

Oil Tracking on the TX-LA Shelf

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1 Introduction

1.1 Particle Tracking

1.2 Timing

On Rainier:

galvcon_b: 5 days: 1 model output read in at a time:

```
run time:          40.5501658916
-----
Time spent on:
  Initial stuff:      1.68 (4.14%)
  Reading in fields: 37.73 (93.06%)
  Z interpolation:   0.00 (0.00%)
  Tracmass:           0.27 (0.66%)
```

galvcon_b: 5 days: 1 model output read in, new formulation:

```
run time:          68.2703919411
-----
Time spent on:
  Initial stuff:      1.60 (2.35%)
  Reading in fields: 66.14 (96.88%)
  Z interpolation:   0.00 (0.00%)
  Tracmass:           0.35 (0.51%)
```

galvcon_b: 5 days: 10 model output read in at a time:

run time: 36.4923648834

Time spent on:

Initial stuff: 1.65 (4.51%)
Reading in fields: 34.30 (93.98%)
Z interpolation: 0.00 (0.00%)
Tracmass: 0.37 (1.01%)

galvcon_b: 30 days: 1 model output read in at a time:

run time: 255.796955109

Time spent on:

Initial stuff: 1.66 (0.65%)
Reading in fields: 247.67 (96.82%)
Z interpolation: 0.00 (0.00%)
Tracmass: 1.44 (0.56%)

galvcon_b: 30 days: 10 model output read in at a time:

run time: 217.657314062

Time spent on:

Initial stuff: 1.83 (0.84%)
Reading in fields: 212.95 (97.84%)
Z interpolation: 0.00 (0.00%)
Tracmass: 1.91 (0.88%)

galvcon_b: 30 days: 30 model output read in at a time:

run time: 230.847060919

Time spent on:

Initial stuff: 1.78 (0.77%)
Reading in fields: 224.09 (97.07%)
Z interpolation: 0.00 (0.00%)
Tracmass: 3.78 (1.64%)

On Hafen:

galvcon_b: 30 days: 1 model output read in at a time:

```
run time:          99.7389910221
-----
Time spent on:
    Initial stuff:      0.64 (0.64%)
    Reading in fields:  95.47 (95.72%)
    Z interpolation:   0.00 (0.00%)
    Tracmass:          2.37 (2.38%)

galvcon_b: 30 days: 10 model output read in at a time:

run time:          84.7083859444
-----
Time spent on:
    Initial stuff:      0.63 (0.74%)
    Reading in fields:  80.84 (95.44%)
    Z interpolation:   0.00 (0.00%)
    Tracmass:          2.57 (3.04%)

galvcon_b: 30 days: 30 model output read in at a time:

run time:          79.918667078
-----
Time spent on:
    Initial stuff:      0.62 (0.78%)
    Reading in fields:  76.07 (95.19%)
    Z interpolation:   0.00 (0.00%)
    Tracmass:          2.57 (3.21%)

galvcon_b: 30 days: 50 model output read in at a time:

run time:          81.5699141026
-----
Time spent on:
    Initial stuff:      0.65 (0.80%)
    Reading in fields:  77.70 (95.26%)
    Z interpolation:   0.00 (0.00%)
    Tracmass:          2.57 (3.15%)

galvcon_b: 30 days: 100 model output read in at a time:
```

```

run time:          77.1890599728
-----
Time spent on:
    Initial stuff:      0.65 (0.84%)
    Reading in fields: 73.33 (95.00%)
    Z interpolation:   0.00 (0.00%)
    Tracmass:          2.55 (3.31%)

galvcon_b: 30 days: 200 model output read in at a time:

```

```

run time:          78.2113389969
-----
Time spent on:
    Initial stuff:      0.62 (0.79%)
    Reading in fields: 74.38 (95.10%)
    Z interpolation:   0.00 (0.00%)
    Tracmass:          2.57 (3.28%)

```

2 Tracking Algorithm Sensitivity and Details

2.1 Explain Algorithm

2.1.1 2D Boundaries

Due to the basic algorithm of TRACMASS, at boundaries within the numerical domain, drifters will be stopped according to the bounding fluxes. For a given grid cell in the 2D case, there are four fluxes controlling a drifter's movement. Drifters have nonzero fluxes on active sides of the cell and zero fluxes along masked land. They can run along these walls but should not penetrate them. At open numerical boundaries, the drifters will be stopped according to a check built into tracmass itself, and will be left with their final position along the open boundary and a flag indicating that they have exited the domain so they will not be stepped forward.

