Trajectory Analysis
--models, forecasts and uncertainty--
Or more typically…
Why do we need a trajectory?

“Technical experts discussing means of combating a giant oil slick ... have no idea where the slick is, a spokesman said Tuesday.”

Oil slick location not known--expert

MANAMA, June 29 (AP) -- Technical experts discussing means of combating a giant oil slick threatening Gulf countries have no idea where the slick is, a spokesman said Tuesday.

“None of the (Gulf) countries, including Iran, has been able yet to pinpoint the exact location of the larger slicks or their size,” said Khaled Fakhro, chairman of the eight-state meeting.

The experts have been meeting since Saturday in an effort to work out a stopgap plan to fight the fragmenting, five-month-old slick on the high seas, before it spreads in bulk from Iran's war-damaged Nowruz oilfield to other countries in the region.

Fakhro said tar balls in varying quantities have reached four countries in the region so far: Saudi Arabia, Kuwait, Bahrain and Qatar.
(Bushy’s) Steps to Successful Oil Spill Forecast

• Visualize the time and length scale of the challenge
• Understand the questions that need to be answered
• Pick the correct tools (model) for the problem
• Obtain and use the appropriate data
• Understand the uncertainties involved
• Craft the deliverable to the audience

3K gallon diesel off N.J. May 2011

Deepwater Horizon Oil Spill
Trajectory Analysis

Primary product of NOAA’s Emergency Response Division

The questions you need to answer determine the approach taken.

Primary questions to support response:
• Where is the bulk of the oil going to go?
• When will it get there?

➔ What can we do to mitigate damage?
Trajectory Analysis

One of the first requests from responders is a **Trajectory Analysis:**

- Where is the oil going to go?
- When will it get there?
- Will there be shoreline impacts?

- We usually start with a “verbal” (written) trajectory:
  - Scales the problem for the response:
    What do they need to do?
  - Ranges from:
    • Nothing
    • Start a full scale response
Trajectory Analysis

Scale of the problem determines What is done.

Typical Example:

Small Vessel with 800 gal of Diesel Fuel
LTJG Matthew Bissell
Regional Response Officer
Northwest Region/USCG District 13

7600 Sand Point Way NE
Suite 2029A
Seattle, WA 98115

Telephone: 206-455-1760
24/7 Emergency: 206-526-4911
Matthew.Bissell@noaa.gov

Cape Flattery Vessel in Trouble

1/31/2018: 1430 PST
At 1:45 PST, The NOAA Regional Response Officer was notified that there was a vessel in trouble and in danger of sinking off Cape Flattery WA.

The vessel is heading for Neah Bay, but is in danger of sinking before it can make it to safety.

The Vessel is carrying 800gal of Diesel Fuel

It’s location as of 1:45pm was reported as:
48° 10’ 25” N -- 124° 53’ 5” W

About 6 miles offshore, and 16 miles south of Cape Flattery
Map

Location: 1/31/2018 13:45 PST

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REGULATED NAVIGATION AREA
CFR 165.1310 (see note A)
<table>
<thead>
<tr>
<th>Day</th>
<th>Weather Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>This Afternoon</td>
<td>S wind around 13 kt. Rain. W swell 9 ft at 11 seconds. Wind waves around 2 ft.</td>
</tr>
<tr>
<td>Tonight</td>
<td>WSW wind 9 to 14 kt. Rain. W swell 7 to 8 ft at 10 seconds. Wind waves 1 to 2 ft.</td>
</tr>
<tr>
<td>Thursday</td>
<td>SSE wind 11 to 17 kt. Rain. W swell 5 to 6 ft at 9 seconds. Wind waves 1 to 2 ft.</td>
</tr>
<tr>
<td>Thursday Night</td>
<td>SE wind 9 to 15 kt becoming S after midnight. Rain, mainly before 10pm. W swell 5 ft. Wind waves 1 to 2 ft.</td>
</tr>
<tr>
<td>Friday</td>
<td>W wind 16 to 18 kt. Rain likely, mainly before 10am. W swell 6 ft. Wind waves 2 to 3 ft.</td>
</tr>
<tr>
<td>Friday Night</td>
<td>WSW wind around 11 kt. Rain, mainly between 10pm and 4am. W swell 5 ft. Wind waves around 1 ft.</td>
</tr>
<tr>
<td>Saturday</td>
<td>WSW wind 8 to 13 kt. Rain likely, mainly after 10am. W swell 6 ft. Wind waves 1 to 2 ft.</td>
</tr>
<tr>
<td>Saturday Night</td>
<td>SW wind 11 to 18 kt. Rain likely. W swell 5 ft. Wind waves 1 to 3 ft.</td>
</tr>
<tr>
<td>Sunday</td>
<td>SW wind 14 to 17 kt. Rain likely. W swell 4 ft. Wind waves around 2 ft.</td>
</tr>
</tbody>
</table>
If the vessel sinks and releases its fuel, there will be a resulting sheen of up to a mile in length, moving in the downwind direction.

