AOSN-II in Monterey Bay: Modeling and Predicting Multiple Scales for Adaptive Sampling

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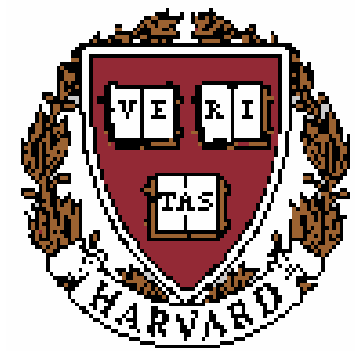
Division of Engineering and Applied Sciences



Department of Earth and Planetary Sciences

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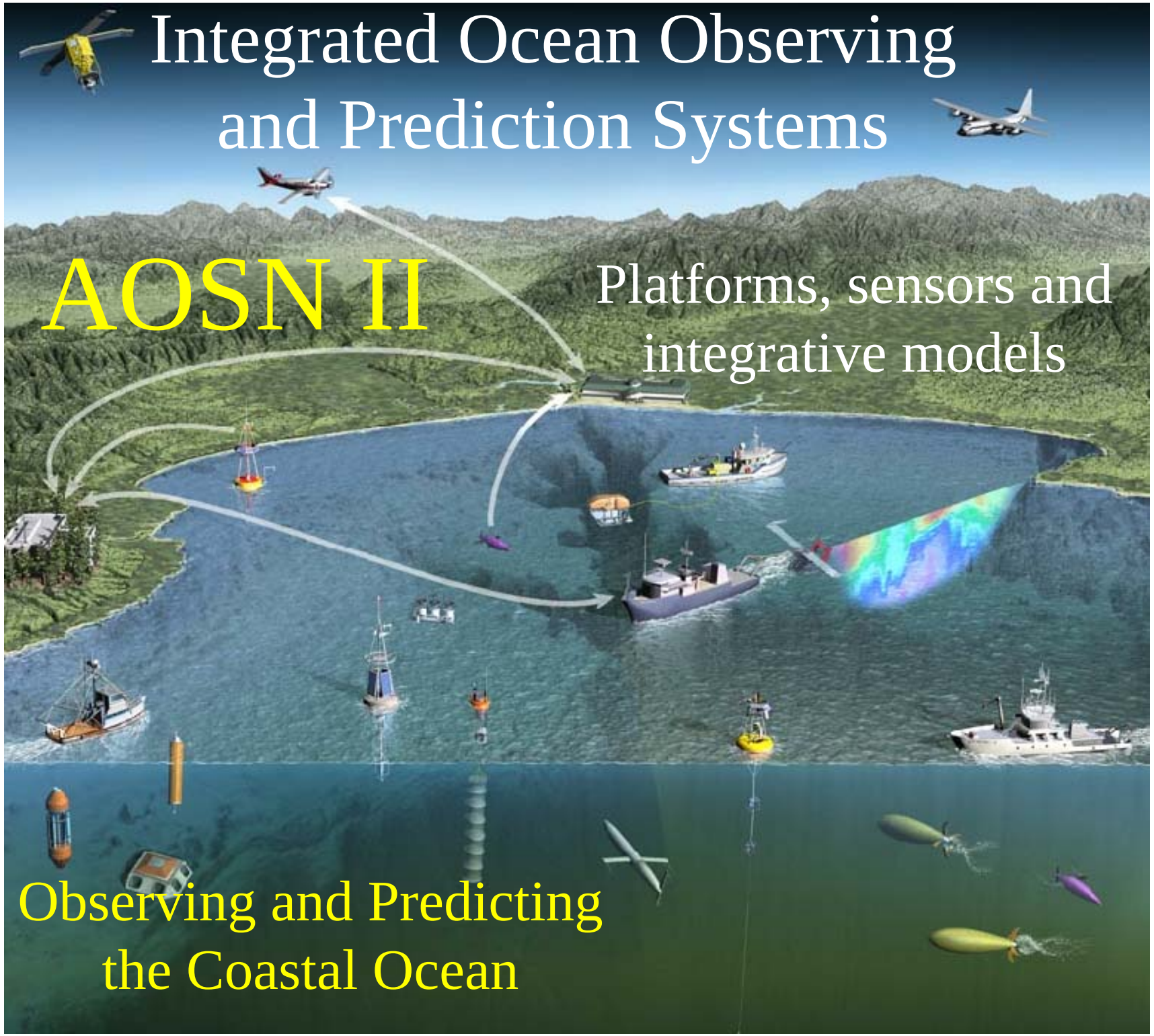
AOSN-II Executive Team:
Bellingham (MBARI), Chao (JPL), Chavez (MBARI), Davis (SIO), Fratantoni (WHOI), Haddock (MBARI), Leonard (Princeton), Marsden (CalTech), Ramp (NPS), Robinson (Harvard), Shulman (NRL)

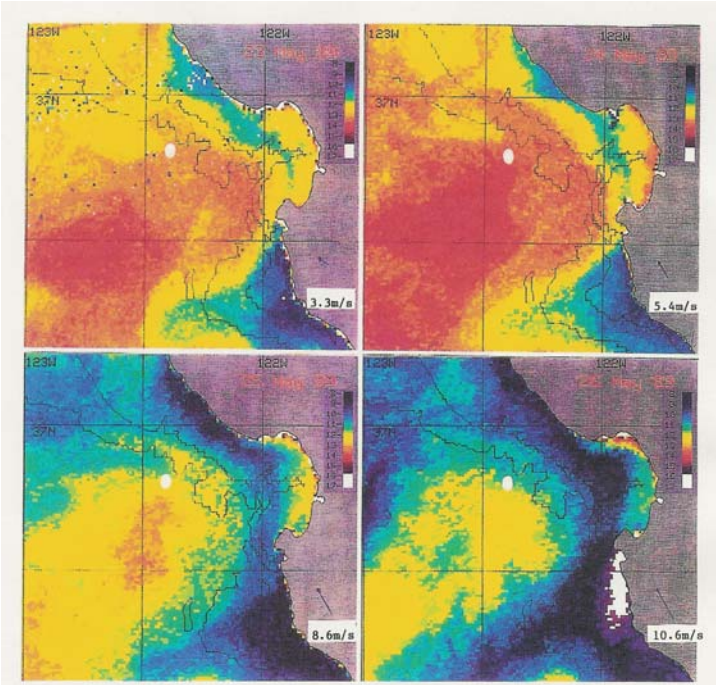
AOSN II Objectives:

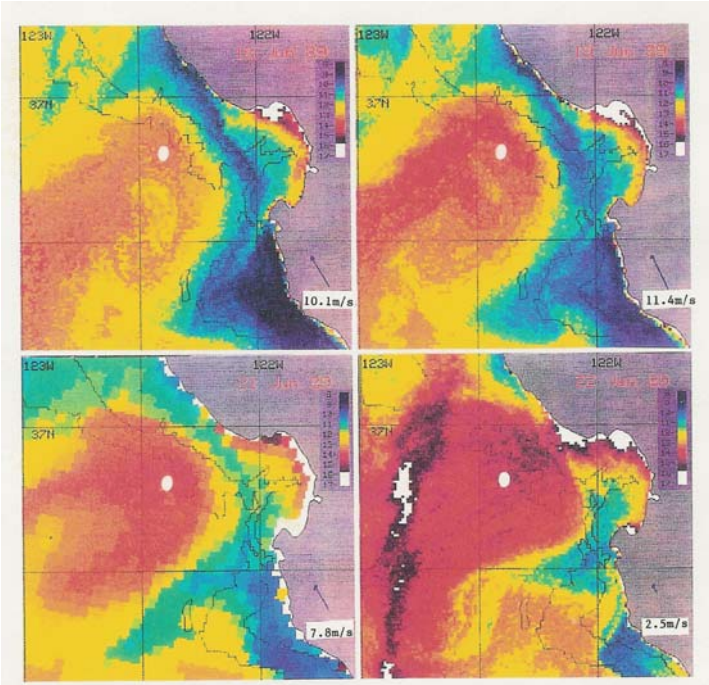
To design and build an adaptive coupled observation/modeling system. The system should be sustainable in its operation and capable of being readily relocated, in its final form.

- Use autonomous *in situ* platforms to achieve economic operation.
- Use oceanographic models to assimilate data from a variety of platforms and sensors into synoptic views of oceanographic fields and fluxes.
- Adapt deployment of mobile assets to improve performance.
- Test performance of the system in a quantitative fashion.
- Post results in real-time.
- Use the results of those tests to guide research and development to improve system performance.


Integrated Ocean Observing
and Prediction Systems
AOSN II
Platforms, sensors and
integrative models
Observing and Predicting
the Coastal Ocean

Conceptual model: Rosenfeld *et al*., 1994. Bifurcated flow from an upwelling center