The addition of subgrid turbulence parameterizations can affect this. One method is to add parameterized turbulent values to the fluxes used to calculate drifter movements. These do not affect the fact that fluxes will be zero at masked land because they are multiplied by the original ufluxes to get the fluctuation to add to the original flux values.

However, there are two methods of adding in a random walk to the particle positions directly, and these were affecting the boundary behavior of drifters near walls. The problem was that when a drifter was alongside a masked land cell, if the random new position of the drifter was just right to move the drifter from its current cell into the land cell, then an error check later in the code for the volume of the cell would catch the drifter (due to its cell

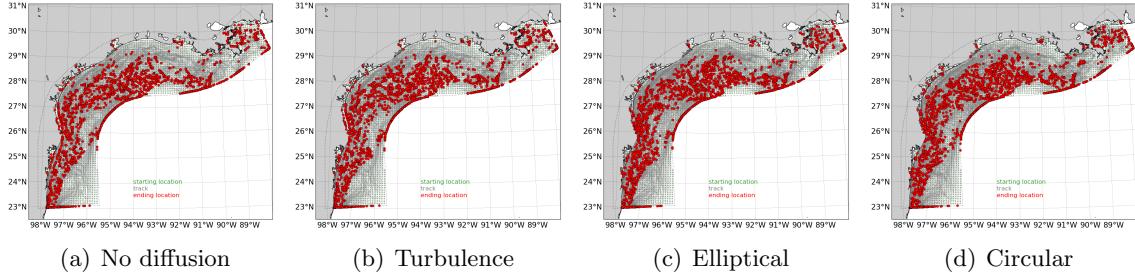


Figure 1: Comparison of types of diffusion for $A_H = 20 \text{ m}^2/\text{s}$, initial spacing of 10km

having zero volume since it was on land) and the drifter would be stopped at its location near land. Since drifters in the advection-only and turbulent velocity methods do not hit land, the overall behavior was different along the coastline for the diffusion and anisodiffusion methods (in these methods, many more drifters were congregated alongshore). I changed this by adding a check in the diffusion subroutine in tracmass to not accept a new displacement location for a drifter if the layer thickness (dzt) of that new location is zero. Now, I think that all of the routines will have similar coastline behavior. If, on the other hand, it is desired that drifters should be able to hit the coastline and “beach,” then this behavior in the diffusion routines might be desired.

2.2 Examine Sensivity of Results to Input Parameters

A series of numerical surface drifter experiments were run for 16 days forward in time from 11/20/2009 with several changing parameters to understand their importance to the results.

There is little overall difference for the number of time interpolation steps for these simulations (not shown).

The difference in the results from diffusion types is illustrated in Figure 1. For numerical drifter experiments with drifters initially seeded 10 km apart and using the same horizontal diffusivity, the difference in tracks and final positions is not extreme, but is noticeable. The cases with no diffusion and parameterized turbulent velocities (Figures 1(a) and 1(b)) are similar, though a larger value of A_H would presumably change this more. The cases with a random walk-type diffusion added to the particle tracks themselves (Figures 1(c) and 1(d)) show more diffused behavior and are fairly similar to each other.

Drifter tracks and final locations are shown in Figure 2 for changing the size of the horizontal diffusivity, A_H . The overall behavior is the same in all of the plots, but the drifters are somewhat noticeably more spread out as the value of the horizontal diffusivity increases. This is shown for adding diffusion using a random walk on a circle to the drifter positions, but the same type of behavior is found in the results of all of the parameterization techniques (not shown).

