

Eddy-Wind-Topography Interaction Dynamics

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LONG-TERM GOALS

This research is seeking to advance the fundamental understanding of eddy-wind-topography interaction dynamics, thereby improving our ability of predicting meso- and sub-mesoscale eddy variability.

OBJECTIVES

We hypothesize that eddy dissipation/propagation and meso-scale features associated with eddy-topography interactions can be significantly affected by the surface forcing. Specific research questions that we will address include:

- How does an eddy moving on a flat bottom respond to wind forcing coming from different directions?
- How does an eddy moving on a sloping bottom respond to wind forcing coming from different directions?
- How do wind induced Ekman dynamics and mixing affect the eddy-topography collision process?
- To the extreme of wind forcing, what are the impacts of hurricane on eddy propagation and eddy-topography collision?

APPROACH

We address these questions through systematic numerical sensitivity experiments using the Hybrid Coordinate Ocean Model (HYCOM). We begin with idealized model experiment on f-plane and flat bottom, which provides insights on the follow-up experiments of more complicated eddy-wind-topography dynamics on beta-plane in a more realistic coastal ocean setting (i.e. the Gulf of Mexico). In the GoM experiments, we will focus on how meso-scale features associated with eddy-topography collision change due to the surface forcing and how the surface forcing affects cross-shelf propagation, eddy erosion/distortion, and formations of vortex filament. We take the same approach of Hyun and Hogan (2008a) to investigate eddy-wind-topography interactions using HYCOM. The following non-

dimensional parameters are used to interpret the dynamics in the parameter space. The eddy intensity number ε , the planetary β effect number α , and the eddy barotropy number δ are defined as

$$\varepsilon = \frac{\omega}{f_0}, \quad \alpha = \frac{\beta_0 R}{f_0}, \quad \delta = \frac{h_e}{h},$$

where ω is the eddy angular frequency, β_0 is the planetary β ($2 \times 10^{-11} m^{-1} s^{-1}$), R is the eddy radius, h_e is the reference eddy depth and h is the total depth where the eddy center is positioned. In addition, the topographic β effect number $\alpha_{(\tau_x, \tau_y)}$ is used i.e.

$$\alpha_{(\tau_x, \tau_y)} = \frac{\beta_{(\tau_x, \tau_y)} R}{f_0} = \frac{f}{h} \frac{\partial h}{(\partial x, \partial y)} \frac{R}{f_0},$$

where $\beta_{(\tau_x, \tau_y)}$ is the topographic β in (x, y) directions and f is the Coriolis parameter. Additionally the Rossby number c/f and the Ekman number ν/fD^2 , where ν is the kinematic eddy viscosity and D is the thickness of an Ekman layer, are utilized to examine Ekman dynamics due to eddy-wind interactions.

Dr. He oversees the project and experiment designs, whereas research associate Dr. Hyun focuses on carrying out numerical sensitivity experiments. They will work together on model interpretations, processing and assembling various data sets for validating and diagnosing model fields, and manuscript preparations.

WORK COMPLETED

We have made significant progress in examining Eddy-Wind-Topography Interaction Dynamics in the idealized topographic setting. A series of idealized model experiments have been conducted. In each case, an isolated warm core eddy is embedded in the HYCOM following the method of Hyun and Hogan (2008a). For model domains, a flat bottom and a generic western shelf-slope ($\beta_\tau=30$) are generated with a domain size of 2000 km and a grid resolution of $1/20^\circ$ (~ 5 km). The spatially uniform initial stratification and an east-west periodic boundary condition are used in all idealized model experiments. The closed land boundary condition is used at the model north-south edges.

Table 1 and 2 list the experiments that have been completed so far. We have examined the model sensitivity to eddy sizes (80, 100, 150, 200km i.e., Exps F1-F4), sensitivity to eddy intensity ($-5f$, $-8f$, $-10f$, $-12f$, Exps F6-9), and sensitivities to different wind intensity (0.01, 0.05, 0.1, 0.15, 0.2 $N m^{-2}$, i.e., Exps F11-F15) first on a flat bottom. For β -plane experiments, we additionally vary wind directions (easterly, westerly, southerly, northerly wind, i.e., Exps B6-9). Subsequent experiments will be performed on a slopping bottom (i.e., Exps F16-F24, not yet completed). For hurricane scenarios (i.e., Exps HB1-HB6, not yet completed), a synthetic hurricane wind field of Holland (1980) with intensity ranging category 1-5 will be utilized.

