Monitoring Dispersed Oil and its Effects in the Sea

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Why Consider Dispersants?

- Aerial application of dispersants can mitigate large amounts of oil if treated promptly.
  - Mitigate -- reduce the overall impact of an oil spill to the environment as a whole.
  - However, dispersant use is a trade-off with increased risks to the water column balanced against reduced injury to surface water and shoreline resources.

Dispersant Use in California

PAST:

- Quick-approval process (RRT)
- Hesitation to use dispersants
- Concerns about effectiveness and impacts
- Limited equipment and supplies

Dispersant Use in California

NOW:

- Pre-approval zones
- Quick-approval zones (through RRT)
- California Dispersant Use Plan
- Equipment & supplies
- Education
- Acceptance of dispersants
- USCG SMART

Future use of dispersants in CA likely

The DOMP

- OPA 90 and Lempert Keene Seastrand 90 require NRDA

- California Dispersant Use Plan:

  Dispersant Application only if:

  "Net Environmental Benefit"

- Development of Dispersed Oil Monitoring Plan (DOMP) to quantify impact

California Dispersed Oil Monitoring Plan (DOMP)

Principle investigators:

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- Dr. D. French McCay
- Dr. J. Payne

Collaborators:

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California Dispersed Oil Monitoring Plan (DOMP)

Objectives

- Develop a plan to quantify and evaluate impacts to aquatic organisms after a spill where dispersants are used
- Provide data for NRDA
- Evaluate effects for decision making for future spills

Dispersed Oil Monitoring Plan

HOW ?

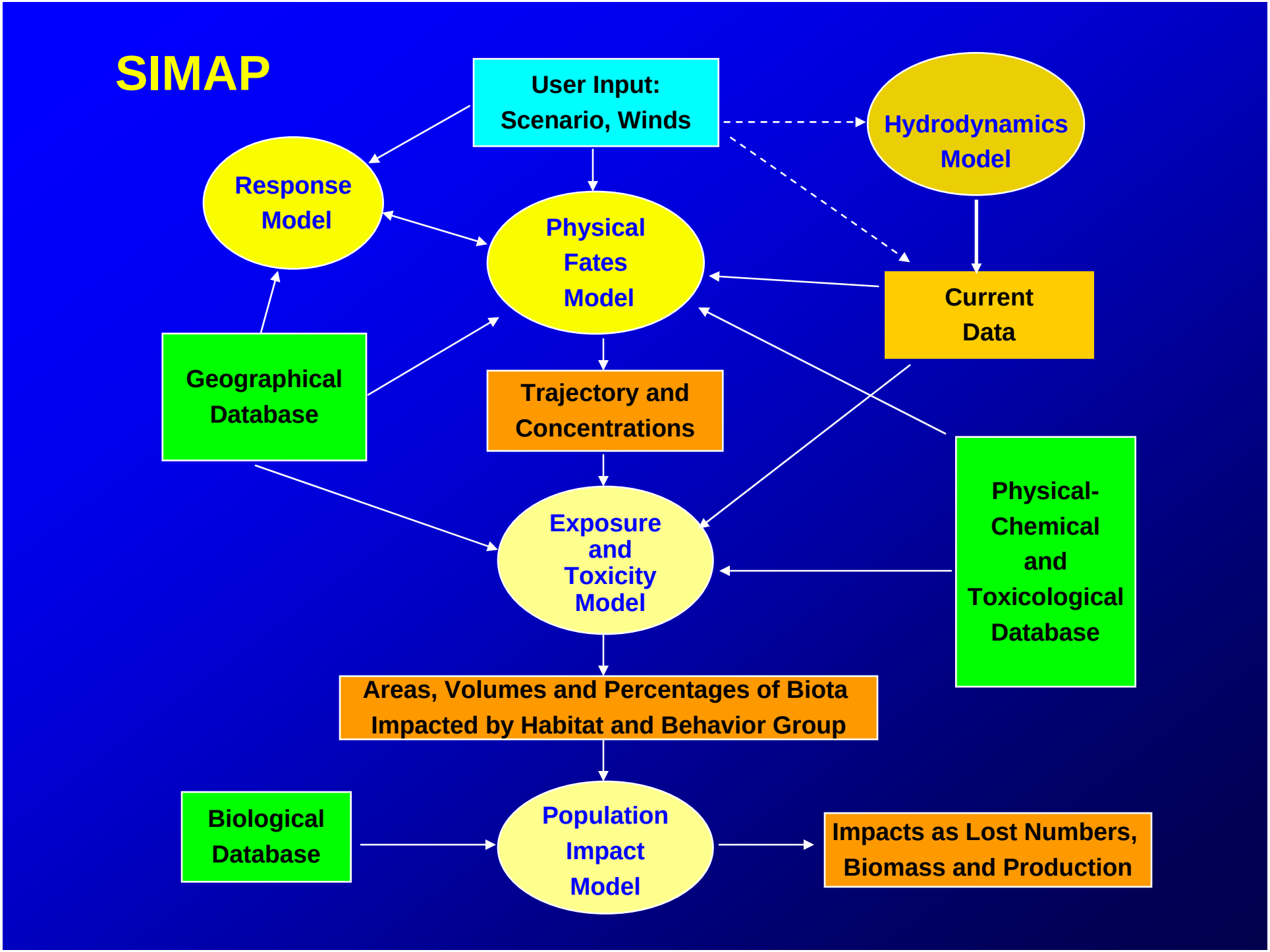
- Quantity (size of dispersed oil plume)
- Components (dissolved-phase & oil droplets)
- Concentration
- Duration
- Environmental impact
- Documentation

→ Sampling plan

Dispersed Oil Monitoring Plan

Our approach…

- **Computer simulations using ASA's Spill Impact Model Application Package (SIMAP)**
- **Prepare sampling plan based on simulation results**
- **Field test sampling plan**
- **Prepare standby equipment & retain contractors**


SIMAP
User Input: Scenario, Winds
Hydrodynamics Model
Response Model
Physical Fates Model
Current Data
Geographical Database
Trajectory and Concentrations
Physical-Chemical and Toxicological Database
Exposure and Toxicity Model
Areas, Volumes and Percentages of Biota Impacted by Habitat and Behavior Group
Biological Database
Population Impact Model
Impacts as Lost Numbers, Biomass and Production

Potential Impacts of Oil Spills

- Surface smothering/coating exposure
  - Wildlife (birds, marine mammals, sea turtles)
  - Shorelines
  - Nearshore structured habitats (wetlands, mangroves, seagrasses, coral and mollusk reefs)
- Subsurface toxicity (soluble aromatics)
  - Direct on fish, invertebrates, algae
  - Indirect via food web
  - Submerged aquatic habitats

Modeling Matrix

- Hypothetical spills in open water (similar all locations under same environmental conditions)
- Oil type: Light Arabian crude
- Spill volume: maximum volume of oil dispersed by a single sortie of a C-130 (80%, 45% or 20% efficiency)
- Oil thickness: median value for dispersant application (100 μm)
- 3 dispersant application scenarios: none; after weathered 8 hrs, 16 hrs
- 2 wind speed and associated turbulence conditions
  - 5 kts (2.5 m/s), 1 m^2/s
  - 15 kts (7.5 m/s), 10 m^2/s
- Restricted to surface mixed layer: 10m, 20m
- Background currents: none, 0.25 kts (13 cm/s) downwind, 0.25 kts (13 cm/s) upwind

Initial Conditions

- 5,000 gal (18.9 m^3) of dispersant
- 20:1 oil : dispersant ratio
- 100,000 gal (2381 bbl = 378.5 m^3 = 326 tonnes) oil treated
- Properties for pre-weathered oil (8 or 16 hrs in 5 kt winds)
- Since 100 μm thick, initially circle with area = 3.8 km^2
- 80%, or 45% or 20% of oil dispersed in 0.5 hr

Trajectory and Concentrations: Examples

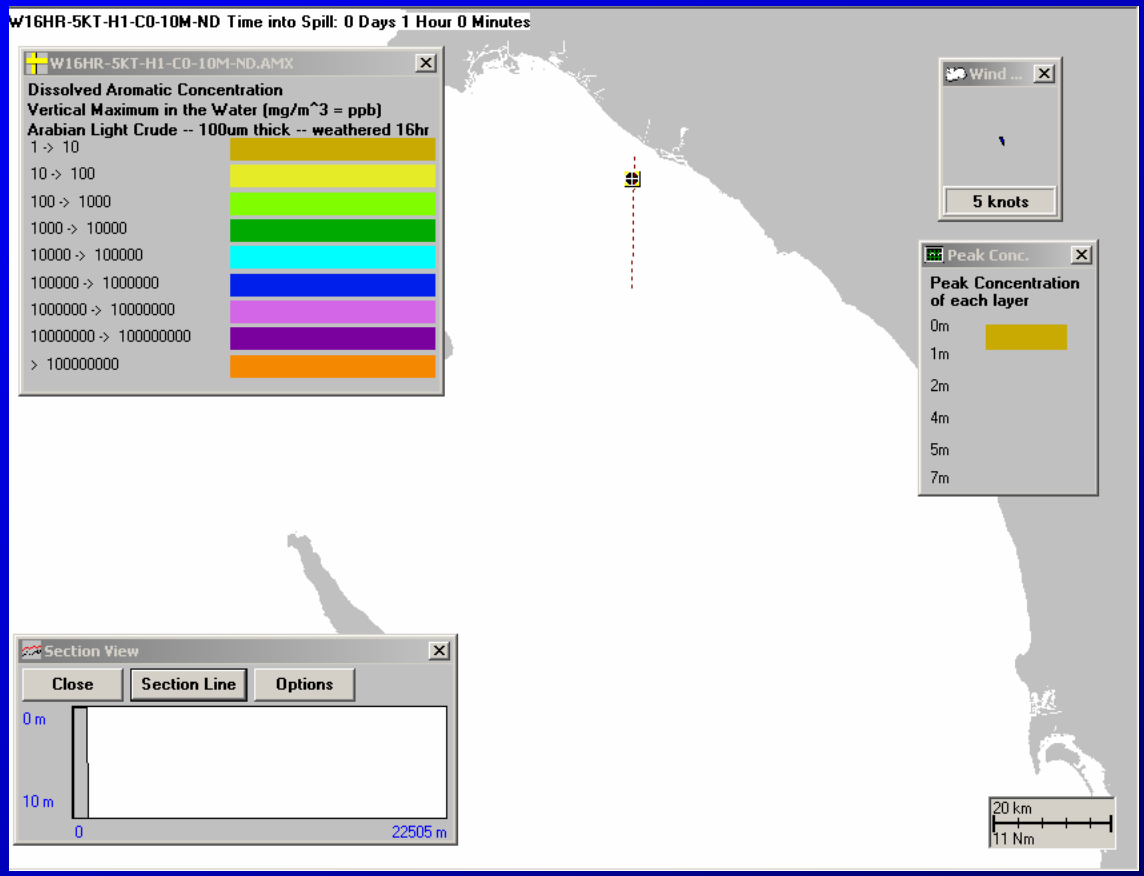
- 5 kt (2.5 m/s) winds, no dispersant
- 5 kt (2.5 m/s) winds, with dispersant

Dispersant: none;

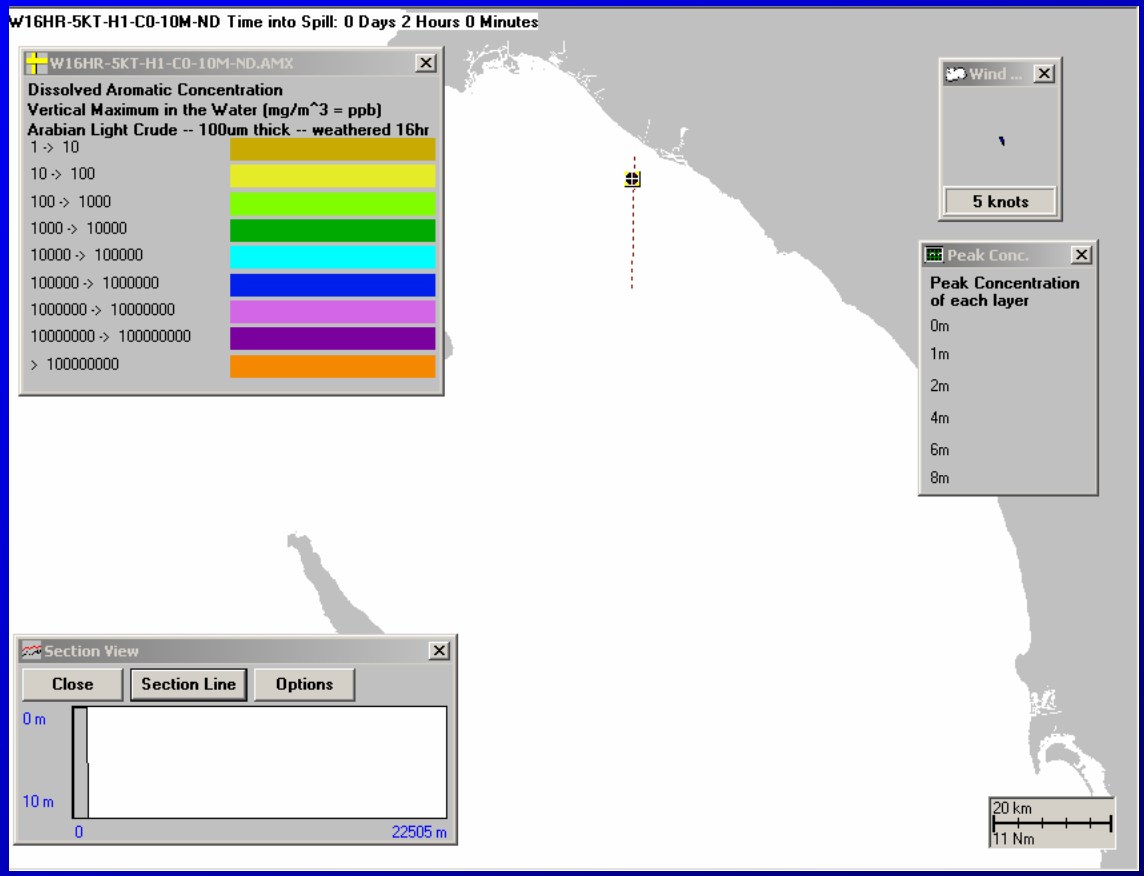
Wind from NNW 5 kts; Currents: 0 kt;
Turbulent mixing to 10m deep:

Dissolved Aromatic Concentrations

Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 1 hr after potential treatment



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 2 hrs after potential treatment



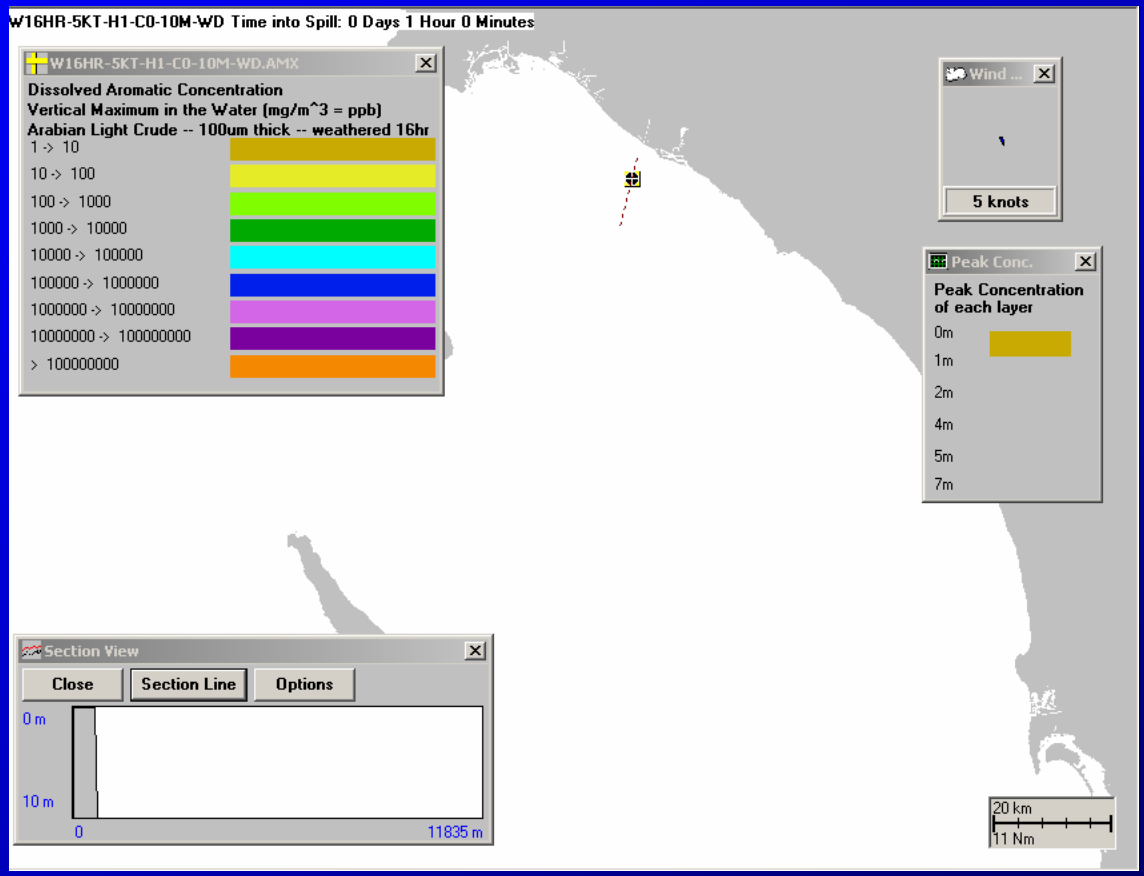
*No dissolved aromatic conc. > 1ppb (averaged) in any grid cell after 2 hrs

Dispersant: at 16 hrs;

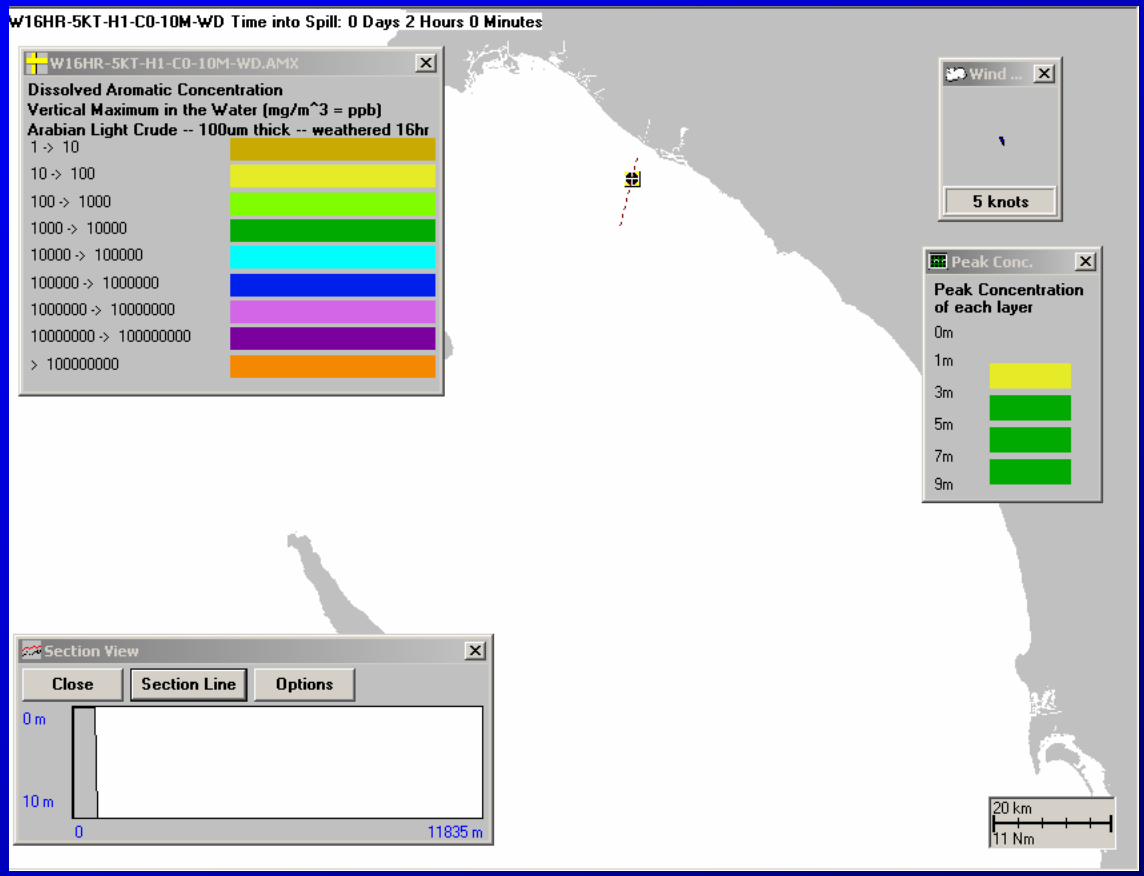
Wind from NNW 5 kts; Currents: 0 kt;
Turbulent mixing to 10m deep;

Dissolved Aromatic Concentrations

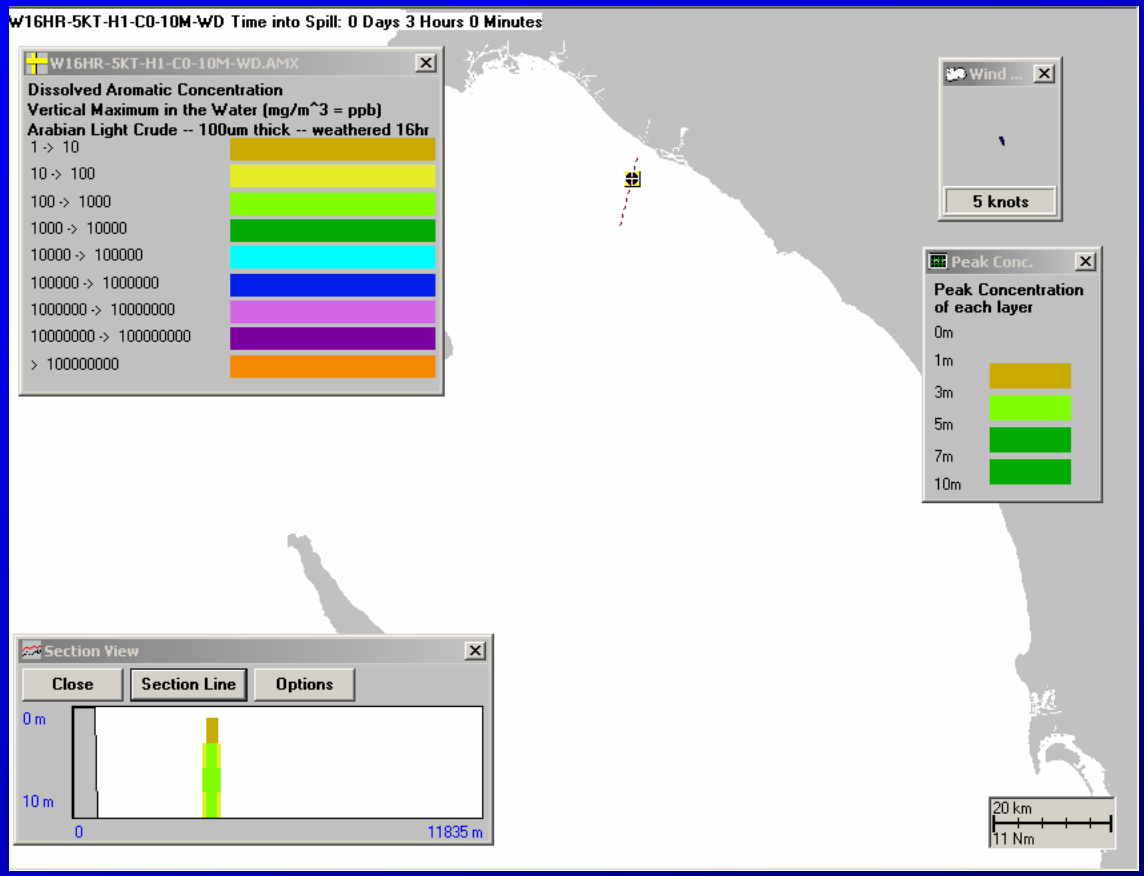
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 1 hr after dispersant application



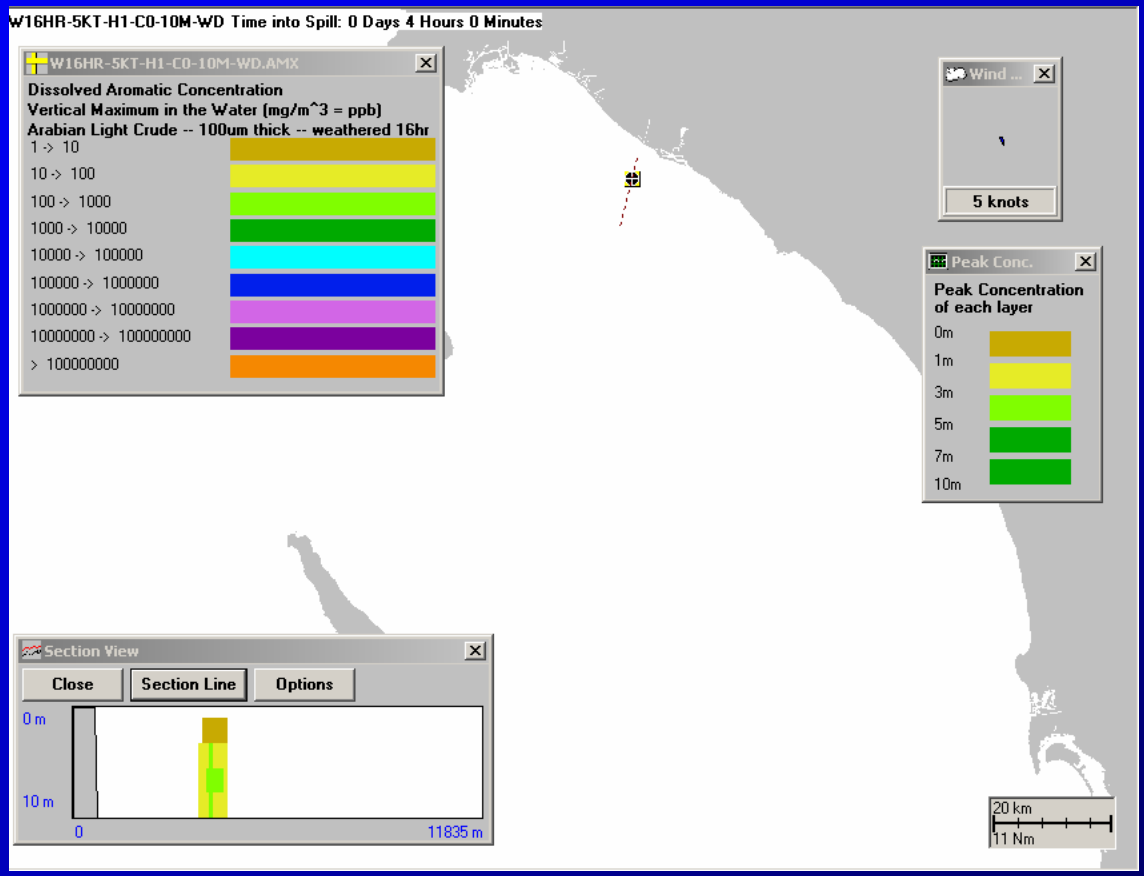
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 2 hrs after dispersant application