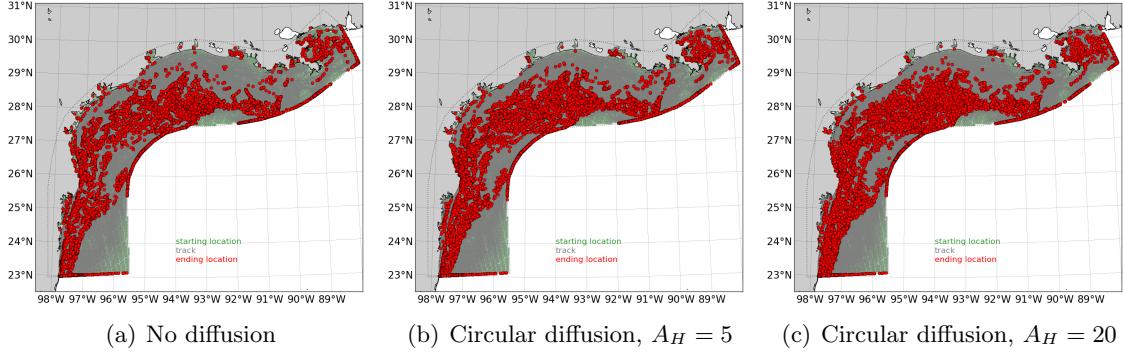


Figure 2: Comparison of size of A_H for initial spacing of 5km and circular trajectory diffusion

2.3 Forward/Backward

3 Performance of Model and Tracker

3.1 Mass Flux Comparison

3.2 Gyre Test

3.3 Sensitivity to Waves, Tides, and Model Output Frequency

4 Drifter Transport

4.1 Methodology

The idea is to assign an initial volume transport property to the drifters based on their initial placement and velocity and, given a high enough density that the result does not change with more drifters, track the x and y transport as the drifters pass numerical grid cell walls. The initial volume transport is found by summing the overall flux into or out of the grid cells in which drifters are initially located and dividing by the number of initial drifters in the cells, or

$$T_0 = \frac{1}{N_0} \left(|u[i_0, j_0, k_0, t_0]| \Delta y_{i_0, j_0} \Delta z_{i_0, j_0, k_0, t_0} + |v[i_0, j_0, k_0, t_0]| \Delta x_{i_0, j_0} \Delta z_{i_0, j_0, k_0, t_0} \right),$$

where N_0 is the number of drifters initialized in a grid cell or grid cells (in which case N_0 is a vector), $u[i_0, j_0, k_0, t_0]$ and $v[i_0, j_0, k_0, t_0]$ are the zonal and meridional velocities for the initial grid cell(s) at grid index locations i_0, j_0, k_0 , the drifters are seeded at time t_0 , and the grid cell spacing in the zonal and meridional directions is given by $\Delta x_{i_0, j_0}$ and $\Delta y_{i_0, j_0}$ (assuming they can change horizontally but not vertically or in time), and in the vertical direction is given by $\Delta z_{i_0, j_0, k_0, t_0}$ (which can change in all dimensions) (Döös, 1995).

Assuming that all drifters that enter a grid cell will exit via another grid cell wall, the 3D transport field is non-divergent, that is,

$$\partial_i U + \partial_j V + \partial_k W = 0, \quad (1)$$

for zonal, meridional, and vertical volume transports U, V, W and directions i, j, k . Alternatively, this can be written in terms of the numerical discretization as:

$$U_{i,j,k,n} - U_{i-1,j,k,n} + V_{i,j,k,n} - V_{i,j-1,k,n} + W_{i,j,k,n} + W_{i,j,k-1,n} = 0, \quad (2)$$

where $U_{i,j,k,n}, V_{i,j,k,n}, W_{i,j,k,n}$ are the (x, y, z) volume transports registered for drifter instance n for grid cell located at indices (i, j, k) .

In this work, the vertical direction is assumed to be unimportant (these are surface-only drifters), so only the zonal and meridional directions are used. Everytime a drifter crosses a grid cell wall in the positive zonal or meridional direction, its initial volume transport (which is a property of the drifter) is registered at that cell wall by adding it to the running total. Drifters moving past a wall in a negative zonal or meridional direction are subtracted from the transport total at that wall. Thus, an array that is the size of the cell walls of the numerical grid for the u direction and one for the v direction is generated of the volume transport as represented by the drifters that pass the cell walls.

