# OBSERVATION, THEORY, AND MODELLING OF WESTWARD PROPAGATION IN THE OCEANS

Rémi Tailleux(1), Thierry Penduff(2), Dudley Chelton(3), Julien Le Sommer(2), Angela Maharaj(4)

(1) Department of Meteorology, University of Reading, United Kingdom, (2) LEGI, Universite Joseph Fourier, Grenoble, France
(3) COAS, Oregon State University, Corvallis, United States, (4) Department of Geography, Macquarie University, Sydney, Australia

## 1.INTRODUCTION

A major outcome of satellite altimetry has been to reveal the ubiquitous presence of westward propagating signals with characteristics close to those expected for first-mode standard baroclinic Rossby waves at nearly all latitudes, in all the oceans. Observed propagation speeds, however, appear to be two to three times faster than those anticipated by the standard linear theory (SLT). These findings prompted the investigation of effects neglected by the SLT, such as those due to the background mean flow and bottom topography, in a linear framework, which were found to improve the comparison with observations. Recently, however, a closer look at westward propagating signals revealed that most of such signals seem to appear in the form of eddy-like features, found to be nonlinear by several measures (Chelton et al., 2007). This poster discusses the implications for oceanic Rossby wave theories.

## 2. LINEAR THEORIES FOR ROSSBY WAVES

There have been two main theories seeking to resolve the discrepancy between observed and theoretical phase speeds. Thus, Killworth et al. (1997) argued that the discrepancy was due to the neglect of the background mean flow, while Tailleux and McWilliams (2001) argued that the discrepancy was due to the neglect of rough topography/nonlinear effects. KCS97 showed that the mean flow effect is the sum of: 1) Doppler-shift effect; 2) modification of the background planetary vorticity gradient associated with the tilting of the isopycnals. The important result is that these two effects tend to cancel out, so that that theoretical phase speeds still underestimate observations (Fig 1).

The TMC01 mechanism, on the other hand, is based on the observation that rough topography/nonlinearities surface-intensify the Rossby waves, which speeds up the propagation. This time, the resulting predictions overestimate observations. Arguably, both effects could act together, which is supported by recent numerical ocean modeling studies. Although the theories are linear, the physical existence of the mean flow and bottom pressure decoupling effects that such theories describe are not necessarily affected by nonlinear effects. If so, the linear theories would become invalid only if it can be established that nonlinearities can forbid the mean flow and bottom pressure decoupling effects to act in the oceans, which appears to be unlikely.

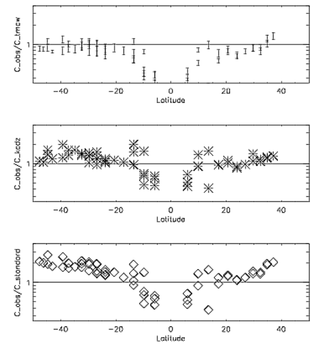


***Figure 1:*** *Comparison of nondispersive wave theories predictions for the ratio of predicted to observed phase speeds. TMC01's theory (top), KCS97's theory (middle), Standard theory (bottom).*

## 3. IMPORTANCE OF DISPERSION

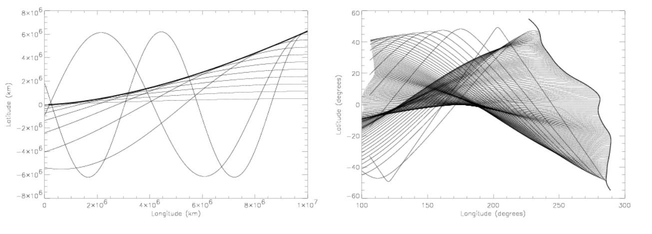


***Figure 2****: Without dispersion, waves of a given frequency would exist at all latitudes, and could propagate nondispersively across an ocean basin. Dispersion, however, introduces a critical latitude poleward of which a wave of given frequency no longer exists. Near the critical latitude, dispersion strongly distorts the westward pathway of energy propagation. Connected to the critical latitude is a caustics that introduce a natural barrier to the westward penetration of the wave, so that the waves can travel significant distances across an ocean basin only at sufficiently low latitudes. The left figure shows an example of what happens on an idealized beta-plane geometry, whereas the right figure shows what happens for the coast of South America. Dispersion is directly responsible for the beta-refraction pattern characteristics of the waves generated along eastern boundaries.*

The fact that westward propagation occurs predominantly in the form of eddy like features with horizontal scales close to the Rossby radius of deformation clearly suggests that dispersive effects need to be included in any realistic Rossby wave theory. Dispersion is a crucial effects, as illustrated in Fig. 2/3.

