Examining the role of model bias in limiting tropical Atlantic prediction skill

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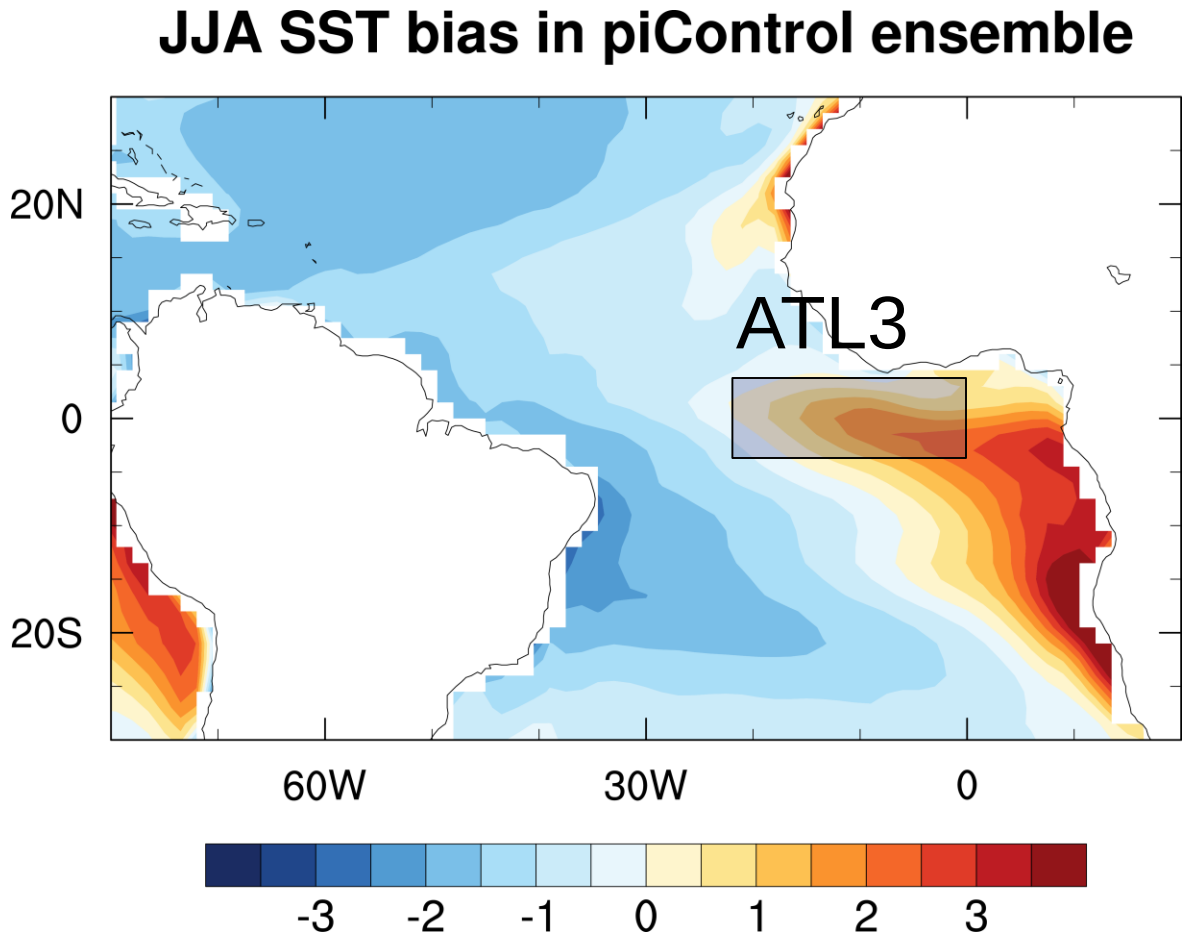
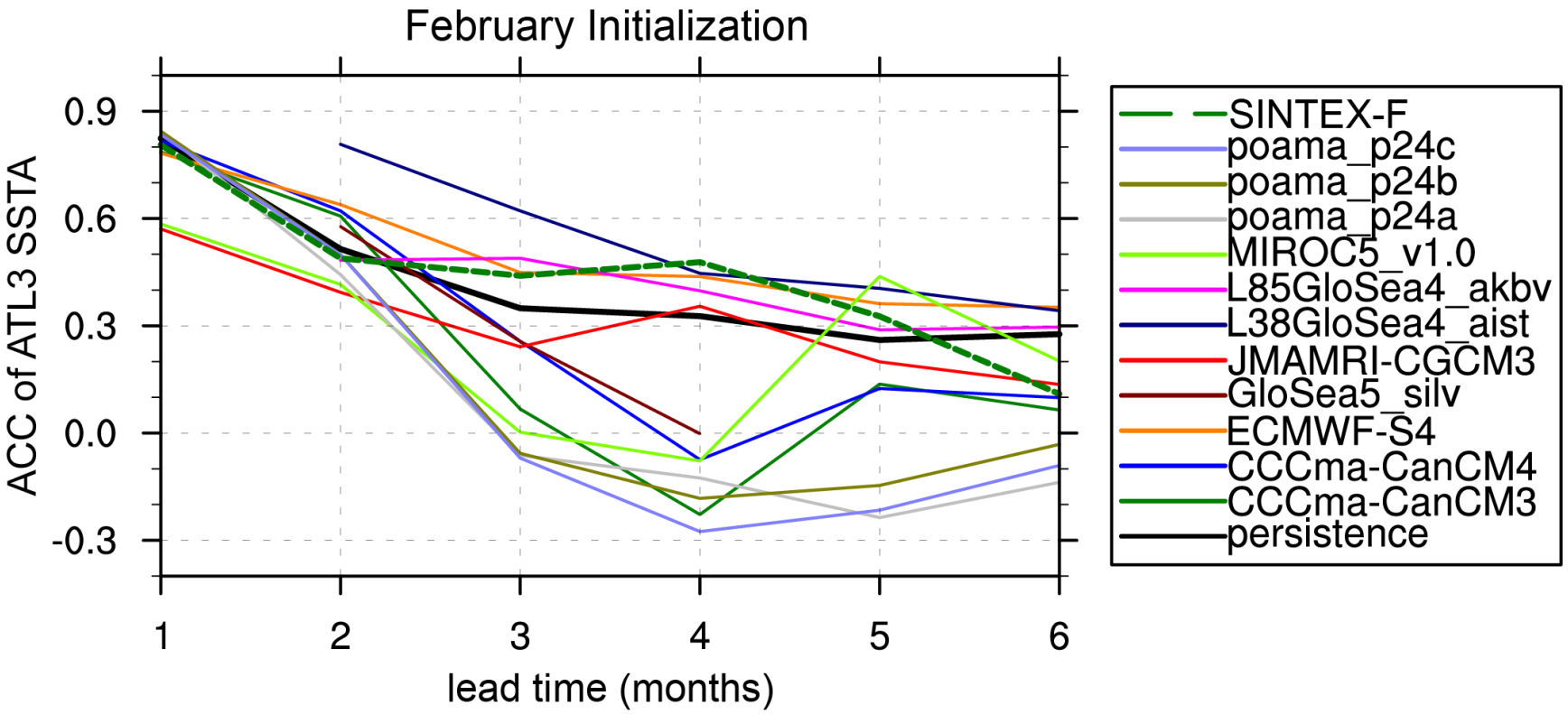
PIRATA 23 Meeting
Marseille, France
23 October 2018

