Theme I: Days to Seasons

Review and Discussion

Theme I Participants & Collaborators

Co-Investigators, RAs, PDFs

University of Victoria - Mike Foreman, Tsuyoshi Wakamatsu
University of Alberta - Paul Myers
UQAM - Pierre Gauthier, Sergey Skachko
Royal Military College - Michael Stacey, Yunfeng Shao
Dalhousie University - Keith Thompson, Yimin Liu
Dalhousie University - Hal Ritchie, Faez Bakalian
Dalhousie University - Jinyu Sheng
Dalhousie University - Dan Wright, Frederic Dupont, Zeliang Wang
Memorial University - Entcho Demirov, Jieshun Zhu

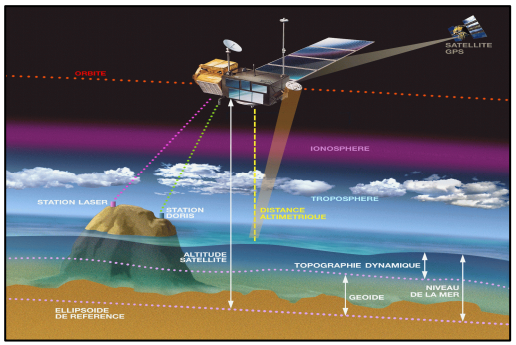
Students

University of Alberta - Veronique Lego, Mattea Turnbull, Anna Katavouta
Royal Military College - Shawn Donohue
Dalhousie - Jorge Urrego Blanco, Simon Higginson, Eric Oliver, Xu Zhang
Memorial University - Madlena Hakobyan, Colin Pike-Thackray

Technician

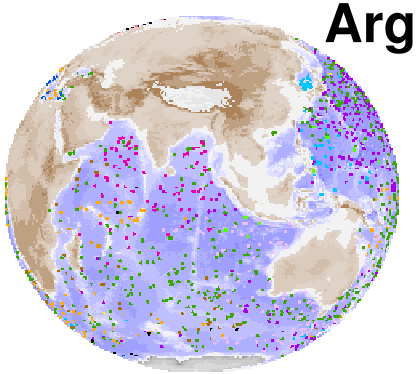
Dalhousie University - Fred Woslyng

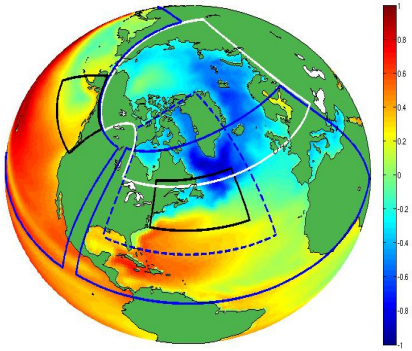
Altimeter

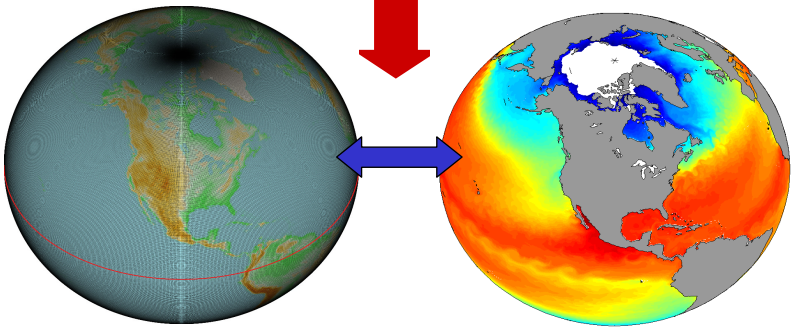


Theme I Roadmap

Argo







Coupled Modeling and Assimilation

Assimilation into coupled models (Pierre Gauthier)

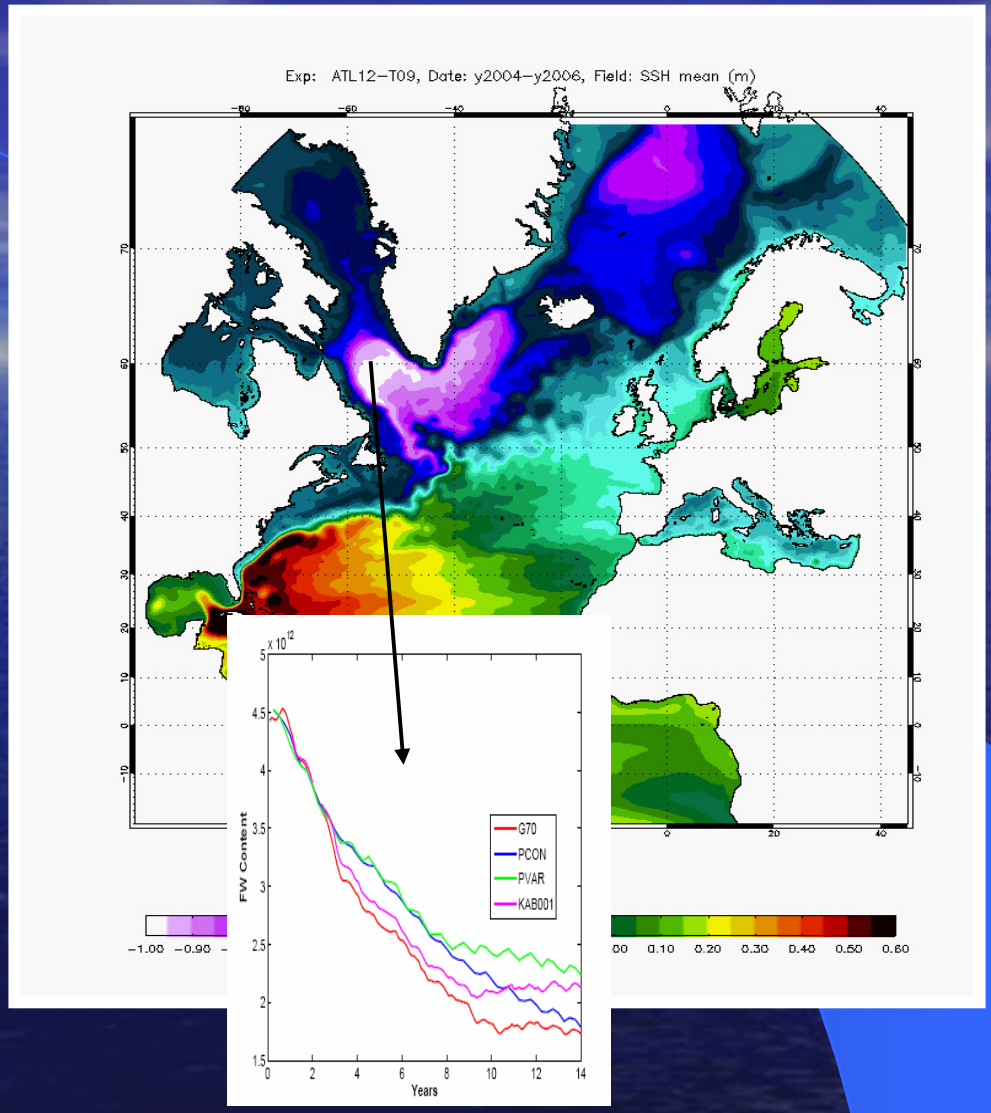
Studies on joint assimilation into coupled models (Hal Ritchie)

Spectral Nudging of Ocean Models

- **Suppresses model drift and bias (some evidence later)**
- **Used in some of our POP and NEMO models of the North Atlantic, North Pacific and global ocean**
- **Improves hindcasts and forecasts**
- **Implementation in CCCMa's seasonal forecast model appears successful (more from Bill after lunch)**
- **Continues to be modified and tested and hopefully eliminated**

Spectral Nudging is a temporary fix (??)

- Still significant drift in ice-ocean models
- E.g., same behavior in LS with regional & global models and with different forcing data sets
- Spectral Nudging has been quite successful at controlling model drift but we still aim to eliminate the need for it.
- Paul is focusing on understanding the causes of drift in the LS.



