# On data assimilation and ENSO dynamical prediction

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IRI - Columbia University

*With:*

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*GFDL - Andrew Wittenberg, Matt Harrison, Tony Rosati*

*GFSC: Michele Rienecker and others*

*IRI – June 2004*

# Outline

- The new IRI ocean data assimilation system
- ENSO forecast experiments and the role of stochastic forcing
- The TAO array east/west experiment
- Measuring impact of observing system’s lifetime in a simple model

# IRI new ocean initialization and forecast system

*(In collaboration with GFDL)*

- Develop local capability at IRI to initialize and forecast the tropical global SST.
- Global domain, medium resolution (Tropics focused)
- GFDL 3Dvar data assimilation scheme
- Run in real-time – update every month
- Initialization and forecast experiments with both hybrid and coupled GCM forecast systems.

# The ocean model setup

- GFDL new GCM (MOM4)
- Mixing: vertical – KPP, horizontal – constant.
- Partial cells, free surface, etc…
- Surface forcing (NCEP reanalysis-2):

  Monthly mean winds (NCEP anomalies + SSMI climatology)

  Climatological heat fluxes

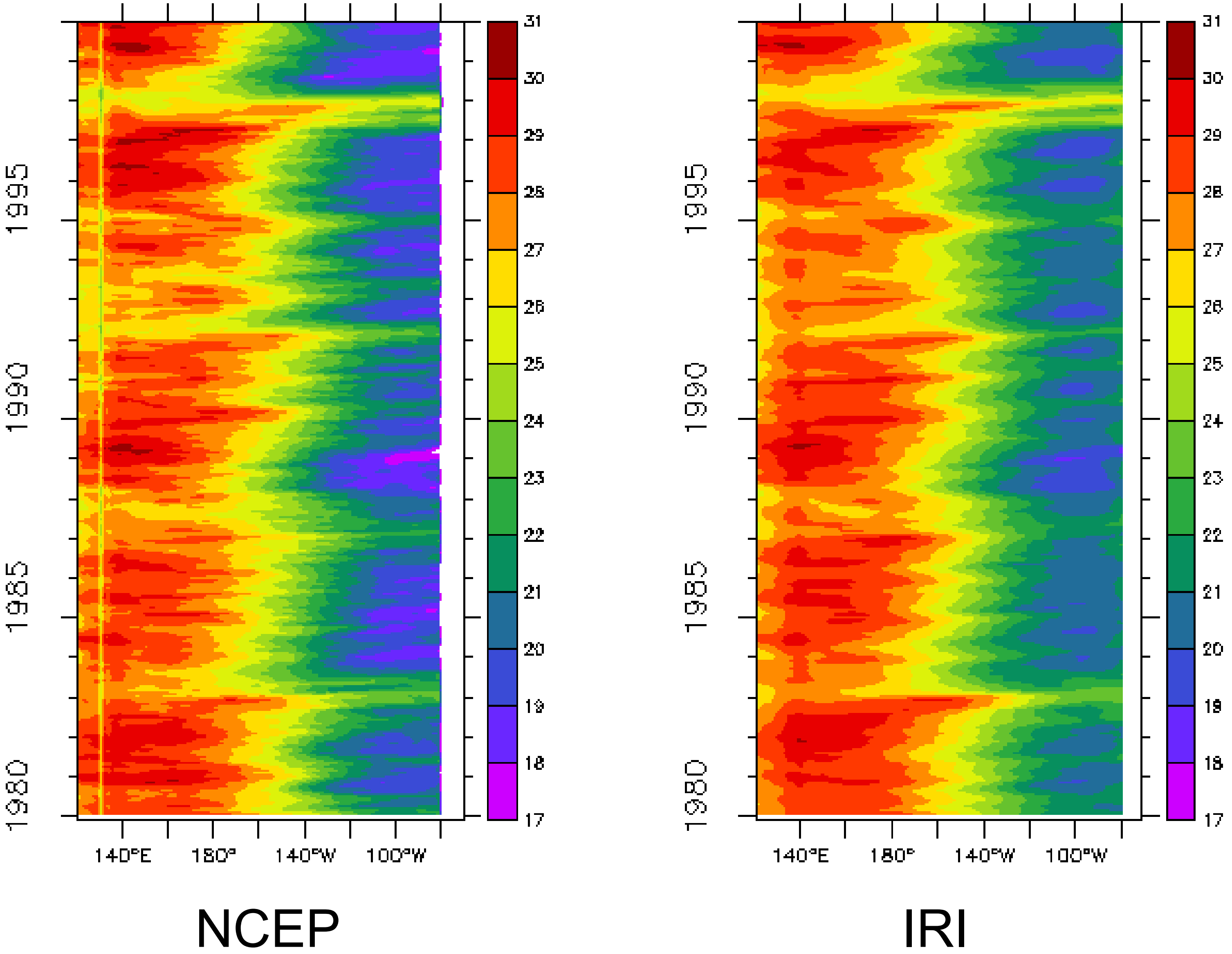
  Monthly mean Reynolds SST

# The ocean data assimilation (ODA)

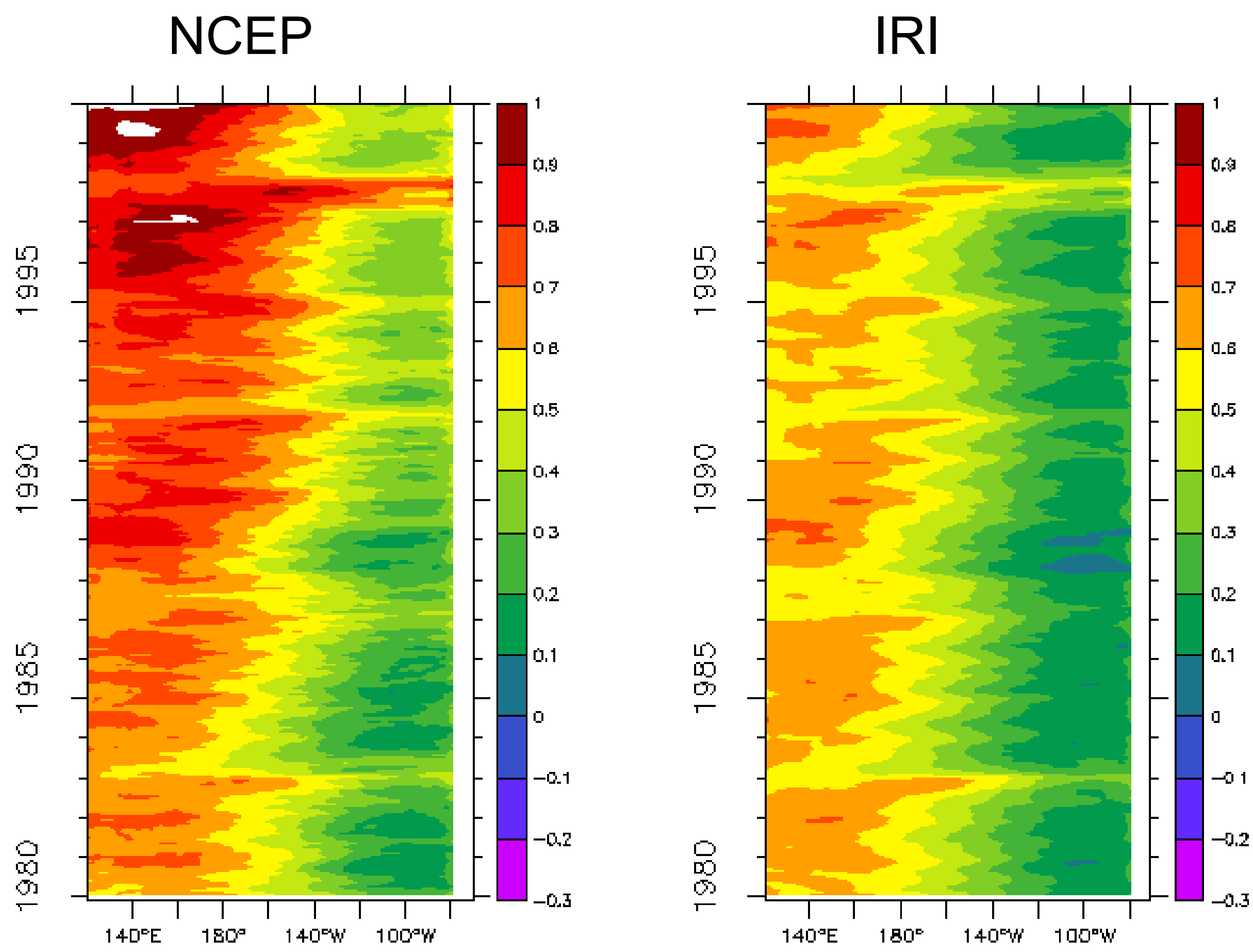
- GFDL 3Dvar (sequential)
- Assimilate TAO, XBT, ARGO
- Run 1980 – present

- Experiment with strength of data assimilation.
- Future plans: improve assimilation by incorporating information on model dynamics.

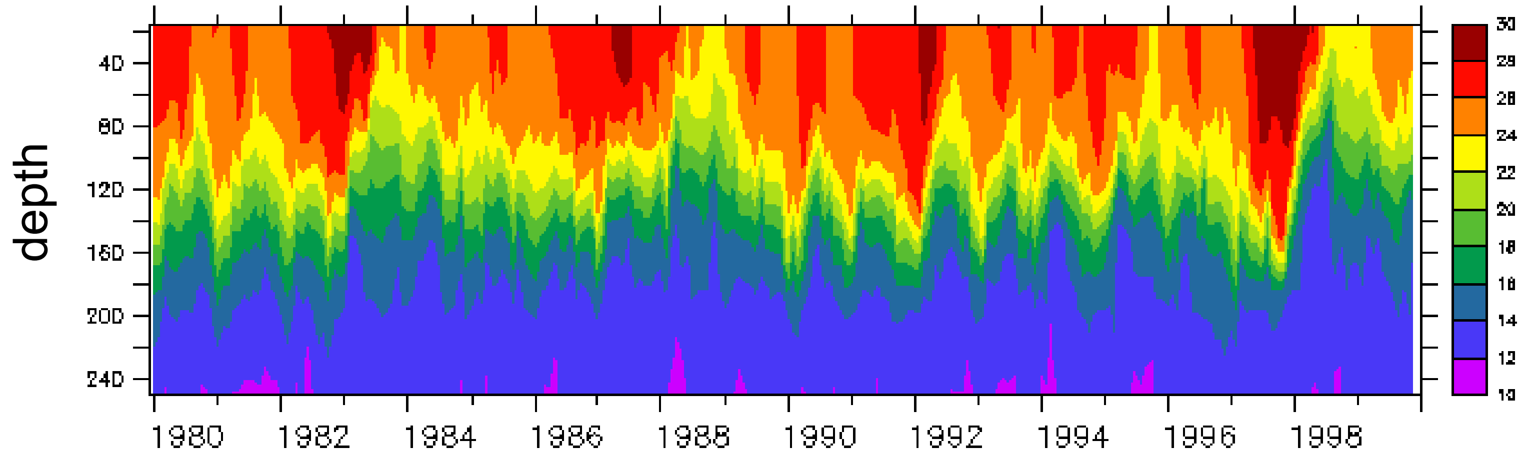
# comparison to NCEP ocean analysis (currently used at IRI to initialize forecasts) – *heat content ($J/m^2/1.e9$)*



