2014 INTERNATIONAL OIL SPILL CONFERENCE

Utilization of the Northern Gulf Operational Forecast System to Predict Trajectories of Surface Oil from a Persistent Source Offshore of the Mississippi River Delta

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ABSTRACT 299976:

In this paper, we demonstrate the use of a new operational, unstructured-grid hydrodynamic model within the oil spill trajectory model GNOME (the General NOAA Operational Modeling Environment) to examine the transport of surface oil from a known source approximately 10 miles offshore of the Mississippi River Delta. At this location, a cluster of wells and/or contaminated sediments have been persistently leaking small amounts of oil since they were damaged in 2004. Slicks associated with this source are frequently detected in satellite imagery analysis, which indicates they are often oriented in the along isobath direction with typical dimensions of 0.5-2 km by 10-30 km varying with wind conditions.

The Northern Gulf of Mexico Operation Forecast System (NGOFS) has recently been deployed by NOAA and includes this region. The underlying hydrodynamic model is an unstructured grid finite-volume model which allows variable grid resolution ranging from 10 km offshore to ~600 m near the coastline. Unstructured grid models are ideally suited for coastal areas as they allow flexible resolution to resolve complex bathymetry and coastlines. However, large model domains combined with high grid resolution can provide a challenge for operational trajectory models as sub-setting the model grid is not as straightforward as in the structured grid case. The utility of any hydrodynamic model for emergency response depends not only on its accuracy, but on the trajectory modeler's ability to access and use the information in a timely manner. As part of this study, we have developed tools to allow the NGOFS results (in addition to other unstructured grid models) to be readily available to GNOME users. Using output from the NGOFS in GNOME, a one year modeled simulation was run in which surface particles were released continuously from the location of the damaged wells. Predicted trajectories of modeled particles less than ~24-hours in age compare qualitatively well with the satellite observations.

INTRODUCTION:

Operational forecasting of oil movement is critical to spill response for planning, allocation of resources, and direction of assets. Although spills like the Deepwater Horizon incident are relatively infrequent, NOAA's Emergency Response Division (ERD) provides trajectories for numerous small spills (typically ~140 per year). To provide timely support to nation-wide spills, ERD continues to improve their spill trajectory model, the General NOAA Operational Modeling Environment, or GNOME (Beegle-Krause, 2001). Within GNOME, the oil is divided into a large number of small particles which move under the influence of ocean currents, wind drift, and turbulent motions. In order to leverage available high-resolution regional forecast models for currents and winds, GNOME has been designed to be flexible in input data types. For example, it can currently utilize model output on regular, curvilinear, or unstructured (triangle) grids.

Unstructured grids allow for improved representation of complex boundaries such as coastlines and also provide the flexibility to increase resolution in areas of interest (e.g., regions of strong bathymetric variations). NOAA's National Operational Coastal Modeling Program (NOCMP), which aims to develop and operate a national network of Operational Nowcast and Forecast Hydrodynamic Model Systems (called OFSs), has recently brought online several new OFSs which are based on unstructured grid hydrodynamic models. A challenge for utilizing output from these newer models within GNOME is the large size of the model grids. For example, the Northern Gulf of Mexico Operational Forecast System (NGOFS), which became operational in late February 2012, has 90,267 nodes and 174,473 elements. Downloading and processing such a large grid can cause a prohibitive load on network bandwidth and computational resources. However, sub-setting the model output to a region of interest is much less straightforward than in the structured grid case, and for use in GNOME or other particle tracking models, should be done in a way that preserves the topological and boundary information of the grid.

In this paper, we demonstrate the use of the new Northern Gulf Operational Forecast System within GNOME, to examine the transport of surface oil from a known source approximately 10 miles offshore of the Mississippi River Delta – a cluster of wells owned by Taylor Energy. Some of the wells and/or contaminated sediments have been persistently leaking in this area since the destruction of a production platform in 2004. The platform was toppled by a subsurface mud slide triggered by storm surges associated with Hurricane Ivan. The mudslide also resulted in the wells being covered with more than 100 feet of mud and sediment complicating mitigation efforts (Taylor Energy statement). Although numerous interventions have been conducted, associated surface slicks are frequently observed by overflight observers and detected in analysis of satellite imagery. These slicks are generally too thin to be recoverable and response activities to date have been focused on stemming the source rather than on-water recovery operations. However, the repeated sheen observations may provide an opportunity to validate modeling results in this region of extensive oil and gas development. Such evaluation of trajectory forecast accuracy is critical to understanding uncertainty and improving our future modeling capability.