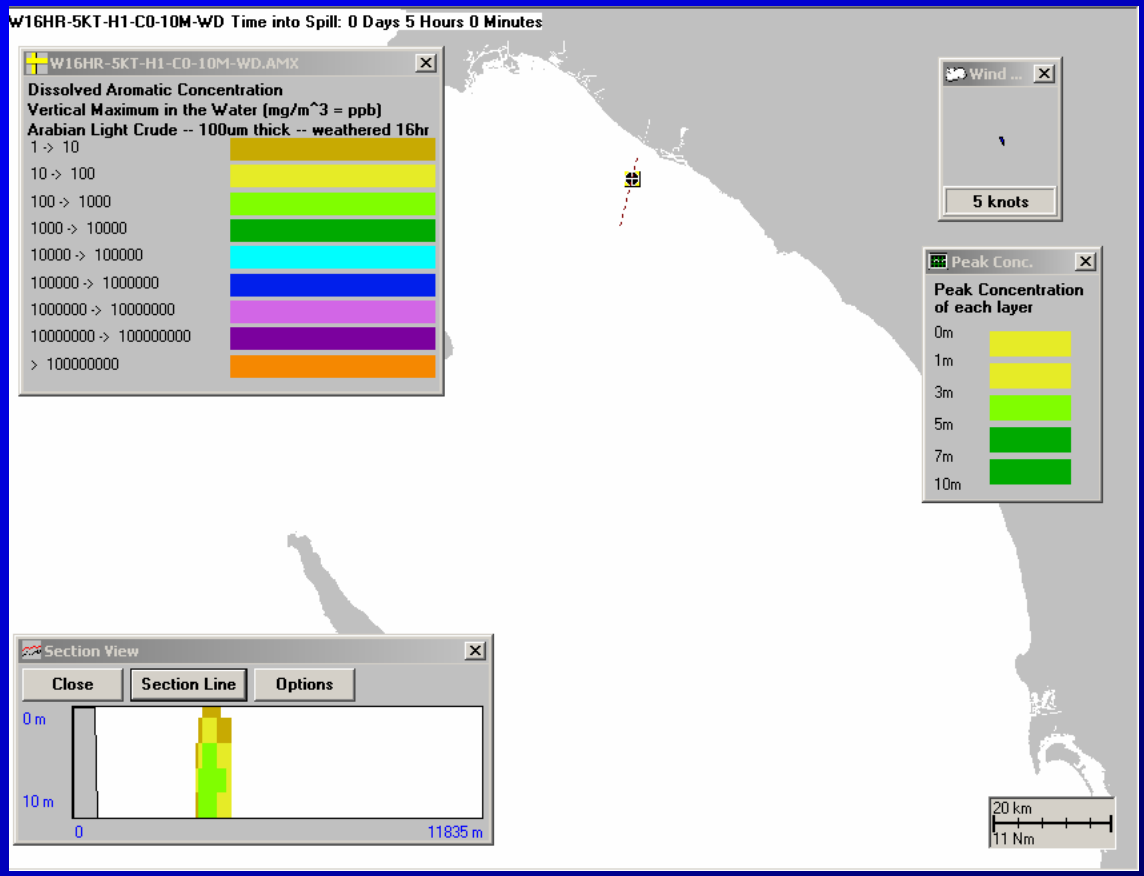
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 3 hrs after dispersant application



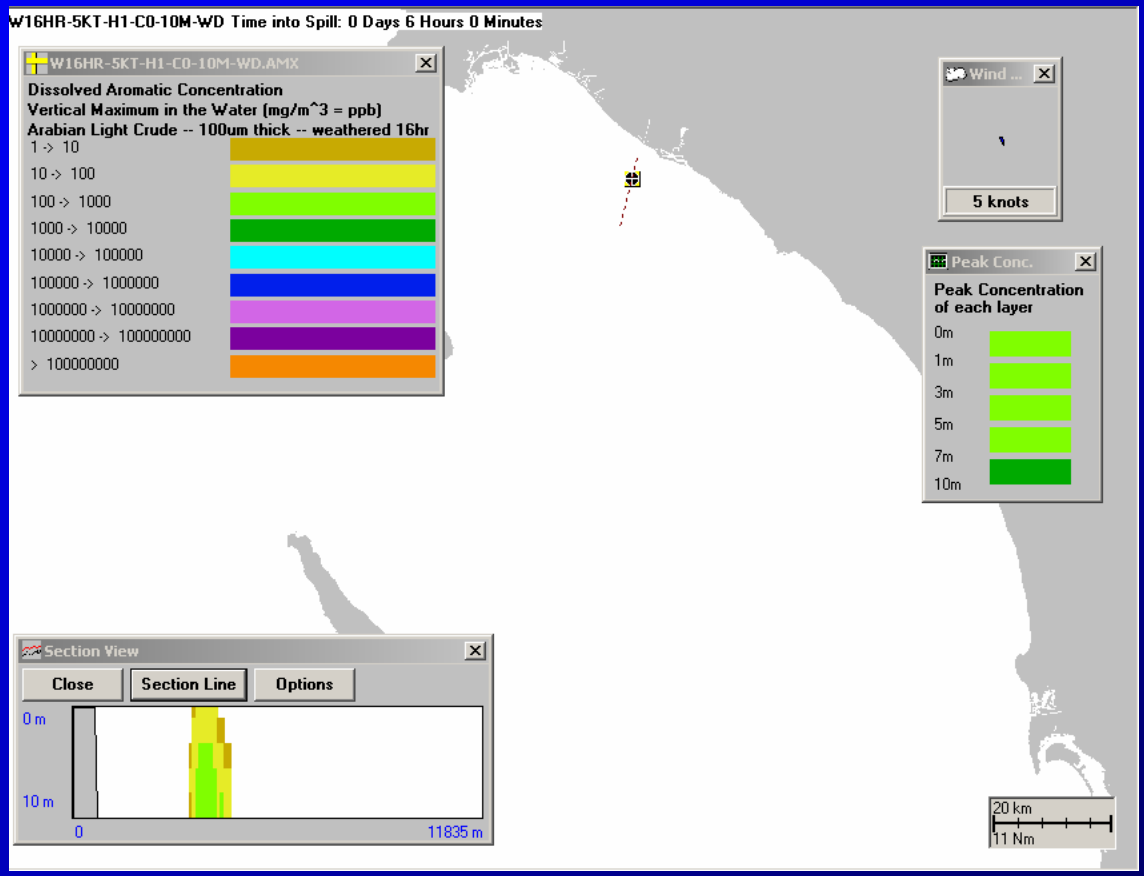
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 4 hrs after dispersant application



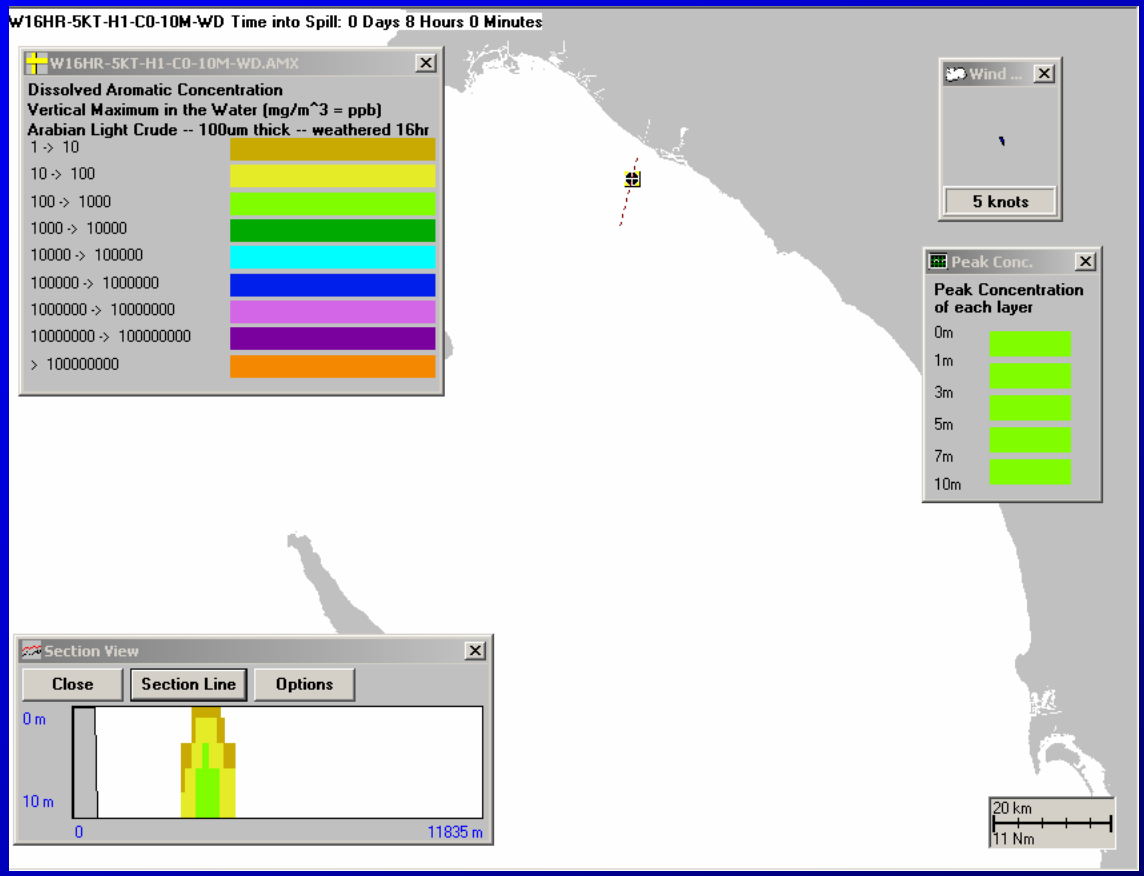
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 5 hrs after dispersant application



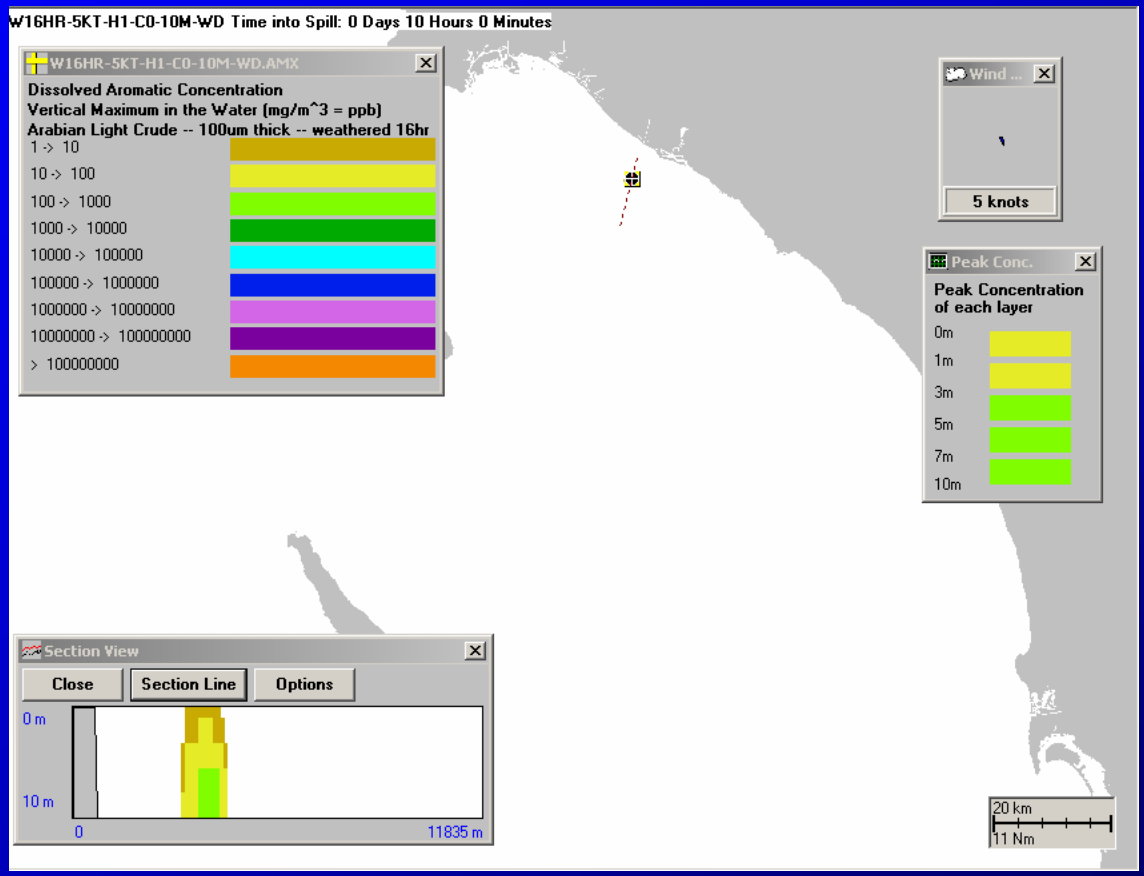
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 6 hrs after dispersant application



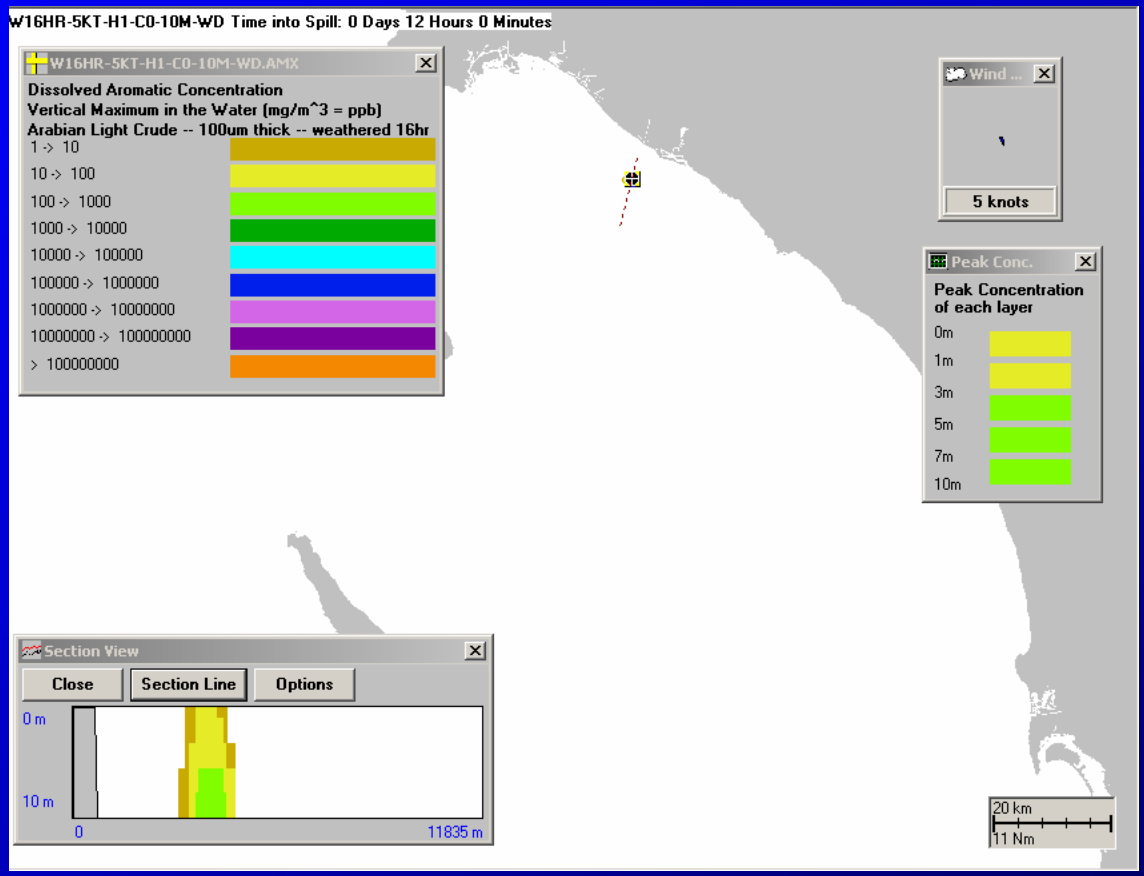
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 8 hrs after dispersant application



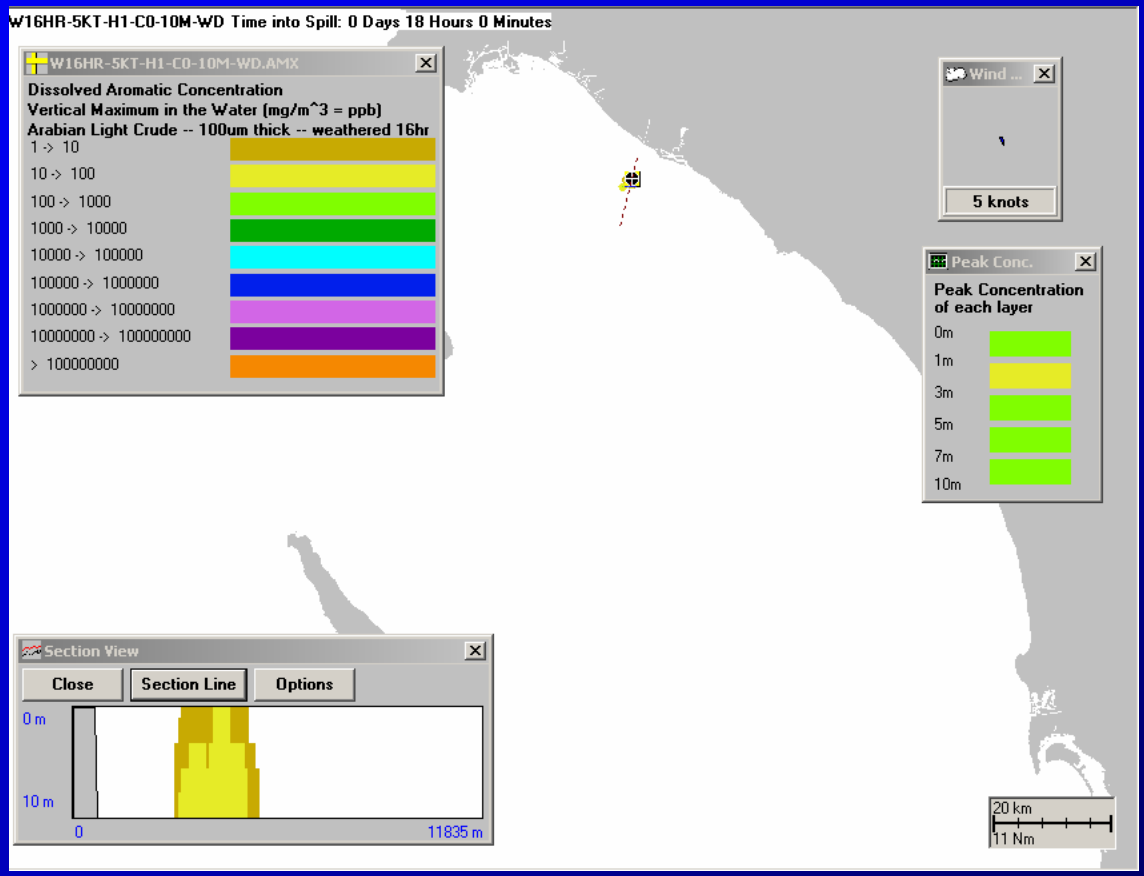
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 10 hrs after dispersant application



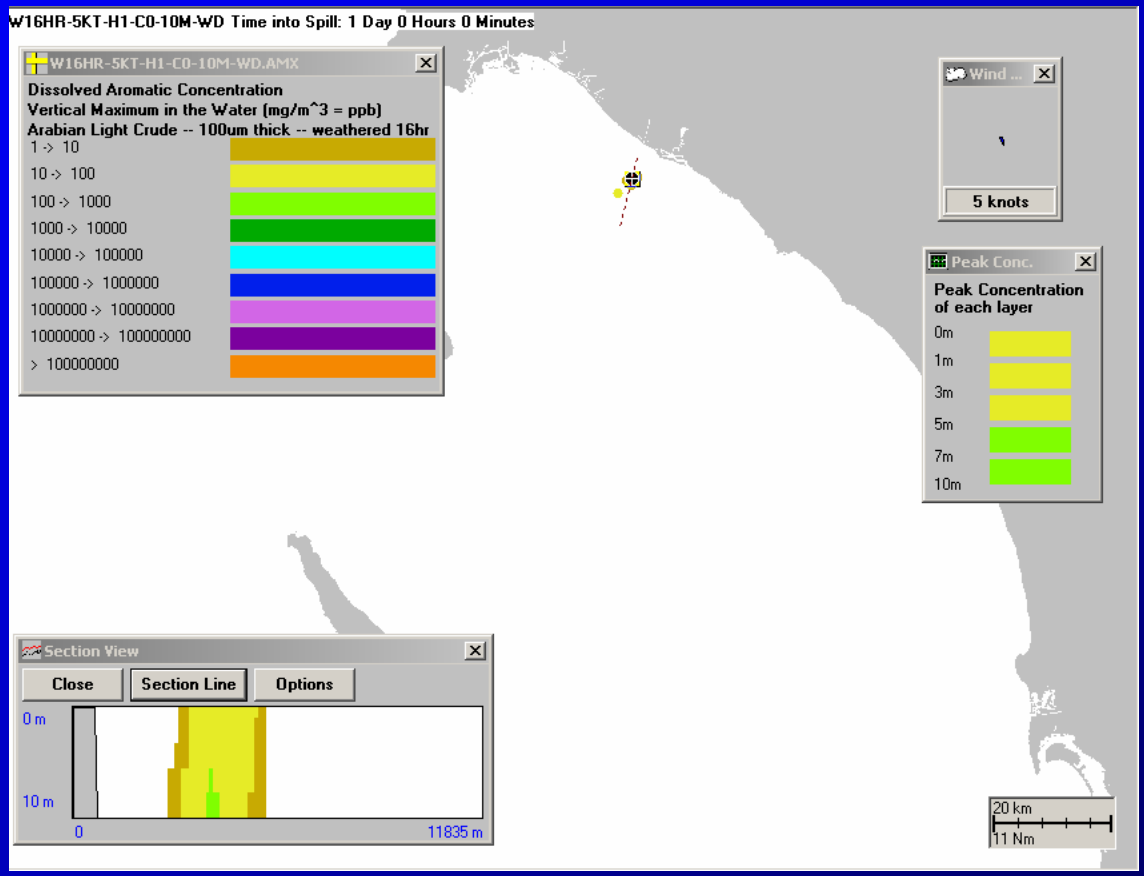
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 12 hrs after dispersant application



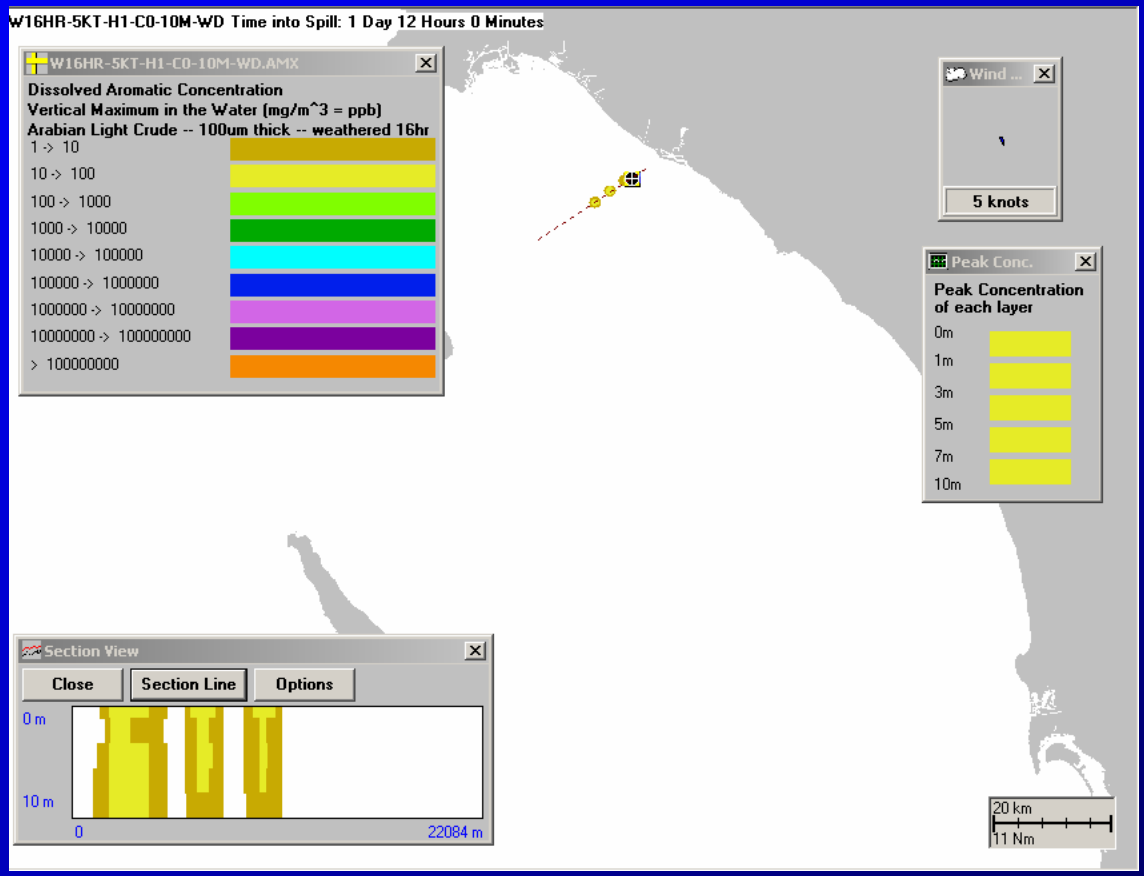
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 18 hrs after dispersant application



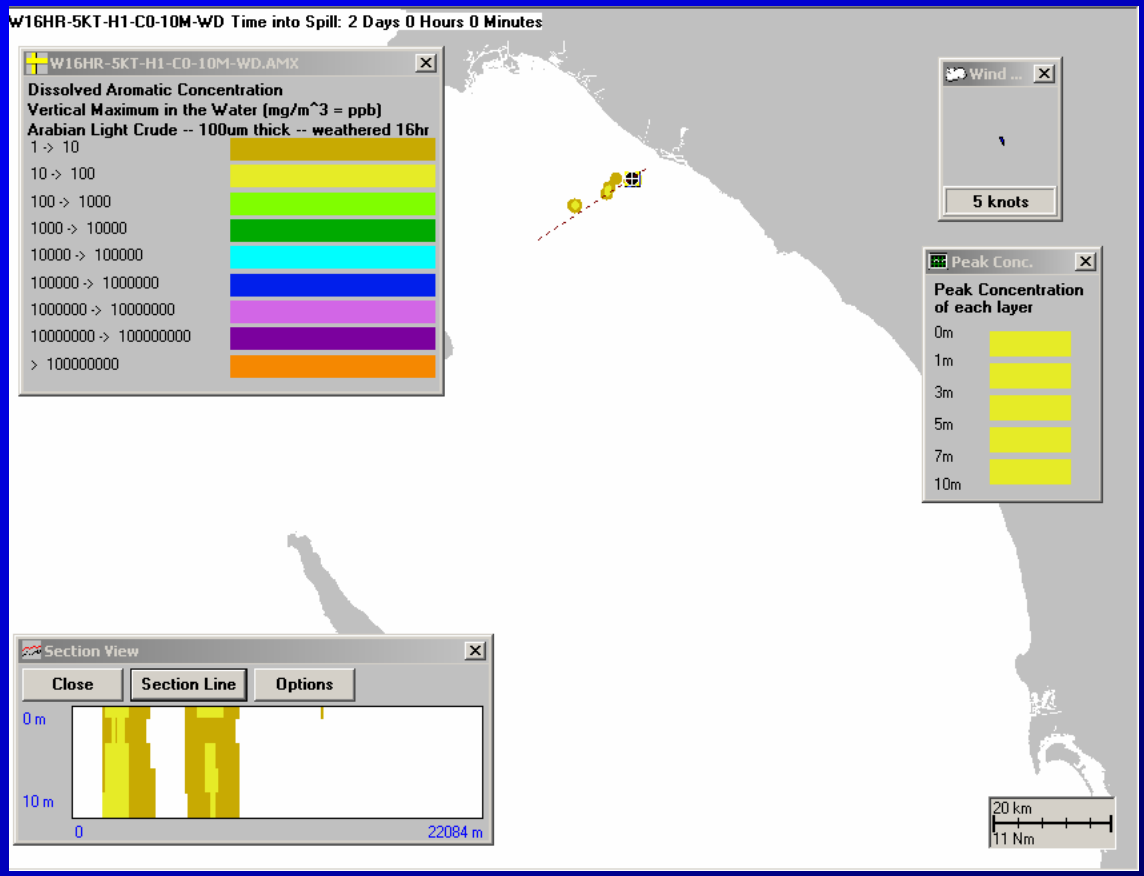
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 24 hrs after dispersant application



