

Improvements to the Work on Integration of NOAA's GNOME Model with CDOG Model

A Final Report Submitted to

The Coastal Response Research Center

Submitted by

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July 29, 2005



This project was funded by a grant from NOAA/UNH Coastal Response Research Center.
NOAA Grant Number(s): 04-840.



Abstract

CDOG (Clarkson Deepwater Oil and Gas) model simulates the behavior of oil and gas released from deepwater. GNOME (General NOAA Oil Modeling Environment) is the National Oceanic and Atmospheric Administration (NOAA) spill response trajectory model. CDOG integrates the hydrodynamics of the jet/plume, the thermodynamics, and the hydrate formation and decomposition. CDOG simulates both the dynamics of the jet/plume phase and the far-field conditions during the rise of oil/gas/hydrates through the water column. CDOG allows gas/hydrates to separate from the main plume if there are strong cross currents. CDOG was redesigned to integrate with GNOME, so GNOME provides the Graphical User Interface (GUI) and surface oil trajectory. GNOME is designed to be flexible; allowing the model to use circulation fields from circulation models on different grids (rectangular, curvilinear or finite element), and includes a number of diagnostic tools. This paper reports the improvements to the integration of CDOG with GNOME so that users can set up CDOG from GNOME, run CDOG, and then easily transition to running GNOME for the surface trajectories. CDOG version 2 can simulate variable discharge conditions for oil and gas and is now also compatible with GNOME. This integration allows the users to run complete scenarios – the types that are required in comprehensive contingency planning. During the integration, other features were introduced. Among them are: compatibility checks; much better error trapping procedures; dual format output; and the ability to use netCDF data.

Keywords:

CDOG, GNOME, Integration, NetCDF, Error Checking, Compatibility

Acknowledgements

The integration of CDOG with GNOME was made possible through the support of Corporate Institute for Coastal and Estuarine Environment Technology (CICEET) at the University of New Hampshire. This research was administered by the Coastal Response Research and Research Center (CRRC) under the project No. 04-840. Drs. Nancy E. Kinner and Carol-Ann Mannen are the co-directors of CRRC. The support of Debbie Payton, and Glen Watabayashi from NOAA/HAZMAT during this integration is acknowledged.

CDOG was developed during an earlier project supported by the Minerals Management Service (MMS) of the U.S. Department of the Interior and the Deep Spill Task Force (DSTF). The authors acknowledge the support of Robert LaBelle and Walter Johnson of the MMS, Cortis Cooper, Dan Allen, and Timothy Finnigan of Chevron, USA and all other members of the DSTF for the development of CDOG.

The GNOME Development team encompasses much of NOAA/HAZMAT response team. We thank them for continuing to actively participate in worksheet and dialog construction meetings in order to bring forth great response tools.

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1.0 Introduction

With the increasing oil exploration and production from deepwater locations, models are needed for emergencies and contingency planning. In 1998, the Minerals Management Service of the U.S. Department of the Interior in co-operation with a consortium of 24 oil companies created the Deep Spill Task Force (DSTF), and embarked on a plan to develop a computer model that can simulate oil and gas behavior from a deepwater blowout. This model, the Clarkson Deepwater Oil and Gas (CDOG) model, was completed a few years ago. The DSTF also sponsored large-scale field experiments where oil and gas were released from an ocean depth of 844 m off the coast of Norway. A major objective of the field experiments was to provide data for improving the computer models. Conducting these field experiments is very complex and costly. Furthermore, very few countries in the world allow them because of environmental constraints due to intentionally releasing oil. The fact that a 4-day field experiment cost \$2.5 million gives the reader an idea of how complex it is to get field data relevant for deepwater spills. More details of these experiments can be found in Johansen et al. (2001) and Chen and Yapa (2003).

Moving a research oriented model like CDOG into operational use requires more than adding a Graphical User Interface (GUI). Particularly for emergency response, the user has a task to accomplish as part of the response. That “task” is not running the model, though the task may involve running the model. For example, NOAA/HAZMAT provides trajectory analysis during a spill response. The GNOME model may be run, but the GNOME output is post-processed to add additional information from the trajectory forecaster to the Federal On Scene Coordinator (FOSC).

Principles of User Centered Design (Gould and Lewis 1985, Barnum 2002) should drive the development of the operational tool. The emergency response users want to accomplish their task in the minimum amount of time while maximizing the quality of the answer. For example, the first CDOG model could run a deepwater well blowout scenario with some inputs outside of realistic ranges. However, adding error trapping, and helping the user find and correct any errors ensure higher quality results from the model, thus higher quality products for the response.

CDOG simulates the behavior of oil and gas released from deepwater (generally considered depths of 800 m or more). The model integrates the hydrodynamics of the jet/plume, the thermodynamics, and the hydrate formation and decomposition. Despite the comprehensive nature of CDOG, it is designed to simulate the oil and gas behavior only until they reach the water surface. No Graphical User Interface (GUI) or data visualization were included in the original CDOG design. The US National Oceanic and Atmospheric Administration’s (NOAA) GNOME (General NOAA Oil Modeling Environment, Beegle-Krause 2001; Gnome web site) is the trajectory model developed and used by NOAA for oil spill response. GNOME is used as the interface for setting up the CDOG model, and then simulates the transport and spread of oil on the water surface after CDOG is run. GNOME is designed with a GUI to make the application easy to use during spill response, and has several user “modes” to allow users of different levels of sophistication to setup and use the model. This paper discusses the integration of the latest version of CDOG with GNOME so that complete three-dimensional behavior of releases of oil and gas from the deepwater can be simulated. The GUI for the merged version was based on the NOAA/HAZMAT Deepwater Spill Incident Data Preparation Sheet (Appendix A), developed

during a potential deepwater incident (Beegle-Krause and Lynch 2005). The integration of the GNOME and CDOG models was sponsored by the Coastal Response Research Center at the University of New Hampshire. The integrated version of GNOME/CDOG will provide the users better tools that are critical for both response and planning needs, and allows the users to run complete scenarios – the types that are required in comprehensive contingency planning.

The integration of the latest version of CDOG with NOAA's GNOME involved the following: (1) modify CDOG output to satisfy GNOME input data format requirements, (2) condense the CDOG input file structure for run-time and code efficiency, (3) provide error trapping procedures and messages within GNOME and CDOG, (4) design a strategy to maintain backwards compatibility of CDOG so that older input files could still be used and (5) design the GUI from GNOME to run CDOG. Because of the prevalence of netCDF (Unidata 2005) in the oceanographic community Clarkson developed an internal module to take netCDF formatted input data.

2.0 Objectives

The main objective of this project is to integrate the latest version of Clarkson Deepwater Oil and Gas blowout model (CDOG) with NOAA's GNOME. The tasks involved in this integration can be listed as follows

- Integrate CDOG and GNOME so that CDOG can be run from GNOME and CDOG output can satisfy GNOME format
- Modify CDOG input file structure and make it easier to run
- Provide error trapping procedures and messages
- Design a strategy to maintain backwards compatibility of CDOG
- Develop an internal module to take NetCDF format input data (not in the original project scope)

3.0 Methods

This section briefly describes the CDOG model and the methods used in integrating CDOG with GNOME.