For each experiment, we have tracked simulated eddy evolution using T/S and passive tracer fields, 3d velocity fields within and adjacent to the eddy, along with eddy propagation and dissipation properties and non-dimensional numbers described above.

Table 1. Sensitivity experiments for eddy-wind interactions on a flat bottom in a f -plane approximation.

Exp.	Eddy (radius/ Initial intensity)	Wind (direction/ intensity)	β_τ	β_0	Model integration (days)	Remark
F0	150km/ $-10f_0$	No wind	0	0	30	No wind, flat bottom on f -plane
F1-F4	80, 100, 150, 200 km/ $-10f_0$	Westerly/ 0.1 N m^{-2}	0	0	30	Sensitivities to eddy size
F6-F9	150km/ -5, -8, -10, -12 f_0	Westerly/ 0.1 N m^{-2}	0	0	30	Sensitivity to eddy intensity
F11- F15	150km/ $-10f_0$	Westerly/ 0.01, 0.05, 0.1, 0.15, 0.2 N m^{-2}	0	0	30	Sensitivity to wind strength

Table 2. Sensitivity experiments for eddy-wind interactions on a flat bottom in a β -plane.

Exp.	Eddy (radius/ intensity)	Wind (direction/ intensity)	β_τ	β_0	Model integration (days)	Remark
B0	150km/ $-10f_0$	No wind	0	2	30	No wind, flat bottom on a β -plane
B1- B5	150km/ $-10f_0$	Westerly/ $0.01\text{-}0.2 \text{ N m}^{-2}$	0	2	30	Sensitivity to wind strength on β -plane (flat bottom)
B6- B9	150km/ $-10f_0$	EWSN winds/ 0.01 N m^{-2}	30	2	30	Sensitivity to wind direction on β -plane (generic shelf-slope)
B10- B14	150km/ $-10f_0$	westerly/ $0.01, 0.05, 0.1,$ 0.2 N m^{-2}	30	2	30	Sensitivity to wind strength on β -plane (generic shelf-slope)

RESULTS

All sensitivity experiments start with the same initial conditions: an idealized symmetric anticyclonic eddy in the middle of ocean model domain (Figure 1). Collectively, our model sensitivity analyses show the surface wind forcing has an important impact on changing eddy properties. The difference in the relative air-water velocity (and consequently wind stress) felt on diametrically opposite sides of the

anticyclonic eddy induces an upward Ekman pumping velocity. The resulting isopycnal tilting can lead to variations in vortex intensity (Figure 2). Stronger wind forcing can weaken the eddy intensity more quickly (Figure 3). These model simulations also suggest that under strong wind impact, the decay of eddy occurs through vigorous horizontal mixing and transport. Wind-eddy interaction constitutes a major driving force for the evolution of Eddies and the generations of numerous meso-scale features, such as smaller cyclones, jets, and waves. Some sub-mesoscale effects on an anticyclonic eddy, including intensifications of the ageostrophic secondary circulation and nonlinear Ekman transport, can result in much local larger vertical velocities (on the order of 10 to 100 m/day). All these findings are consistent with recent observational and modeling studies (Martin and Richard, 2001; McGillicuddy et al., 2007, and Mahadevan et al., 2008).