4.2 Results

In this simulation, surface-restricted drifters were released at a location $(-88.5159, 28.8881)$ near the Deepwater Horizontal Oil Spill $(-88.3659, 28.7381)$ (the actual site is just outside the model domain). 100 drifters were seeded at the same location every four hours (due to the frequency of model output) from April 20, 2010 through July 15, 2010, to represent a fixed amount of material regularly moving away from the initial site, and followed forward in time for 90 days (with 5 interpolation steps between each model output). Subgrid scale effects were represented using an added random turbulence to the grid cell fluxes used to calculate the drifter paths, with a horizontal diffusion of $A_h = 20 \text{ m}^2/\text{s}$. Drifters were initialized with a volume transport, T_0 , representing the initial flux out of the cells when they were released (divided by the number of drifters). This is used to track the transport of the drifters over all of the simulations together, to understand where the model predicts surface oil from the spill traveled. To present the information, the square root of the sum of the squares of the two components of volume flux on the grid is calculated.

Figure 3 shows the transport away from the surface near the Deepwater Horizon site averaged over the drifter simulations from the entire spill period. The transport is normalized by the initial volume transport represented by the drifters, that is, $\sum_n T_{0n}$, where n represents a drifter. A large part of the transport went immediately outside of the numerical domain. However, of the drifters that stayed within the numerical domain, transport was directed along the Louisiana coastline. In particular, a portion of drifter transport is indicated near Barataria Bay, an area in which oil is known to have been found.

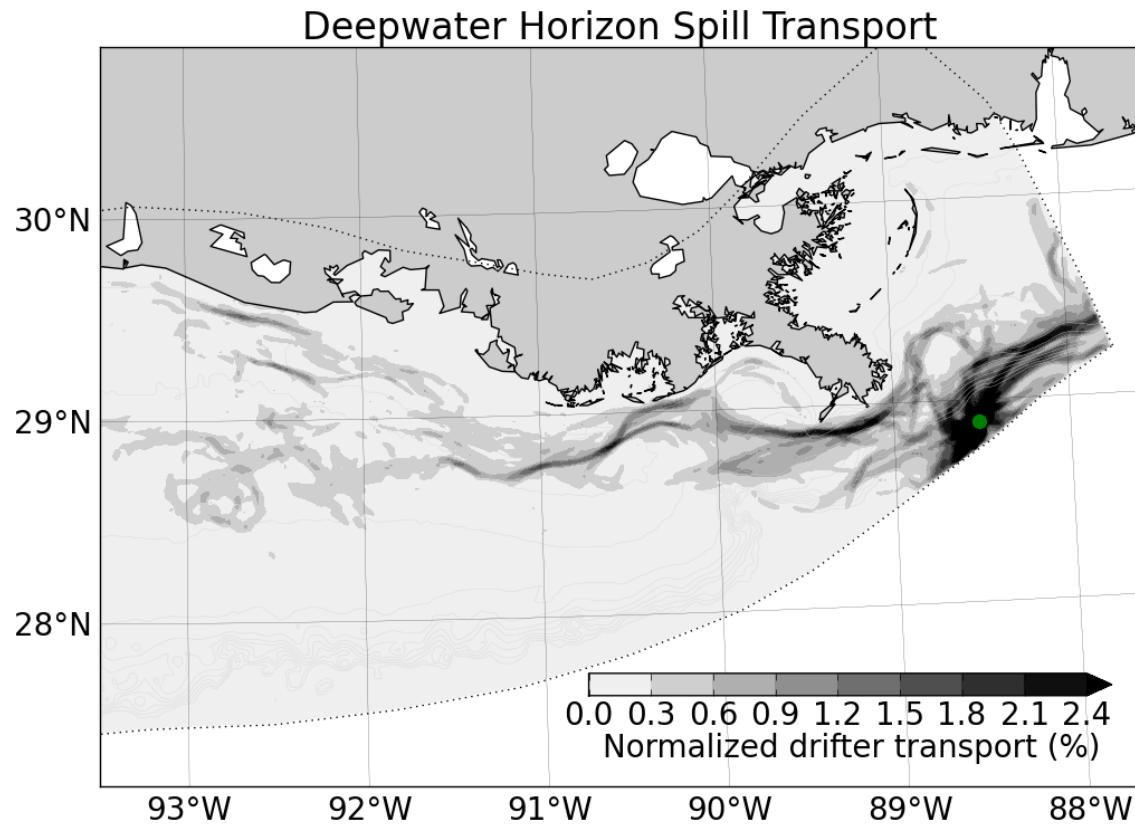


Figure 3: Transport of surface material from a site representing the Deepwater Horizon oil spill (in green), as calculated from Lagrangian drifters. The transport values have been normalized by the volume transport represented by the drifters and multiplied by 100 to find percentage transport values. Note that the colorbar has been set to a lower value than the true maximum in order to demonstrate more transport paths than would otherwise be visible.

