Application of the Generic Harvard Ocean Prediction System (HOPS) to Real-Time Forecasting with Adaptive Sampling off the Central California Coast During AOSN-II

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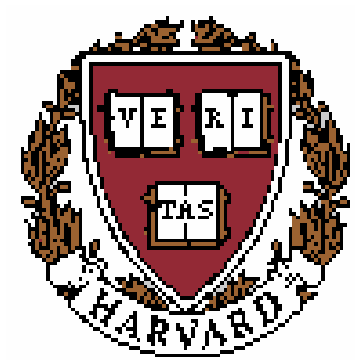
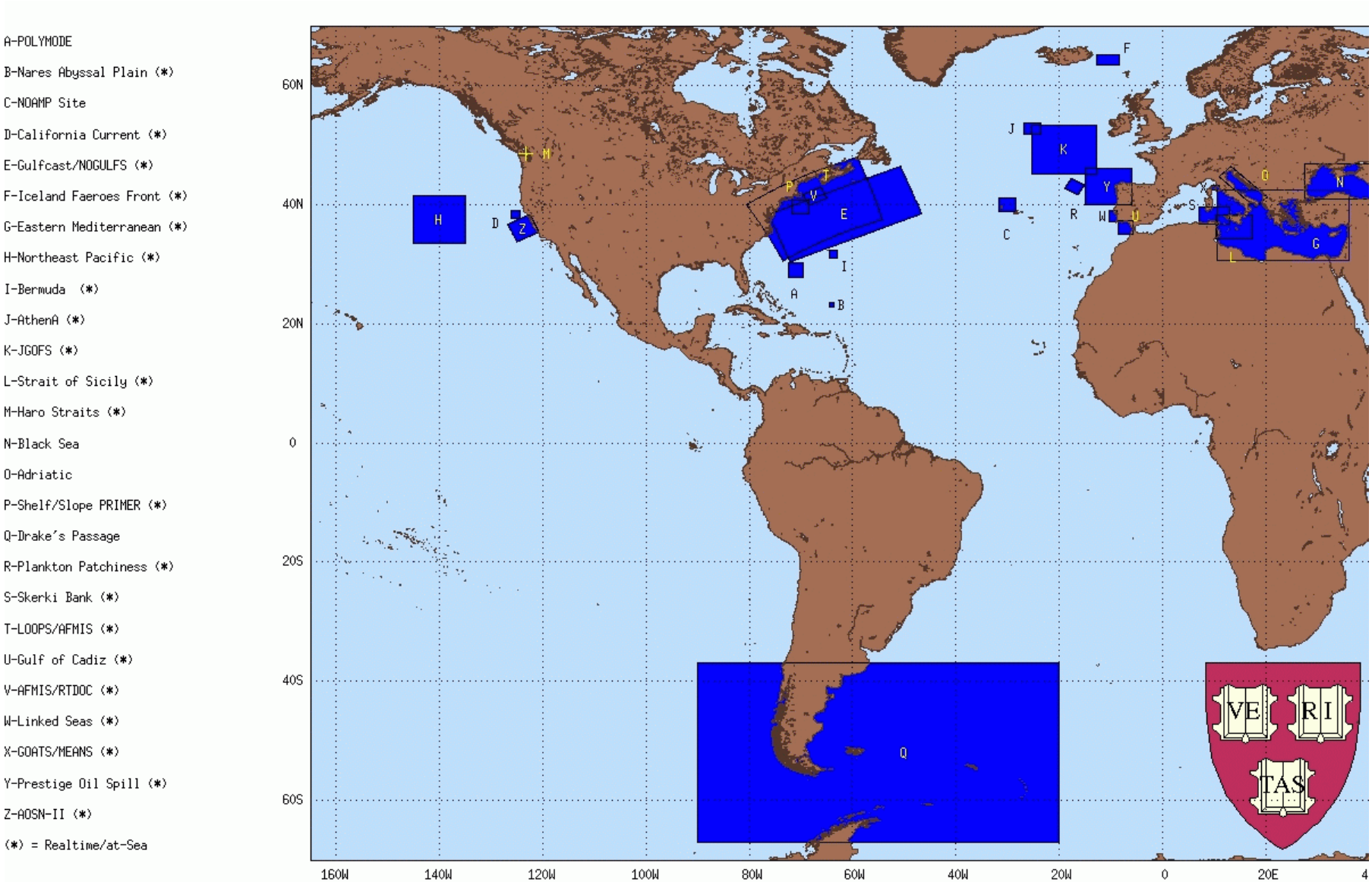


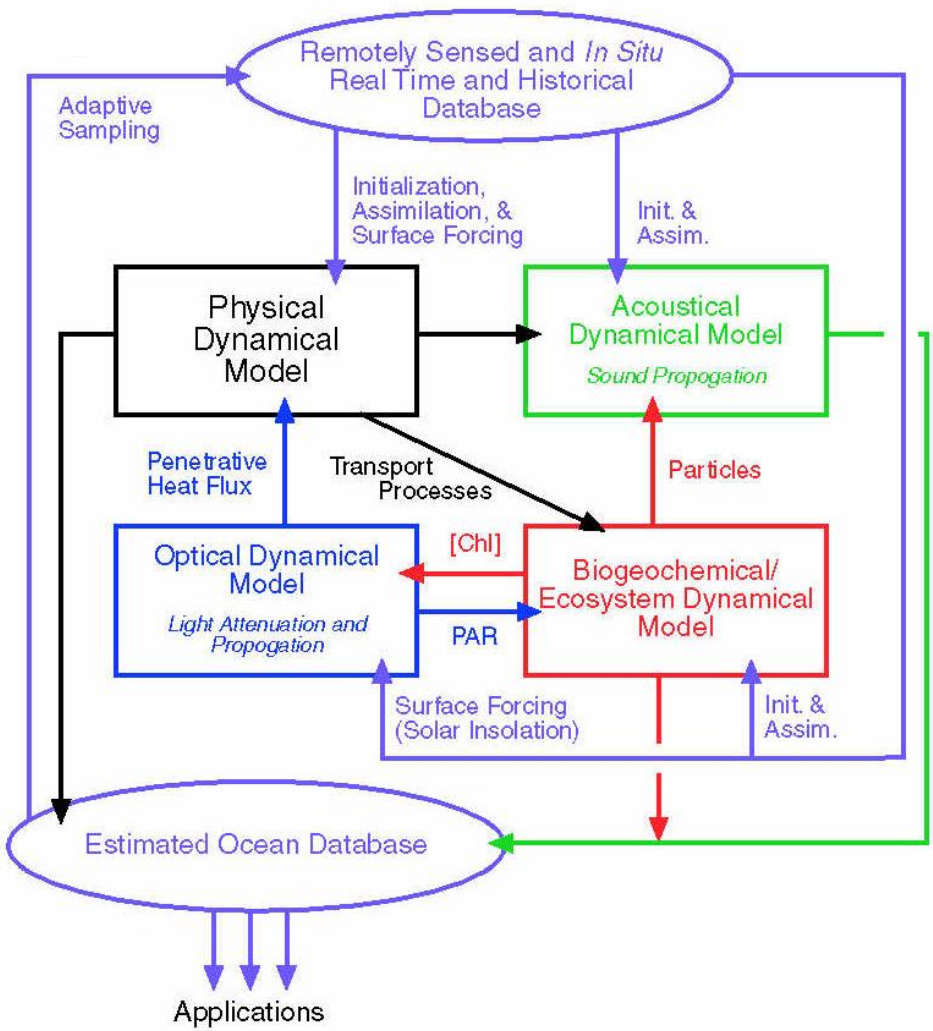
AMS Annual Meeting, Seattle, Washington
January 13, 2004
http://www.deas.harvard.edu/~robinson

- **HOPS – a generic, relocatable, regional forecast system**
- **Coastal shelf, slope and deep sea regions**
- **Real-time forecasts of internal ocean weather, atmospheric forcing response, and their non-linear interactions**

