Final Programmatic Report Narrative

Instructions: Save this document on your computer and complete the narrative in the format provided. The final narrative should not exceed ten (10) pages; do not delete the text provided below. Once complete, upload this document into the on-line final programmatic report task as instructed.

1. Summary of Accomplishments

In four to five sentences, provide a brief summary of the project's key accomplishments and outcomes that were observed or measured.

The SCUD (Surface CUrrents from Diagnostic model) dataset has been developed and released to public. The model uses satellite data of the QuikSCAT winds and altimetry sea level to generate daily quarter-degree near-surface velocities best agreeing with trajectories of Lagrangian drifters that represent a kind of standardized marine debris. The SCUD velocities and statistical model were used jointly to study pathways and areas of aggregation of marine debris in the global World Ocean. Results can be used for planning future observations and cleaning operations. Wind-induced convergences of near-surface currents in the subtropics (not geostrophic circulations in gyres) are confirmed to be the main mechanism of the debris collection.

2. Project Activities & Outcomes

Activities

- Describe and quantify (using the approved metrics referenced in your grant agreement) the primary activities conducted during this grant.

A diagnostic model (SCUD) has been developed that is regressing velocities of real Lagrangian drifters, drogued at 15 meter depth, to concurrent vectors of ocean wind and sea level gradient, sensed by satellite QuikSCAT scatterometer and multiple altimeters. Optimal filters, interpolations, quality criteria, and data masks were derived during the project.

Experiments were performed with the SCUD and with the statistical model to quantify locations, shapes, and sizes of five convergent zones detected in the subtropical North and South Pacific and Atlantic, and South Indian oceans.

- Briefly explain discrepancies between the activities conducted during the grant and the activities agreed upon in your grant agreement.

During the project, the model was expanded from the initially proposed North Pacific to the global World Ocean.

Failure of the QuikSCAT satellite in November of 2009, prevented the SCUD from being a near-real time product available to support ongoing regional operations. Yet, even in the current form it will be helpful in planning future field programs and cleaning efforts.

Also spatial heterogeneity of the SCUD coefficients, their variability on seasonal, intra- and interannual time scales, combined with the limited number of drifters, restricted the model to locally stationary processes. Additional data, such as satellite sea surface temperature (SST) and the mixed layer depth from the Argo float profiles may help to take into account various modes of variability in the future effort.

Outcomes

- Describe and quantify progress towards achieving the project outcomes described in your grant agreement. (Quantify using the approved metrics referenced in your grant agreement or by using more relevant metrics not included in the application.)

The SCUD dataset of in situ surface velocities, diagnosed from 1999 through 2009, has been made fully public and available for research on marine debris, upper ocean dynamics, tracking pollutions, search and rescue, navigation, etc. The model error (or the drifter velocity signal not explained by the SCUD) is reduced to 0.162 m/s from the total r.m.s. value of drifter velocity of 0.286 m/s.

- Briefly explain discrepancies between what actually happened compared to what was anticipated to happen.

While the SCUD dataset was constructed as a near-real time product, after the failure of the QuikSCAT satellite in November 2010, it became a hindcast dataset. Even so, it is valuable for planning future missions and operations.

Also the amount of available drifter data was not sufficient to include into consideration the temporal variability of the model coefficients that slightly increased the model errors.

On the bright side, the model was expanded from the initially proposed North Pacific to the global World Ocean.

- Provide any further information (such as unexpected outcomes) important for understanding project activities and outcome results.

The project linked our group with researchers from 'Algalita', 'The Sea', 'Kaisei', and other companies. In each case, the data of the SCUD and statistical velocities were or will be used to advice on the optimal strategy for future observations. Maximenko became the advisor of the '5Gyres' website (www.5gyres.org). Numerous discussions took place with individual sailors about the future network of volunteer boats.

Additional, weaker convergent zones, smaller in size were detected in the western North and South Pacific (possibly, sensed earlier by Ebbesmeyer and other inverstigators) and in the North Indian Ocean.

While convergence is generally pre-defined by the large-scale convergence of Ekman currents, exact location of the accumulation site is determined by a complex interplay between the Ekman and geostrophic velocities.

