Advanced Systems for Operational Ocean Forecasting of Interdisciplinary Fields and Uncertainties

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Interdisciplinary Ocean Science Today

- **Research advances in interdisciplinary ocean science have led to the emergence of new dynamical concepts**
- **Non-linear interdisciplinary processes are now known to occur on multiple interactive scales in space and time with bi-directional feedbacks**
- **Such processes importantly can be dominated by strong sporadic events intermittent in both space and time.**
- **Understanding specific non-linear dynamics of known events and identification of important additional multi-scale interactive processes provides a framework for realistic understanding of the interdisciplinary coastal ocean**

System Concept

- **A system approach which synthesizes theory, data and numerical computations is essential for rapid and efficient progress**

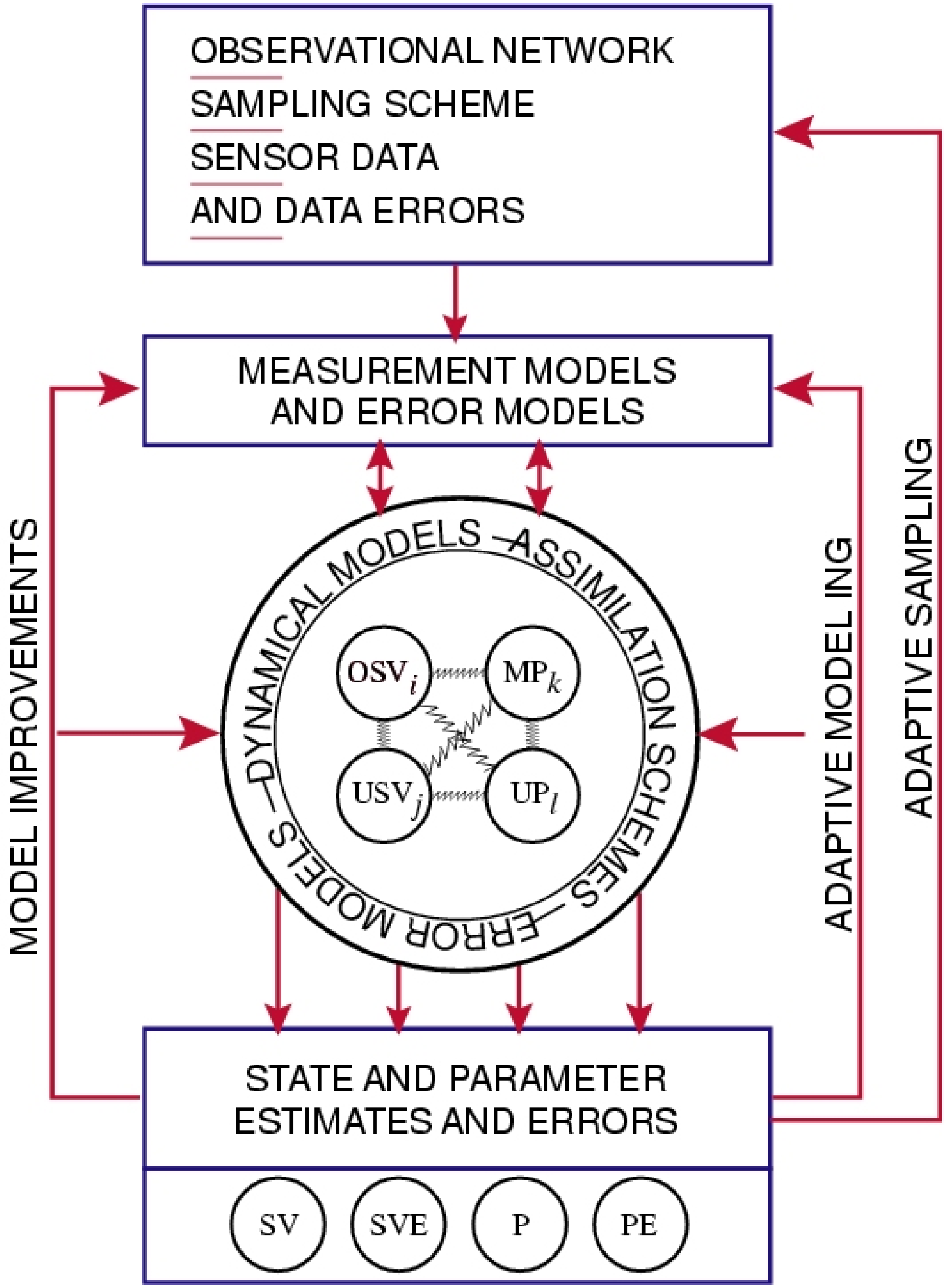
- **The concept of Ocean Observing and Prediction Systems for field and parameter estimations has recently crystallized with three major components**
  - **An observational network: a suite of platforms and sensors for specific tasks**
  - **A suite of interdisciplinary dynamical models**
  - **Data management, analysis and assimilation schemes**

- **Systems are modular, based on distributed information providing shareable, scalable, flexible and efficient workflow and management**

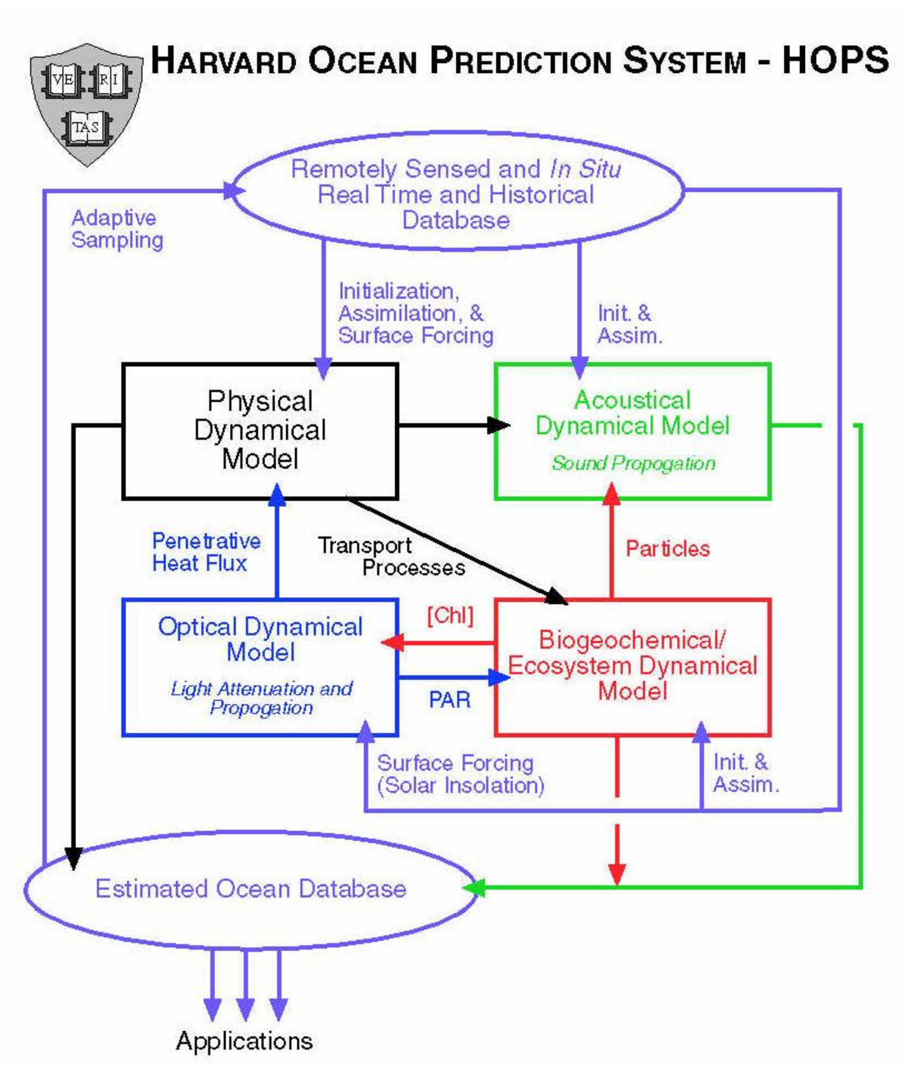
Systems to be Presented

- ***Rapid Real-Time Interdisciplinary Ocean Forecasting: Adaptive Sampling and Adaptive Modeling in a Distributed Environment***; LOOPS/Poseidon; Harvard/MIT; N. Patrikalakis, J. McCarthy, A. Robinson, H. Schmidt; NSF-ITR/ONR
- ***Assessment of Skill for Coastal Ocean Transients*** (ASCOT); Predictive skill experiments; NRV Alliance and Harvard Ocean Prediction System (HOPS); SACLANTCEN/Harvard; E. Coelho, J. Sellschopp, A. Robinson; SACLANTCEN/ONR
- ***Uncertainties and Interdisciplinary Transfers Through the End-To-End System*** (UNITES); Multi-institutional; P. Abbot (OASIS), A. Robinson; ONR
- ***Autonomous Ocean Sampling Networks-II*** (AOSN-II); Multi-institutional; J. Bellingham (MBARI - Lead), A. Robinson (Deputy-Lead); ONR

