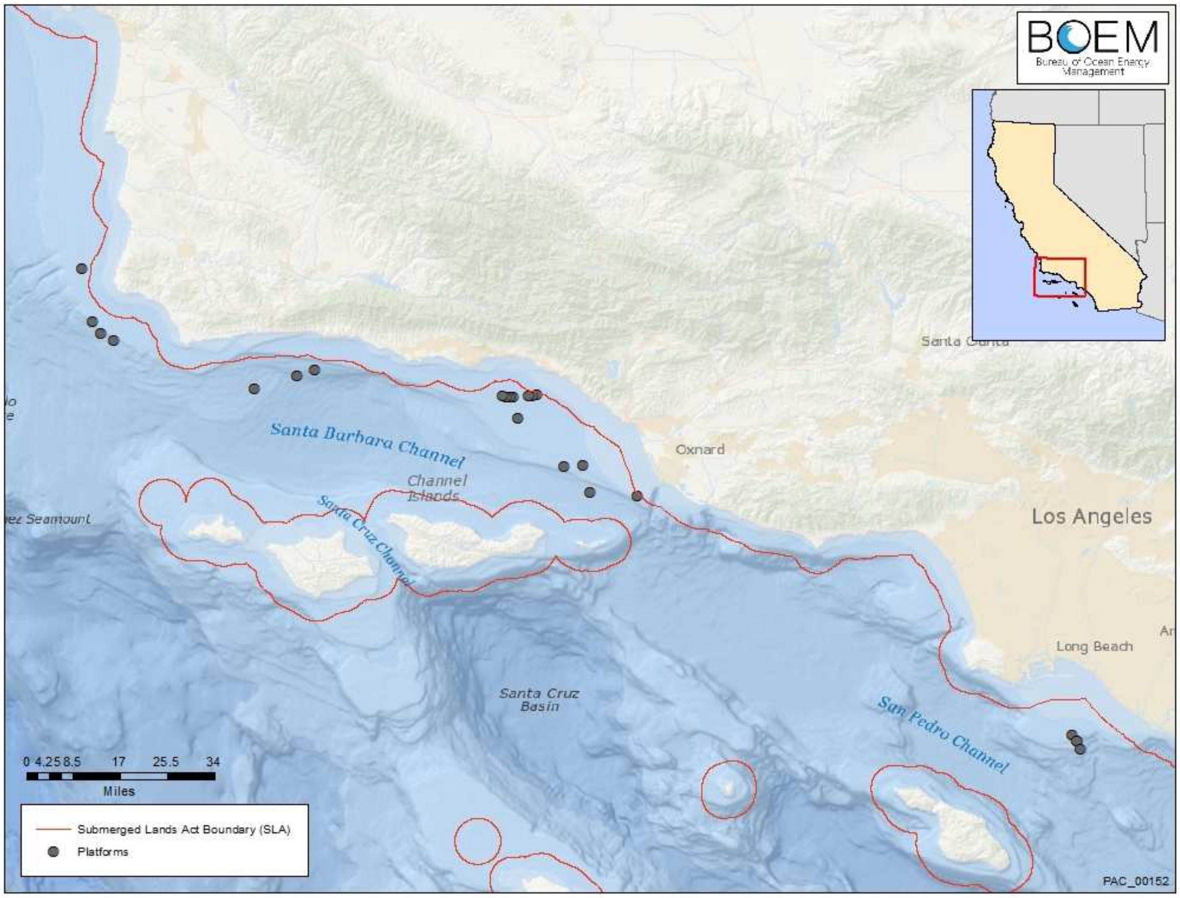
OCS Study
BOEM 2024-042

Assessing the Threat from Oil Spills in the Southern California Bight



U.S. Department of the Interior
Bureau of Ocean Energy Management
Pacific Regional Office, Camarillo, CA

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Assessing the Threat from Oil Spills in the Southern California Bight

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U.S. Department of the Interior
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Pacific Regional Office, Camarillo, CA

DISCLAIMER

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ABOUT THE COVER

Map of twenty-three drilling platform locations in the northern Southern California Bight used as source sites for the TAP development.

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List of Abbreviations and Acronyms

°C	degrees Celsius
3D	three-dimensional
ADIOS	Automated Data Inquiry for Oil Spills
API	American Petroleum Institute
bbl	barrel(s)
BOEM	Bureau of Ocean Energy Management
cm	centimeter(s)
cSt	centistokes
DOI	US Department of the Interior
DSD	Droplet Size Distribution
GNOME	General NOAA Operational Modeling Environment
g/cm^3	gram per cubic centimeter
km	kilometer(s)
LOC	Level of Concern
m	meter(s)
mm	millimeter(s)
µm	micron(s)
NDBC	National Data Buoy Center
N/m	Newton meter
NOAA	National Oceanic and Atmospheric Administration
ORR	Office of Response and Restoration
ppm	parts per million
ROMS	Regional Ocean Modeling System
scf	standard cubic feet
sq km	square kilometer(s)
sq m	square meter(s)
TAMOC	Texas A&M Oilspill Calculator
TAP	Trajectory Analysis Planner
UCLA	University of California Los Angeles

1 Introduction

Through an Interagency Agreement, the National Oceanic and Atmospheric Administration's (NOAA) Office of Response and Restoration (ORR) and the Bureau of Ocean Energy Management (BOEM) partnered to develop an oil spill Trajectory Analysis Planner (TAP) implementation for the Southern California Planning Area.

The General NOAA Operational Modeling Environment (GNOME) is an oil fate and transport model developed and used operationally by NOAA for emergency spill response. These predictions rely on environmental information such as ocean currents and winds, which are highly variable and can typically be predicted with reasonable accuracy for only a few days. For applications relevant to BOEM, like planning and preparedness work, the user doesn't know when or where a spill might occur. In this case, it is more informative to have a tool that incorporates historic weather and ocean currents to explore a wide range of possible outcomes in the case of a spill. In order to address this need, NOAA developed TAP.

TAP provides a regional analysis of the most probable impacts for use in spill planning and preparedness work when the user doesn't know when or where a spill might occur. A regional TAP implementation involves the development of a database of the results from a large number of simulated spill trajectories. These trajectories are computed with the GNOME model with realistic spill scenarios and historical environmental information. For this project, the trajectories were run using forcing from a high-resolution (1 km) Regional Ocean Modeling System (ROMS) (Shchepetkin and McWilliams 2005) hindcast. This extensive model output allows modeling of realistic oil spill scenarios over a range of different regional oceanographic regimes (such as upwelling, relaxation, and eddy-driven flow). Modeled spills were started at the locations of Federal offshore oil and gas operations in southern California, and at four locations representing pipelines servicing a subset of those platforms.

The TAP viewer accesses this database and visualizes the results allowing response planners to answer a myriad of questions about possible spill behavior in the region. As part of this project, NOAA's Emergency Response Division has developed a web-based version of the TAP viewer (WebTAP) to enable this tool to be more flexible and easily available for oil spill response planners. The interactive TAP viewer allows response planners to tailor the output to examine the most relevant regional concerns. The web-based TAP viewer (https://tap.orr.noaa.gov) hosts results from not only this present study but also from previous and future TAP studies developed by ORR (including the U.S. Arctic, San Francisco Bay, San Diego Bay, Lake Sabine and Lake Calcasieu).

In the report, we begin by describing the TAP methodology (Section 2) and the underlying NOAA GNOME model used for the spill fate and transport simulations (Section 3). We then provide a brief overview in Section 4 of the models used for environmental fields (surface currents and winds) that are inputs to GNOME. The Southern California TAP implementation is described in detail in Section 5. Finally, in Section 6, we present some sample results that can be visualized and interpreted in the WebTAP viewer. Lastly, Appendix A discusses three-dimensional (3D) oil trajectories and justifies the use of surface releases in TAP to represent potential sub-surface blowouts.

2 The TAP Approach

Once oil is released into the sea, it is moved and transformed by the surface winds and ocean currents, potentially impacting regions far from the source location. During a spill response, modeling systems such as NOAA's GNOME are used to forecast where the oil might go and how it will be transformed while in the environment. This information can be used to direct responders to where they can clean up the oil or protect sensitive areas.

Preparing for a potential oil spill requires an assessment both of the spills that might occur and what the possible consequences might be. Those consequences and the response resources required to mitigate them depend on the transport, or trajectory, of the oil after a release. But when planning for a possible spill, there is no way to know exactly what the ocean currents and winds will be in some unknown future time. Often planners address this issue by selecting a “worst case” scenario, or using average or “typical” conditions. The response planning process is then based around the resultant single-scenario or a small number of oil trajectories. Decisions are made about response resource allocation and response times to sensitive sites based upon the trajectories of how oil will move and where it will impact during that particular set of environmental conditions. Clearly, if all the resources to respond to oil spills are stored at locations that expedite response to the chosen scenario, the response community may be set up for failure (delayed response time) if the spill that does occur happens from a different start location or under different environmental conditions.

The shortfalls of determining response resource amounts and allocation are evident when focusing planning efforts solely on a single-scenario trajectory. An innovative and more appropriate approach is statistics-based planning. If planners use statistical information about how an oil spill might behave, they can determine where oil spilled from one location is likely to go most of the time, where it can go during extreme conditions, and where it will most likely never go.

The TAP approach generates statistics through ensemble modeling. By examining an entire ensemble of oil spill trajectories from a particular location, but under the entire range of possible environmental conditions, statistics can be generated that facilitate planning for the full range of possible outcomes, rather than an arbitrary small set of scenarios.

With the ability to examine the statistics resulting from this sample of the "population" of all possible spill trajectories, planners can quickly build their intuition of how spilled oil behaves in their area. Secondly, statistics-based planning helps the response community determine the total amount of response resources they should have in their area to respond to most of the possible spills in their area, rather than just one spill scenario. Ensemble modeling can show how well prepared the community is for the full range of possibilities.

TAP accomplishes this ensemble approach by building up a database of possible oil spill trajectories, based on measured historical data or modeled hindcasts of the atmospheric and oceanographic conditions over a long enough period to capture the regional climatology. The most challenging part of this process is the development of a hindcast oceanographic model with sufficient accuracy and precision to simulate oil spill behavior.

Once a suitable hindcast has been developed, the process involves:

- Selecting locations in the region where spills might occur (source sites).
- Determining likely types and quantities of potential spills.
- Running an oil spill trajectory model multiple times for each spill location, randomly sampling the period of the hindcast.
- Recording the locations (and timing) of oil impacts on a suitable grid.

All the details of this process are specific to the region of interest.

After the database of spill impacts has been generated, it can be analyzed to answer a variety of questions about possible spill behavior in the region. As there are many different questions that could be asked, and multiple perspectives about important resources to protect, NOAA provides the WebTAP tool to aid in performing custom analysis of this database of spill results, so individual planners can address the specific issues that they have. This tool has multiple modes that help answer specific questions:

- Impact Analysis helps answer the question: If oil is spilled at a given spot, what shoreline locations are likely to be impacted?
- Oiling Analysis provides a way to visualize how a particular receptor site is likely to be oiled by a spill originating at a particular location.
- Response Time Analysis displays information about how quickly a response must be established at a given location in order to precede the arrival of the oil.
- Threat Analysis provides information on what source locations are most likely to threaten a particular region or resource of interest.

All of these analyses provide statistical assessments: probabilities, not absolute values.

3 NOAA GNOME Modeling Suite

NOAA's oil spill modeling software, the General NOAA Operational Modeling Environment (GNOME) has been under active development in recent years. The original desktop GNOME application (Zelenke et al. 2012) was completely refactored to separate the computational code base from the graphical user interface. Oil weathering algorithms from the stand-alone NOAA model Automated Data Inquiry for Oil Spills (ADIOS2) were also incorporated into GNOME. A new web-based user interface, WebGNOME (https://gnome.orr.noaa.gov) was developed and at present supports deterministic (single) model runs for simulating surface spills. A Python scripting environment (PyGNOME) can be utilized for more computationally expensive or ensemble model runs (e.g., for conducting the multiple spill simulations necessary for TAP). Subsurface releases (e.g., well blowouts) can also be modeled using the scripting environment and a user interface is currently being designed for incorporation into WebGNOME. The GNOME computational code is Open Source and can be downloaded via GitHub (https://github.com/NOAA-ORR-ERD/PyGnome).

Similar to most oil spill models, GNOME utilizes a Lagrangian particle tracking approach which essentially divides spilled oil into a large number of particles that move under the influence of ocean currents, wind drift, and horizontal and vertical mixing. GNOME is purposely designed to be flexible in its inputs; currents and winds used in GNOME can be derived from available model output on structured or unstructured grids. In the case of a surface spill, GNOME transport algorithms include advection due to currents, a user specified wind-drift parameterization, and a random walk to simulate the effect of turbulent diffusive processes that spread spills horizontally.

Individual particles also have weathering algorithms applied to them using algorithms similar to the ADIOS2 model (Lehr et al. 2002). For a surface spill, these include spreading, evaporation, vertical dispersion, sedimentation, and emulsification. With the exception of emulsification, these algorithms essentially result in a loss of mass from the surface slick. The mass lost from the ocean surface due to weathering is typically not tracked further in the model, although this could be implemented through the scripting environment (i.e., oil droplets permanently dispersed into the water column).

An updated technical manual detailing the coupled transport/weathering algorithms utilized in GNOME for surface and subsurface releases will be released later this year. Meanwhile, the GNOME and ADIOS2 references cited above provide more detail on individual algorithms.

4 Environmental Model Forcing

To predict oil spill trajectories for TAP, GNOME requires regional ocean currents and wind information. For TAP statistics to be significant, it is important that these current and wind data-sets are over a long enough period of time that multi-scale (interannual, seasonal, and intra-seasonal scales) variations of physical processes (wind, current, and wave) are represented.

An associated study, also funded by BOEM, titled “Expansion of West Coast Oceanographic Modeling Capability”, provided long time-series modeled outputs that were utilized for this Southern California TAP project (Dong et al. 2017). That project yielded a 10-year high-resolution hindcast product, including hourly sea surface wind and sea surface currents.

The oceanic simulations were performed with ROMS (Regional Ocean Model System) (Shchepetkin and McWilliams 2005) and produced a hindcast for 2004–2013 (Dong et al. 2017). The model domain extends from just south of Monterey Bay, California south to the border with Mexico (Figure 1). The model spatial resolution is 1 km in the horizontal, with 42 terrain-following vertical levels. The temporal resolution of the model data is 1 hour.

The ROMS model used nested boundary conditions from a larger model extending along the entire U.S. west coast with a horizontal grid resolution of 4 km.

