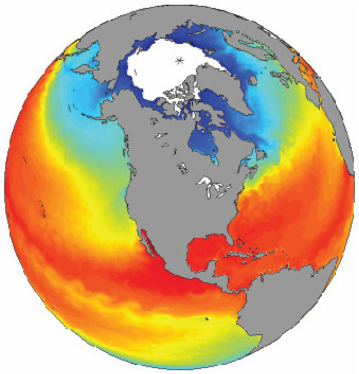
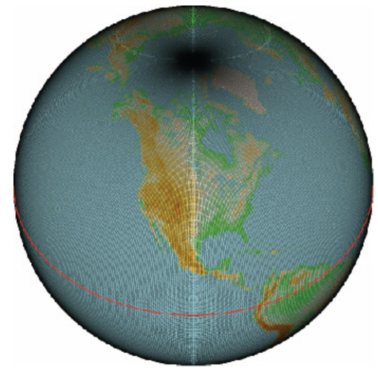


GOAPP
Global Ocean-Atmosphere Prediction and Predictability



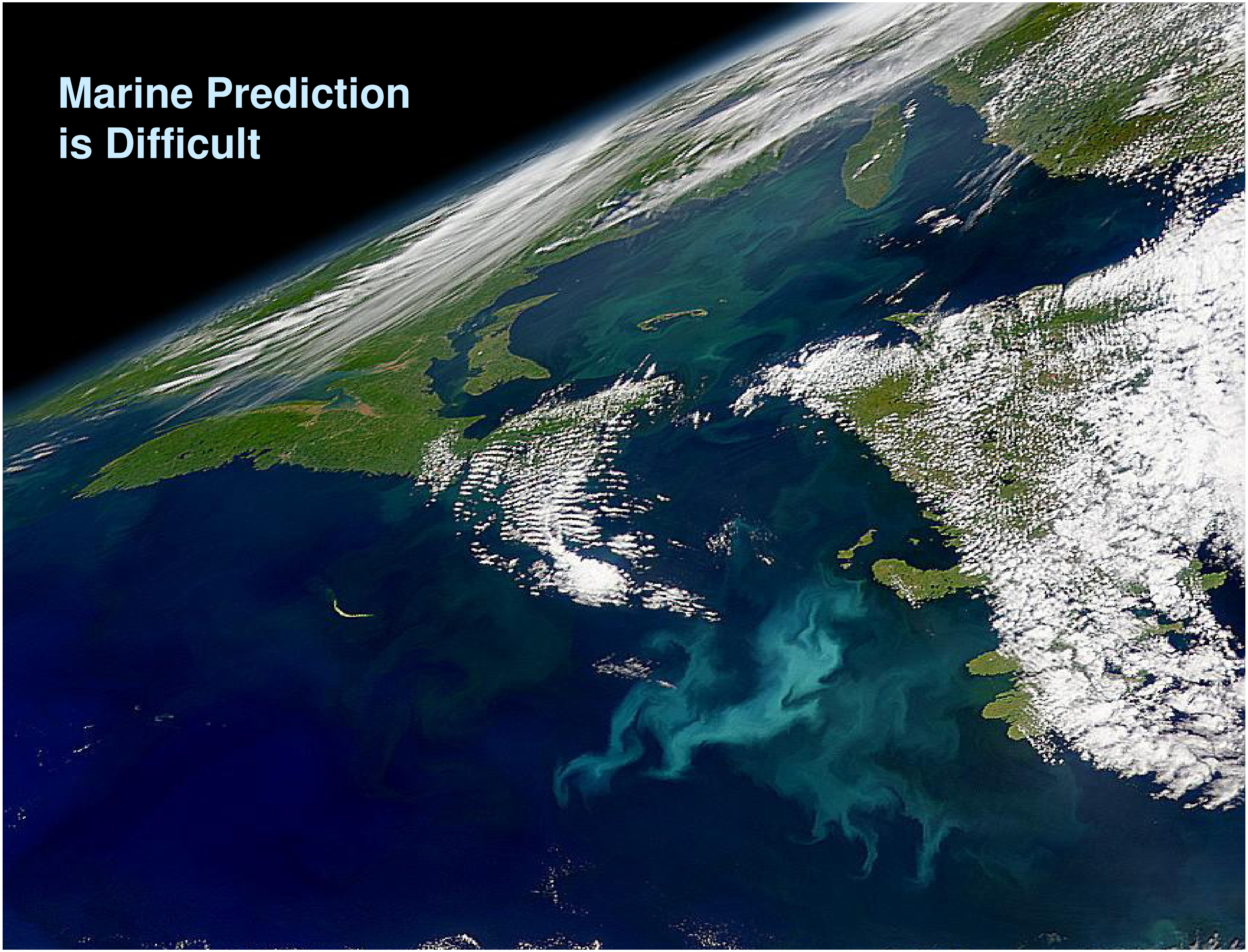
Progress and Plans, Issues and Opportunities

Keith Thompson and Hal Ritchie
Bill Merryfield and Dan Wright

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

Applications of a Coupled Atmosphere-Ocean Forecast System

- Short term forecasting of maritime weather such as hurricanes and "bomb" storms, and accompanying storm surges and flooding
- Short term forecasting of currents and sea ice for search and rescue, navigation, ship routing and pollution containment
- Assist Canadian exercises and operations in regions of strategic interest (e.g., the Arctic Archipelago)
- Providing multi-season and multi-year climate predictions to assist with planning of seasonally dependent economic activities such as agriculture, oil refining, hydro-electric generation and transportation
- Sustaining a healthy and productive marine environment through ecosystem modeling and informed fisheries management


Marine Prediction
is Difficult

GOAPP in a Nutshell

- CFCAS research network, close to $3 Million from CFCAS
- In-kind (EC, DFO, DND) ~ $975 k/yr over 4 years
- Objective: Improve forecasts of the coupled atmosphere-ocean system on time-scales of days to decades, and space scales of tens of kilometers to global
- Outcomes: Better models and assimilation schemes, a deeper understanding of contributors and limits to predictability
- Complements the EC-DFO-DND Canadian Operational Network of Coupled Environmental PredicTion Systems (CONCEPTS) and EC's operational seasonal forecast activity

Multiple agency (EC, DFO, DND) interest in coupled atmosphere-ice-ocean prediction ⇒

CONCEPTS: Canadian Operational Network of Coupled Environmental PredicTion Systems

To coordinate the national development and implementation of ocean models, DFO has established

COMDA: Centre for Ocean Model Development and Application

GOAPP contributes to, and benefits from, CONCEPTS.

Structure of the Research

Two themes distinguished by time-scale:

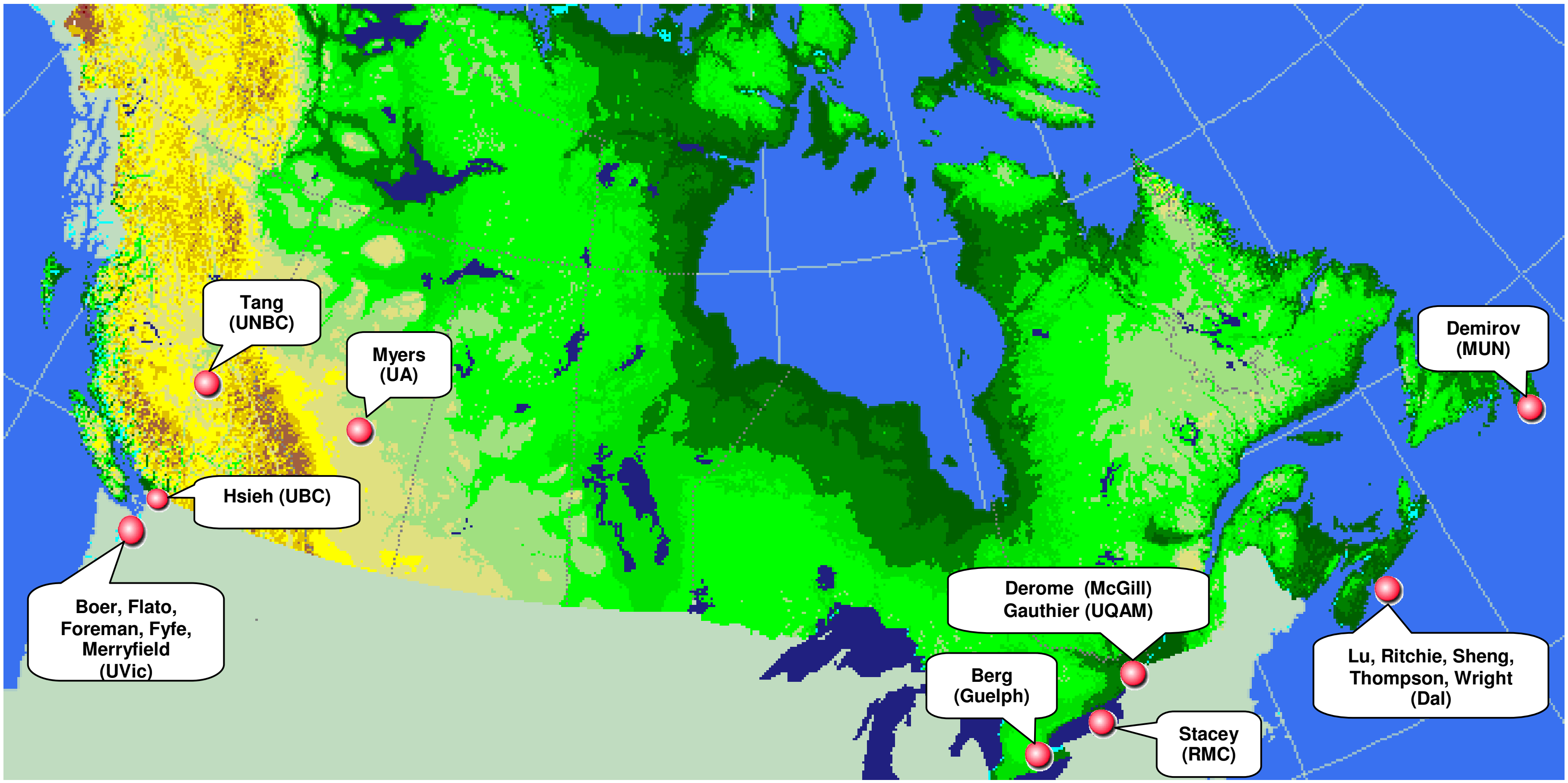
Theme I: Days to Seasons
Theme II: Seasons to Decades

These two themes reflect:

- ❑ **Present expertise in weather and climate modelling and prediction in Canada**
- ❑ **Potential advantages of a multi-model approach**

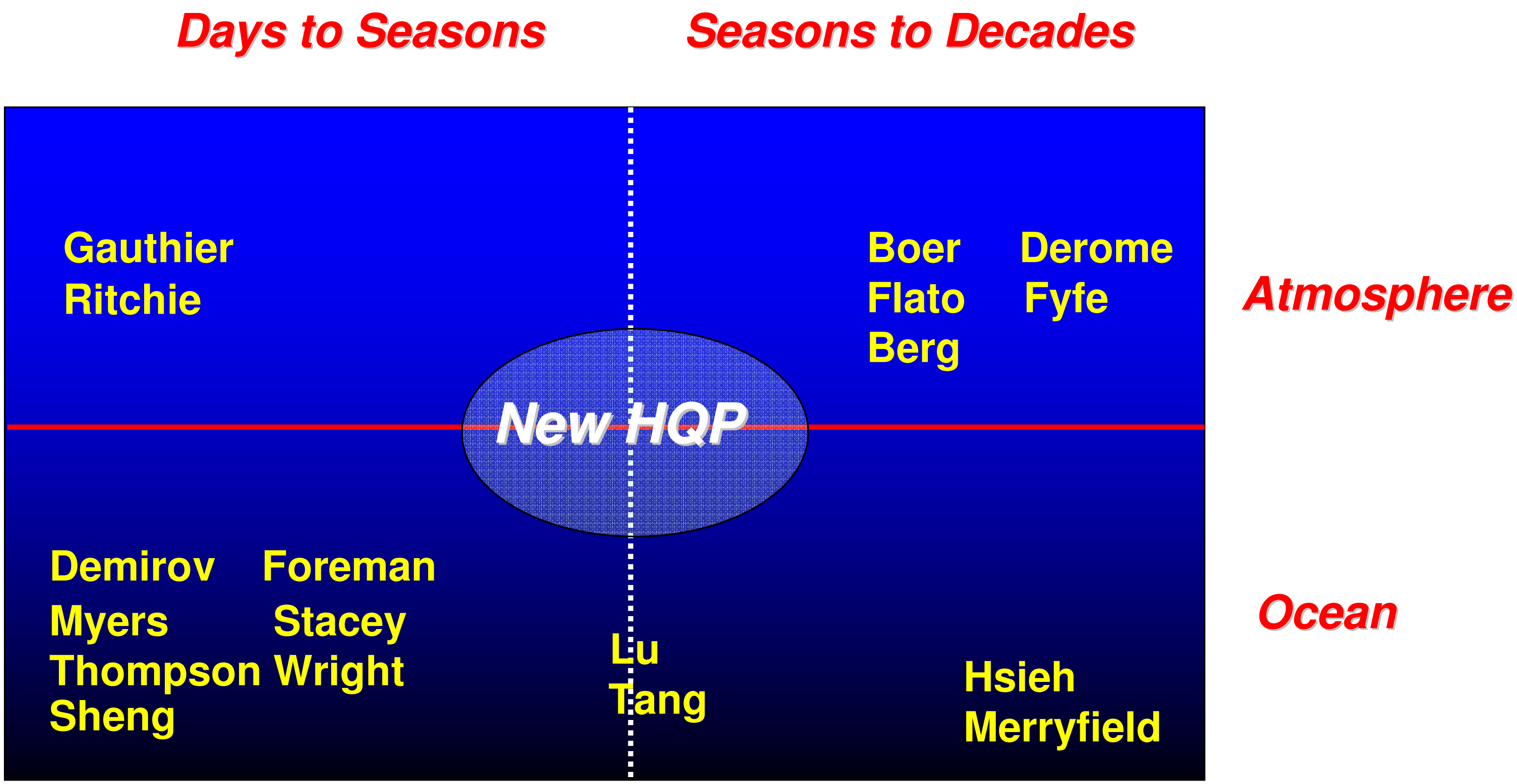
Working toward a *seamless prediction capability* that bridges these time-scales (consistent with developing international activities e.g. THORPEX, WCRP)