The problem

SST bias in CMIP5 piControl

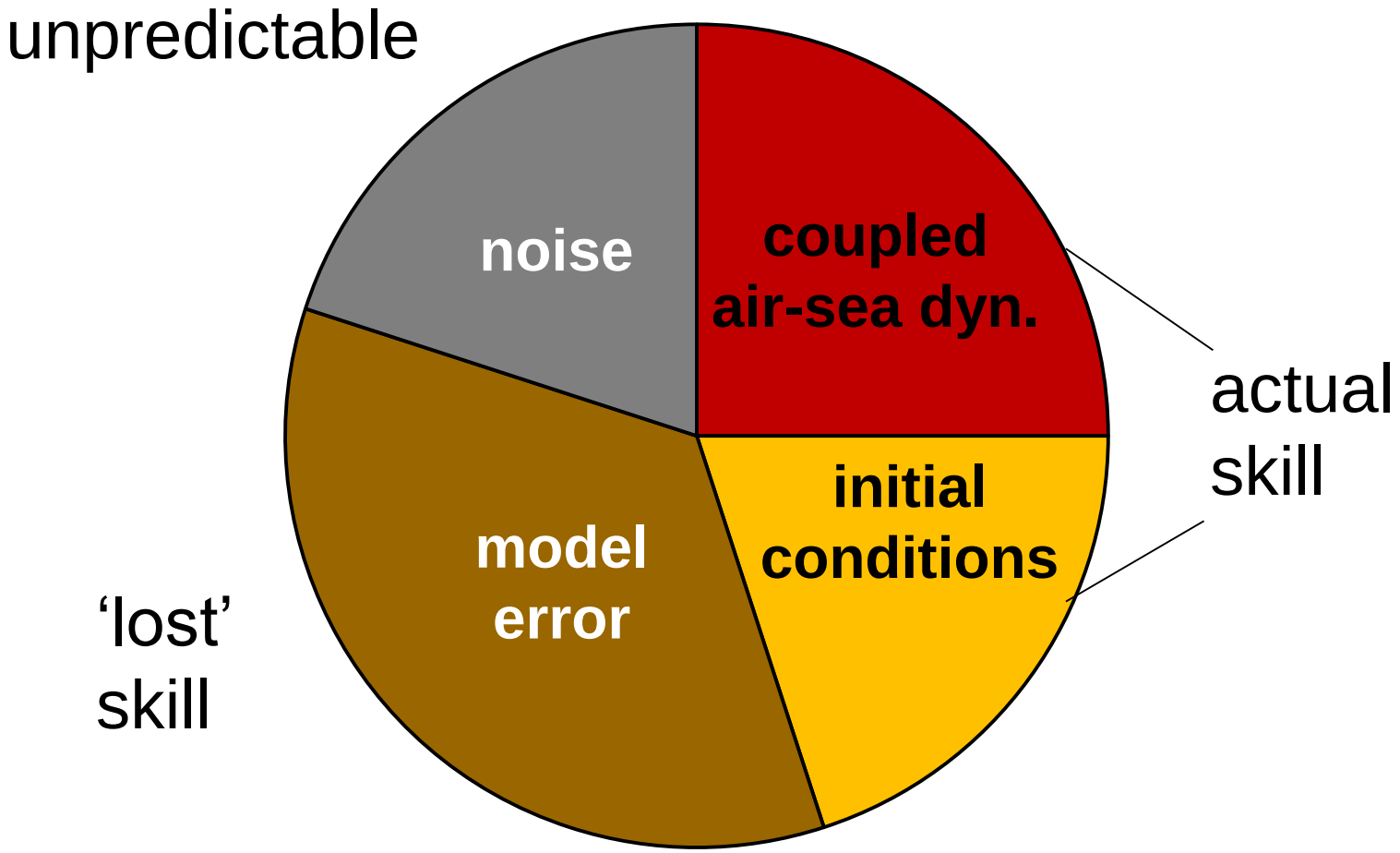


Prediction skill in the equatorial Atlantic

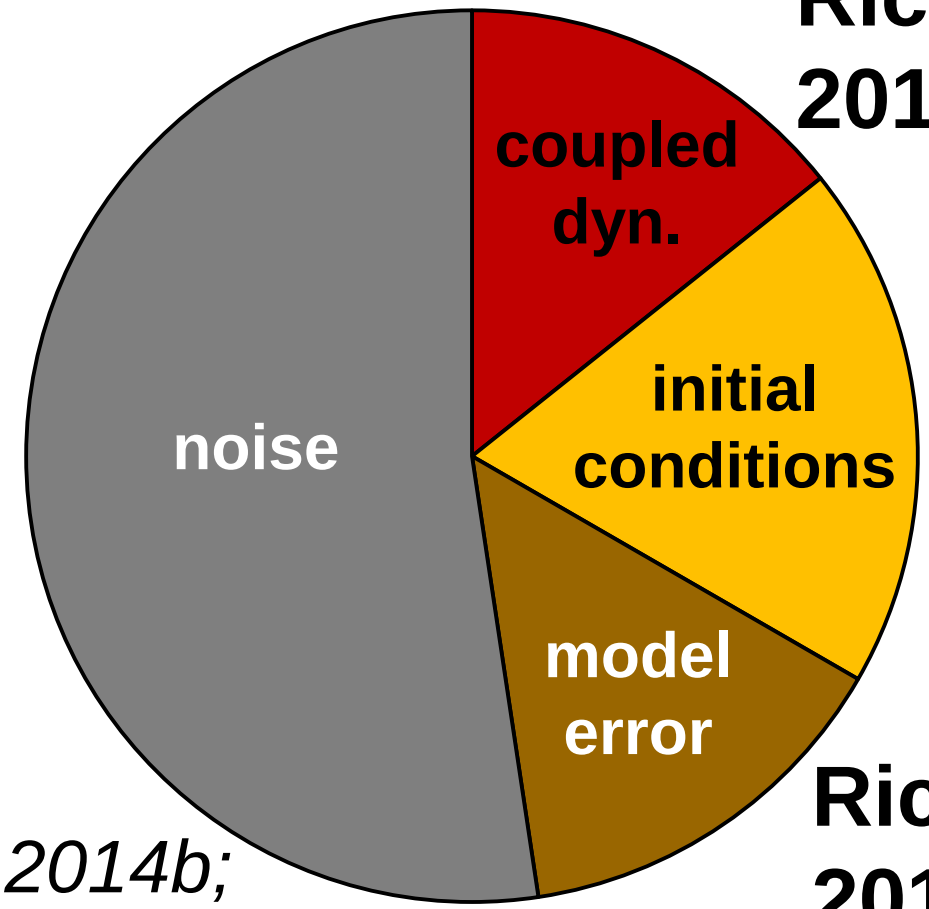


from *Richter et al. 2018*

Predictability



In the tropical Atlantic:



Richter et al. 2014a; 2017

Richter et al. 2018

+ this talk

Richter et al. 2014b; 2019 (under review)

Previous studies

- noise plays important role (Richter et al. 2014b, 2019)
- some models reproduce variability patterns despite pronounced biases (Richter et al. 2014a)
- coupled feedbacks cut short by seasonal ITCZ migration (Richter et al. 2017)
- remote influences strong (Richter et al. 2019, under review)
- SST biases do not affect reproduction of sfc wind anomalies (Richter et al. 2018)

Conflicting views

arguments in favor of high predictability

- Bjerknes feedback plays a crucial role in the equatorial Atlantic (Keenlyside and Latif 2007; Lübbecke et al. 2014; Deppenmeier et al. 2016; Dippe et al. 2017)
- skillful prediction at 5-6 months lead time may be possible (Keenlyside and Latif 2007; Ding et al. 2015)

counter arguments

- equatorial mode not self-sustained (Zebiak 1993)
- low prediction skill despite model improvement (Stockdale et al. 2006; Richter et al. 2017)
- lack of consistent Pacific influence (Chang et al. 2007)

Goal of this study

- reexamine the link between bias and prediction skill in a large multi-model ensemble (cont. from Richter et al. 2018)
- CMIP5 contains many models but does not feature seasonal prediction experiments
- -> use CMIP5 output to derive statistical prediction model
- statistical model to be used: Linear Inverse Model (LIM)

Basic idea behind LIM

- extract dynamical properties from observed statistics
- assume linear system

$$\frac{d\boldsymbol{x}}{dt} = L\boldsymbol{x} + \boldsymbol{\xi}(\boldsymbol{t})$$

- determine L using essentially lagged linear regression (usually in PC space)
- most commonly used on SST
- identify ”precursor” of warm/cold events

Idea of this study

- model misrepresentation of TAV will be reflected in LIM
- such a “distorted” LIM will have inferior prediction skill
- examine the link between mean state biases and prediction skill using 35 CMIP5 piControl models

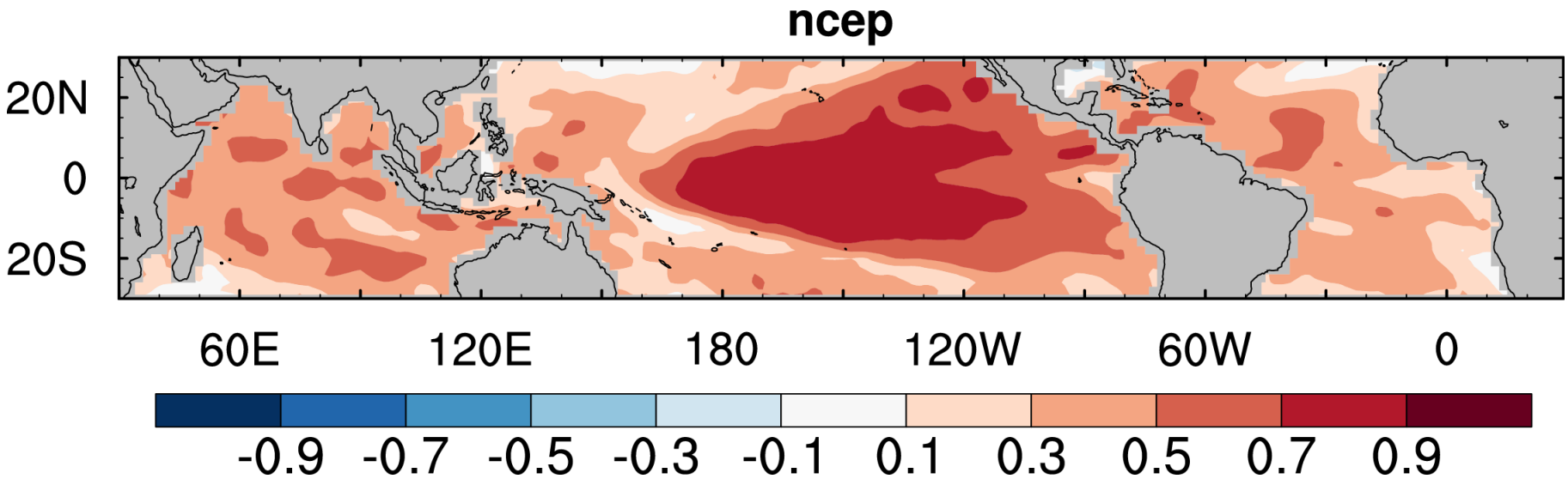
Data & Method

- data: CMIP5 piControl simulations and NCEP/NCAR reanalysis
- step 1
  - construct LIM from NCEP-R using training period 1948-1999
  - predict SST for validation period 2000-2017
- step 2
  - construct LIM from each piControl model
  - predict NCEP-R SST for period 1948-2017