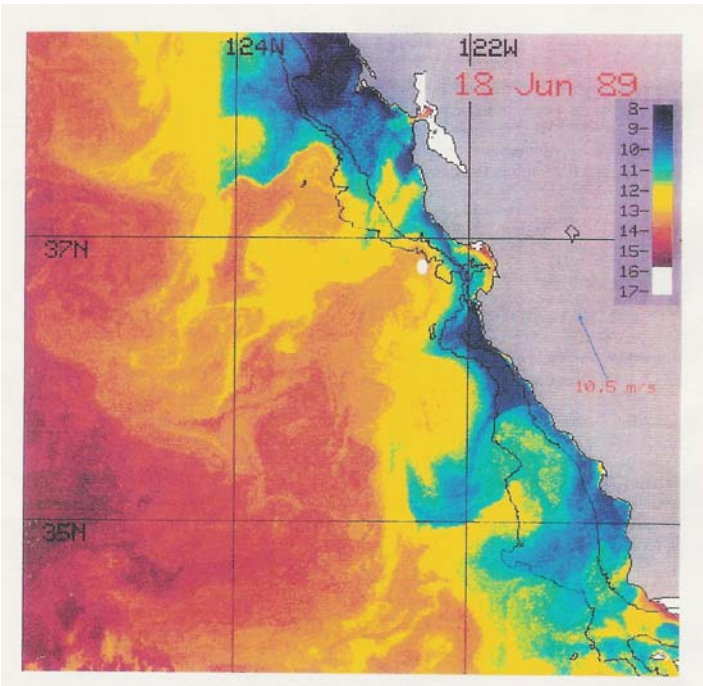


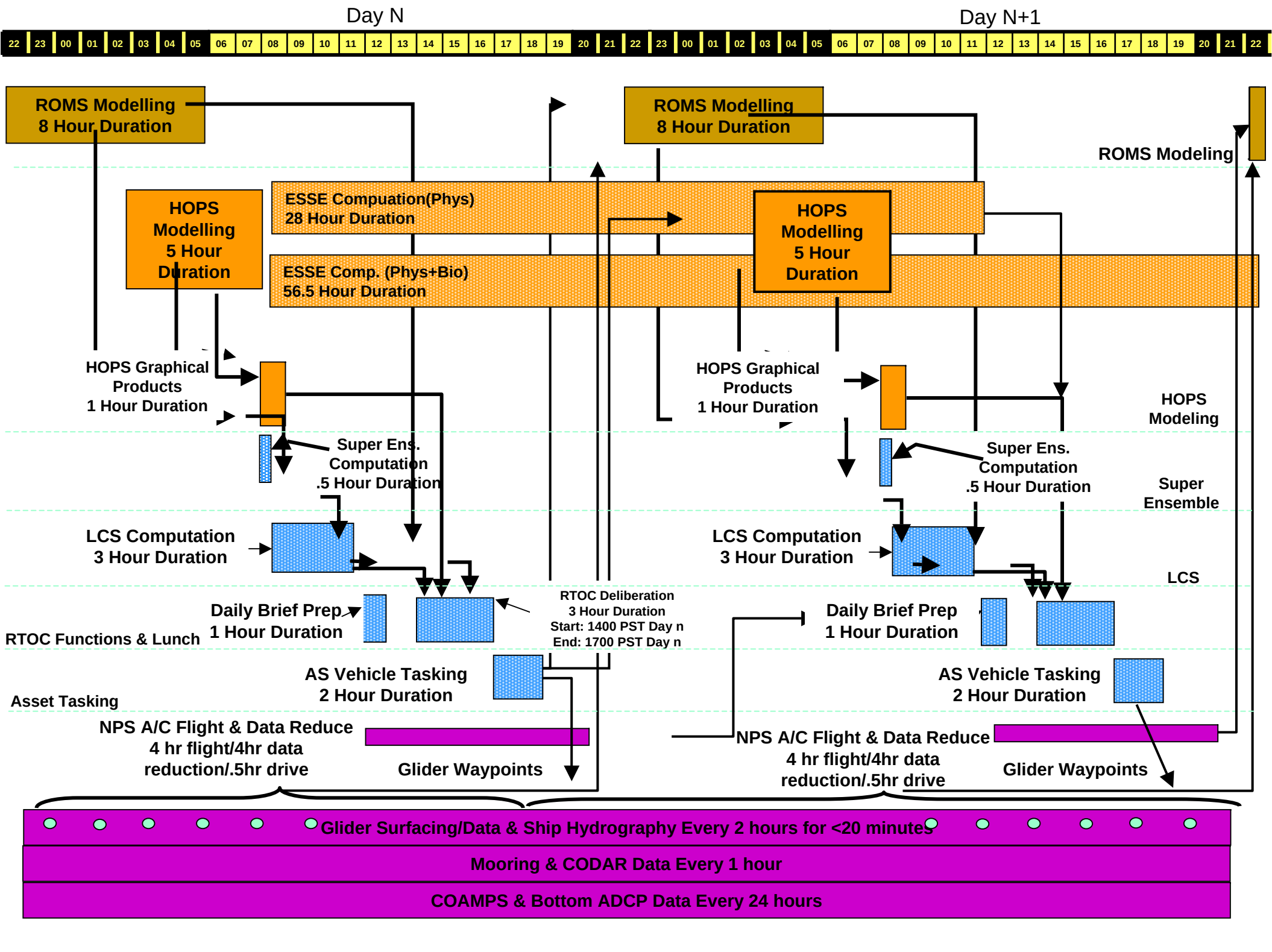


Top left – **Upwelling State** – 23-26 May 1989 – upwelled water from points moves equatorward and seaward – Point Año Nuevo water crosses entrance to Monterey Bay

Top right – **Relaxation State** – 18 -22 June 1989 – California Current anti-cyclonic meander moves coastward

Bottom right – **Larger regional context** – 18 June 1989 – California Current System

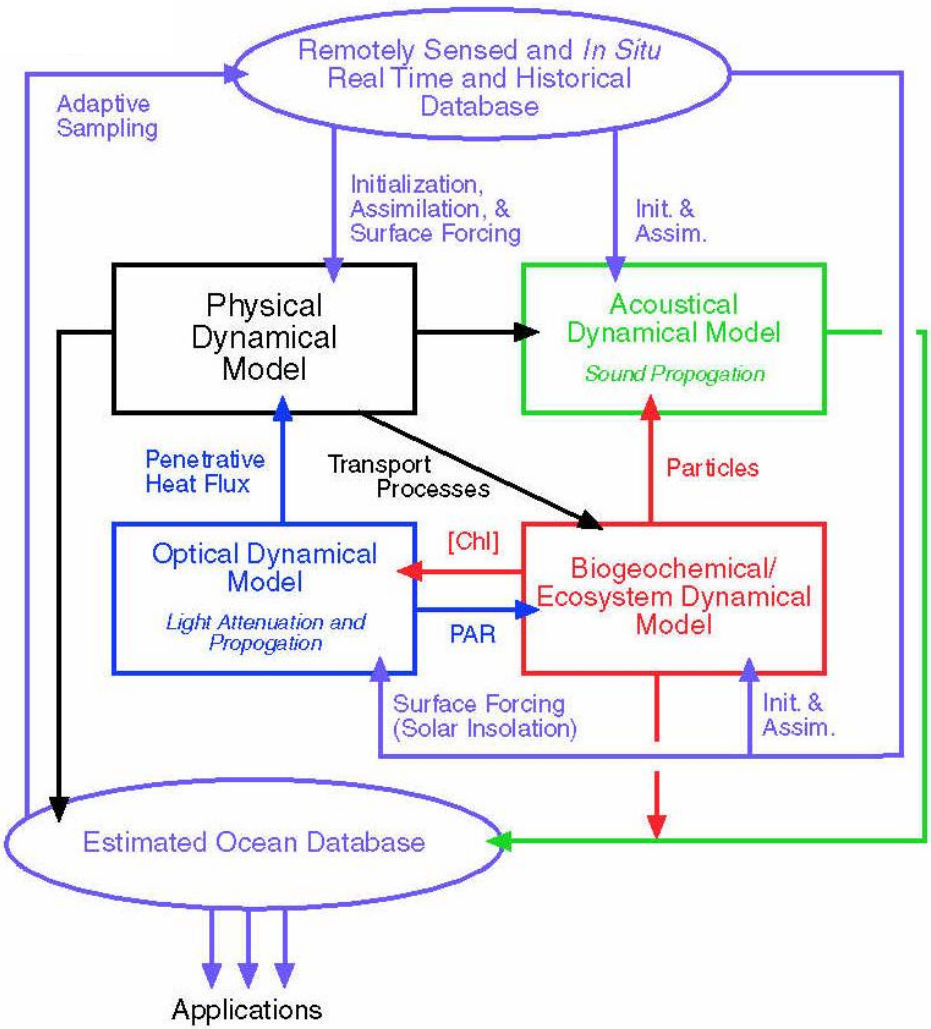



Day N
Day N+1
22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22
ROMS Modelling
8 Hour Duration
ROMS Modelling
8 Hour Duration
ROMS Modeling
HOPS
Modelling
5 Hour
Duration
ESSE Compuation(Phys)
28 Hour Duration
HOPS
Modelling
5 Hour
Duration
ESSE Comp. (Phys+Bio)
56.5 Hour Duration
HOPS Graphical
Products
1 Hour Duration
HOPS Graphical
Products
1 Hour Duration
HOPS
Modeling
Super Ens.
Computation
.5 Hour Duration
Super Ens.
Computation
.5 Hour Duration
Super
Ensemble
LCS Computation
3 Hour Duration
LCS Computation
3 Hour Duration
LCS
RTOC Deliberation
3 Hour Duration
Start: 1400 PST Day n
End: 1700 PST Day n
Daily Brief Prep
1 Hour Duration
Daily Brief Prep
1 Hour Duration
RTOC Functions & Lunch
AS Vehicle Tasking
2 Hour Duration
AS Vehicle Tasking
2 Hour Duration
Asset Tasking
NPS A/C Flight & Data Reduce
4 hr flight/4hr data
reduction/.5hr drive
Glider Waypoints
NPS A/C Flight & Data Reduce
4 hr flight/4hr data
reduction/.5hr drive
Glider Waypoints
Glider Surfacing/Data & Ship Hydrography Every 2 hours for <20 minutes
Mooring & CODAR Data Every 1 hour
COAMPS & Bottom ADCP Data Every 24 hours

Harvard Ocean Prediction System - HOPS

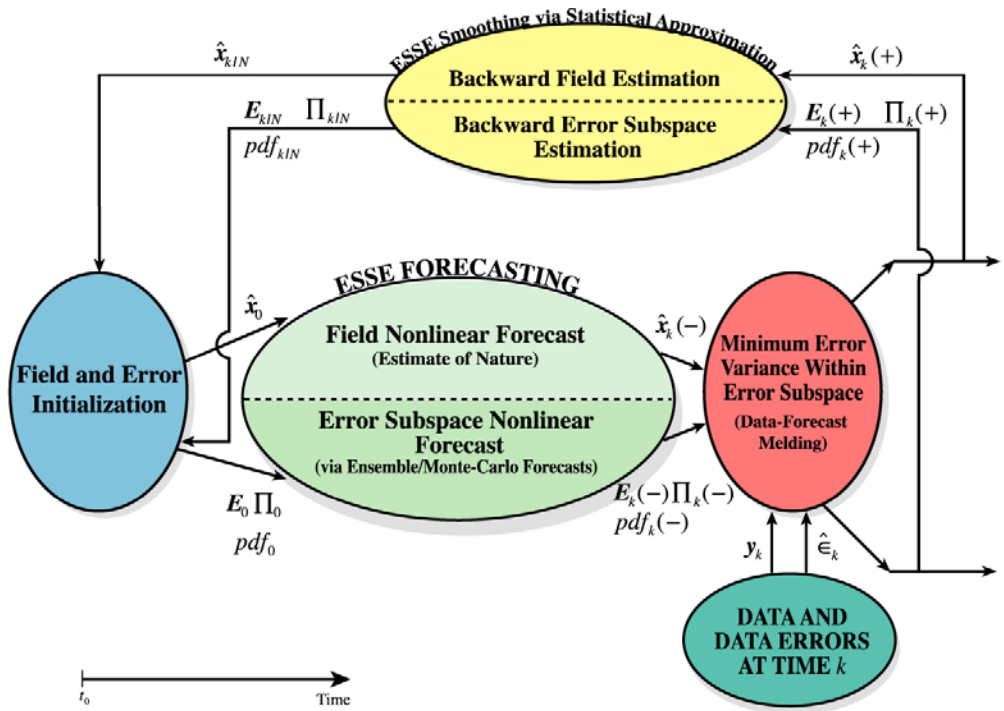
A Generic, Relocatable, Regional Forecast System

