P5.3

LONG-RANGE OIL SPILL TRAJECTORY RESEARCH TO DETERMINE THE OPTIMAL MIX OF REAL-TIME FORECASTS AND CLIMATOLOGY FOR VARIOUS TEMPORAL AND SPATIAL SCALES.

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1. INTRODUCTION:

In the arena of oil spill trajectory forecasting, standard nowcast/forecast models predict the movement of spilled oil out to 48 hours. Generally, most models are unreliable if used beyond 48 hours due to the cumulative errors that compound due to the uncertainty in the input parameters. Research conducted at NOAA's Hazardous Materials Response Division (HAZMAT) indicates that the primary error that prohibits accurate long-range forecasting is the wind forecast uncertainty. This paper will investigate methods to analytically compare forecast winds to historical winds for two particular spill events.

Although there have been many papers on analogues (Lorenz, 1969), this paper will present a simplified approach for comparing a given forecast to a region's climatological record and ascertaining the uncertainty in the winds of that particular area.

2. PROCEDURE:

The procedure involves saving a set of past wind records corresponding to the forecasted wind records, to within a user-determined error value (E_g). This set of past wind records can then be extrapolated into the future, yielding a distribution of likely future wind values.

If we turn the time dependent forecast into a complex wind variable A_{kj}

$$A_{kj}(t = t_j) = U_k(t_j) + iV(t_j)$$

Here $U_k(t_j)$ is the kth forecasted x-component of the wind at time t_j. $V(t_j)$ represents the y-component. A similar set of historical wind segments B_{kj} can be generated by choosing different starting times in the past wind history of the location of interest.

The mean difference between the forecasted and historical winds can be calculated by

$$E_k = \frac{\sum_{t_j < T} | A_{kj} - B_{kj} |}{T}$$

If E_k is less than the user-determined error E_g over the time period T, then the start time of the historical wind, D_j is saved and a new comparison is made starting at a time by incrementing the original interval by time T (See Figure 1). Otherwise, a new test segment of the historical wind record is used at some time T+Q where Q<T (See Figure 2). Repeating this process generates a set of D_j that is used for stochastic wind records for subsequent oil spill trajectory runs.

Shown in Figure 3, at some time T, the forecast error will become greater than that of climatology. Depending on the region, T is generally 36 to 48 hours. The variability of this mean error E_k, in relation to the data, will give a general scale of regional wind uncertainty.

Therefore, for each user-determined error E_g where

$$E_{g1} < E_{g2} < \ldots < E_{gn}$$

there will be corresponding start time arrays D_j such that

$$j_1 < j_2 < \ldots < j_n.$$

This paper will look at oil spill trajectories for two spill incidents which occurred in two topographically different areas.

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3. THE REGIONS:

Two topographically different areas were chosen. Both of these areas had archived oil spill data or on-going oil spill data. The first spill region analyzed was Tampa Bay, Florida. On August 10, 1993, two barges and a freighter collided in the entrance to Tampa Bay. The barge Bouchard 155 spilled approximately 210,000 gallons of #6 fuel oil into the bay.
The second spill region analyzed was 12 miles west of the entrance to San Francisco Bay. The SS Luckenbach sank in 1953 due to a collision but only recently has the vessel started to leak. A salvage operation began in May 2002 to lighter the oil from the sunken remains. Since then, several small oil spills have occurred.

WIND COMPARISONS:

The initial forecast during the Bouchard spill in Tampa Bay was E-NE winds at 15 knots shifting to be from the west at 5 knots by the afternoon hours. E-SE winds at 15 knots were predicted through the evening hours. E-NE winds at 10-15 knots were forecast throughout the next day. The method for the interpretation of the wind forecasts is described in (Lehr, et al, 2002). Using this method, the forecast translates into day, month, year, hour, minute, wind speed, wind direction format, as follows:

```
10,08,1993,06,00,15,070
10,08,1993,13,00,05,270
10,08,1993,17,00,05,270
10,08,1993,18,00,15,110
11,08,1993,06,00,12,070
12,08,1993,06,00,12,070
```

A comparison of the number of matching forecasts j and the user-defined error E_g with

$$n=12,\ E_g = \{4,5,6,\ \ldots\ ,27\}\ ,\ Q=\{24,6\ \text{hr}\}$$

is shown in Figure 4. The maximum difference in matches between Q=6 hours and Q=24 hours is

$$\Delta_{max} = 203 \text{ matches.}$$

Hence, in this region, a smaller Q, where Q is the non-matching time shift interval, results in more matches. This could mean that the initial forecast winds with interval T does not readily overlap with the historical record when Q=24 hours.

For the Luckenbach spill off the coast of San Francisco Bay, the initial forecast was NW winds at 15-20 knots increasing to 20-25 knots by the afternoon. NW winds at 20-25 knots were predicted through the evening hours with NW winds at 20 knots forecast for the next day. The forecast was interpreted to the following text file:

```
30,05,2002,06,00,18,315
30,05,2002,11,00,18,315
30,05,2002,12,00,22,315
30,05,2002,17,00,22,315
30,05,2002,18,00,22,315
31,05,2002,05,00,22,315
31,05,2002,06,00,20,315
01,06,2002,05,00,20,315
```

With

$$n = 15,\ E_g = \{2,3,\ \ldots\ ,33\} \text{ and } Q = \{24,\ 6 \text{ hrs}\},$$

is shown is Figure 5.

