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

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**California Office of Spill Prevention and Response**

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# Acknowledgement

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**www.crrc.unh.edu**

**and**

**The California Department of Fish & Game Office of Spill Prevention and Response**

# Objectives

**This CRRC/OSPR 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)

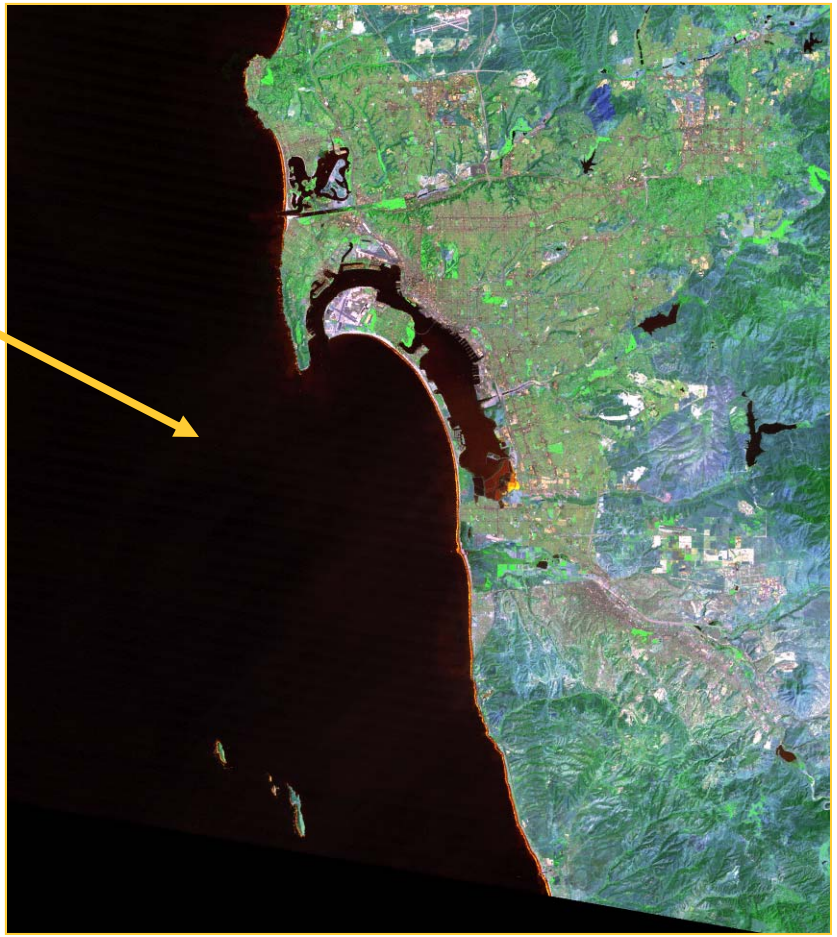
- Dye dispersal vessel: 32' work boat operated by Marine Spill Response Corporation (MSRC)
- Plume sampling vessel: 22' or 26' work boat operated by the USCG and/or Scripps Institution of Oceanography (SIO)
  - USCG SMART system operated by Pacific Strike Team
  - SIO Scientists with CTD + towed fluorometer
- 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

8 November 2005, 21 & 22 March 2006 (CA OSPR)
21 & 22 June 2006, 1 & 2 November 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

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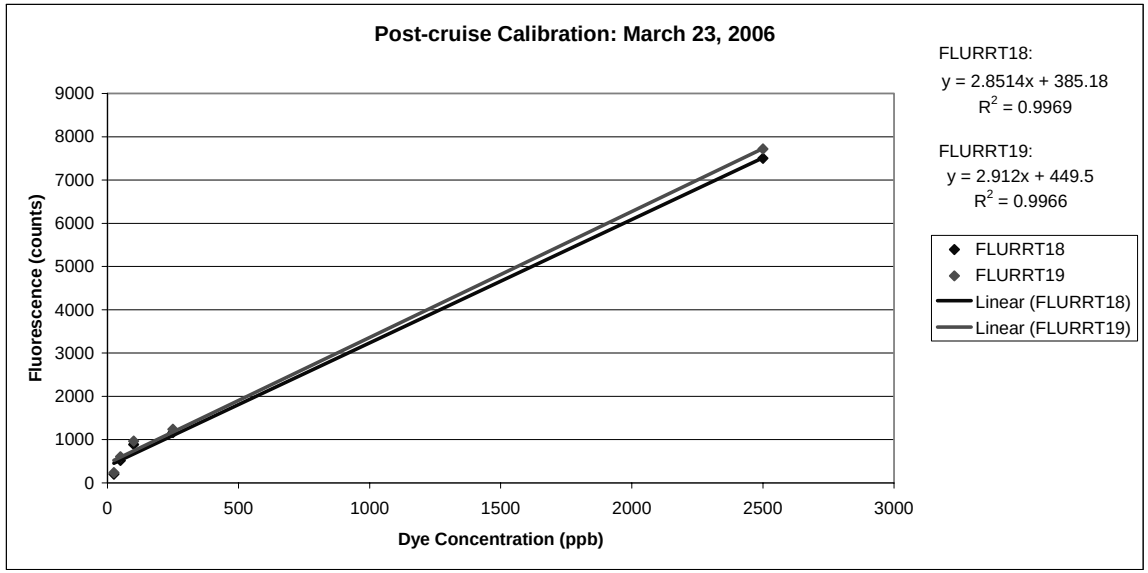
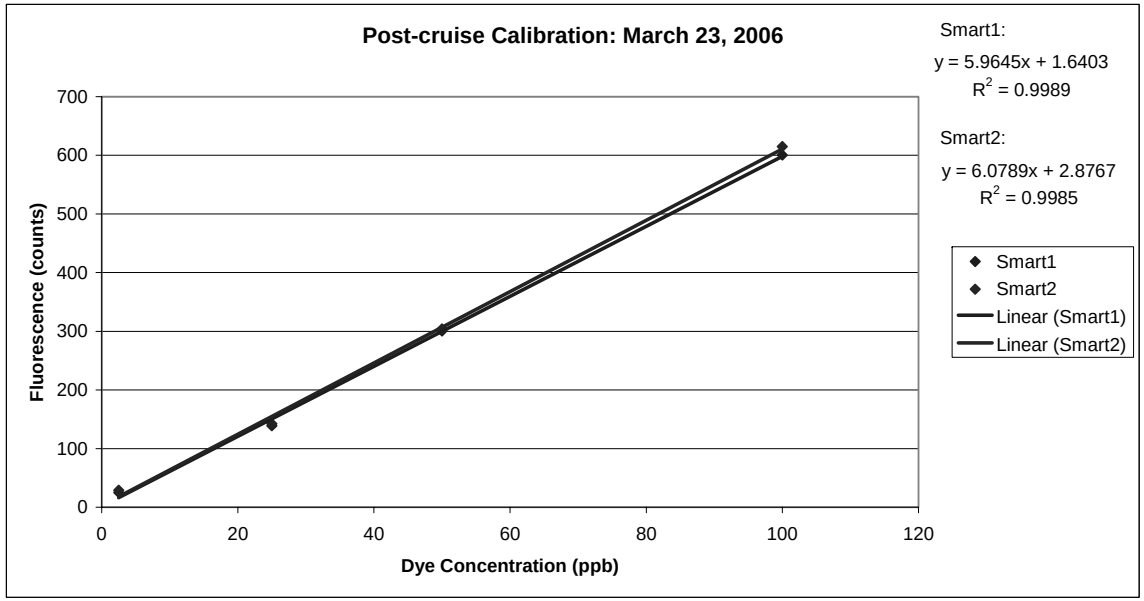
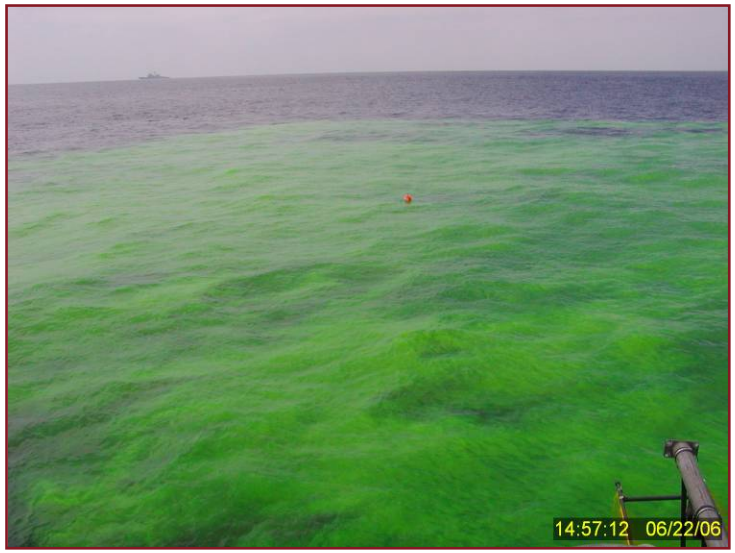
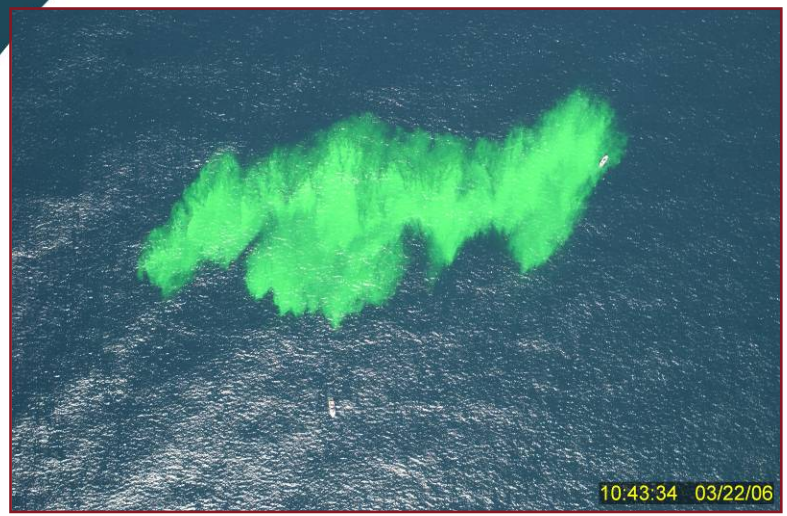
# USCG SMART Team Turner Designs A-10 and SIO *in situ* Wet Labs Fluorometer Calibration



