Digital Distribution Standard for NOAA Trajectory Analysis Information

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Hazardous Materials Response and Assessment Division
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and

Florida Marine Research Institute
Florida Department of Environmental Protection

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Abstract

During emergency oil spill response efforts, estimates of the movement and spreading of the pollutant provide critical information. These estimates are typically obtained by analyzing a series of models or database look-ups. The strategy described in this paper for conducting this analysis can be likened to game theory's "minimum regret" approach.

We describe alternate model use techniques and identify a well-defined series of model runs required to support minimum-regret trajectory analysis. This standard series of model runs is generic and could be carried out by any of the oil spill trajectory models commonly available for emergency response.

We describe specific algorithmic procedures that can be applied to a minimum-regret set of model runs and define a standard digital file format. The standard trajectory analysis files that make up a "message" are in a public domain ASCII format easily transmitted over any electronic mail system. The standard files contain all of the data necessary to produce a simple, one-page graphic display that provides the minimum-regret trajectory analysis for operational emergency response planning. In addition, the standard message contains geo-referenced topological information so that the pollutant distribution information can be used in Geographical Information Systems (GISs) with additional resource data to answer geographic and thematic queries. We further describe plans for data distribution and simple viewing and mapping import applications.

1 Introduction

During an oil spill, accurate information on the movement and spreading of the pollutant is a factor in virtually every facet of the spill response activities.

To predict pollutant movement you must understand a number of different physical processes, computational procedures, and observational techniques (Galt 1994). In general, the information used to describe where the oil may be at some future time comes from many sources and must be woven together from data that are of questionable accuracy and often incompatible with other components of the data set. A number of computer models solve the mass balance distribution equation for oil, usually described as "oil trajectory models" (ASCE in press). In addition, many model developers and users falsely contend that these products present a deterministic, realistic representation of the future distribution of the oil. In fact, all of these formulations require external models that are approximations controlled by numerous parameters, which in turn are based on the subjective interpretation of sparse data. Thus, the same trajectory model could give vastly different answers, depending on how it is used. Two different trajectory models are almost certain to produce differing estimates. Given the uncertainty of this process, it is important to understand that, regardless of how the estimates are obtained, the results are due to analysis, not deterministic modeling (Galt 1995).

Defining standard-use protocols is an integral part of model development since the output of any particular oil trajectory model varies considerably, depending on how the model is applied. This, after all, is a pretty normal thing to do. You could not buy an airplane without directions describing it's safe operational use. The same is true for much less complex products, such as lawnmowers. It is likewise appropriate for spill modelers to use standardized guidelines. Any use protocol must consider the context in which the model is intended for use. Clearly, planning activities, emergency response, and damage assessment phases of spill response may require somewhat different use strategies and input data. For example, emergency spill response is an extremely complex, multidisciplinary activity. The information that is developed will have to be used in a larger context. Modern "command and control" or "integrated information systems" typically will separate the production of the trajectory analysis from the team that created it.

To better understand the context of the problem, we will focus on trajectory analysis support for oil spill emergency response, since this is where the interpretation of results is the most time-critical. During emergency response operations, the fragments of information that are available may be highly uncertain. Any forecasts of environmental conditions or the arrival of needed response equipment will thus also be uncertain. In the face of all this, the response community must sort out what is known, grab what can be had in terms of equipment, and get it to the places it might do some good. While this is going on, hundreds of non-responders—in government, industry, private groups and the press—are forming opinions based on sparse, possibly wrong data. These opinions rapidly become translated into advice, or demands on response personnel, setting the stage for the general cacophony that characterizes most large oil spills. In the face of this chaotic activity, is there anything that an experienced investigation of available information and trajectory analysis can do to help guide the response? What can be done to ensure that any possible gains in environmental protection are realized? How can responders keep critical attention and resources from being deflected and focused on false positives?

To answer these questions, we must consider the general standard-use strategies that would be appropriate and, specifically, the kind of information that trajectory analysis should add to the information stream that is supporting the emergency response efforts. When evaluating various standard-use options for models it is useful to consider some of the lessons derived from classical "game theory" (Dresher 1961; Operations Analysis Study Group 1977; Mesterton-Gibbons 1992). In any game that is played with some unknown, or chance, factors the player can use available information to try to achieve a "maximum-win" result. An alternate strategy could begin with the same information (and uncertainty) and pursue a more conservative option to achieve a "minimum-regret" result. In general, the more valuable the resources that the player is using, the more preferable a minimum-regret strategy is. As an example, if you had a dollar and wanted to become rich it might make good sense to put it on the lottery with the chance of a maximum win. If, on the other hand, you were in control of your pension fund, a minimum-regret strategy based on bonds and blue-chip stocks would seem more appropriate.

In emergency spill response, the inherent uncertainties in understanding the spill situation and its potential to unfold into the future, suggest that trajectory analysis should be aimed at supporting a minimum-regret rather than a maximum-win strategy. The argument becomes even more compelling when you consider the valuable resources that can be threatened by spills. To put this into context, a maximum-win strategy would be one where the very best estimates of winds, currents, and initial distribution of pollutants were collected with the resulting forecast taken as "the" threat that needs to be responded to. This is where a trajectory modeler, or analyst, would "give it their best shot" and come up with a most probable scenario. This is, in fact, what most oil spill modelers and builders of automated decision-support systems seem to think they want. A minimum-regret strategy, on the other hand, would use whatever analysis techniques are available to investigate the sensitivity of various estimates of errors in the input data and would explore the implications of alternate, plausible scenarios in the geophysical forcing functions. For example, what would be the significance of an atmospheric frontal passage arriving six hours before the forecasted time of arrival? Or, if the coastal current is known to reverse this time of year what would be the consequences of such a reversal on the planned response options? Clearly, to carry out this type of analysis, the modeler must understand not only the capabilities of the models, but must also know what the models cannot provide. This is obviously more difficult, but, once done, it can be used to develop briefing material that can provide response organizations with a “best guess” that covers alternate possibilities that might present a significant threat. The major difference between these approaches is that the minimum-regret strategy can identify less likely, but extremely dangerous or expensive, scenarios that may require the development of alternate protection strategies.

The next section describes alternate ways that any response model can be formulated to examine various facets of the trajectory analysis problem. The third section briefly describes the post-processor analysis procedures that could be used on any of the mixed Eulerian/Lagrangian models to produce a standard trajectory analysis data presentation that would support a minimum-regret response activity. The fourth section describes specific digital formats for electronically transferring both the pollutant distribution and topological information associated with the trajectory analysis products. Section 5 discusses the proposed implementation of this standard by NOAA’s Hazardous Materials Response and Assessment Division. This section concludes with a description of NOAA’s cooperative effort with the Florida Department of Environmental Protection, Florida Marine Research Institute to develop data transfer protocols to facilitate using trajectory products with Geographic Information System (GIS) based spill response systems. File formats and examples are given in the appendices.

2 Alternate Model Scenario Development

Any spill trajectory model that is robust enough to represent a realistic range of geophysical processes is also flexible enough to be used in a number of different ways, depending on the supporting computational algorithms and scenario descriptors. This feature, which clearly makes the models useful, also makes them produce results that are, by themselves, vague with regard to their own credibility. Since there are so many different ways to modify the behavior of the models, it is impossible to understand the response options they suggest by simply looking at the undocumented output.

To make model output more useful and understandable in an emergency spill response, the standard-use protocols need to internally check for algorithmic accuracy limitations and uncertainty in the scenario descriptors. The output would not be the result of a single model run, but rather the composite of a specific set of runs that includes deterministic and statistical applications of the same model (Galt 1995). This composite should result in a technically sound trajectory analysis that provides enough information to support minimum-regret decision-making. In addition, the standard-use protocols should not be specific to a particular trajectory model, but general enough so that all of the models that are intended for use during a spill event can produce results that can be compared and evaluated in the same context. Such a standardized approach to trajectory analysis should go a long way towards reducing the potential problem of having more than one estimate on where the pollutant will go and no way to determine the likelihood of either being correct or, for that matter, whether they are even “significantly” different.

To develop a standard-use protocol, we will consider how oil trajectory models have been developed and used. At the core of any oil trajectory modeling procedure is a series of computational algorithms, or numerical look-ups, into databases. Trajectory models must be able to handle mixed-scale problems and, as a result, all major models have gone to a mixed Eulerian/Lagrangian formulation where the oil is represented by a series of pollutant particles embedded in a series of vector fields representing the regional dynamics and dispersive effects. Each of the oil particles can have associated attributes that represent its state (age, weathering condition, beached status, etc.). The distribution of the oil as a function of time is given by the distribution of the particles that represent the oil. The raw graphic output appears as a cluster, or swarm, of particles (Figure 1). All known operational models share these characteristics.

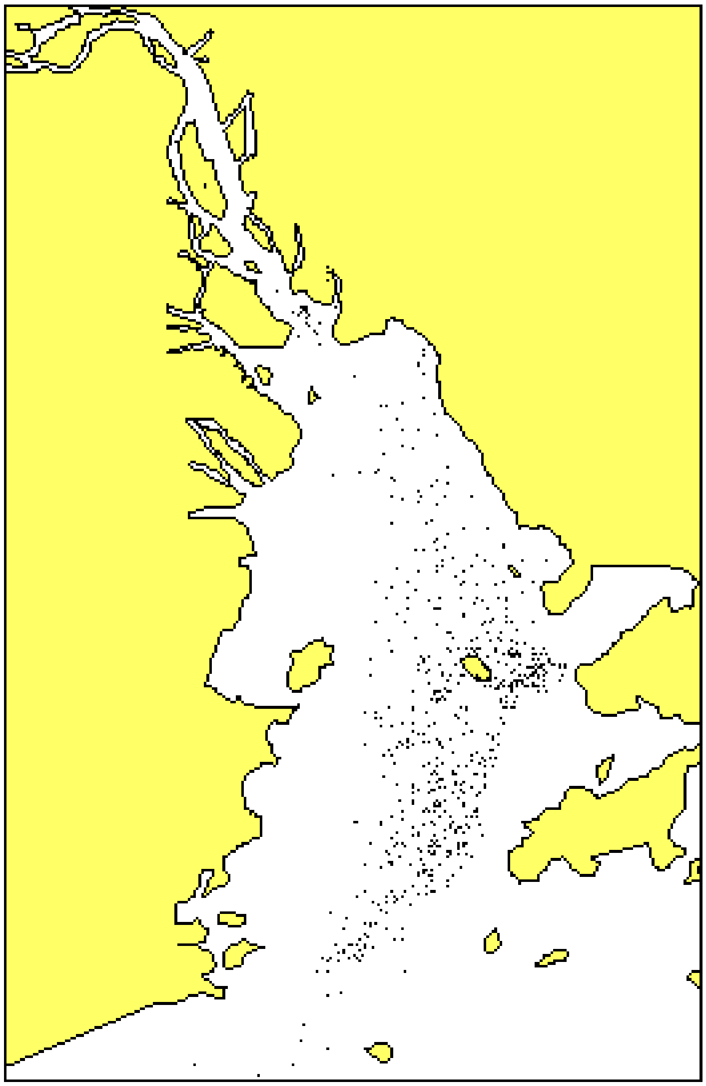

Figure 1. Trajectory forecast with oil represented as Lagrangian Elements.