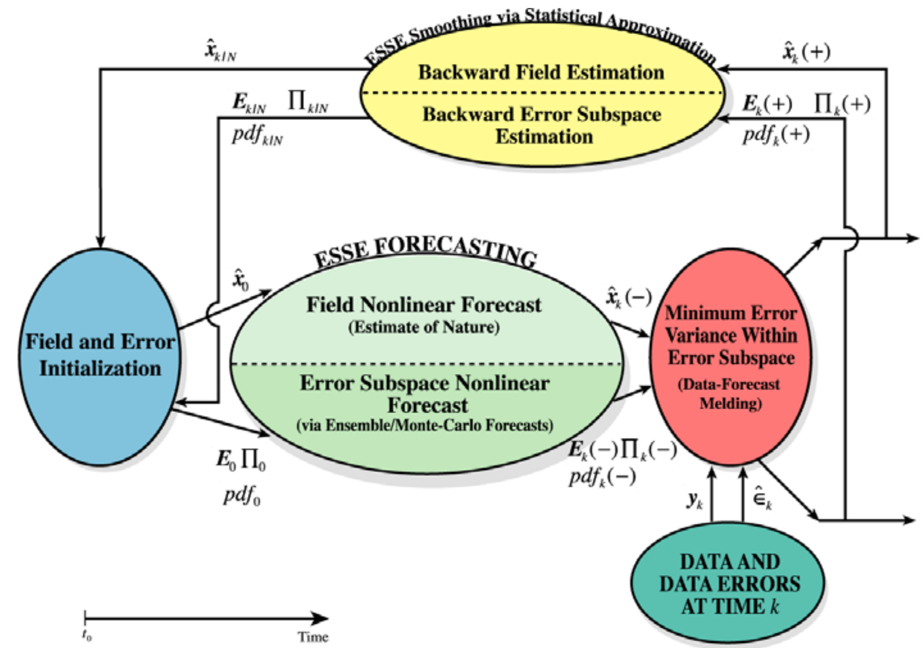
System Schematic for the Interdisciplinary Physical, Acoustical, Biological Ocean



SV: STATE VARIABLE
P: PARAMETER
O: OBSERVED
M: MEASURED
U: UNOBSERVED OR UNMEASURED
E: ERROR
(hatched symbol): DYNAMICAL LINKAGES



Error Subspace Statistical Estimation - ESSE



Multi-Variate Coupled Physical-Acoustical-Biological System

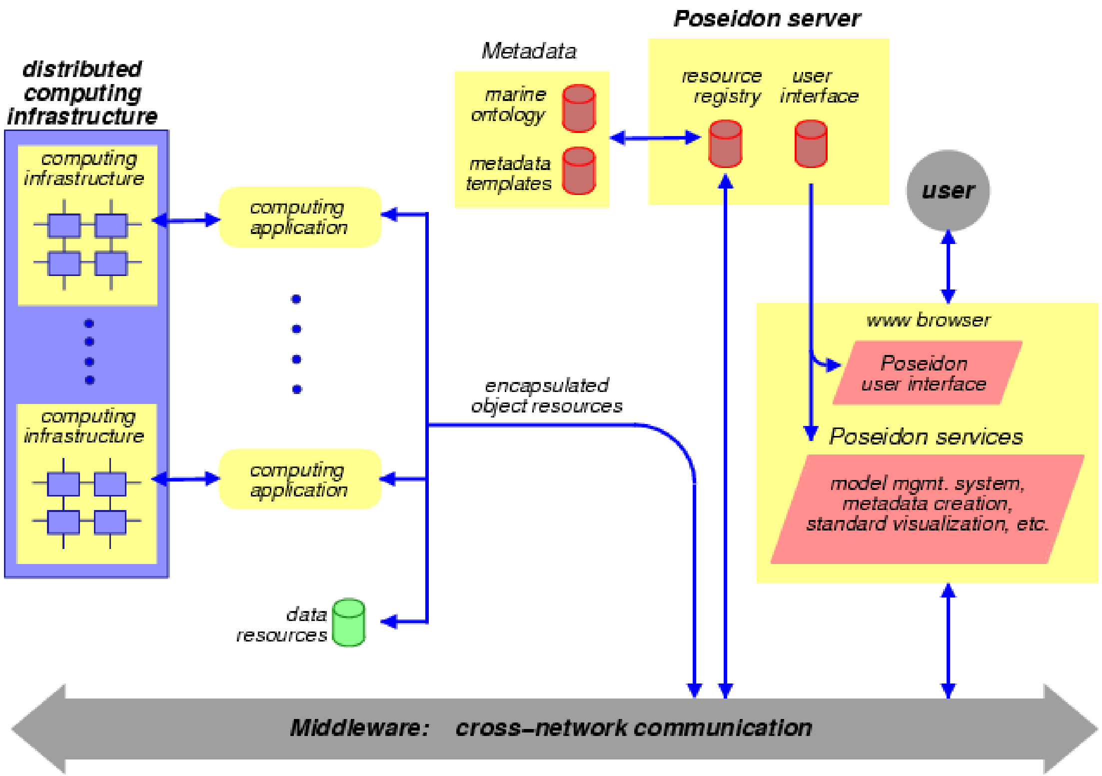
LOOPS/Poseidon

Ocean Forecasting in a Distributed Computing Environment

- Interdisciplinary research coupling Physical and Biological Oceanography with Ocean Acoustics.
- More effective Real-Time Ocean Forecasting for Naval and Maritime Operations, Pollution Control, Fisheries Management, etc.
- MIT OE (IT, Acoustics) and Harvard DEAS (Physical and Biological Oceanography).

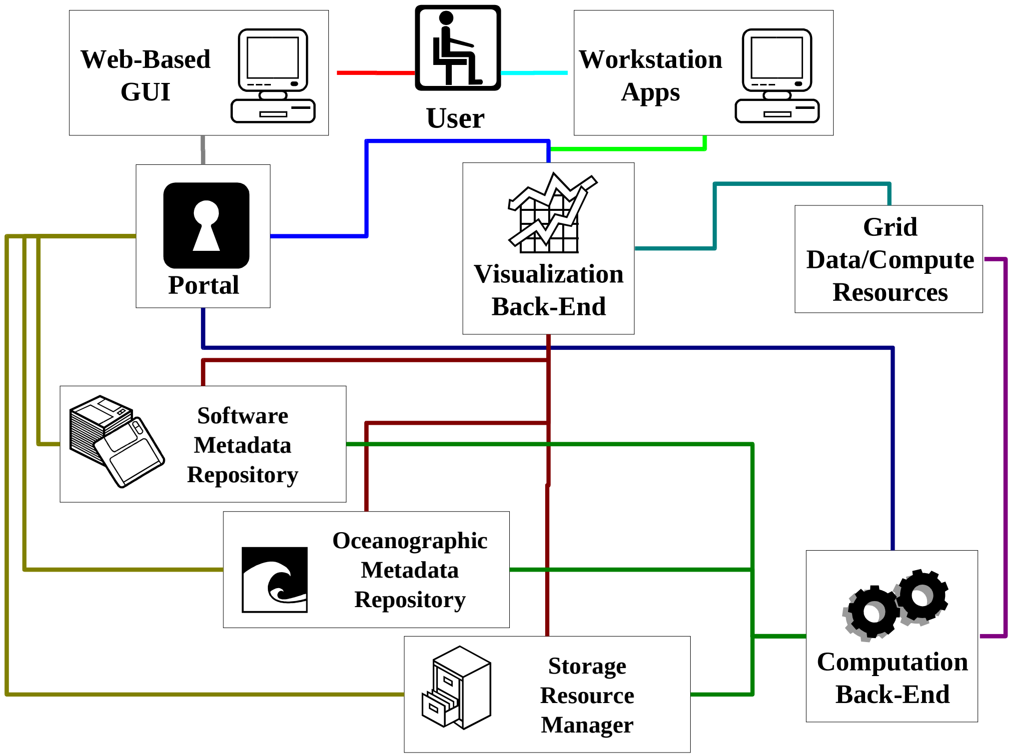
Key points

- Web interface
- Remote visualization
- Metadata for code and data
- Metadata/Ontology editors
- Legacy application support
- Grid computing infrastructure
- Transparent data access
- Data assimilation
- Interdisciplinary interactions
- Adaptive modeling
- Adaptive sampling
- Feature Extraction



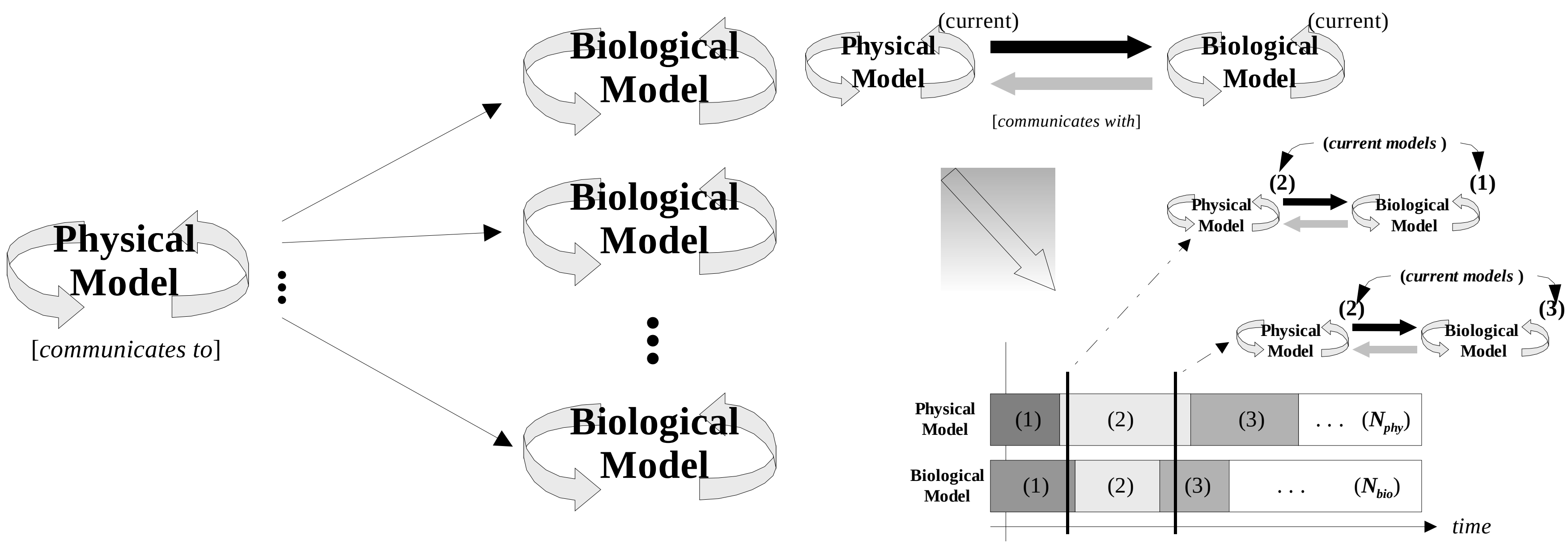
Distributed/Grid Computing and Ocean Forecasting

- Advanced Data Assimilation methods require significant computation and data storage resources
- The inherent parallelism is ideal for high throughput independent computations
- Local (dedicated and shared) and remote computers are used
- Remote data access can be transparent to the user
- We are employing Grid Computing technologies (Globus, Sun Grid Engine, Condor) with a web portal front end
- Various data grid storage solutions with domain specific support (DODS etc.)