Geographical Distribution of the 18 GOAPP Co-Investigators



20 Collaborators from EC and DFO

The GOAPP Researchers



Highly Qualified Personnel

Trainees	**2009**	**Anticipated Total**
Research Associates	7	8
Post Doctoral Fellows	5	6
PhD	6	12
Masters	9	17
Undergraduates	2	7
Total	**29**	**50**

Theme I Projects: Days to Seasons

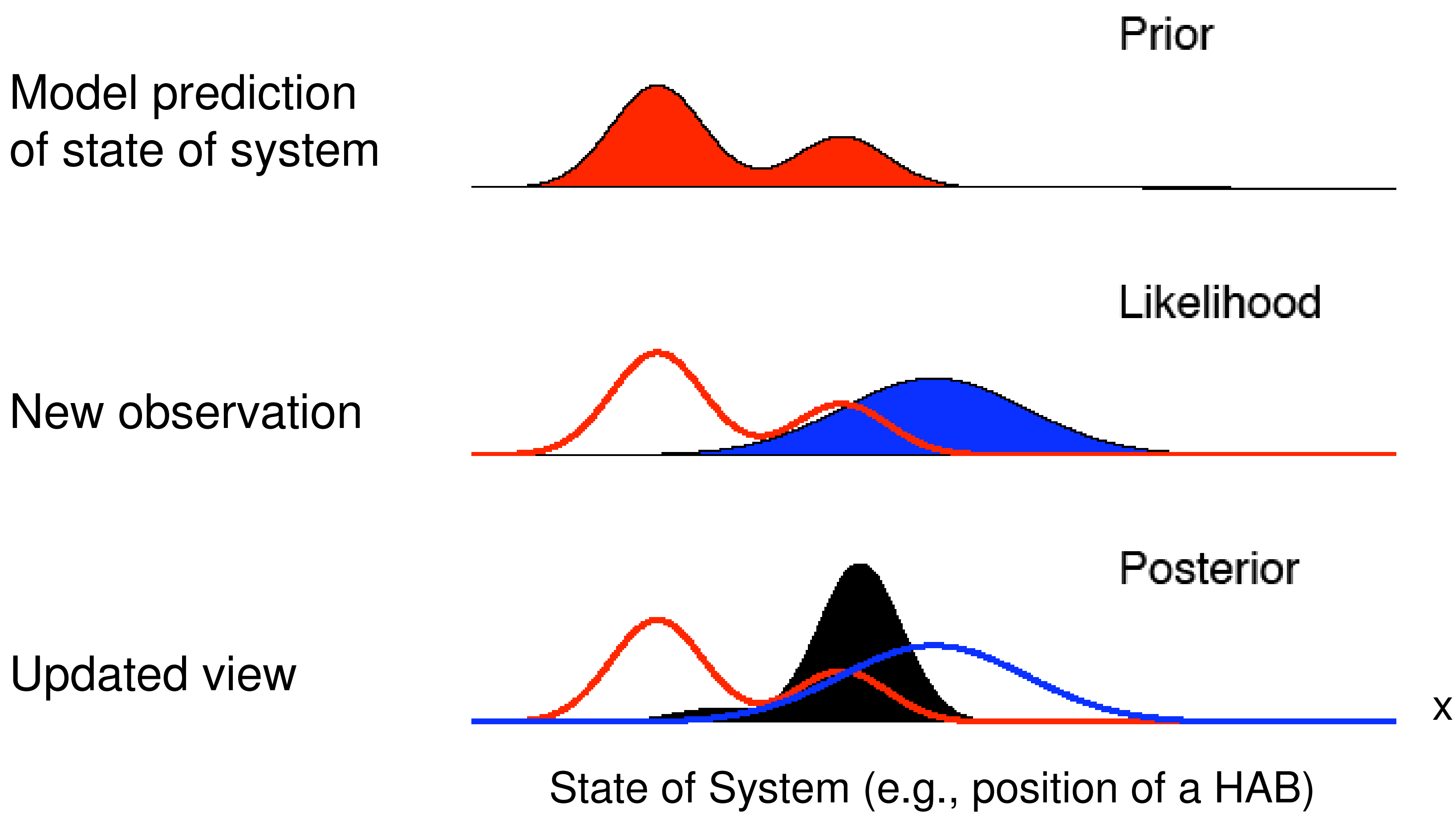
Ocean Modeling and Data Assimilation

- Suppression of bias and drift in ocean model components
- Statistics of observed variability for model testing and improvement
- Multivariate assimilation of altimeter and Argo data
- Ocean reanalysis and forecasting
- Modelling and assimilation of sea ice
- Assessing the capability of a nested-grid shelf circulation model for the Eastern Canadian Shelf

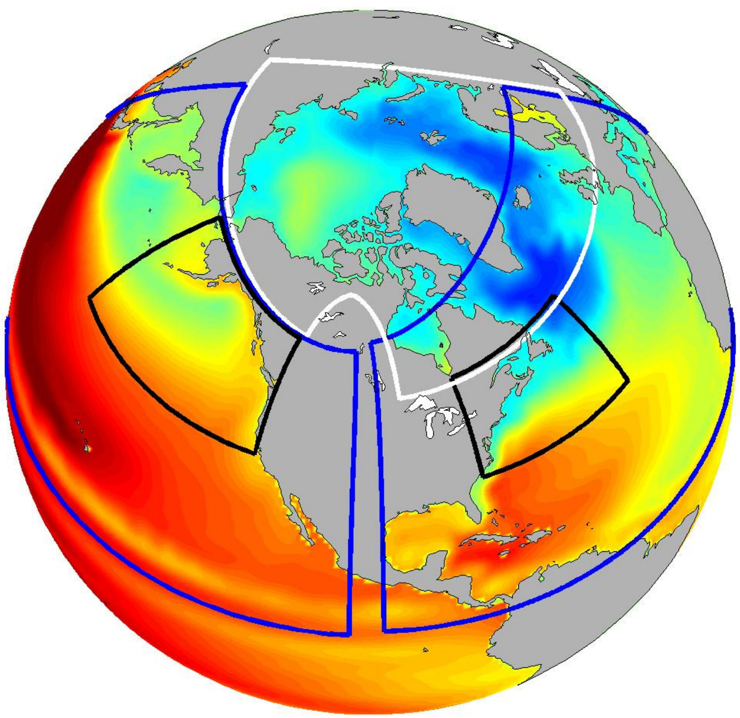
Coupled AO Modeling and Data Assimilation

- Assimilation into coupled atmosphere-ocean models
- Studies on joint assimilation into coupled models

Uncertainty in Models and Observations: The Need for Data Assimilation



Theme I: Ocean Modelling and Assimilation
Suite of Nested Ocean Models
Based on the NEMO Code

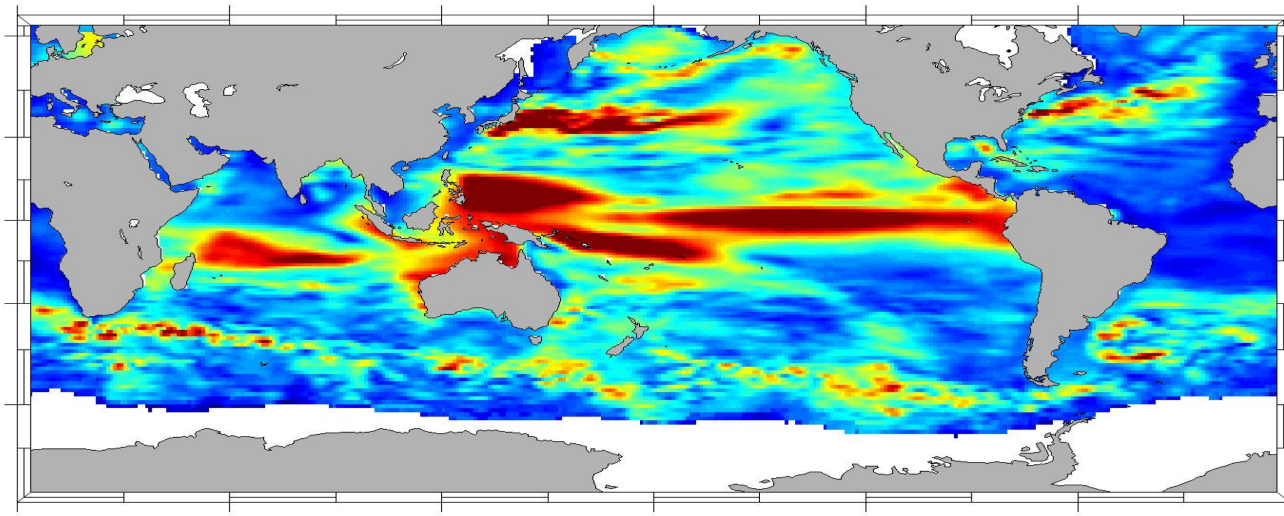


- Suppression of bias and drift in ocean model components
- Statistics of observed variability for model testing and improvement
- Multivariate assimilation of altimeter and Argo data
- Ocean reanalysis and forecasting
- Modelling and assimilation of sea ice
- Assessing the capability of a nested-grid shelf circulation model for the Eastern Canadian Shelf

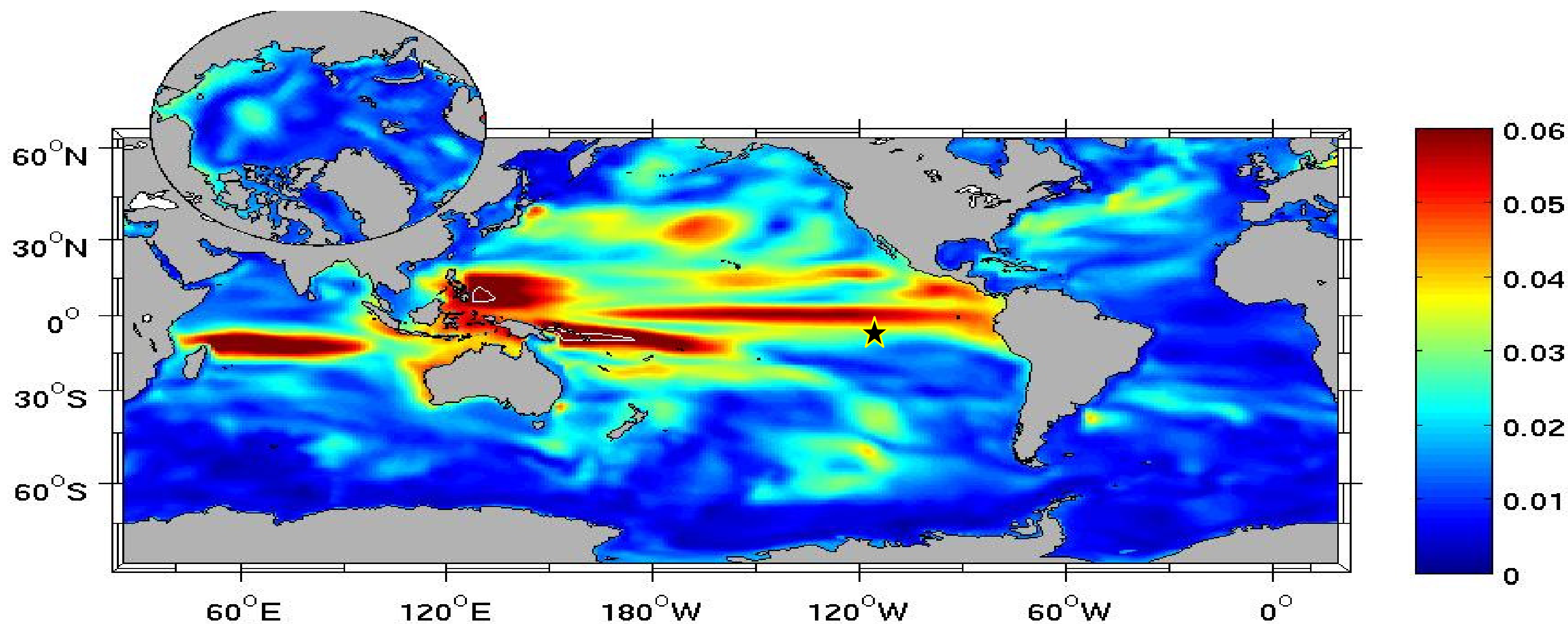
NEMO: Nucleus for European Modelling of the Ocean

Inter-Annual Sea-Level RMS 1993-2004 (m)