The potential for alternate model use strategies now becomes important. Significant differences start to appear in how various models are used.

When most people think of trajectory modeling, they assume that the activity will forecast the future distribution of the oil based on its initial or present distribution. In this case, the modeler sets the initial distribution of the particles to quantitatively represent the actual distribution of the oil at the beginning of the forecast period. Next add the best available representation of the vector fields that describe the regional currents and add them into the transport modules of the model formulation. An additional vector field is usually added to represent the effects of the forecast winds on the surface oil particles. Finally, a random vector component is typically added to represent sub-grid scale uncertainty associated with turbulence or mixing processes that are not resolved by the previous transport representations.

The model is now run forward in time, with all the pollutant particles moved by the various process vectors, weathered to change their state variables, and plotted out for various future times (Figure 2). The result is the oil distribution forecast, or cumulative model "best guess" of the oil's movement over time. In this formulation, the clustering of the oil particles actually represents a quantitative measure of the amount of oil found in any particular area. That is, the number of particles per square kilometer would be proportional to the forecast number of tons per square kilometer. From a game theory perspective, this is a maximum-win strategy. The most probable future position of the oil is what most responders expect from a trajectory model, but the problem with this output, by itself, is that there is absolutely no indication of its accuracy. Again, using a game analogy, if one were to throw a pair of dice, the most probable result would be 7, but responding continually to that expectation would find you wrong five out of six times. Some trajectory models have used climatological components where the most probable cases do not come close to representing a majority of the potential scenarios and, as in the dice case, you would be wrong more often than right. Another problem with unaccompanied model forecast output is that two different models would give two different results and the differences would be hidden in the set-up assumptions. Once again, the end-users have no way to resolve conflicts or estimate the reliability of the advice that is dependent on the model results.

Although the model forecast is useful, it is necessary to identify alternate model scenarios that could add the required additional information. This can be done since virtually all of the mixed Eulerian/Lagrangian trajectory models can be run in a statistical mode such that each individual particle or fragment of the spill can be assigned an independent set of vector fields representing currents, winds, and dispersive processes. In this case, each of the oil particles can be thought of as an individual piece or fragment of an independent spill.

Obviously, model results depend on the statistical choices that are made for the independent currents, winds, and dispersive vector fields that are applied to each of the separate particles. The model output presents the position of particles as a function of time and, in most respects, will look like the results from a straight forecast run, but the interpretation would be quite different. In this case, clusters of particles will not represent higher concentrations of oil, but rather areas that have a higher probability that the represented spills would lead to oil in those locations.

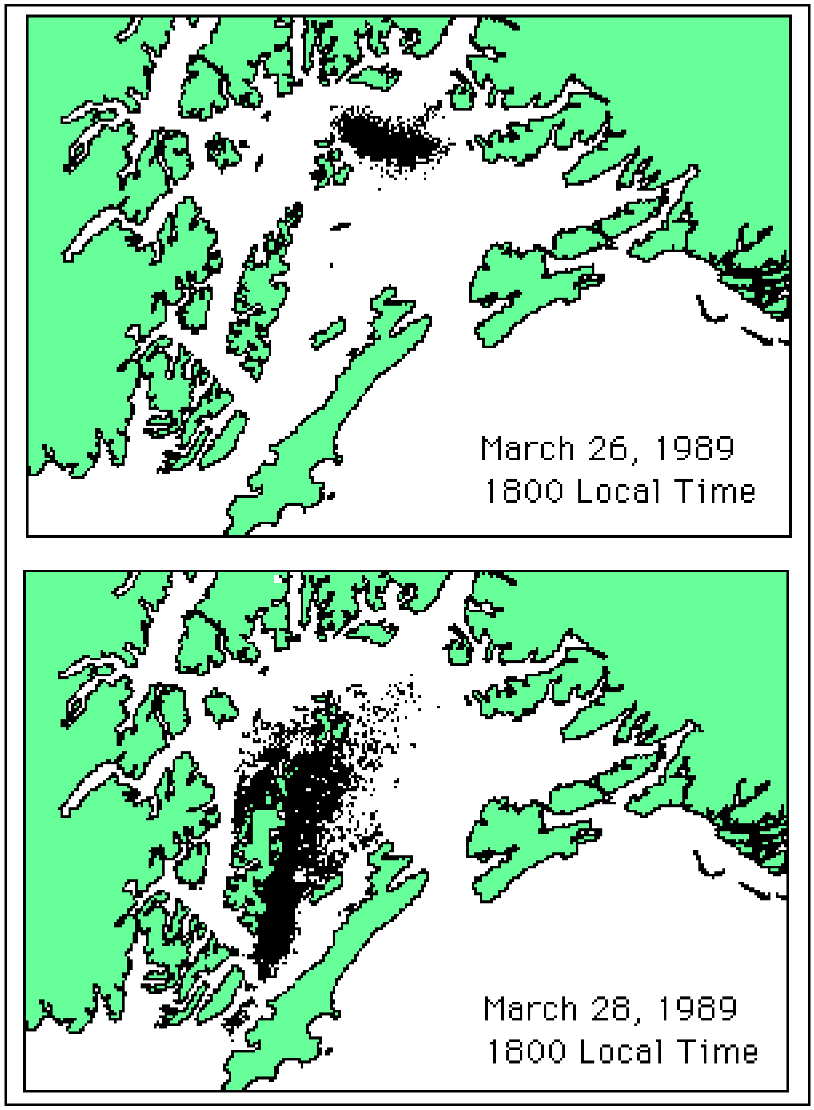

Figure 2. Typical trajectory stepped forward in time.

More specifically, when choosing the independent vector fields used to statistically represent the probabilistic spill distributions the modeler should have some idea of the expected errors for all of the model inputs that are taken as deterministic in the initial forecast. For example, the hydrodynamic models that are used to approximate the current patterns may have known error bounds or skill levels.

The weather forecast will certainly not be exact and the expectation is that there will be errors in wind speed and direction as well as the timing of frontal passages (Haltiner 1971). If all of the vector transport and dispersion processes are represented by the deterministic forecast values plus a random component that realistically spans the expected errors, then the statistical ensemble will cover the uncertainty that is likely in the forecast. This approach can be recognized as a Monte Carlo representation of a formal, first-order error analysis applied to the deterministic forecast. An appropriate bound that surrounds this probability distribution will provide the uncertainty analysis that was lacking in the simple unaccompanied forecast. From a responder's point of view, this combination offers a major improvement over just the forecast by itself.

Minimum regret strategies can now be implemented by looking at both the forecast and at potentially high-cost problems appearing within the uncertainty zone. For response to emergency situations in which real uncertainties are present, adaptive management methodologies are possible (Holling 1978). This information enables responders to alter tactics as necessary and redistribute resources or initiate additional field reconnaissance to empirically check model uncertainties. Additionally, if each model comes packaged with its own uncertainty bounds two different models can more readily be compared. If the differences in the forecasts are simply different realizations within the expected bounds of the model reliability, then responders do not need to agonize over conflicting advice. These are examples of practical response options that would not be possible using stand-alone model forecasts.

A third strategy is often useful for major spills, even though it is not technically required to support minimum-regret response activities. This strategy is, again, based on a statistical representation (achievable for any of the commonly used trajectory models) where each individual particle or fragment of oil is subject to an independent set of vector fields representing currents, winds, and dispersive processes. The major difference between this and the previous statistical approach (which developed the uncertainty bounds) is that this method concentrates on a joint probability distribution that considers where the oil is initially observed and the likelihood that it will arrive at predesignated high-value or environmentally sensitive target areas. This is referred to as receptor-mode analysis (Gilbert 1983). The spill response problem that receptor-mode analysis attempts to address is associated with the fact that major spills will invariably remain a problem for longer periods than any form of deterministic forecast is possible. It is useful to develop an “extended outlook” estimate of the threat to specific locations. This is the type of analysis that the National Weather Service has developed using historical statistics to estimate extended outlook threats from hurricanes as they move through the formation areas in the inter-tropical convergence zone of the Atlantic. These estimates will give at least relative threat information. Tracking these esimates over time will indicate which problem areas are subject to growing risk and may need to have protection strategy resources moved to staging areas for implementation if the probability of actual impact becomes significant.

The easiest way to describe the formulation of a receptor-mode analysis is to consider a statistical model where the spill originates at the high-value target for which an extended outlook is desired. The vector fields representing currents, winds, and dispersive processes are all run backwards so that the oil moves to where it would have come from, rather than in a forward direction, as would be expected in a normal forecast model. Since the oil elements are statistically independent, the resulting distribution is a probability density map. The probability density at any point in time is the likelihood that oil starting from that location could impact the receptor site in the time given. Given any initial oil distribution, the receptor joint-probability maps can be used to calculate the cumulative threat. A statistically equivalent formulation that has been used by the Minerals Management Service formulates the problem in a computationally more efficient forward algorithm (Smith et al. 1982). In this case, the model is run forward for the desired “extended outlook” period and a region is defined to represent the impact zone associated with each of the receptor sites. The fraction of mass-weighted oil particles in the site's region represents the probability that that region will be affected.

There are some questions as to the appropriate way to develop the statistical vector fields to support an extended outlook, or receptor-mode analysis. If, by “extended” you mean only slightly beyond the forecast period, then an estimate of deterministic fields with increased random-error components is probably appropriate. If, on the other hand, the desired forecast time is longer than the typical auto-correlation time for the geophysical processes that are considered, then a statistical representation of the climatology is more appropriate. In general, you would start with a deterministic forecast that would degrade over time and smoothly transition into climatology.

These model scenarios provide the framework for a set of trajectory-analysis components that support minimum-regret emergency response to spills. The complexity of spill response organizations and the technical ability of computational modeling components have gone beyond the point where a simple unaccompanied model forecast is an acceptable product for the demanding requirements of spill information management systems. At a minimum, standards should require all trajectory forecasts to be supported by sensitivity analysis that defines the uncertainty in the forecast. Optionally, there should be a standard method of including an extended outlook threat to high-value receptor sites.

3 Data Analysis Methods

Run in a forecast mode, the mixed Eulerian/Lagrangian trajectory analysis models track a number of individual spill components that represent actual quantities of oil with associated attributes, such as mass, density, type, age, and coordinate information. Alternatively, the models may be run in a statistical mode, where the individual particles represent a probability element. In either case, the actual model output is a list of particles and their associated attributes. Although most models preserve this data in files that are tabular images of these lists, virtually all of them provide graphic displays to help the end user visualize the distribution of the oil with respect to a background map. The standard minimal result is a background map with an overplot of particles that typically resembles a swarm of bees (Figure 1). Many models have gone beyond this primitive representation and can provide alternate views that include animated movie loops and various color presentations. Given all of the possible alternate data presentations, we will describe a minimum set of some relatively simple analysis techniques that could be easily applied to any trajectory model results. These techniques provide responders with consistent, well-defined packages of information that directly support minimum-regret decision logic. These procedures do not preclude model developers from providing additional value-added packages and presentations, but make results understandable and provide a basis for comparison in real-time response environments.