- Individual computational components are serial (or parallel) platform-optimized Fortran based (“legacy”) codes
- Support for data visualization using local and remote resources
- Metadata repositories for locating relevant data or software descriptions

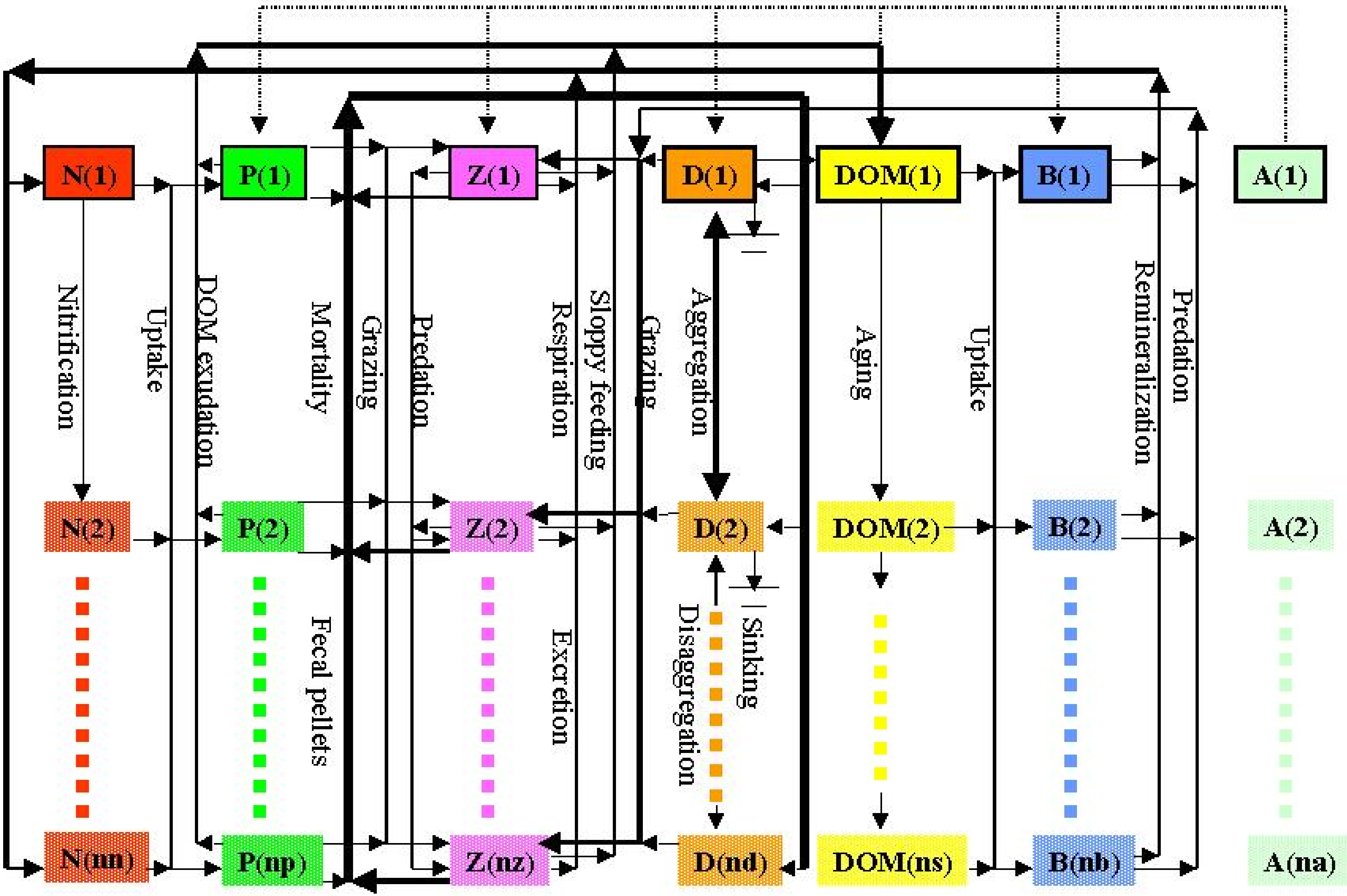
Real-time Time-adaptive Coupled Models



Various Adaptive Physical and Biological models can be coupled in more than one way:

- An (adaptive) physical model can drive multiple biological models when there is no way to ascertain *a priori* which is best for a given case
- An adaptive physical model and an adaptive biological model proceed in parallel, independently adapting and driving each other
- For performance reasons (tight coupling) both modes are being implemented using message passing for parallel execution
- Mixed language programming (using C function pointers and wrappers) for code adaptivity

Generalized Adaptable Biological Model

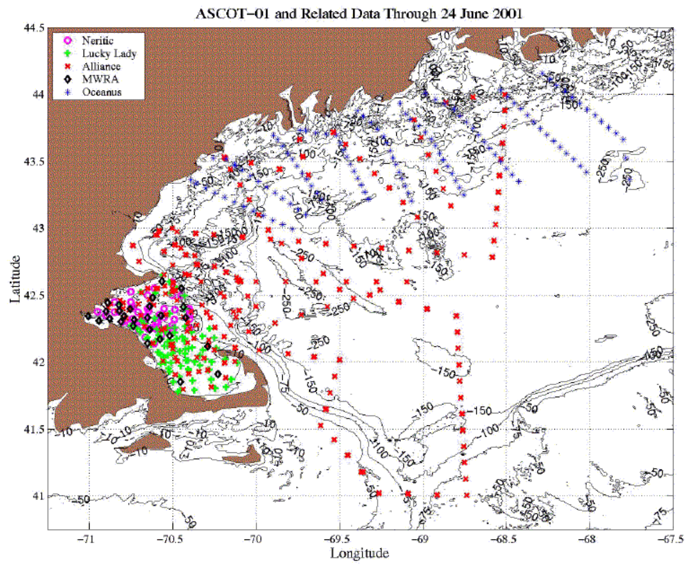


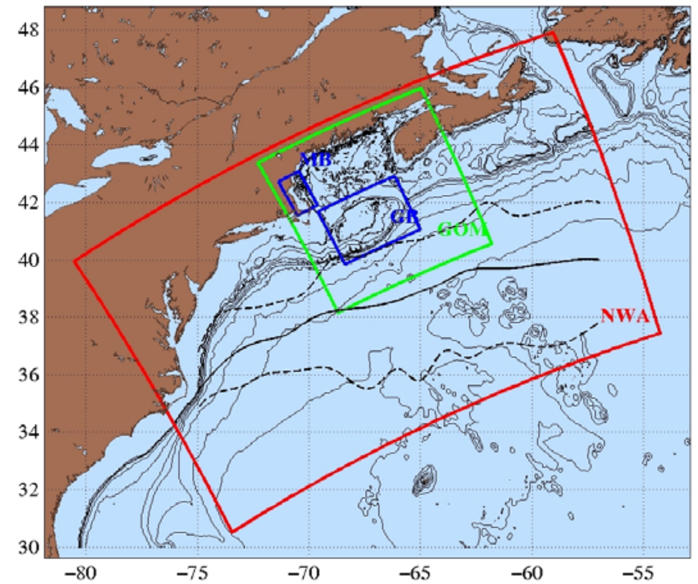
N.B.: Arrow thickness=number of processes

Predictive Skill

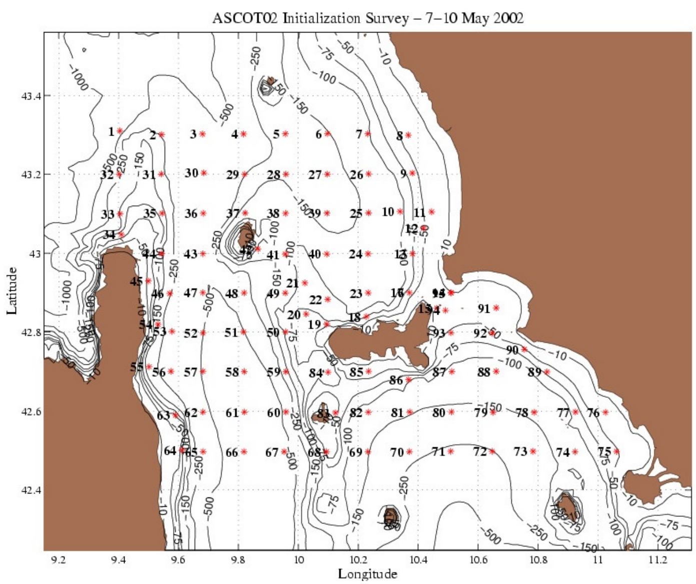
- Qualitative and quantitative evaluation of ocean forecasts by generic and regional-specific skill criteria and skill metrics is essential
- Phase errors, structural errors and their sources need to be identified and attributed
- Predictive skill experiments for regional and generic forecast systems require over-sampling for validation and to determine minimal data requirements.
- SACLANTCEN/Harvard: ASCOT-01, ASCOT-02/BP02