3.1 Characteristics of a Deepwater Blowout

A model for simulating the behavior of oil and gas from a deepwater blowout differs from those developed for simulating oil or gas from relatively shallow water depth in several aspects. Some of the key features are listed below.

- i. Under high pressure and low temperature, gas may be converted to a solid like phase called gas hydrate. Gas hydrates consist of gas and water, and are a slush like (similar to frazil ice) compound.

- ii. Free gas may dissolve into water during its long journey to the surface and thus change the buoyancy of the jet/plume as well.
- iii. Under high pressure, gas behavior is better described by a non-ideal gas state equation instead of an ideal one.
- iv. Size of gas bubbles and their buoyant velocities (or slip velocities) can no longer be approximated as constant, considering the processes of gas hydrate formation, decomposition, gas dissolution, and gas expansion.
- v. Gas may escape from a jet/plume due to the gas bubble slip velocity if the jet/plume is significantly bent in a cross flow.

3.2 CDOG Model description

CDOG is a three-dimensional model to simulate the behavior of oil and gas released from deepwater. The model integrates the hydrodynamics and thermodynamics of the jet/plume, the thermodynamics and kinetics of hydrate formation and decomposition, and gas dissolution. CDOG simulates both the dynamics of the jet/plume phase and the far-field conditions during the rise of oil/gas/hydrates through the water column. CDOG uses an integrated formulation for computing buoyant velocity of gases and hydrates. This integrated formulation gives better results compared to more commonly used Stokes-Reynolds criteria for a wide range of oil droplet sizes (Zheng and Yapa, 2000). In CDOG, gas dissolution, as the gas bubbles travel through the water, computed using simple Henry's law deviates significantly from the actual values in ultra-high pressure conditions (Zheng and Yapa, 2002). The dissolution computed in CDOG accounts for the non-ideal behavior of gases under ultra-high pressure. CDOG can simulate the behavior of oil and gas in strong cross flow conditions where gases may separate from the main plume. The CDOG formulations were given in Yapa et al. (2001). An updated and more detailed formulation can be found in Zheng et al. (2003). A schematic diagram showing the key oil/gas processes during a deepwater spill is given in Fig. 1.

The latest version of CDOG can simulate scenarios with variable oil and gas discharge and uses a new concept of Discrete Jets (DJ). Using this concept, CDOG can simulate scenarios where the gas and oil discharge rates are constant or vary over time and the discharge periods for oil and gas can be independent of each other. The discharge variation is discretized in time separately from the model time step. For each model time step the discharge is considered to form a Discrete Jet (DJ). The simulation capability includes the plume dynamics and advective diffusion in the water column, and the surface transport. The integrated GNOME / CDOG models can be set up quickly in real emergencies.

CDOG was used to simulate the large-scale deepwater oil and gas discharge experiments "Deepspill" conducted off the coast of Norway (Chen and Yapa, 2003). The detailed comparison between the field experiments and the CDOG model simulations were in good agreement. CDOG model was also used to simulate a series of realistic field scenarios. A complete analysis of these scenarios can be found in Yapa and Chen (2004). CDOG was also used for response planning in the BP Thunder Horse potential deepwater blowout (Beegle-Krause and Lynch 2005).

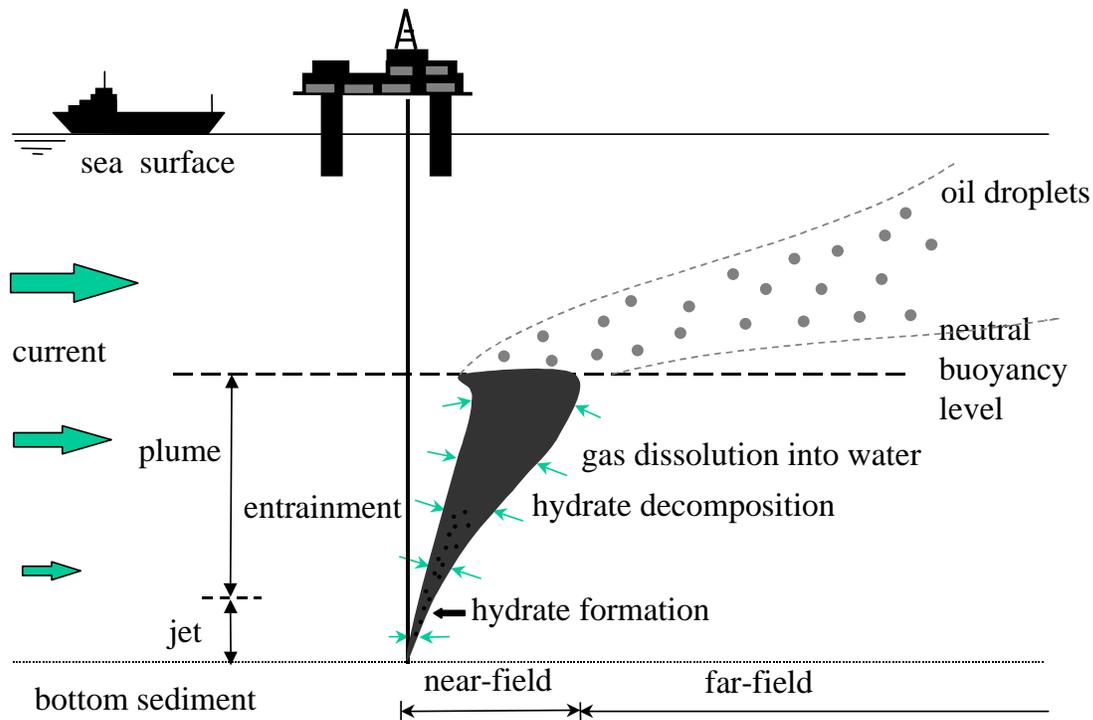


Figure 1. Schematic Diagram showing key processes during a deepwater spill (Zheng et al 2003)

3.3 GNOME Model Description

GNOME is the trajectory model developed and used by NOAA for spill response. GNOME's flexibility and usability are the keys to making the model functional as a quickly customized trajectory tool for emergency response. GNOME is a two-dimensional model that simulates the transport and spread of oil on the water's surface. The model is available as a free download and incorporates two user modes for different user levels of experience. In Standard/GIS Mode, GNOME can be used for analyzing the behavior of oil during a potential oil spill, and as a drill scenario tool using a Location File with a wizard interface. In Diagnostic Mode GNOME can use circulation fields from a number of different models in either ASCII or netCDF formats (Beegle-Krause et al 2003, Beegle-Krause 2003), and includes a number of diagnostic tools.

3.4 Design Strategy for Integration

The two models CDOG and GNOME evolved independently. GNOME is constantly under development as an emergency spill response tool, with the NOAA responders always looking for ways to make the model better for their needs. CDOG was a research model being moved into the response arena during the model integration. The CDOG and GNOME user interaction, input/output structure, and file management styles were very different. A concern during the integration was the likelihood of future CDOG development to meet the industry and governmental needs. The process had to be organized to minimize the chance that the integration would have to be done over again. In particular, maintaining backwards compatibility of older

input files between CDOG versions 1, 2 and any future versions was important. Therefore, the integration of the models required careful thought based on knowledge of the potential users and each model. Note that modifications to CDOG were made at Clarkson and modifications to GNOME were made at NOAA/HAZMAT, with NOAA/HAZMAT providing the overall vision for the merged applications. The paper also discusses some modifications to CDOG input that relate to a user setting up the files by hand rather than through the GNOME interface.