We will focus first on the output from trajectory models run in a forecast mode. The Lagrangian particle lists and their associated data are the core model output. Although not the most compact form of trajectory analysis output, any standard should at least support the ability to transmit each particle's geographic and attribute data so that the recipient can use it for additional analysis. A much more compact and, in many respects, more useful representation of the Lagrangian point data can be developed by converting the distribution to an Eulerian density field, which can then be described by a small number of vector contours. This is equivalent to going from clusters of particles to a measure of particles per area. This relates directly to a distribution of oil concentration or thickness, which is a much more useful response parameter than particle locations. This conversion can be done by dividing the region into small boxes and counting the number of particles in each box. Although this is computationally easy it has some defects, such as depending on the size of the box that is selected. This method would thus not be suitable for a standard.

A second, more robust, method of converting Lagrangian to Eulerian data, which self-scales itself to the particle distribution, is to partition the region occupied by the points into Thiessen polygons or a "Voronoi diagram." These polygons associate an area with each point that defines its exclusive neighborhood relative to any other point. Dividing the mass of each point by its associated area gives the required Eulerian density. This technique is commonly used in hydrology studies to analyze rainfall data (Linsley, et. al. 1982). An alternate approach is to use the Lagrangian points as the vertices for a Delaunay triangulation, the topological equivalent of the Thiessen polygons. With either of these representations the other can be quickly and easily calculated. Once the Eulerian density data are obtained, any number of contouring routines can be used. Since the generation process has produced all of the information necessary for a triangular interpolation, any of the Triangulated Irregular Network (TIN) routines should be fast and computationally efficient (Green and Sibson 1978; Diggle 1983; Sedgewick 1992; Preparata and Shamos 1988). A number of standard software graphics libraries (such as Stanford Graphics and Harvard Graphics) include Delaunay triangulation subroutines. Finally, most of the general GIS packages provide a variety of TIN routines that include interpolation and Voronoi diagrams or Delaunay triangles.

The proposed Thiessen analysis assumes that the distribution of floating oil results from an individual spill in an essentially "singly connected" domain. If there are multiple spill events on a single map, or if there are complex channels or barrier islands that lead to a bifurcation of the spill, a modified standard analysis should be carried out. The distinct and disjoint segments of the floating oil distribution should be analyzed separately and all the concentration contours included in the final analysis.

To develop standard trajectory analysis results we need to define the "relatively few" vector contours of the Eulerian particle density that should be included in the basic presentation. Since these considerations are for the models run in a forecast mode, the Eulerian data correspond to an absolute number of particles per unit area. In theory, you can translate these values into tons of oil per square kilometer (one ton per square kilometer would average one micron thick and appear as dull to dark rainbow colors under light wind conditions (Fingas et al. 1979)). Experience suggests that contouring absolute concentration values is not particularly useful. During the emergency phases of a response the actual amount of oil spilled is usually not known. Because of this, it is common for the particles used in the model to be assigned a relative rather than an absolute mass. That is, each particle will initially represent a fraction of a percent of the entire spill. An additional factor against absolute concentration estimates has to do with the way oil appears when floating in the marine environment. Most observers, even experienced observers, see relative concentrations. On major spills hundreds of people will be involved in making observations of the oil; virtually all of the distribution estimates tend to come back with areas of heavy concentration, medium concentration, and light concentrations (Figure 3). Over the life of the spill, as the oil spreads and dissipates, the heavy concentrations lessen each day, but they always look heavy compared to other areas.

For these reasons, the standard emergency response contours of oil concentration should be based on relative rather than absolute values. The easiest way to do this is to calculate the maximum concentration value in the distribution and define the standard contours as some fraction of this value. We need to rely on observational experience to select the relative contour levels . Observers' understanding of "heavy," "medium," and "light" is non-linear. Medium concentrations of oil are typically about

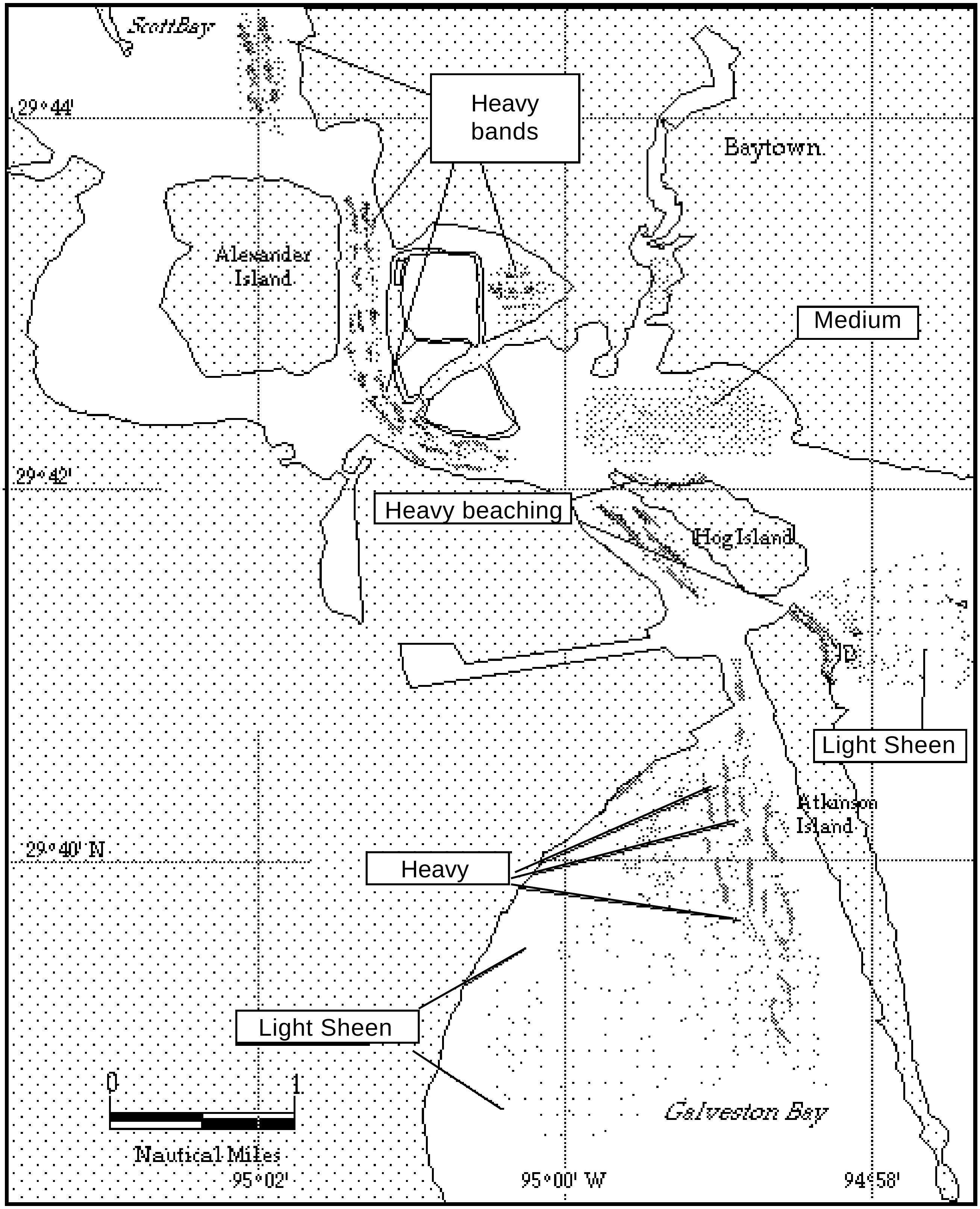

Figure 3. Example of oil distribution reported from an overflight.

four times as heavy as light concentrations, and heavy concentrations are typically about four times as heavy as medium concentrations. A practical set of contours that defines the density distribution of the model trajectory forecast includes:

1) forecast areas of light oil concentrations at one percent of the maximum value for the distribution;
2) forecast areas of medium oil concentrations at four percent of the maximum value for the distribution; and
3) forecast areas of heavy oil concentrations at sixteen percent of the maximum value for the distribution (Figure 4).

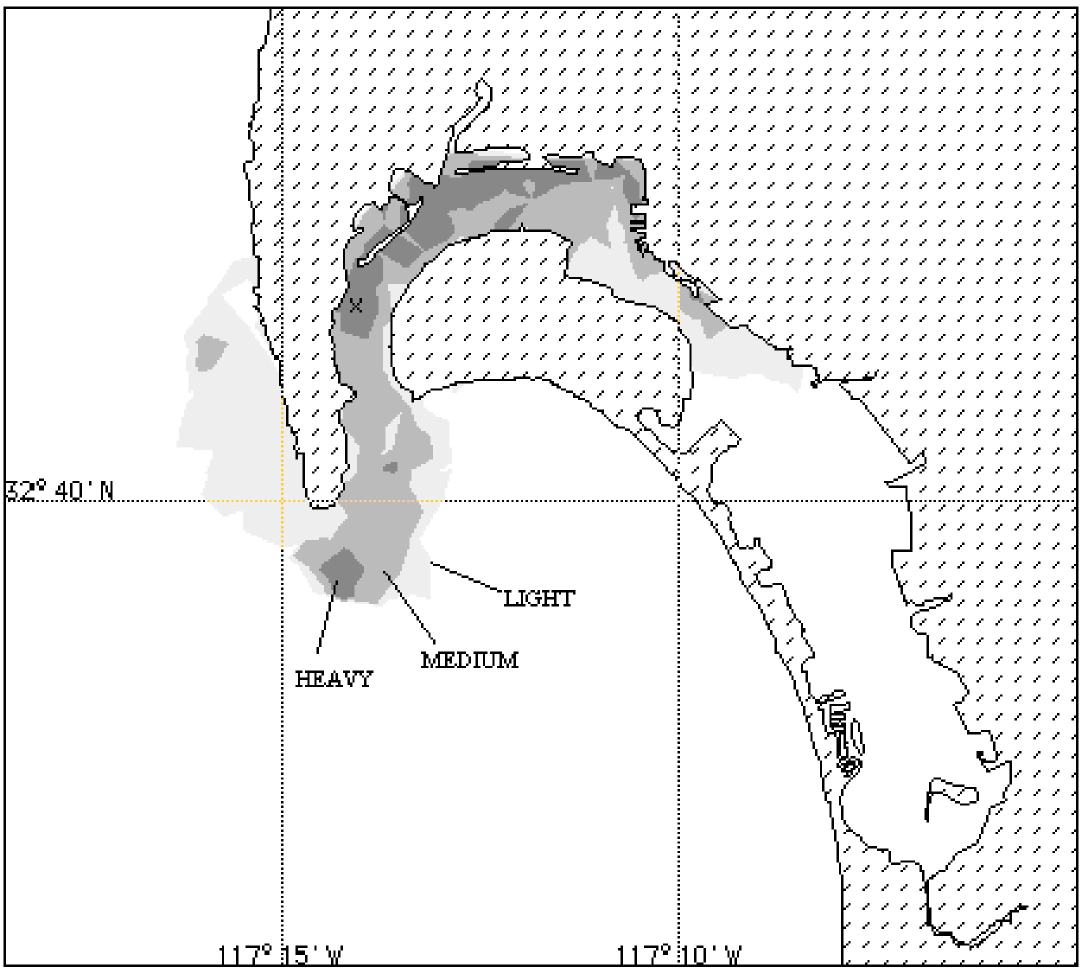

Figure 4. Example of predicted distribution of heavy, medium and light concentrations of oil shown as contours.