Here Δ_{max} = 122. This number of matching forecasts in the San Francisco incident is half as many as the number in Tampa Bay and leads to the possible conclusion that the cycle of wind events off the coast of San Francisco is not as variable as that in Tampa Bay.

4. LONG-RANGE OIL TRAJECTORY FORECASTING:

For each incident the sensitivity of Q has been determined. Next, choose an array of start times that is large enough to sample the historical winds and is also accurate enough to minimize the user-determined error E_g.

General NOAA Oil Modeling Environment, GNOME (Beegle-Krause, 2001) is the nowcast/forecast model that is used by HAZMAT. This is a simple model that uses two dimensional physical processes to move lagrangian elements (LE's), representing quantities of oil, throughout the water. GNOME uses tides, hydrology, currents, winds and diffusion to move the LE's. Trajectory Analysis Planner (TAP) (Barker, 2000) and TAP Extended Outlook (TAP_EO) are, respectively, HAZMAT's area contingency planner and long-range forecasting model. TAP_EO uses three dimensional arrays (cubes) generated by GNOME and other post processors and displays the output on a waterbased grid. Since D_j is the array of start times, j is the number of runs that must be computed by the GNOME model.

For the Bouchard spill in Tampa Bay, since Q=6 hours achieved more matches with a smaller user-determined error, E_g =5 with D2 and E_g =7 with D125 was therefore used in the analysis.

With E_g =5, two start times are shown in Figure 6.

Using the previously described wind forecast for this event, a user-determined error E_g = 5 and a non-matching shift interval Q=6 hours, two start times were matched (D2). These start times were used in GNOME to begin to sample the climatology out to 96 hours. Although this time was selected to match this archived spill, any time could have been selected. Looking at Figure 6, it is apparent that there is a wide variability in both spills (green). (The red area represents the overlap area that both spills have in common.) Hence, two start times into the historical record are not sufficient.

Next, with the user-defined error E_g =7 and still with Q=6 hours, the analysis resulted in 125 possible start times (D125). Sampling 96 hours after each start time, the TAP Extended Outlook run is shown in Figure 7.

Hence, the majority of the winds 96 hours after the Bouchard forecast will tend to be from the SE (with approximately 20 percent of the winds curiously being from the NE).

The results from the actual overflight during the Bouchard spill after 96 hours is shown in Figure 8.

Even though both long-range trajectories contain the actual event, it is apparent that a larger j in D_j refines the cumulative output and minimizes the uncertainty in the winds. Unfortunately, a larger j means a greater user-determined error E_g.

Using the Luckenbach incident off the coast of San Francisco Bay, the forecast matched up with climatology almost as well when Q=6 hours as when Q=24 hours. Therefore, the research will focus on the latter match data when E_g = 3 (D2) and E_g = 5 (D76).

A user-defined error, E_g =3, resulted in two start times and the long-range oil trajectory associated with those times appears in Figure 9. As before, the time, in this case 120 hours, was chosen to match the spill event. During an actual response, this run time after each start time could vary from 2 to 14 or more days.

Notice in Figure 9, unlike the Bouchard incident in Tampa Bay, the variability in the winds after the given forecast is small. This suggests the winds following a NW at 10-20 knot event are also NW. But there were only two start times into the climatology.

When E_g = 5, there are 76 resulting matches in the historical record. Figure 10 shows the TAP Extended Outlook trajectory.

There were several small spills from the Luckenbach and all of those were contained within the cumulative trajectories in Figure 10.

Unlike the Bouchard incident where the cumulative trajectories minimized the wind uncertainty, more match data in the Luckenbach incident slightly increased the trajectory footprint. Hence a NW flow off the coast of San Francisco will vary slightly and a light SE (and ENE) flow in Tampa Bay will trend to the NW but with much more uncertainty.

More detailed research is necessary to optimize a particular region with the shift interval Q, the initial error E_g and the resulting start times (“dart throws” D_j in order to obtain the ideal output.

5. CONCLUSION

This paper presented a simple approach for comparing a given area forecast to a region’s climatology and, by selecting a few variables (T, Q and E_g), accumulating specific start time arrays that can be used to enhance long-range spill trajectories and ascertain the nature of a region’s wind uncertainty.

There are obvious limitations to this analysis. This process can only be used in data rich areas, specifically, areas with long robust historical wind records (C-Man stations, buoys, ASOS and AFOS stations).

Future research should include applying this technique to several other topographically different spill areas, seasonalizing the historical winds, building in an analytical method to optimize Q and E_g to obtain the best match results and removing interpolation from the historical wind analysis to “fill” data holes. The latter a potential source of error. Ideally, any data gap larger than some time Ψ should be flagged and skipped.

