Field Verification of Oil Fate & Transport Modeling and Linking CODAR Observation System Data with Model Predictions

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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Objectives

This CRRC project was undertaken to utilize the release and surface vessel/aircraft tracking of fluorescein dye and subsurface drogues to:

- **measure small-scale transport processes,**
- **develop/validate oil-spill model algorithms for application to subsurface dispersion modeling of naturally-entrained and chemically-dispersed oil, and**
- **validate sampling protocols in the CA OSPR Dispersed Oil Monitoring Plan (DOMP).**

Model development and field validation are essential to the evaluation of environmental trade-offs justified in the decision to use dispersants under certain circumstances, with direct applicability to:

- spill response/dispersant use decision making,
- net environmental benefit analysis,
- Natural Resource Damage Assessments after an oil spill, and
- educating the spill community and public.

Project Implementation:
Data are available from seven cruises (four funded by CRRC and three by CA OSPR)

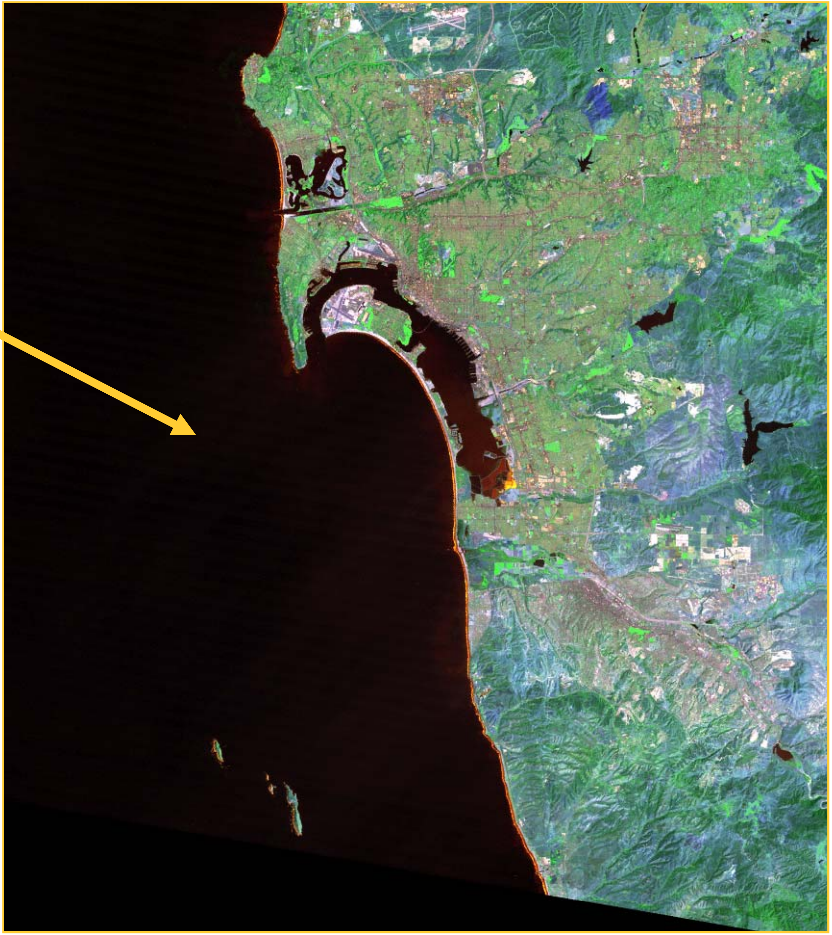
- Dye dispersal vessel: 32’ work boat operated by Marine Spill Response Corporation (MSRC)
- Plume sampling vessel: 22’ or 26’ work boat operated by the USCG and/or Scripps Institution of Oceanography (SIO)
  - USCG SMART system operated by Pacific Strike Team
  - SIO Scientists with CTD + fluorometer
- GPS tracked drifter array operated by SIO and UCSB
- Surface Current Maps created by HF radar
  - Integrated Ocean Observatory
- CA OSPR aircraft overflights for aerial imaging
- SIMAP modeling of plume dispersion and advection

NEPA-Permitted Cruise Dates

Nov. 8, 2005, March 21 & 22, 2006 (CA OSPR)
June 21 & 22, 2006, Nov. 1 & 2, 2006 (CRRC)

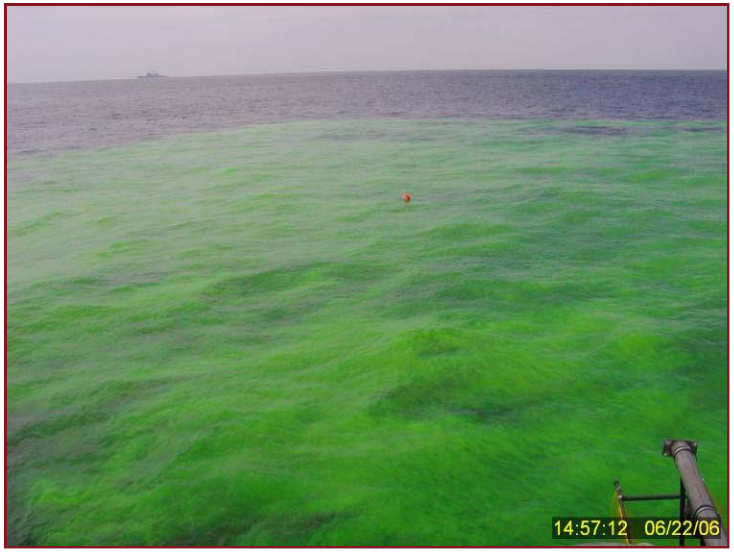
Dye release site:
32° 37' N
117° 17' W

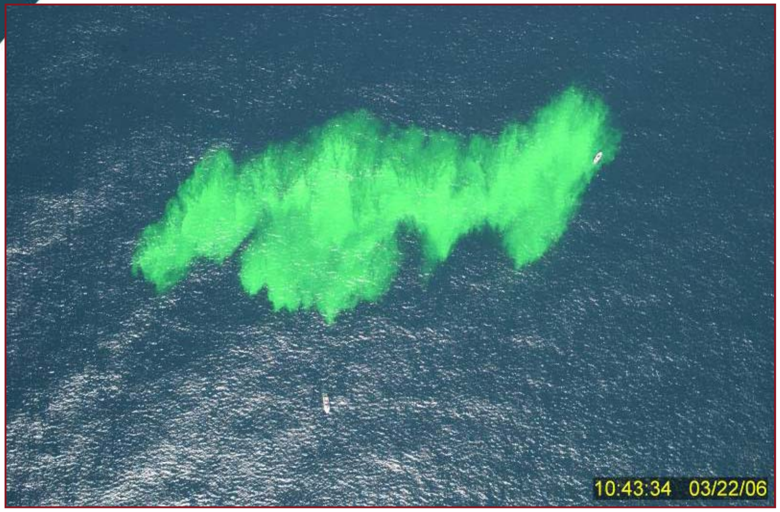
Site selected to be over 3 nmi from shore



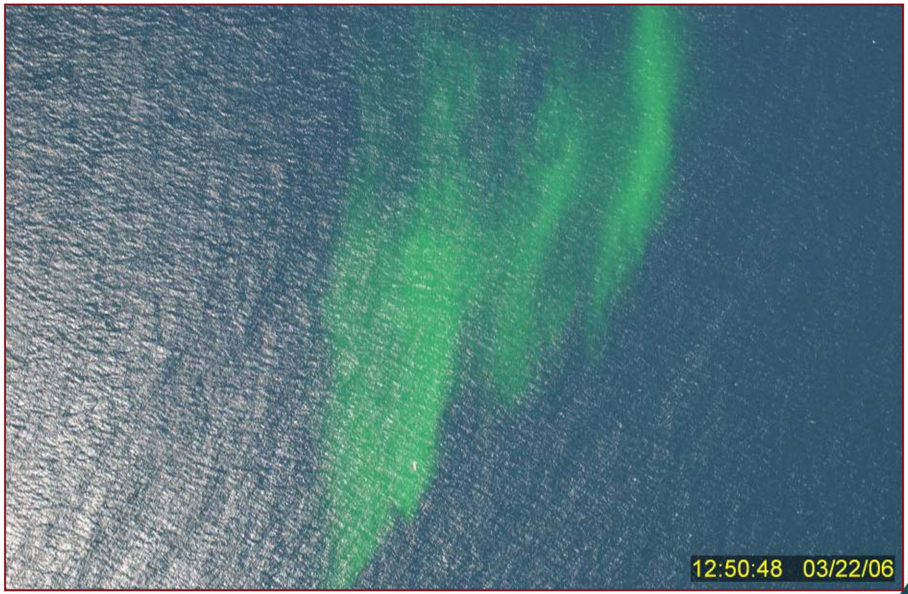
Instrument Calibration and Cruise Preparations

Dye and GPS drogue deployment from the MSRC *Response 2*





Plume dispersed as function of time (~2 hrs).