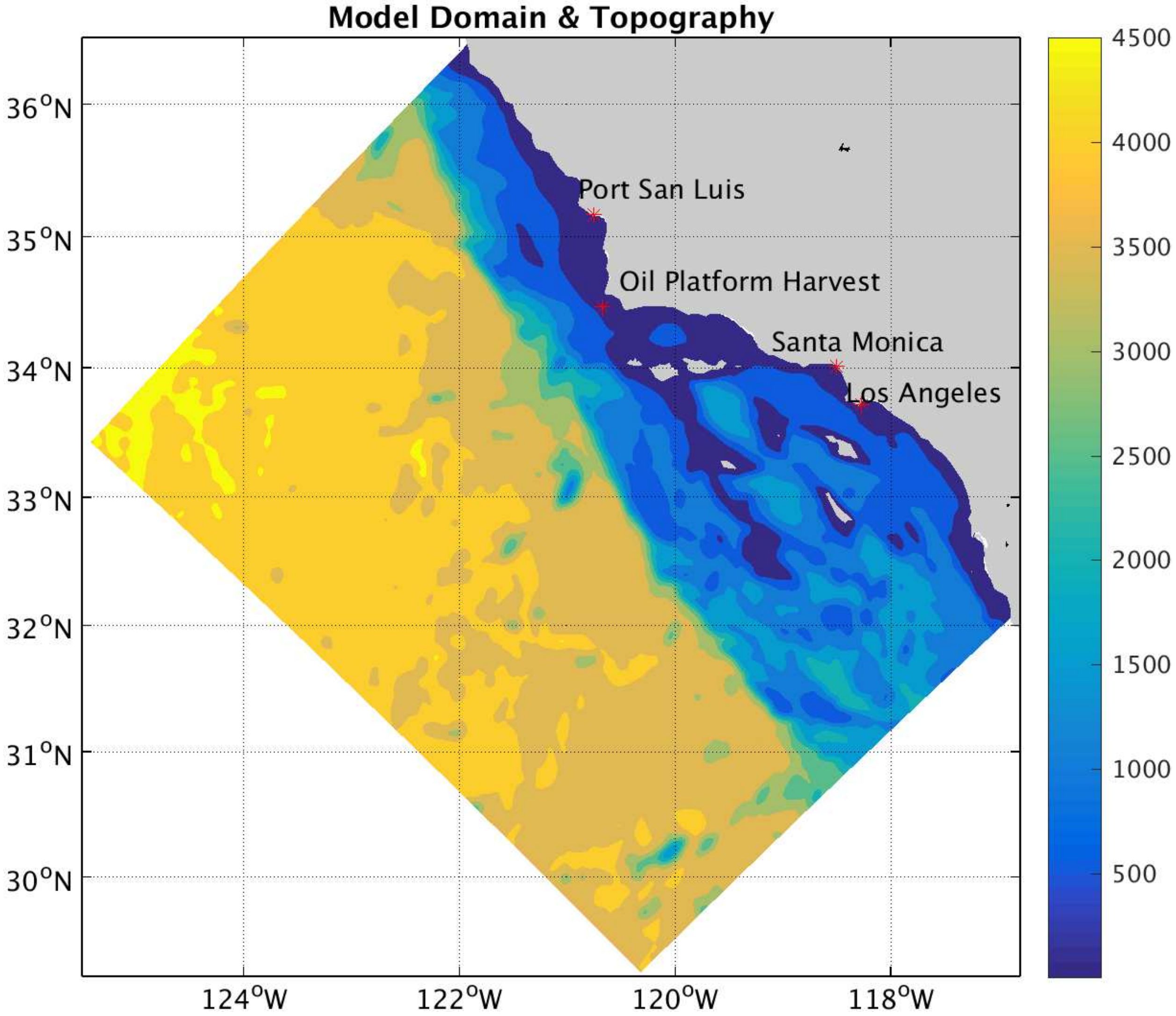


Figure 1. University of California Los Angeles (UCLA) ROMS model domain
Color shows ocean bathymetry (meters).

The meteorological model used in this study was the Weather Research and Forecasting model (WRF) (Skamarock et al. 2008), a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. Output from the 6-km WRF model was used both to force the ROMS mode and as a direct forcing for GNOME via the wind-drift parameterization. A full description of the WRF/ROMS model implementations and their validation is provided in Dong et al. 2017.

5 Southern California TAP

Although the TAP methodology described above is common to every implementation, each regional study has unique characteristics. For instance, the relevant risk of spills in the region due to the presence of offshore drilling or vessel traffic varies widely and this influences the spill scenario parameters (spill sites, types and duration of releases). Some regions also have strong seasonal variability in transport that should be included whereas other regions may be dominated by tidal or larger-scale ocean currents. In this section, the details specific to the Southern California TAP are described.

5.1 Source Sites

The source sites for the Southern California Planning Area TAP study were chosen based on the 23 Federal drilling platforms in the region and four pipeline locations. These platforms and pipelines are listed in Table 1 below along with summary information (location, the oil field, and the specific oil type each produces/carries as selected from the ADIOS database). The majority of the sources are in the Santa Barbara Channel, to the north and northeast of the Channel Islands. Five are outside of the Channel, to the west of Point Arguello, and five more are found south of Los Angeles, between Catalina Island and Long Beach. Figure 2 shows the locations of the platforms.

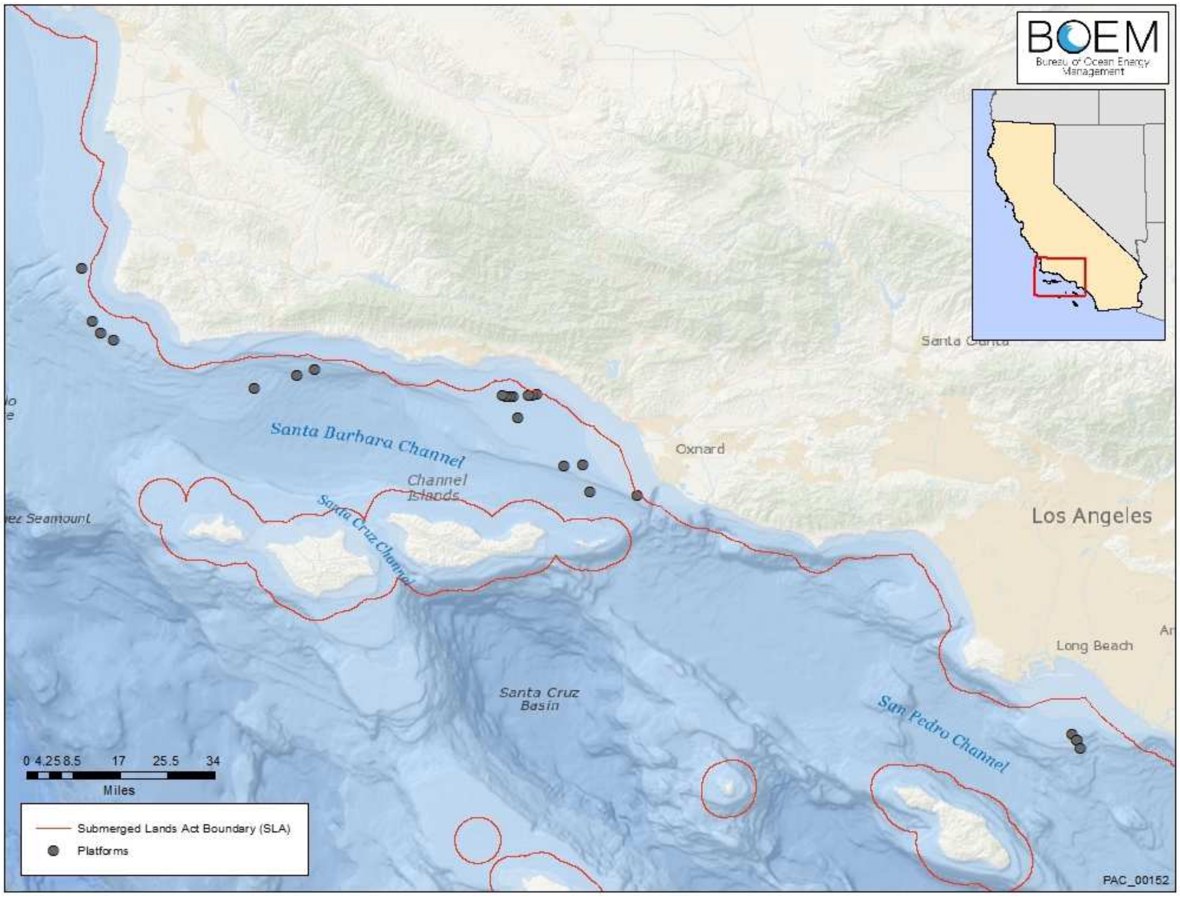


Figure 2. Map of twenty-three drilling platform locations in the northern Southern California Bight used as source sites for the TAP development

To generate the TAP database, the GNOME model was run 200 times for each designated source site within each “season” (described below). This is intended to capture the variability in winds and ocean currents; each model run or “scenario” uses a randomly selected start date from the 10-year ROMS and WRF model outputs available for currents and winds. Each scenario predicts oil weathering and movement over 21 days from a 5-day continuous release of 200 barrels (bbl) per day.

The modeled oil released from each source site is specific to the platform and pipeline at that location. Tables 1 and 2 present the names and locations of the platforms and pipelines and the oil type used for each, and its ADIOS database identifier. Using a specific oil type for each individual source site is an approach that is unique to the Southern California TAP project.

Table 1. Platform names, locations and oil types used for running the GNOME spill trajectory model

Geographic coordinates are given in decimal degrees per the World Geodetic System 1984 (WGS 84) datum. The American Petroleum Institute (API) gravity values provide a measure of the density of the oil types compared to water.

Platform	Latitude (°N)	Longitude (°W)	Field	ADIOS Name	ADIOS API
Irene	34.61041944	120.7294278	Point Pedernales	Point Arguello Heavy	18.2
Hidalgo	34.49501389	120.7022889	Point Arguello	Point Arguello Heavy	18.2
Harvest	34.46913611	120.6808167	Point Arguello	Point Arguello Heavy	18.2
Hermosa	34.45550833	120.6463889	Point Arguello	Point Arguello Heavy	18.2
Heritage	34.39073056	120.2791833	Pescado	Hondo Blend	20.8
Harmony	34.35039167	120.167525	Hondo	Hondo Blend	20.8
Hondo	34.39073056	120.1205306	Hondo	Hondo Blend	20.8
A	34.3318861	119.6124694	Dos Cuadras	Dos Cuadras	25.6
B	34.33234167	119.6215361	Dos Cuadras	Dos Cuadras	25.6
C	34.332925	119.6307667	Dos Cuadras	Dos Cuadras	25.6
Hillhouse	34.33134444	119.6032472	Dos Cuadras	Dos Cuadras	25.6
Habitat	34.28661667	119.5880944	Pitas Point	Pitas Point	38
Henry	34.33325556	119.5603972	Carpinteria	Carpinteria	22.9
Houchin	34.33499167	119.5521167	Carpinteria	Carpinteria	22.9
Hogan	34.337675	119.5414861	Carpinteria	Carpinteria	22.9
Grace	34.17959667	119.4693917	Santa Clara	Santa Clara	22.1
Gilda	34.18234167	119.4185639	Santa Clara	Santa Clara	22.1
Gail	34.12510833	119.4002167	Sockeye	Platform Gail	20.6
Gina	34.11749722	119.2762583	Hueneme	Port Hueneme	14.8
Edith	33.59578611	118.1406861	Beta	Beta Production	15.1
Ellen	33.58236667	118.1282222	Beta	Beta Production	15.1
Elly	33.58340278	118.1270889	Beta	Beta Production	15.1
Eureka	33.56378056	118.1164944	Beta	Beta Production	15.1

Table 2. Pipeline names, locations and oil types used for running the GNOME spill trajectory model

Geographic coordinates are given in decimal degrees per the World Geodetic System 1984 (WGS 84) datum. The API gravity values provide a measure of the density of the oil types compared to water.

Pipeline	Latitude (°N)	Longitude (°W)	Field	ADIOS Name	ADIOS API
Irene	34.6412	120.6910	Point Pedernales	Point Arguello Heavy	18.2
Hondo/Harmony/Heritage	34.4103	120.1030	Hondo	Hondo Blend	20.8
Hillhouse/A/B/C	34.3267	119.503	Dos Cuadras	Dos Cuadras	25.6
Edith/Ellen/Eureka	33.67	118.1022	Beta	Beta Production	15.1

Another aspect of the oil trajectory modeling that is unique to this project is that oil released underwent modeled weathering processes along its trajectory simulated with the GNOME model. Previous TAP projects applied weathering in a post-processing approach as a simple half-life decay dependent on oil type. In this application, weathering (spreading, evaporation of the lighter components of the oil into the atmosphere, vertical dispersion of some of the oil into the water column by the action of wind and waves, sedimentation, and emulsification) was done using wind, wave, and temperature data from the forcing models along each oil particle's trajectory at each time step in the model integration. This approach provides a more exact and localized result for the oil mass loss due to weathering.

5.2 GNOME Model Setup

To run a GNOME trajectory model, certain spill parameters must be defined. For this project the oil type was determined by what a likely spill from one of the platforms or pipelines would look like. A release duration of 5 days was chosen based on estimates from BOEM of how long a worst-case platform release from Southern California Platforms could occur. The total GNOME model run time of 21 days was set based on transport distances over that time period being similar to the scale of the TAP grid domain. Each GNOME spill was modeled with 10,000 Lagrangian elements (LEs).

In spill trajectory models, it is common to combine a number of physical processes related to wind forcing (e.g., Stokes drift, surface drift, Langmuir circulation) into a wind-drift factor (Galt 1994). This has been determined experimentally to be approximately 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 or temporally constant. In this simulation, wind drift parameter values were specified as 2-4% with a persistence time scale of 15 minutes.

Turbulent diffusive processes that spread spills horizontally are simulated in GNOME by a random walk. A diffusion coefficient of 1 m^2s^{-1} was 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 variability in the horizontal diffusion, so this results in a uniform spreading of the particles over time.

Trajectory data was output every 12 hours and archived. The TAP analysis for the Southern California project processes this data at 1, 2, 3, 5, 7, 14, and 21 days from release, allowing spill statistics to be viewed at intermediate time intervals within the entire 21 day run.

5.3 Seasonality

To study the variability of oil spill impacts over different seasons, it is useful to look at TAP results for those specific seasons. TAP is set up to do this by computing statistics for only GNOME runs that are started within specified time intervals. Previous TAP projects have designated seasons as defined traditionally (e.g., summer as June/July/August), or due to other forcing; for instance, the Arctic TAP project defined seasons as “Ice” or “No Ice” based on data showing when ice was present in the majority of the TAP domain being considered.

For the Southern California domain, the wind is the strongest factor in determining current and transport patterns. Wind data from a set of National Data Buoy Center (NDBC) buoys in the region, and from the Santa Barbara pier were studied to test if there is strong seasonality present. Figure 3 shows the monthly averaged winds at the buoy in the Santa Barbara Channel (NDBC #46053) as wind roses (where the frequency of wind direction is represented by the length of the bars and the magnitude by the bar colors). It was determined that the majority of the variability could be covered by defining two seasons: “Summer” as May through October, and “Winter” as November through April. Dorman and Winant (2000) describe the summer winds to be westerly and consistently strong south of Point Conception into the Santa Barbara Channel and decreasing in magnitude to further east into the Channel. Winter winds are driven by travelling cyclones and accompanying fronts, bringing strong southeast and then northwest winds.

Two hundred GNOME run start dates were randomly selected within each of these periods over the 10-year ROMS forcing data set. Also, if more general planning is required, the “All Year” season is included in the viewer. This is constructed with another 200 GNOME runs started at times randomly chosen over the entire 10-year record.