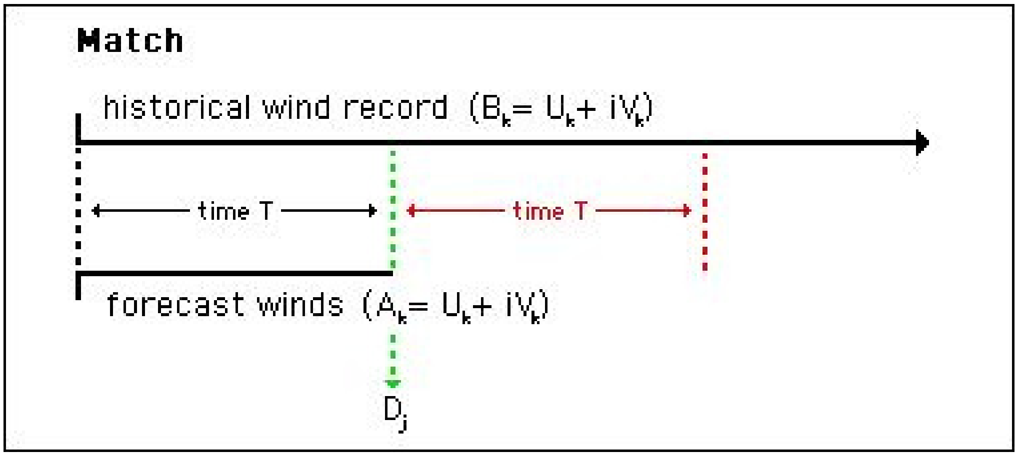


Figure 1

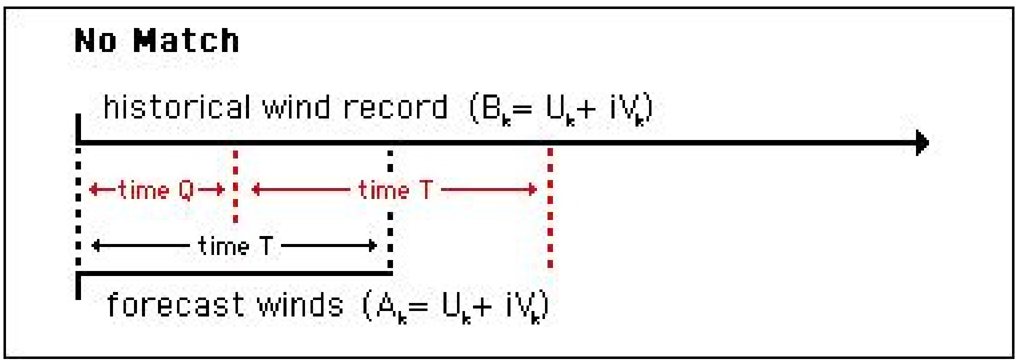