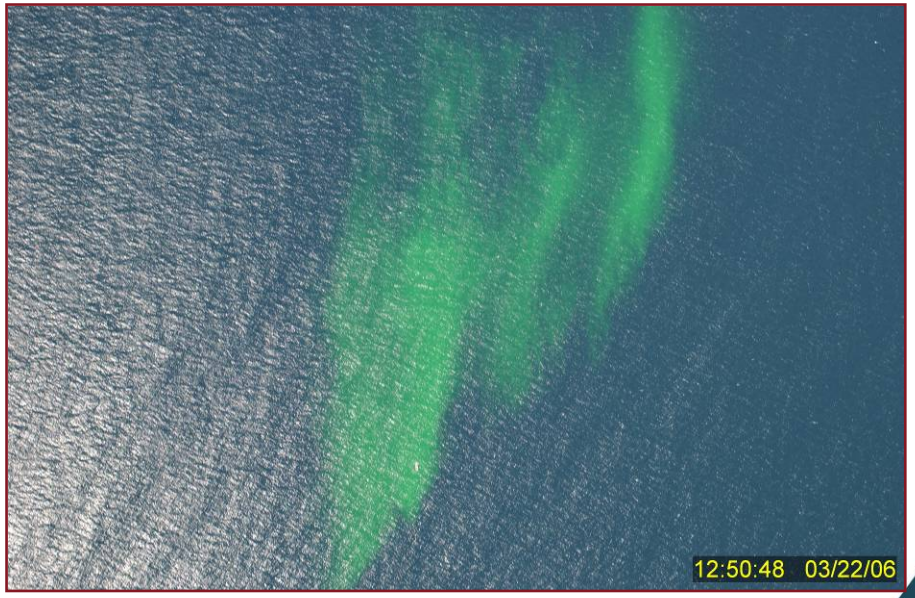



# Dye and GPS drogue deployment from the MSRC *Response 2*



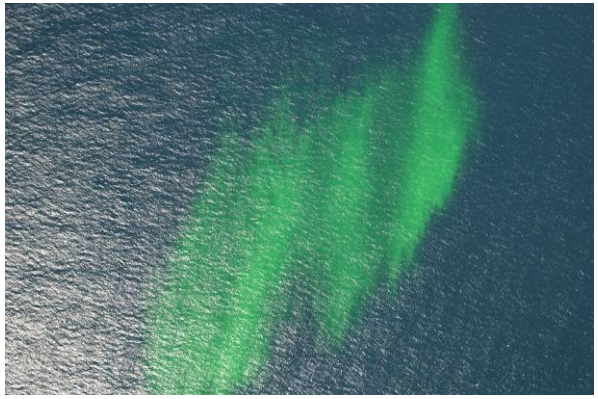



**Plume dispersed as function of time (~2 hrs).**

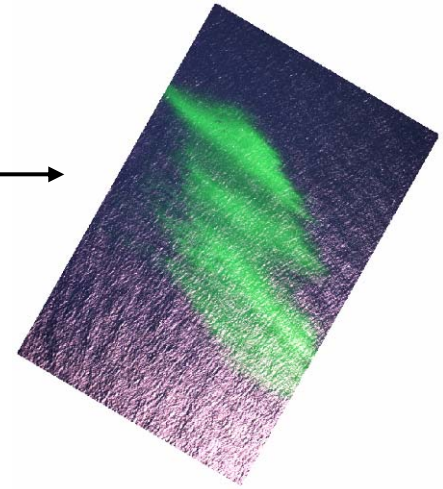


# Aerial Photograph Processing Steps

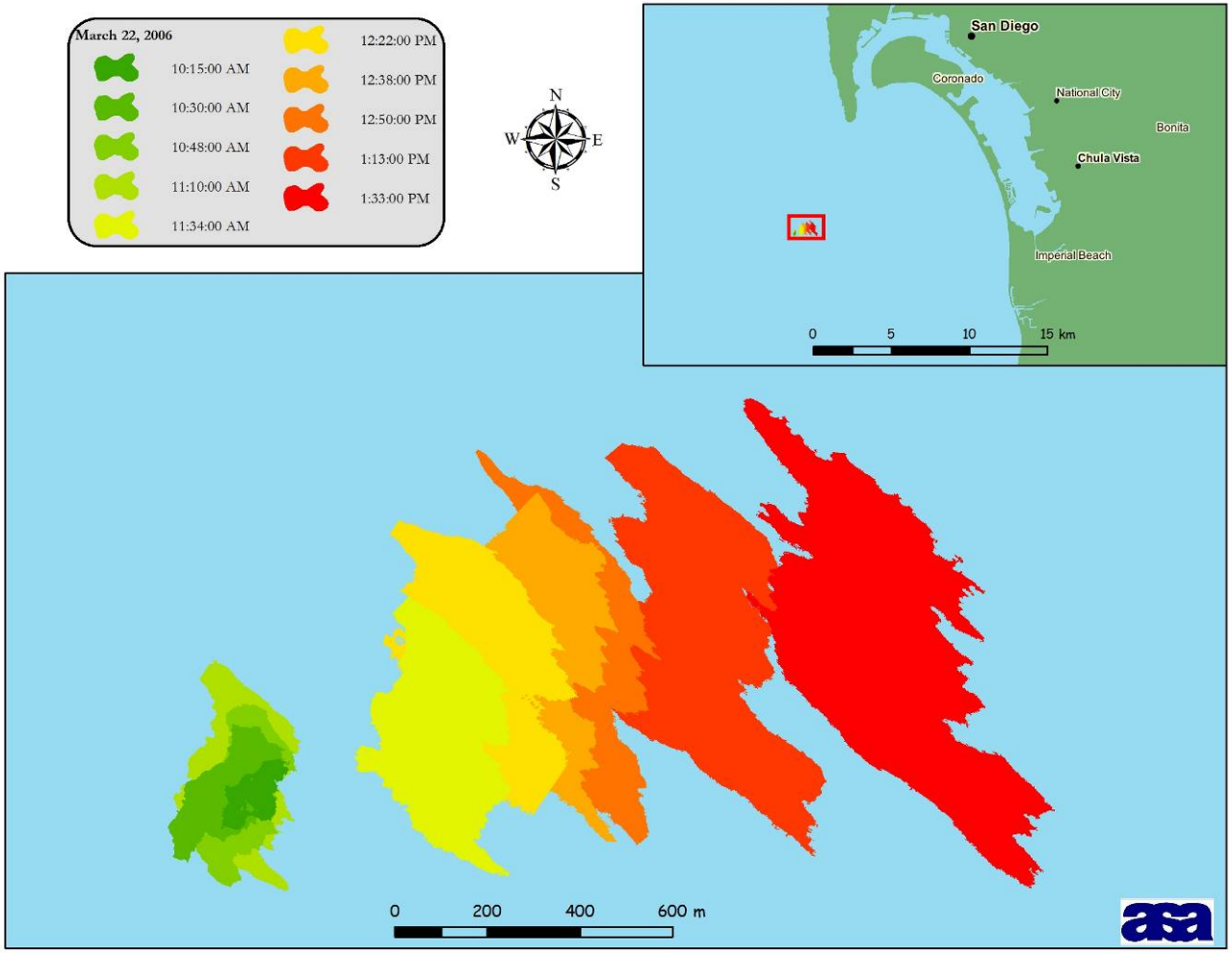
Original image



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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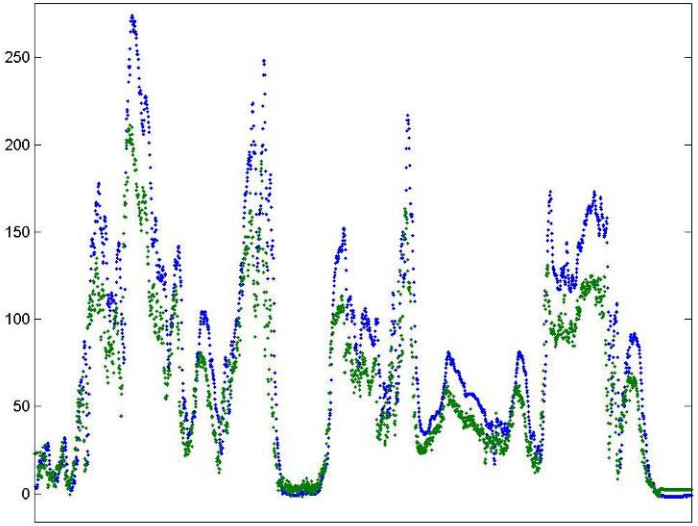
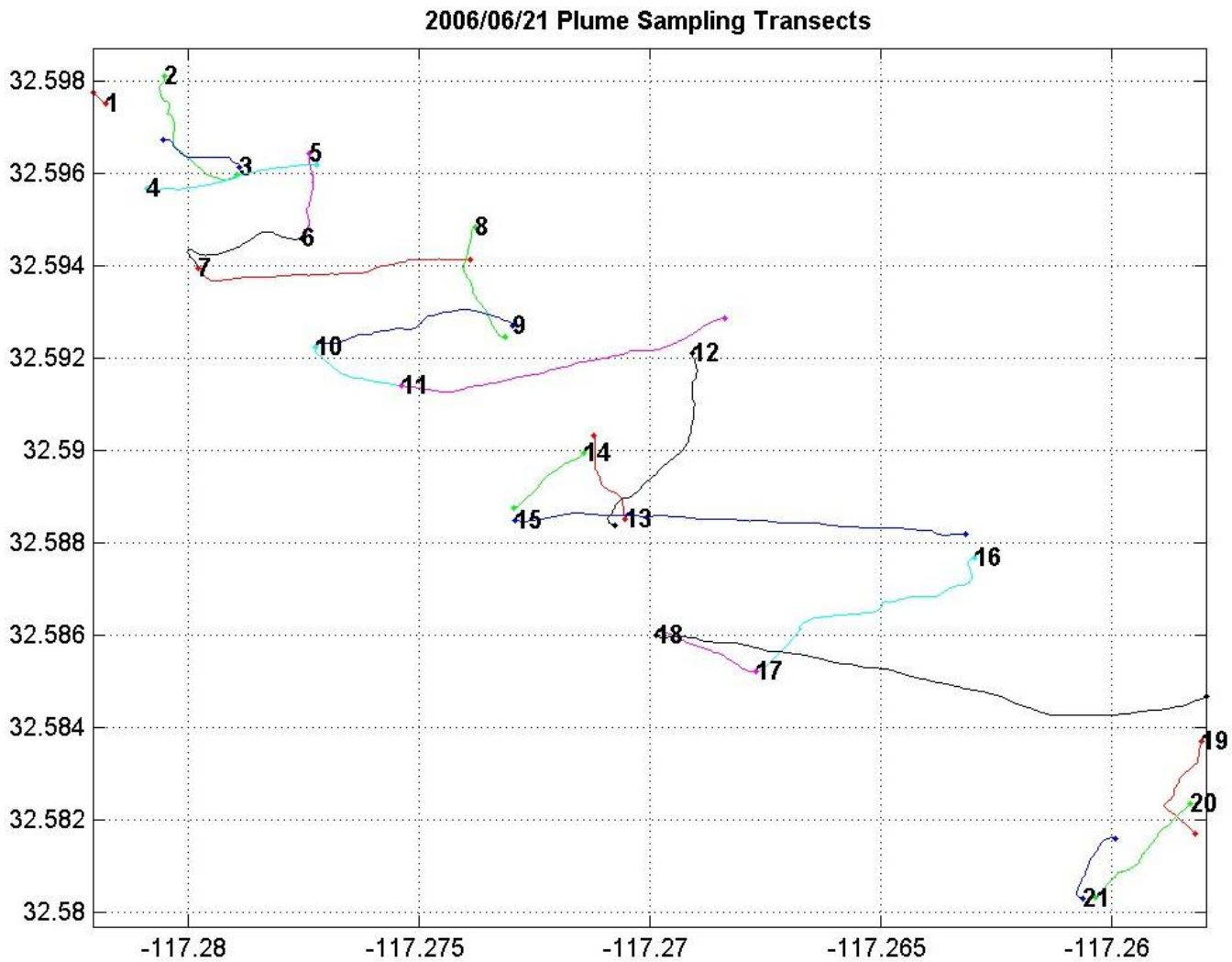
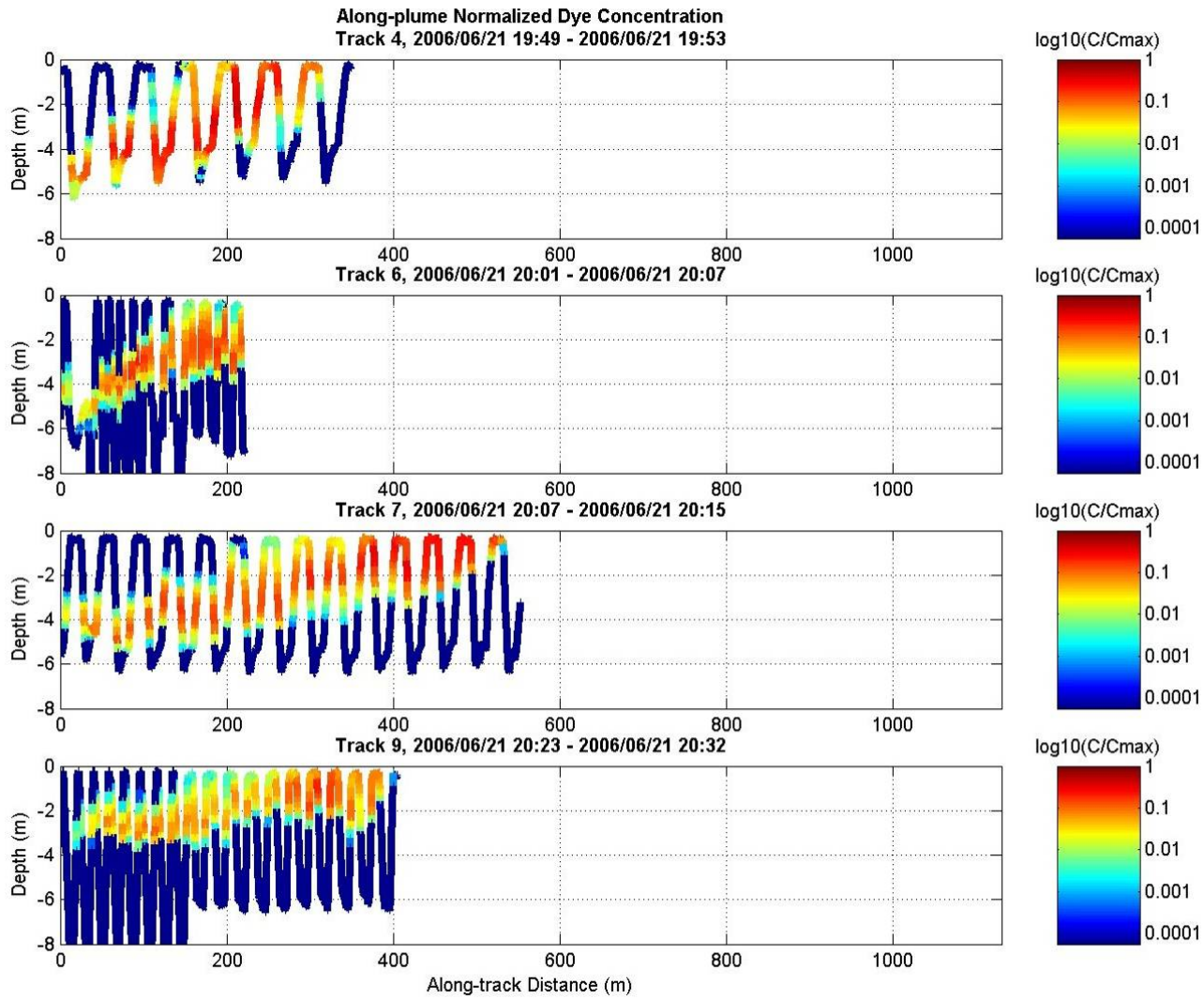
NOAA