3.4.1 Simplification to the Data File Structure

A number of simplifications to the CDOG input file structure were made. The total number of input files was reduced by consolidating small files containing related data in order to reduce the CDOG file I/O time and reduce file clutter in the data input folder. The CDOG code was also modified to collect all the file I/O code into routines to make porting the code from the PC to the Macintosh simpler.

Simplifying input data in CDOG and data entry in GNOME were both done for the constant profile conditions (i.e. $du/dt=0$, $du/dx=0$, $dv/dy=0$ and $w=0$). CDOG takes the single profile and copies it to each vertical profile computationally rather than having the same profile repeated in the input file. GNOME's input dialogs for the oceanographic data have an option for the user to easily enter a constant profile by hand.

3.4.2 Error Checking and Messages

Spill response requires designing software that minimizes the time to run and maximizes the quality of the answer. Error checking at every stage of setting up the model prevents time lost from typos. Research models have little need for the detailed error checking required by responders. In the redesigned CDOG, if errors are found the program will indicate all the errors at this time step and then stop (*rather than crash*). When any errors occur, detailed error messages are displayed on screen. At the same time, the same messages will be written to a file "error_msg.txt". This is convenient for reference at a later point since the run time screen can disappear when the simulation is completed. The different types of error checks provided are listed below. The system is set up to allow the user to quickly identify where exactly there is a problem.¹ Certainly a responder could put in realistic data that is incorrect, and neither GNOME nor CDOG could catch that type error, but a good trajectory analyst should know enough to anticipate what the answer should be and catch these types of errors based on experience.

3.4.3 Missing data or missing file checks

When preparing the input data for using the model, there are two types of mistakes that occur related to the data: missing data in a file or missing an entire data file. The identification of these two types requires different checks. In the missing-data-in-a-file category there are two possibilities: single data is missing in a line or an entire line of data is missing. The integrated version now prints warnings for such missing data. Most importantly, it will identify in which file and the location within the file where the data is missing. For missing data files, error messages are issued indicating which file is missing. This also aided in debugging the GNOME code developed to create the CDOG input files.

¹ There is the possibility that a responder may alter a CDOG input file by hand rather than going through the GNOME/CDOG interface. Thus we have both models do data checks.

All CDOG input data has been made to be free format to reduce data entry errors and increase the speed of reading data. Because the input files use a free format, the program would not know where the end of a line is when a file only contains numeric data. To implement the above error-trapping scheme, a pair of parentheses is now required at the end of each line except the header line. The pair of parentheses can be used to indicate to the program the end of a line for free format input. This allows the program to show the users in which line the error has occurred.

3.4.4 Out of range parametric values or unreasonable input

Users may try to input data that are either unreasonable or beyond the range originally anticipated, which could result in the model crashing. To provide a protection against this type of problem, both CDOG and GNOME check to see if the key input parameters are outside a previously identified range. This includes errors such as oil release point being below the bottom of the sea. If any input data is found to be outside the pre-decided ranges, they are considered to be in error and the model will warn the user. Most of the data value error checks are “soft”, so the user can override them in case the scenario really is beyond what has been anticipated.

The list of parameters for error checking inside the model has been extended and is given in Table 1. The data ranges are based on suggestions from several oil companies, NOAA, and the CDOG development team. These parametric range limits are in a “read-only” file in a separate protected folder. This allows the user to clean the input data folder for fresh simulations without having to worry about deleting important model parametric values.

3.4.5 Sample screen captures of error messages

Figure 2 shows an example of error messages written in the file “error_msg.txt”. In this case, five errors occur in several input data files. These errors are:

- i. Input data file “geninf.dat” is missing (data file missing)
- ii. Data is missing in line 3 of the file “grid.dat” (data missing)
- iii. The version number for the file “u001.dat” is CDOG1.3, which doesn’t agree with the version number of the present model (compatibility checking).
- iv. The value of ambient salinity 105.525 in the line 6 of the file “sal001.dat” is out of the range from 0 to 50 psu (data is out of range, Error 1 in one file).
- v. The value of ambient salinity –4.525 in the line 9 of the file “sal001.dat” is out of the range (data is out of range, Error 2 in one file).

Table 1: Data ranges for the input parameters

Parameter	Data Range	Unit
The depth of spill position	0 — 12000	m
Initial bubble radius	0 — 0.01	m
Gas molecular weight	15 — 36	g/mol
Gas hydrate density	900 — 940	kg/m ³
No. of output files within a period	>0	
Time step of advection/turbulent diffusion simulation	>0	min
Output skip with respect to time step	>=0	
Number of points to decide discharges	>=2	
Oil discharge rate	0 — 0.92	m ³ /s
Gas discharge rate	0 — 165	m ³ /s
Gas to oil ratio	0 — 2000 Note: For gas oil mixtures the limit is 2000. For gas only cases – no limit.	SI
Temperature of discharge	-1 — 232	°C
Diameter of orifice	0 — 2	m
Density of oil	700 — 1060	kg/m ³
Output interval with respect to time step (in the plume phase)	>0	
Grid number in x direction	>0	
Grid number in y direction	>0	
Grid number in z direction	>0	
Length of grid in x and y direction	>0	km
Depth of the ocean bottom	0 — 12000	m
Diffusivity horizontal	0 — 10 ⁶	cm/s ²
Diffusivity vertical	0 — 10	cm/s ²
Number of oil droplet size	0 — 20	
Time interval for inputting wind data	>0	hr
Wind speed	0 — 50	m/s
Current speed in x direction	0 — 50	m/s
Current speed in y direction	0 — 50	m/s
Current speed in z direction	0 — 5	m/s
Temperature (x, y, z, t)	-4 — 35	°C
Salinity (x, y, z, t)	0 — 50	psu

```
error_msg.txt - Notepad
File Edit Format View Help

Error Message: The input data file geninf.dat doesn't exist.

Error Message: Some data is missed in the input data file grid.dat.
The error is in line 3

Error Message: The version of the file u001.dat is CDOGG1.3
It doesn't agree with the version of the program CDOGG2.1
Please check the file line 1
The file is skipped

Error Message: The input ambient salinity 105.5250015000000
is outside the recommended range from 0.0000000E+00 to 50.00000 (psu)
The error is in the file sal001.dat line 6

Error Message: The input ambient salinity -4.525001500000000
is outside the recommended range from 0.0000000E+00 to 50.00000 (psu)
The error is in the file sal001.dat line 9

Due to the 5 errors listed above, the program stops
```

Figure 2. A screen capture of the output file “error_msg.txt”

3.5 Maintain Backwards Compatibility

There is a need to maintain version compatibility between the data and the model. The objective is to maintain, to the extent possible, the ability of future versions of the model to read older data files. The following scheme has been implemented to fulfill this objective. Each data file will have a header line indicating which version the data file belongs to. When reading each input data file CDOG will check these files against the model version number, and then use the correct input routines to read the data. This feature will secure that the investments made to integrate CDOG with GNOME will not be wasted and future versions of CDOG can be incorporated into GNOME without major efforts.

