Environment Canada Environnement Canada

Canada

Review and Discussion of Theme II

Bill Merryfield
Canadian Centre for Climate Modelling and Analysis
Environment Canada

GOAPP Workshop 31 May 2009 *Halifax*

Seasons to Decades

- **Sub-Theme II.1 Analysis and Mechanisms**

  What are the origins of predictability?

- **Sub-Theme II.2 Predictability of the Coupled System**

  What are the limits of predictability?

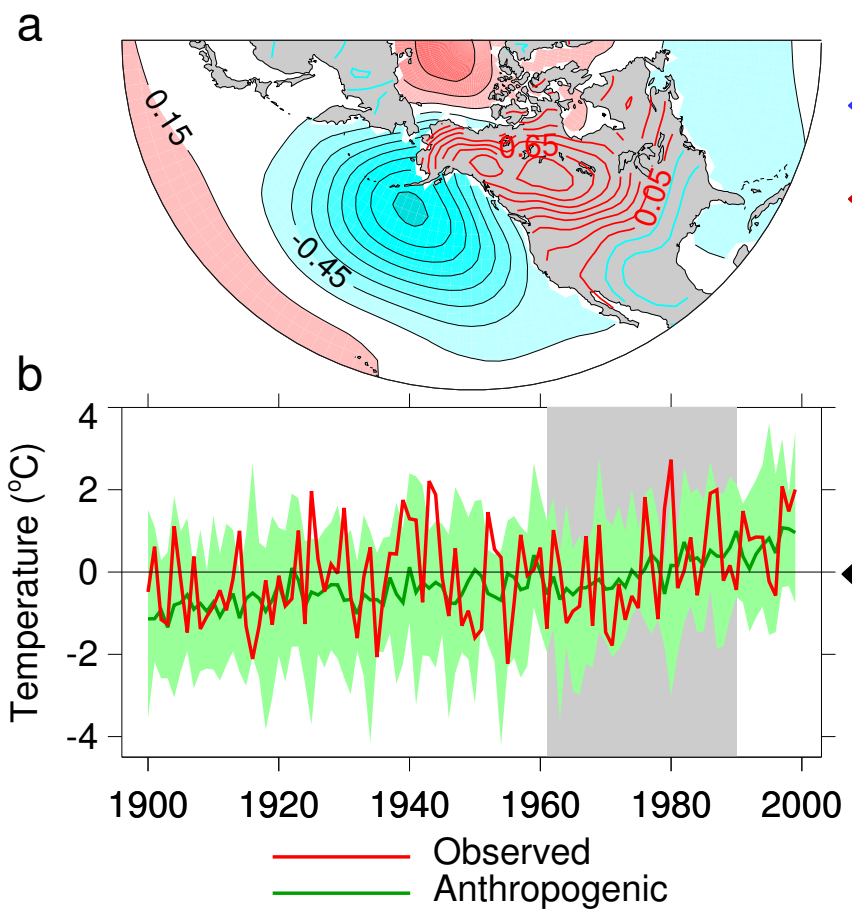
- **Sub-Theme II.3 Prediction**

  How well can we predict in practice?

• Sub-Theme II.1 Analysis and Mechanisms

- Northern Annular Mode

J. Fyfe (CCCma)
A. Monahan (UVic)



Contours:

Over ocean: SLP correlation with Aleutian Low depth

Over land: T correlation with Aleutian Low depth

~ 1/2 of observed N American warming explained by secular deepening of Aleutian Low

- **Sub-Theme II.1 Analysis and Mechanisms**

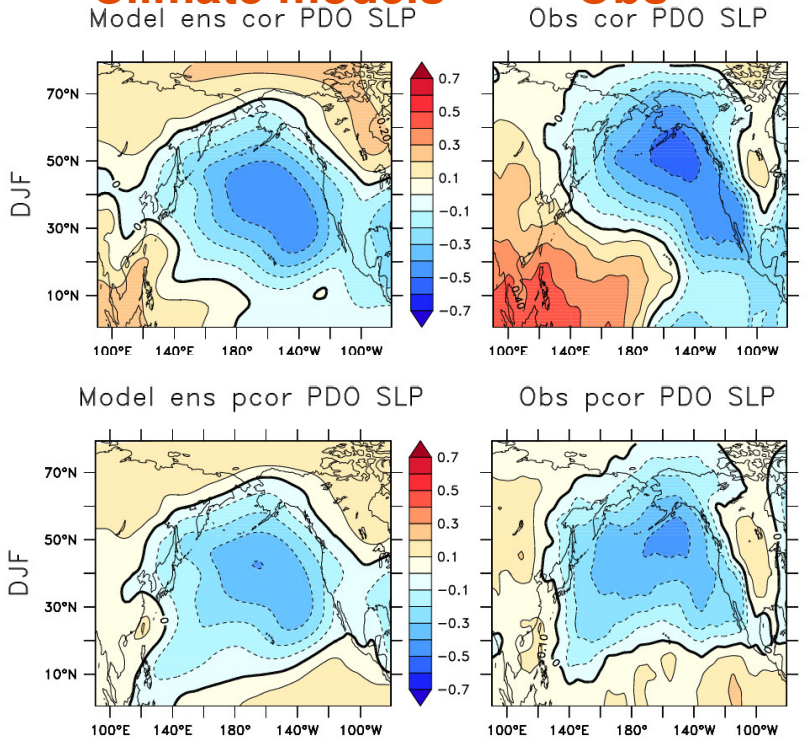
- Pacific Decadal Oscillation in climate models

→ *model biases*

→ *relation to ENSO*

F. Lienert ***Mon 14:45***

Climate models **Obs**



SLP correlation with *full* PDO

SLP correlation with *ENSO-correlated PDO removed*

- **Sub-Theme II.2 Predictability of the Coupled System**

  - **Predictability in a warming world**
  - 21st century decadal predictability
  - Likelihood and predictability of cooling episodes in a warming climate
  - Regional impacts of air-sea coupling on climate variability and predictability
  - Bred Vector and ENSO predictability
  - Prognostic predictability of large ensembles

Potential predictability in a warmer world

- Climate dynamics can be characterized as having two components:

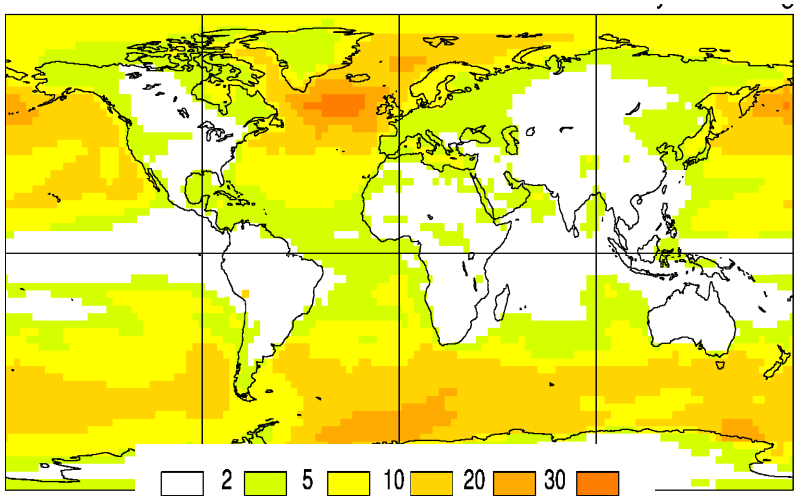
'Signal': dynamics *deterministic*, potentially predictable, variance σ^2_ν

'Noise' : dynamics *random*, unpredictable, variance σ^2_ε

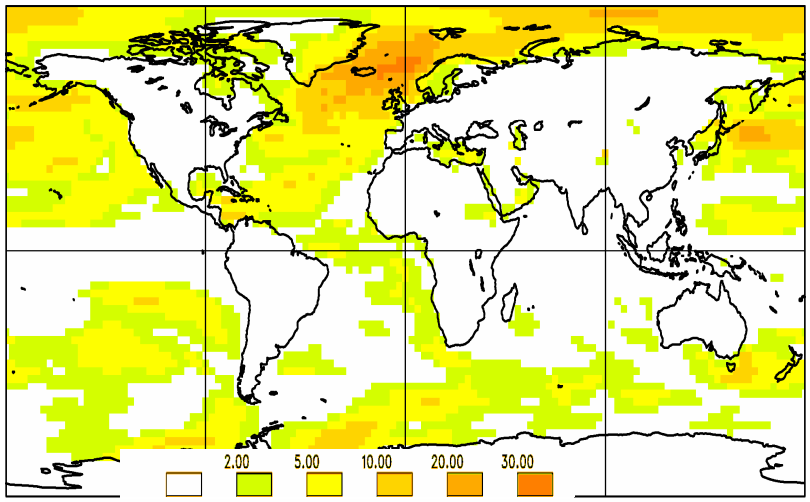
- $\sigma^2_{Total} = \sigma^2_\nu + \sigma^2_\varepsilon$

  → *potentially predictable variance fraction* = $\sigma^2_\nu/\sigma^2_{Total}$ ***(ppvf)***

Control simulations



B1 stabilization



Decadal ppvf (%) for Temperature

Boer, J. Climate 2009

- **Sub-Theme II.2 Predictability of the Coupled System**

  - Predictability in a warming world
  - 21st century decadal predictability — G. Boer *Mon 11:45*
  - Likelihood and predictability of cooling episodes in a warming climate
  - Regional impacts of air-sea coupling on climate variability and predictability
  - Bred Vector and ENSO predictability
  - Prognostic predictability of large ensembles

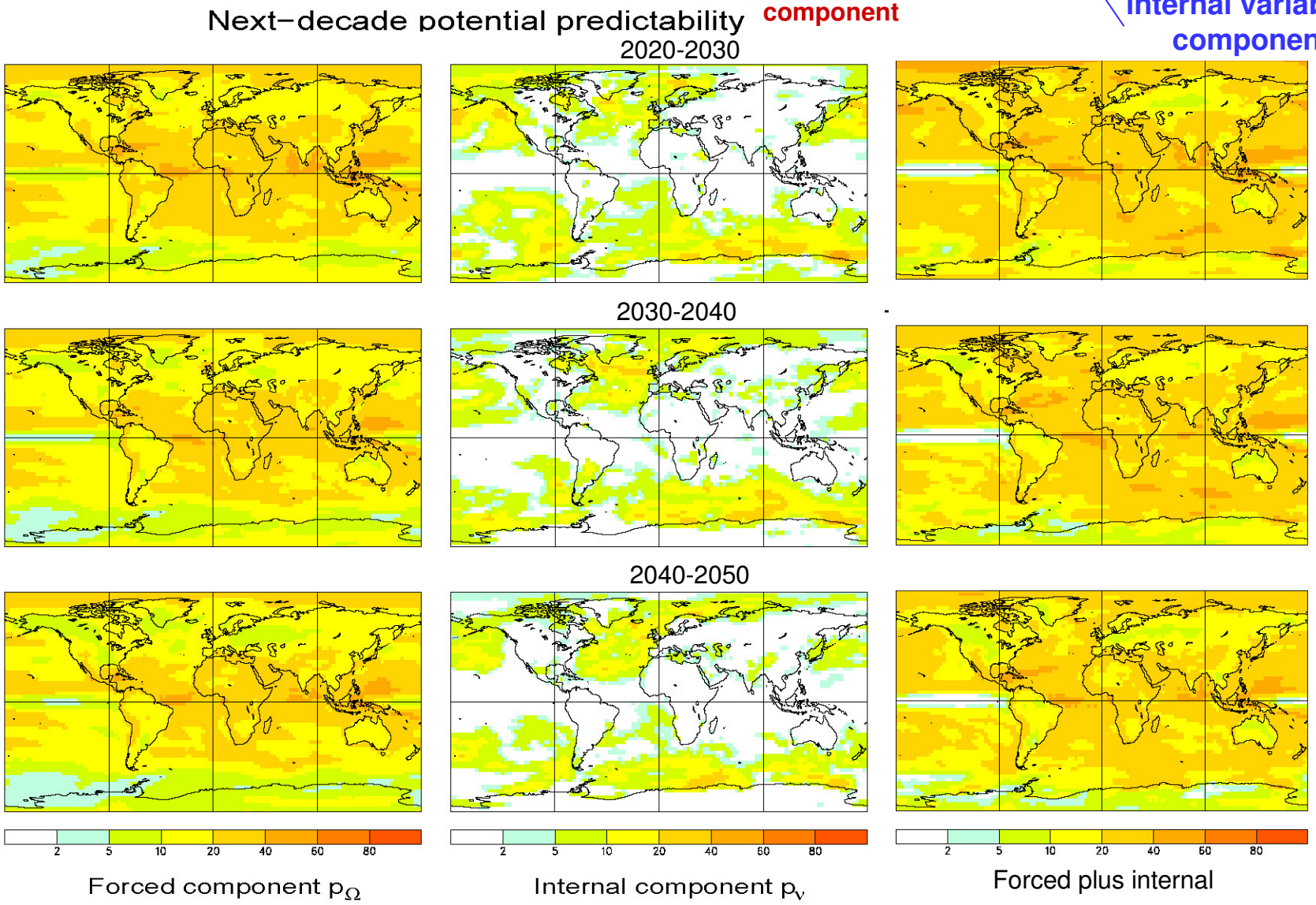
Decadal potential predictability of 21st Century climate