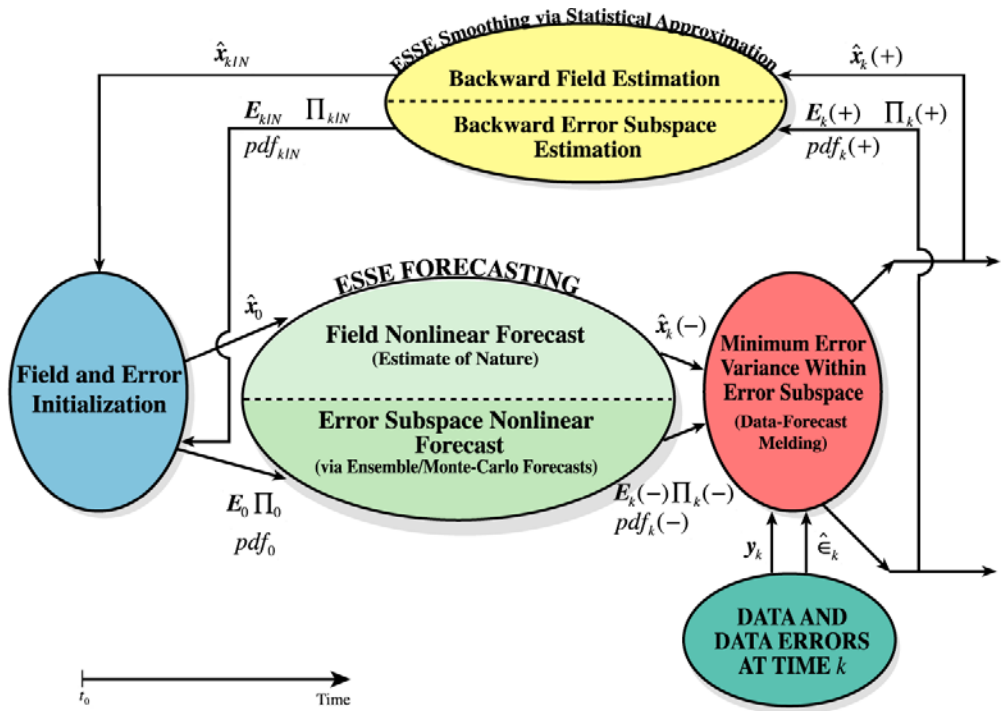


Harvard Ocean Prediction System - HOPS

Multivariate Coupled Physical-Acoustical-Biological System

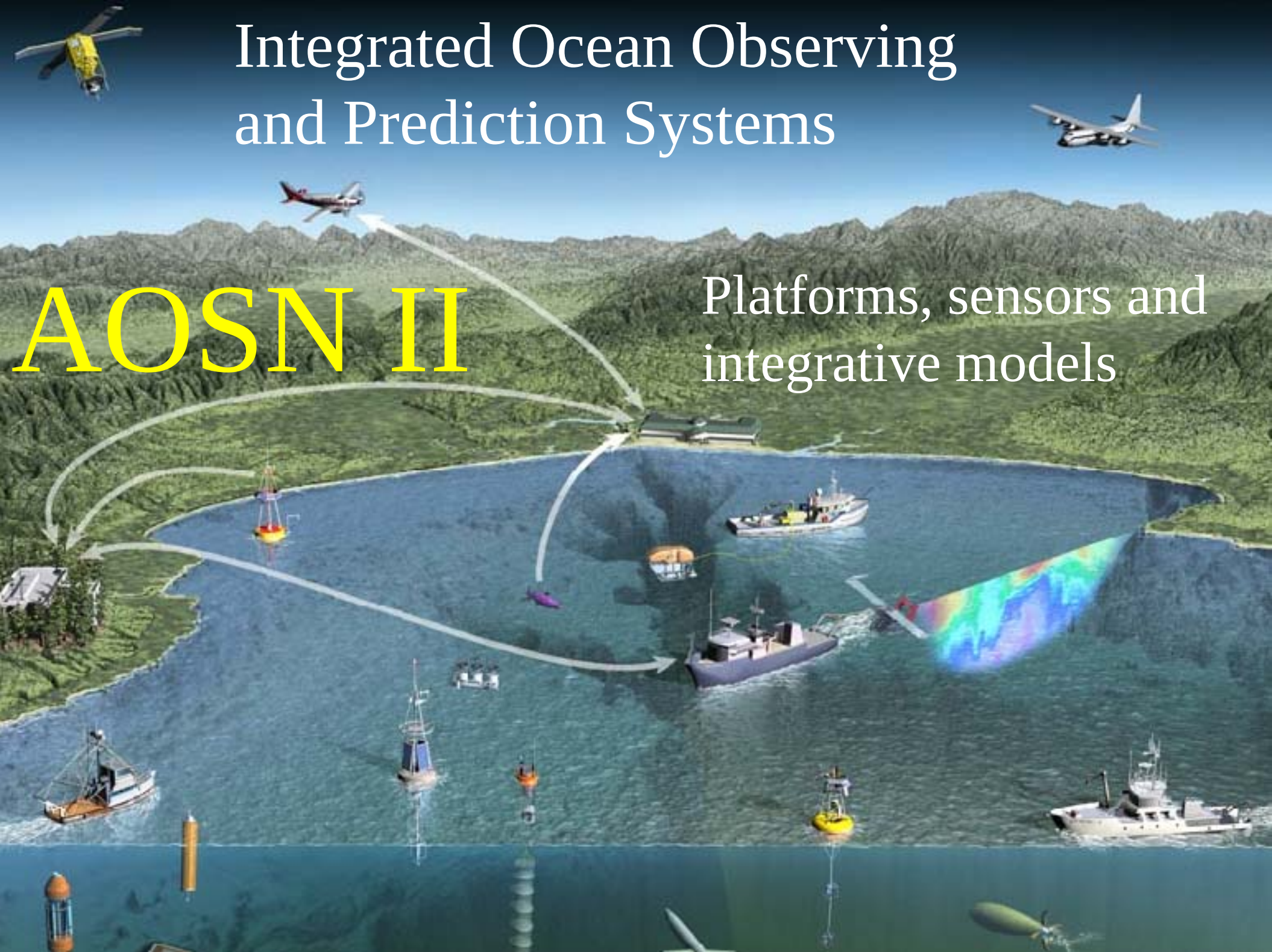


Data Assimilation: combines model and data for best ocean estimate: optimal interpolation (OI) or Error Subspace Statistical Estimation (ESSE)

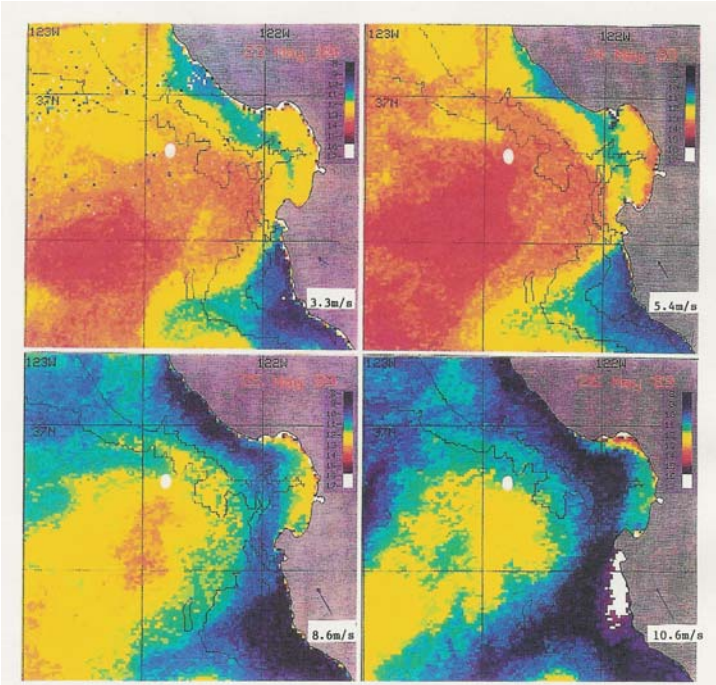


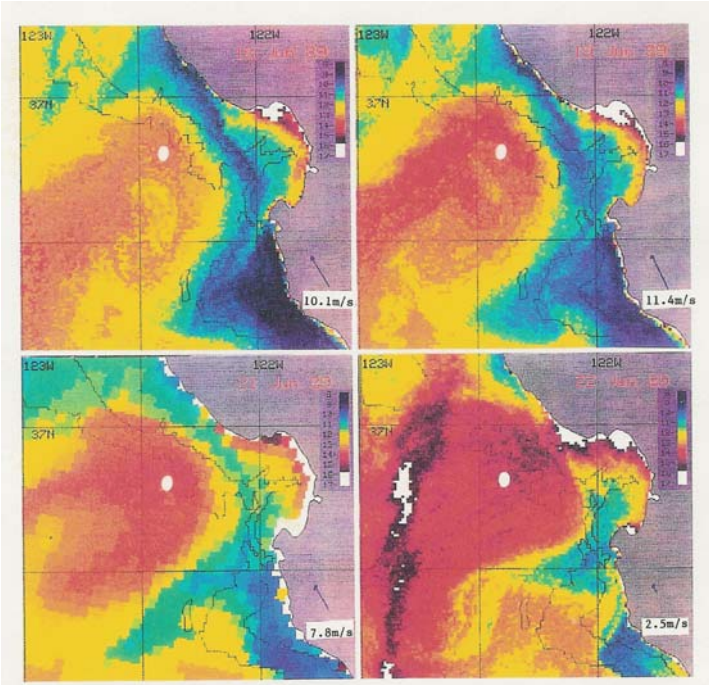
HOPS – Regional Forecast Methodology

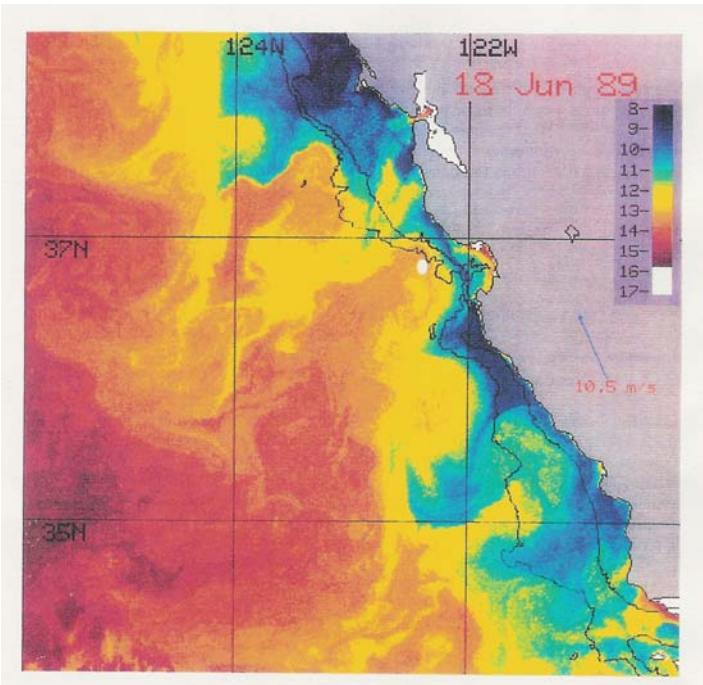
- Region of operational forecast interest is generally two-way nested with larger influential regional domain(s)
- Largest domain (which can be stand-alone operational interest domain) has open boundary conditions
- Initialization via a combination of: historical synoptic data; feature models (synoptic climatology); and contemporary synoptic mesoscale data
- Contemporary data gradually replaces prior options and is assimilated throughout the course of the operation
- Open boundary condition options include: specification of fields, fluxes; and radiation conditions in various forms and combinations
- Assimilates data from satellites, aircraft, ships, drifters, autonomous underwater vehicles (AUVs), gliders, and moorings