The next component of the standard trajectory analysis is the forecast uncertainty. This, in addition to the most probable forecast distribution, is essential for minimum-regret trajectory analysis. For this case, the uncertainty in the vector fields representing currents, winds, and dispersive processes produces a particle probability distribution that gives the location of some component from each member of an independent ensemble of spills. The Eulerian representation of this Lagrangian distribution will be a probability density. A useful measure of this distribution is the contour of a relatively low probability density value. A conservative value is obtained by using the Thiessen analysis described above and contour the one tenth of a percent. You then add this uncertainty boundary to the deterministic contours produced by the model runs representing the forecast (Figure 5).

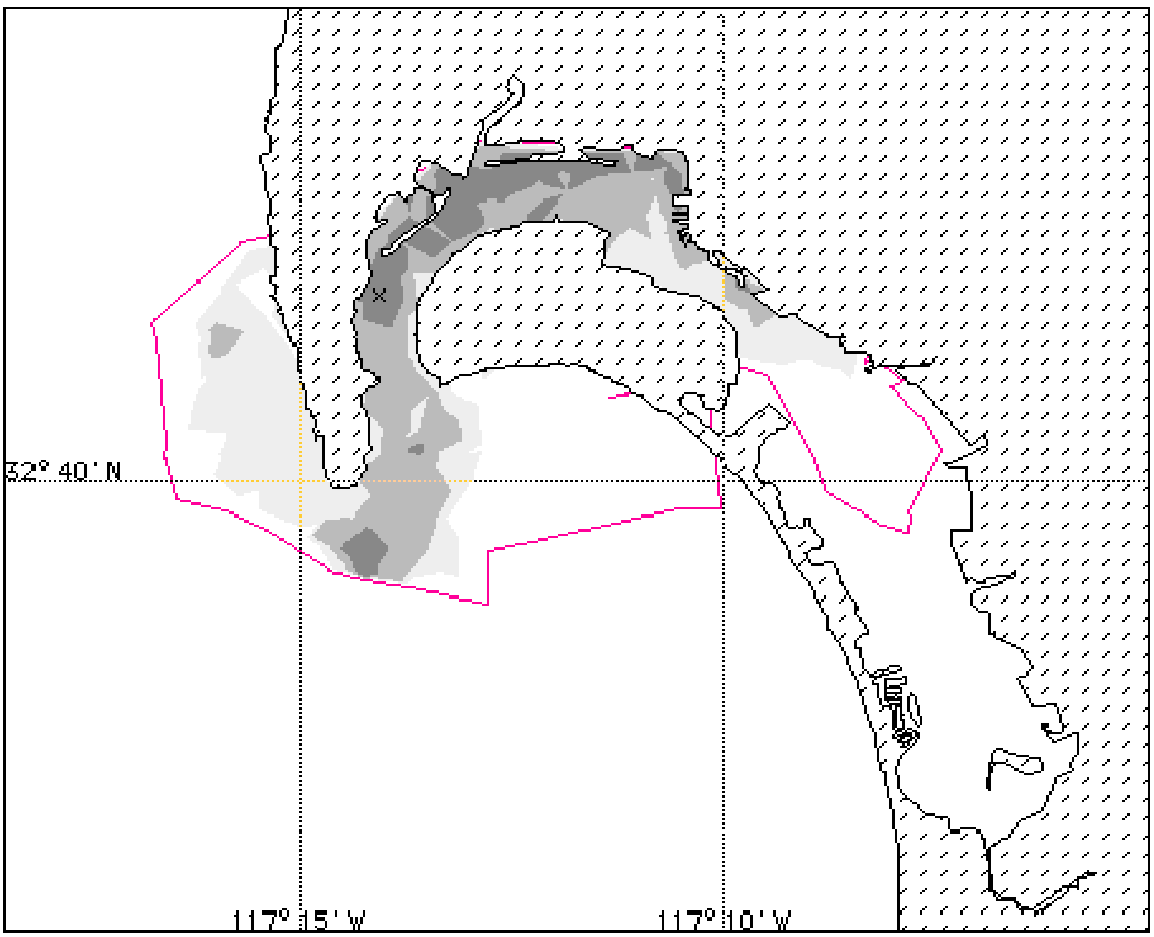

Figure 5. Contours of predicted heavy, medium and light oil concentrations and associated uncertainty bound.

The contours produced as part of the standard trajectory analysis forecast and uncertainty bound are derived directly from the Lagrangian distribution data developed by the basic spill trajectory model. These contours will scale to the distribution of particles and show high concentrations wherever particles tend to accumulate. Since no particular attention has been given to whether the particles represent floating or beached oil, the contour lines will intersect shorelines and, in some cases, may even cross peninsulas and small islands. This is not an indication that concentrations of oil are found on land or under islands, but rather that some segments of land are relatively close to significant concentrations of pollutant. From a graphic information or information content point-of-view, there is no problem if the base map features are drawn after the contours. In this way, the land features simply overprint the oil distribution contour data, information covered up by the land is not relevant.

The final components of the standard trajectory output relate to receptor mode, or extended outlook, analysis. This would typically be an optional addition that might not appear as part of the initial trajectory analysis support. However, for most large spills, as issues in the response become clearer and high-value targets are identified, this type of analysis becomes more important. To develop long-range planning and resolve potential competition for available response equipment, information provided by an extended-outlook analysis can help guide the formulation of response options. The computational procedures for extended outlook analysis are straightforward:

- The statistical model formulation used for the uncertainty analysis continues beyond the forecast period;
- The probabilistic accumulation of particles in the vicinity of a high-value target provides an estimate of the relative threat to that resource; and
- The graphic output to support this analysis is simply the vector polygon surrounding the area that defines the high-value area's threat region, and a numerical value that gives probability of impact (Figure 6).

Figure 7 summarizes the model runs required to provide a standard minimum regret analysis. These procedures can be applied to any of the mixed Eulerian/Lagrangian trajectory model formulations typically used for emergency oil spill response. The basic steps in providing the necessary data to support the analysis are as follows:

1) Define the conditions that initialize the oil distribution;

2) Run a standard forecast (typically 24 hours) using best-available estimates for the vector fields representing currents, winds, and dispersive processes;

3) Return the model to the initial state given in step 1 and run an uncertainty analysis for the standard forecast period (again, typically 24 hours) using vector transport and dispersion processes represented by the deterministic forecast values plus a random component that realistically spans the expected errors; and

4) Beginning with the results from step 3, extend the model another forecast period (out to 48 hours).

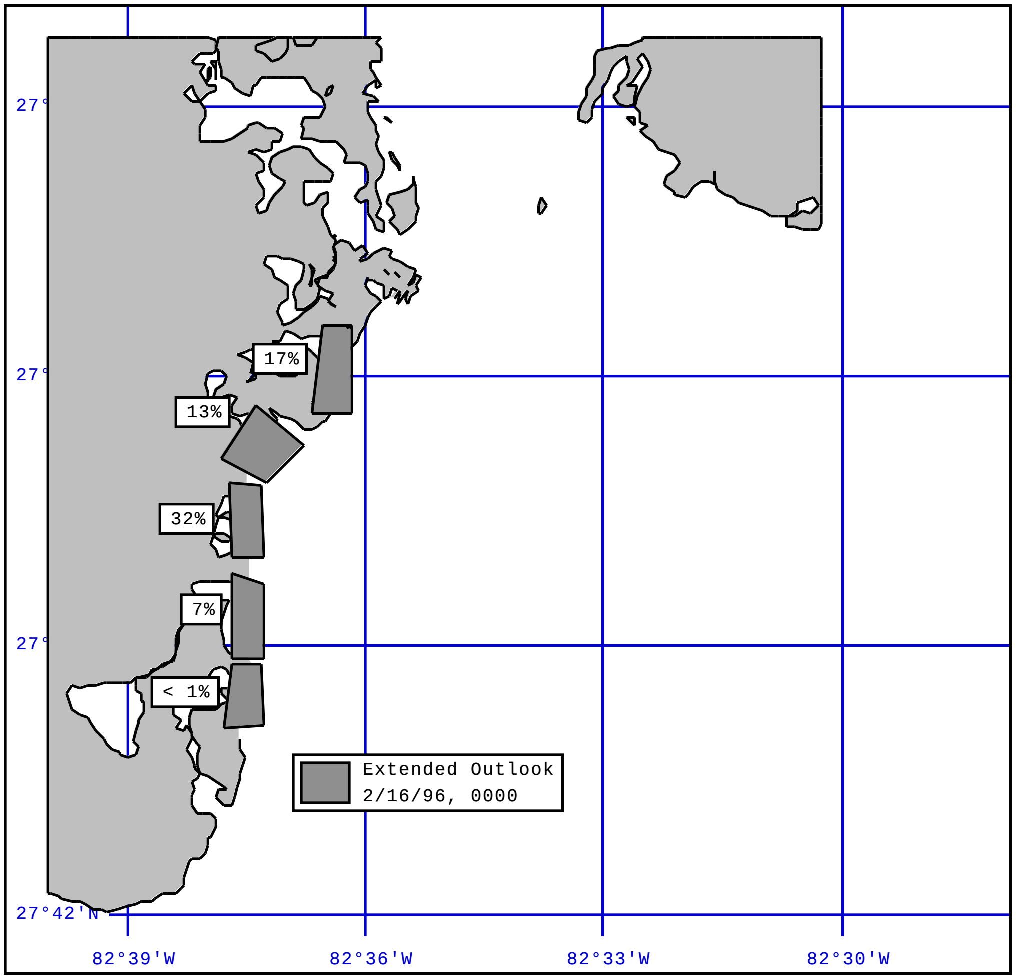

Figure 6. Probability of impact graphic (extended outlook).

