Advances in Adaptive, Interdisciplinary, Multiscale, Distributed, Web-Based, Ocean Prediction

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AGU Ocean Sciences Mtg., 20 Feb. 2006

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Advanced Ocean Prediction Systems

Interdisciplinary

Multiscale

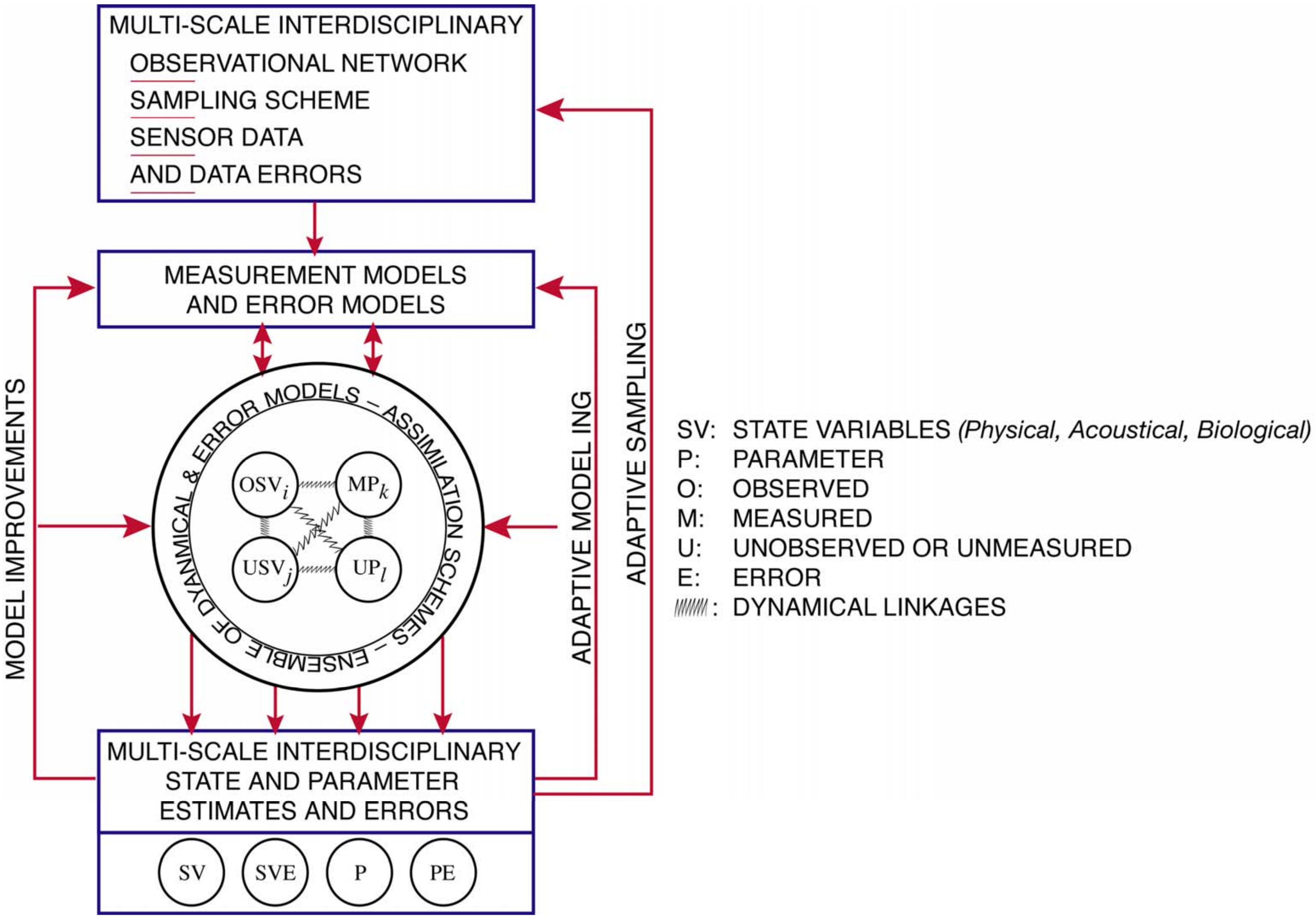
Ensemble and Multi-model Based

Automated Adaptive Sampling

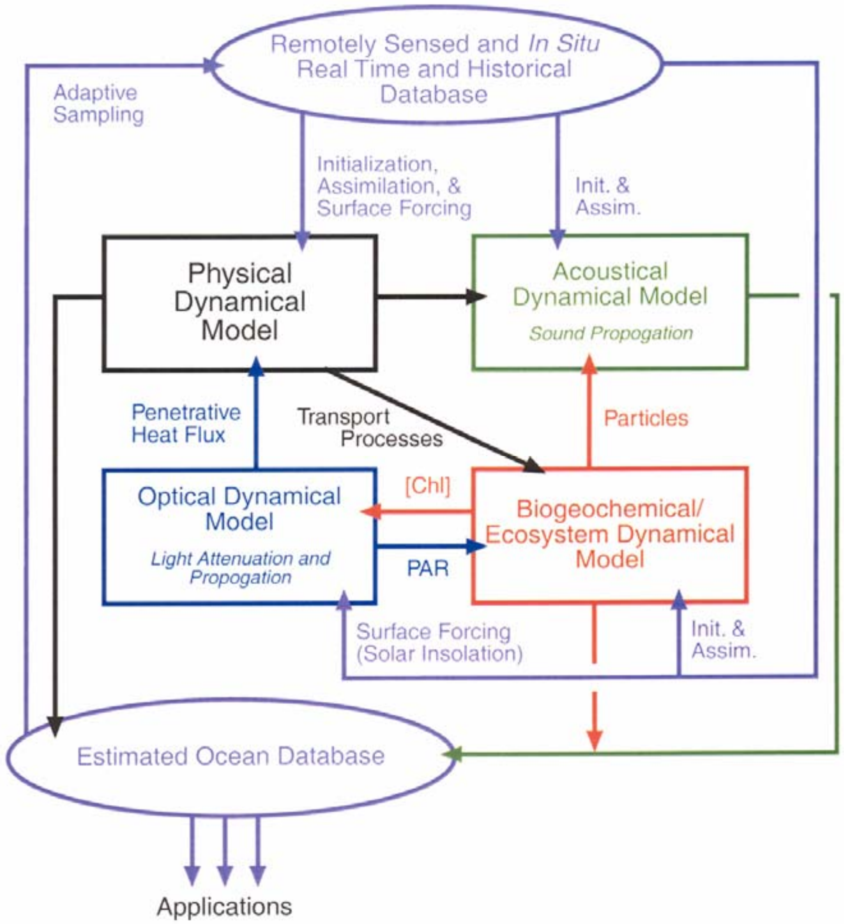
Automated Adaptive Modeling

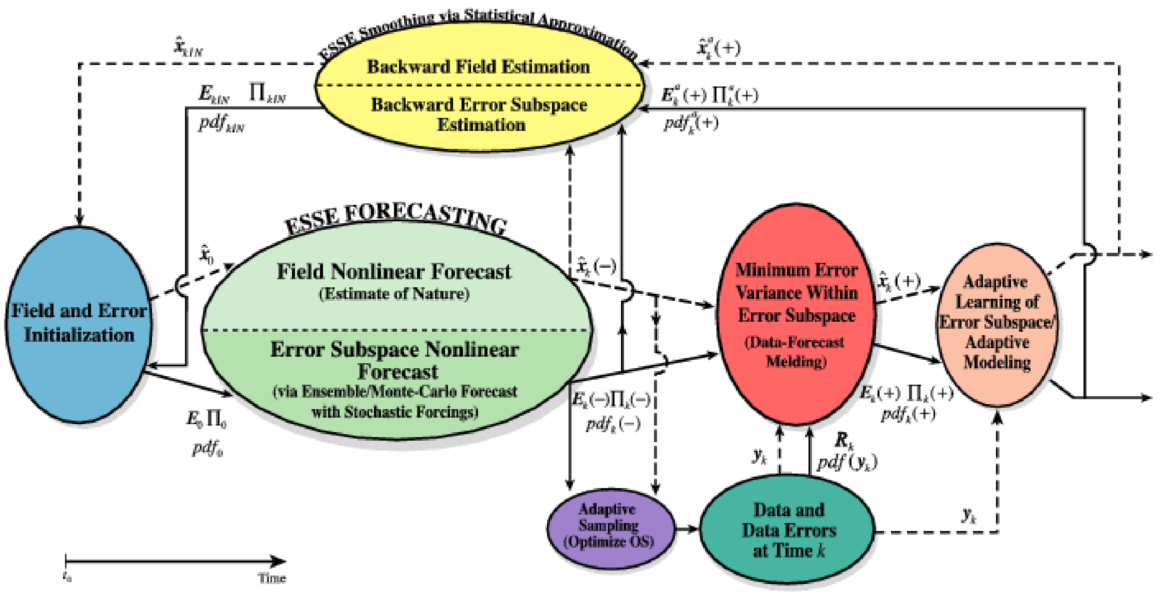
Distributed, Web-Based

Advanced Ocean Prediction Systems



HOPS/ESSE System





Harvard Ocean Prediction System **Error Subspace Statistical Estimation**

Coupled Interdisciplinary Data Assimilation

$\boldsymbol{x} = [\boldsymbol{x}_A \;\; \boldsymbol{x}_O \;\; \boldsymbol{x}_B]$ **Unified interdisciplinary state vector**

