GoMRI SYNTHESIS WORKSHOP REPORT

Core Area 7A Workshop

"Operational oil spill forecasting"

October 15-17, Washington DC

Report prepared by

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LIST OF ATTENDEES *(OC: Organizing Committee)*

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Workshop Charge: What new research and methods have been developed that can be applied to operational oil spill modeling in the future and how do we do it?

- Review the state of the art of operational modelling before GoMRI.
- Establish the advances that have already been made or are now achievable as a result of GoMRI research.
- Discuss how the different session topics inter-relate, and where the new science has been (or still needs to be) incorporated into modeling.
- Identify desirable future developments, the opportunities for achieving them, and remaining gaps in the knowledge and technology required.

AGENDA

Day 1: Tuesday October 15, 2019

8:00 Breakfast

8:45 – 9:00 *Welcome/Introductions*, Callan Yanoff, GoMRI

9:00 – 9:15 *GoMRI Synthesis and workshop vision*, John Shepherd and David Halpern, GoMRI Research Board

9:15 – 9:30 *Workshop overview*, Villy Kourafalou, University of Miami and Chris Barker, NOAA

9:30 – 9:45 *NOAA's outlook on operational oil spill modeling*, Scott Lundgren, NOAA

I. Operational Oil Spill Modeling Aspects

9:45 – 10:30 **Operational center examples (Chair: Gregg Jacobs, Naval Research Laboratory)**
(describe state-of-the-art w/ examples before and after the DwH oil spill.)

- Chris Barker
  How did NOAA (National Oceanic and Atmospheric Administration) support the oil spill emergency with oil spill forecasts, and how researchers and operative staff cooperate during the DwH (Deepwater Horizon) in 2010.
- Guillaume Marcotte, Environment and Climate Change Canada
  Environment and Climate Change Canada operational support to oil spills and technological transfer frameworks
- Knut-Frode Dagestad, Norwegian Meteorological Institute
  How the NMI supports an oil spill emergency with oil spill forecasts and how researchers and operative staff cooperate.

10:30 – 11:00 Morning break

11:00 – 12:00 **Government, industry and other users: How to prepare for and operate through oil spills (Chair: Greg Jacobs)**

(describe state-of-the-art w/ examples before and after the DwH oil spill: Risk assessment, preparedness and emergency procedures, incl. how researchers & operative staff cooperate.)

- Brian Zelenke, BOEM
  Oil Spill Risk Analysis (OSRA) at the Bureau of Ocean Energy Management
- Don Danmeier, Chevron
  An operator's perspective on subsea modeling
- CJ Beegle-Krause, SINTEF
- Steve Buschang, Texas General Land Office

12:00 – 1:00 Lunch

1:00 – 1:10 Recap on morning sessions **(Gregg Jacobs)**

II. Operational Oil Spill Modeling Aspects part II

(*Research for process understanding, modeling & operationalization globally and regionally in the Gulf of Mexico*)

1:10 – 2:30 **Ocean circulation models and operationalization (Chair: Villy Kourafalou)**
(including data assimilation, observational needs for forcing and evaluation)

- Keynote speaker: Nadia Pinardi, University of Bologna
  Operational ocean forecasting: state of the art and future challenges
- Aijun Zhang, NOAA
  Overview of NOS Coastal Ocean Forecast Systems
- Rafael Schiller, FUGRO
  Operational modeling within the O&G Industry: challenges and lessons-learned
- Eric Chassignet, Florida State University
  New frontiers in Gulf of Mexico ocean circulation modeling and prediction
- Shuyi Chen, University of Washington
  Earth System Modeling for Integrated Environmental Prediction over the Gulf of Mexico: Progress, Challenges, and Ways Forward

2:30 – 3:00 Afternoon break

3:00 – 4:00 **Processes influencing oil transport (Chair: Lianyuan Zheng, NOAA)**

- Villy Kourafalou
  Land-sea interaction: River fronts influencing hydrocarbon transport
- Yannis Androulidakis, University of Miami
  Coastal to offshore interaction: hydrocarbon transport in the open sea
- Tamay Ozgokmen, University of Miami
  Submesoscale processes influencing hydrocarbon transport
- Gregg Jacobs, Naval Research Laboratory
  Observational needs for forecasting ocean transport

4:00 – 4:15 Recap on afternoon sessions **(Villy Kourafalou and Lianyuan Zheng)**

4:15 – 5:30 Plenary discussion on afternoon sessions **(Moderator: Nadia Pinardi)**

5:30 Adjourn for the day; Reception on the rooftop (refreshments provided)

Day 2: Wednesday, October 16, 2019

8:00 Breakfast

8:30 – 8:45 Second-day welcome and introductions, Villy Kourafalou and Chris Barker