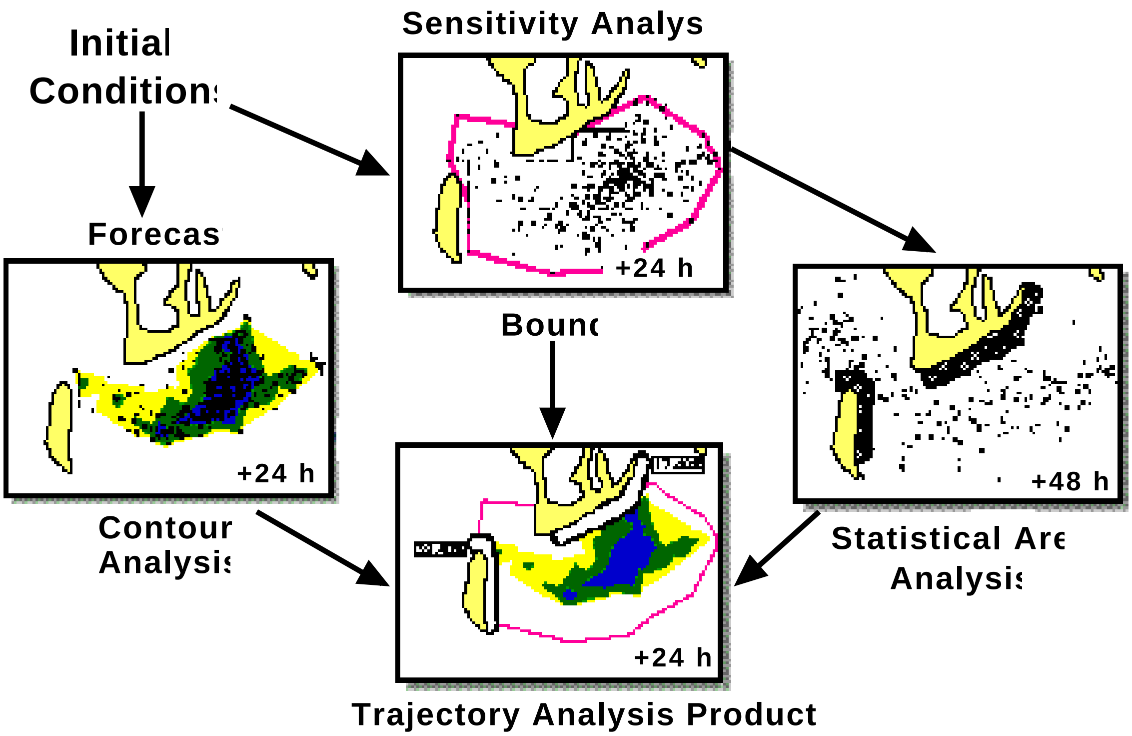

Figure 7. Summary of standard products.

The standard trajectory analysis product digitally represents:

a) The 1%, 4%, and 16% filled contours from the results of step 2;

b) The 0.1% contour bound from the results of step 3; and

c) Optionally, using the results from step 4, a number of polygons identifying high-value resource regions and the numerical probability that they include oil particles.

There must also be a representation of map data, legends, caveats or restrictions in the model formulation, and some sort of header that describes the incident name, initialization times, forecast periods, and originator of the analysis. These will be described in more detail in the next section.

4 Data Formats

A number of data components are required to define a standard-use trajectory analysis. NOAA is introducing a simplified, public-domain format to present these data elements digitally. These data can easily be subdivided into graphic and annotation entities.

The graphic entities will consist of polygons and sets of point data. The polygon data will include:

1) A graphic representation of the “best available” forecast of where oil will be at a particular time;

2) A graphic representation of uncertainty analysis so that the reliability of the forecast can be evaluated;

3) A background map that localizes the graphic displays and identifies recognizable land forms for reference to the general position of the spilled pollutant; and

4) An optional graphic of the statistical threat to specific high-value resources for an extended forecast period.

The sets of point data consist of the geo-coordinates of parcels that represent either the quantitative distribution of pollutant or the probability density of finding pollutant in a particular region. Both the polygon and point graphic data will typically have attributes describing the graphic entities. This information will be included in separate ASCII text files made up of line-feed delineated records that consist of a fixed number of fields.

In addition to the graphic entities that make up the trajectory analysis presentation, necessary annotation includes:

1) A legend that defines the contours of the distribution that are included as graphic objects;

2) A scenario description and caveat block that describes the limitations of the analysis as well as contact information; and

3) A title block that identifies the incident name, the sender of the analysis and the time that it was transmitted as well as the period for which it is valid.

The annotation information will be presented as polygons that define their recommended position on the composite graphic product, attributes that contain drawing recommendations, and a reference to the actual text of the annotation.

The proposed standard-use trajectory analysis message will be made up of either three or five files, depending on whether the actual Lagrangian point data will be sent with the analysis. These will be ASCII text files that can be sent over any electronic mail system. They will include all of the information necessary to produce a final screen copy or paper product in color, half-tone gray scales, or black-and-white images. They will also contain all of the topological information developed during the analysis so that they can be loaded into Geographical Information Systems (GISs) that support geographical analysis with other resource or response data sets. With planned versions of display software the end user can produce trajectory analysis results in a format that will support specific secondary distribution needs. Typically, black and white for facsimile, half-tone for photocopy, and color for Local Area Networks (LANs) or direct presentation.

The five files that make up the standard-use trajectory analysis will be:

1) A Map Overlay Statistical System (MOSS) exchange format file of polygons that describes the graphic entities to draft the trajectory analysis product. Table A1 lists the MOSS polygon primatives that would be included in this file. Appendix A describes the MOSS exchange format files;

2) A text file that is made up of one record for each of the polygon primatives defined in the first file. Individual records are keyed on the entries in File 1 and separated by a line-feed character. Each record is made up of 15 fields, separated by commas, that provide the drawing and quantitative attributes associated with their keyed polygon. Appendix B describes the data fields in the records of File 2;

3) A file of ordered ASCII text strings, each of which is preceded by an index and terminated by a line-feed character. The index of the string can be referenced by the value field in the File 2 records for any annotation that is

recommended as part of the trajectory analysis product. This file will also contain strings that are preceded by a zero (0) index. These contain header information that describes the complete set of files that make up the trajectory analysis message. These zero (0) fields will not be referenced by any of the records in File 2. Details of these fields are described in Appendix C;

4) A MOSS exchange format file of points that describes the positions of the Lagrangian particles that were generated for the forecast portion of the standard-use trajectory analysis. This could be a large file with up to 10,000 points. Unless the recipient of the trajectory message intends to carry out additional analysis, it should be considered as an optional part of the information set; and

5) A text file made up of one record for each of the Lagrangian particles in the fourth file. Individual records will be keyed on the entries in File 4 and separated by a line-feed character. Each record will be made up of fields, separated by commas, that describe the attributes of the individual particles. Appendix D describes the data fields in the records of File 5 for the NOAA model.

The order in which the elements occur in Trajectory analysis File 1 is significant. This is the order in which they should be drawn to ensure proper masking for the final product. If you were to think of these as layers in a GIS representation, there would be a “forecast layer” beneath a “map layer” which in turn would be under an “extended outlook” layer. Finally, a legend, caveats, and a title would be overprinted on the final presentation.

Each of the spatial elements listed in Trajectory Analysis File 1 will have additional information that describes its recommended presentation characteristics found in Trajectory Analysis File 2. The first field in the information record is the index-element name. This field must be unique and link back to the graphic elements in Trajectory Analysis File 1. In the first file, which is in MOSS format, each graphic object is defined by an index which is 1 through n where there are n total graphic objects represented in the file. This provides a unique index. The additional fields in the information record cover how the polygon boundary is to be presented. Next are a series of fields that describe how the polygon will be used to produce a color or a half-tone, gray-scale map and, finally, how the information would be used to produce a black-and-white map. The next three fields describe the text characters that annotate the map in its legend, caveats, and title. The final two fields in the information record present a numerical value associated with the graphic object or, in the case of text, a record number to the actual text record that will be contained in Trajectory Analysis File 3.

Trajectory Analysis File 4 and Trajectory Analysis File 5 are defined in the standard as optional, because they are not required to develop the standard graphic minimum-regret trajectory analysis product. This is because the data represented by the distribution of the Lagrangian oil particles have been summarized in the Thiessen analysis that is already included in the first three required files. Under certain situations, there may be need for more detailed spatial analysis and, thus, this information should be available within the defined standard. Trajectory Analysis File 4 will be a MOSS point file where each of the Lagrangian Elements or oil particles will be represented by a header line containing an index, an attribute name, and a coordinate pair count, followed by a line containing the longitude-latitude coordinate pair in decimal degrees.

Trajectory Analysis File 5 is a list of records separated by line-feed characters. The individual records are made up of eight required data fields and may be followed by additional custom fields. The intention here is to make sure that the standard provides a way for the transmission of essential information that any mixed Eulerian/Lagrangian formulation would create and at the same time provide for modelers to present custom enhanced data that specialized models or sub-models may develop. For example, in the future advanced weathering models may wish to present distillation data or toxicological potential for various stages of aging oil. These extended records would still fit within the standard and they could still be analyzed using present versions of GIS development software. In addition, the new data would be available, although the end user would have to communicate with the model developer to obtain documentation for use and use strategies. Appendix D describes the fields that are required in Trajectory Analysis File 5.

Appendix G gives examples of the standard-use trajectory analysis message files. Figure 8 is a black-and-white version of the associated graphic product.

During the emergency phase of spill response there is additional distribution information that may be of interest. For example, observational oil-distribution maps, typically drawn from overflight reconnaissance by trained observers, are useful to a number of different responders for planning and evaluation of ongoing activities. This is information that must be rapidly distributed in an intelligible format. A digital version or message sent out over an electronic mail system would be useful, particularly if it can be easily downloaded as a graphic or integrated into a larger GIS system. These are clearly the same kinds of issues that are important in developing the standard-use trajectory analysis procedures. A small addition to the list of general polygon objects shown as the last group in Table A1 means that the digital standard and any specific display packages can be used to distribute the standard-use trajectory analysis products, the observational overflight information, and other operational distribution information that may be generated.