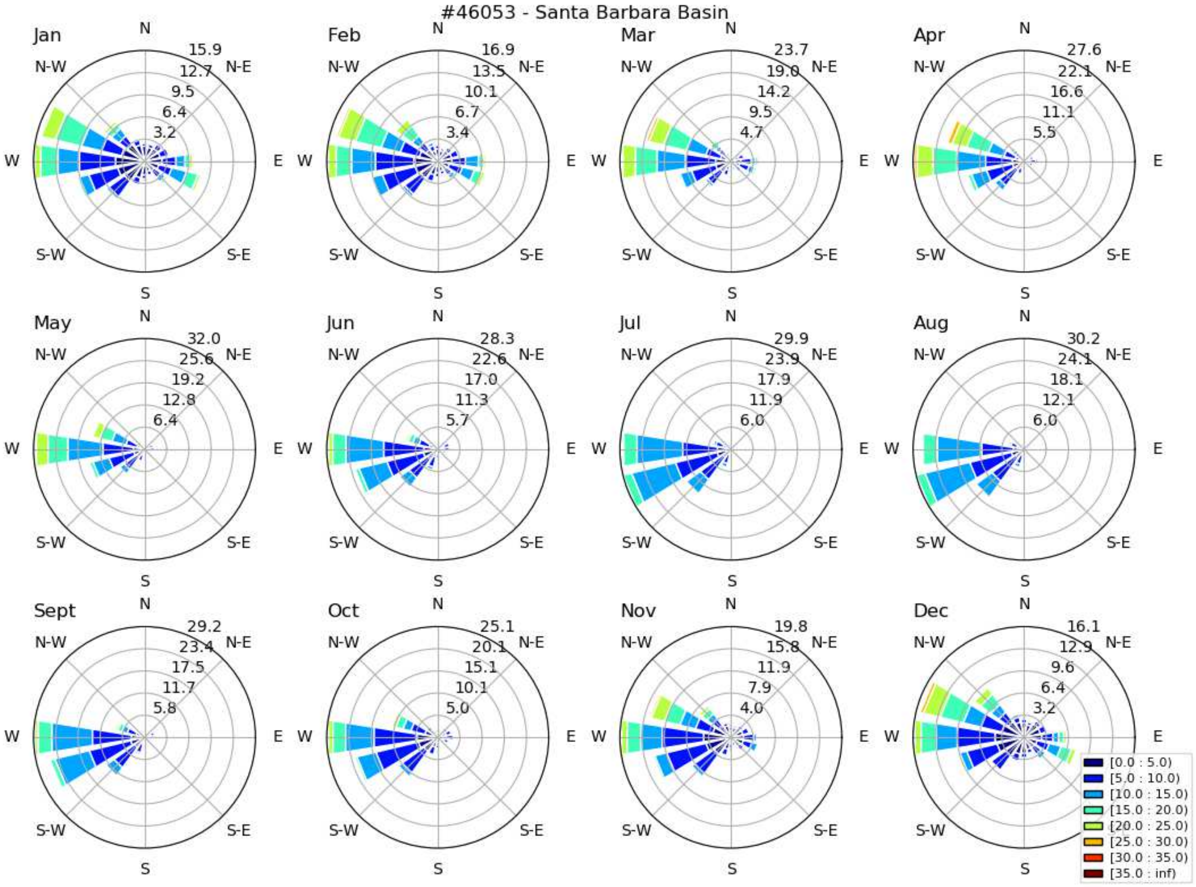


Figure 3. Monthly averaged wind roses from NDBC Buoy #46053, located in the Channel, approximately 12 miles south of Santa Barbara, California

The length of the bar represents the frequency of occurrence of wind direction, while the color shows the wind magnitudes. Note the direction of the “spokes” indicates the direction the wind is coming from.

5.4 Receptor Grid

Results of the GNOME trajectory analyses were compiled into data files containing statistics for where, when, and how much oil would be predicted to impact receptor cells in the Southern California Bight. The receptor sites were defined by an approximately 2.3-kilometer (km) by 2.3-km grid as seen in Figure 4. The grid extends from 32° to 32.5°N, and from 116.26° to 121.5°W, covering from San Luis Obispo in the north, to beyond the Mexican border in the south. The grid is 176 × 211 (37,136 cells), which is reduced to 20,220 receptor cells after filtering out cells that are completely on land.

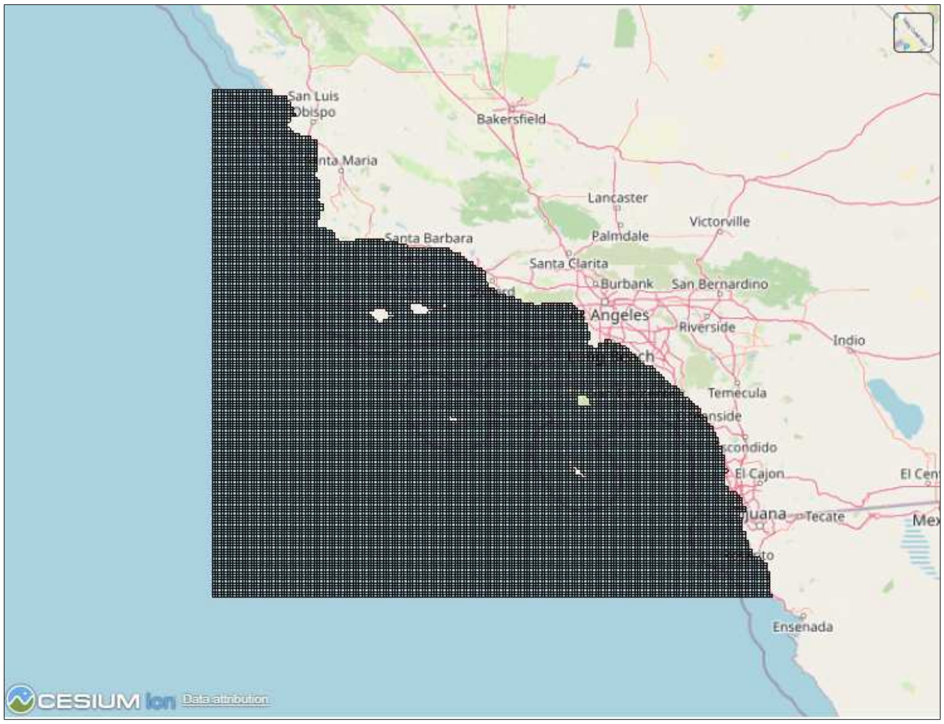


Figure 4. Southern California TAP receptor grid
The grid covers from 32° to 32.5°N, and from 116.26° to 121.5°W, with an approximate resolution of 2.3 km.

The definition of the receptor grid is a trade-off between obtaining a high-resolution grid sufficient to show variation of oil impacts along the coast and limiting the data files to reasonable sizes for serving over a web application. Also of importance is comparing the receptor cell resolution to the forcing grid resolution: having receptor cells smaller than the forcing grid (here, the 1 km grid ROMS) is redundant and will not produce "higher resolution" maps. Lastly, smaller grid cells require many more Lagrangian elements in the GNOME model runs in order to ensure cells get enough hits to build statistically significant results. Figure 5 shows the receptor cell resolution in the 9 km pass between Santa Rosa and Santa Cruz Islands, which was one determinant of the grid resolution.

Figure 5. Close-up of receptor grid, showing resolution between Santa Cruz and Santa Rosa Islands

6 Visualizing and Interpreting the Results

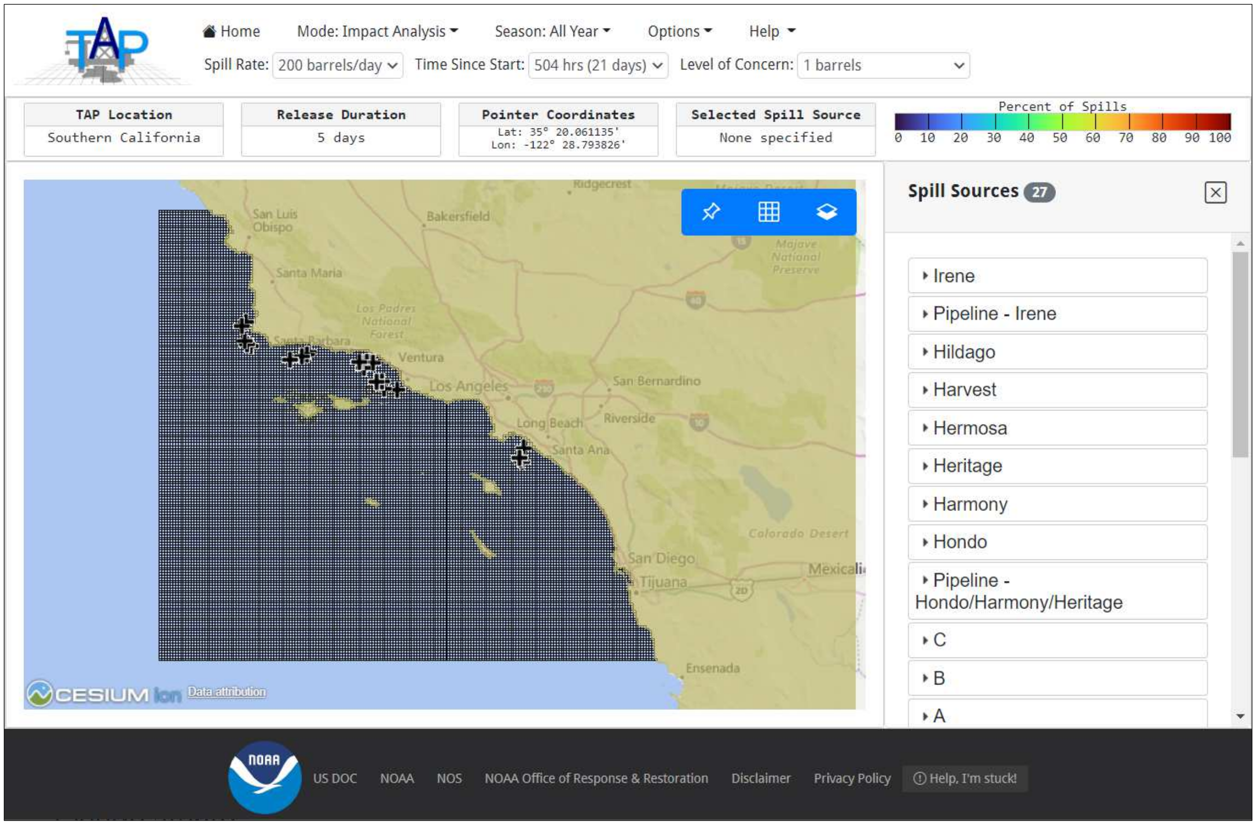
This project resulted in the development of a new web-based interactive viewer. The "WebTAP" viewer replaces the TAP desktop application which required downloading and installing the relevant regional databases. The WebTAP viewer is faster and more flexible than the desktop viewer, and allows view customizations and an improved user experience. In this section, we demonstrate the utility of the WebTAP viewer by presenting results from the Southern California TAP for one platform release site. The TAP results are viewed in the different analysis modes and the results are summarized.

The initial WebTAP landing page, found at https://tap.orr.noaa.gov presents an introduction to the TAP approach, a link to the TAP user manual, and a list of the available TAP projects hosted in the viewer. NOAA ORR is currently hosting all the TAP projects that have been developed. A full list of TAP projects can be found at https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-tools/trajectory-analysis-planner.html. (Also available at that link are downloadable packages that contain the TAP data-structures and the desktop viewer.)

Once you start by choosing the TAP region of interest from the landing page the viewer will load. The user will see a few components:

- a menu bar for selecting among visualization "modes" and customizing other parameters
- an interactive map window in which results are displayed, and which initially shows the TAP receptor grid
- a right-side panel listing the available spill sites with their platform names, locations, and oil types (if used for that particular TAP project)

Figure 6 shows the viewer after selecting the Southern California TAP. The TAP User Manual, which is linked from the landing page and from the Help Menu, describes how to use the TAP menu and set parameters for each analysis mode. Selecting a source site, either by clicking on the map or selecting from the Spill Sources panel, will display results of the Impact Analysis Mode (default initial view) for that site as color-coding on the map.



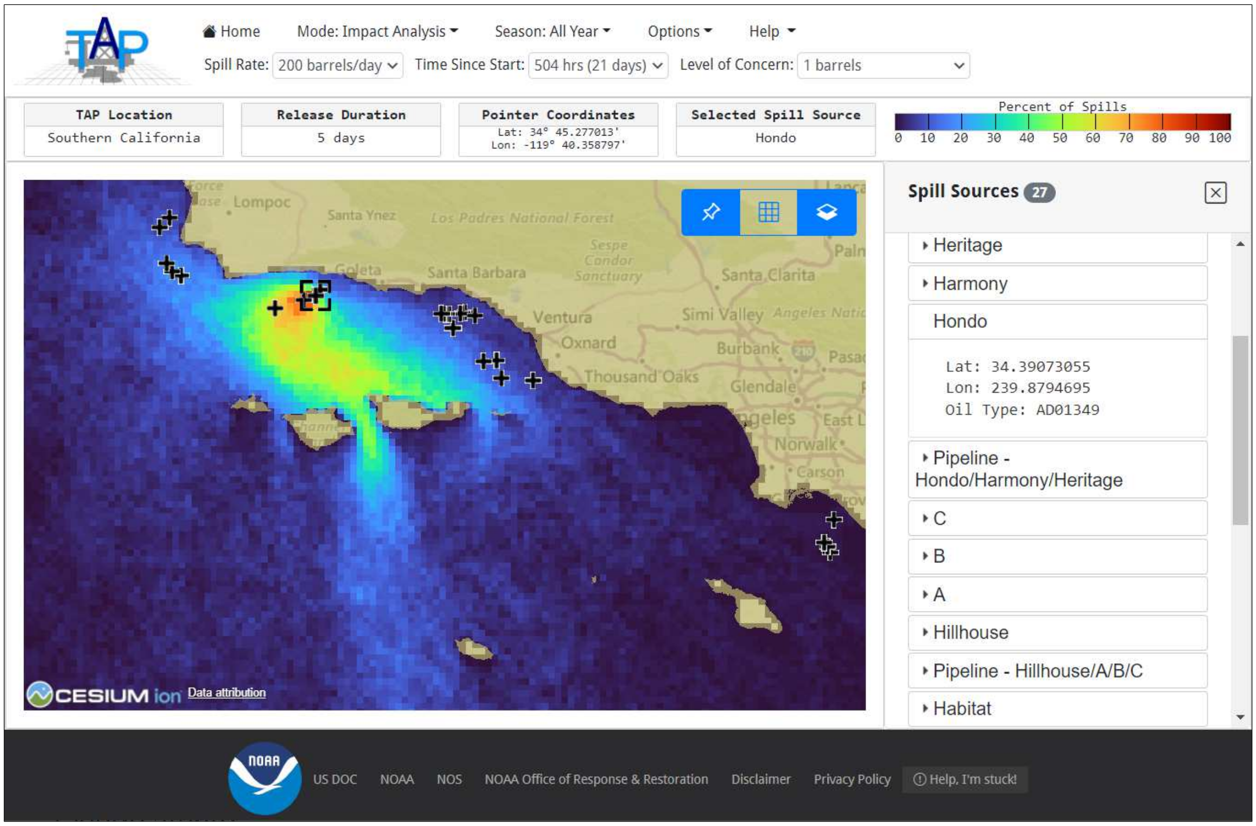
Spill Rate: 200 barrels/day
Time Since Start: 504 hrs (21 days)
Level of Concern: 1 barrels

TAP Location: Southern California
Release Duration: 5 days
Pointer Coordinates: Lat: 35° 20.061135' Lon: -122° 28.793826'
Selected Spill Source: None specified

Figure 6. TAP viewer for Southern California

6.1 Impact Analysis Mode

To examine the threat of oiling to specific areas from a worst-case discharge at the Hondo platform select the Hondo spill source either by clicking on the platform location on the map, or by selecting it from the spill source list on the right panel. The resulting plot is shown in Figure 7 (after turning off the Show Grid option in the View menu).