3.6 Input Formats Extended to netCDF

To ensure that GNOME and CDOG are compatible with the Integrated Ocean Observing System (IOOS, <http://www.ocean.us>) Data Management and Access Committee (DMAC) standards (Ocean.US 2005), both models accept Network Common Data Form (netCDF). GNOME had previously been modified to accept netCDF (Beegle-Krause et al 2003) in order to be more compatible with the NOAA Live Access Server (LAS, <http://ferret.wrc.noaa.gov/Ferret/LAS/>). The ultimate goal is to use LAS to custom subset and reformat nowcast/forecast models available through IOOS for GNOME input, and then have GNOME make any secondary format or grid adjustments for CDOG input. NOAA’s experiments have indicated that using the LAS, NOAA can contact, examine and download customized model subsets for GNOME in under 2 minutes.

The CDOG model needs two kinds of input data: spill related data and circulation data. The spill related data is entered using ASCII files. Circulation data can be entered using either netCDF or ASCII format. NetCDF is designed for large circulation numerical model I/O files and requires the use of special tools and libraries to create, read and manipulate these files. However, the

resulting data files are platform independent, self describing and direct read. These attributes allow netCDF enabled applications to easily open an unknown file and extract custom subsets. With an ASCII input file, the time to read the file is proportional to the file size; with netCDF data, the time to remove a desired subset of data is virtually independent of the amount of data in the file.

HAZMAT has set up GNOME to use forecast data sets from outside circulation forecast models such as the Princeton Ocean Model (POM), Regional Ocean Modeling System (ROMS) or QUODDY and climatologies such as the National Virtual Ocean Data System (NVODS) that are already formatted using netCDF, so adding netCDF capability to CDOG will reduce the amount of data reformatting between GNOME and CDOG.

Since there are benefits with the native CDOG ASCII input format, it was also retained. Native CDOG format is very easy for human's to understand – a data error can be detected directly from the file – and for people who are not familiar with netCDF native CDOG format is easy to use. For output, all the post-plume phase can be output in both the CDOG and GNOME formats. Users are allowed to choose between the two options. Output files other than post-plume phase output are independent of the format option used and are always output in native CDOG format after a simulation.

3.7 Running CDOG from GNOME

After the integration, the CDOG model can be run from the GNOME interface. The user initiates a GNOME session and sets up the scenario from GNOME. Then the user starts the CDOG model to begin the simulation of the subsurface oil/gas/hydrate behaviors in the water column after a blowout. The GNOME model then takes the CDOG data for the time and locations of oil surfacing and then calculates the surface oil slick trajectory. The simulated results can be visualized on the GNOME interface or through the GNOME GIS extension.

4.0 Results

The scenario we are using is for an area of deepwater oil exploration in the northern Gulf of Mexico. Our fictitious well “Gulf Pride” is located at 27.5° N, 89.7° W with an overall water depth of 1989 m. This spill is a “burp” of oil and gas presumably from the well head at 1985 m at 3:30 AM CST April 1, 2005. Total oil lost is estimated to be 3,000 bbls. NOAA/HAZMAT would trajectory information for the visualized oil and decides to run CDOG as a training exercise. The platform personnel have the following CDOG related information: the well pipe diameter is 10 cm, the oil density is 36.46 degrees API (36.46 o API = 0.9425 g/ml); the Gas Oil Ratio is 900 MSCF/bopd (thousand standard cubic feet/ barrels of oil per day) and the release temperature is 80°C.

As in a real situation, current profile data would be available through most of the water column, as on-site operations need to monitor the currents, particularly passages of the Loop Current as it meanders about. However, limited temperature and salinity data is available. The available T,S data would be expanded using data archive such as the NOAA National Ocean Data Center World Ocean Database online search capabilities, and climatologies, such as the Levitus (1982) Climatology of the World Ocean access via the online National Virtual Ocean Database. See

Figs. 3, 4, and Table 2 for the hydrographic profile data used. The trajectory modeler would have to decide if the climatological data were appropriate to conditions, particularly the Loop Current position.

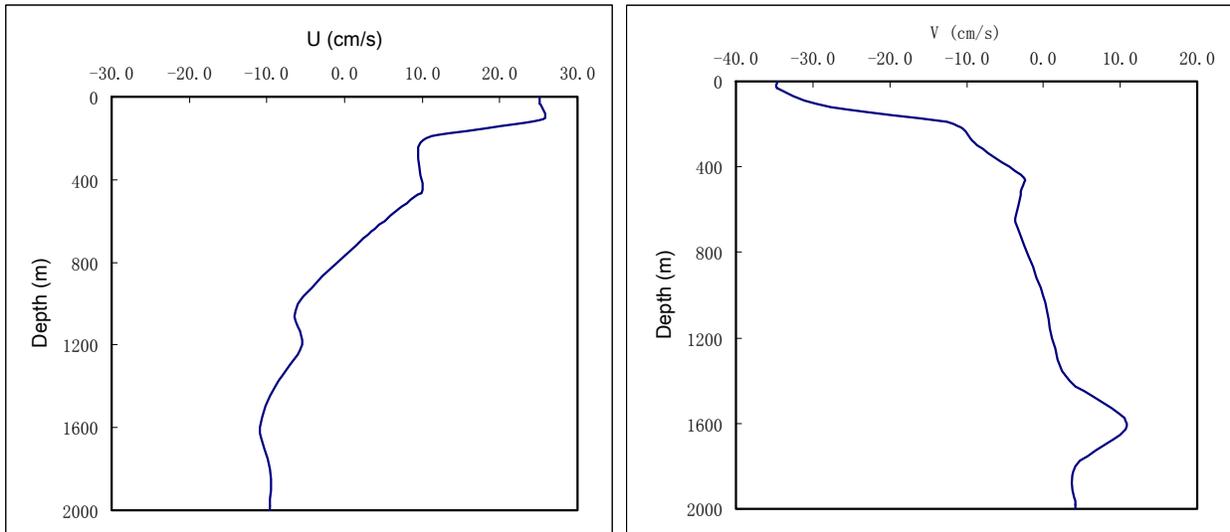


Figure 3. Ambient velocity profile for the scenario simulation; (a): East-West and (b): North-South

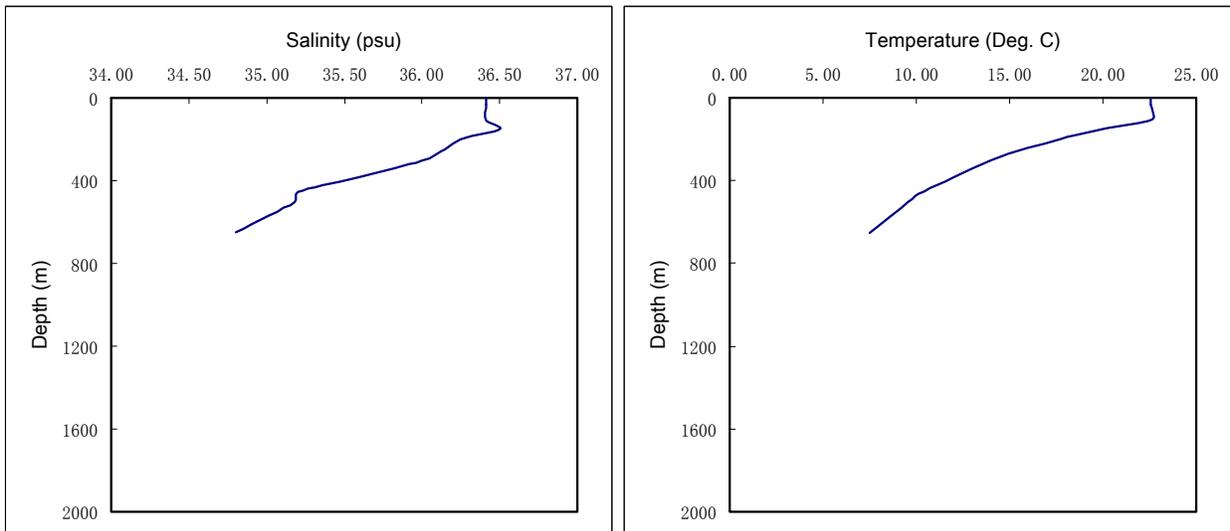


Figure 4. Salinity and Temperature profiles used for the scenario simulation; (a): Salinity; and (b): Temperature