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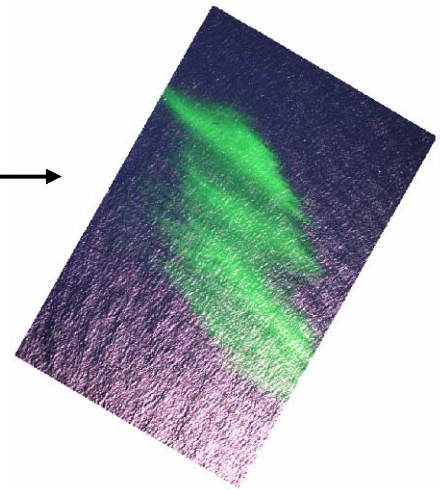
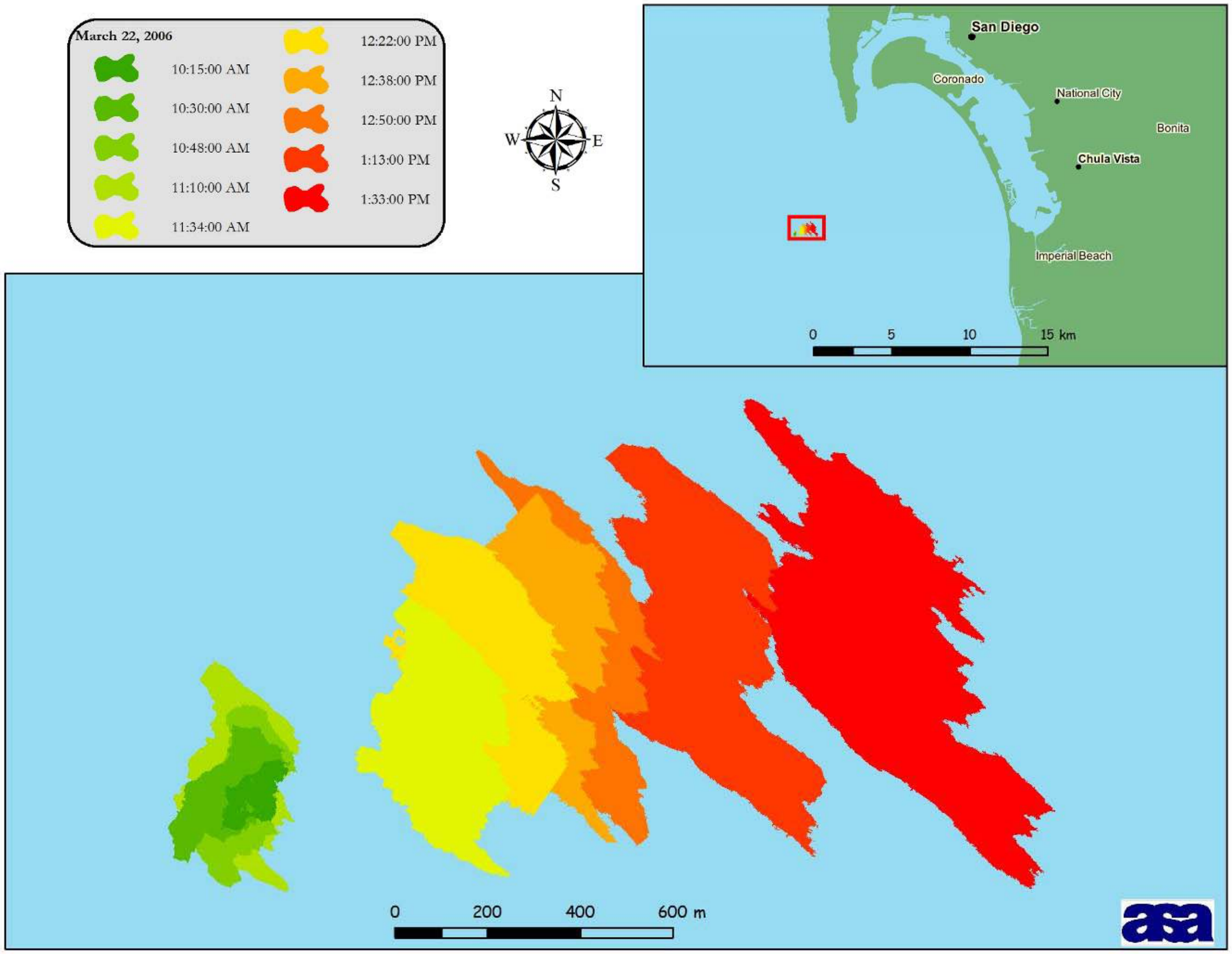
Aerial Photograph Processing Steps

Original image | Georeferenced Image | Final Shape file





Locations of dye over time as interpreted from aerial photographs.

In plume sampling conducted by SIO and USCG Strike Team with SMART system.