"noise"

$$\sigma^2 = \sigma^2_{\Omega} + \sigma^2_{\nu} + \sigma^2_{\varepsilon}$$

externally forced component

internal variability component



Boer (2009) submitted

- **Sub-Theme II.2 Predictability of the Coupled System**

  - Predictability in a warming world

  - 21st century decadal predictability — G. Boer *Mon 11:45*

  - Likelihood and predictability of cooling episodes in a warming climate — *A. Ravindran morning talk*

  - Regional impacts of air-sea coupling on climate variability and predictability

  - Bred Vector and ENSO predictability

  - Prognostic predictability of large ensembles

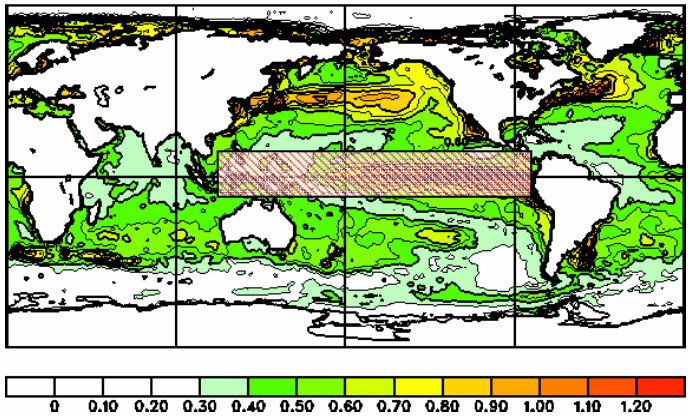
- **Sub-Theme II.2 Predictability of the Coupled System**

  - Predictability in a warming world
  - 21st century decadal predictability — G. Boer *Mon 11:45*
  - Likelihood and predictability of cooling episodes in a warming climate — *A. Ravindran morning talk*
  - Regional impacts of air-sea coupling on climate variability and predictability
  - Bred Vector and ENSO predictability
  - Prognostic predictability of large ensembles

Regional impacts of air-sea coupling on climate variability and predictability

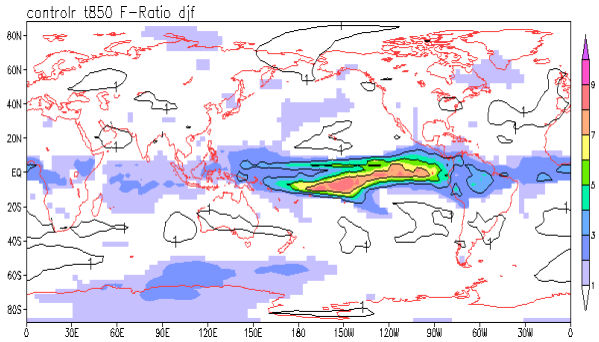
A. Ravindran, W. Merryfield, S. Kharin, G. Boer

- Examine climate variability and potential predictability when atmosphere sees only *climatological* SSTs in specified regions:

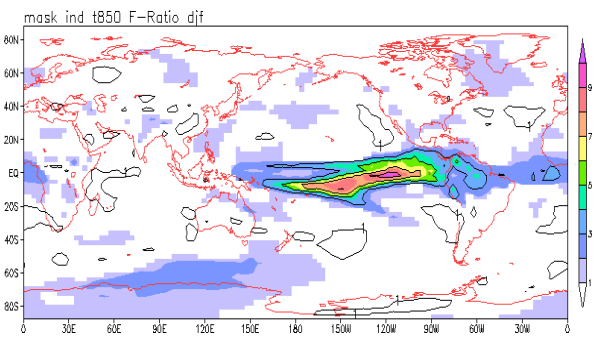


Potential predictability of DJF seasonal means

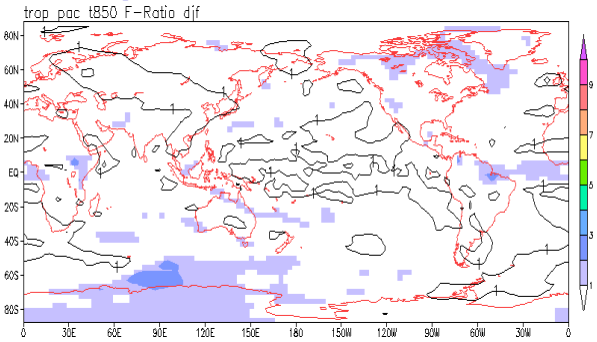
Control run



Indian Ocean masked



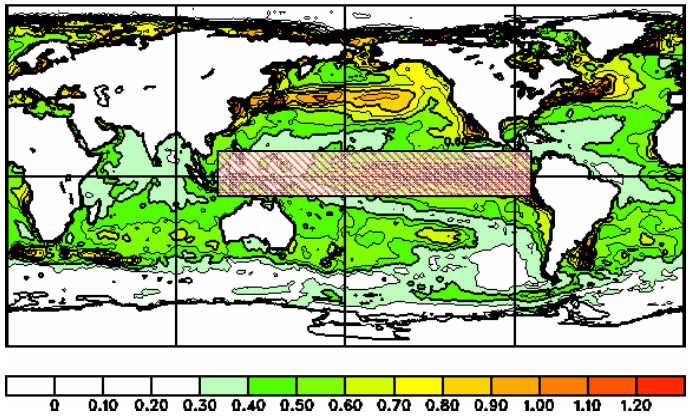
tropical Pacific masked



Regional impacts of air-sea coupling on climate variability and predictability

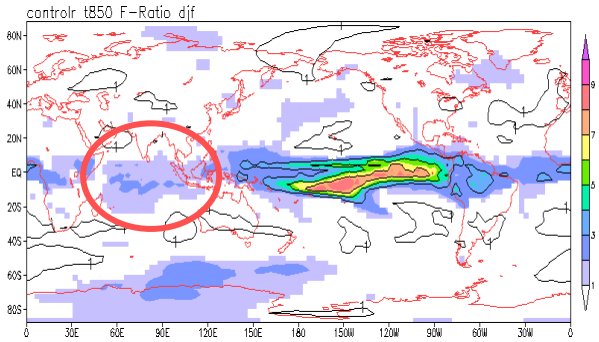
A. Ravindran, W. Merryfield, S. Kharin, G. Boer

- Examine climate variability and potential predictability when atmosphere sees only *climatological* SSTs in specified regions →

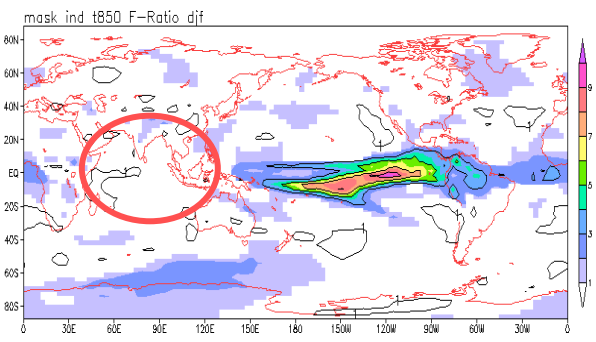


Potential predictability of DJF seasonal means

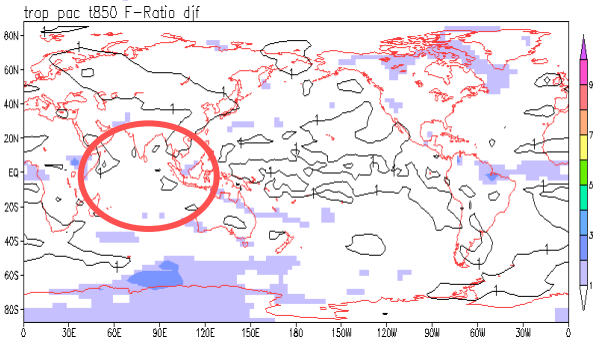
Control run



Indian Ocean masked



tropical Pacific masked



- **Sub-Theme II.2 Predictability of the Coupled System**

  - Predictability in a warming world
  - 21st century decadal predictability — G. Boer *Mon 11:45*
  - Likelihood and predictability of cooling episodes in a warming climate — *A. Ravindran morning talk*
  - Regional impacts of air-sea coupling on climate variability and predictability
  - Bred Vector and ENSO predictability — Y. Tang *Mon 15:15*
  - Prognostic predictability of large ensembles

- **Sub-Theme II.2 Predictability of the Coupled System**

  - Predictability in a warming world

  - 21st century decadal predictability — G. Boer *Mon 11:45*

  - Likelihood and predictability of cooling episodes in a warming climate — *A. Ravindran morning talk*

  - Regional impacts of air-sea coupling on climate variability and predictability

  - Bred Vector and ENSO predictability — Y. Tang *Mon 15:15*

  - Prognostic predictability of large ensembles

W. Merryfield, A. Ravindran, J. Scinocca, S. Kharin

- **Sub-Theme II.3 Prediction**

  - II.3.1 Coupled Model Initialization — W.-S. Lee *Mon 12:00*

  - II.3.2 The Coupled Model Historical Forecasting Project — W. Merryfield *Mon 11:30*

  - II.3.3 Forecast Combination, Calibration and Verification — J. Finnis *poster*

  - II.3.4 Sensitivity of Seasonal Climate Forecasts in the CCCma GCM to Initialization of Land Surface Hydrological States — G. Drewitt *Mon 12:15*

The Coupled Model Historical Forecasting Project (CHFP)

- Under GOAPP, develop *coupled* forecast system → *SSTA part of forecast*
- **CHFP1**: modest pilot project
- **CHFP2**: incorporate model + initialization + calibration improvements

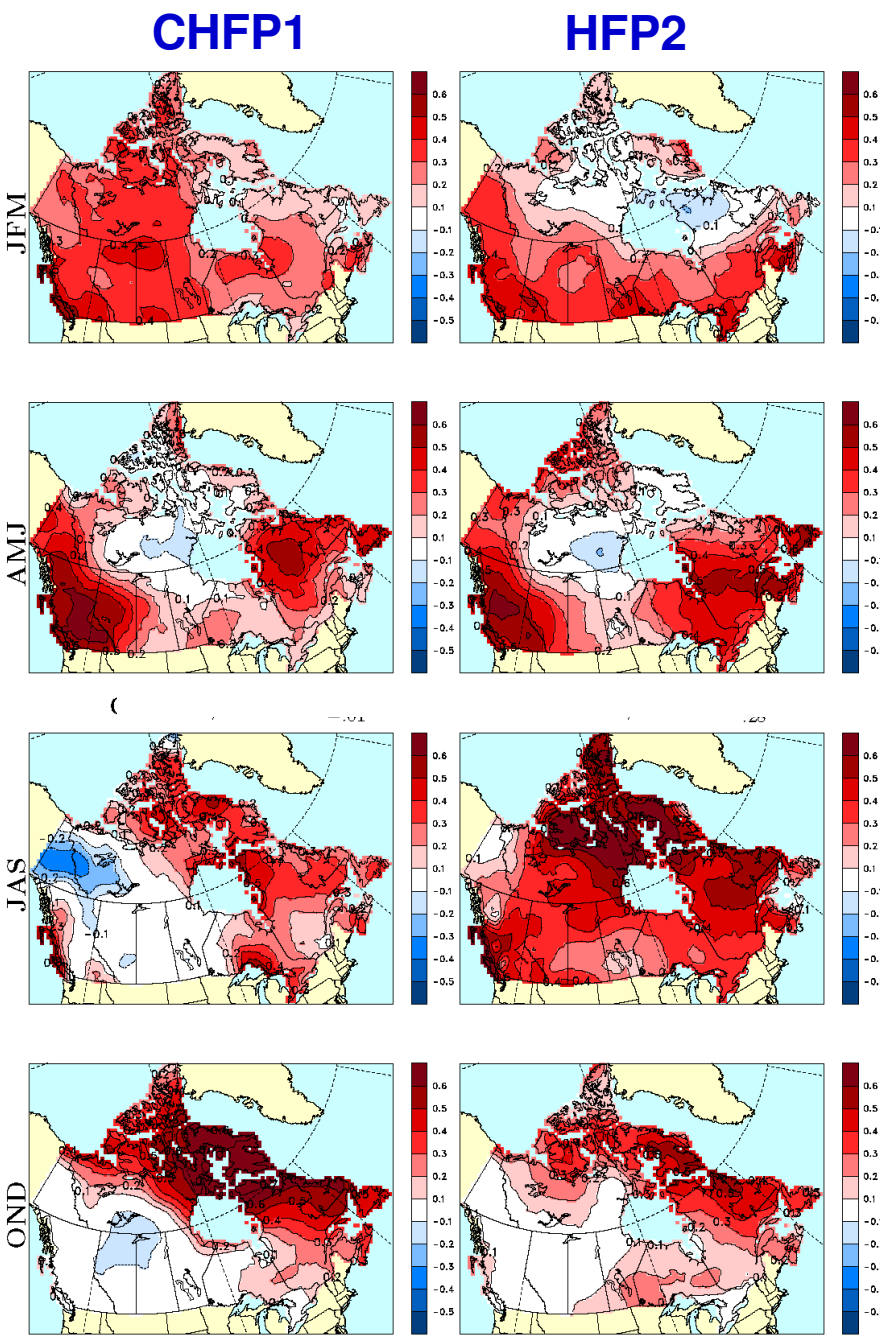
  → contribution to international CHFP ("*Climate-system Historical Forecast Project*") organized by Clivar Working Group on Seasonal to Interannual Prediction

