**ACCESS NUMBER: M11PC00034**

**STUDY TITLE.** Update to the BOEMRE Oil Spill Risk Analysis (OSRA) Model: Applying Lagrangian Stochastic Model to Track Oil Spills

**REPORT TITLE:** Implementation of Lagrangian stochastic models to parameterize submesoscale transport for tracking oil spills in the Gulf of Mexico.

CONTRACT NUMBER(S): M11PC00034.

SPONSORING OCS REGION: Headquarters

APPLICABLE PLANNING AREA(S): Gulf of Mexico.

FISCAL YEAR(S) OF PROJECT FUNDING: 2011;

COMPLETION DATE OF REPORT: February 2014

COST(S): (BY FISCAL YEAR); CUMULATIVE PROJECT COST:
FY 2011: $194,992

PROJECT MANAGER(S): A. C. Haza

AFFILIATION: University of Miami

ADDRESS: 4600 Rickenbacker Causeway, Miami, Florida, 33149

PRINCIPAL INVESTIGATOR(S)*: A. C. Haza, T. M. Özgökmen, A. Griffa

KEY WORDS: Lagrangian parameterization; submesoscales; mesoscales; surface circulation; scale-dependent relative dispersion; particle distributions; relative dispersion; mixing; oil spill tracking; stochastic model.

**BACKGROUND:** The submesoscales (SMS) refer to the types of motions in the spatial scale range of 100m – 10 km and time scales of few days only. One particular class of SMS is known to emerge from mixed-layer instabilities. In the presence of a mesoscale field, a necessary condition for these instabilities is a weak stratification combined with a mixed-layer deep enough to allow vertical recirculation on the edges of fronts; these conditions usually occur in winter and fall. The SMS filaments and eddies then act to enhance particle pair separations, affecting the dispersion and mixing at their own scales. This translates into an increase in the scale-dependent relative dispersion or Finite Scale Lyapunov Exponent (FSLE) at scales up to the first internal baroclinic radius of deformation (Rd), slightly modifying the mesoscale transport barriers, and causing particles to exit and join other pathways. Ocean models used at the present time for forecasts and Lagrangian prediction are so-called eddy-permitting ocean models. With a grid resolution around 3-4 km, their ability to resolve any feature below the Rd is very limited. This results in an underestimation of the strain field, and a dispersion of particle pairs at the SMS entirely controlled by mesoscale features.

**OBJECTIVES:** In this study, the Lagrangian parameterization aims at enhancing the low strain level of the ocean model in the SMS range. Due to the increasing complexities of the transport barriers at these scales, the parameterizations are of a statistical nature for computational efficiency. A novel method is applied to the Gulf of Mexico (GoM) to correct the surface Lagrangian transport by combining Lagrangian stochastic models (LSM) in the SMS range, with Lagrangian coherent structures (LCS) from the ocean model in the mesoscale range. More specifically, the objective has been to enhance the scale-dependent relative dispersion of a HYbrid Coordinate Ocean Model (HYCOM) 1/25° simulation from the small scales of about 1 km to twice the Rd, (Rd ~ 40 km in the GoM interior) while preserving the relative dispersion at the larger scales.

**DESCRIPTION:** In the GoM interior where the mesoscale circulation dominates, a recently developed Lagrangian subgrid-scale (and stochastic) model (the LSM-3) is applied. It is Markovian both in the position and velocity, and requires an intrinsic flow decomposition. A stochastic component $\boldsymbol{\eta}(t)$ is added to the turbulent velocity of the ocean model with a continuous Lagrangian acceleration. The corrected turbulent velocity fluctuations enhance the scale-dependent rates of dispersion at the spatial scales $\delta \leq 2$ Rd, and yield a significant improvement of the relative dispersion at the intermediate scales and SMS. On the continental shelf, the circulation is less controlled by mesoscale features, and the classic Random Walk (LSM-1) and Random Flight (LSM-2) are used as well. In the LSM implementation, both a high-resolution (1 km) ocean simulation and a dispersion experiment from recent observations in the GoM are considered for reference. The Grand LAgrangian Deployment (GLAD) was a multi-scale dispersion experiment conducted by the Consortium of Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE), funded by the Gulf of Mexico Research Initiative (GoMRI). It consisted of measuring scale-dependent relative dispersion from fractal launches of more than 300 surface drifters in the De Soto canyon.