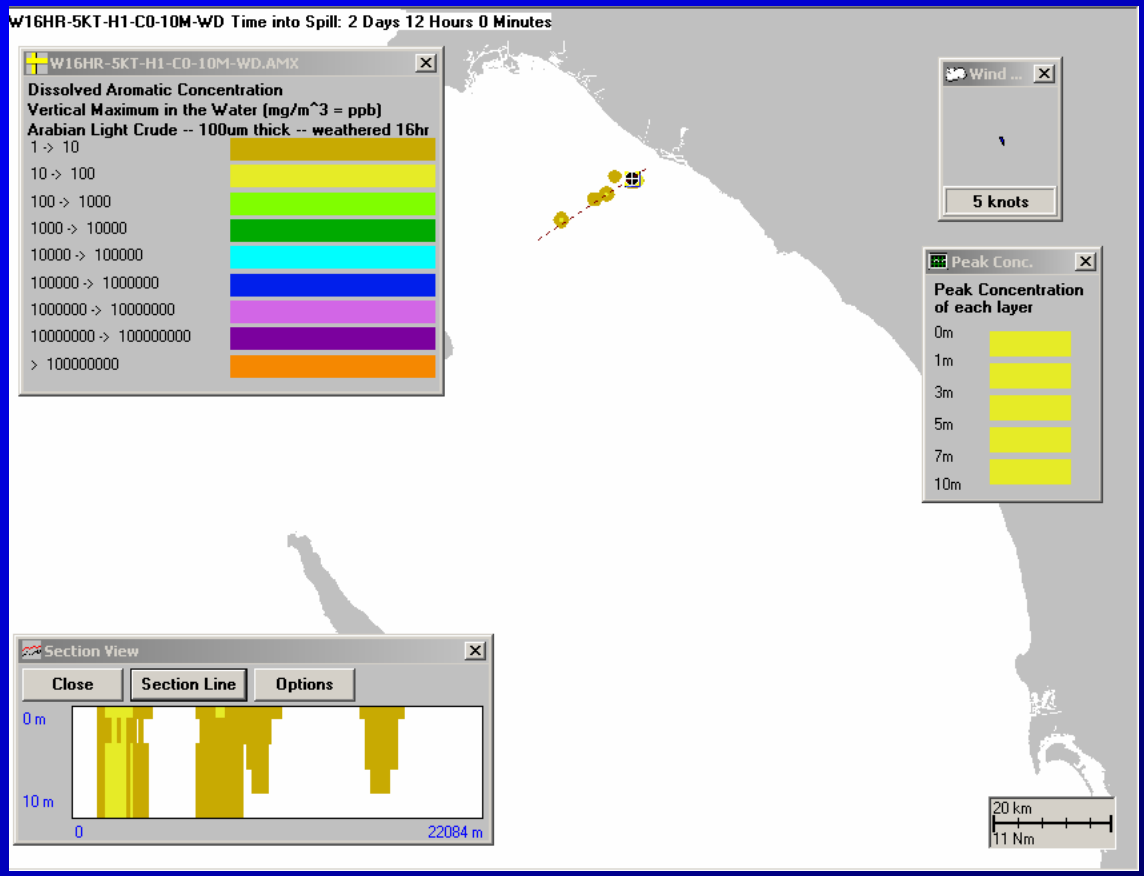
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 36 hrs after dispersant application



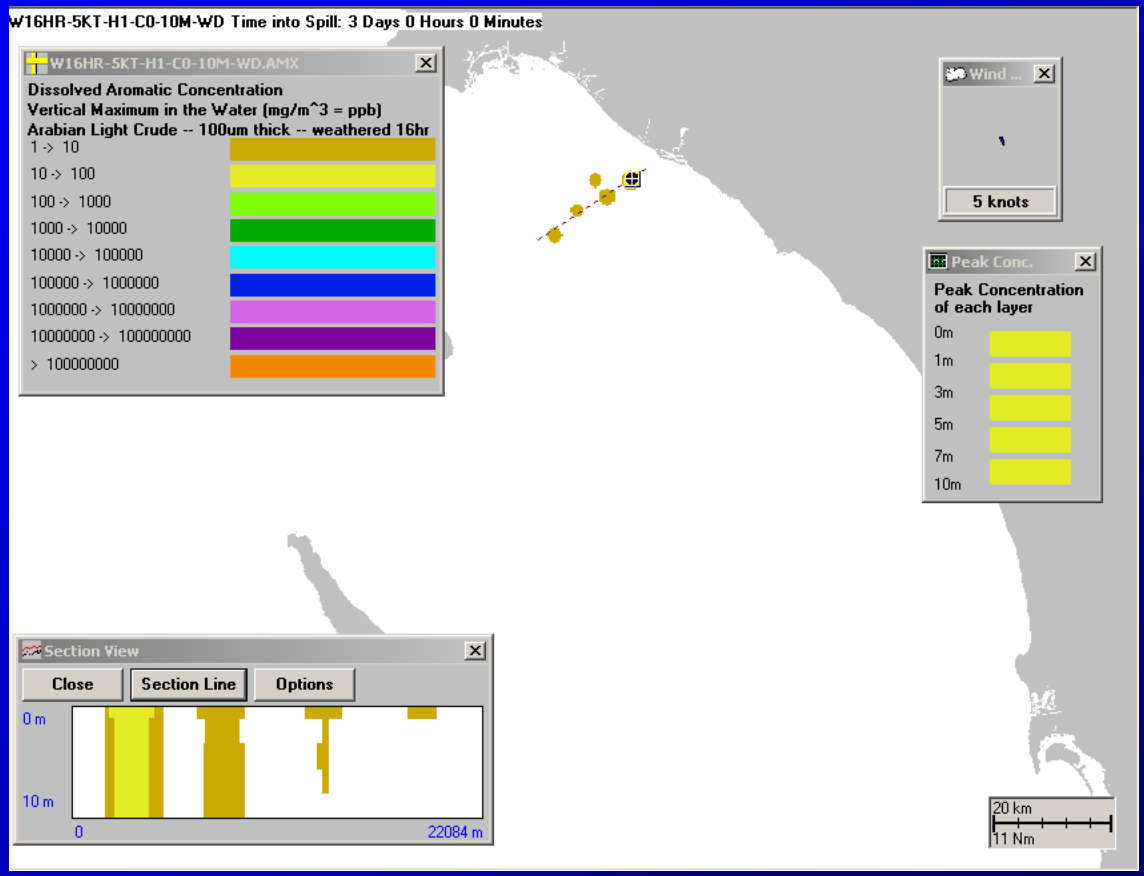
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 48 hrs after dispersant application



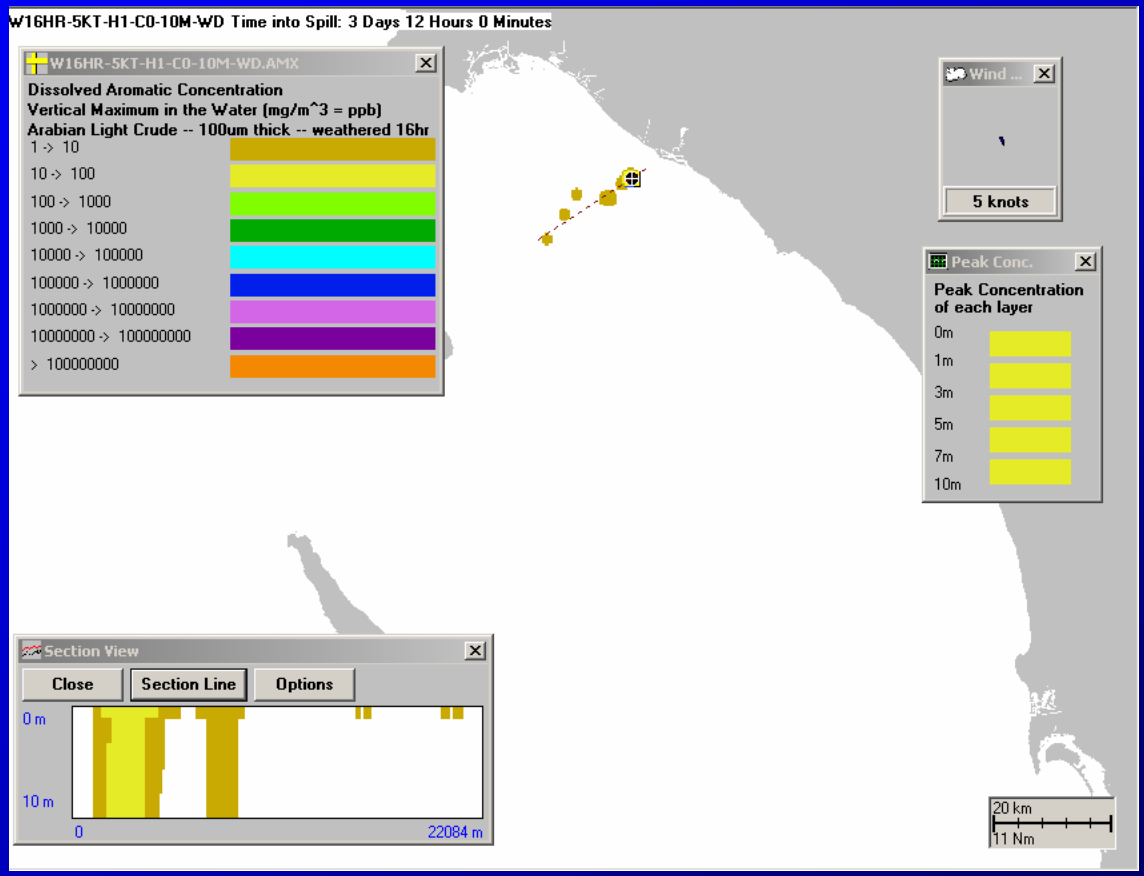
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 60 hrs after dispersant application



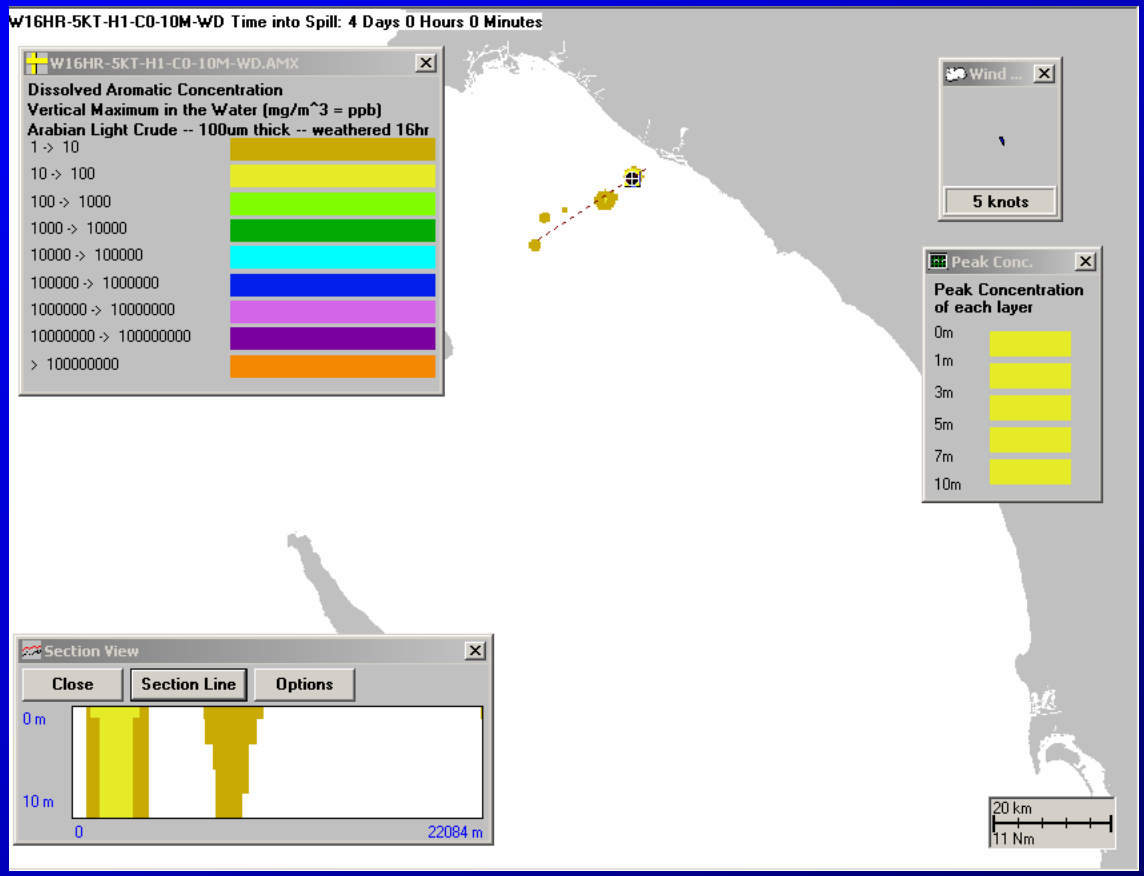
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 72 hrs after dispersant application



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 84 hrs after dispersant application



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Dissolved Aromatic Concentrations: 96 hrs after dispersant application



Modeling Matrix

- Hypothetical spills in open water (similar all locations under same environmental conditions)
- Oil type: Light Arabian crude
- Spill volume: maximum volume of oil dispersed by a single sortie of a C-130 (80%, 45% or 20% efficiency)
- Oil thickness: median value for dispersant application (100 μm)
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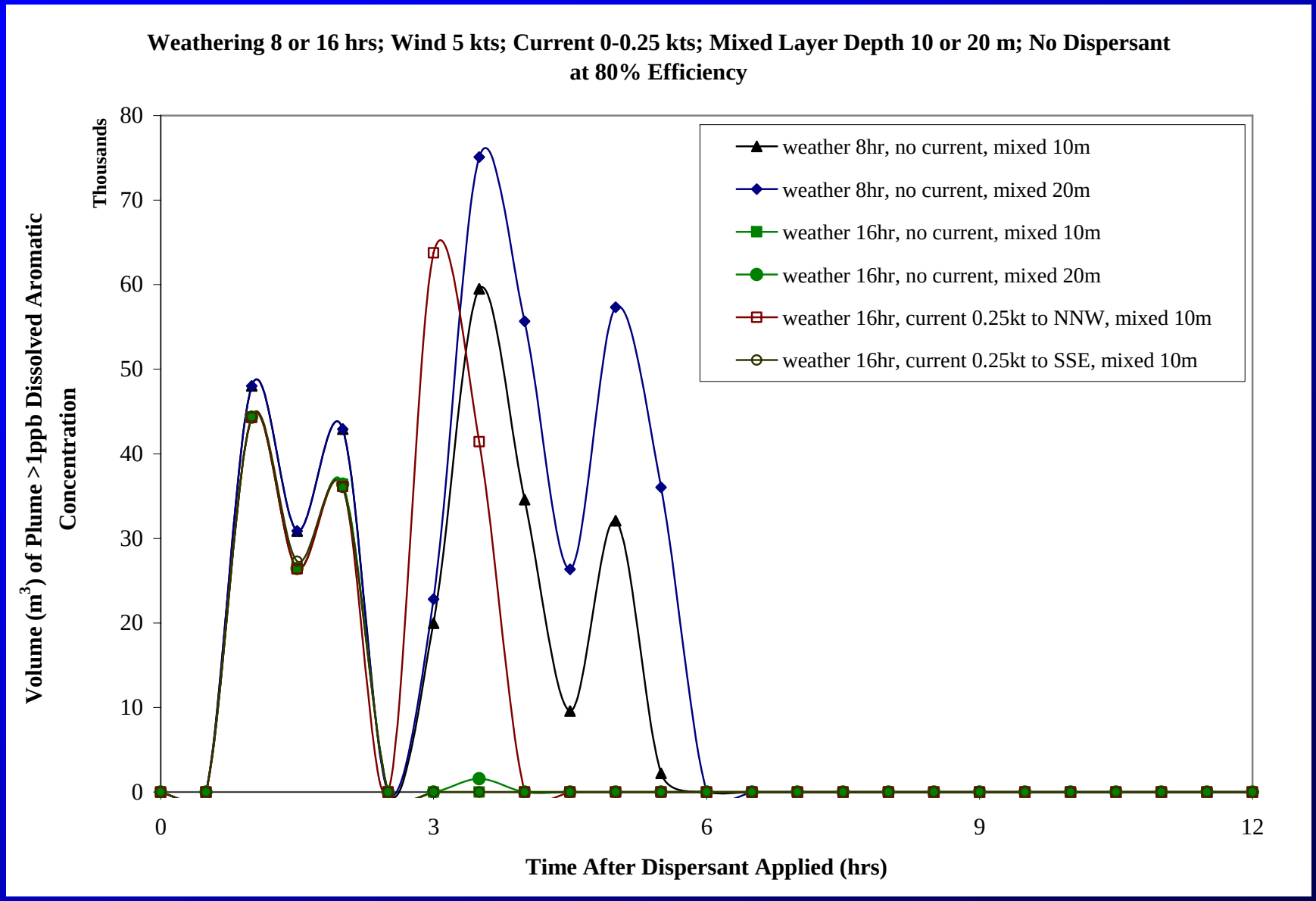
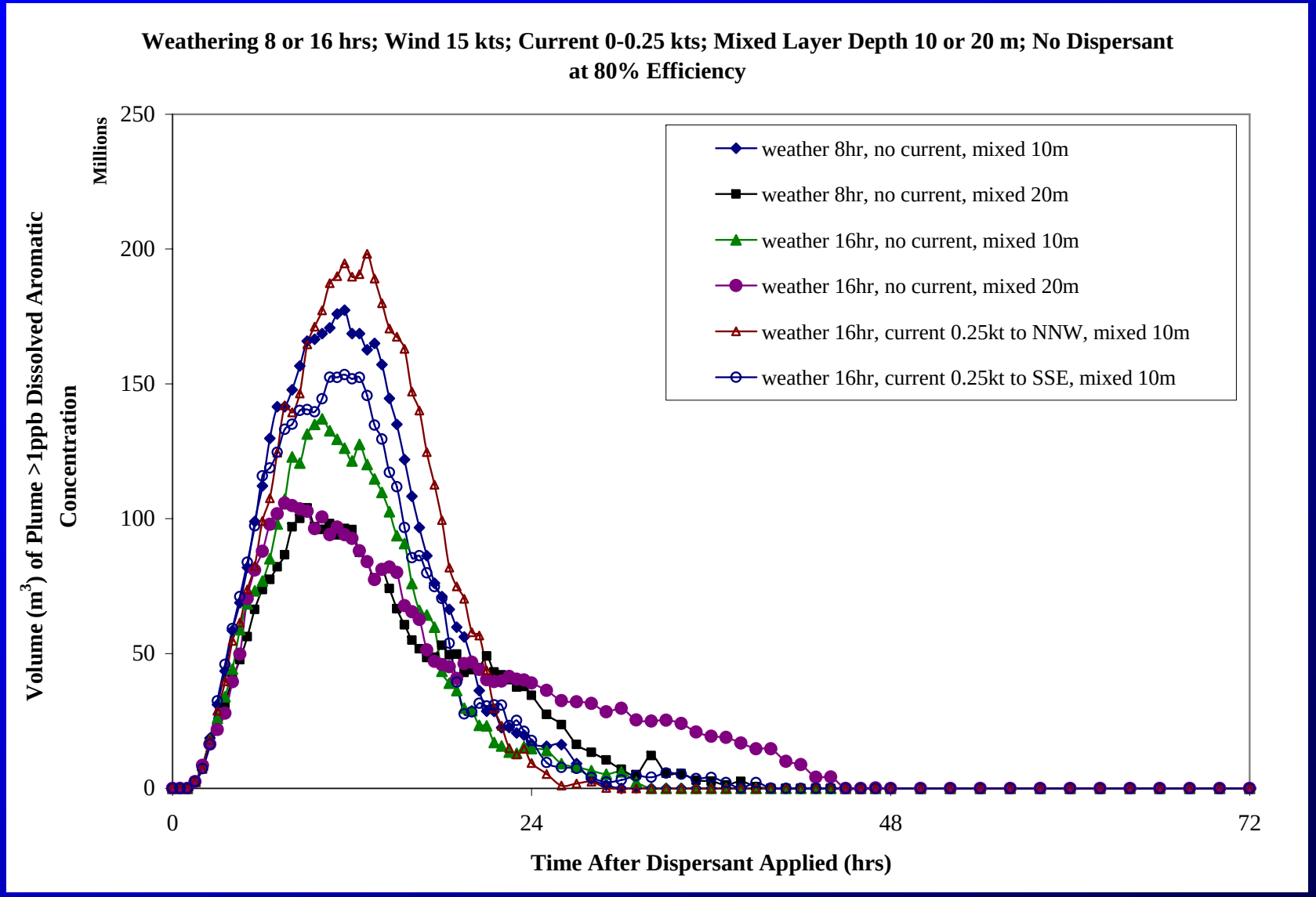
  - 5 kts (2.5 m/s), 1 m^2/s
  - 15 kts (7.5 m/s), 10 m^2/s
- Restricted to surface mixed layer: 10m, 20m
- Background currents: none, 0.25 kts (13 cm/s) downwind, 0.25 kts (13 cm/s) upwind

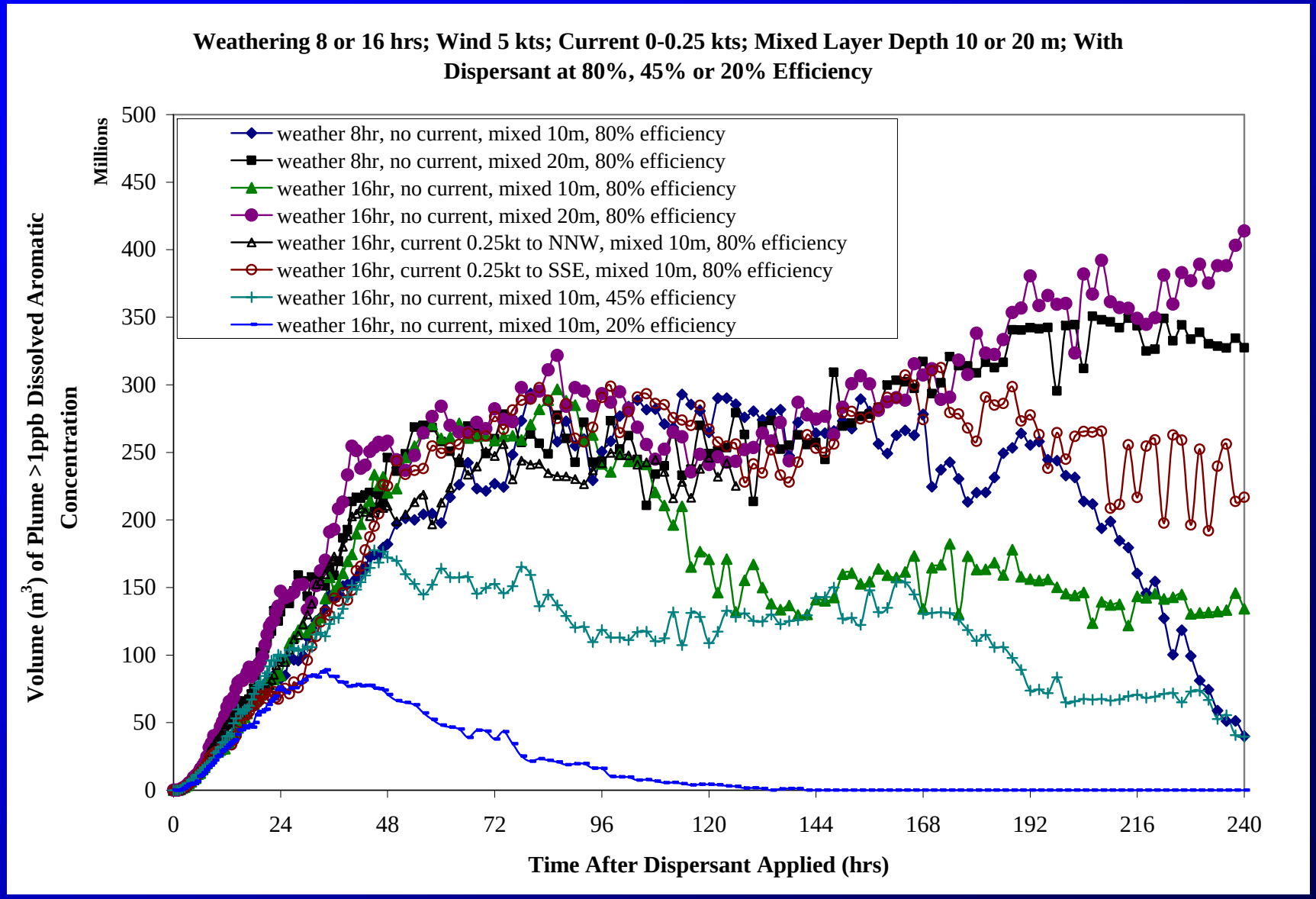
5 kt (2.5m/s) wind; with no dispersant



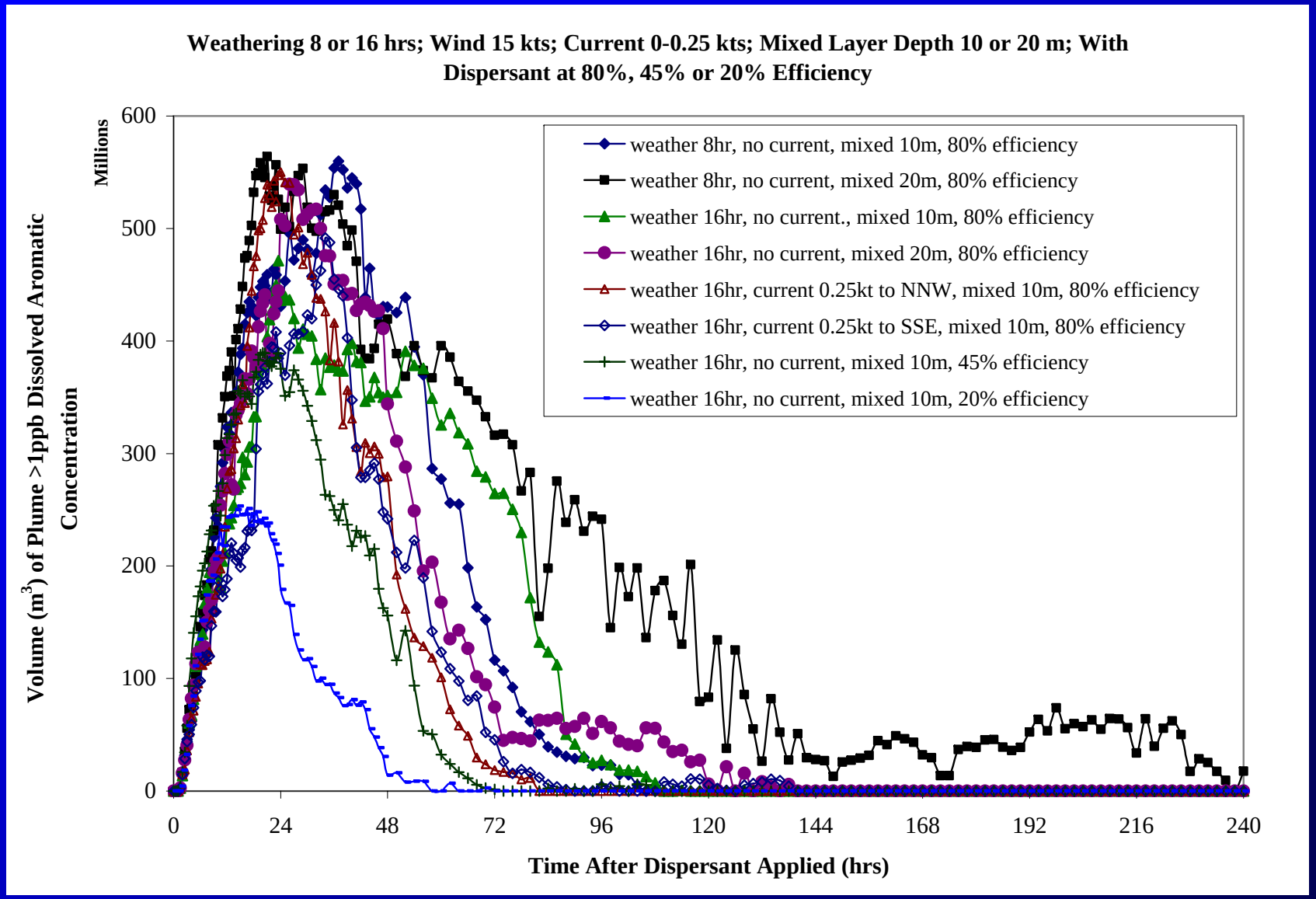
15 kt (7.5m/s) wind; with no dispersant



5 kt (2.5m/s) wind; with dispersant



15 kt (7.5m/s) wind; with dispersant



Summary of Plume Volumes (80% efficiency of 100,000 gal)

Wind Speed	No Dispersant	With Dispersant
5 kt (2.5 m/s)	Small, short lived (few hrs)	Large, lasts > 10 days
15 kt (7.5 m/s)	Moderately large, lasts 2-3 days	Large, lasts 3-6 days

Effects of Other Factors on Plume Volume

- Lower efficiency → proportionately smaller plume volume

Subtle changes:

- With weathering (8 hrs versus 16 hrs)
- Deeper mixed layer
  - If no dispersant → faster dilution
  - With dispersant, more intense plume, so stretching increases plume volume >1ppb
- Background currents generally stretch plume

Biological Impacts: Equivalent Areas of 100% Loss

Wildlife (Birds primarily)

Area swept by oil >10 μm thick multiplied by probability of encounter with water surface

Water Column (Plankton)

Sum of volumes affected divided by mixed layer depth to calculate area affected

Summary of Impacts - Area (km^2)

(80% efficiency; no currents, 10-20m mixed depth)

W = wildlife
PA = Plankton: Average species
PS = Plankton: Sensitive Species

Wind Speed	No Dispersant	With Dispersant
5 kt (2.5 m/s)	W: 197-209 PA: 0 PS: 0	W: 83-100 PA: 0.6-1.8 PS: 7-15
15 kt (7.5 m/s)	W: 391-425 PA: 0 PS: 0.03-0.20	W: 68-108 PA: 0.06-0.09 PS: 1.4-2.2

Water Column Impacts

- Highest for
  - Large spill volumes
  - High turbulence (storms, blowouts)
  - Maximum dispersant application with high efficiency in one contiguous area (higher in lower winds)
- This analysis was worst case
  - Entire C-130 application in one location
  - 80% efficiency and 20:1 ratio (theoretical maximum)
  - In reality oil is patchy and spread out

Conclusions

- **Tradeoff in favor of dispersant use**
  - **Wildlife impacts scale of 100s km^2, even if patchy oil**
  - **Water column impact – worst case scale of 1 km^2 in mixed layer (10-20 m deep)**

- **Dispersant use <u>not</u> indicated if**
  - **Sensitive species or life stages concentrated in area**
  - **In confined water body where dilution restricted**

    Shallow water < 10m deep

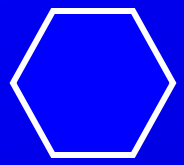
    In bays and inlets

Questions?