Also: Sea ice concentrations under-estimated

- Examination of the impact of assimilating sea ice concentration data is ongoing
- See Anna Katavouta's presentation

Model Testing and Improvement by Assimilating Moments of Variability

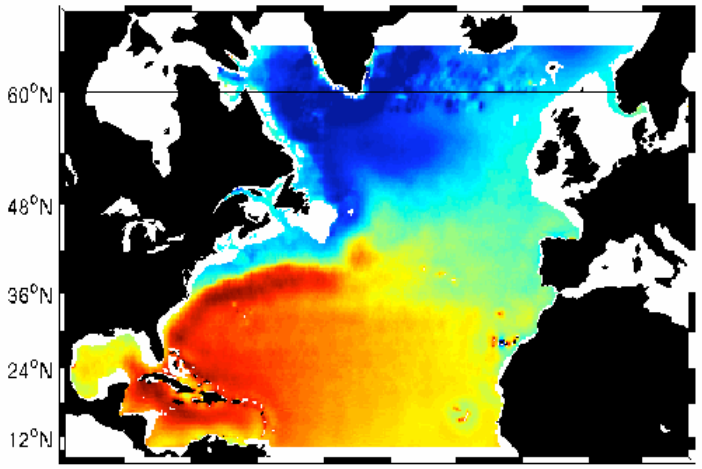
"Use statistics describing mean ocean state and its variability (2nd and 3rd moments) to improve eddy resolving models of North Atlantic, North Pacific and their forcing fields."

- *MSST (altimeter + GRACE + terrestrial gravity)*
- *Variance and skewness of altimeter sea level*
- *Mean and variance of surface drifter velocities*

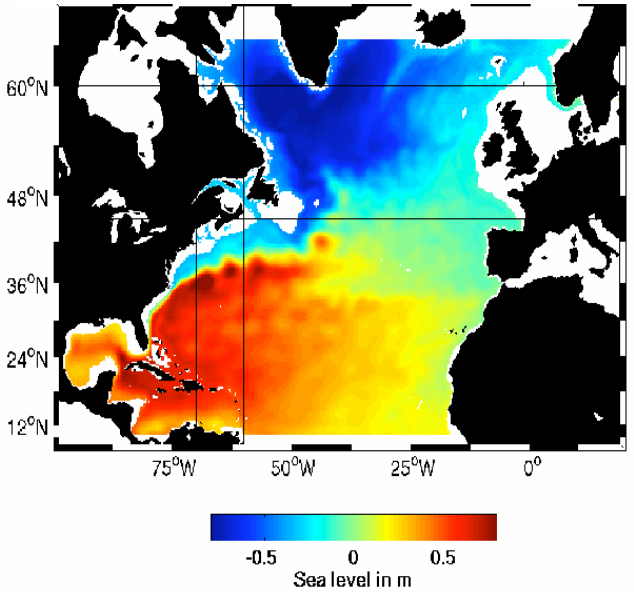
- *Improved TS climatologies*

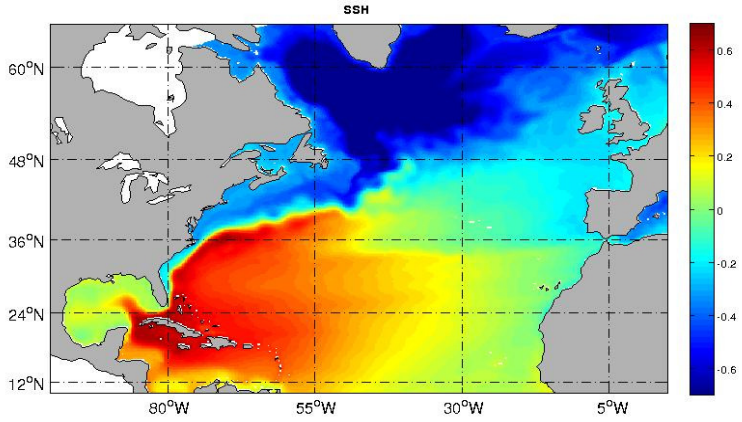
Mean Sea Surface Topography From Space

Satellite-Based Estimate



POP/Yashayaev estimate

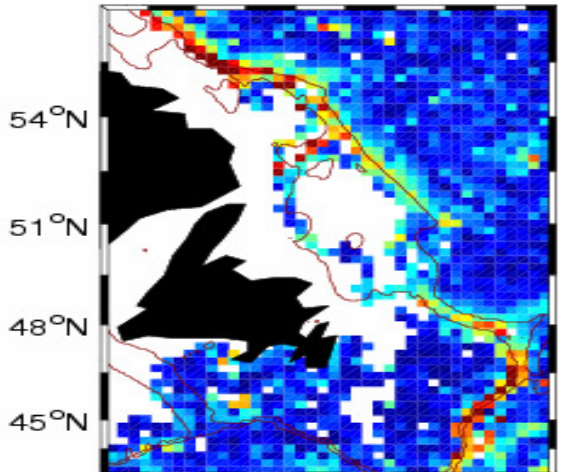




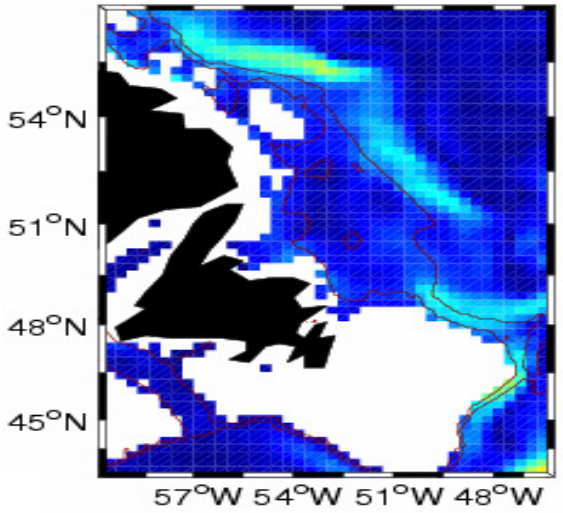
A new spatial smoother has been developed to smooth unrealistic structures in the nudges while still constraining larger scales. Implemented in NEMO and at CCCma.

Also improving climatology by de-eddying Argo (Simon Higginson).

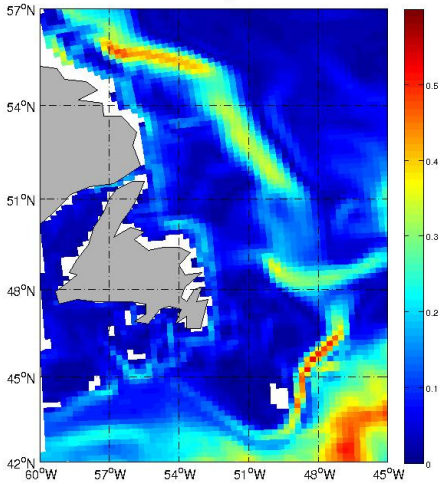
Drifters: the benchmark



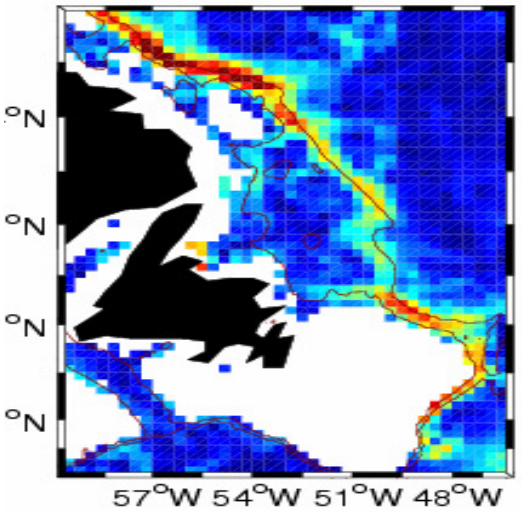
Old nudged model result



New nudged model result



$MSST_{G1}$



Satellite-based result

The old nudged model results have currents significantly too weak in the sub-polar gyre. The new result is significantly improved in spite of greatly reduced nudging.