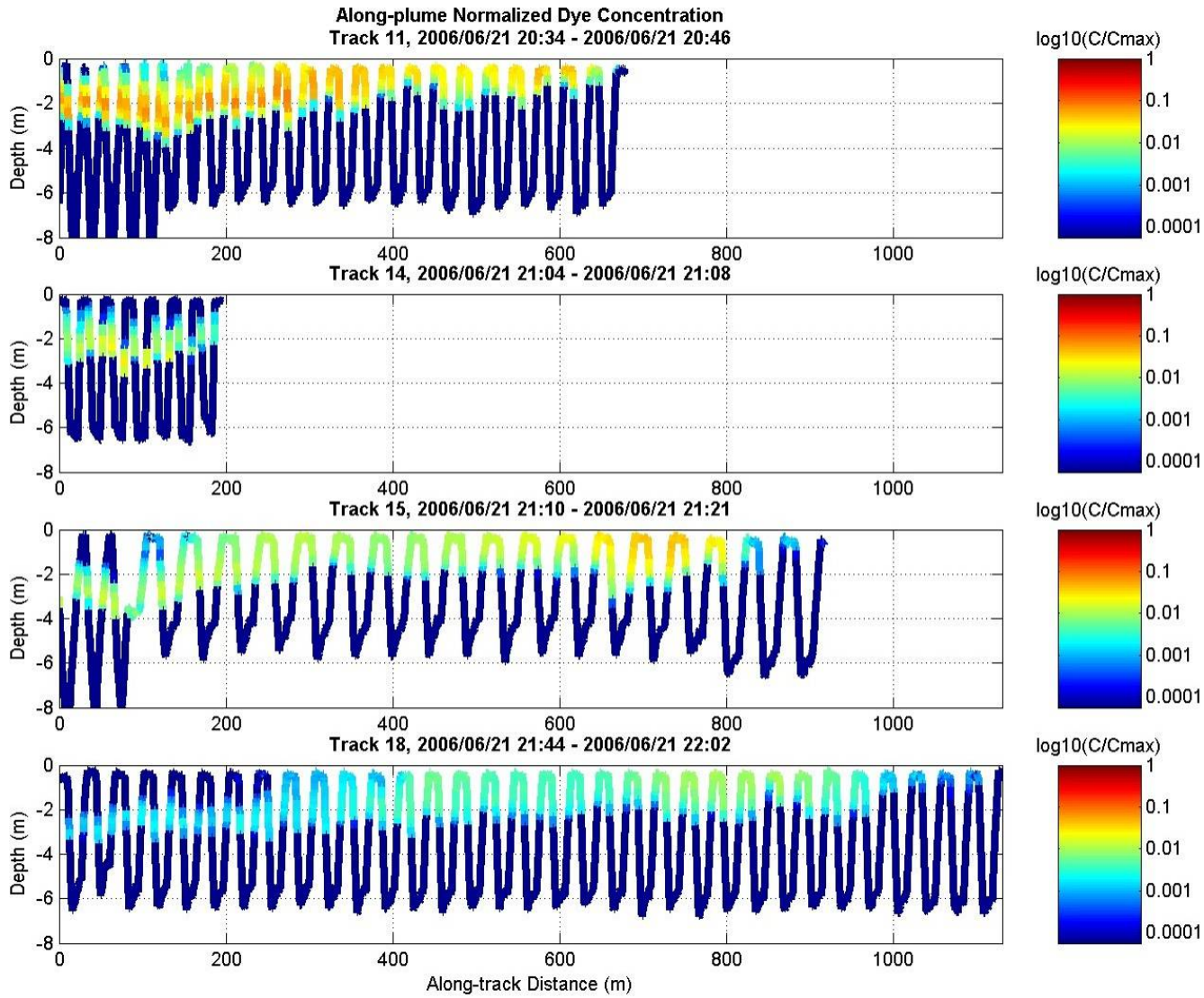
Scripps designed rapid profiling fluorometer system

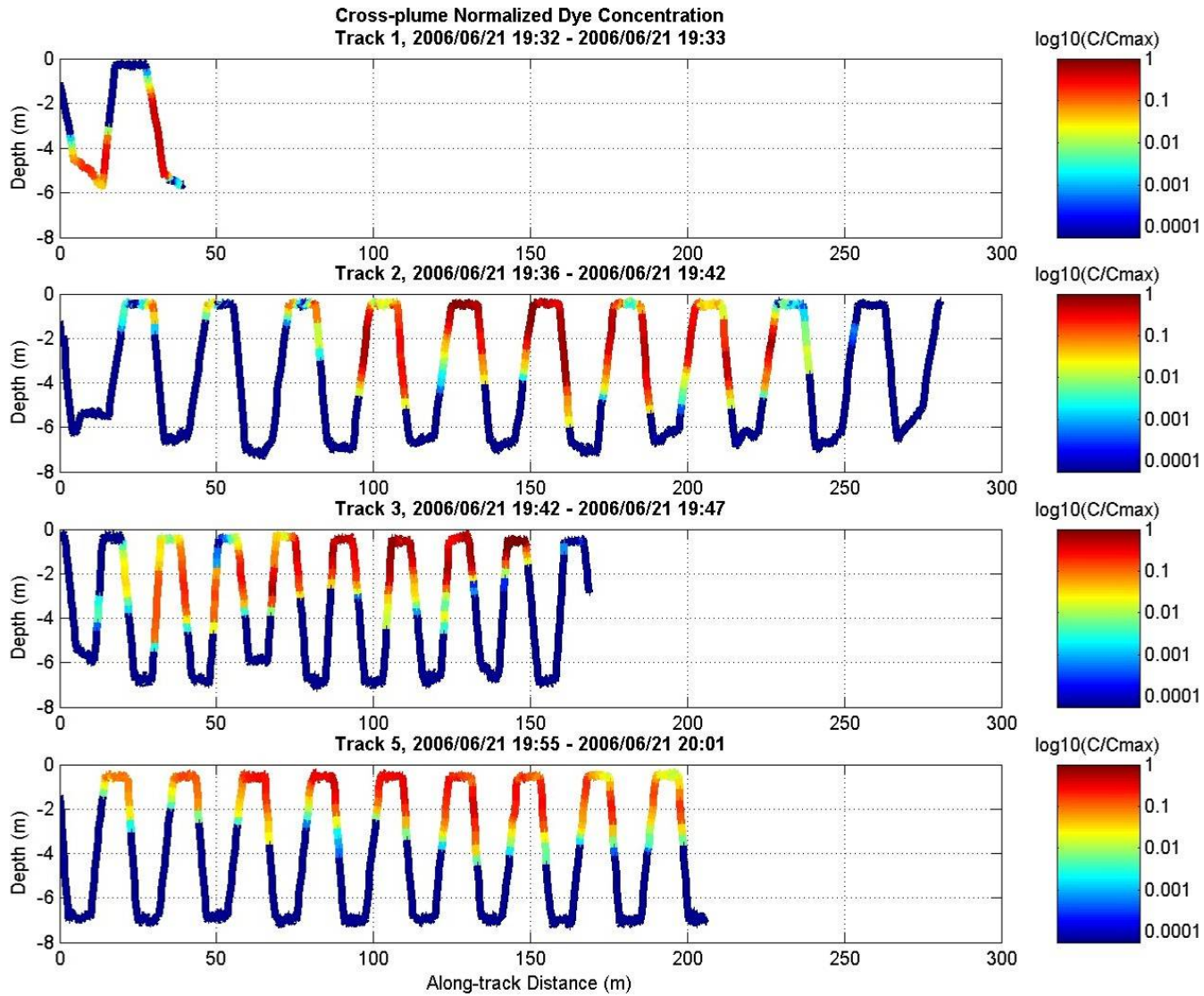
Wet Labs fluorometer vs. USCG SMART readout during cross-plume transect