III. Modeling Oil Fate and Transport

8:45 – 9:45 **Operational oil trajectory modelling (Chair: John Shepherd)**
(describe state-of-the-art w/ examples before and after the DwH oil spill)

- Chris Barker
  GNOME (General NOAA Operational Modeling Environment) trajectory predictions
- CJ Beegle-Krause
  OSCAR (Oil Spill Contingency And Response) trajectory predictions
- Knut-Frode Dagestad, Norwegian Meteorological Institute
  Oil trajectory predictions and operational applications using OpenDrift
- Nadia Pinardi
  Operational applications with the MedslikII oil spill model

9:45 – 9:50 Plenary discussion on 1st morning session (**John Shepherd)**

9:50 – 10:30 Recap of 1st morning session **(Moderator: John Shepherd)**

10:30 – 11:00 Morning break

11:00 – 12:15 **Recent advances in operational oil models and future needs (Chair: Chris Barker)**
(describe state-of-the-art w/ examples before and after the DwH oil spill)

- Keynote speaker: Jerry Galt, Genwest Systems Inc
  History and Current State of the art of Oil Spill Modeling
- Scott Socolofsky, Texas A&M University
  Plume modeling / Dissolution
- Michel Boufadel, New Jersey Institute of Technology
  Droplet size distributions
- Dalina Thrift-Viveros, NOAA
  New developments: degradation
- Anusha Dissanayake, RPS
  Oil fate process modeling/MOSSFA

12:15 – 1:15 Lunch

1:15 – 1:20 Recap of 2nd morning session **(Chris Barker)**

1:15 – 2:30 Panel and plenary discussion on 2nd morning session **(Moderator: Chris Barker)**
(*Panelists will consist of the speakers from the previous session***)**

Oil fate processes:
New developments: importance of vertical entrainment and mixing
New developments: degradation
Current state of the art:
Oil-Sediment Aggregate formation
Evaporation/Dissolution/ Emulsification
Modeling gaps:
Marine snow sedimentation and flocculent accumulation (MOSSFA) formation
Photolysis -- role in emulsification and/or tarball formation

IV. Discussion of the Most Important Aspects for Synthesis

2:30 – 3:15 U.S. agency and organizational perspectives on science in support of operational oil spill modeling **(Chair: David Halpern)**

- Eric Lindstrom, NASA
- Dana Savidge, NSF
- Kelly Oskvig, NASEM

3:15– 3:20 Plenary and breakout group assignments **(Chair: Eric Chassignet)**

3:20 – 5:30 Breakout group discussions (Coffee break provided)

There are three breakout groups led by a moderator and a rapporteur. Each breakout group should address the same questions. Each group is responsible for a write up and report out Friday morning.

1) Progress in ocean circulation modeling

a. What are the limitations of current ocean circulation models, especially their ability to drive oil fate and transport models (eg. physics, scales resolved, couplings, etc.)?
b. What physical processes and parameters that are essential for oil spill prediction and forecast need to be better captured in ocean circulation models (eg. submesoscale, diffusion, near-surface and vertical velocities etc.)?
c. How can the ocean circulation models be improved (eg. algorithms, data assimilation, etc.)?
d. Where do you see the ocean circulation models in 5 to 10 years from now? What should the priorities be (eg. higher resolution, improved forcing, more data to better constrain/validate the models, etc.)?

2) Progress in oil spill modeling

a. What are the limitations of current oil spill models, especially for prediction and forecast?
b. Are the current oil spill operational models missing critical processes?
c. How can the oil spill models be improved *(in addition to improvements linked to ocean circulation models)*? Is there a mechanism in place to incorporate the latest research?

d. Are there operational requirements that should be included in ocean circulation models? (e.g. file formats, grid definitions, export of parameterizations and forcing functions, etc.).
e. Where do you see the oil spill models in 5 to 10 years from now? What should the priorities be?

3) Addressing model uncertainty

a. How do we understand and quantify the uncertainty in ocean circulation models?
    i. And how to pass that on to oil spill models?
b. How do we understand and quantify the uncertainty in oil spill models?
    i. How can that uncertainty be communicated to users?
c. Do ensemble forecasts reduce uncertainty, how should they be done, and are they feasible operationally?

5:30 Adjourn for the day; Self-organized dinners

Day 3: Thursday, October 17, 2019

8:00 Breakfast

V. <u>Getting Ready for Synthesis and Legacy</u>

9:00 – 12:00 Synergizing workshop objectives and Synthesis **(Chair: Eric Chassignet)**

- Reporting-out from breakout groups (group leaders)
- Plenary discussion: Identify desirable future developments, the opportunities for achieving them, and remaining gaps in the knowledge and technology required
- Finalize writing responsibilities for synthesis

12:00 – 1:00 Adjourn for the day; Lunch provided

1:00 – 3:00 Organizing committee meeting

SESSION SUMMARIES

Operational oil spill modelling aspects - I

Operational oil spill forecasting: state-of-the-art

1) **oil spill forecasting accuracy is strongly connected to process-resolved Lagrangian currents** (turbulent currents+tides+Stokes drift).