OBSERVATIONS:

Summary observations from overflights of the area dating back to 2008 were provided by Taylor Energy. These overflights have occurred daily (weather permitting) and record the length and width of the sheen as visually observed. In addition, the overflight observers estimated percent coverage, and describe the composition of the slick (percent barely visible, percent silver sheen, or colored etc.). During the Deepwater Horizon oil spill in 2010, sheens from the Taylor site were often indistinguishable from the larger oil spill and observers were not able to estimate any of these parameters.

Since 2010, the Marine Pollution Program of NOAA/NESDIS's Satellite Analysis Branch (SAB) has also analyzed the surface expression of this spill through the use of available moderate to high resolution visible imagery and synthetic aperture radar (available until 2012; details in Warren et al., IOSC Poster, 2014). This analysis identifies an outline of an anomaly but provides no information on oil thickness. The results are made available in Marine Pollution Surveillance Reports (MPSRs) which summarize the results and provide information on sensor type and environmental conditions (example MPSR in Figure 1).

MODELING TRAJECTORIES IN GNOME:

Trajectories for the movement of oil were run using the General NOAA Operational Modeling Environment (GNOME). GNOME is an Eulerian/Lagrangian spill-trajectory model in which the regional physics are simulated as Eulerian (continuous) fields within which the slick's Lagrangian Elements move (Beegle-Krause, 2001). Although GNOME can track particles in 3-dimensions, in this case, the particles were continuously released on the surface for one-year at a location corresponding to the slick origin frequently observed in satellite imagery analysis. Particles were then moved in GNOME under the influence of surface ocean currents, wind drift and horizontal dispersion. The fate and transport of oil spilled into the marine environment also depends on a suite of physical, chemical, and biological processes, collectively termed "weathering". Although the GNOME model includes simple algorithms for oil weathering, in this application trajectories were run as conservative particle due to the lack of information on release rate and product type. Without this information, it is impossible to explicitly model persistence of the surface slick. Instead we track the age of the particles (time since release) and compare the extent of the modeled trajectories with overflight and satellite observations to indirectly examine persistence.

Surface ocean currents were derived from the Northern Gulf of Mexico Operational Forecast System (NGOFS) which became operational in late February 2012. NGOFS was developed to serve the maritime user community as a joint project of the NOAA/National Ocean Service (NOS)/Office of Coast Survey, the NOAA/NOS/Center for Operational Oceanographic Products and Services (CO-OPS), the NOAA/National Weather Service (NWS)/National Centers for Environmental Prediction (NCEP) Central Operations (NCO), and the University of Massachusetts, Dartmouth. NGOFS generates water level, current, temperature and salinity nowcast and forecast guidance four times per day. The system is based on a three-dimensional, high resolution hydrodynamic model model (Chen et al., 2006). The wind data used to force NGOFS are from the National Weather Service (NWS) nested, high resolution (4 km) North American Mesoscale (NAM) weather prediction model. Additionally, NGOFS relies on CO-OPS real-time water level, temperature and salinity observations; NWS Extratropical Storm Surge (ETSS) forecasts; the Advanced CIRCulation Model (ADCIRC) ec2001 tide database; U.S. Geological Survey (USGS) river data; and the NOAA/NWS/NCEP Global Real-Time Operational Forecast System (RTOFS) for open-water boundary information . The NGOFS grid domain covers the Northern Gulf of Mexico from the Texas/Mexico border to the Florida

Panhandle with resolution ranging from 10 km on the open ocean boundary to approximately 600 m near the coast (Figure 2).