Physics: $\boldsymbol{x}_O = [T, S, U, V, W]$

Biology: $\boldsymbol{x}_B = [N_i, P_i, Z_i, B_i, D_i, C_i]$

Acoustics: $\boldsymbol{x}_A = [\text{Pressure } (p), \text{Phase } (\varphi)]$

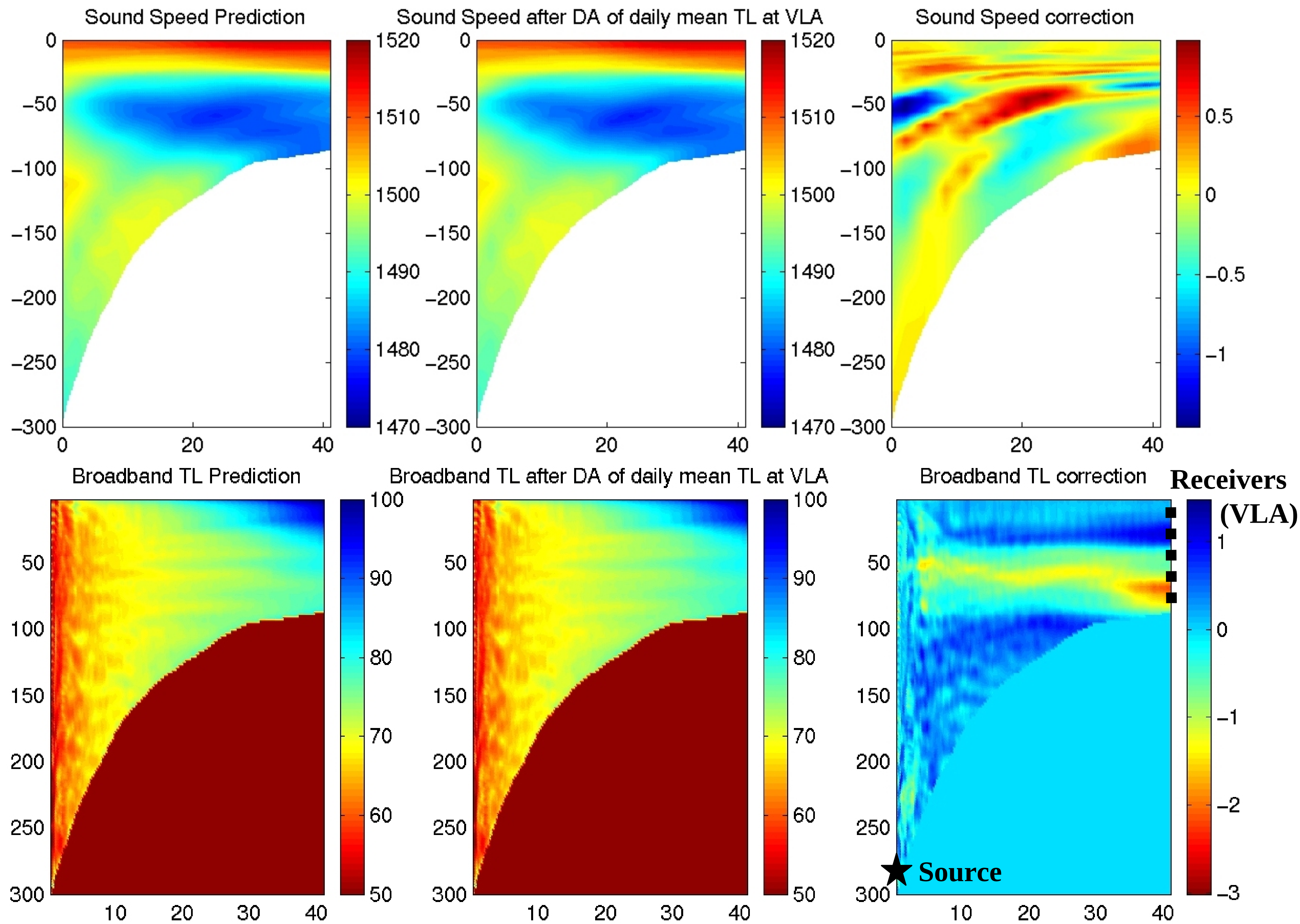
$$\boldsymbol{P} = \varepsilon \left\{ (\hat{\boldsymbol{x}} - \boldsymbol{x}^t)(\hat{\boldsymbol{x}} - \boldsymbol{x}^t)^T \right\}$$

Coupled error covariance with off-diagonal terms

$$\boldsymbol{P} = \begin{pmatrix} P_{AA} & P_{AO} & P_{AB} \\ P_{OA} & P_{OO} & P_{OB} \\ P_{BA} & P_{BO} & P_{BB} \end{pmatrix}$$

Coupled Physical-Acoustical Data Assimilation of real TL-CTD data:

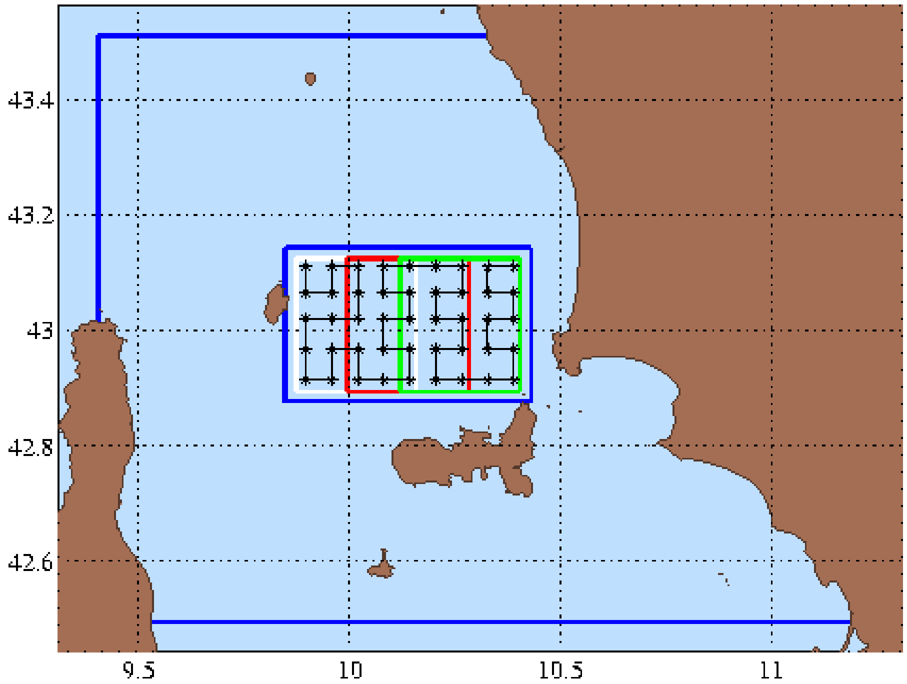
Transmission Loss measurements affect TL and Sound Speed everywhere.



MREA-03 Mini-HOPS

- Designed to locally solve the problem of accurate representation of sub-mesoscale synopticity
- Involves rapid real-time assimilation of high-resolution data in a high-resolution model domain nested in a regional model
- Produces locally more accurate oceanographic field estimates and short-term forecasts and improves the impact of local field high-resolution data assimilation

MREA-03 Domains



- Dynamically interpolated and extrapolated high-resolution fields are assimilated through 2-way nesting into large domain models

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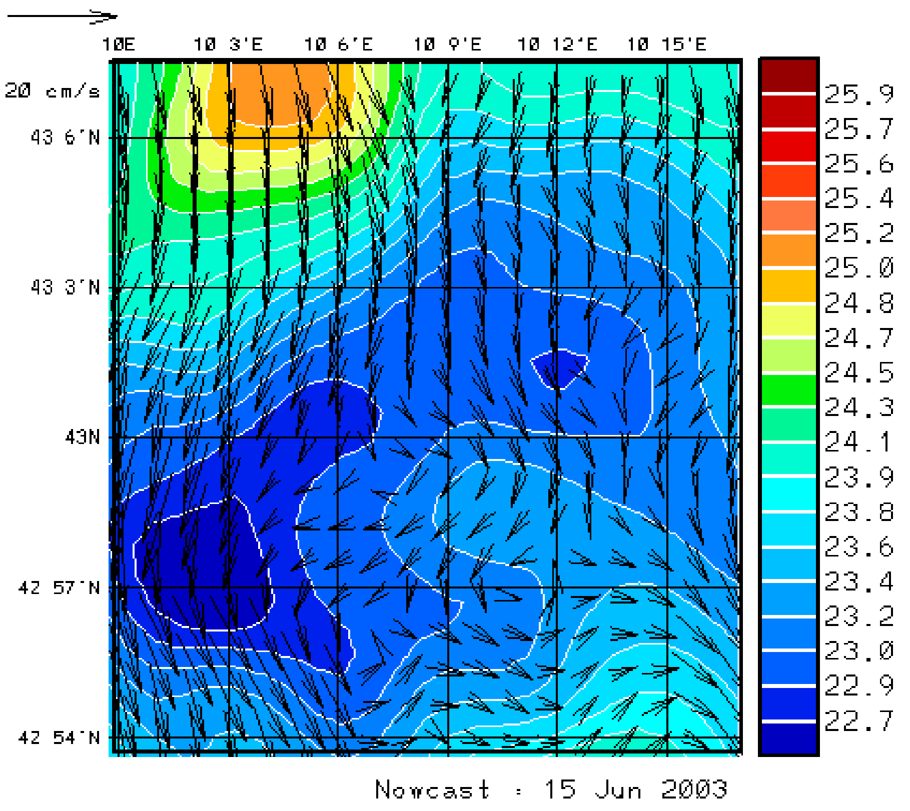
In collaboration with Dr. Emanuel Coelho (NATO Undersea Research Centre)