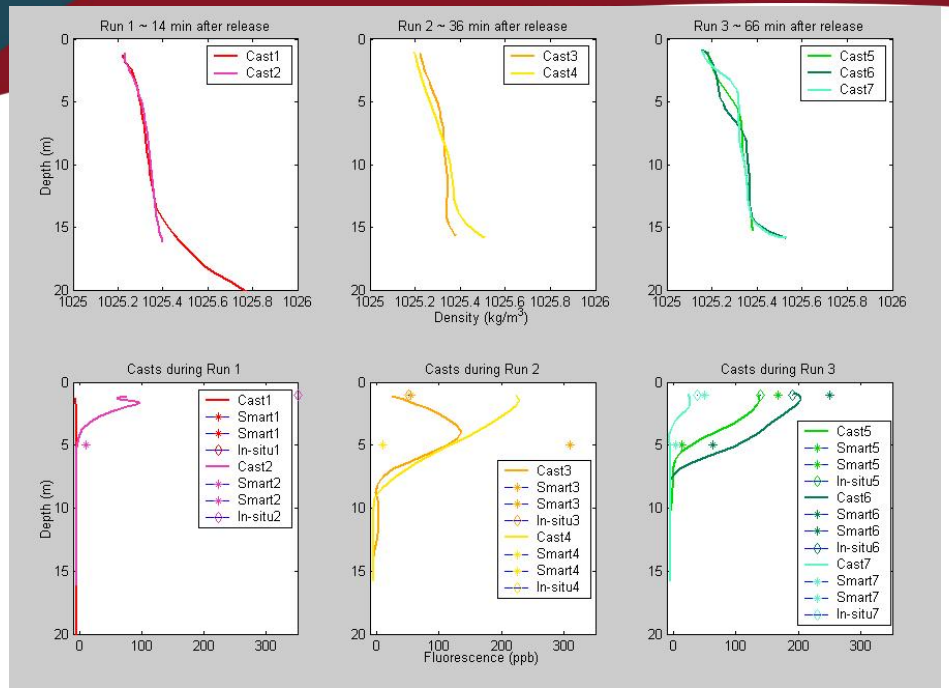


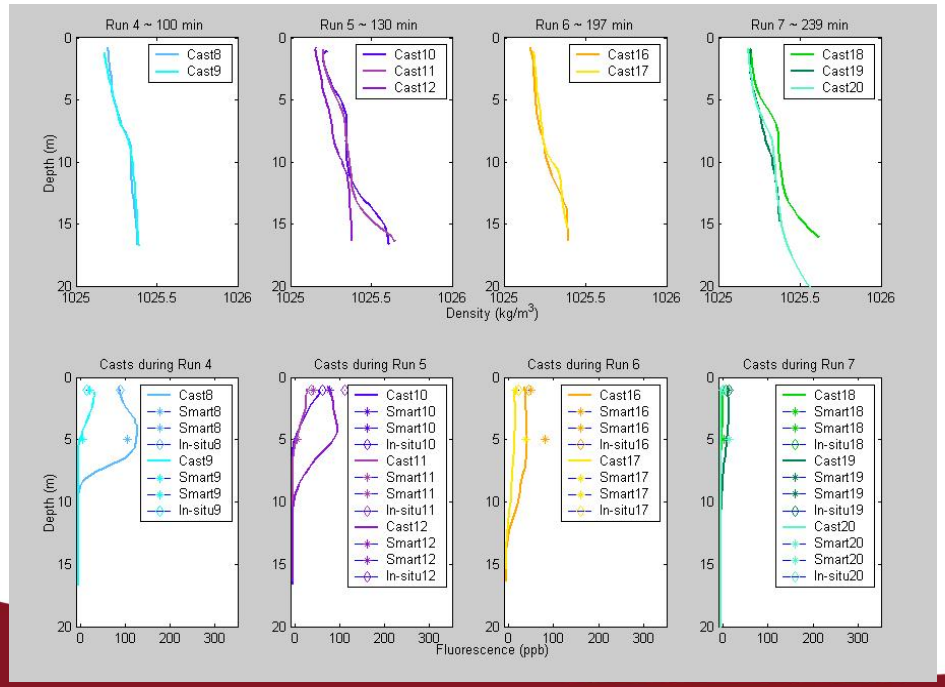

2006/06/21 Plume Sampling Transects
32.598
32.596
32.594
32.592
32.59
32.588
32.586
32.584
32.582
32.58
-117.28
-117.275
-117.27
-117.265
-117.26
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21


Along-plume Normalized Dye Concentration
Track 4, 2006/06/21 19:49 - 2006/06/21 19:53
Track 6, 2006/06/21 20:01 - 2006/06/21 20:07
Track 7, 2006/06/21 20:07 - 2006/06/21 20:15
Track 9, 2006/06/21 20:23 - 2006/06/21 20:32
Depth (m)
0
-2
-4
-6
-8
0
200
400
600
800
1000
Along-track Distance (m)
log10(C/Cmax)
1
0.1
0.01
0.001
0.0001


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)
0
-2
-4
-6
-8
0
200
400
600
800
1000
Along-track Distance (m)
log10(C/Cmax)
1
0.1
0.01
0.001
0.0001


Cross-plume Normalized Dye Concentration
Track 1, 2006/06/21 19:32 - 2006/06/21 19:33
Track 2, 2006/06/21 19:36 - 2006/06/21 19:42
Track 3, 2006/06/21 19:42 - 2006/06/21 19:47
Track 5, 2006/06/21 19:55 - 2006/06/21 20:01
Depth (m)
Along-track Distance (m)
log10(C/Cmax)
1
0.1
0.01
0.001
0.0001




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.

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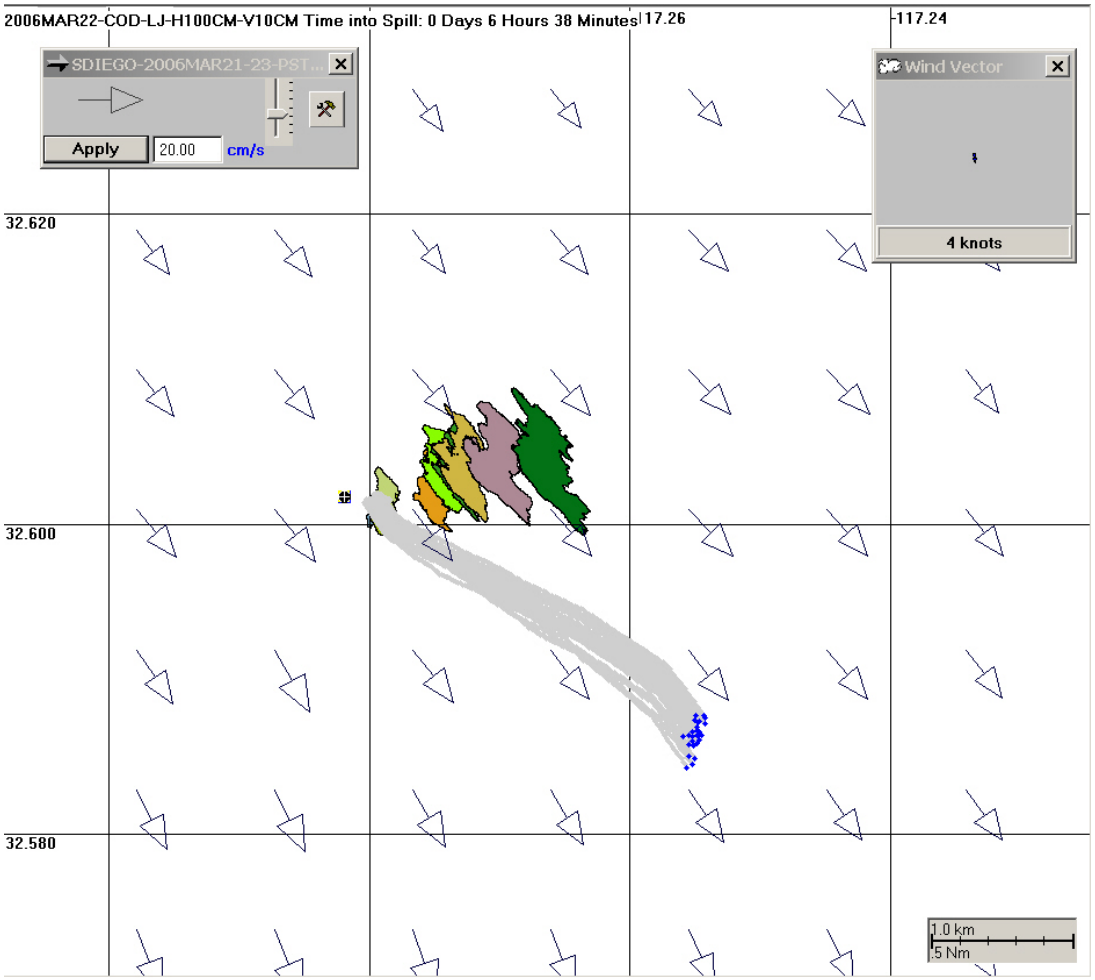
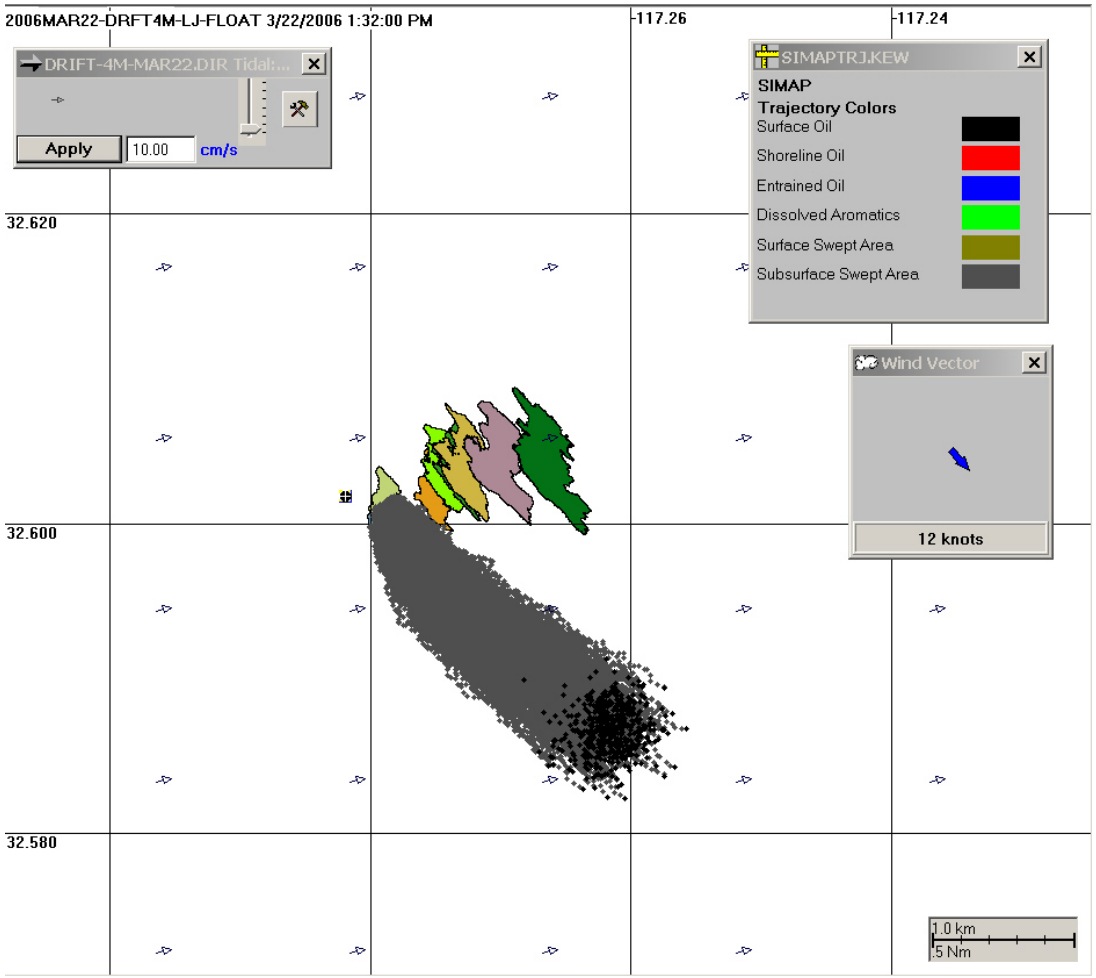
# CODAR Surface Currents vs. Subsurface Dye



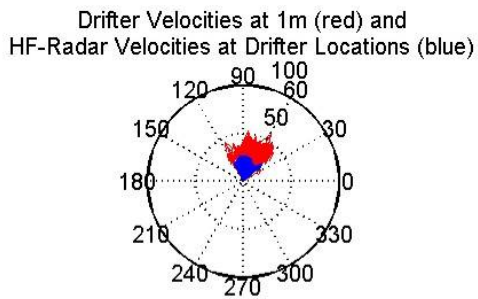

CODAR surface current data (6.5 hrs after release on 22 March 2006) and indicated trajectory to the ESE, south of the observed subsurface dye movements (which were to the east).