2) Operational, data assimilative and forecasting oceanographic models are now at 4-7 km resolution and they are successfully coupled to oil spill models. In many instances this resolution and the process resolved by the models are not enough so **we need to develop limited area modelling and relocatable capabilities**

3) **Ensemble forecasting with multi-oil spill models and multi-current-wave models** can help to understand the uncertainties associated to answering the question: where will the oil go after it is released?

Example 1: Environment and Climate Change Canada operational response

The main reason to develop an in-house model is that it is embedded with our computational infrastructure. We **run the model on the same cluster that produce environmental and atmospheric forecasts.** This ensures that we always have access to the latest forecasts, have a lot of computational power and are running the model in an operational 24/7 infrastructure with redundancy. To improve our level of service to oil spill response, we developed a suite of **oceanic forecasting tools that goes from a global model to regional, coastal, and finally port models.** High risks sites for spill and navigation were identified based on historical spills and shipping routes to identify which ports would need a high-resolution model. Each of those models are routinely verified against available observations and scored with respect to models from other centers. Additionally, having the model run on a cluster allows us to prioritize emergency response calculations over development jobs. **When a relocatable solution becomes available,** the response team will be able to set it up and request computational resources to have it running in an acceptable time.

For spill response, we are developing supporting tools to help modelers choose the best model solution within the forecasts available to them. An example of this is the production of drift maps. We plan to have **verification of drifter tracks for the past forecasts** to allow a responder to look at the performance of a model in surface drift. Using this tool, they can choose to use the coastal or the regional model solution, depending which one gives reliable results in the area of the drifters.

Example 2: Norway operational oil spill capabilities (Meteorological Institute)

1) From our perspective of doing operational forecasting on short time scales (1-2 days), the **low accuracy of ocean model surface currents** at a given time and position is the major concern. All methods to improve on this are thus important, including: assimilation into ocean models, estimates of diffusivities, and using both ensemble input, as well as multi-model-ensembles.

2) Entrainment of oil from breaking surface waves is very important. We would therefore welcome more research (field studies) on this, as well as parameterisations where uncertainties are included (e.g. coefficients with standard deviations).

3) Almost all oil drift models are using a Lagrangian framework and are based on very much the same ideas, and therefore not fully independent. **Having oil drift models based on Eulerian framework** would be useful for "independent" verification.

Example 3: Norway operational oil spill capabilities (SINTEF)

1) There are more ship based spills than well blowouts, yet **we don't have sophisticated operational leaking tank models**, e.g. the recent TV Sanchi incident, where the oil was NOT transport stabilized, and the accident caused many fatalities.
2) We need a write-up that discussed the different ways oil is simulated, e.g. the NOAA SPLOT (spill dot), the spillet, etc, so that we can evaluate the strengths and weaknesses of each method.
3) We did not **evaluate response modeling**, e.g. skimmers picking up oil, boom placement, etc. This **could be used to improve development of response plans**.

<u>Operational oil spill modelling aspects - II</u>

Ocean circulation models and operationalization

- MED forecast system within Copernicus Marine Environment
- HYCOM (global) system
- NOAA/NOS coastal focus
- FUGRO industry development/applications
- Earth System Modeling (development under GoMRI, incl. data)

Common aspects

- Data dissemination
- Operational
- Physics focus, but with BGC development/applications
- Serving a variety of users (including for oil spill prediction), big range of time scales
- Importance of obs. (for DA, model validation and improving initial conditions)
- Providing a “backbone” for limited domain (esp. coastal) nested models
- Importance of couplings
- Importance of forcing

Important issues

Challenges when global models move to higher resolution

- Constrain smaller scales / DA of mesoscale features in the presence of sub-mesoscale
- Deterministic vs ensemble prediction
- Coupled (ocean-atm) DA
- DA of high-res. measurements, esp near the coast (HF radar…)
- Feedback of DA nested models to outer model
- How to disseminate high res model outputs

Model evaluation / accuracy / uncertainty

- Error decreasing due to model improvement (VERY important, incl atm forcing, coupling, mixing…)
- Error decreasing due to additional data in DA
- Nested models use well defined metrics to test accuracy – use of regional data not in DA
- International coordination needed to examine methods in different systems (eg. OceanPredict)