Table 2: Profiles of U, V, salinity, and temperature

Depth	Velocity (cm/s)		Salinity (psu)	Temperature (°C)
	N	E		
0	-34.6	25.1	36.41	22.57
32	-34.6	25.1	36.41	22.57
106	-29.6	25.5	36.41	22.57
150	-21.0	18.3	36.50	20.00
198	-11.7	10.4	36.25	17.71
300	-8.7	9.5	36.00	14.00
452	-2.5	10.0	35.20	10.44
500	-2.8	8.4	35.18	9.61
650	-3.6	3.5	34.80	7.50
658	-3.7	3.2	Use above ²	6.7 ³
1000	0.0	-6.0	Use above	4.79 ⁴
1200	1.1	-5.5	Use above	Use above
1400	3.5	-8.9	Use above	Use above
1600	10.8	-11.0	Use above	Use above
1800	4.2	-9.6	Use above	Use above
1979	4.2	-9.6	Use above	Use above
1989	4.2	-9.6	Use above	Use above

The trajectory modeler would open GNOME in Diagnostic Mode and begin the steps to set up and run CDOG (see Fig. 5). The spill time and location information would be entered into GNOME’s “CDOG Spill Information” dialog (see Fig. 6). Gulf of Mexico shoreline is visible as a frame of reference in the window. GNOME’s left hand list keeps the responder updated on the information that has been added for a scenario. Notice in the lower left of the dialog that the units for the position information may easily be changed. Pull-down menus are used elsewhere for unit selection. This allows the responders to select the units used in the incoming information rather than calculating unit conversions. The three buttons on the lower right are the steps to setting up the CDOG specific information.

² Climatological salinity data is not available for the deep Gulf of Mexico at this time.

³ From NOAA National Ocean Data Center World Ocean Database. Only one near station was found in the month of April, but sampling extended only down to 831 m.

⁴ Levitus 1982 monthly world ocean atlas has temperature down to 1,000 m.

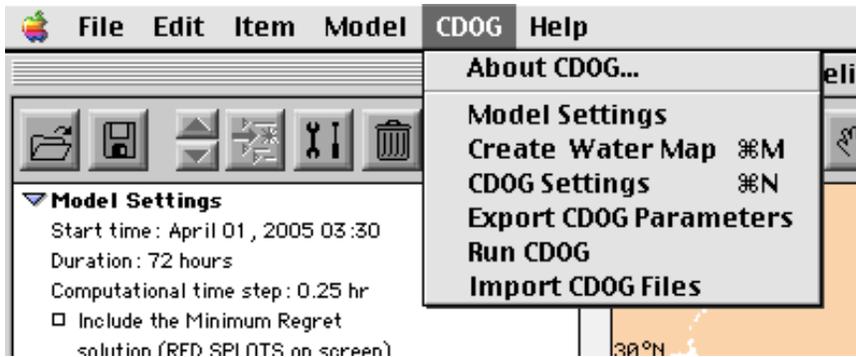


Figure 5. GNOME adds a CDOG menu item when the responder has the CDOG model. The menu has the steps to creating the full simulation in order from top to bottom.

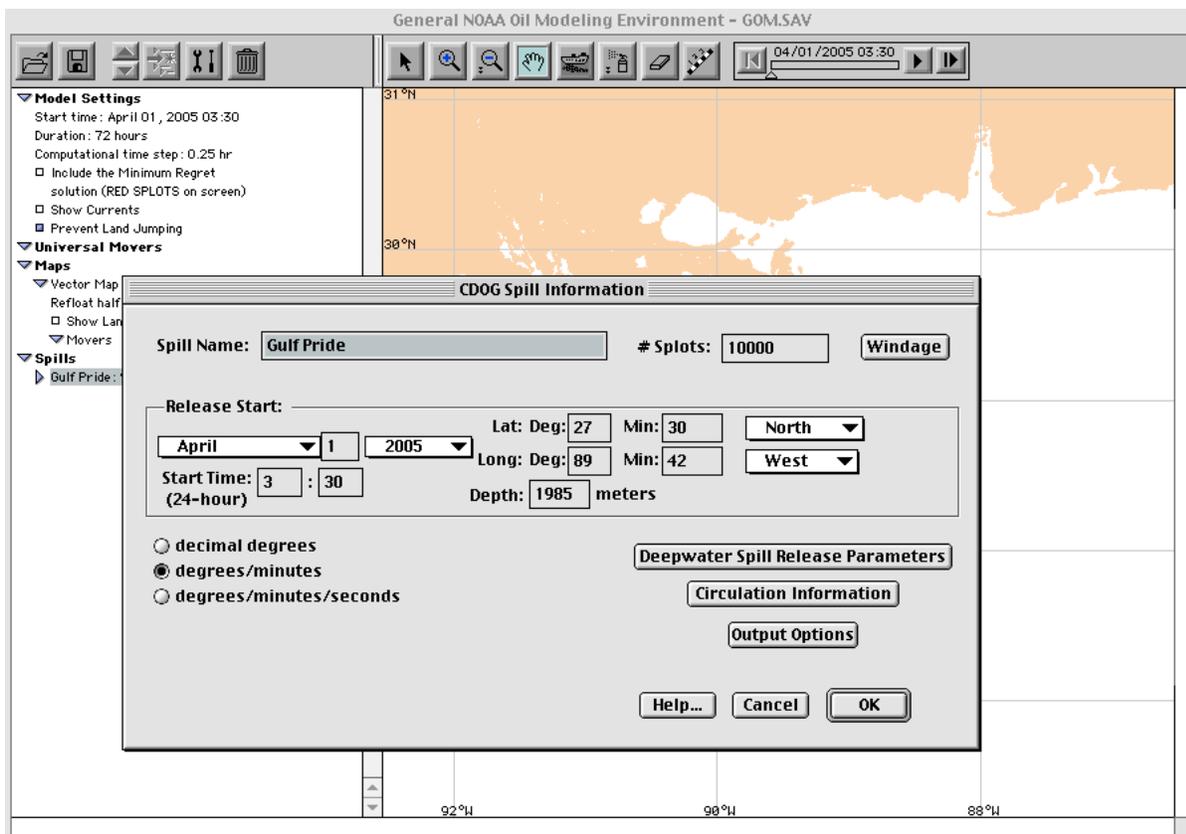


Figure 6. The GNOME map window is shown with the map loaded and scenario data summarized in the left hand list. The CDOG Spill Information Dialog takes the initial spill location information shows buttons for adding different types of CDOG specific information. The release parameters, hydrodynamic data and output options are set up next before GNOME would take the user back to the map window to run the model.