MREA-03 Mini-HOPS

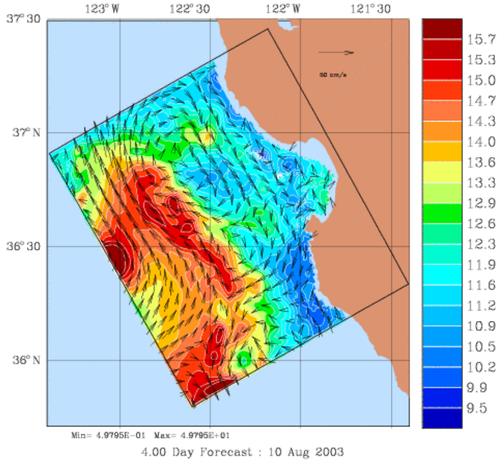
- **Regional Domain (1km) run at Harvard in a 2-way nested configuration with a super-mini domain.**
  - **Super mini has the same resolution (1/3 km) as the mini-HOPS domains and is collocated with them**
- **From the super-mini domain, initial and boundary conditions were extracted for all 3 mini-HOPS domains for the following day and transmitted to the NRV Alliance.**
- **Aboard the NRV Alliance, the mini-HOPS domains were run the following day, with updated atmospheric forcing and assimilating new data.**

Mini-HOPS simulation run aboard NRV Alliance in Central mini-HOPS domain (0m temperature and velocity)

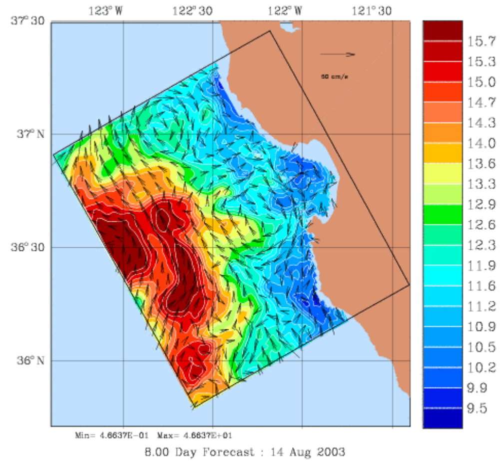


Harvard Ocean Prediction System AOSN-II Fields

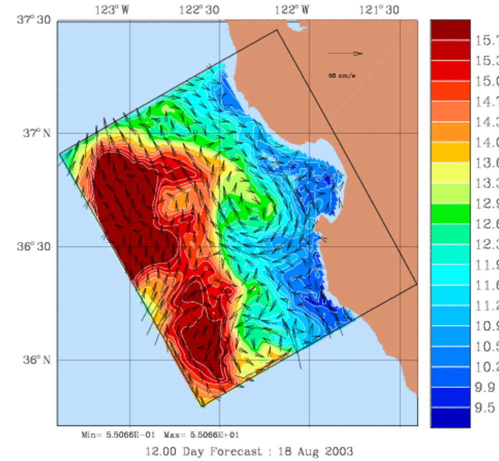
30m Temperature: 10 - 30 August 2003 (4 day intervals)