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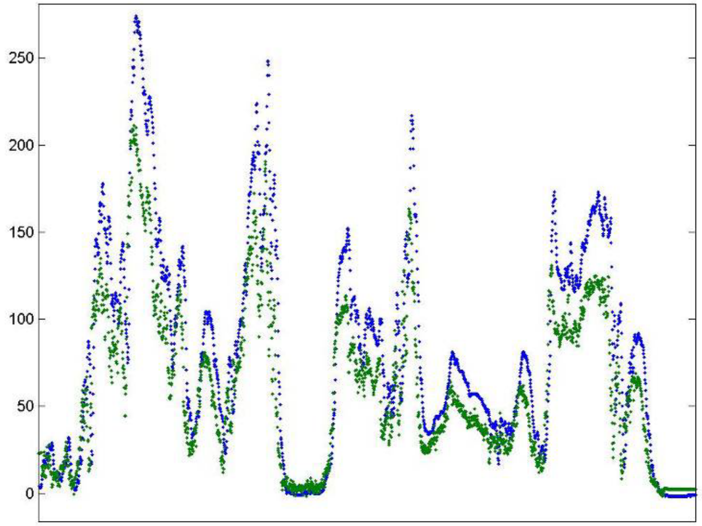
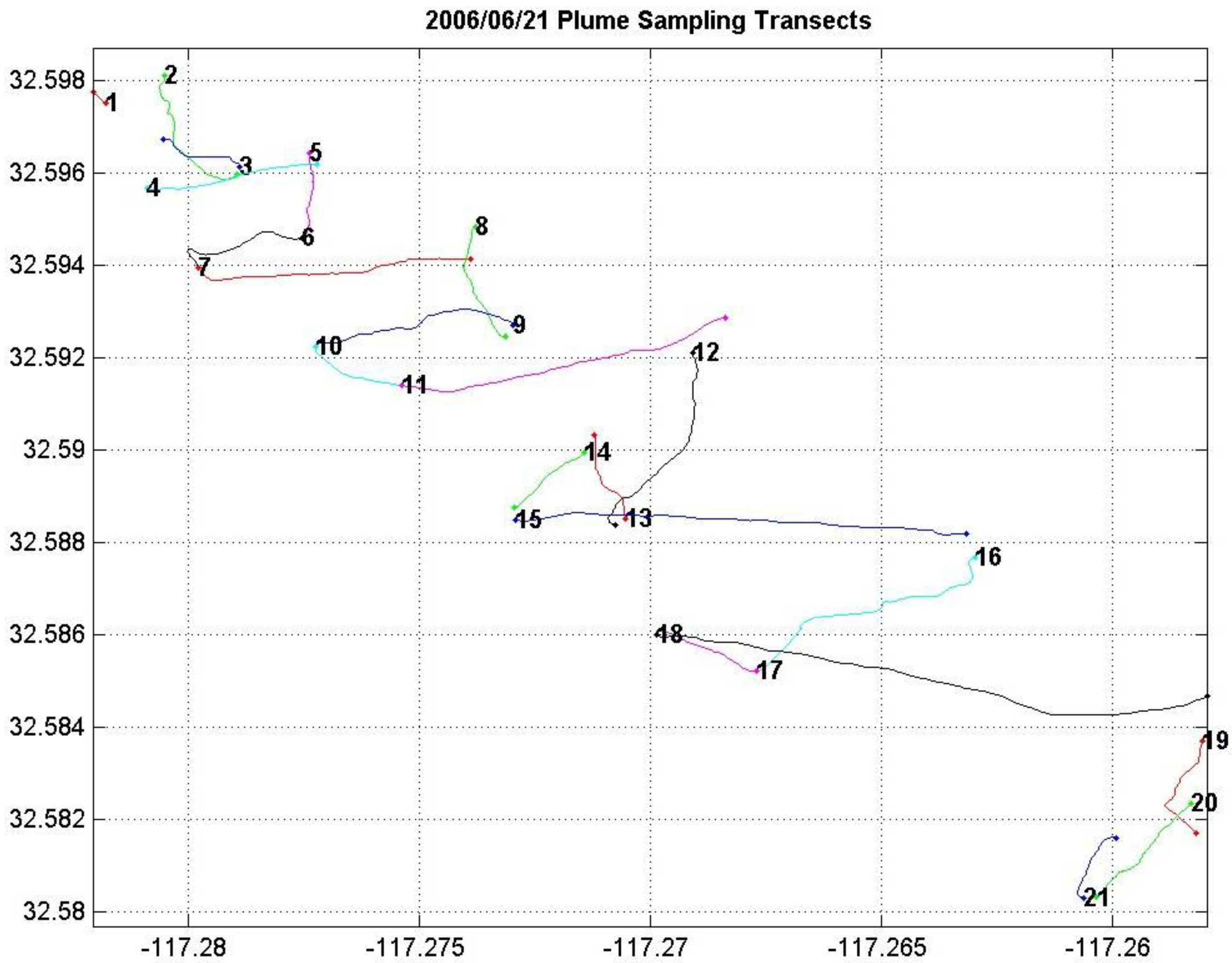
Scripps designed rapid profiling fluorometer system

Wet Labs fluorometer vs. USCG SMART readout during cross-plume transect





2006/06/21 Plume Sampling Transects
32.598
32.596
32.594
32.592
32.59
32.588
32.586
32.584
32.582
32.58
-117.28
-117.275
-117.27
-117.265
-117.26
1
2
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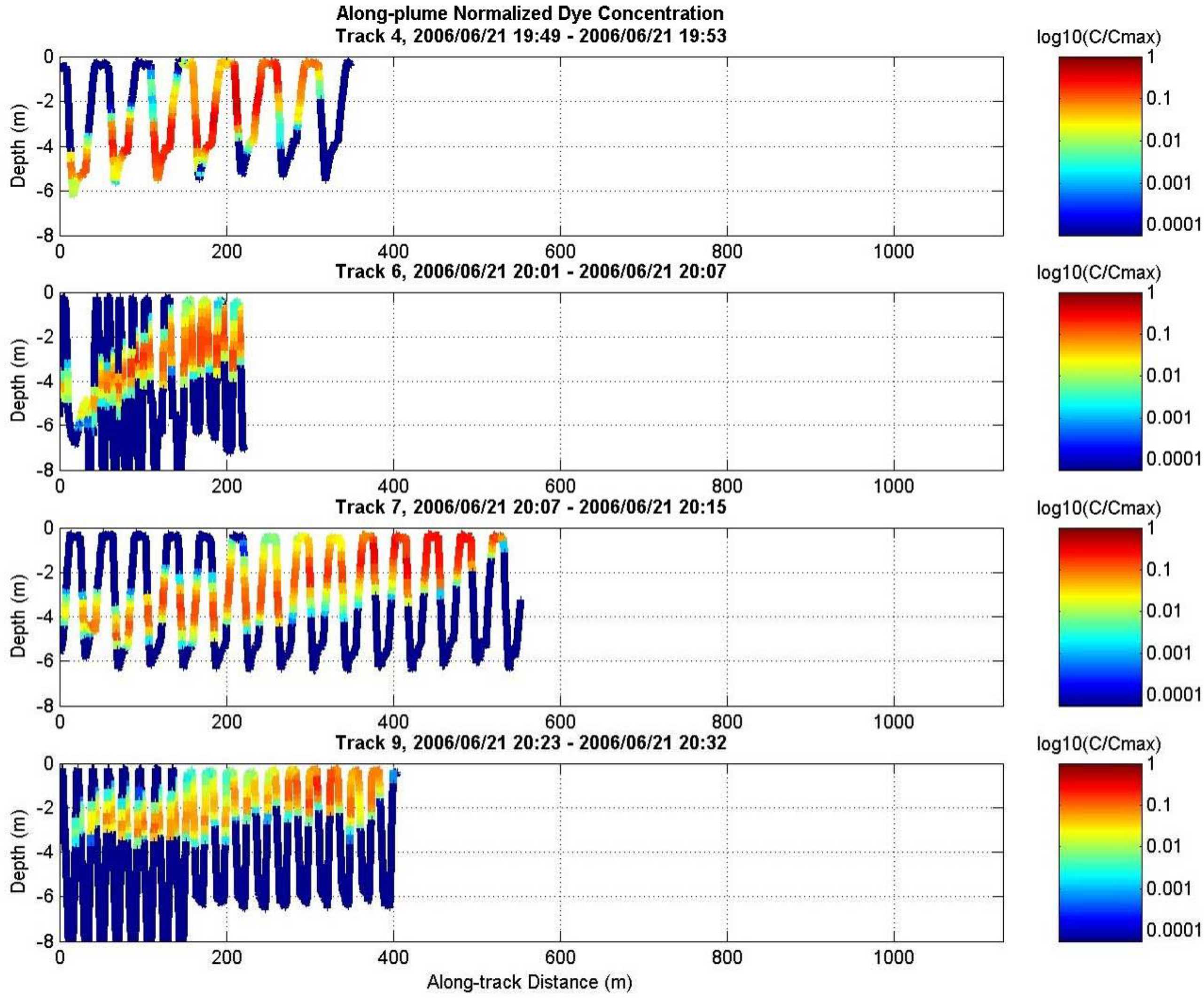