Next the spill release information are entered in the CDOG Spill Release Parameters dialog (see Fig. 7). Note the large number of pull-down menus in the dialog box. The options for the dialog

box change depending on the information the responder has. For example, the time series box on the upper right is not present until the modeler chooses a variable discharge, and the space to enter molecular weight and hydrate density only appears with the choice of natural gas. The last item at the bottom on the dialog asks the modeler if the gas contains hydrogen sulfide (H₂S) and has nothing to do with running CDOG. Having the question reminds responders to check whether or not H₂S is present, and provides a human health and safety warning when “yes” is selected from the pull-down. We don’t know if H₂S would reach the surface in concentrations that could be dangerous, but we would suggest responders monitor if the gas is known to contain H₂S. The hypothesized time series of the oil release is given in Table 3. Note that the trajectory calculations are extremely sensitive to the initial bubble radius and the initial oil droplet distribution, but these parameters are highly unlikely to be known during an incident. During an event the trajectory modeler would have to decide how many model runs with different parameters would be necessary to cover the spill’s “situation space”.

CDOG Spill Release Parameters

Variable Discharge ▼

Auto-increment time by: 0.5 hours

Discharge Time: 3.5 hours since convection output

Oil Discharge Rate: 2400 BOPD ▼

Gas to Oil Ratio (by Volume): 900 SCFD/BOPD ▼

Temperature: 80 deg C ▼

Diameter of orifice: 10 cm ▼

Oil Density: 36.46 API ▼

Time	Q oil	GOR	Temp	Diam	Dens
0	9600	900	80	10	36.5
0.5	14400	900	80	10	36.5
1	19200	900	80	10	36.5
1.5	14400	900	80	10	36.5
2	7200	900	80	10	36.5
2.5	4800	900	80	10	36.5
3	2400	900	80	10	36.5
****	****	****	****	****	****

Initial bubble radius: 2.5 mm (max 10mm)

Drop size: Use CDOG default ▼

Gas Type: Natural Gas ▼

Molecular weight of gas: 0.0191 kg/mol

Density of Hydrate: 920 kg/m**3 (900-940)

Hydrate process: do not suppress ▼

Separation of gas from plume: Separation Possible ▼

Does Gas Contain Hydrogen Sulfide? No ▼

Buttons: Add New Record, Delete Selected, Delete All, Help..., Cancel, OK

Figure 7. The CDOG Spill Release Parameters is used for the CDOG specific spill information. Note the use of pulldowns for unit selection, so the modeler does not have to make unnecessary calculations. The time series window only appears when a variable discharge is selected. For the gas type, molecular weight and hydrate density blanks only appear when natural gas is selected rather than methane. The final question regarding Hydrogen Sulfide is a human health and safety check, rather than information for CDOG. A warning message appears if “yes” is selected to remind the modeler to check this information.

Table 3: Times series of the release estimated to be a total of 3,000 bbls.

Time [hrs]	Volume [bbls]
0.0	400
0.5	600
1.0	800
1.5	600
2.0	300
2.5	200
3.0	100

After setting up the spill, the circulation fields need to be either loaded or constructed in GNOME. Figure 8 shows the choices for the modeler. GNOME is designed to be a flexible tool that can use a simple profile or a 3D time dependent circulation model on a variety of numerical grids. GNOME restructures the circulation data for CDOG. Within this scenario the profile data is constructed by the modeler (Fig. 9). All hand constructed time series information (file loading is also allowed) in GNOME (e.g. winds, currents, spill release) uses a similar interface where records can be added, replaced or deleted. Consistency allows modelers to work more quickly during a response. At this point some housekeeping issues are taken care of such as CDOG output file selection, GNOME outputting the CDOG files, running CDOG and then taking the CDOG file for GNOME.

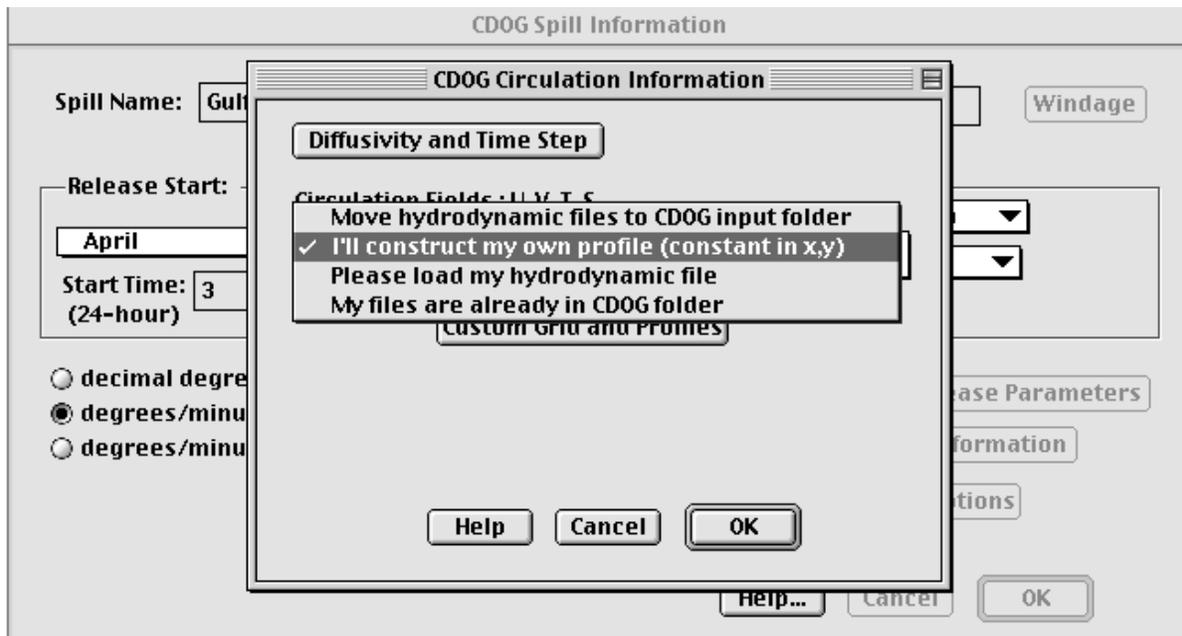


Figure 8. The GNOME model is set to take different types of circulation data to be translated into CDOG format. A simple profile can be constructed by hand, as in the example, or a 3D circulation model can be loaded. The other options are for users that already have data ready for CDOG, for example, if new spill information was added and the same circulation data would be used.