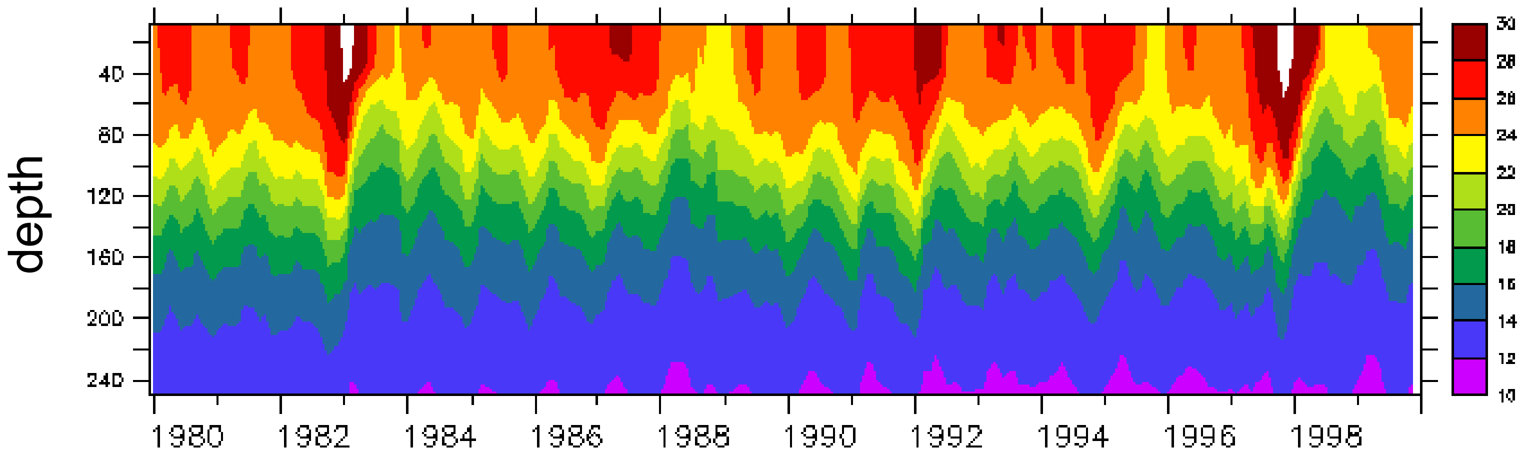
# comparison to NCEP – *surface height*



# comparison to NCEP – *temp 140W*




NCEP

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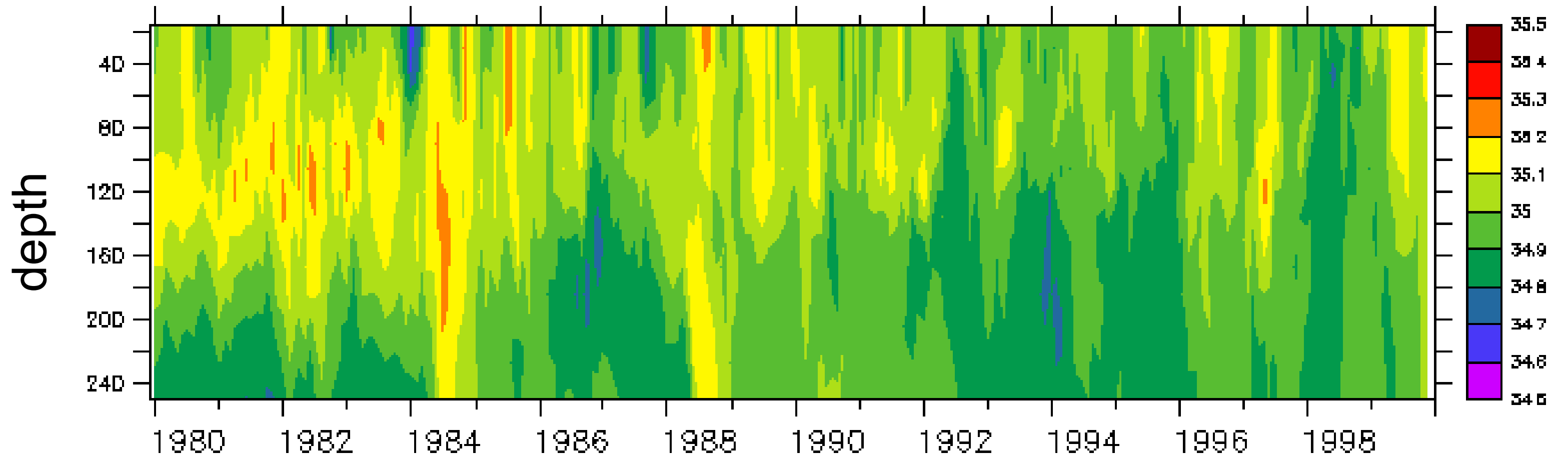
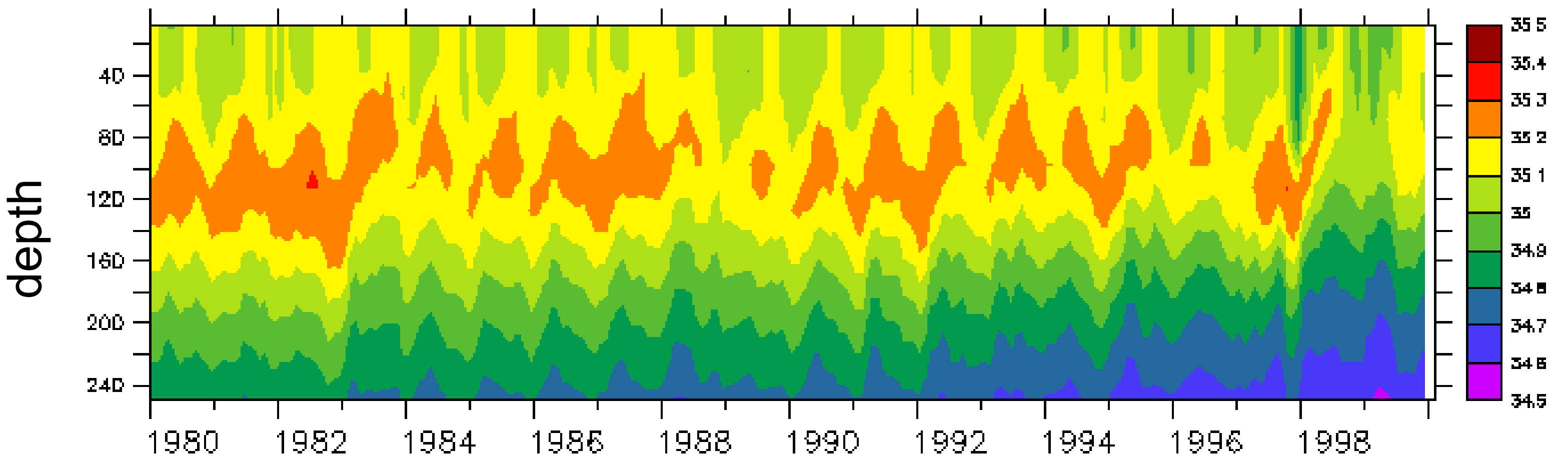
# comparison to NCEP – *salt 140W*




NCEP

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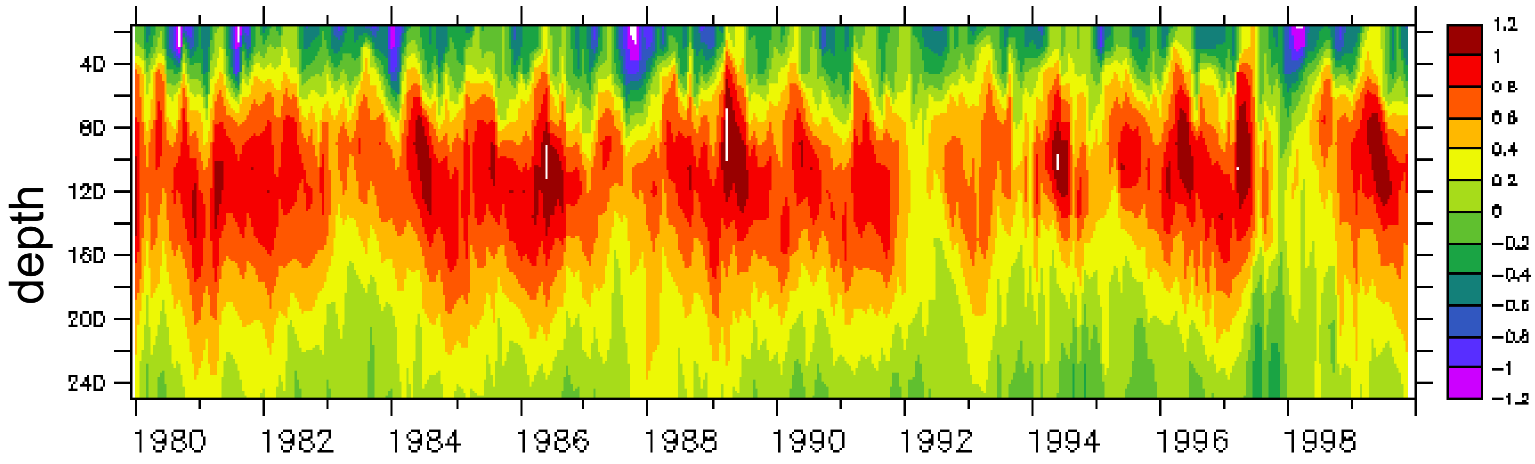
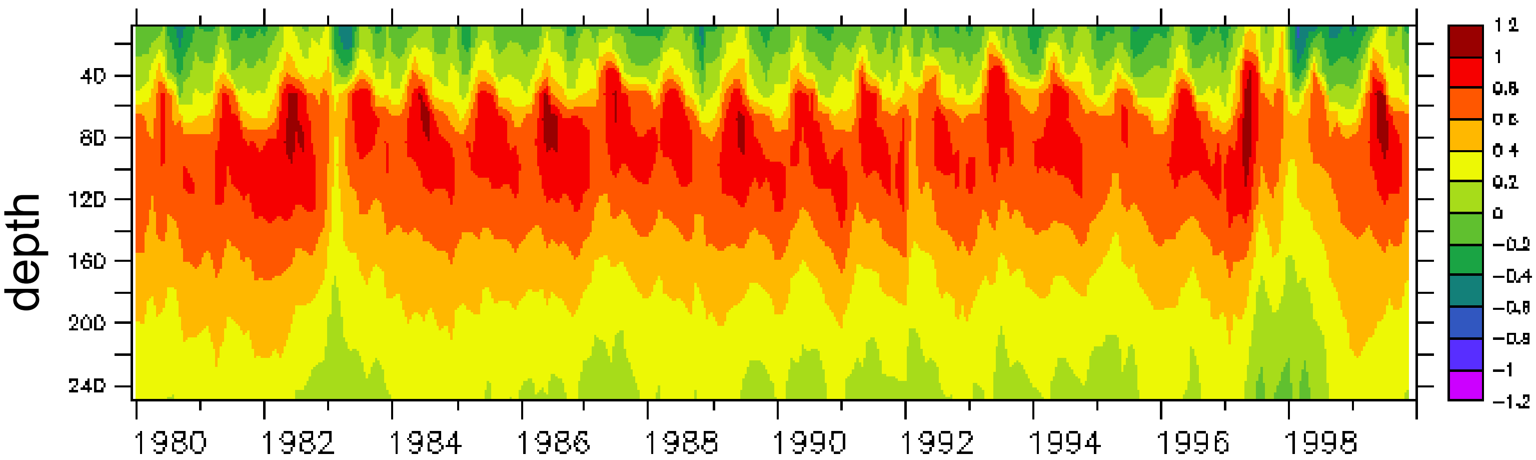
# comparison to NCEP – *zonal current 140W*




NCEP

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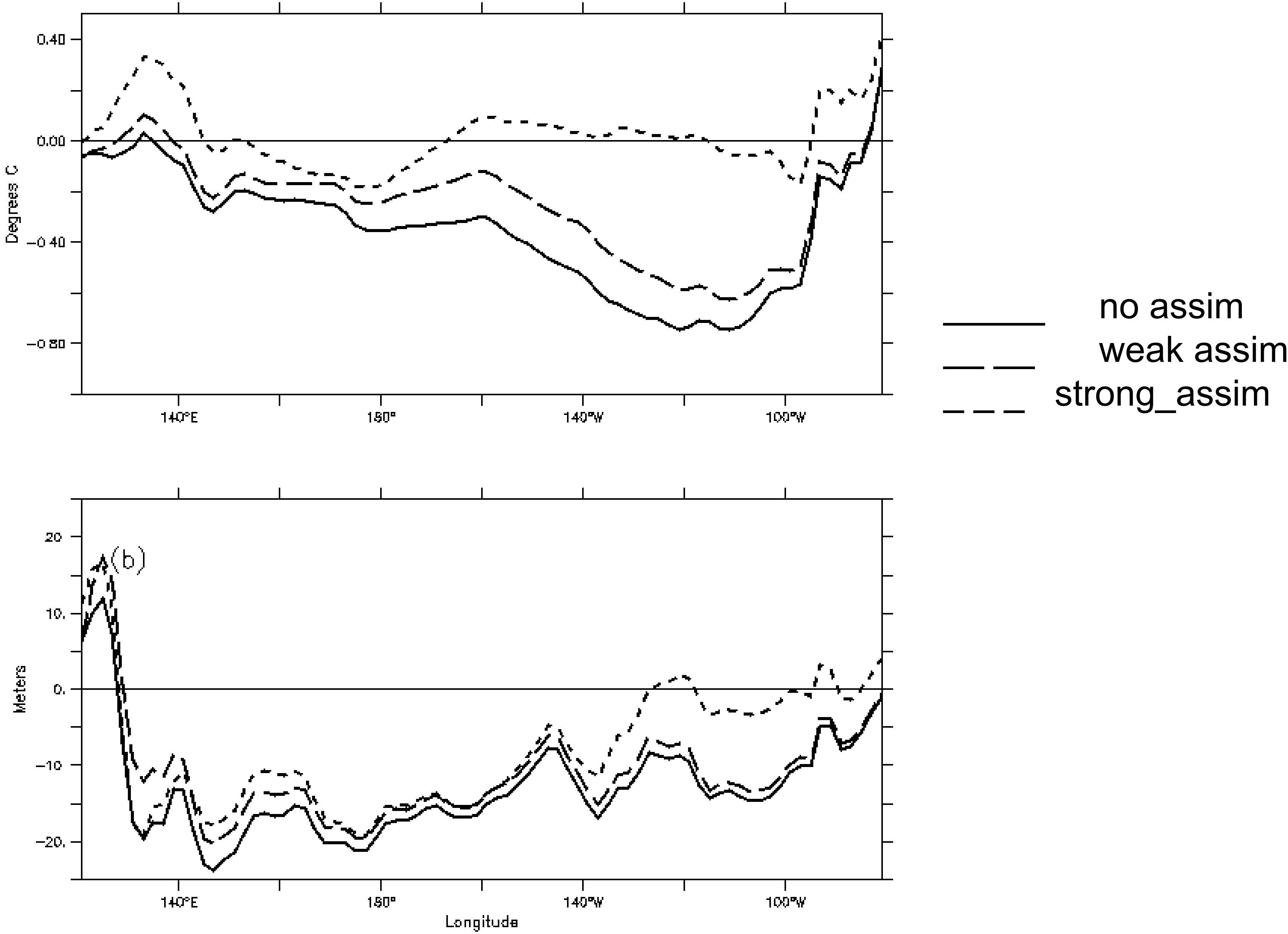
# Strong vs. weak assimilation

(Analysis – observations)