The NGOFS output was accessed through a web server that provides metadata and data access for scientific datasets (THREDDS) using the Open source Project for a Network Data Access Protocol (OPeNDAP). A major advantage of using OPeNDAP is the ability to perform server-side operations to subset and/or subsample data. However, sub-setting an unstructured grid to a geographic region is not straightforward and server-side functions that preserve topological and geometric relationships still need to be developed and implemented. As the NGOFS domain is far larger than the area of interest for this study, we attempted to decrease both the data download time and the model run time for this one-year simulation by developing scripts using the Python programming language to subset the unstructured model grid. This “client-side” sub-setting was successful in decreasing the amount of data downloaded. However, because the model output arrays could only be indexed in contiguous sections, it was necessary to download the model data in multiple chunks – in the end, the download time was no less than that for downloading the entire geographic domain. However, the subset did allow for an improvement in model setup and run-time due to the much smaller size of the input files.

The wind data used in GNOME was also from NWS\NAM 4 km weather prediction model used to force NGOFS. In spill trajectory models, it is common to combine a number of physical processes related to wind forcing (e.g., wave stress, Stokes drift, dispersion, surface drift, Langmuir circulation) into a wind-drift factor (Galt, 1994). This has been determined experimentally to be ~3-4% of the wind speed for fresh oil in light winds without breaking waves (Reed et al., 1994). As the oil weathers and/or if wind speed increases the oil may spend a significant portion of time away from the surface and out of the influence of many of the processes associated with the wind forcing and the average drift factor may be much lower. In general, this parameterization is a very useful approach but requires observational feedback during spill events (Galt, 1994). GNOME allows the user to specify a range of values for the wind drift along with a persistence time scale – simulating the time-varying windage as the wind and wave conditions are not generally spatially uniform nor is the oil all of the same age since release (varying degrees of weathering). In computing trajectories for this study, a range of 1-4% of the wind speed was specified, with a persistence of 15 minutes.

Finally, turbulent diffusive processes that spread spills horizontally are simulated in GNOME by a random walk. A diffusion coefficient is used to calculate random step lengths in the x- and y-directions from a uniform distribution. The current version of GNOME does not allow for spatial dependence in the diffusion. For these trajectories, a value of 1 m^2s^{-1} was specified. This value was based on comparison of the width of the modeled slick with the width observed in satellite imagery.

RESULTS:

Observations from daily overflights of the region indicate a persistent source – in over 1700 flights to the region over 5 years, only 44 times was “no visible oil” reported. Typical dimensions of the observed slick are 1-10 km in length by 0.5-1 km in width. Observers typically report coverage within this area of 10-30% comprised of barely visible to silvery and brightly colored sheens with very little dark or recoverable oil (<5%). Anomalies associated with this source are also frequently detected in the satellite imagery analysis; as of November 2013, 134 Marine Pollution Surveillance Reports (MPSRs) associated with the Taylor site have been released (for example MPSR, see Figure 1). In their analysis, the anomalies associated with this source have typical dimensions of 0.5-2 km in width by 10-30 km in length (see also Warren et al., IOSC 2014).

In order to examine the time scales of transport associated with the observed slick extents, we compare these observations with modeled trajectory results for a one year simulation (March 2012-2013). In this one year continuous run, surface particles are released continuously from the Taylor wells location and move under the influence of modeled currents, winds, and horizontal diffusion as described in the previous section. Within 12 hours of release, particles are typically transported a maximum of 5-20 km from the source location; or within 24 hours a maximum of 10-40 km. Based on the maximum observed extent, this suggests that the age of the visible slick is ~1-3 days.

In the satellite imagery analysis, the observed anomalies associated with this source are most typically oriented in the along isobath direction (>50% of the time; Figure 3). The modeled particle trajectories also exhibit a strong tendency towards alongshore or east/west movement. Example 24 hour trajectories of particles are shown in Figure 4 – the color of the particles represents their “age”, or time since release from 0-24 hours. The left panel is representative of movement during the time period from mid-spring to mid-fall, when winds are predominantly from the south and transport tends to be towards the east – for example, in July and August of this one year simulation, particles originating from the Taylor wells location move to the east >85% of the time. The right panel is a representative fall/winter trajectory when the passage of frequent cold fronts shifts the mean winds to northeasterly or northerly and westward transport is more frequently observed. This seasonal variability observed in particle trajectories is consistent with previous studies examining advection of low salinity water from the Mississippi River eastward in the spring and summer and westward in the fall and winter (for example, Morey et al., 2003).