Future work here: make sure that “enough” drifters are being used such that the results do not change by adding more drifters. Also want to calculate an appropriate horizontal diffusion to use in the subgrid parameterizations based on that found from drifters in the Gulf.

5 Galveston Bay

Drifters were seeded at points near Galveston Bay for multiple purposes. First, simulations were run in the TX-LA shelf model moving both backward and forward from the same locations and times in order to investigate connectivity in time and space while ensuring that the drifters moved near Galveston Bay at some point. Second, simulations moving forward from the same locations and times near the Bay were also accomplished using a SUNTANS model of the Bay, in order to compare results between the models.

Shelf model output is available every four hours and this output was subdivided linearly in time into five steps for tracking. For each simulation, drifters are initialized near Galveston Bay, within the numerical domain of the Bay model, approximately 500 meters to 1 km apart. A simulation is started every four hours (corresponding to the frequency of available model output) for the period 5-23-10 through 5-28-10, which was an interesting, dynamic period of time on the shelf. No subgrid-scale parameterization is used in these simulations.

5.1 Shelf Simulations

Drifters were seeded near Galveston Bay and tracked both backward (for 90 days) and forward (for 60 days) from the same locations and time. These tracks were then combined together, with the backward tracks flipped in time, to create long drifter tracks that move near Galveston Bay. Figure 4 shows these tracks from start to finish, chronologically.

Unfortunately, there are so many tracks that it is hard to tell what is going on, other than that there is a lot going on. Alternatively, separate views of the tracks may be informative. The 90-day backward tracks from near Galveston Bay are shown as tracks and for transport in Figure 5 (see Section 4 for details on transport). The forward simulations, Figure 6, are not as dynamic as the backward simulations, but are further studied near the Bay in the next section.

Figures 4 and 5 show that a wide variety of area can have an effect on Galveston Bay, and this will certainly change with wind conditions.

5.2 Bay Comparisons

Tracks moving forward in time from outside Galveston Bay are shown in Figure 7 for the shelf and the Bay models. Drifters in the more highly-resolved SUNTANS Bay model have regular pulsing with the tides, which leads to regular, realistic tracks. The shelf model does