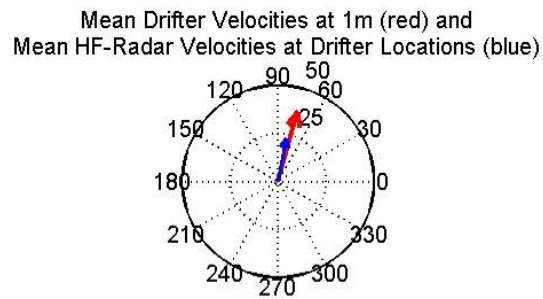
# Surface Oil Trajectory vs. CODAR

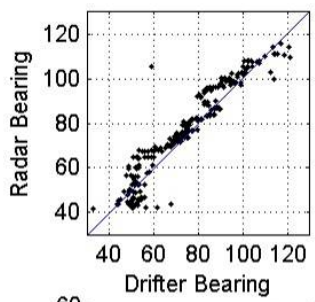


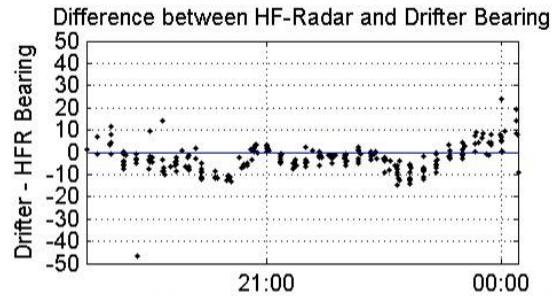

SIMAP simulation of floating oil trajectory (March 22), using drifter-measured currents and wind data from the La Jolla station LJPC1.

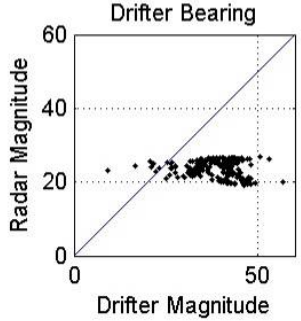
# CODAR vs. 1-m Drifter Measurements
# 8 November 2005

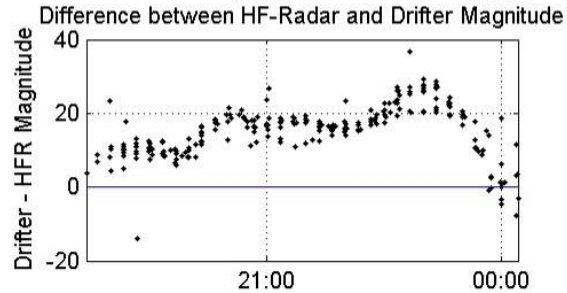


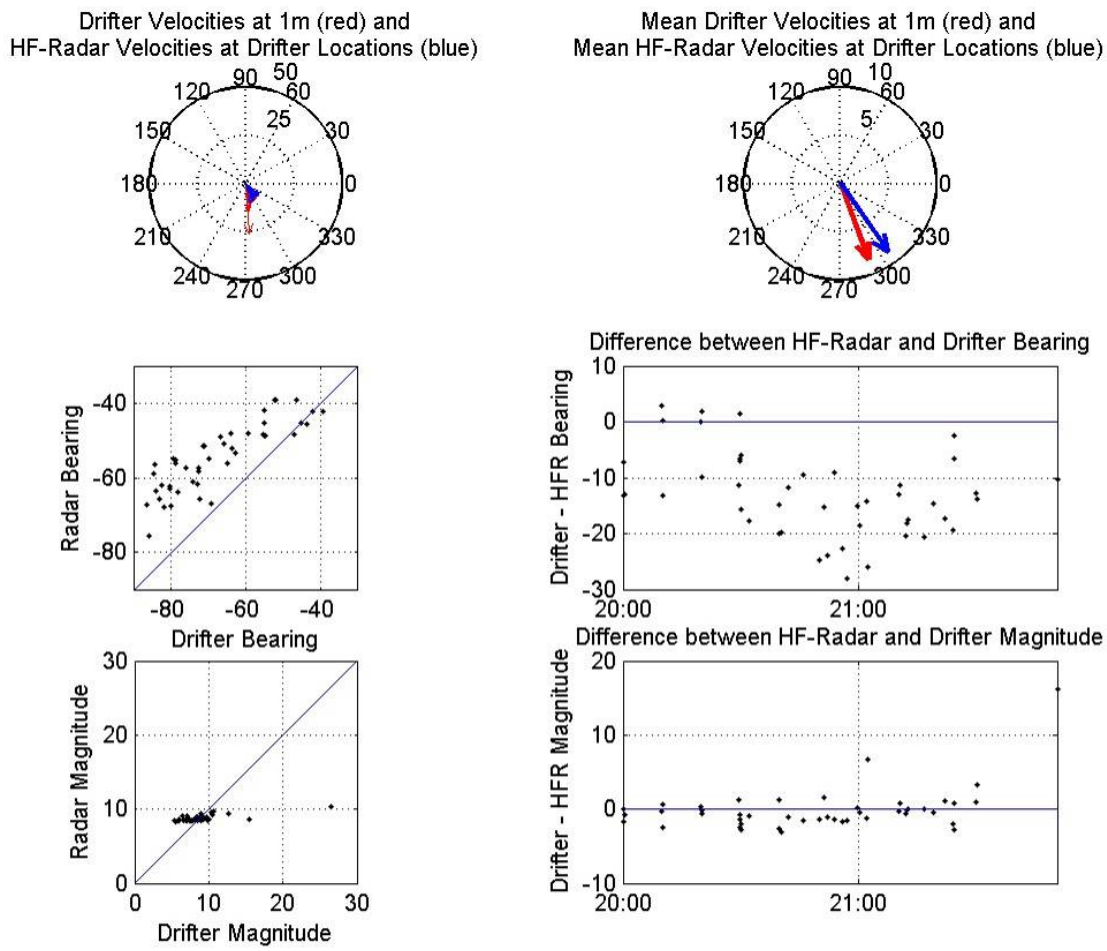



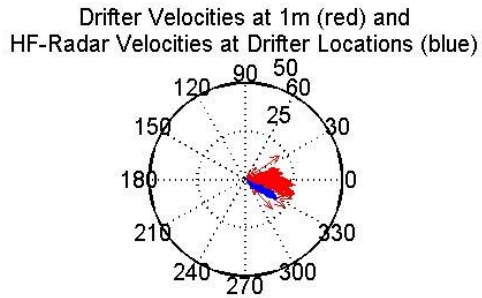



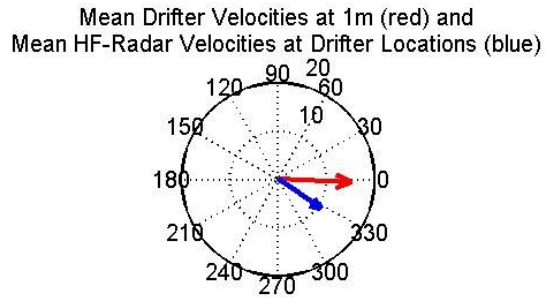



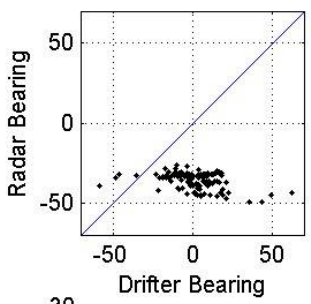
# CODAR vs. 1-m Drifter Measurements 21 March 2006

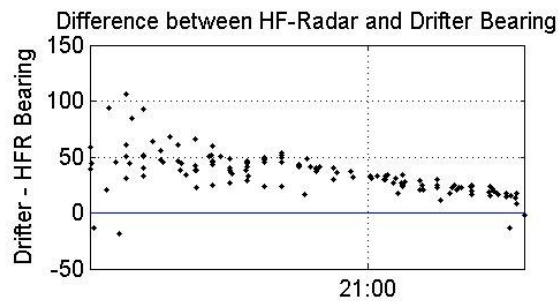


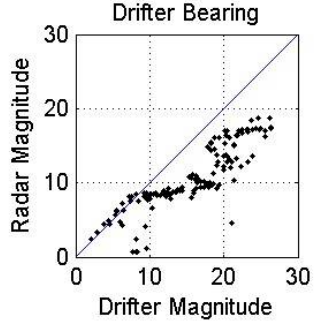
# CODAR vs. 1-m Drifter Measurements 22 March 2006