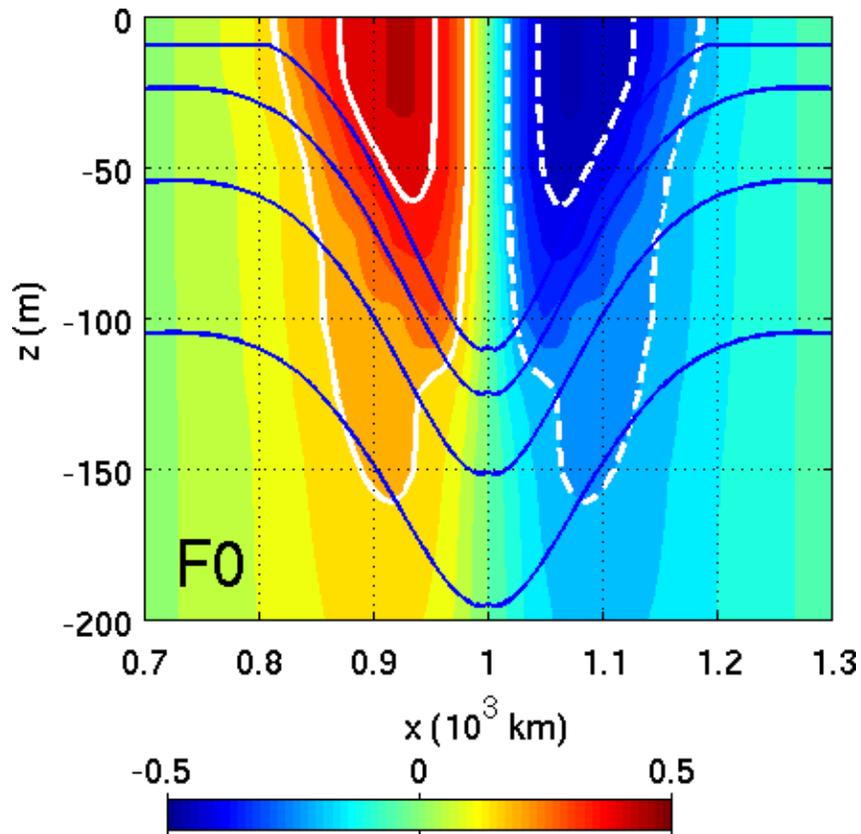


Figure 1. The east-west vertical transect of the idealized anticyclonic eddy structure. This eddy is used in all model sensitivity experiments. Its meridional velocity field is color shaded (positive – northward) with its magnitude indicated by a color bar [in ms^{-1}] and white contour lines (solid 0.2, 0.4 ms^{-1} ; dashed -0.2, -0.4 ms^{-1}). The isopycnal layer thickness is indicated by blue contoured lines.