Hawaii is found to be the final destination of marine debris originating from the entire North Pacific. This finding will be used to create a future program, centered at the University of Hawaii.

3. Lessons Learned

Describe the key lessons learned from this project, such as the least and most effective conservation practices or notable aspects of the project's methods, monitoring, or results. How could other conservation organizations adapt their projects to build upon some of these key lessons about what worked best and what did not?

Dynamics of near-surface currents is tremendously complex. Real-time distribution of debris is a function of many factors. Knowledge necessary for the progress in marine debris monitoring includes:
- data of the spatiotemporal distribution of the sources of debris at sea and along the coast;
- correspondence between behavior of various kinds of debris and behavior of a standard drifter under the same sea and wind conditions;
- further study of impact of temporal variability (from eddies to seasonal cycle to interannual scale) on the drifter responce to local wind.

Distribution of debris at submesoscale (scales smaller than 100 km) requires higher-resolution satellite data to monitor locations of fronts and eddies and more sophisticated dynamical models to simulate local convergences/divergences of surface fluxes.

4. Dissemination

Briefly identify any dissemination of lessons learned or other project results to external audiences, such as the public or other conservation organizations.

The computed dataset was announced at the AGU Ocean Sciences Meeting in Portland, Oregon in February 2010 and is made freely accessible via servers of the Asia Pacific Data Research Center (http://apdrc.soest.hawaii.edu/projects/SCUD/). The manual for the dataset is published at IPRC as

Maximenko, N. A., and J. Hafner, 2010: *SCUD: Surface CUrrents from Diagnostic model,* IPRC Tech. Note 5

and is available at http://apdrc.soest.hawaii.edu/projects/SCUD/ .

Results of the project were and will be presented at the following meetings and press conference:

- Workshop on At-sea Detection and Removal of Derelict Fishing Gear, December 9-10, 2008, Honolulu, Hawaii.
- "Fluxes and Structures in Fluid: Physics on Geospheres", June 24-27, 2009, Moscow, Russia
- "Environmental Information and Trajectory Prediction in Oil Spill Response", September 14, 2009, Portland, Oregon.
- American Geophysical Union Ocean Sciences Meeting, February 21-26, 2010, Portland, Oregon
- Press-conference at AGU Ocean Sciences Meeting, February 24, 2010, Portland, Oregon
- European Geophysical Union Meeting, May 2-6, 2010, Vienna, Austria
- PACON Meeting, June 2-5, 2010, Hilo, Hawaii

The following scientific papers are in preparation:

Maximenko, N., J. Hafner, and P. Niiler, 2010: Pathways of marine debris derived from trajectories of Lagrangian drifters, *Marine Pollution Bulletin, special issue (Eds. K. McElwee and C. Morishige).*

Law K. L., S. Moret-Ferguson, N. Maximenko, G. Proskurowski, E. Peacock, J. Hafner, C. Reddy, 2010: Plastic in the North Atlantic, *Science*.

Maximenko et al., 2010: Hawaii as a final destination of the North Pacific marine debris, *Nature*.

5. Project Documents
Include in your final programmatic report, via the Uploads section of this task, the following:

- 2-10 representative photos from the project. Photos need to have a minimum resolution of 300 dpi;

The following images have being uploaded
- gif animation of the debris evolution from the homogeneous initial condition as simulated by the statistical model;
- model debris distribution on model year 10;
- ensemble-mean currents measured by drifters and time-mean current diagnosed by the SCUD model to illustrate the remarkable correspondence between the two);
- example of near-surface SCUD currents on August 20, 2008.

- report publications, GIS data, brochures, videos, outreach tools, press releases, media coverage;

The following reports, presentations, and publications have been uploaded:

- manual for the SCUD product;
- Power Point presentation at the OSM press-conference;
- handout of the SCUD announcement;
- handout of the poster at OSM

- any project deliverables per the terms of your grant agreement.