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

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





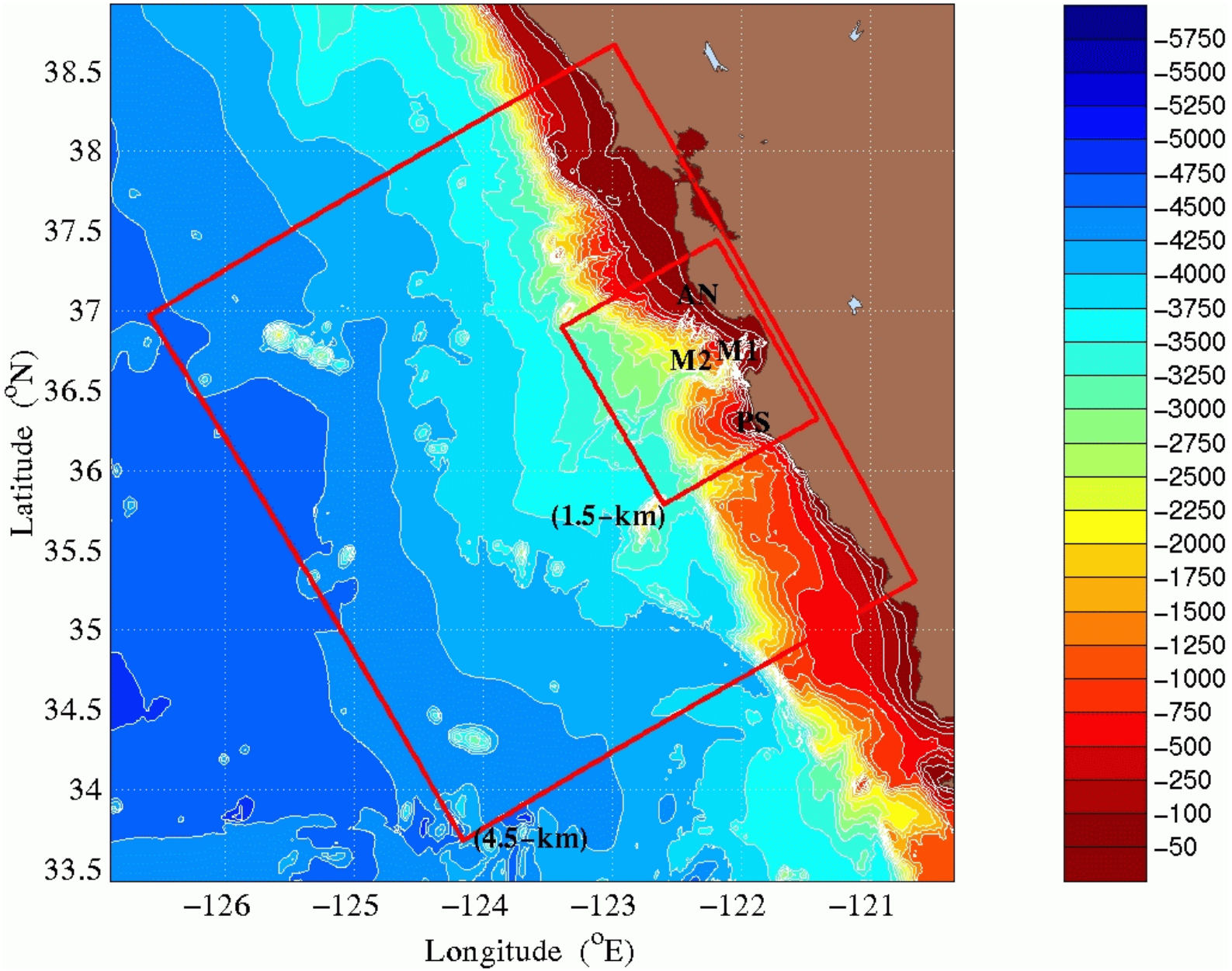


Top left – **Upwelling State** – 23-26 May 1989 – upwelled water from points moves equatorward and seaward – Point Año Nuevo water crosses entrance to Monterey Bay

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

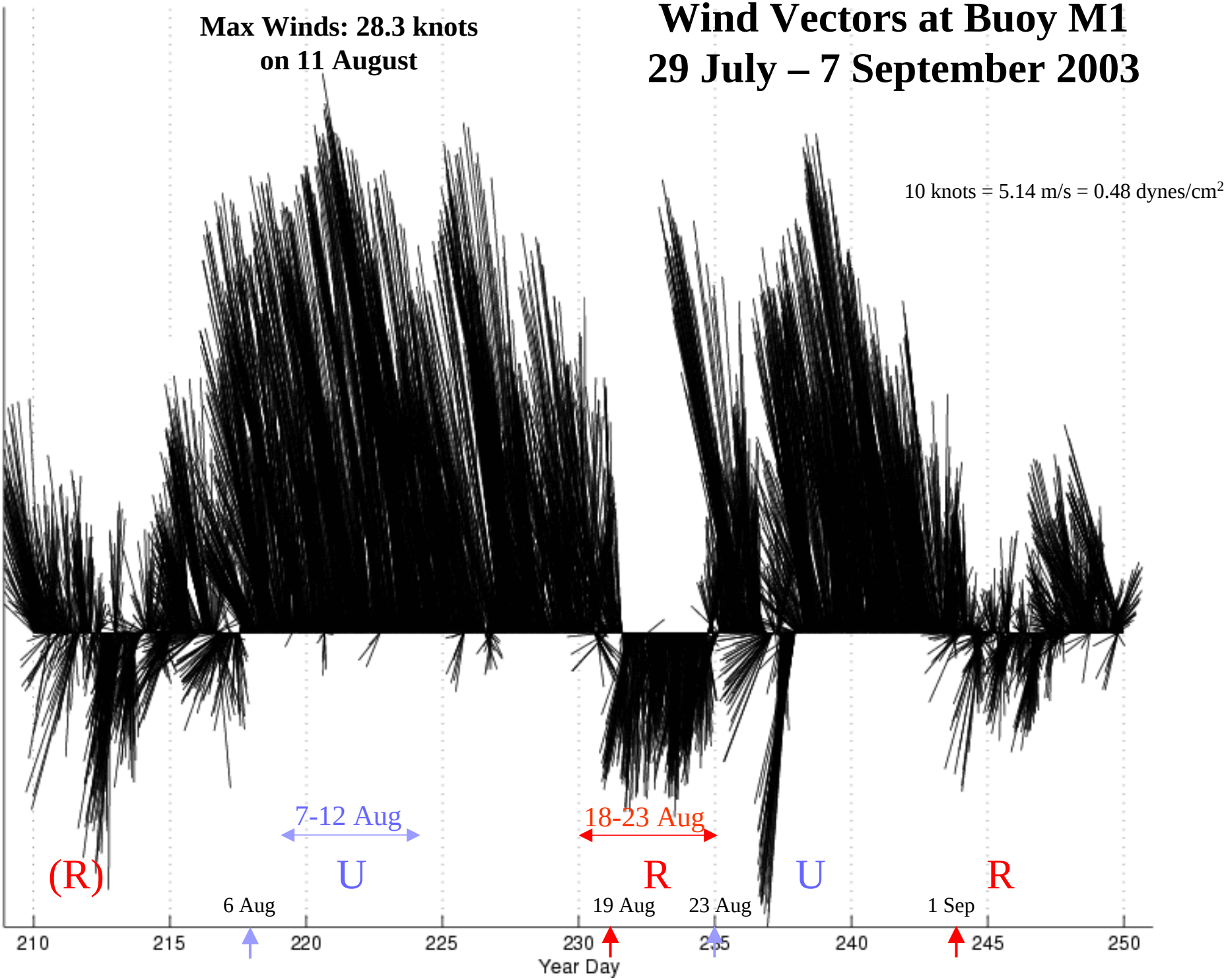
Bottom right – **Larger regional context** – 18 June 1989 – California Current System

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

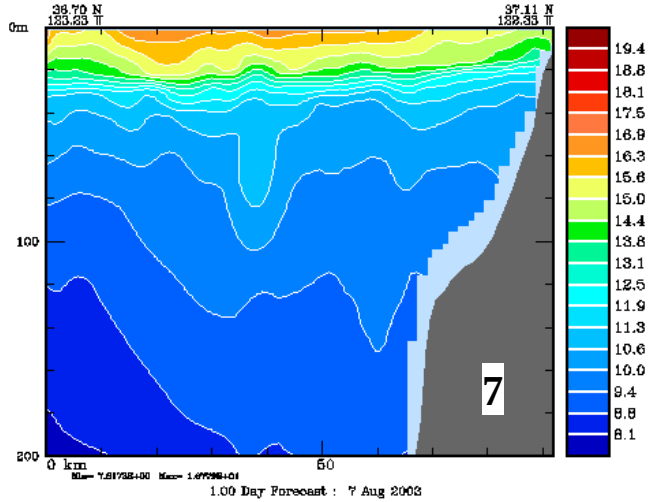


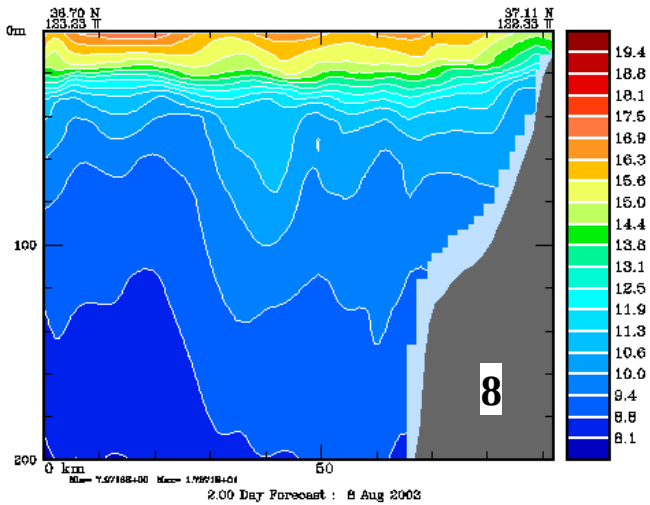
HOPS – AOSN-II Real-Time Forecasting

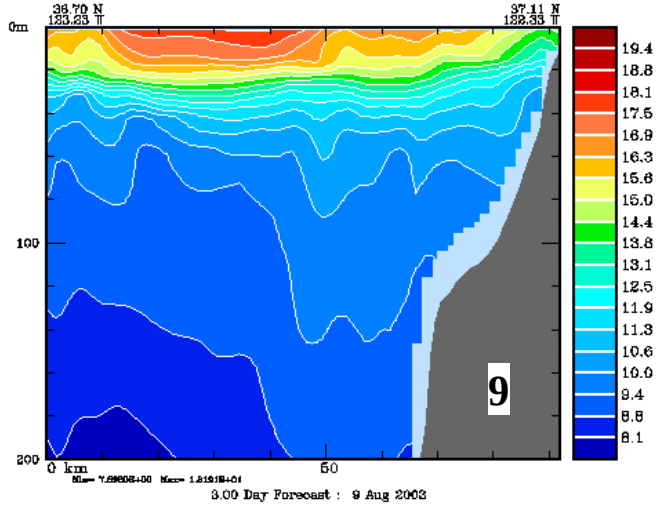
- 23 sets of real-time nowcasts and forecasts of temperature, salinity and velocity released from 4 August to 3 September
- Data from glider fleets, aircraft, ships, etc. archived in real-time at MBARI. Daily ftp to Harvard for quality control and analysis at 9AM EDT. Processed for initialization by 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