SST

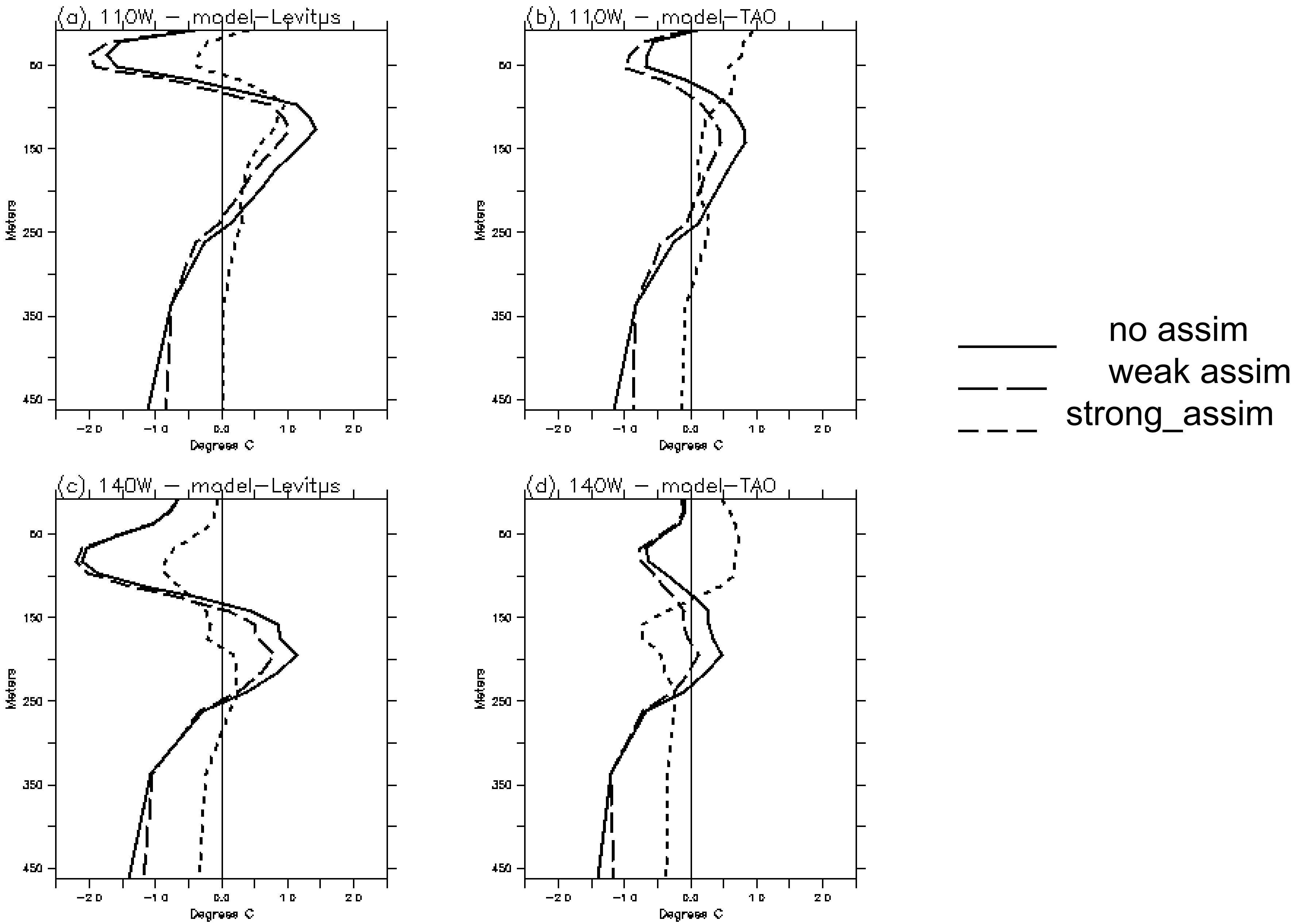



Z20

# Strong vs. weak assimilation

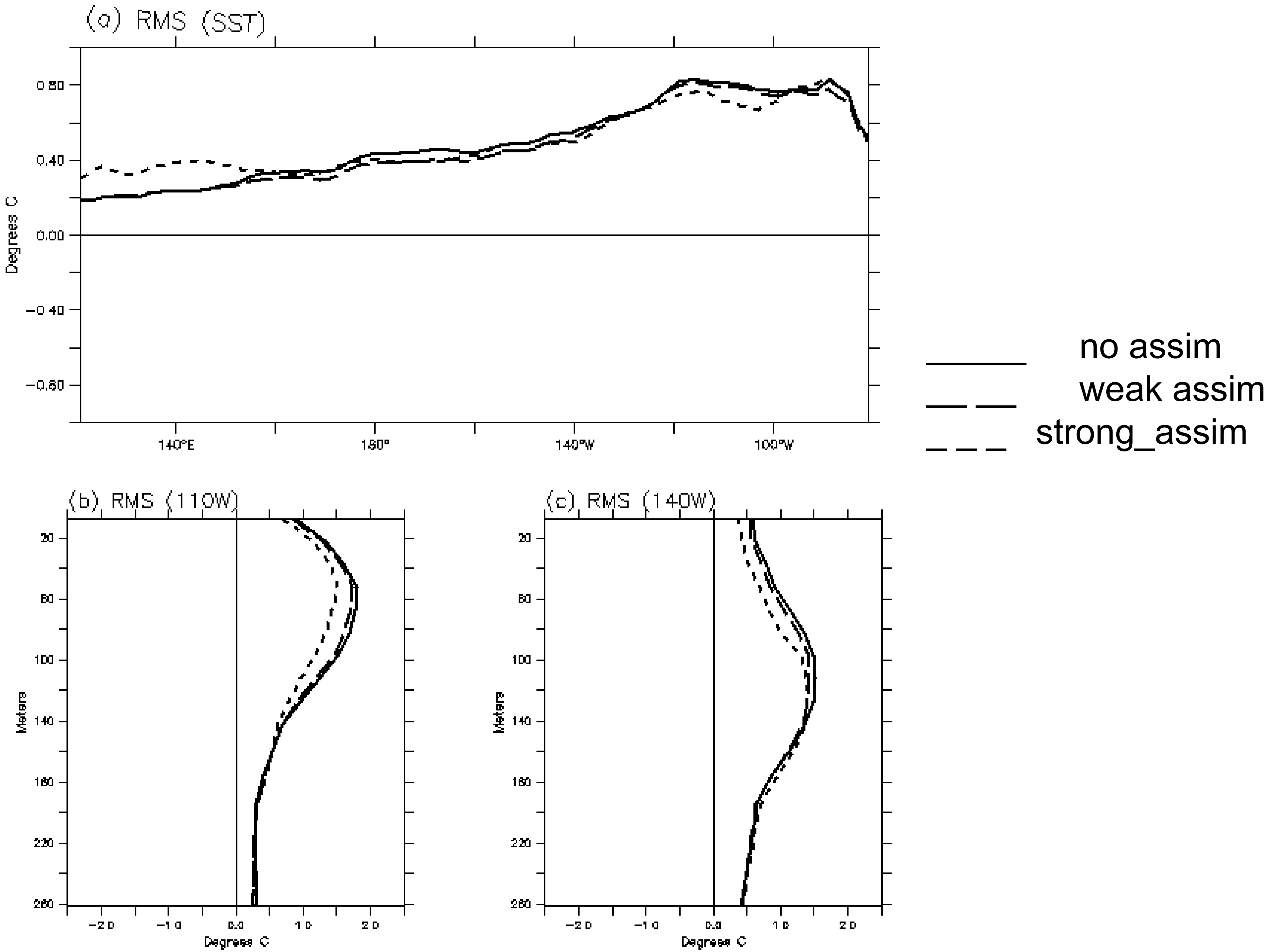
Temp
110W

Temp
140W



# Strong vs. weak assimilation

Interannual variability



Now that the system is set up, we want to experiment with:

• model resolution (higher)

• model physics

• surface forcings

• data assimilation scheme

⇒Try to find the optimum for IRI needs

But we can already take advantage of the new system and use it for various studies…

# ENSO forecast experiments

- Setup a hybrid coupled model, using the ocean model and a statistically derived atmospheric model

- Atmospheric model is based on NCEP Re-2 winds and Reynolds SST.
- Use first 7 modes of variability

- Initialize forecasts every January and July of 1980-2002

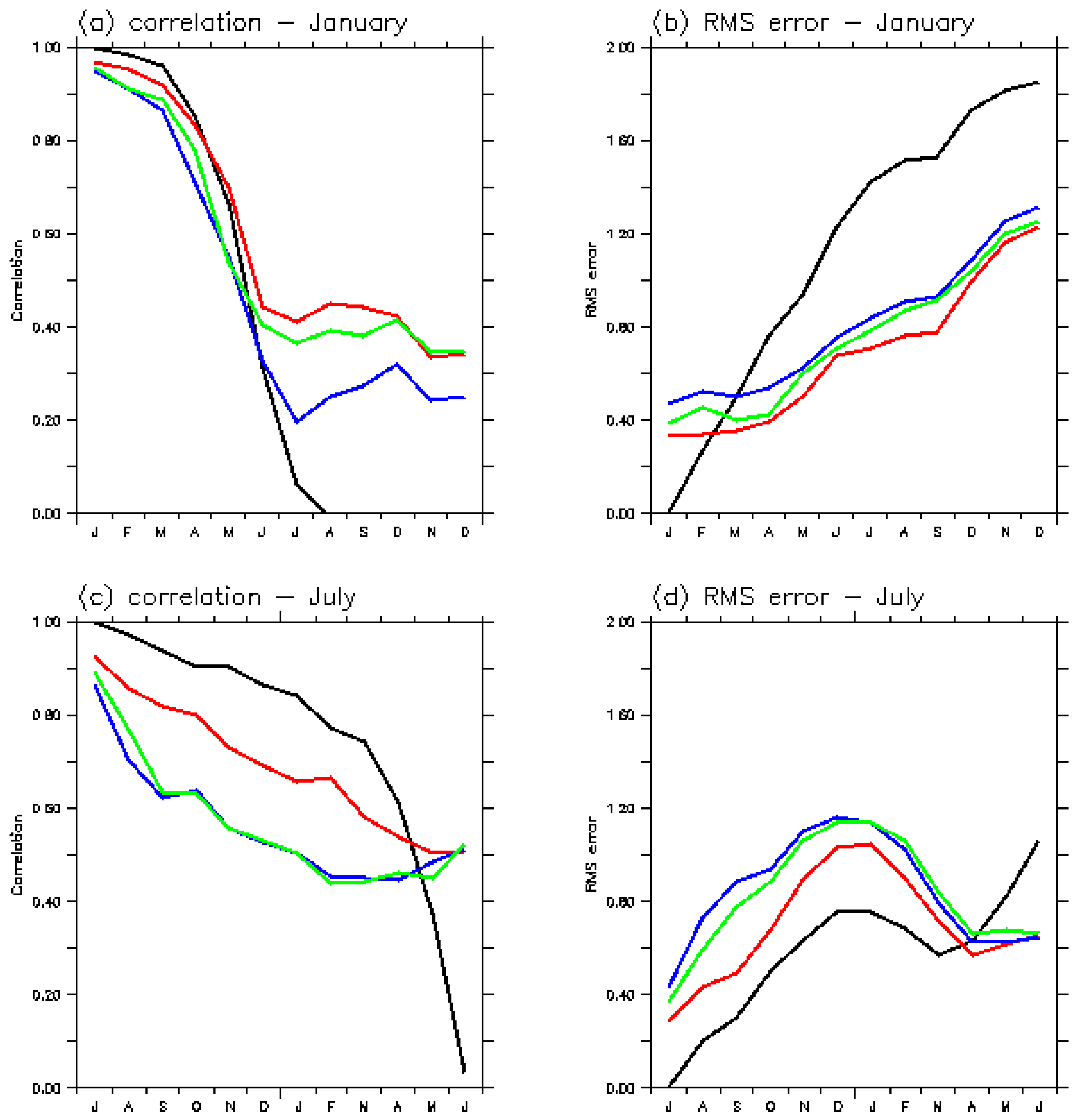
- Change coupling strength and number of modes used in statistical atmosphere

# ENSO forecast experiments

Coupling = 1.0

January initialization

July initialization




no assim

weak assim

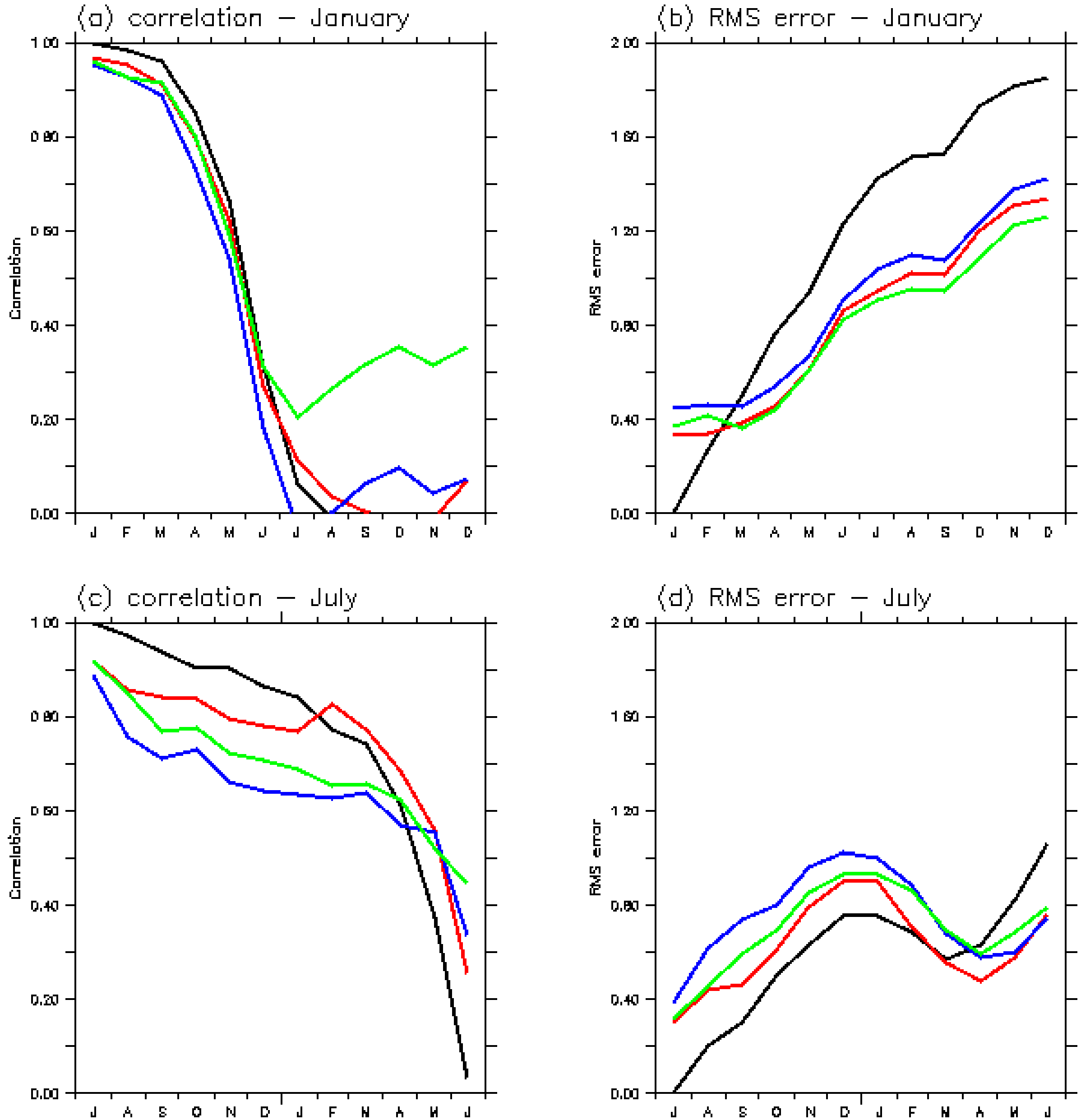
strong_assim

# ENSO forecast experiments

Coupling = 1.5

January initialization

July initialization




no assim
weak assim
strong_assim

## *Is the atmospheric model the problem?*

$\Rightarrow$ Assessing the impact of stochastic forcing on ENSO events – the 1997 event

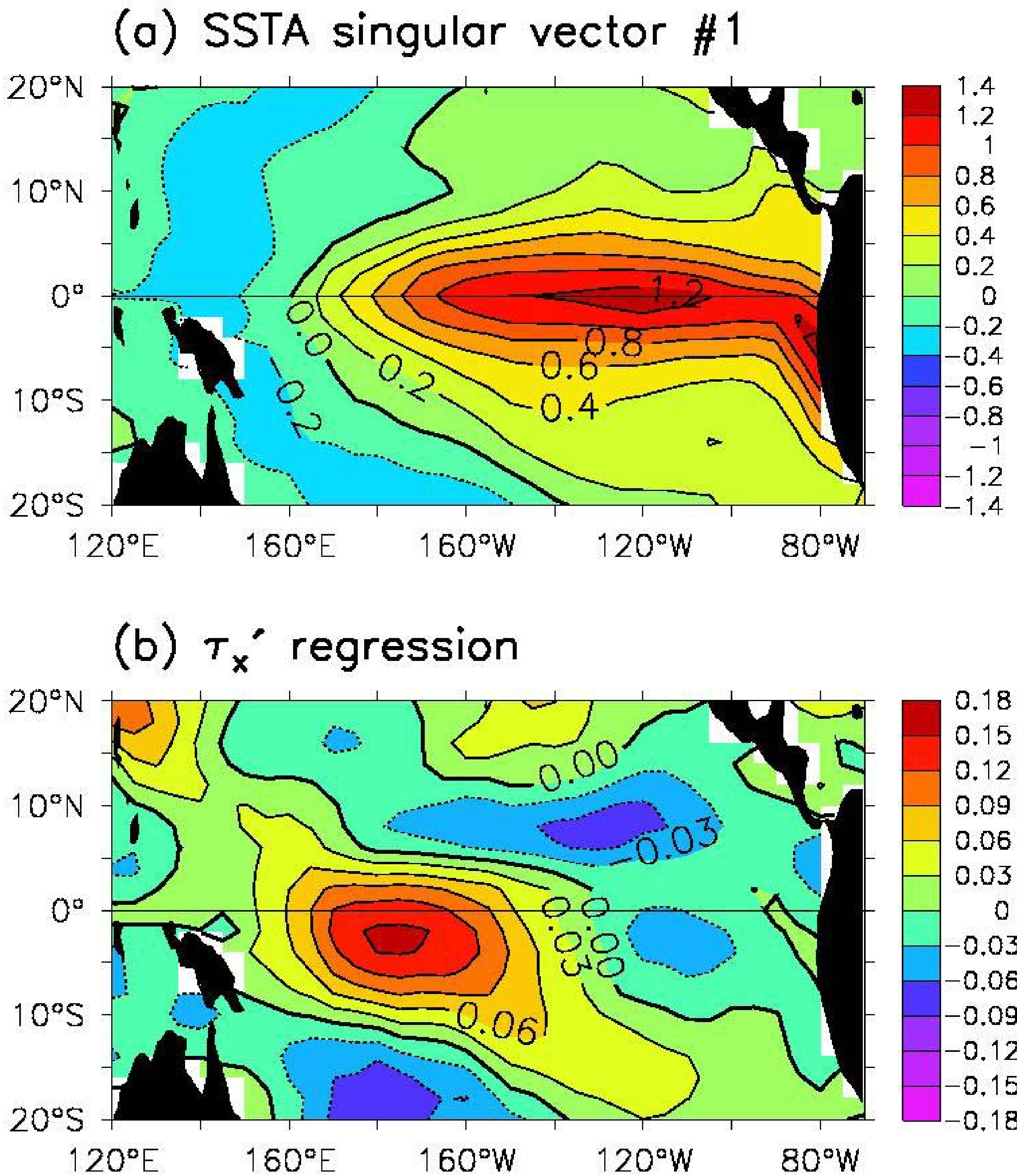
With Andrew Wittenberg (GFDL)

•How statistical atmospheric model is derived?