In Figure 5 (left panels), we compare the 24-hour modeled trajectories with results from the satellite imagery analysis during the passage of a cold front in April 2012. A series of images were available during this time, capturing a transition from westward to eastward flow following the passage of the front. The model trajectories capture this transition reasonably well although the extent of the modeled slick varies considerably from the observations, likely due to the lack of weathering in this simulation. To quantitatively access the skill of this model in reproducing observed trajectories in this region requires knowledge of release rate and product chemistry so that weathering could be included. However, considering the transport direction only, the inclusion of currents from the NGOFS substantially increases the accuracy of the trajectories as compared to trajectories solely derived from wind drift (right panels).

DISCUSSION AND CONCLUSIONS:

The development of an operational, high-resolution regional model for the coastal Northern Gulf of Mexico, an oceanographically complex region of extensive oil and gas exploration and development, is an important step for aiding in trajectory prediction of oil slicks for use in emergency response. The utility of any hydrodynamic model for emergency response depends not only on its accuracy, but on the trajectory modeler's ability to access and use the information in a timely manner. As part of this study, we have developed tools to allow the NGOFS results (in addition to other operational unstructured grid models) to be readily available to GNOME users. For example, an online website at http://gnome.orr.noaa.gov/GOODS provides access to the latest forecasts in a format that can be loaded directly into GNOME. However, decreasing the download times for small regional subsets of these larger model domains will require implementation of server-side sub-setting functions. Work is ongoing on developing a protocol and server software that would allow the sub-setting of unstructured grids on the server side, allowing efficient access to sub-domains of large unstructured grid models (e.g., see http://docs.opendap.org/index.php/OPULS:_UGrid_Subsetting).

Using output from the NGOFS in GNOME, a one year modeled simulation was run which surface particles released continuously from the Taylor wells location. Although weathering was not explicitly modeled, based on the extent of the slick as observed by satellite observations and the timescales associated with this transport we estimate the persistence of the visible surface slick to be ~1-3 days. The persistence based on the overflight observations is less than one day. The larger dimensions of the slick as detected by satellite analysis may be in part due to sensor resolution – in particular, the width of the slick may be overestimated as it is often a very thin linear feature. However, the satellite analysis also often results in a much longer anomaly associated with the slick compared to overflight observations from the same day. It was observed during the Deepwater Horizon oil spill, when these types of satellite analyses were used extensively in conjunction with observations from NOAA observers on overflights, that under calm conditions, the satellite analysis detected very thin transparent sheens that overflight observers might not discern or might not categorize as oil (potentially biogenic).

In the entire 1-year simulation, only on 7 days did model particles less than 24 hours in age make landfall. Most of the landfalls occurred between March 8-22 when modeled particles beached on Southwest Pass and South Pass. During this period, the Mississippi River discharge was relatively low and winds were persistently from the SE (onshore) at speeds of 5-10 kts. The outflow from the Mississippi river creates a convergence zone at the freshwater-saltwater interface which can inhibit oil from reaching the shoreline of the Mississippi River Delta (this was frequently observed during the Deepwater Horizon oil spill). Hence, shorelines on the Mississippi River Delta are most vulnerable during conditions similar to these, with low-river flow conditions and onshore winds. We note that no shoreline impacts have been observed to date associated with the discharge from the Taylor wells site. The stronger winds necessary to move floating oil towards the Delta across the convergence zone are also likely to increase evaporation and dispersion of the slick, which, along with potential scavenging by sediment laden plume waters, may inhibit this relatively small volume of oil from reaching the shorelines. The only other time period during which model particles beached in this simulation was following the passage of Hurricane Isaac on August 30.