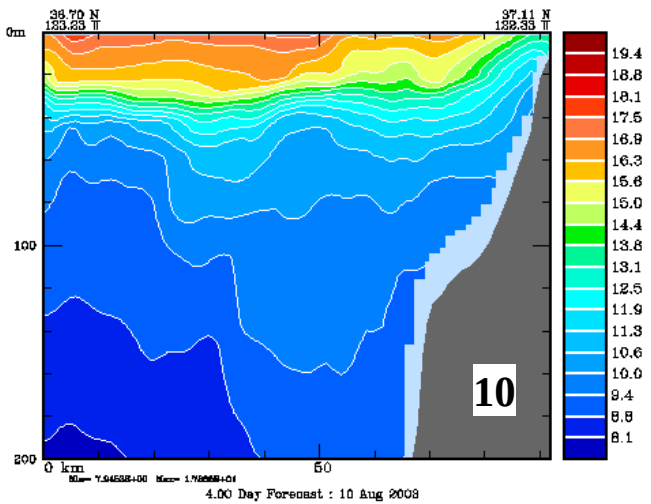

Max Winds: 28.3 knots
on 11 August
Wind Vectors at Buoy M1
29 July – 7 September 2003
10 knots = 5.14 m/s = 0.48 dynes/cm2
7-12 Aug
18-23 Aug
(R)
U
R
U
R
6 Aug
19 Aug
23 Aug
1 Sep
210
215
220
225
230
235
240
245
250
Year Day

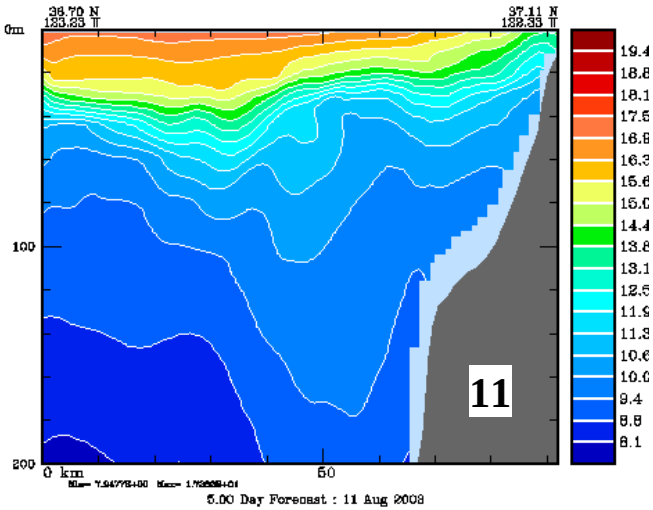
7-12 August – Onset and Sustained Upwelling Conditions

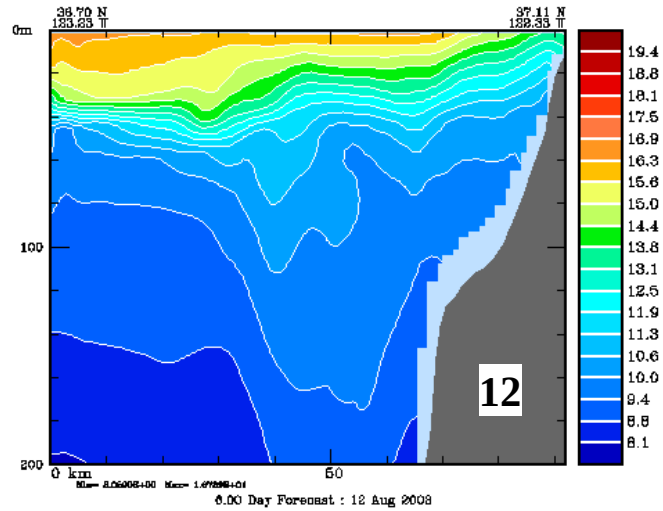


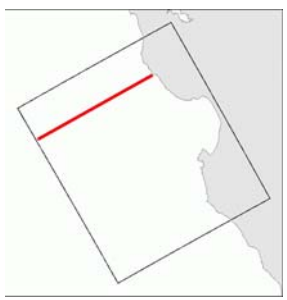




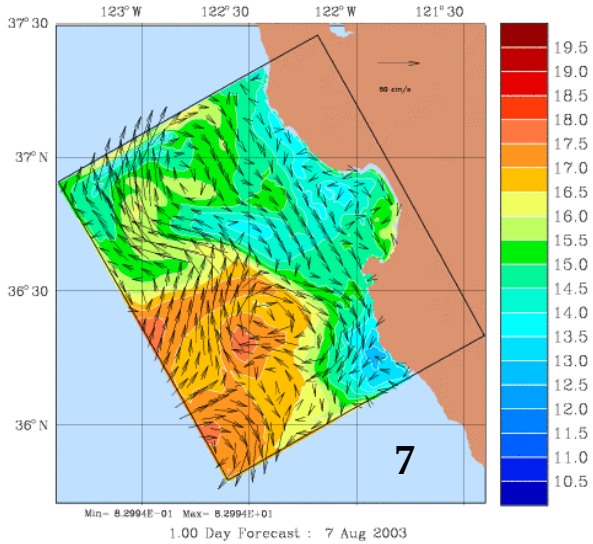


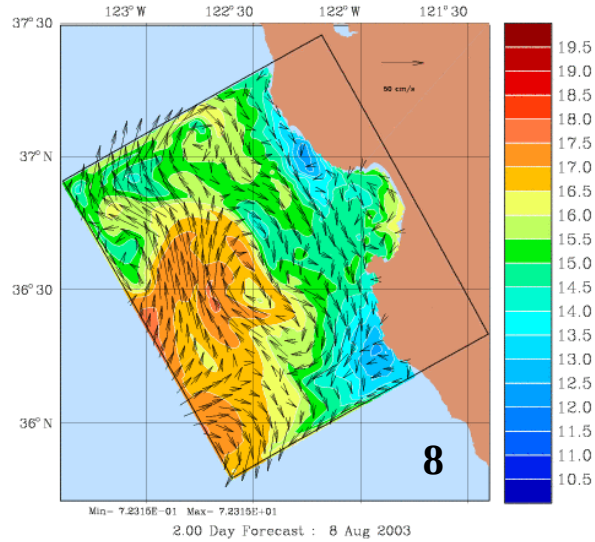


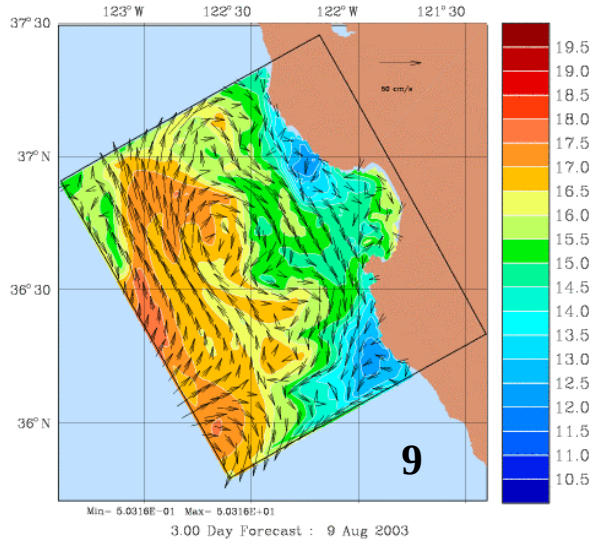


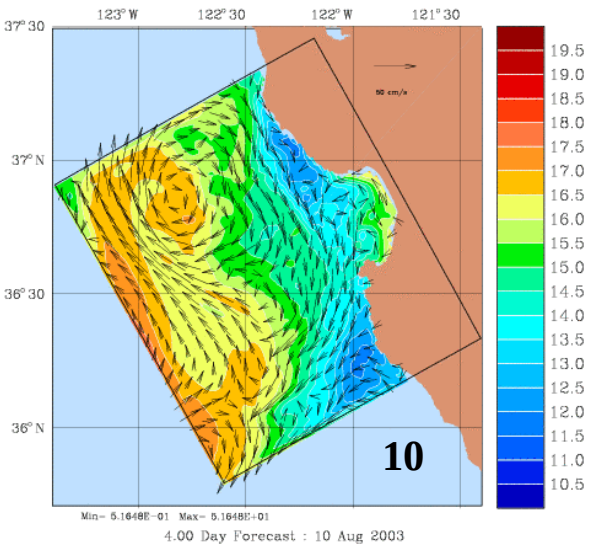


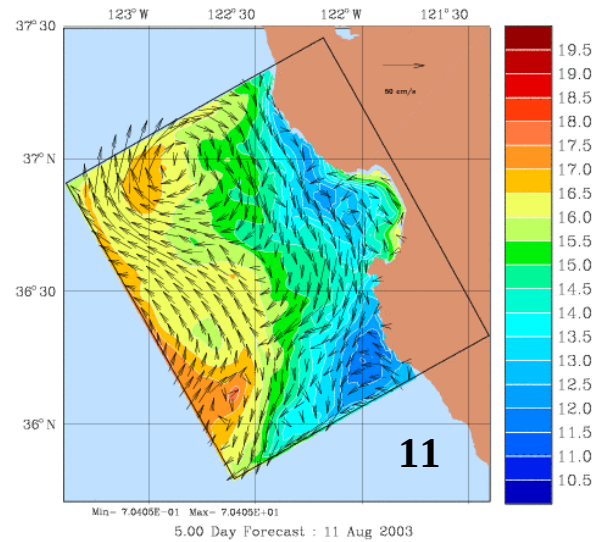
7-12 August – Onset and Sustained Upwelling Conditions