•Find linear relationship between observed winds and SST.

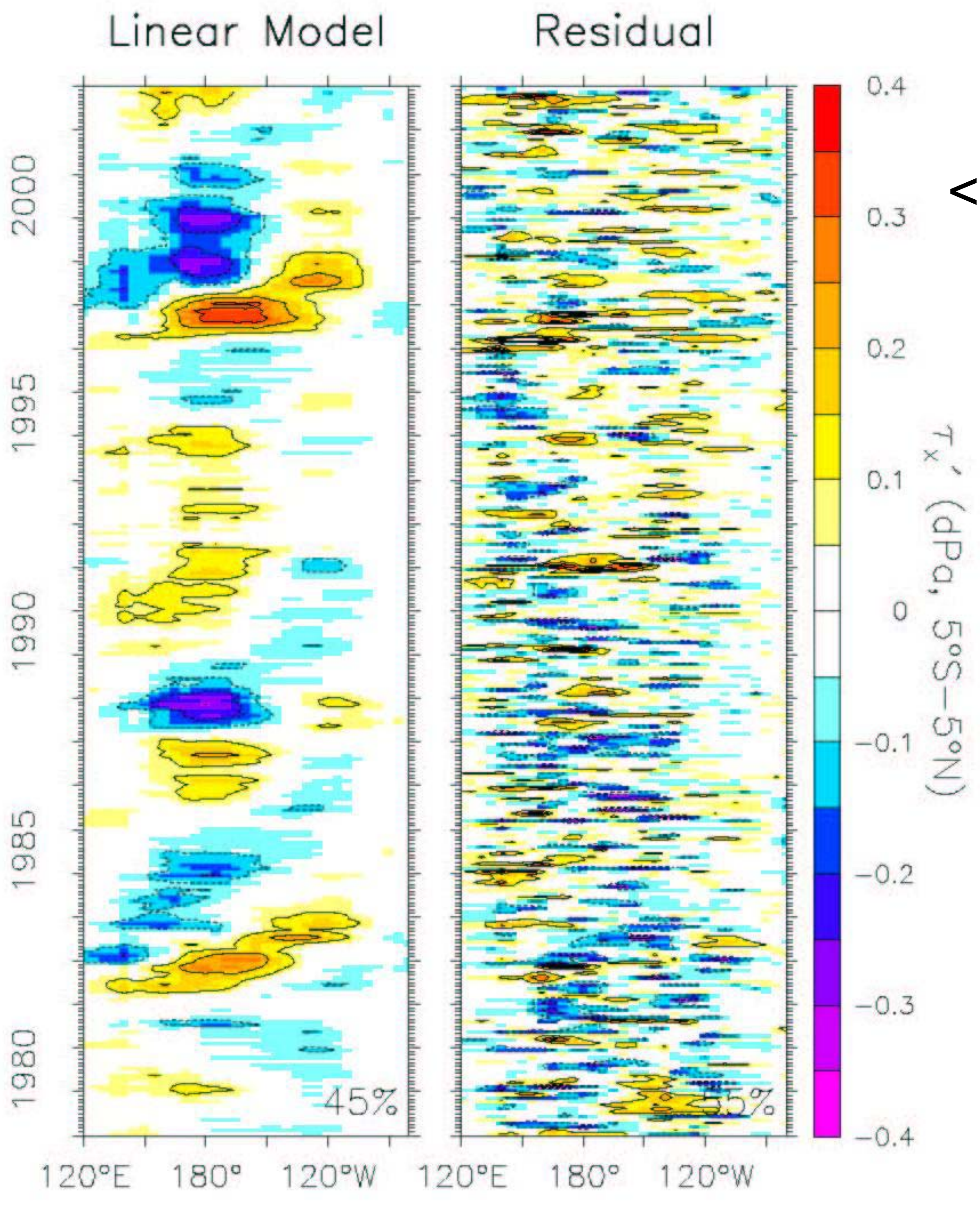
•What is left out?

•Is it atmospheric noise, non-linearity, or connection to extra-tropics/other-oceans



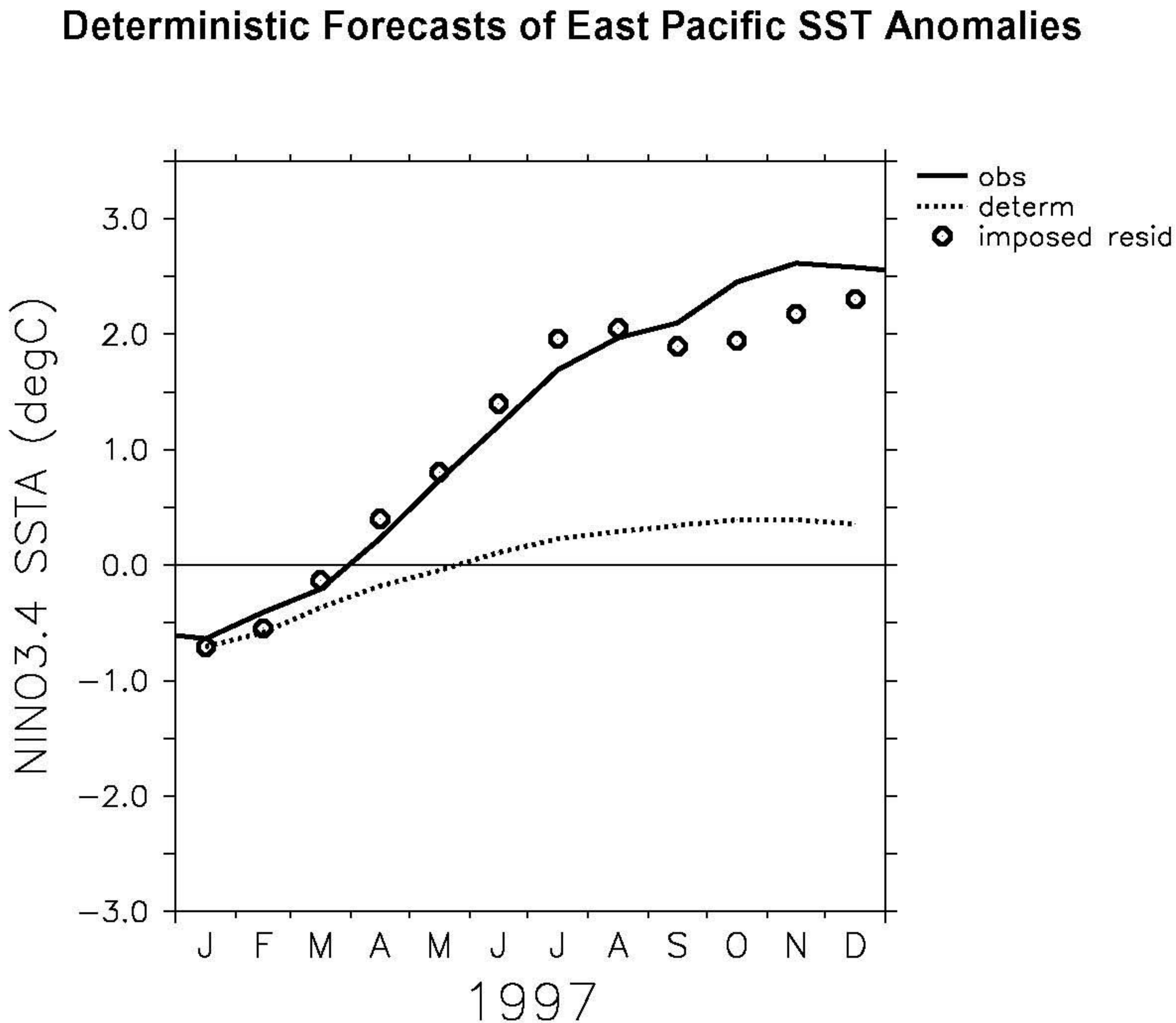
**Wind Stress Decomposition:** monthly NCEP2 obs

What we use ->

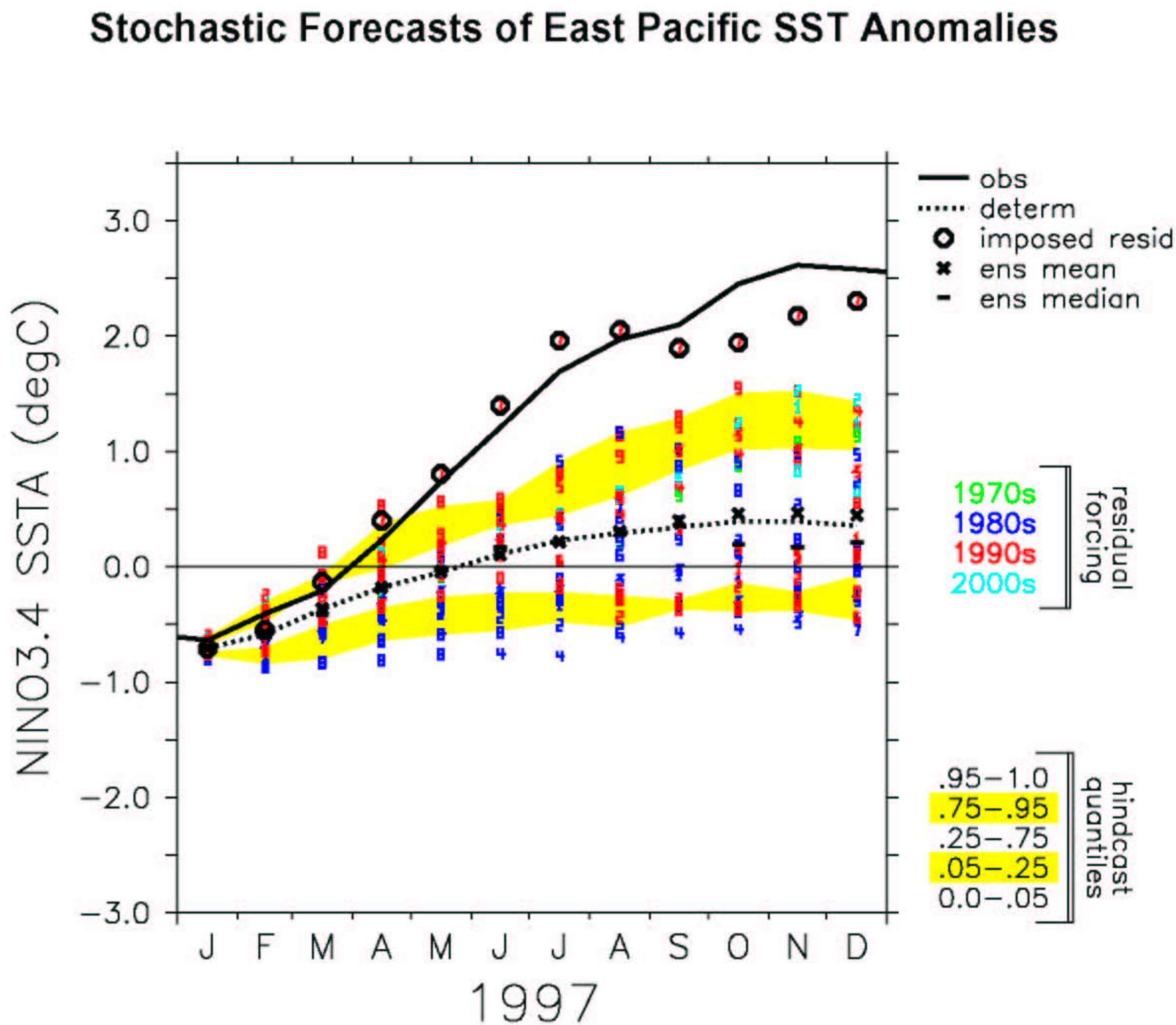



<- what is left out

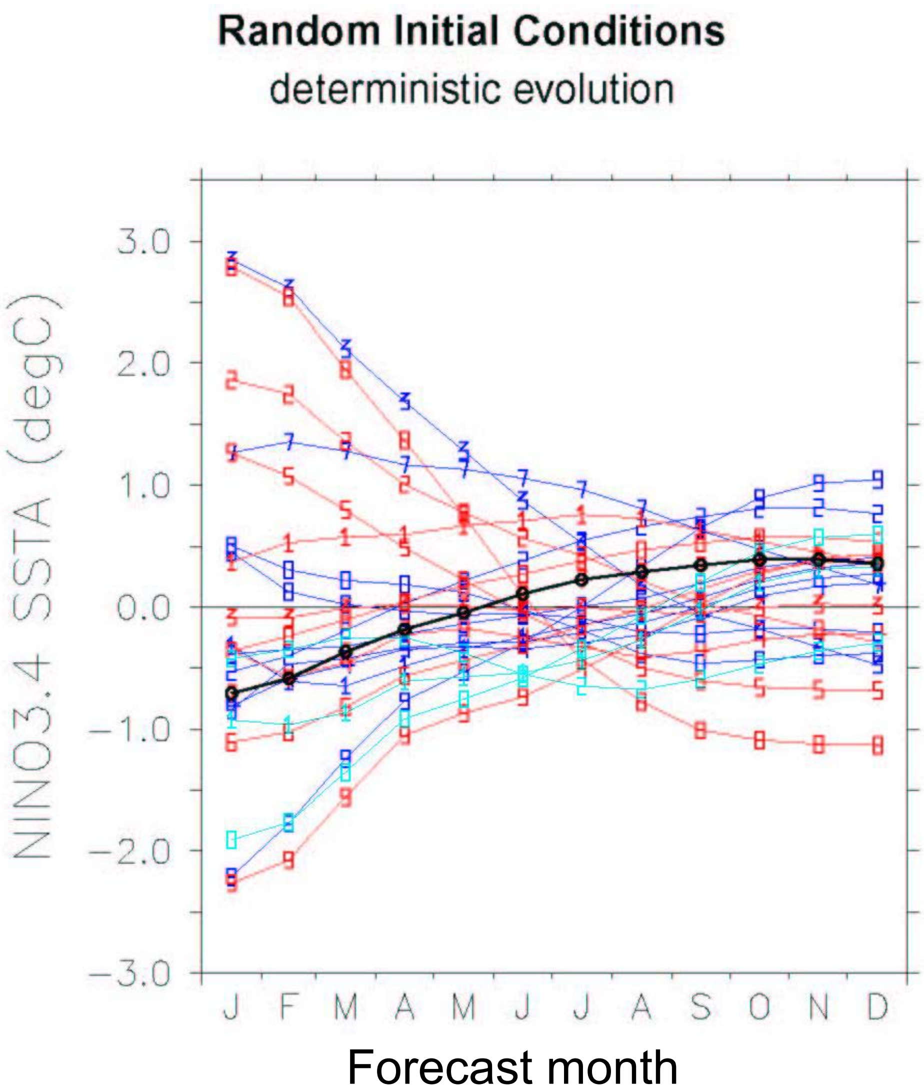
• The 1997 El-Nino event:

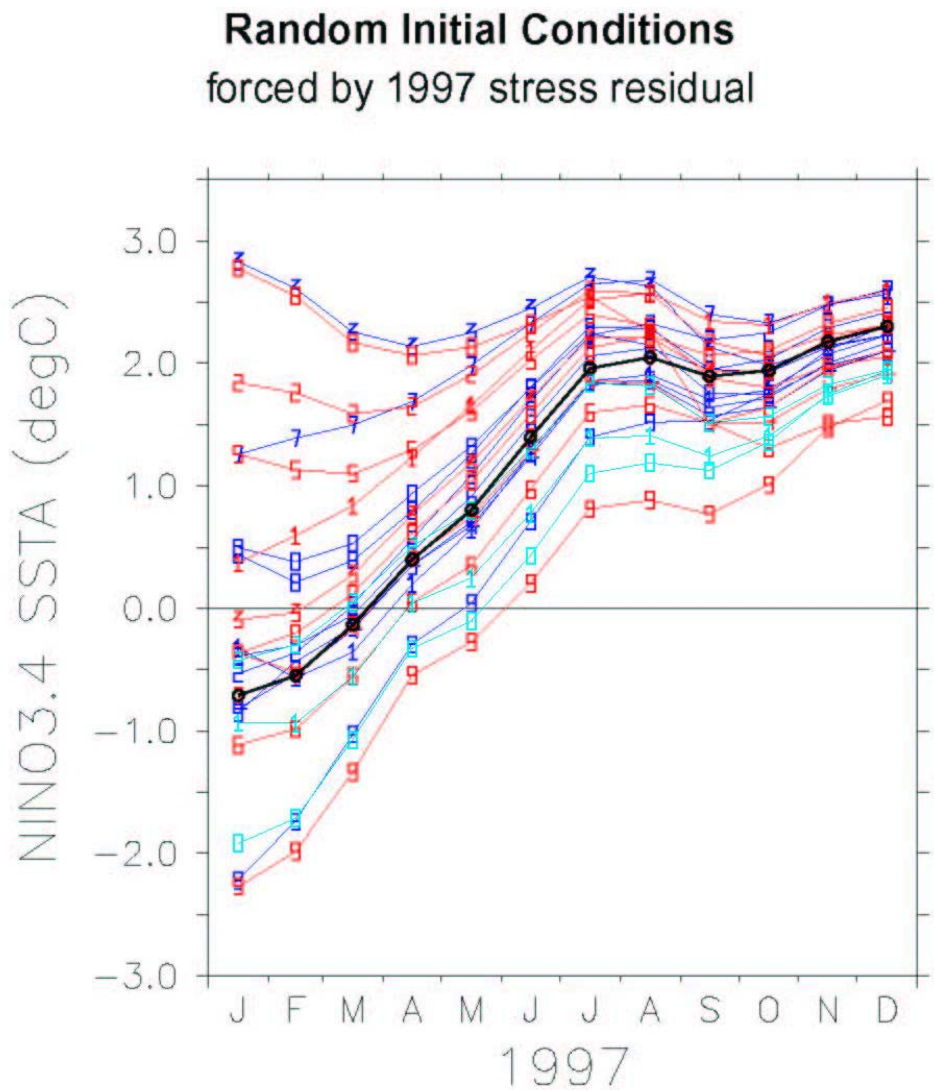


• The 1997 El-Nino event:



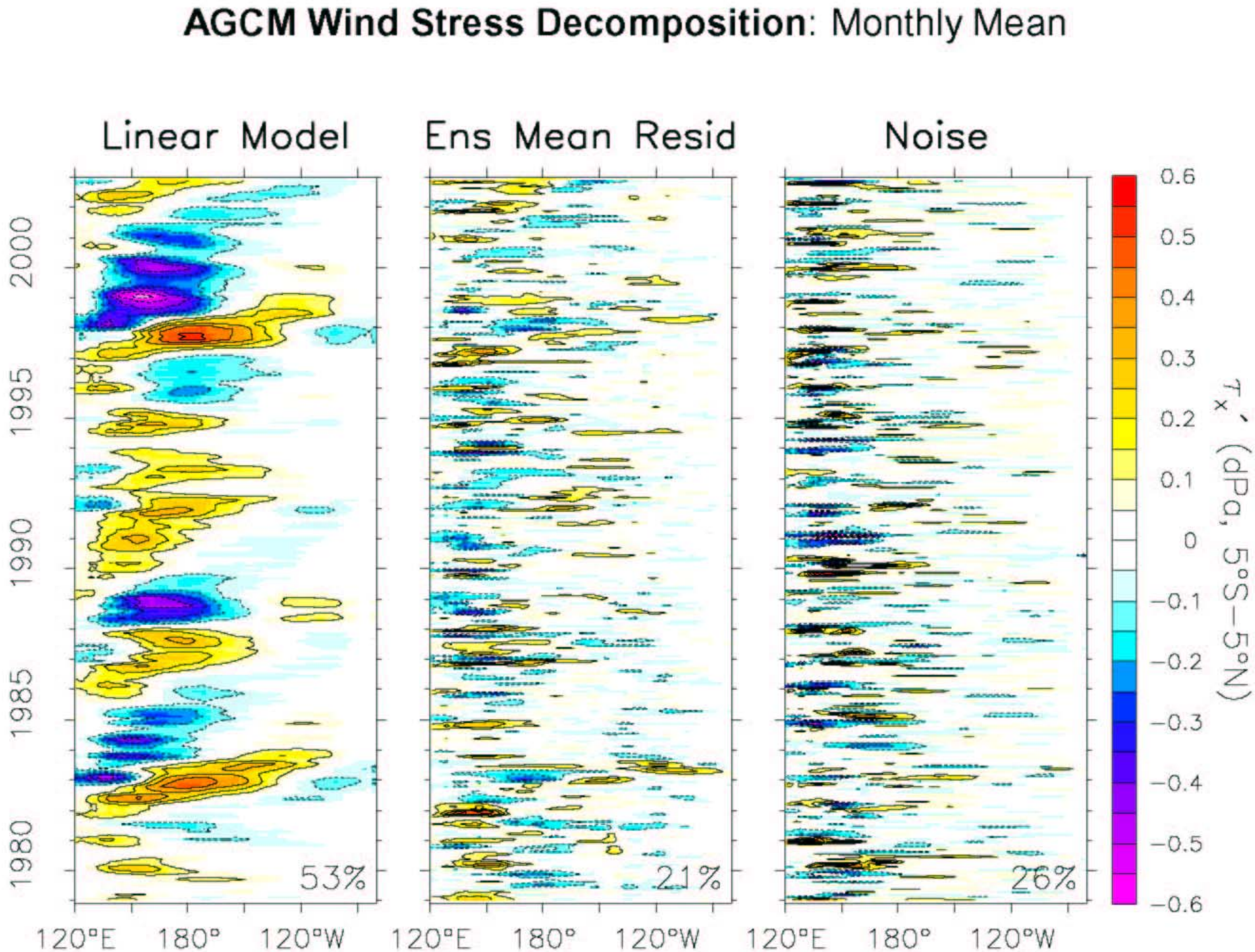

Stochastic forcing doesn’t change mean, but important for uncertainty!




- The 1997 wind stress residual can force an event, regardless of initial conditions
- Is it all atmospheric noise, or does it have a deterministic part?

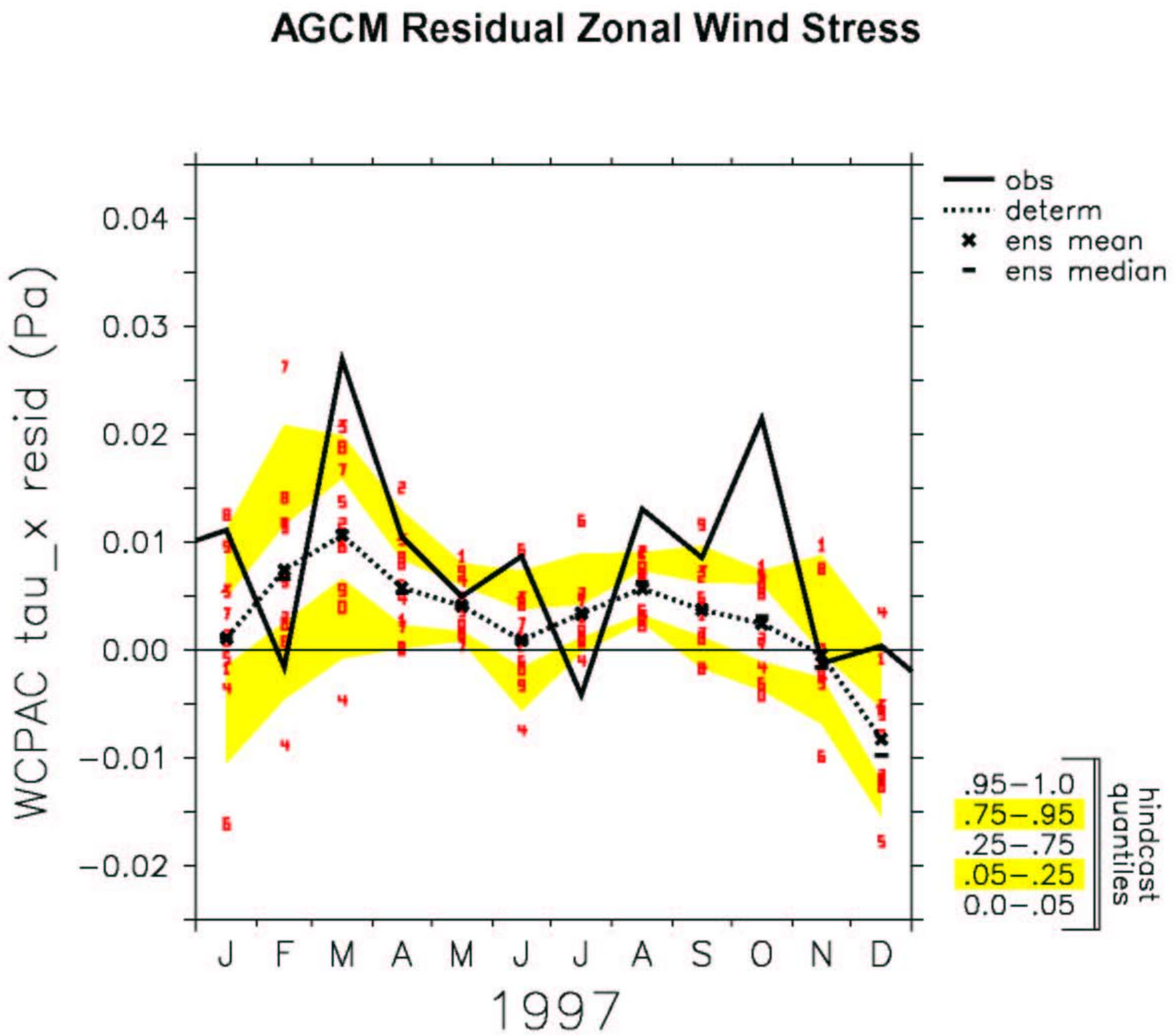
• Ensemble of 10 atmospheric GCM simulations forced by observed SST
• Derive statistical atmosphere from simulations *(thanks to Gabriel Vecchi)*



- Look at the 1997 El-Nino event:

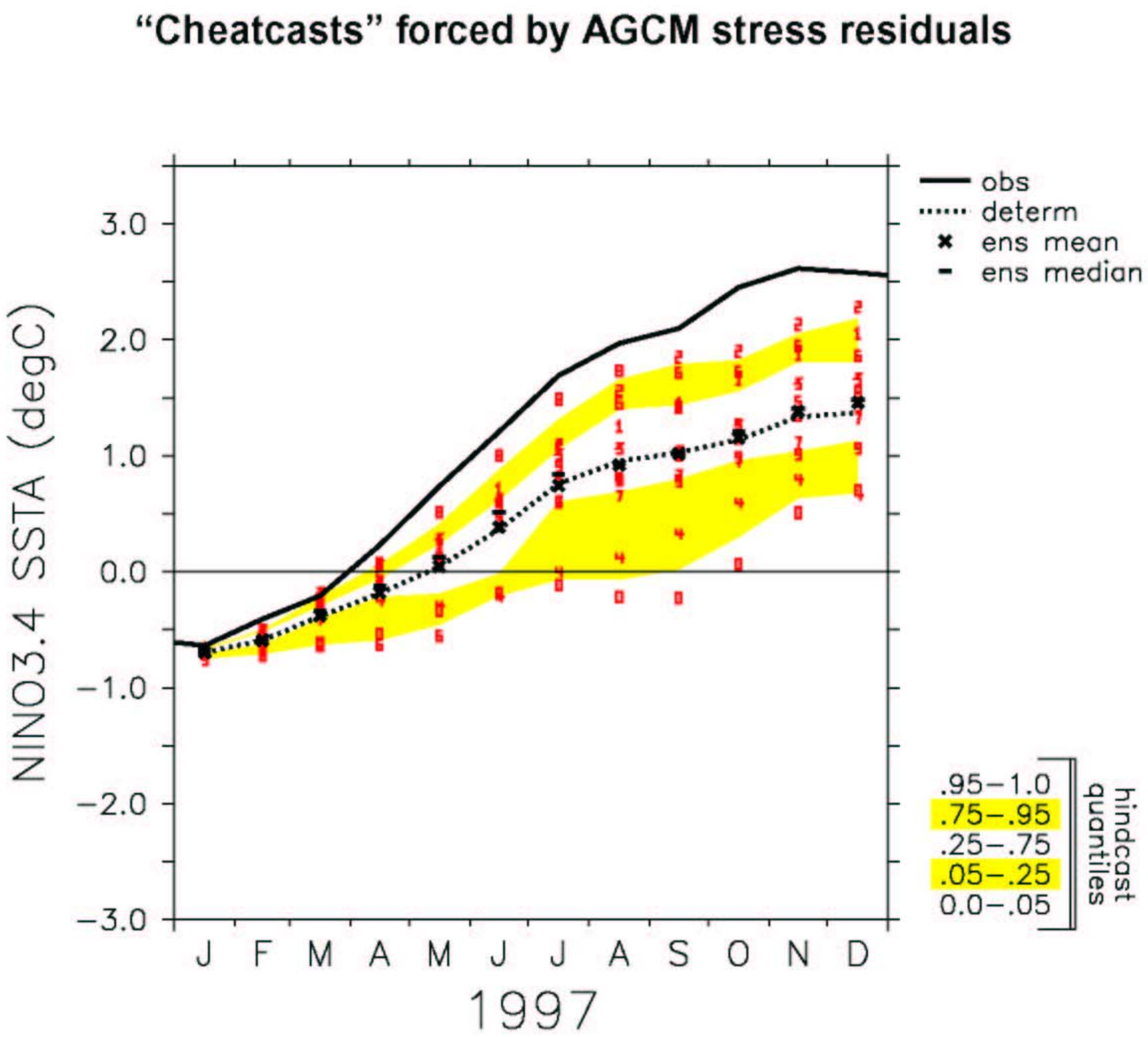
Ensemble mean is not zero.

Therefore, there is a deterministic part in the residual!



• Use residuals to force the coupled model at the 1997 El-Nino event:

Wind residuals push forecast towards the observed.



# Summary of hybrid model forecasts:

- Even though Regression onto tropical Pacific SST captures most interannual variance of equatorial Pacific , the residual stress matters. It induces strong dispersion of ENSO forecasts.

- Pacific was preconditioned for warming in 1997, but unusually intense residual westerlies greatly amplified the warming.

- The residual stress is not entirely random. Even the “noise part” has structure.

- Is it non-linearity or dependence of wind on other regions SST?

# The TAO east/west experiment

Thanks to Michele Rienecker (GMAO/NASA)

*What can we say about the TAO array using current ENSO forecast models?*

# CDEP Consortium

Ocean Data Assimilation Consortium for Seasonal-to-Interannual Prediction (ODASI)

COLA, GFDL, IRI, LDEO, NCEP, GMAO

GFDL
Tony Rosati
Matt Harrison
Andrew Wittenberg

GMAO
Michele Rienecker
Chaojiao Sun
Jossy Jacob
Nicole Kurkowski
Robin Kovach
Anna Borovikov

COLA
Jim Kinter
Ed Schneider
Ben Kirtman
Bohua Huang

IRI
Steve Zebiak
Eli Galanti
Michael Tippett

LDEO
Alexey Kaplan
Dake Chen

NCEP
Dave Behringer

**http://nsipp.gsfc.nasa.gov/ODASI**

## The Experiments:

** initial conditions for 1 January and 1 July, 1993 to 2002

** Forecast duration: 12 months

** The observations:
historical XBTs, TAO array, and Argo profiles

** Surface forcing:
NCEP reanalysis, and restoration to observed SST and SSS

Initial conditions for forecast experiments prepared using
1. All in situ temperature profiles, including the full TAO array
2. Western Pacific (west of 170°W) TAO moorings
3. Eastern Pacific TAO moorings

Hypothesis: the Eastern Pacific data important for shorter lead forecasts and the Western Pacific data important for longer lead forecasts.