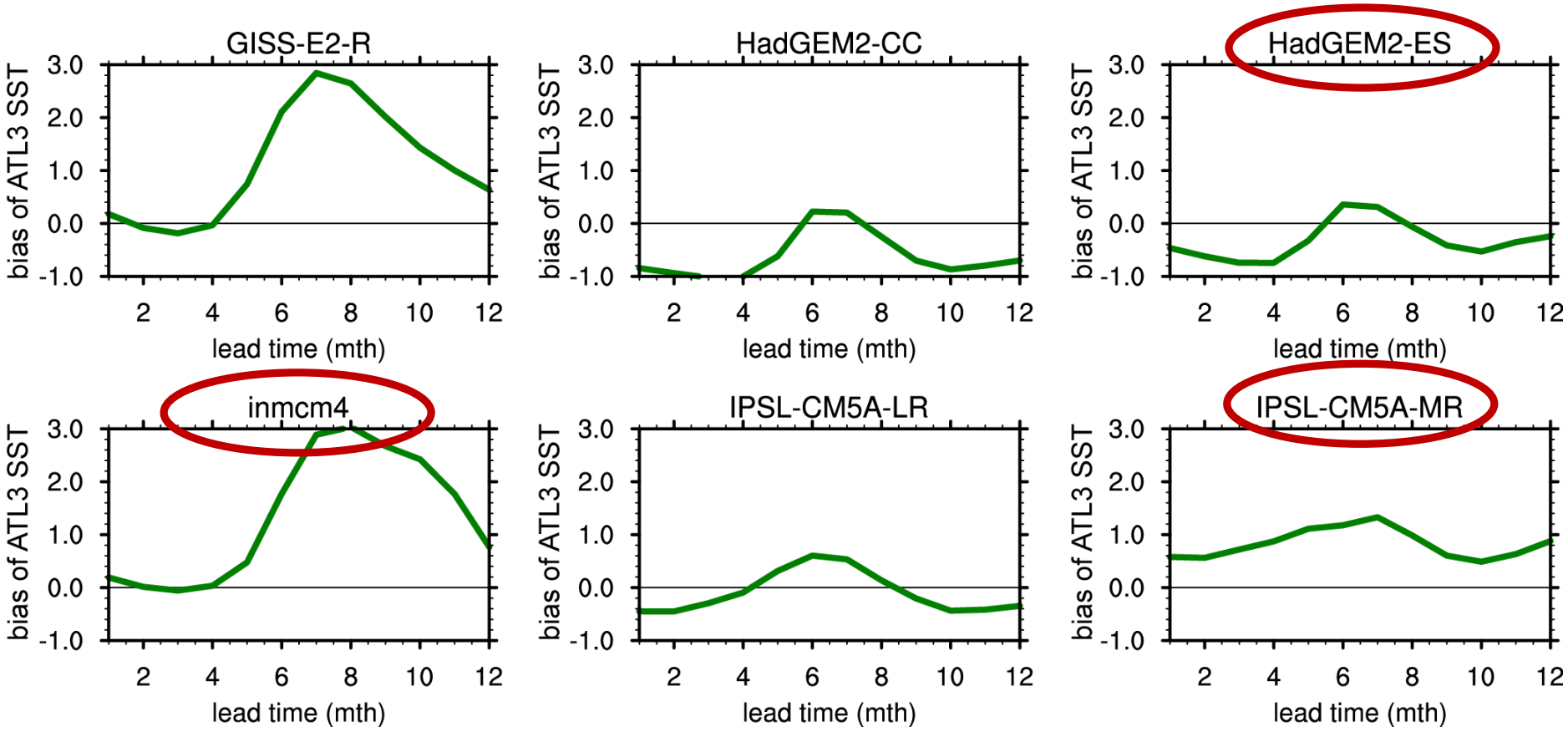
Anomaly corr. (ACC) of NCEP-R LIM

training: 1948-1999; validation: 2000-2017

lead = 3 months

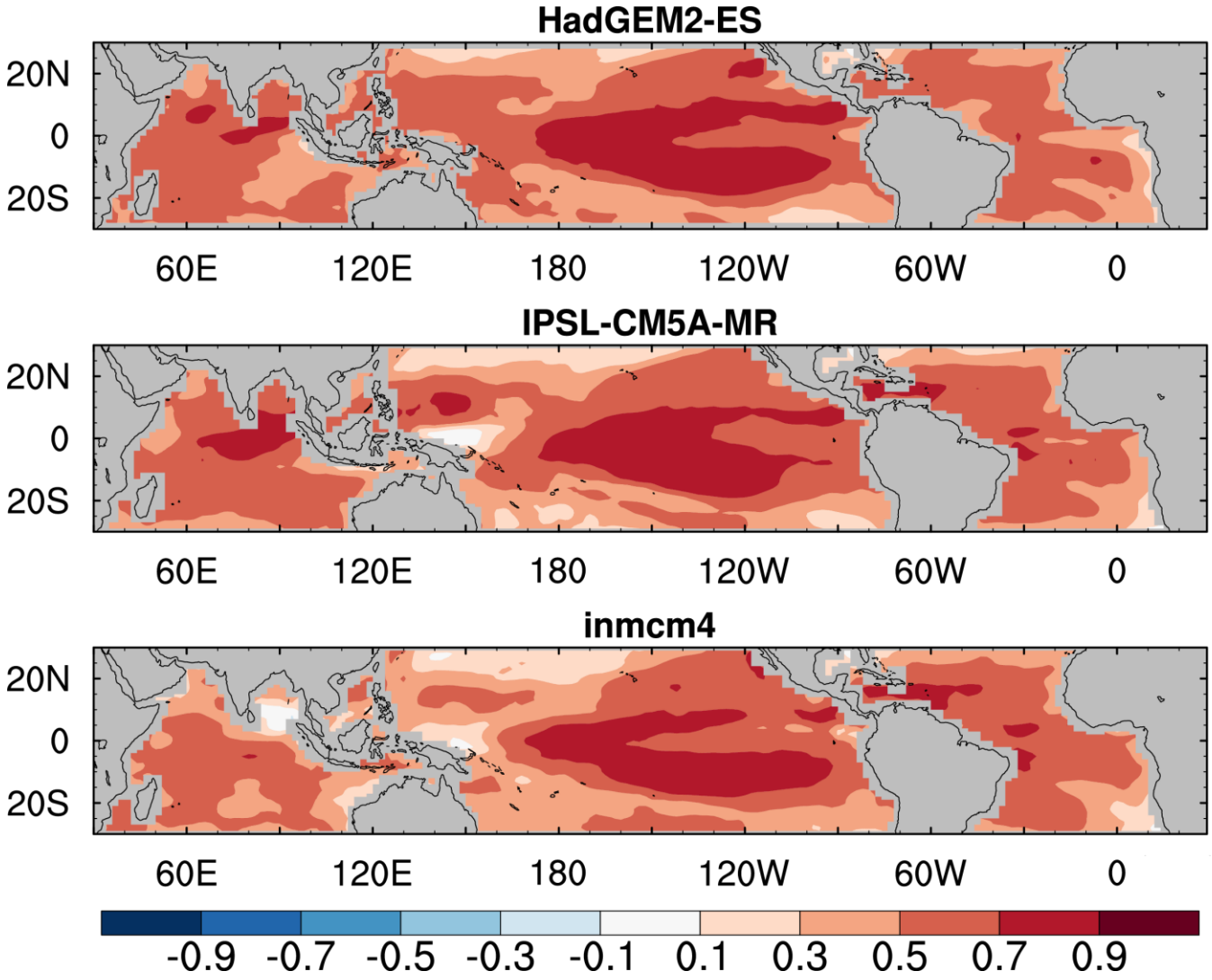


SST biases in some selected CMIP5 piControl models

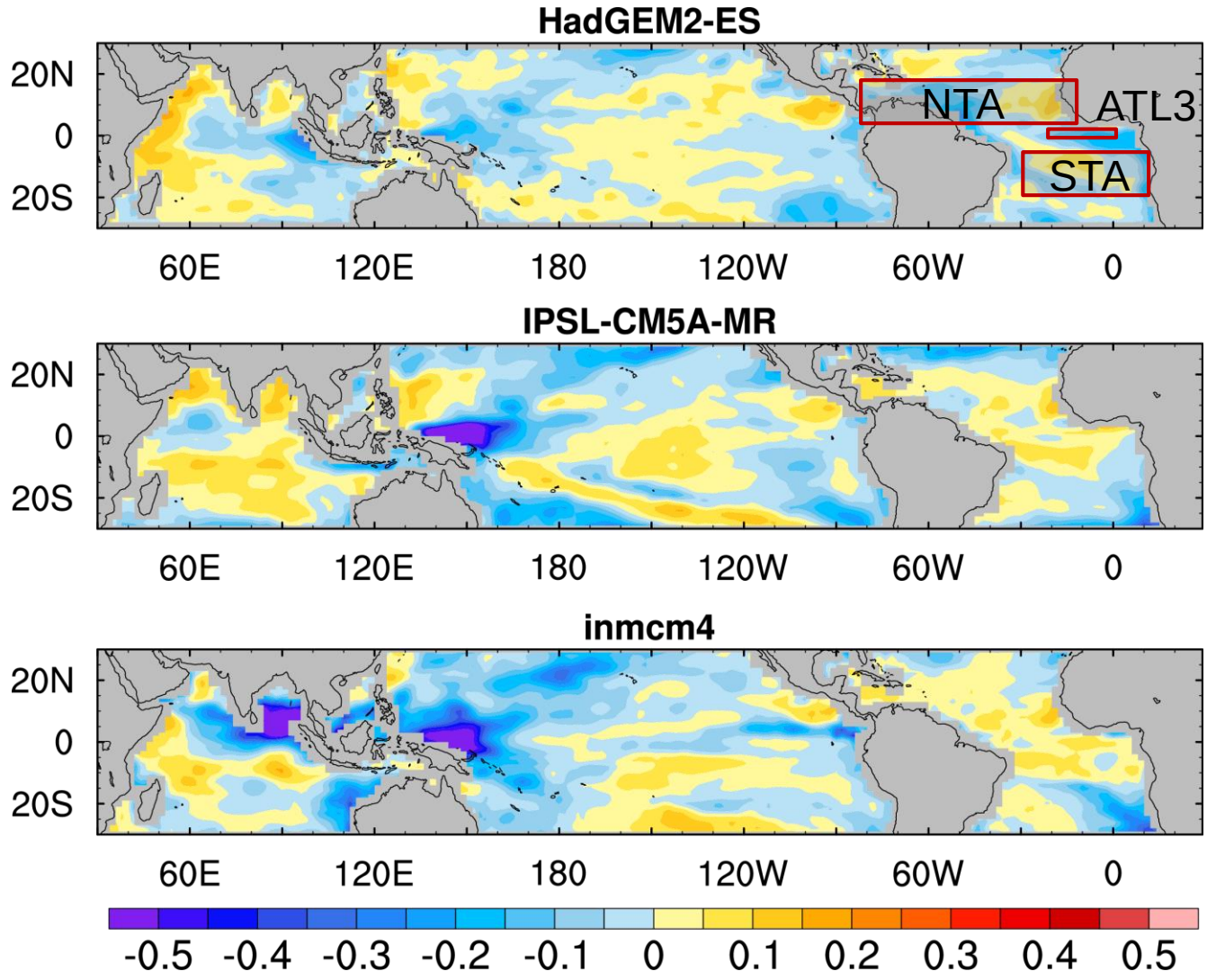


Anomaly correlation (ACC) of LIM prediction and NCEP-R (lead=3)

training: piControl; validation: 1948-2017 (NCEP-R)

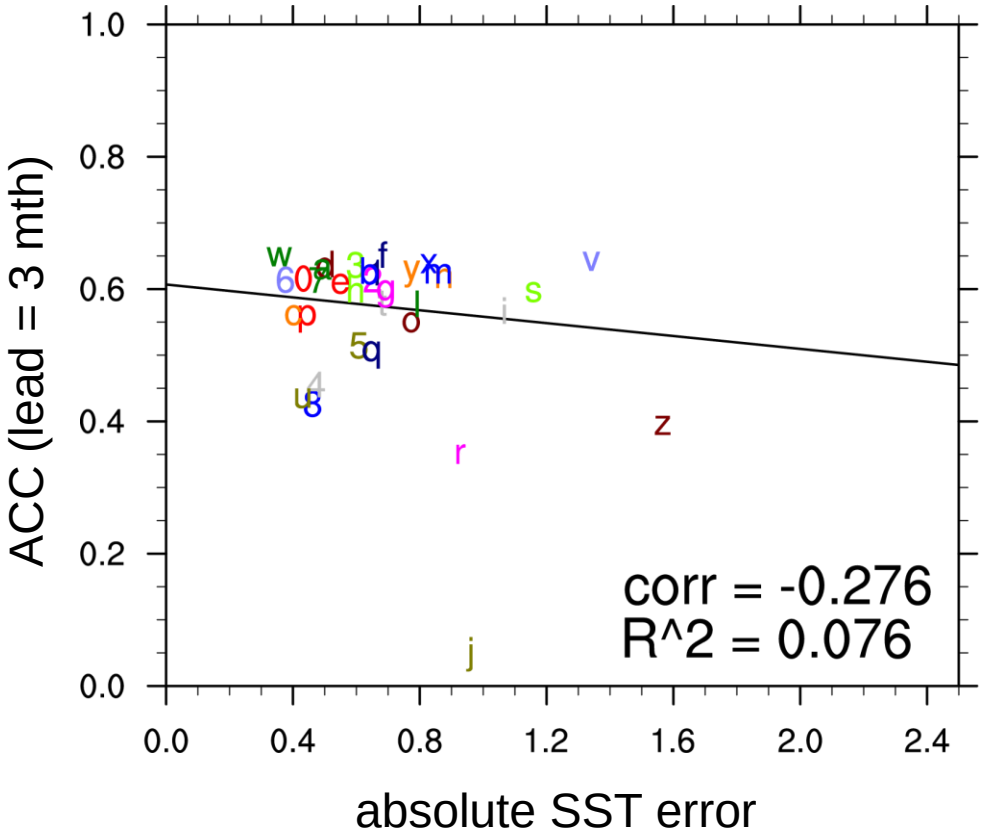


LIM ACC minus persistence (lead=3)