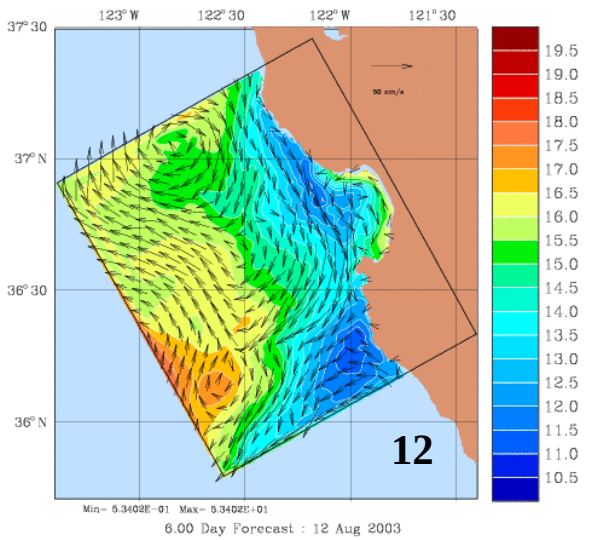




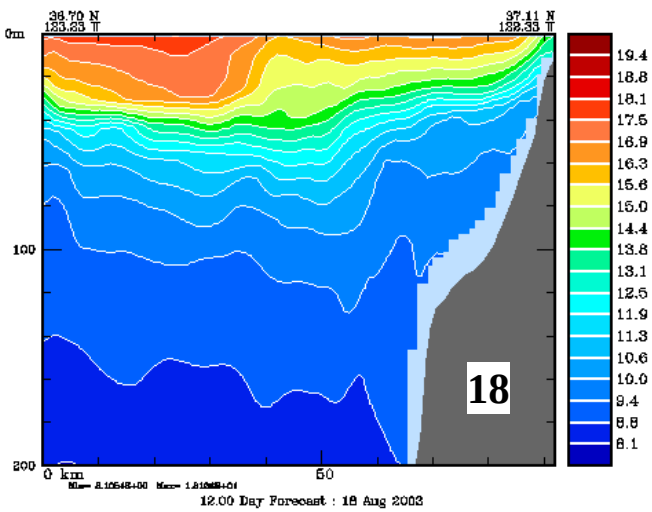


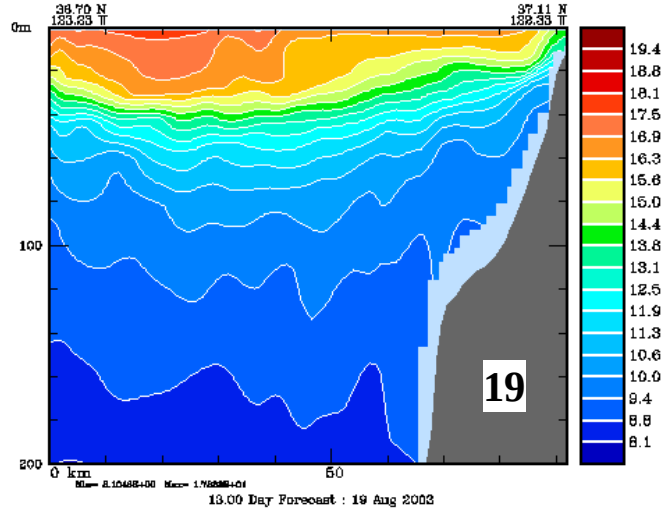


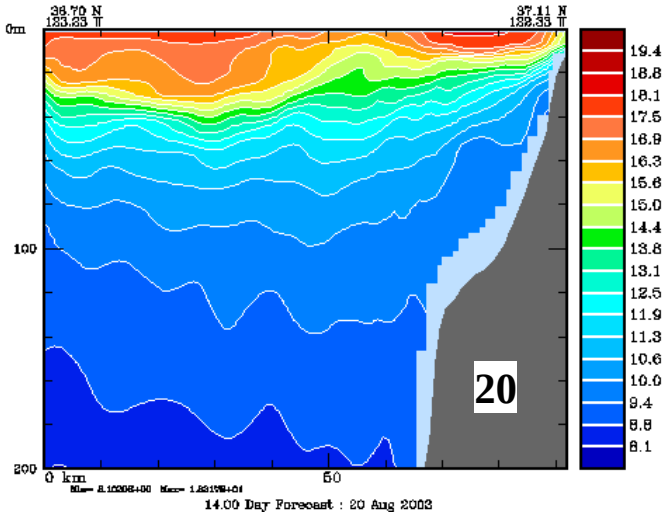


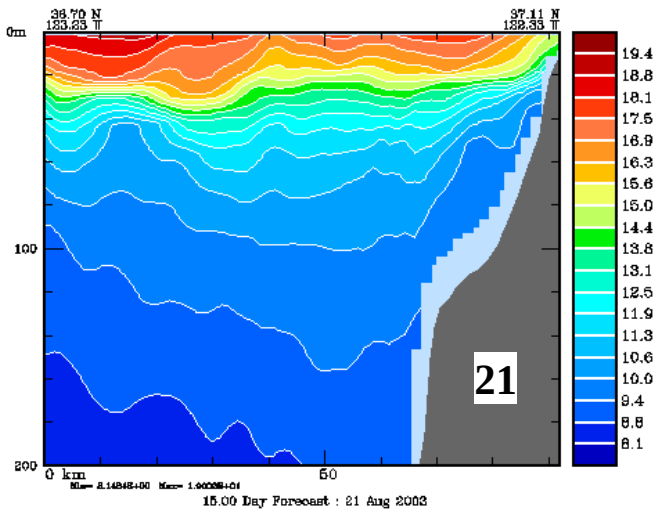


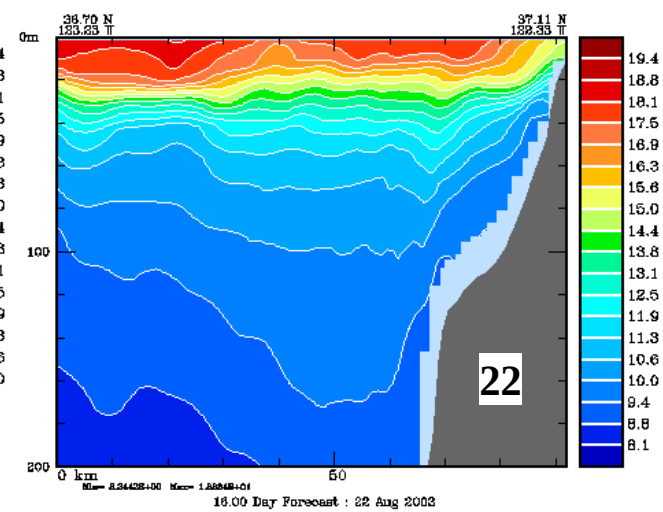
18-23 August – Development of Relaxation Conditions