Earth System Modeling framework

- Importance of coupled system, challenging to do for GoM / GoMRI funding made it possible
- Advantage to have obs supporting the coupled system components (eg compute Stokes drift, have Lagrangian currents…)
- Multi-year real-time forecasts, represent seasonal variation and storm scale - get multi-scale phenomena, inter-annual variability (depending on LC location, transport can be very different)
- Storm surge models are not coupled to ocean models so they have low accuracy

Future outlook

- Toward a seamless coupling land-coastal-shelf-open sea (unstructured grids for shallow water) – resolve sub-mesoscale
- Need to integrate forecasts with communication and decision-making system
- More data
- More collaboration / coordination / sharing – new science to reach operations
- Long-term prediction (important for applications)

Processes influencing Oil Transport

1. Land-Sea Interaction: River front influencing hydrocarbon transport
    - Large river freshwater discharge, such as Mississippi River, under different wind magnitudes and directions, can significantly influence on water transport pathway.
    - Salinity front location is critical to control the water transport pathway.

2. Coastal to offshore interaction: hydrocarbon transport in the open sea
    - Deep ocean current, such as Loop Current and its adjacent eddy, can influence on water transport in both the coastal and deep water regions.
    - Local upwelling-favorable wind transports the surface water offshore and bottom water onshore.

3. Submesoscale process influencing hydrocarbon transport
    - High resolution model can resolve the submesoscale process.
    - Drifter deploying can help to understand the submesoscale process.

Observational needs for forecasting ocean transport

- More observation data can increase the skill to provide the Front Forcing, Divergence, Mixed Layer Depth, and Steric Height.
- Presently, the model capability has outpaced the observation capability.

Future work

- All presentations mainly discussed the surface trajectory. However, subsurface trajectory is needed for bottom pipe breaking oil spill, such as DWH case.
- Three dimensional tracer concentration simulation is important to understand how the diffusive process effect on oil transport.
- Hydrodynamical circulation contributes to move oil onshore, whereas wave-induced Stokes Drift is responsible for the oil tarball moving to coastal beach.

Important considerations for Earth System Modeling

A **fully coupled system** is important, but very challenging to do for the Gulf of Mexico - GoMRI funding made it possible.

There is a big advantage to have **observations supporting the coupled system** components (e.g. compute Stokes drift, have Lagrangian currents…) – including the Lagrangian component makes a 20%-30% difference.

Multi-year real-time forecasts are important, as per the need to represent seasonal variation and storm scale; need to represent multi-scale phenomena, inter-annual variability (depending on LC location, transport can be very different).

Storm surge models are not coupled to ocean models so these ocean models might have low accuracy (e.g. effect of offshore winds is not accounted for).

Need to have **land-sea interaction** in the coupled system.

Need to integrate forecast with **communication** and **decision-making** system.

Important considerations for oil spill modeling

Velocity fields vary a lot near the sea surface, and **we do not know well the vertical distribution of oil** when it is being dispersed by wind and waves. Current models can handle the velocity field, but we need better understanding of oil dispersibility.

Model currents that drive the advection of Lagrangian particles have errors, and these **errors accumulate in Lagrangian particle tracking** routines, so that **trajectories loose their value** after several hours to a couple of days. **In situ observations with data assimilation** to correct all models are needed to abate this.

There are many ideas **how to incorporate uncertainty into the particle tracking predictions**. There needs to be a **systematic and theoretic analysis** to understand best practices for this, and **modelers should converge on their needs** to make this analysis. For example, do they need multiple circulation model runs, or is one velocity field prediction adequate, etc.?

BREAKOUT GROUP SUMMARIES

1) Breakout Group 1

Michel Boufadel, Dalina Thrift-Viveros, Yannis Androulidakis, Chris Barker, Knut-Frode Dagestad, Dana Savidge, Monica Wilson

Topic 1 – Ocean Circulation Models: Limitations

- Lack of Water Column Data
  => Either measured or assimilated into models
- Mismatch of scale of atmospheric and ocean models
  => Does not capture upwelling and nearshore currents
- Capturing sub-mesoscale features
  => In particular offshore, doesn't matter as much nearshore
- Capturing nearshore and shoreline dynamics
  => Beaching, onshore winds...
- Lack of smaller scale nearshore models (e.g. capturing dynamics of a single estuary)
  => This is most relevant size scale for majority of oil spills
  => Also most ports (and oil spills) are in estuaries, so having estuarine models can be very useful for oil spill response

Topic 1 – Ocean Circulation Models: Solutions

- Use drifters (during spills), ARGO Floats, and ADCPs to collect more consistent data about the water column
- Encourage the development and maintenance of smaller-scale nearshore models
  => Especially coupled estuary-coastal models
  => Would like to have these available for all major estuaries in the US (and whole US coastline too!)
  => Features at the sub-mesoscale and smaller can be resolved more easily if the total area being covered is small (i.e. not the entire northern GOM)
- Communication before a spill
  => Talk to USCG to get them to allow researchers to test experimental sensors during future spills
  => Enlist Regional Associations to develop and maintain operational models and baseline physicochemical measurements for their regions