Toxic Components of Oil

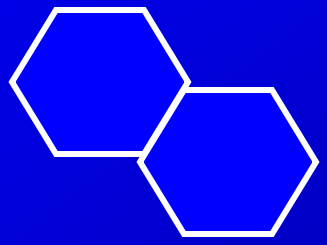
C-C-C-C-C-C

Aliphatics = Straight chain hydrocarbons (e.g., alkanes) –more volatile than soluble



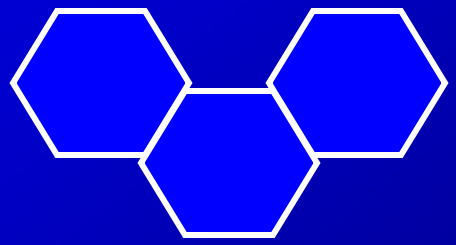
Monoaromatic Hydrocarbons (MAHs)

- **Benzene, Toluene, Ethylbenzene and Xylenes = BTEX – highly soluble, highly volatile, moderately toxic**
- **Alkyl-substituted Benzenes – soluble, less volatile, more toxic**



Polynuclear Aromatic Hydrocarbons (PAHs)

- **Naphthalenes (2-ring PAHs)**
  - **soluble, less volatile, more toxic**
  - **with more alkyl chains, less soluble but more toxic**
- **3 ring PAHs**
  - **Phenanthrenes**
  - **Fluorenes**
  - **Dibenzothiophenes**
- **4-ring PAHs – parent compounds bioavailable**
- **larger PAHs insoluble**



Biological Exposure Model

- Organisms classified by behavior
  - Wildlife
    - % of time on water surface
    - Habitats used
    - Feathers & fur
  - Fish and Invertebrates
    - Swimming
    - Drift with currents
    - Stationary
- Movements of organisms are tracked to calculate exposure of individuals

- Impact a function of dose
  - Wildlife
    - Area swept by oil
    - Oil thickness
  - Fish and Invertebrates
    - Concentration
    - Exposure time
    - Temperature

Oil Toxicity

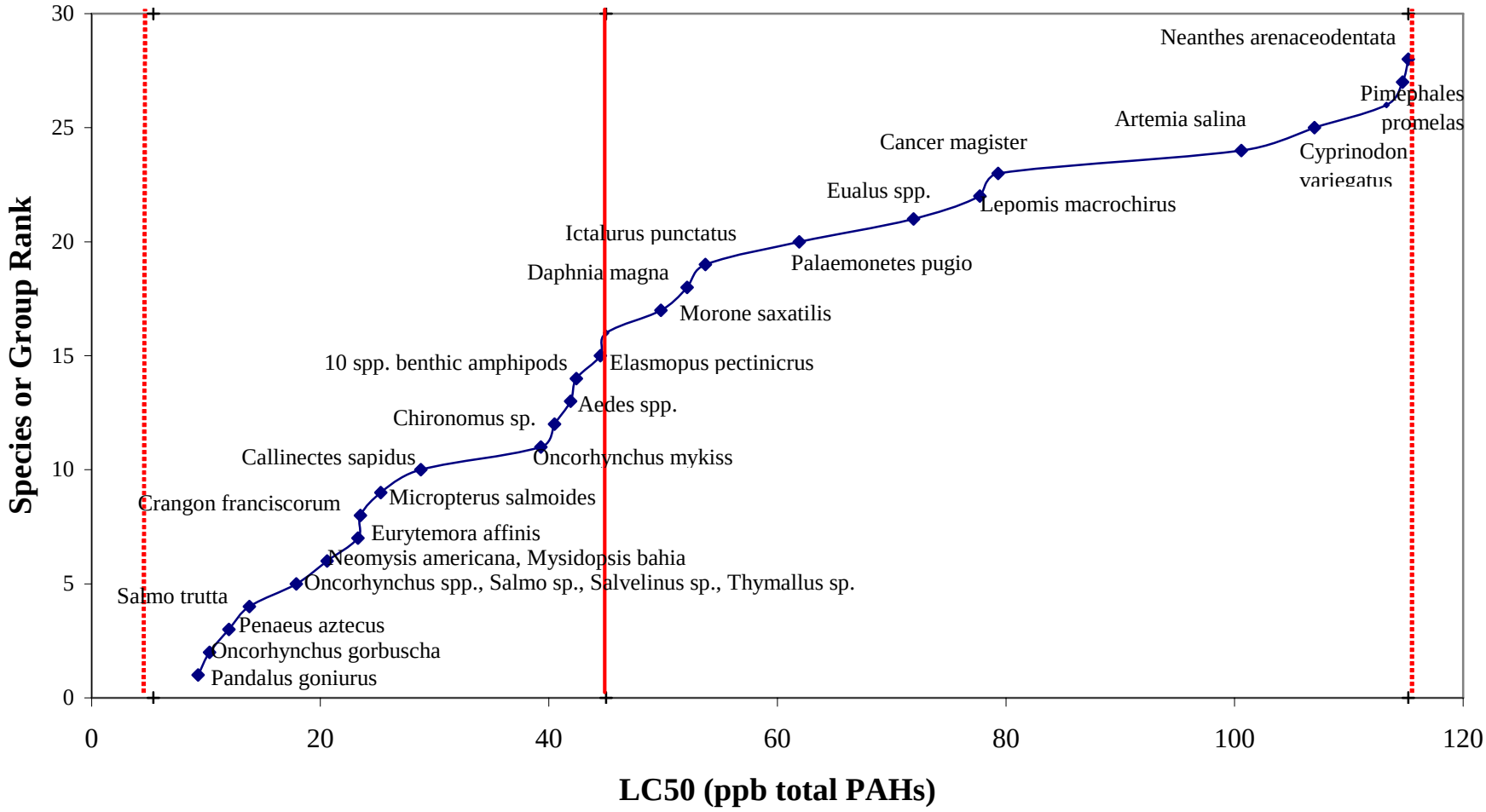
- 1-3 ring aromatics cause most of acute toxicity
  - in diesel, heavy fuel and crude oil, most from PAHs
  - for gasoline, MAHs also
- Dissolved aromatic concentration bioavailable

- Narcotic mode of action
- Additive toxicity – all dissolved aromatics contribute
- $LC50_{mix}$ from published and verified estimates, based on review of laboratory bioassays with aromatics and oils

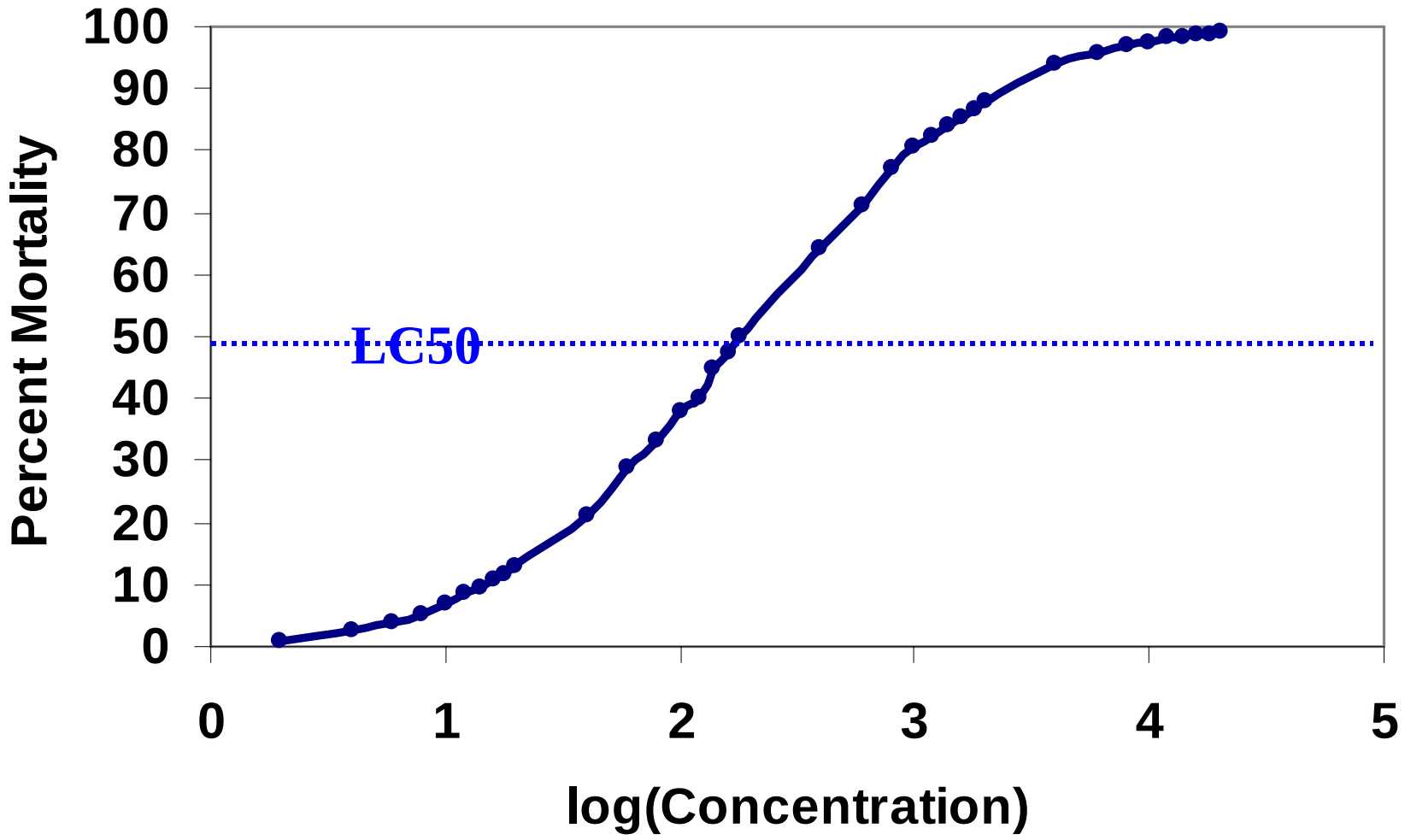
Species Sensitivity Ranking -- PAHs in Crudes and Fuel Oils

Vertical Red Lines are Geometric Mean and Range for 95% of Species

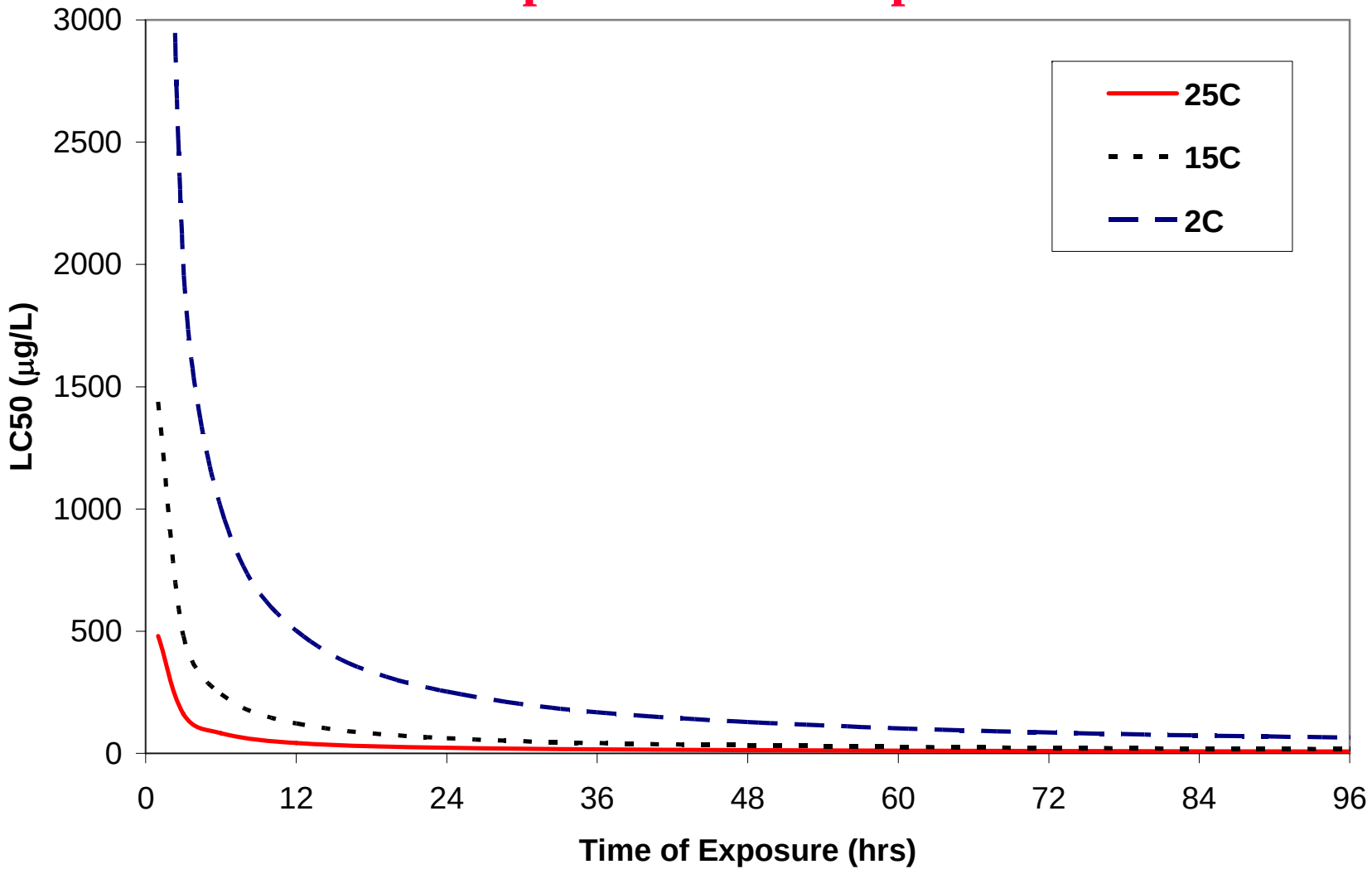
(French McCay, 2002)



Model Calculates Percent Mortality from LC50 and Concentration



Model Corrects LC50 for Duration of Exposure and Temperature



Biological Impacts: Equivalent Areas of 100% Loss

Wildlife (Birds primarily)

Area swept by oil >10 μm thick multiplied by probability of encounter with water surface:

[Area Swept] [Probability]

Water Column (Plankton)

Weighted sum of volumes affected at λ% loss:

Σ [Volume] [λ/100]

Divide by mixed layer depth to calculate area affected

Scenario

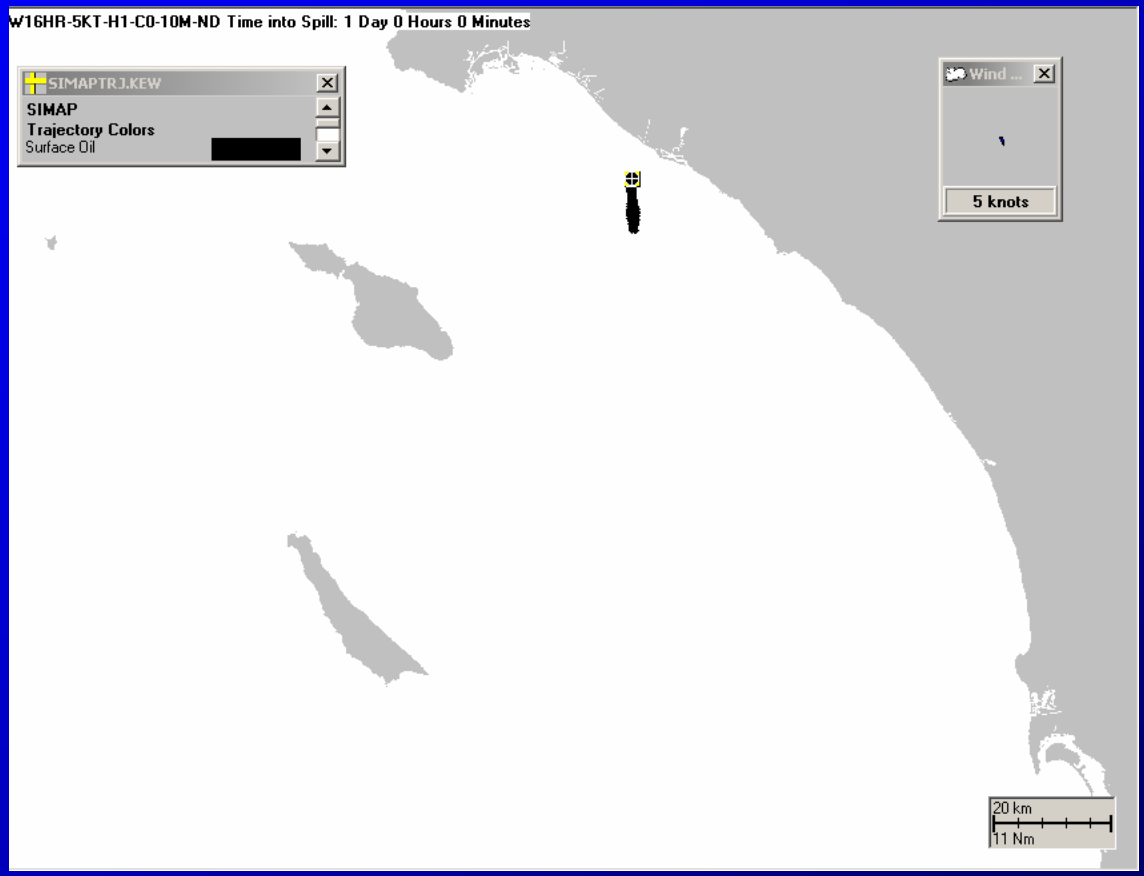
Pre-Weathering for 16 hrs before potential treatment

Wind from NNW 5 kts;
Currents: 0 kt;

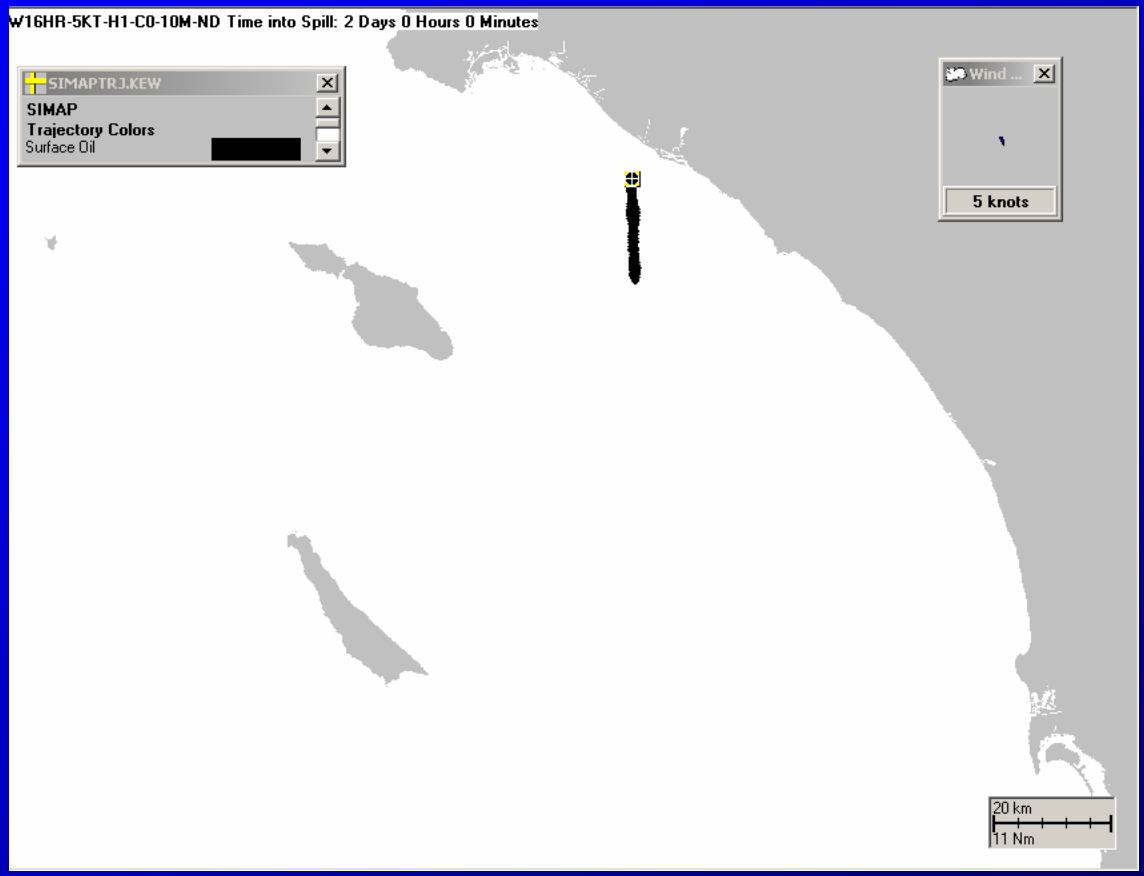
Dispersant: none

Turbulent Mixing to 10m deep in Surface Mixed Layer

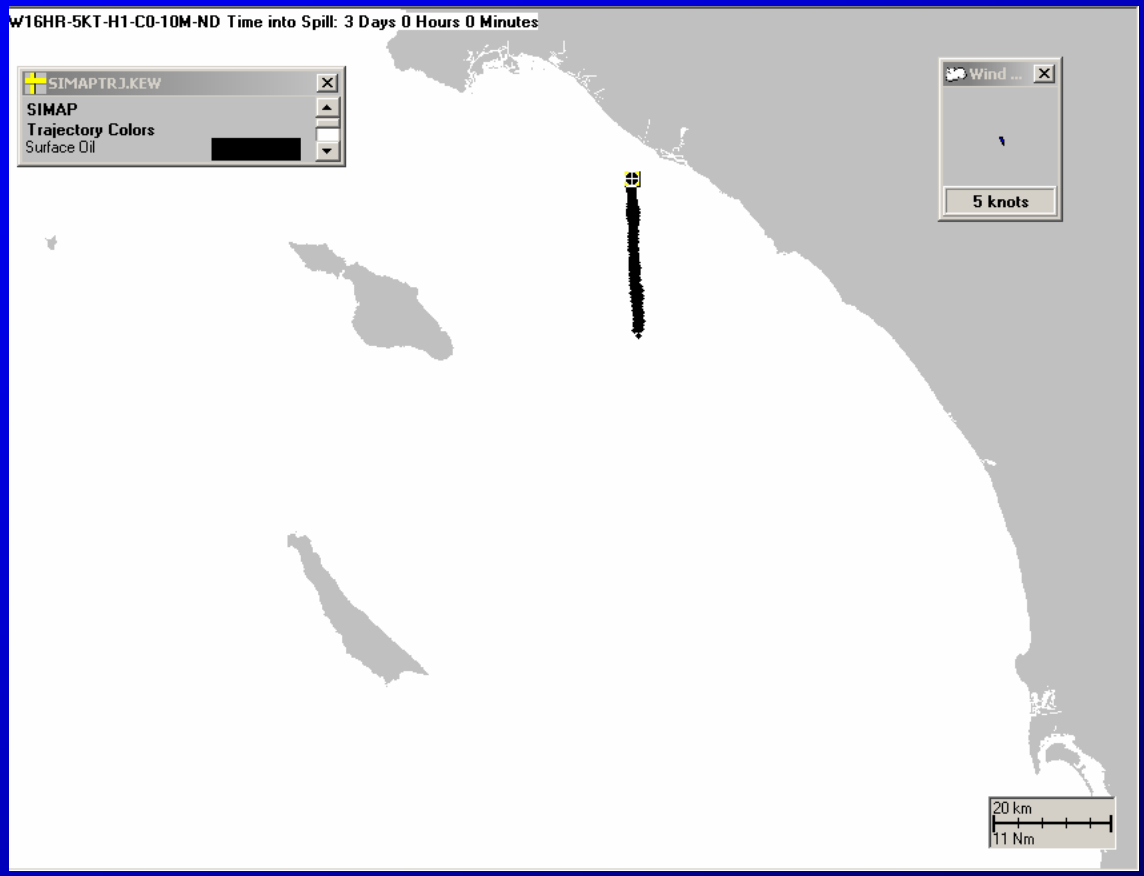
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Trajectory: 24 hrs after potential treatment



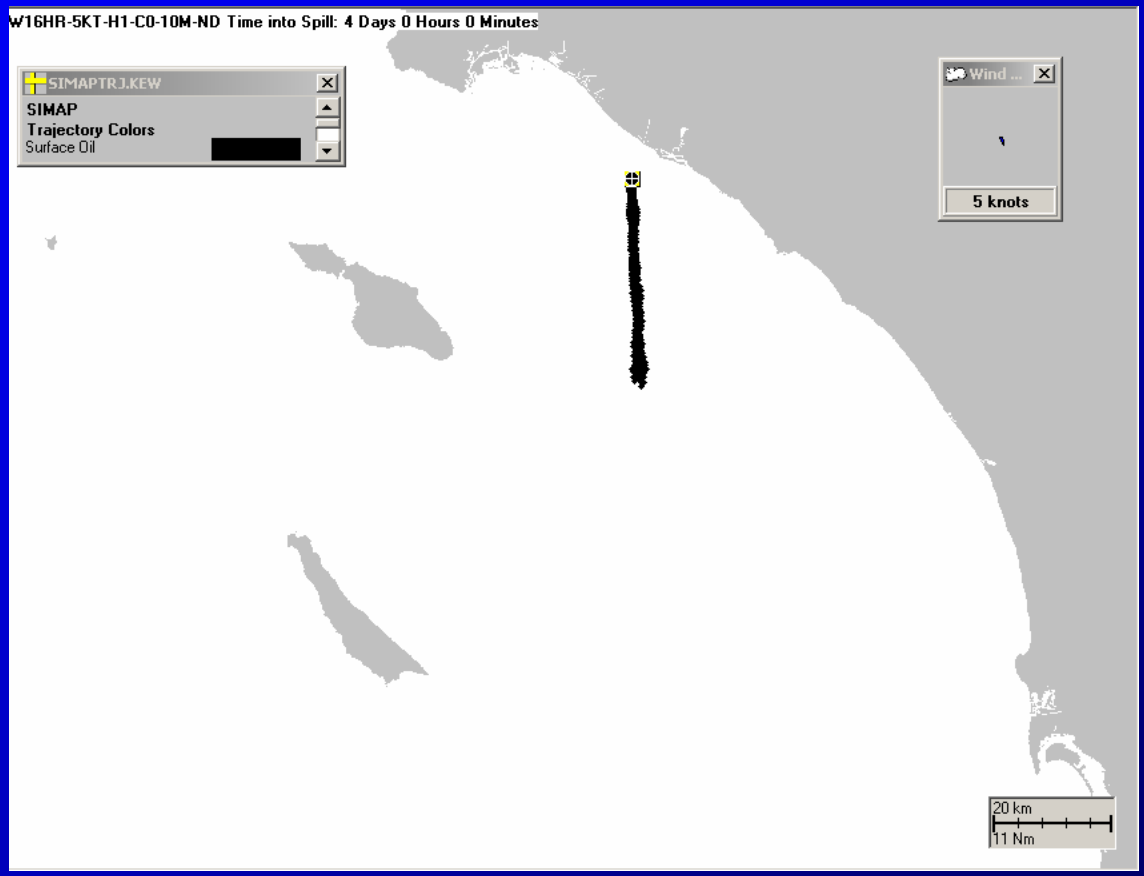
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Trajectory: 48 hrs after potential treatment



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Trajectory: 72 hrs after potential treatment