The sheen will persist less than 12 hours, depending on the wind speed at the time of the release.

It is unlikely that there would be any shoreline impacts unless the vessel sank within Neah Bay, as the South and West Southwest winds would tend to move any resulting sheen away from the shoreline.
Trajectory Analysis

Scale of the problem determines what is done.

Larger Scale Problem calls for modeling
What is a model?

A simplified representation of a system or phenomenon, with any hypotheses required to describe the system or explain the phenomenon, often mathematically.

A simple model:
Approximate tidal currents by sine function
Integrate a sinusoidal tidal velocity over a half of tidal cycle to get:

Tidal Excursion = \(\frac{2}{\pi} \times u_{\text{max}} \times \text{Tidal period} / 2\)

Tidal Excursion (miles) = Max Flood(Ebb) velocity (mph) \(\times 4\)

Tidal Excursion

<table>
<thead>
<tr>
<th>Wed 15</th>
<th>Thu 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood 2.28N</td>
<td>Ebb 1.10N</td>
</tr>
<tr>
<td>Flood 2.28N</td>
<td>Ebb 1.10N</td>
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\[\text{Tidal Excursion} = \frac{2}{\pi} \times u_{\text{max}} \times \frac{\text{Tidal period}}{2}\]
Oil spill modeling

• Approach determined by **Scale** of the Problem, **Questions** and when answers are needed
Uncertainty

As a consumer of model data, it’s also important to consider what questions the model was designed to answer and whether it’s appropriate for your application.

Consider:

– Resolution (spatial and temporal)
– Accuracy/validation
Oil spill modeling

• Approach determined by Scale of the Problem, Questions and when answers are needed
• Models need to include *Transport and Fate*
The huge oil slick that has spread across the Gulf of Mexico could soon extend its reach, traveling around the tip of Florida and entering Atlantic waters, a computer model suggests.

"I've had a lot of people ask me, 'Will the oil reach Florida?'" said one of the scientists who worked on the model, Synte Peacock of the National Center for Atmospheric Research (NCAR). "Actually, our best knowledge says the scope of this environmental disaster is likely to reach far beyond Florida, with impacts that have yet to be understood."

The dye tracer used in the model has no actual physical resemblance to true oil. Unlike oil, the dye has the same density as the surrounding water, does not coagulate or form slicks, and is not subject to chemical breakdown by bacteria or other forces.
Fate Modeling

ADIOS 2 Weathering model

• Oil library
• Spreading $\rightarrow$ 2D gravity + wind + diffusion
• Evaporation $\rightarrow$ pseudo components with associated vapor pressure
• Dispersion $\rightarrow$ oil entrainment proportional to dissipation energy of breaking waves
• Emulsification $\rightarrow$ based on “emulsification constant”
 GNOME transport model

• Spills are modeled as discrete particles that are moved by ocean current and wind fields
• Surface wind effects are combined into “Wind Drift” parameter
• Horizontal diffusion by random-walk
WebGNOME

- Couples fate and transport in one model
- Updated algorithms

- Open-source code base on GitHub
- Python scripting environment

https://gnome.orr.noaa.gov/
https://github.com/NOAA-ORR-ERD
Advection

Can be estimated as the vector sum of:

• Wind Drift

• Surface Currents
GNOME Inputs

Wind forecasts
- NOAA National Weather Service models
- Gridded products and/or “spot forecasts”

Ocean current forecasts
- Response models
- Operational models
  - Navy, NOAA
- Academic models
GOODS: http://gnome.orr.noaa.gov/goods
(GNOME Online Operational Data Server)
Transport Modeling Demo
(If we have time...)