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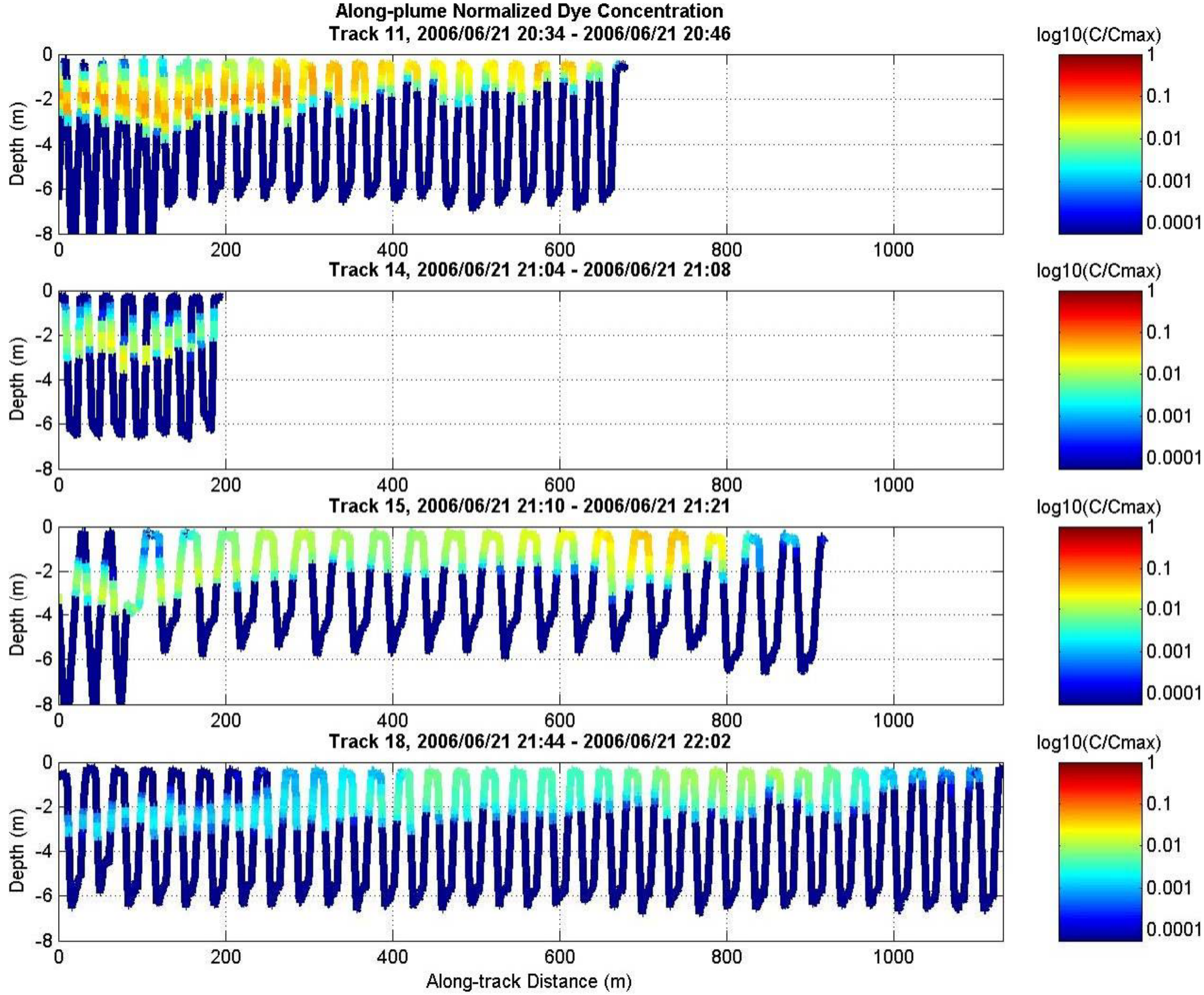
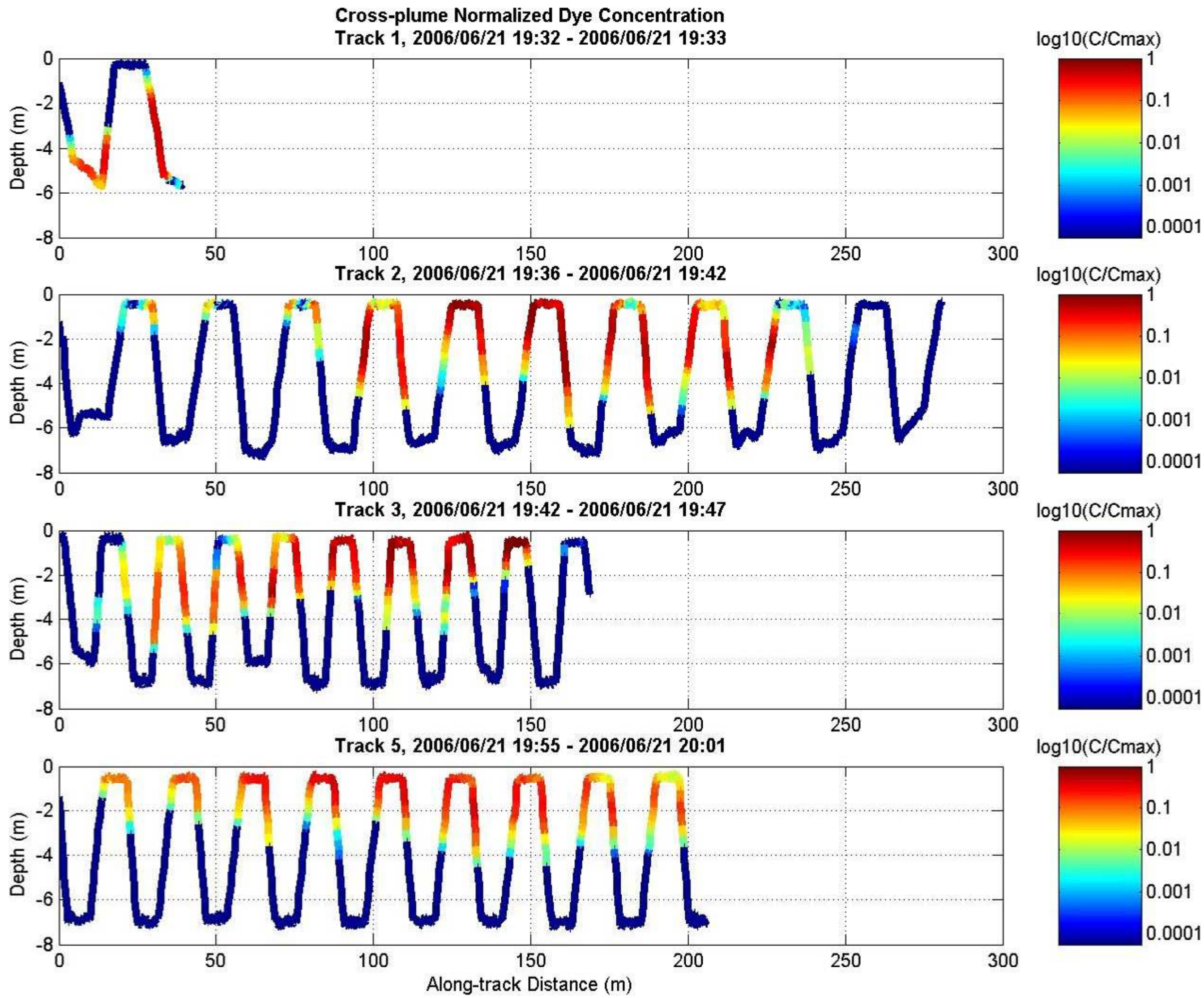


Along-plume Normalized Dye Concentration
Track 11, 2006/06/21 20:34 - 2006/06/21 20:46
Track 14, 2006/06/21 21:04 - 2006/06/21 21:08
Track 15, 2006/06/21 21:10 - 2006/06/21 21:21
Track 18, 2006/06/21 21:44 - 2006/06/21 22:02
Depth (m)
Along-track Distance (m)
log10(C/Cmax)
1
0.1
0.01
0.001
0.0001