CHFP1 vs HFP2

Correlation skill
Surface air temperature over Canada
1-month lead

Season	JFM	AMJ	JAS	OND	ALL
Correlation					
CHFP1	$.\mathbf{29}^{.43}_{.11}$	$.23^{.42}_{.04}$	$.14^{+.27}_{-.01}$	$.\mathbf{23}^{.38}_{.08}$	$.22^{.30}_{.12}$
HFP2/MM4	$.20^{.38}_{.04}$	$.\mathbf{25}^{.42}_{.07}$	$.\mathbf{41}^{.55}_{.28}$	$.19^{.32}_{.05}$	$.\mathbf{26}^{.37}_{.17}$
HFP2/GCM3	$.22^{.41}_{.05}$	$.15^{+.32}_{-.06}$	$.23^{.35}_{.12}$	$.05^{+.23}_{-.11}$	$.16^{.28}_{.08}$

Merryfield, W. J., W.-S. Lee, G. J. Boer, V. V. Kharin, B. Pal, J. F. Scinocca and G. M. Flato, 2009: The first Coupled Historical Forecasting Project (CHFP1). *Atmosphere-Ocean*, submitted.



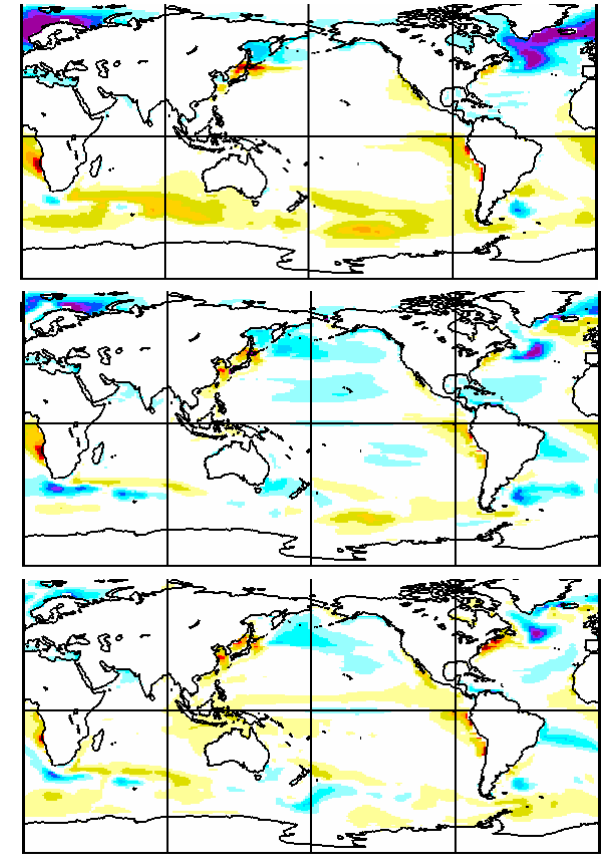
Forecast model configurations

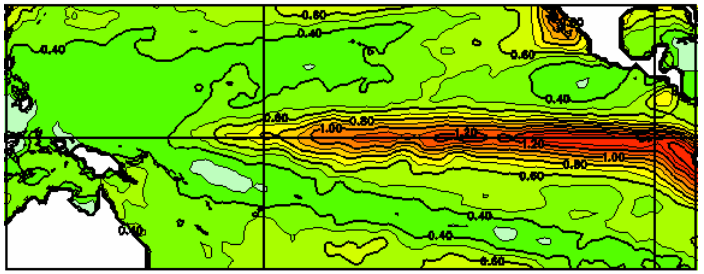
	AGCM3	AGCM4
OGCM3	CHFP1	–
OGCM4	$CHFP2_1$	$CHFP2_2$

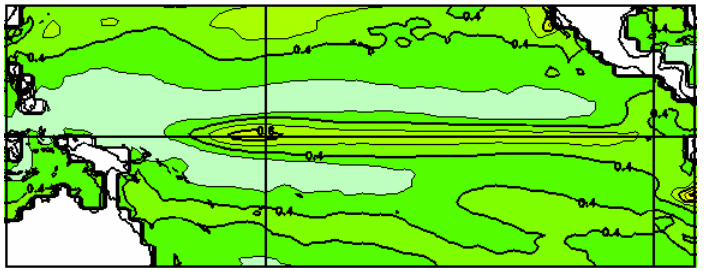
- **OGCM4**: higher vertical resolution (10m in upper ocean), new physics
- **AGCM4:** many new physical parameterizations, prognostic aerosols…
- Same horizontal resolution (≈ 2.8°×2.8° AGCM, 1.4°lon×0.9°lat OGCM)

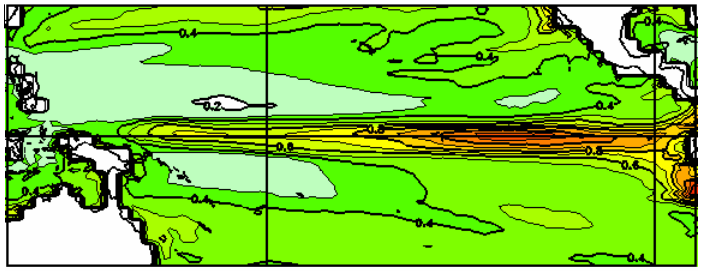
SST Bias

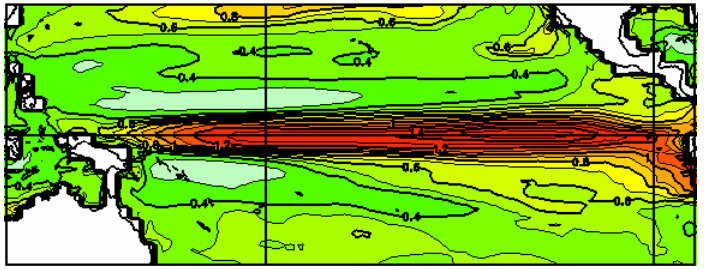
Monthly SSTA standard deviation

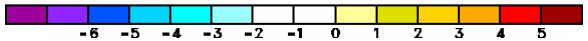












Observations: HadISST 1970-99

AGCM3+OGCM3

CHFP1

AGCM3+OGCM4

CHFP2$_1$

AGCM4+OGCM4

CHFP2$_2$

Impact of Model improvements on ENSO Prediction

	OGCM AGCM	Ens size N	Avg skill
CHFP2 (initialized as CHFP1)	OGCM4 + AGCM3	1	0.55
	OGCM4 + AGCM4	1	0.64
CHFP1	OGCM3 + AGCM3	1	0.48
	OGCM3 + AGCM3	10	**0.60**

N=1 CHFP2$_2$ skill exceeds N=10 CHFP1 skill

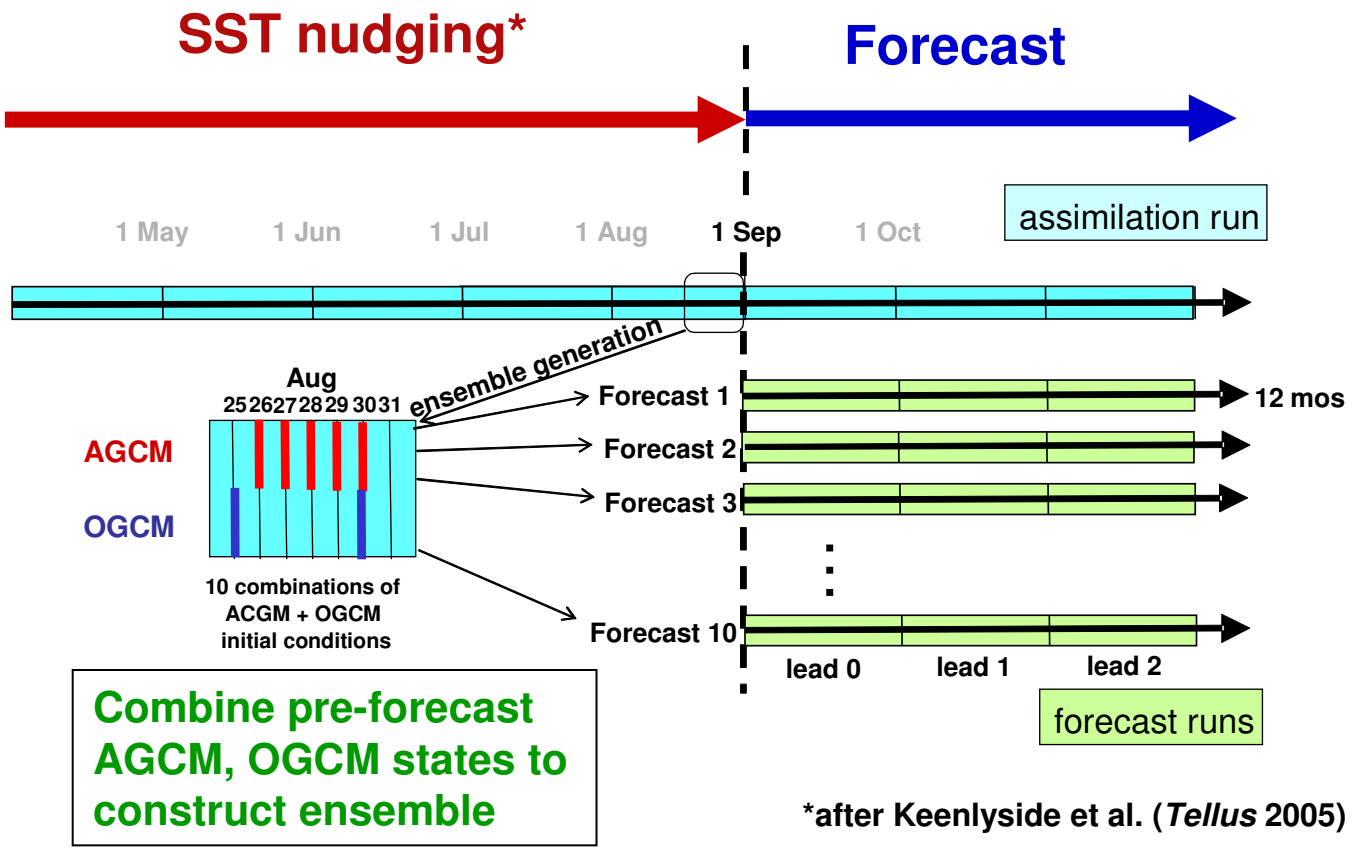
→ much room for further improvement through ensembles + better initialization