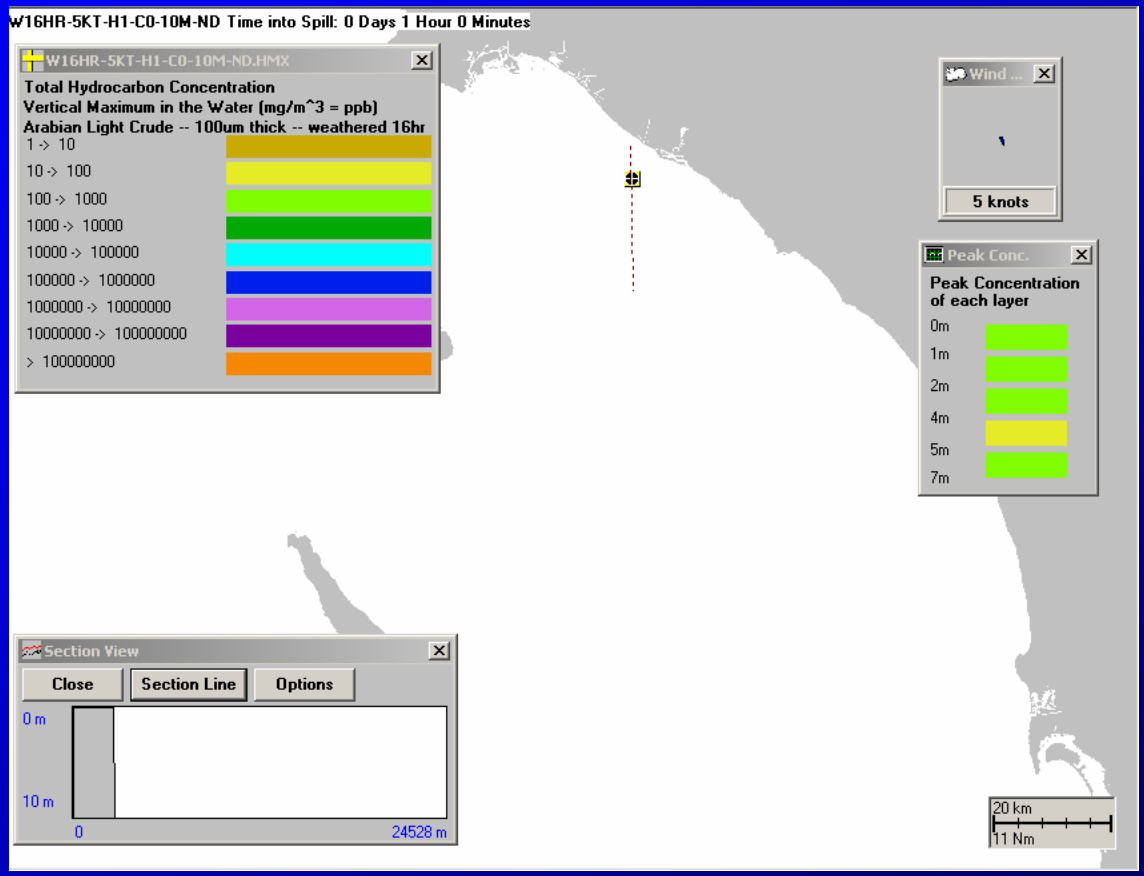


Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Trajectory: 96 hrs after potential treatment

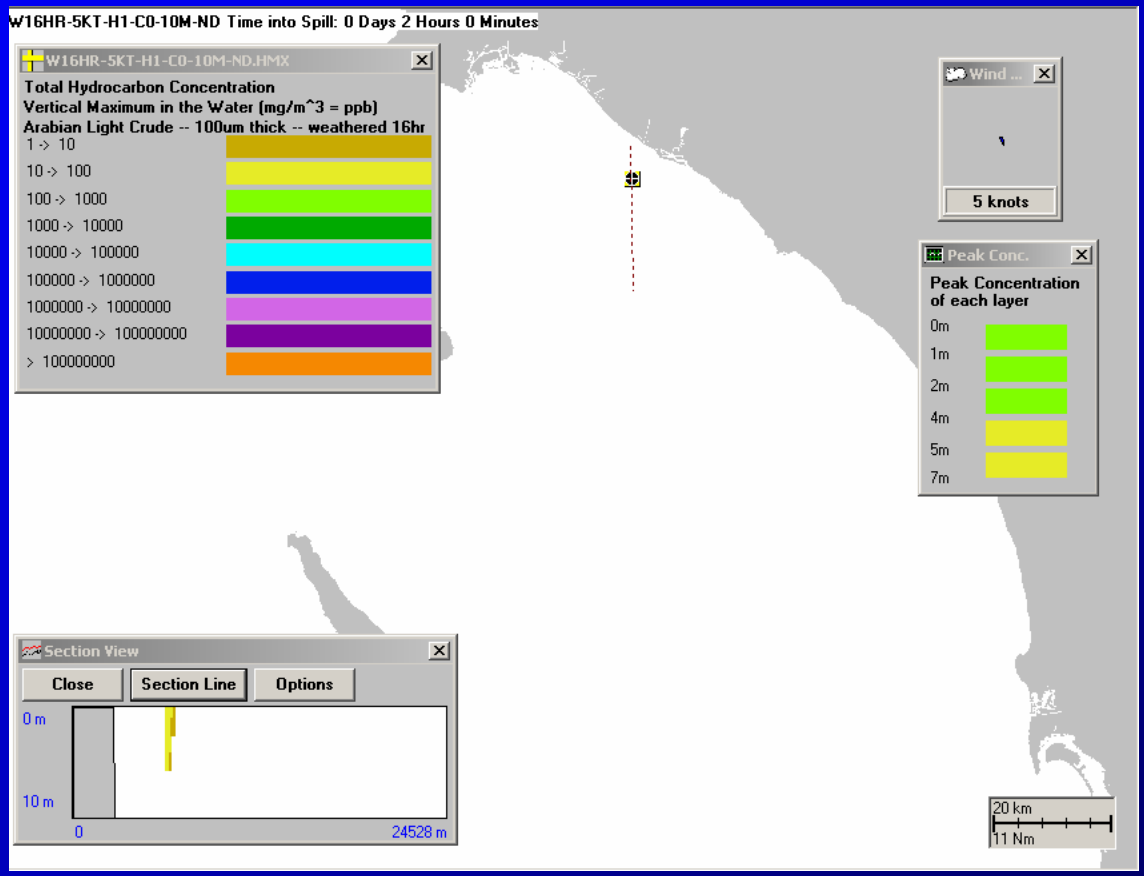


Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations

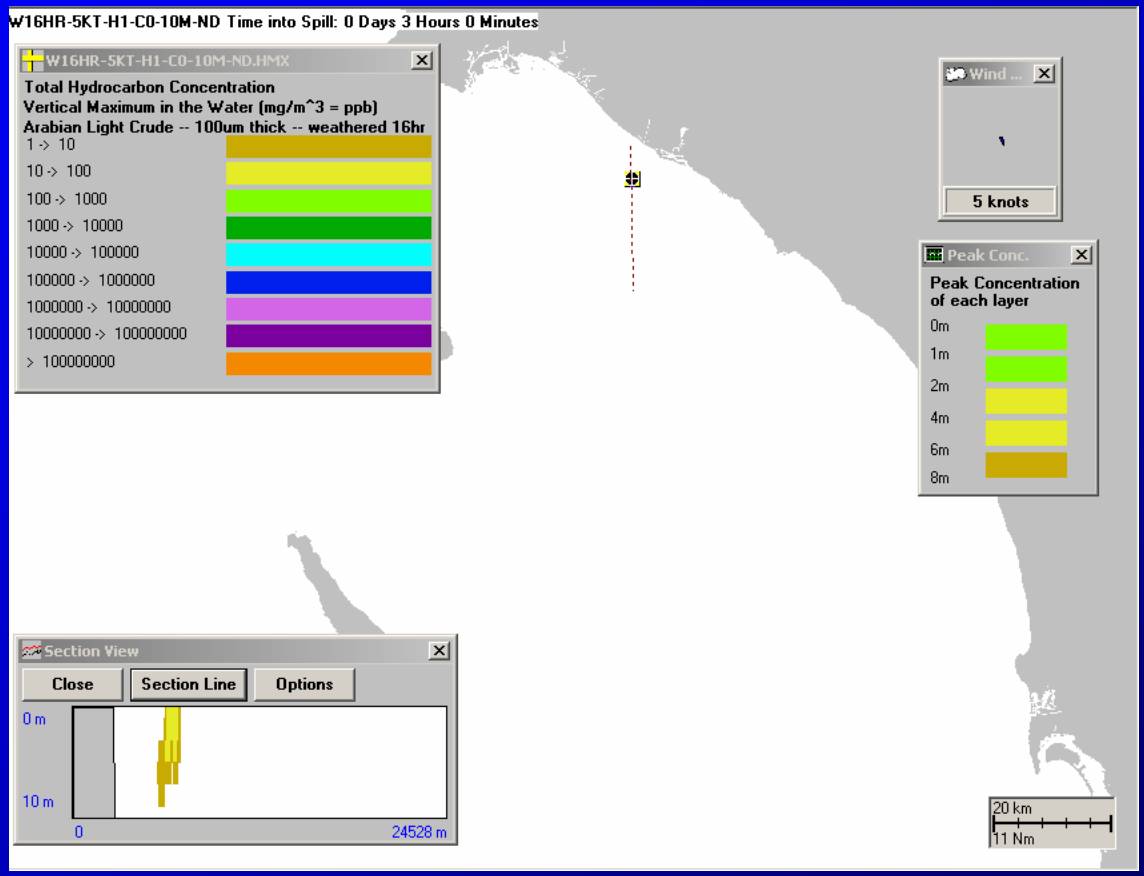
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 1 hr after potential treatment



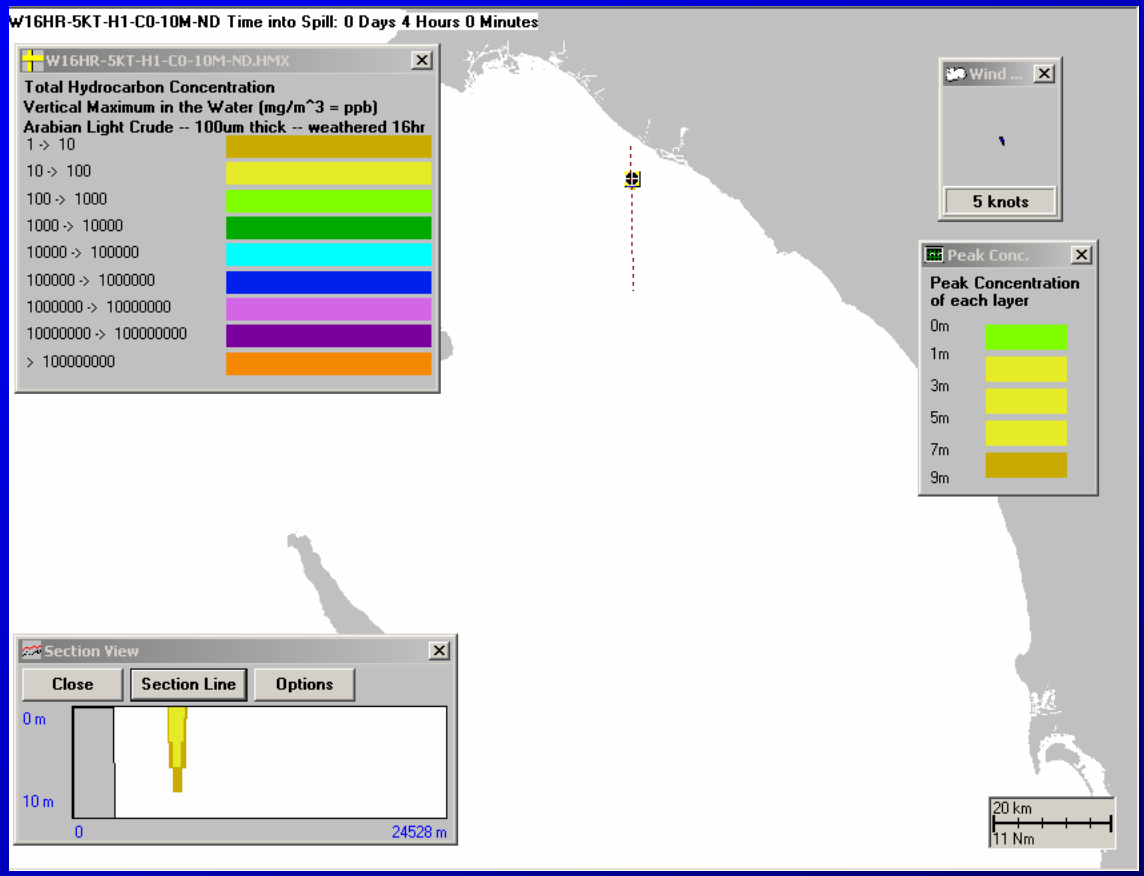
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 2 hrs after potential treatment



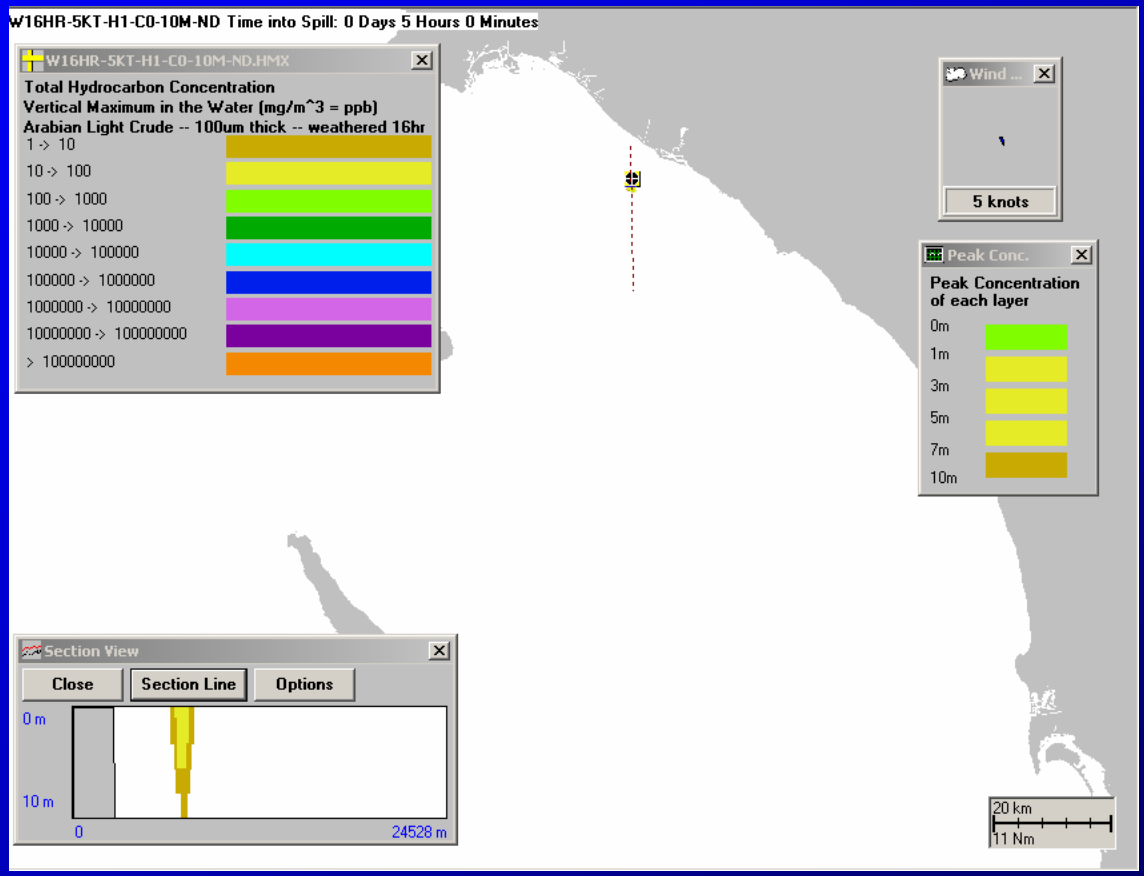
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 3 hrs after potential treatment



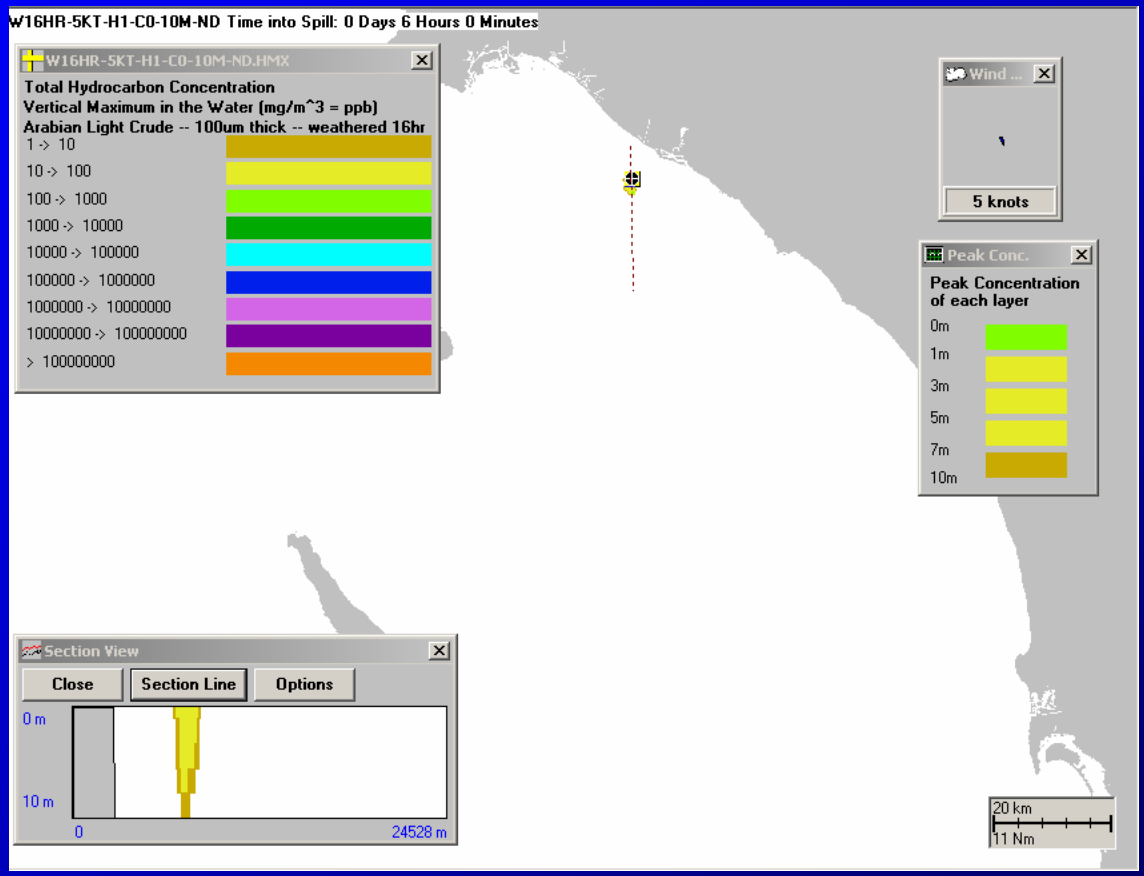
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 4 hrs after potential treatment



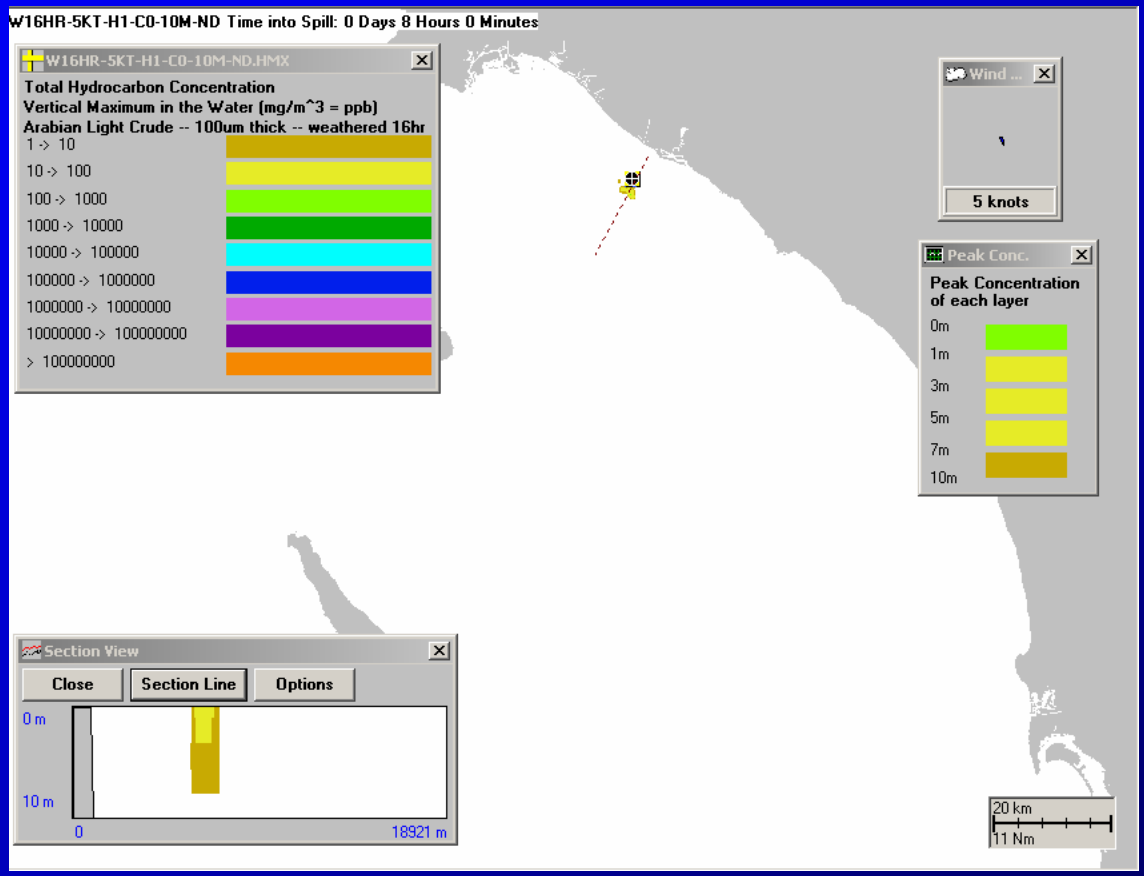
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 5 hrs after potential treatment



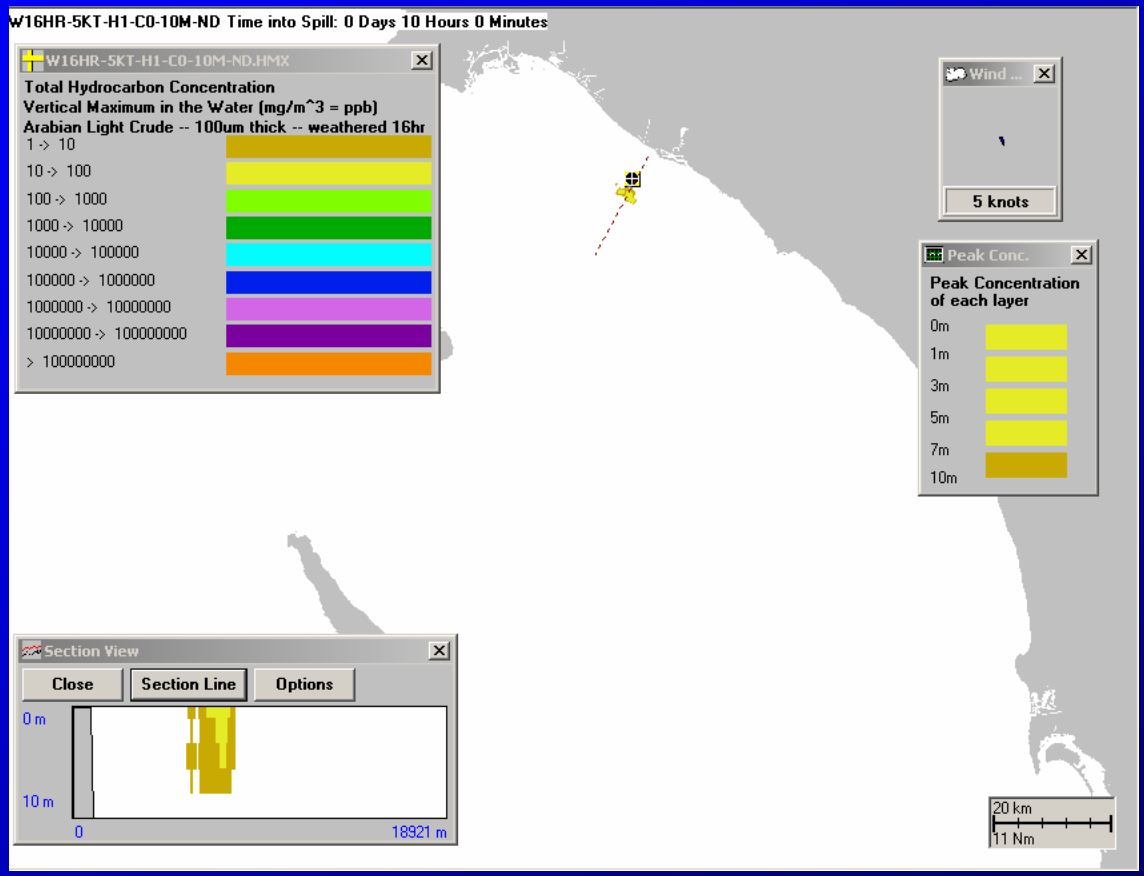
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 6 hrs after potential treatment



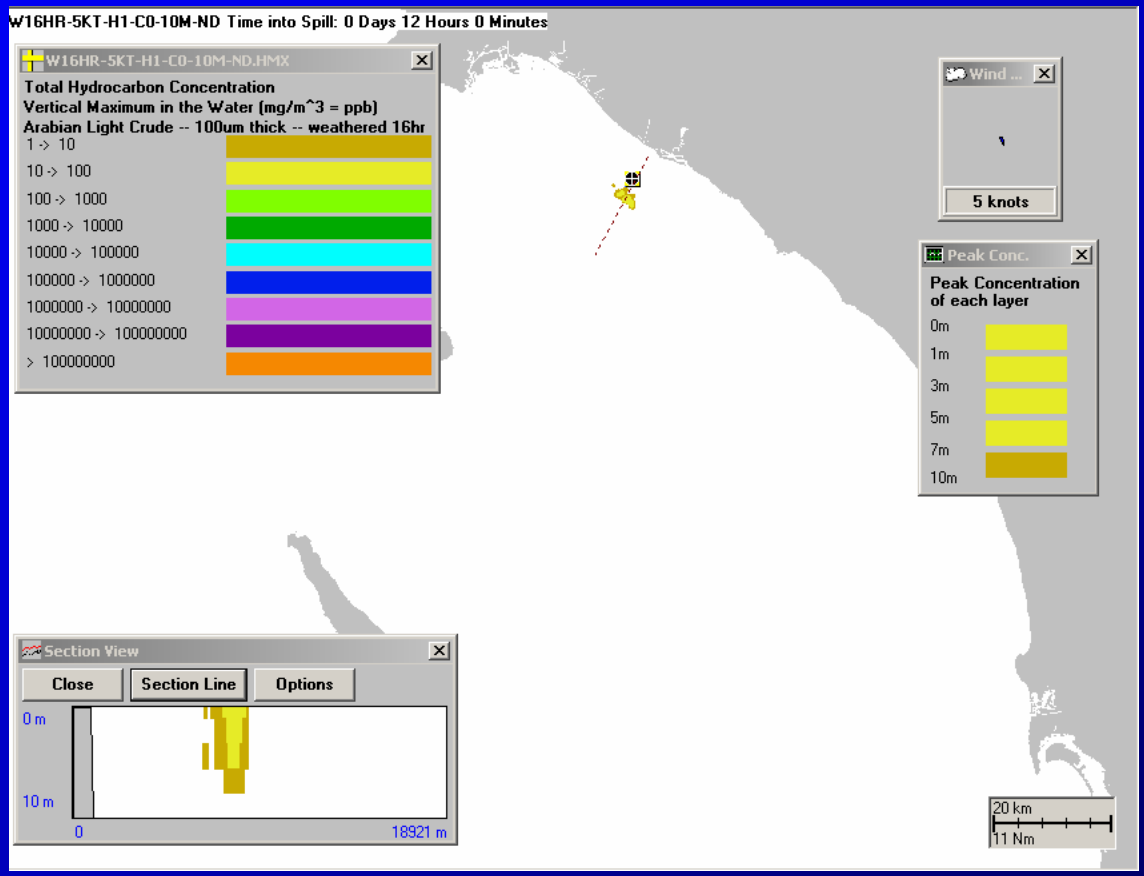
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 8 hrs after potential treatment