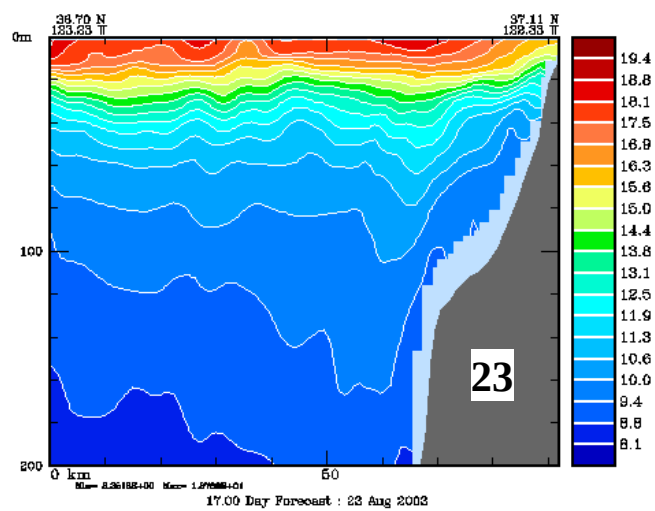


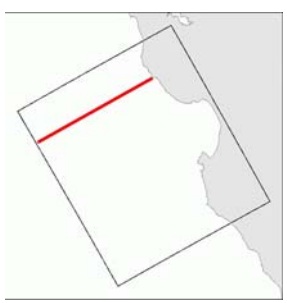




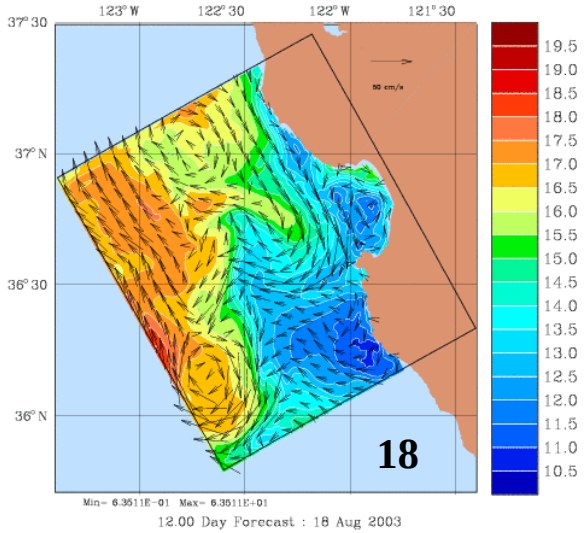


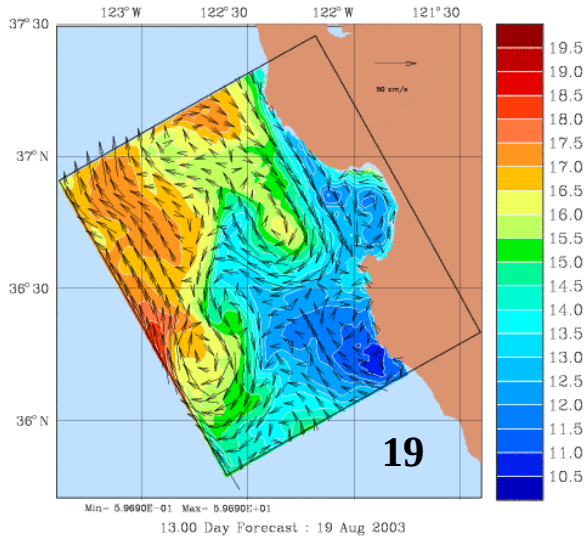


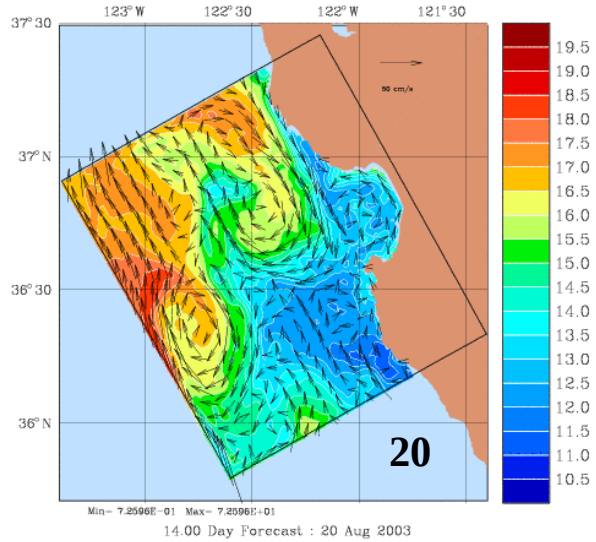


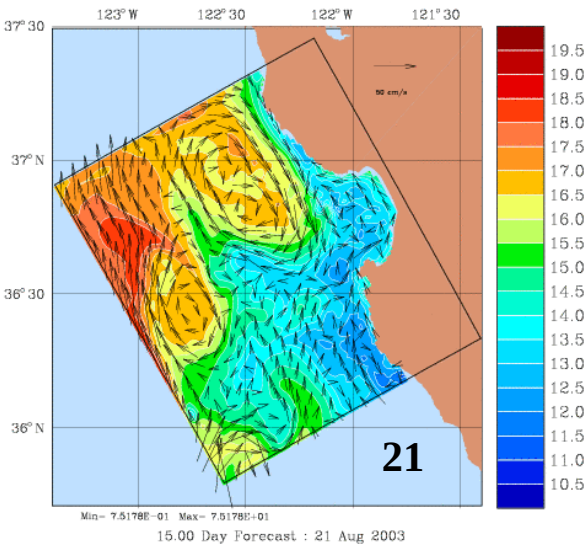


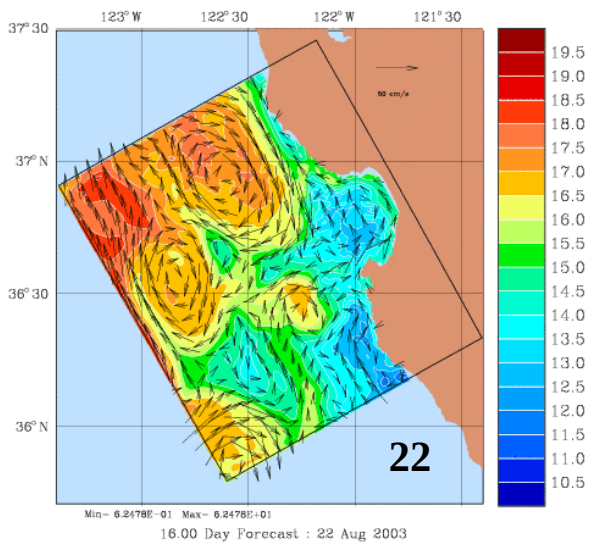
18-23 August – Development of Relaxation Conditions

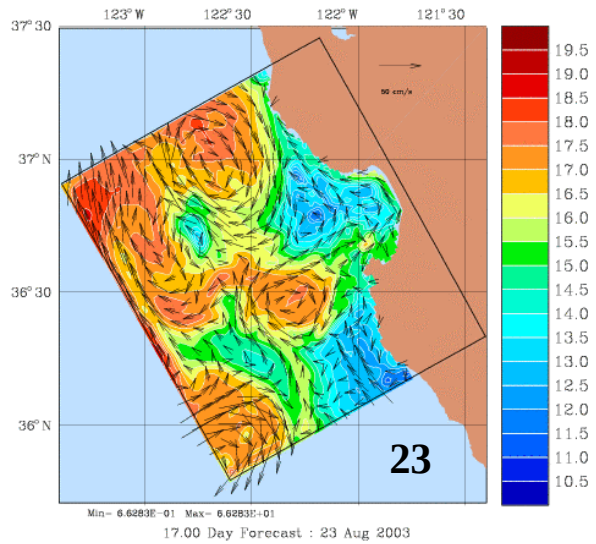










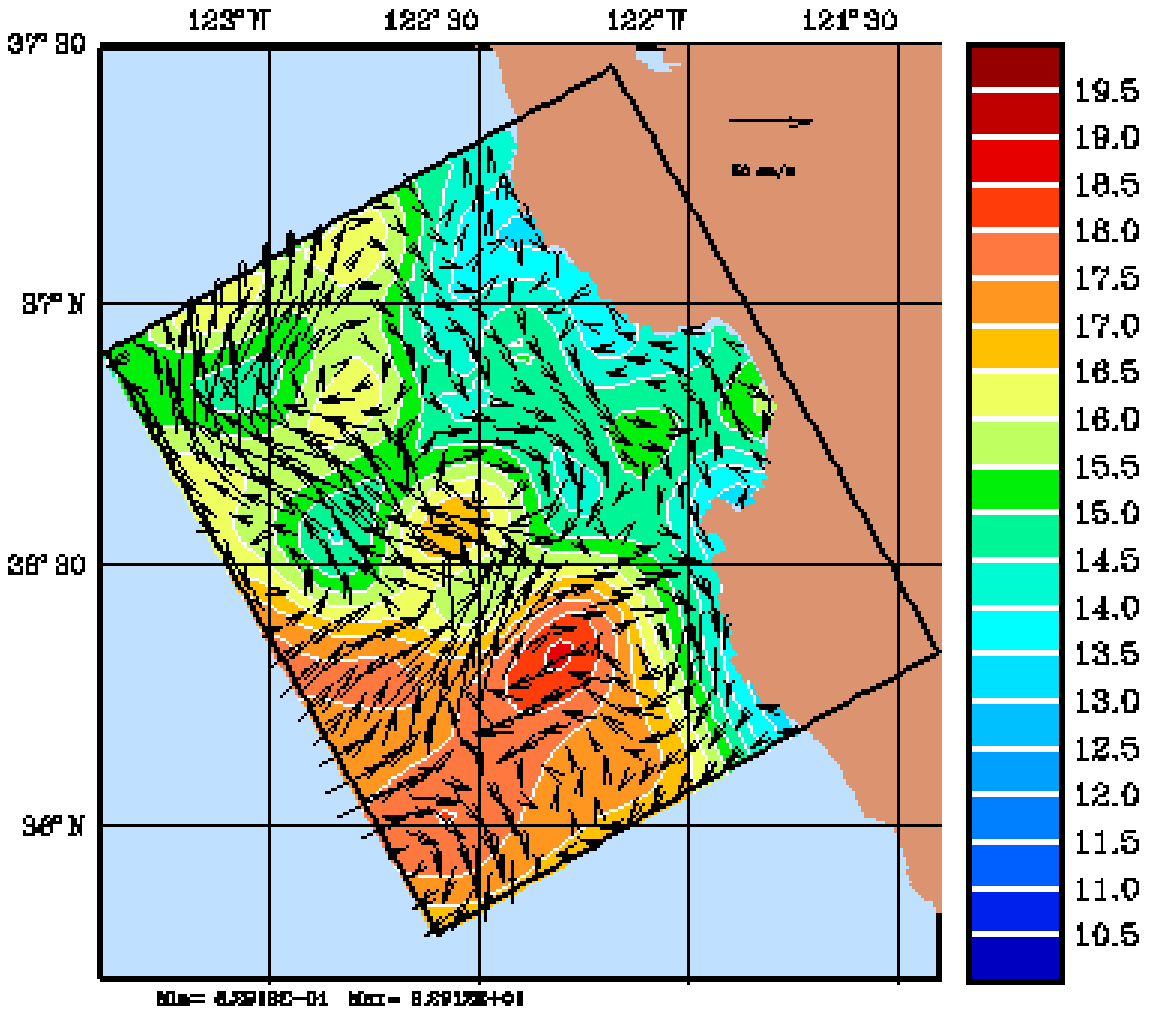


10m Temperature

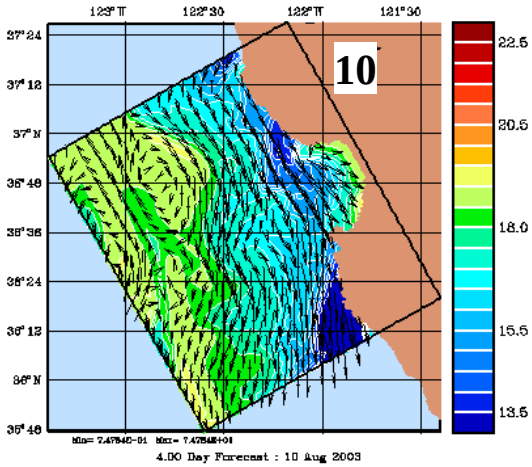
AOSN-II (run 486)

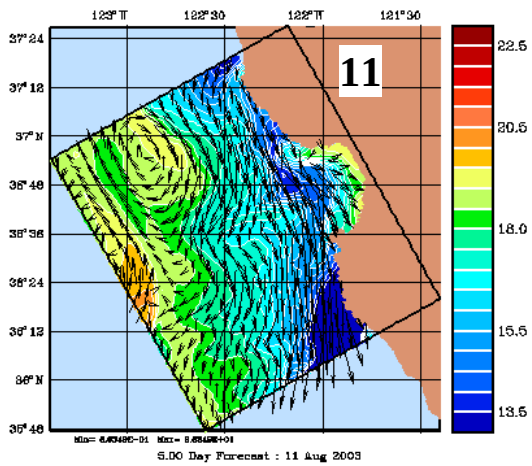
Aug 2- Sep 8 Pt Sur, Martin & Lobos CTD, WHOI & SIO gliders; NPS SST