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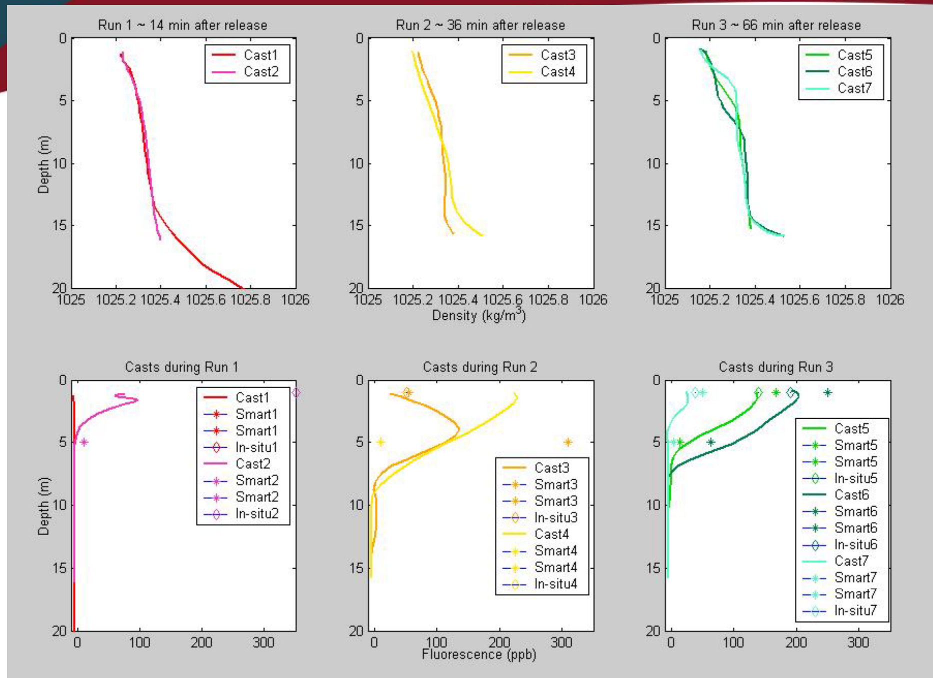
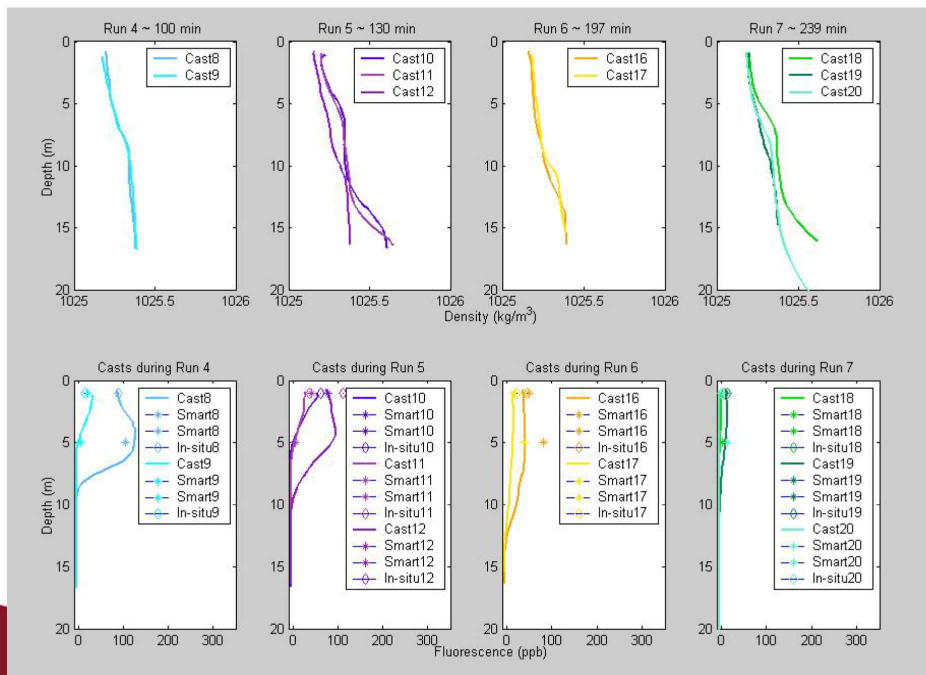
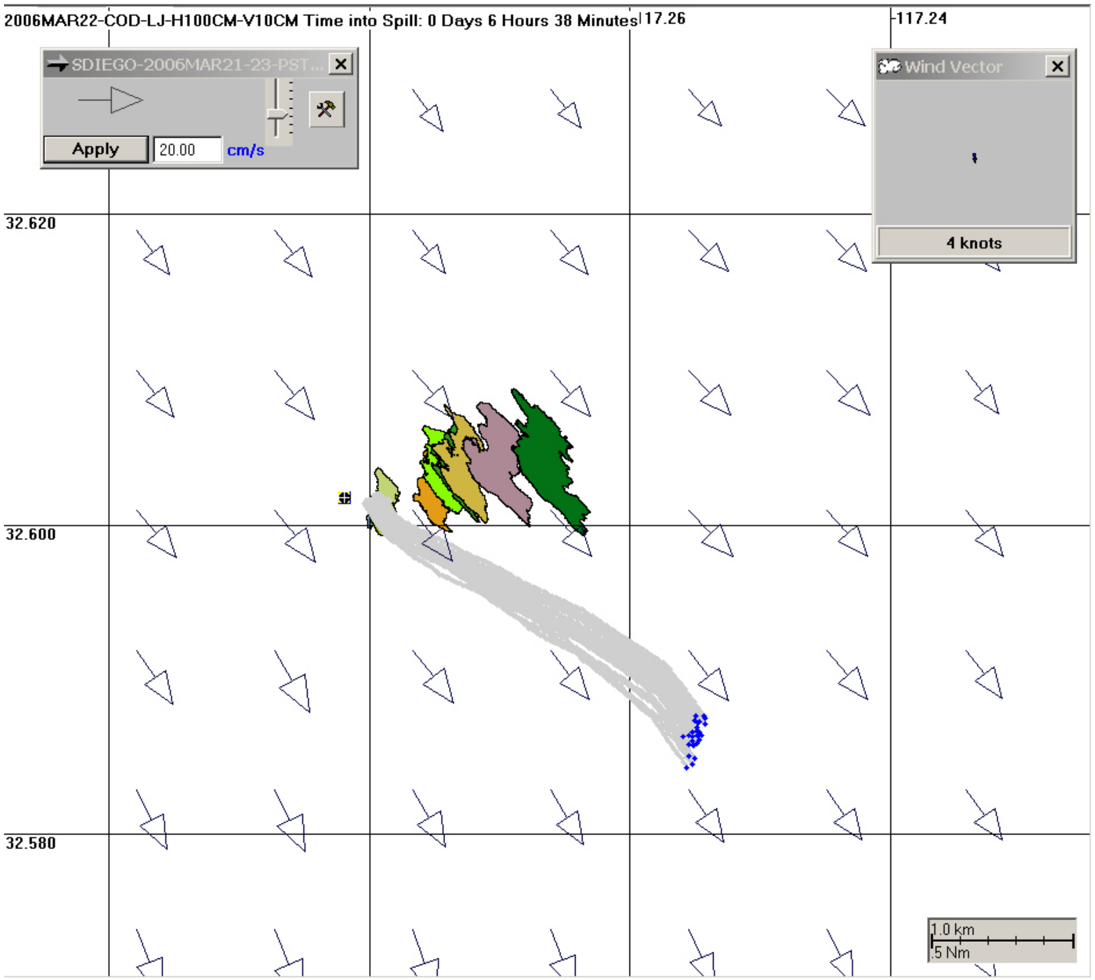