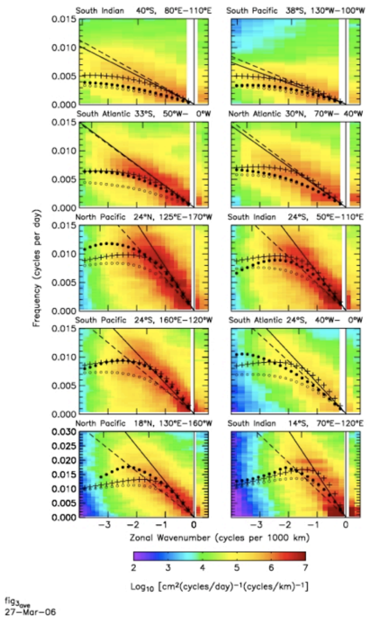


**Fig. 3** *Empirical dispersion relations estimated at selected locations in the oceans (color) superimposed with the predictions of different theories. The plus signs correspond to the dispersive extension of the bottom pressure compensation theory of Tailleux and McWilliams (2001), simply obtained from the following relationship:*

$$\omega = -\frac{\beta c_{tmc01}^2 k_x}{f^2(1+R_{tmc01}^2\|\mathbf{k}\|^2)}$$

*The white circles correspond to the classical dispersive theory for Rossby Waves over a flat bottom, and in absence of background mean flow. The filled black circles correspond to a straightforward dispersive extension of the zonal mean flow theory over a flat bottom of Killworth et al. (1997).*

## 4. PURPOSE OF THE PROJECT

The purpose of the project will be to improve our theoretical understanding of westward propagation in the oceans by:

1) Refining the empirical description of such signals in observations
2) By analyzing the behavior of numerically simulated westward propagation in state-of-the-art eddy-resolving OGCMs
3) By improving upon existing theories

The project will seek to address the following outstanding issues:

a) Are the mean flow and bottom-pressure decoupling effects robust to nonlinearities in the oceans?
b) Do westward propagating signals have a well-defined vertical structure, and if so, is it predictable as a solution of a linear eigenvalue problem?
c) What is the physical mechanisms limiting the westward penetration of boundary-driven Rossby waves? Is it classical linear dispersion, or nonlinearities?
d) What are the physical mechanisms responsible for the surface intensification of meso-scale eddy features? Mean flow? Critical layers? Rough topography?
e) What is the generation mechanisms for westward propagating signals?

**Acknowledgements**: I am grateful to Dudley Chelton and Michael Schlax for supplying Fig. 3.

**References**:

Chelton, D.B., and M.G. Schlax (1996): Global observations of oceanic Rossby Waves. *Science*, **272**, 234-238.

Chelton, D.B., M.G. Schlax, R.M. Samelson, and R.A.deSzoeke (2007): Global observations of large oceanic eddies. Geophys. Res. Lett., 34, doi: 1029/2007GL03812

Killworth, P.D., D.B. Chelton, and R.A. de Szoeke, R.A. (1997): The speed of observed and theoretical long extratropical planetary waves. *J. Phys. Oceanogr.*, **27**, 1946-1966

Tailleux, R., and J.C. McWilliams (2001): The effect of bottom-pressure decoupling on the speed of extratropical, baroclinic Rossby waves. *J. Phys. Oceanogr.*, **31**, 1461-1476.

**5. CONCLUSIONS** The recent realization that the observed westward propagation in the oceans appears to be mostly in the form of eddy-like features that are nonlinear by several measures legitimately raises the issues of the validity and usefulness of linear theories to describe such signals. The linear character of existing theories, however, is secondary if the physical effects considered, ie., mean flow and bottom pressure decoupling, can be shown to be robust to nonlinearities. In that case, the main question becomes to understand how the nonlinearities modify such effects.