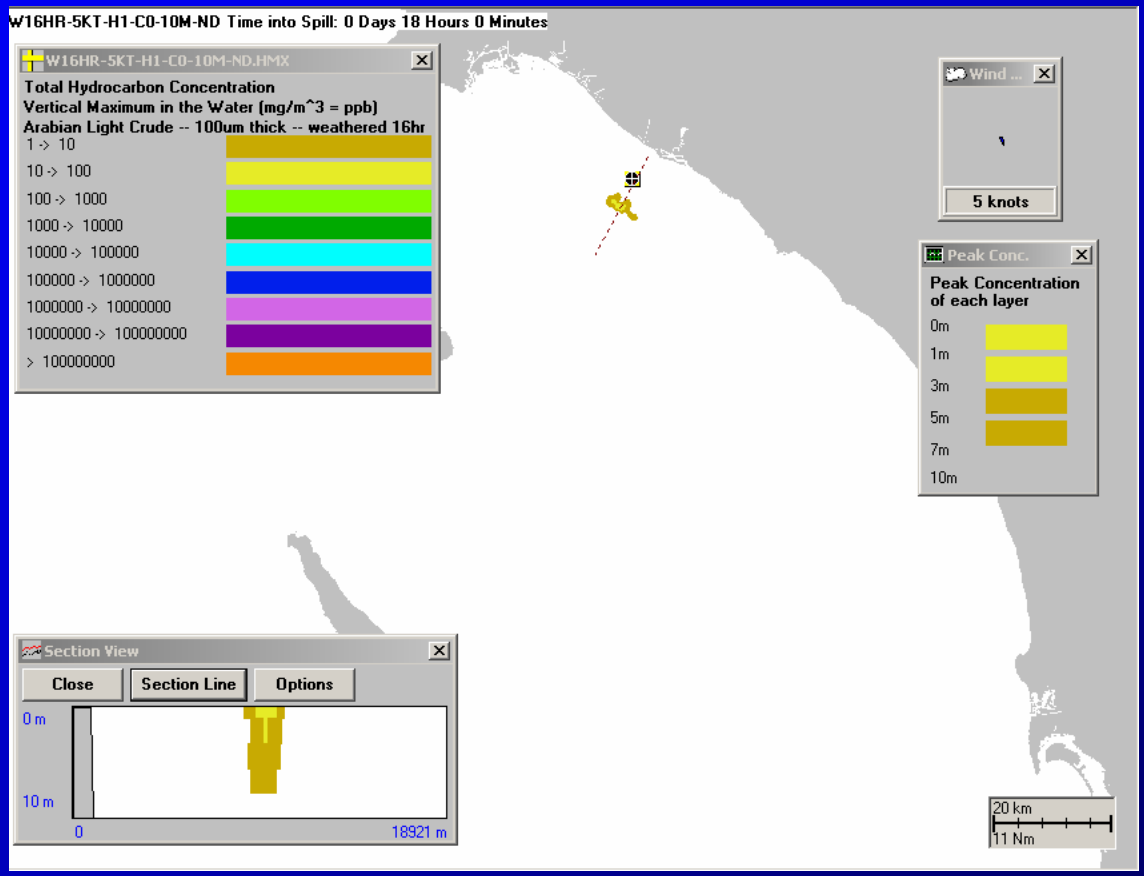
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 10 hrs after potential treatment



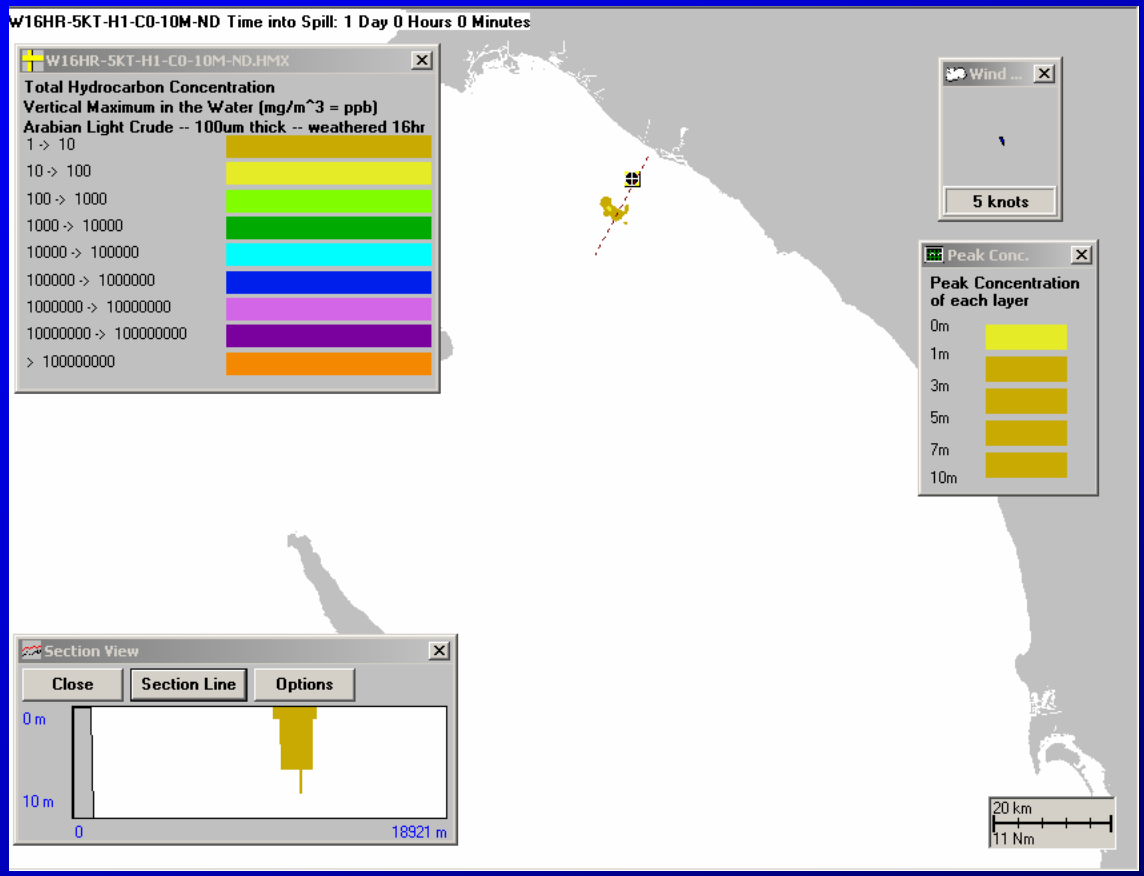
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 12 hrs after potential treatment



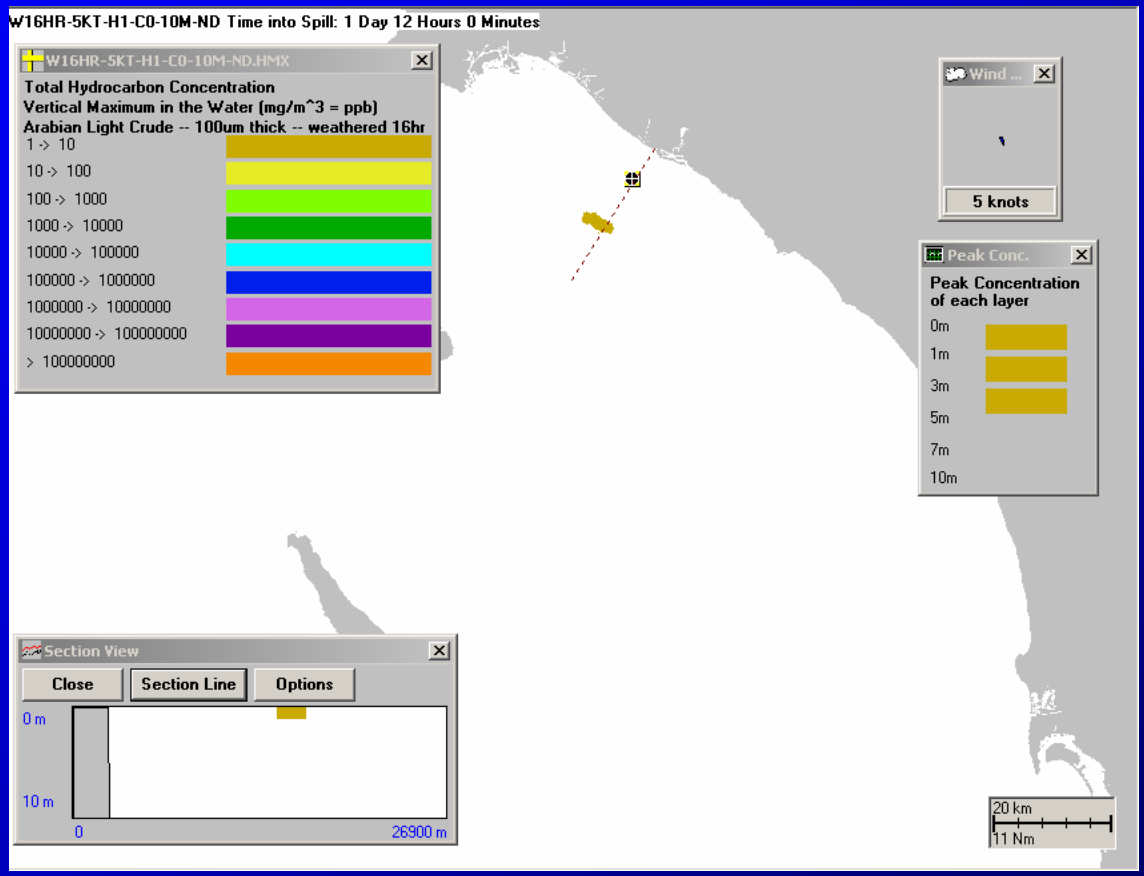
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 18 hrs after potential treatment



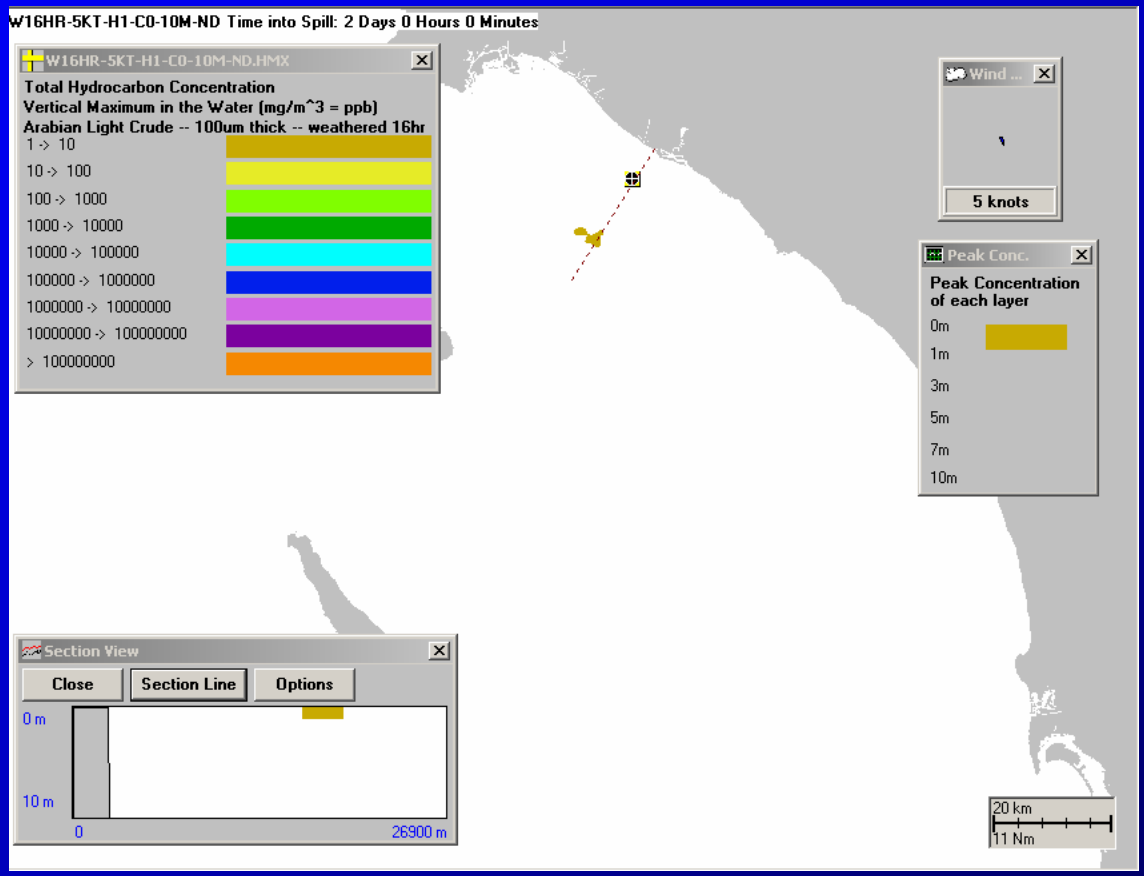
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 24 hrs after potential treatment



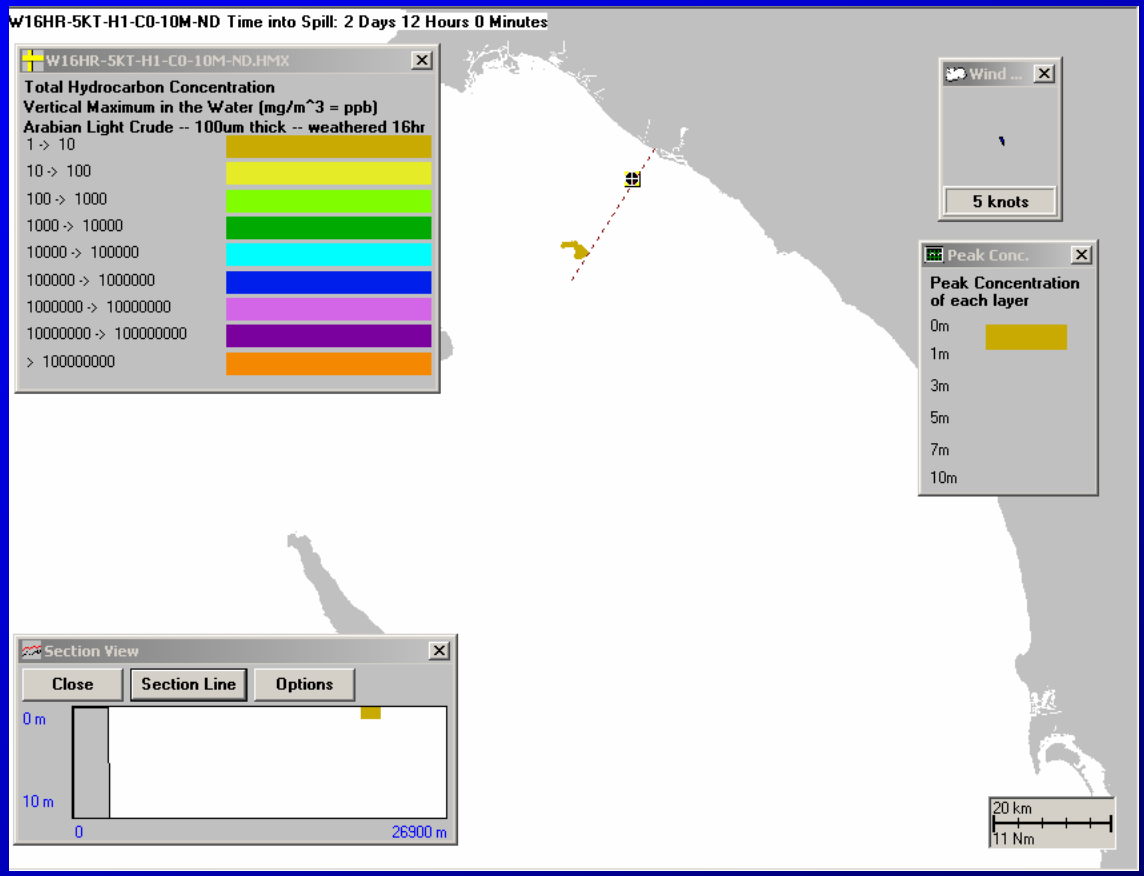
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 36 hrs after potential treatment



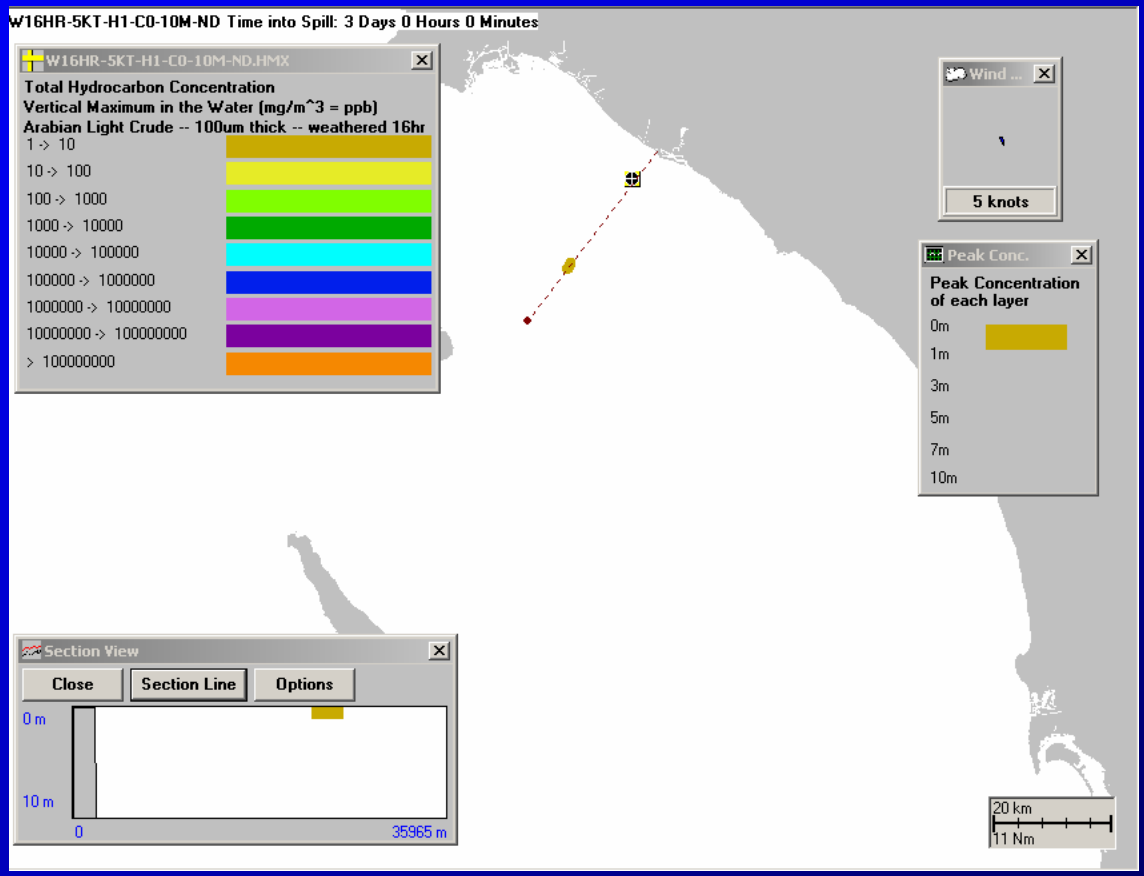
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 48 hrs after potential treatment



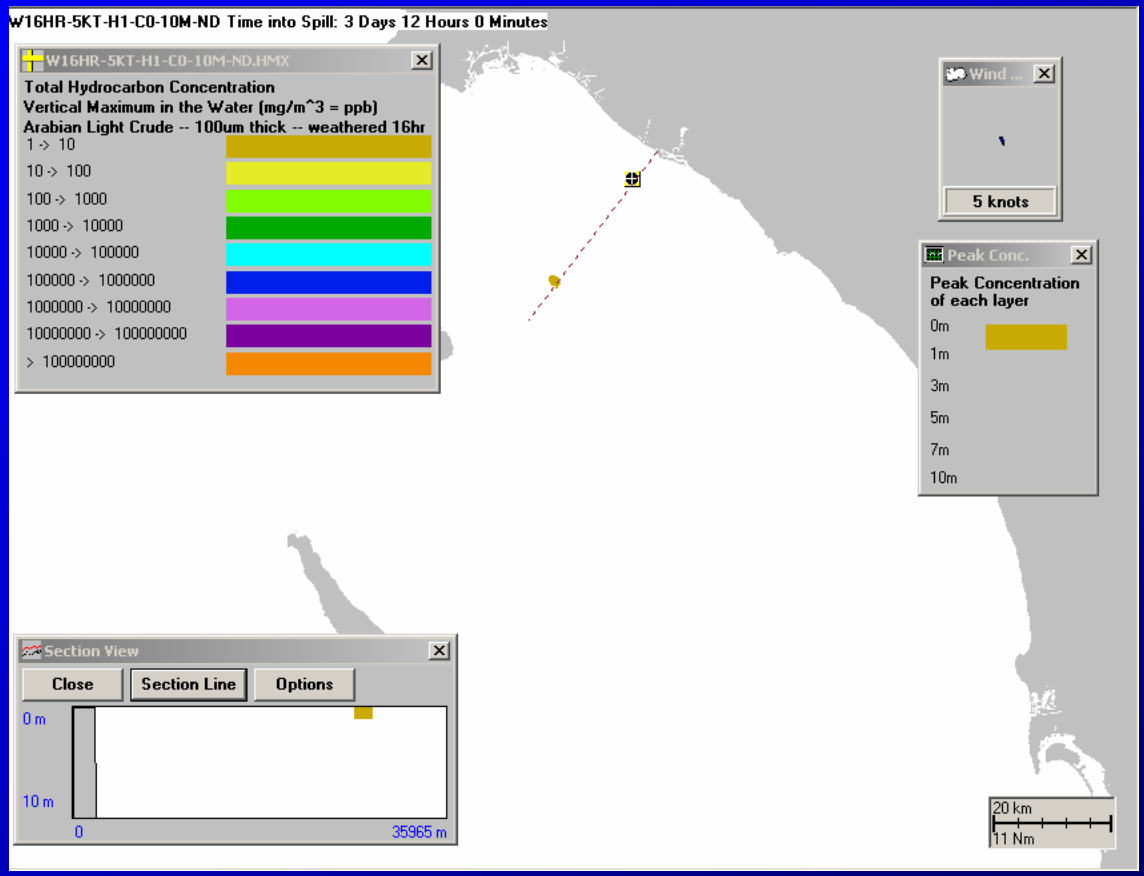
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 60 hrs after potential treatment



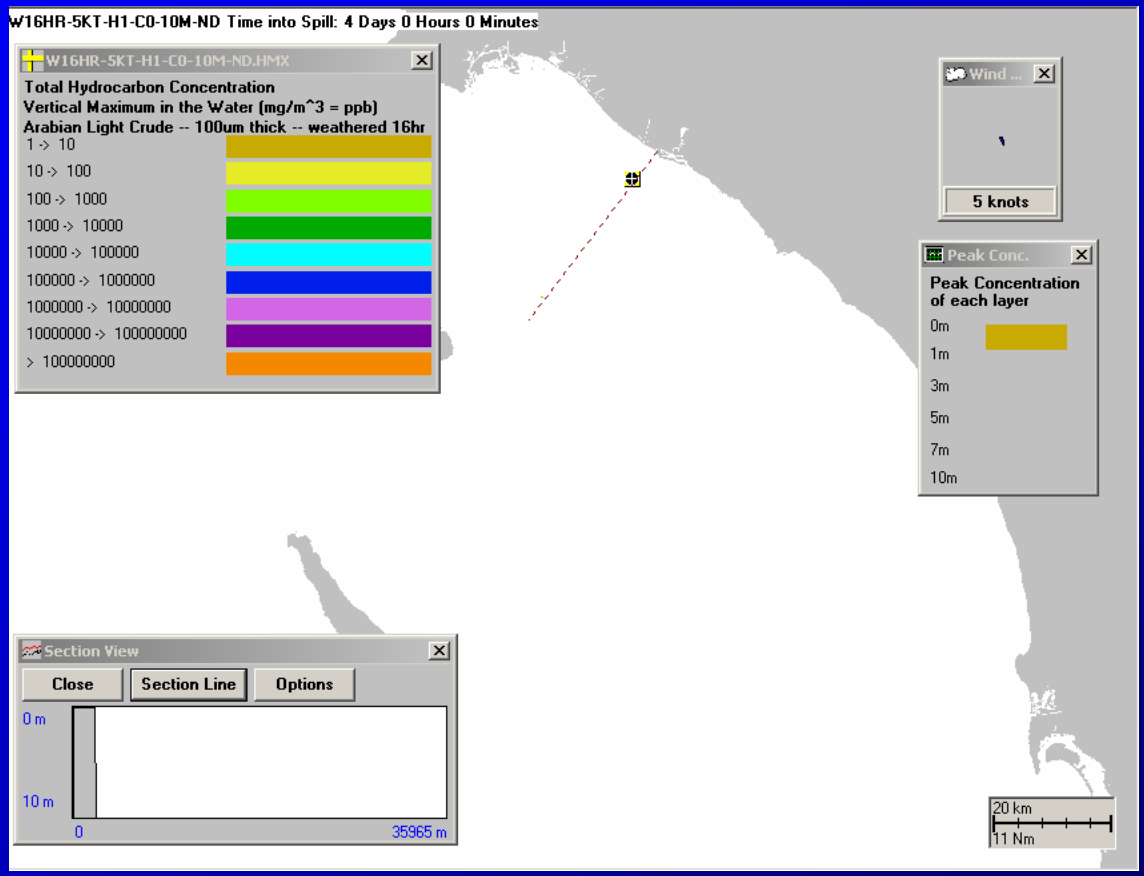
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 72 hrs after potential treatment



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 84 hrs after potential treatment



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: none; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 96 hrs after potential treatment



Scenario

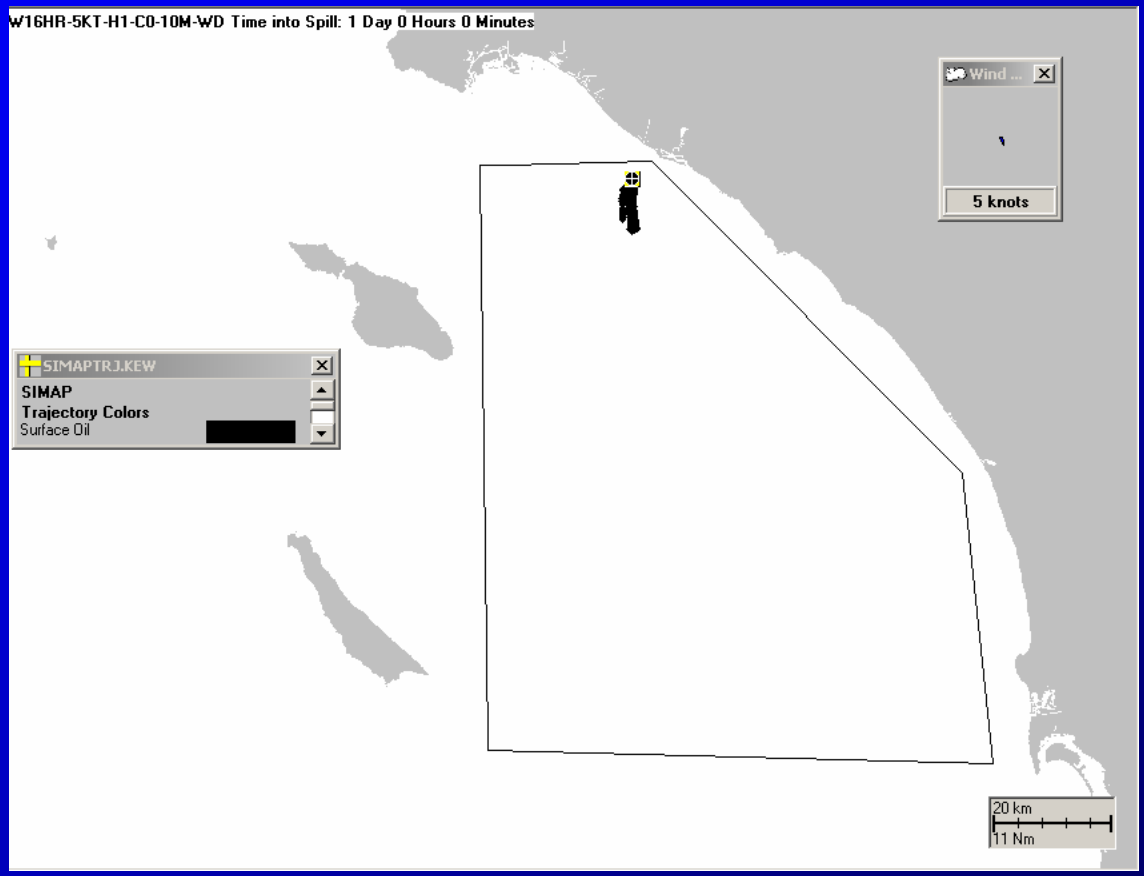
Pre-Weathering for 16 hrs before dispersant treatment

Wind from NNW 5 kts;
Currents: 0 kt;