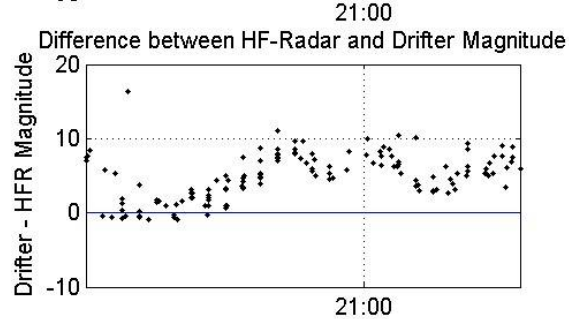


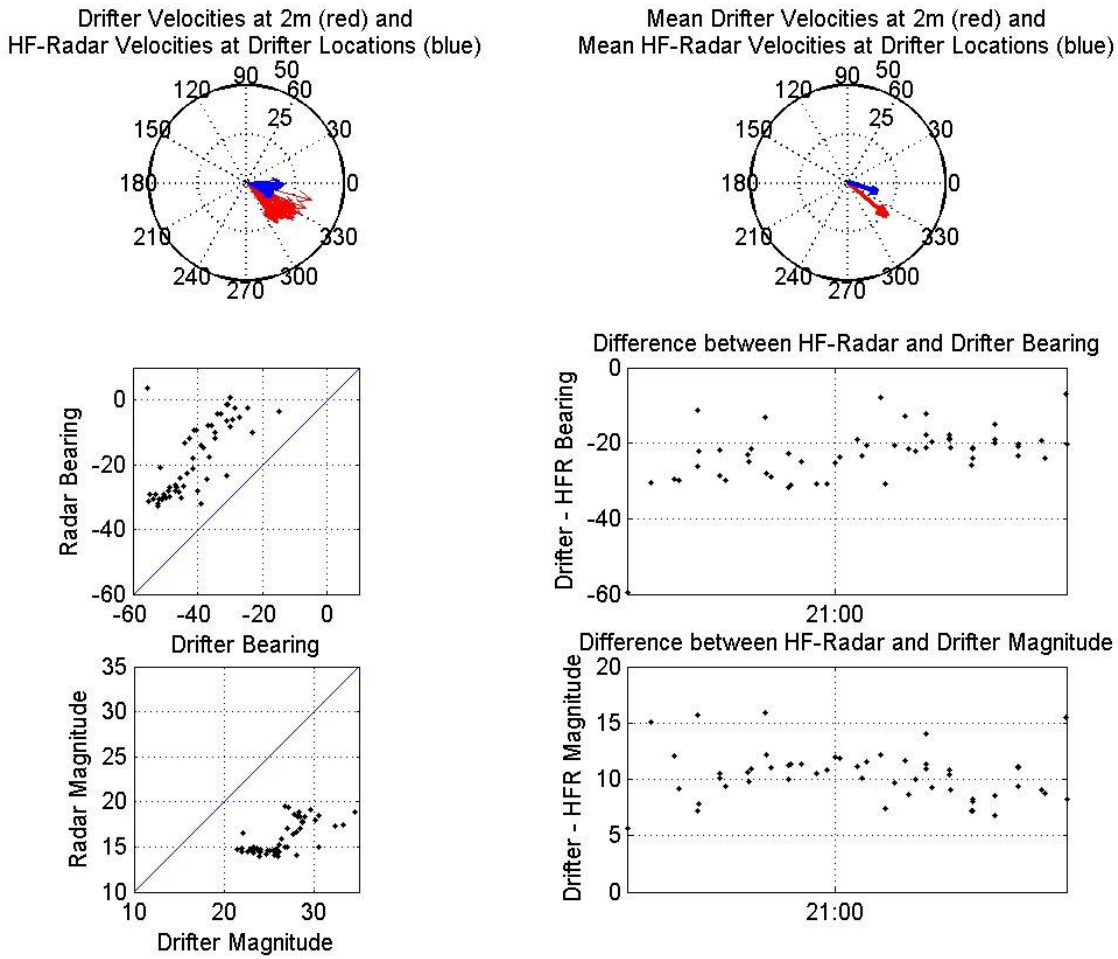



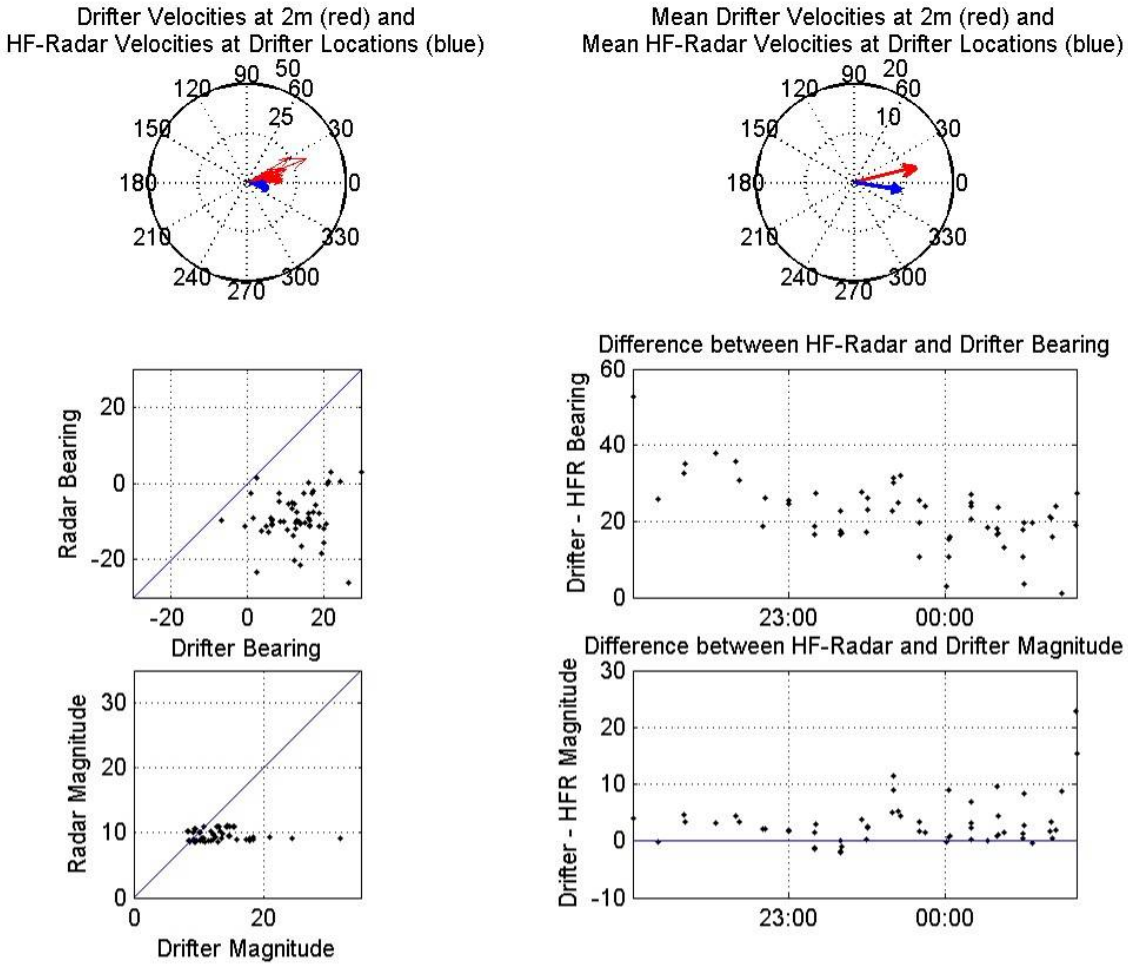



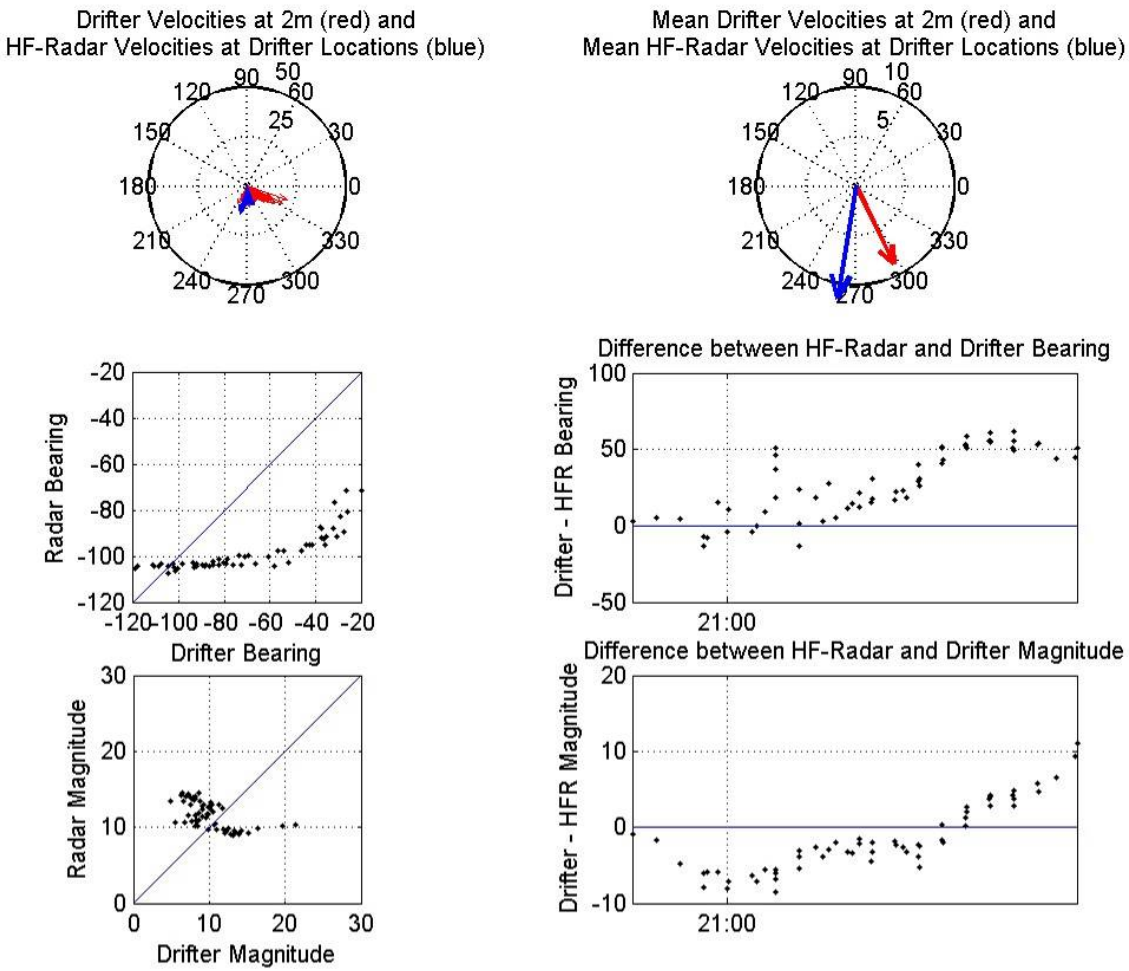
# CODAR vs. 2-m Drifter Measurements 21 June 2006



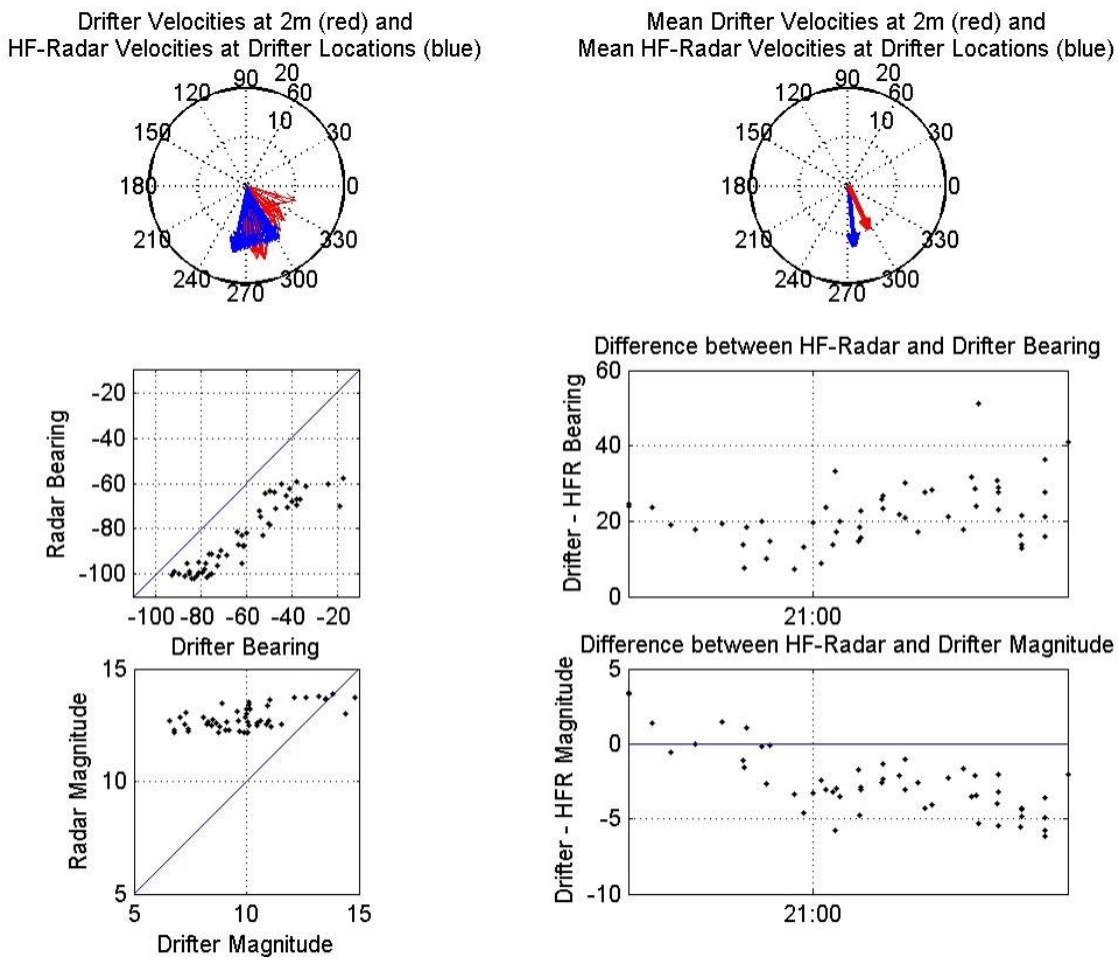
# CODAR vs. 2-m Drifter Measurements 22 June 2006