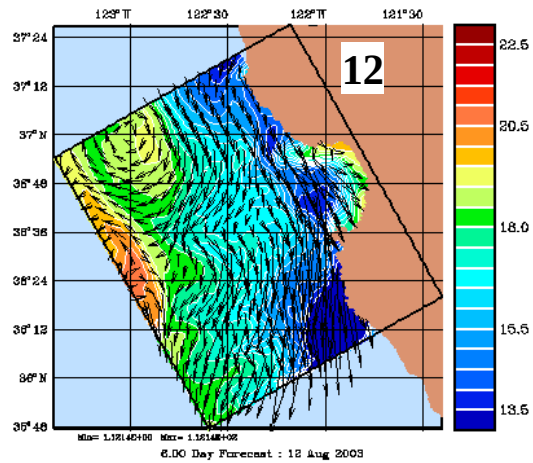
COAMPS atmospheric fluxes



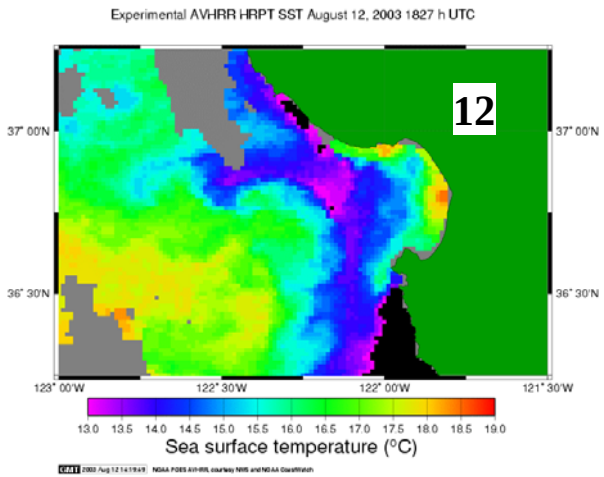
Nowcast : 6 Aug 2003

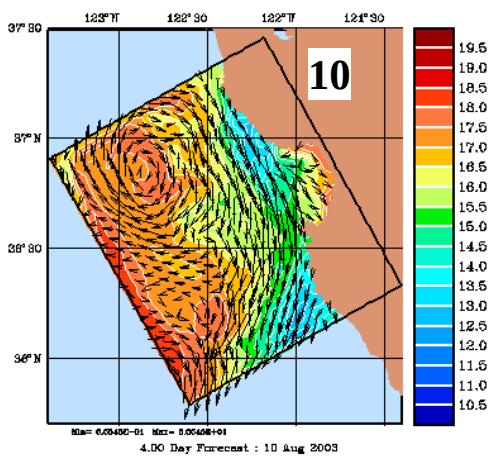


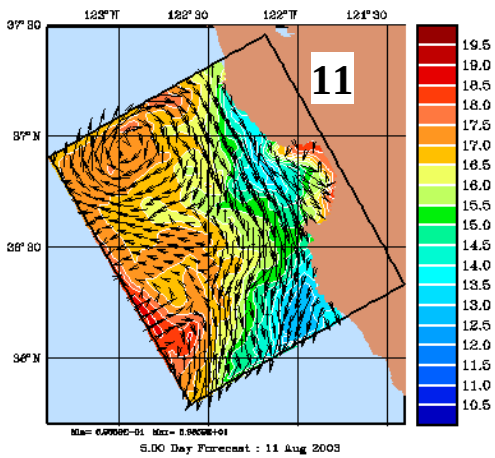


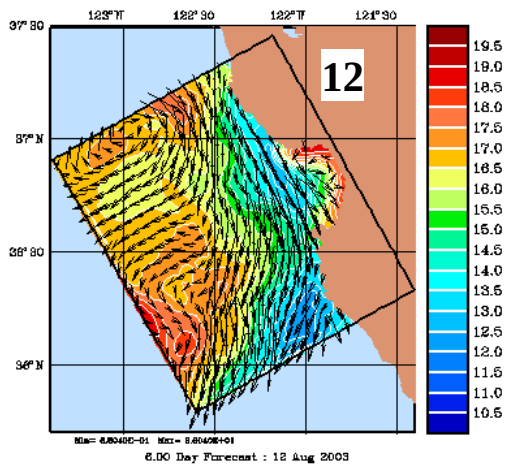


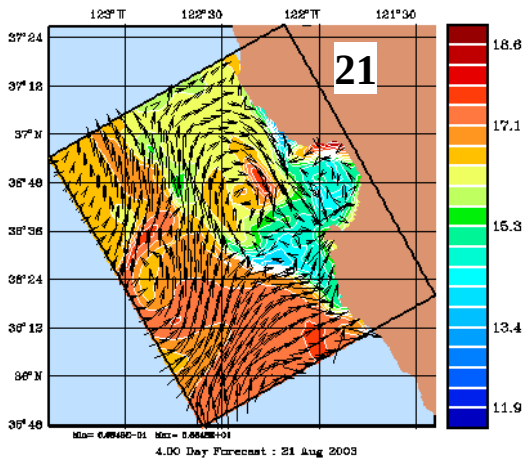
Sustained upwelling: comparison of real-time forecasts (top) with AVHRR SST (right) and re-analysis fields (bottom)

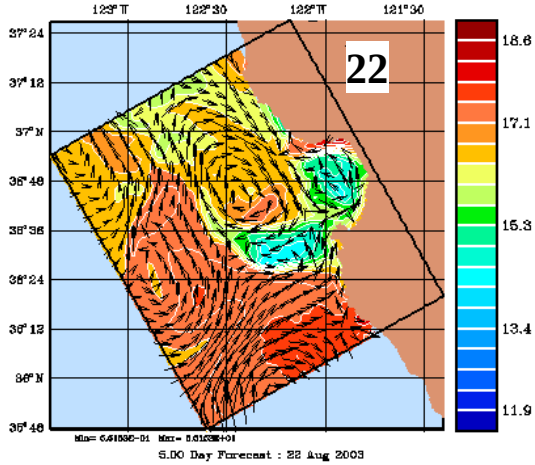


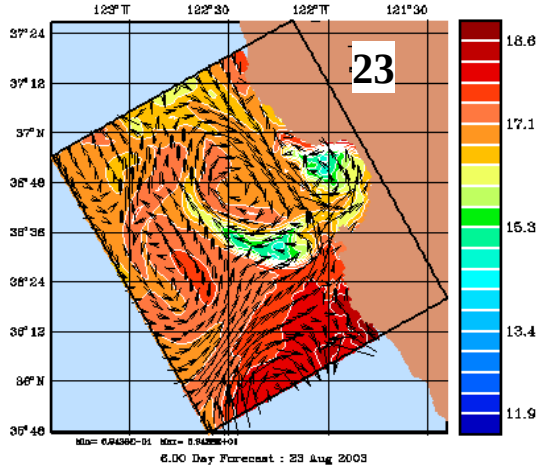




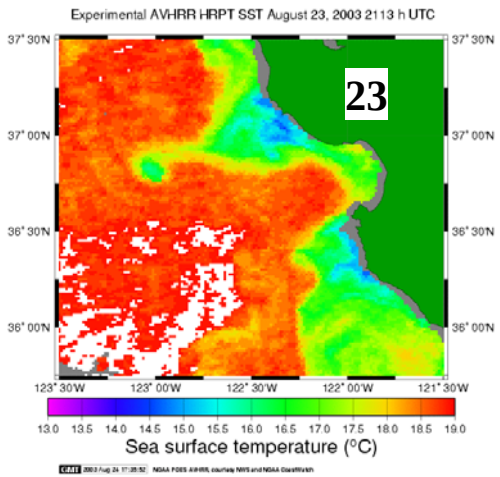


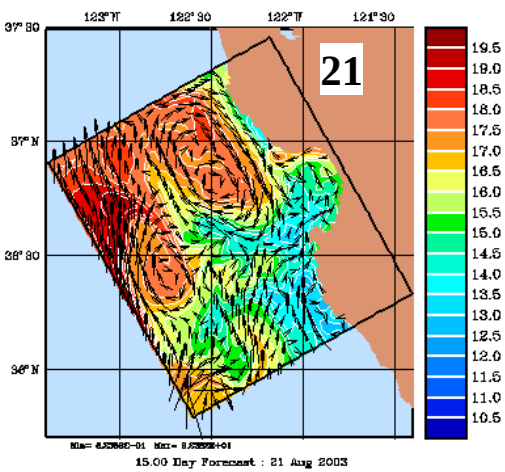


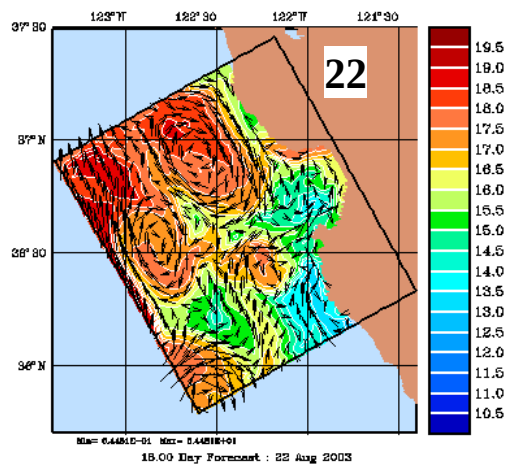


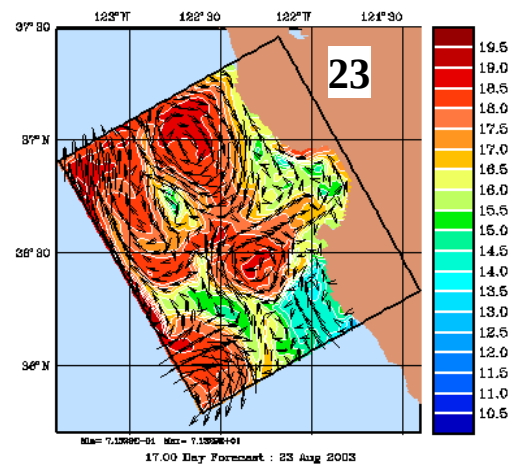


Relaxation: comparison of real-time forecasts (top) with AVHRR SST (right) and re-analysis fields (bottom)