# Niño-3 SST anomalies

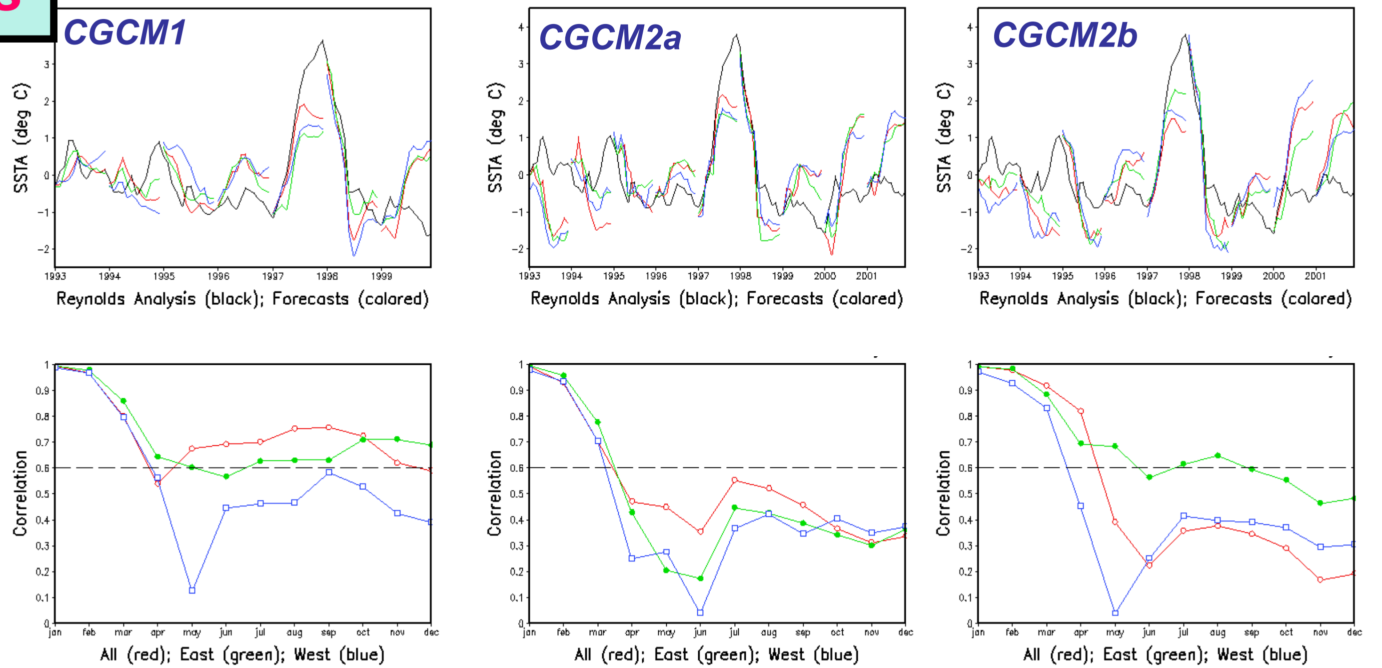
## January Starts

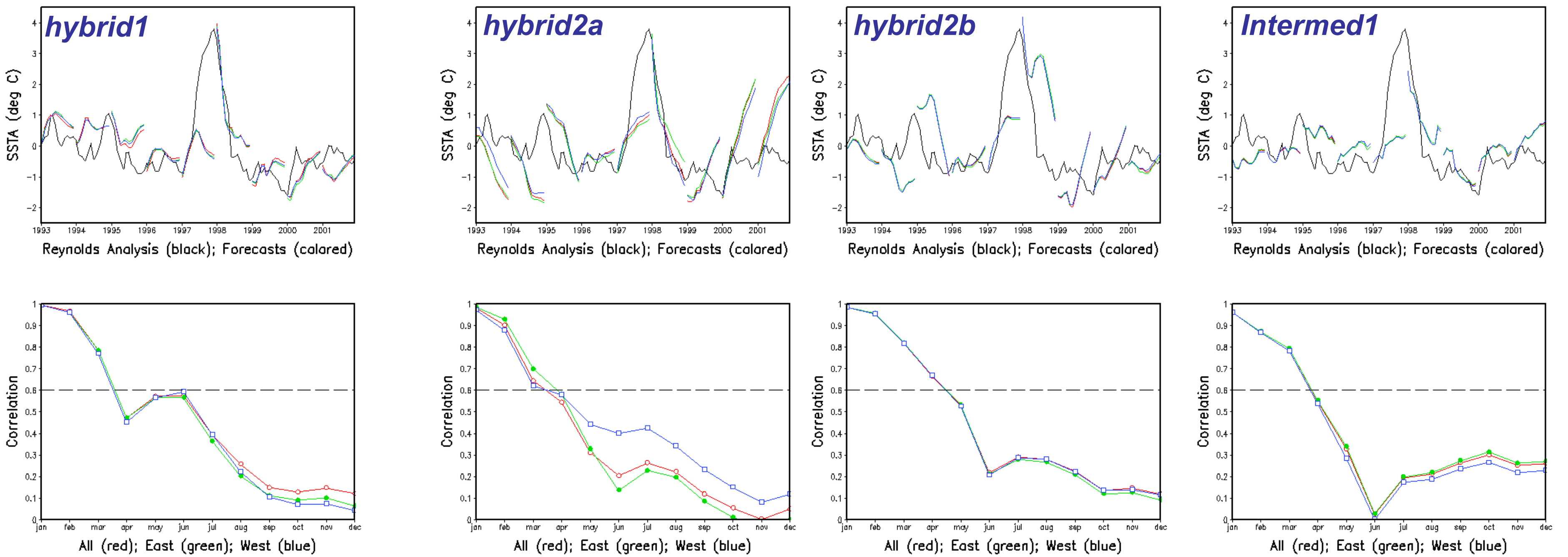
All TAO moorings

West TAO moorings

East TAO moorings

Obs (Reynolds)

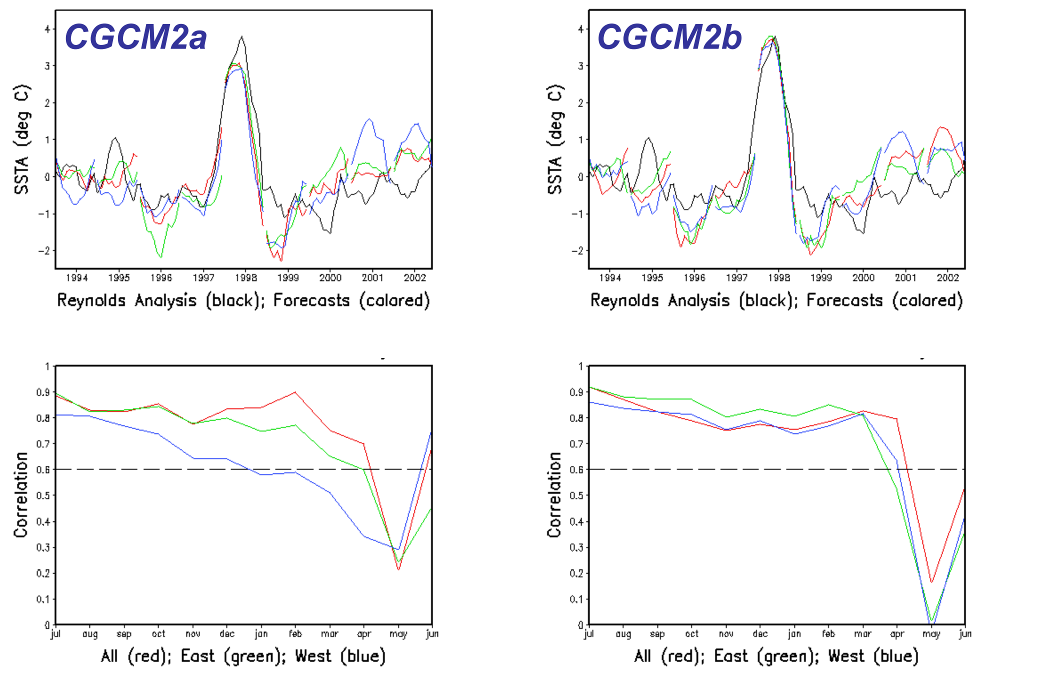


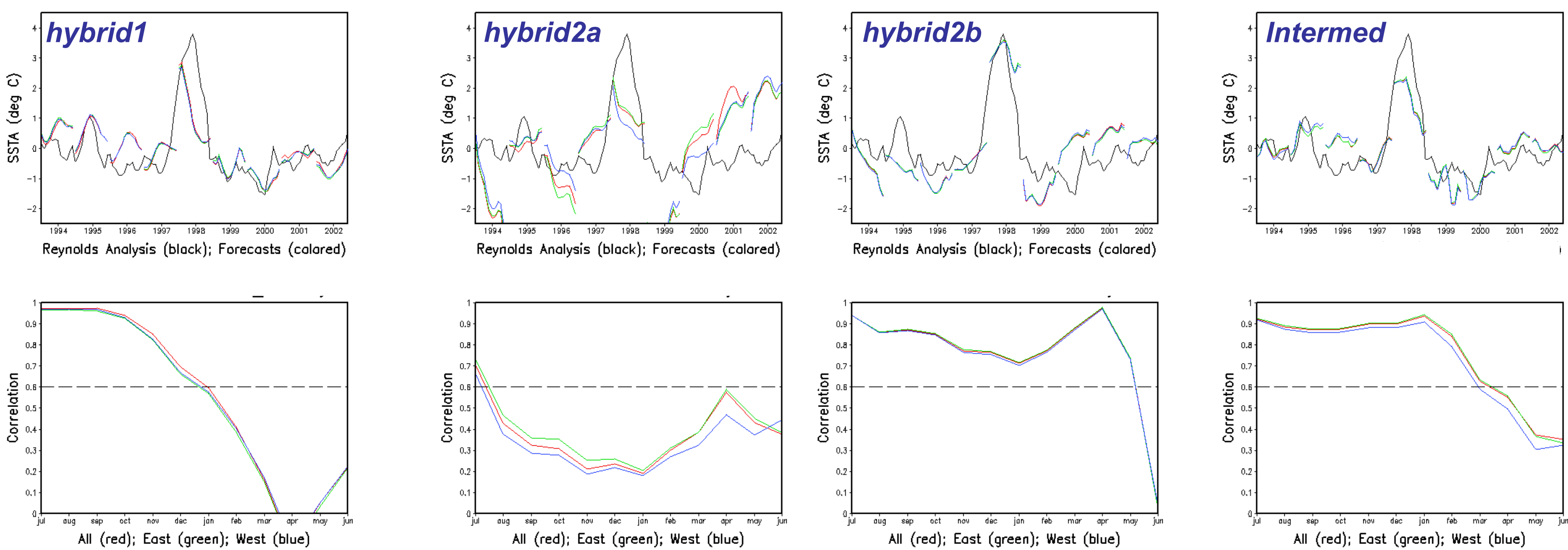



# Niño-3 SST anomalies

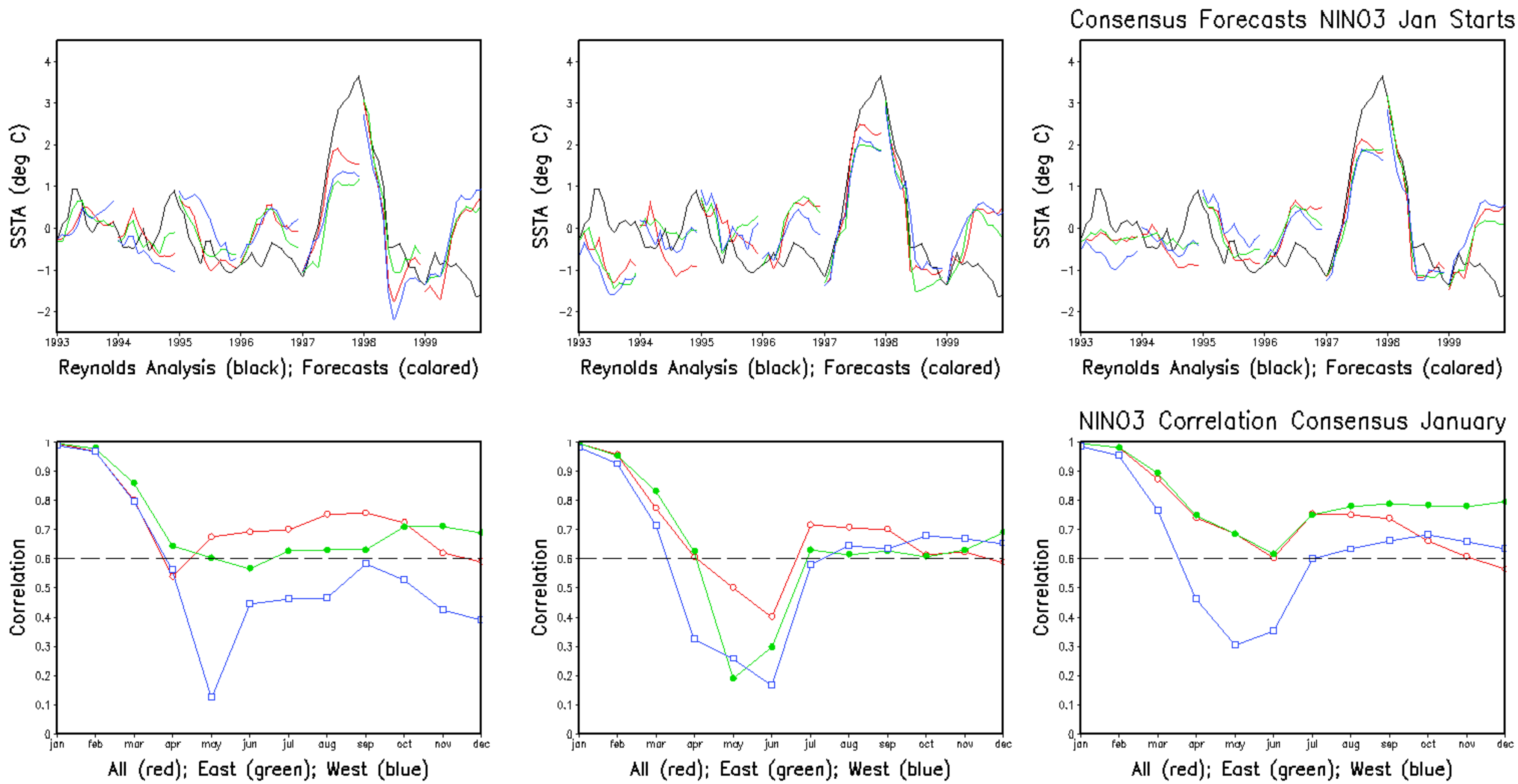
## July Starts

All TAO moorings
West TAO moorings
East TAO moorings
Obs (Reynolds)