ATL3 SST: LIM ACC vs abs(error)

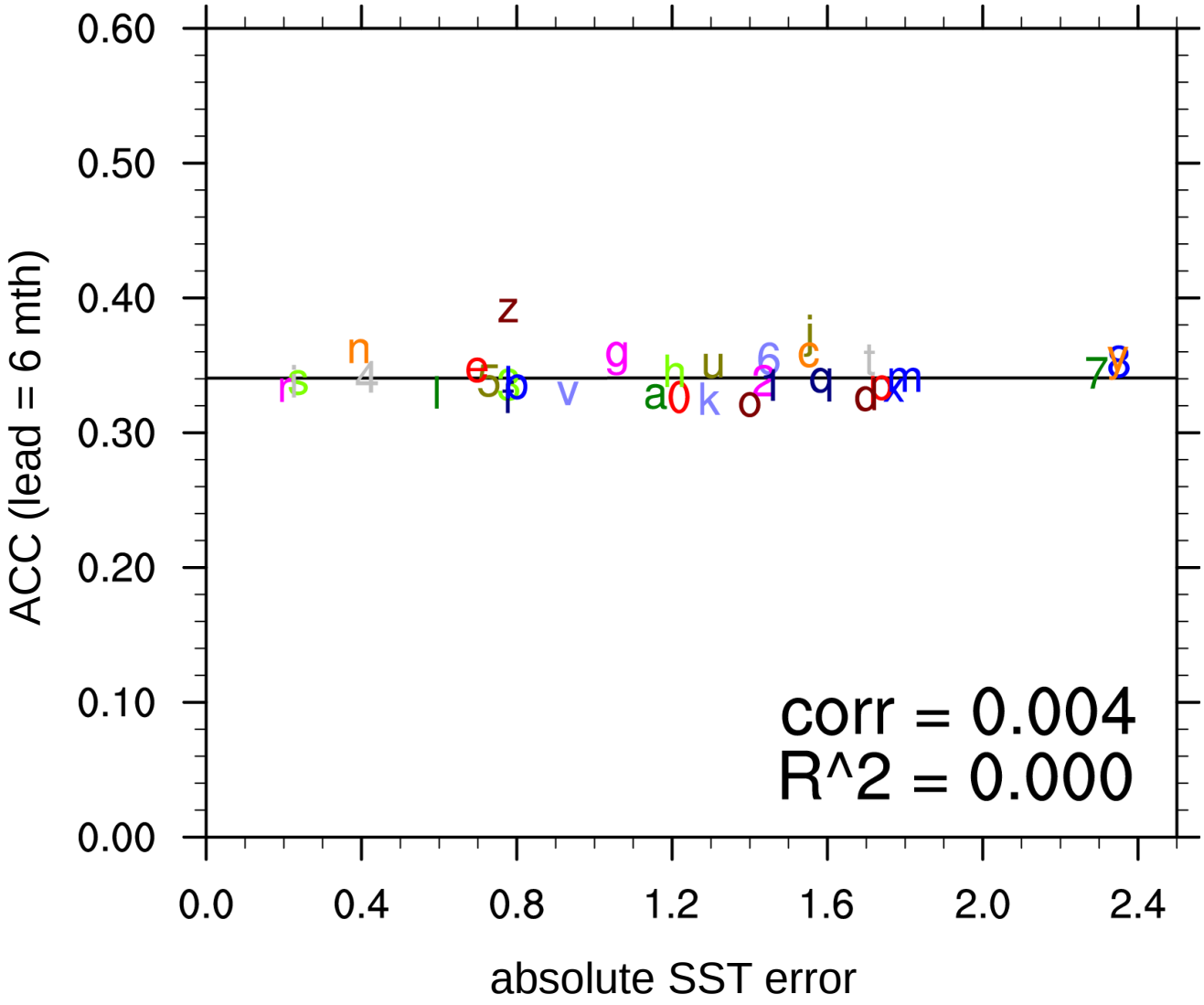
abs(error) averaged over seasonal cycle



a	ACCESS1-0	s	GISS-E2-R
b	ACCESS1-3	t	HadGEM2-CC
c	bcc-csm1-1	u	HadGEM2-ES
d	bcc-csm1-1-m	v	inmcm4
e	BNU-ESM	w	IPSL-CM5A-LR
f	CanESM2	x	IPSL-CM5A-MR
g	CCSM4	y	IPSL-CM5B-LR
h	CESM1-CAM5	z	MIROC4h
i	CMCC-CM	0	MIROC5
j	CNRM-CM5	1	MIROC-ESM
k	CSIRO-Mk3-6-0	2	MIROC-ESM-CHEM
l	FGOALS-g2	3	MPI-ESM-LR
m	FGOALS-s2	4	MPI-ESM-MR
n	FIO-ESM	5	MPI-ESM-P
o	GFDL-CM3	6	MRI-CGCM3
p	GFDL-ESM2G	7	NorESM1-M
q	GFDL-ESM2M	8	NorESM1-ME
r	GISS-E2-H		

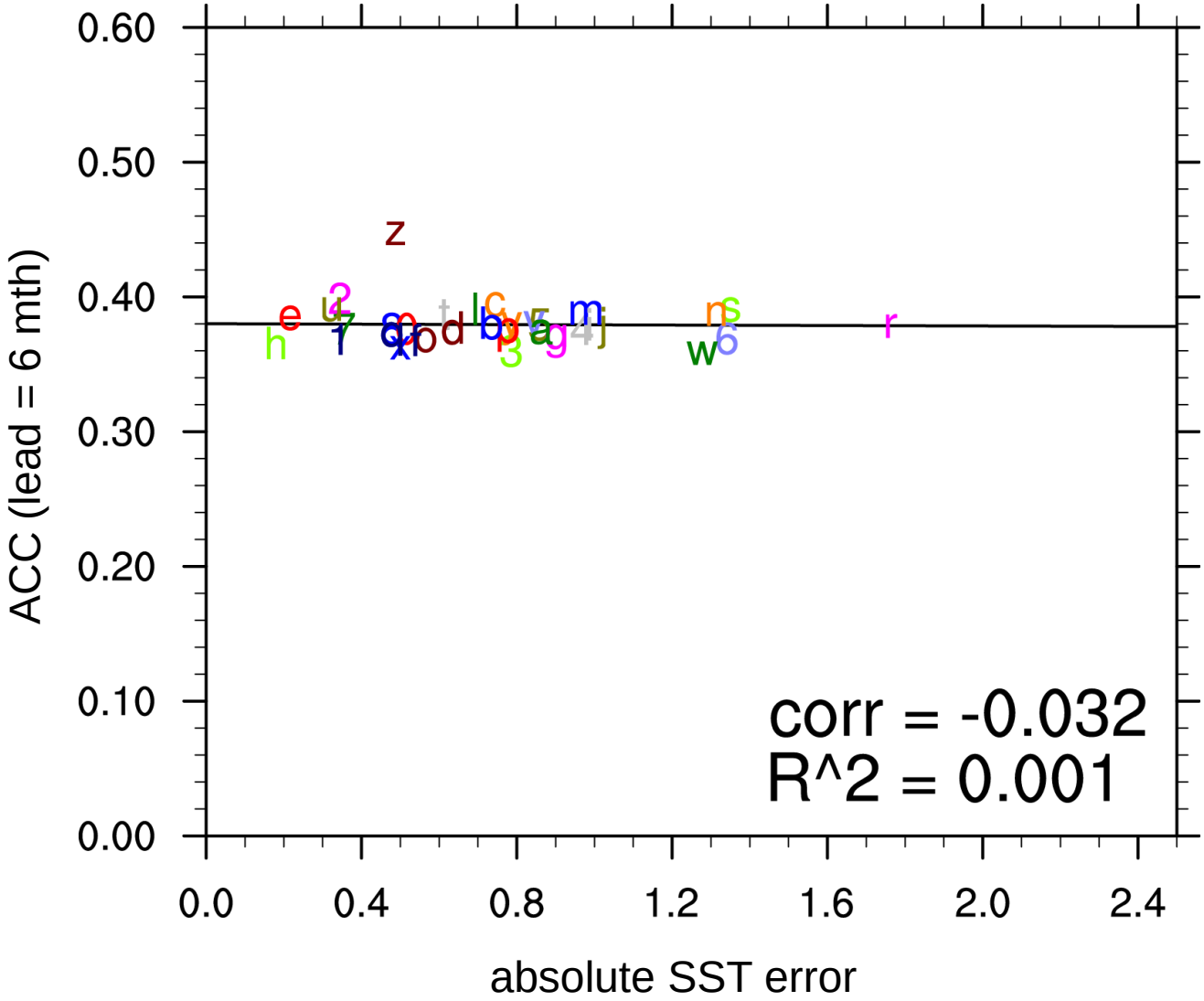
NTA SST: LIM ACC vs abs(error)

abs(error) averaged over seasonal cycle



STA SST: LIM ACC vs abs(error)

abs(error) averaged over seasonal cycle



Conclusions

- trained linear inverse model (LIM) on SST from piControl simulations
- LIMs perform better than most GCMs at predicting tropical Atlantic SSTs
- link to mean-state SST biases weak to non-existent
- further evidence that mean-state biases not the main reason for poor prediction skill

Caveats/Future work

- only preliminary results; further analysis necessary
  - seasonal stratification
  - different metrics of model performance
  - sensitivity to hindcast period
- construct more complete statistical model using additional variables: sfc wind, thermocline depth

Linear inverse model (LIM)

linear system:

$$\frac{d\boldsymbol{x}}{dt} = L\boldsymbol{x} + \boldsymbol{\xi}(\boldsymbol{t})$$

x: state vector; L: linear operator (matrix); ξ(t): noise forcing

integration:

$$x(t + \tau_0) = \exp(L\tau_0)\, x(t)$$

solve for L:

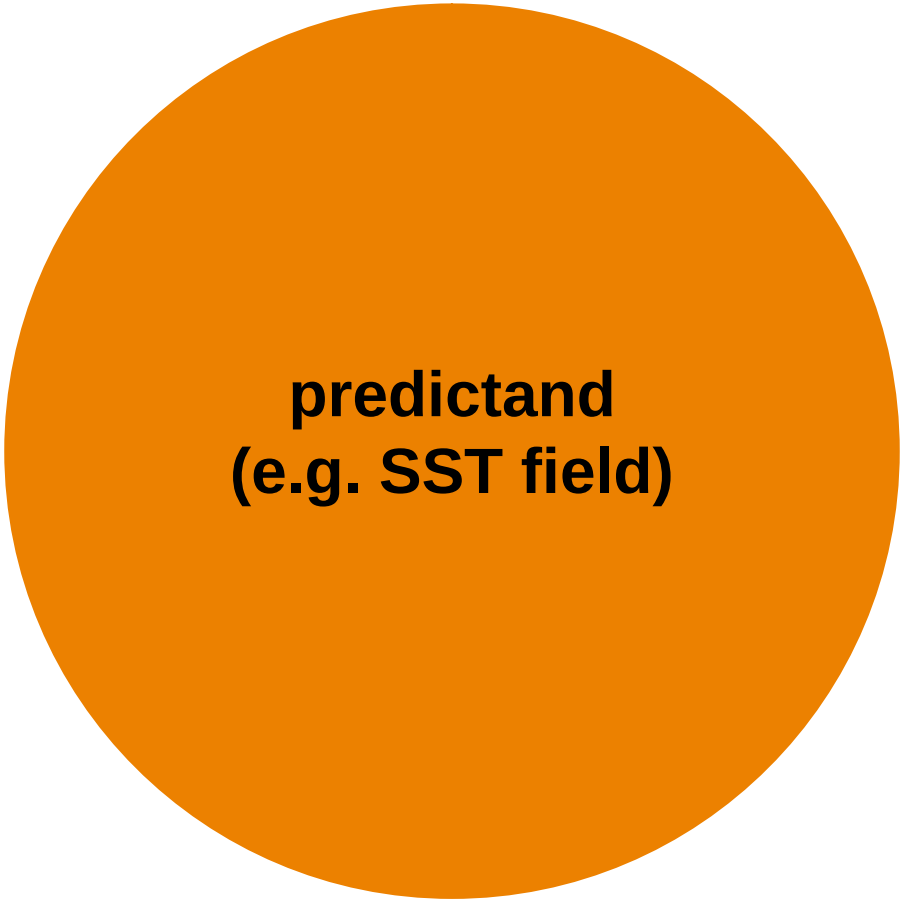
$$L = \tau_0^{-1} \ln\{\mathrm{C}(\tau_0) C(0)^{-1}\}$$

with $C(\tau_0) = \langle x(t + \tau_0) x^T(t) \rangle,\ C(0) = \langle x(t) x^T(t) \rangle$

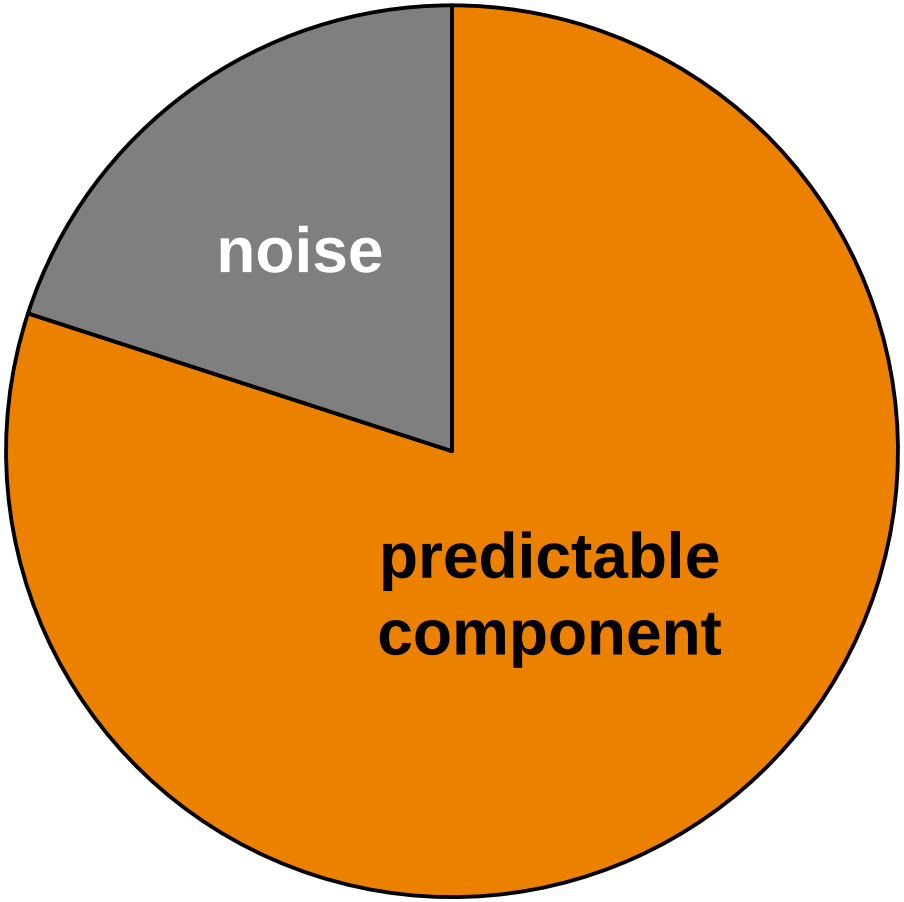
The pie of predictability

The pie of predictability

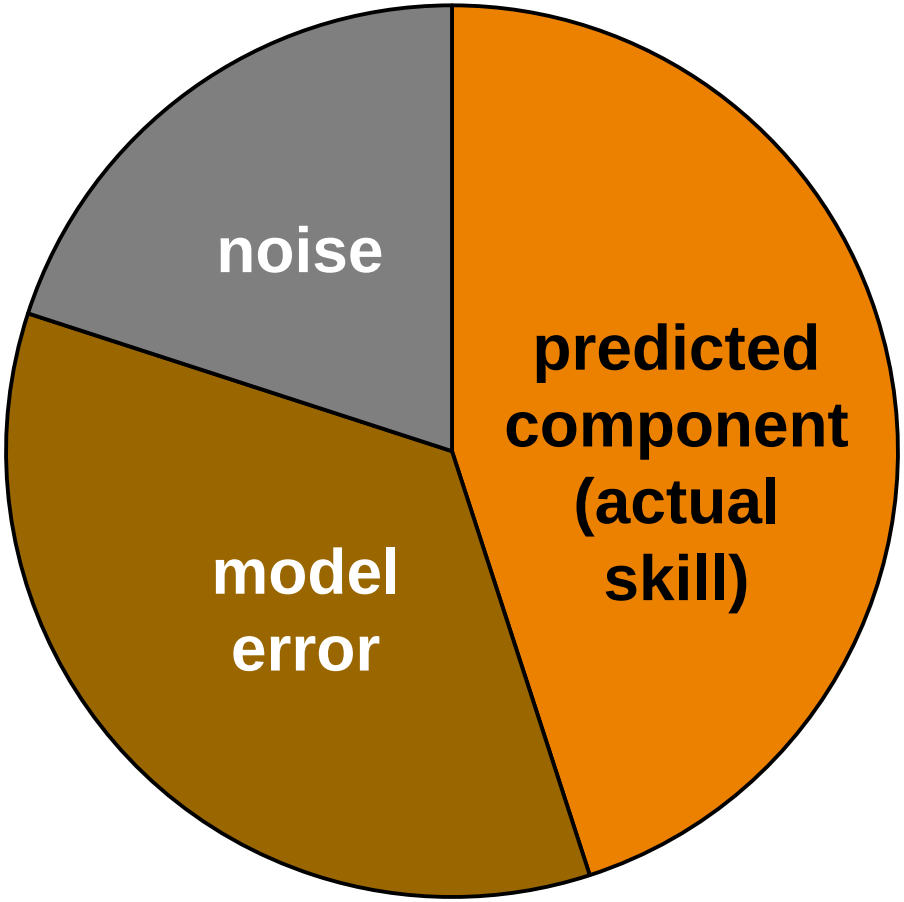
(idealized model)



Noise takes out one bite



Noise and model error



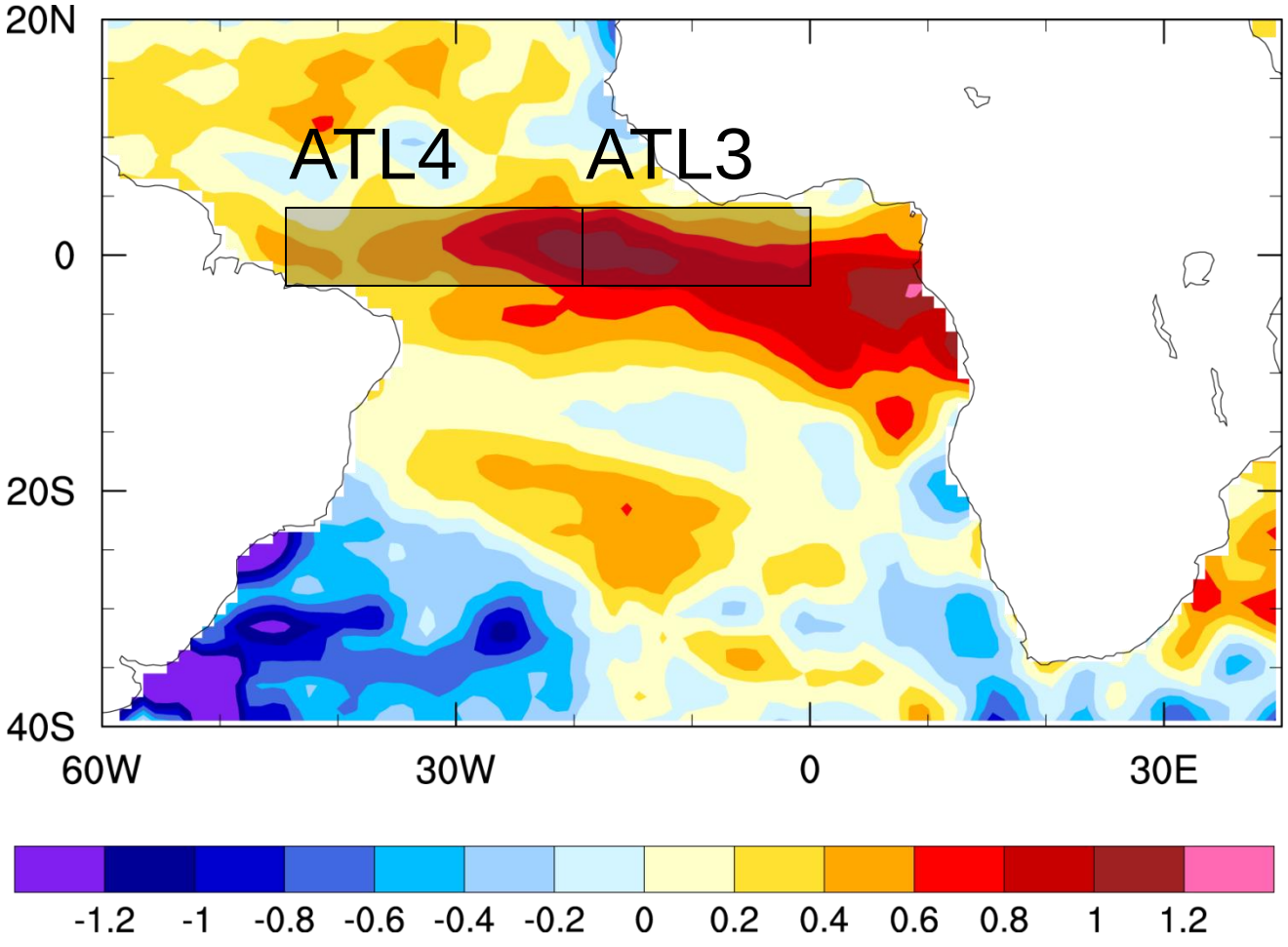
Equatorial Atlantic variability

Interannual Variability in the equatorial Atlantic

- warm events (Atlantic Niños) preferentially occur in boreal summer
- typical amplitude: 1K
- impact on rainfall over the surrounding continents
- coupled air-sea feedbacks (Bjerknes feedback) are thought to play a role