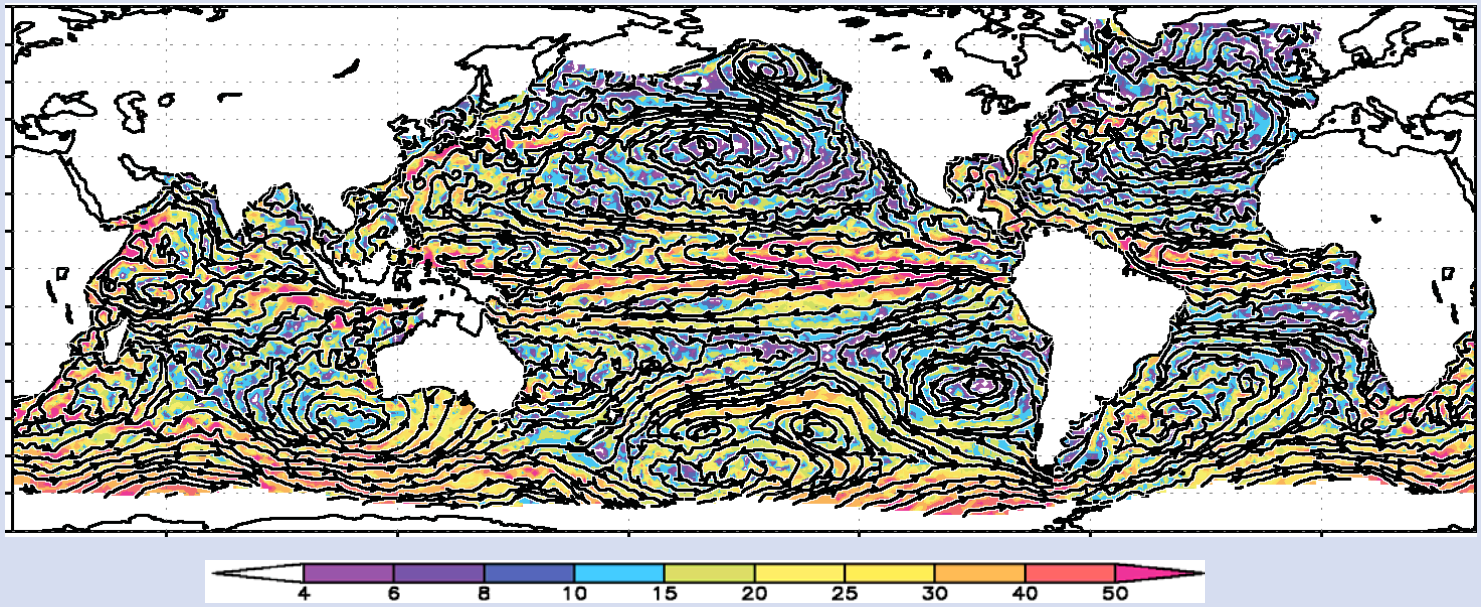
POSTING OF FINAL REPORT: *This report and attached project documents may be shared by the Foundation and any Funding Source for the Project via their respective websites. In the event that the Recipient intends to claim that its final report or project documents contains material that does not have to be posted on such websites because it is protected from disclosure by statutory or regulatory provisions, the Recipient shall clearly mark all such potentially protected materials as "PROTECTED" and provide an explanation and complete citation to the statutory or regulatory source for such protection.*

New!

Released at OSM'10

Surface CUrrents from Diagnostic model (SCUD)

A model is developed to diagnose near-surface currents consistent with trajectories of Lagrangian drifters using satellite observations of sea level anomaly and vector wind. The product aims the tasks of tracer dynamics floating at or near the sea surface, such as marine debris, oil spills, etc.