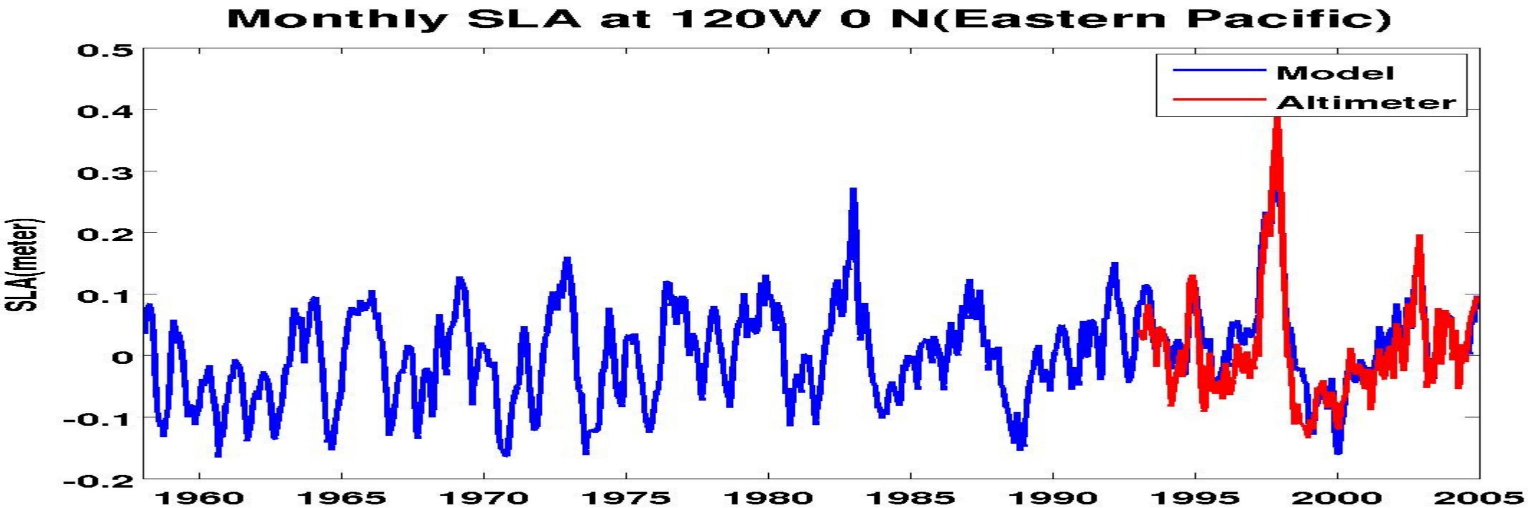
Altimeter

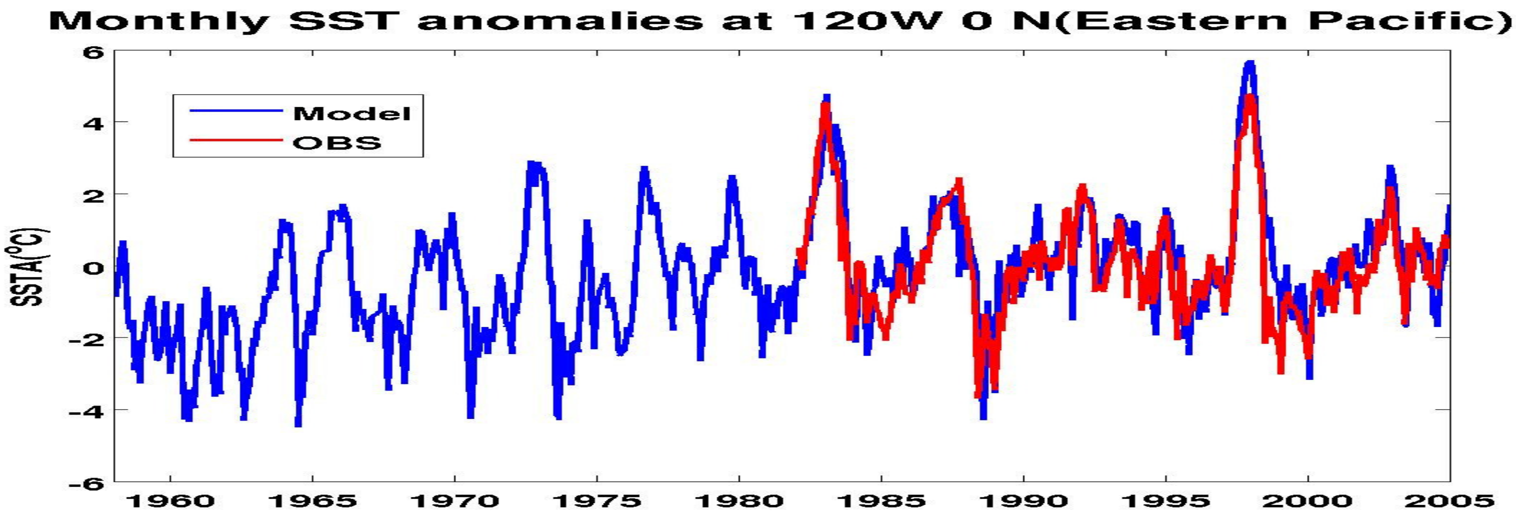


Model
1º outside tropics
tropics



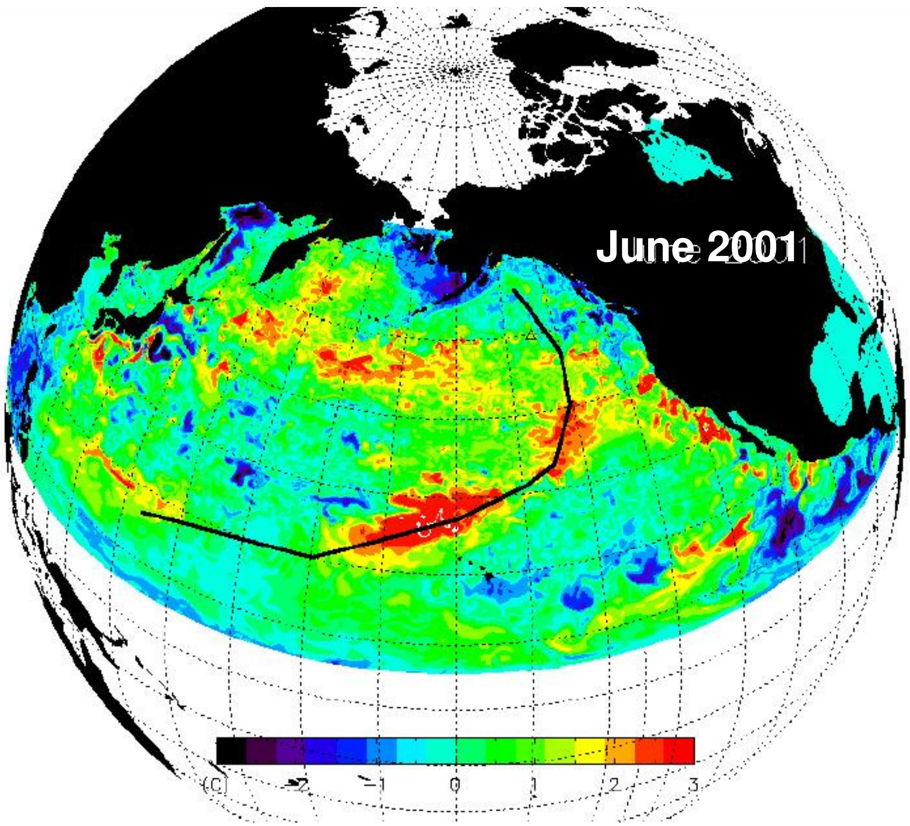
Predicted Variability In Tropical Pacific





Conclusion: Sea level and SST are predicted accurately in Tropical Pacific using reanalysis atmospheric forcing.

Potential Predictability of North Pacific SST

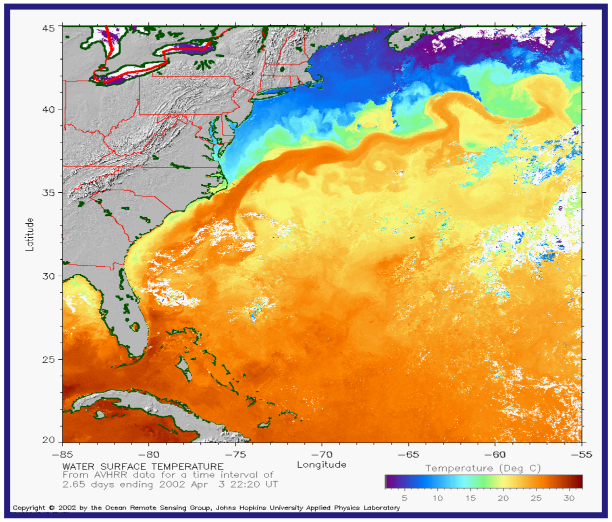


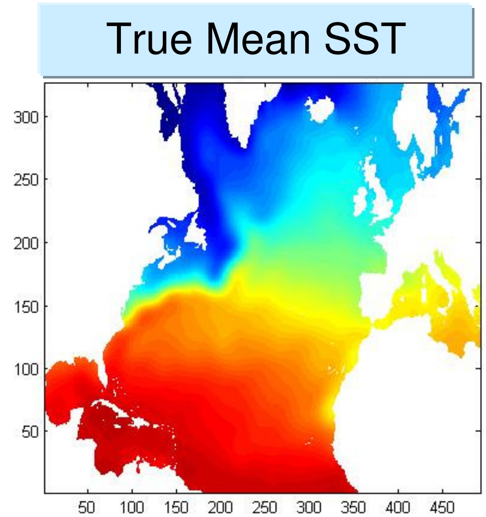
Black line shows theoretical position of Rossby wave front, generated at the coast 3y earlier by 1997-8 ENSO event.

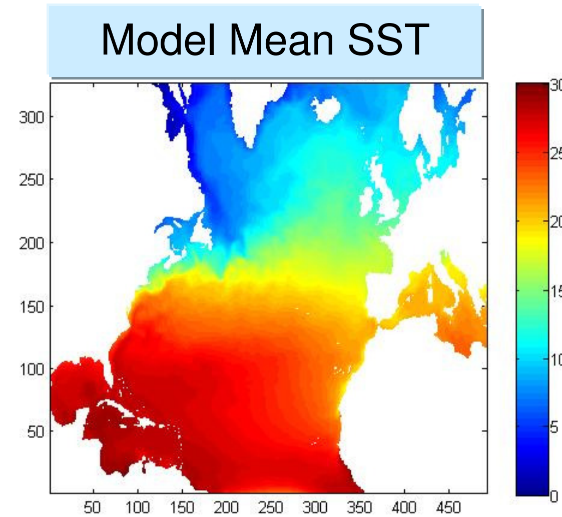
Note correspondence of the black line with maxima in the simulated SST anomaly.

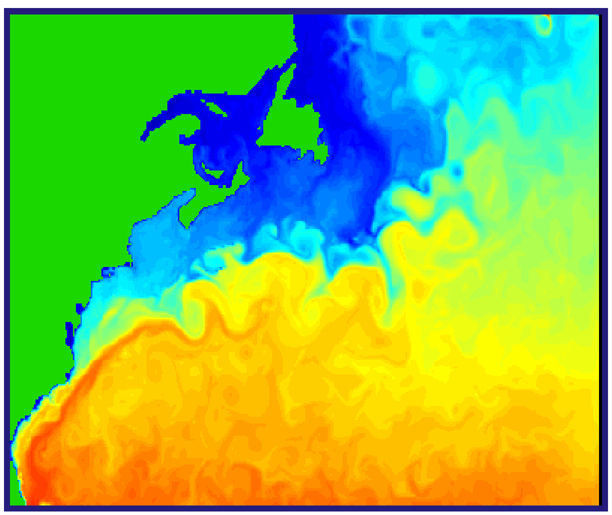
Implication: Possible predictability of hydrographic conditions in the northeast Pacific with lead times of years.

Gulf Stream Separation





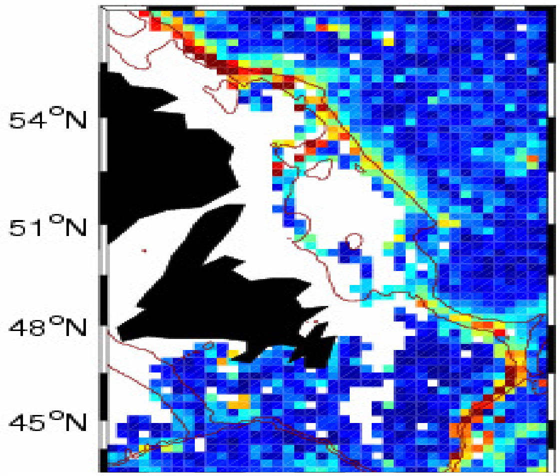




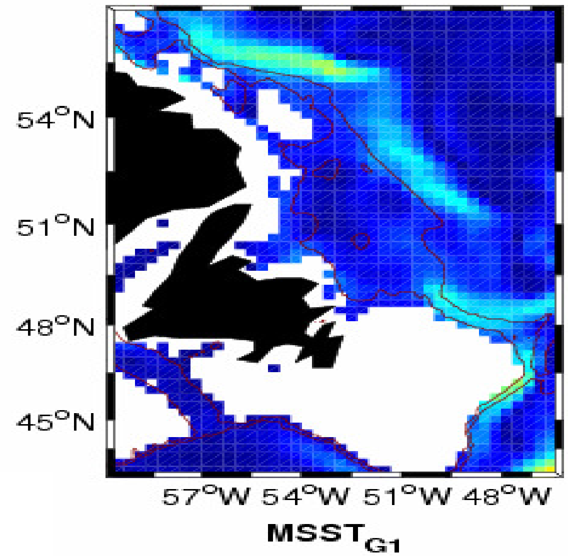
Improvements can now be obtained through assimilation of climatological data

$$\frac{\partial T}{\partial t} = adv. + diff. + \gamma \langle T_{obs} - T \rangle$$