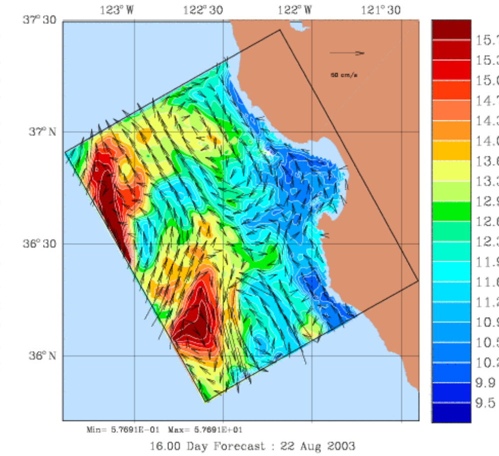
10 Aug



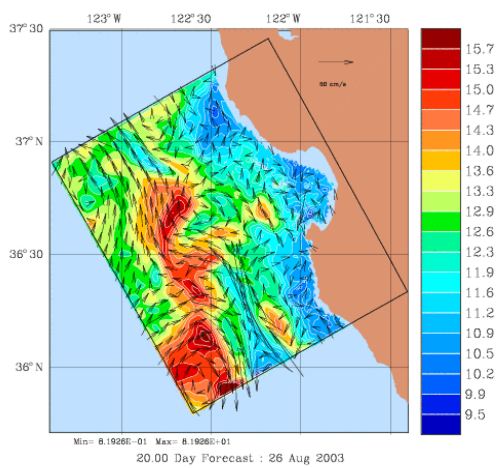
14 Aug



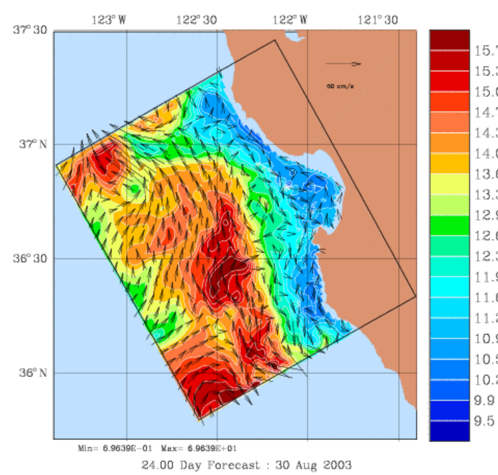
18 Aug



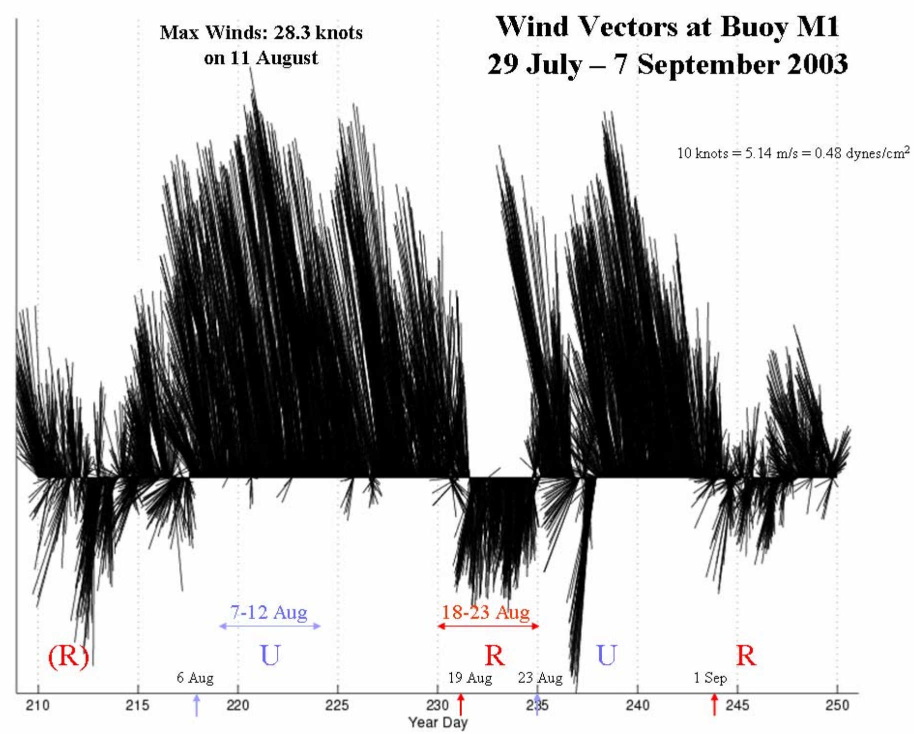
22 Aug



26 Aug



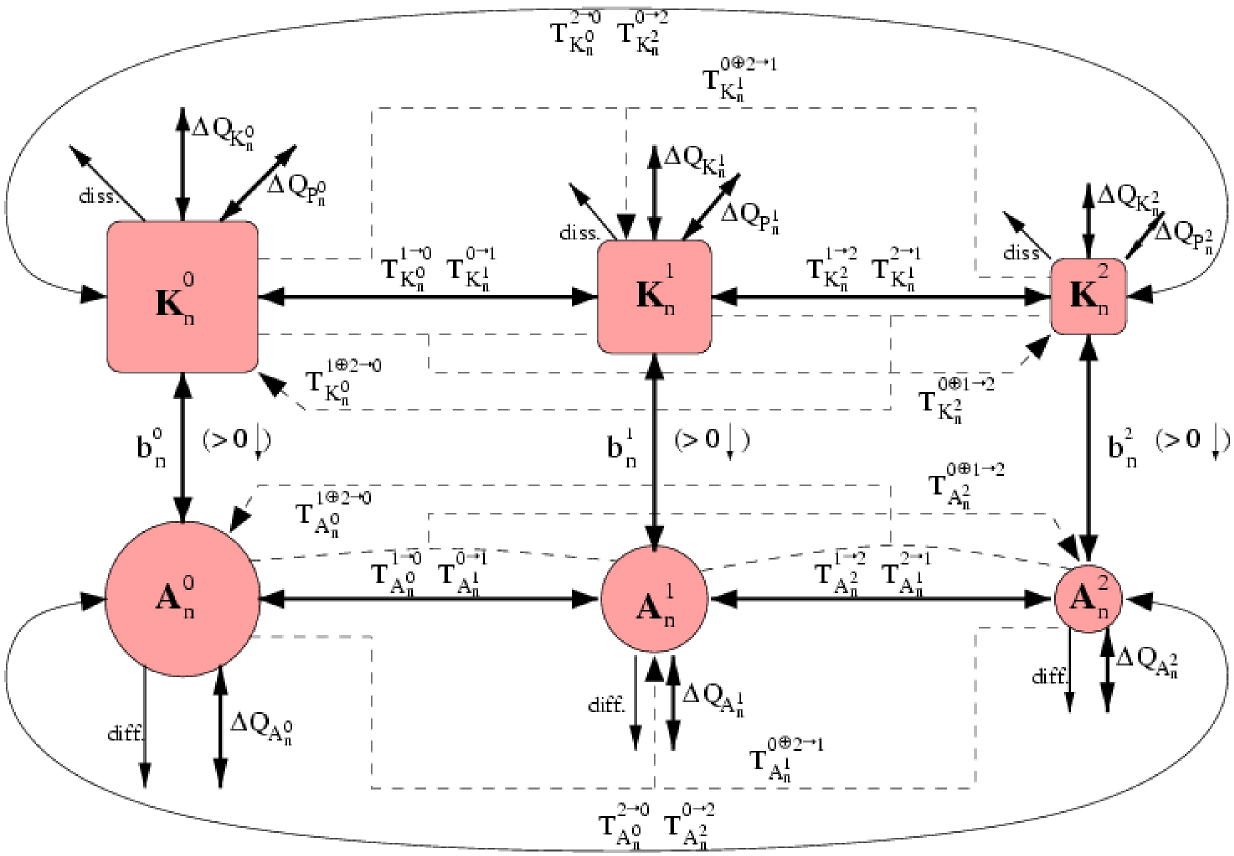
30 Aug



Multi-Scale Energy and Vorticity Analysis

MS-EVA is a new methodology utilizing multiple scale window decomposition in space and time for the investigation of processes which are:

- multi-scale interactive
- nonlinear
- intermittent in space
- episodic in time



Through exploring:

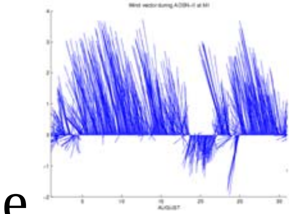
- pattern generation and
- energy and enstrophy
  - transfers
  - transports, and
  - conversions

MS-EVA helps unravel the intricate relationships between events on different scales and locations in phase and physical space.

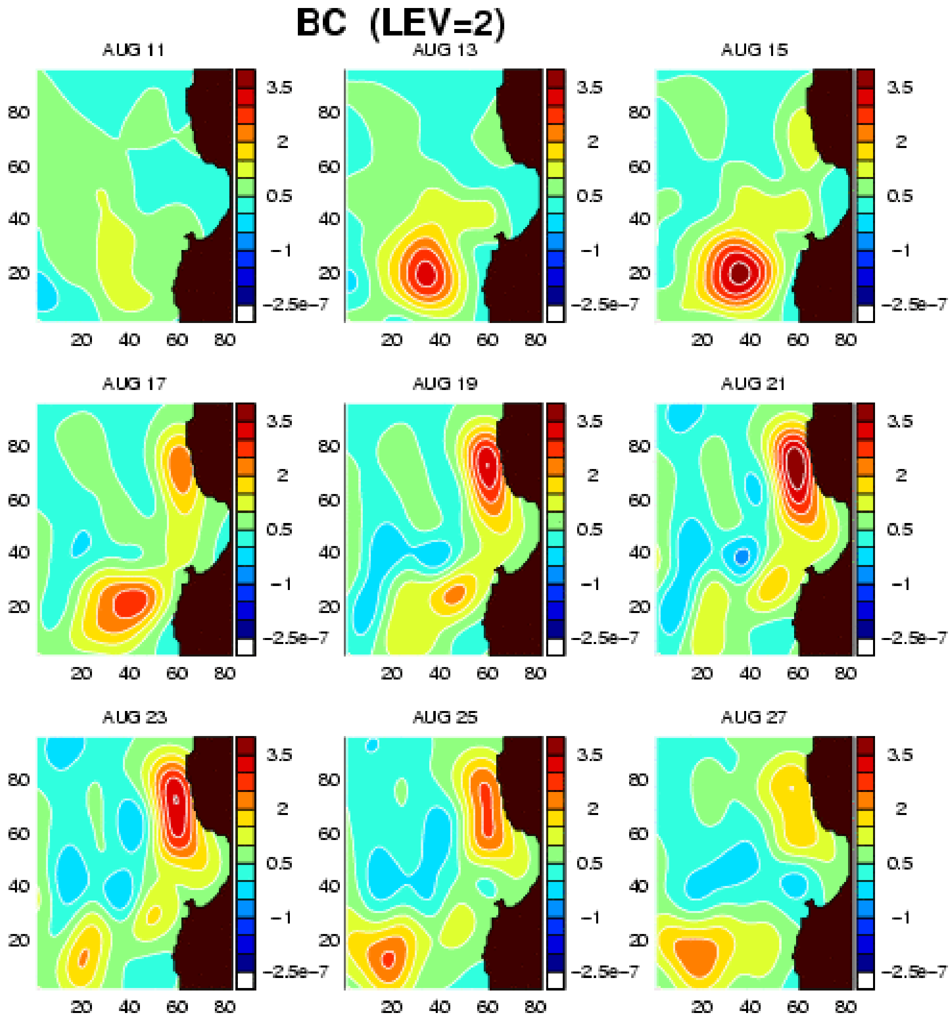
Dr. X. San Liang

M-S. Energy and Vorticity Analysis

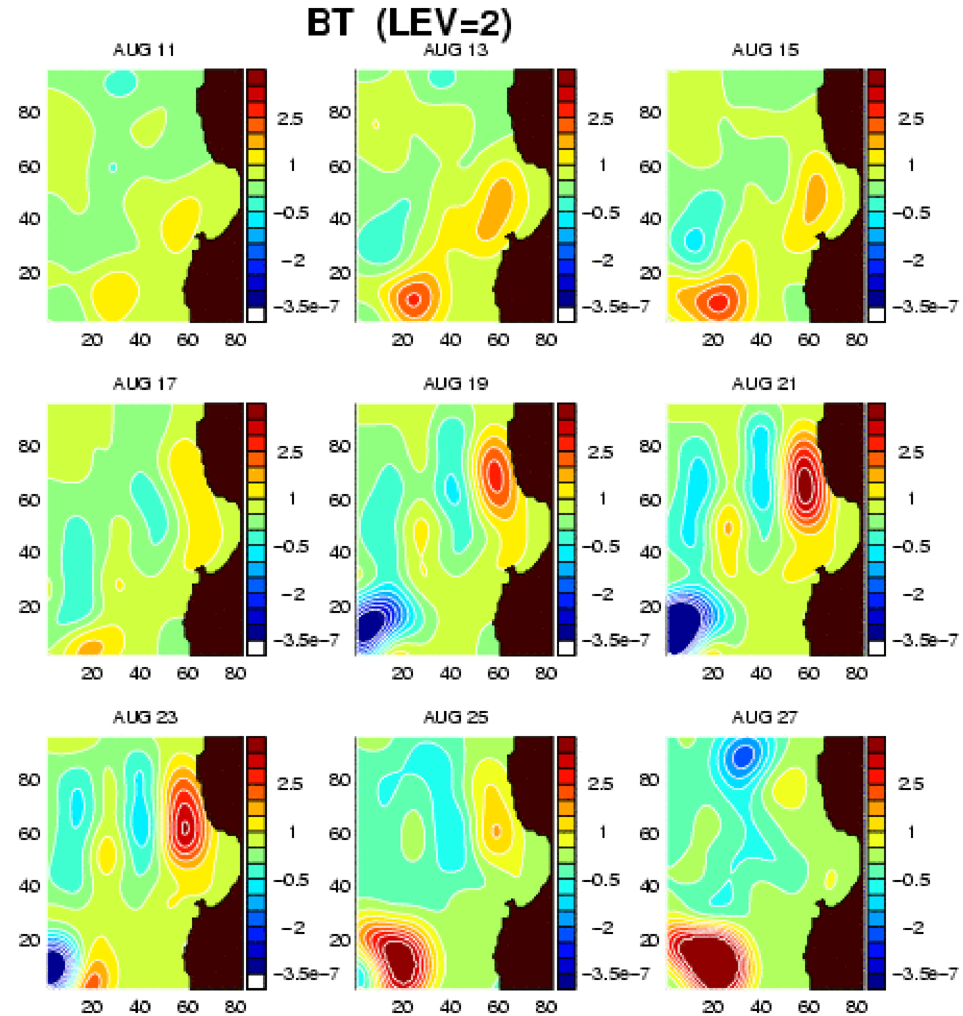
Two-scale window decomposition in space and time of energy eqns: 11-27 August 2003



Transfer of APE from large-scale to meso-scale



Transfer of KE from large-scale to meso-scale



- Center west of Pt. Sur: winds destabilize the ocean directly.
- Center near the Bay: winds enter the balance on the large-scale window and release energy to the meso-scale window during relaxation.