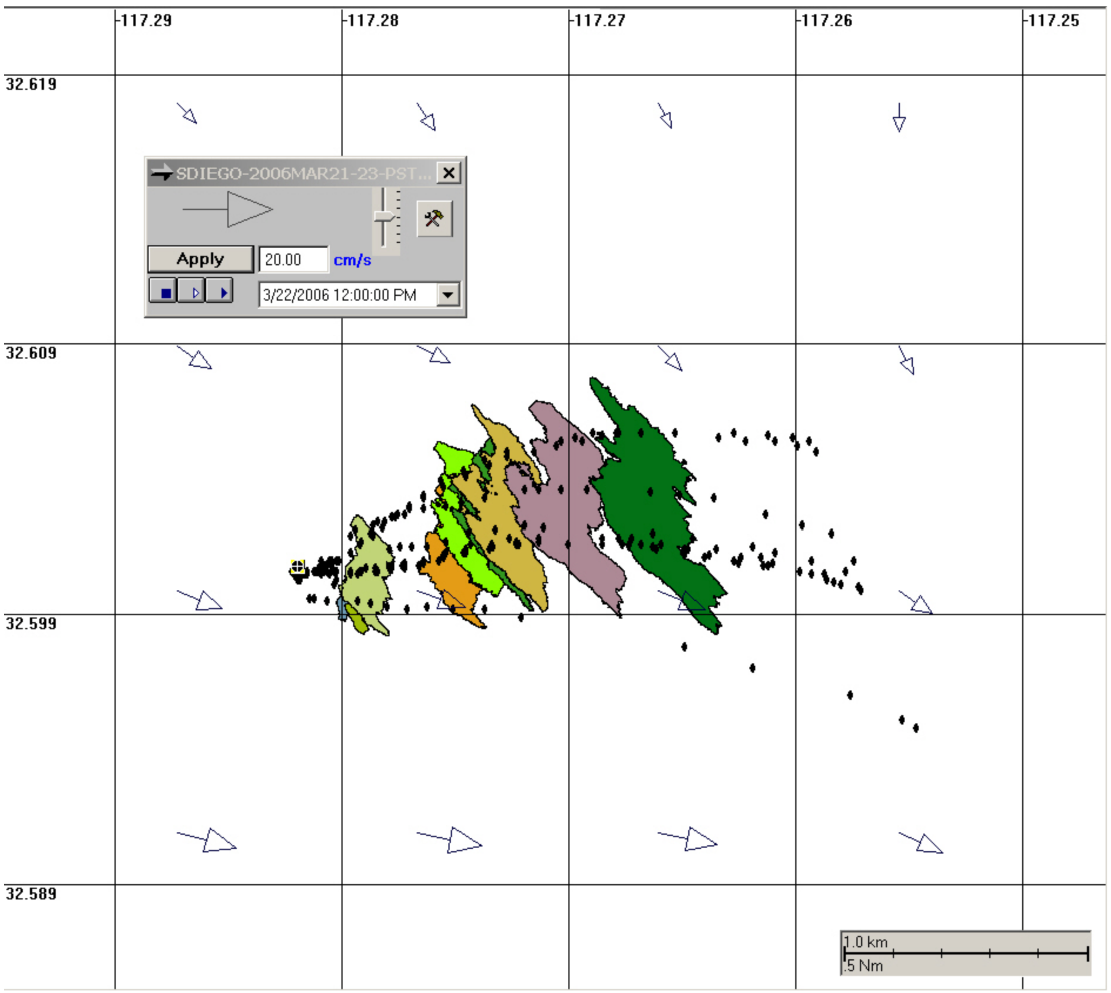
Density (top) and dye concentrations (bottom) in ppb measured by CTD and fluorometers on March 22, 2006. The series of figures illustrates the mixing and decay of the plume as a function of time and the agreement between measurements using various sensors.

CODAR Surface Currents vs. Subsurface Dye



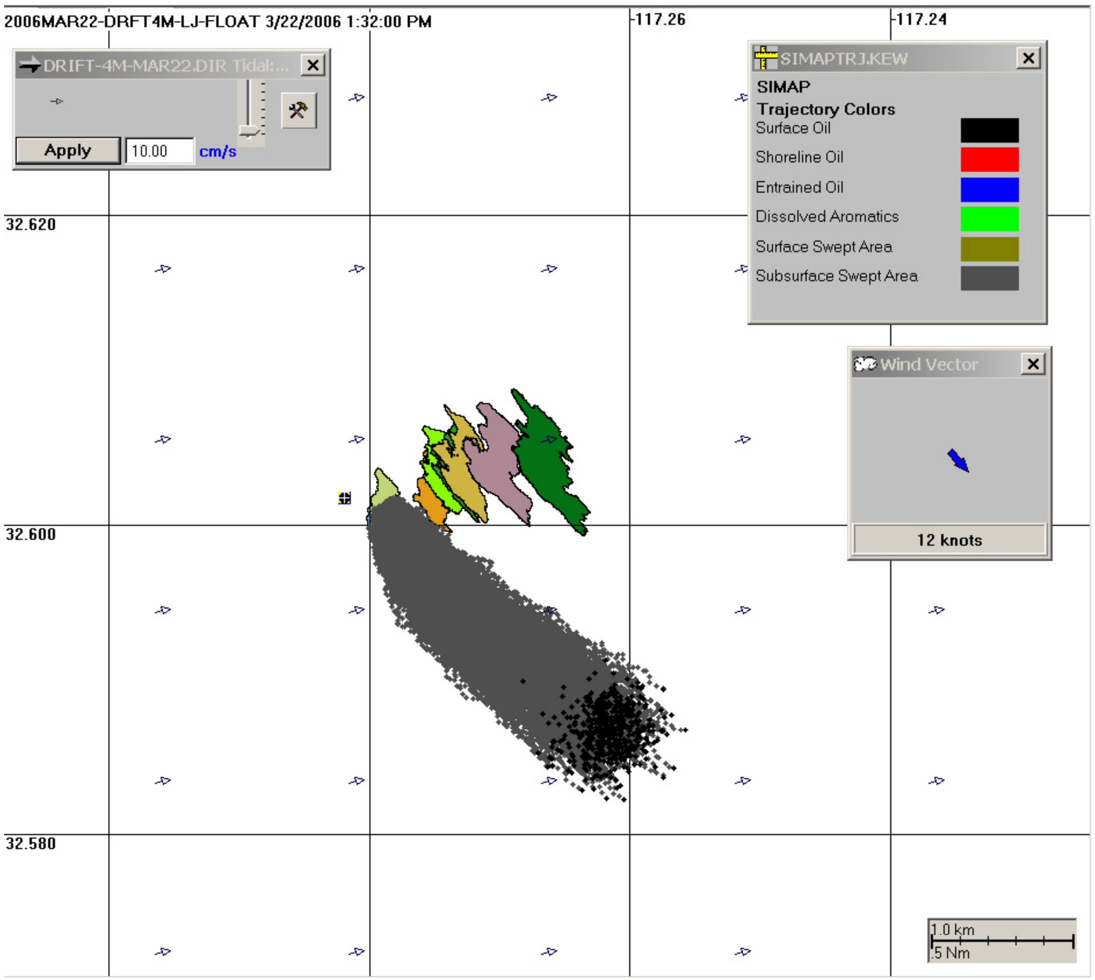
CODAR surface current data (6.5 hrs after release) and indicated trajectory to the ESE, south of the observed subsurface dye movements (which were to the east).

CODAR Surface Currents vs. Subsurface Dye



GPS drifter movements (to the east, indicated by black diamonds) during the March 22 experiment, overlaid on observed dye plume tracks and CODAR vectors 2 hrs after release.

Surface Oil Trajectory vs. CODAR



SIMAP simulation of floating oil trajectory (March 22), using drifter-measured currents and wind data from the La Jolla station LJPC1.