Spill Rate: 200 barrels/day
Time Since Start: 504 hrs (21 days)
Level of Concern: 1 barrels

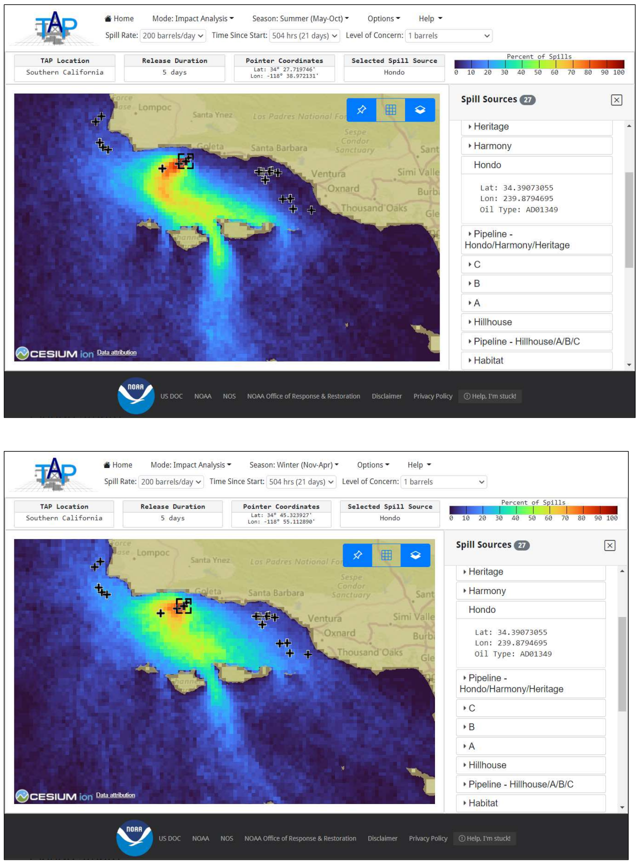
TAP Location	Release Duration	Pointer Coordinates	Selected Spill Source
Southern California	5 days	Lat: 34° 45.277013' Lon: -119° 40.358797'	Hondo

Hondo
Lat: 34.39073055
Lon: 239.8794695
Oil Type: AD01349

Figure 7. Impact Analysis Mode in the WebTAP viewer for the Hondo platform source site for the “All Year” season

This image is a statistical composite of the 200 individual GNOME scenarios. Each scenario predicts oil weathering and movement over 21 days from a 5 day continuous release of 200 bbl per day. Note that this is the “All Year” season, meaning that the start times for those 200 GNOME scenarios are randomly distributed over the entire 10 year ROMS forcing record. The colors indicate the percentage of the spill scenarios that resulted in a volume of oil greater than the Level of Concern (LOC) in a particular grid cell, at least once within the 21 days since the start of the spill. Here the LOC is specified as 1 bbl/cell. The threat map suggests that the strongest threat from this platform is to the south and southeast, towards the shorelines of Santa Rosa and Santa Cruz Islands. For more precise estimates of the likelihood of oiling, the threat levels in certain receptor cells can be displayed by hovering the mouse over individual cells in the map panel of the viewer; doing so shows that over 40% of the scenarios result in oil over the LOC moving between Santa Rosa and Santa Cruz, and then being transported further southward. The TAP results here suggest that beaches to the east of Santa Barbara are at a lower risk from this source site, with estimates that 10% or less of the 200 releases result in oil on the shorelines over the specified LOC. Hovering the mouse over a cell also displays the cells identification number, if it is needed for later comparisons.

The variation of oil impact with seasons can be displayed by selecting the Summer or Winter season from the Season pull-down menu. A comparison of those seasons is shown in Figure 8. These modes display, again, a composite of 200 GNOME scenarios, but with start times that fall within May–October for summer, and November–April for winter. The winter vs. summer results are similar in this scenario, with summer results showing a tendency for oil to be transported further to the west of the Channel Islands, while winter winds and currents tend to keep transport within the Southern California Bight.


Mode: Impact Analysis
Season: Summer (May-Oct)
Spill Rate: 200 barrels/day
Time Since Start: 504 hrs (21 days)
Level of Concern: 1 barrels

TAP Location	Release Duration	Pointer Coordinates	Selected Spill Source
Southern California	5 days	Lat: 34° 27.719746' Lon: -118° 38.972131'	Hondo

Hondo
Lat: 34.39073055
Lon: 239.8794695
Oil Type: AD01349

Mode: Impact Analysis
Season: Winter (Nov-Apr)
Spill Rate: 200 barrels/day
Time Since Start: 504 hrs (21 days)
Level of Concern: 1 barrels

TAP Location	Release Duration	Pointer Coordinates	Selected Spill Source
Southern California	5 days	Lat: 34° 45.323927' Lon: -118° 55.112890'	Hondo

Hondo
Lat: 34.39073055
Lon: 239.8794695
Oil Type: AD01349

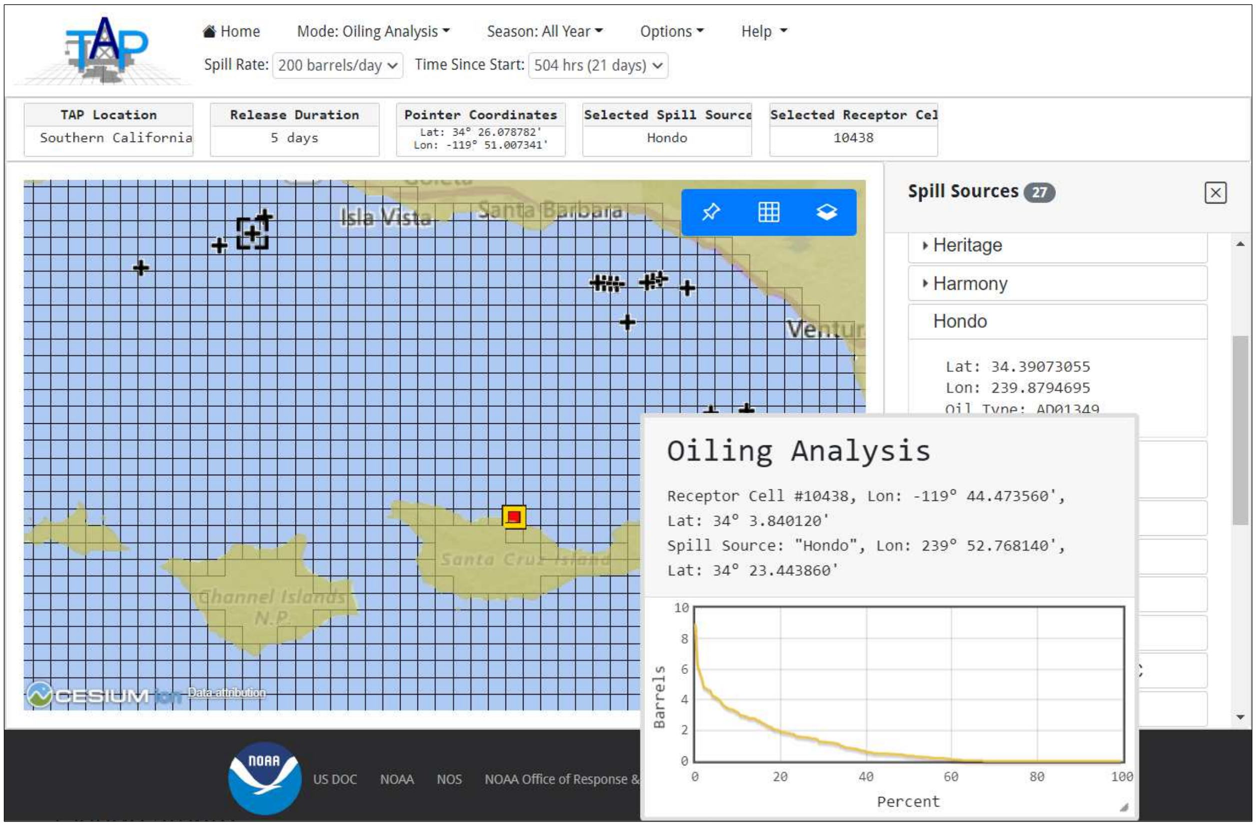
Figure 8. A comparison for the Impact Analysis for releases from the Hondo platform in Summer (top) and Winter (bottom)

Lastly, a very important note is that the colors on the map in Impact Analysis mode do not provide any information about the amounts of oil that could reach cells, beyond indicating that the LOC is predicted to be exceeded at least once during one or more of the modeled spills.

6.2 Oiling Analysis

The Impact Analysis mode generates a picture of how the whole Southern California region could be affected by an oil spill. In contrast, the Oiling Analysis mode focuses on specific locations of concern, such as specific environmentally sensitive shoreline areas or marinas, to explore this question: How much oil from a release site could reach a particular location of concern?

Selecting the Oiling Analysis mode for the Hondo source site, and then selecting a receptor cell on the northern side of Santa Cruz Island results in the view shown in Figure 9. The inset window displays the selected cell's ID number, its center latitude and longitude, and information about the selected spill source location. The plot shows the amount of oil predicted to be transported to the receptor cell as a function of the percent of the spills that reach that amount. Hovering the mouse over the graph shows a vertical red line on the graph and the corresponding predicted values. For instance, in the presented scenario, 10% of the spills are expected to bring 3 bbl or more of oil to that cell.



Spill Rate: 200 barrels/day

Time Since Start: 504 hrs (21 days)

TAP Location	Release Duration	Pointer Coordinates	Selected Spill Source	Selected Receptor Cel
Southern California	5 days	Lat: 34° 26.078782' Lon: -119° 51.007341'	Hondo	10438

Hondo

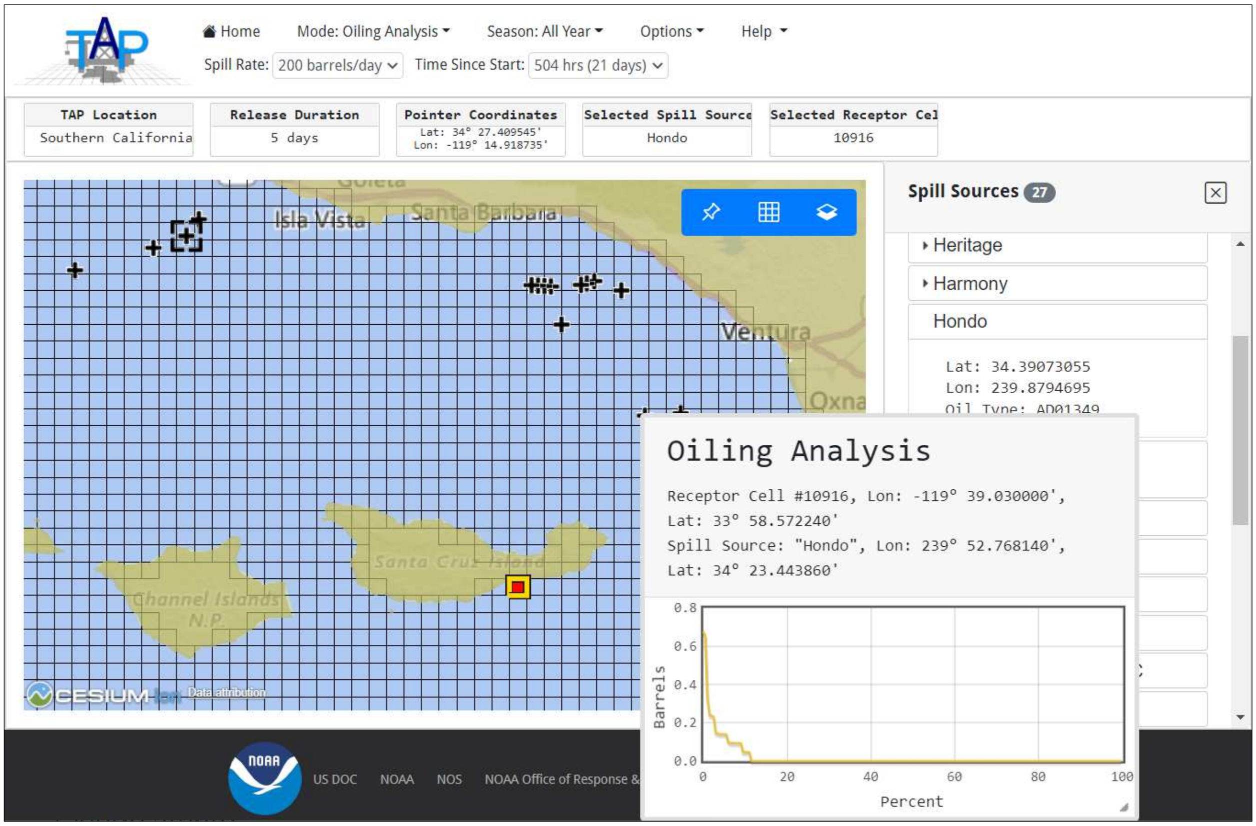
Lat: 34.39073055
Lon: 239.8794695
Oil Type: AD01349

Oiling Analysis

Receptor Cell #10438, Lon: -119° 44.473560', Lat: 34° 3.840120'
Spill Source: "Hondo", Lon: 239° 52.768140', Lat: 34° 23.443860'

Figure 9. Oiling Analysis Mode in the WebTAP viewer for the Hondo platform source site and a receptor cell on the northern side of Santa Cruz Island

As a contrast, Figure 10 shows the same result for a receptor cell on the southern shore of Santa Cruz Island. From the Impact Analysis mode discussion, we know that this site should have less oil impact. This is reflected in the Oiling Analysis graph, that shows less than 10% of the spills will bring any oil at all to this cell.



Spill Rate: 200 barrels/day
Time Since Start: 504 hrs (21 days)

TAP Location	Release Duration	Pointer Coordinates	Selected Spill Source	Selected Receptor Cel
Southern California	5 days	Lat: 34° 27.409545' Lon: -119° 14.918735'	Hondo	10916

Hondo

Lat: 34.39073055
Lon: 239.8794695
Oil Type: AD01349

Oiling Analysis

Receptor Cell #10916, Lon: -119° 39.030000',
Lat: 33° 58.572240'
Spill Source: "Hondo", Lon: 239° 52.768140',
Lat: 34° 23.443860'

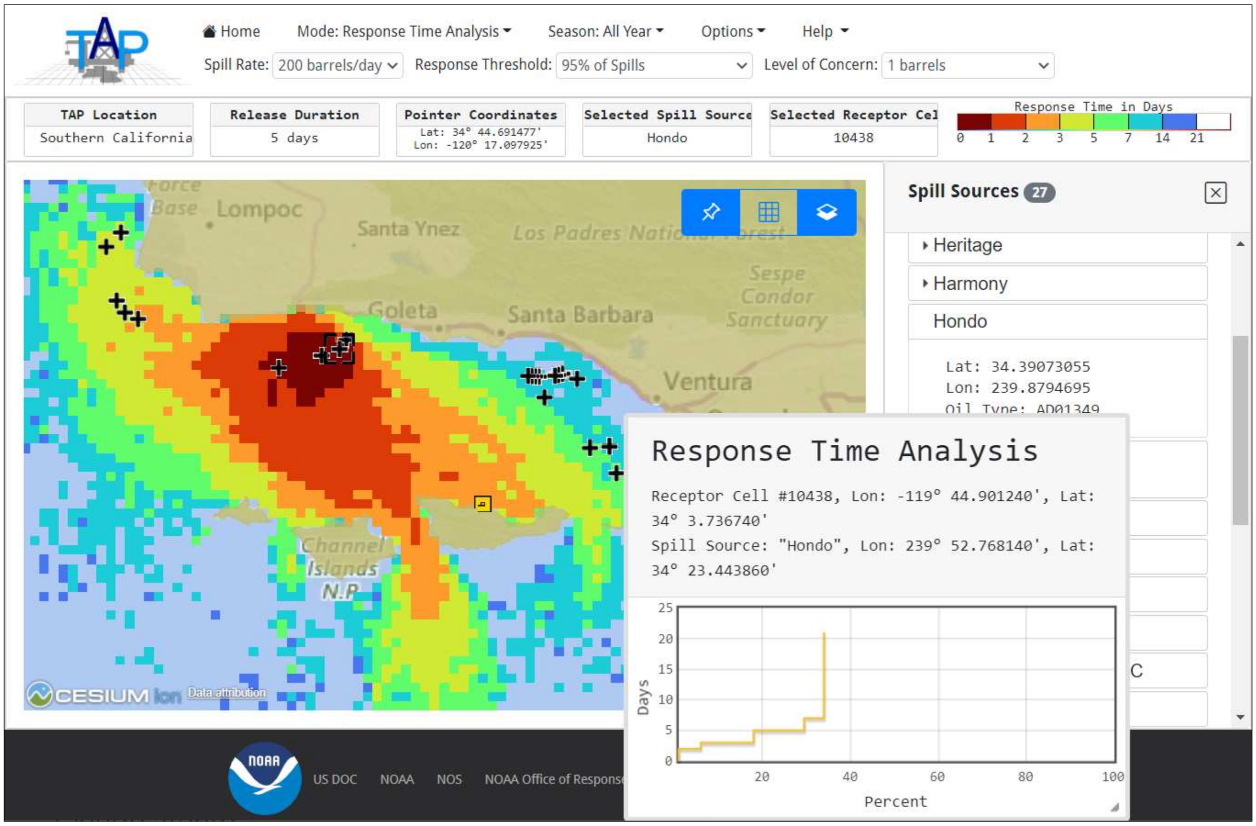
Figure 10. Oiling Analysis Mode in the WebTAP viewer for the Hondo platform source site and a receptor cell on the southern side of Santa Cruz Island

6.3 Response Time Analysis

If oil were released from the Hondo platform, the amount of time it would take that oil to transit to a threatened shoreline has implications both for the potential impacts and the response. Figure 11 shows the Response Time Analysis mode for the Hondo platform source. The color levels on the map represent the shortest time (in days) for oil to impact each receptor cell, over the LOC. Note that the time is defined as the time since the start of the spill; in the Southern California TAP scenarios the oil release occurs over 5 days, which has implications for arrival times.