Figure 2

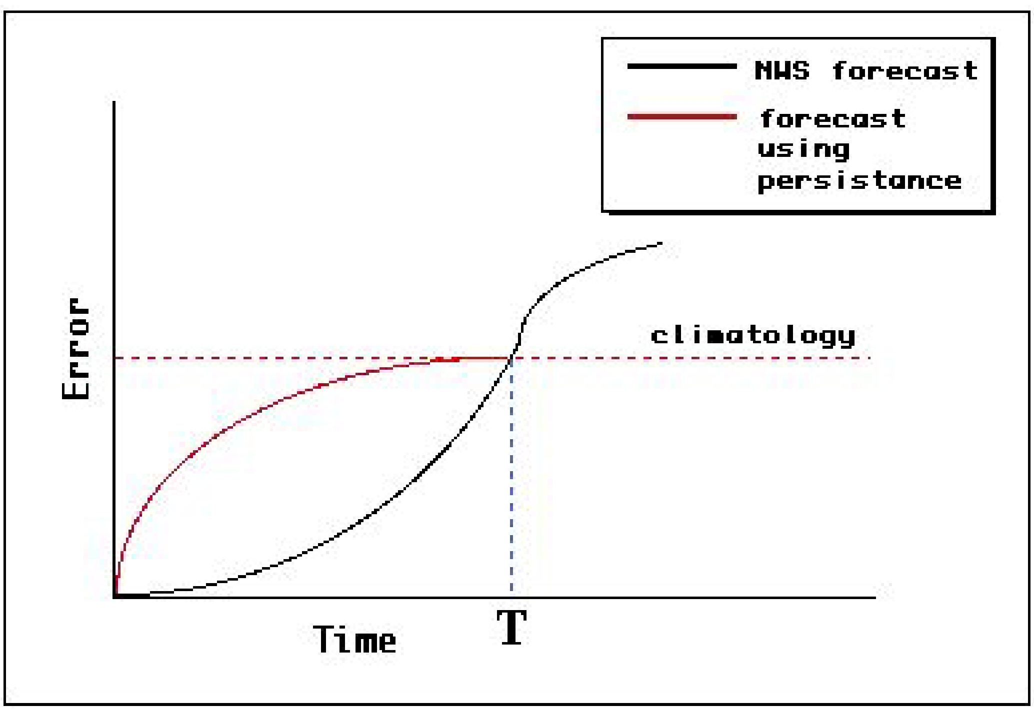
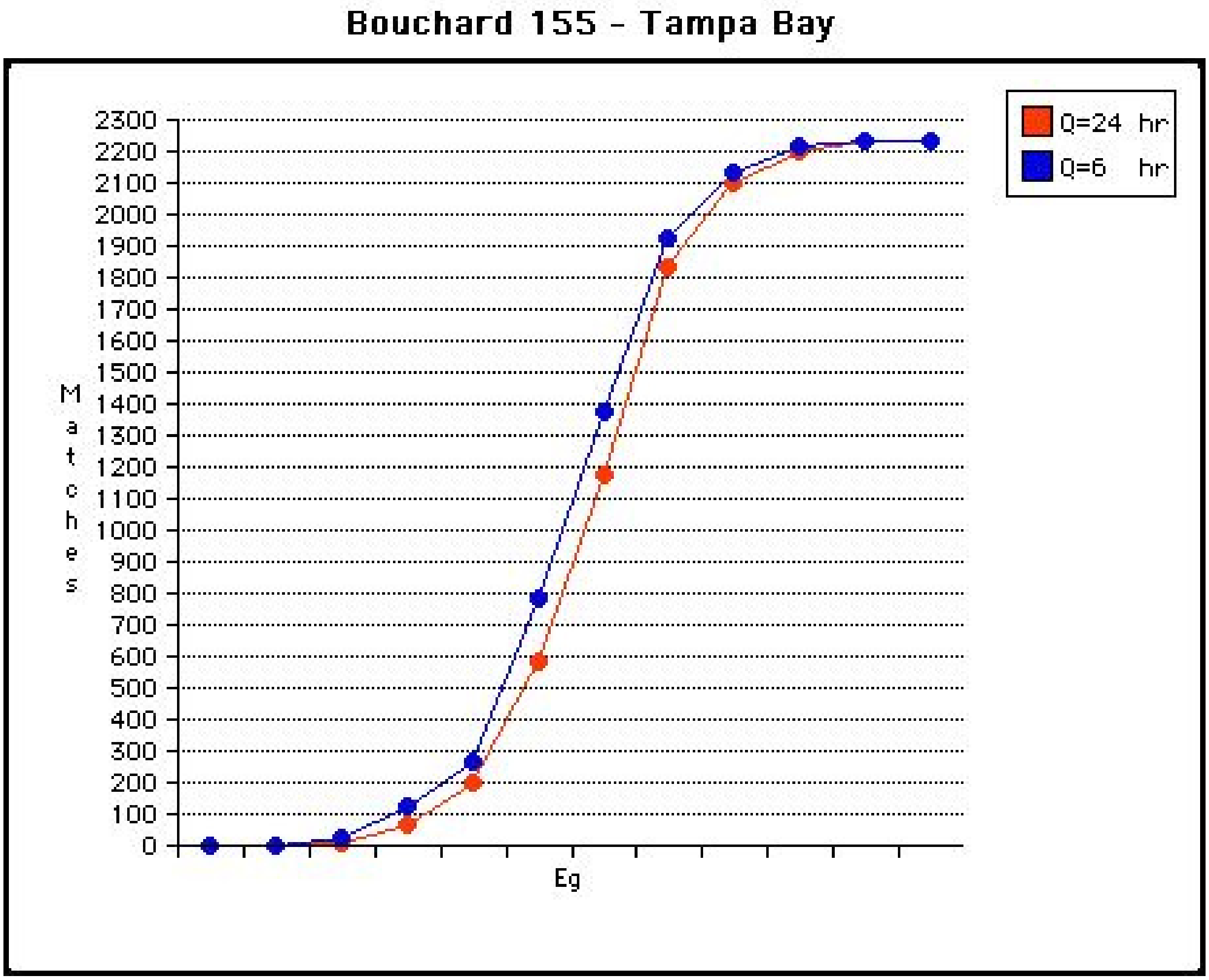


