The National Academies of SCIENCES ENGINEERING MEDICINE

GULF RESEARCH PROGRAM

Healthy Ecosystems Grants 2 Final Report

Project Title: The Transport of Oil to the Coast in the Top Centimeter of the Water Column
Award Amount: $432,574
Awardee: Florida State University
Award Start Date: 12/04/15
Award End Date: 06/03/18
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Project Key Personnel:
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I. PROJECT SUMMARY (from proposal)

Through Stokes drift, surface waves strongly affect the surface offshore-to-coast transport of oil, fish eggs and larvae, red tide and other floating material. Because the wave-driven Stokes drift depends on the cube of the wave frequency, it is crucially dependent upon the surface wave spectrum's high-frequency tail which is not accurately known. Preliminary calculations for the northern Gulf of Mexico based on commonly-used theoretical models of wave spectra that include their high-frequency tails predict vastly different Stokes drift surface speeds. One consistent property that all model speeds share is that they decay rapidly from the surface, dropping to half their surface value at a depth of less than half a meter. Therefore, to measure the surface flow accurately, drifters should have a very shallow draft, much less than half a meter, and usually they do not. Without a reliable estimate of the flow at the surface, the predictions of the movement of the oil and where and when it would reach the coast are inaccurate.

During 2013 and 2014 the Gulf Integrated Spill Response Consortium (GISR) deployed nearly 1800 drift cards at several points in the northern Gulf of Mexico. Professor Piers Chapman has kindly provided the drift card data set for use in the project proposed here. These cards have a draft of less than 1 cm, and so can be used to estimate surface flow connectivity to the coast. About 16 percent of the cards were retrieved and resulted in 287 estimates of offshore to coast connectivity in the top centimeter of the water column. Preliminary calculations using the drift card data, theory, and wind and directional surface wave data from NDBC NOAA buoys suggest (i) that the drift card spatial dispersion from each release point by random variability is small compared to the distance to the coast; and (ii) that surface particle movement to the coast can be described by the Eulerian velocity (velocity at a point) plus a Stokes drift estimated as a constant (to be determined) times the wind stress direction. The Eulerian flow will be estimated using data from two comprehensive state-of-the-art high-resolution Gulf of Mexico numerical models and used with drift card and wind stress data to estimate the constant. In this way an improved model of oil spill connectivity to the coast can be constructed.

In summary, our specific objectives are to show that there is a crucial very near-surface wave-driven flow that is not properly taken into account by present surface oil transport models, but can easily be included in state-of-the-art high resolution numerical models. The proposed work responds to the RFA in that it provides new insight into the connectivity of the offshore surface transport to the coast by integrating several existing experimental and monitoring data sets using theory and model data. The results of the proposed project are also relevant to Goal 1 of the Gulf Research Program in that they foster an innovative improvement to protecting the environment from an oil spill.

II. PROJECT SUMMARY (from final report)

Although crucial to the movement of oil spills, red tide, fish eggs and larvae, floating plastic garbage and airplane crash debris like that of Malaysian Airline flight MH370 in March 2014, much has yet to be learned about the transport of material in the top 2 meters of the water column. A major component of this transport is the drift of a particle due to the ocean waves. We used many years of simultaneous hourly buoy wind and wave data in the Gulf of Mexico and the Pacific, together with theory, to show how the wave-induced movement of near-surface particles can be estimated from the local wind. Our results have the potential to improve the prediction of where oil spills, red tide and crash debris will go, as well as better understand the life cycles of several species of fish which spawn at sea.

III. PROJECT RESULTS

Accomplishments

Problem being addressed: The role of surface waves in the transport of oil to the coast and how this transport could be estimated.

How we addressed this problem: We analyzed many years of simultaneous hourly buoy wind and directional wave spectra in the Gulf of Mexico and the Pacific. We calculated the simultaneous hourly Stokes drift and wind stress vectors and estimated the vector correlation between them for each buoy. We extended the analysis to take into account the higher frequency waves, wave breaking and wave spreading.

Results: We showed that the Stokes drift and wind stress were strongly correlated and that they were essentially parallel to one another. Our results showed that the Stokes drift was strongly dependent on the high frequency waves and was mainly trapped within 2 meters of the surface even when low frequency swell was present. In the presence of realistic turbulence, this implied theoretically that the Stokes drift was not canceled by an induced Eulerian flow. Thus Stokes drift is a major contributor to surface transport. Because of the high vector correlation, Stokes drift can be estimated directly from the wind stress, making it easy to estimate, incorporate it into a numerical model and calculate the surface transport of oil and other near-surface material.