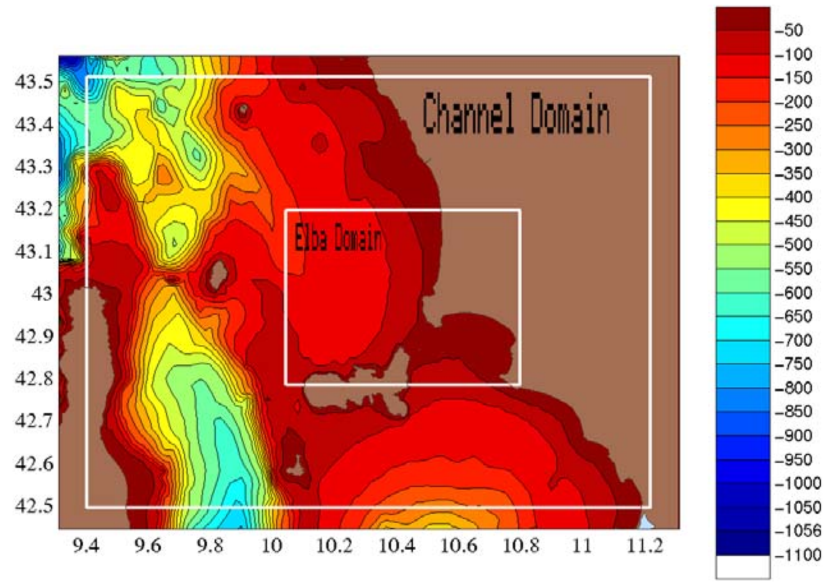
ASCOT-01: 6-26 June 2001





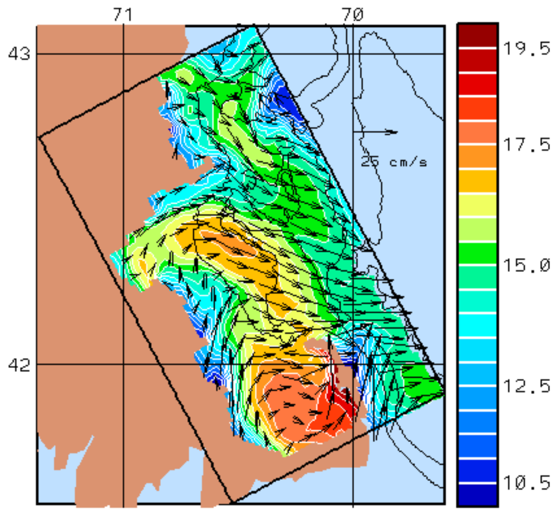
ASCOT-02/BP02: 7-17 May 2002



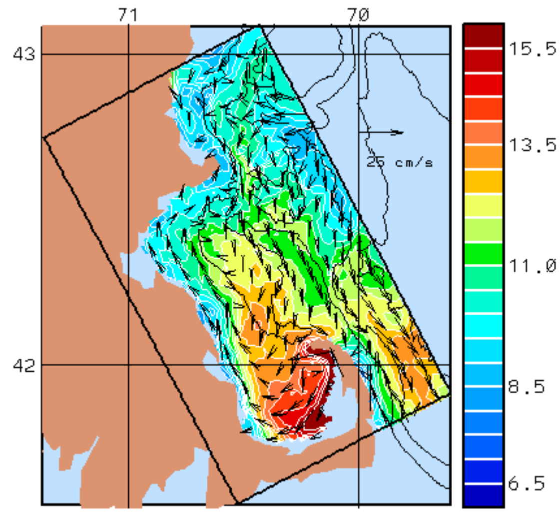


ASCOT-01 Real-Time Products

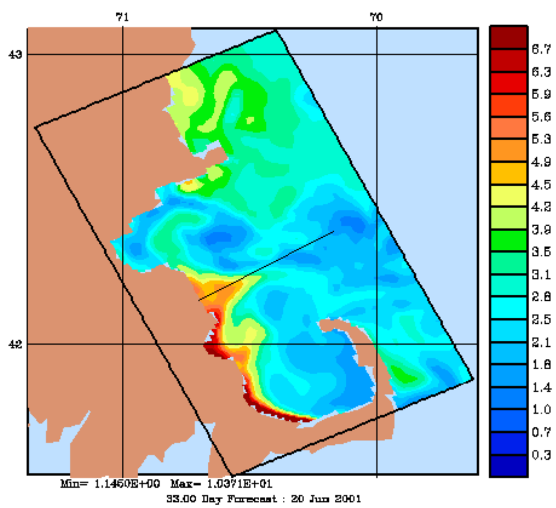
Massachusetts Bay



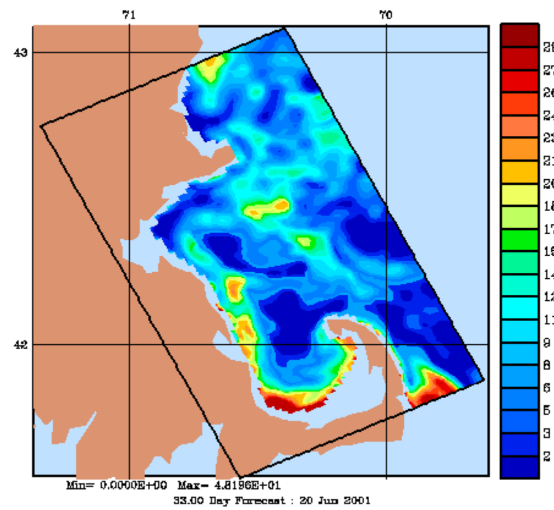
2m Temp.



10m Temp.

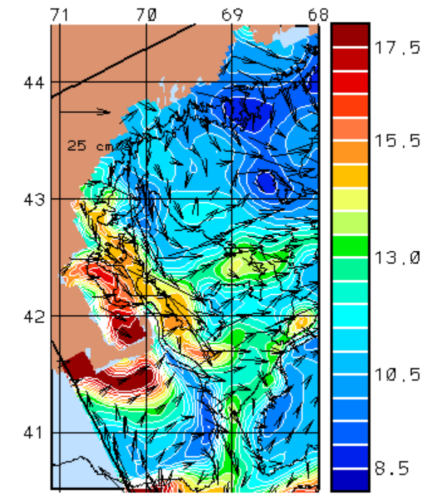


5m Chlorophyll

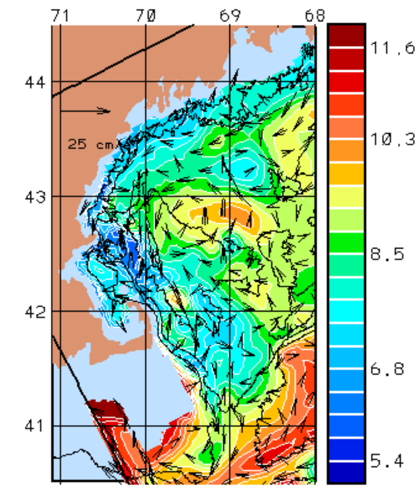


15m Nitrate

Gulf of Maine



3m Temp.

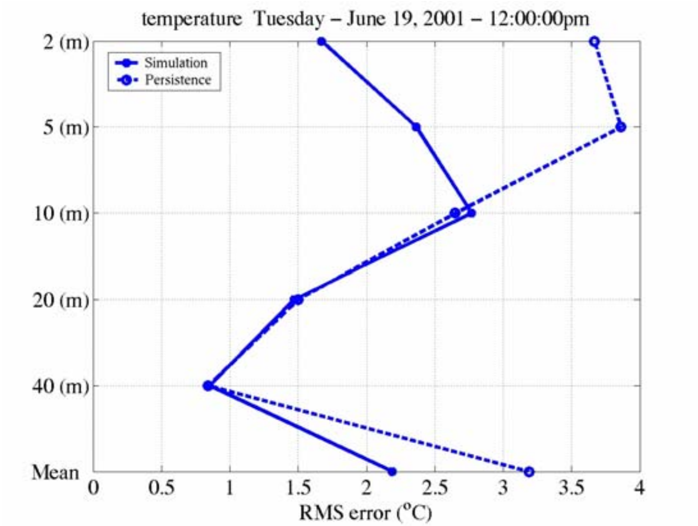


25m Temp.

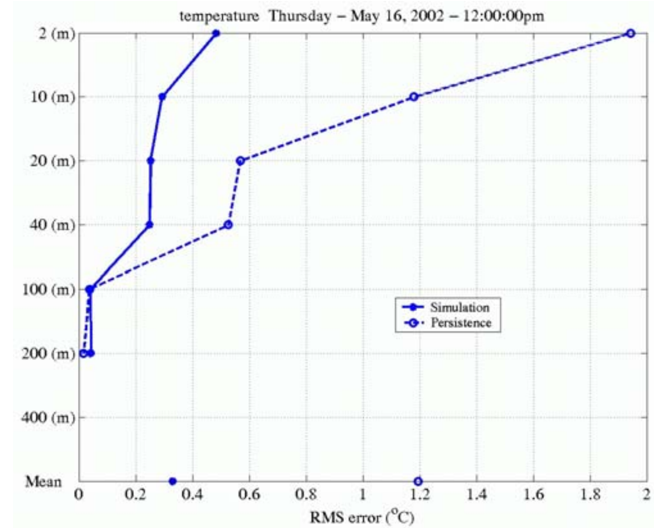
ASCOT-01

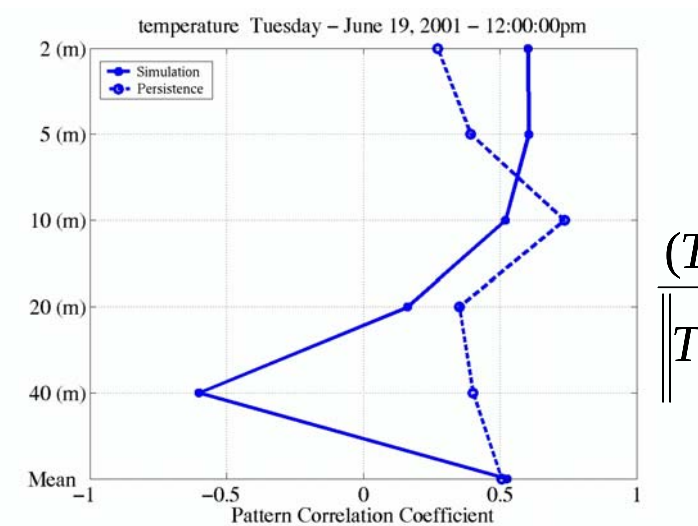
Skill Metrics

ASCOT-02/BP02

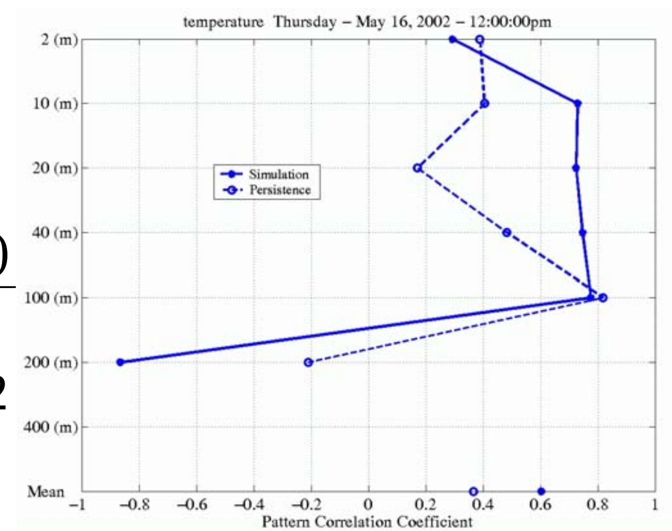


$$\text{RMSE} \equiv \sqrt{(T^f - \hat{T})^T (T^f - \hat{T})} \equiv \left\| T^f - \hat{T} \right\|_2$$