Mean NINO3.4 correlation skill of rolling 3-month forecasts

Dec → Nov Mar → Feb Jun → May Sep → Aug

SST nudging only 1972-2001

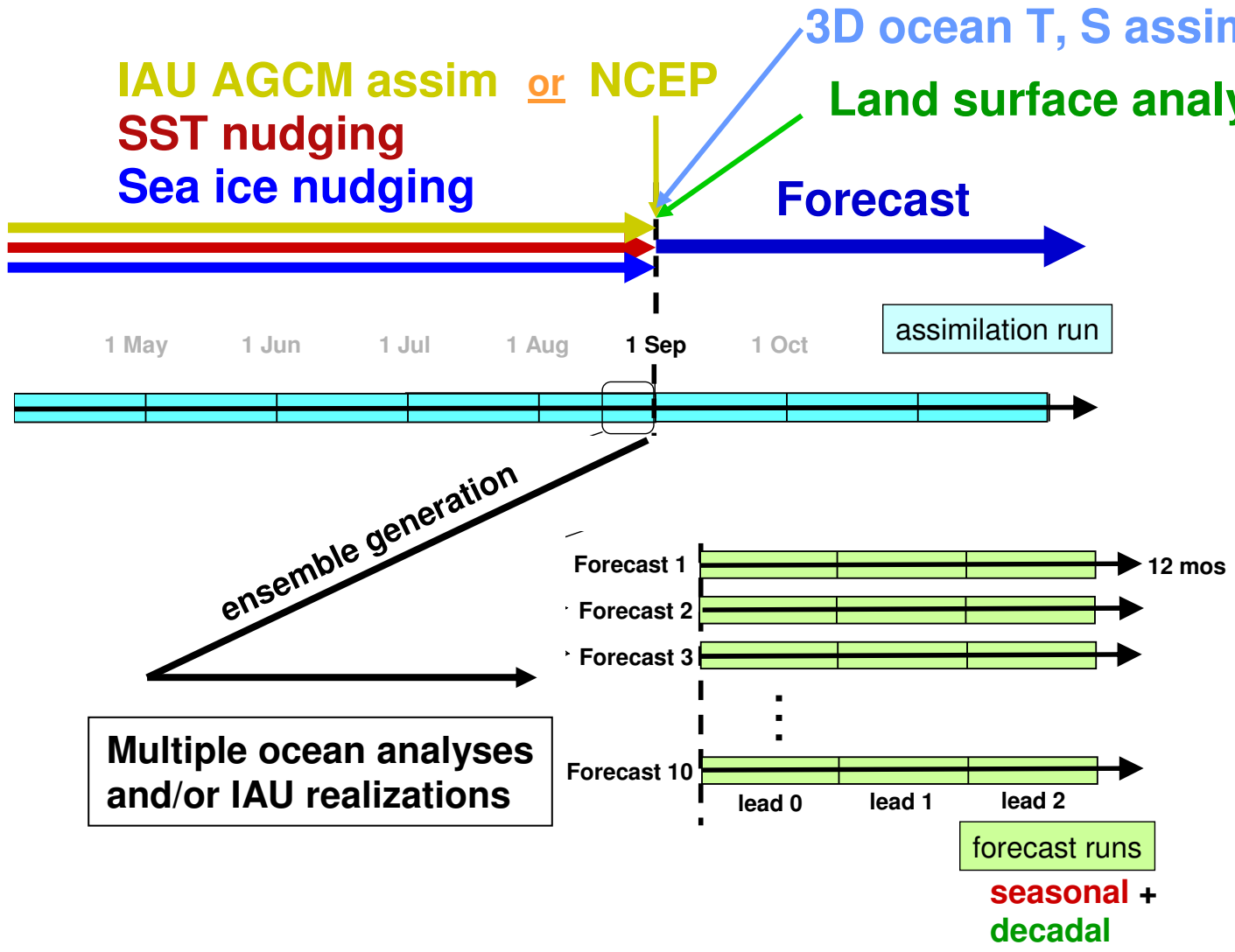
CHFP1 initialization



Combine pre-forecast AGCM, OGCM states to construct ensemble

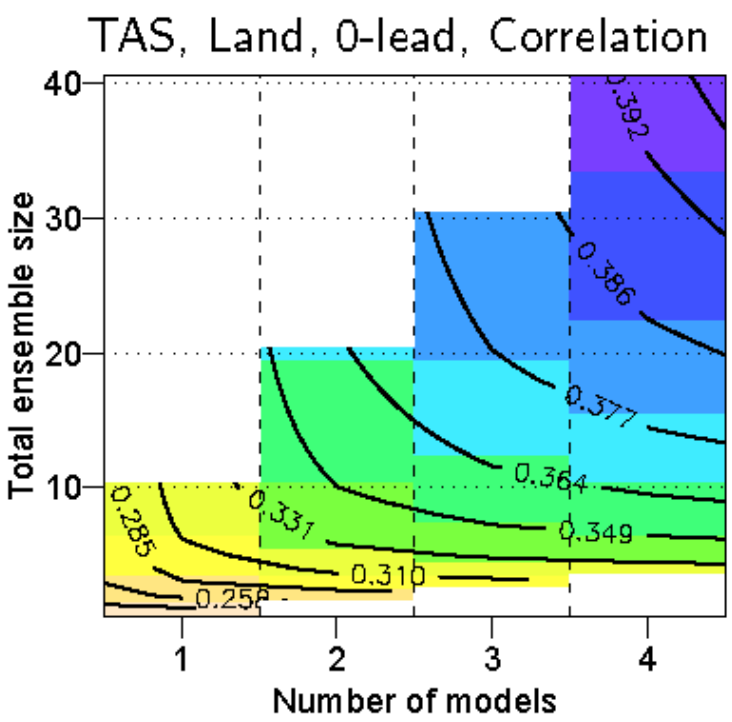
***after Keenlyside et al. (*Tellus* 2005)**

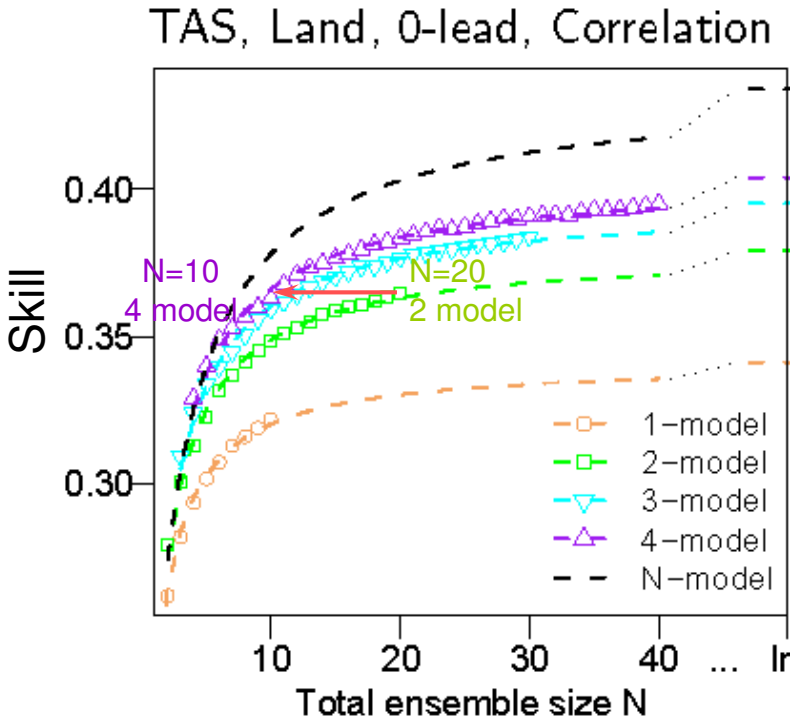
CHFP2 initialization



Skills of multi-model ensembles

Consider all possible 1-, 2-, 3-, 4-model combinations in 4x10 HFP2 ensemble





→ better skill for given ensemble size if multiple models

Kharin et al. *Atmos-Ocean* 2009

Conclusions

- II.1 improving understanding of Pacific/N America climate variability & change, how it is represented in models
- II.2 probing array of questions relating to how effectively seasonal-to-decadal predictions can be made
- **CHFP2** model components finalized; initialization procedures undergoing final testing/evaluation
- Several aspects of Theme II as originally proposed are being exceeded. These include
  - multimodel CHFP
  - initialization of AGCM/sea ice/land surface/ocean S
- *Spectral nudging* represents Theme I ↔Theme II interaction with potential to improve seasonal-to-decadal forecasts

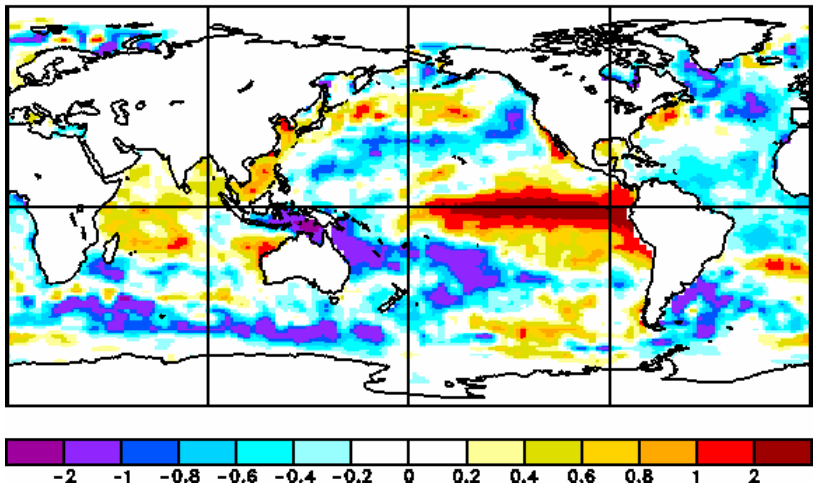
Environment Canada Environnement Canada

Canadian Centre for Climate Modelling and Analysis
Centre canadien de la modélisation et l'analyse climatique

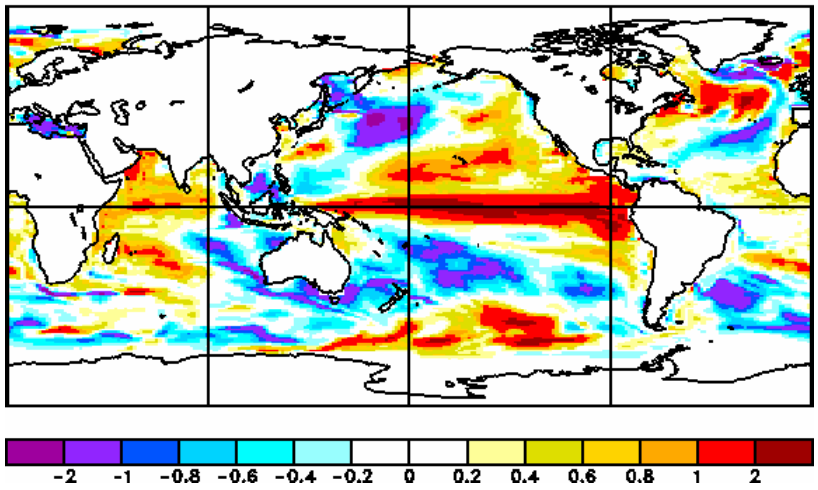
Canada

• Potential for improved prediction skill exemplified by “hit” for 11-month lead prediction of 1982/83 El Nino:

Obs SSTA Nov 1982

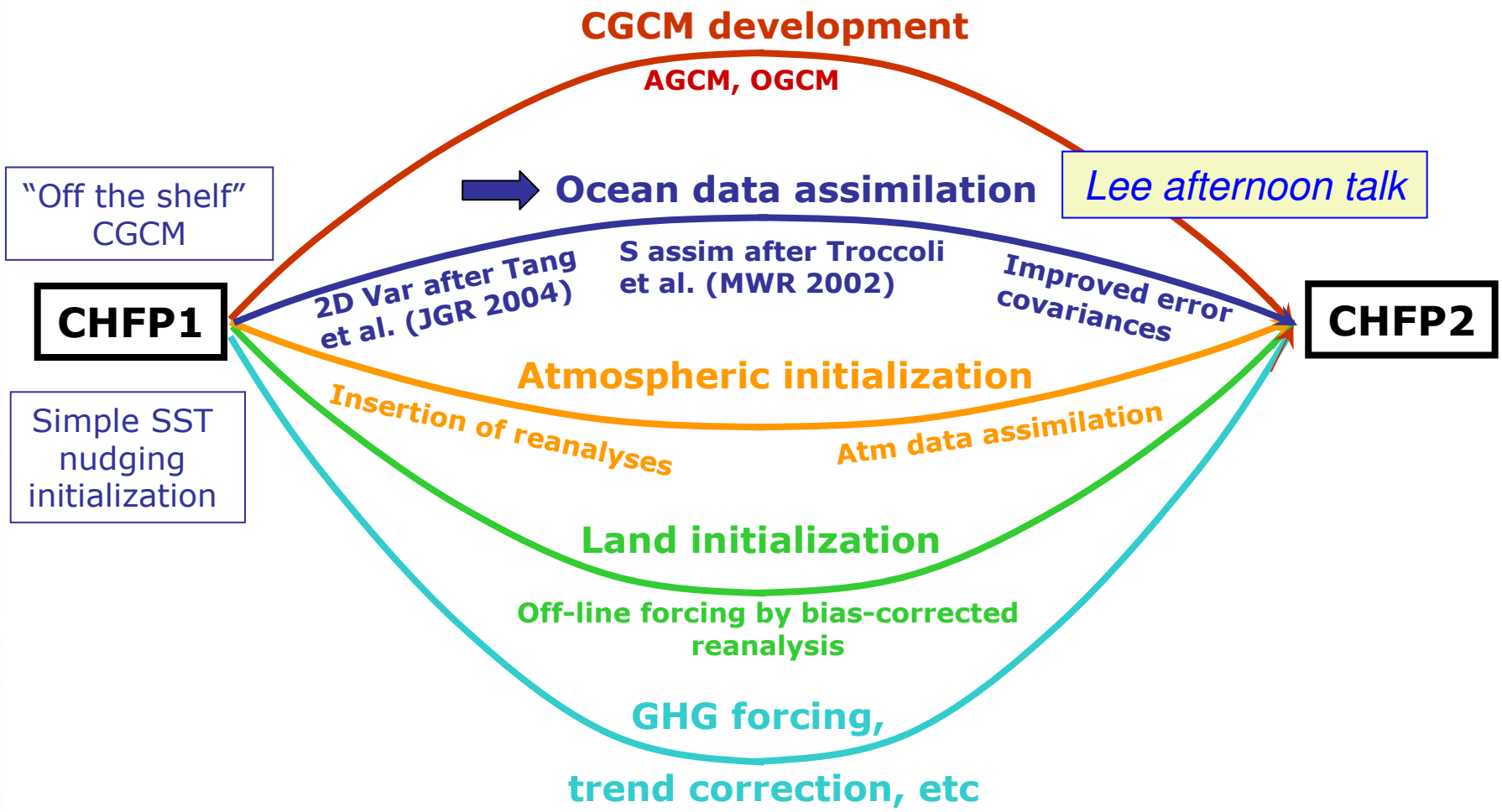


Deterministic forecast SSTA Nov 1982
AGCM4 + OGCM4 Lead=11 mo



• While such outcomes not always possible (even in theory), a *strong El Nino is now within the range of possibilities admitted by the model*

Coupled Forecast System Development Path



Ocean Initialization by multi-analysis assimilation

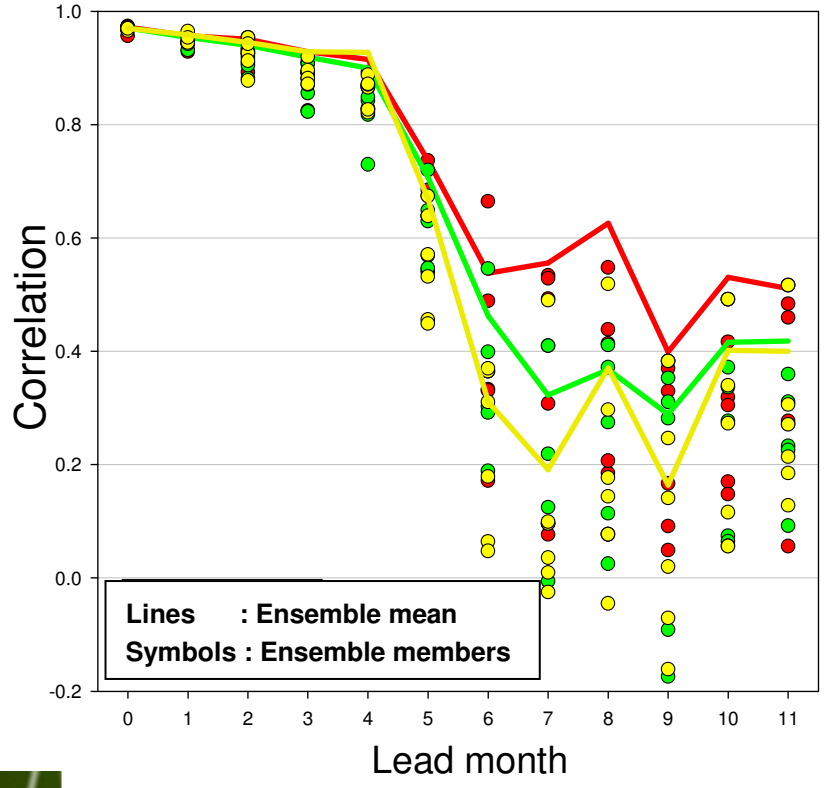
- Experiment: compare NINO3.4 *skill* and *ensemble spread* for three ensemble initialization strategies:
  - Multi-analysis: off-line assimilation of 6 ocean analysis products (same atm)
  - Exp_atmos: 6 AGCM states from consecutive days prior to forecast start (same ocn)
  - Exp_ocean: 6 OGCM states from consecutive days prior to forecast start (same ocn)

	MULTI-ANALYSIS						EXP_ATMOS						EXP_OCEAN					
Ensemble member	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Atmosphere Initial State	8/31						8/31	8/30	8/29	8/28	8/27	8/26	8/31					
Ocean Initial state	8/31						8/31						8/31	8/30	8/29	8/28	8/27	8/26
Used Reanalysis Data for ocean assimilation	GODAS	ECMWF	GFDL	SODA	INGV	METUK	GODAS						GODAS					

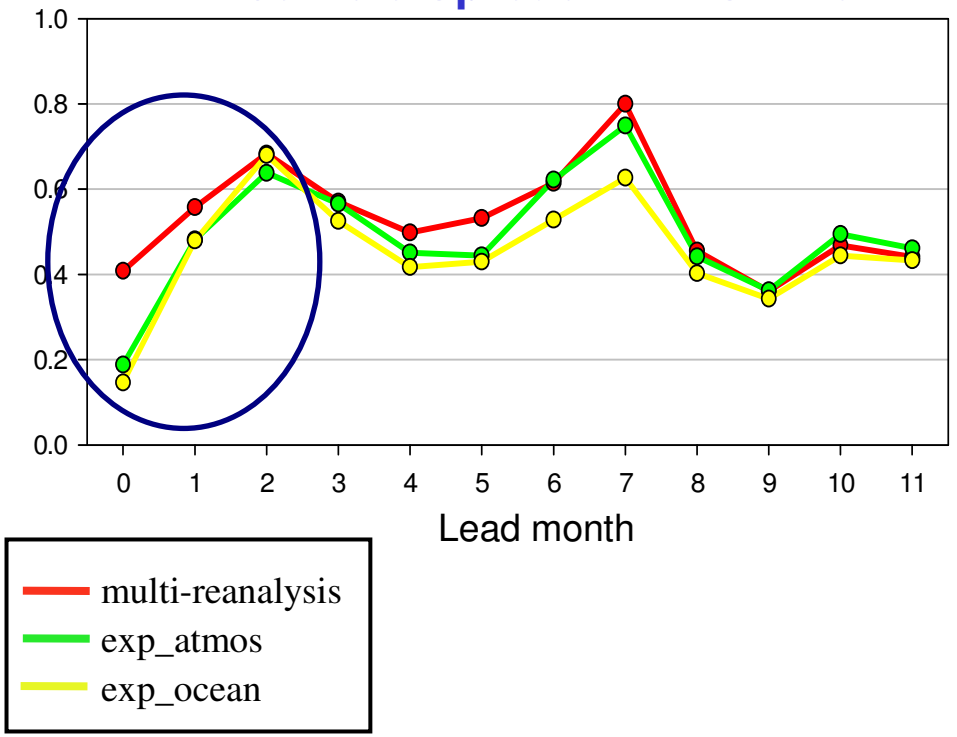
- 1980-2001: 22 years of Sep 1–initialized forecasts