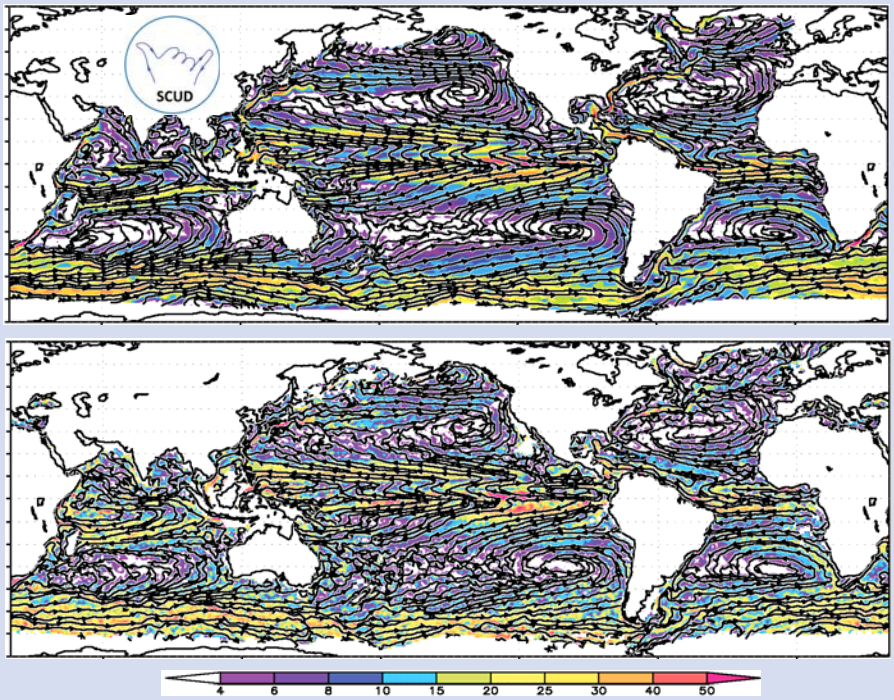


Streamlines of SCUD velocity on August 20, 2008 overlaid on speed (colors). Units are cm/s.

New!

Released at OSM'10

Surface CUrrents from Diagnostic model (SCUD)



Streamlines and magnitudes (colors) of mean SCUD model (top) and drifter (bottom) velocities. SCUD reproduces well locations and strength of all major oceanic features detected by drifters.

Coverage: nearly global
Time span: Jul 20, 1999 – Nov 19, 2009 (same as the QuikSCAT lifetime)
Spatial resolution: ¼ degree
Frequency: daily

Data used in the SCUD model:
-NOAA AOML drifter trajectories
- QuikSCAT wind
- AVISO gridded sea level anomaly
- mean dynamic ocean topography (Maximenko et al., 2009)

Status: fully public
LAS and OPeNDAP access: http://apdrc.soest.hawaii.edu/
Project webpage:
http://apdrc.soest.hawaii.edu/projects/projects.php
Product manual:
http://iprc.soest.hawaii.edu/publications/tech_notes.php
Subscription to mailing list:
http://iprc.soest.hawaii.edu/users/hafner/NIKOLAI/SCUD/registration.html

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Convergent Zones at the Ocean Surface with Implication for Marine Debris Distribution

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Abstract

Modern, multi-instrumental Global Ocean Observing System (GOOS) includes satellites and in situ observations, monitoring the ocean state at the highest accuracy and resolution ever. By combining data of satellite altimetry, surface drifters, wind, and gravity, ocean surface currents can be assessed globally and at research quality. The map of the mean surface currents in Figure 2 shows a complex pattern of oceanic fronts and gyres. Distinct are the convergences of Ekman currents in subtropical gyres that, through the 'Sverdrup mechanism', are feeding anticyclonic circulations in the gyres.

Drifter trajectories can also be utilized to simulate the evolution of the marine debris. Main problem is the inhomogeneous drifter data density, both due to convergence/divergence of ocean currents and due to the drifter deployment scheme. A model constructed from the statistics of the drifter exchange between small bins corrects this bias and was run from the uniform initial condition to study the fate of debris in the ocean. In addition to such actively studied debris accumulation areas as the Great Garbage Patch in the North Pacific, a new, so far unrecognized, the world-strongest convergence is discovered in the South Pacific from the model solution shown in Figure 5.

The same model reveals a complex pattern of convergence/divergence on the cold/warm flanks of major oceanic fronts. The pattern is studied in the framework of nonlinear interaction between Ekman drift and geostropfic baroclinic fronts outcropping at the sea surface. Results are generalized to assess the dynamic of internal Ekman layers distributed along the thermocline and controlling the secondary circulation at the fronts.