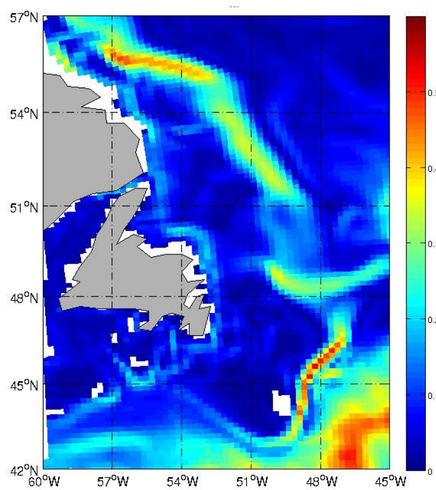
Drifters: the benchmark



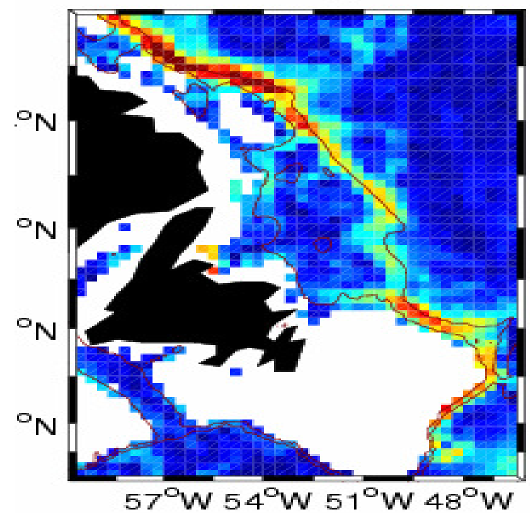
Old nudged model result



New nudged model result



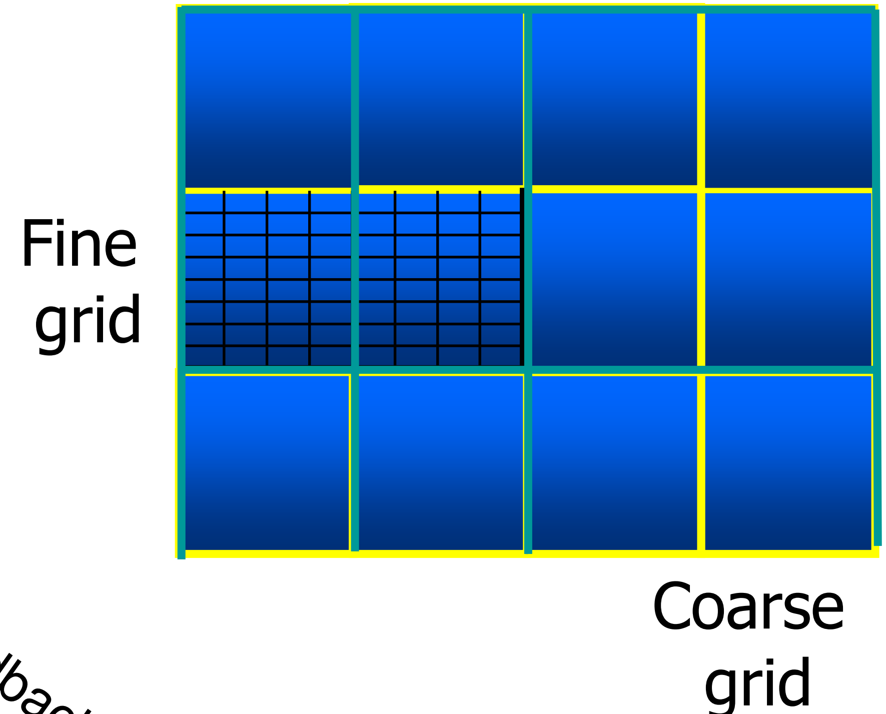
Satellite-based result

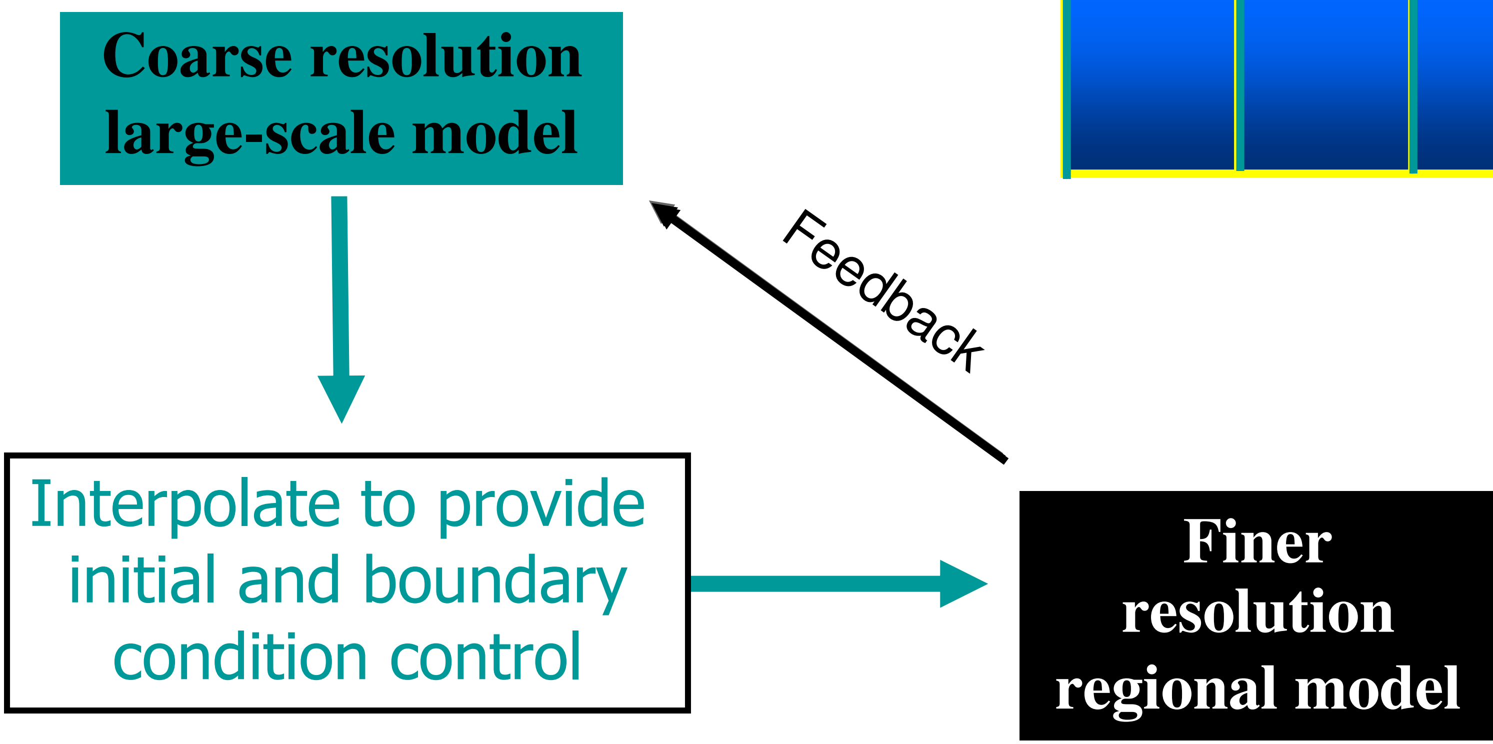


The old nudged model results have currents significantly too weak in the sub-polar gyre.
The new result is significantly improved in spite of greatly reduced nudging.

2-way nesting using AGRIF

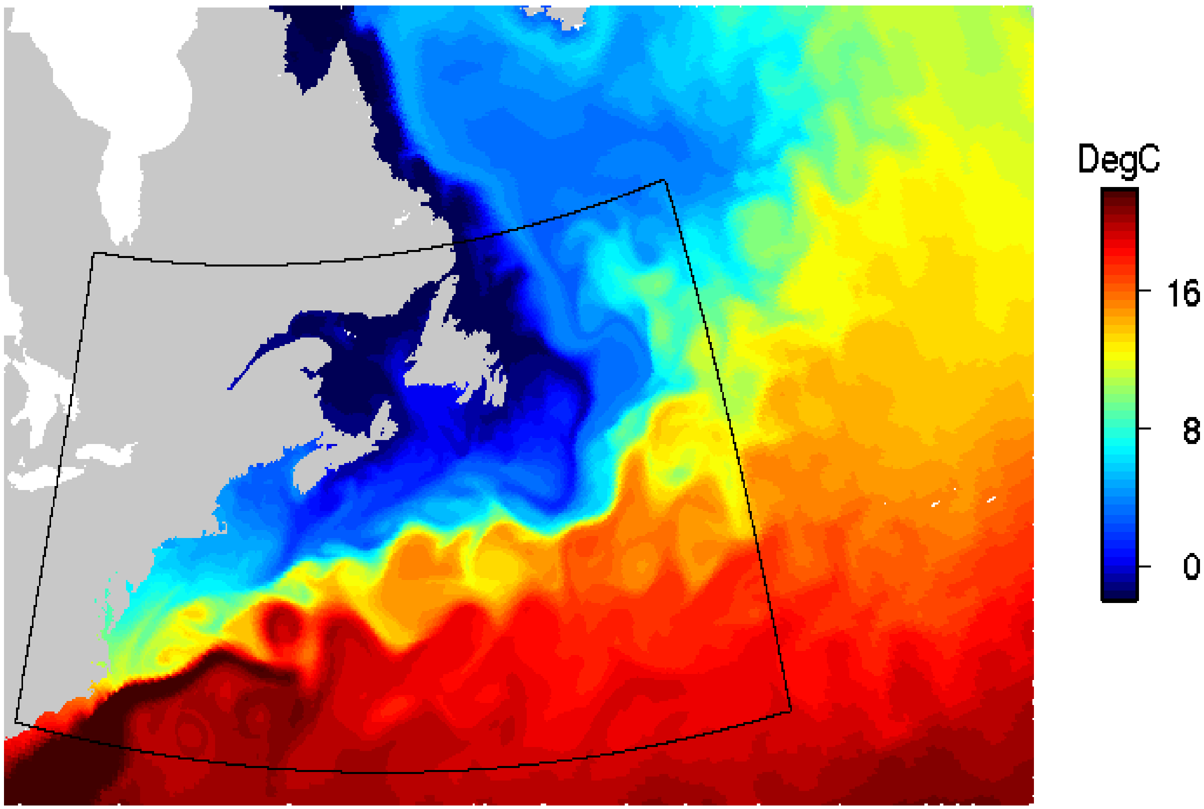
A regional modelling strategy





AGRIF: Adaptive grid refinement in Fortran

Testing AGRIF: 1/12º Gulf Stream submodel embedded within a ¼º North Atlantic model



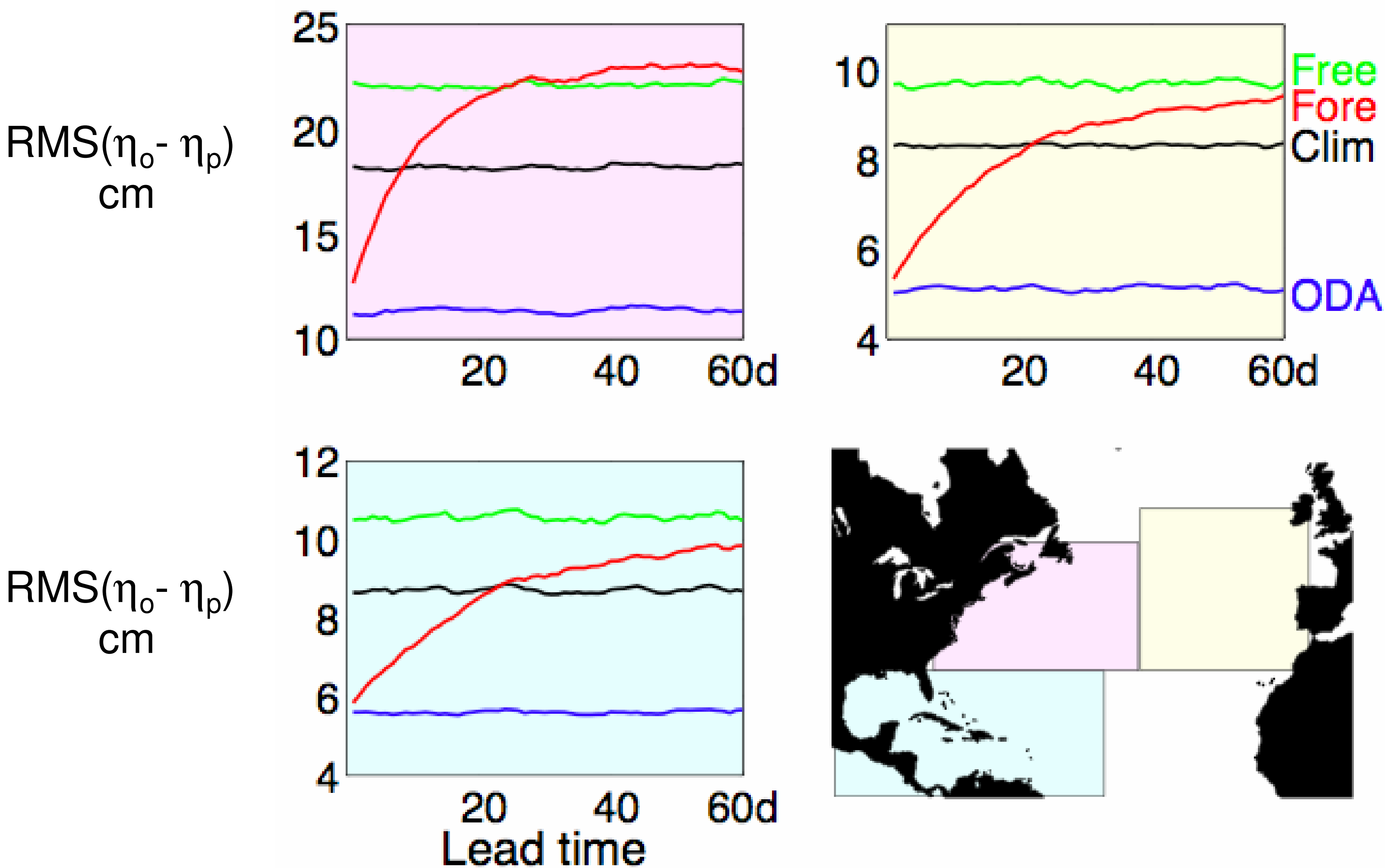
Surface temperature after 9 y of integration with no nudging. GS separation problems usually occur within first 5 y.