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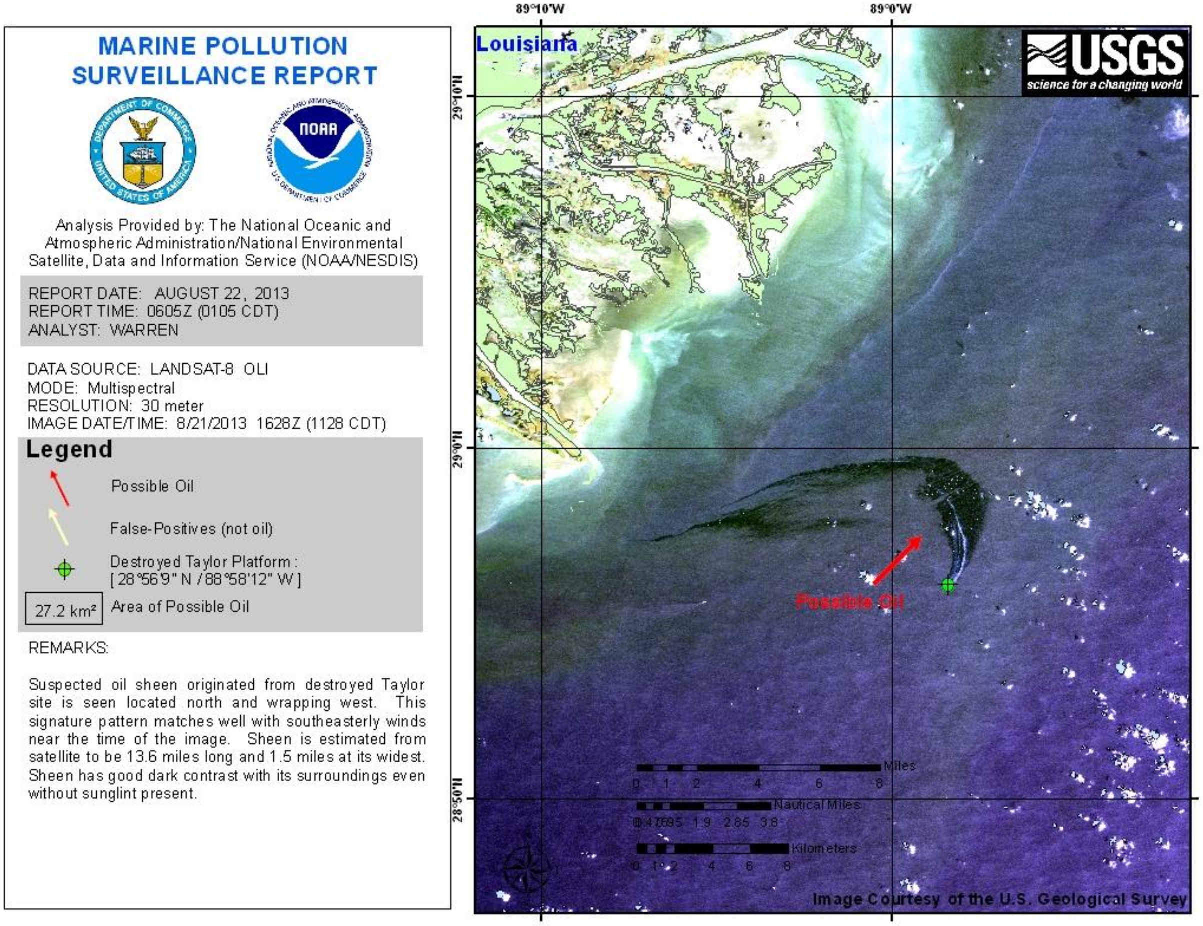

MARINE POLLUTION SURVEILLANCE REPORT

Analysis Provided by: The National Oceanic and Atmospheric Administration/National Environmental Satellite, Data and Information Service (NOAA/NESDIS)

REPORT DATE: AUGUST 22, 2013
REPORT TIME: 0605Z (0105 CDT)
ANALYST: WARREN

DATA SOURCE: LANDSAT-8 OLI
MODE: Multispectral
RESOLUTION: 30 meter
IMAGE DATE/TIME: 8/21/2013 1628Z (1128 CDT)

Legend
Possible Oil
False-Positives (not oil)
Destroyed Taylor Platform : [28°56'9" N / 88°58'12" W]
27.2 km² Area of Possible Oil

REMARKS:

Suspected oil sheen originated from destroyed Taylor site is seen located north and wrapping west. This signature pattern matches well with southeasterly winds near the time of the image. Sheen is estimated from satellite to be 13.6 miles long and 1.5 miles at its widest. Sheen has good dark contrast with its surroundings even without sunglint present.