Implications

Implications of the project results for future work: We had planned to test the results of 3.1 with drift card data previously gathered by the GISR research consortium. In collaboration with Piers Chapman

(TAMU), who provided the data, we have made very good progress in confirming our results. We intend to seek funding to complete this work.

Implications of the project results for the research of others: Our results demonstrate how Stokes drift, a major effect on surface transport, can be simply incorporated into existing oil spill prediction and other surface transport models.

Importance of our results to science and society: Our results will improve our ability to track and predict the movement of surface oil, red tide, ocean garbage and debris. Dr. David Griffin, who analyzed the surface drift of the debris of Malaysia Airlines flight MH370 which was lost in the Indian Ocean in March 2014, commented that our surface drift results were in agreement with what he found.

Unexpected Results

N/A

Project Relevance

The following audiences would be most interested in the results of this project:

- Researchers

Our analysis provides a simple way to incorporate into existing numerical models the effect of surface waves on surface ocean drift. It provides the theoretical and observational support for how to do this.

Education and Training

Number of students, postdoctoral scholars, or educational components involved in the project:

- Undergraduate students: 0
- Graduate students: 0
- Postdoctoral scholars: 0
- Other educational components: 0

The project was directed by the Principal Investigator (PI) Professor Allan Clarke and Research Associate Steve Van Gorder at Florida State University. The project involved extensive data analysis and theoretical development and funding only lasted for two years. The schedule was tight, and could only be done by scientists who already had the required expertise; there was no time available to educate a postdoc or a student. We should point out, however, that the PI will incorporate the results from the project into at least 3 graduate courses that he teaches at Florida State University.

IV. DATA AND INFORMATION PRODUCTS

This project produced data and information products of the following types:

- Data
- Scholarly publications, reports or monographs, workshop summaries or conference proceedings

DATA

See attached Data Report.

Relationships Between Data Sets:
The single dataset submitted to the National Centers for Environmental Information (NCEI) contains quality controlled observed wind and derived wind stress data, observed directional wave spectra data and a processed Stokes drift, spectral wave data, wind and wind stress data. All these data are derived from moored buoys and were used by us to analyze the relationship between the wind stress and the Stokes drift.

Additional Documentation Produced to Describe Data:
We submitted documentation to the NOAA National Centers for Environmental Information (NCEI) data repository describing the data processing procedures.

Other Activities to Make Data Discoverable:
We have published the research paper: Clarke, A. J., & Van Gorder, S. (2018). The relationship of near-surface flow, Stokes drift, and the wind stress. Journal of Geophysical Research: Oceans, 123. https://doi.org/10.1029/2018JC014102. This paper is another way for researchers to easily discover the project data.

INFORMATION PRODUCTS
See attached Information Products Report.

Citations for Project Publications, Reports and Monographs, and Workshop and Conference Proceedings:
Clarke, A.J. and S. Van Gorder, 2016: Subinertial canyon resonance. Geophysical Research Letters, vol.43, doi:10.1002/2016GL068258.

Clarke, A.J. and S. Van Gorder, 2018: The Relationship of Near-Surface Flow, Stokes Drift and the Wind Stress. Journal of Geophysical Research: Oceans, 123. https://doi.org/10.1029/2018JC014102.

Other Activities to Ensure Access to Information Products:
We have made it clear in our publications where the data can be found.

V. PUBLIC INTEREST AND COMMUNICATIONS

Most Unique or Innovative Aspect of the Project
George Gabriel Stokes showed mathematically way back in 1847 that surface waves may affect the net movement of particles at the ocean surface, but over a 100 years later it was shown that because we live on a rotating Earth, the net particle movement in the direction of the waves (the "Stokes drift") might be canceled by another opposite flow. However, our analysis of many years of wind and wave buoy data showed that because of the ocean turbulence driven by the local wind, the main part of the Stokes drift in the top two meters of the water column is in fact not canceled, and that therefore the Stokes drift due to the waves should indeed be a major contributor to the movement of surface particles. Stokes drift is mainly due to the locally wind-driven waves, and by taking into account when these waves break, we were able to show how Stokes drift can be calculated directly from the local wind.

Most Exciting or Surprising Thing Learned During the Project

Probably the most surprising thing is how strongly Stokes drift depends on the local wind, and that therefore it can be calculated from the local wind.

Most Important Outcome or Benefit of Project

The research we have done provides a foundation for the better prediction of the movement oil spills, red tide, fish eggs and larvae, floating plastic garbage and airplane crash debris like that of Malaysian Airline flight MH370 in March 2014.

Communications, Outreach, and Dissemination Activities of Project

Our work took a lot longer than we thought. Consequently, our results only became available at the end of the project, too late to communicate information about our results except for the scientific literature and this report.