NINO3.4 skill and ensemble spread

SST Forecast Skill



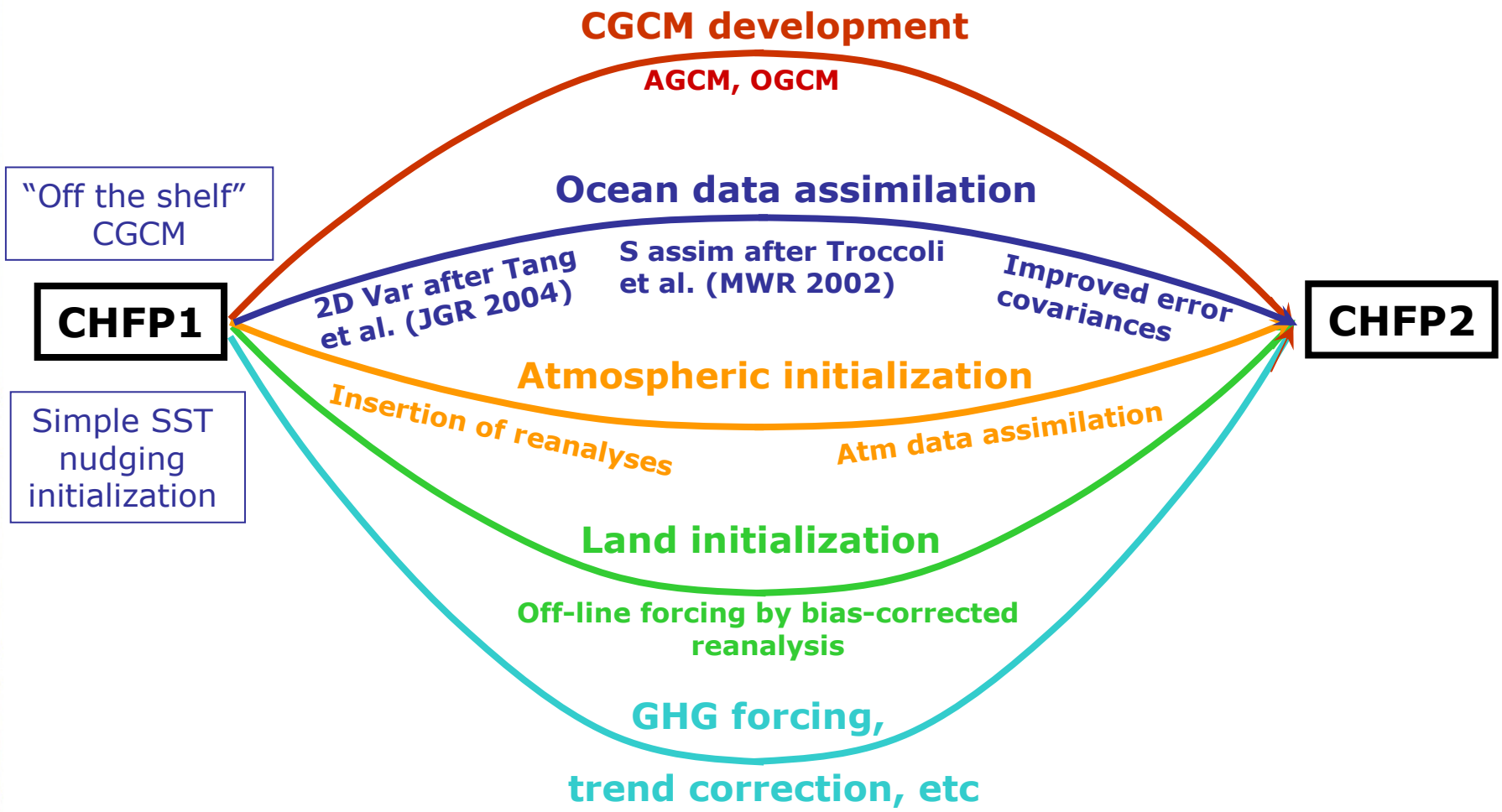
Ensemble Spread ÷ RMS Error



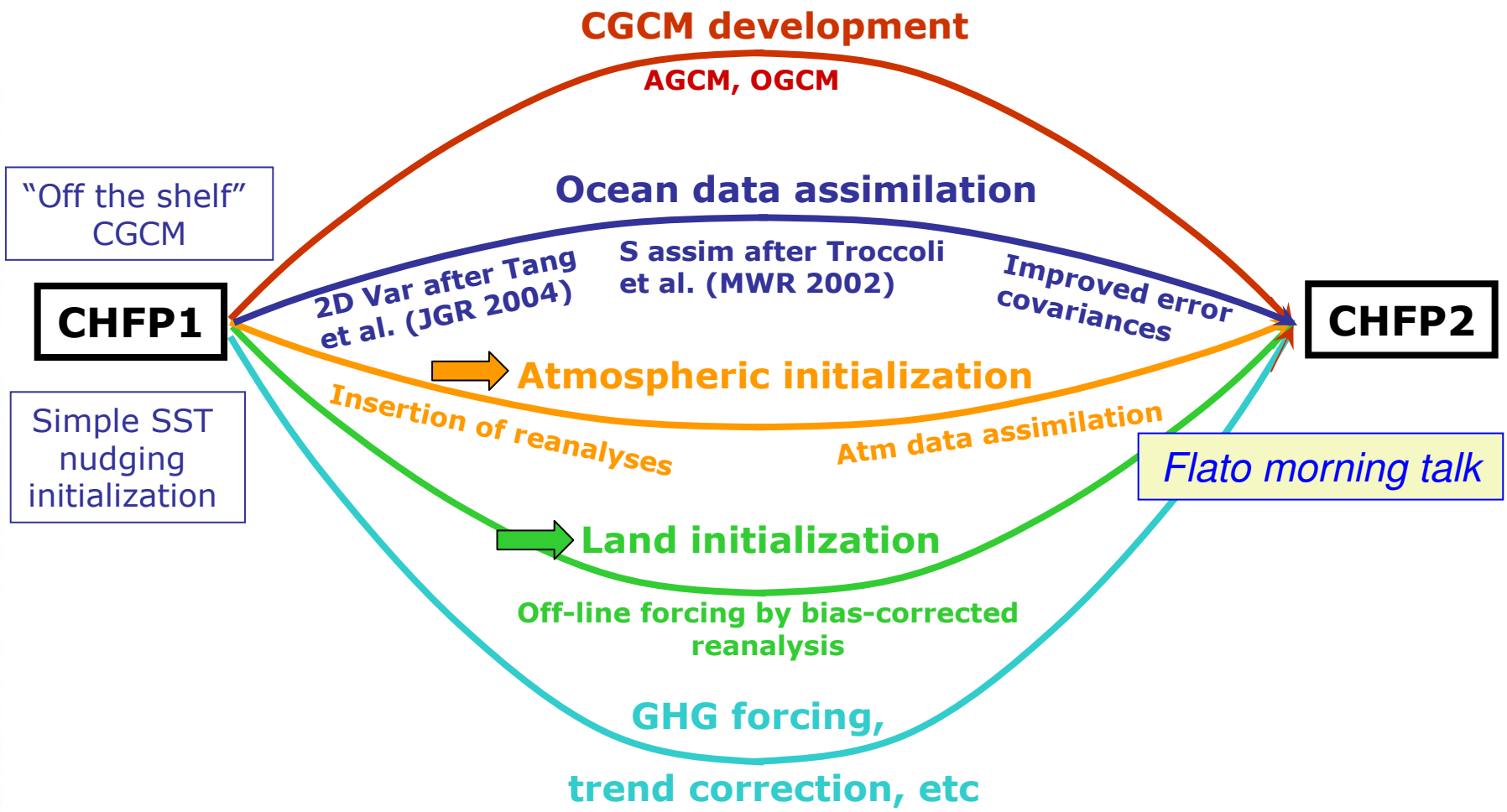
➡ Multi-analysis ocean initialization leads to

- Improved skill at longer leads
- Larger ensemble spread in first two months

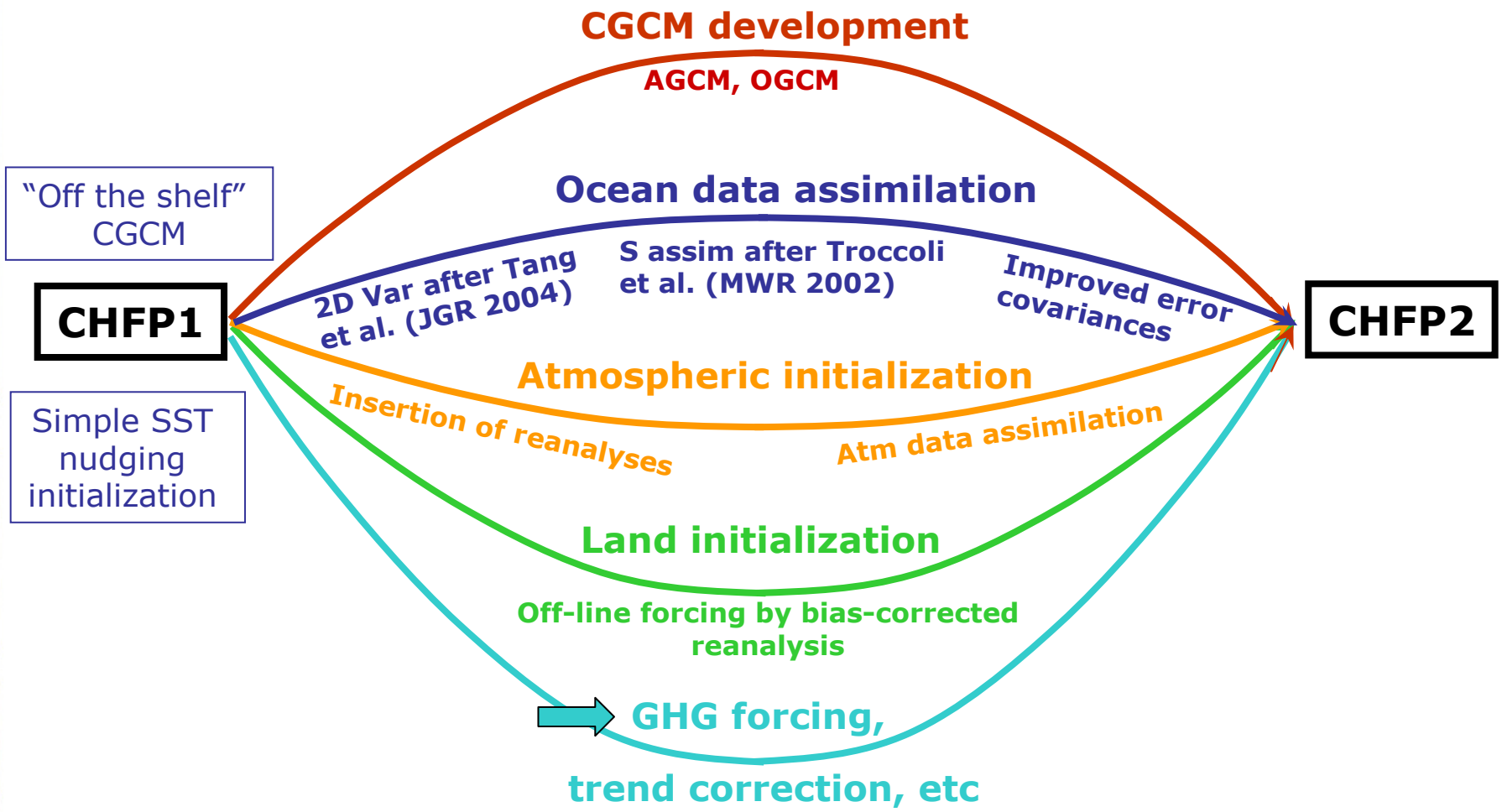
Coupled Forecast System Development Path



Coupled Forecast System Development Path

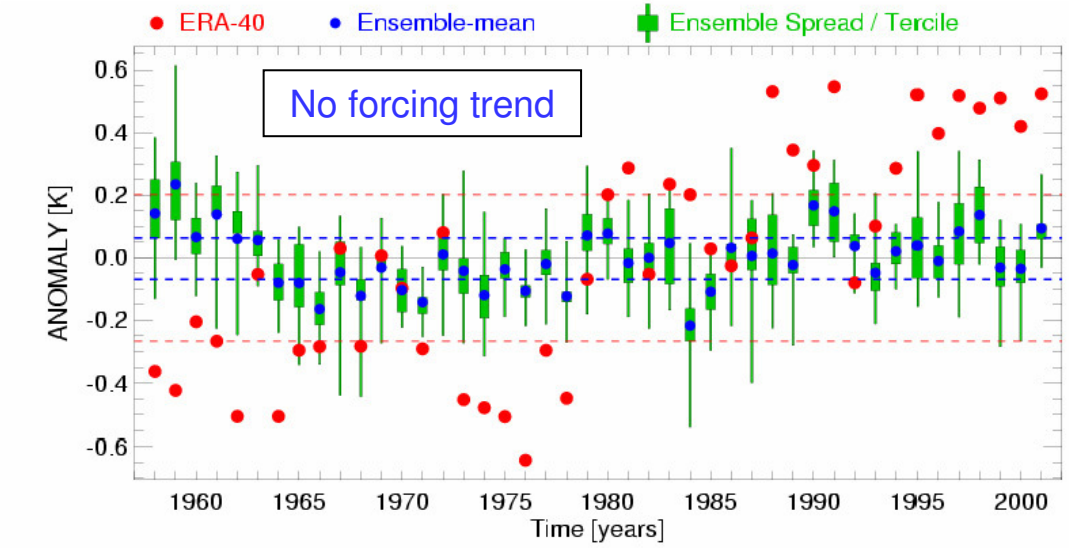


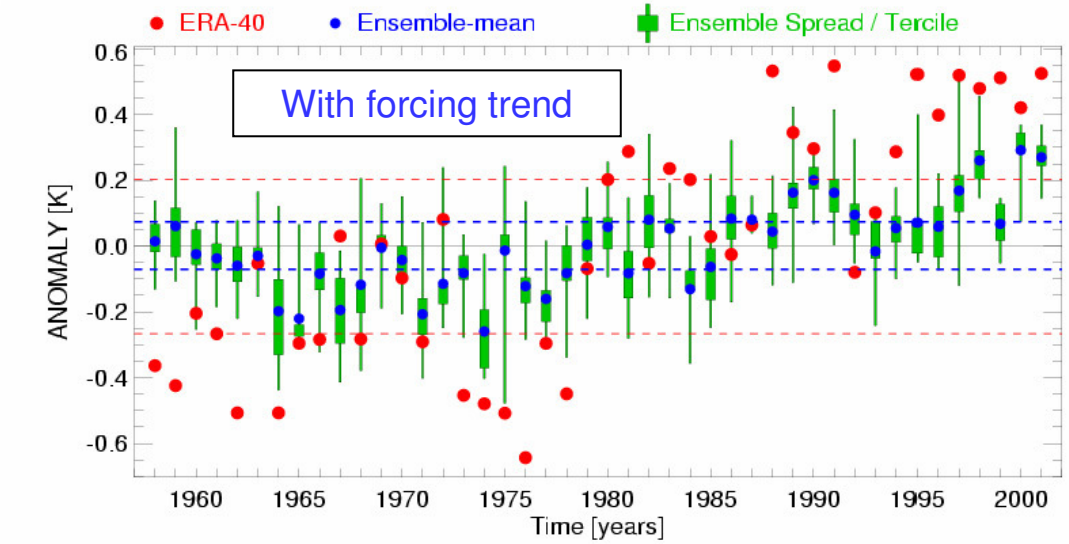
Coupled Forecast System Development Path



Importance of radiative forcing for Seasonal Forecasts

Global-mean temperatures: ***Red*** **= obs** ***Blue/green*** **= forecasts**





← May start
Month 4-6 forecasts)