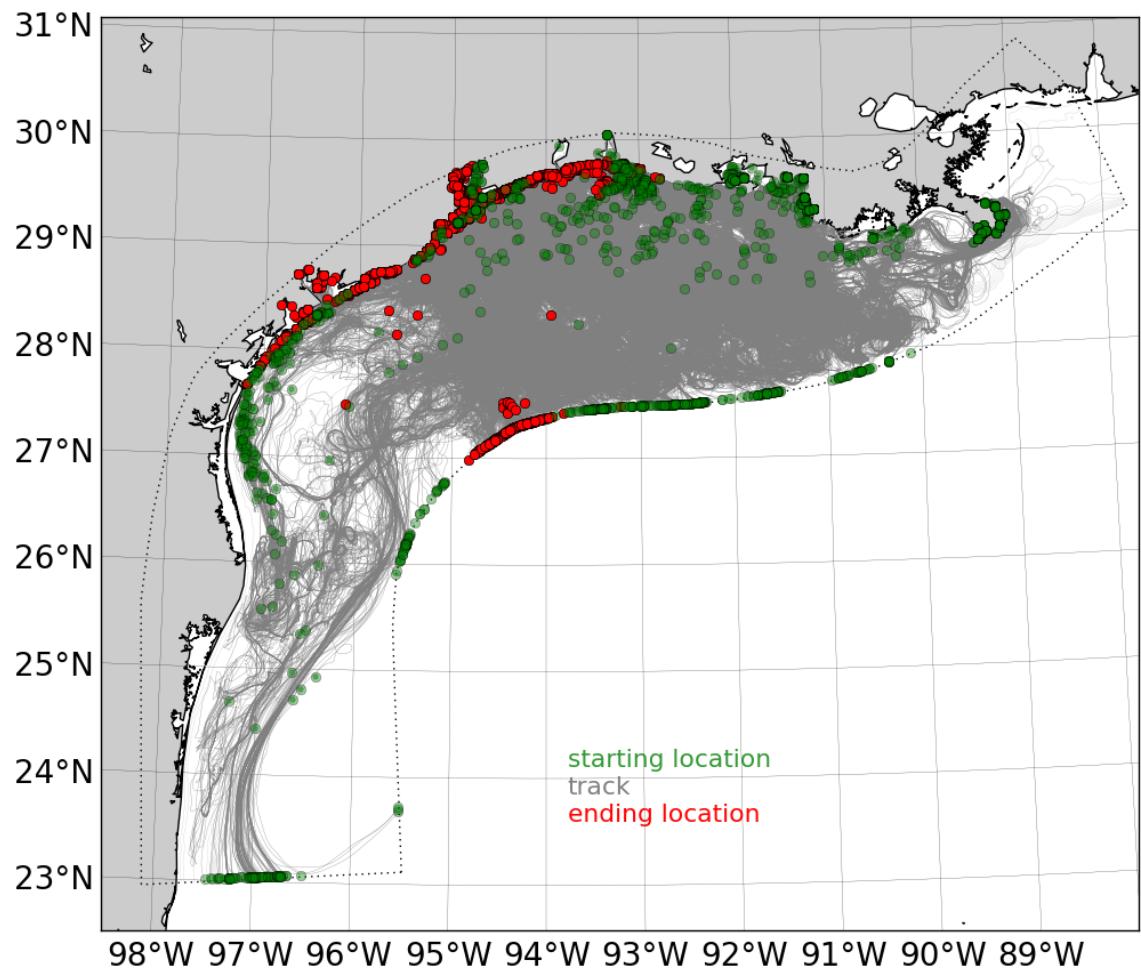


Figure 4: Drifter tracks that move near Galveston Bay and beyond.

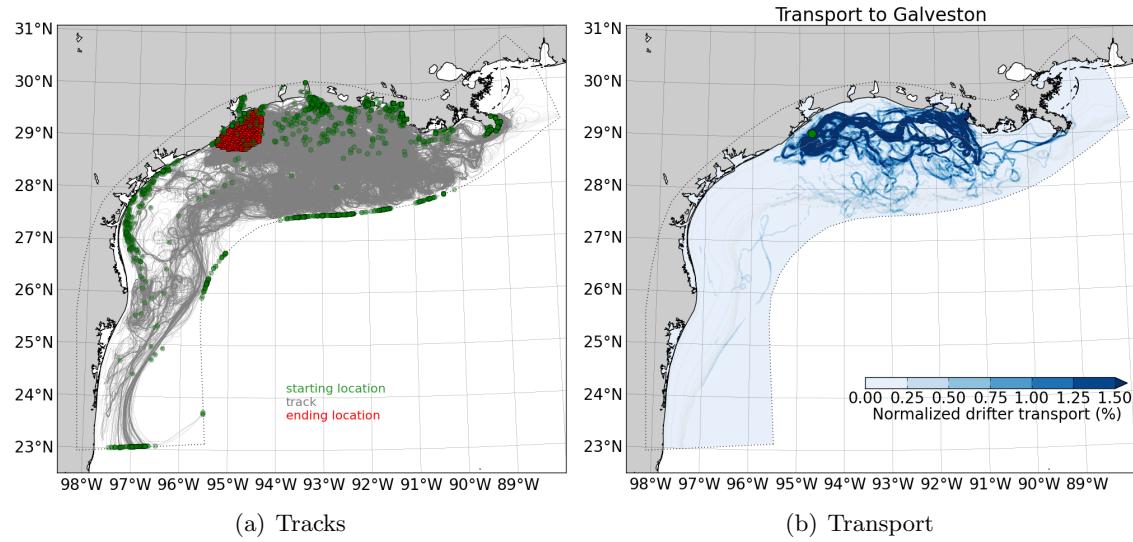


Figure 5: Drifter tracks that move to near Galveston Bay and beyond.