The “Response Threshold” default of 95% limits the displayed data by excluding the fastest 5% of the spill transports in order to attempt to filter out outlier cases. The WebTAP user guide provides more information on choosing an appropriate Response Threshold.

If there is an area of particular concern, the inset window displays predictions for a specific receptor cell. The header in the inset displays the selected cell’s ID number, its center latitude and longitude, and information about the selected spill source location. The plot shows the arrival time estimates for that cell in days, as a function of the percentage of spill scenarios that reach the cell in that time frame. By hovering the mouse over the plot, we can see that 20% of the spills from the Hondo platform are predicted to impact that cell above the specified LOC within 5 days.



Mode: Response Time Analysis
Season: All Year
Spill Rate: 200 barrels/day
Response Threshold: 95% of Spills
Level of Concern: 1 barrels

TAP Location	Release Duration	Pointer Coordinates	Selected Spill Source	Selected Receptor Cel
Southern California	5 days	Lat: 34° 44.691477' Lon: -120° 17.097925'	Hondo	10438

Lat: 34.39073055
Lon: 239.8794695
Oil Type: AD01349

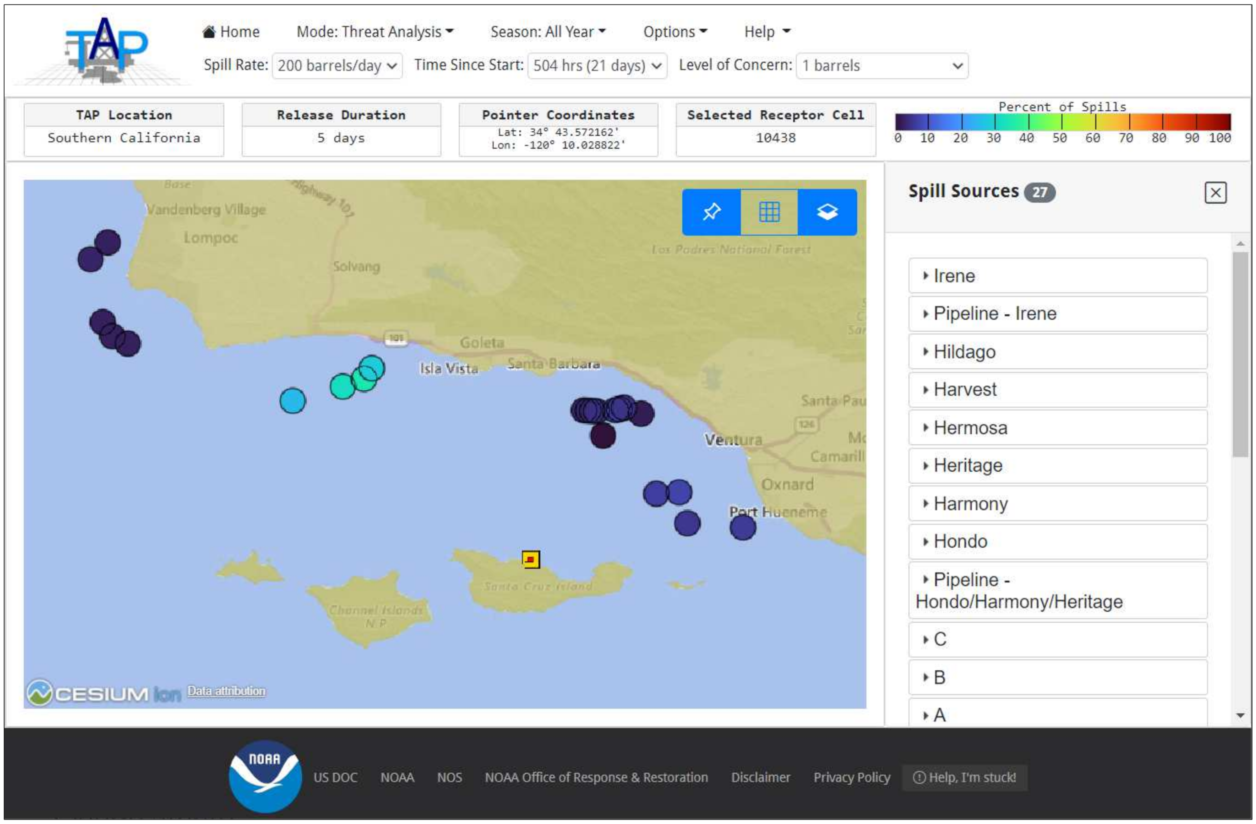
Response Time Analysis

Receptor Cell #10438, Lon: -119° 44.901240', Lat: 34° 3.736740'
Spill Source: "Hondo", Lon: 239° 52.768140', Lat: 34° 23.443860'

Figure 11. Response Time Analysis mode in the WebTAP viewer for the Hondo platform source site and a receptor cell on the northern side of Santa Cruz Island

6.4 Threat Analysis

Threat Analysis mode is useful when you have an area of particular concern and need to know which spill sites have the most potential for impacting that area. After selecting the mode, a receptor cell of concern is chosen. Figure 12 shows the Threat Analysis for the same receptor cell on the northern side of Santa Cruz Island as the previous section. The colors of circles at each platform source represent the percentage of spills from that site that will impact the selected receptor cell over the chosen LOC. This provides an easy and quick way to understand where a threat could come from, and to scale the risk of damage at an important or sensitive location. In the map the largest threat comes from spills that originate at the Heritage, Hondo and Harmony platforms, with about 25% of the spill scenarios starting at these sites impacting the Santa Cruz Island shoreline. The platforms to the northeast of Santa Cruz island, while closer, have lower threat values due to the nature of the currents and winds in the region. If exact values are needed, instead of just the color scale information, hovering the mouse pointer over a source site will show the exact threat percentage from that source.



Spill Rate: 200 barrels/day
Time Since Start: 504 hrs (21 days)
Level of Concern: 1 barrels

TAP Location	Release Duration	Pointer Coordinates	Selected Receptor Cell
Southern California	5 days	Lat: 34° 43.572162' Lon: -120° 10.028822'	10438

Percent of Spills
0 10 20 30 40 50 60 70 80 90 100

Spill Sources 27

- Irene
- Pipeline - Irene
- Hildago
- Harvest
- Hermosa
- Heritage
- Harmony
- Hondo
- Pipeline - Hondo/Harmony/Heritage
- C
- B
- A

Figure 12. Threat Analysis Mode in the WebTAP viewer for a receptor cell on the northern side of Santa Cruz Island
The color of the circles at the source locations predicts what percentage of spills from each site will impact the selected receptor cell.

6.5 Level of Concern

For most of TAP's display modes, a LOC must be specified and this value strongly impacts the results. In TAP, this is the volume of spilled oil on the water surface within one map cell, above which a responder would plan to take particular response actions in order to mitigate the expected impacts of that oil. Choosing a LOC that reflects the potential impacts of the oil is one part of determining the response actions taken. The other part has to do with the question of resource constraints in terms of how much oil can realistically be responded to. To assist in selecting a LOC for planning work, the tables below (Tables 3 through 6) are provided. When setting up a scenario in TAP, the default LOC can be selected, or a different LOC can be chosen. In either case, the LOCs chosen in TAP should be meaningful for the scenario being investigated.

6.5.1 Relating TAP's Levels of Concern to Amounts of Shoreline Oiling

One way to relate TAP's LOCs to the "real world" is to visualize how the amount of oil equivalent to a LOC might appear if it were to beach on a shoreline. For example, if the 5 bbl of oil in one 2.5 by 2.5-km cell were driven straight to shore by an onshore wind, forming a swath of oil 10 km long and 2 meters (m) wide, then that swath of oil would be about 0.08 centimeters (cm) deep at 50% cover. When a swath of oil on a shoreline is patchy or broken so that it covers about 50% of the area under it, the percent cover is considered to be 50%. Table 3 shows how deep the swath of beached oil would be for amounts of oil equivalent to selected TAP LOCs.

Table 3. Levels of Concern in TAP and depths of a swath of equivalent amounts of beached oil 1 km long and 2 m wide, at 50% cover

TAP Level of Concern (bbl/cell)	TAP Level of Concern (bbl/sq km)	TAP Level of Concern (liter/sq km)	Average thickness of a swath of an equivalent amount of beached oil 1 km long and 2 m wide at 50% cover (cm)
1	0.16	0.25	0.016
2	0.32	0.50	0.032
5	0.8	0.99	0.08
10	1.6	2.48	0.16
20	3.2	4.95	0.32

6.5.2 Relating TAP's Levels of Concern to Amounts of Oil on the Sea Surface

Another way to relate TAP's LOCs to real oil spills is to visualize how the oil could appear on the sea surface. For simplicity's sake, consider a 2.5 by 2.5-km cell, representative of the Southern California TAP receptor cells. As Table 3 shows, if 10 bbl of oil were spread out in an even layer at 25% cover across the sea surface within each 6.25-square kilometer (sq km) cell, that layer of oil would be about 1 micron (µm) thick (1 µm = 4 × 10-5 inches). This is the approximate thickness of rainbow sheen (0.30–5.0 µm), as defined in the Bonn Agreement Oil Appearance Code (BAOAC, http://www.bonnagreement.org/eng/html/welcome.html).

Table 4. TAP's Levels of Concern in terms of estimated thickness and appearance of the liquid oil if evenly distributed on the sea surface at 25% cover

TAP Level of Concern (bbl/cell)	TAP Level of Concern (bbl/sq km)	Average thickness of liquid oil at 25% cover (µm))	Average thickness of liquid oil at 25% cover (inches)	Expected appearance of liquid oil at 25% cover if evenly distributed on surface and not emulsified (µm)
1	0.16	0.1	4 x 10-6	Silver/gray sheen (0.04 – 0.30 µm)
2	0.32	0.2	8*10-6	Silver/gray sheen (0.04 – 0.30 µm)
5	0.8	0.5	2 x 10-5	Rainbow (0.30 – 5.0 µm)
10	1.6	1	4 x 10-5	Rainbow (0.30 – 5.0 µm)
20	3.2	2	8 x 10-5	Rainbow (0.30 – 5.0 µm)

If the same 10 bbl were spread out in an even layer at 100% cover across the sea surface within each 6.25-sq km cell, the oil layer would be four times thinner, about ¼ µm in this example (Table 4).

Table 5. TAP's Levels of Concern in terms of estimated thickness and appearance of the liquid oil if evenly distributed on the sea surface at 100% cover

TAP Level of Concern (bbl/cell)	TAP Level of Concern (bbl/sq km)	Average thickness of liquid oil at 100% cover (μm))	Average thickness of liquid oil at 100% cover (inches)	Expected appearance of liquid oil at 100% cover if evenly distributed on surface and not emulsified (μm)
1	0.16	0.06	2.4 x 10-6	Silver/gray sheen (0.04 – 0.30 μm)
2	0.32	0.13	5 x 10-6	Silver/gray sheen (0.04 – 0.30 μm)
5	0.8	0.25	1.0 x 10-5	Silver/gray sheen (0.04 – 0.30 μm)
10	1.6	0.6	2.4 x 10-5	Silver/gray sheen (0.04 – 0.30 μm)
20	3.2	1.25	4.9 x 10-5	Silver/gray sheen (0.04 – 0.30 μm)

In reality spilled oil is never distributed uniformly on the water surface. It will be in variable thickness slicks, bands, tarmats, or tarballs with clean water in between. Table 6 shows amounts of oil equivalent to each of TAP's LOCs if that oil is distributed as tarballs.

Table 6. TAP's Levels of Concern in terms of the average number of tarballs per hectare and average area per tarball, if all the spilled oil was evenly distributed in the form of 1-cm diameter tarballs

TAP Level of Concern (bbl/cell)	TAP Level of Concern (bbl/sq km)	Average area per tarball (sq m)	Average number of tarballs per hectare (#)
1	0.16	20.6	486
2	0.32	10.3	972
5	0.8	4	2430
10	1.6	2	4860
20	3.2	1	9720

7 Summary

The work presented will be important for BOEM, and other planners, to better understand the risk from an oil spill in the Southern California Planning Area. By using realistic weather and ocean current forcing to develop oil spill trajectory statistics for potential spills, this TAP project allows a user to predict what areas could be impacted by a potential spill from one of the region's platforms or pipelines. How much oil could be present at threatened locations? How long do responders have to respond? And what sources are the most likely threats to sensitive locations and resources? These questions can be explored using the TAP results.

As part of this project, the WebTAP viewer was developed to make the TAP statistics more available to emergency response planners. All the TAP results images in this report are from the developed WebTAP viewer. The previous TAP viewer was only available through a desktop application. As a web application this new version of the viewer is much more accessible and will make it easier to explore the TAP statistics for the Southern California region. ORR is also hosting data from other TAP projects on the web viewer, making the TAP data and results available to the larger emergency response community. And lastly, while the trajectories and TAP analysis here were developed explicitly for spills from oil platforms, it is possible that the ROMS data and the TAP approach could be applied to other areas of interest: such as marine debris transport (Righi et al. 2018) or possible spills from vessels impacting otter populations (T. Tinker, email communication, Dec. 2020).

The WebTAP viewer is still in development, and is being designed such that features can be added in the future, such as allowing the user to define a "season" for the TAP statistics to be computed from, or, ultimately, for the user to define a spill type and location and build the TAP statistics from GNOME runs carried out on demand.

It is important to understand that the Southern California TAP can't provide all the information needed for planning efforts, but provides a solid starting point for further investigations. Some caveats to keep in mind when working with TAP:

- This TAP analysis does not address the subsurface transport of oil.
- This analysis does not take into account any response actions (skimming, dispersant application, burning, booming of oil).
- The statistics presented by TAP are derived from 10 years of data from 2004 to 2013. We do not know how valid these statistics are for future years. Long-term variations in climate and forcing could change the statistics of the transport in the area.
- The Southern California TAP results (or any TAP project results) **should not be used in the event of an actual spill**. It is a planning tool that can be used to investigate "what if?" situations based on the region's long-term variability in currents and winds. TAP will not predict the trajectory of oil under specific conditions of winds and ocean currents. When modeling support is needed during an actual spill response, contact a NOAA ORR Scientific Support Coordinator. They can ask NOAA's oil spill scientists to run GNOME to narrow the possibilities of where the oil will go under the specific conditions of a real-time oil spill.

Two factors that are more difficult to obtain from the TAP analysis, but pertinent for developing plans, are the duration of shoreline impacts and the type of impacts expected. As pointed out earlier, onshore winds are required for oil to come ashore. This fact implies that shoreline impacts will be episodic. In an example extreme case, a stretch of beach may receive 100 bbl of oil over a span of 2 days, but no oil before or after. It is unlikely that any stretch of beach would receive oil for more than a week or two at a time because of the episodic nature of the winds.