X. San

Multi-Model Ensemble Estimates of Fields and Errors

Strategies For Multi-Model Adaptive Forecasting

- Error Analyses: *Learn individual model forecast errors in an on-line fashion through developed formalism of multi-model error parameter estimation*
- Model Fusion: *Combine models via Maximum-Likelihood based on the current estimates of their forecast errors*

3-steps strategy, using model-data misfits and error parameter estimation

1. Select forecast error covariance $\mathbf{B}$ and bias $\boldsymbol{\mu}$ parameterization $\boldsymbol{\alpha}$, $\boldsymbol{\beta}$

$$\mathrm{B} \approx \tilde{\mathrm{B}}(\boldsymbol{\alpha}); \qquad \boldsymbol{\mu} \approx \tilde{\boldsymbol{\mu}}(\boldsymbol{\beta}); \qquad \boldsymbol{\Theta} = \{\boldsymbol{\alpha}, \boldsymbol{\beta}\}$$

2. Adaptively determine forecast error parameters from **model-data misfits** based on the Maximum-Likelihood principle:

$\boldsymbol{\Theta}^* = \arg\max_{\boldsymbol{\Theta}} p(\boldsymbol{\mathcal{Y}}|\boldsymbol{\Theta})$ Where $\boldsymbol{\mathcal{Y}} = \{\mathbf{y}_1^o, \mathbf{y}_2^o, \ldots, \mathbf{y}_T^o\}$ is the observational data

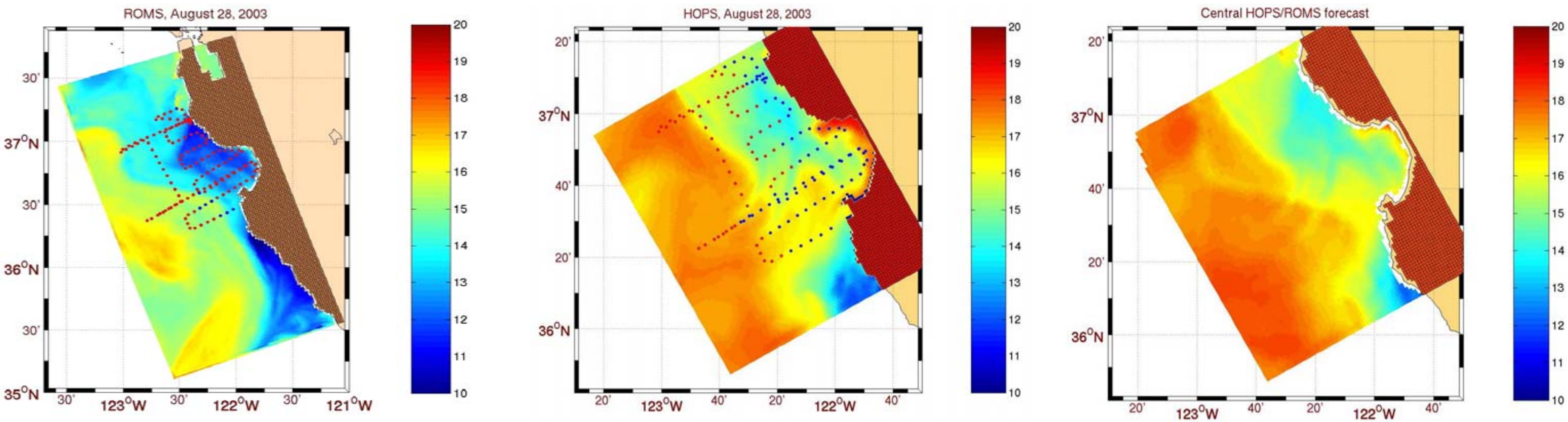
3. Combine model forecasts $\mathbf{x}_i$ via Maximum-Likelihood based on the current estimates of error parameters (Bayesian Model Fusion)

O. Logoutov

$$\mathbf{x}^* = \arg\min_{\mathbf{x}} \sum_{m=1}^{M} \left(\mathbf{x} - \mathbf{H}_m \mathbf{x}_m\right)^T \mathcal{B}^{-1}_{(\boldsymbol{\Theta}_m)} \left(\mathbf{x} - \mathbf{H}_m \mathbf{x}_m\right)$$

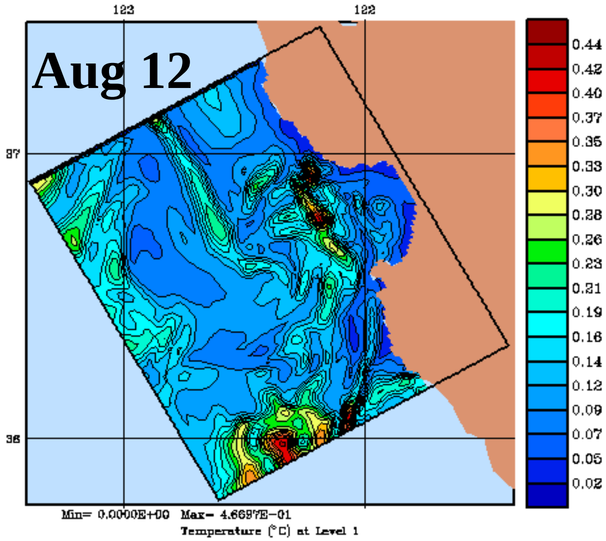
Two Models and Data Combined via Bayesian Fusion

ROMS and HOPS individual SST forecasts and the NPS aircraft SST data are combined based on their estimated uncertainties to form the central forecast

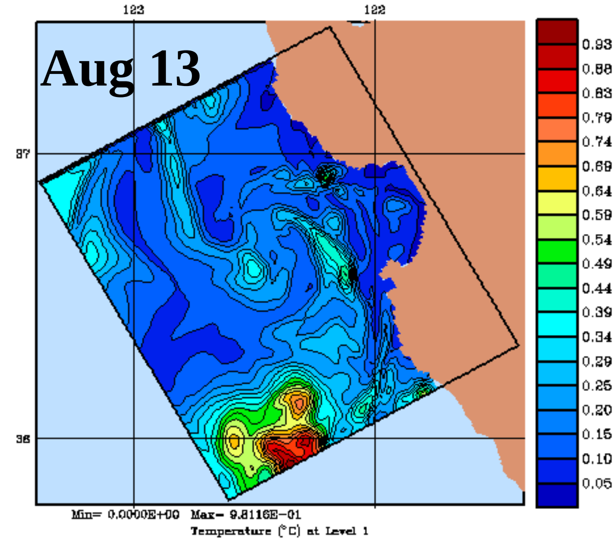


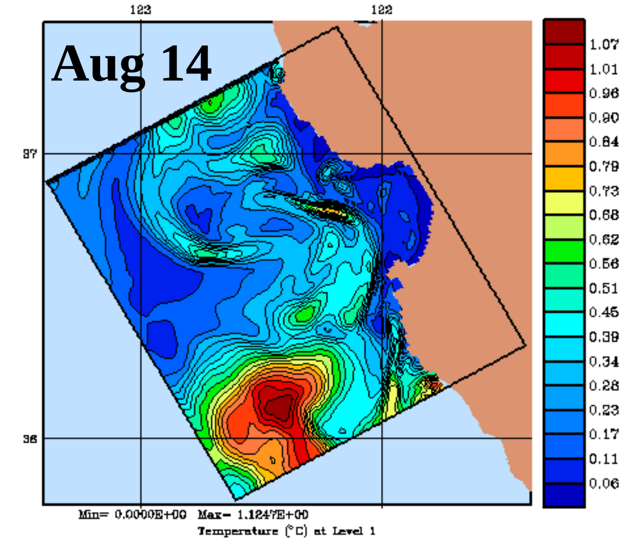
A new batch of model-data misfits and priors on uncertainty parameters determine via the Bayesian principle uncertainty parameter values that are employed to combine the forecasts.