Input CDOG Hydrodynamic Profiles

Depth: meters (z positive down)

U: V: m/s

Temperature: degrees C

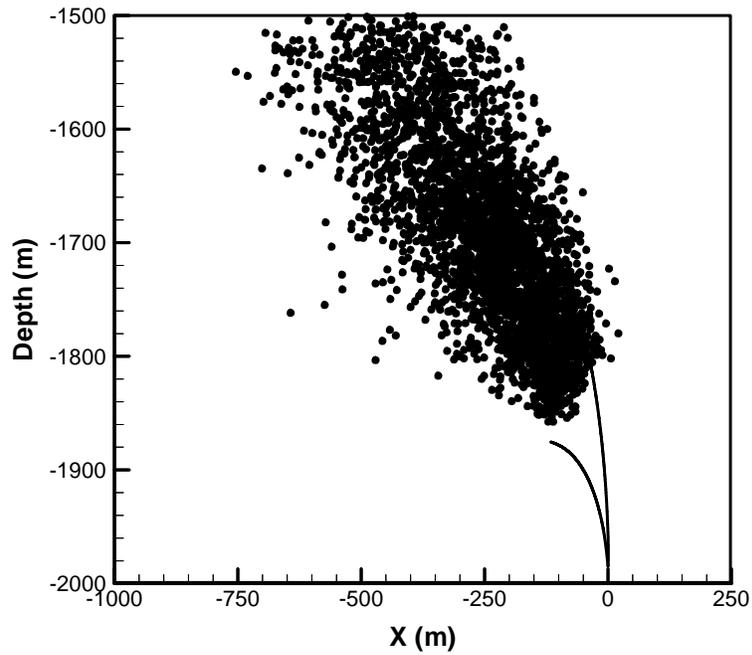
Salinity: ppt

Auto-increment depth by: meters

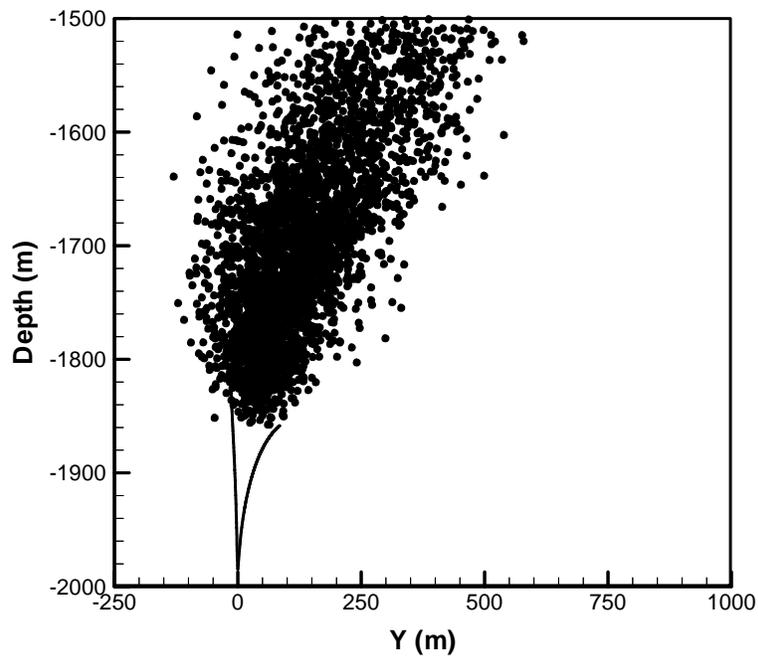
Depth	U	V	W	Temp	Sal
32	0.251	-0.346	0	22.6	36.4
106	0.251	-0.296	0	22.6	36.4
150	0.183	-0.21	0	20	36.5
198	0.104	-0.117	0	17.7	36.2
300	0.095	-0.087	0	14	36
452	0.1	-0.025	0	10.4	35.2
650	0.035	-0.036	0	7.5	34.8
****	****	****	****	****	****

Figure 9. The hydrodynamic profile construction dialog box. Since W velocity data is required in CDOG, but identically zero in the constant profile case, GNOME fills in the value for the user. All the time series dialog boxes (oil source, wind, hydrodynamics) use the same look and feel in GNOME to make it easier for the user.

CDOG does not contain any graphics, but the subsurface plume trajectory can be visualized from the output data files (Fig. 10). The surface trajectory in GNOME shows the footprint of oil reaching the surface over time (Fig. 11). Local wind data in combination with a wind forecast from the NOAA National Weather Service would be used to predict the surface trajectory of the oil. In this scenario, the oil is unlikely to contact any shoreline from such a large distance.



a)



b)

Figure 10. Side View of submerged oil and gas release simulation within CDOG at T=1.2 hrs: a) East-West; b) North-South.

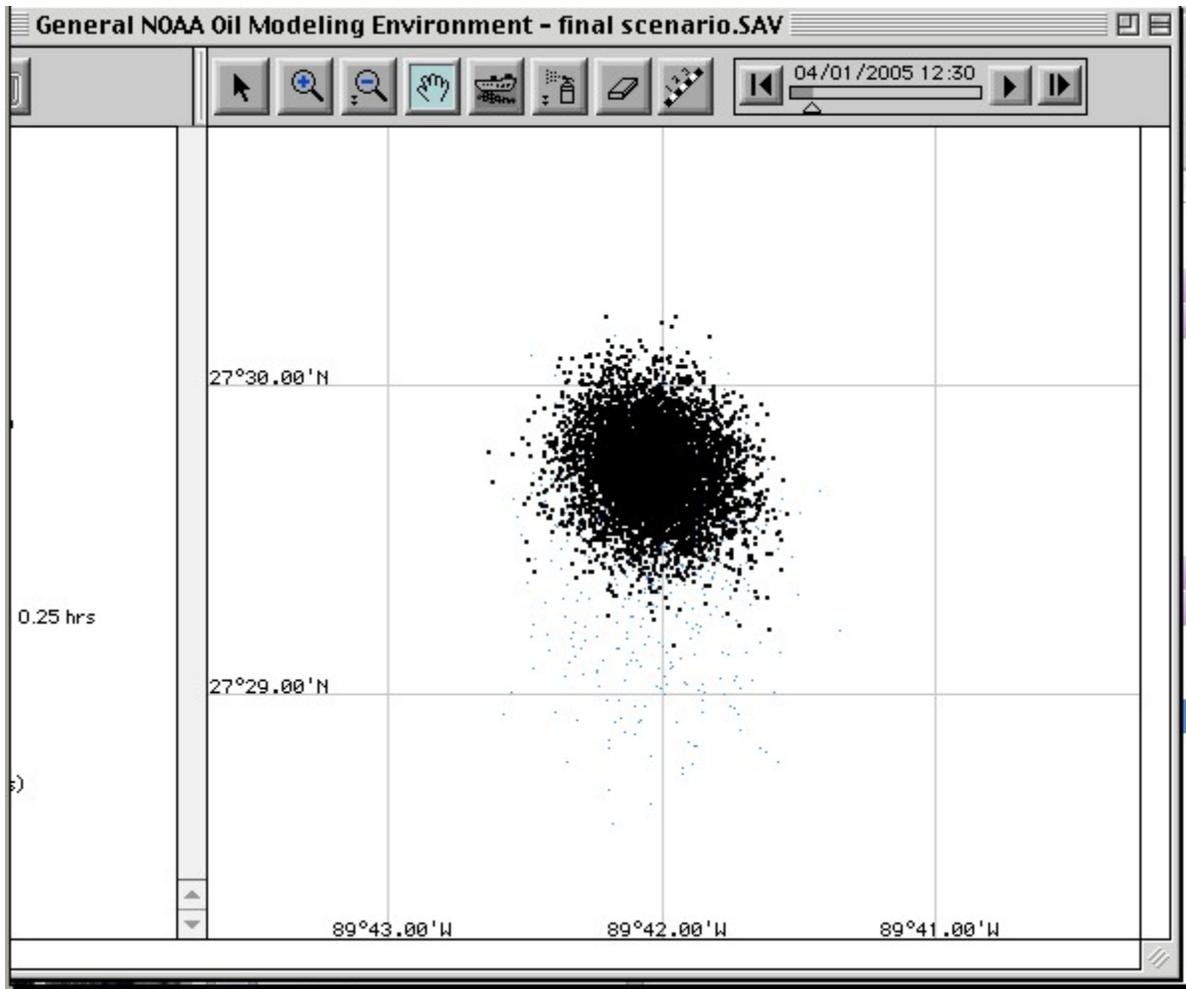


Figure 11. Sample GNOME interface screen capture for visualization of output from a CDOG and GNOME integrated simulation.