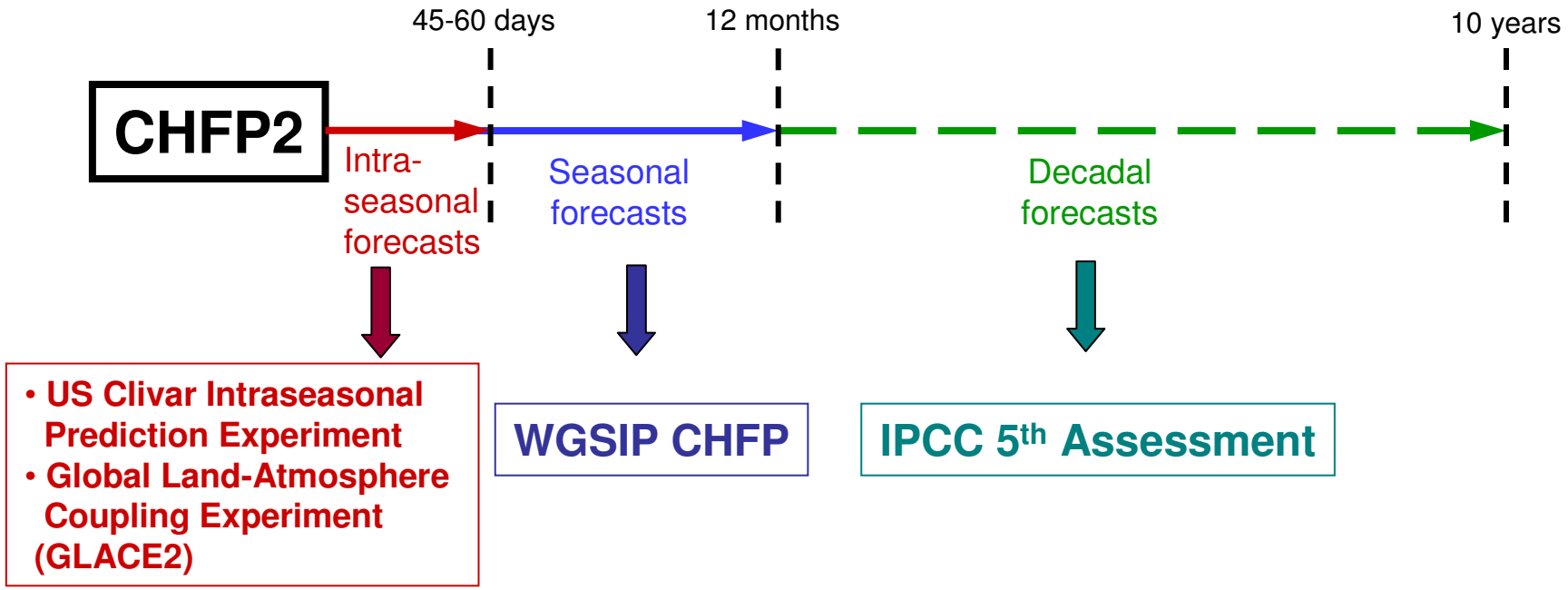
Corr skill*

Forecast month(s)	No forcing trend		**With forcing trend**
1	0.78	→	**0.80**
2-4	0.49	→	**0.73**
4-6	0.27	→	**0.63**

*averaged over May and Nov starts

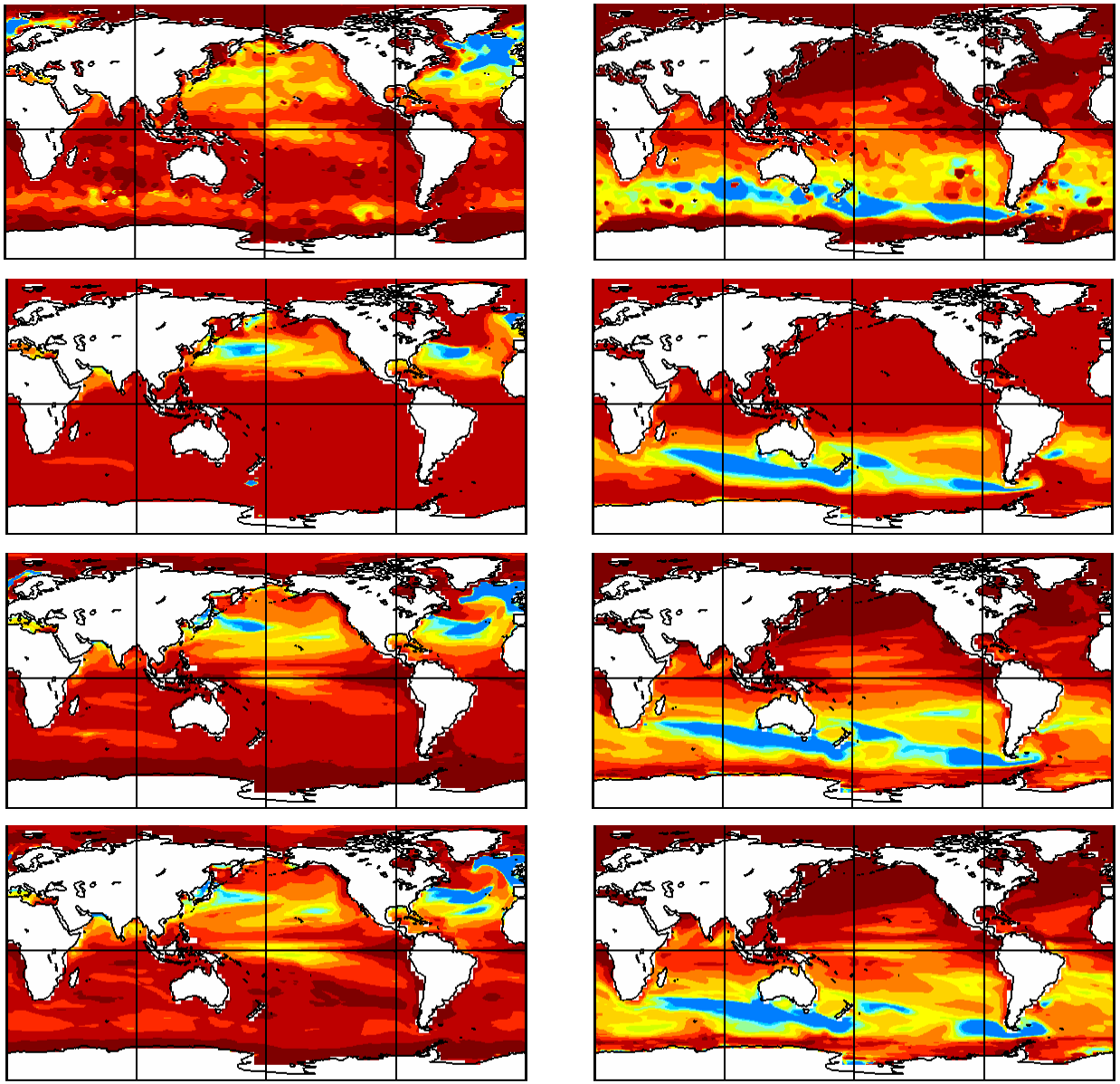
Doblas-Reyes et al. *GRL* 2006

CHFP2 potential contributions



Jan mixed layer depth

Jul mixed layer depth

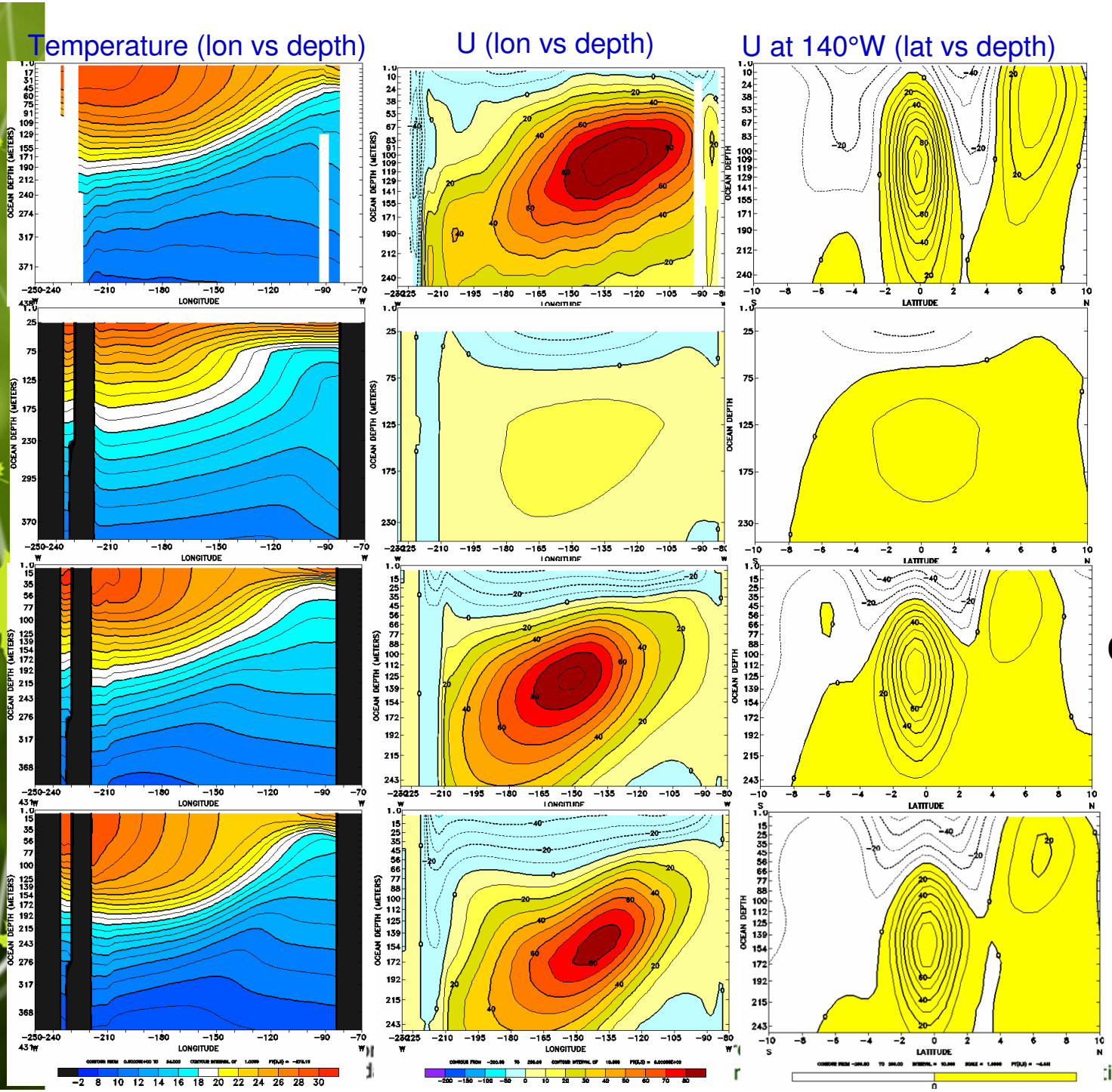


Observations: WOA/PHC

AGCM3+OGCM3

AGCM3+OGCM4

AGCM4+OGCM4



Equatorial Pacific

Observations: SODA

CGCM3.5

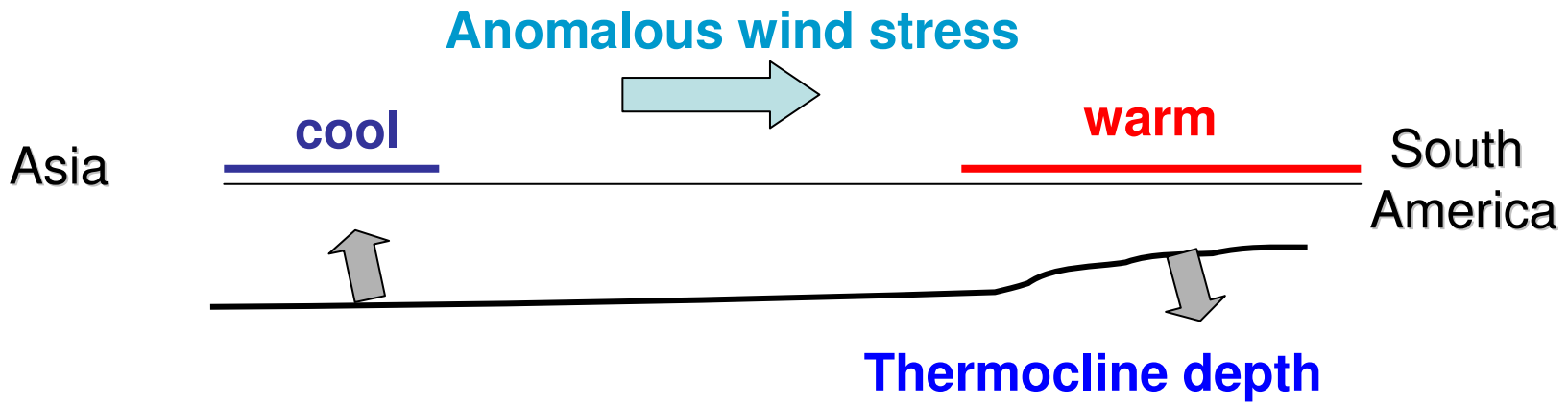
CGCM3.8

Canada

Atmospheric initialization

- CHFP1: atmosphere initialized by SST nudging alone
  - some skill initializing trop Pacific winds, subsurface ocean → ENSO skill