ESSE Surface Temperature Uncertainty Forecasts

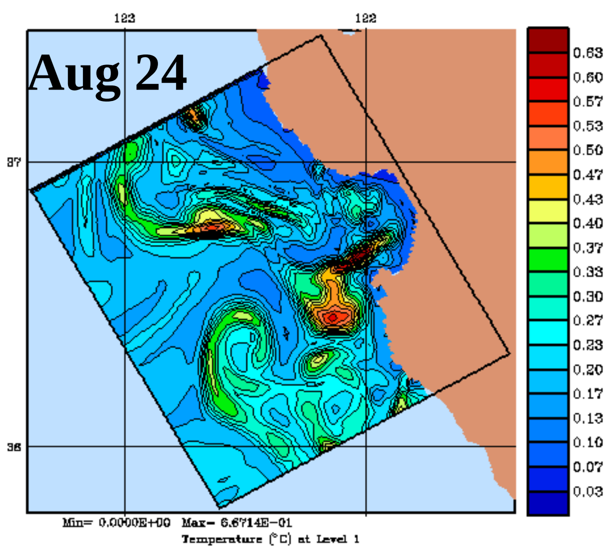


Start of Upwelling

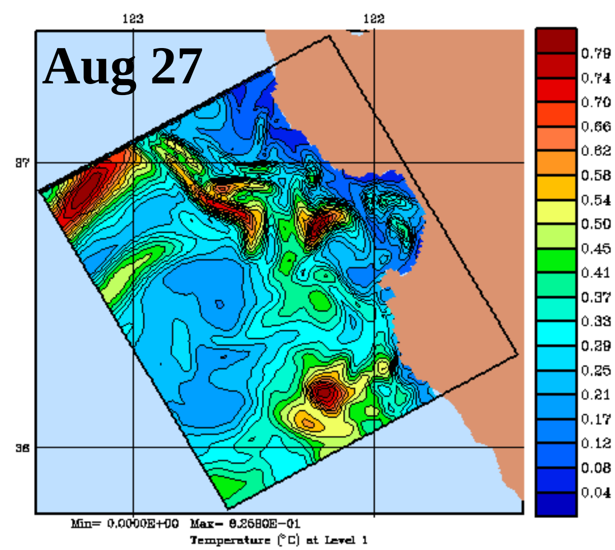


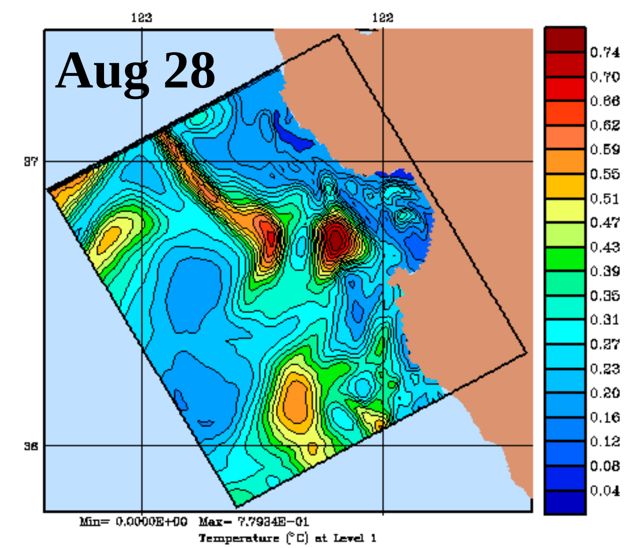


First Upwelling period



End of Relaxation



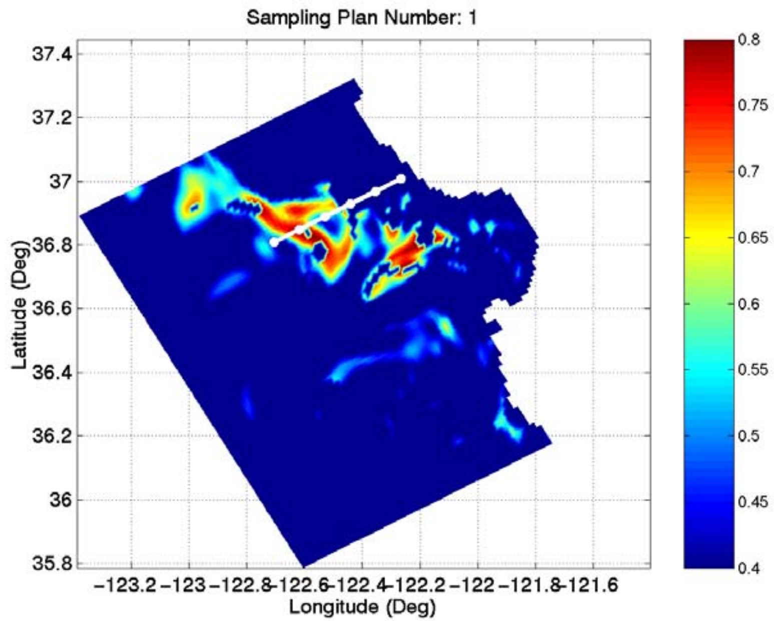


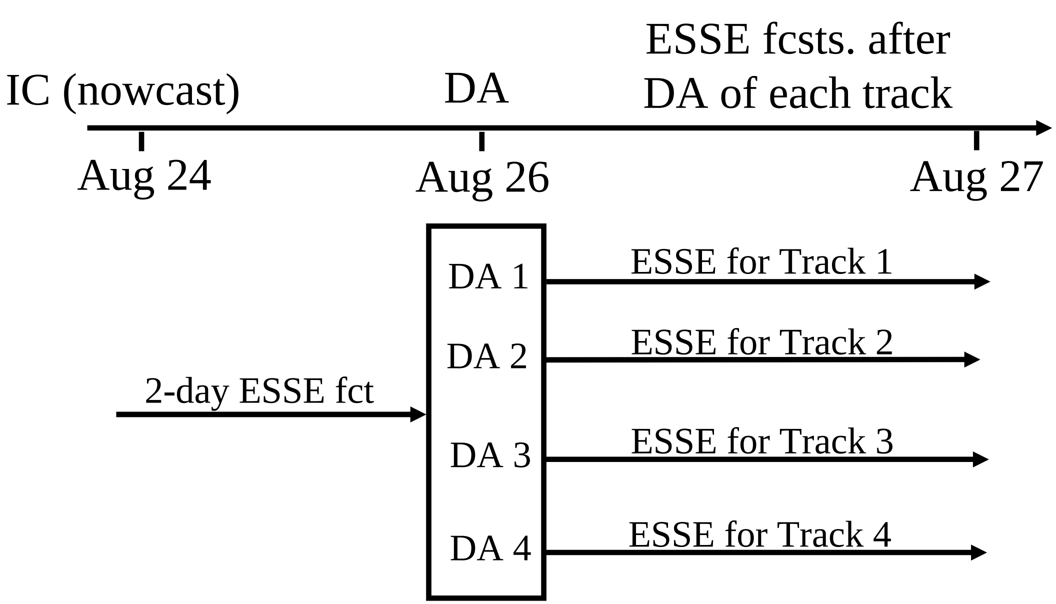
Second Upwelling period

- **Real-time consistent error forecasting, data assimilation and adaptive sampling (1 month)**
- **ESSE results described in details and posted on the Web daily (see AOSN-II page at HU)**

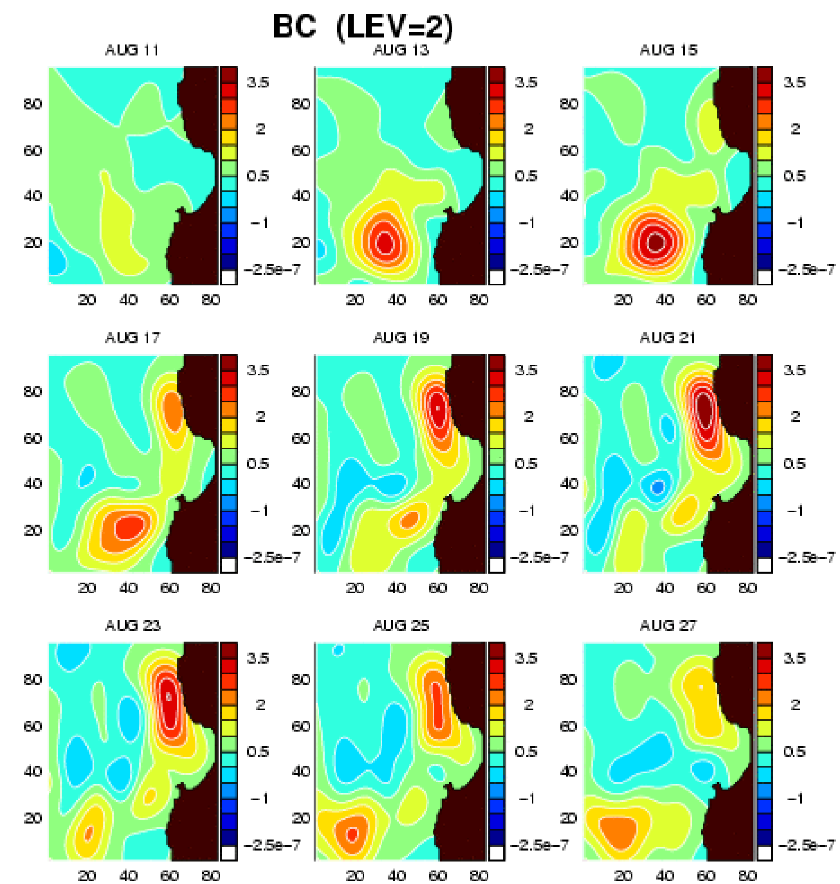
Adaptive Sampling e.g. to
Control Uncertainty or Optimize Dynamical Knowledge