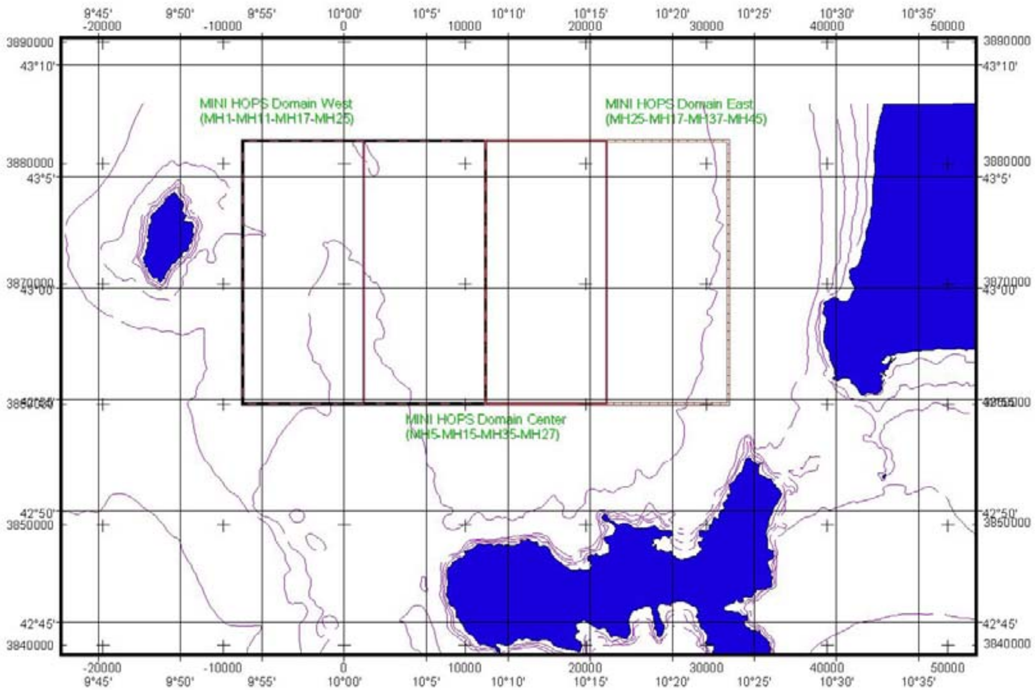


$$\text{PCC} \equiv \frac{(T^f - T^b)^T (\hat{T} - T^b)}{\left\| T^f - T^b \right\|_2 \left\| \hat{T} - T^b \right\|_2}$$

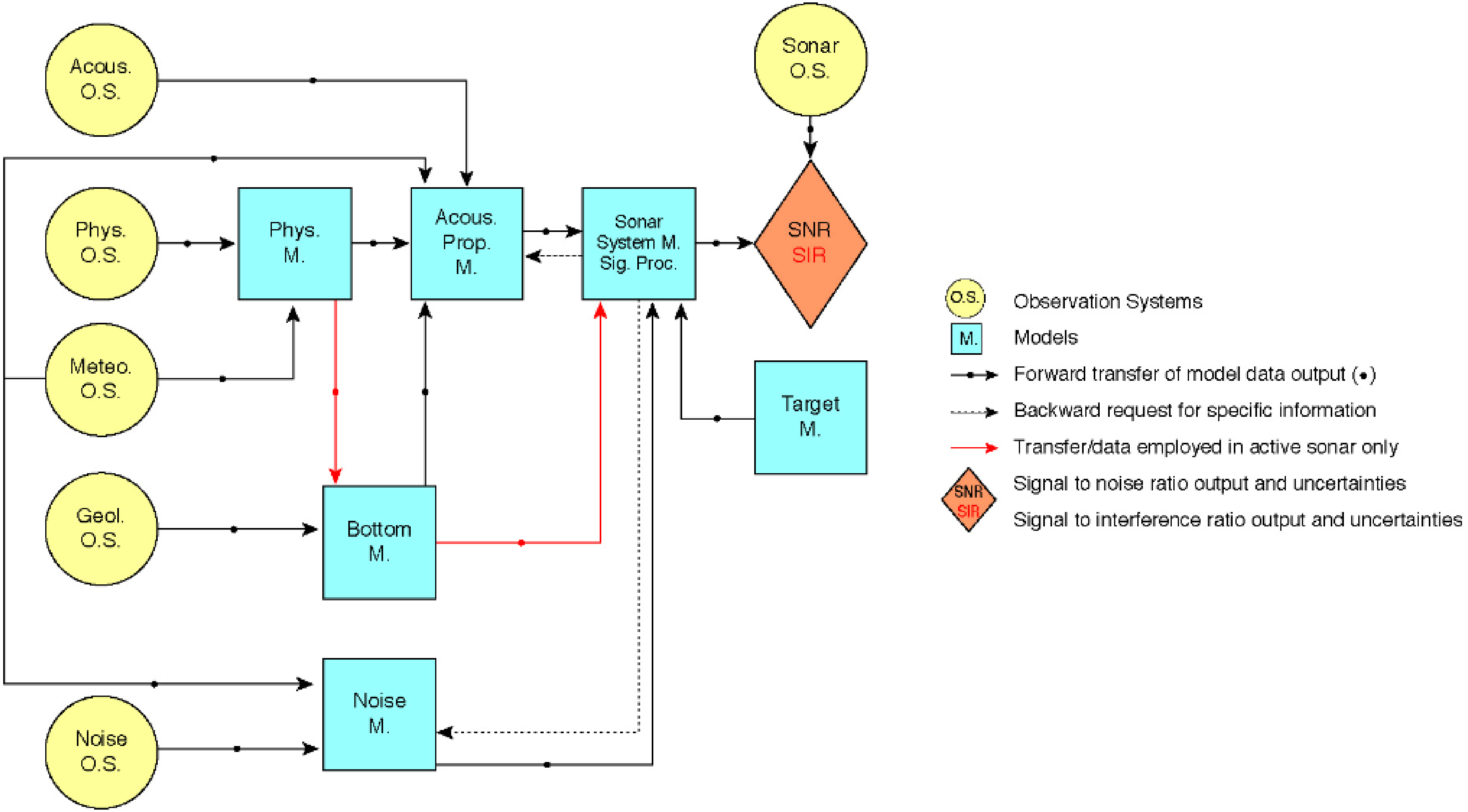


MREA03/BP03 – Mini-HOPS Modeling

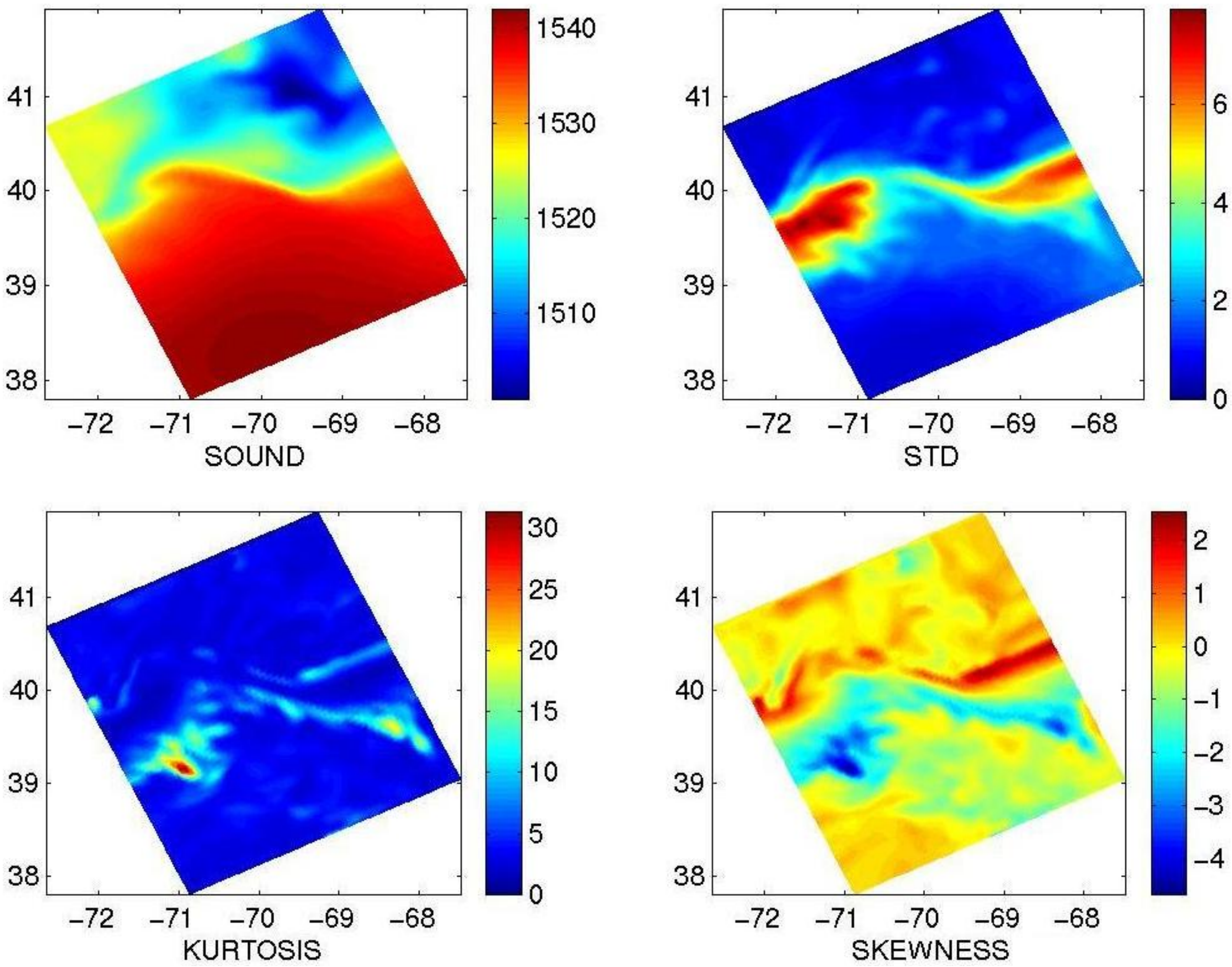
- One domain survey within an inertial period (app. 13 hours).
- Small domains will be initialised from a regional HOPS run.
- Inertial motion and sub-mesoscale features identified from the collected data and assimilated into the small domains following a progressive pattern (from west most domain to the east most domain) on a cycle basis.
- The mini-HOPS will be producing short term forecasts (24-48 hours) with hourly resolution.
- Over-sampling will be carried out so redundancy exists to evaluate the accuracy and persistency of the sub-mesoscale, short term forecasts.