Multivariate Assimilation of Altimeter and Argo Data

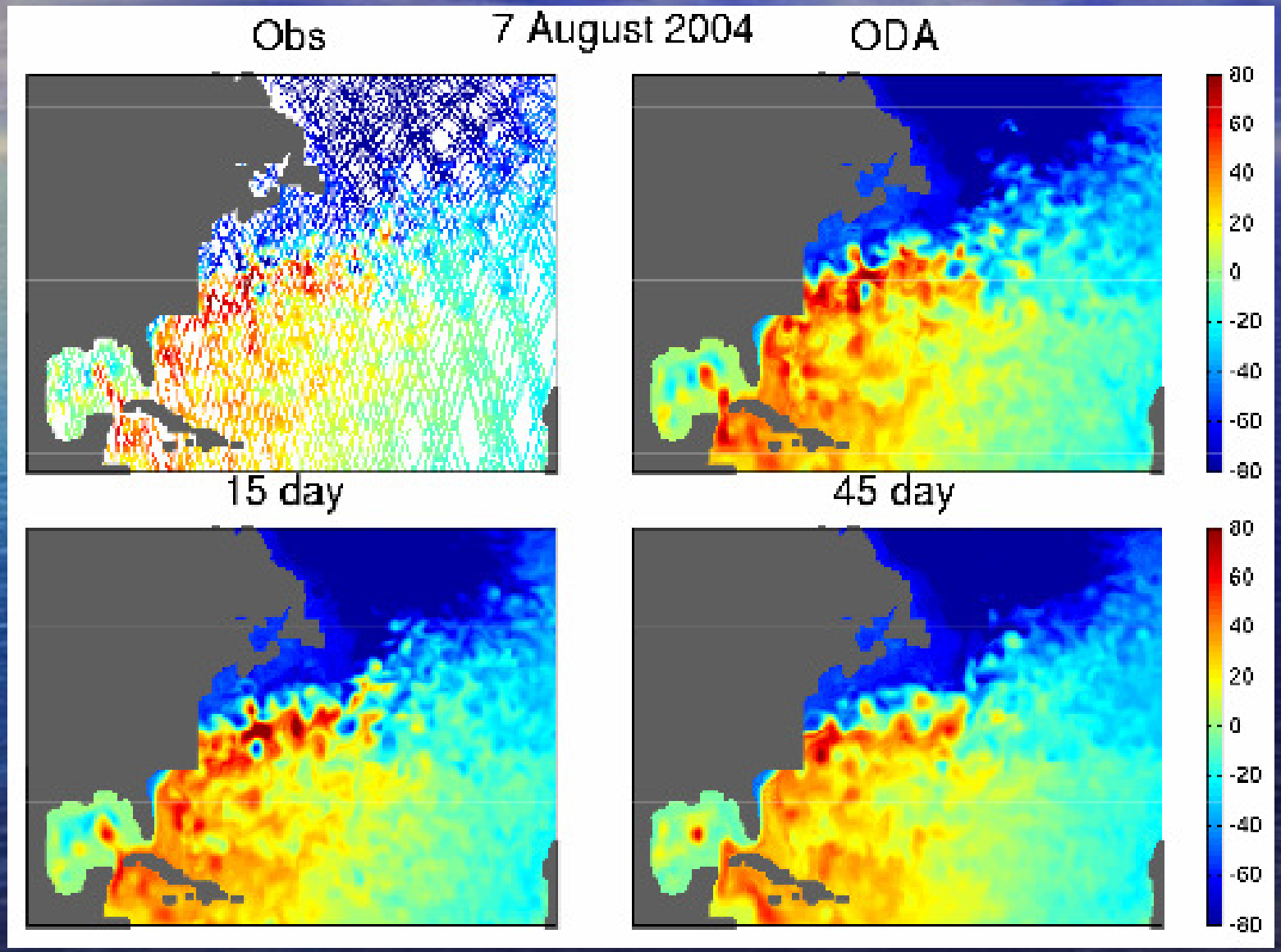
✓ ***Estimate statistics of short-term forecast and observation errors***

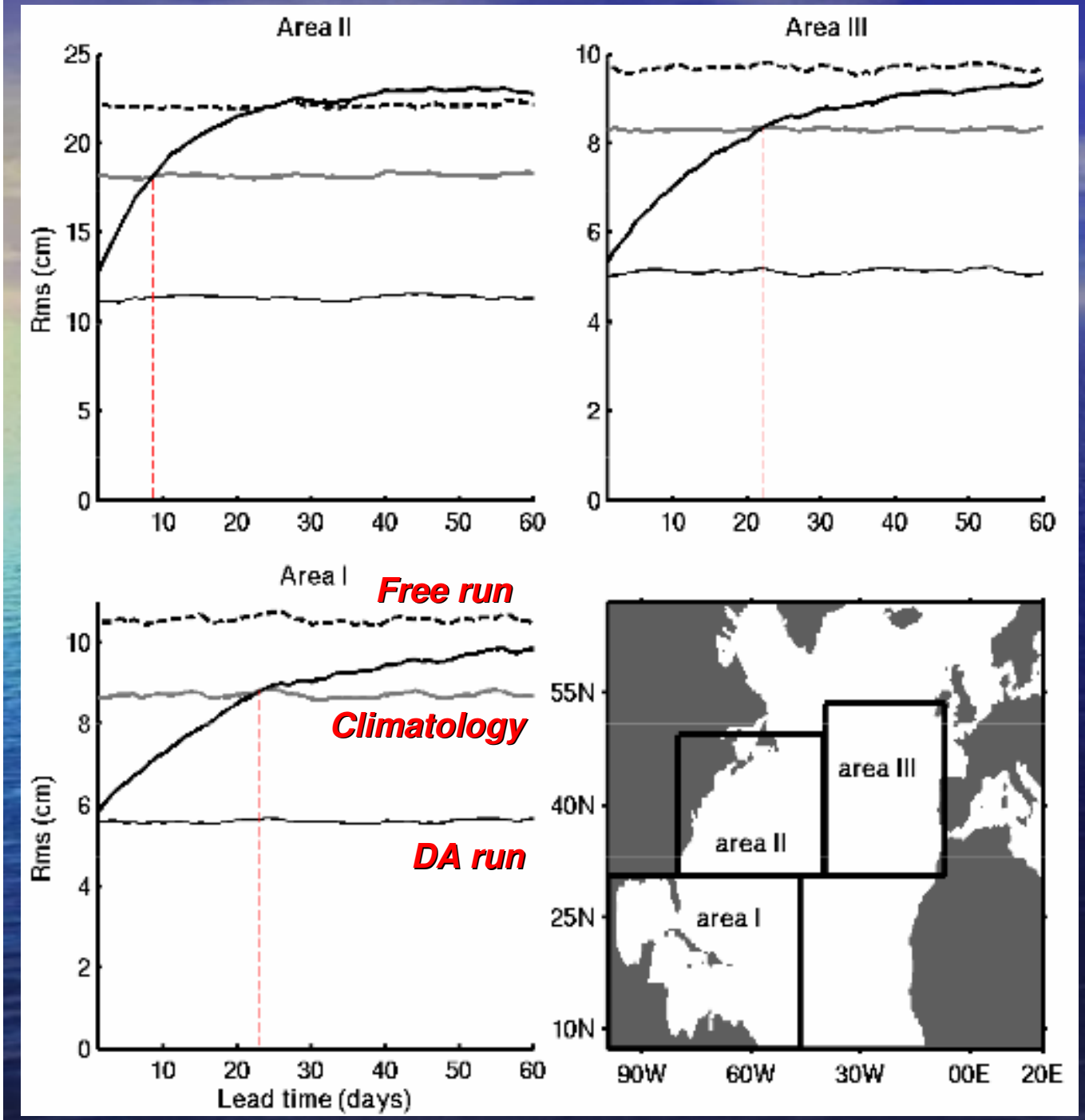
✓ ***Test and evaluate new schemes for assimilating altimeter and Argo profile data into basin and global models.***

North Atlantic Example using POP

- 1/3 degree ocean model with 23 levels.
- Daily atmospheric forcing from NCEP reanalysis.
- Assimilate Argo and altimeter data, 2003-5.
- 3D-Var extension of Cooper-Haines method.
- Covariance information is updated every two days.
- The DA scheme is both evolutive and efficient.

Typical Snapshot of Sea Level





Forecast Skill For Sea Level

- Rms of obs-pred vs lead time
- Based on 24 forecast runs, each 60d in length
- Method implemented in NEMO – progress will be discussed in context of the supplementary project.