Figure 1 Example Marine Pollution Surveillance Report provided by NOAA/NESDIS

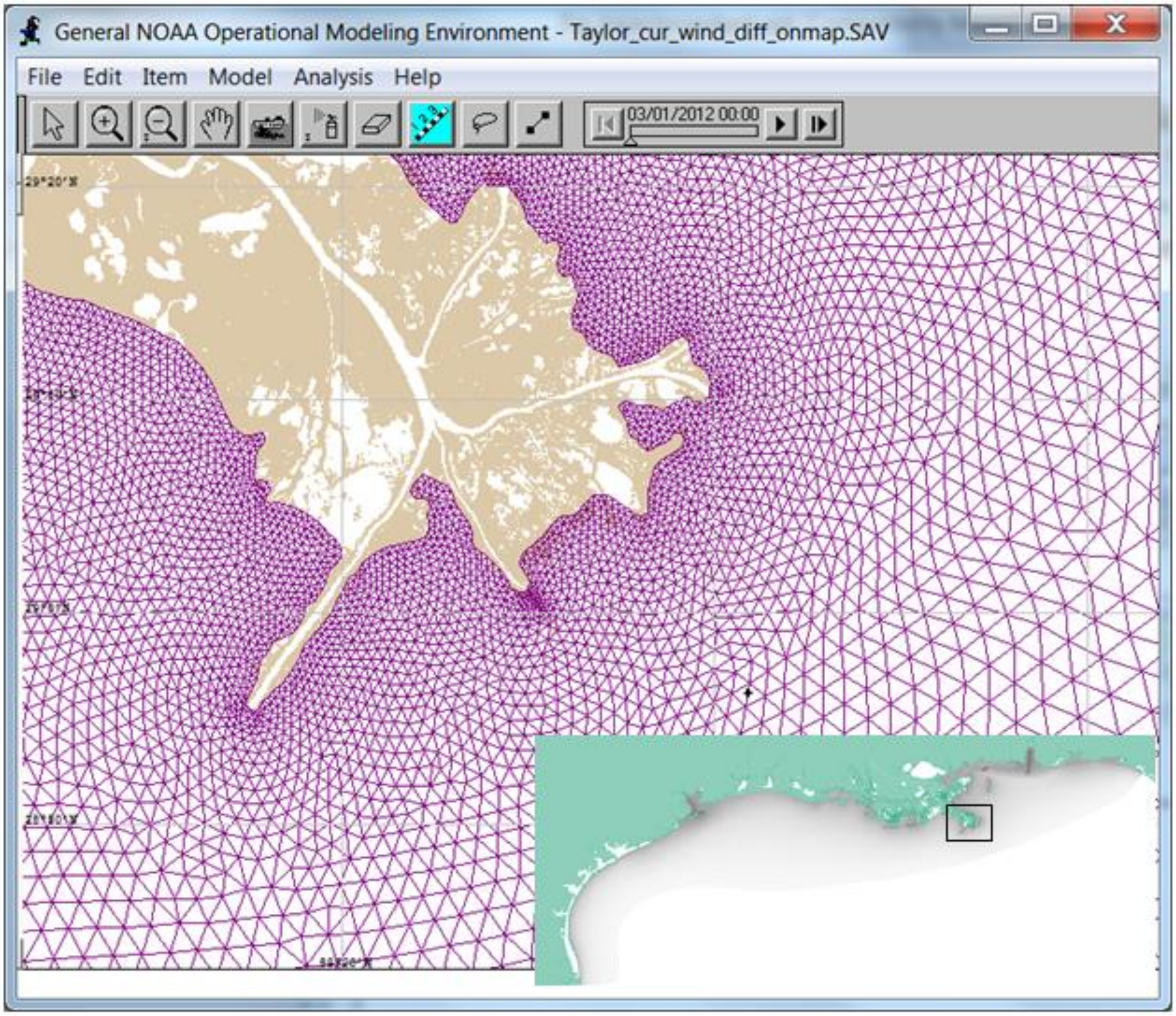

Figure 2 NGOFS model grid in GNOME. Inset at lower right shows model domain.