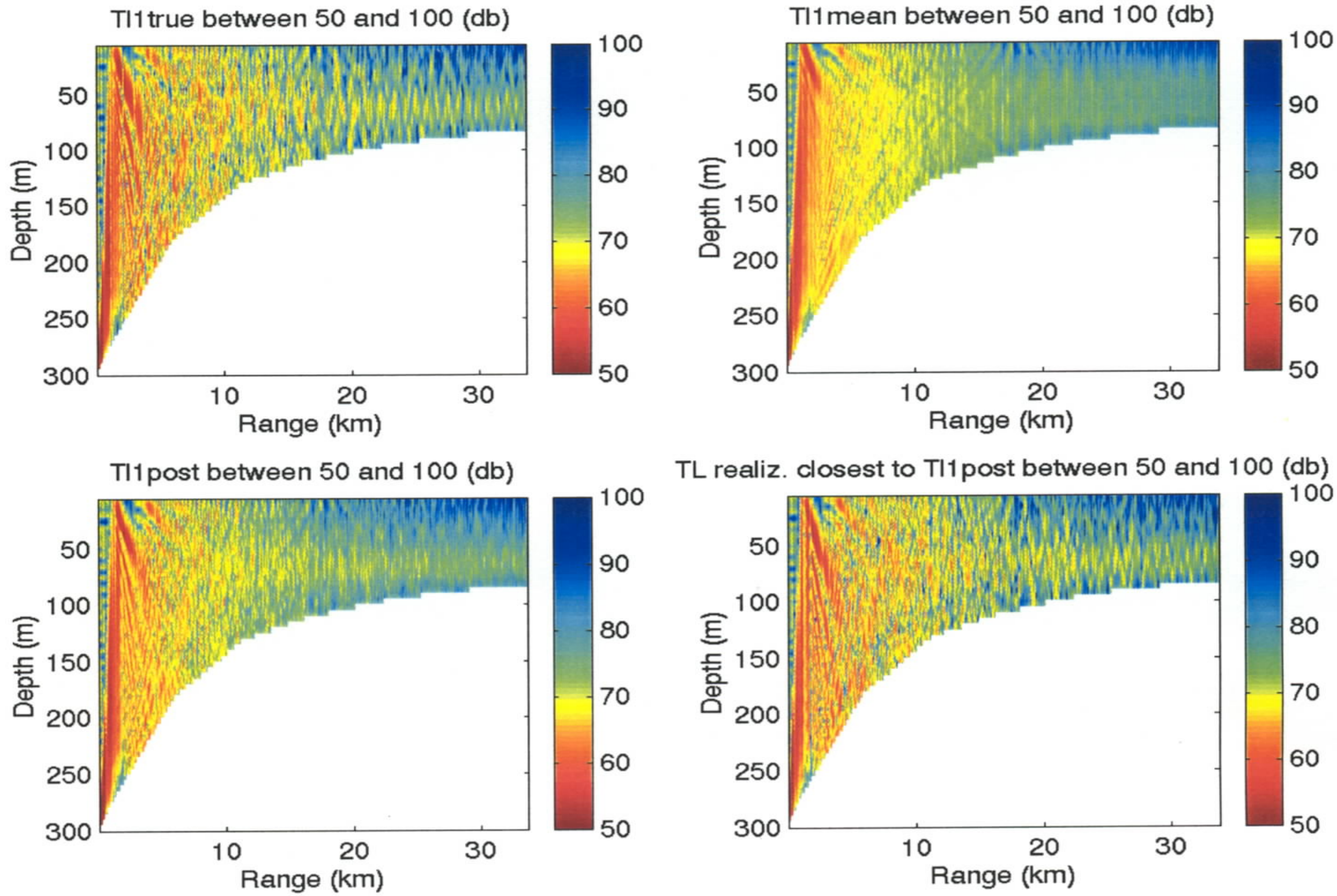


The End-to-End System



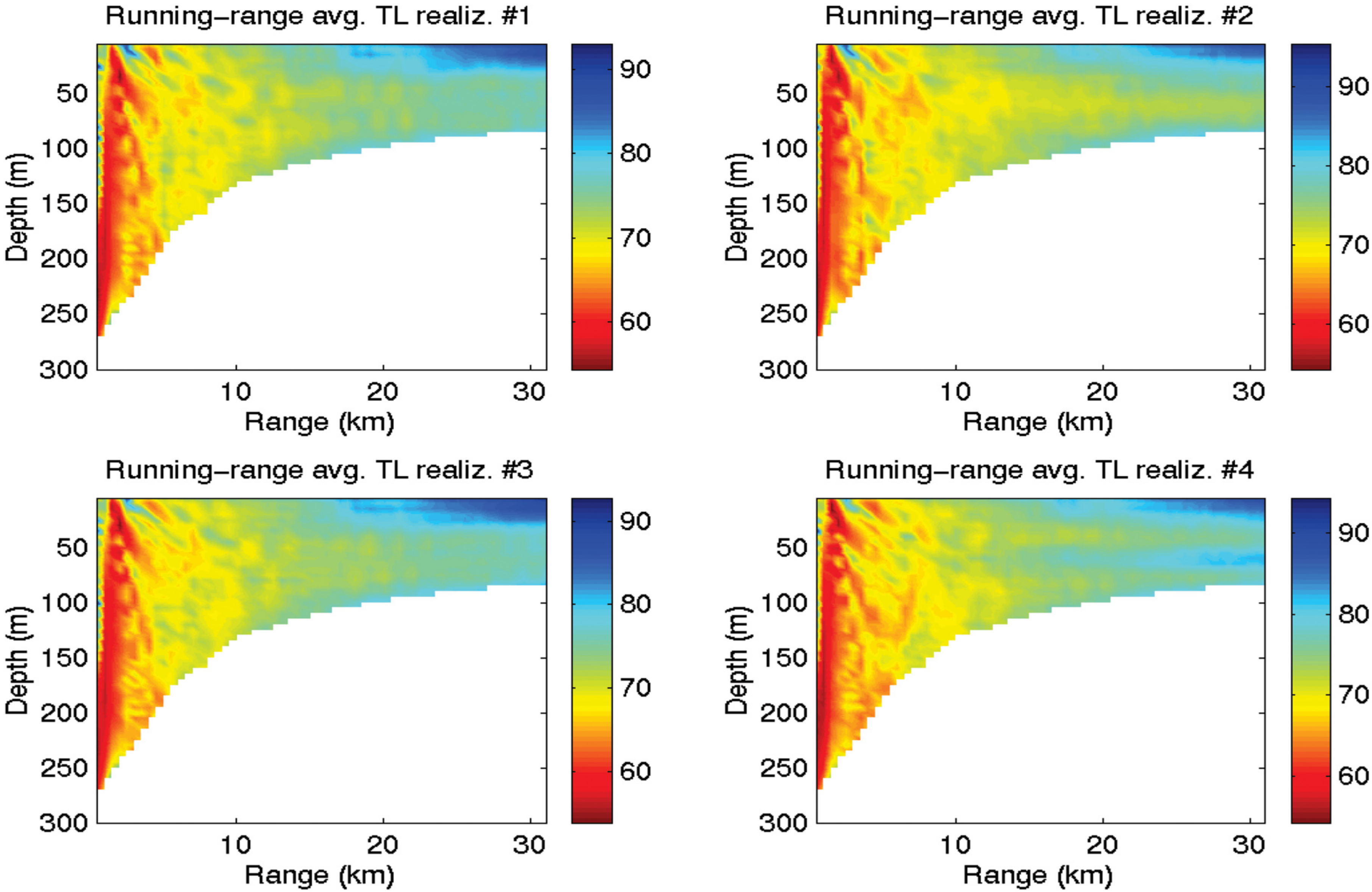
Monte Carlo simulation example: transfer of ocean physical forecast uncertainty to acoustic prediction uncertainty in a shelfbreak environment.