Figure 3



Bouchard 155 - Tampa Bay
Q=24 hr
Q=6 hr
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Matches
Eg

Figure 4

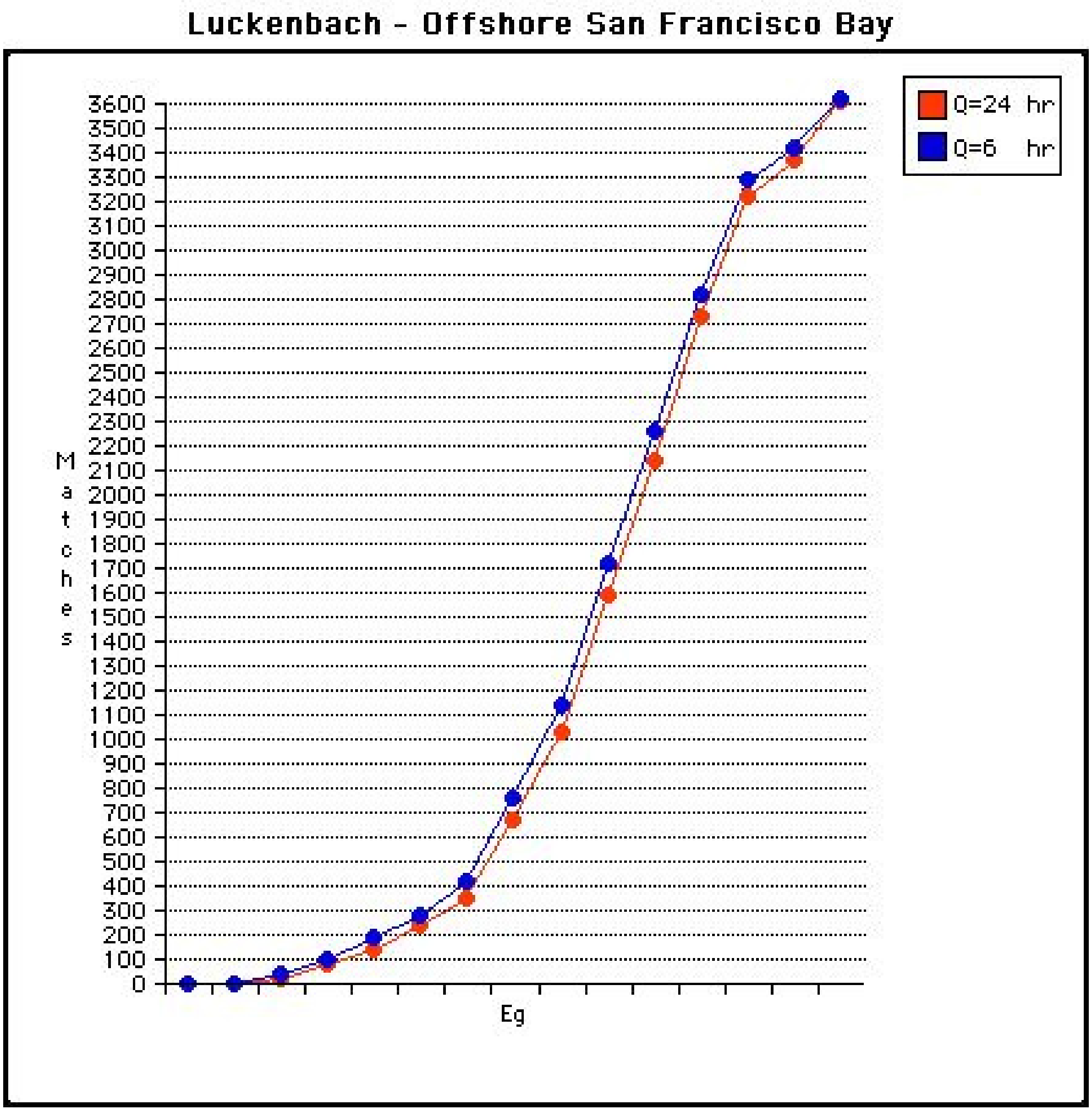
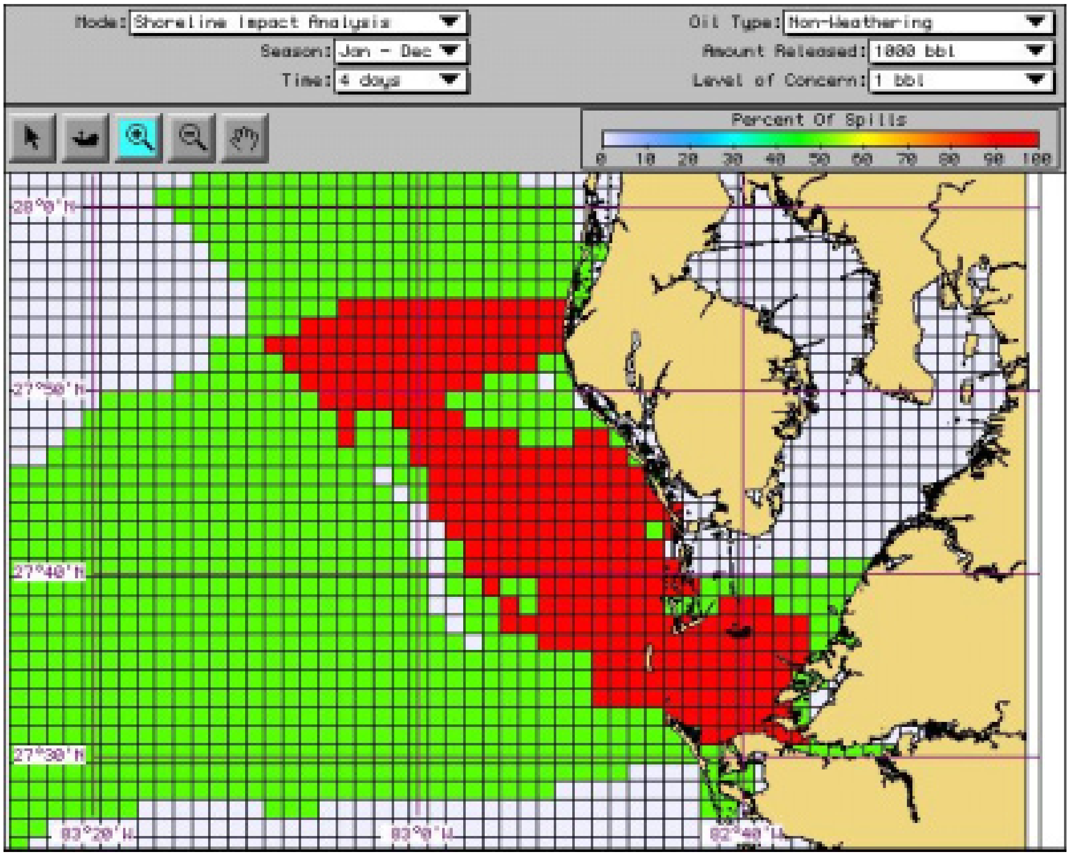

Luckenbach - Offshore San Francisco Bay
Q=24 hr
Q=6 hr
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Matches
Eg

Figure 5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Season: Jan - Dec
Time: 4 days
Oil Type: Non-Weathering
Amount Released: 1000 bbl
Level of Concern: 1 bbl
Percent Of Spills
0 10 20 30 40 50 60 70 80 90 100
28°0'N
27°50'N
27°40'N
27°30'N
83°20'W
83°0'W
82°40'W