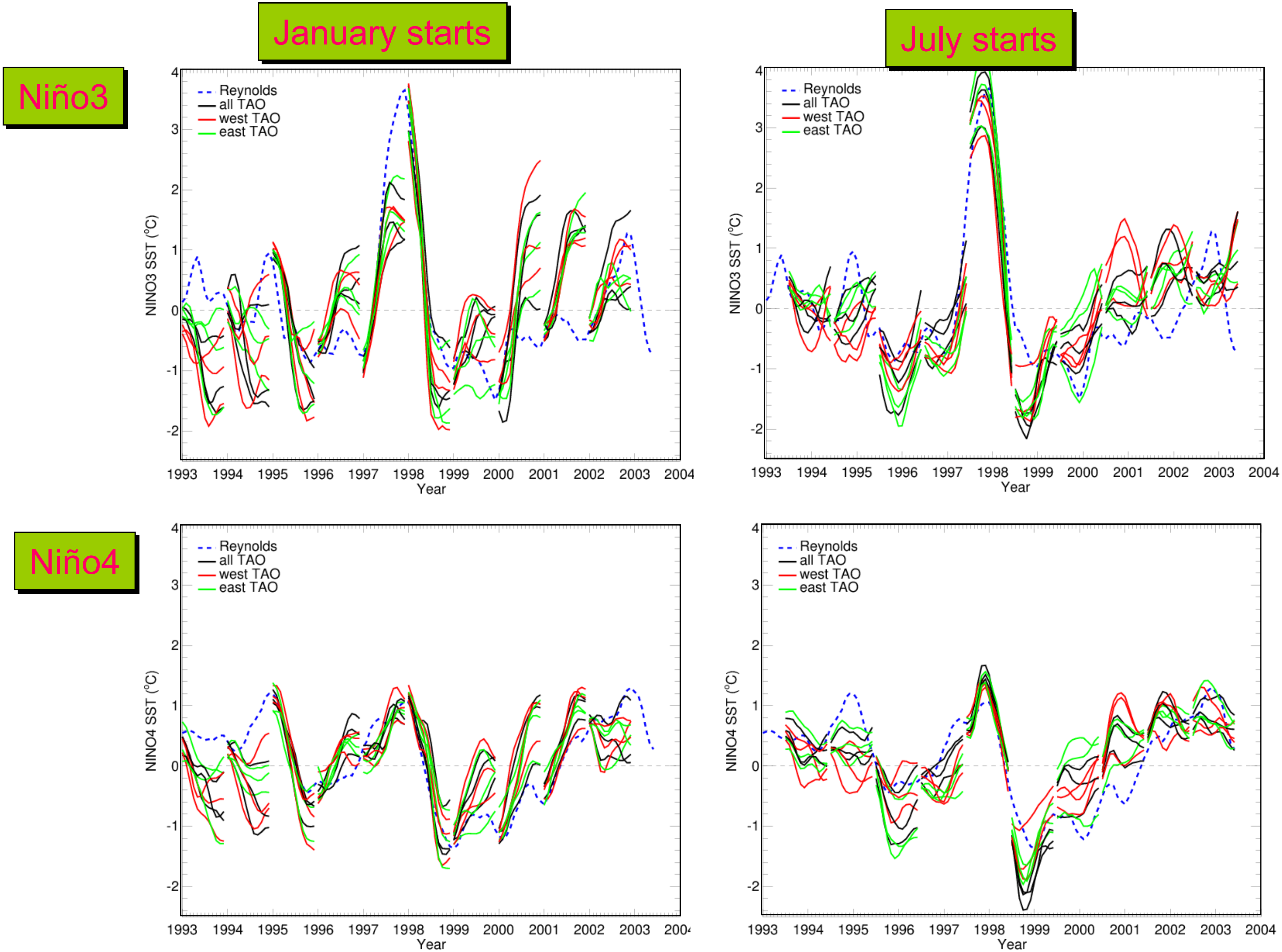



# CGCM Forecast skill - January starts - multimodel ensemble



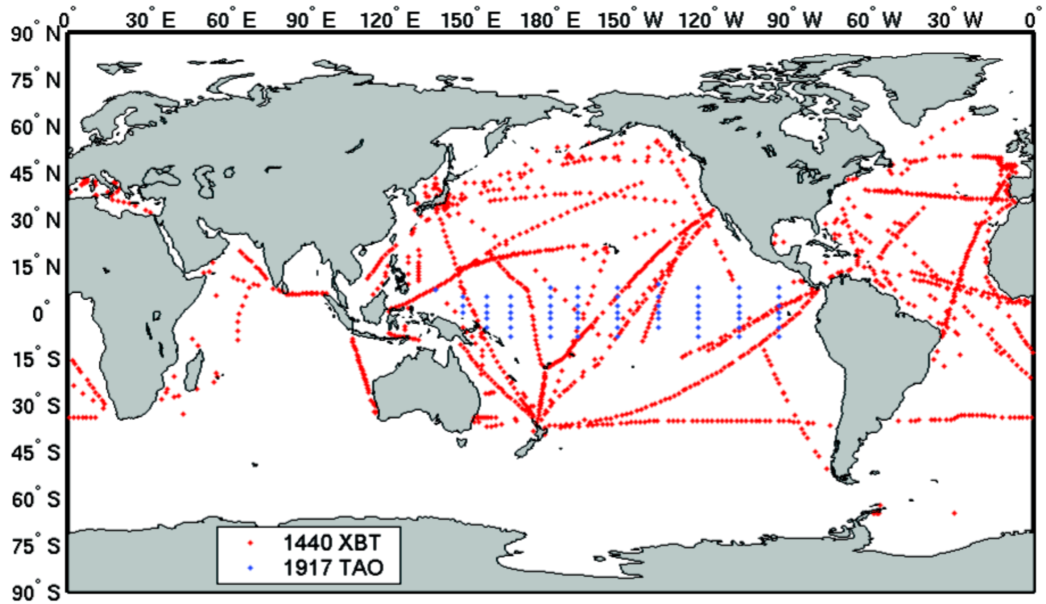

All TAO moorings
West TAO moorings
East TAO moorings
Obs (Reynolds)

- •multimodel ensemble skill is increased vs. individual skill
- •West TAO experiment has less skill, but proved to be important in central Pacific

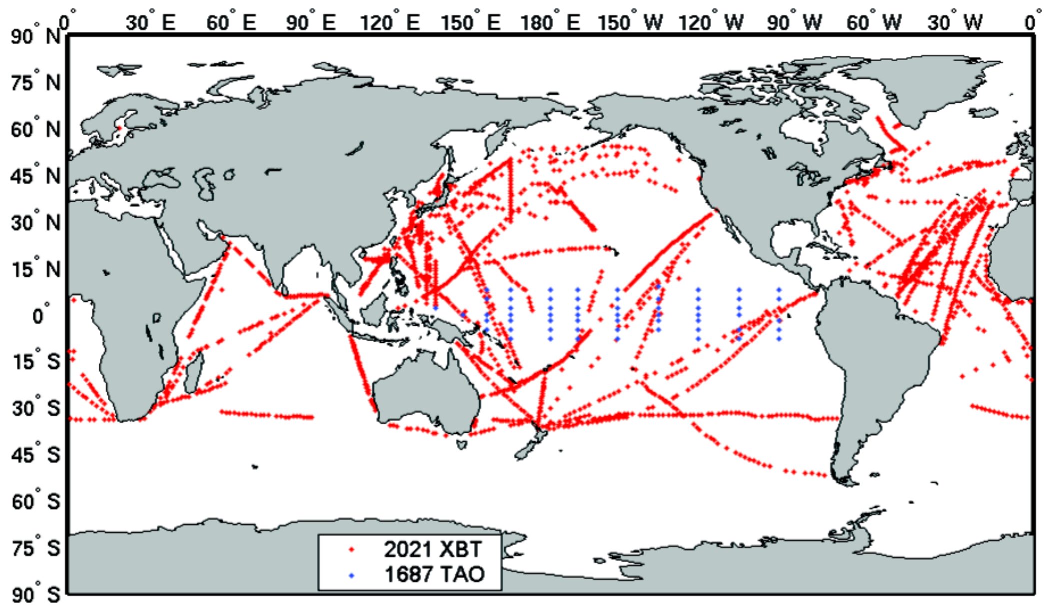



•Tendency for “all” ensemble to have tighter spread than the “east” or “west” ensembles results are complicated by the fact that we include the XBT data base. However, there aren't a lot of observations in the eastern equatorial pacific.

XBT and TAO profile locations for Dec 1996




XBT and TAO profile locations for June 1997



# Conclusions from TAO east/west experiments:

Statistical significance of results - need more ensemble members and more cases of both warm and cold events for robust conclusions

- Eastern array definitely improves forecast skill
- Western array improves skill in central Pacific
- Entire array
  - best results
  - probably associated with atmospheric response across the entire Pacific
  - some indication that get a tighter spread

- results are subtle - complicated by coupled model shocks and drifts

# Predictability dependence on observing system lifespan in a simple ENSO model

with Mike Tippett (IRI)

*How long should we observe in order to see improvement in forecast skill?*

# The strategy

- Derive ‘reality’ from integration of simple ENSO model

- Predict ‘reality’ when initial state is not perfectly known (lack of observations)

- Improve observation in central equatorial Pacific

- Compare skill of improved system to standard one, for different lifetimes of new observing system.

# The ENSO toy model

*(used in Galanti and Tziperman 2000)*

Delayed equation for the east equatorial SST, function of:

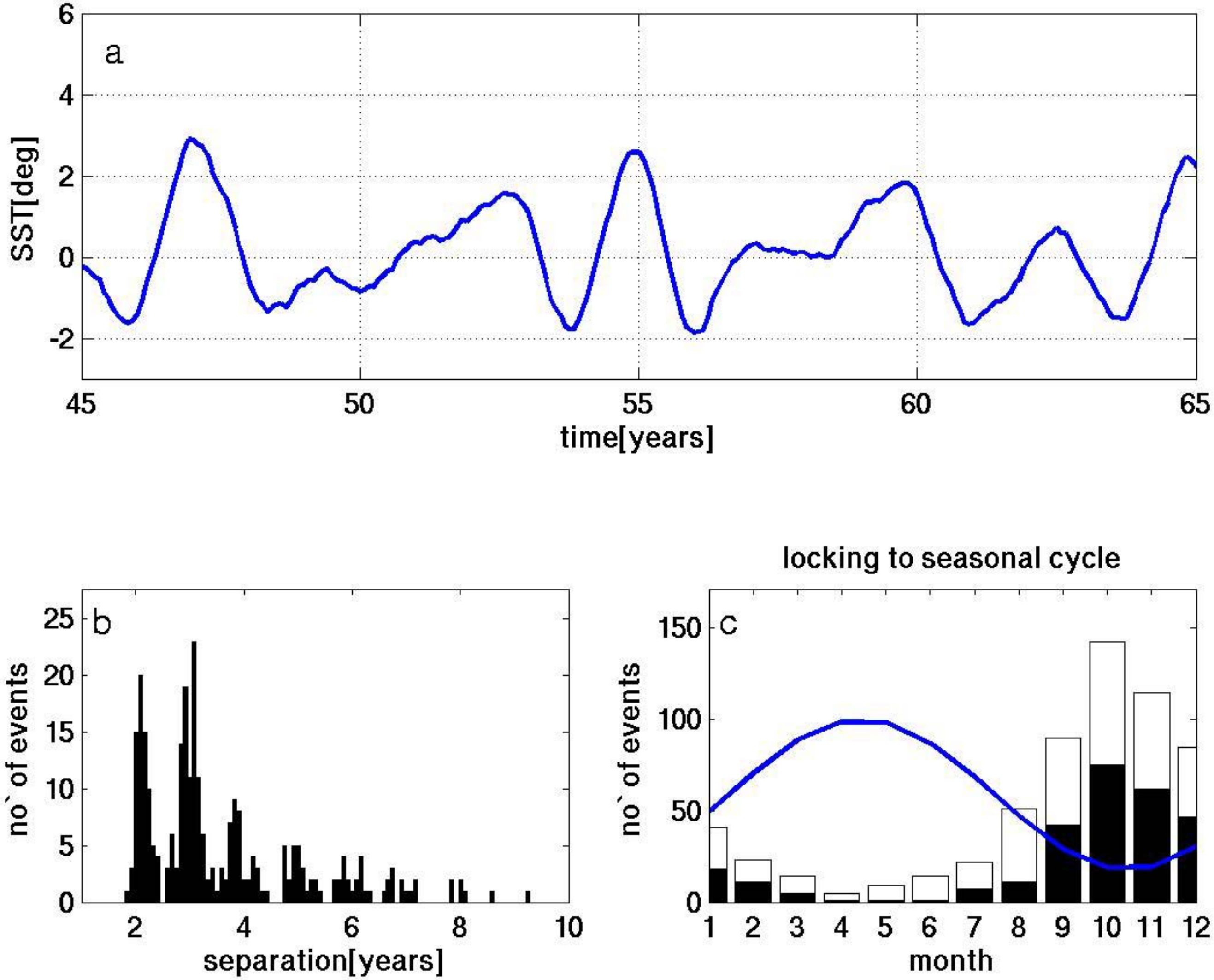
- Kelvin waves – equatorial central and west Pacific subsurface

- Rossby waves – equatorial west Pacific and off-equatorial Pacific subsurface

- SST – east equatorial subsurface

- Stochastic noise

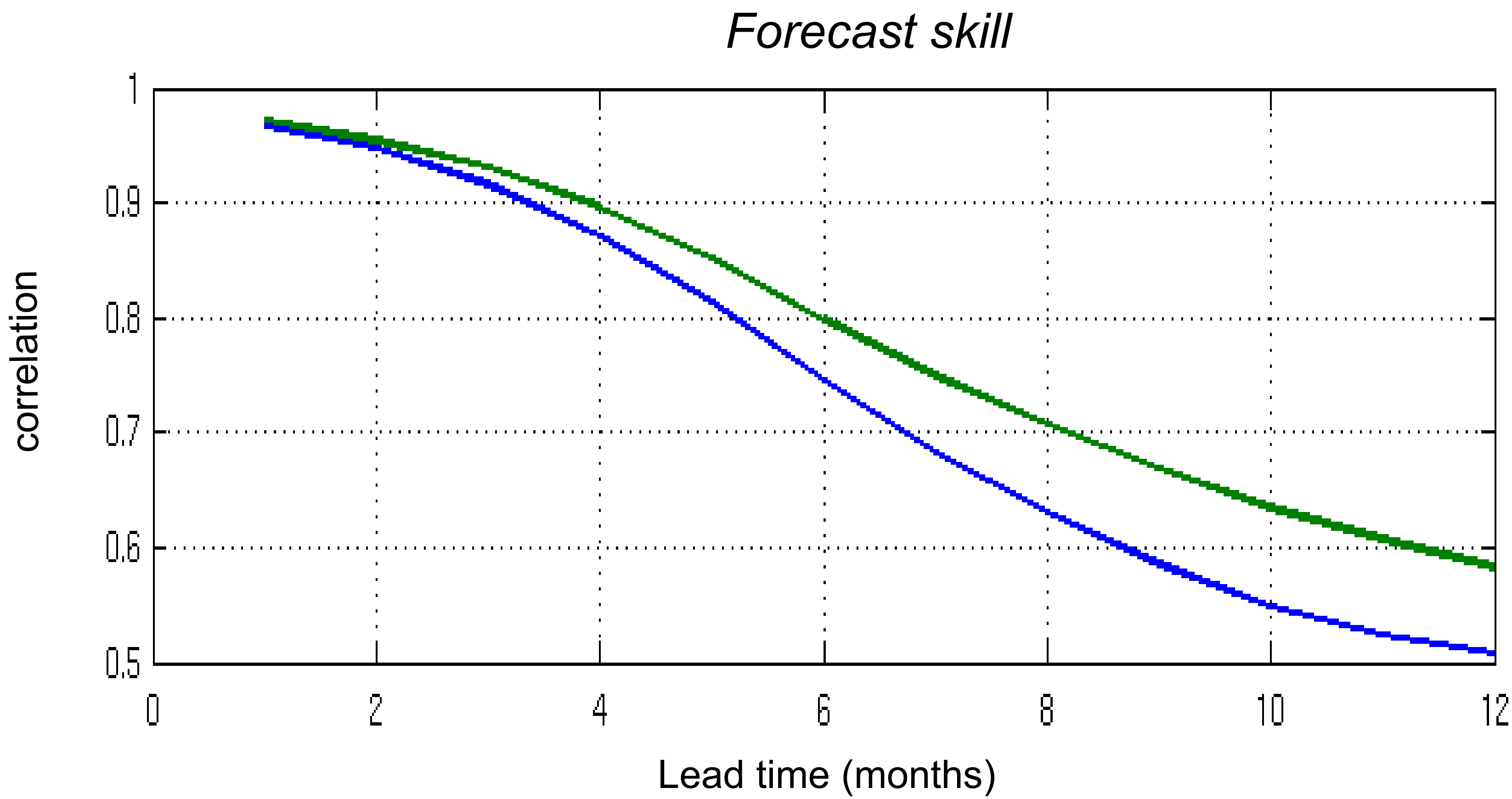
# The ‘reality’