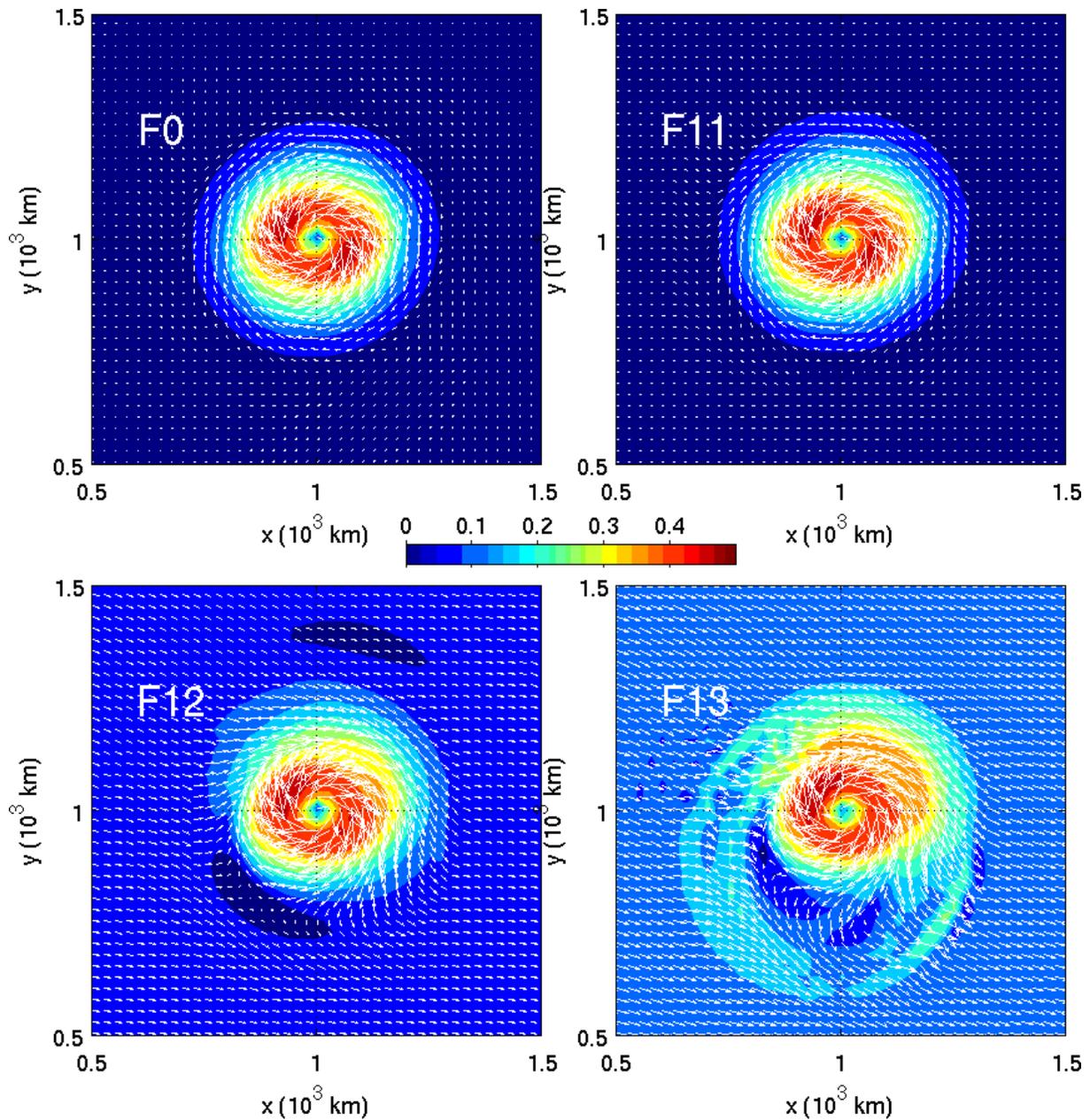


Figure 2. The plane-view of surface velocity fields of the anticyclonic eddy under no wind forcing (F0), 0.01 Nm^{-2} westerly wind forcing (F11), 0.05 Nm^{-2} westerly wind forcing (F12), and 0.1 Nm^{-2} westerly wind forcing (F13) on day 10 of each simulation. The colorbar indicate the speed of surface velocity. As the wind forcing increases, the difference in the relative air-water velocity (and consequently wind stress) felt on diametrically opposite sides of the anticyclonic eddy induces an upward Ekman pumping velocity. The resulting isopycnal tilting lead to variations in the vortex intensity, and generations of numerous meso-scale features, such as smaller cyclones, jets, and waves (e.g., F13).

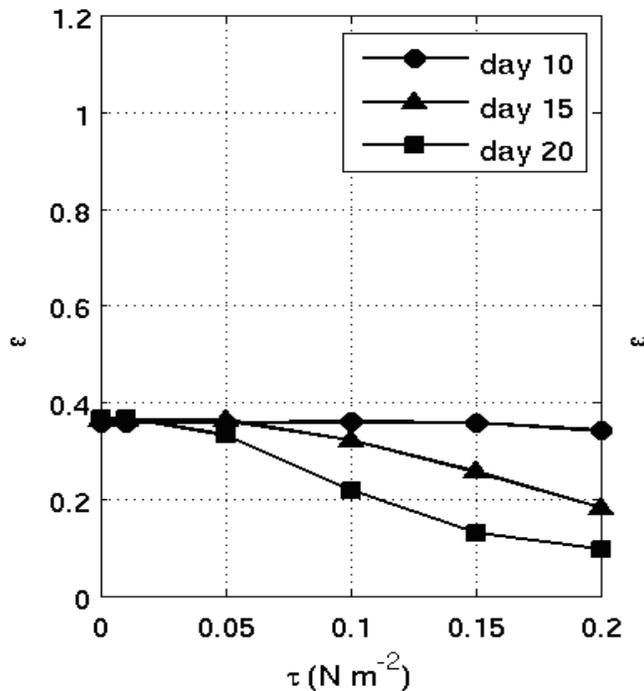


Figure 3. The variations of the eddy intensity number (ϵ) from the wind intensity sensitivity experiments. The parameter is depicted for three time snapshots on day 10, 15, 20. The analysis indicates that after the initial wind-eddy interaction adjustment, the intensity of eddy decreases over time. The stronger the wind forcing is, the quicker the eddy intensity decays (Figure 3).

IMPACT/APPLICATIONS

This project is closely related to “meso-, and sub-mesoscale variability associated with eddies, front and jets”, one of the program’s thrust research areas. Findings of this research will significantly advance the fundamental understanding of eddy-wind-topography interaction dynamics, thereby improving our ability to predict meso- and sub-mesoscale eddy variability.

The project also makes extensive use of model tools developed by ONR support – the Hybrid Coordinate Ocean Model and its associated processing/analysis techniques, thereby extending the application of HYCOM to theoretical and idealized modeling frameworks for fundamental physical oceanography problem studies.

TRANSITIONS

None

RELATED PROJECTS

None

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PUBLICATIONS

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