5.0 Discussion

The Clarkson University CDOG model was a previously developed research model to simulate the behavior of oil and gas released from the deepwater. The model considers hydrodynamics and thermodynamics of the jet/plume, hydrate formation and decomposition, free gas dissolution into seawater, oil and gas transport in the far-field, and possible gas or hydrate separation during the plume phase. The CDOG model was designed to be integrated with NOAA's GNOME spill response trajectory model once major development of CDOG was complete. No Graphical User Interface (GUI) or data visualization were included because GNOME could provide these. GNOME is designed to be flexible; allowing the model to use circulation fields from a number of different models on different numerical grids, and includes a number of diagnostic tools. After the integration of CDOG and GNOME model, the user can run CDOG from GNOME. Once CDOG is run, GNOME takes over modeling the surface transport of the spill.

The latest versions of CDOG and GNOME have been integrated to provide NOAA and the oil spill response community with a comprehensive deepwater well blowout model. The guiding

principle for the integration from NOAA was “usability.” The integrated modeling system uses the NOAA Deepwater Spill Incident Data Preparation Sheet (see Fig. 12) as the starting point for the interface, as a responder is likely to be working from this paged faxed in during the incident. Since the worksheet has a number of unit options, so does GNOME’s interface for setting up CDOG. Both GNOME and CDOG have extensive error checking, not only to prevent unrealistic scenarios due to typos, both to quickly help the responder pinpoint exactly where the problem is. The integration was also designed with backward and forward compatibility in mind, so that further CDOG or GNOME development will not invalidate previously created scenarios. Further optimization of the CDOG code was done to drop the run-time I/O requirements by consolidating input files, and to increase code portability to different operating systems by consolidating read/write activities into single routines. CDOG now accepts netCDF formatted data, as does the GNOME model in order to make the integrated tool ready for development of more operationally available forecast models through the IOOS Regional Associations. These alterations are tedious, but necessary for tools used operationally.

No blowouts have affected U.S. waters since the IXTOC I exploratory well in 1979, and no deepwater well blowouts have occurred that affected the U.S. During the final drafting of this paper, the BP Thunder Horse production platform approx 60 nm offshore from the Mississippi Delta (Gulf of Mexico) was reported as severely tilted on 12 July 2005, By 19 July 2005 the platform was reported to be level again. During that time NOAA/HAZMAT was on alert in case the situation became more serious, including identifying data sources for the integrated GNOME and CDOG models. This case highlights a scenario in which the availability of this integrated model was extremely useful. With many deepwater wells being developed in the path of hurricanes and meanders of the Loop Current, we know there is a potential for an incident. We always hope that the integrated GNOME and CDOG models will only be run for planning purposes rather than response.



NOAA Office of Response and Restoration
*In the event of a spill, please contact your
 NOAA Scientific Support Coordinator (SSC)
 or the US Coast Guard.*

NOAA/HAZMAT Deepwater Spill Incident Data Preparation Sheet

Incident Name: _____

Spill Location: Latitude: _____ Longitude: _____

General Description: _____

Spill Depth: _____ [ft] [m]

Spill Start Date/Time: _____

Spill End Date/Time: _____ or Ongoing

CDOG Spill Release Parameters

(Choose 2) Oil discharge rate: _____ [m^3/s] [Bbls/day]

Gas discharge rate: _____ [m^3/s] [MSCF/day]¹

Gas to oil ratio: _____ [by volume]

Diameter of orifice: _____ [in] [cm] [m]

Initial bubble radius: _____ [mm] or Unknown

Temperature of discharge mixture: _____ [deg C] [deg F]

Density of product at average water temp: _____ [kg/m^3] [API]

Oil droplet size distribution: _____ or Attached or Unknown

Gas type: Methane or Natural Gas

Molecular weight: _____ [g/mol]

Density of hydrate: _____ [kg/m^3]

Does gas contain hydrogen sulfide? Yes No

Hydrodynamics – Check off as data sent to NOAA

_____ Ocean Current Data - Observed Profile Available? Yes No

_____ Temperature/Salinity Data - Observed Profile Available? Yes No

_____ Horizontal Diffusivity: _____ [cm^2/s^2]

_____ Vertical Diffusivity: _____ [cm^2/s^2]

¹ MSCF = thousand standard cubic feet

Figure 12. NOAA Deepwater Spill Incident Data Preparation Sheet

6.0 Technology Transfer

This is a collaborative effort between Clarkson University and NOAA/HAZAMT Seattle, WA. The final product is an enhanced version of GNOME to be used for deepwater oil and gas blowout simulations. As NOAA is a major organization involved in spill emergencies, the finished product will aid the oil spill response and restoration community once the integration is complete.

7.0 Achievement and Dissemination

The integrated version of the model can be downloaded from <http://response.restoration.noaa.gov/software/gnome/gnome.html>

<http://response.restoration.noaa.gov/software/software.html> can also be a useful location

The manuscripts and papers related to the project are listed as follows:

- 1) Yapa, P.D., Chen, F.H. and Beegle Krause, C.J (2003). “Integration of the CDOG Deep Water Oil and Gas Blowout Model with the NOAA GNOME Trajectory Model,” *Proceedings, 26th Arctic Marine Oil Spills Technical Program*, Victoria, B.C , Canada, June.
- 2) Yapa, P. D. 2004. CRRC Progress Report –for the period ending 9/30/04. Clarkson University.
- 3) Yapa, P. D., Beegle-Krause, C. J., Xie, H., and O'Connor, C. 2005. Integrating CDOG and GNOME - for Simulating Complete Behavior of Oil and Gas from Deep Water Blowouts – Phase II, 8th International Marine Environmental Modeling Seminar, IMMES, Helsinki, Finland (scheduled to appear in the proceedings).

The workshops, conferences and outreach opportunities related to the project are listed as follows:

- 1) “Improvements to the Work on Integration of NOAA’s GNOME Model with CDOG Model,” presented by Yapa, P.D. CRRC sponsored workshop, NOAA Headquarters, Silver Springs, MD, Mar 2005.
- 2) “Integrating CDOG and GNOME - for Simulating Complete Behavior of Oil and Gas from Deep Water Blowouts – Phase II,” 8th International Marine Environmental Modeling Seminar, IMMES, Helsinki, Finland, Aug 2005

Clarkson personnel who worked in this phase of the integration project are:

- 1) *Poojitha, D. Yapa*, Professor and Principal Investigator of the project
- 2) *Hao Xie*, Post-Doctoral Research Associate

Above personnel were attached to the Department of Civil and Environmental Engineering at Clarkson University, Potsdam, NY

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