A 1000 years integration of the coupled model

# The forecasts

- Add uncertainty to initial conditions using normally distributed errors (blue curve)
- Reduce uncertainty in Kelvin waves initial conditions (green curve)



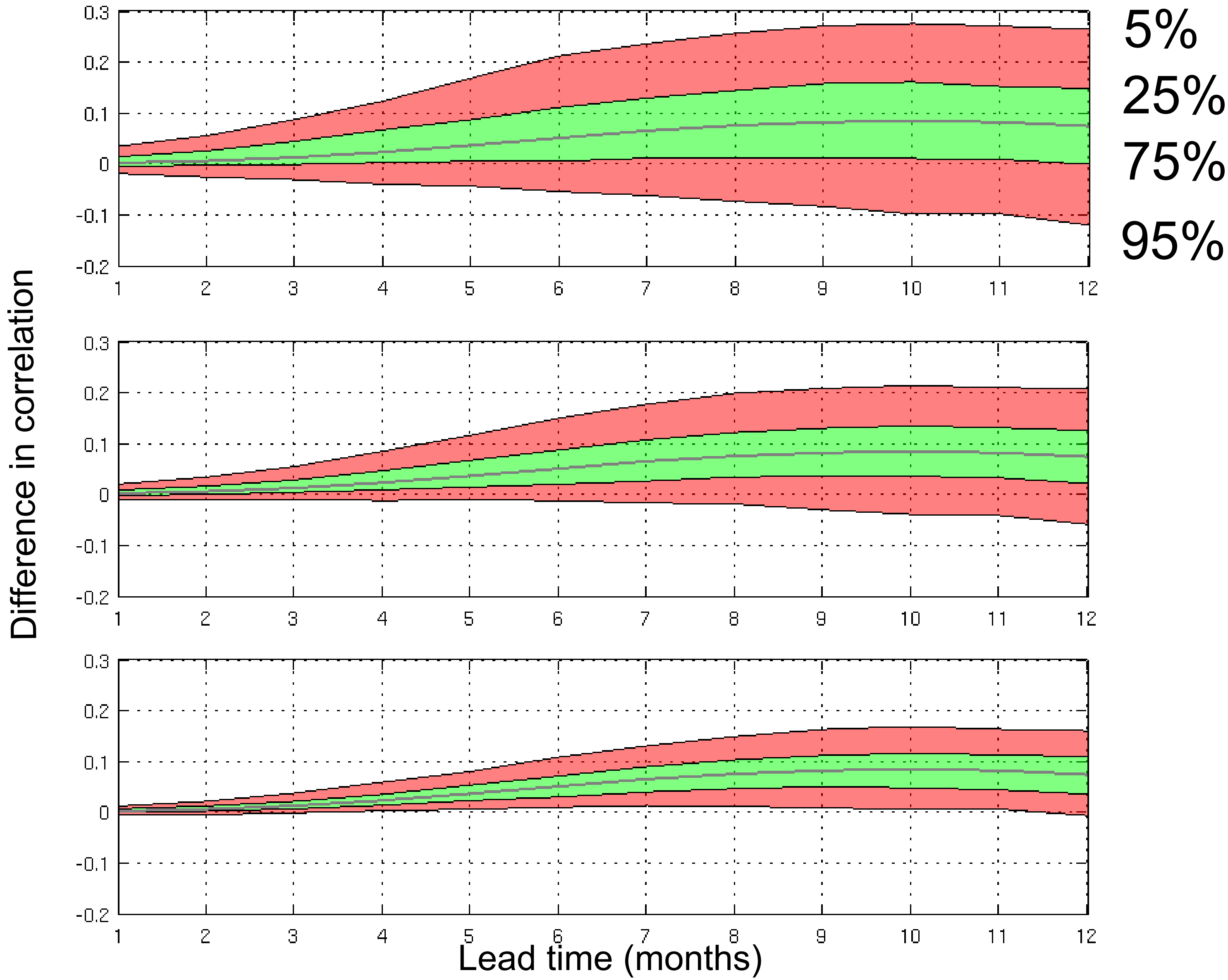

What happens to improvement in skill when new observing system is limited in time?

# Distribution of skill improvement as function of duration of new observing system

5 years

10 years

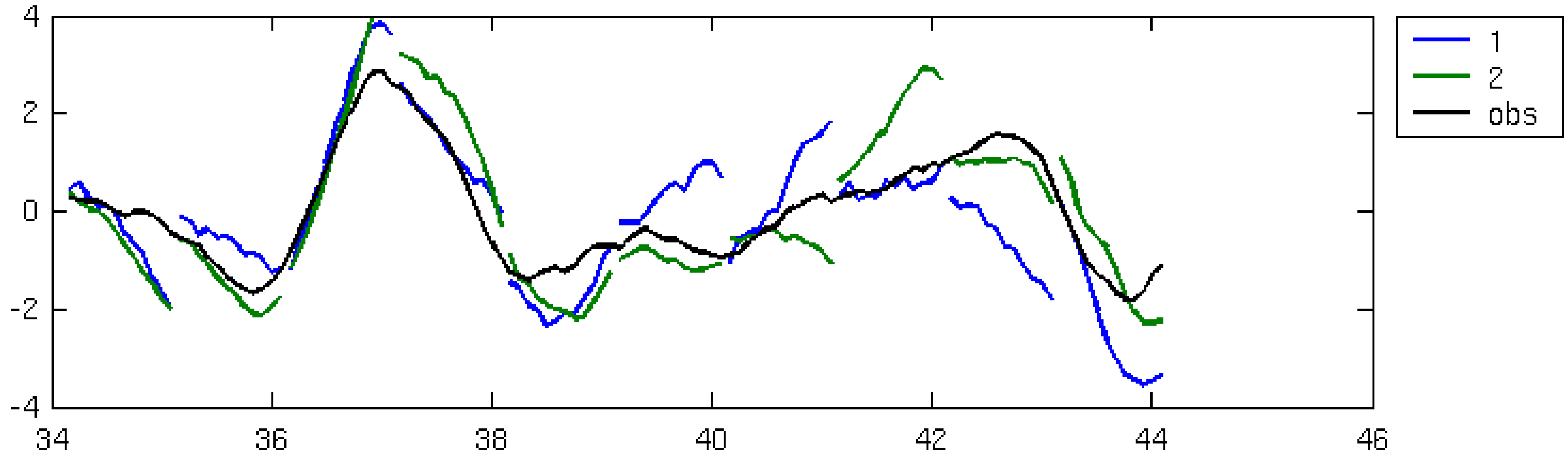
20 years



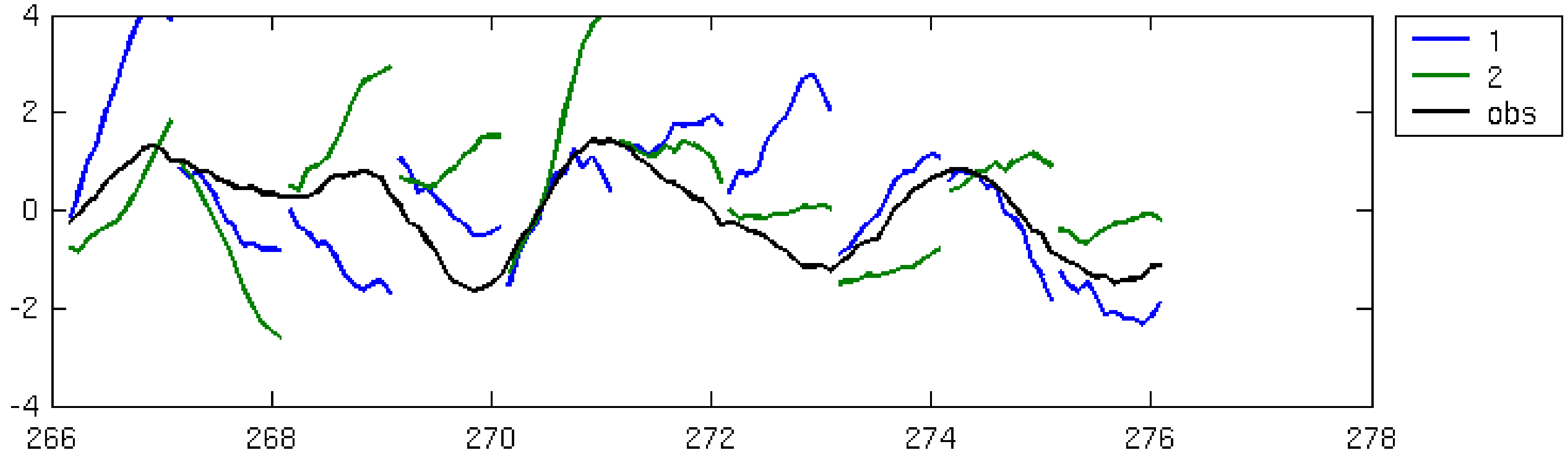

Might not see higher skill, especially of statistical significance!

# Example of skill improvement and skill degradation

good luck…



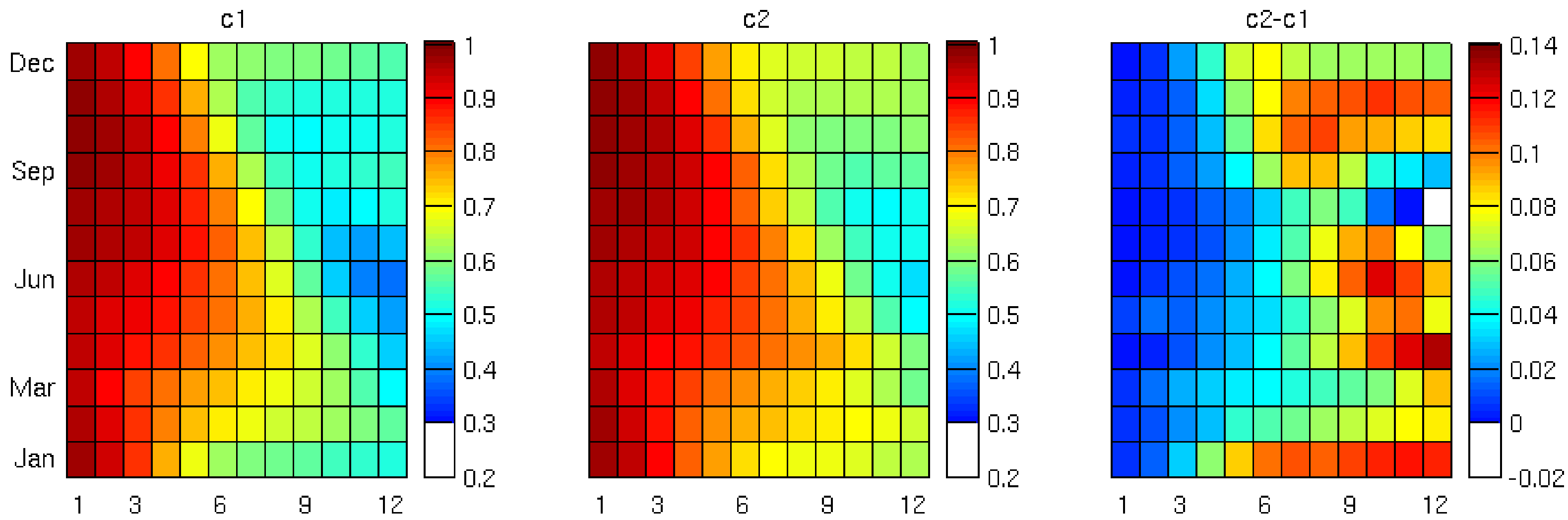

bad luck…



# Seasonality in skill improvement

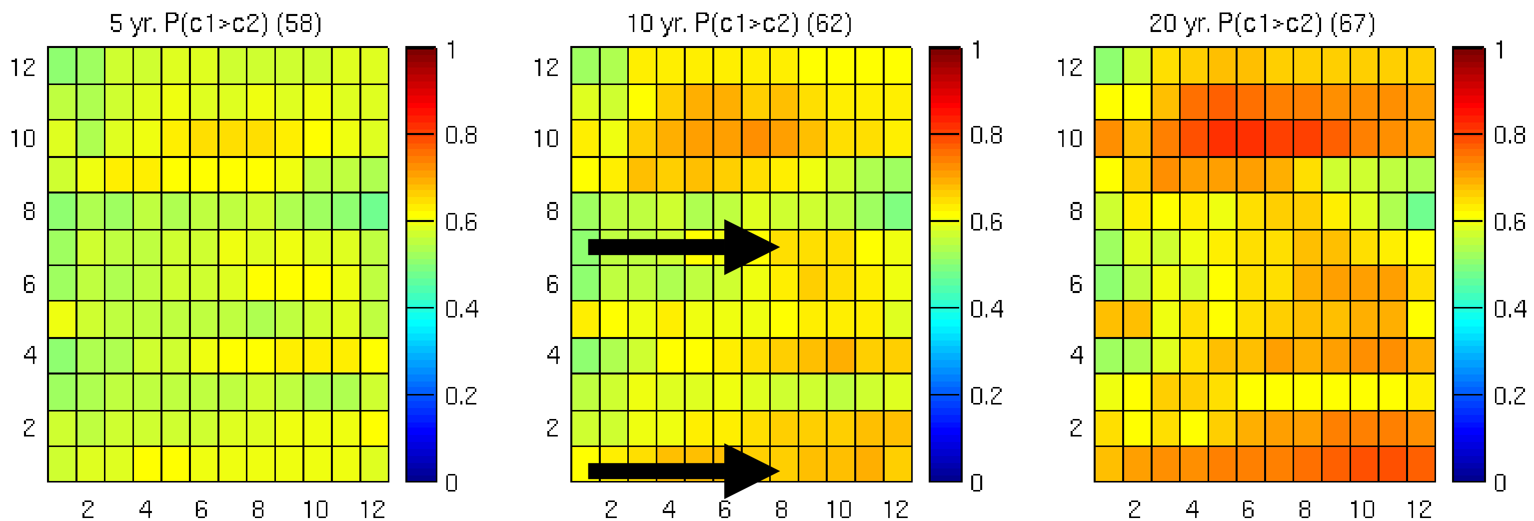
standard improved difference

Forecast skill
From the 1000yr




TAO east/west

Probability of
improving skill




5 years 10 years 20 years

# Take home message…

- Given that a new observing system exists for only a short period, even within a framework of a simplified reality and model, improvement in forecast skill is not guaranteed to be seen.

- Including seasonality in analysis makes judgment of skill improvement even harder.

# Summary of talk:

- The new IRI ocean data assimilation system
- ENSO forecast experiments and the role of stochastic forcing
- The TAO array east/west experiment
- Measuring impact of observing system’s lifetime in a simple model