Figure 6

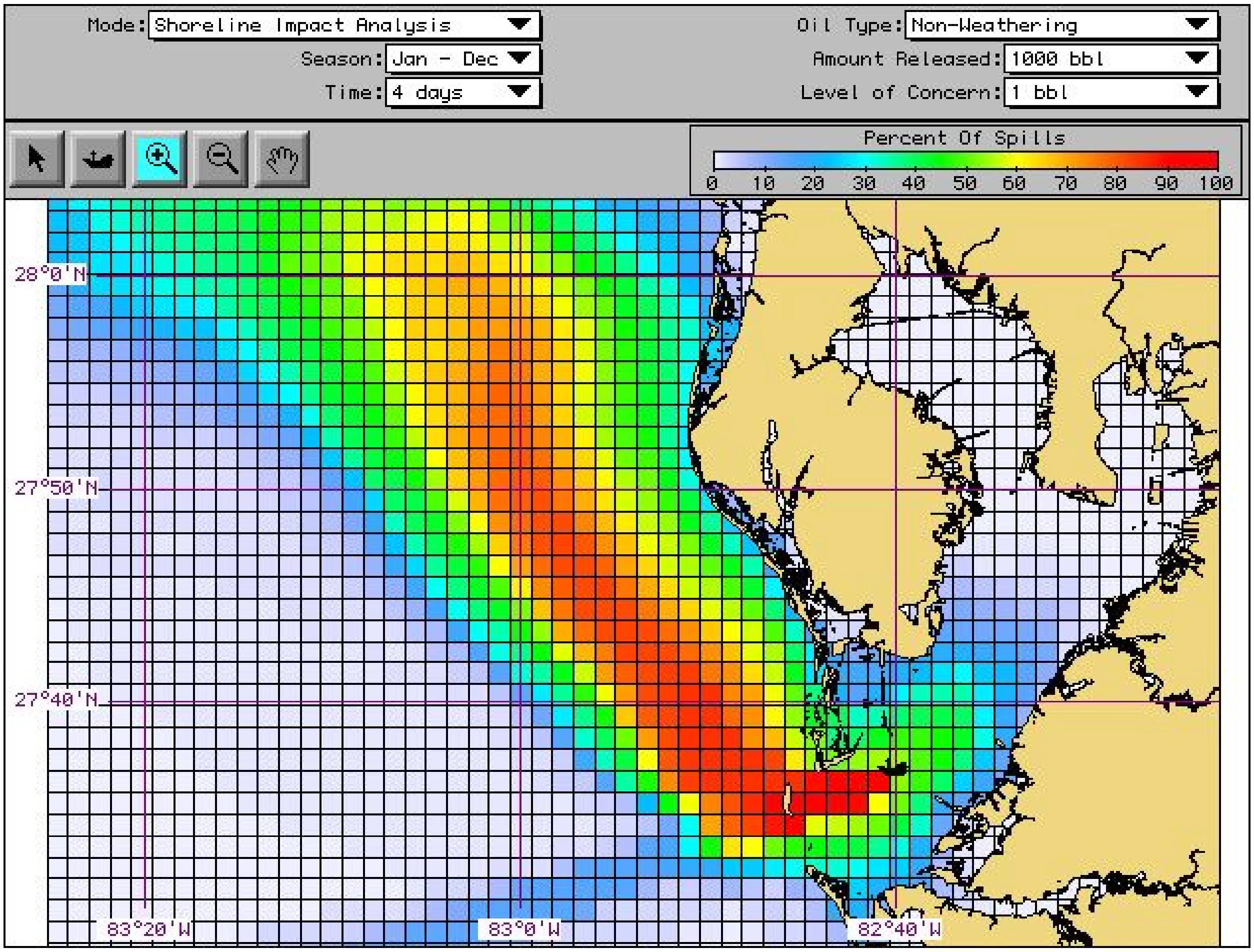
Mode: Shoreline Impact Analysis
Season: Jan - Dec
Time: 4 days
Oil Type: Non-Weathering
Amount Released: 1000 bbl
Level of Concern: 1 bbl
Percent Of Spills
0 10 20 30 40 50 60 70 80 90 100
28°0'N
27°50'N
27°40'N
83°20'W
83°0'W
82°40'W