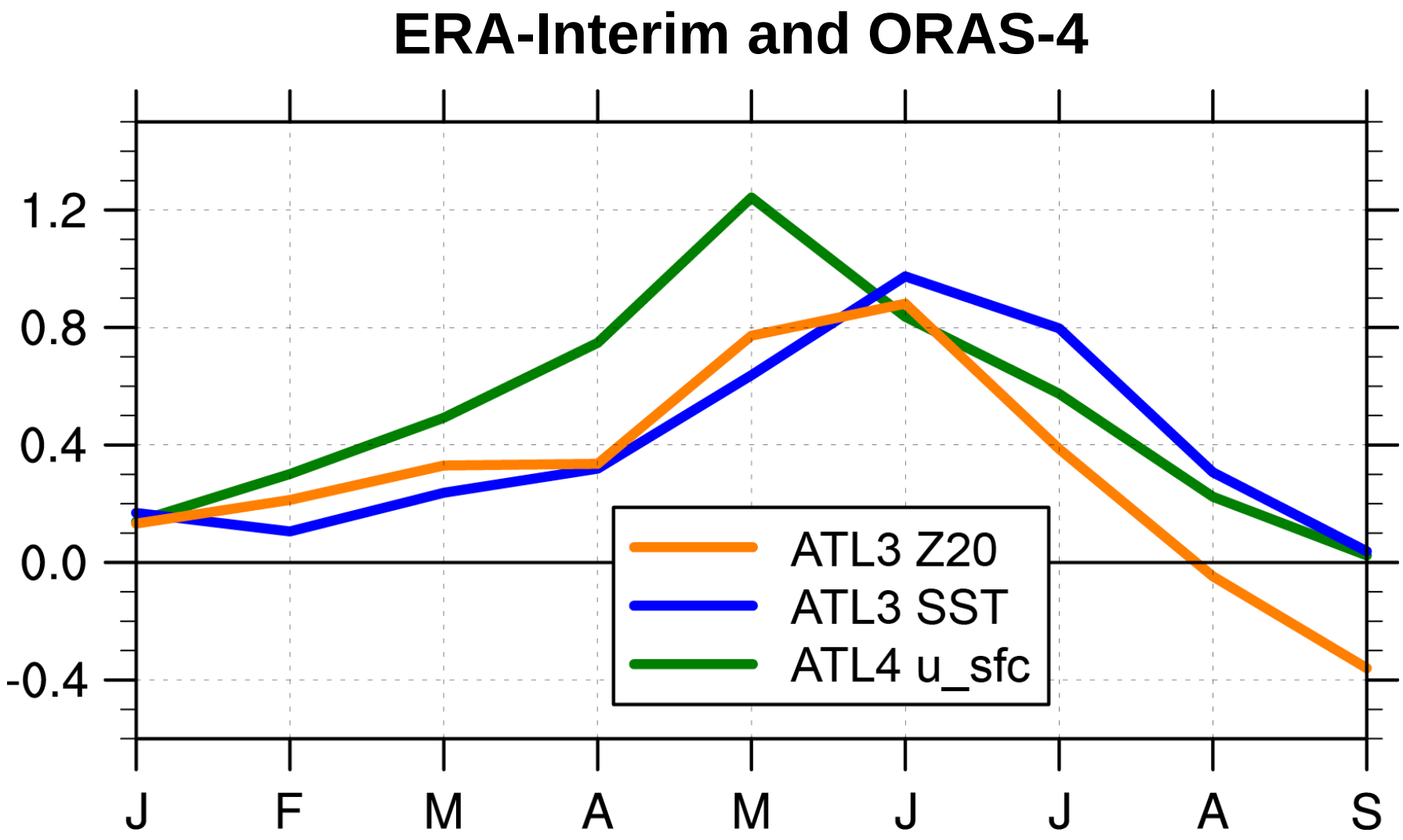
Example of an Atlantic Niño: 1988 event

JJA SST anomalies [K]; dataset: OISST

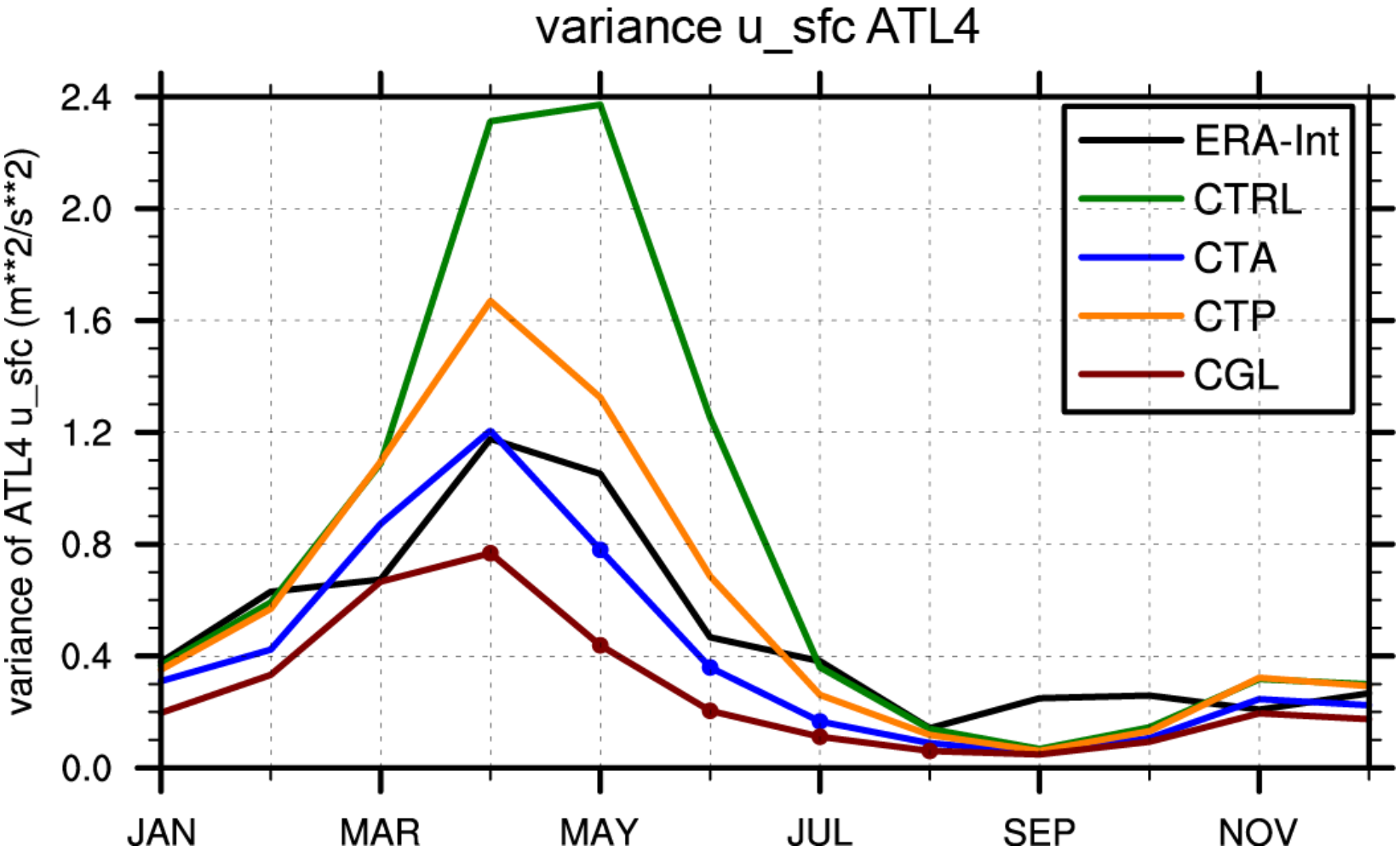


Composite evolution of Atlantic Niños

units: K (SST), m/s (U), 0.1*m (Z20)