Multivariate Coupled Physical-Acoustical-Biological System

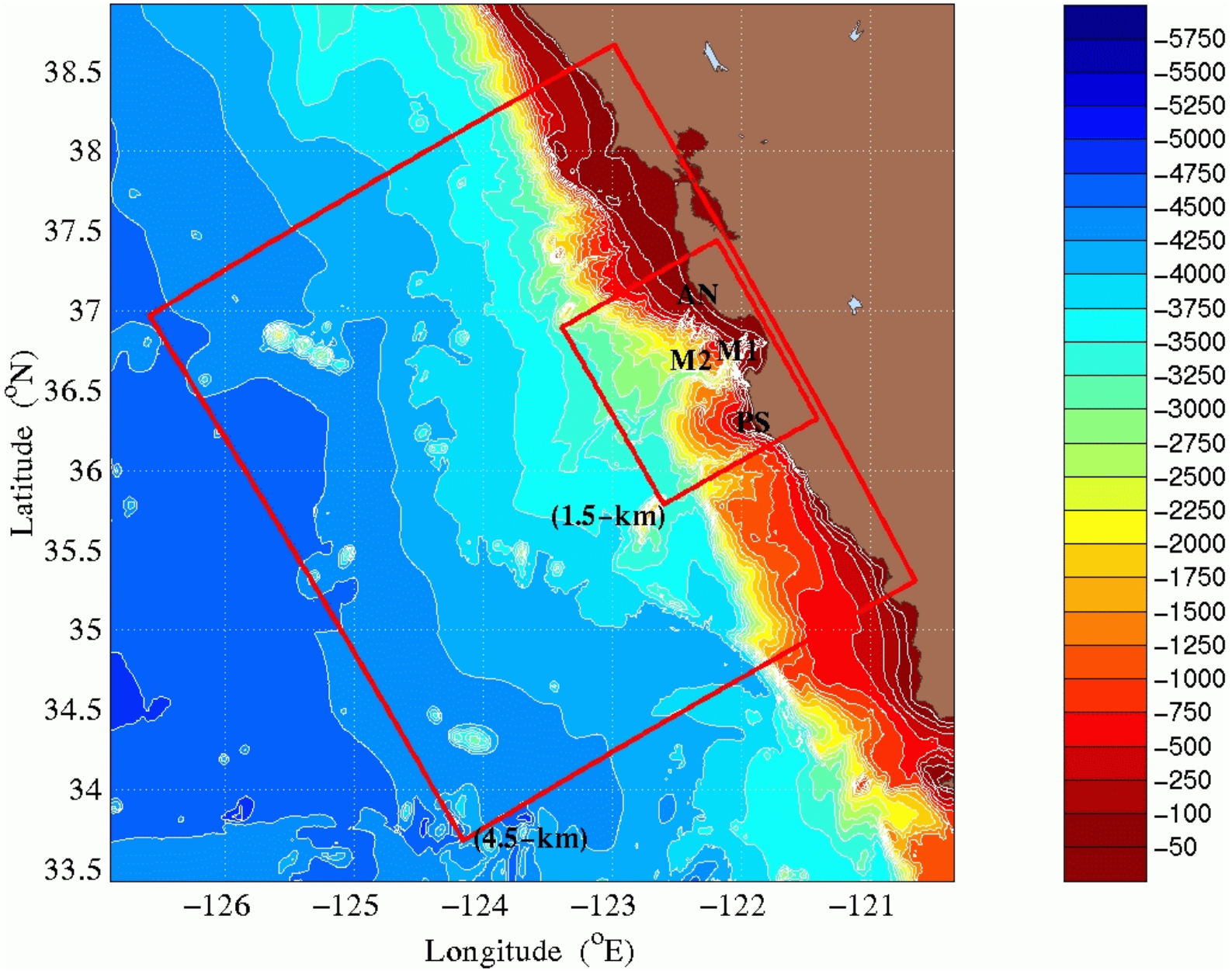


Data Assimilation: combines model and data for best ocean estimate: optimal interpolation (OI) or

Error Subspace Statistical Estimation (ESSE)