# CODAR vs. 2-m Drifter Measurements
# 1 November 2006



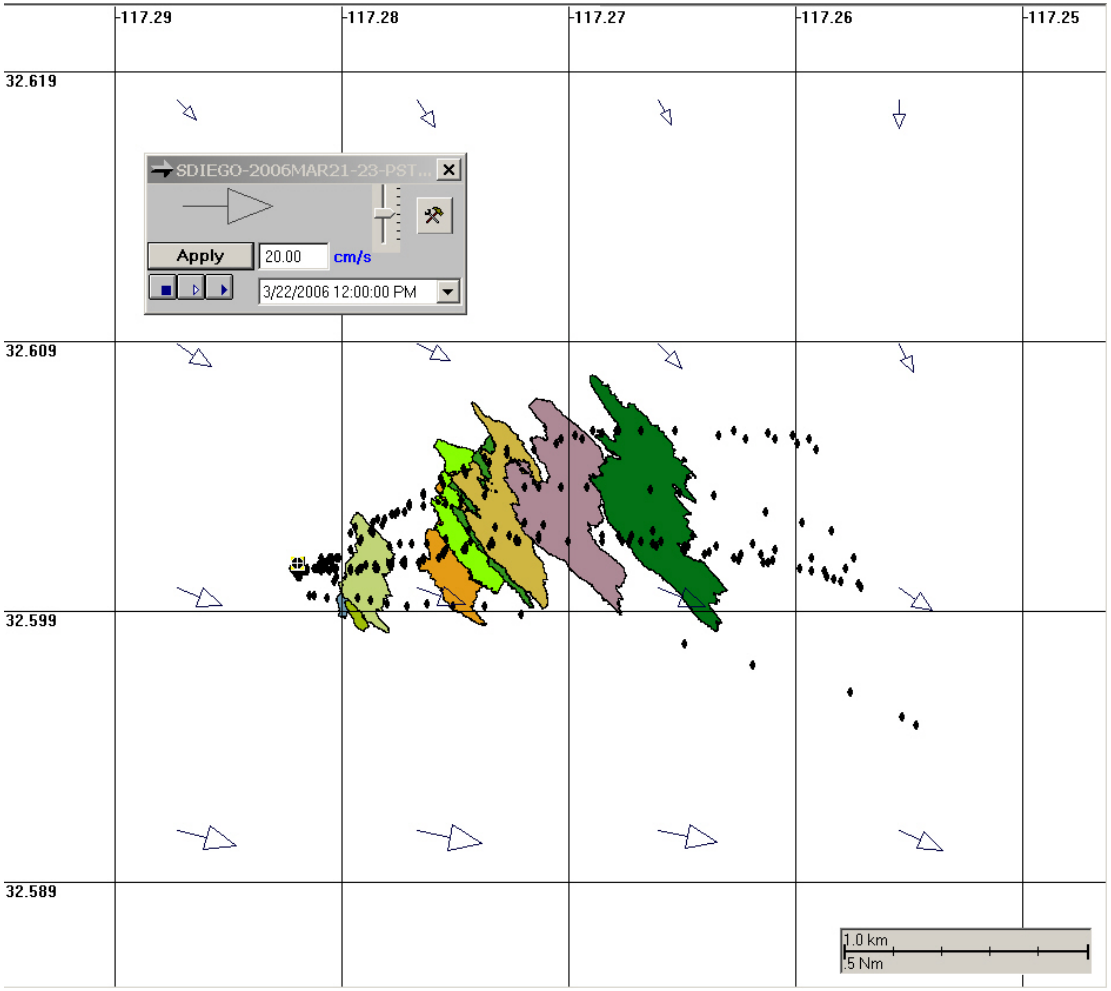
# CODAR vs. 2-m Drifter Measurements
# 2 November 2006



# CODAR vs. Drifter Comparisons

- Better CODAR vs. drifter agreement was generally observed with drifters drogued at 1-m vs. 2-m.
- With the exception of the November 2006 measurements, the mean drifter velocities were greater than those from HF-Radar.
- Both time-varying positive (HF-Radar to the right of the drifters) and negative differences (up to 60$^{o}$) in bearing were noted.

# Drifter Movement vs. Subsurface Dye




GPS drifter movements (to the east, indicated by black diamonds) during the 22 March 2006 experiment, overlaid on observed dye plume tracks and CODAR vectors 2 hrs after release.

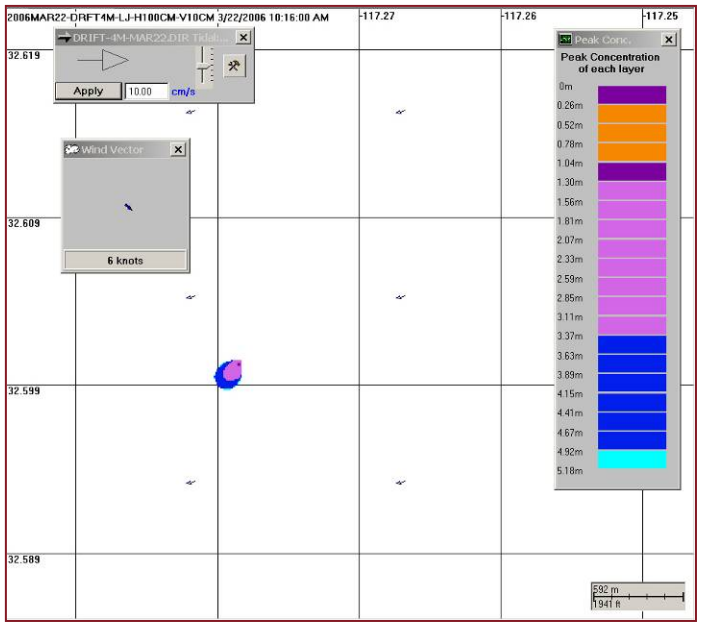
# Comparison of Drifters at Different Depths to Subsurface Dye Movement

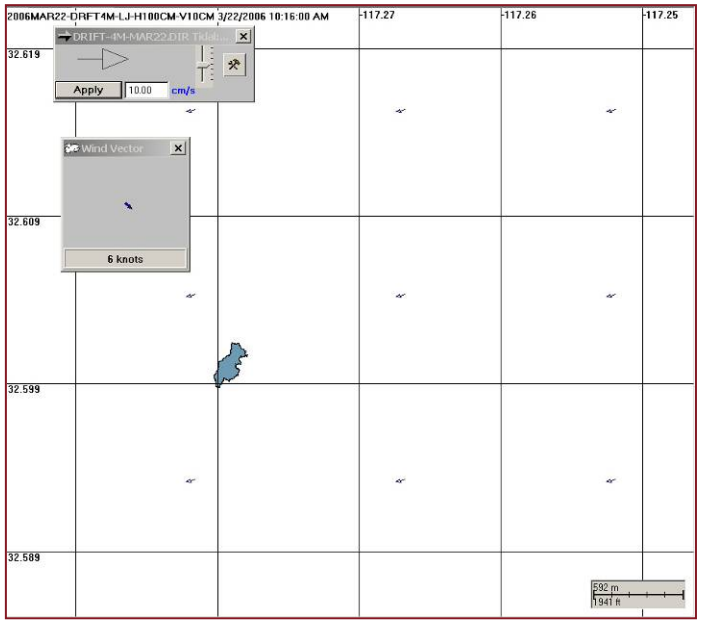
- In the 8 November 2005 & 21 March 2006 experiments, all of the drifters, which were drogued at 1 m, moved in advance of the observed dye plumes.
- In the 22 March 2006 experiment, with a mixed layer depth of 8 m, drifters drogued at 5 m best tracked the dye, while drifters drogued at 1 m advanced it.
- In the 1 & 2 November 2006 experiments with a mixed layer depth of 8 m, drifters drogued at 4 m best tracked the dye, whereas drifters drogued at 2 m advanced it.
- In the 21 & 22 June 2006 experiments with a shallower mixed layer depth of 6 m, drifters drogued at 2 m best tracked the dye, whereas drifters drogued at 4 m lagged slightly behind it.

# 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

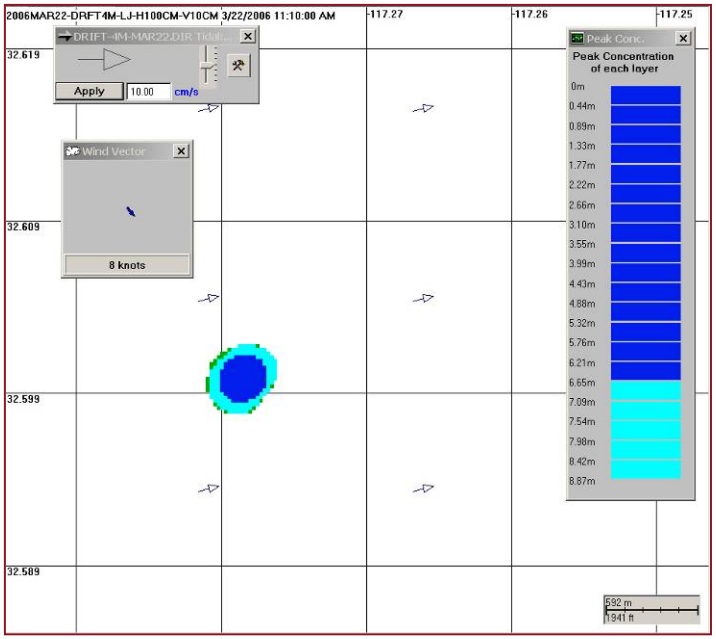
# Modeled and Observed Subsurface Plume Trajectories over Time

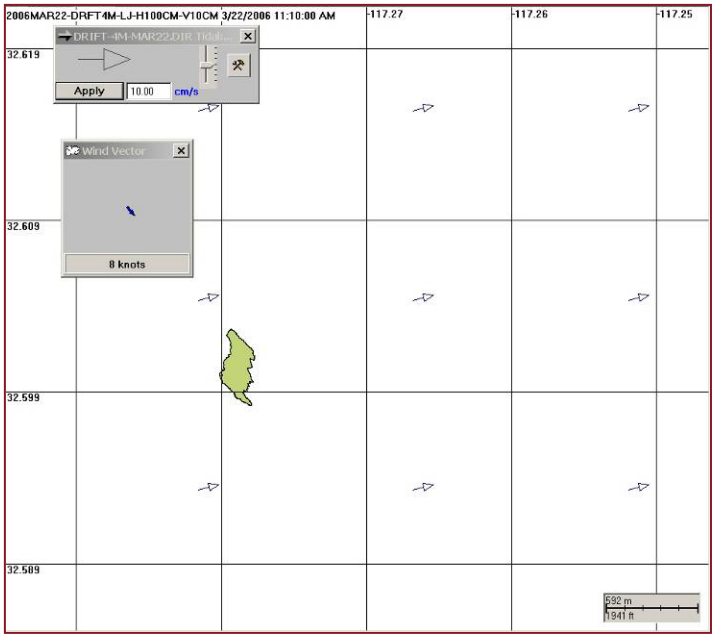



Simulation of dye plume on 22 March 2006 (left), using drifter-measured currents and wind data from the La Jolla station LJPC1 (11 min after the release) and measured dye location from aerial photographs (right).