The type of beach impacts one can expect will depend upon the amount of oil and the environmental conditions to which the oil was exposed. If oil were to come ashore in a short duration of time, an outcome that would require strong winds and high seas, we would expect that oil to be broken into widely scattered tarballs of varying sizes. If oil were to come ashore under moderate and sustained wind conditions, shoreline impacts would be more in the form of large tarmats and slicks.

8 References

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Appendix A: Subsurface Source Modeling

A.1 Introduction

The main report has focused on the surface transport from spills originating at platform and pipeline locations in BOEM's Southern California planning area. In the model simulations for the Southern California TAP project, the oil was initialized at the ocean surface where it moves under the influence of winds and surface ocean currents. These results illustrate which shorelines are at highest risk of being impacted along with the response times for implementing protection strategies. While informative for developing response plans, these results do not provide information on the scale of subsurface water column impacts in the event of a well blowout or pipeline release.

Much of the recent literature examining well blowout dynamics stems from the 2010 Macondo oil well blowout in the Gulf of Mexico (the Deepwater Horizon oil spill). This incident demonstrated the wide range of processes that affect oil droplets and gas bubbles released from a subsea blowout (Socolofsky et al. 2016). These processes begin with the breakup of the blowout jet into small droplets and bubbles and their vertical transport as a buoyant plume. These dynamics are modeled with specialized "near-field" models, which can simulate the rising buoyant mixture of oil, gas, entrained seawater and formation of gas hydrate, and determine the plume evolution including formation of "intrusion layers" due to ocean stratification. Once the liquid hydrocarbon leaves the plume mixture in the form of individual droplets, advection by ocean currents controls their distribution and particle tracking models like GNOME are well suited to track the individual movement and fate of droplet size classes.

A key difference between the location of the 2010 Deepwater Horizon incident and the platform locations in the Southern California Planning area are the relatively shallow water depths which range from approximately 30 m (Platform Gina) to 370 m (Platform Harmony). In a shallow water blowout, the entrained oil and water in the vertical buoyant plume may interact with the ocean surface. At the surface the upward flow of water and oil turns and moves in a horizontal layer away from the center of the plume. The surface oil slick then spreads and moves with the prevailing currents and winds. The gas exits from the center of the plume and causes a surface disturbance or "boil zone". In the shallow water case, there is less potential for large volumes of the oil to travel subsurface in intrusion layers and subsurface impacts may be more constrained to the vicinity of the blowout.

In addition to the water depth, key factors in determining the partitioning of oil between the surface and subsurface include the nature of the release (i.e., how turbulent), the water depth, the gas to oil ratio, and the droplet size distribution. In Appendix A, we use results from a near field well blowout (plume) model coupled with a 3D particle tracking simulation to examine how far subsurface oil might travel before concentrations are reduced below a biologically significant LOC. We simulate scenarios to examine the likelihood for significant volumes of oil to remain subsurface and to estimate the extent of potential subsurface impacts.

A.2 Methods

The Texas A&M Oil spill Calculator (TAMOC) modeling suite was used for predicting the nearfield fate and transport of oil and gas released (Socolofsky et al. 2015). The model contains modules for handling ambient water column information, hydrocarbon equations of state, and bubble and droplet dynamics, including particle rise velocity, shape, surface area, and heat and mass transfer rates. It uses these modules to estimate the dynamics of the buoyant plume resulting from a subsurface release of oil and gas.

The TAMOC results are used to initialize subsurface spills in PyGNOME, a 3D particle tracking model that is the computational core of NOAA's GNOME model used for predicting oil spill trajectories (Zelenke et al. 2012). Once the liquid hydrocarbon leaves the plume mixture in the form of individual droplets, rise velocities and advection by ocean currents control their distribution and PyGNOME is used to track the individual movement and fate of the droplet size classes.

The California ROMS model developed for BOEM (Dong et al. 2017) and previously described in this report is used to drive subsurface trajectories in TAMOC and PyGNOME. A 2-week subset of 3D current velocities was selected by searching the model current data for the fastest subsurface velocities in order to maximize the possible horizontal transport of oil from the subsurface release.

For these simulations, an idealized well blowout from the Heritage Platform (located in the Santa Barbara Channel approximately 13 km from the coast) was considered. At approximately 330 m, this site is one of the deeper well locations in the region. The oil type used for the release is a Hondo Blend, which is described in the online ADIOS Oil Database (https://adios.orr.noaa.gov/oils/AD02174). The Hondo Blend is a result of the blending of a few wells, including the Heritage well, that feed into the same pipeline to shore. There is no similar data available for the Heritage platform alone. The oil properties of nearby wells are similar and the results of the modeling done here are not highly sensitive to oil properties. The oil properties for the Hondo Blend used in these simulations are shown in Table A-1.

Table A-1. Oil properties used in the model simulations

Property	Value
API Gravity	20.8
Density	0.929 g/cm³ at 15 °C
Kinematic Viscosity	511 cSt at 16 °C
Interfacial Tension	0.0241 N/m at 15 °C
Gas to Oil Ratio (Heritage)	1545 scf/bbl

We present results from two scenarios: a worst-case discharge scenario in which the plume rises to the surface quickly and a reduced release rate scenario in which the plume is trapped subsurface. A release rate of 33,986 bbl of oil per day was chosen in order to characterize a worst case discharge scenario (Susan Zaleski, personal communication). A smaller release rate of magnitude 2000 bbl per day was also simulated to examine a case in which the buoyant plume might not interact directly with the surface. In the second case the near-field model results are used to initialize the GNOME particle tracking model.

A.3 Results and Discussion

A.3.1 Plume Dynamics Overview

When oil and gas are released below the surface of the ocean, a buoyant plume is formed. The oil and gas are less dense than the surrounding water, and will rise in the water column. As a plume rises away from its source, it entrains water from the surrounding ocean, and widens as the plume rises. In addition, gas bubbles are dissolving into the water in the plume. With the addition of more dense seawater and loss of gas bubbles due to dissolution, the fluid in the plume increases in density. When the density becomes close to that of the surrounding water, there is no longer buoyancy to drive the plume, and the plume "breaks up" releasing the oil droplets and gas bubbles into the surrounding water where they will then rise independently and move with the currents. This is known as "trapping" the plume and the height at which the plume dynamics no longer dominate is known as the "trap height". Depending on the parameters of the release and the water column, the plume can trap at mid-water column or rise to the surface and release the oil and gas at the surface. The water entrained in the plume near the bottom is typically more saline and colder, and therefore denser, than the water higher in the water column. Hence, as the plume loses buoyancy due to the dissolution of gas and entrainment of denser water, the plume can “slump” and move downward before it fully breaks up.

For both the oil droplets and gas bubbles, there is dissolution into the water as the plume develops. Oil has only a small fraction of soluble compounds, so this is typically a minor effect. Conversely, the bulk of natural gas is methane, which is highly soluble, so it rapidly dissolves into the water of the plume. Depending on the amount of gas and other factors (e.g., release depth, bubble diameter), the methane may fully dissolve before the plume reaches the surface or traps. However, if a large amount of methane reaches the surface it can create a hazardous atmosphere at the location of the surfacing plume. Dissolved methane in the water column has a low toxicity and is rapidly biodegraded. However, due to the high biodegradation rates, the dissolution of methane in seawater can result in local oxygen depletion that may lead to ecological effects. A decrease in oxygen was observed during the Deepwater Horizon incident associated with a deep plume of hydrocarbons located at approximately 1000 m depth (Kessler et al. 2011). However, even with that very large release, the oxygen reduction never approached levels considered hypoxic.

A.3.2 Droplet Size Distribution

Due to the high interfacial tension between oil and water, oil released in the water column tends to form individual droplets of varying sizes. The size of the droplets has a large influence on the fate and transport of the oil: larger droplets rise faster through the water column and dissolve and biodegrade more slowly. Because of this, the selection of the droplet sizes used in modeling is an important part of model setup.

In a release, droplets of a range of sizes are created, resulting in not a single size, but a distribution of sizes. The Droplet Size Distribution, or (DSD) resulting from a release is determined by the oil properties and the turbulent energy of the release. Critical oil properties are the density, viscosity, and interfacial tension with sea water. In practice, most petroleum products have a similar interfacial tension, unless chemical dispersants have been introduced. In an underwater release, the level of turbulence is determined by the flow rate, velocity and oil-gas ratio.

In the years since the Deepwater Horizon incident, many studies have attempted to characterize the DSD resulting from a subsurface blowout based on these parameters. There is still a lot of uncertainty in this work, as experiments must necessarily be conducted on much smaller scales than a real blowout, and it is unclear how well the results can be scaled up to field scale. Nevertheless, there have been a few models published in the peer reviewed literature that can guide analysis of transport of oil from a potential undersea release. For this study, the droplet size distribution model from Johansen et al. (2013) was used.

A.3.3 Worst-case Discharge Scenario

In the worst-case discharge scenario, we simulate a spill originating from a total well blowout. In this case the orifice diameter for the release is set as 17.2 cm, which is approximately the well bore diameter. The release rate is based on a worst-case discharge number provided by BOEM of 33,986 bbl of oil per day with a gas-oil ratio of 1545 standard cubic feet (scf)/bbl (Susan Zaleski, personal communication).

The water column properties were derived from the UCLA ROMS model at the location of the Heritage Platform (Figures A-1 and A-2).

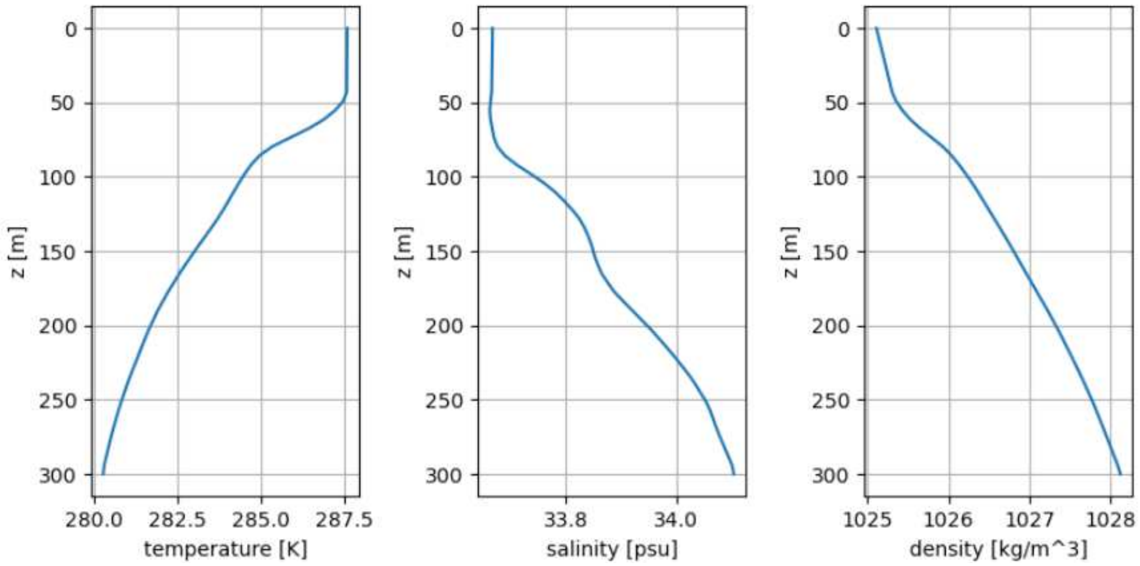

Figure A-1. Water column properties extracted from the UCLA Southern California ROMS model at the beginning of the simulation
Note that the salinity increases and the temperature decreases with depth, resulting in higher density water at the bottom. The small changes in temperature and salinity in the top 50 m indicate a mixed layer to that depth.

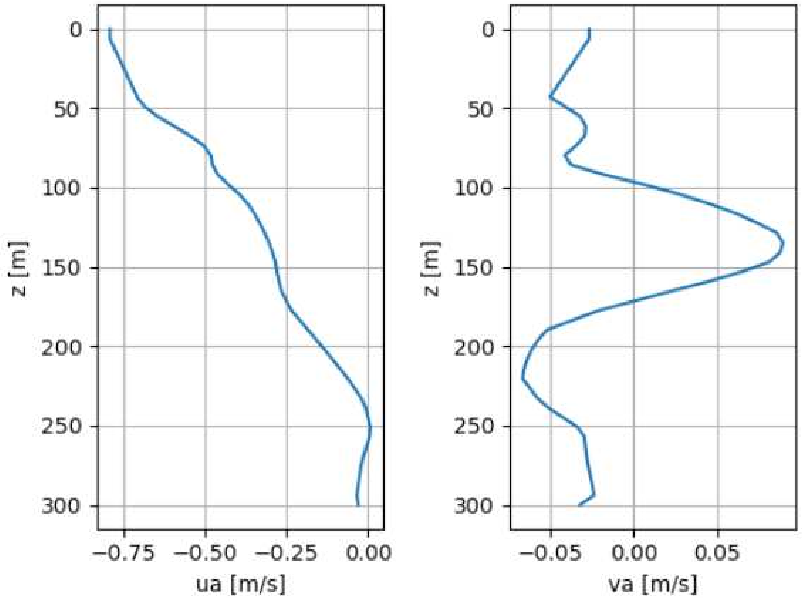

Figure A-2. Flow velocity throughout the water column at the beginning of the simulation
The “ua” is the flow in the east-west direction, and the “va” is the flow in the north-south direction. Note that the flow decreases from a maximum at the surface to near zero at the bottom. There is a change in direction between 100 and 150 m depth indicated by the reversal in the N-S (va) direction. Note that the scales are different; the flow is mostly in the westerly direction.

Under these conditions, the high release rate coupled with the buoyancy of the oil and gas results in a buoyant plume that quickly reaches the ocean surface (Figures A-3 through A-6). The plume entrains water on its way up, so it does not release oil into the water column; i.e., all the oil reaches the surface. Due to the rapid rise time (oil surfaces in less than ten minutes), the extent of surfacing oil is constrained to within an approximately 80-m diameter around the well head location. Under these circumstances, the surface transport can thus be adequately modeled as a surface point release using a similar approach to the TAP modeling results presented in this report.

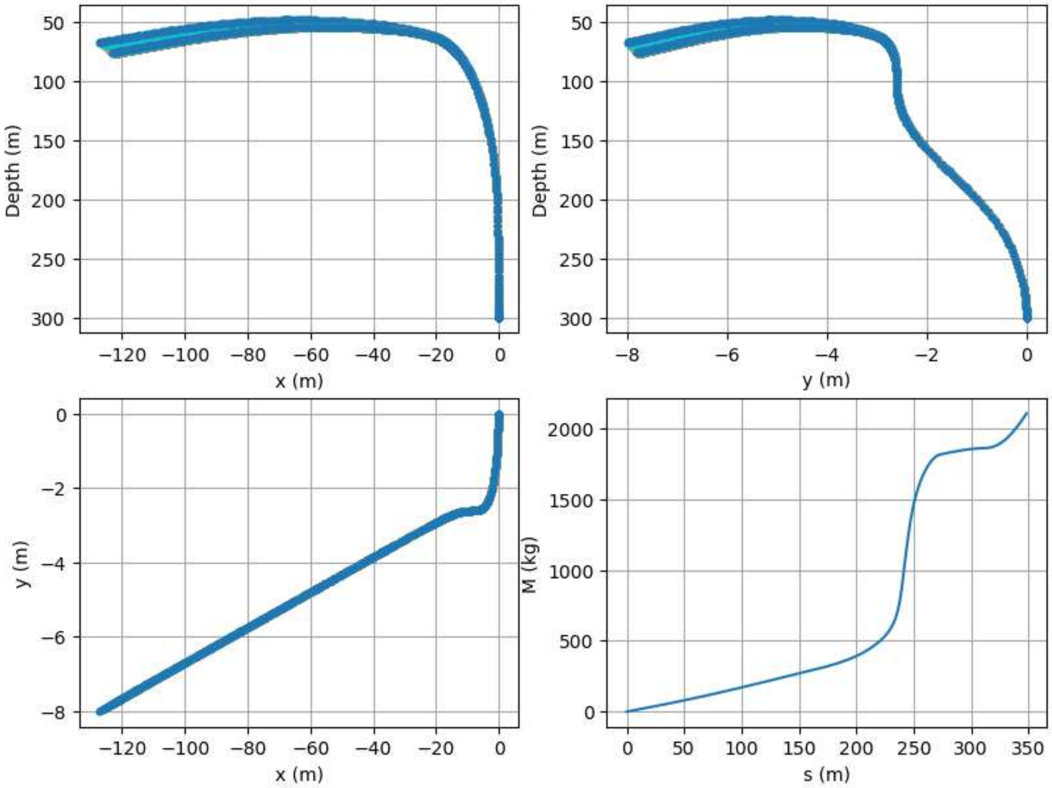

Figure A-3. Results of the TAMOC simulation for the worst-case discharge
The two views in the top plots are of the centerline of the plume from the south and the east. The plume has risen quickly, while being bent over by the cross current, with the current velocity strongest near the surface. The lower left plot is the view from the top. Note that the plume reaches the surface just over 100 m from the source. The lower right plot is the total mass in the plume along the plume centerline.