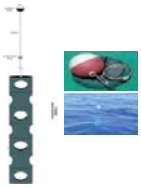

Figure 1. Standard SVP drifter: schematic and views on deck and in water.

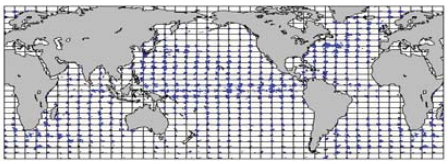

Figure 4. Statistics of 5-day drifter displacements from 10º x 5º grid points.

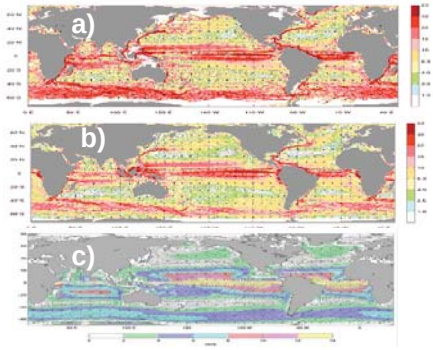

Figure 2. Mean streamlines calculated (a) from 0.25º ensemble-mean velocities of the drifters drogued at 15 m depth between Feb 15, 1979 and May 1, 2007 smoothed to 1º , (b) from a combination of the mean geostrophic and Ekman velocities [Maximenko et al., 2009], and from the mean Ekman currents parameterized to NCEP re-analysis wind. Colors are magnitudes of (a) mean drifter velocity and (b) mean geostrophic plus Ekman velocity used to compute the streamlines, and units are cm/s. Noteworthy is the coexistence of sharp, mostly geostrophic fronts and large convergences of the Ekman flow.

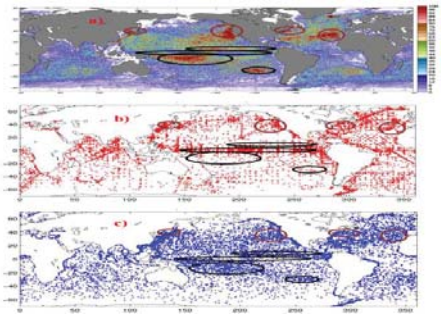

Figure 3. Number of 6-hourly drifter fixes in 1/4-degree boxes (a), locations where drifters were released (b) and where they were last reported (c). Brown ellipses indicate regions where higher density of drifter data is consistent with the massive drifter deployments. Black ellipses indicate maxima and minimum in drifter density that occur due to ocean currents.

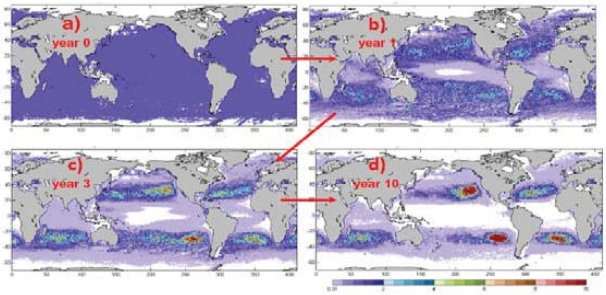

Figure 5. Relative change of density of marine debris (drifter tracer) from initially homogeneous state (a) after 1 year (b), 3 years (c) and 10 years of model simulation. Simulative is performed by successive application of the statistics of drifter displacements shown in Figure 4.

In 1 year tracer is removed from the areas of equatorial and coastal upwellings, in 3 years it is concentrated in subtropics, and then accumulated in relatively compact convergent zones, the strongest of which are located in the eastern North and South Pacific. The convergence in the South Pacific is still to be discovered.