Ocean Reanalysis and Forecasting

✓ **Assess reanalyses and forecasts using NEMO and new assimilation schemes**

✓ **Embed finer resolution models to improve specific features in critical regions**

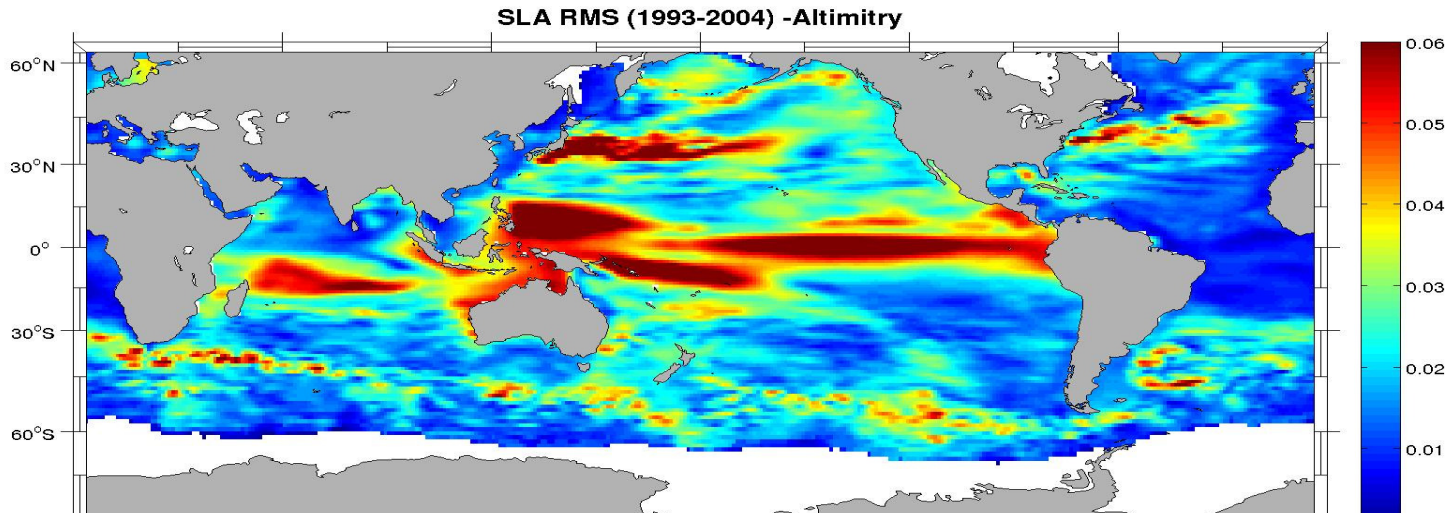
✓ **Investigate physical causes of variability where good agreement with observations is found**

✓ **Improve the global coupled system for Theme I and, ultimately, the operational coupled system**