Modeling Subsurface Concentrations

- Oil spill models use Lagrangian element approach
- Movement of mass vector sum of:
  - Advection = tidal and oceanic currents, measured by
    - CODAR-generated surface current field
    - Drifters
  - Wind-driven wave transport = Stokes Drift
    - Leeway drift factor (2-4% of wind speed) and angle to right (N)
    - Model (Youssef and Spaulding, 1993, 1994) includes vertical shear
  - Small scale mixing = diffusion
    - Subscale movements not measured in advective field:
      - Eddies
      - Langmuir cells
      - Convection caused by cooling at surface
    - 3d: horizontal and vertical diffusivities
    - Most influential to concentration estimates, yet often most uncertain input to model

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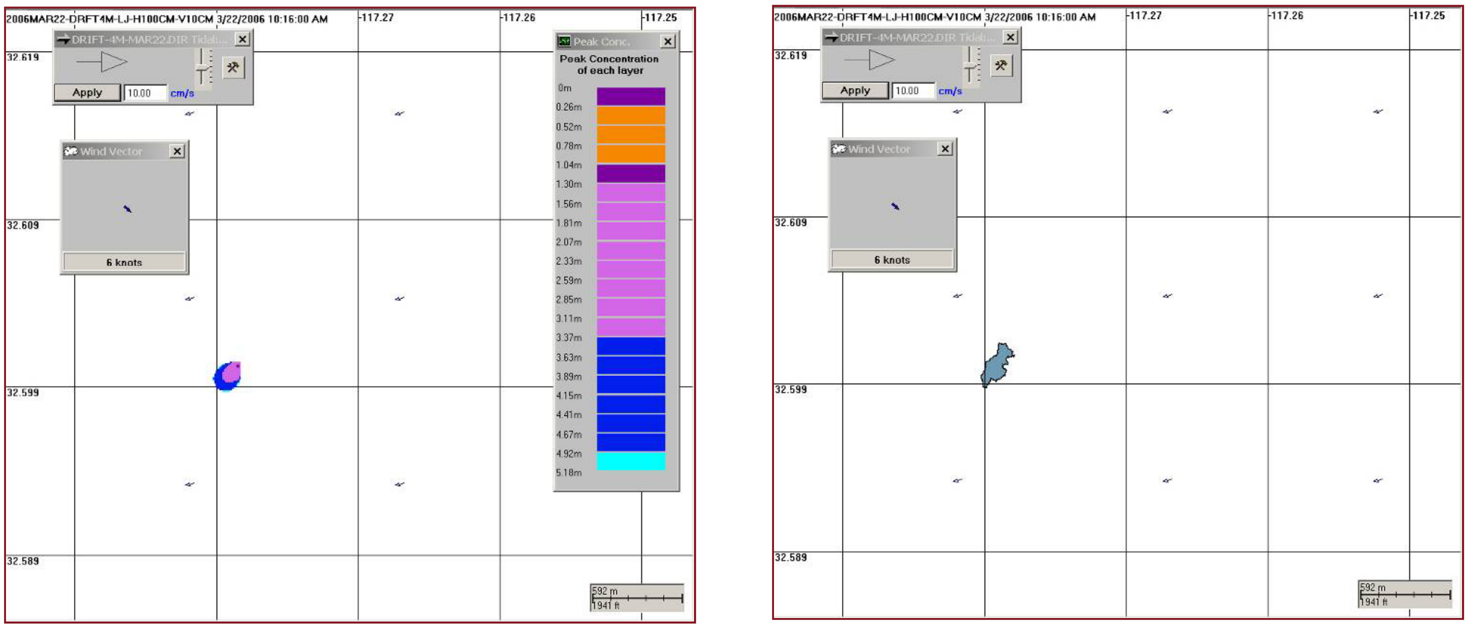
Modeled and Observed Subsurface Plume Trajectories over Time



Simulation of dye plume (left), using drifter-measured currents and wind data from the La Jolla station LJPC1 (11 min after the release) and measured dye location from aerial photographs (right).

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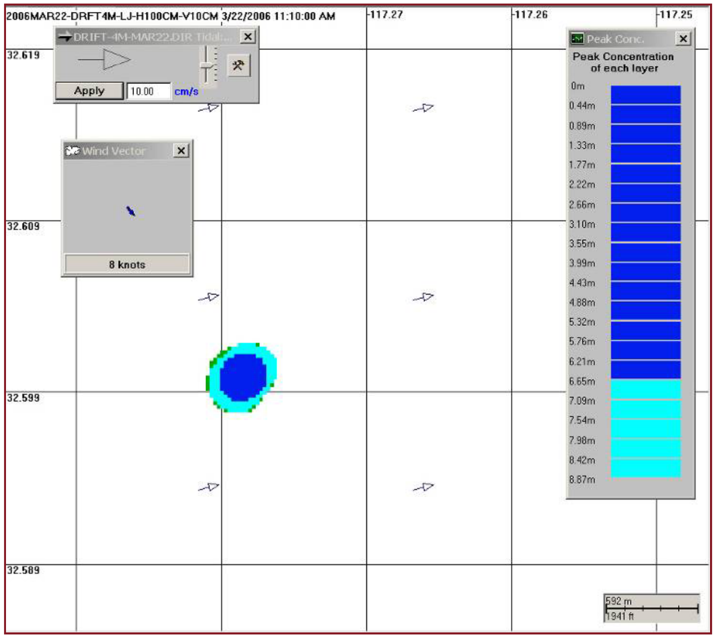
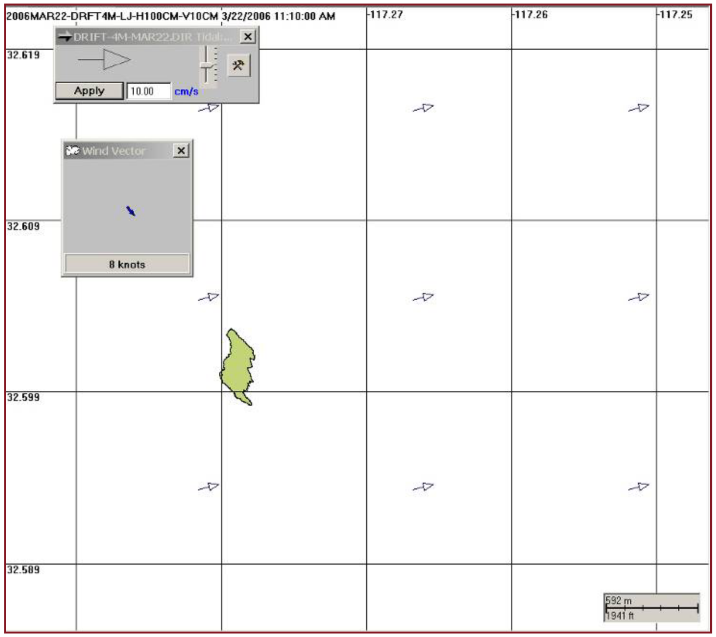
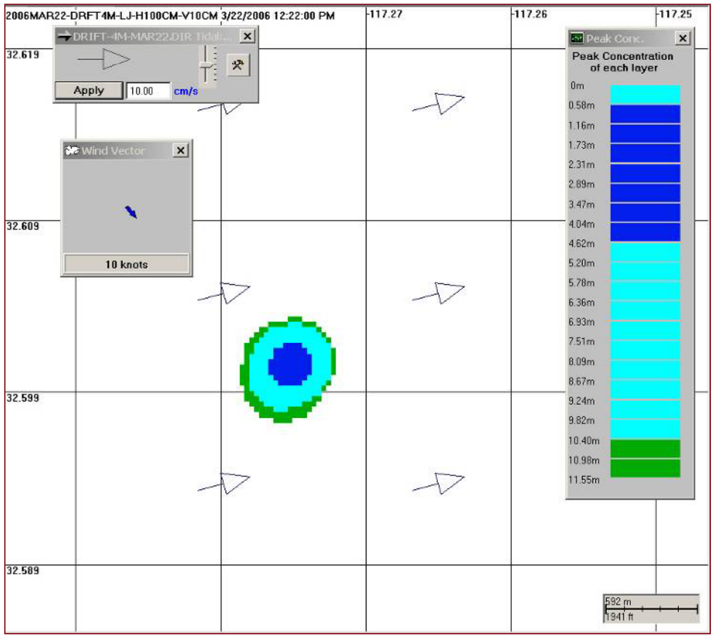
Modeled and Observed Subsurface Plume Trajectories over Time