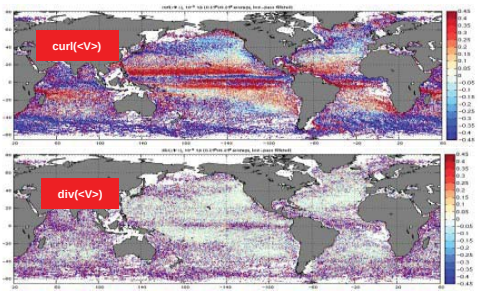

Figure 8. Curl (top) and convergence (bottom) of mean surface currents measured by drifters (Figure 2a). Because currents are quasi-geostrophic, convergence is remarkably weaker and noisier than curl. Note that colors are same on both panels.

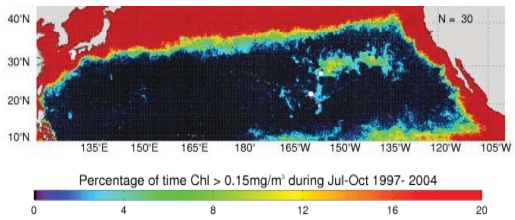

Figure 7. Maximum of probability of summer chlorophyll blooms is collocated with the center of the convergence of surface currents (Figures 2 and 5). Wilson et al. [2007] suggested that it is induced by floating debris reach with nutrients collected from large areas.

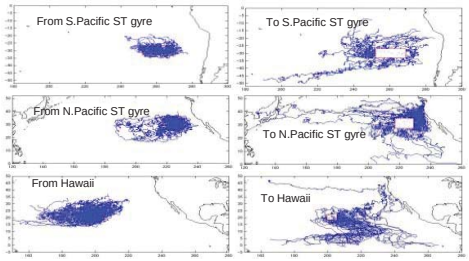

Figure 6. Trajectories of real drifter starting from (left column) and ending in (right column) the South Pacific (top row), North Pacific (middle row), and Hawaii (bottom row).

Currently,

work is under way to develop a diagnostic model of near-surface currents that parameterizes drifter trajectories to satellite observations (altimetry, QuikSCAT, SST, and ocean colors) and best reproduces the pathways of marine debris in the North Pacific.

Good agreement between Figures 2a and 2b is an indicator of feasibility of such simple modeling, even if the complex dynamics of the mixed layer remains largely not understood.

The product will use the experience of previous datasets, such as OSCAR, but will specifically focus on the tasks of the marine debris monitoring. If Successful, it will be offered to coordinate in field operations.

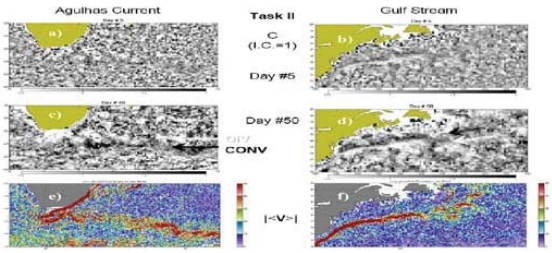

Figure 9. Relative concentration of model tracer in the Agulhas Retroflexion and the Gulf Stream regions after 5 (a and b) and 50 (c and d) days of evolution from homogeneous initial condition. (e and f) indicate the intensity of the mean near-surface currents estimated from drifter trajectories.

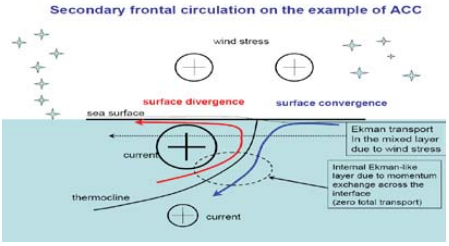

Figure 10. Schematic of the 3D Ekman circulation induced by interaction of the near-surface wind-driven Ekman current with outcropping geostrophic ront. Deep extension of the surface Ekman boundary layer along the thermocline is hypothesized to be maintained by the diapycnal exchange of momentum in baroclinically sheared flow.

Acknowledgments

This work was supported by the NASA Physical Oceanography Program through its Ocean Surface Topography Science Team (grant No. NNX08AR49G) and the by the US National Fish and Wildlife Foundation through grant No. 2008-0066-006, and also by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), by NASA through grant NNX07AG53G, and by NOAA through grant NA17RJ1230, which sponsor research at the International Pacific Research Center.