More work is needed but this is a major step forward.

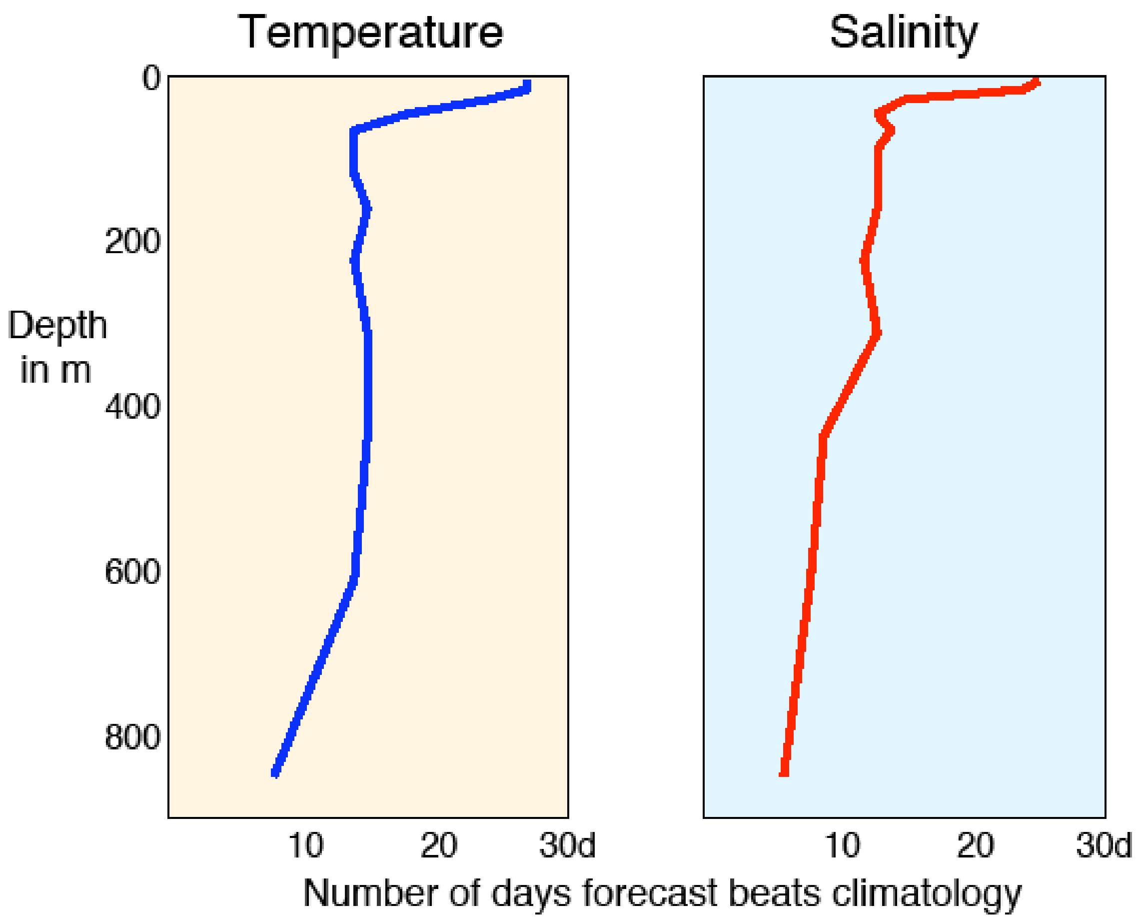
Assimilating Altimeter and ARGO Data: North Atlantic Example

- 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.
- The DA scheme is both evolutive and efficient.

Forecast Skill For Sea Level



Forecast Skill for Temperature and Salinity



Theme II Projects: Seasons to Decades

Analysis and Mechanisms

What are the origins of predictability?

- Pacific Decadal Oscillation
- Southern and Northern Annular Modes

Predictability of the Coupled System

What are the limits of predictability?

- Potential Predictability Of Current And Future Climates
- Prognostic predictability from ensembles of coupled model simulations

Prediction

"Climate forecasting"

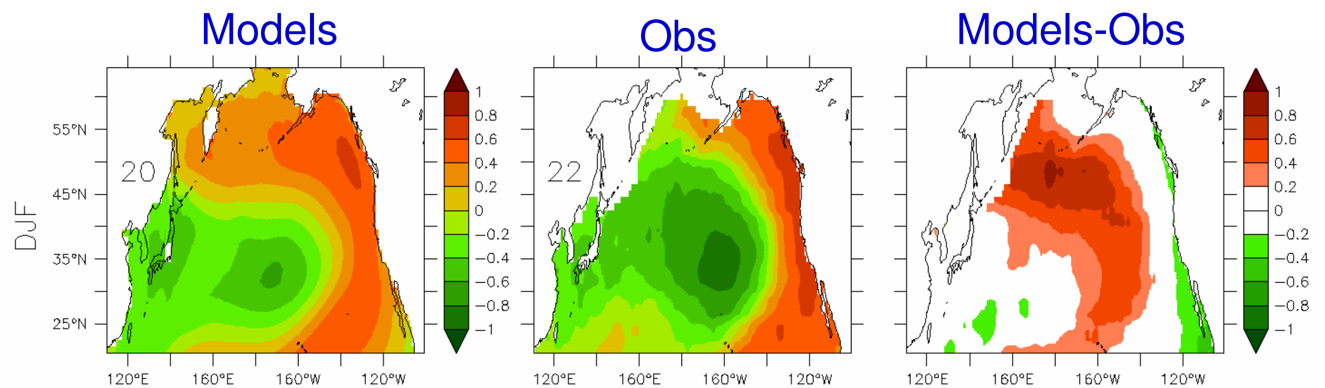
How well can we predict in practice?

- Coupled Model Initialization
- The Coupled Model Historical Forecasting Project
- Forecast Combination, Calibration and Verification
- Sensitivity of Climate Forecasts to Initialization of Land Surface

Theme I → Ocean bias correction for climate forecasts

Analysis & Mechanisms

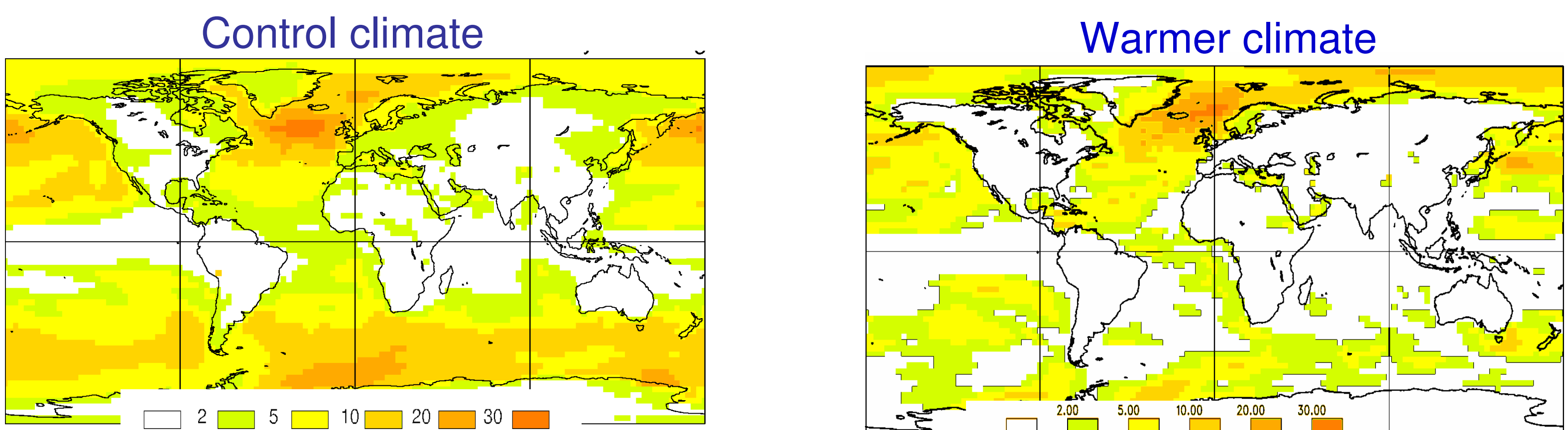
North Pacific decadal variability (1st EOF of North Pacific SST)



F. Lienert (Uvic) & J Fyfe (CCCma)

Predictability of the climate system

Potentially predictable variance fraction: decadal mean temperature



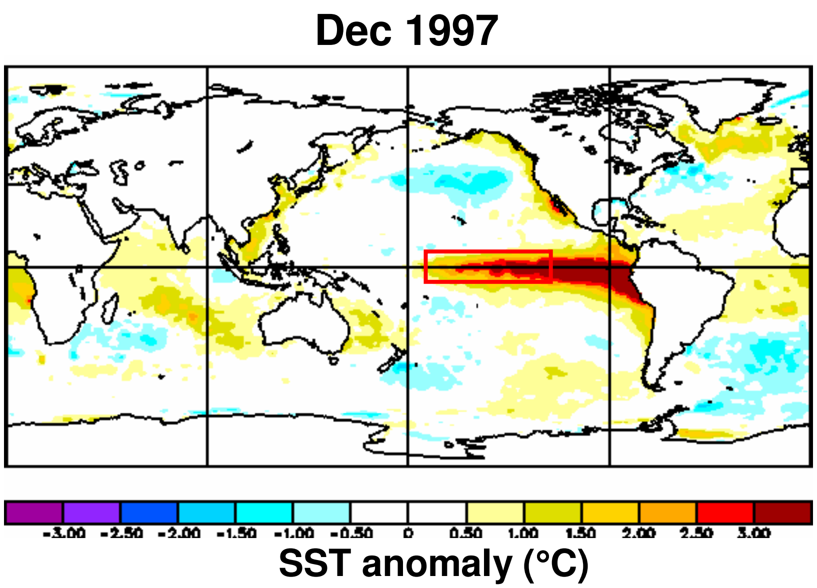
G. Boer (CCCma)

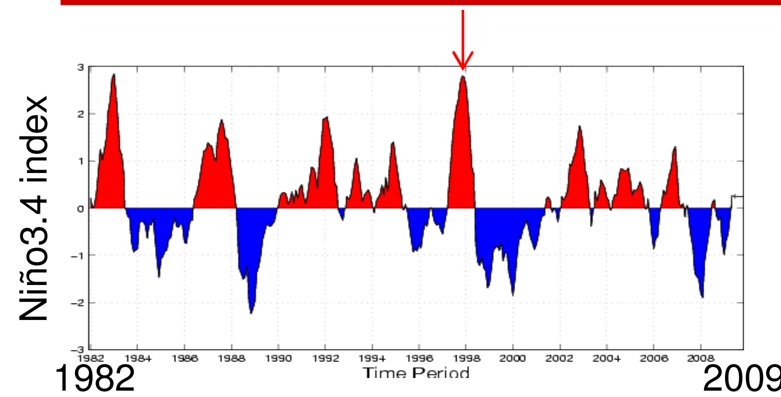
Basis for climate prediction

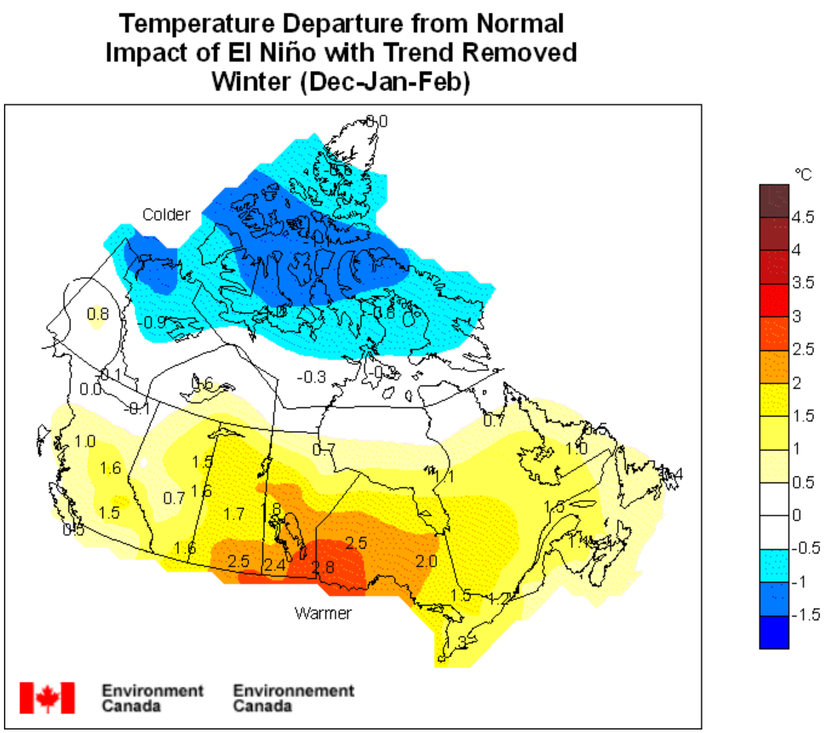
Guiding principle: climate modulated by slowly varying, predictable influences such as SST anomalies

