eddy will have closed recirculation regions which may detach and propagate away from the boundary like Gulf Stream rings.

top