5 Conclusions

We have outlined the standard-use trajectory analysis procedures that can be used with any mixed Lagrangian/Eulerian model to produce an informative spill response product that can effectively support minimum-regret decision-making. Minimum-regret decision support is essential for trajectory analysis results that are intended for integration into general “command and control” or “information management” systems. The NOAA/HAZMAT spill response team experimented with this standard-use trajectory analysis product in 1995 and has tested its use in a number of spill drills and regional planning efforts. The majority of end users in the response community who have had the opportunity to view the product conclude that the resulting graphic product is both compact and informative. NOAA is now moving to make the standard-use trajectory analysis message a routine part of our emergency response

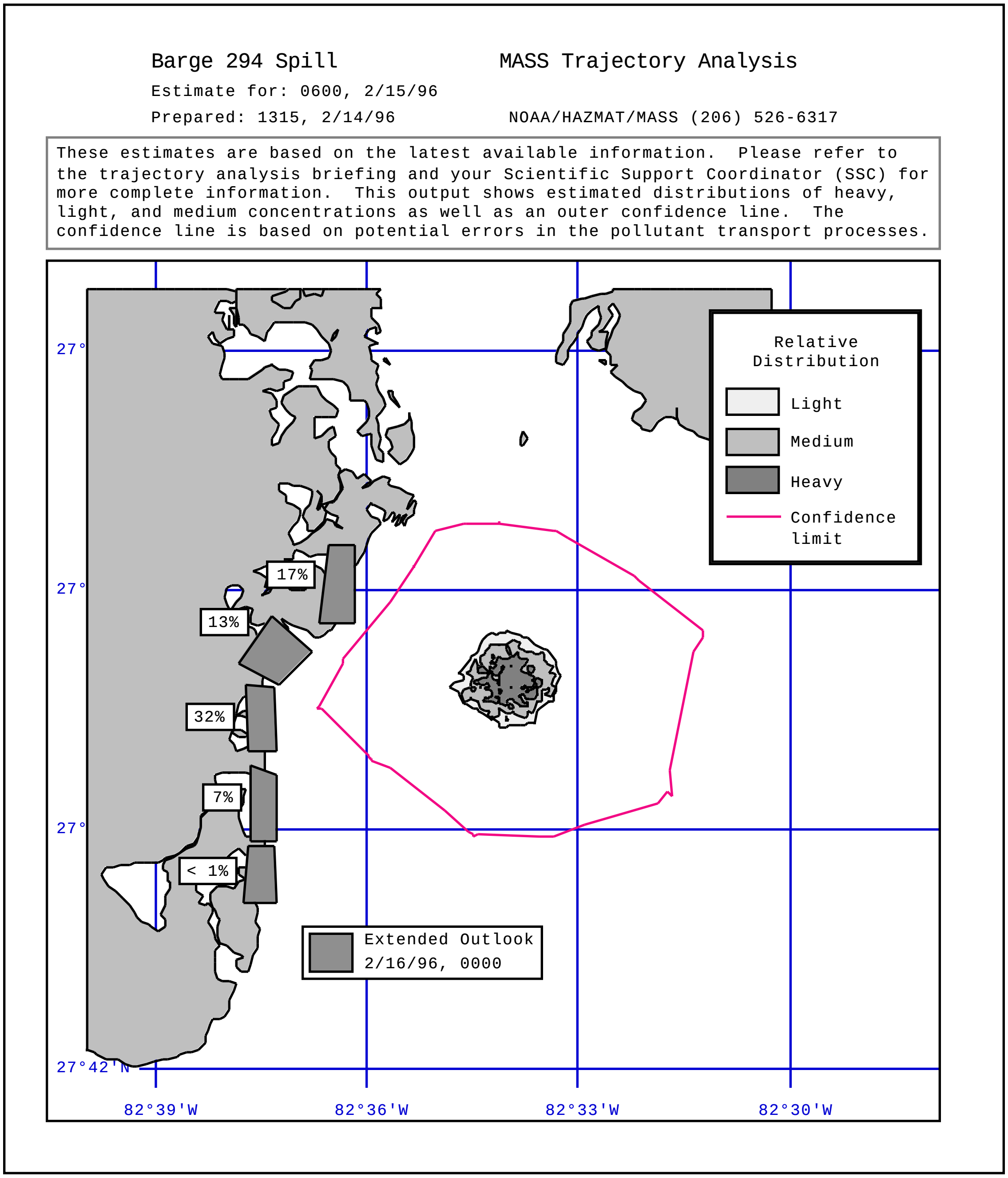

Figure 8. Composite Trajectory Analysis Standard

support. The digital message format that is described in this report will provide a uniform way to distribute the group's trajectory analysis results over the "Hotline" electronic mail system that is part of the NOAA spill information management system. This information will thus be available to the U.S. Coast Guard, NOAA, industry, and state responders as quickly as it is produced. In addition, it will also be available to various managers through their connections to Regional Response Team representatives. Testing is underway to introduce observational overflight analysis into the same message stream, using the same digital format protocols.

Responders, planners, and managers can obtain immediate access to the digital messages that contain pollutant distribution data in the form of observational overflight analysis and trajectory analysis information. It will be necessary for them to have an application that will take the message as input and produce the graphic screen image, or paper product, that the information is intended to represent. Thus, the second part of the information distribution system will be the development and transmission of a viewing application. This product should be simple and user-friendly to the point of requiring no training. A graphical user interface would provide functionality to allow the user to select a digital message for display. Options would be available to select a color, half-tone, or black-and-white product. If the optional Files 4 and 5 are included in the message, an additional option will make it possible to display beached oil elements. The product would be displayed on the screen with a final option to send the image to a printer. NOAA will develop these simple viewing engines for both Windows™ and Macintosh™ personal computer systems. We will provide consultation for anyone who would like to develop a viewer for some alternate system. In addition, the proposed file format lends itself to importation to a variety of commercially available mapping packages.

The digital message formats described in this report contain a good deal more information than what is presented in the standard-use trajectory analysis product. The Lagrangian point data and the topological relationships in the MOSS files can provide new insights when used with additional map-based resource data and pre-compiled response plans. In general, responders and planners who have access to these additional information resources will be using GIS-based programs that deal with spatial data in a more structured format that is capable of both topological and thematic queries. Working together, the Florida Department of Environmental Protection and NOAA/HAZMAT are developing translators and application specific scripts to import the standard-use trajectory analysis results with all of the associated topological data into

NOAA's Mapping Application for Response, Planning, and Local Operational Tasks (MARPLOT™, a display mapping program) and ARC INFO™ based systems, including Florida's ArcView2 based Marine Spill Analysis System (FMAS).

Any of the view engines, translators, or ARC Macro Language (AML) scripts developed as part of this project will be freely distributed to responders, planners, and managers who need the oil-spill distribution observations and trajectory analysis estimates of future pollutant distributions. The system is based on a public-domain message format so that other model developers can package their information in the standard-use trajectory analysis format and take advantage of the same sort of distribution network.

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Appendix A: Trajectory Analysis Files 1 & 4 (MOSS format)

Trajectory Analysis Files 1 and 4 use the MOSS standard input file format. Unlike the formats for Files 2, 3, and 5, the MOSS standard format uses fixed-length records.

MOSS STANDARD INPUT FILE FORMAT

```
FILE TYPE:         STANDARD MOSS INPUT
FILE LENGTH:       VARIABLE

RECORD TYPE:       HEADER (REPEATING SERIES OF HEADER RECORDS PRE-
                           CEEDING ASSOCIATED COORDINATE PAIR DATA)
                          (READ IN I5,10X,15A2,5X,I5 FORMAT)
RECORD LENGTH:     56 CHARACTERS
RECORD POSITION:   (1) BEFORE START OF ASSOCIATED COORDINATE DATA
```

*WORD NUMBER	BYTE NUMBER	FIELD LENGTH	FIELD TYPE	FIELD DESCRIPTION
1-3	1-5	5	CHAR	Item Number(NEGATIVE IF THE COORDINATES ARE LON/LAT)
3-8	6-15	10	CHAR	Blanks
8-23	16-45	30	CHAR	Attribute Name
23-25	46-50	5	CHAR	Blanks
26-28	51-55	5	CHAR	Number of coord. pairs
28	56	1	CHAR	ASCII NEW LINE CHARACTER

```
FILE TYPE:         STANDARD MOSS INPUT
FILE LENGTH:       VARIABLE LENGTH

RECORD TYPE:       COORDINATE PAIRS (SERIES OF X,Y COORDINATES
                                      FOLLOWING HEADER RECORD)
RECORD LENGTH:     23 CHARACTERS
RECORD POSITION:   AFTER HEADER RECORD (NUMBER OF COORDINATE RECORDS
                   EQUALS THE VALUE INDICATED BY BYTES 51-55 IN THE
                   HEADER RECORD)  (READ IN 2F11.2 FORMAT)
```

*WORD NUMBER	BYTE NUMBER	FIELD LENGTH	FIELD TYPE	FIELD DESCRIPTION
1-6	1-11	11	CHAR	X Coordinate
6-11	12-22	11	CHAR	Y Coordinate
12	23	1	CHAR	ASCII NEW LINE CHARACTER

IF COORDINATES ARE LONGITUDE/LATITUDE (READ IN 2F10.5,I2 FORMAT)

1-5	1-10	10	CHAR	LONGITUDE
6-10	11-20	10	CHAR	LATITUDE
11	21-22	2	CHAR	FLAG 0-NORMAL 1-INDICATES FIRST POINT OF ISLAND POLYGON
12	23	1	CHAR	ASCII NEW LINE CHARACTER

*NOTE: Assumes 2 Alpha characters (2 bytes) to one word.

File 1 & 4 record names and order

In the MOSS standard input file format each each object in Files 1 and 4 start with a header record line. The header includes a 30-character "attribute name," i.e., the name of the object that starts with the given header.

In File 4, each Lagrangian Element (LE) point object is given the name LE POINT. The points are not assumed to be in any particular order; they are not sorted by type, location, status, etc.

In File 1, however, objects are named according to their function in the overall trajectory analysis graphic, and the order in which the objects appear in the file is important. In particular, the objects are listed in draw order, so that the first object in the file should be drawn first, and the last object should be drawn last. This is important in case two or more objects overlay each other. For example, if the legend overlaps part of the map, it is drawn over tha map and partially obscures it.

The table below lists the names of the objects in File 1 in the order they are written by NOAA's standard trajectory analysis program. (Note, however, that any given file written by the trajectory analysis might not contain every type of object listed in the table).

A check in the multiple column means that more than one object with the given name can appear sequentially. For instance, the file may start with a run of several objects with the name BACKGROUND.

The check in the rectangle column means that the object is a rectangle, as opposed to a general polygon. (Note that a rectangle is just a special case of a polygon and thus all records in File 1 represent polygons, as they must to fit the MOSS standard.)

For information on the display column, see Appendix B. F represents FILLED. B represents BOUNDED. B+F represents BOUNDED+FILLED. T represents CLIPTEXT.

Table A1. File 1 objects.

attribute (object) name	multiple	rectangle	display
BACKGROUND			F
FORECASTLIGHT			B (+F)
FORECASTMEDIUM			B (+F)
FORECASTHEAVY			B (+F)
FORECASTUNCERTAINTY			B
MAPLAND			(B+) F
MAPBOUND			B
EXTENDEDOUTLOOKTHREAT			B+F
LEGENDBOUND			B+F
LEGENDTEXT			T
LEGENDBAR			(B+) F
ARROW			B
CAVEATBOUND			B
CAVEATTEXT			T
TITLETEXT			T
OVERFLIGHTFEATURE			F
ANNOTATIONNOTE			T
OBSERVATIONALTRACKLINE			B

The lines for the different types of contour polygons (BACKGROUND ... FORECASTUNCERTAINTY) are blocked off and contain only a single check in the multiple column to indicate that, due to the complex nature of the contour graphics, these objects may appear in any order within the group.

Also, the lines of the table for LEGENDBOUND, LEGENDTEXT, and LEGENDBAR are blocked off to indicate that this sequence of three types of objects can be repeated any number of times. That is, you might see one sequence (a LEGENDBOUND followed by some number of

LEGENDTEXT objects followed by a LEGENDBAR) followed by one or more other such sequences.

Appendix B: Trajectory Analysis File 2

This file is a list of text records, one per line, that specify the extended attributes of the objects in File 1. Each record consists of the 15 fields listed below. The fields are separated from each other by the comma character (ASCII 44), and the line is terminated with a LINEFEED character (ASCII 10).