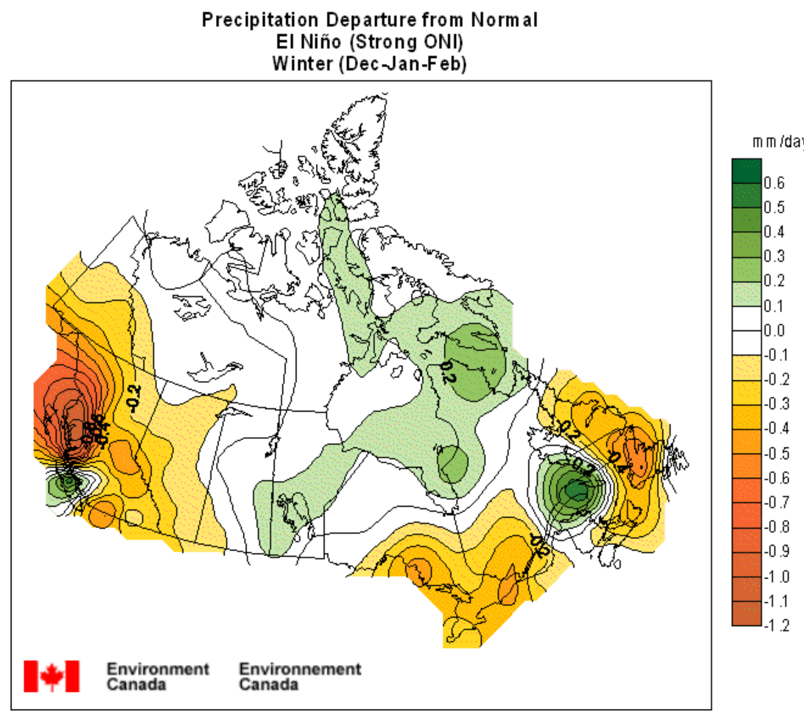
timescale	sources of predictability
Subseasonal ~15-60 days	Madden-Julian Oscillation Land surface "memory"
Seasonal to interannual ~2 months-2 years	El Niño-Southern Oscillation (ENSO)
Interannual to Multidecadal ~2-20 years	Atlantic Multidecadal Oscillation
Multidecadal to Centennial ~20-100 years	Anthropogenic forcing trends

El Niño and its impacts on Canada









Climate forecast methods

- **Two-tier forecast**
  - Atmospheric model(s) see *prescribed* future SSTs
  - *Basis for current EC operational system (HFP2)*

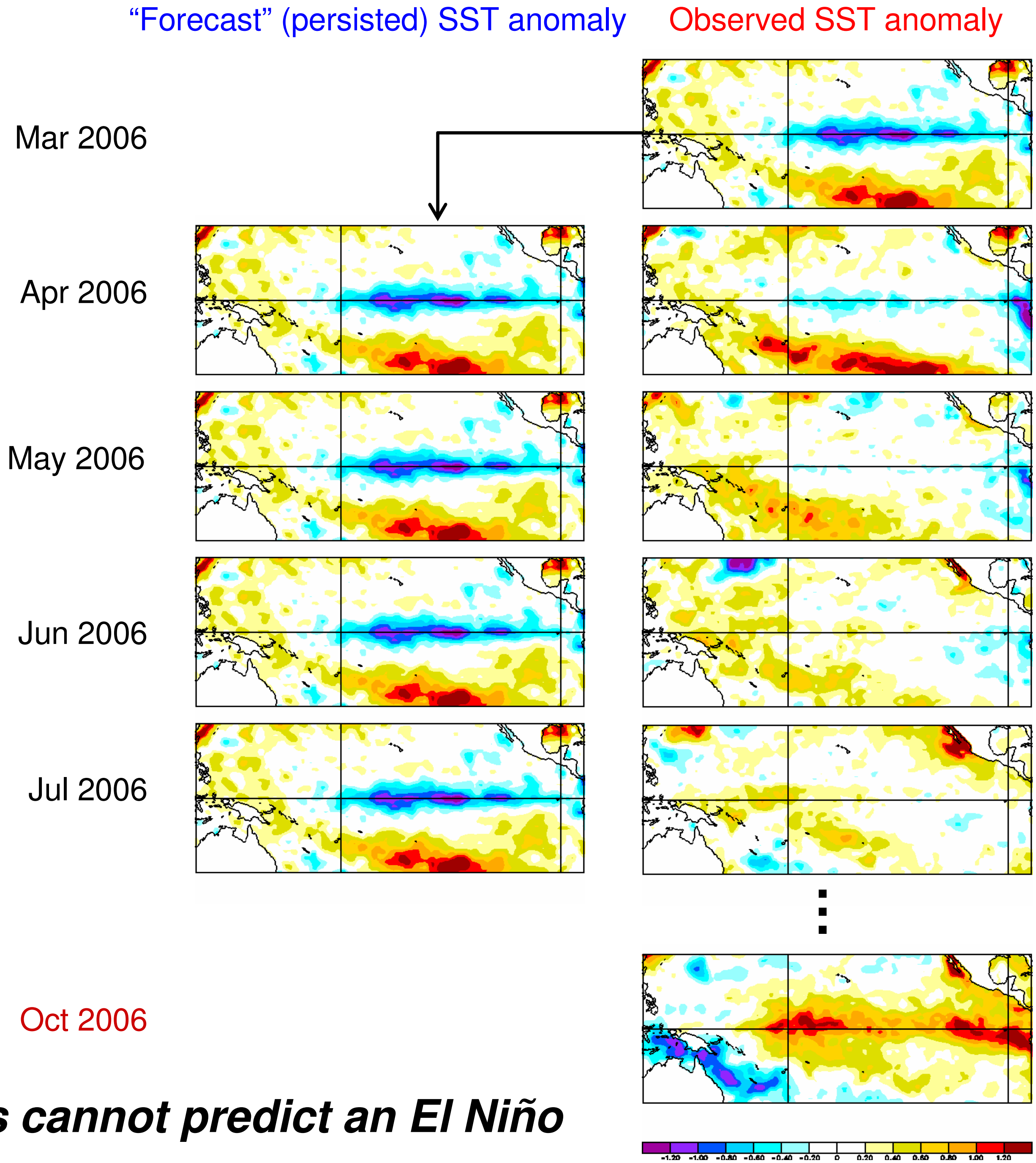
    → 4 different AGCMs, 4×10 ensemble

    → persisted SSTA, forecasts to 4 months only

- **One-tier (coupled) forecast**
  - Future SSTs *predicted* as part of forecast → *potential skill at much longer leads*
  - Requires initializing coupled climate model to realistic observed states → *data assimilation*