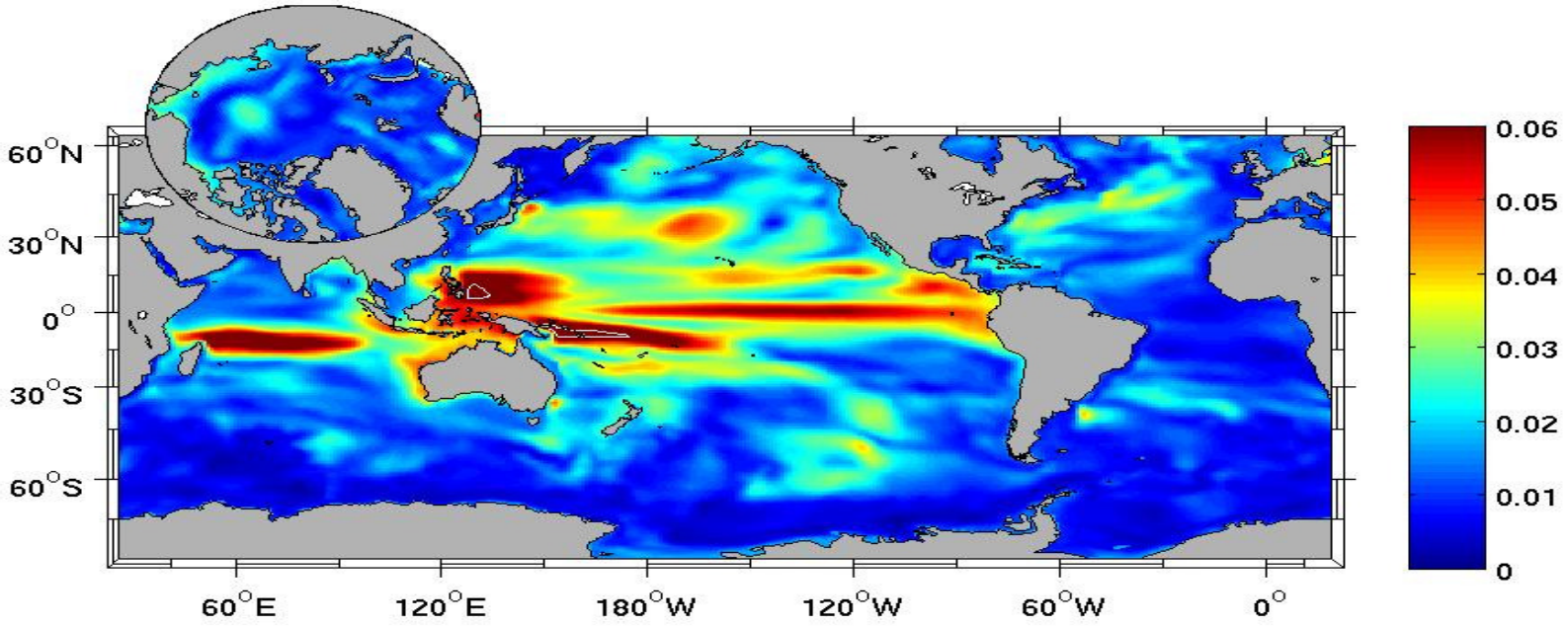
Pacific Results

RMS of InterAnnual Sea-Level 1993-2004

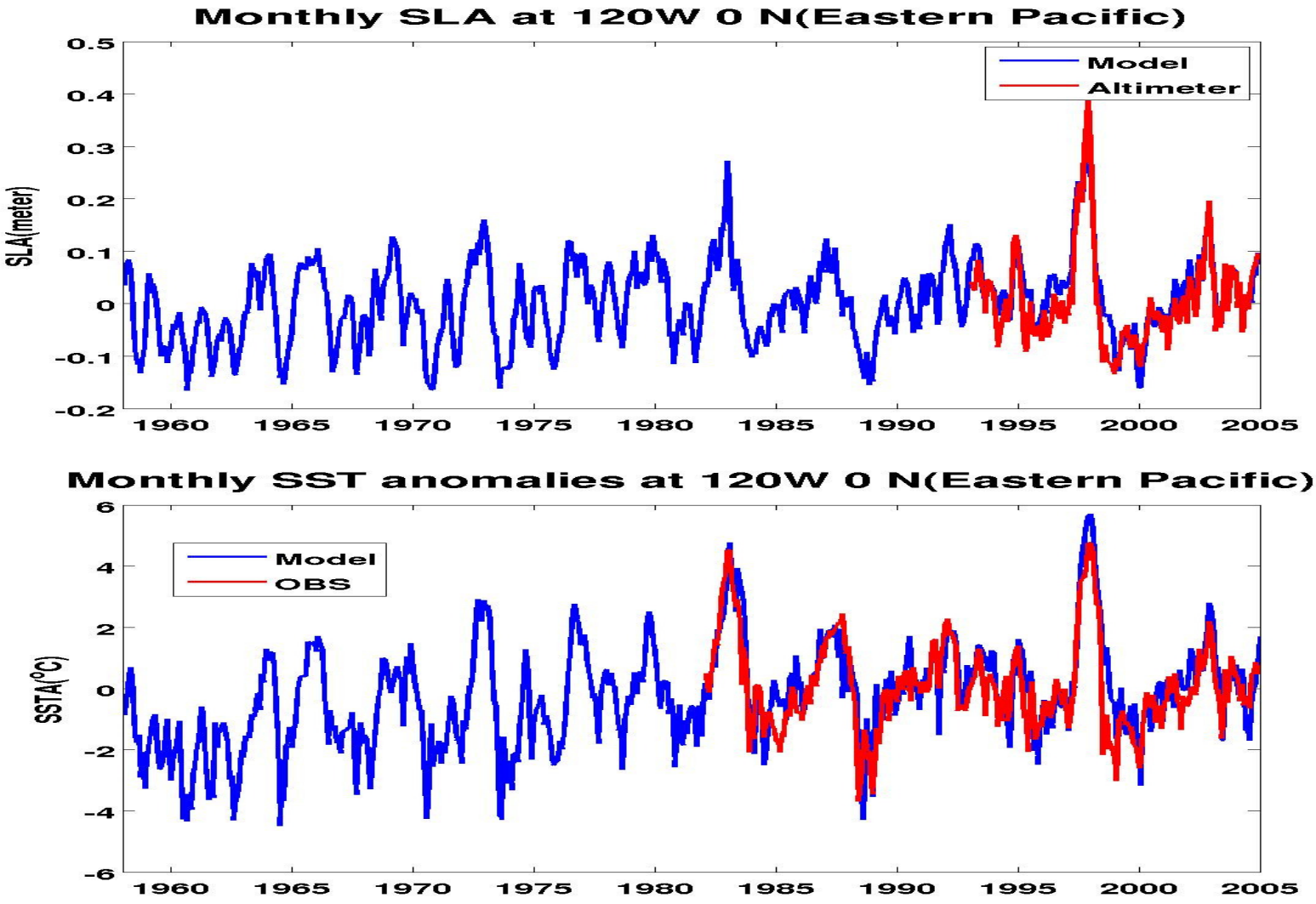
Obs



Model



Tropical Pacific Variability

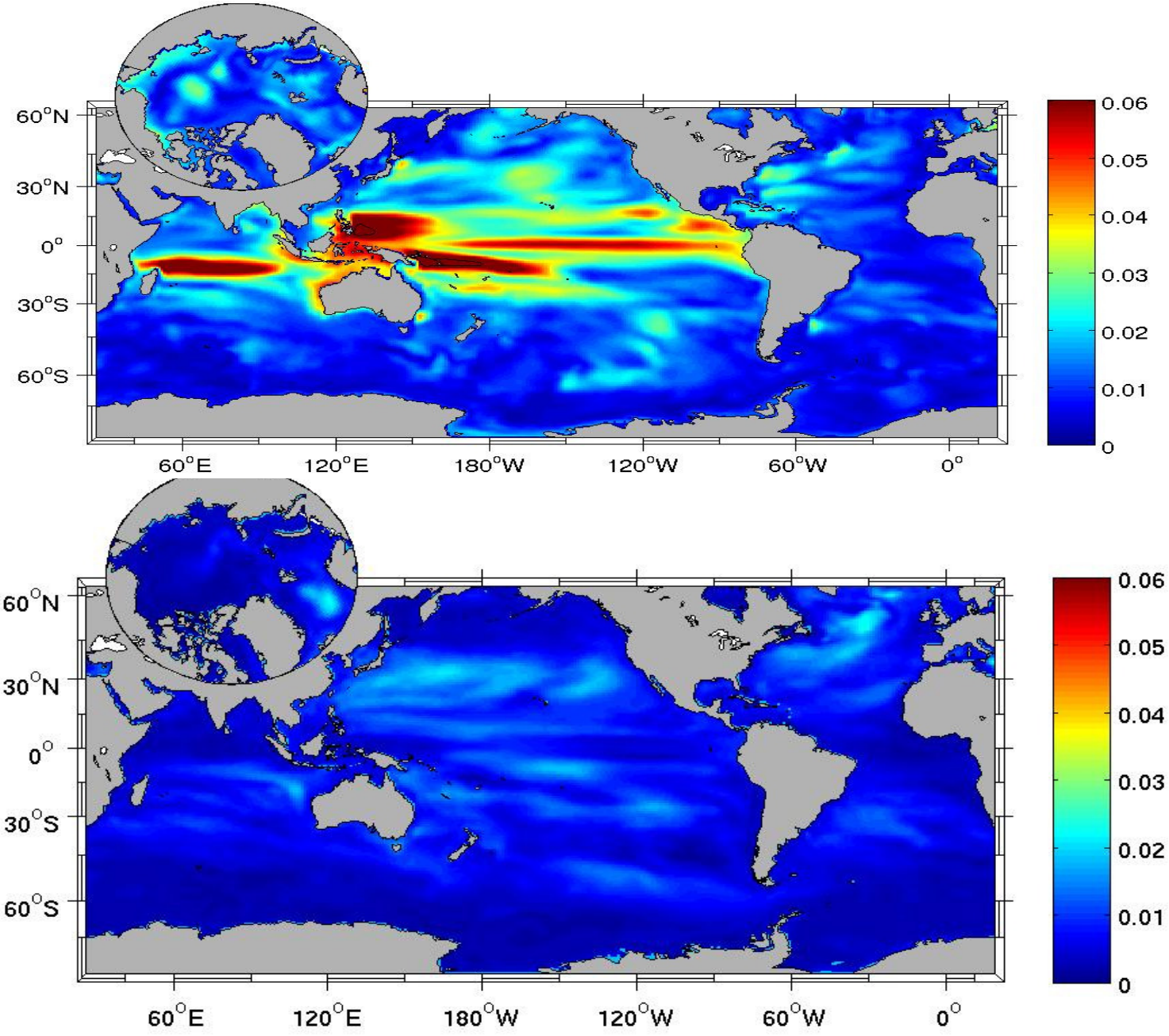


Also reproduces changes associated with MJO

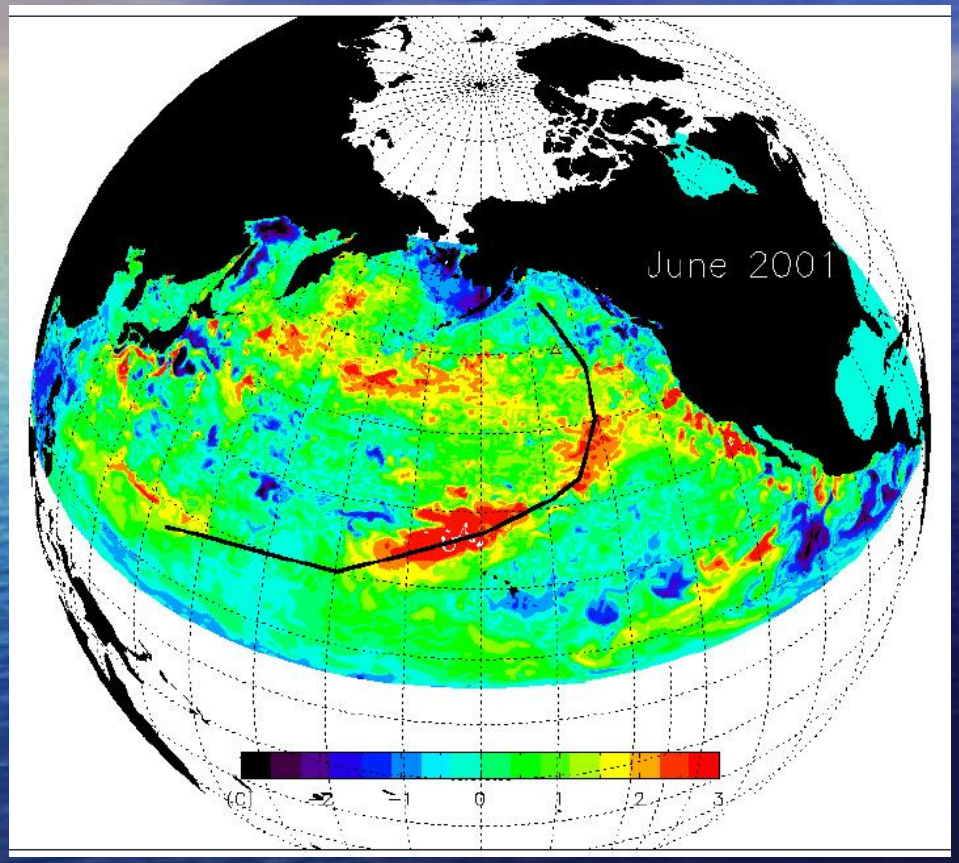
Forcing sensitivity – Interannual Variability

Wind

Heat



Predicting North Pacific SST



Black line shows theoretical position of Rossby wave front, generated at the coast 3y earlier by ENSO event.