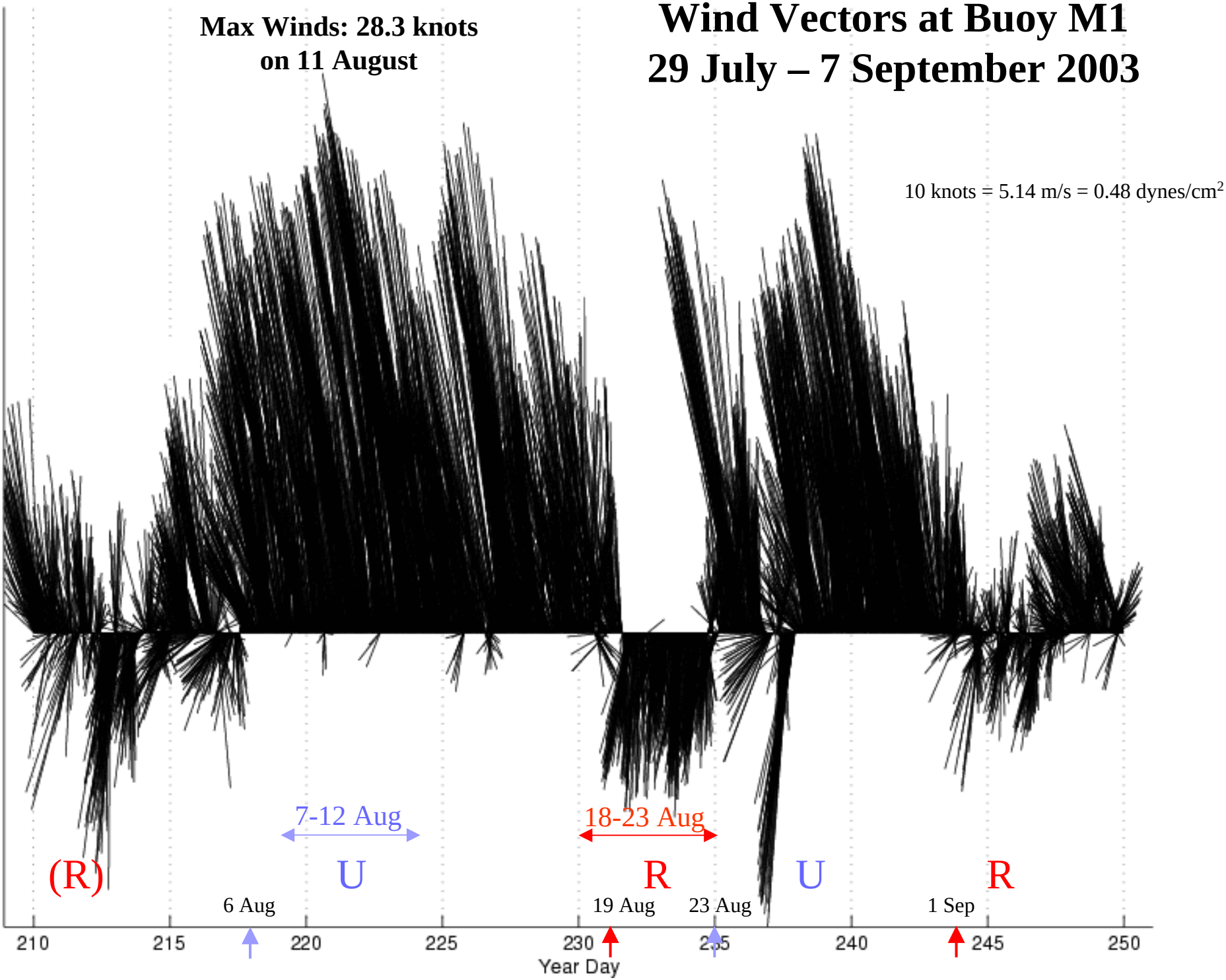


HOPS – Real-time Nested Modeling Domains
4 August – 3 September 2003

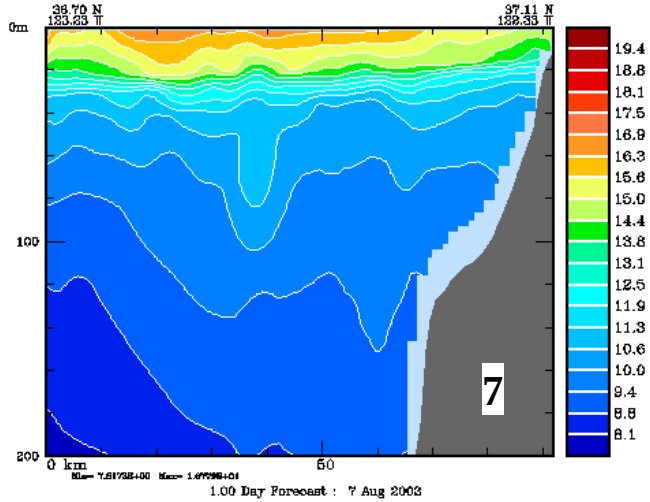


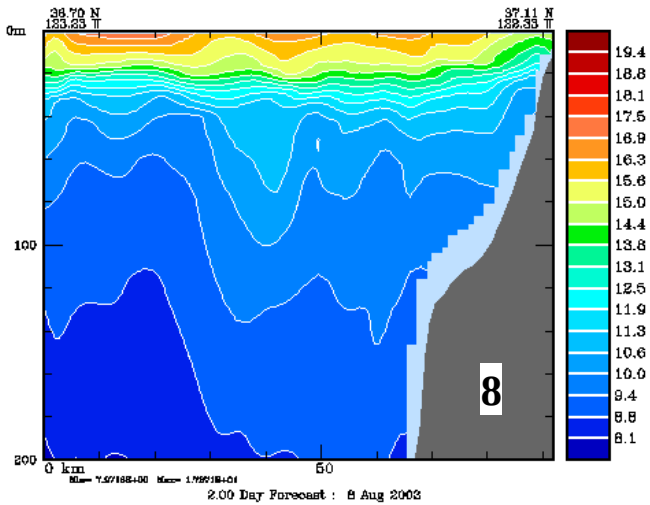
HOPS – AOSN-II Real-Time Forecasting

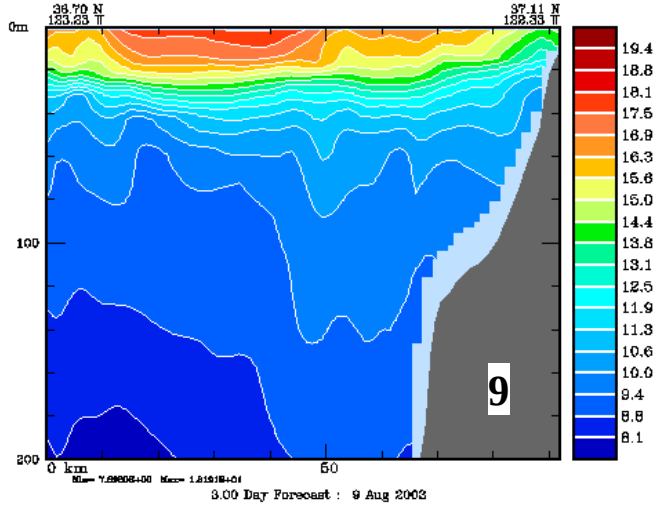
- 23 sets of real-time nowcasts and forecasts of temperature, salinity and velocity released from 4 August to 3 September
- Forcing by 3km COAMPS fluxes and Cal. Current System flow-through
- Data from glider fleets, aircraft, ships, etc. archived in real-time at MBARI. Daily ftp to Harvard for quality control and analysis at 9AM EDT. Processed for initialization by 2PM EDT.
- Real-time daily operational five day runs with OI (two assimilation days, nowcast, two forecast days) were available for post-processing at 4PM.
- Forecast features analyzed and described daily formed the basis for adaptive sampling recommendations for the 2PM (PDT) Real-Time Operational Committee (RTOC) meetings at MBARI.
- Web: http://www.deas.harvard.edu/~leslie/AOSNII/index.html for distribution of field and error forecasts, scientific analyses, data analyses, special products and control-room presentations
- 10 sets of real-time ESSE forecasts issued from 4 Aug. to 3 Sep. – total of 4323 ensemble members (stochastic model, BCs and forcings), 270 – 500 members per day; Lermusiaux *et al*., Joint Session 7, Paper J7.5

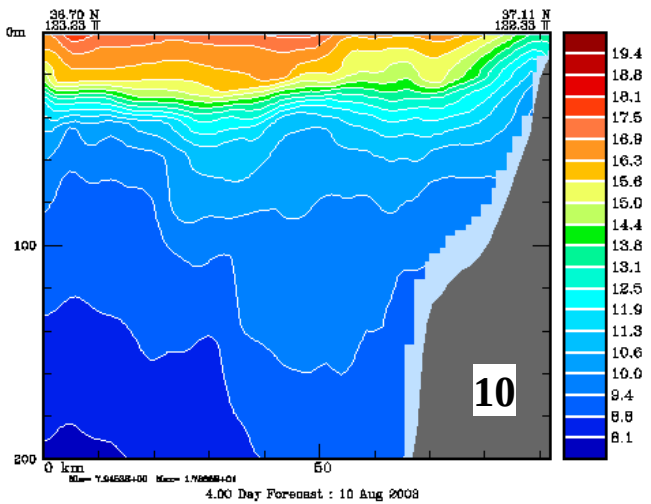

Max Winds: 28.3 knots
on 11 August
Wind Vectors at Buoy M1
29 July – 7 September 2003
10 knots = 5.14 m/s = 0.48 dynes/cm2
7-12 Aug
18-23 Aug
(R)
U
R
U
R
6 Aug
19 Aug
23 Aug
1 Sep
210
215
220
225
230
235
240
245
250
Year Day

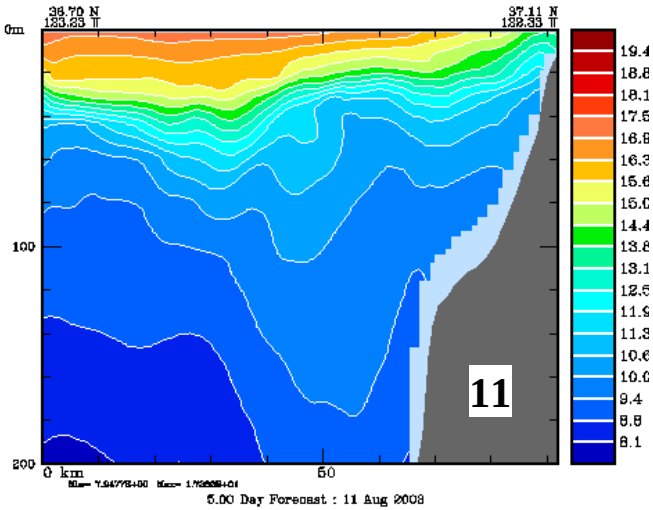
7-12 August – Onset and Sustained Upwelling Conditions