Best predicted relative error reduction: track 1



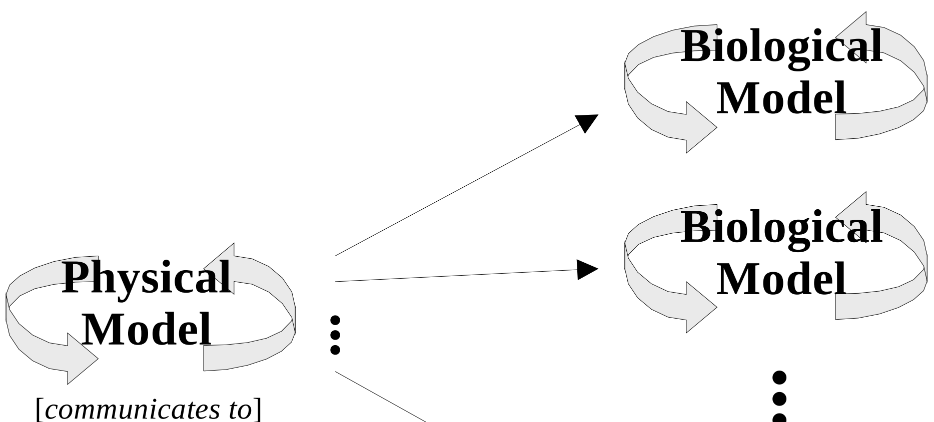


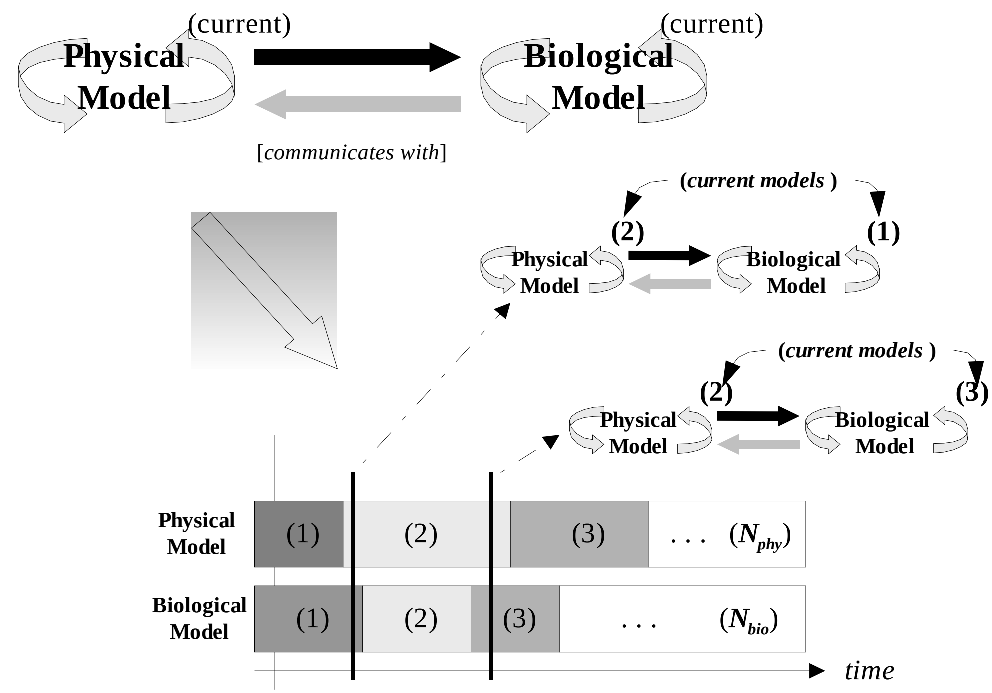
- **Concentrating resources in regions of important dynamical events (dynamical hot spots)**



Towards Real-time Adaptive Physical and Coupled Models

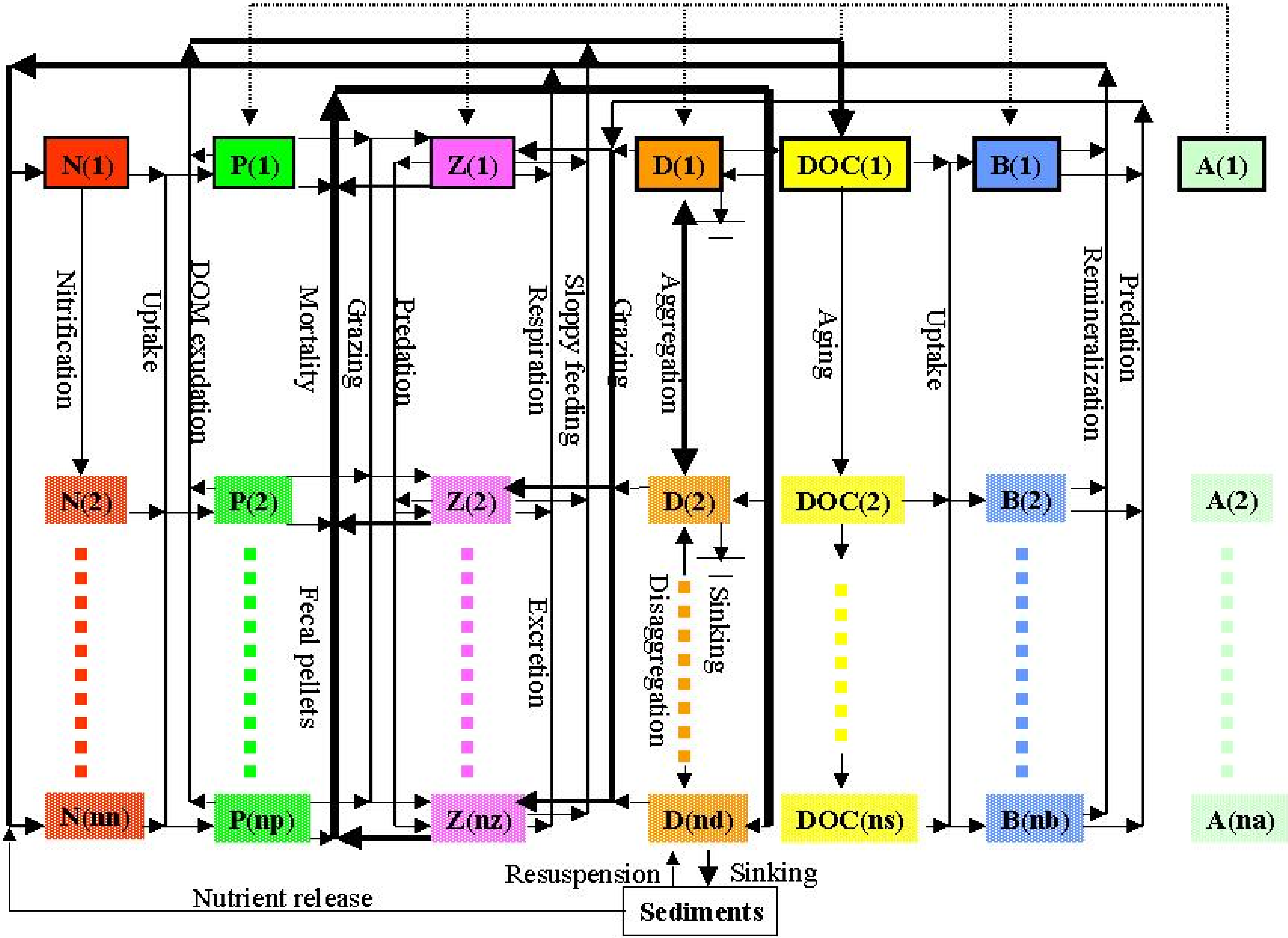
- Different Types of Adaptation:
  - Physical model with multiple parameterizations in parallel (hypothesis testing)
  - Physical model with a single adaptive parameterization (adaptive physical evolution)
  - Adaptive physical model drives multiple biological models (biology hypothesis testing)
  - Adaptive physical model and adaptive biological model proceed in parallel





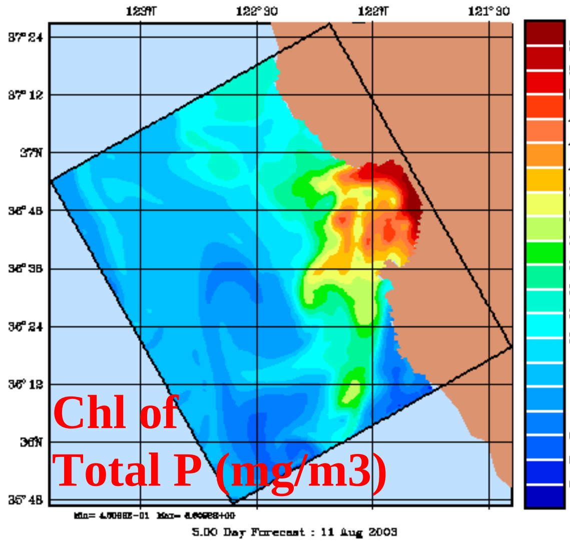
- Model selection based on quantitative dynamical/statistical study of data-model misfits
- Mixed language programming (C function pointers and wrappers for functional choices) to be used for numerical implementation

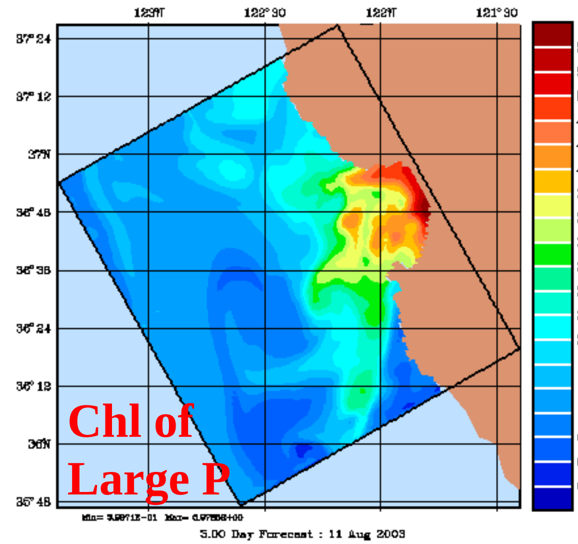
Harvard Generalized Adaptable Biological Model