Note correspondence of the black line with maxima in the simulated SST anomaly.

For example, Rossby waves take 3-5y to propagate from coast to OWSP, implying predictability in the northeast Pacific.

IOS Data Assimilation Package Development & Analyses

a. Green's Function Method Development

- Have developed a flexible I/O interface for data assimilation studies
- Green's function method (under construction)

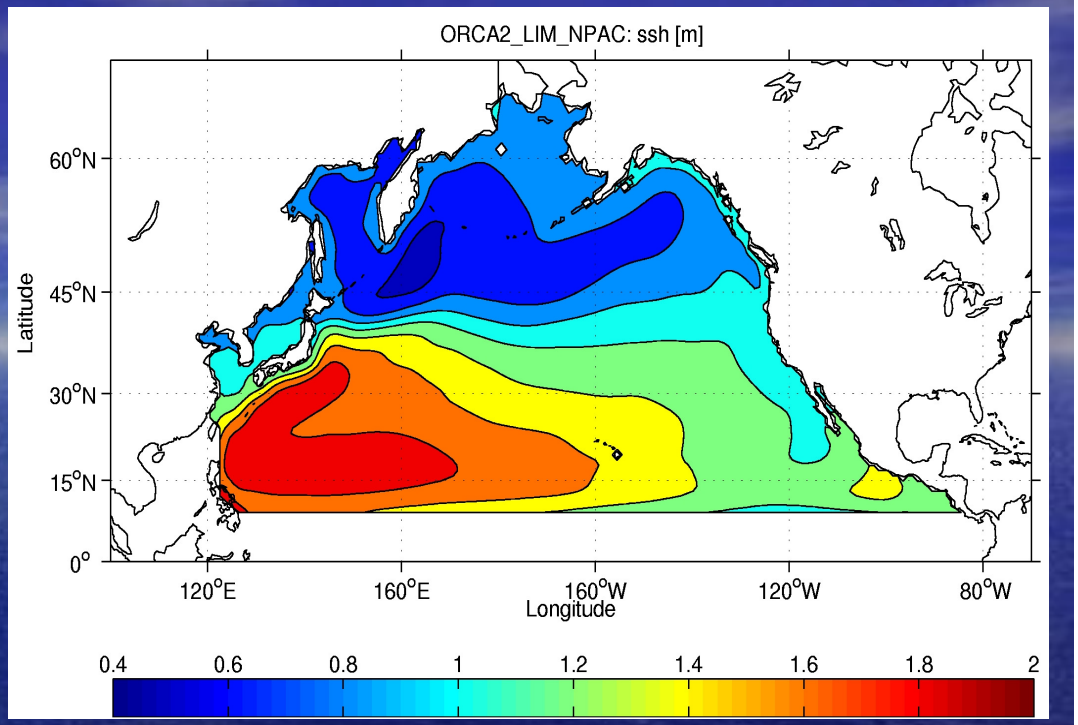
b. 4D-Var

- Role of wind stress error covariance fnc in a 4D-Var analysis (in press)
- Theory on observability of a large control vector in a 4D-Var system
- OPAVAR code (A. Weaver, CERFACS) obtained Spring 2009
  - package of adjoint and tangent linear software for OPA8.0
  - will implement at IOS

IOS North Pacific Model Output

NEMO_v2

- 1°x1°, 46 levels
- 10 year spin-up run with OMIP annual climatology
- forcing with seasonal cycle now underway
- will be used for testing Green's function method & 3D-Var in year 4

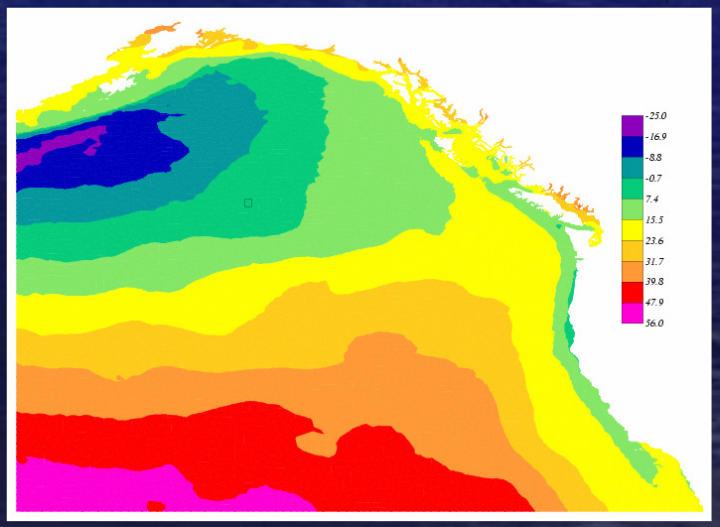


FEM average summer SSH (cm)

Diagnostic Finite Element Model for NE Pacific

Forcing from

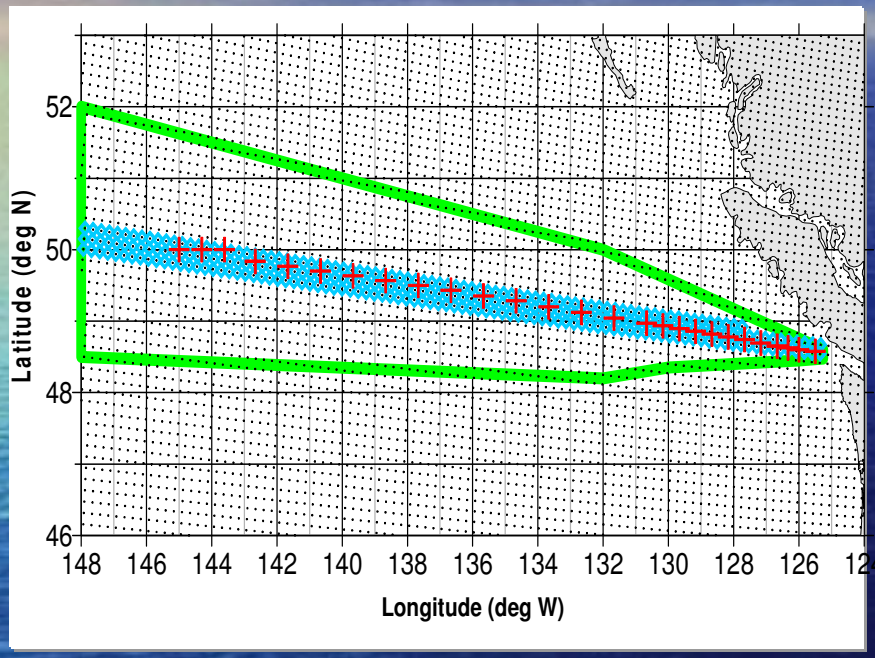
- Seasonal temperature and salinity climatologies (CTD & Argo)
- Seasonal wind stress (NCEP)



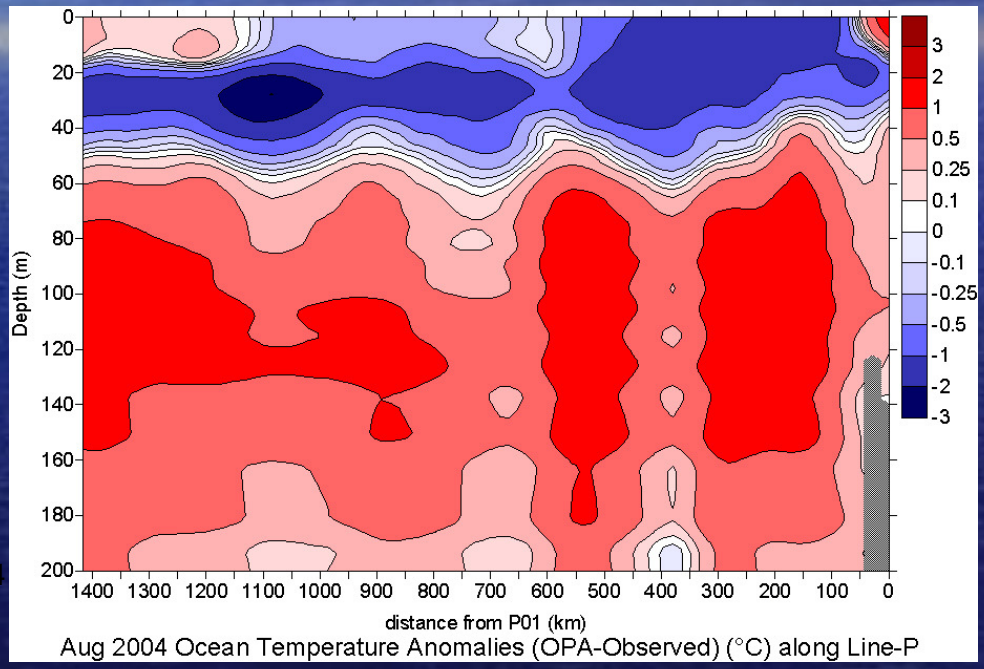
Wakamatsu and Foreman, 3rd GOAPP workshop