Figure 7

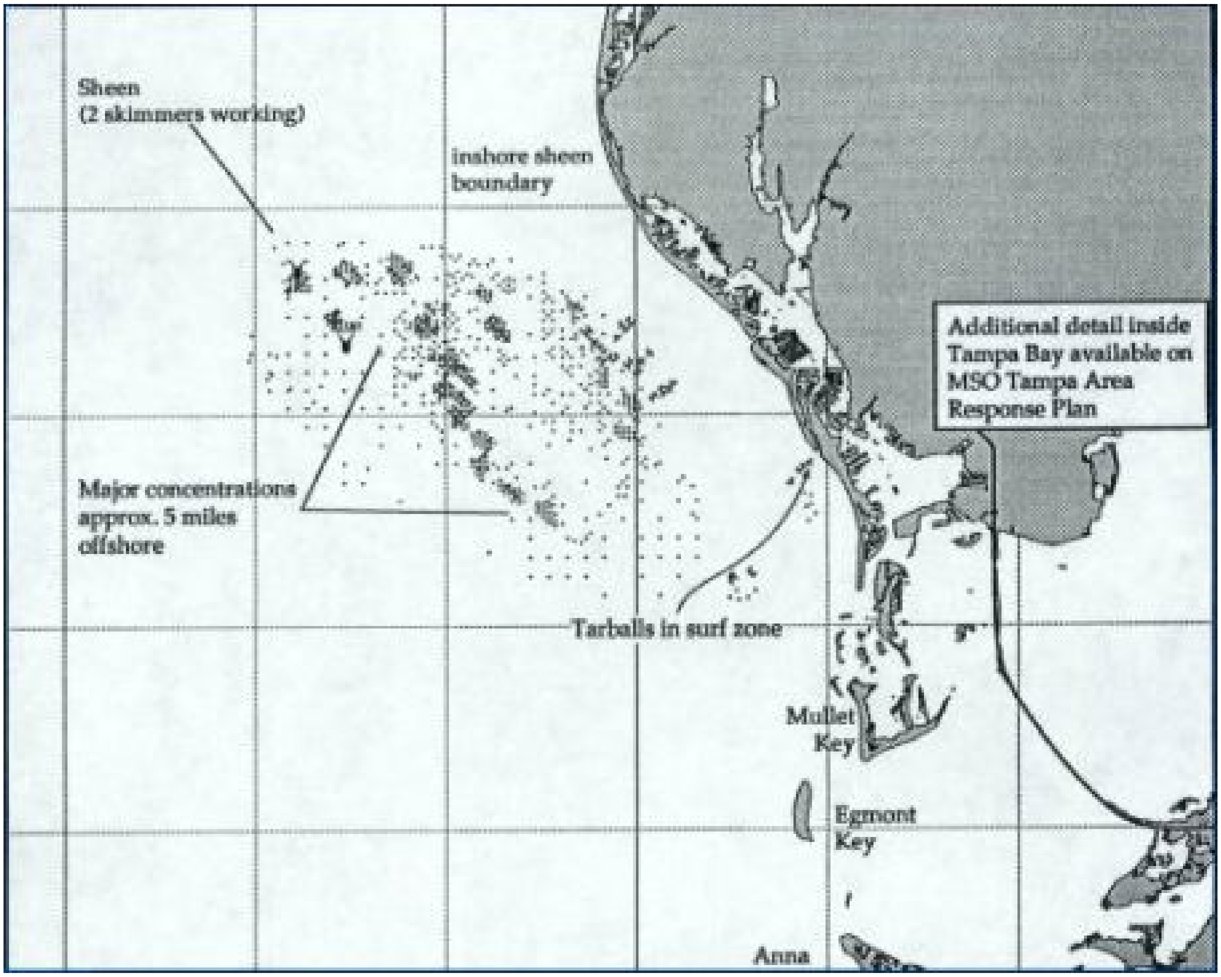
Sheen
(2 skimmers working)
inshore sheen
boundary
Additional detail inside
Tampa Bay available on
MSO Tampa Area
Response Plan
Major concentrations
approx. 5 miles
offshore
Tarballs in surf zone
Mullet
Key
Egmont
Key
Anna

Figure 8

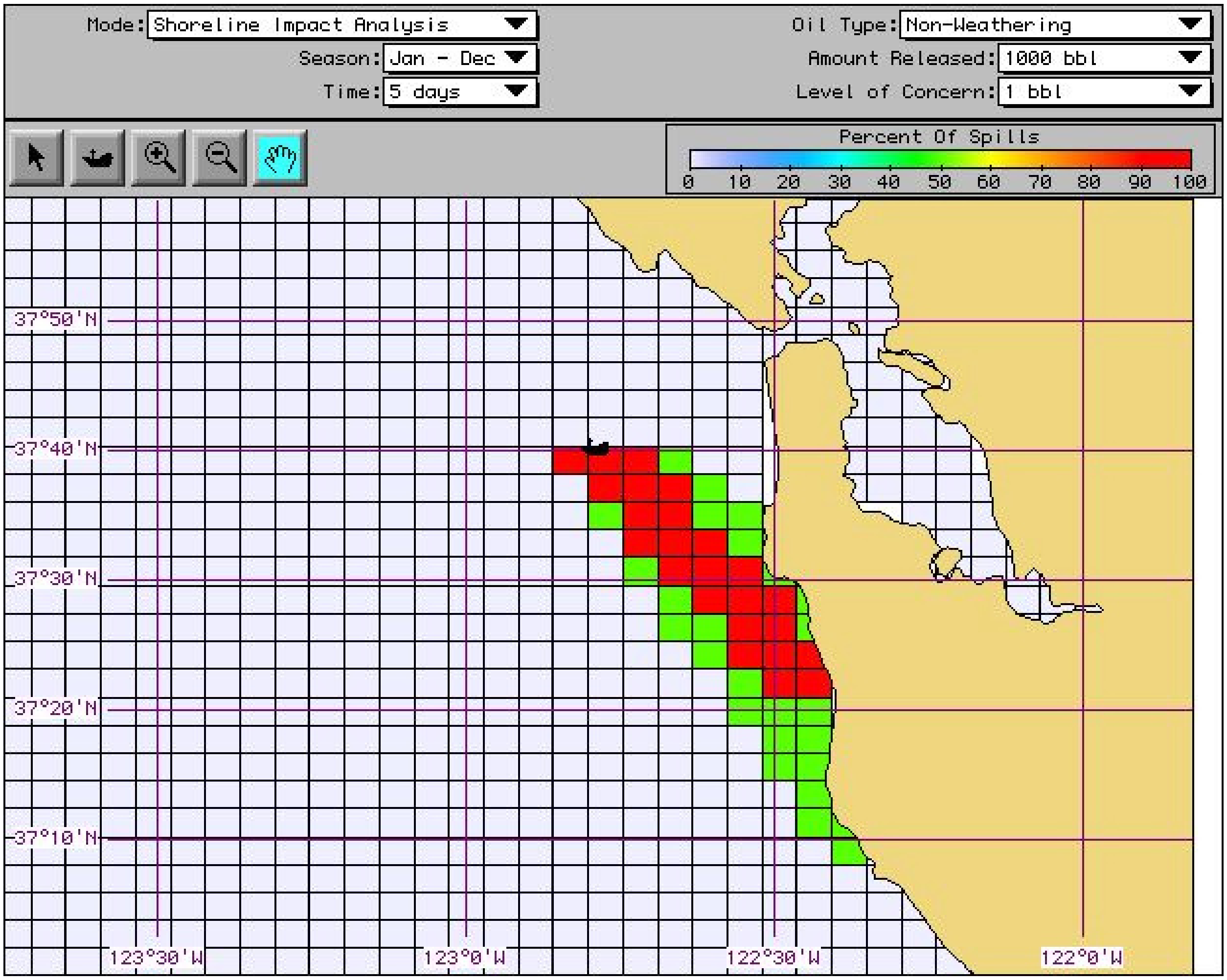
Mode: Shoreline Impact Analysis
Season: Jan - Dec
Time: 5 days
Oil Type: Non-Weathering
Amount Released: 1000 bbl
Level of Concern: 1 bbl
Percent Of Spills
0 10 20 30 40 50 60 70 80 90 100
37°50'N
37°40'N
37°30'N
37°20'N
37°10'N
123°30'W
123°0'W
122°30'W
122°0'W