Topic 1 – Ocean Circulation Models: 5-10 years

- Network of Regional Associations and other local partners in place to provide local/estuarine level ocean circulation models during response
- Ensemble models will be more common for ocean circulation modeling, and operational modelers will use them regularly
- More spatial coverage nearshore

Topic 2 – Oil Spill Modeling: Limitations

- First cut models (i.e. for first day) are fine as is; models looking out on the week timescale are incomplete, particularly for weathering
  => Emulsification, tarball formation
    @ Can potentially affect transport and response options
  => Bio and photodegradation, partitioning between evaporation and dispersion, sedimentation (bio and not)

Doesn't change response in first few days, but is important for human and environmental health impacts

- Modeling concentration and transport in surface mix layer
  => Whitecapping and entrainment rate, droplet generation and droplet size distributions, Langmuir circulation
- Modeling droplet size distribution for subsea releases

Topic 2 – Oil Spill Modeling: Solutions and Outlook

- More data!
  => Degradation rates with droplet size distribution measured
- Incorporation of new data into models

Topic 3 – Uncertainty

- Ocean circulation models, wind models, and wave models are calibrated to certain assimilated measurements
  => Information on uncertainty is not often reported or included in model output
  => This info should be assessed and provided to users on a more regular basis – oil spill modelers can then use uncertainty information to recalibrate their models
- Most important uncertainties to know about
  => Direction of wind and currents
  => Which errors are the worst and when
- Ensemble modeling can help reduce errors, but may be difficult to quantify the uncertainty

2) Breakout Group 2

Aijun Zhang (mod), Nadia Pinardi (rapp), Gregg Jacobs (telconf), Jerry Galt, Villy Kourafalou, Guillaume Marcotte, John Shepherd, Brian Zelenke, Don Danmeier, Chuck Wilson

What should the Synthesis contain?

- Main theme: progress in operational oil spill models and existing gaps
- Overview of the progress up to date and where to go in the foreseeable future (5 years) in oil spill modelling and its underlying components (1 and 2 below).
- Component 1: met-hydro-wave-ocean forcings
- Limitations in ocean numerical modelling:
  => Have the ability of getting enough good observational data (to be assimilated in the model) and using the best model for the case of interest
  => Numerical models for forecasting (or hindcasting) should be covering as much as possible the different compartments of the earth system, i.e. hydrology , ocean, waves, ice and atmosphere
  => Have a continuous feedback between the large scale and the coastal, nested models
  => For those areas of the continental US that have significant risks from oil spills, integrated models of a specified resolution are needed to provide accurate oil spill forecasts
  => Repositories are needed to make accessible the hydrodynamic data, co-locating numerical models and data of various kind

Where do you see the numerical ocean models for oil spill forecasting in 5 to 10 years from now?

=> A relocatable model approach is recommended together with permanent, high resolution, high accuracy and process resolving models in high priority areas. Such models should be as much as possible fully integrated met-hydro-wave-ocean models
=> In recognition that the expertise would need to be developed in the operational centers, the focused effort could initially target implementation of the relocatable system within the high priority areas. As capability and expertise within the operational center develops, additional areas could be brought on line.
=> To decrease forecast errors during an event, re-forecasting is recommended when and if new obs data is made available.

- Component 2: oil spill modelling
- Limitations in trajectory modelling:
  => Issues remain in the specification of lagrangian diffusion for particles especially in the subsurface
- Limitations of oil spill forecasting/models
  => GOMRI plume and droplet models are not integrated in operational oil spill models
  => Uncertainties in forecasts are associated to unknown initial conditions (where the spill is, how much oil was spilt, which oil, etc.). Metrics to evaluate quality of oil spill model forecasts to be developed by the modelling community (departure of oil spill

trajectories from observed trajectories is one way)

=> Sedimentation is not adequately captured in existing spill models

=> A variety of interdisciplinary data sets are required to assess impact and risks, i.e. sediment grain size, type, seabed habitats, chemical pollutants in the water, human activities and they are not yet interfaced with oil spill models

Where do you see the oil spill models in 5 to 10 years from now?

=> Have plume, droplets source models (for deep spills) fully integrated in operational settings

=> Have a more complete set of weathering processes (photo-oxidation, photolysis, etc.) and subsurface processes (dissolution, etc.)

=> Be able to calculate concentrations of pollutants in all three phases (gas-liquid-dissolved) to inform exposure assessment

=> Estimate tar ball formation

=> Forecast of pollutants entering the atmosphere to inform human health risks

=> Use community best practice standards for data transfer and warehousing

=> Standards for visualization of oil spill forecast outputs established

What should the Synthesis contain?