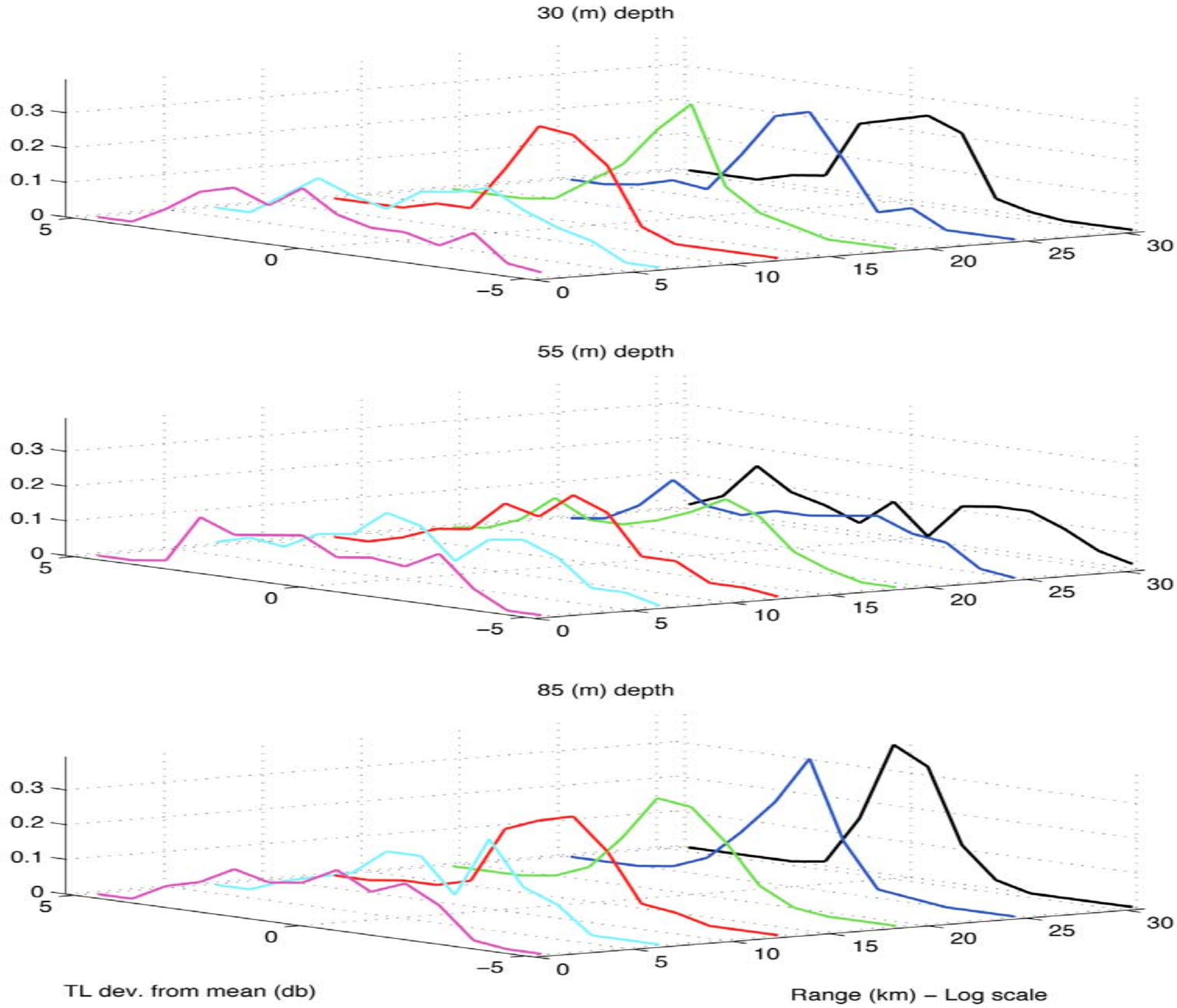


ESSE assimilation results (Twin Experiment):
"True" TL (from which towed-receiver data are sub-sampled),
a priori **TL (ensemble mean forecast),**
a posteriori **TL (after data assimilation) and**
TL realization closest to *a posteriori* **TL.**

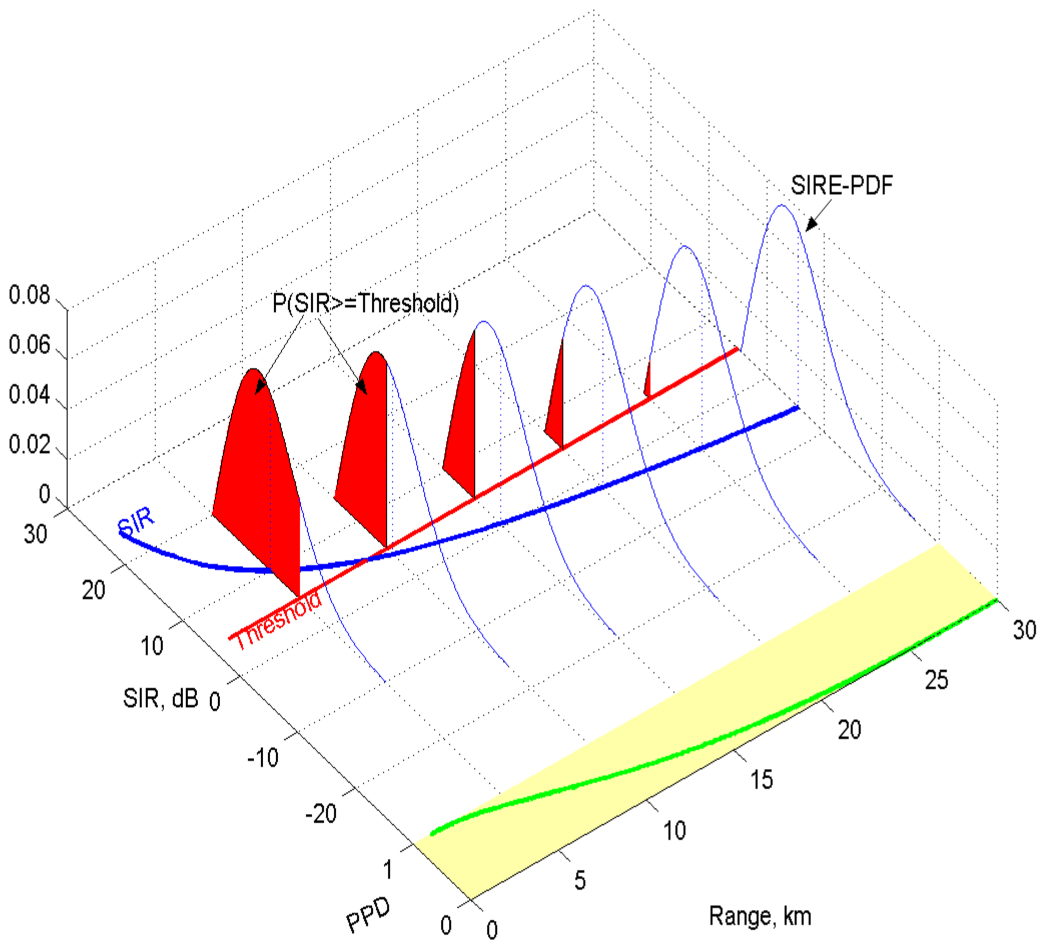
Var.-width (32Hz/224Hz) running-range avg. TL realiz. #1-4 (from 50 to 100 db)