- the item number (corresponding to the item number for the given object in File 1)

- the item name (corresponding to the attribute name for the given object in File 1)

- one of the following keywords specifying the overall display characteristics of the polygon:

BOUNDED:	draw a solid line around the border of the object
FILLED:	fill the interior of the object with the given pattern
BOUNDED+FILLED:	both BOUNDED and FILLED
CLIPTEXT:	the object is a rectangle into which a line of text is to be drawn (the object is neither bounded nor filled with a pattern)

- the penwidth in points to use when drawing the object; for CLIPTEXT objects, specify 1

- one of the following keywords specifying the type of line to use when drawing the boundary of the object: SOLID, DOTTED, DASHED, NONE; use NONE for any object that is not BOUNDED

  NOTE: The boundary should only be drawn when the object is filled with one of the patterns in appendix E or when the object is filled with the color white. In all other cases, treat the object as if the boundary value were NONE. When drawing a boundary, draw it in black, unless the object is not filled, in which case draw it using the object's color or gray scale value (black when in black and white mode).

- a number giving the red component of the RGB specification of the color of the object, expressed as a percent value from 0 (no red) to 100 (full red).

- the green component of the RGB value

- the blue component of the RGB value

- a percent value (0 - 100) specifying the grayscale "darkness" of the object (how dark the object would appear when viewed in black-and-white)

- one of the following keywords specifying the pattern to use when filling the interior of the object (see Appendix E for pattern samples): LIGHTOIL, MEDIUMOIL, HEAVYOIL, MESH, LAND, SOLID, NONE; use NONE for any object that is not FILLED

- the name of the font to use when drawing the text of a CLIPTEXT object; use a standard font name such as COURIER (see Appendix F for font samples); for non-text objects, specify NONE

- the font size in points to use when drawing the text of a CLIPTEXT object; for non-text objects, specify 0

- the font style to use when drawing the text of a CLIPTEXT object; use one of the following keywords: PLAIN, BOLD, ITALICS ; for non-text objects, specify NONE

- a number specifying the value of the object; this value varies depending on the type of object

- one of the following keywords specifying the units or "type" of the value in the preceding field:

TEXTINDEX:	use this keyword for all CLIPTEXT objects. In this case, the value field specifies the index number of the object's text in File 3

RELATIVE: use this value for oil contour polygons, where the contoured Eulerian density value has been computed as falling a certain percent of the distance between the lowest and highest density among all LE points in the data set. In this case, the value field specifies that percent value

TONSPERSQKM: use this value for oil contour polygons, where the contoured Eulerian density value is an absolute number of metric tons per square kilometer. In this case, the value field specifies that density

PROBABILITY: use this value for oil contour polygons that represent probabilities of finding oil in a given region. In this case, the value field specifies the probability as a percent value of finding oil in the given region

NONE: use this value for all other objects. In this case, specify 0 in the value field

Appendix C: Trajectory Analysis File 3

This file is a list of text records, one per line. Each line contains a non-negative integer index number followed by a comma character (ASCII 44) followed by a string of text. Each line is terminated with a LINEFEED character (ASCII 10).

There are actually two types of records in this file. The first six or more lines have zero as their index number, as described below. The remaining lines have positive index numbers counting up incrementally from one. Each corresponds to the “value” field of a CLIPTEXT rectangle in Files 1 and 2, and which represents a line of text to be drawn on the trajectory analysis graphic picture. Thus, Files 1, 2, and 3 work together to define a text object. A record in File 1 gives the bounding rectangle into which the text is to be drawn. A corresponding record in File 2 (which has the same item number as the File 1 record) gives extended graphical attributes and contains a positive integer index in its “value” field. Finally, File 3 contains a line whose positive index matches the value, and which contains the actual text to be written into the rectangle.

Because the text of each object must appear on its own line in File 3, each rectangular text object can only contain a single line of text. Thus, to represent multiple lines of text, you must include one text object for each line. In addition to keeping the File 3 format simpler, this one-line-per-object policy allows for a greater degree of consistency in the look of multiple-line text across platforms.

Returning now to the first several lines at the top of File 3, these records all have zero (0) as their index number. For these records, the string of text following the comma is not meant to be drawn on the analysis picture (although there may be a text object in the picture that contains the same text as one of these records), but rather represents general information that applies to the set of all five files as a whole. Each of these strings starts with a keyword-colon sequence, where the keyword specifies type of information provided on the given line. Any File 3 must start with the following six lines:

> 0, SPILLID: <the name of the spill/trajectory>
> 0, FROM: <person or organization that generated the output>
> 0, CONTACT: <name and phone number of person or organization>

0, ISSUED: <date and time that files were generated>
0, VALIDFOR: <date and time represented by trajectory in the file>
0, ADDLEDATA: <tags for additional LE data (see below)>

The text in <brackets> would be replaced with text appropriate for the given set of files. Date and time information is specified in the following format: mm/dd/yy, tttt. For example, if the file was generated January 10, 1996, at 3:30 pm, the fourth line of File 3 would read

0, ISSUED: 1/10/96, 1530

Optionally, any number of additional zero-keyword-colon records (beyond the six required ones) can be provided, using any user-defined keywords. These fields can hold user-defined information that applies to the set of all five files as a whole. However, only the six keywords above are guaranteed to be recognized by any particular reader of the files.

The ADDLEDATA field is used to indicate the presence of user-defined LE-specific data. File 5 contains eight standard data fields associated with each LE (in addition to the latitude/longitude fields in File 4). Suppose that, in addition to these fields, you also wanted to keep values representing toxicological potential and distillation information for each LE point. You could do this by specifying two tags on the ADDLEDATA line (separated by commas):

0, ADDLEDATA: TOXPOTENTIAL, DISTILLINFO

This is a flag that two additional fields (following the eight standard ones) are expected on each line of File 5. Like the other fields of File 5, these additional fields are separated by commas.

If you do not have additional LE data, do not list any tags on the ADDLEDATA line.

Appendix D: Trajectory Analysis File 5

This file lists text records, one per line, that specify the extended attributes of the points in File 4 . Each record consists of the eight fields listed below, plus optional user-defined fields (see Appendix C). The fields are separated by the comma character (ASCII 44), and the line is terminated with a LINEFEED character (ASCII 10).

- the item number (corresponding to the item number for the given point in File 4)

- one of the following keywords specifying the type of the LE: ABSOLUTEMASS, RELATIVEMASS, RELATIVEPROBABILITY

- one of the following keywords specifying the pollutant substance that the point represents: GAS, JP4, JP5, DIESEL, IFO, BUNKER, LIGHTCRUDE, MEDIUMCRUDE, HEAVYCRUDE, LAPIO, CONSERVATIVE

- a number specifying the depth (z-coordinate) of the LE, in meters

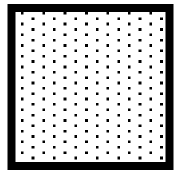
- a number specifying the mass of the LE in kilograms

- a number specifying the density of the LE in grams/cubic centimeter

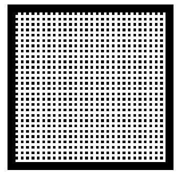
- the age of the LE since release, in seconds

- one of the following keywords specifying the status of the LE: INWATER, ONBEACH, OFFMAP

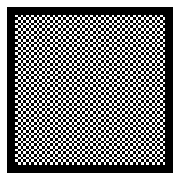
Appendix E: Pattern Samples



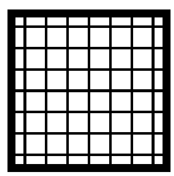
LIGHTOIL: a sparse pixel pattern giving a “light gray” look



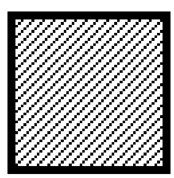
MEDIUMOIL: a medium pixel pattern giving a “gray” look



HEAVYOIL: a dense pixel pattern giving a “dark gray” look



MESH: a box pixel pattern giving a “mesh” look



LAND: diagonal stripes

Appendix F: Font Samples

Courier is a fixed-width, serif font.

Courier PLAIN:

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
0123456789
!@#$%^&*()-+[]{}=_<>,./?;:

Courier BOLD:

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
0123456789
!@#$%^&*()-+[]{}=_<>,./?;:

Courier ITALICS:

ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
0123456789
!@#$%^&()-+[]{}=_<>,./?;:*

Appendix G: Sample Trajectory Analysis Files

Trajectory Analysis File 1

```
   -1          FORECASTLIGHT                        199
 -82.55445  27.78205 0
 -82.55524  27.78013 0
 -82.55535  27.77981 0
 -82.55520  27.77967 0
 -82.55577  27.77876 0
 ...
 ...
 -82.56727  27.77258 0
 -82.56712  27.77260 0
 -82.56663  27.77284 0
   -2          FORECASTMEDIUM                       359
 -82.55576  27.77926 0
 -82.55614  27.77864 0
 -82.55634  27.77745 0
 -82.55797  27.77791 0
 ...
 ...
 -82.57507  27.77873 0
 -82.57459  27.77916 0
 -82.57455  27.77960 0
   -3          FORECASTMEDIUM                         7
 -82.56663  27.77284 0
 -82.56712  27.77260 0
 -82.56727  27.77258 0
 -82.56732  27.77287 0
 -82.56736  27.77346 0
 -82.56689  27.77307 0
 -82.56663  27.77284 0
   -4          FORECASTHEAVY                        221
 -82.55889  27.78050 0
 -82.55902  27.78032 0
 -82.55960  27.77986 0
 -82.55982  27.77980 0
 ...
 ...
 -82.56995  27.77759 0
 -82.56975  27.77745 0
 -82.56915  27.77708 0
...
...
  -16          FORECASTUNCERTAINTY                   52
 -82.52065  27.78998 0
 -82.52280  27.78676 0
 -82.52868  27.76246 0
 -82.52784  27.75668 0
 -82.52905  27.75800 0
 ...
 ...
 -82.53584  27.80169 0
 -82.52071  27.79122 0
 -82.52065  27.78998 0
  -17          MAPLAND                              532
```

```
 -82.66626  27.86255 0
 -82.66626  27.70407 0
 -82.66601  27.70400 0
 ...
 ...
 -82.65968  27.86255 0
 -82.66170  27.86255 0
 -82.66374  27.86255 0
 -82.66578  27.86255 0
 -82.66626  27.86255 0
...
...
  -33          MAPBOUND                                  5
 -82.67815  27.68012 0
 -82.46128  27.68012 0
 -82.46128  27.86496 0
 -82.67815  27.86496 0
 -82.67815  27.68012 0
  -34          EXTENDEDOUTLOOKTHREAT                     5
 -82.60910  27.80966 0
 -82.61135  27.79272 0
 -82.60290  27.79272 0
 -82.60290  27.80966 0
 -82.60910  27.80966 0
  -35          EXTENDEDOUTLOOKTHREAT                     5
 -82.62824  27.74640 0
 -82.62936  27.73445 0
 -82.62148  27.73495 0
 -82.62205  27.74640 0
 -82.62824  27.74640 0
  -36          EXTENDEDOUTLOOKTHREAT                     5
 -82.62767  27.76334 0
 -82.62767  27.74742 0
 -82.62148  27.74742 0
 -82.62148  27.76135 0
 -82.62767  27.76334 0
...
...
  -39          LEGENDBOUND                               5
 -82.51990  27.79999 0
 -82.46754  27.79999 0
 -82.46754  27.85489 0
 -82.51990  27.85489 0
 -82.51990  27.79999 0
  -40          LEGENDTEXT                                5
 -82.50507  27.84638 0
 -82.46842  27.84638 0
 -82.46842  27.85025 0
 -82.50507  27.85025 0
 -82.50507  27.84638 0
  -41          LEGENDTEXT                                5
 -82.51030  27.84213 0
 -82.46842  27.84213 0
 -82.46842  27.84599 0
 -82.51030  27.84599 0
 -82.51030  27.84213 0
...
...
```

```
  -65          CAVEATBOUND                                        5
 -82.67815  27.86496 0
 -82.46128  27.86496 0
 -82.46128  27.89583 0
 -82.67815  27.89583 0
 -82.67815  27.86496 0
  -66          CAVEATTEXT                                         5
 -82.67815  27.88966 0
 -82.46128  27.88966 0
 -82.46128  27.89583 0
 -82.67815  27.89583 0
 -82.67815  27.88966 0
...
...
  -71          TITLETEXT                                          5
 -82.65646  27.91267 0
 -82.48297  27.91267 0
 -82.48297  27.92109 0
 -82.65646  27.92109 0
 -82.65646  27.91267 0
  -72          TITLETEXT                                          5
 -82.65646  27.90425 0
 -82.48297  27.90425 0
 -82.48297  27.91267 0
 -82.65646  27.91267 0
 -82.65646  27.90425 0
  -73          TITLETEXT                                          5
 -82.65646  27.89584 0
 -82.48297  27.89584 0
 -82.48297  27.90425 0
 -82.65646  27.90425 0
 -82.65646  27.89584 0
```