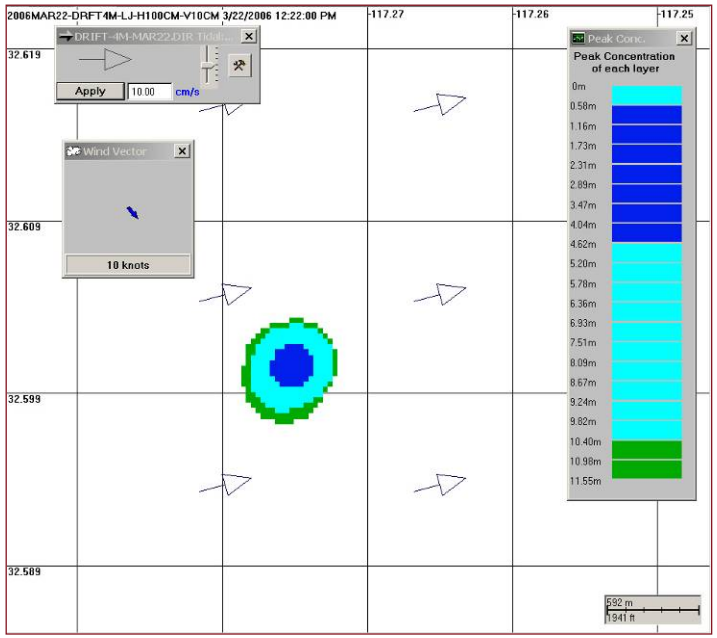
# Modeled and Observed Subsurface Plume Trajectories over Time

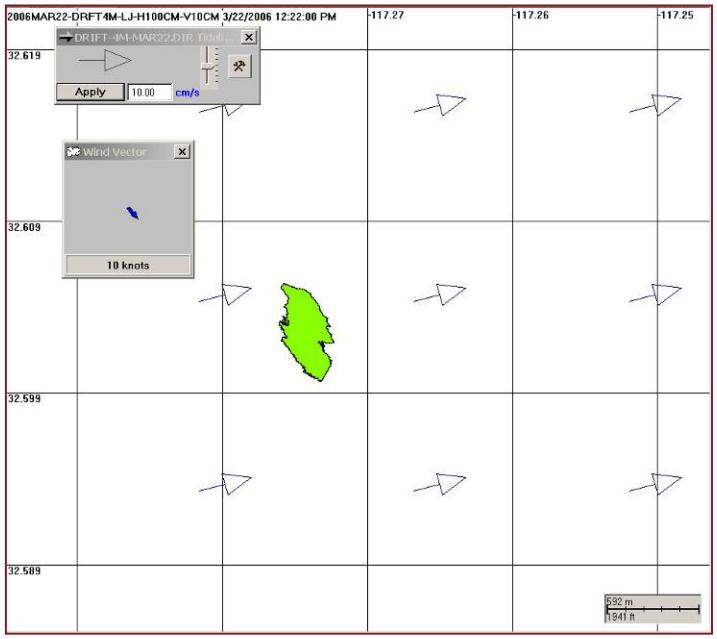



Simulation of dye plume on 22 March 2006 (left), using drifter-measured currents and wind data from the La Jolla station LJPC1 (65 min after the release) and measured dye location from aerial photographs (right).

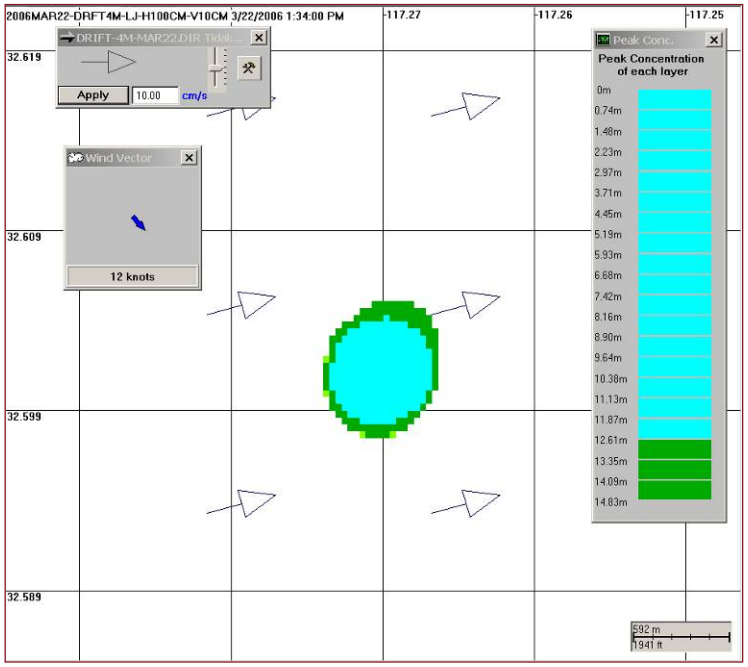
# Modeled and Observed Subsurface Plume Trajectories over Time

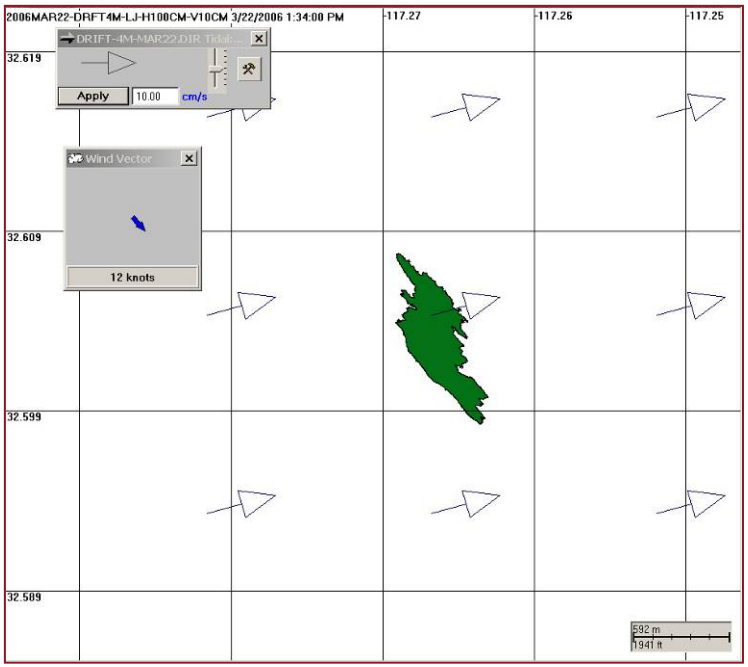



Simulation of dye plume on 22 March 2006 (left), using drifter-measured currents and wind data from the La Jolla station LJPC1 (2.3 hours after the release) and measured dye location from aerial photographs (right).

# Modeled and Observed Subsurface Plume Trajectories over Time




Simulation of dye plume on 22 March 2006 (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).

# Preliminary Findings from Modeling Effort

- The estimated horizontal turbulent diffusion coefficients ranged from 0.1-30 $m^2$/sec over the seven field-experiments considered. These values did not correlate with wind speed, but the range of wind conditions was not large (4.8 – 13.2 knots), and these experiments were all made in fairly low turbulence conditions (1.0 – 1.8 m waves).
- The estimated vertical turbulent diffusion coefficients ranged from 6-30 $cm^2$/sec. Mixing, apparently by Langmuir circulation, to the depth of the surface mixed layer (6-8 m) occurred within 30 minutes, and the dye did not penetrate deeper over the duration of the experiments.

# 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 always track the observed subsurface dye plume movements.
- Sometimes the CODAR surface currents tracked the near-surface (1-m) drogues and at other times, they did not.
- Additional data analyses and modeling efforts are ongoing in an attempt to explain the discrepancies.

# 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 may be somewhat 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 drifters and CODAR-predicted or observed surface oil.

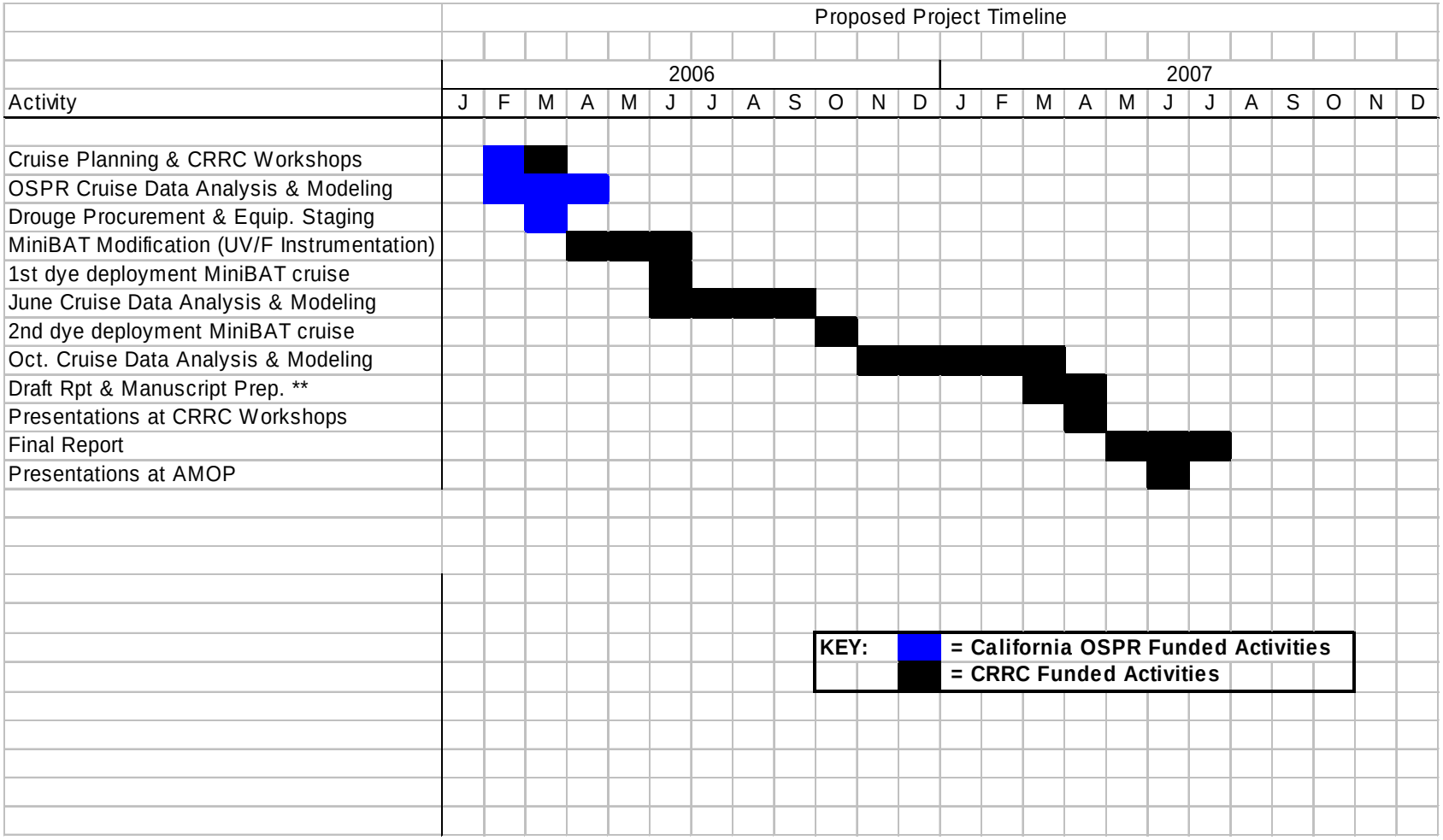
# The CRRC/OSPR-funded field experiments and algorithm development have provided:

- 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.
- A significant (web-accessible) database for additional algorithm development for quantifying small scale transport processes and the associated uncertainty that can be included in oil fates models.
- Validation of the sampling approach for the CA OSPR Dispersed Oil Monitoring Plan (DOMP).

# Modeling products will include:

- A fitting algorithm for estimating diffusion coefficients from conservative (dye) tracer concentrations and georeferenced aerial photo images.
- Algorithms for incorporating into oil transport models the magnitudes of:
  - non-wind-drift currents from water surface observational current data,
  - wind (Stokes) drift, and
  - diffusion rates.
- Quantitative techniques for uncertainty analysis based on uncertainty in input data by:
  - describing the range and uncertainty of each input parameter as a probability distribution (even, Gaussian, or skewed),
  - repeatedly sampling the distribution for multiple model runs (Monte Carlo), and
  - providing uncertainty estimates of predicted concentrations.

# Final Schedule




** Two manuscripts have been accepted for presentation at the 2007 AMOP Conference, two abstracts have been submitted for the 2008 IOSC, and the Draft Final Report will be submitted to CRRC on 30 April 2007.