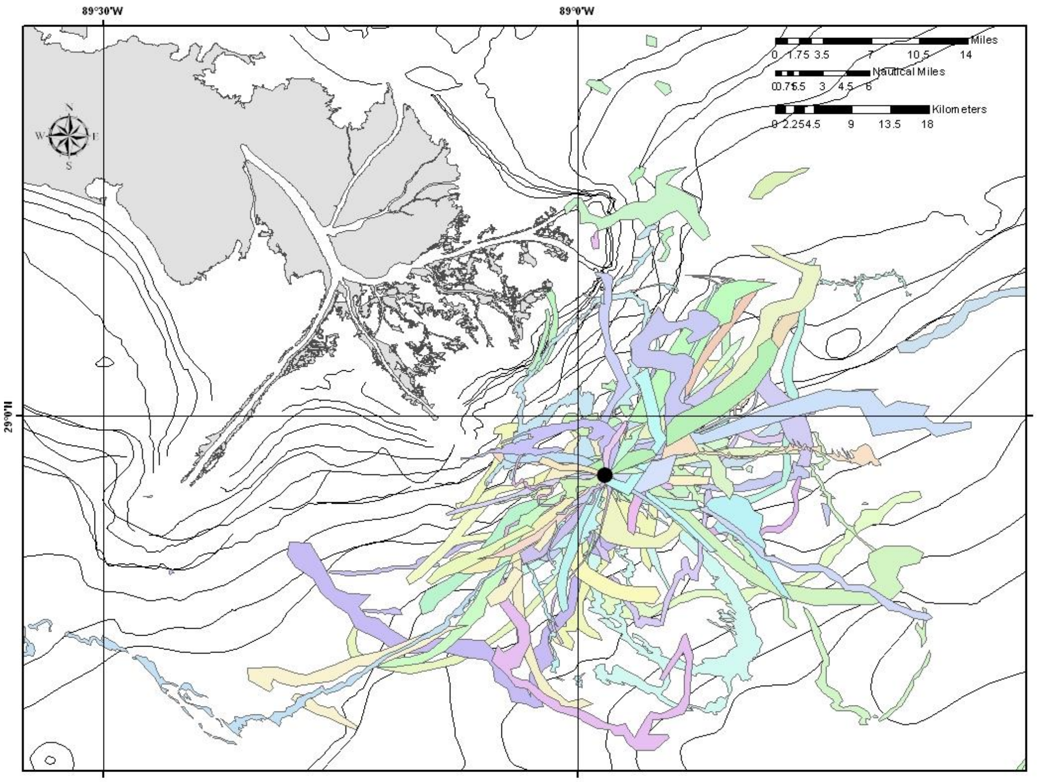

Figure 3 All anomalies detected in MPSRs since 2010

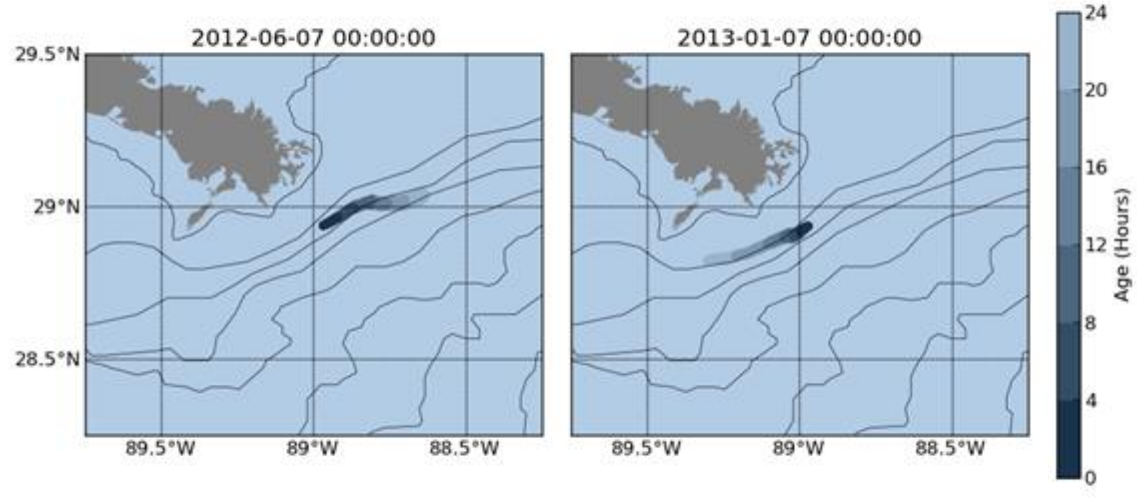

Figure 4 Representative 24-hour model trajectories for sping/summer (left) and winter (right). Isobaths in this and subsequent figures are 10 m, 50 m, 100 m, 200 m, 500 m, 1000 m, 1500 m, and 2000 m.