**SIGNIFICANT CONCLUSIONS:** The GLAD experiment confirmed the presence of SMS motions controlling the relative dispersion at those scales, with rates of pair separations up to 10 times faster than today's ocean forecast models. Similarly, the HYCOM 1/100° simulation of the GoM enhanced the rate of pair separations up to twice the Rd, albeit not as fast as the observations. Both GLAD and this simulation have nevertheless similar scale-dependent relative dispersion at the intermediate scales around the Rd. We relied therefore mostly on HYCOM 1/100° for LSM validation.

On the continental shelf, the surface circulation is less kinetic than the GoM interior, while the wind-forcing exerts a strong constraint on the flow direction, affecting the horizontal velocities in a synoptic pattern with weak dependence on the particle location. It is also characterized by weak relative dispersion (compared to the GoM interior), which is suitable to the implementation of the Random Walk and Random Flight LSMs, as well as the LSM-3.

**STUDY RESULTS:** The LSM-3 applied to the GoM interior is found to increase the scale-dependent relative dispersion to the level of HYCOM 1/100°, while preserving the large-scale dispersion. Evolutions of tracer dispersions illustrate the drastic differences between this stochastic model and the classic Random Walk and Random Flight, as the stochastic model preserves the tendency of the flow to stretch and elongate patches of particles along the mesoscale LCS. This is due to the fact that the addition of diffusion by the missing turbulent component $\boldsymbol{\eta}$ is continuous in time, and to a certain degree correlated in space. The increase in the Lagrangian velocity fluctuations is more pronounced whenever particles get advected by highly kinetic flows, thus resulting in a spatially polarized parameterization where the edges of the mesoscale features are favored. The modified fluctuations are still an order of magnitude lower than the typical velocity scales in the region, so

that the corrected Lagrangian transport is still constrained by the mesoscale pathways. The Random Walk and Random Flight LSMs do not reach such high rates of dispersion after few days without affecting substantially the model LCS.

On the continental shelf, the LSM-3 can only be implemented with a weak low-pass filter, such that changes in the flow direction remain minimal compared to the changes imposed by the surface winds. In all cases including the LSM-1 and LSM-2, the tracer coverage and time-dependent relative dispersion are improved by the LSMs to the levels of the high-resolution run.

The LSM-3 was also tested with a smooth geostrophic velocity field derived from altimetry, and compared with the GLAD drifter trajectories in the GoM interior. Although part of the mesoscale field was correctly captured by the altimetry, the lower kinetic energy levels and smooth fields yielded a particularly low strain field. Tracer releases after LSM adjustment displayed significant qualitative improvement in particle dispersion with respect to the drifters' coverage, while both GLAD drifters and parameterized particles kept following the mesoscale pathways.

Overall, this LSM implementation has yielded a substantial modification of the particle-based tracer distribution, which is seen to approach statistically the spatial coverage of the SMS-permitting ocean model. It will lead to improved statistical estimates for oil spill risk analysis, provided an accurate representation of the mesoscale field by the available ocean model.

**STUDY PRODUCT(S):**

- Final report for the U.S. Department of the Interior, Bureau of Ocean Energy Management: Implementation of Lagrangian stochastic models to parameterize submesoscale transport for tracking oil spills in the Gulf of Mexico. 2014. Contract no M11PC00034. 69+ pp.
- Scientific conference presentations
    - Parameterization of particle transport at submesoscales. LAPCOD meeting. June 2012, Miami, Florida.
    - Parameterization of particle transport at submesoscales in the Gulf of Mexico. Gulf of Mexico Oil Spill & Ecosystem Science Conference. January 2013, New Orleans, Louisiana.
    - Lagrangian submesoscale parameterization for the Gulf of Mexico. All Hands CARTHE meeting. May 2013, Miami, Florida.
- Code for a Lagrangian Stochastic Model calibrated for the GoM surface circulation of a $1/25^{o}$ ocean model
- Code manual: Instruction Manual. 2013. 17 pp.

* P.I.'s affiliation may be different than that listed for Project Manager(s).