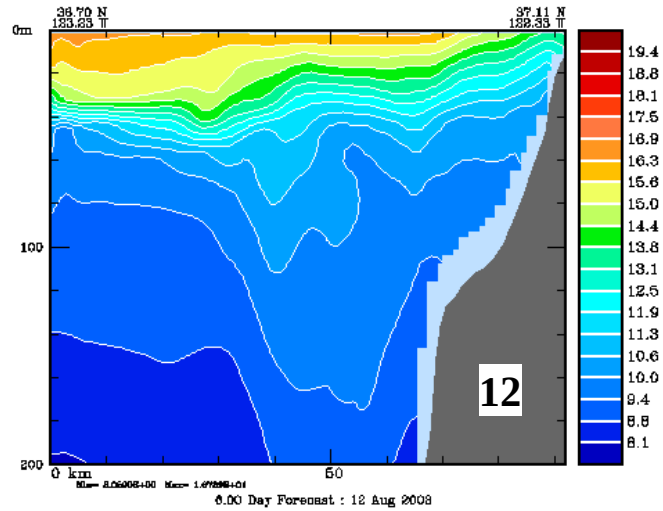


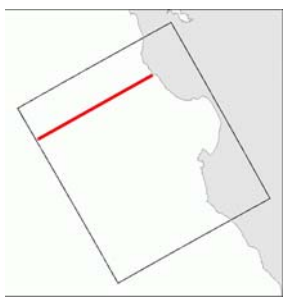




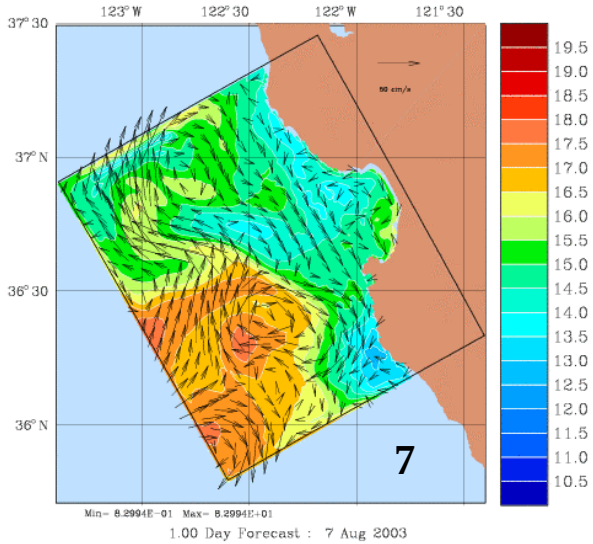


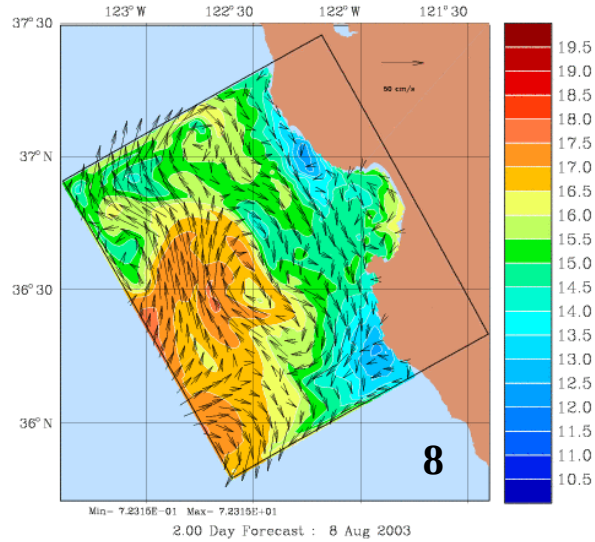


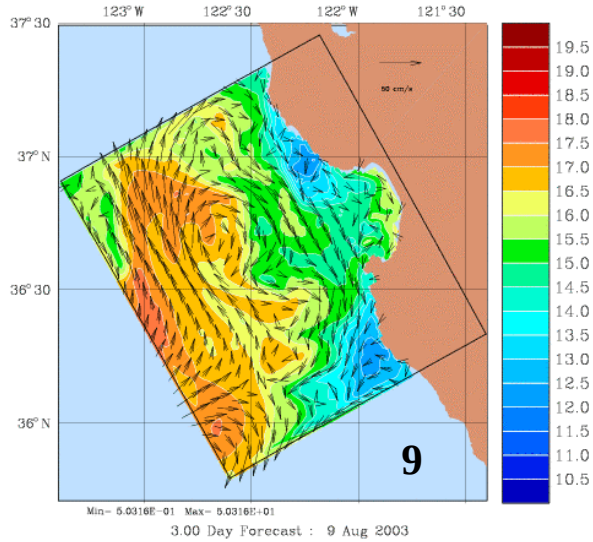


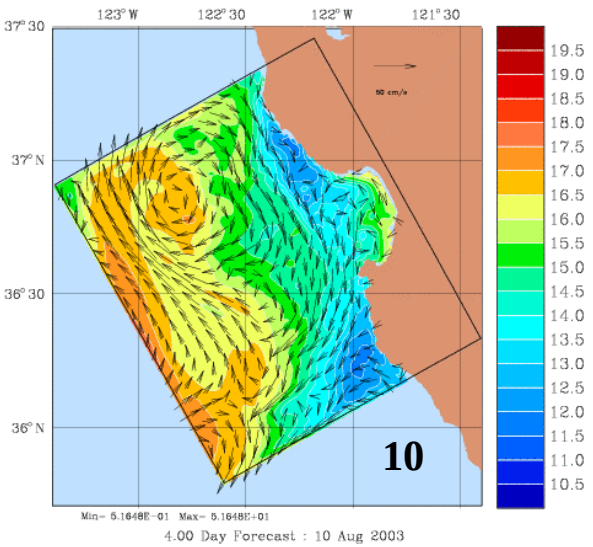


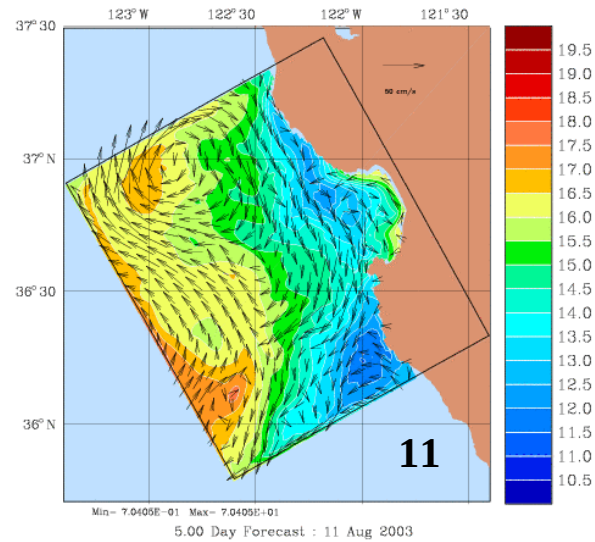
7-12 August – Onset and Sustained Upwelling Conditions

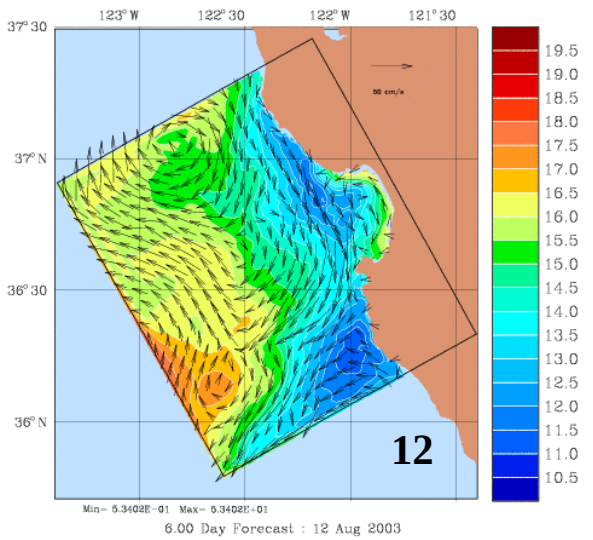


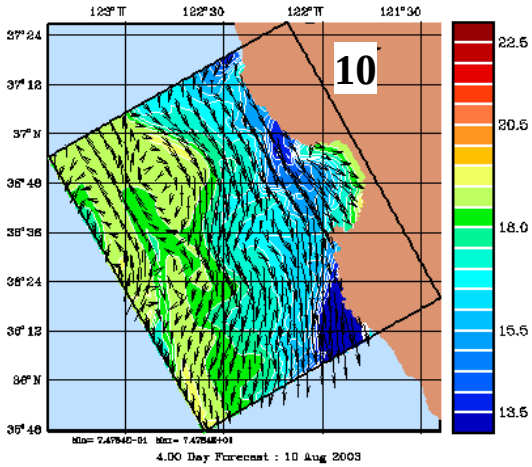


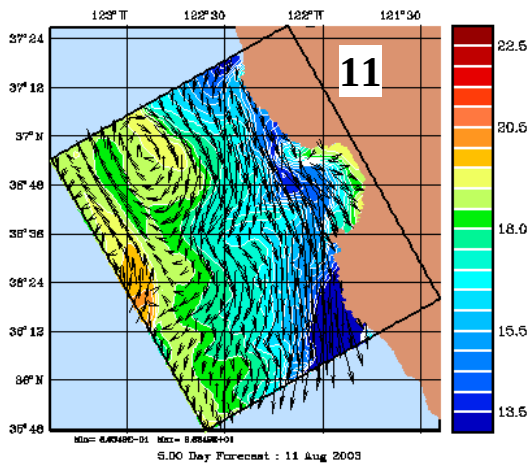


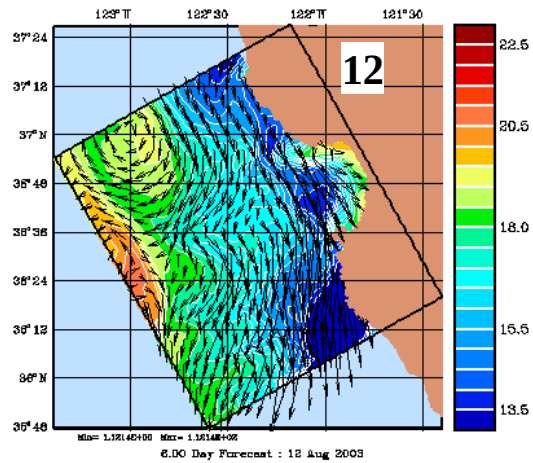




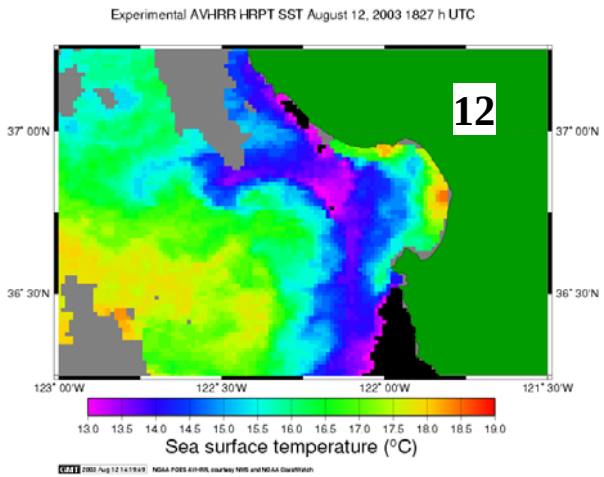


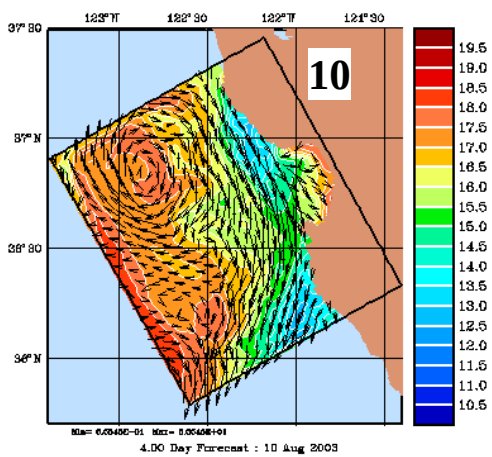


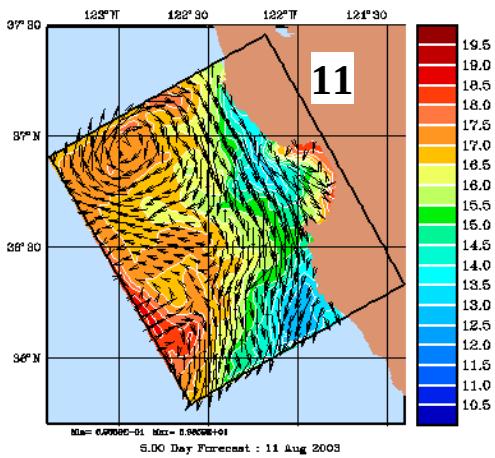


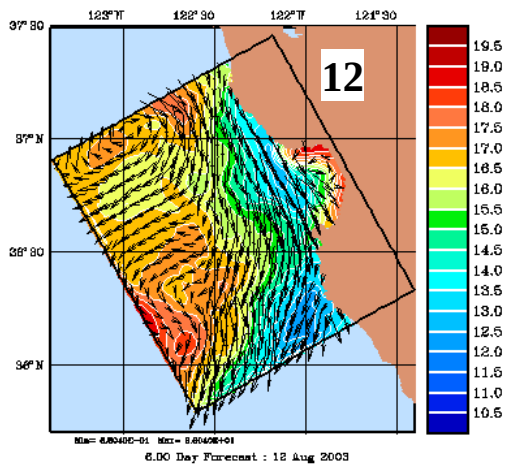


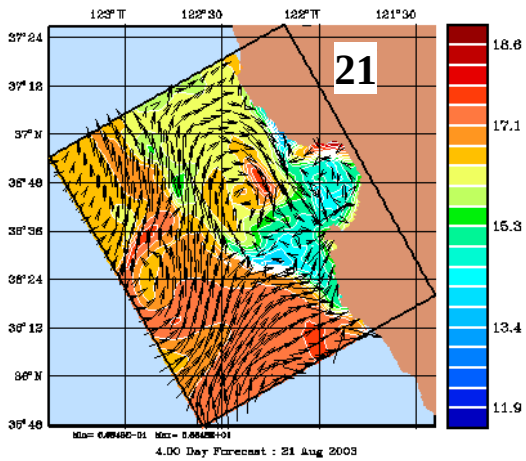
Sustained upwelling: comparison of real-time forecasts (top) with AVHRR SST (right) and re-analysis fields (bottom)