Figure 9

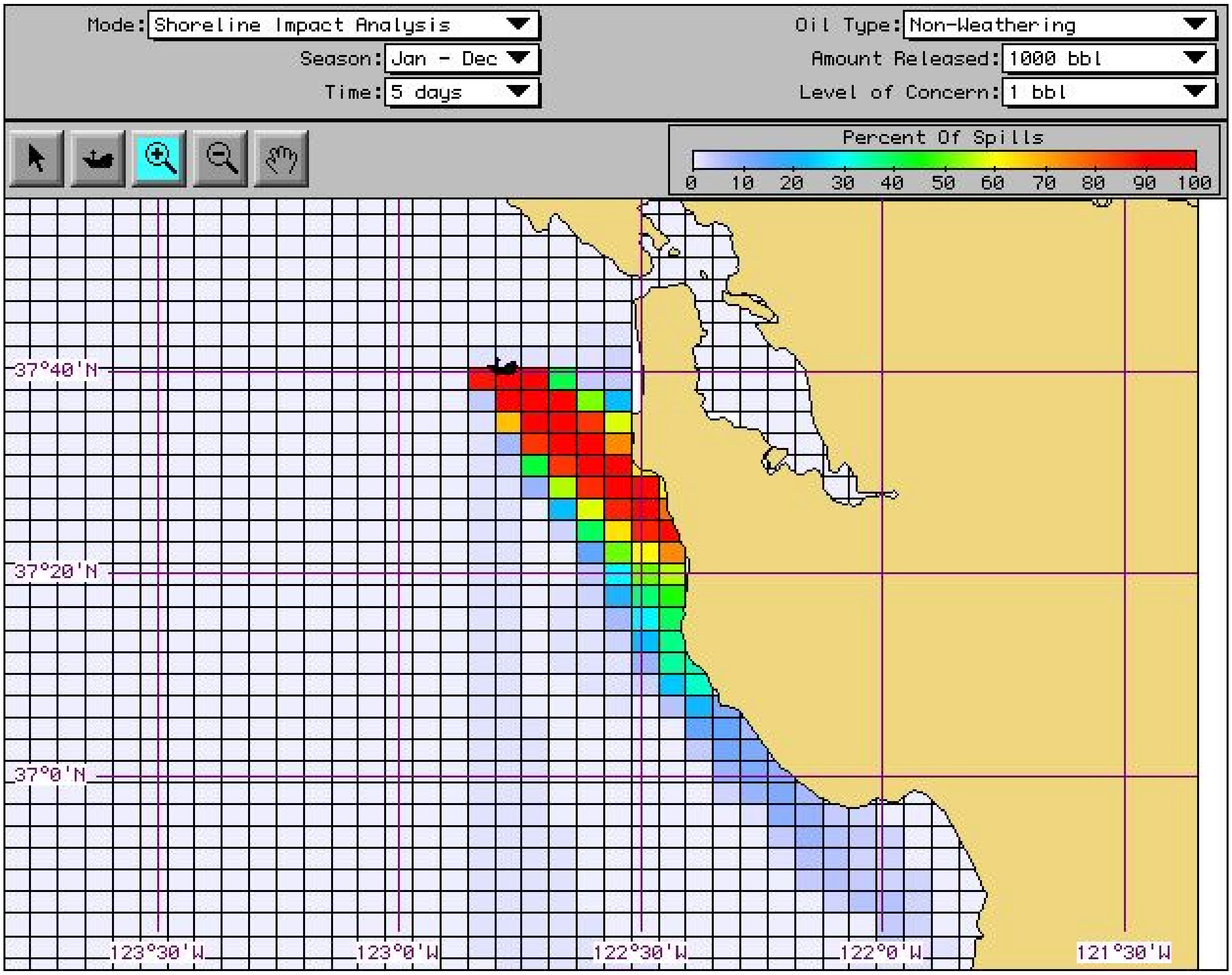
Mode: Shoreline Impact Analysis
Season: Jan - Dec
Time: 5 days
Oil Type: Non-Weathering
Amount Released: 1000 bbl
Level of Concern: 1 bbl
Percent Of Spills
0 10 20 30 40 50 60 70 80 90 100
37°40'N
37°20'N
37°0'N
123°30'W
123°0'W
122°30'W
122°0'W
121°30'W

Figure 10

6. REFERENCES

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