• Scenario Parameters:
  • 1,000,000gal Palanca Crude
  • Winds from the NE at 30 knots
  • Spill Location: 38.70°N --74.50°W

• What else do we need?
Oil spill modeling

- Approach determined by questions and when answers are needed
- Models need to include transport and fate
- Depends on availability and quality of inputs
GNOME Inputs

- Forecasting movement and fate of oil depends on **forecasts** of ocean currents and surface winds
- Need to evaluate both appropriateness and quality

Wind forecasts
- NOAA National Weather Service models
- Gridded products and/or “spot forecasts”

Ocean current forecasts
- Response models
- Operational models
  - Navy, NOAA
- Academic models
 GNOME Location Files

- Contain prepackaged tides and currents for a region of interest
- Currents simulate climatological (average) conditions
- User input winds
- Informative, easy to use, and valuable for planning
- Not appropriate for use (out of the box) during spill response

 GNOME and location files available at: response.restoration.noaa.gov/gnome
GNOME Location Files

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*Instantaneous vs. average*

From: A. Gangopadhyay et al. / Dynamics of Atmospheres and Oceans 52 (2011) 131–169
Modeling strategies

• Hindcasts/reanalyses and forecasts
• Deterministic vs. stochastic (statistical)
Hindcast model applications

• Testing a model – how are we doing compared to previous observations
• Aiding in determining origin of “mystery” pollution
• Gaining improved understanding of a past event (e.g. damage assessment modeling)
  – Can assimilate available data (“reanalysis”)
Hindcast example: Japan Tsunami Debris Modeling

6 months

1 year

2 years

3 years
The 20-foot Sai-shou-maru washed up on Long Beach on March 22, 2013.

Left and below: The “Sai-Shou-Maru” Photographs courtesy: Allen Pleus and Travis Haring, WDFW.
Statistical modeling application: Response Planning

• Trajectory requests are often for potential releases – e.g. grounded vessels
• Usually assume “worst case” discharge
• Trajectories have to span the situation space of varying environmental conditions

• Spring 2011 – asked to evaluate threat to US East Coast shorelines from exploratory deep water drilling in the Florida Straits
Florida Straits TAP

- For each site, ran multiple trajectories in GNOME for 75K barrels/day 90 day continuous release of medium crude; trajectories run for 120 days
- Primary weathering processes included (evaporation, natural dispersion, biodegradation)
- No emulsification, sedimentation or any chemical dispersion or countermeasures

Percent of models runs that impact grid cell above a specified level of concern (from one site)
Trajectory Analysis / Modeling

• Approach determined by questions and when answers are needed
• Models need to include transport and fate
• Depends on availability and quality of inputs
• Forecasts must consider **uncertainty**
Deepwater Horizon Surface Oil Forecasts

From April 21 through Aug 23, NOAA provided daily surface oil forecasts for 24, 48 and 72 hr periods
Constraining uncertainty

- 24/48/72 hr output from multiple trajectories
- Particle distributions from the “best estimate” are used to contour oil concentration
- Output from multiple trajectories scenarios are used to determine uncertainty boundary
Including uncertainty

Best estimate
- If oil observations, wind and current forecasts were exactly right

Description of uncertainty ("minimum regret solution")
- What if onshore winds are 20% stronger than predicted
- What if spill occurred 6 hours later
- Can incorporate differences among ocean models
Trajectory Analysis / Modeling

- Approach determined by questions and when answers are needed
- Models need to include transport and fate
- Depends on availability and quality of inputs
- Forecasts must consider uncertainty
- Craft the **output** to the audience
Audience – expected and actual

- NOAA Scientific Support Coordinator → briefs command
- Common Operational Picture → GIS files shared widely
Representing and Communicating Uncertainty
Representing and Communicating Uncertainty

These estimates are based on the latest available information. Please refer to the trajectory analysis briefing and your Scientific Support Coordinator (SSC) for more complete information. This output shows estimated distributions of heavy, light, and medium concentrations as well as an outer confidence line. The confidence line is based on potential errors in the pollutant transport processes.

* this scale bar shows the meaning of the distribution terms at the current time
Representing and Communicating Uncertainty

M/V Cosco Busan

HAZMAT Trajectory Analysis

Estimate for: 1800, 11/12/07
Prepared: 1336, 11/11/07

NOAA/HAZMAT (206) 526-4911

These estimates are based on the latest available information. Please refer to the trajectory analysis briefing and your Scientific Support Coordinator (SSC) for more complete information. This output shows estimated distributions of heavy, light, and medium concentrations as well as an outer confidence line. The confidence line is based on potential errors in the pollutant transport processes.
Representing and Communicating Uncertainty

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Representing and Communicating Uncertainty
Take Home Thoughts

• Pick the right tool for the right job ("All models are wrong, but some are useful")
  – What are the questions you need answered?
  – How good do the answers need to be?
  – When do you need the answers?

• You want a forecast not just model run (includes expert analysis and interpretation)

• Forecast not perfect ... plan for uncertainty

• Be thoughtful with how you communicate a forecast