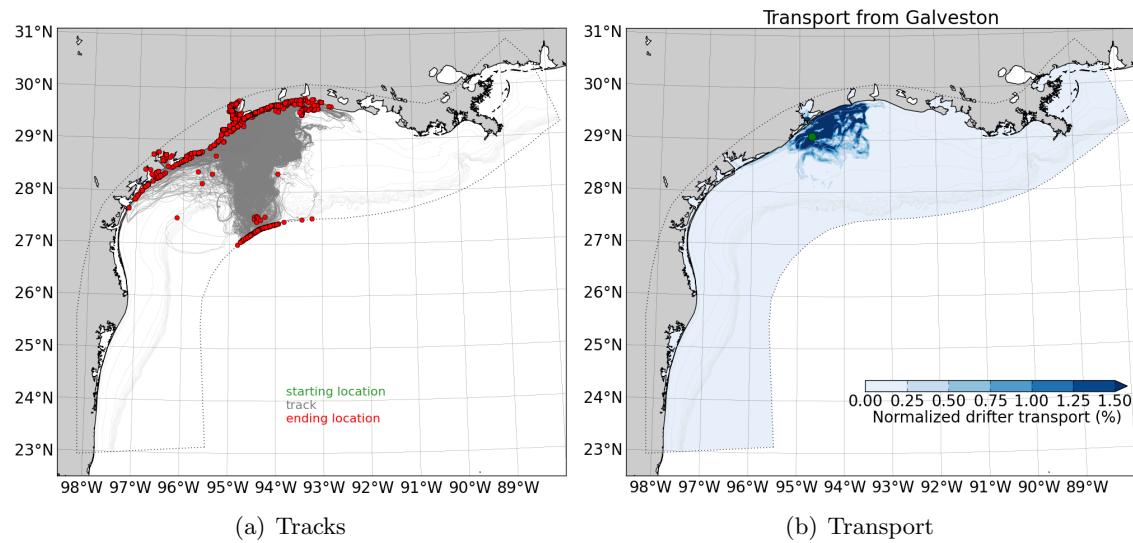


Figure 6: Drifter tracks that move from near Galveston Bay and beyond.

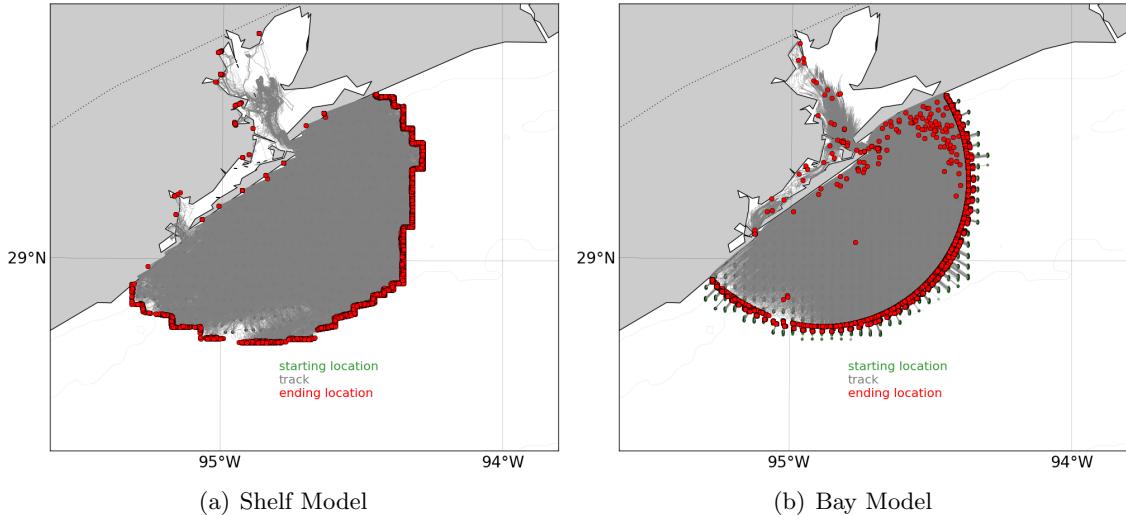


Figure 7: Drifter tracks moving forward from outside Galveston Bay for two separate models. Gray lines indicate separate drifter tracks and red circles indicate ending locations after 60 days.

not model tides and cannot resolve the complicate channels in the Bay nearly as well, so while drifters are able to make it into the Bay in the shelf model and travel around, more realistic paths are seen in the Bay model.