Dispersant: at 16 hrs after Spill

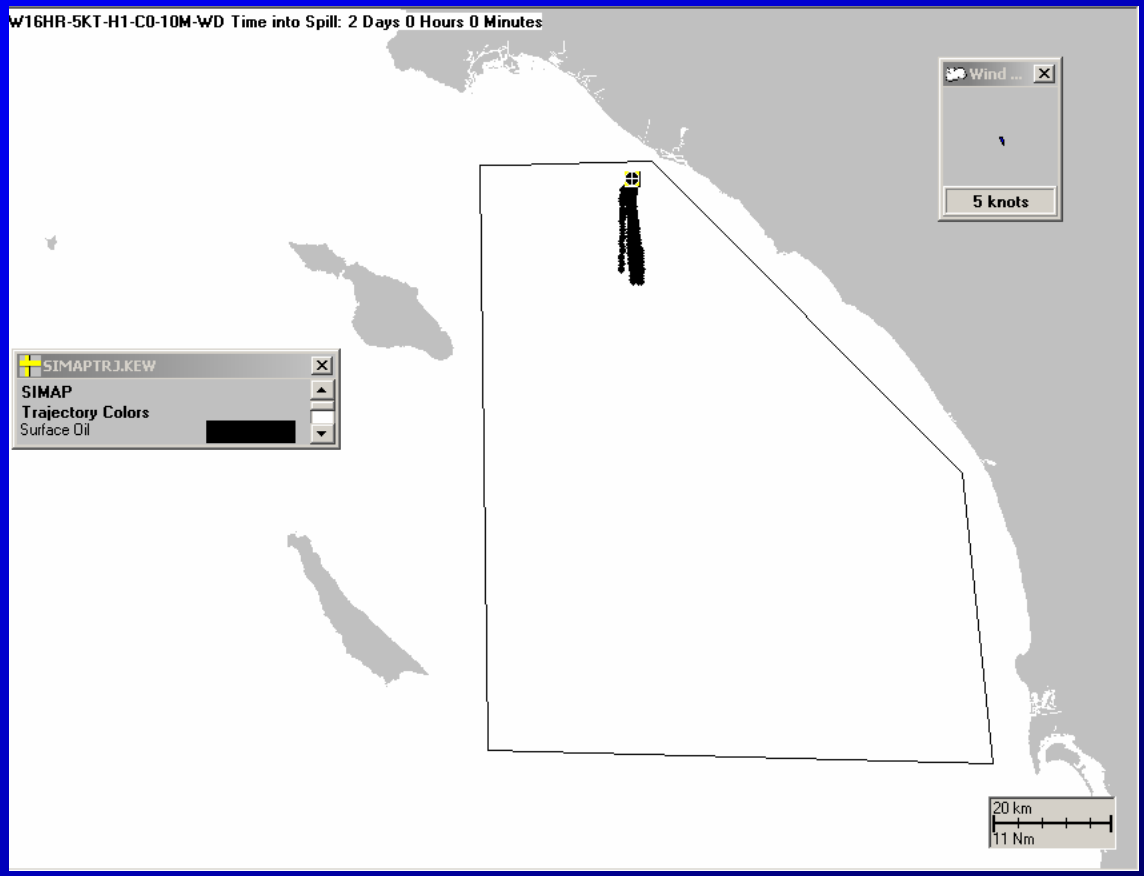
Turbulent Mixing to 10m deep in Surface Mixed Layer

Wind from NNW 5 kts; Currents: 0 kt; Dispersant: at 16 hrs; Turbulent mixing to 10m deep; Trajectory: 24 hrs after dispersant application

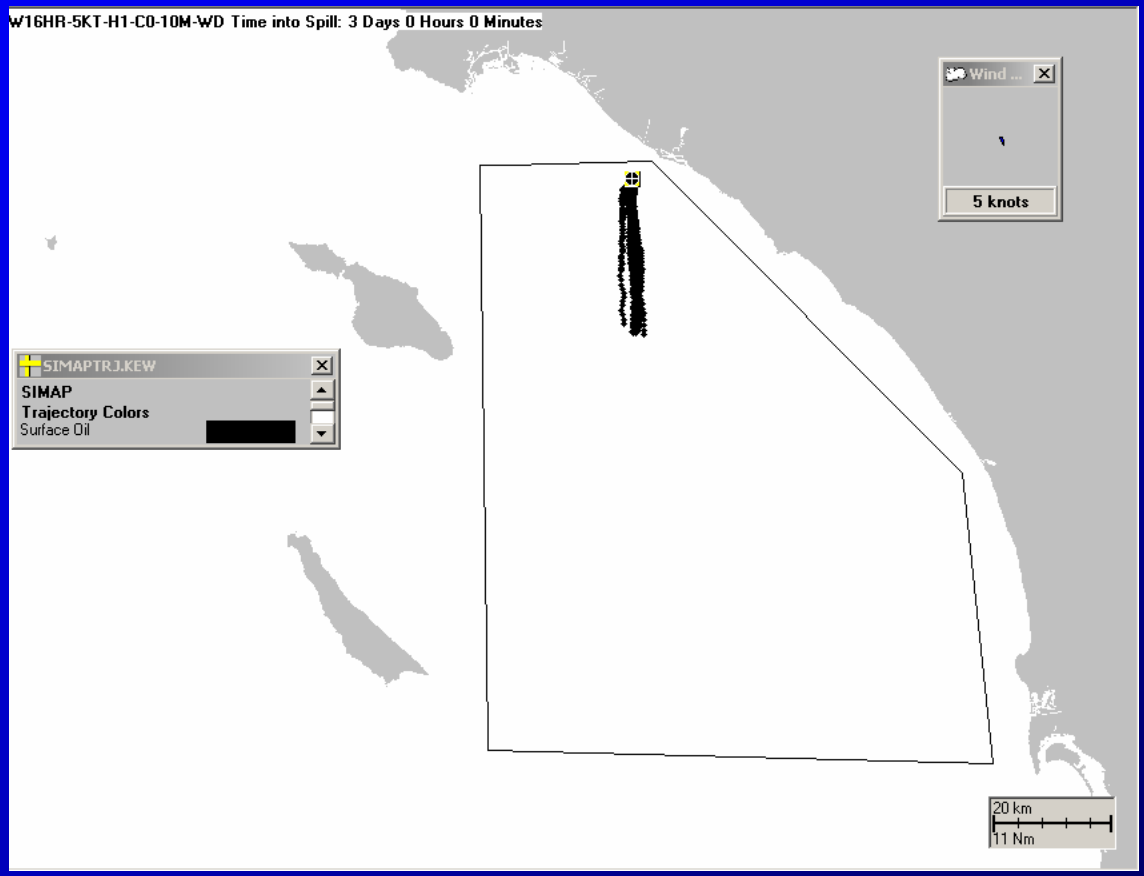


[Polygon indicates area where dispersant could be applied]

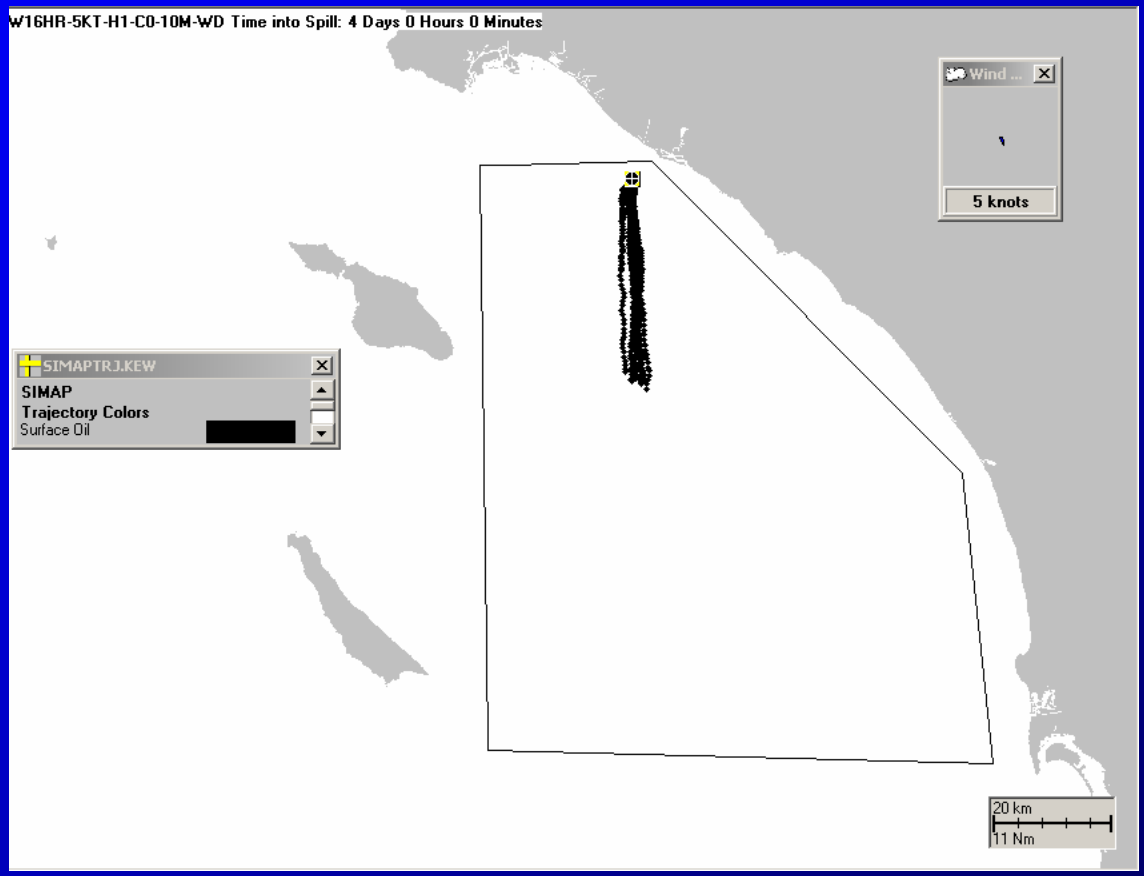
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Trajectory: 48 hrs after dispersant application



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Trajectory: 72 hrs after dispersant application

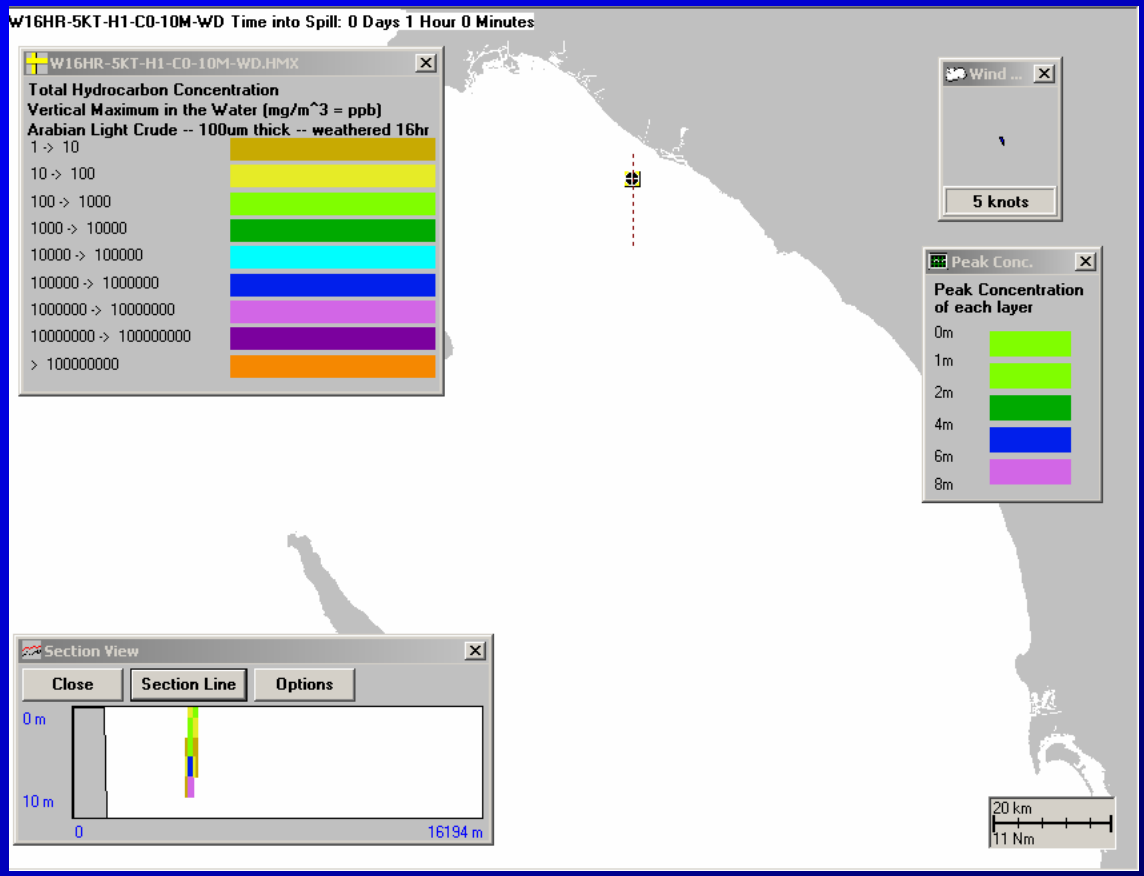


Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Trajectory: 96 hrs after dispersant application

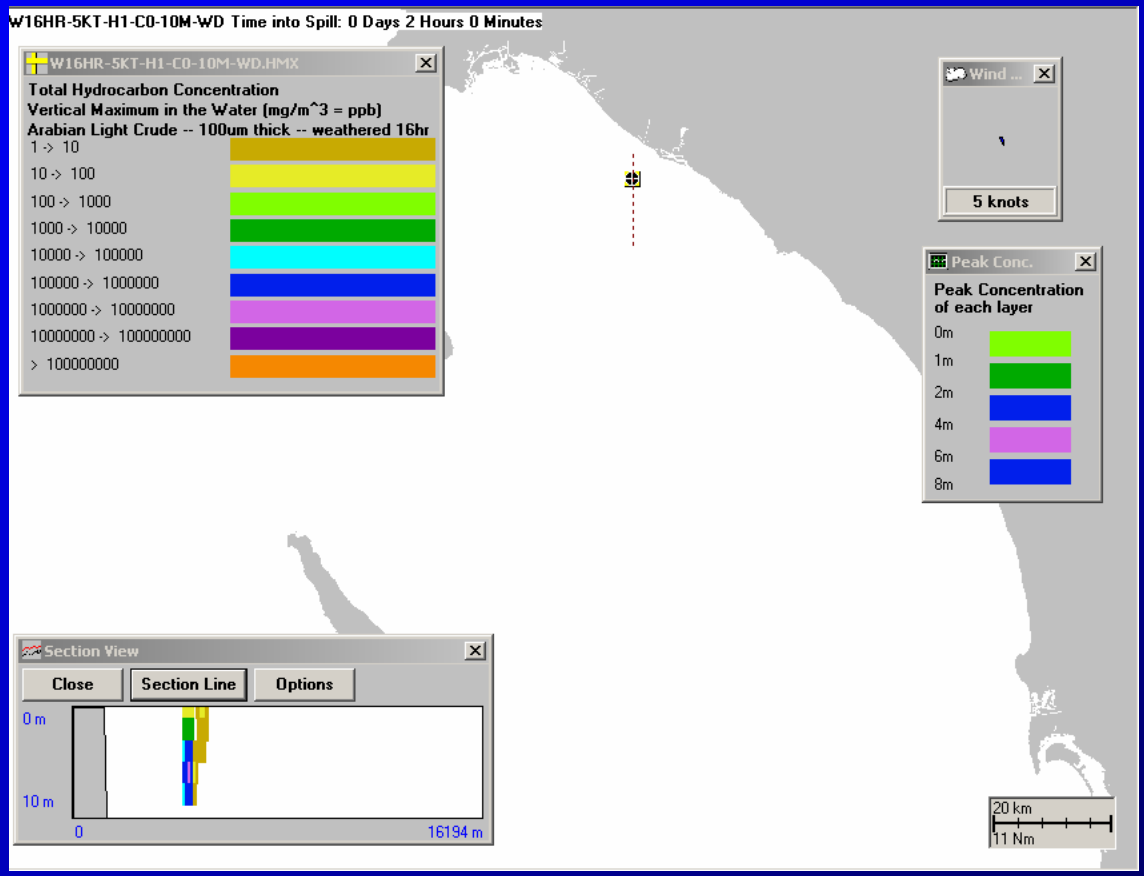


Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations

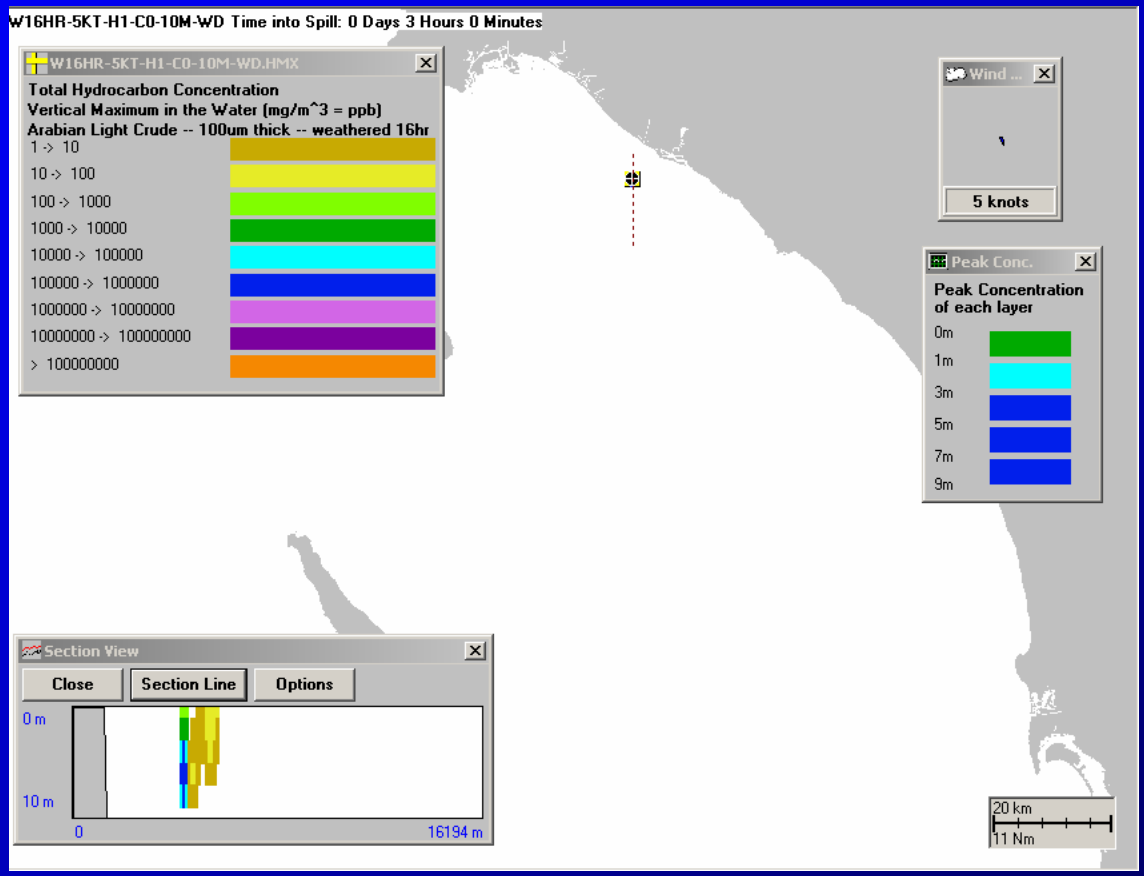
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 1 hr after dispersant application



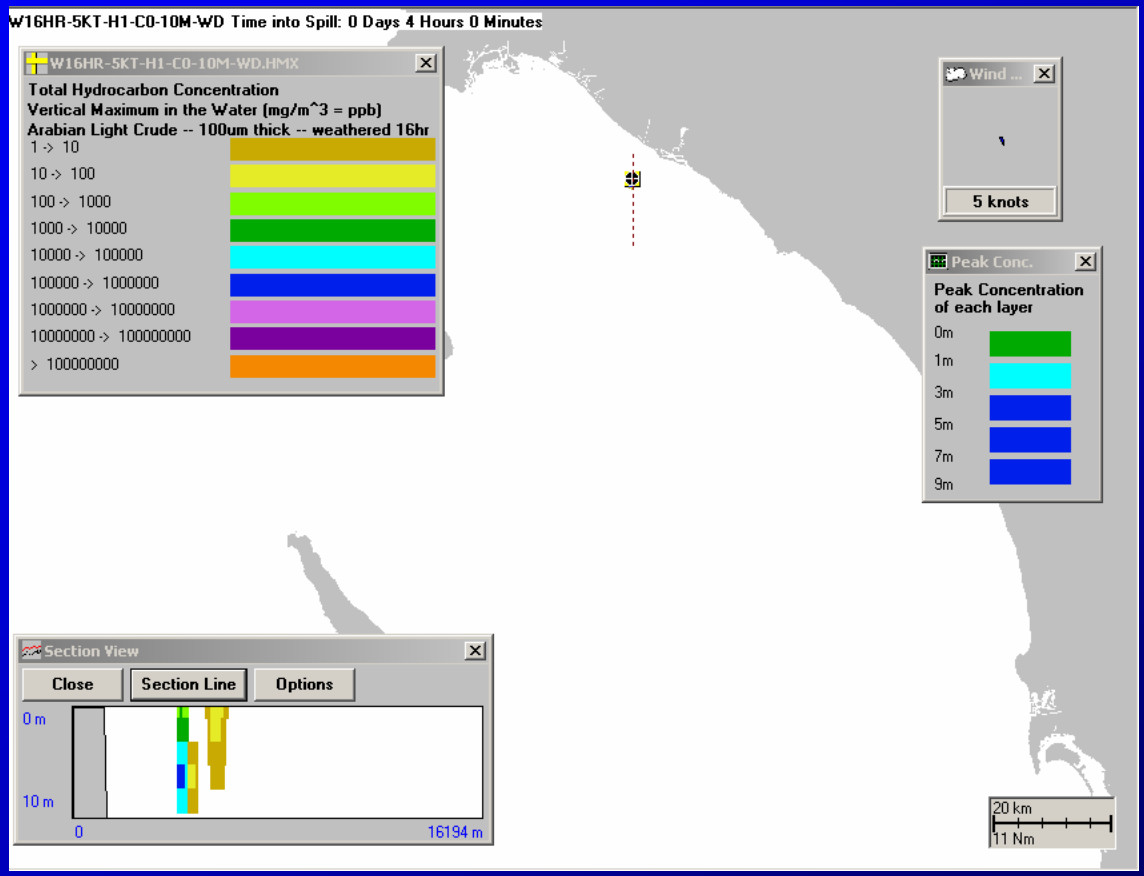
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 2 hrs after dispersant application



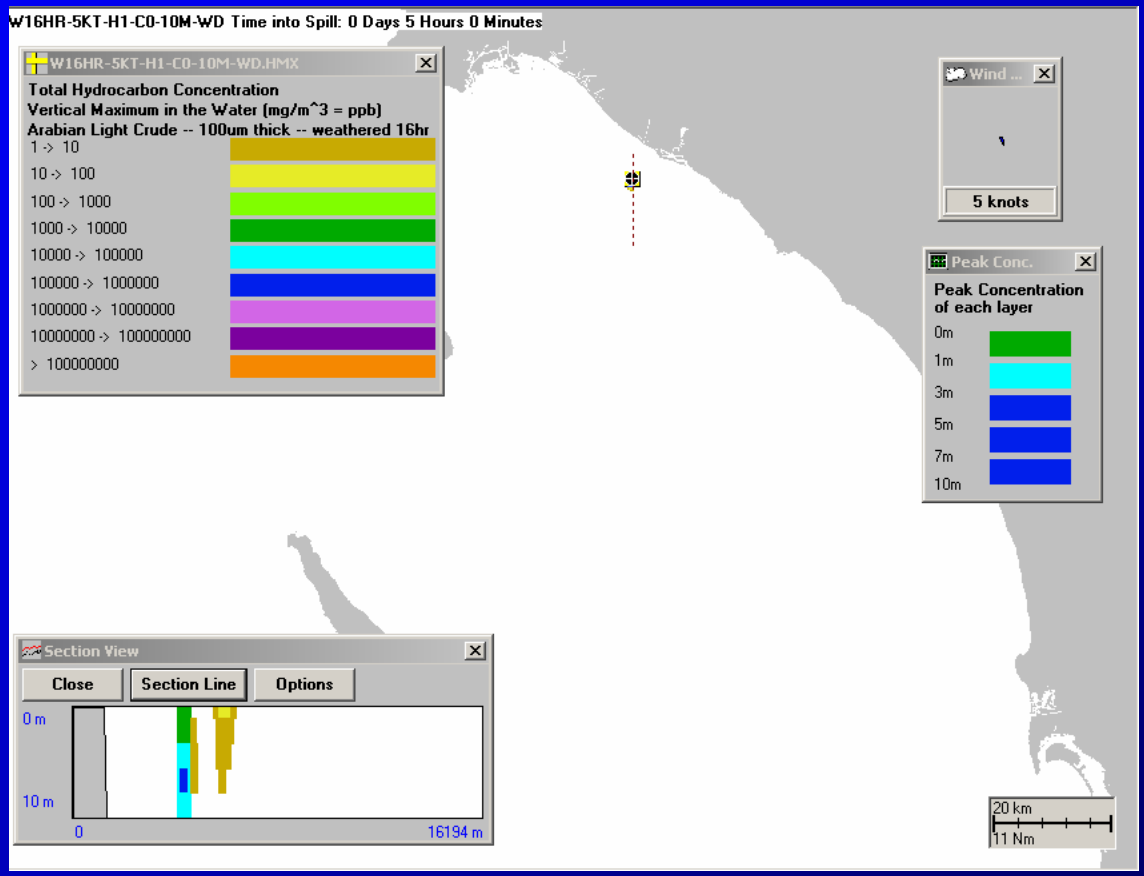
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 3 hrs after dispersant application



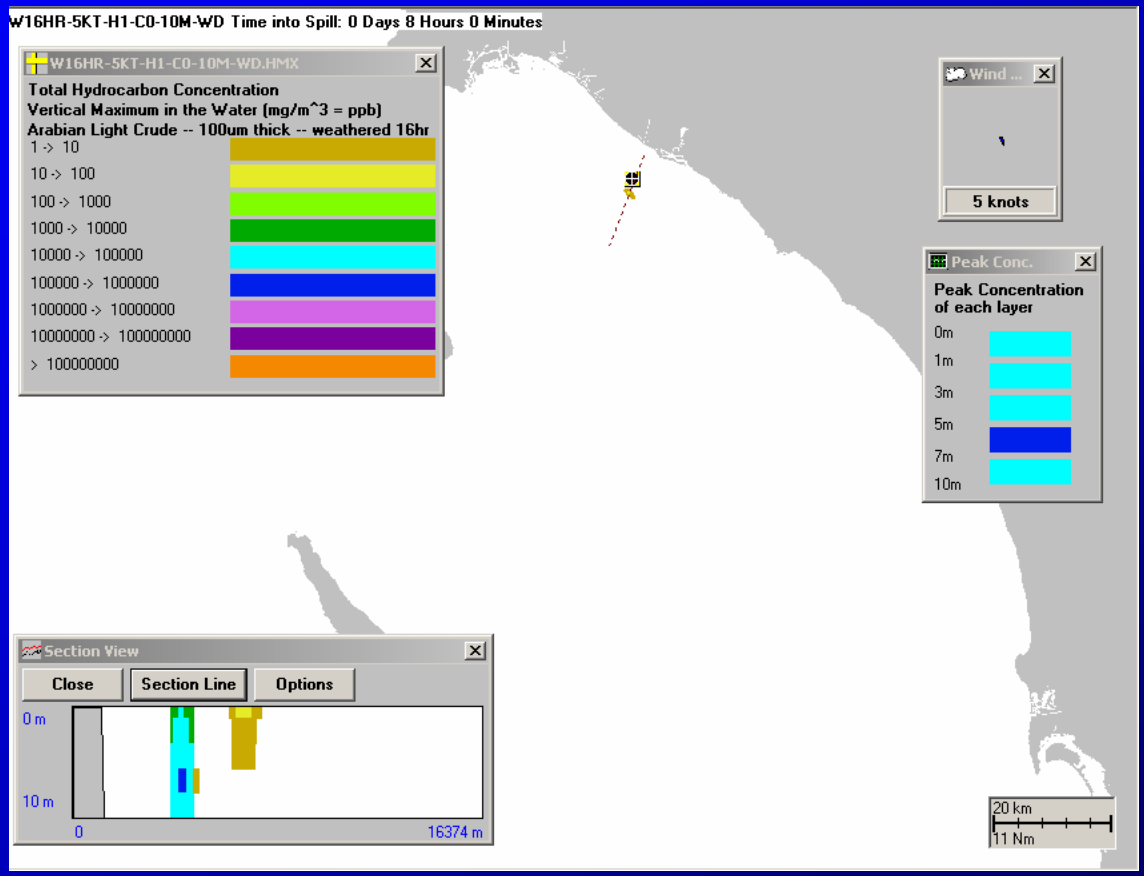
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 4 hrs after dispersant application