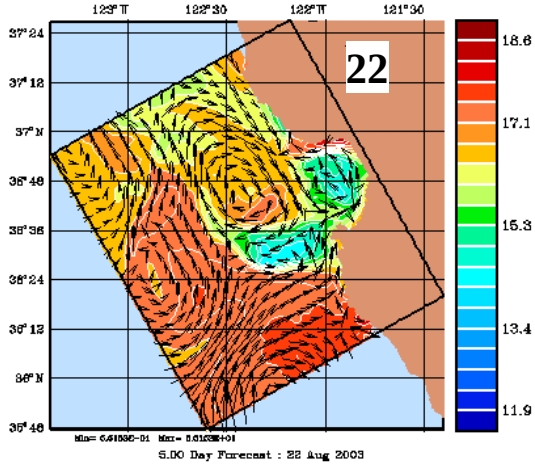


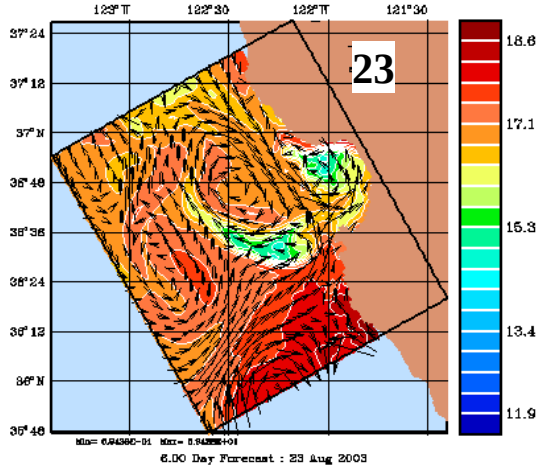




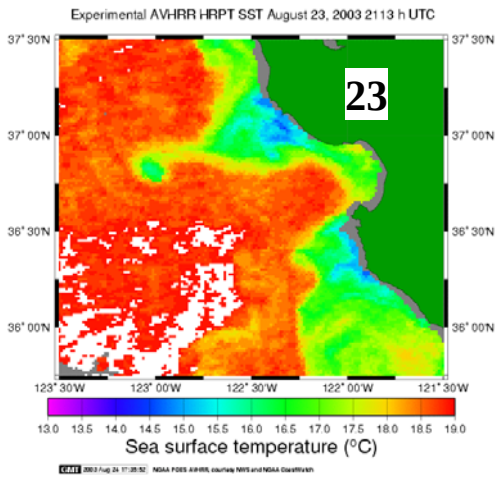


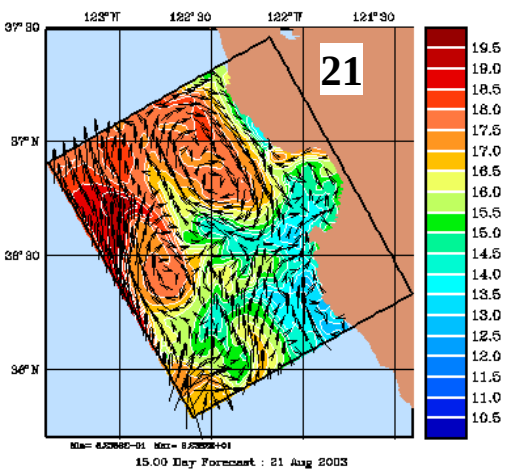


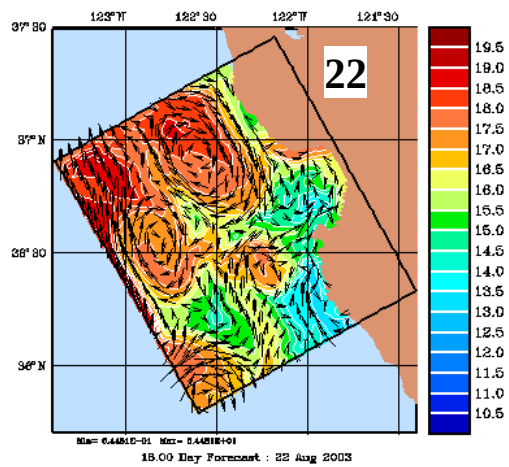


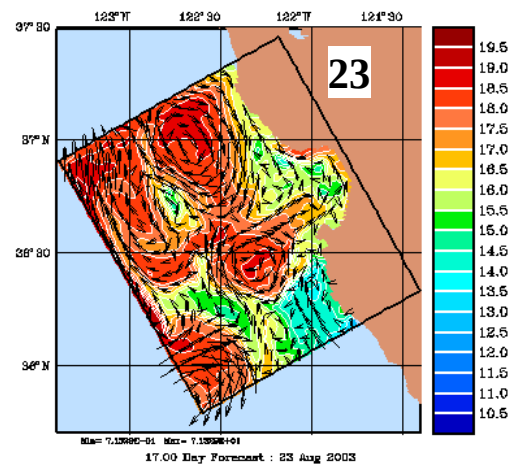


Relaxation: comparison of real-time forecasts (top) with AVHRR SST (right) and re-analysis fields (bottom)



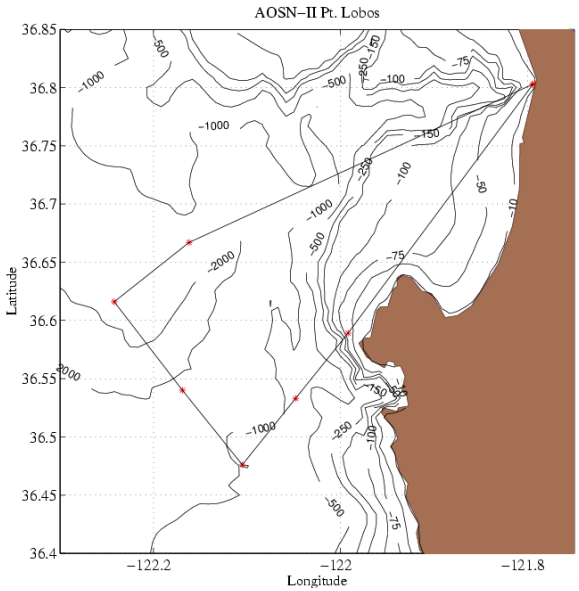




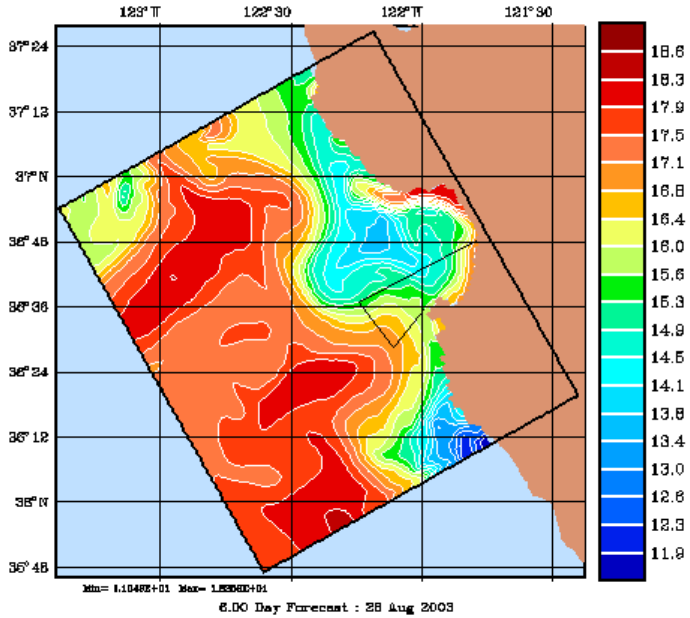


Real-time Adaptive Sampling – Pt. Lobos

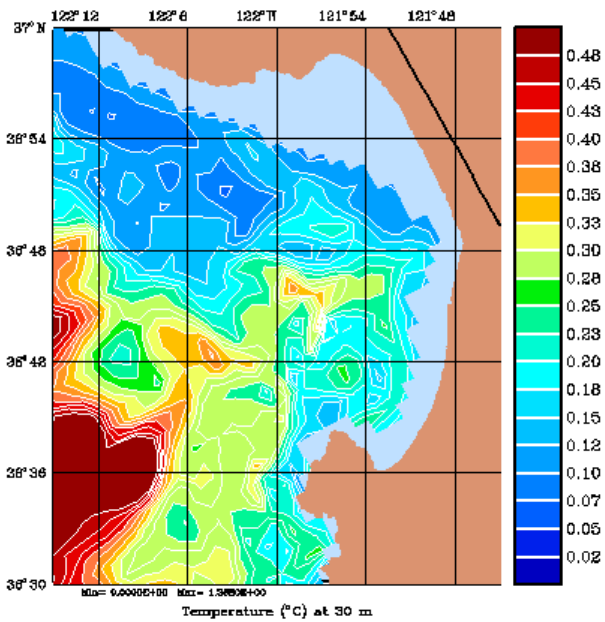
- Large uncertainty forecast on 26 Aug. related to predicted meander of the coastal current which advected warm and fresh waters towards Monterey Bay Peninsula.
- Position and strength of meander were very uncertain (e.g. T and S error St. Dev., based on 450 2-day fcsts).
- Different ensemble members showed that the meander could be very weak (almost not present) or further north than in the central forecast
- Sampling plan designed to investigate position and strength of meander and region of high forecast uncertainty.



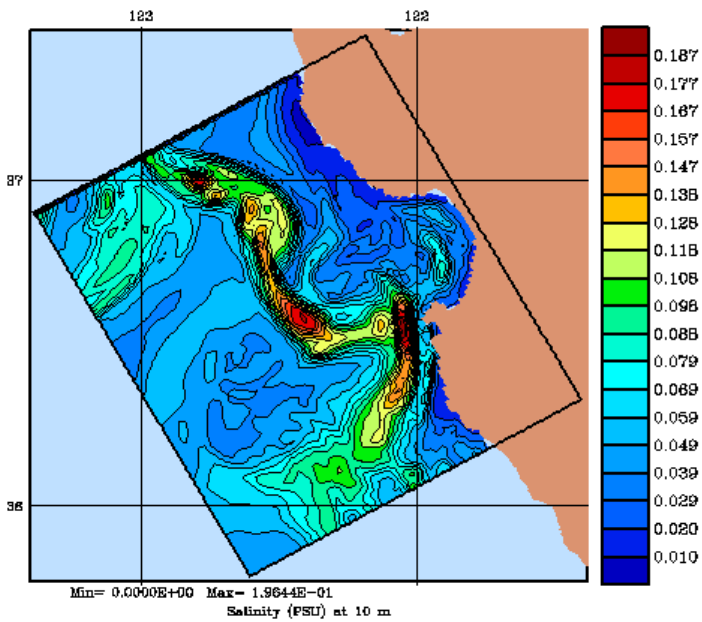
Surf. Temperature Fcst.



Temperature Error Fcst.