This is also shown in Figure 8 in histograms of the drifter final locations that moved forward in time from outside Galveston Bay. The overall behavior is generally the same between the two models, but clearly much more nuanced events occur in the Bay model, leading to more drifters ending up in the Bay and along the western barrier island. The grid for the Bay model is much more refined in the Bay than that of the shelf model.

5.3 Weatherband

What weatherband effects can cause cross-shelf transport? For drifters originating near Galveston Bay to be potentially transported across the shelf to the east (for non-summer winds), there has to be a consistent wind pattern toward the coastline without a storm that pushes the drifters away from the coast too late in the timing when the drifters are near a bend (or toward the coast if we are thinking about drifters moving backwards). Days that for backward moving drifters have only wind that pulls them away from the coast for the first 10 days are: 2004-03-08T04 through 2004-03-09T08, 2004-03-10T20 through 2004-03-11T12. 2004-03-29T00 travels along the coastline into LA though doesn't cross the shelf.

LOOK FOR PLOTS THAT CLEARLY SHOW DIFFERENT BEHAVIOR FOR DIFFERENT

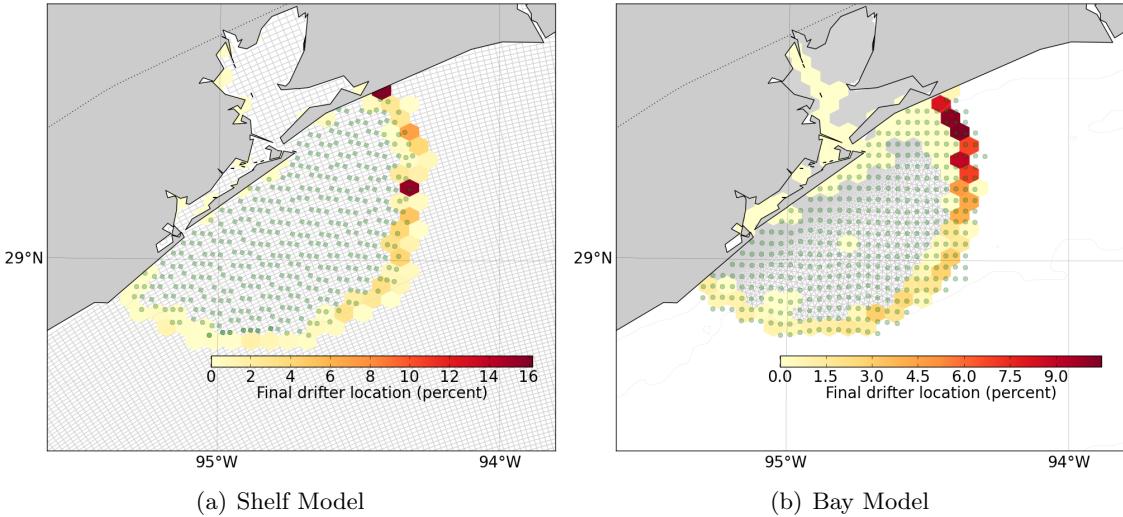


Figure 8: Histograms of the final locations of drifters moving forward in time from outside Galveston Bay. Green circles indicate the drifter starting locations and the numerical grid is overlaid for both models.

FERENT STORMS

5.4 Seasonality

Besides the weatherband, I can look at differences throughout the year, for different amounts of time moving backward, and over multiple years. I expect that there will be clear differences between summer and non-summer behavior due to upcoast versus down-coast winds. But, I am curious about the timescales and timing differences for when the most cross-shelf transport occurs. Having tracking information going backward for different amounts of time for every day for a decade tells us a lot of information about the possible behavior that can lead to material near Galveston Bay. Potentially, material from across the shelf can only reach Galveston Bay at certain times of the year, which would be important for oil spills that occur off the shelf. Maybe there will be a time scale of variability that changes throughout the year.

PLOTS THAT SHOW SUMMER TO NON-SUMMER DIFFERENCES

5.5 Interannual variability

PLOTS THAT SHOW DIFFERENCES IN SUMMER YEAR TO YEAR?

6 Results for Different Conditions

6.1 Dependence of Circulation on Weatherband

6.2 Seasonal Variability

6.3 Cross-Shelf Behavior

7 Analysis

References

Döös, K. (1995). Interocean exchange of water masses. *Journal of Geophysical Research*, 100(C7):13499–13–514.