Analysis of Mercator products (no data assimilation)

- 1/4° (eddy permitting), 2000-2006
  - completed comparison with observed temperatures in vicinity of Line-P



model-data misfit along line P



- 1/12° (eddy resolving), 2002-2007 (obtained, Spring 2009)
  - will compare observed temperatures in vicinity of Line-P, as above
  - will compare SSH moments with altimeter data

Atlantic Results

- Spectral nudging improves numerous aspects of model
- Need has been reduced by a factor of order 5 – How?
  - NEMO vs POP
  - 1/4° vs 1/3°
  - Slip BCs
  - Improved OBCs
  - Reduced near-bottom diffusion
  - Improved forcing
  - Improved filtering of nudges
- Validation studies show good agreement between first two NA model EOFS of SSS and SST with corresponding altimeter and radiometer observations

➢ Entcho will discuss modelling and applications of the SEEK filter to the Labrador Sea.

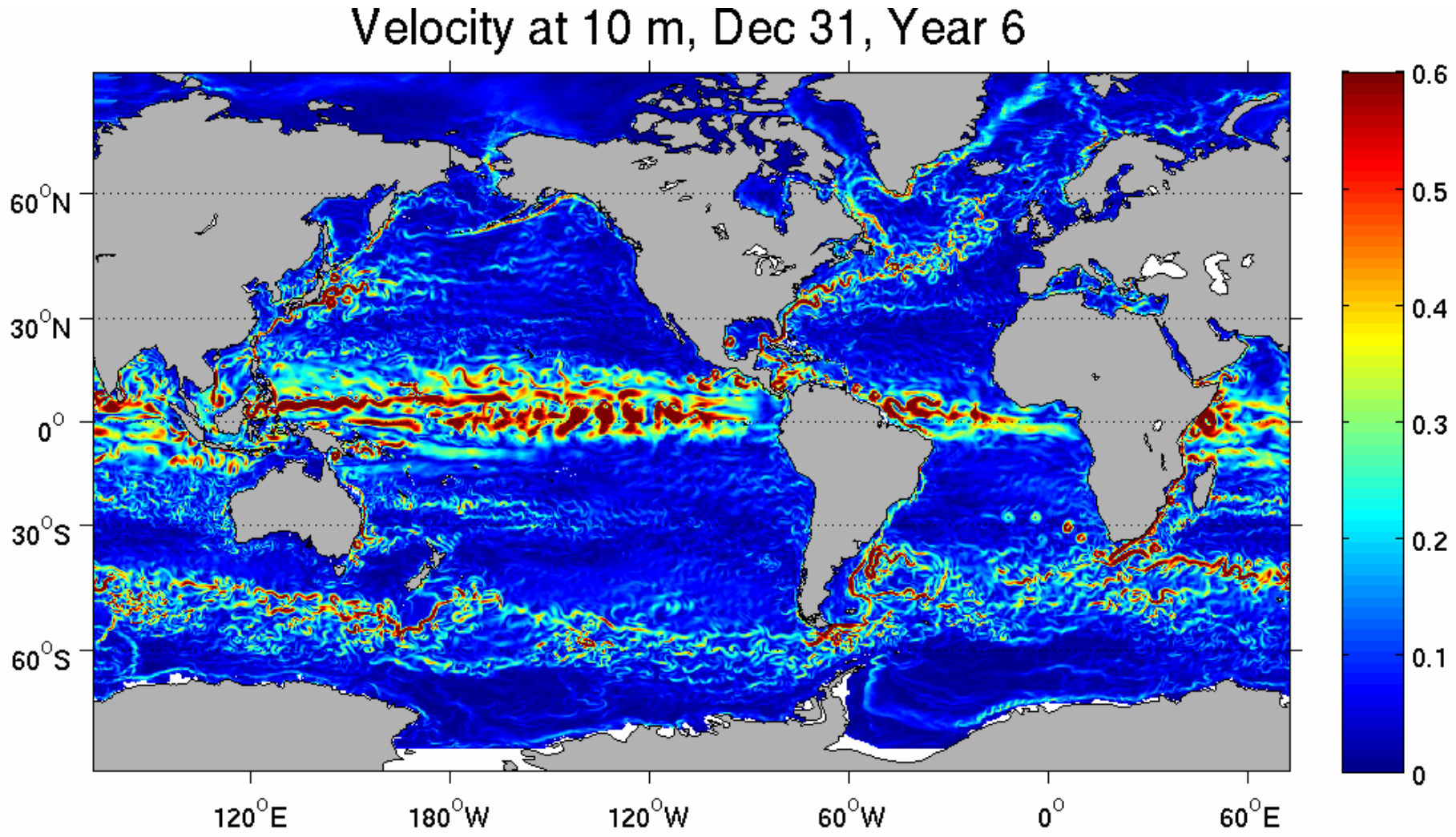
Arctic Results

- Studied as a subset of the global 1 degree model
- The seasonal cycle in areal sea ice coverage is good

- Inter-annual variations in sea ice area are good to 1997
- Sea ice area decreases too quickly after 1997
- Sensitivity studies and model-data comparisons indicate:
  - Not local redistribution by wind
  - Not excess export through Fram Strait
  - Seems to be due to a warm bias in NCEP Arctic T^{air}

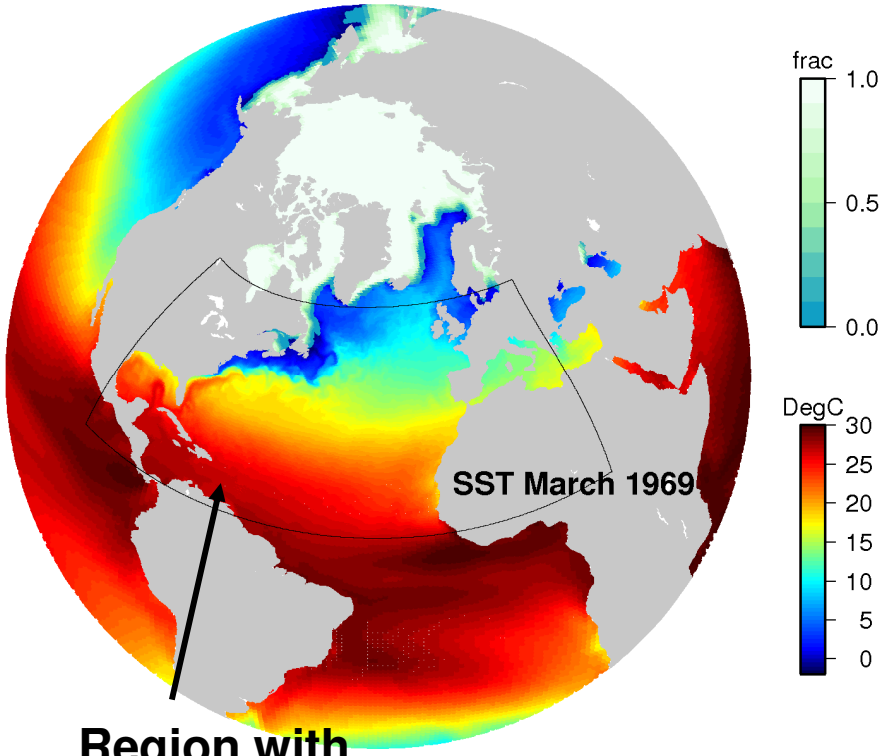
- The Atlantic layer plunges too deep (500m => 1000m)
  - The problem is not in the 1/4° results
  - Student in China is investigating possible causes
  - Neptune considered as possible correction approach