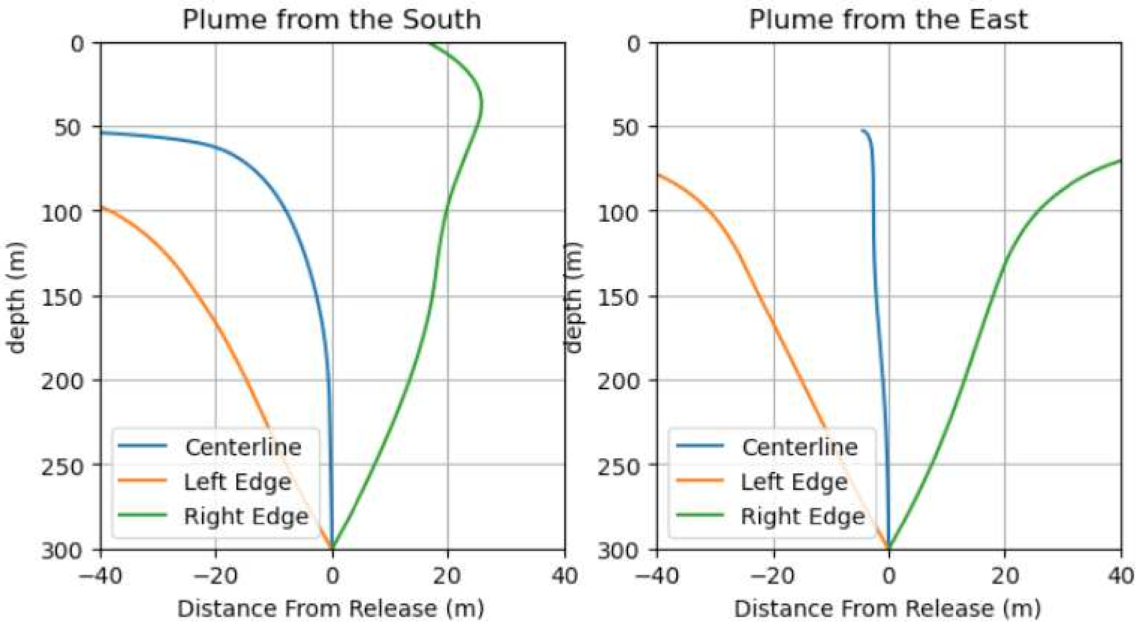

Figure A-4. Results of the TAMOC simulation for the worst-case discharge
The two views are from the south and the east. The centerline of the plume has been bent over by the currents, strongest near the surface. Near the surface, the plume no longer has clearly defined edges. The plume reached the mixed layer before trapping.

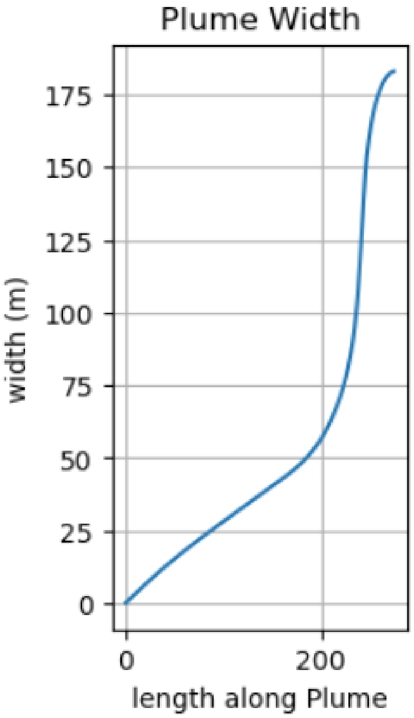

Figure A-5. Results of the TAMOC simulation for the worst-case discharge
The plume width increases as it entrains water, reaching a maximum width of 180 m before reaching the surface.

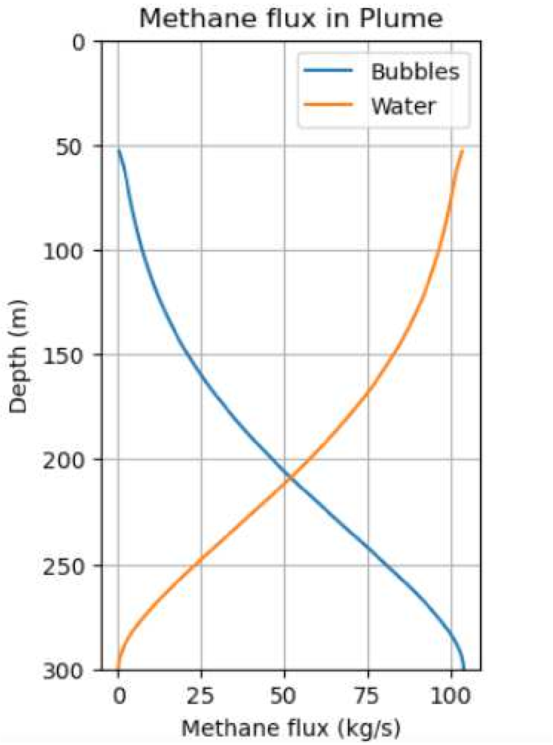

Figure A-6. Methane flux in the plume for the worst-case discharge
The blue line is the amount of methane in the bubbles (of all size classes), the orange line is the amount of methane in the water of the plume. As the bubbles dissolve, the methane in the bubbles transfers to the water; in this case, all the methane has dissolved into the water before the plume reaches the surface.

A.3.4 Plume-trapping Scenario

If a release were of a smaller rate, the resulting plume would be weaker, and might reach its trap height below the ocean surface. This would result in the oil droplets being released from the plume to be advected by ambient currents. Simulating these conditions in the relatively shallow water locations of wells in the Southern California Planning region necessitated reducing the flow rate and hence the buoyancy force of the oil-gas mixture. A reduction of the flow rate by an order of magnitude resulted in the plume "trapping" in the mid-water column.

The plume trapping simulation used the same water column conditions as the previous one, with a slower release rate of 2000 bbl/day and a hole diameter of 5 cm (assuming a slower release rate would likely result from a smaller orifice than the full bore hole). The resulting plume loses buoyancy and releases oil droplets at a depth of approximately 120 m above the well depth (180 m below the surface) as depicted in Figures A-7 through A-10.

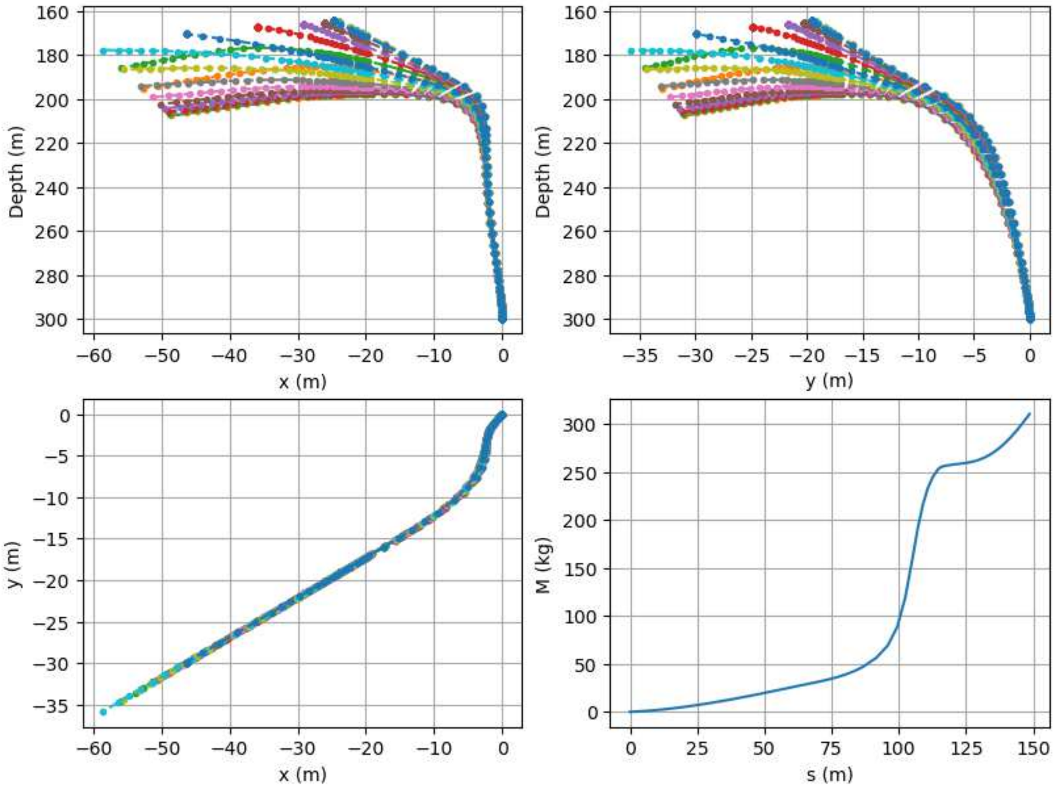

Figure A-7. Results of the TAMOC simulation for a moderate discharge
The varying colors are different size classes of oil and gas droplets; larger droplets rise more quickly. The two views in the top plots are from the south and the east. Note that the droplets are moving independently once they reach the trap height of approximately 120 m above the release (180 m below the surface). At this point, the oil droplets are released from the plume, and will move with the ambient currents (and their own rise velocity) The lower left plot is the view from the top, and the lower right plot is the mass in the plume along the plume centerline.

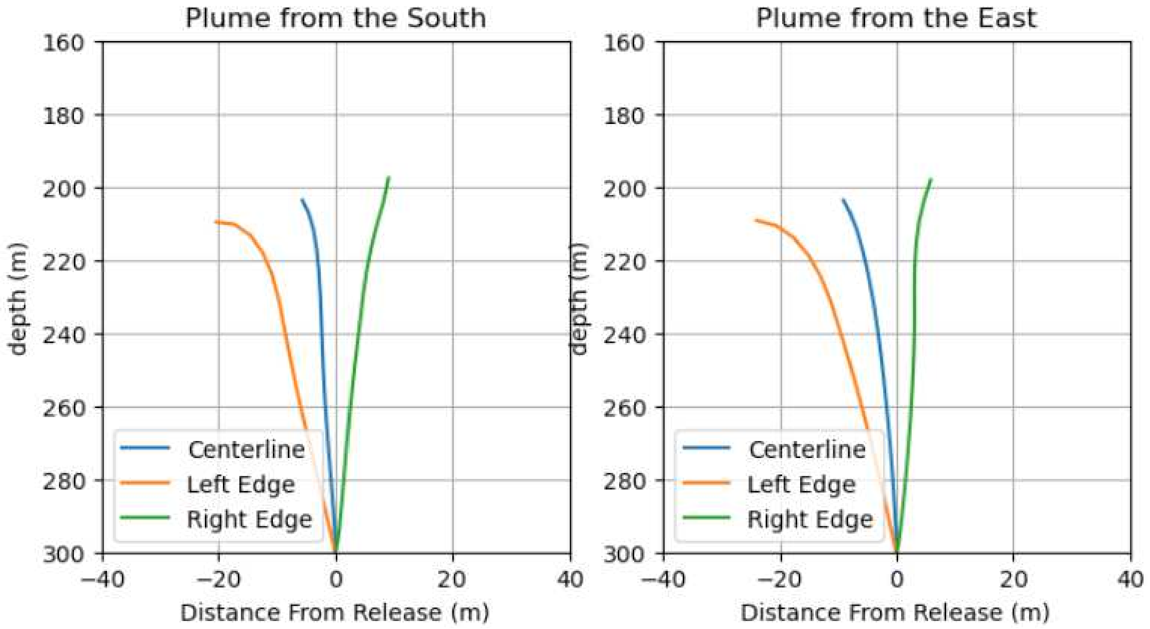

Figure A-8. Results of the TAMOC simulation for a moderate discharge
The two views are from the south and the east. The centerline of the plume has only moderately been bent over by the modest currents at depth.

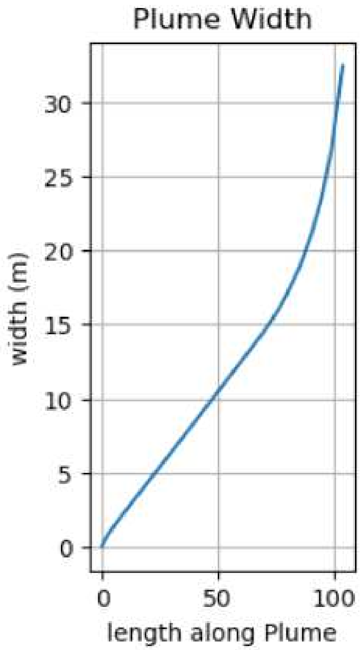

Figure A-9. Results of the TAMOC simulation for a moderate discharge
The plume width increases as it entrains water, reaching a maximum width of 32 m before trapping.

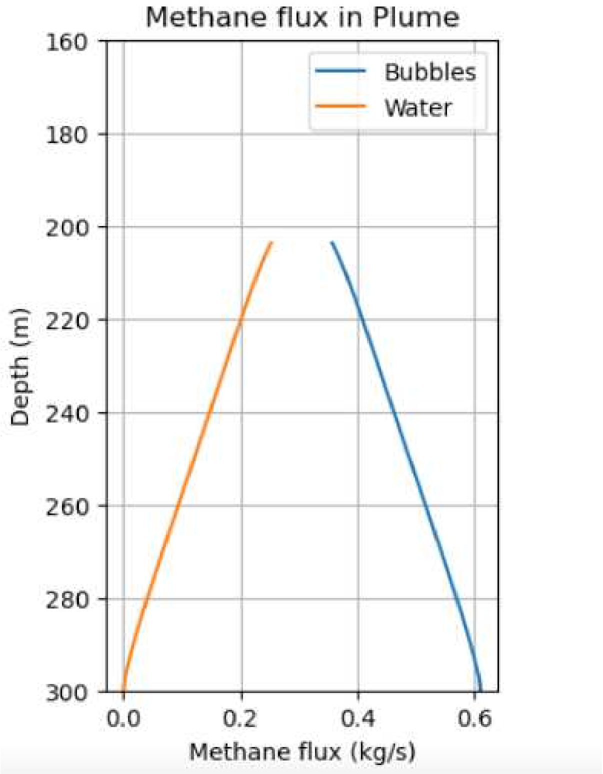

Figure A-10. Methane flux in the plume for a moderate discharge
The blue line is the amount of methane in the bubbles (of all size classes), the orange line is the amount of methane in the water of the plume. As the bubbles dissolve, the methane in the bubbles transfers to the water; in this case, about half of the methane has dissolved into the water before the plume traps, releasing the bubbles into the water column. Those bubbles will rise through the water column and continue to dissolve on their way up.