- Overall discussion on uncertainty understanding and management

=> Ensemble and super-ensemble methods should be used to define the uncertainties in oil spill forecasts

=> Major issue is "communicating uncertainties": use as much as possible the precautionary principle but also advanced communication tools.

=> Engage social scientists (human performance) and communicators

=> Try to use info-graphics (Infographics are graphic visual representations of information, data, or knowledge intended to present information quickly and clearly)

3) Breakout Group 3

1) Progress in ocean circulation modeling

a) What are the limitations of OGCMs in their ability to drive oil fate and transport models (e.g., physics scales resolved, couplings)?

- ocean slicks are very thin; this vertical scale is too small (mm) to be resolved
- oil collects in convergence zone; prediction or identification of these zones would be useful for clean up
- deep ocean (deeper than the mixed layer 100m) is not well captured
- unclear how well wind is represented in OGCMs (Haza, Ozgokmen, Jacobs et al., JGR Oceans, 2019)
- sea breeze can determine the timing and location of beaching of oil
- inertial gravity wave field and many other associated processes (topographic wave breaking) is missing in OGCMs
- surface waves are missing as well
- mixed layer processes (depth, vertical motion, lateral density gradients) are unreliable
- sea and land breeze processes and other diurnal cycle processes (convection) are poorly represented

b) What physical process and parameters that are essential for oil spill prediction and forecast need to be better capture in OGCMs (e.g., submesoscale, diffusion, near surface and vertical velocities)?

- resolving processes within both atmospheric and oceanic boundary layers, and their interface
- preferably with pollutants (oil, plastics) at this interface

c) How can the ocean circulation models be improved (algorithms, data assimilation)?

- data assimilation is not a cure to everything; models should be appropriate; data should be collected where is matters for assimilation
- fully coupled (atmosphere-wave-ocean) models are expected to be more common in the future
- models need to be ready to assimilate data for the intensive observing period after incidents; these observations should be similar to those used during normal period of model operation
- manpower and expertise an issue since data assimilation machinery is more complex than just running OGCMs

d) Where do you see OGCMs in 5 to 10 years from now? What should the priorities (higher resolution, improved forcing, more data to better constrain/validate the models, ets)?

- improved resolution and physics
- non-hydrostatic ocean models are expected to replace the current situation of supplementing OGCMSs with LES processes studies

- fully coupled (atmosphere-wave-ocean) models
- machine learning algorithms for data exploration, as well as prediction
- more model-usable data could be possible through suggesting instruments to OSRL (industry Tier-3 response agency organization) to deploy these during spills worldwide
- better ideas about a more meaningful combination between data resolution, ocean model resolution, and atmospheric model resolution, waves. At the moment, there are significant mismatches in resolutions vs useful information

2) Progress in oil spill modeling
- The idea of a community (global) open source oil spill model was discussed
- Seems unclear how to incorporate advances in academic research to operational efforts
- On the other hand, there has been advances in physical oceanography due to DwH, so oil spills can contribute to our understanding of physical oceanography

3) Addressing model uncertainty
- Questions were to broad; uncertainty depends on the metrics
- There is quite a bit of effort on Uncertainty Quantification (UQ) which is a fashionable field recently, although it is not clear whether these methods provide more than rudimentary sensitivity analysis
- In general, this I not a new field, and steps taken by the atmospheric community and ECMWF center can be followed.

WORKSHOP PRODUCT

The main workshop product is a paper to be submitted at a peer-review journal. Based on discussions among the Organizing Committee, the following paper outline was prepared by co-chairs Barker and Kourafalou and was disseminated on January 2020.

Core 7a: Operational Modeling - Paper Outline:

1. Introduction

Authors: Barker, Kourafalou

Objectives
GOMRI mission: projects related to operational modeling (oil and ocean)
Previous Work
Motivation and core of the paper
Structure of the paper

2. State of the Practice for Operational Oil Spill modeling.

Authors: Barker, Dagestad, Beegle-Krause, Marcotte, Pinardi, Galt, Zelenke, Danmeier

2a. Structure / Methods of Oil Spill Models [Beegle-Krause, Galt, Zelenke – up to 0.5 page each]

What goes into the operational modeling process

State of the art of operational modeling before GOMRI

2b. Model Use cases: focus on Response Support

Examples Operational Modeling Centers

United States: NOAA [Barker– up to 0.5 page]
Norway: Met Norway [Dagestad– up to 0.5 page]
Canada: Met Canada [Marcotte– up to 0.5 page]
Mediterranean Sea: (Copernicus) [Pinardi– up to 0.5 page]

3. Earth System Modeling

Authors: Chassignet, Kourafalou, Jacobs, Pinardi, Ozgokmen, Androulidakis, Chen, Zhang, Schiller