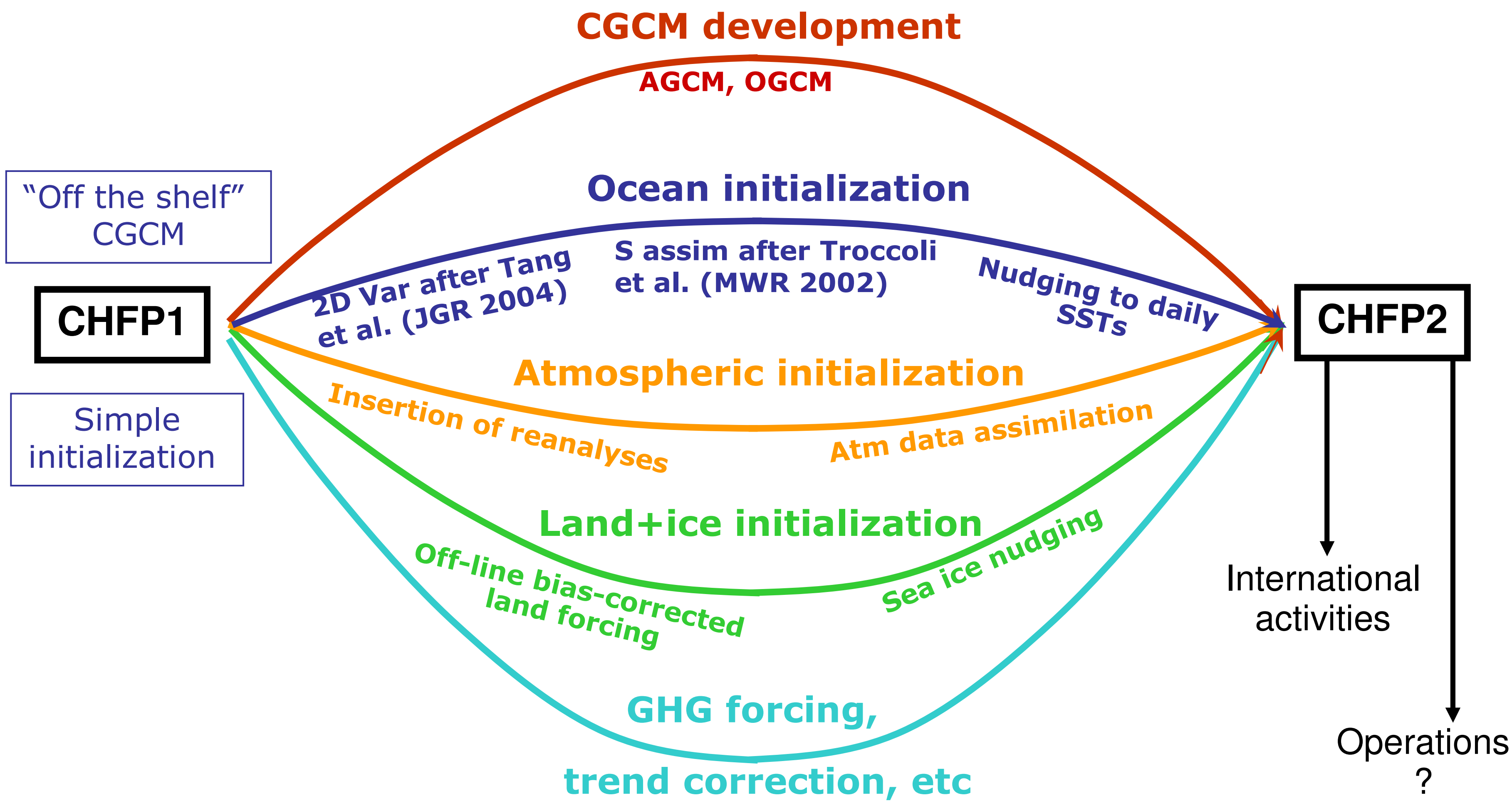
Limitation of 2-tier forecast systems

Example: forecast issued 1 Apr 2006

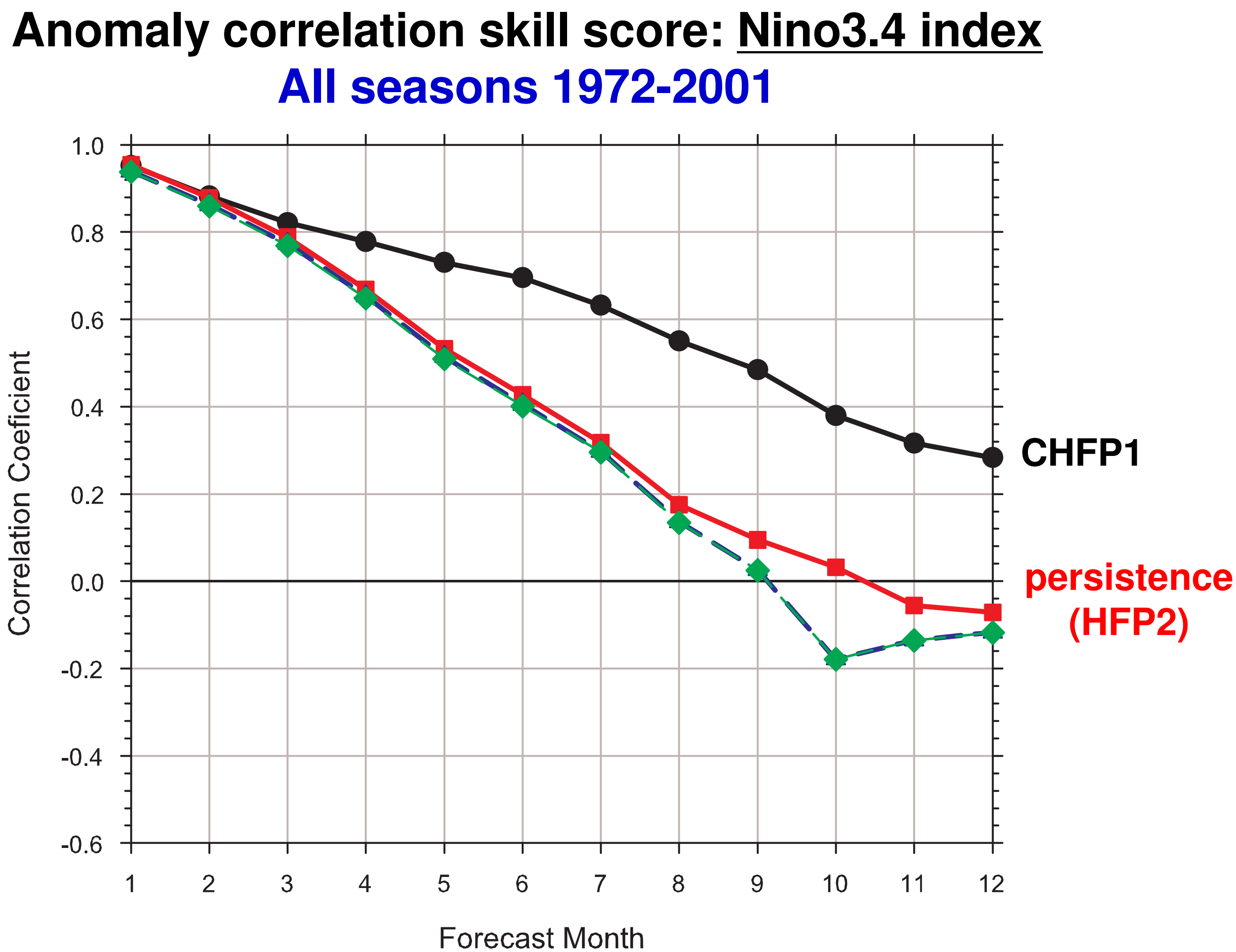


➡ ***2-tier forecasts cannot predict an El Niño***

Developing a climate forecast system



CHFP1 results



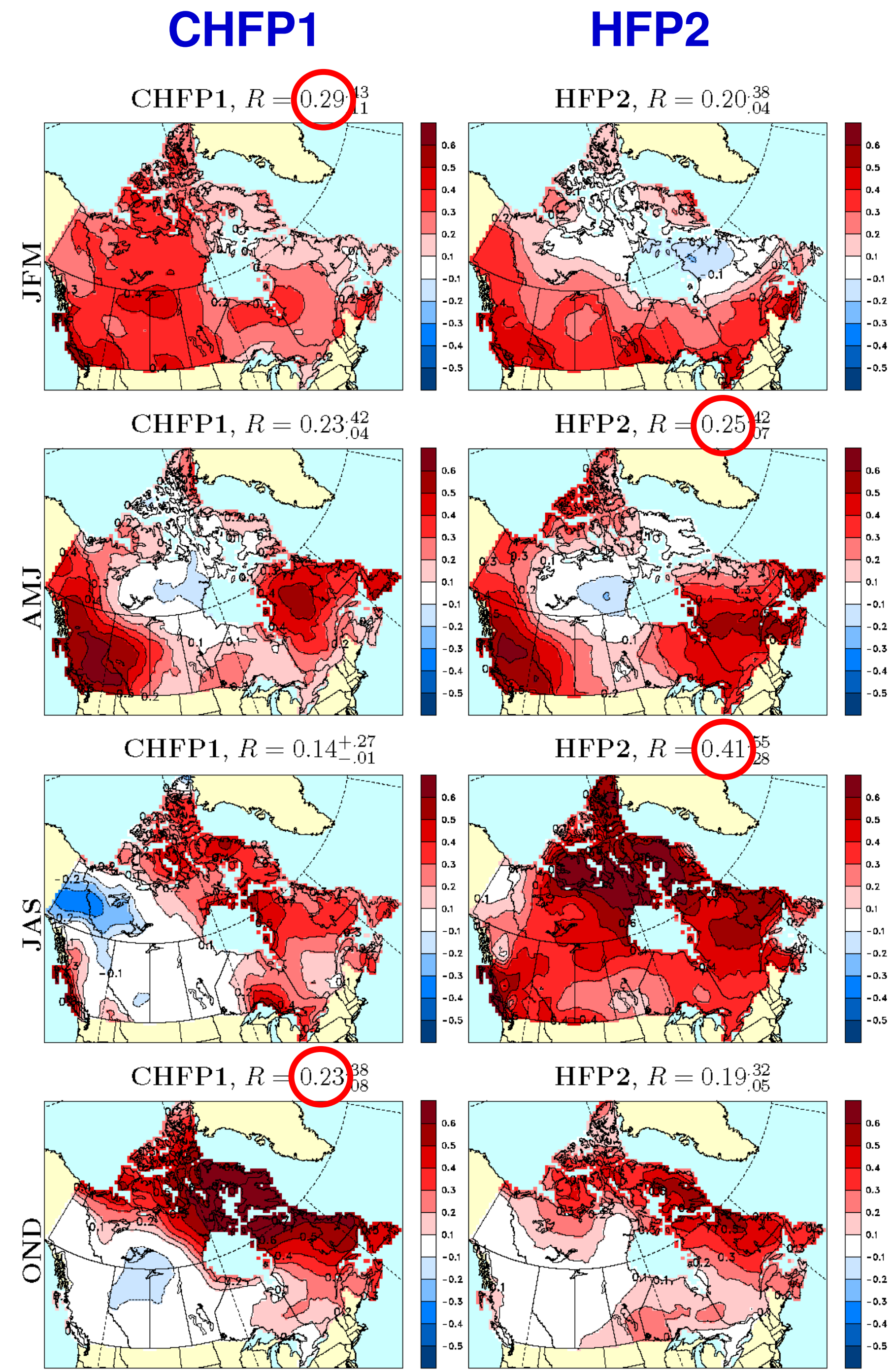
CHFP1 vs HFP2

Correlation skill

Surface air temperature over Canada

1-month lead

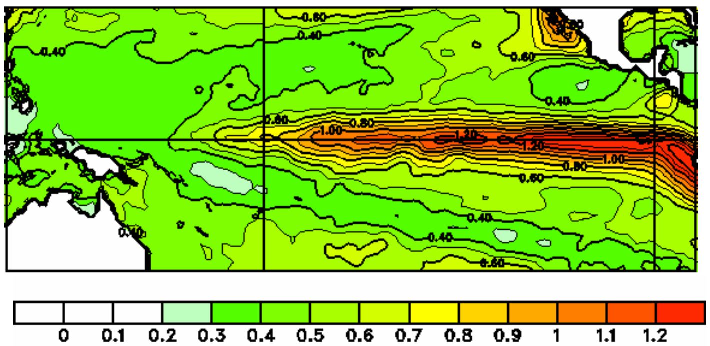
➡ ***CHFP1 competitive with two-tier HFP2 despite smaller ensemble size (1x10 vs 4x10)***



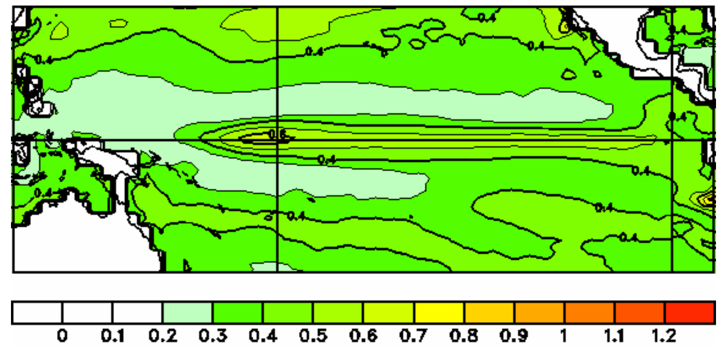
Model improvements: ENSO

Monthly SST standard deviation

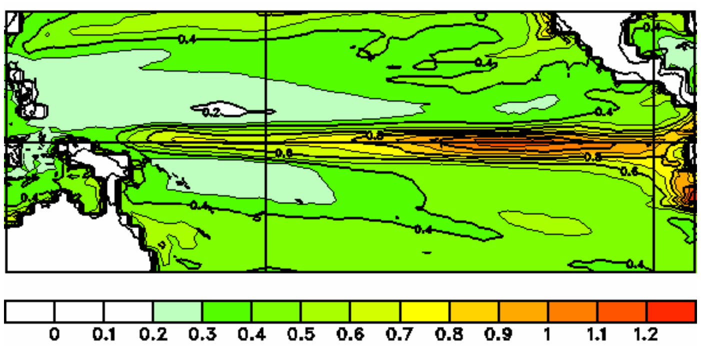
Observations: HadISST 1970-99



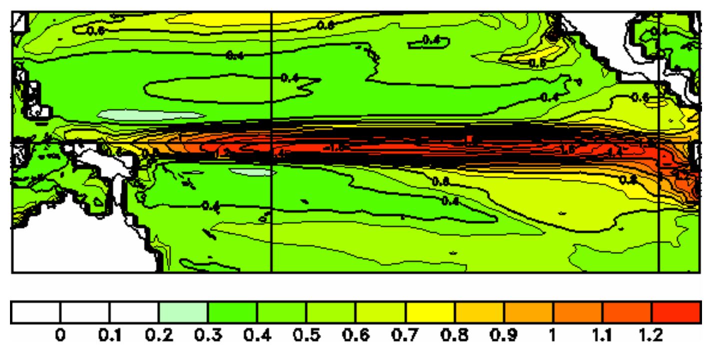
AGCM3+OGCM3
CHFP1



AGCM3+OGCM4



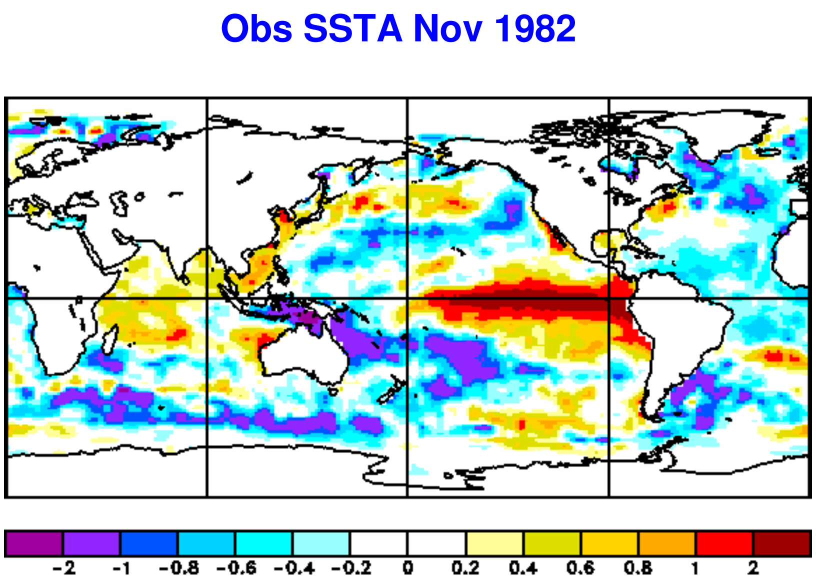
AGCM4+OGCM4
CHFP2

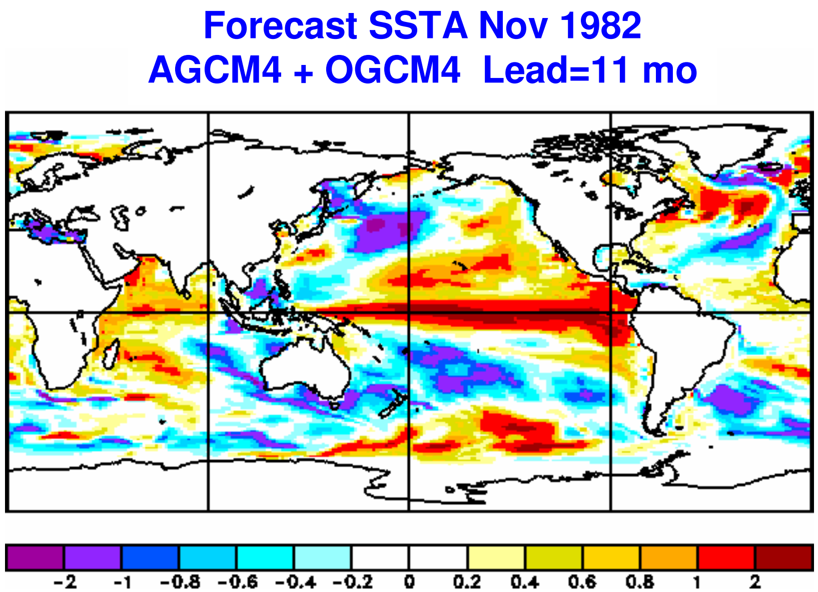


*

Impact of model improvements

- Illustration: 1982/83 El Niño, 11 month lead





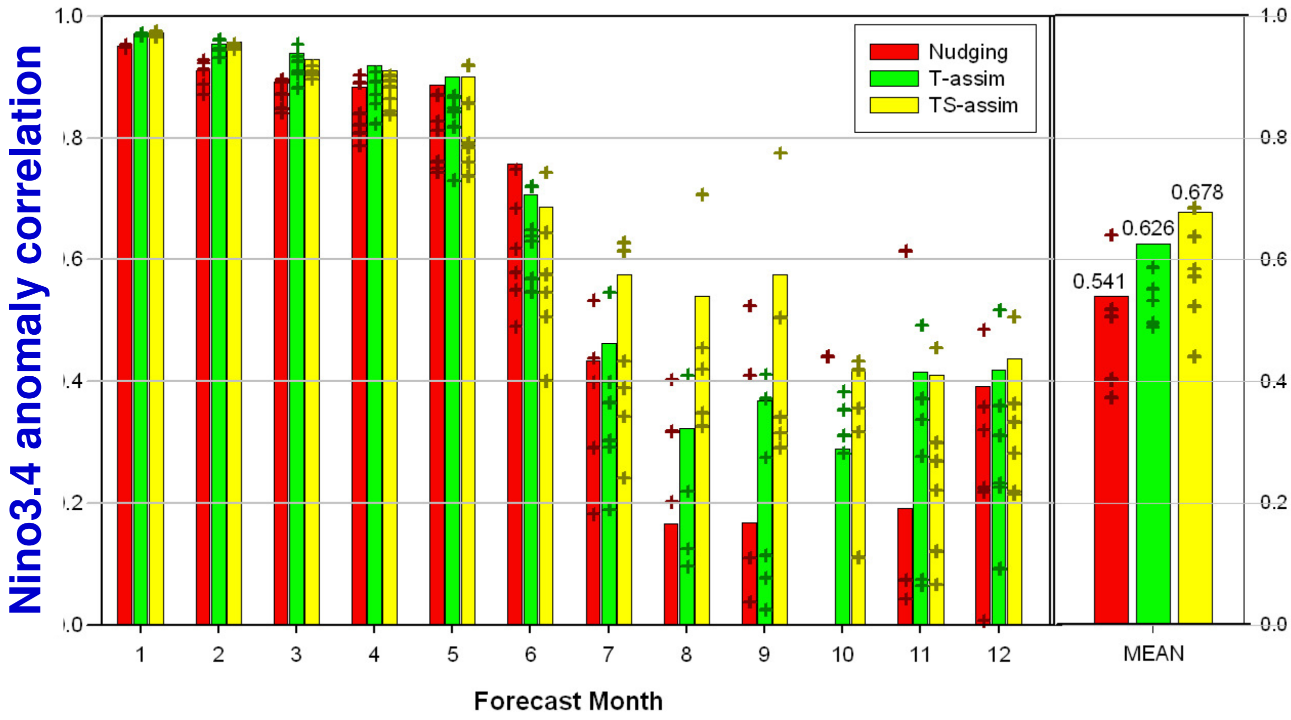
- While such "hits" not always possible (even in theory), a *strong El Niño is now within the range of possibilities that can be forecast*

	CHFP1	CHFP2
Mean Niño3.4 anomaly correlation, months 1-12: ***(ensemble size 1, same initialization)***	**0.48**	**0.64**

Ocean Data Assimilation

University partner: Youmin Tang (UNBC)

- **T assimilation**
  - procedure of Tang et al. *JGR* 2004
  - off-line variational assimilation of 3D gridded analyses
- **S assimilation**
  - procedure of Troccoli et al. *MWR* 2002
  - preservation of T-S relationship: prevents spurious convection, etc.