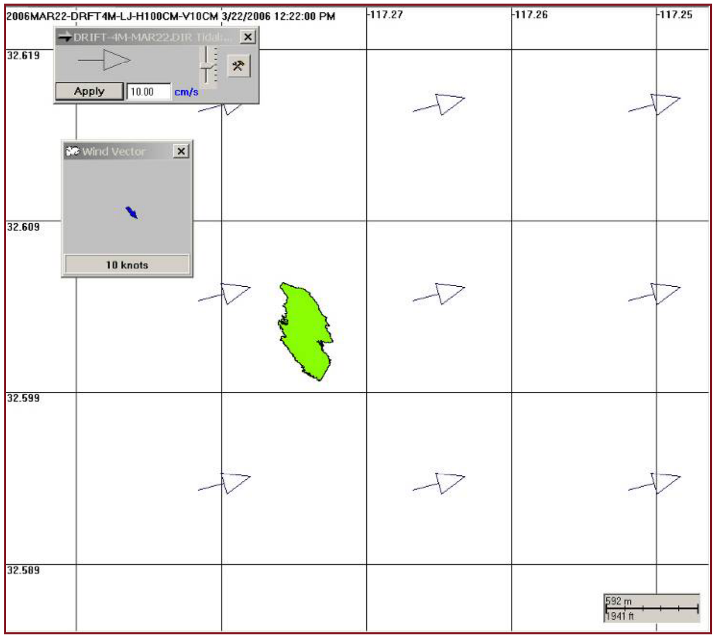




Simulation of dye plume (left), using drifter-measured currents and wind data from the La Jolla station LJPC1 (65 min after the release) and measured dye location from aerial photographs (right).

Modeled and Observed Subsurface Plume Trajectories over Time





Simulation of dye plume (left), using drifter-measured currents and wind data from the La Jolla station LJPC1 (2.3 hours after the release) and measured dye location from aerial photographs (right).

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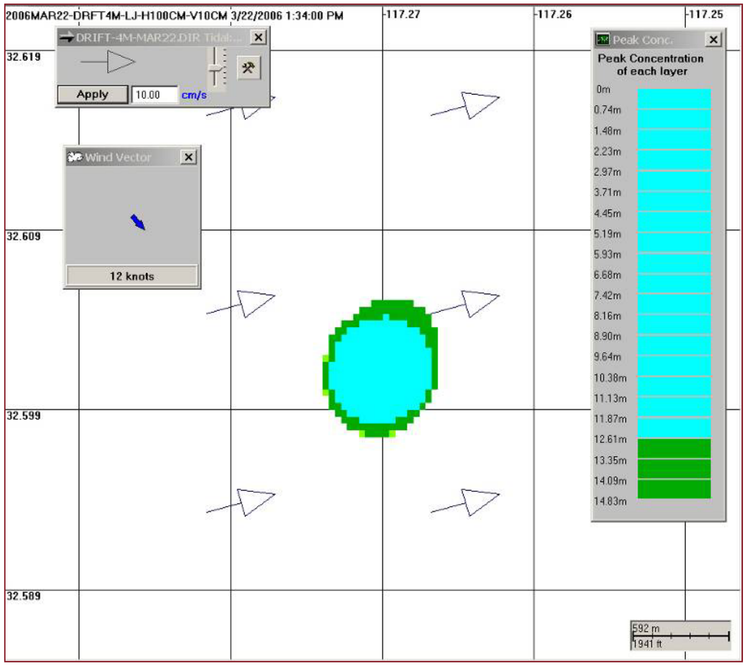
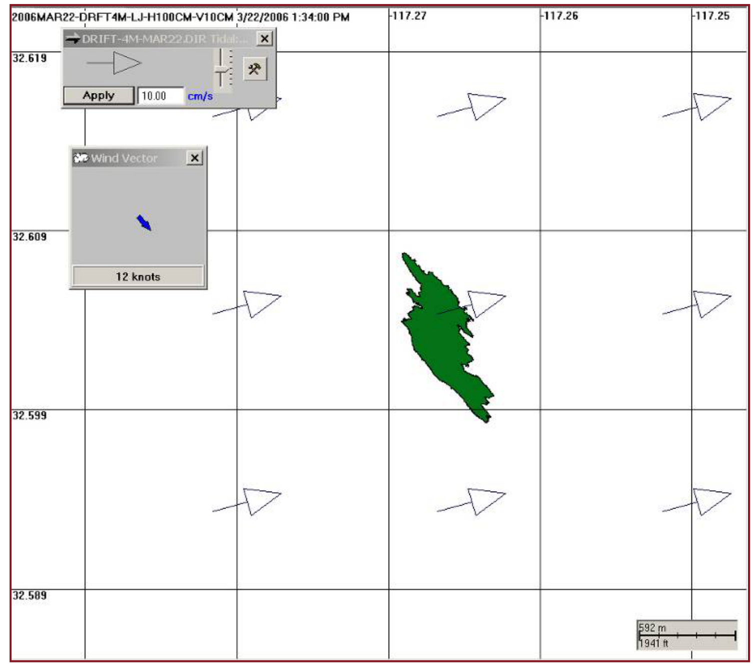
Modeled and Observed Subsurface Plume Trajectories over Time





Simulation of dye plume (left), using drifter-measured currents and wind data from the La Jolla station LJPC1 (3.5 hours after the release) and measured dye location from aerial photographs (right).

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Preliminary Findings from Modeling Effort

- The best estimate of the horizontal turbulent diffusion coefficient was 100-1000 cm^2/sec. The higher value of 1000 cm^2/sec applied to the highest wind condition, but the range of wind conditions was not large and these experiments were all made in fairly low turbulence conditions.
- The best estimate of the vertical turbulent diffusion coefficient was 10 cm^2/sec. The modeled plume depths agreed with the observed dye concentration data using this value.

Preliminary Findings from Modeling Effort

- Using drifter-measured subsurface currents, the SIMAP predictions matched the observed dye plume movements very well.
- Model predictions using CODAR surface currents did not track the observed subsurface dye plume during the March 22, 2006 experiments.
- Additional data analysis and model development using the results from the other cruises are ongoing.

Preliminary Findings from Modeling Effort

- Improved predictive capability of subsurface oil plumes can be obtained using subsurface drifter observation data as input to oil spill models.
- Subsurface drifters will also be critical to successful water-column sampling of dispersed oil plumes over time as described in the CA DOMP.
- CODAR data appears to be predictive of the surface floating oil trajectory, useful for spill response training and response equipment placement.
- While the dissolved components of oil in subsurface plumes would be tracked most faithfully by drifters, resurfacing oil droplets likely would move along an intermediate path between the subsurface drifter and CODAR-predicted trajectory.

The CRRC-funded field experiments and algorithm development have provided:

- More accurate estimates of small-scale horizontal and vertical diffusivities important to modeling water-column transport and impact analysis;
- Evaluation of Coastal Ocean Dynamic Applications Radar (CODAR) for
    1. Providing surface current input data to NOAA and private-sector oil spill models (e.g., SIMAP); and
    2. Predicting movement of surface and subsurface oil (simulated by dye) through comparison to drogue movements and measured dye concentrations over three dimensions and time.
- Additional development of algorithms for quantifying small scale transport processes and the associated uncertainty that can be included in oil fates models.

Ultimately, modeling products will include:

- A fitting algorithm for estimating diffusion coefficients from conservative (dye) tracer concentrations (3d least squares fit to Gaussian shaped model).
- Algorithms for incorporating into oil transport models the magnitudes of:
  - non-wind-drift currents from water surface observational current data in rectilinear grid format,
  - wind (Stokes) drift, and
  - diffusion rates.
- Quantitative techniques for uncertainty analysis based on uncertainty in input data:
  - describe the range and uncertainty of each input parameter as a probability distribution (even, Gaussian, or skewed)
  - repeatedly sample the distribution for multiple model runs (Monte Carlo)
  - provide uncertainty estimates of predicted concentrations