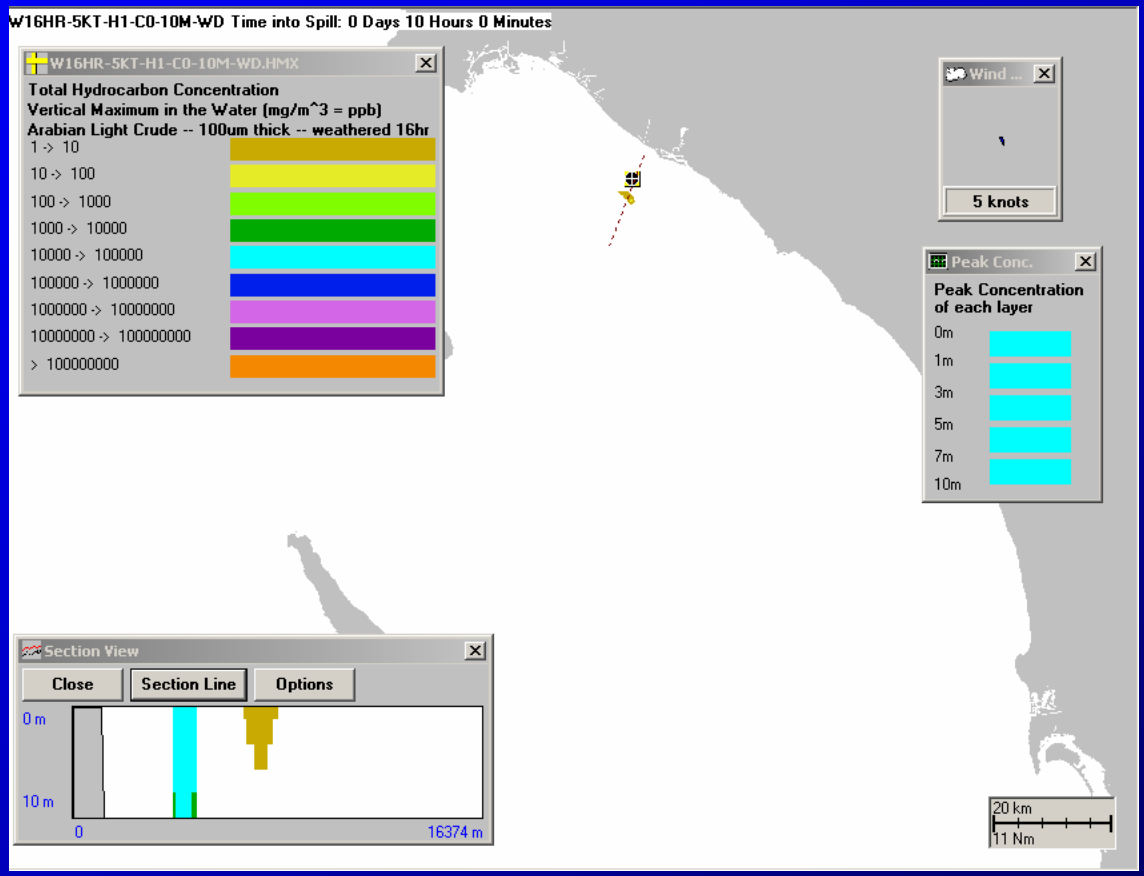
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 5 hrs after dispersant application



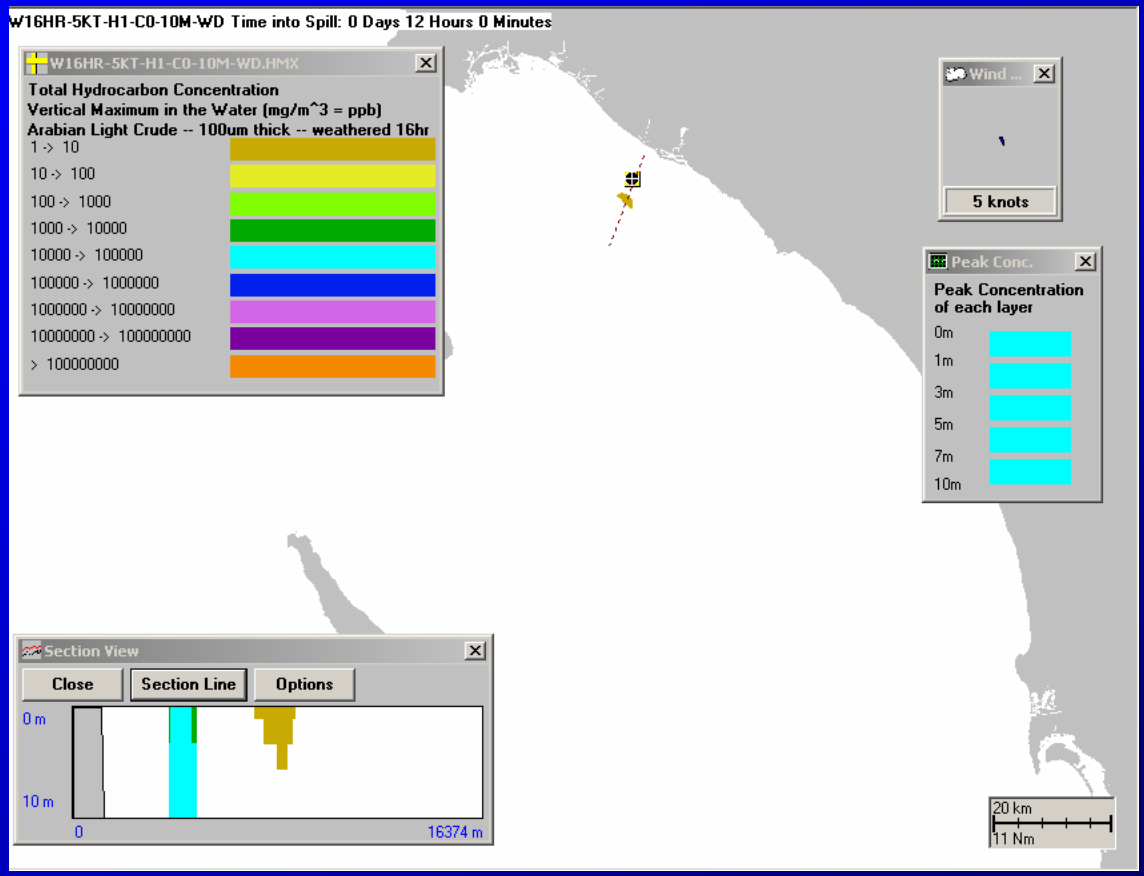
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 8 hrs after dispersant application



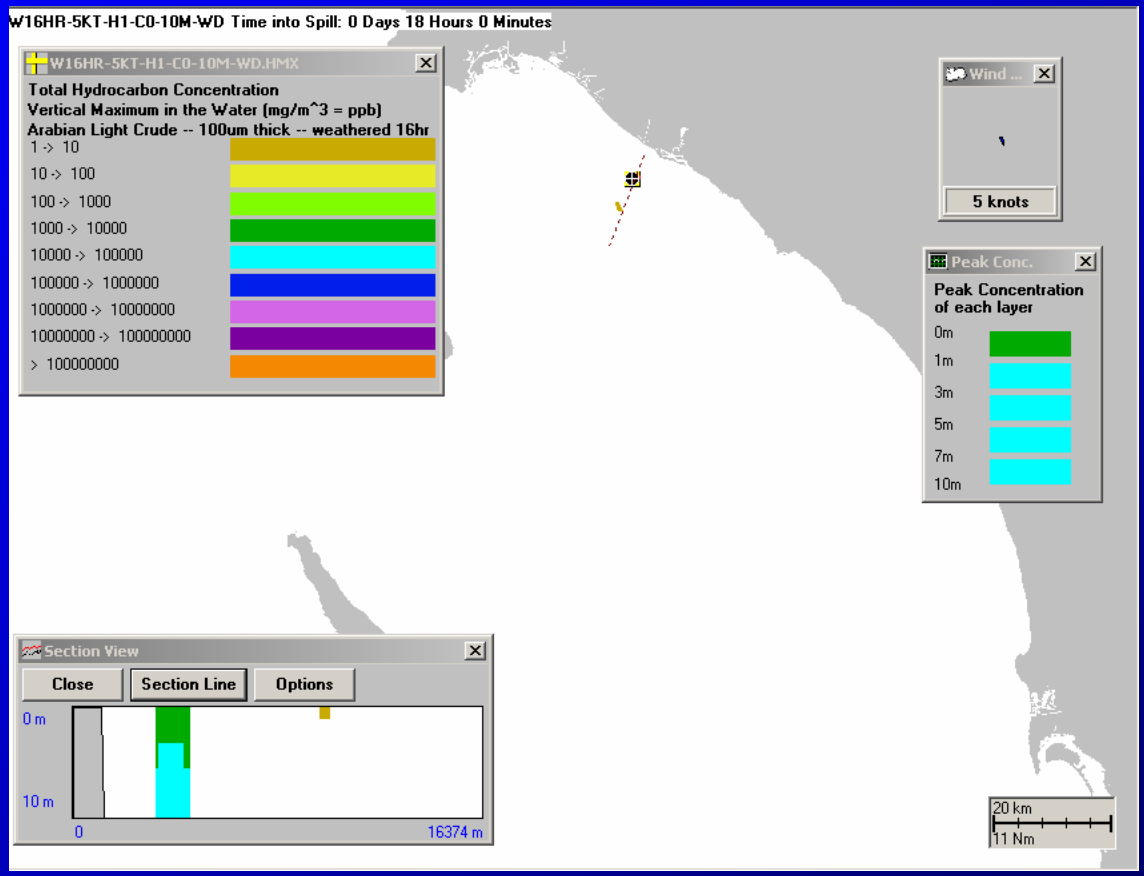
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 10 hrs after dispersant application



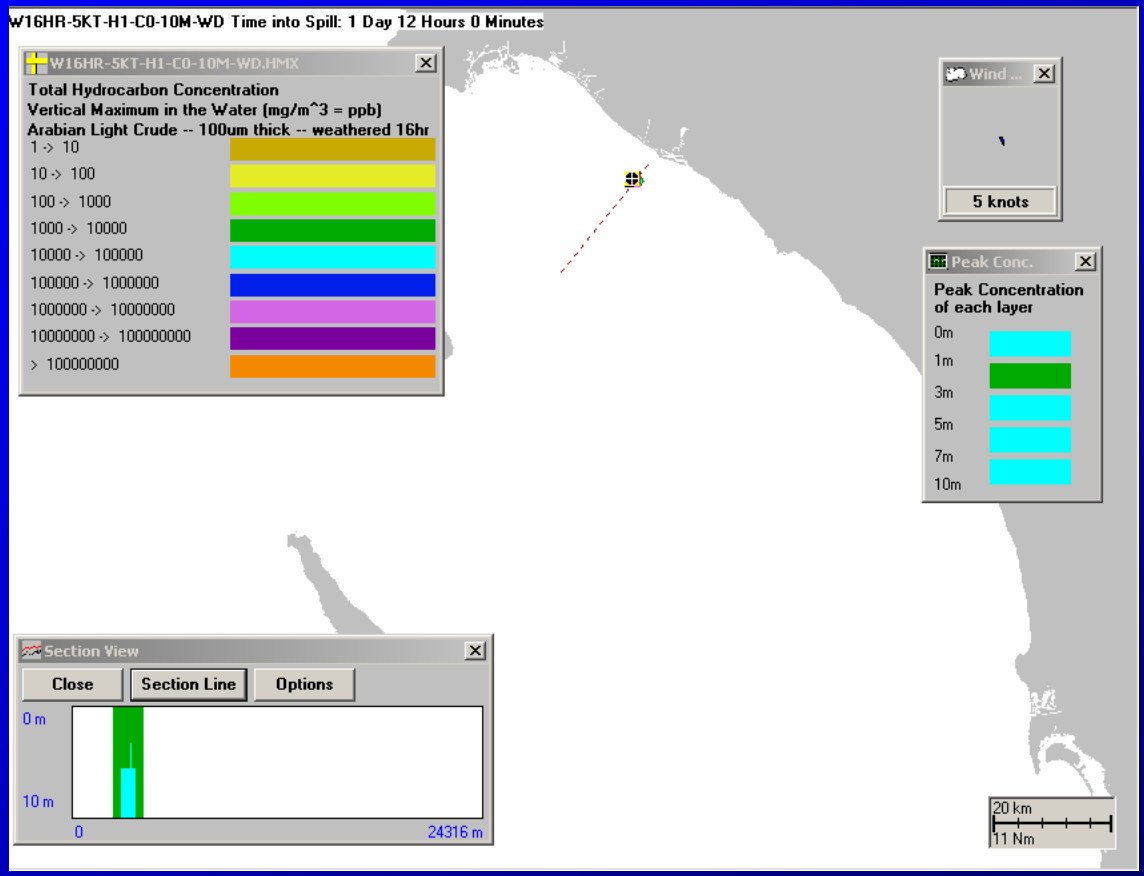
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 12 hrs after dispersant application



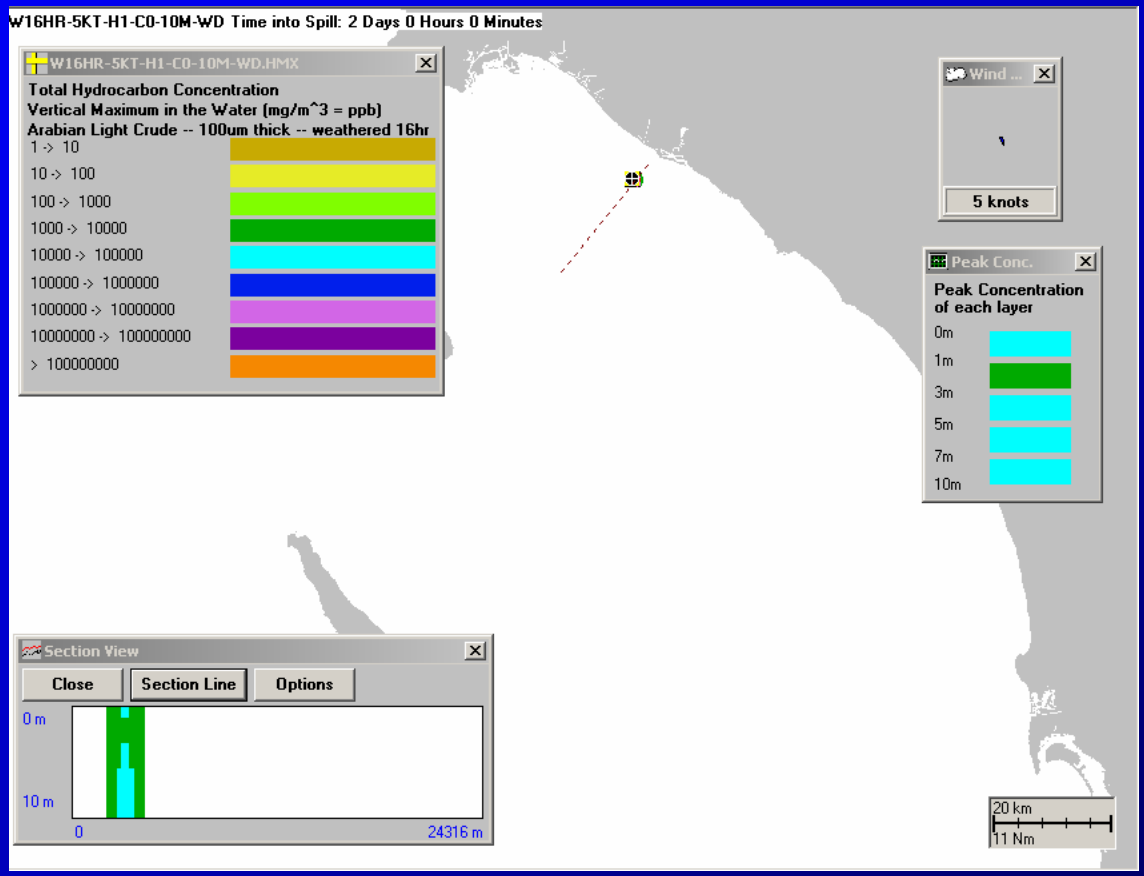
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 18 hrs after dispersant application



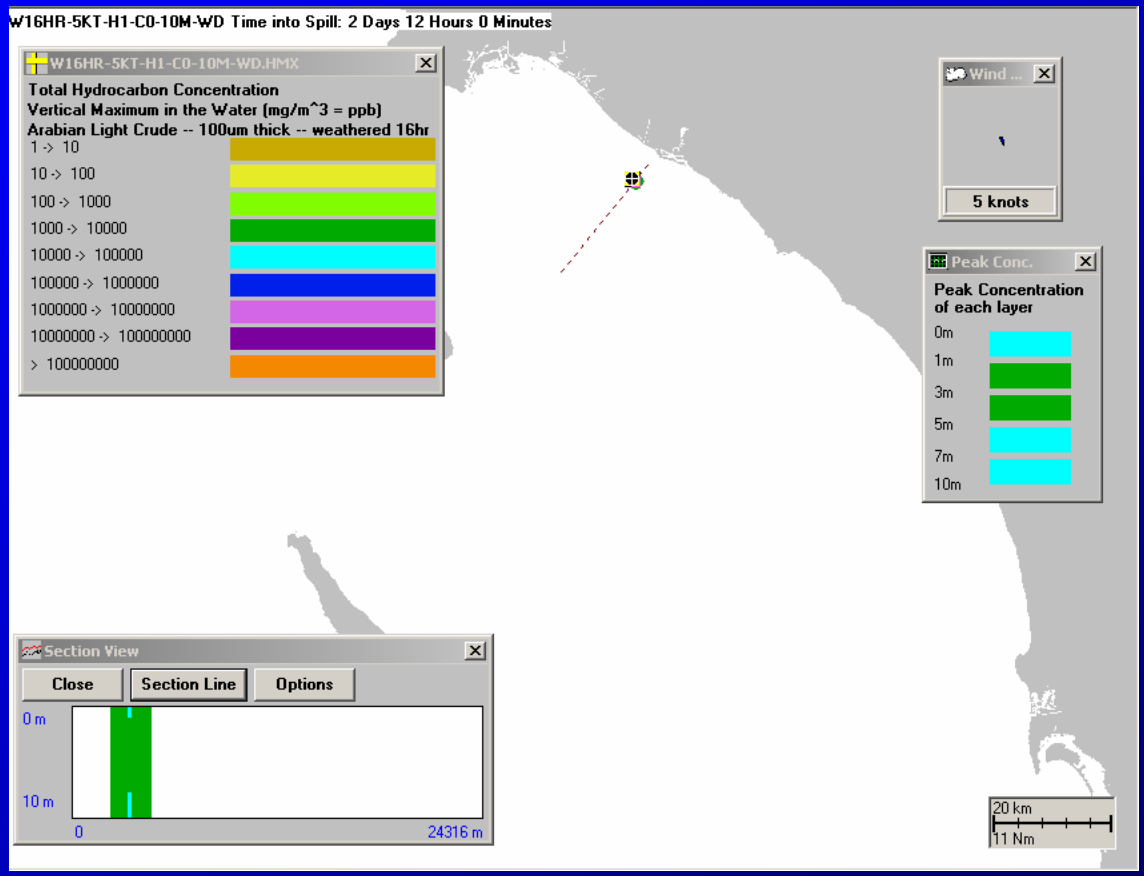
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 36 hrs after dispersant application



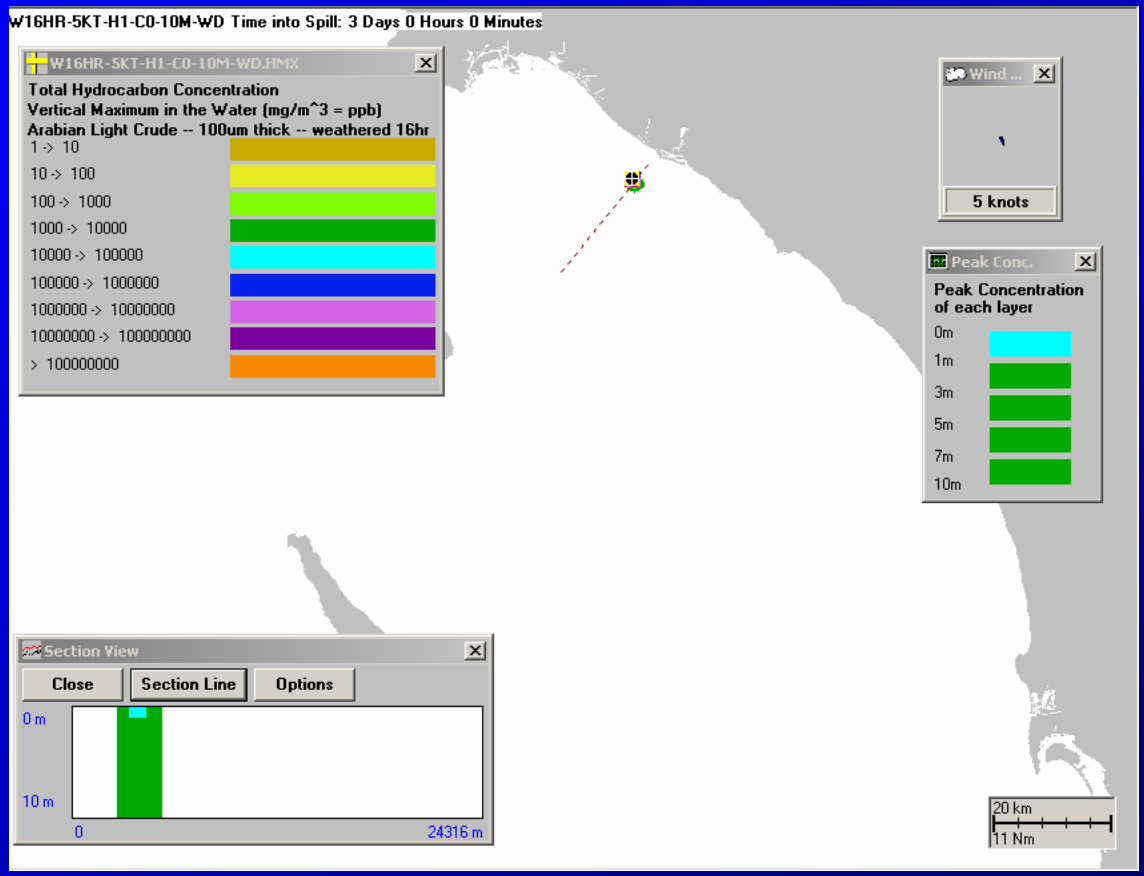
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 48 hrs after dispersant application



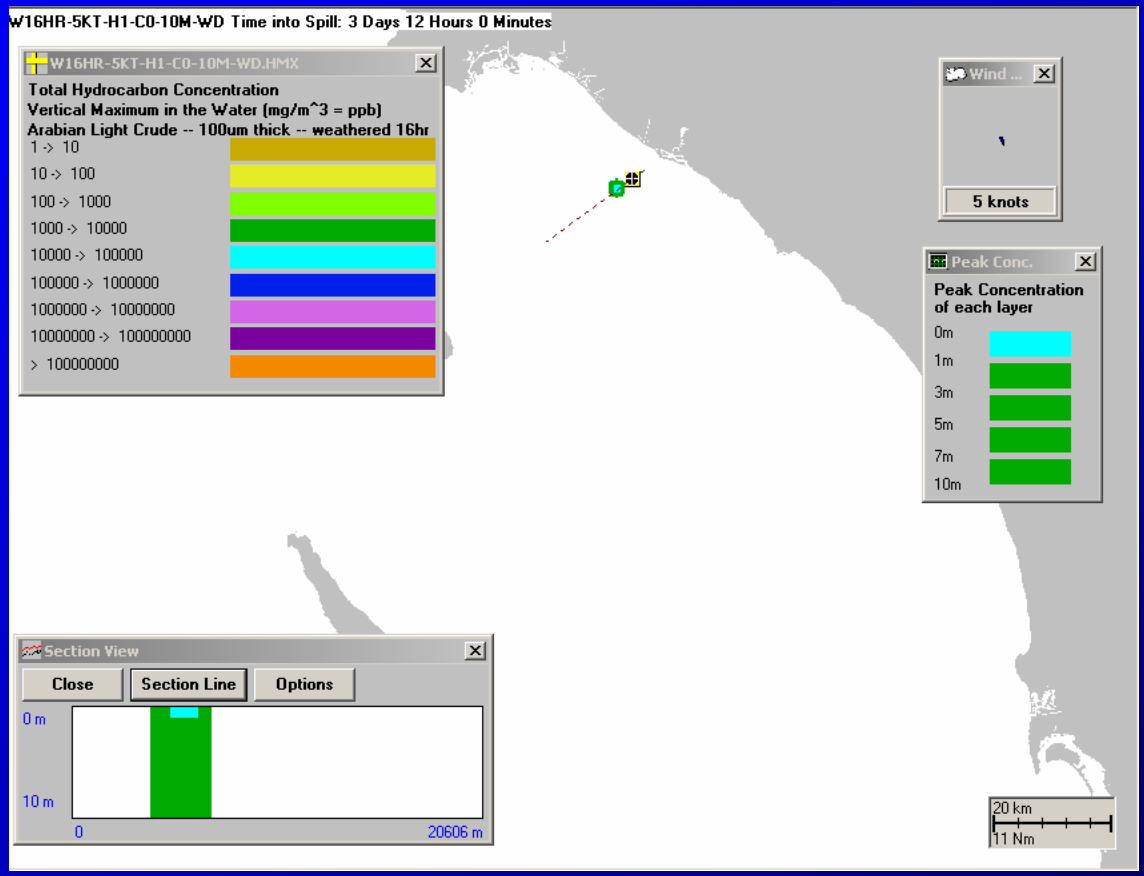
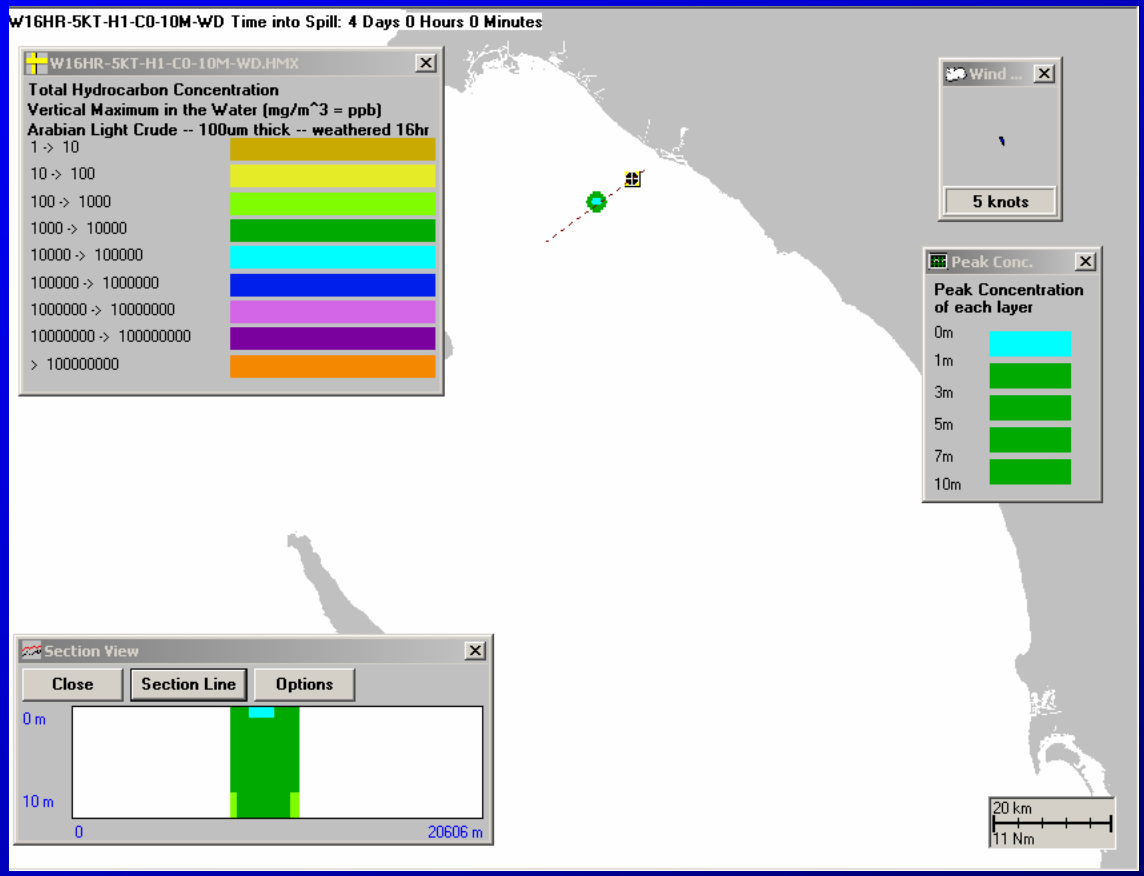
Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 60 hrs after dispersant application



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 72 hrs after dispersant application



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 84 hrs after dispersant application



Wind from NNW 5 kts; Currents: 0 kt;
Dispersant: at 16 hrs; Turbulent mixing to 10m deep;
Subsurface Oil Droplet Concentrations: 96 hrs after dispersant application