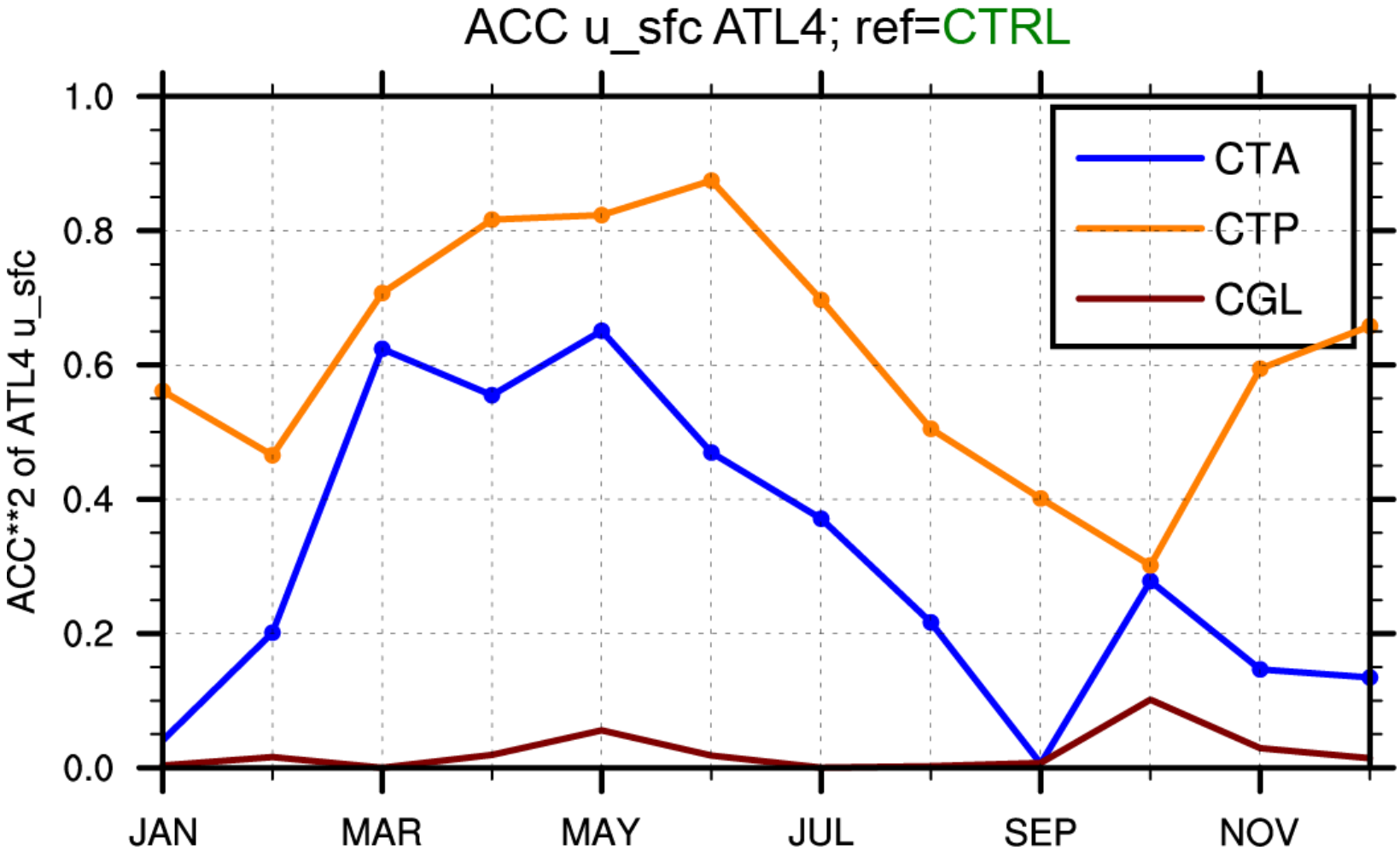


ATL4 variance of sfc zonal wind



ATL4 ACC of sfc zonal wind

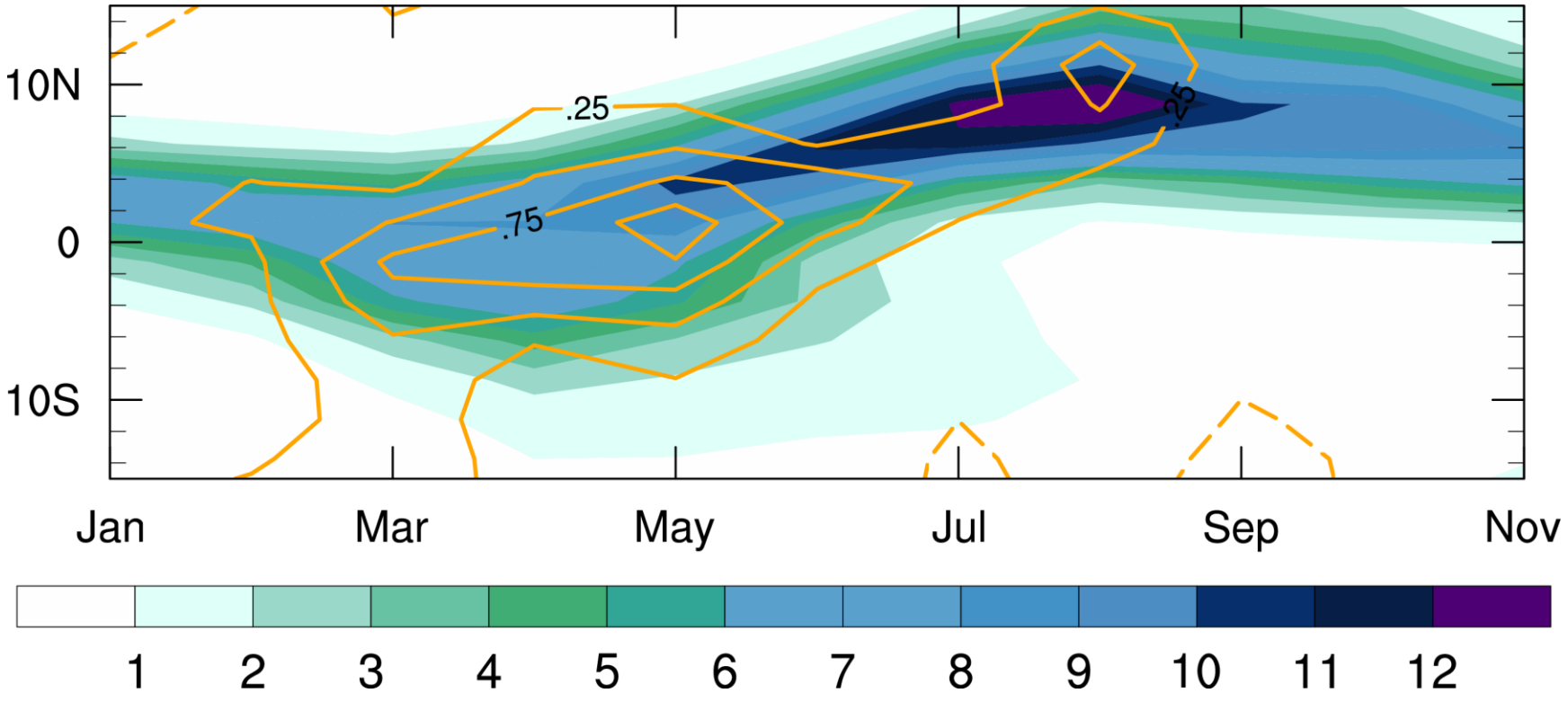
ACC calculated with respect to CTRL



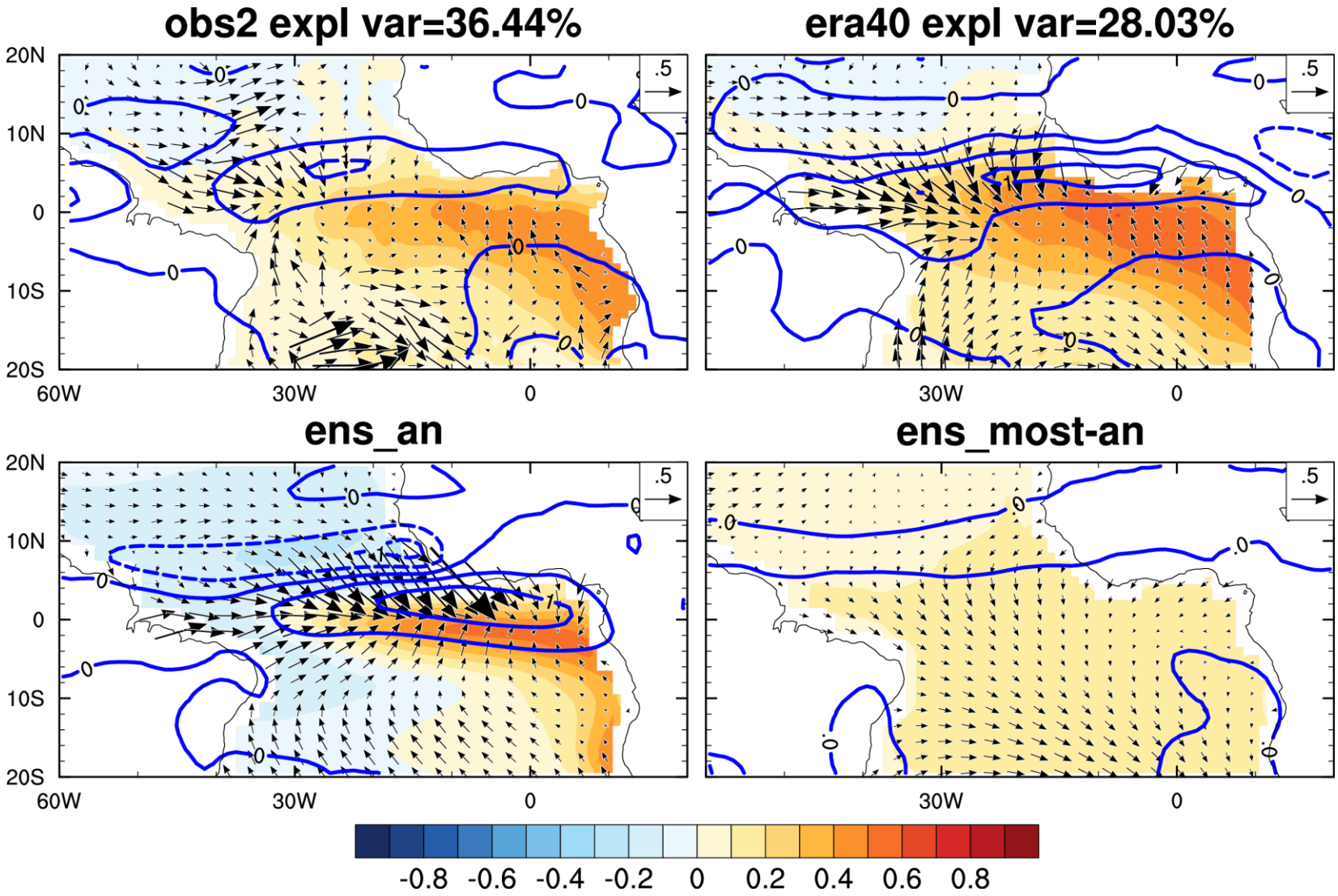
Composite lat-time section of Atl Niño

precip (shd; mm/d) and sfc zonal wind (cnt; m/s)