Benefit of Increased Resolution: Sub-surface Flow from ¼° model

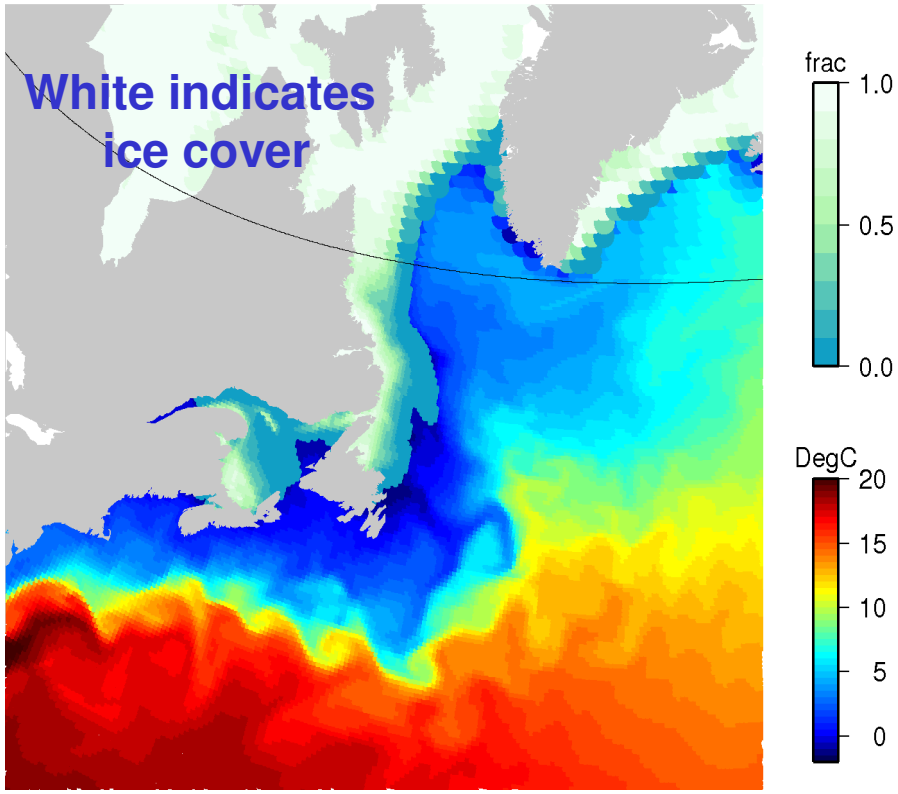


Increasing Resolution Regionally: Example of SST and Sea Ice Prediction Based on Local Grid Refinement

Results from a 1 degree global model with a NA zoom to ¼ degree



Region with ¼ degree resolution



Results from enhanced resolution region illustrating new ability to use AGRIF in ice infested regions

Independent Assimilation into Coupled Atmosphere Ocean Models

- ✓ **Data assimilation into a coupled model raises new issues.**
- ✓ **Recent work focused on parameter estimation to improve heat, momentum and moisture exchange between atmosphere and the ocean. Anticipate significant improvements in quality of the analyses.**
- ✓ **EC is coupling GEM to Mercator's NEMO ocean system.**
- ✓ **Incremental formulation: independent assimilation for ocean and atmosphere in an "inner loop" but full coupled model integrated.**
- ✓ **More from Hal under CONCEPTS umbrella .**

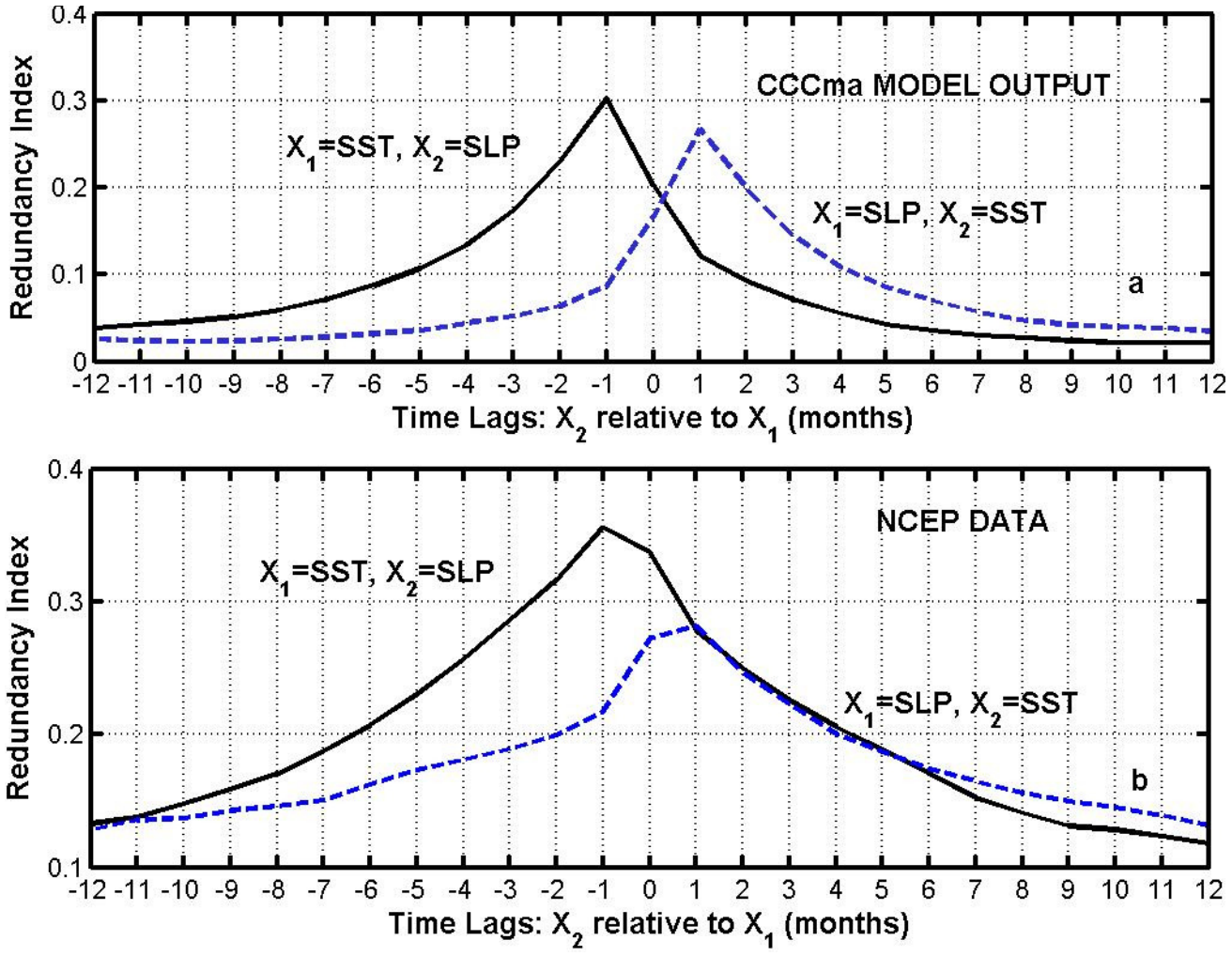
Joint Assimilation into Coupled Atmosphere Ocean Models

Initially work focused on covariance between atm and ocean state variables – in CCCma model and obs.

Redundancy Analysis used to explore "cause-effect" relationships between fluids using low dimensional representations. Complements EOF analysis.

Time-Lagged Redundancy Index may be useful as a predictive tool.

Time-Lagged Redundancy Index



- **Solid line: Pa driver, SST response**
- **Y-axis: proportion of SST variance accounted for by first 20 RA modes**
- **Peak at -1 means SST lags Pa by 1 month**

Same lag relationship for CCCMa and NCEP even though ENSO too weak in model.

Summary

- Building on the NEMO code, now have realistic models of North Atlantic, North Pacific and global ocean with demonstrated predictive capability.
- Ability to use AGRIF in ice infested regions developed and tested.
- Exploring physical reasons for variability (e.g., Rossby waves, wind versus buoyancy forcing).
- Useful schemes have been developed to assimilate climatologies, Argo and altimeter data and downscale.
- Coupled models and assimilation schemes being evaluated.
- Collaborations building with Mercator and other international groups (e.g., University of Reading).