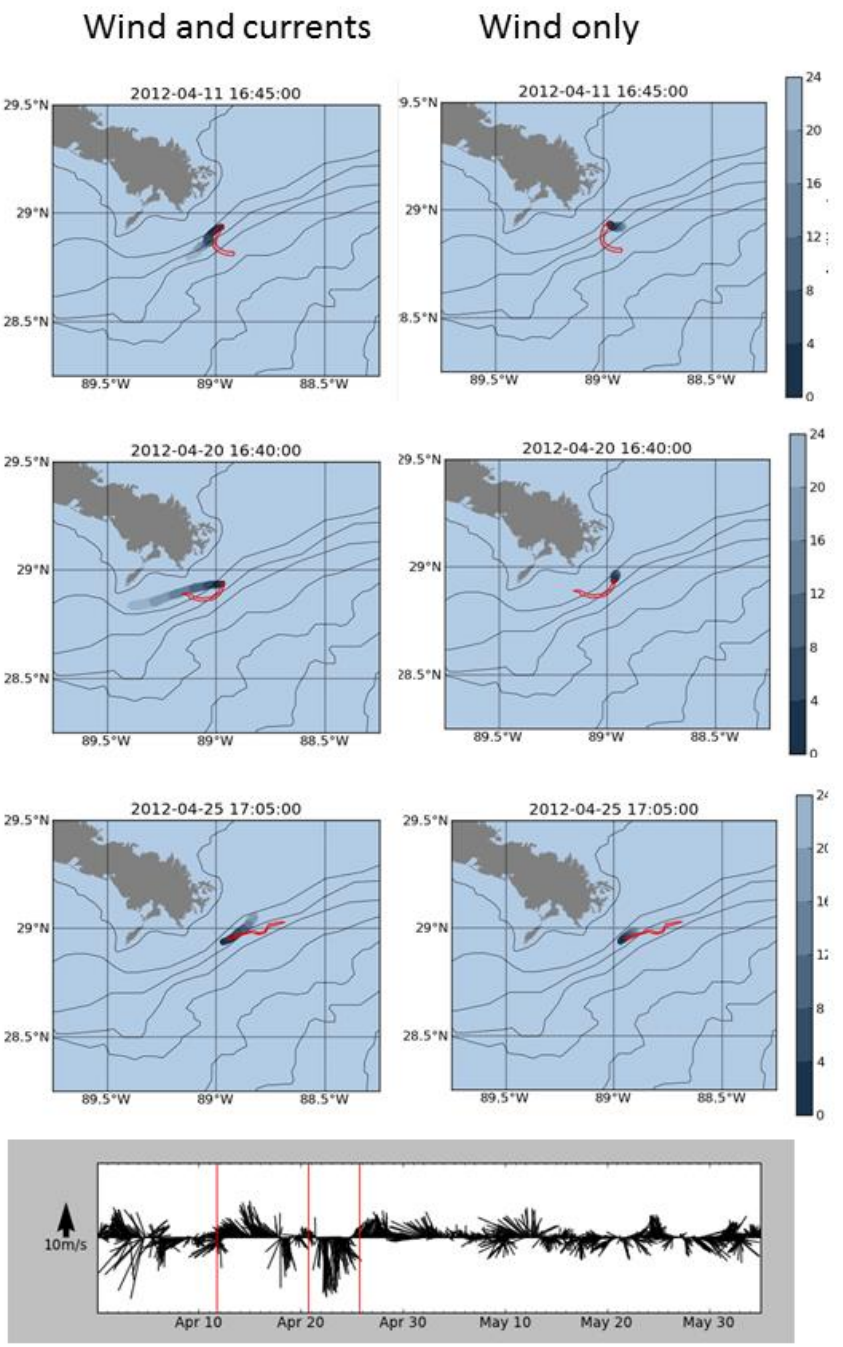

Figure 5 Model trajectories and detected satellite anomalies (red) showing reversal in alongshelf transport following passage of cold front in April 2012