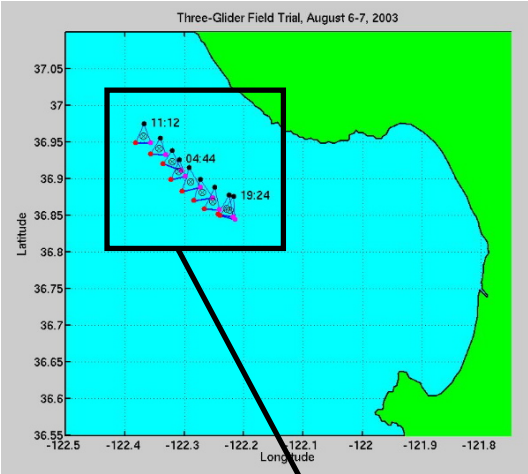


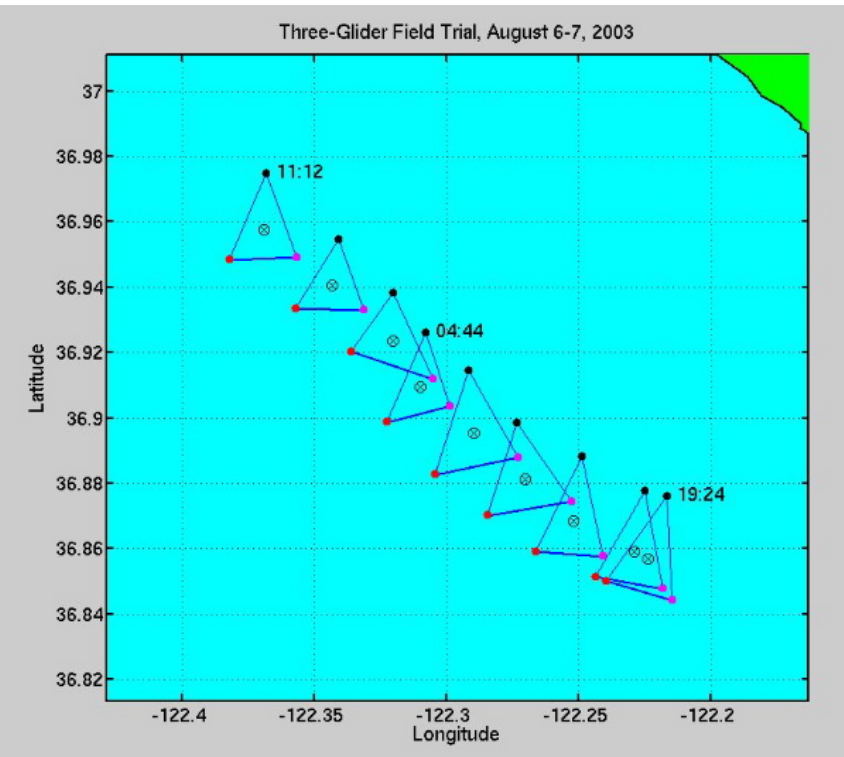
Salinity Error Fcst.

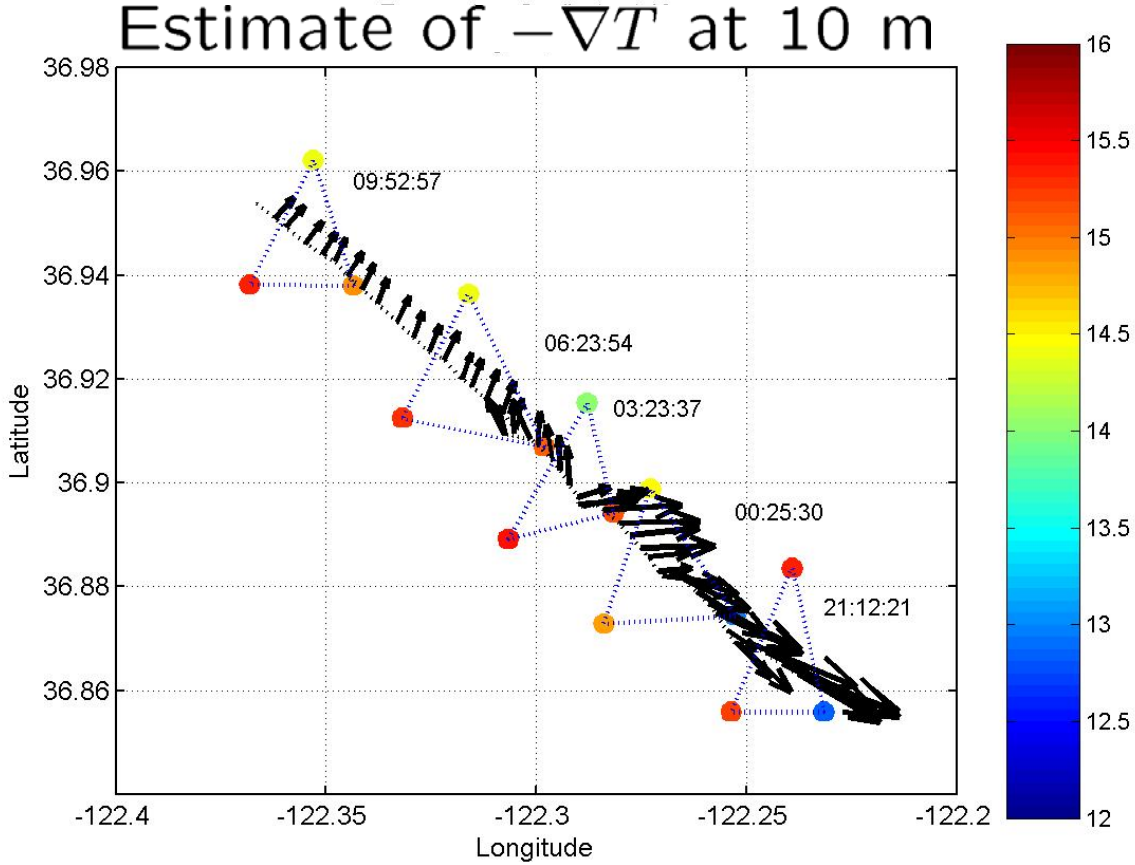


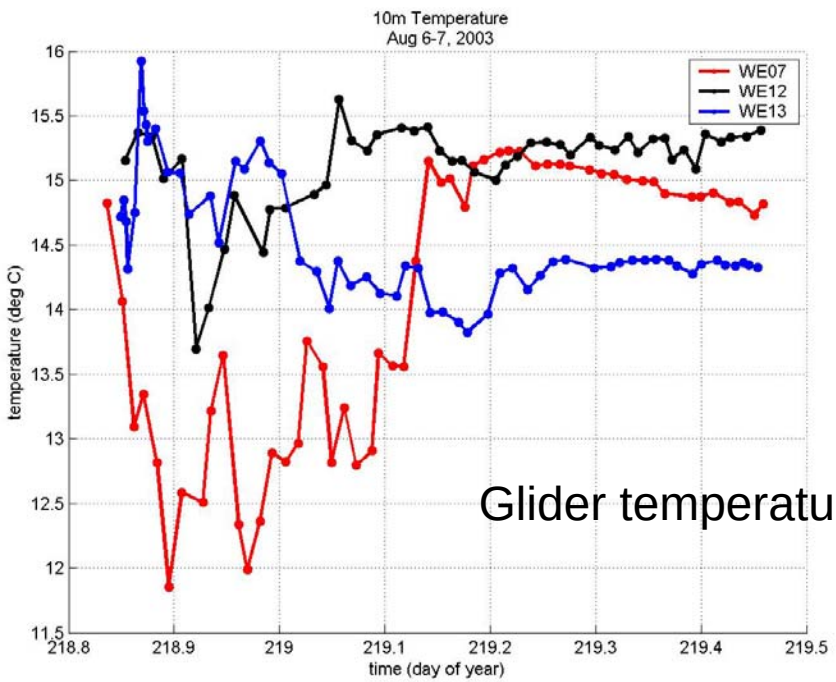
Coordinated 3-Glider Exp. with Gradient Estimate

Aug 6-7, 2003



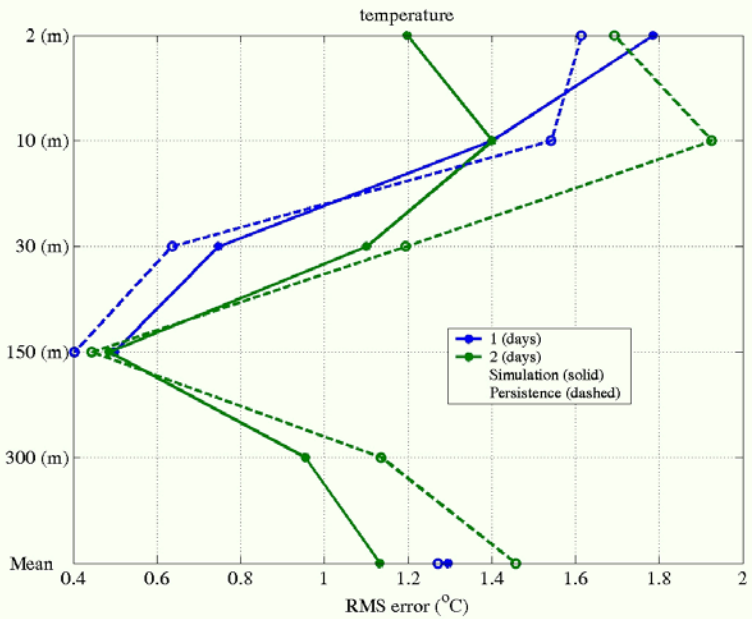


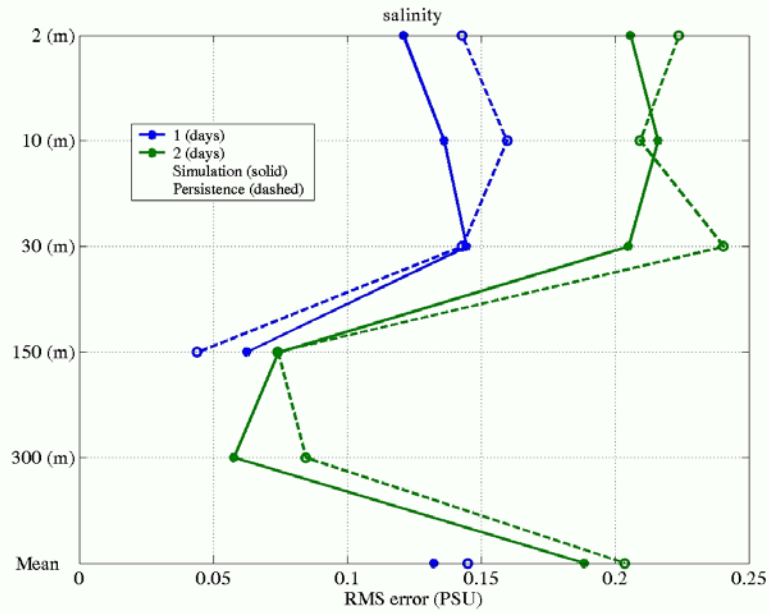




Glider temperature profiles

Forecast RMS Error Estimate– Temperature (left), Salinity (right)