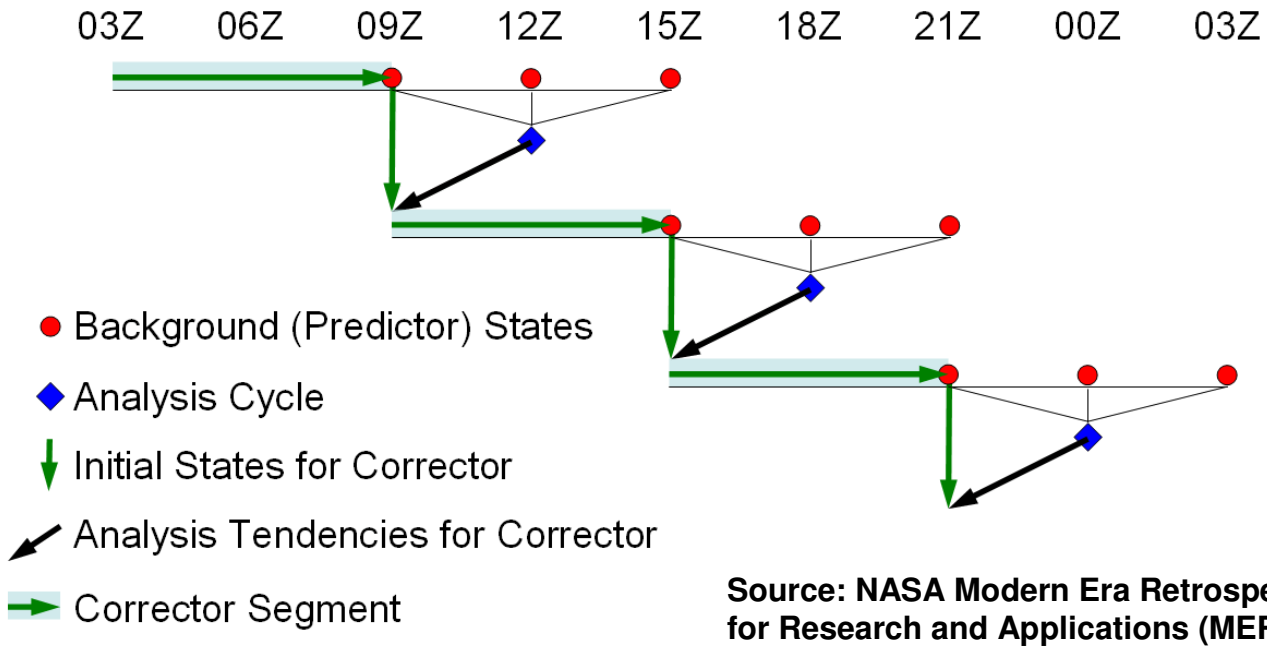
Example: effects of El Nino SSTs in tropical Pacific:



Incremental Analysis Updates (IAU)

To assimilate 6-hourly NCEP states:

- run model freely for 3h ("forecast")
- calculate difference with NCEP → "centered" increments
- rewind, rerun for 6h, adding analysis increments as forcing to model equations: $\frac{d\mathbf{x}}{dt} = M(\mathbf{x}) + h(t)\Delta\mathbf{x}^{\mathbf{a}}$



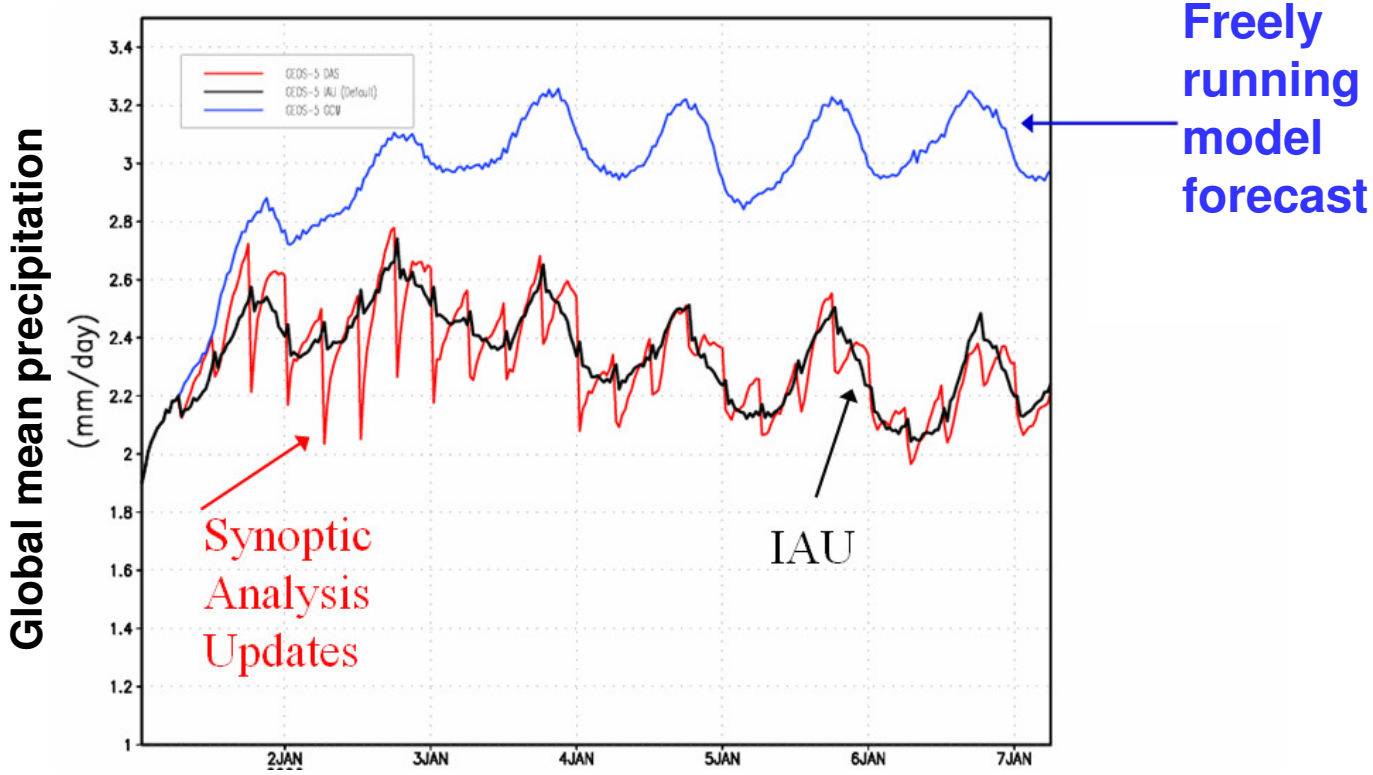
Source: NASA Modern Era Retrospective-analysis for Research and Applications (MERRA)

Incremental Analysis Updates (IAU)

Example: Precipitation forecast

- IAU "cures" initialization shocks from synoptic analysis updates while avoiding bias & skill loss of freely running model

:

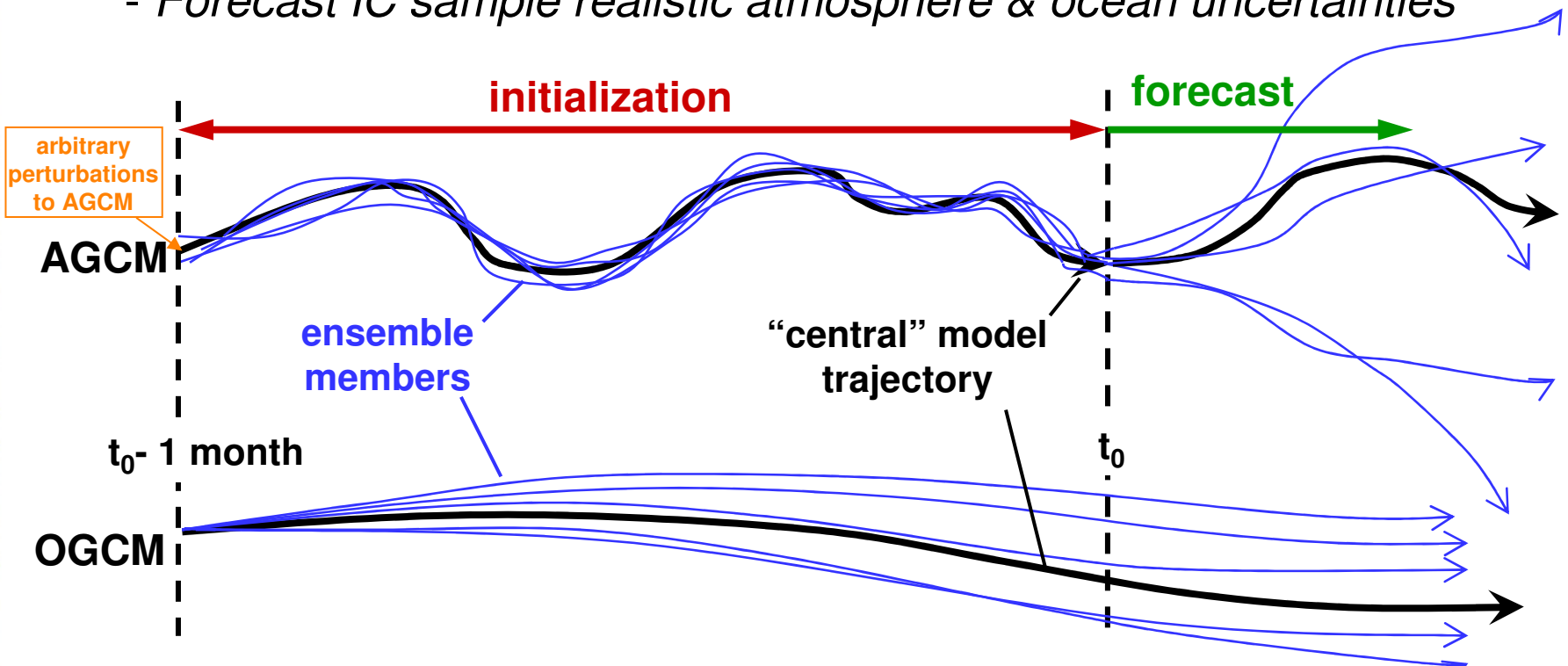


Source: NASA Modern Era Retrospective-analysis for Research and Applications (MERRA)

Prognostic predictability of large ensembles

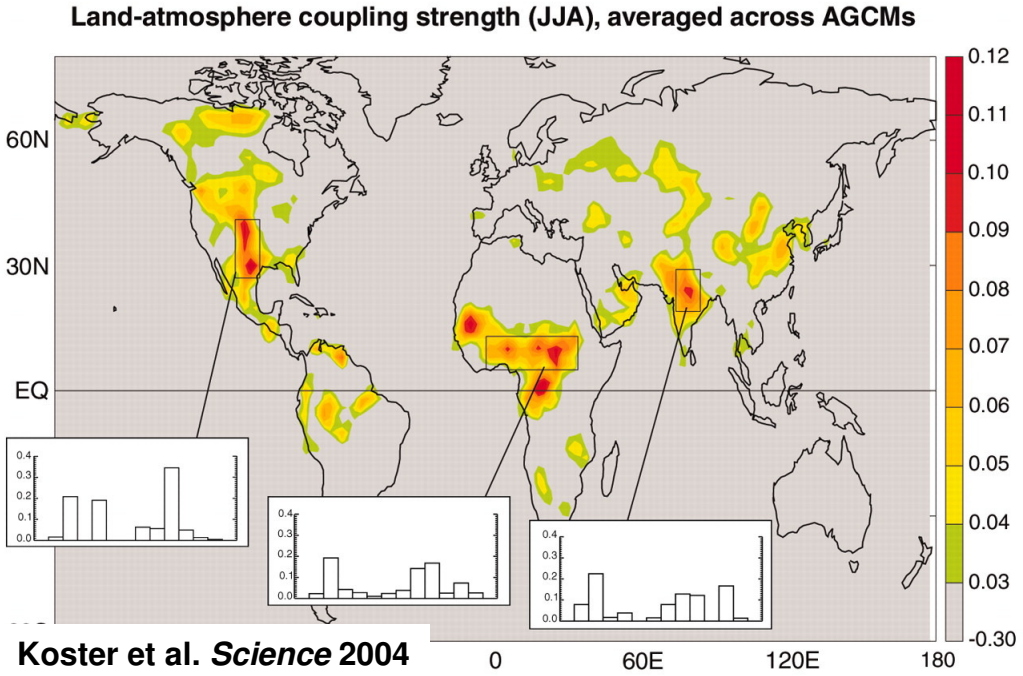
W. Merryfield, A. Ravindran, J. Scinocca, S. Kharin

- Aim: “perfect model” predictability experiment based on large (~100-member) ensemble of coupled model integrations
- Take advantage of new initialization technique: incremental reanalysis updates (IRU):
  - AGCM assimilates “central” model run for ~1 mon prior to fcst
  - *Forecast IC sample realistic atmosphere & ocean uncertainties*



Impact of land surface initial conditions

- Land surface state (especially soil moisture) imparts predictability up to ~1 season



Koster et al. *Science* 2004

- Land-atmosphere feedbacks concentrated in “hot spots” where soil moisture is highly variable (not too dry, not too wet) → Canadian prairies