Introduction to Earth System Modeling [Chassignet—1 paragraph]

3a. Ocean Circulation Modeling Component

- Operational Considerations: [Pinardi, Zhang – up to 0.5 page each]
  - What can be done to Improving results / reduce uncertainty
  - Ways to expand coverage
  - Ways of bringing up new models on a response time scale
  - Delivering Model Results
- Current Status of Operational Circulation Modeling [Kourafalou, Jacobs, Pinardi – up to 0.5 page each]
  - Scales: Ocean/Basin/Coastal/Estuarine
- Advances during GOMRI on ocean modeling and connection to oil spill modeling [Chassignet, Kourafalou – up to 0.5 page each]
  - Operational, techniques, new parameterizations
- Limitations that affect the ability to model oil spills [Ozgokmen, Jacobs, Schiller – up to 0.5 page each]
  - Capturing submesoscale features
  - Capturing nearshore and shoreline dynamics
    - Beaching, onshore winds...
  - Coverage: many smaller scale Bays and estuaries have no operational models
    - May not be well coupled with large scale models
  - Resolving the very near surface (~mms)
  - Mixed layer processes not well covered
  - Currents at depth (well below the mixed layer) not well constrained.
    - Lack of water column observations (assimilation and validation/calibration)
  - Limited Description of convergence zones
  - Surface winds not well represented in OGCMs (Haza, Ozgokmen, Jacobs et al., JGR Oceans, 2019)
  - Surface waves are missing from ocean modeling
  - Bottom boundary layer not well represented
    - key to transport of sinking oils
- Solutions [Jacobs, Androulidakis, Chen]
  - Improved downscaling from existing coarser models

  - Encourage development of coastal and estuarine models
    - maybe can be "on the shelf" and spun up quickly.
  - Unstructured Grids
  - Relocatable nested models
    - Features at the sub-mesoscale and smaller can be resolved more easily if the total area covered is small (i.e. not the entire northern GOM)
  - More / Better Data Assimilation (Data and methods)
    - Models need to be ready to assimilate data for the intensive observing period after incidents. These observations should be similar to those used during normal period of model operation.
    - Argo floats, ADCPS, etc...
  - Atmosphere / Wave / Ocean Coupling
  - Preparedness: Communication before spills
    - Talk to Operational Responders to get them to allow researchers to test experimental sensors (to support operations, not just research) during future spills
    - Enlist Regional Associations to develop and maintain operational models and baseline physicochemical measurements for their regions

3b. Meteorological / Wave models Components [Chen – up to 0.5 page total]

- Limitations
  - small scale features not captured (nearshore)
    - Sea/land breeze
    - topographic steering

3c Coupling of Modeling systems (Ocean/wave/atmosphere/hydrology) [Chen– up to 0.5 page total]

- How does it improve the circulation forecasts?
- Does coupling improve the near-surface circulation?
- Does coupling improve the near-coast circulation, especially around estuaries (river plume dynamics)
- Near Surface representation different than "traditional" circulation models: how to make use in oil spill models, especially in the use of wave input?

3d Data Assimilation Considerations [<u>Jacobs</u>, Zhang– up to 0.5 page total]

- Data needs
- Assimilation methods

4. Oil Spill Modeling

Authors: <u>Barker</u>, Thrift-Viveros, Boufadel, Dissanayake, Marcotte, Dagestad , Beegle-Krause, Burd

4a Advances during GOMRI on oil spill modeling [Barker, Beegle-Krause – up to 0.5 page total]

- Operational Techniques
- New parameterizations

4b Surface Fate/Transport [Marcotte, Beegle-Krause, Barker, Dagestad– up to 0.5 page each]

- Limitations of current models
    - Transport
        - Mostly good, limited by driver fields.
        - Exception:
            - Diffusion parameterizations (horizontal and Vertical)
            - Modeling concentration and transport in surface mixed layer
                - Whitecapping and entrainment rate, droplet generation and droplet size distributions, Langmuir circulation
    - Fate modeling limitations:
        - Emulsification
        - Tarball formation
        - Photo effects: does it influence the above?
        - Biodegradation:
            - Need models that consider composition and droplet size
    - Fate / Transport Interaction:
        - MOSSFA formation / settling [Dissanayake]
        - Droplet size distribution from surface entrainment.
    - Modeling heavy/sinking oil very challenging
- Solutions
    - More data: Degradation rates with droplet size distribution measured
    - Move new models into operations (e.g. plume and droplet models)
    - A variety of interdisciplinary data sets are required to assess impact and risks, i.e. sediment grain size, type, seabed habitats, chemical pollutants in the water, human activities and they are not yet interfaced with oil spill models
    - Community (global) open source oil spill model was discussed.
    - Outside the USA (e.g. Norway and, recently, UK, Netherlands), controlled oil release experiments are done to improve understanding of oil spill processes and modeling, and to provide documentation of oil spill cleanup capabilities
- Operational Considerations
    - Driver models (GOCMs, etc. need to be available in real time for the region of interest)
    - Standardized formats for oil spill model results.