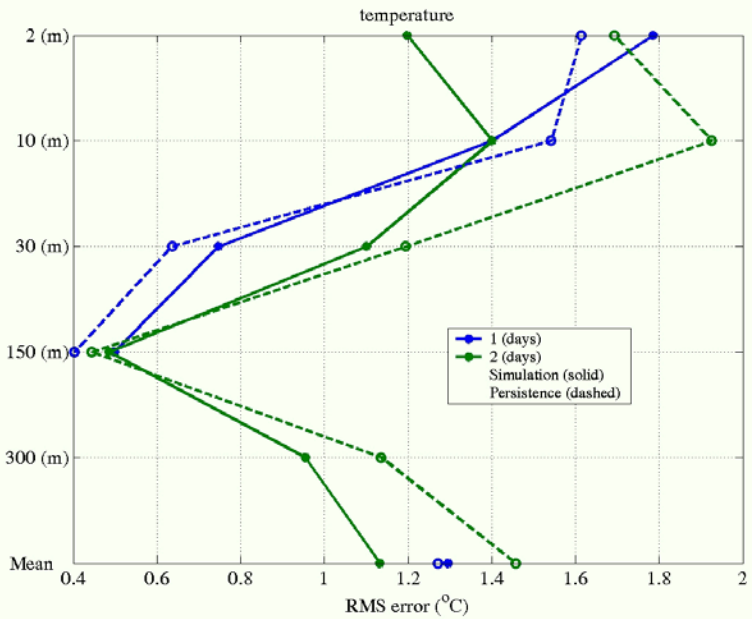


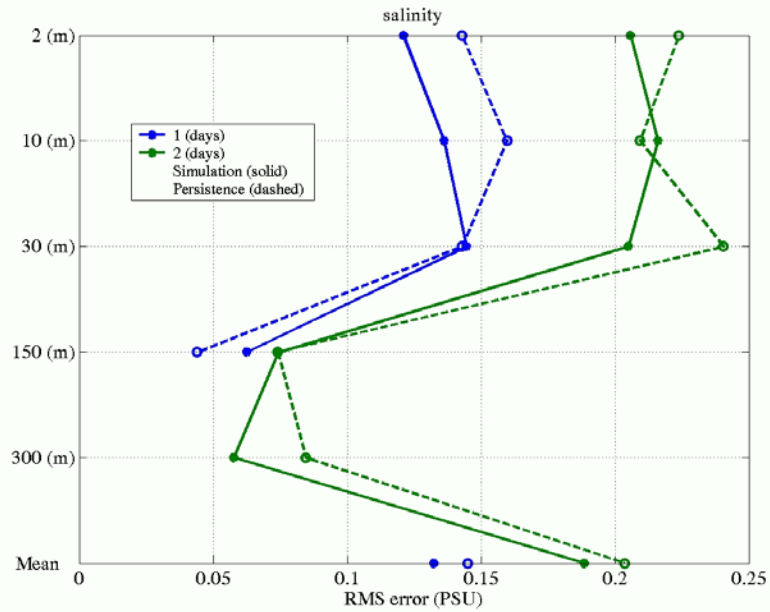






Forecast RMS Error Estimate– Temperature (left), Salinity (right)



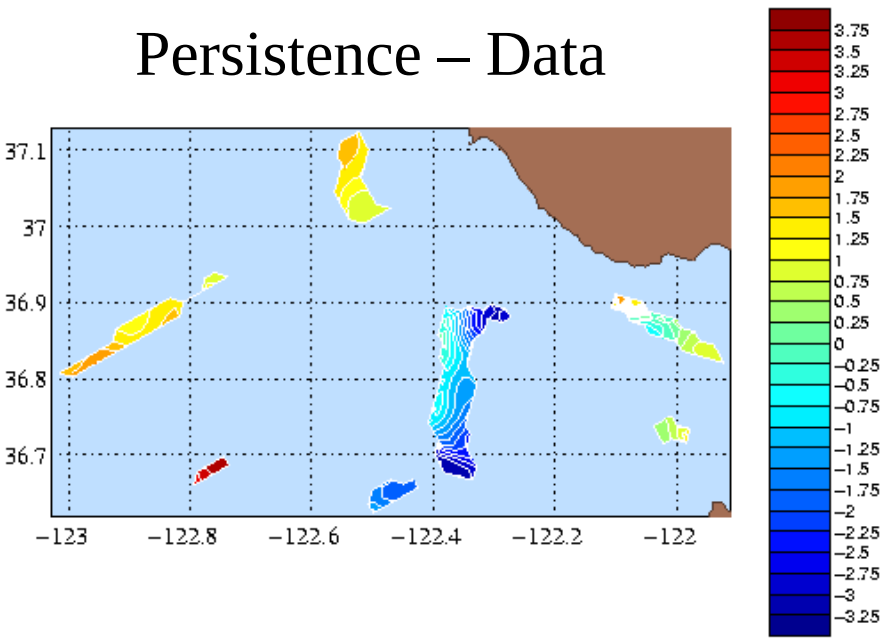


Blue – 12 Aug
Green – 13 Aug

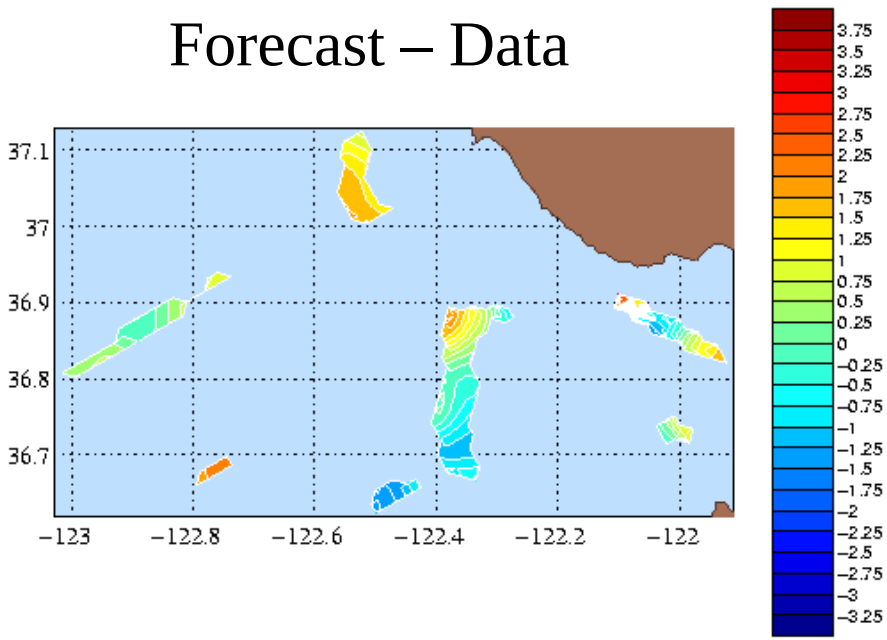
Solid – Forecast
Dash – Persistence

T Difference (at 2m) for 13 August

Persistence – Data

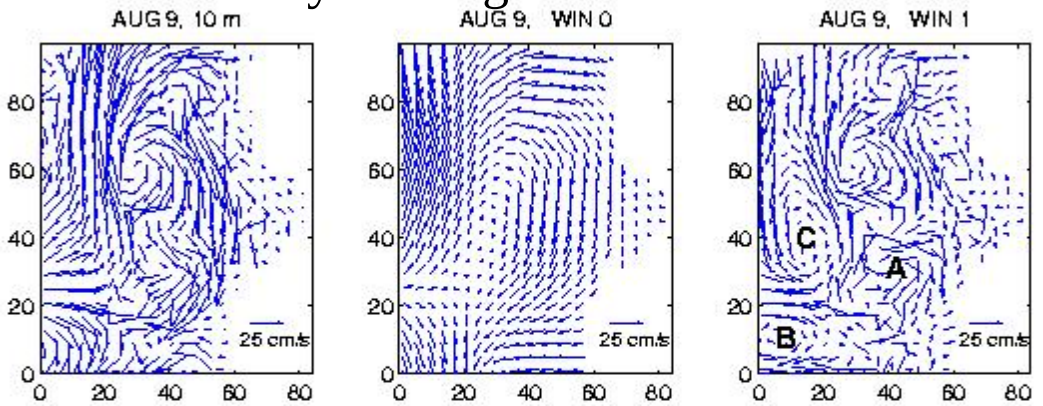


Forecast – Data

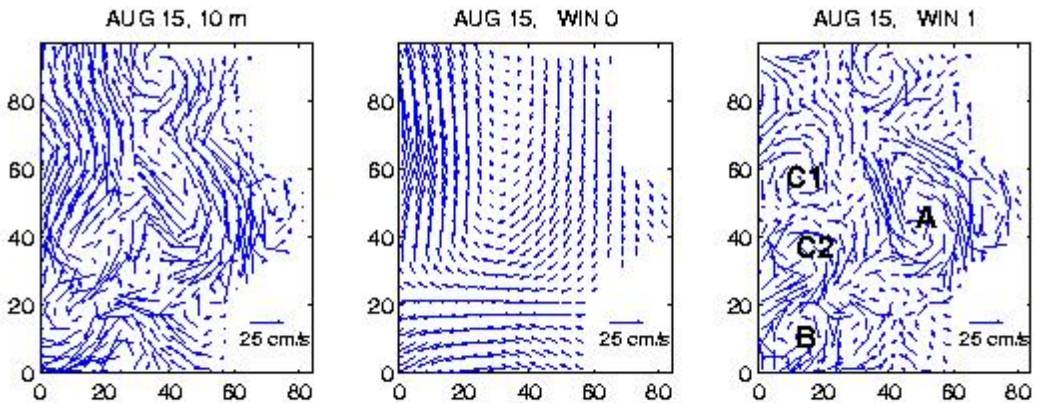


Multi-Scale Energy and Vorticity Analysis

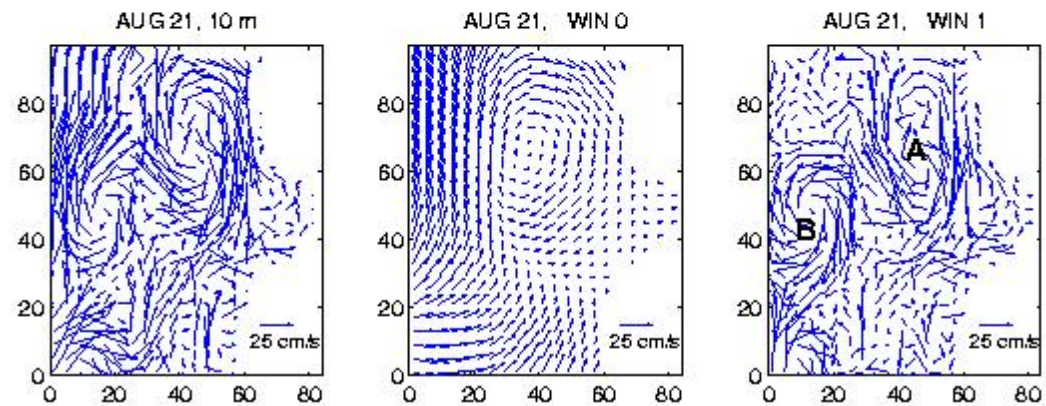
Total Velocity | Large Scale | Mesoscale



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-analysis interpretation of HOPS results together with ROMS results and multi-scale dynamical analyses