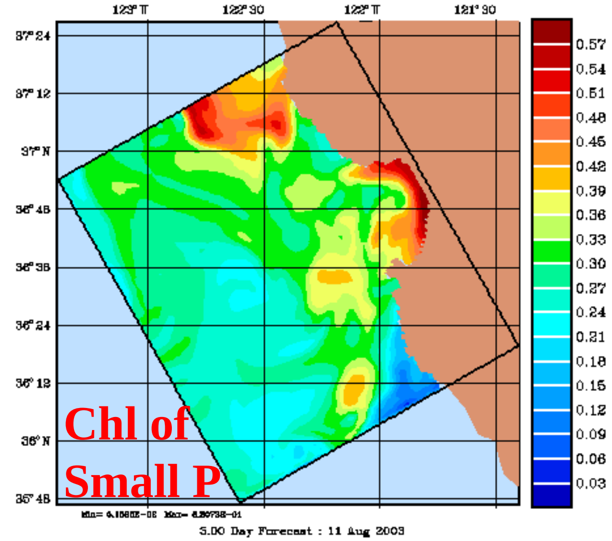


Towards automated quantitative model aggregation and simplification

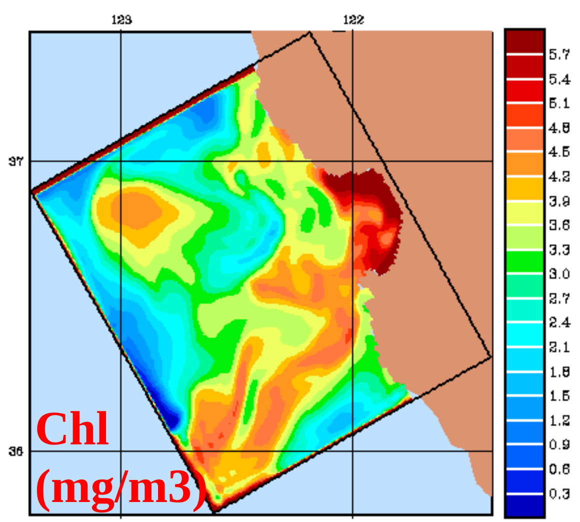
A priori configuration of generalized model on Aug 11 during an upwelling event

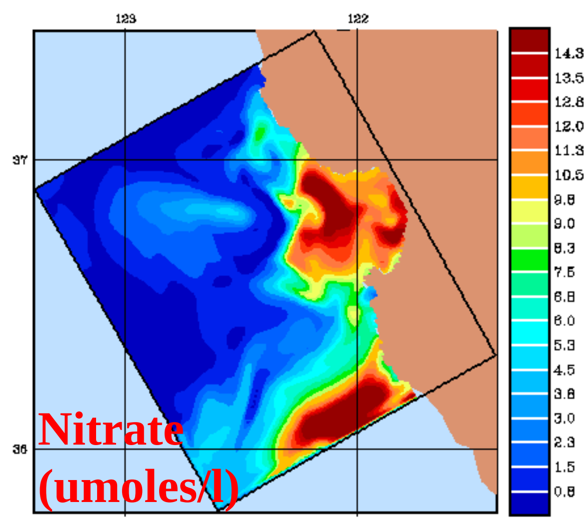


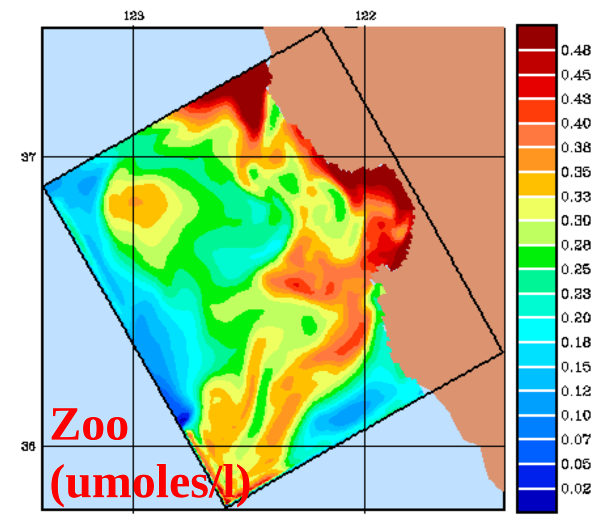




Simple NPZ configuration of generalized model on Aug 11 during same upwelling event







Web-Enabled Configuration and Control of HOPS/ESSE

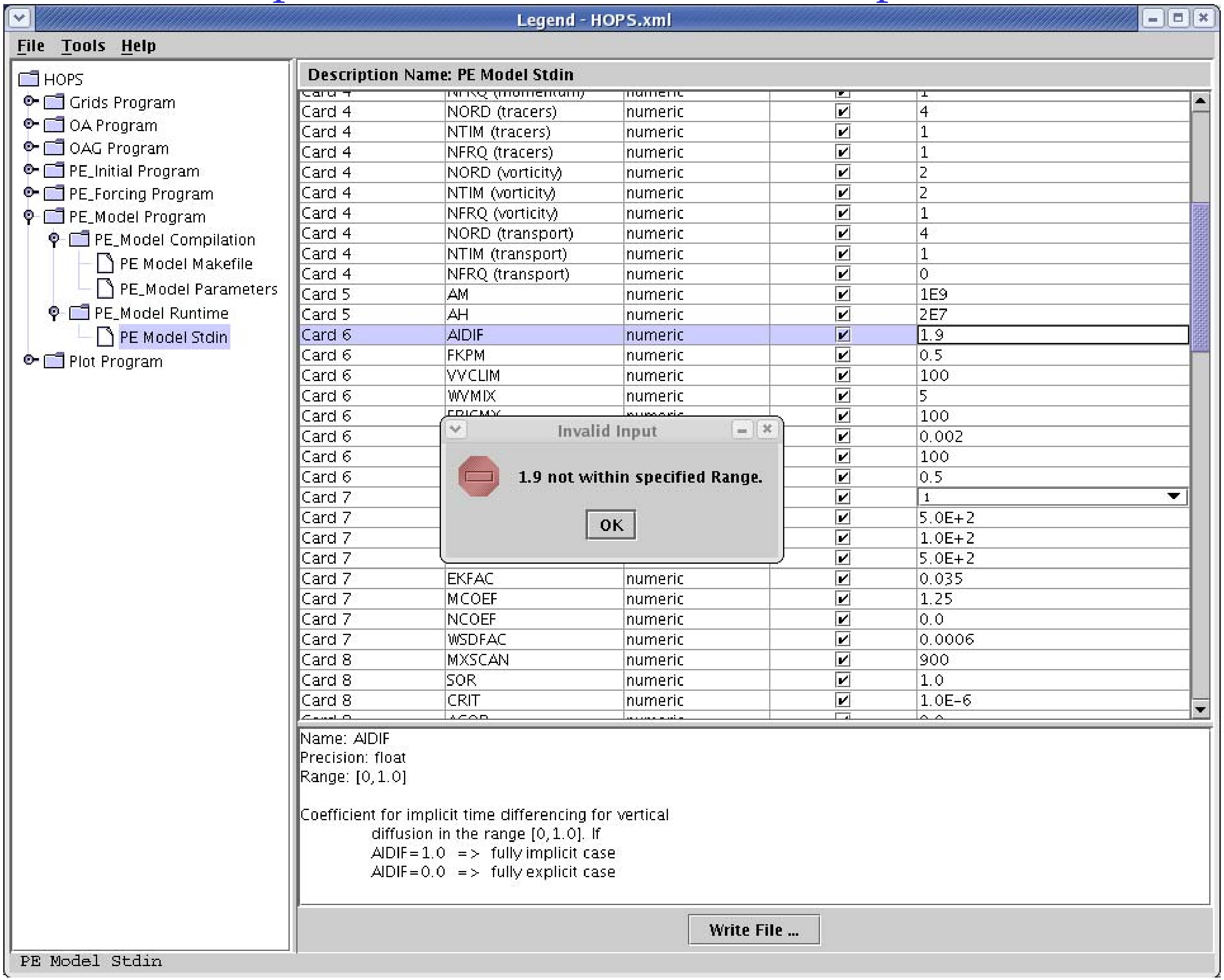
Many setups and parameters for physical, biological and acoustical models.

Software and GUI that controls adequacy and compatibility of options and parameters, at build-time and at run-time

- **Metadata for handling legacy software**
- **eXtensible Markup Language (XML) Encapsulation for Legacy Binaries**
- **Java-Based GUI for Legacy Binaries**

Evangelinos, et al. **Ocean Modeling**, 2006.

Graphical User Interface Developed for HOPS



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Coupled Physical-Acoustical-Biological Multivariate Data Assimilation

Multiscale

Energy and Vorticity Analysis, Mini-HOPS

Ensemble and Multi-Model Based

Bayesian-based Model Fusion

Automated Adaptive Sampling

e.g. Reduce Uncertainty, Dynamical Hotspots

Automated Adaptive Modeling

Real-time Configurations of Generalized Biological Model

Distributed, Web-Based

GUI for HOPS Run Control Over the Web