4c Deep Sea releases: [Socolofsky, Danmeier] (0.5 p each subtopic)
Authors: Socolofsky, Boufadel, Ozgokmen, Danmeier

- Limitations of Plume models.
- Modeling transformation of oil rising through the water column
  - New questions / answers: flammability, worker safety
- Droplet size: key to fate and transport. And key to the SSDI question. [Boufadel]
- Operational Considerations:
  - Data needs in the field
  - Uncertainty in flow rate, oil type, Gas:Oil ratio (everything!)

5. Handling Uncertainty [authors below to provide 1 pa. each on their assigned topic]

Authors: Pinardi, Chen, Ozgokmen, Dagestad, Beegle-Krause, Barker, Galt, Jacobs, Marcotte

- Uncertainty in Ocean Circulation Models [Pinardi]
  - Quantifying uncertainty in a way useful for Oil Spill Modeling: Lagrangian Transport
  - Computing uncertainty "on the fly"
    - How uncertain are results at a particular time and place.
  - Expressing uncertainty in output
    - How can oil spill models make use of uncertainty estimates?
- Using more observations to reduce uncertainty [Jacobs]
- Using uncertainty from Circulation Models in Oil Spill models: [Barker]
  - Each element gets a different time series of forcing?
  - Ensemble of full collection of elements?
- Ensemble Circulation Forecasts [Jacobs]
  - Ensembles of one model
  - Ensembles of Multiple models
- Uncertainty in OIl Spill Models [Beegle-Krause]
  - From uncertain inputs (oil type, quantity, location, etc)
  - From uncertain drivers (currents, winds, …)
  - How to present uncertainty in results.
    - Major issue is "communicating uncertainties": use as much as possible the precautionary principle but also advanced communication tools.
    - Engage social scientists (human performance) and communicators
    - Try to use info-graphics (Infographics are graphic visual representations of information, data, or knowledge intended to present information quickly and clearly)
- Ensemble Oil Spill Models: [Dagestad]
  - Based on Ensembles of Circulation models
  - Based on multiple models
  - Presenting the results
  - Fate and behavior and mass balance uncertainty

6. Discussion: Future Outlook

(mostly pulled from each section)

Alternative Ways of looking at spill transport [Barker] – (authors below to provide a 0.5 page each

- Lagrangian Coherent Structures / Hypergraphs (Mezic 2010) [Ozgokmen, Beegle-Krause]
- Entropy Analysis [Galt]
- Eulerian approach [??] – who can contribute?
- Machine learning algorithms for data exploration, as well as prediction [Ozgokmen]

Better Circulation models [Chassignet - – up to 0.5 page total]

- More / Better Data Assimilation
- Capturing fresh water fronts, etc
- Capturing submesoscale features
- Increase resolution over coastal zones
- Parameterizing submesoscale features:
    - Serve to Diffuse and govern surface expression (exposed area for fate effects)
- Ensemble models will be more common for ocean circulation modeling, and operational modelers will use them regularly
- Non-hydrostatic ocean models are expected to replace the current situation of supplementing OGCMs with LES process studies
- Model-usable data during an oil spill could be obtained through coordinating with responders such as OSRL.
- Better ideas about a more meaningful combination between data resolution, ocean model resolution, atmospheric resolution, and waves. At the moment, there are significant mismatches in resolution vs useful information.

Better Oil Models [Barker – up to 0.5 page total]

- Have plume, droplets source models (for deep spills) fully integrated in operational settings
- Have a more complete set of weathering processes (photo-oxidation, photolysis, etc.) and subsurface processes (dissolution, etc.)
- Be able to calculate concentrations of pollutants in all three phases (gas-liquid-dissolved) to inform exposure assessment
- Estimate tar ball formation
- Forecast of pollutants entering the atmosphere to inform human health risks
- Use community best practice standards for data transfer and warehousing
- Standards for visualization of oil spill forecast outputs established

Better model coverage [Kourafalou – up to 0.5 page total]

- Unstructured Grids
- Regional models
- More spatial coverage nearshore
- A relocatable model approach is recommended together with permanent, high resolution, high accuracy and process resolving models in high priority areas. Such models should be as much as possible fully integrated met-hydro-wave-ocean models
    - In recognition that the expertise would need to be developed in the operational centers, the focused effort could initially target implementation of the relocatable system within the high priority areas. As capability and expertise within the operational center develops, additional areas could be brought on line.