Atmospheric Data Assimilation

EC partner: Saroja Polavarapu (Downsview)

- **Incremental Reanalysis Update (IRU)** assimilation
- improves ocean initialization as well

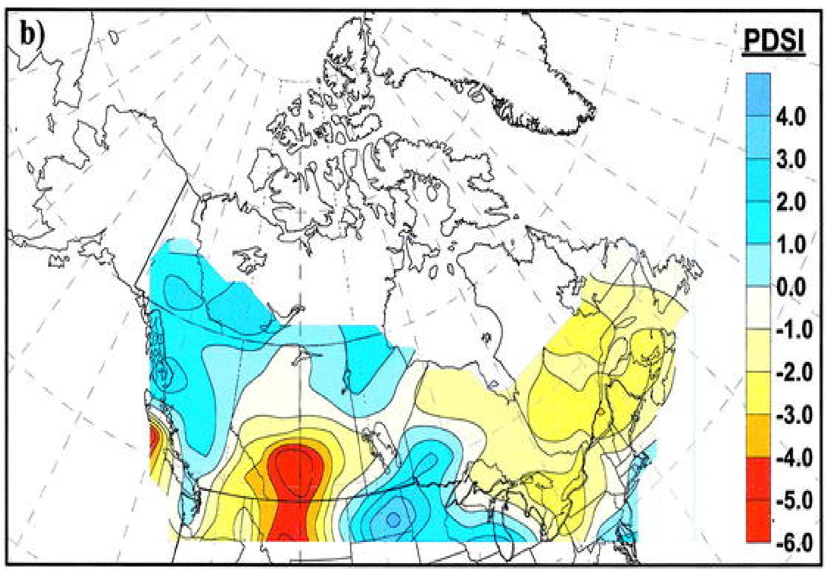
Land surface initialization

University partner: Aaron Berg (Guelph)

- Drive CLASS land surface model with *bias-corrected* reanalysis

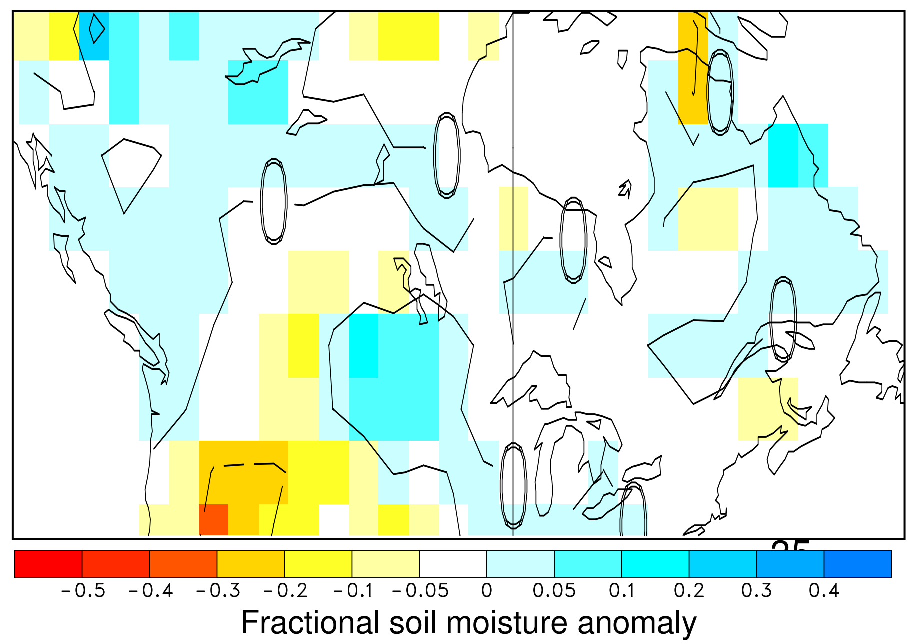
Case study: ***2001-2002 drought***

Observed Palmer Drought Severity Index: JJA 2001



(Shabbar & Skinner 2004)

Soil moisture forecast initialization

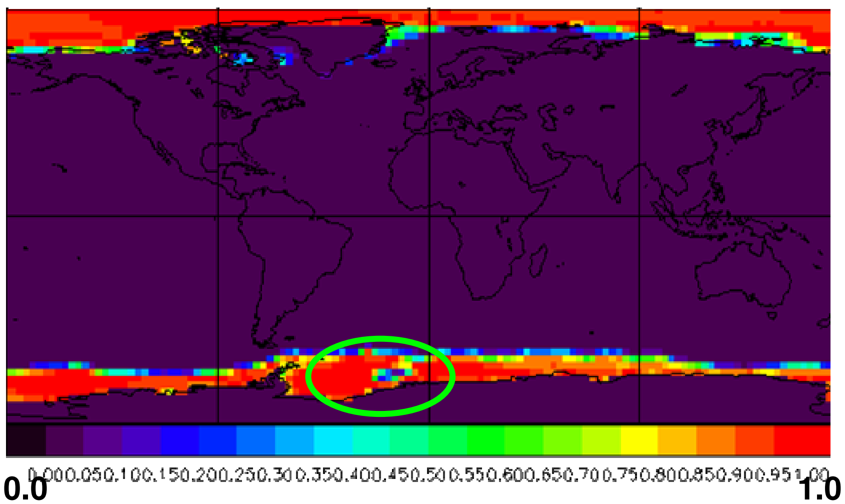


Sea ice initialization

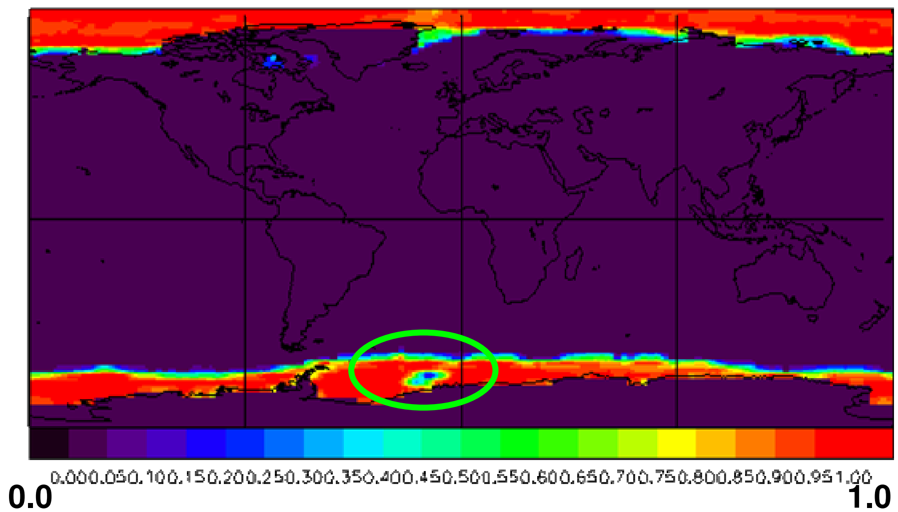
- Nudge concentration and estimated thickness to observations

Sea ice concentration: August 1976

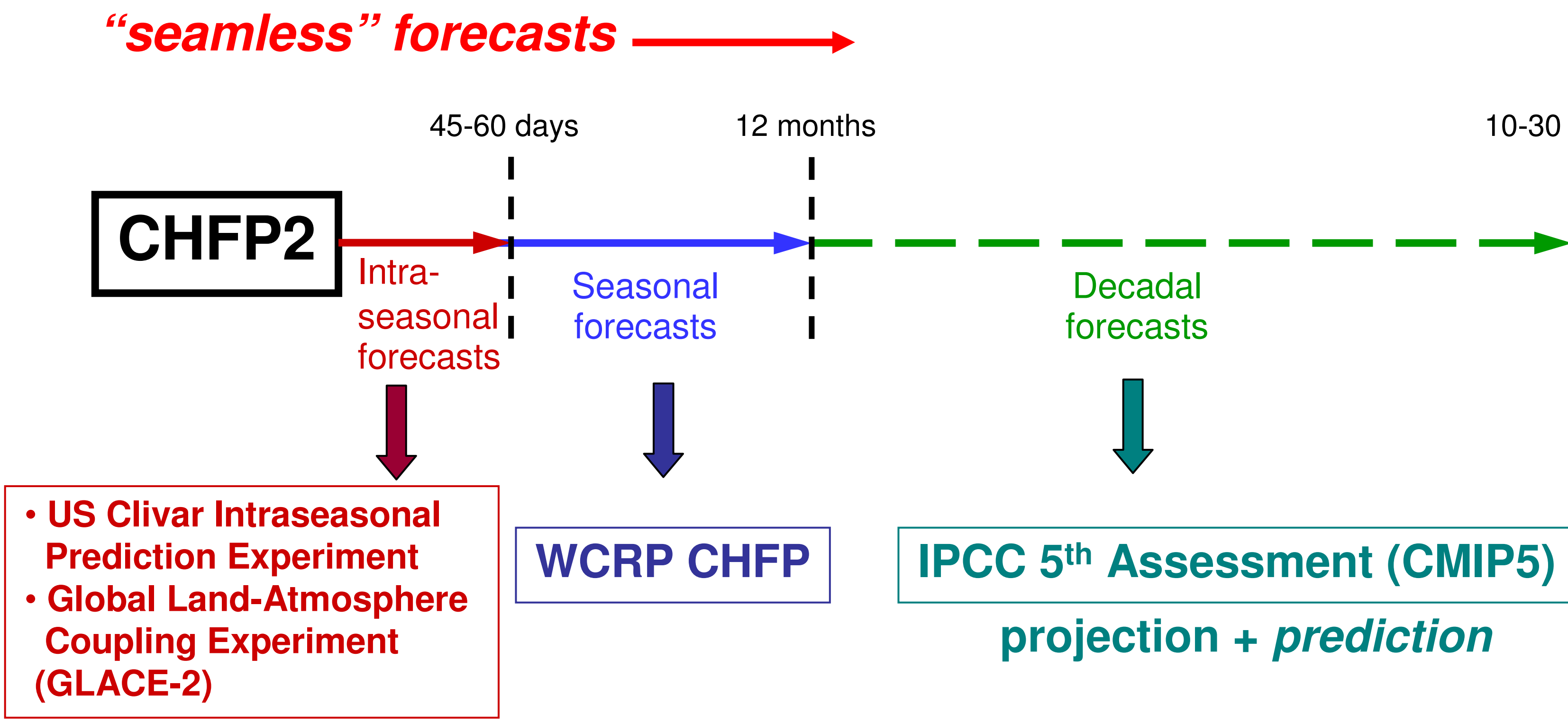
Hadisst



Forecast initial conditons



Contributions to international activities



What has GOAPP Delivered?

Expertise in Critical Areas

- Ocean (e.g. NEMO), coupled and coastal data assimilation
- Seasonal forecasting
- Land surface processes modelling and validation
- Adding value to forecasts (downscaling, statistical enhancement of forecasts)

Ocean Hindcasts

- Reconstructions for the North Atlantic and North Pacific

Access of Government Researchers to the University Environment

- Interaction with students and university faculty
- Helping shape the next generation of HQP
- Improving connections among departments (e.g., EC, DFO, DND)

Funding

- Cost-sharing to support key positions
- Access to university infrastructure, computers, support staff

Development of Operational Systems

- Pre-operational forecast system for ocean weather (CFCAS supplementary funding)
- Seasonal Forecasts Using Coupled Models (CCCma)

Post-GOAPP Wish List

- Maintain momentum after GOAPP finishes December 2010. Continue interactions across disciplines and timescales.
- New government positions to retain HQP trained by GOAPP. Technology transfer.
- Long term R&D program jointly developed by GOC and academia to improve operational coupled assimilation & prediction systems.
- Academia plays an active and sustained role in CONCEPTS and seasonal to decadal prediction.