Trajectory Analysis File 2

```
-1, FORECASTLIGHT, BOUNDED+FILLED, 1, SOLID, 0, 100, 100, 10, LIGHTOIL, NONE, 0, NONE, 1, RELATIVE
-2, FORECASTMEDIUM, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 4, RELATIVE
-3, FORECASTMEDIUM, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 4, RELATIVE
-4, FORECASTHEAVY, BOUNDED+FILLED, 1, SOLID, 0, 0, 82, 50, HEAVYOIL, NONE, 0, NONE, 16, RELATIVE
-5, FORECASTHEAVY, BOUNDED+FILLED, 1, SOLID, 0, 0, 82, 50, HEAVYOIL, NONE, 0, NONE, 16, RELATIVE
-6, FORECASTMEDIUM, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 4, RELATIVE
-7, FORECASTHEAVY, BOUNDED+FILLED, 1, SOLID, 0, 0, 82, 50, HEAVYOIL, NONE, 0, NONE, 16, RELATIVE
-8, FORECASTMEDIUM, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 4, RELATIVE
-9, FORECASTMEDIUM, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 4, RELATIVE
-10, FORECASTMEDIUM, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 4, RELATIVE
-11, FORECASTMEDIUM, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 4, RELATIVE
-12, FORECASTHEAVY, BOUNDED+FILLED, 1, SOLID, 0, 0, 82, 50, HEAVYOIL, NONE, 0, NONE, 16, RELATIVE
-13, FORECASTHEAVY, BOUNDED+FILLED, 1, SOLID, 0, 0, 82, 50, HEAVYOIL, NONE, 0, NONE, 16, RELATIVE
-14, FORECASTHEAVY, BOUNDED+FILLED, 1, SOLID, 0, 0, 82, 50, HEAVYOIL, NONE, 0, NONE, 16, RELATIVE
-15, FORECASTHEAVY, BOUNDED+FILLED, 1, SOLID, 0, 0, 82, 50, HEAVYOIL, NONE, 0, NONE, 16, RELATIVE
-16, FORECASTUNCERTAINTY, BOUNDED, 1, SOLID, 0, 0, 0, 100, NONE, NONE, 0, NONE, 0.100000, RELATIVE
-17, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-18, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-19, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-20, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-21, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-22, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-23, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-24, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-25, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-26, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-27, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-28, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-29, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-30, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-31, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-32, MAPLAND, BOUNDED+FILLED, 1, SOLID, 56, 44, 22, 75, LAND, NONE, 0, NONE, 0, NONE
-33, MAPBOUND, BOUNDED, 1, SOLID, 0, 0, 0, 100, NONE, NONE, 0, NONE, 0, NONE
-34, EXTENDEDOUTLOOKTHREAT, BOUNDED+FILLED, 1, SOLID, 0, 0, 0, 100, MESH, NONE, 0, NONE, 0, NONE
-35, EXTENDEDOUTLOOKTHREAT, BOUNDED+FILLED, 1, SOLID, 0, 0, 0, 100, MESH, NONE, 0, NONE, 0, NONE
-36, EXTENDEDOUTLOOKTHREAT, BOUNDED+FILLED, 1, SOLID, 0, 0, 0, 100, MESH, NONE, 0, NONE, 0, NONE
-37, EXTENDEDOUTLOOKTHREAT, BOUNDED+FILLED, 1, SOLID, 0, 0, 0, 100, MESH, NONE, 0, NONE, 0, NONE
-38, EXTENDEDOUTLOOKTHREAT, BOUNDED+FILLED, 1, SOLID, 0, 0, 0, 100, MESH, NONE, 0, NONE, 0, NONE
-39, LEGENDBOUND, BOUNDED+FILLED, 2, SOLID, 100, 100, 100, 0, ERASE, NONE, 0, NONE, 0, NONE
-40, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 1, TEXTINDEX
-41, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 2, TEXTINDEX
-42, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 3, TEXTINDEX
-43, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 4, TEXTINDEX
-44, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 5, TEXTINDEX
-45, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 6, TEXTINDEX
-46, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 7, TEXTINDEX
-47, LEGENDBAR, BOUNDED+FILLED, 1, SOLID, 0, 100, 100, 10, LIGHTOIL, NONE, 0, NONE, 0, NONE
-48, LEGENDBAR, BOUNDED+FILLED, 1, SOLID, 0, 45, 100, 25, MEDIUMOIL, NONE, 0, NONE, 0, NONE
-49, LEGENDBAR, BOUNDED+FILLED, 1, SOLID, 19, 19, 19, 50, HEAVYOIL, NONE, 0, NONE, 0, NONE
-50, LEGENDBAR, BOUNDED, 1, SOLID, 94, 3, 51, 100, NONE, NONE, 0, NONE, 0, NONE
-51, LEGENDBOUND, BOUNDED+FILLED, 1, SOLID, 100, 100, 100, 0, ERASE, NONE, 0, NONE, 0, NONE
-52, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 8, TEXTINDEX
-53, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 9, TEXTINDEX
-54, LEGENDBAR, BOUNDED+FILLED, 1, SOLID, 0, 0, 0, 100, MESH, NONE, 0, NONE, 0, NONE
-55, LEGENDBOUND, BOUNDED+FILLED, 1, SOLID, 100, 100, 100, 0, ERASE, NONE, 0, NONE, 0, NONE
-56, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 10, TEXTINDEX
-57, LEGENDBOUND, BOUNDED+FILLED, 1, SOLID, 100, 100, 100, 0, ERASE, NONE, 0, NONE, 0, NONE
-58, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 11, TEXTINDEX
-59, LEGENDBOUND, BOUNDED+FILLED, 1, SOLID, 100, 100, 100, 0, ERASE, NONE, 0, NONE, 0, NONE
-60, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 12, TEXTINDEX
-61, LEGENDBOUND, BOUNDED+FILLED, 1, SOLID, 100, 100, 100, 0, ERASE, NONE, 0, NONE, 0, NONE
-62, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 13, TEXTINDEX
-63, LEGENDBOUND, BOUNDED+FILLED, 1, SOLID, 100, 100, 100, 0, ERASE, NONE, 0, NONE, 0, NONE
-64, LEGENDTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 14, TEXTINDEX
-65, CAVEATBOUND, BOUNDED, 1, SOLID, 0, 0, 0, 100, NONE, NONE, 0, NONE, 0, NONE
-66, CAVEATTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 15, TEXTINDEX
-67, CAVEATTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 16, TEXTINDEX
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-68, CAVEATTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 17, TEXTINDEX
-69, CAVEATTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 18, TEXTINDEX
-70, CAVEATTEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 19, TEXTINDEX
-71, TITLETEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 12, BOLD, 20, TEXTINDEX
-72, TITLETEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 21, TEXTINDEX
-73, TITLETEXT, CLIPTEXT, 1, NONE, 0, 0, 0, 100, NONE, COURIER, 9, PLAIN, 22, TEXTINDEX
```

Trajectory Analysis File 3

```
0, SPILLID: Barge 294 Spill
0, FROM: MASS Trajectory Analysis
0, CONTACT: NOAA/HAZMAT/MASS (206) 526-6317
0, ISSUED: 1315, 2/14/96
0, VALIDFOR: 0600, 2/15/96
0, ADDLEDATA:
1, Relative
2, Distribution
3, Light
4, Medium
5, Heavy
6, Confidence
7, limit
8, Extended Outlook
9, 2/16/96, 0000
10, 17%
11, < 1%
12, 7%
13, 32%
14, 13%
15, These estimates are based on the latest available information.  Please refer to
16, the trajectory analysis briefing and your Scientific Support Coordinator (SSC) for
17, more complete information.  This output shows estimated distributions of heavy,
18, light, and medium concentrations as well as an outer confidence line.  The
19, confidence line is based on potential errors in the pollutant transport processes.
20, Barge 294 Spill -- MASS Trajectory Analysis
21, Estimate for: 0600, 2/15/96
22, Prepared: 1315, 2/14/96 -- NOAA/HAZMAT/MASS (206) 526-6317
```

Trajectory Analysis File 4

```
   -1          LE POINT                                  1
 -82.56188  27.78173 0
   -2          LE POINT                                  1
 -82.56647  27.78349 0
   -3          LE POINT                                  1
 -82.57030  27.77765 0
   -4          LE POINT                                  1
 -82.56454  27.77574 0
   -5          LE POINT                                  1
 -82.56149  27.78466 0
   -6          LE POINT                                  1
 -82.56712  27.78156 0
   -7          LE POINT                                  1
 -82.56226  27.78638 0
   -8          LE POINT                                  1
 -82.56493  27.78469 0
   -9          LE POINT                                  1
 -82.56196  27.78148 0
```

```
  -10          LE POINT                                1
 -82.56775  27.77937 0
  -11          LE POINT                                1
 -82.56625  27.78047 0
...
...
```

Trajectory Analysis File 5

```
-1, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-2, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-3, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-4, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-5, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-6, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-7, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-8, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-9, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-10, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
-11, RELATIVEMASS, MEDIUMCRUDE, 0.000000, 1.000000, 0.950000, 18.000000, INWATER
...
...
```