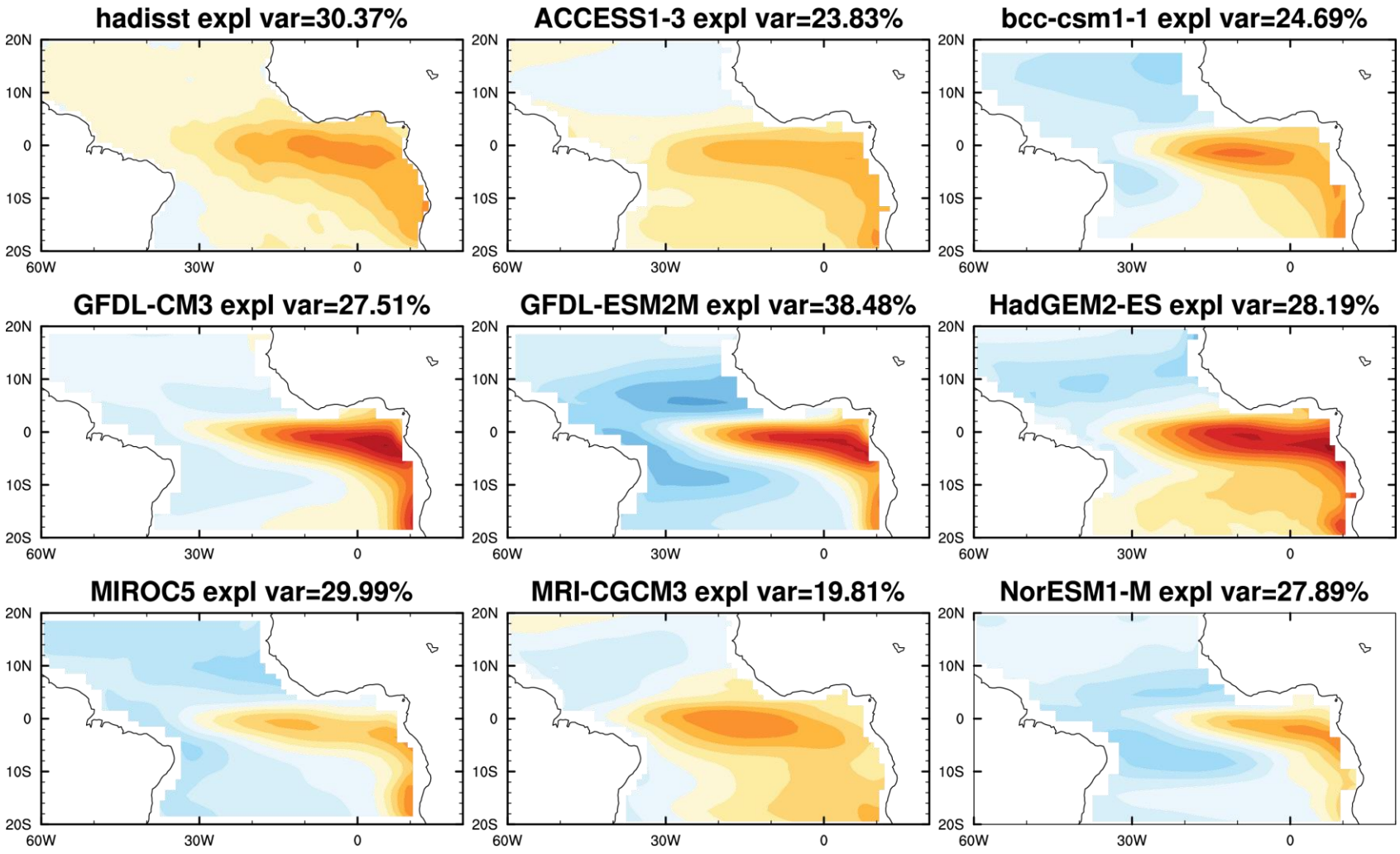
data: GPCP and ERA-Int; ave: 40-10W



EOF#1 of JJA SST (shading; K) and regressed sfc wind stress (vectors) and precip (contours; CI=0.5 mm/day)

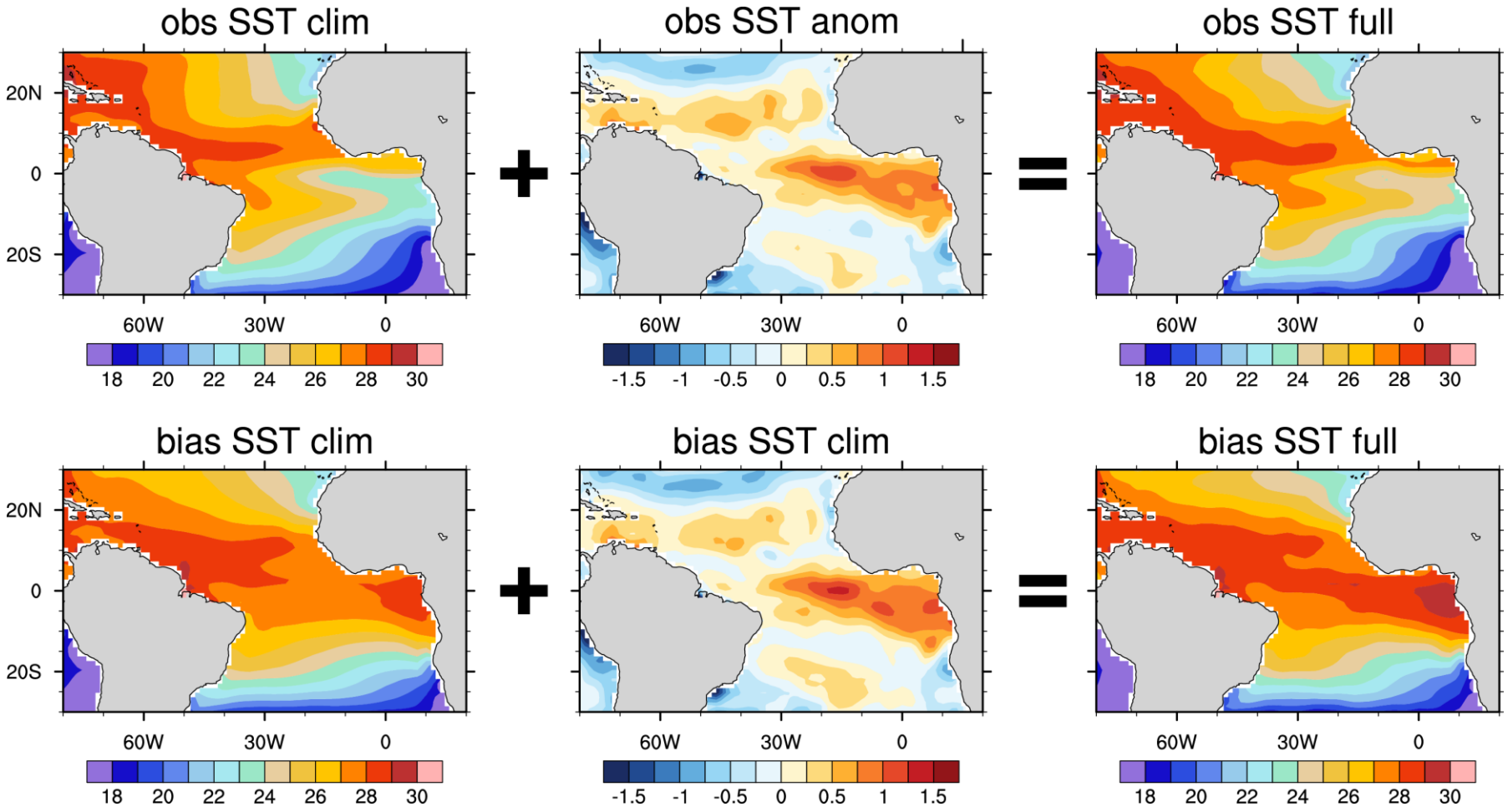


EOF#1 of JJA SST in HadISST (1950-2010) and CMIP5 models



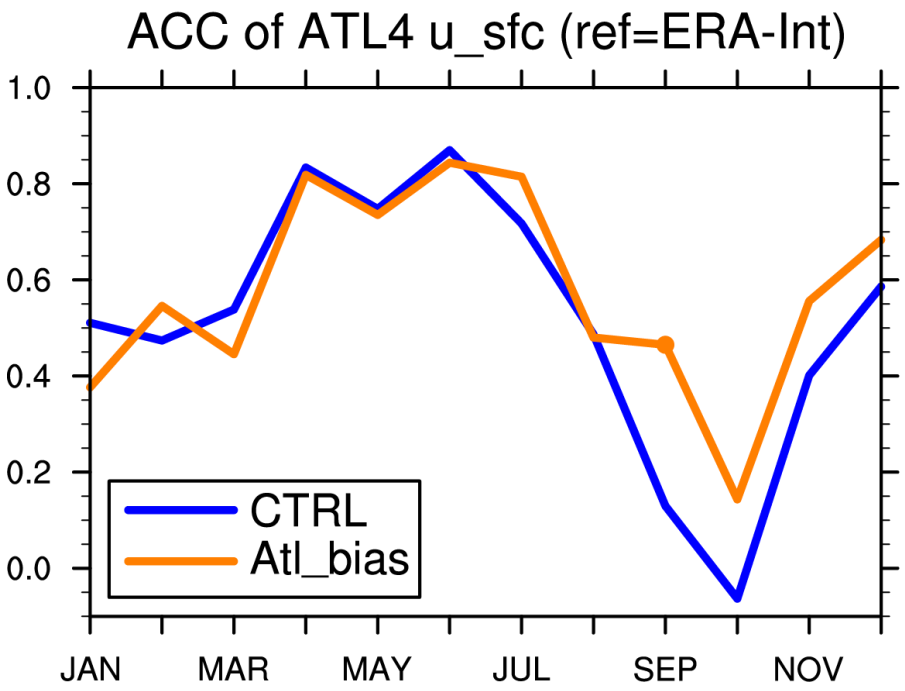
July 1988 SST in CTRL and Atl_bias

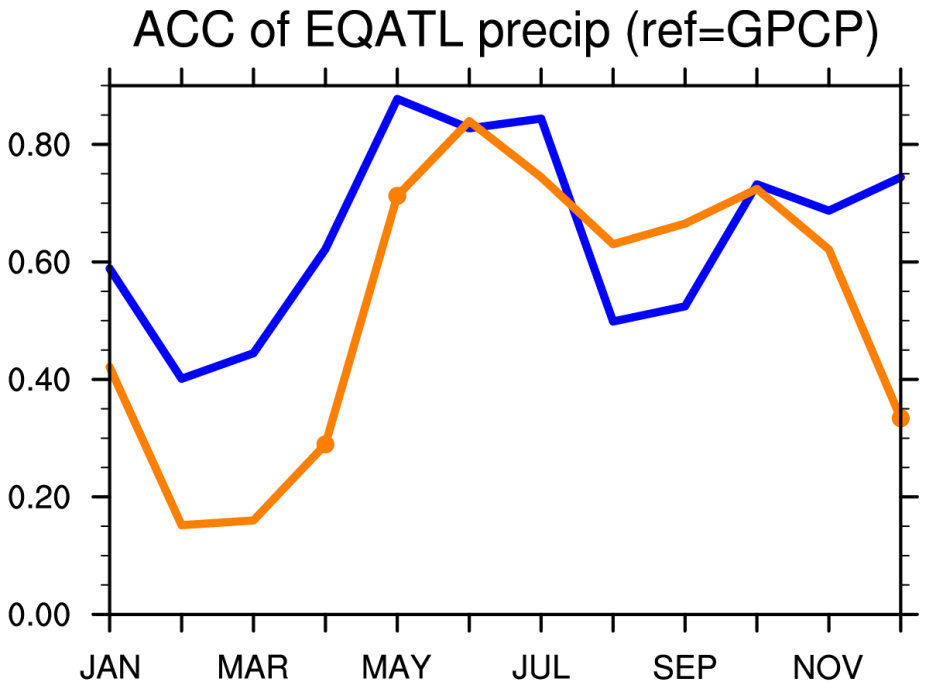
Atlantic Niño event



ACC of ATL4 u_sfc and eqAtl precip

SINTEX-F bias experiments





Richter et al. 2017, revised