When a plume traps below the water surface, the movement of the oil droplets are no longer governed by plume dynamics, and can be more accurately modeled with a 3D simulation that takes into account the currents at depth, as well as the rise velocity of the oil droplets. The rise velocity of the droplets is a function of the droplet size. For reference, Table A-2 shows rise times for droplets from 300 m and 180 m depth based on their diameter, from GNOME based on Galt and Overstreet 2014. In a calm water column, a 100-µm droplet could take almost a week to rise from 300 m, while a 5000-µm (5 millimeter [mm]) diameter droplet could surface in approximately 1 hour from the same depth. In the ocean, droplets smaller than about 50 µm are unlikely to reach the surface and form a slick as the turbulence in the water column will keep them suspended.

Table A-2. Rise velocities for droplets of varying sizes from GNOME
With the bulk of the mass in droplets larger than 1000 µm, most of the oil droplets will reach the surface within about 12 hours.

Droplet size (µm)	Rise velocity (m/sec)	Rise time from a 300 m release (hours)	Rise time from a 180 m release (hours)
100	0.000468	178.0627	106.8376
200	0.00187	44.5633	26.7380
300	0.00237	35.1617	21.0970
400	0.00292	28.5388	17.1233
500	0.00353	23.6072	14.1643
1000	0.00737	11.3071	6.7843
1500	0.0124	6.7204	4.0323
2000	0.0186	4.4803	2.6882
3000	0.0336	2.4802	1.4881
4000	0.0513	1.6244	0.9747
5000	0.0704	1.1837	0.7102

As discussed in Section A.3.2, the DSD is a function of the oil properties and the level of turbulence of the release. For the plume trapping scenario with the reduced spill rate and orifice, the median droplet size was estimated to be 1.8 mm, with the resulting distribution shown in Figure A-11. Referring back to Table A-2, a median droplet leaving the plume at the trap height would take approximately 3 hours to reach the surface.

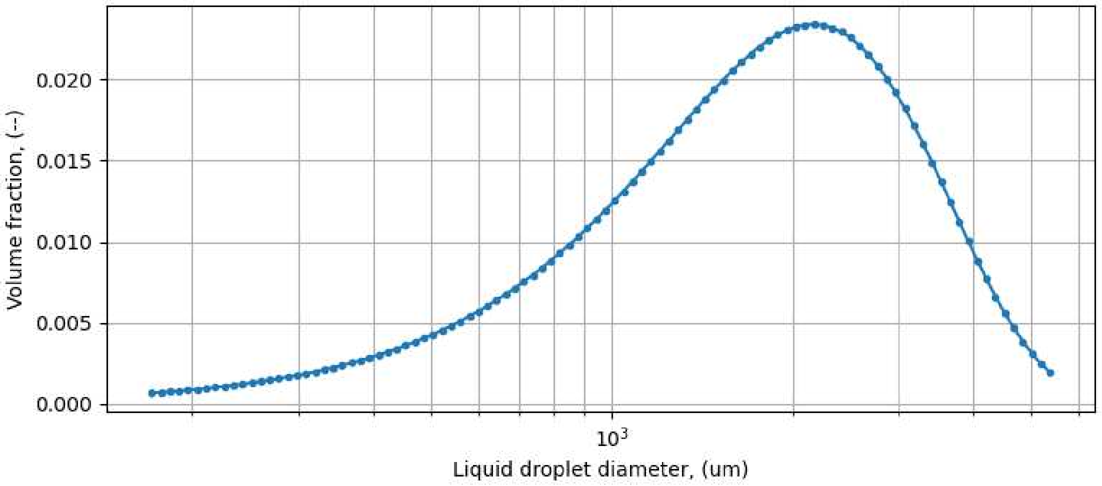

Figure A-11. Estimated droplet size distribution for a moderate discharge
Median (D_{50}) droplet size is 1.8 mm (1,800 µm). Note that most of the mass is in droplets above about 500 µm.

A.3.5 Subsurface Transport Modeling

For a moderate subsurface release that results in a plume that is trapped in the mid-water column, the trajectory of the oil exiting the plume can be modeled with a 3D oil transport model. For this study, the

GNOME model was used; it simulates the oil transport by simulating a range of droplet size classes, and computes the rise of the droplets as a function of oil properties and the droplet size (Galt and Overstreet 2014). The simulated droplets rise through the water column, while being transported by the 3D currents provided by the ROMS model, as well as being mixed and diluted by diffusion in both the vertical and horizontal directions. When a given class of droplets reach the surface, they are then also advected by the near surface winds and currents, just as a surface release would be.

For this simulation, the oil was released at a rate of 2000 bbl/day into the water column at the location of the Heritage Platform, and a water depth of 180 m below sea level, where the plume is trapped and no longer controlling the transport of the oil. The oil is released as droplets from a DSD with a D_{50} of 1.8 mm and the distribution described above.

Figure A-12 shows the oil horizontal locations after a 4 day trajectory run with a continuous release. The predicted oil location reflects the strong westward flow often seen in the Santa Barbara Channel in winter months. Note that this plot only displays the horizontal location of the modeled oil - the oil depth is not shown. Figure A-13 presents a 3D view of the trajectory. Since a continuous release was simulated, oil droplets are still seen to be rising through the water column, generally within approximately 10 km of the source. Further away from the source, the number of droplets in the water column is dwarfed by those at the surface. In total, approximately 95% of the oil is at the surface after 4 days of model simulation.

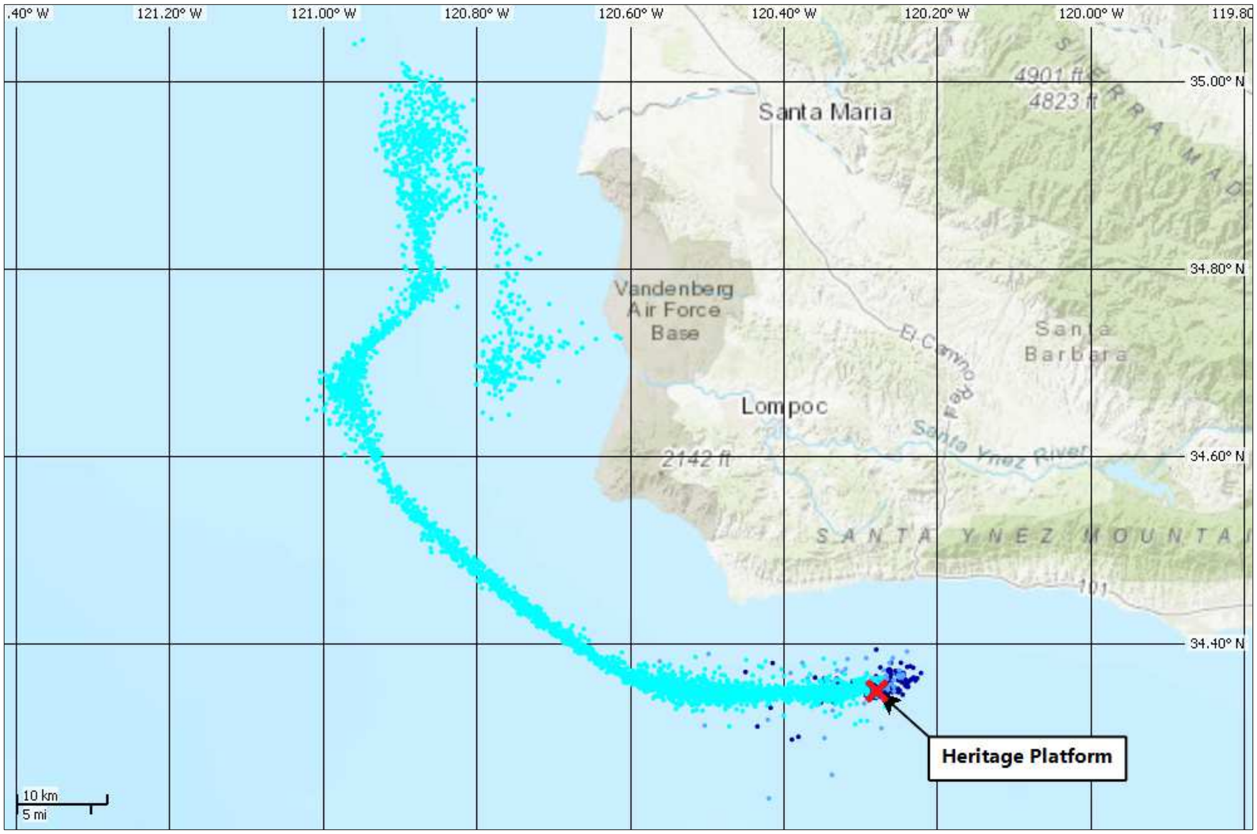

Figure A-12. Trajectory results for the moderate subsurface release
The image shows predicted oil horizontal positions 4 days after release from a continuous blowout spill of 2000 bbl/day. The color represents depth - light blue is on the surface, medium blue is shallower than 50 m (in the mixed layer) and dark blue is between 50 and 180 m deep.

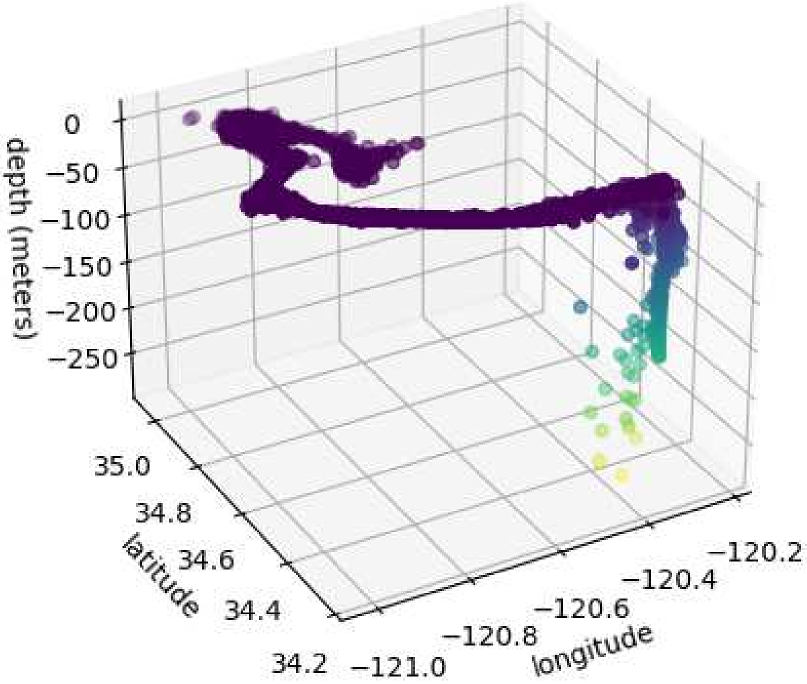

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Figure A-13. Trajectory results for the moderate subsurface release
The image shows predicted oil positions three-dimensionally, 4 days after release from a continuous blowout spill of 2000 bbl/day at 180 m depth. Colors correspond to oil depth.

Maximum subsurface concentrations of oil are shown in Figure A-14, as a function of longitude and depth. Again, the higher subsurface values are seen to be close to the source, as the oil rises to the surface. Subsurface values above 0.2 parts per million (ppm) are only seen within 10 km of the source. The color scale for this plot is selected to focus on the subsurface, meaning the values in the surface are beyond the limits of the color. The higher values in the surface layer close to the source are up to 4.0 ppm.

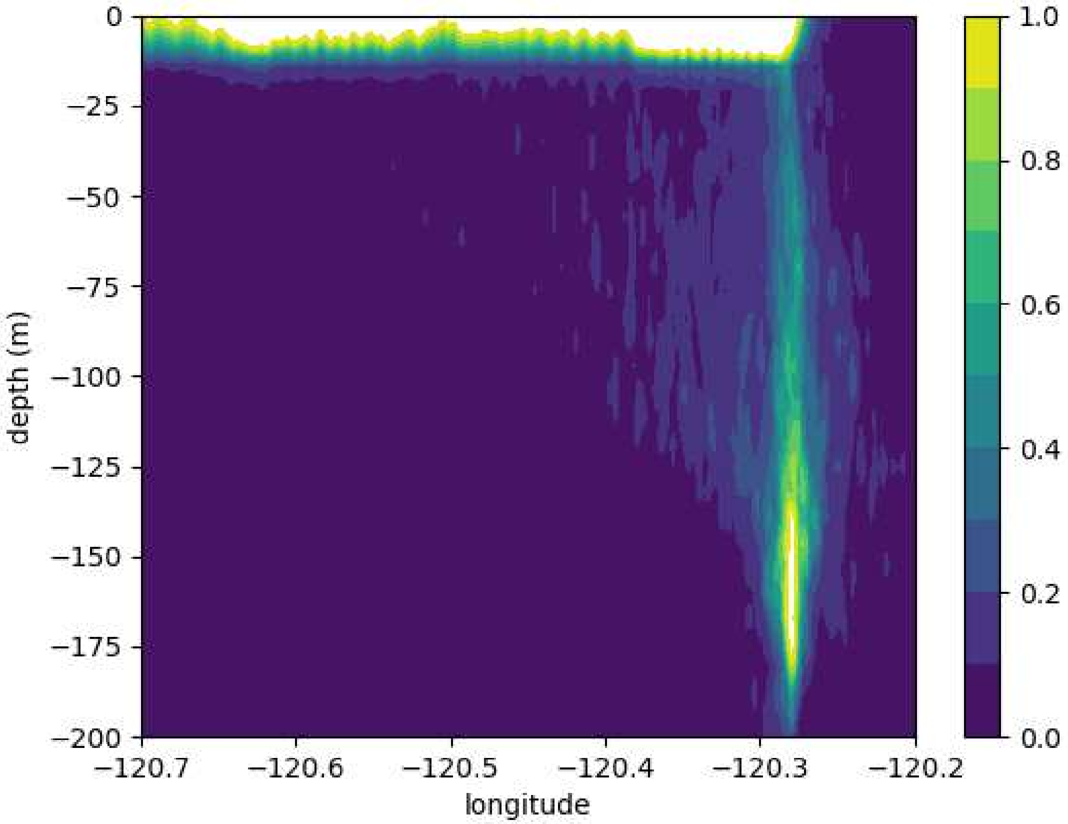

Figure A-14. Maximum concentration of oil as a function of longitude and depth, looking from the south
The color limits are set to focus on the subsurface concentrations, meaning the surface colors are all above 1 ppm.

This 3D test case was designed to examine whether the surface-only runs used in the TAP development for the Southern California Bight region would reflect the fate of oil released from a sub-surface incident. The release time was chosen to be during a time when horizontal velocities were at a maximum, meaning that the horizontal transport while droplets rose through the water column would be maximized. In most cases this horizontal transport will be less, further limiting the surface expression (the area where oil comes to the surface) of the spill.

A.4 Conclusions

These results confirm that from a planning perspective, focusing on surface transport and statistics resulting from those trajectories may be sufficient for scaling the extent of regional impacts. In the scenarios modeled, the bulk of the oil reached the surface fairly rapidly (within hours). Below the mixed layer, oil concentrations fell to <0.1 ppm within 10 km from the source location.

While the surface focused TAP modeling results may be sufficient for scaling regional impacts in terms of illustrating the likely extent of surface oil footprints and threatened shorelines, there are response questions that could only be examined through full 3D modeling simulations. For example, subsurface dispersant application could significantly alter the droplet size distribution and allow more oil to remain in the water column. Although undertaking a full 3D statistical analysis may be unnecessary for answering these planning focused questions, in the event of an actual subsurface spill, a 3D modeling approach like that described here would be essential for examining many response related questions.

A.5 Appendix References

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