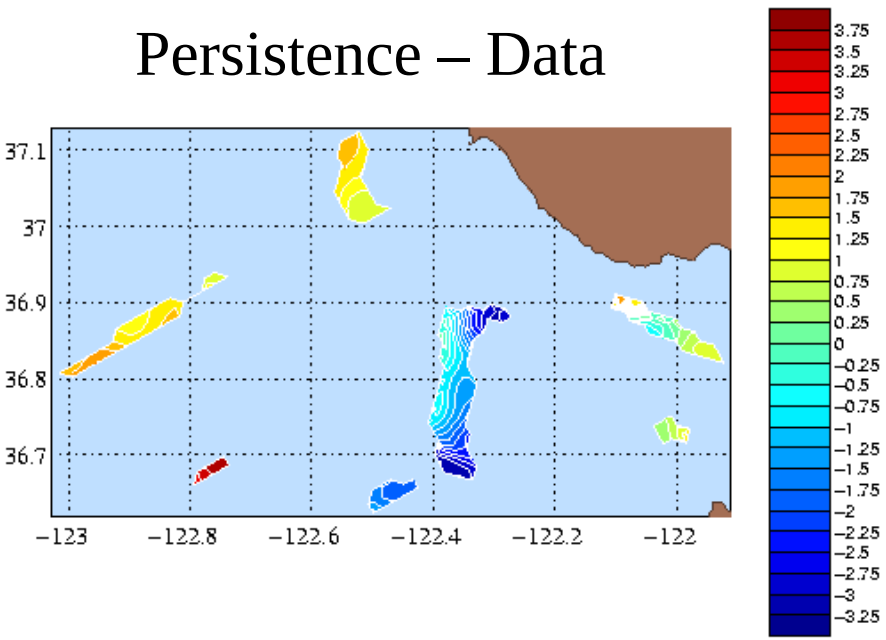


Blue – 12 Aug
Green – 13 Aug

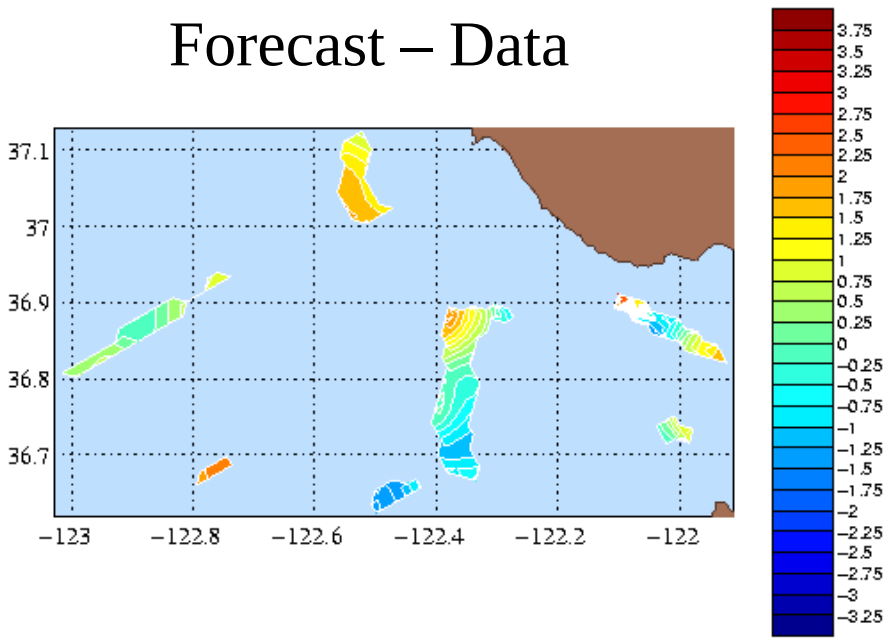
Solid – Forecast
Dash – Persistence

T Difference (at 2m) for 13 August

Persistence – Data

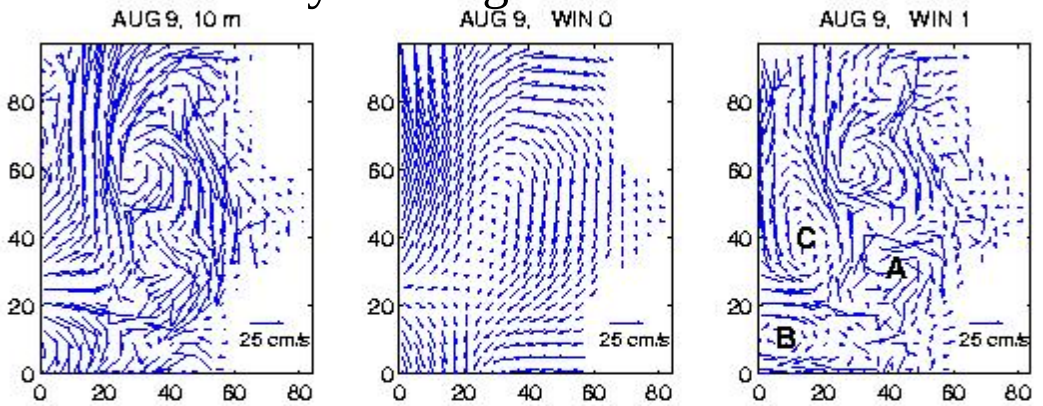


Forecast – Data

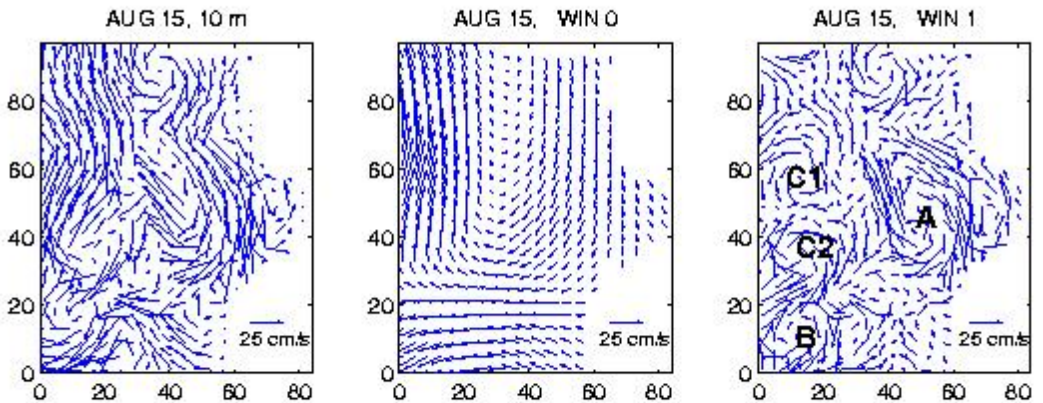


Multi-Scale Energy and Vorticity Analysis

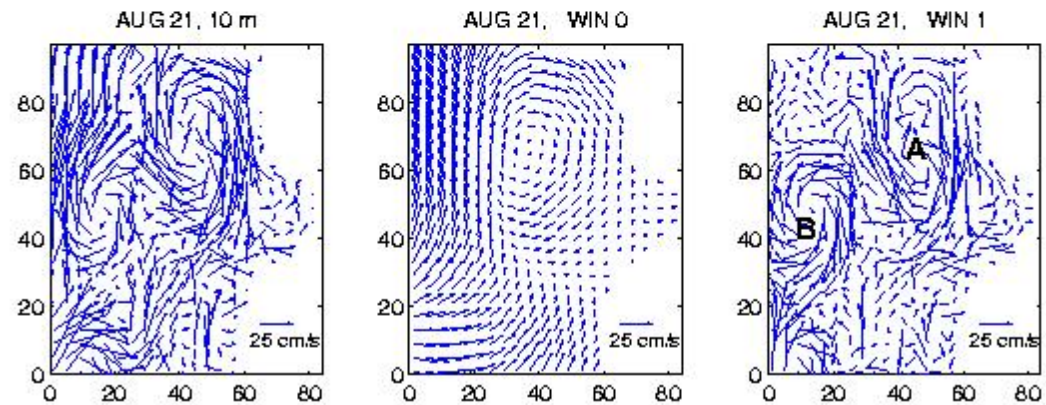
Total Velocity | Large Scale | Mesoscale



Onset of U



Sustained U



Mid-Relaxation

Anticyclonic Eddy A appears on Aug. 9 off southern Monterey Bay. By Aug. 15, it has strengthened outside the Bay. It remains until Aug. 18, when the wind begins to relax. The southward flow on its eastern flank together with the northward coastal current causes a secondary upwelling within the bay. After the wind relaxes, Eddy A propagates northward, and by Aug. 21, its center is close to Point Ano Nuevo. The current accompanying it and the coastal current lead to a northward progression of the upwelling event along the coast during the relaxation period.

Anticyclonic Eddy B is originally very weak at the southwestern corner (Aug. 9). North of it lies a strong cyclonic eddy C. By Aug. 15, C has been split into a cyclone C1 and an anticyclone C2. C1 then disappears, and B and C2 merges into a large anticyclonic eddy (August 16). The new B propagates northward and by Aug. 21, the whole domain is dominated by two anticyclonic eddies: B and A.

In the large scale window, the circulation is dominated by an anticyclonic gyre, with the coastal side current strengthened and weakened under upwelling and relaxation wind conditions.

HOPS – AOSN-II Conclusions

- HOPS is a generic, regional, data assimilative forecast system driven by surface fluxes and historical and contemporary synoptic mesoscale data
- From 4 August – 3 September 2003, daily real-time forecasts of 3 days duration assimilated data from two fleets of gliders, aircraft, ships, etc. and identified features for adaptive sampling
- Onset and sustained upwelling and relaxation phenomena were successfully captured, together with their dynamic mesoscale variabilities
- Preliminary results of real-time forecast evaluation indicates generally good RMS values that beat persistence
- Further research includes re-analysis fields, methodology for skill determination, multi-model interpretation of HOPS results together with ROMS results and multi-scale dynamical analyses