Uncertainty (error PDF) of variable-width (32Hz/224Hz) running-range avg. TL

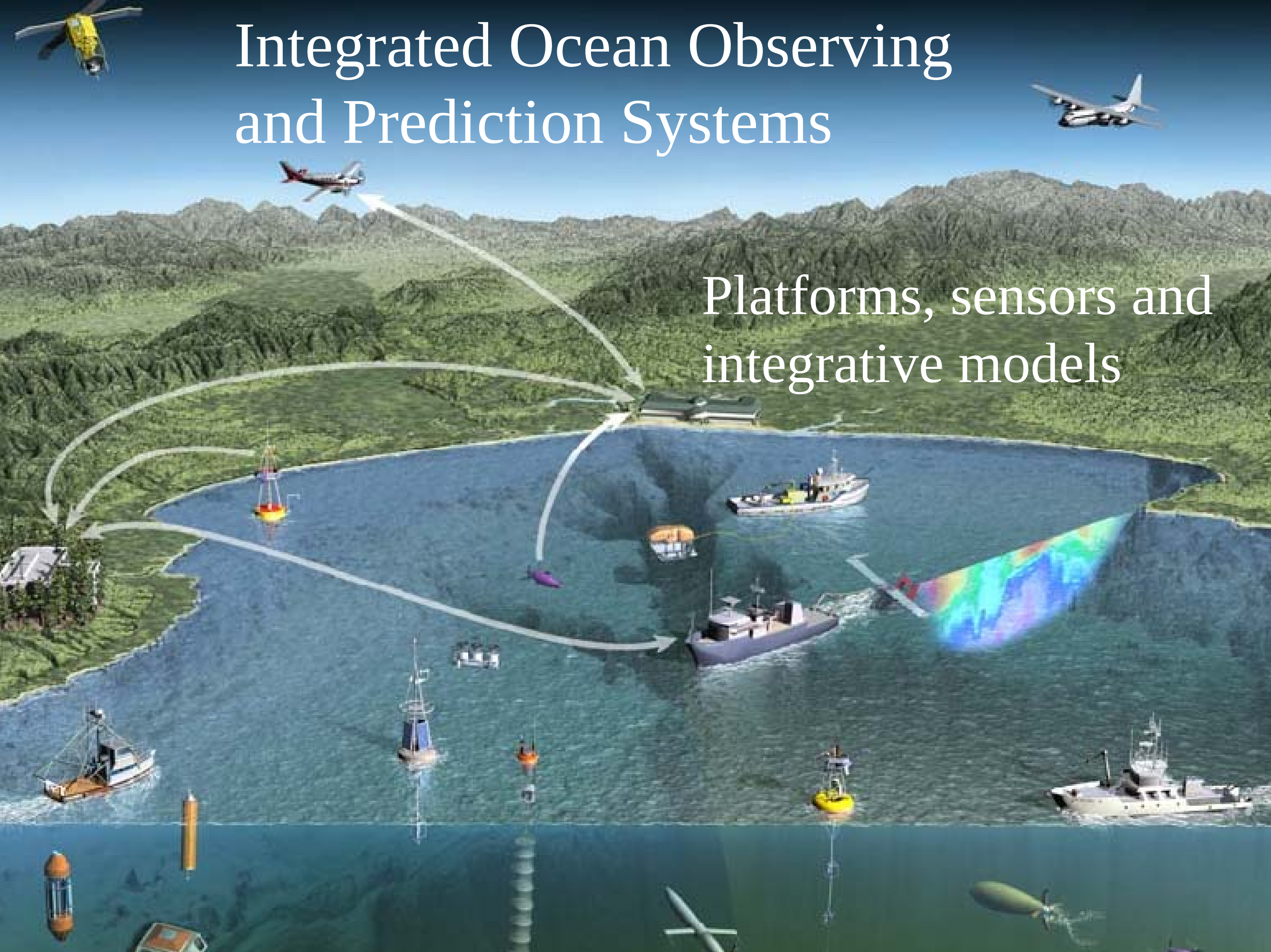


Determination of PPD (predictive probability of detection) using SIRE-PDF



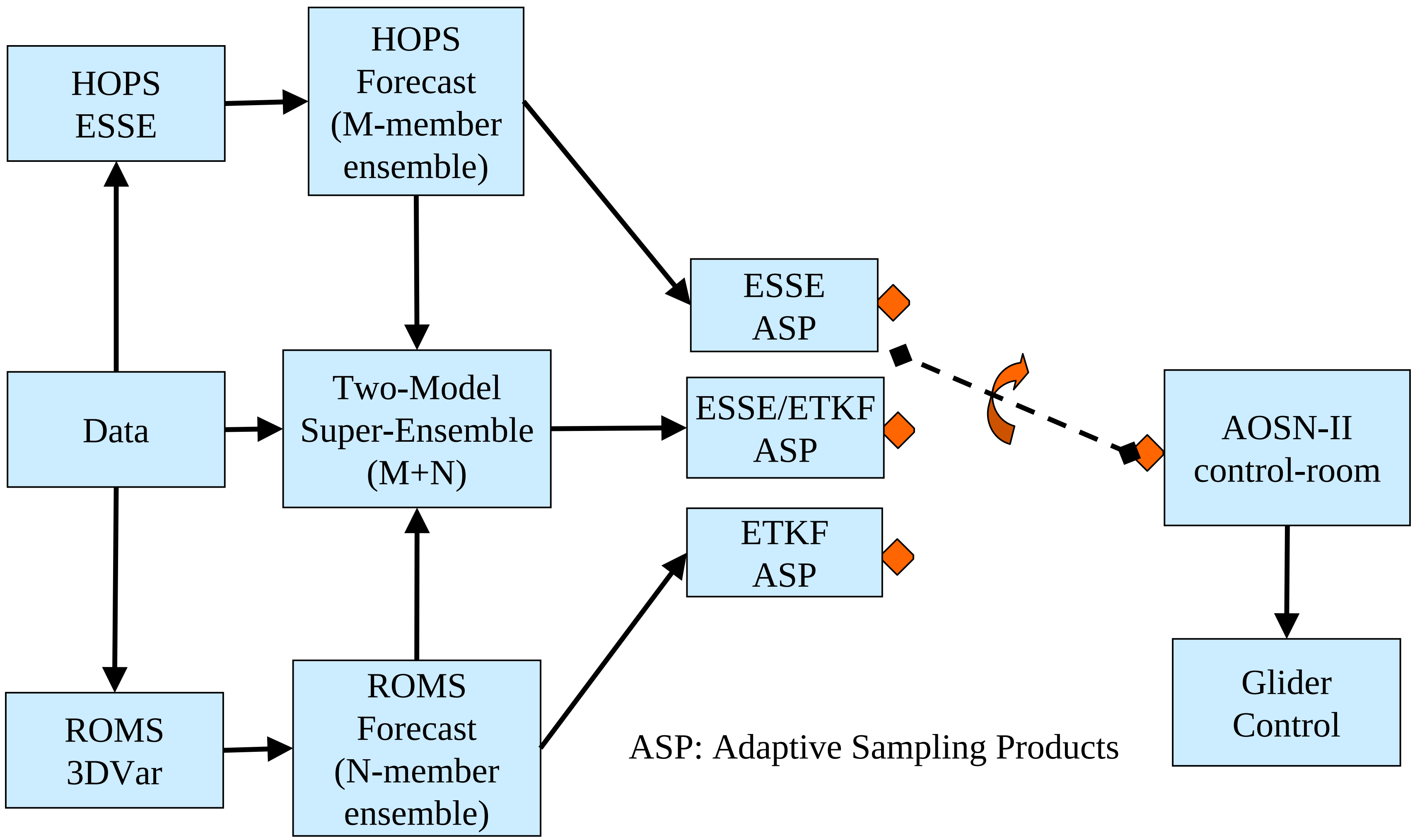
- Probabilistic representation of system performance
- Used by UNITES to characterize and transfer uncertainty from environment through end-to-end problems

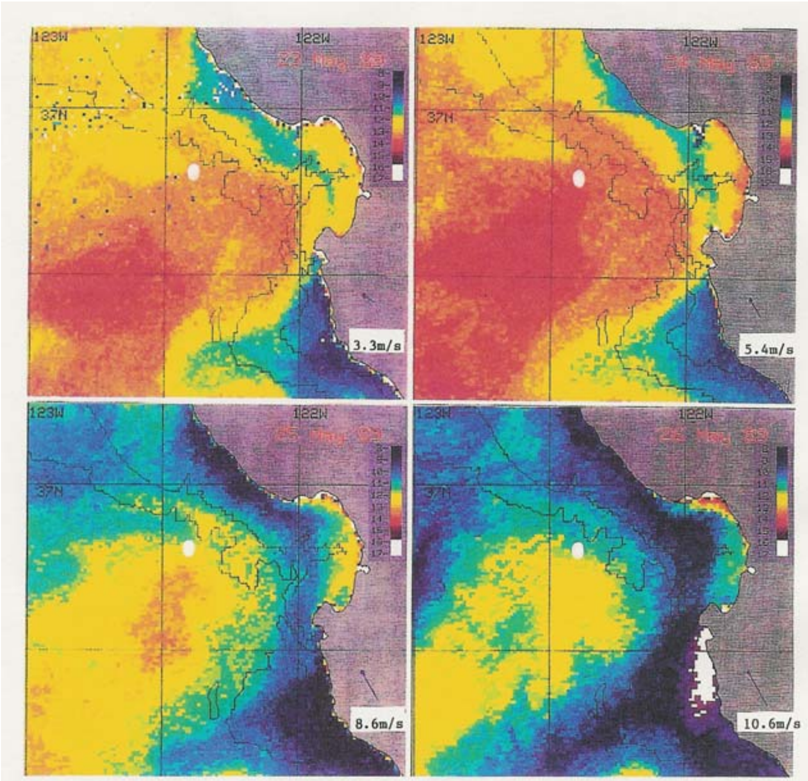
Integrated Ocean Observing and Prediction Systems

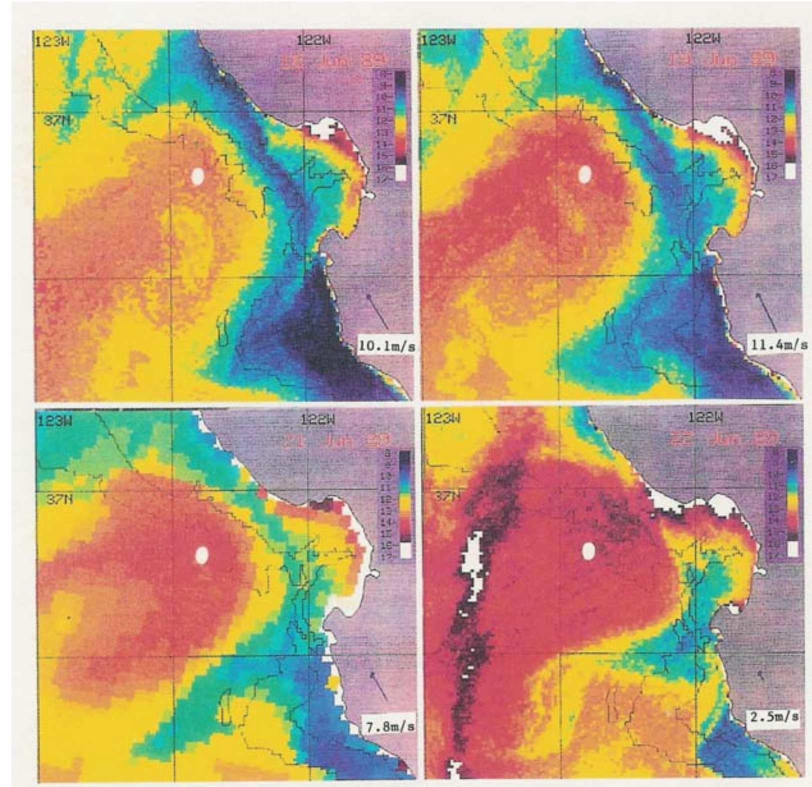


Platforms, sensors and integrative models

AOSN-II Modeling and Adaptive Sampling







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

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

Rosenfeld *et al*., 1994

Summary and Conclusions

- Advanced systems for adaptive sampling and adaptive modeling in a distributed computing environment

- Quantitative predictive skill measured by RMSE and PCC achieved significantly in the dynamic upper ocean

- Environmental uncertainties transferred through acoustic propagation and signal processing to sonar performance

- Integrated ocean observing and prediction system for a predictive skill experiment in Monterey Bay and the California Current System in Summer 2003