TTA 2014, ICTP, Trieste, 23 June – July 4, 2014

Teleconnections of the tropical Atlantic to the South Asian monsoon, Indian Ocean and Pacific

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Thanks to collaborators: F. S. Syed, J. H. Yoo, H., R. Barimalala, A. Bracco, F. Molteni, I-S. Kang, R. Farneti, L. Feudale, A. Burhan, F. Ikram, A. Gohar

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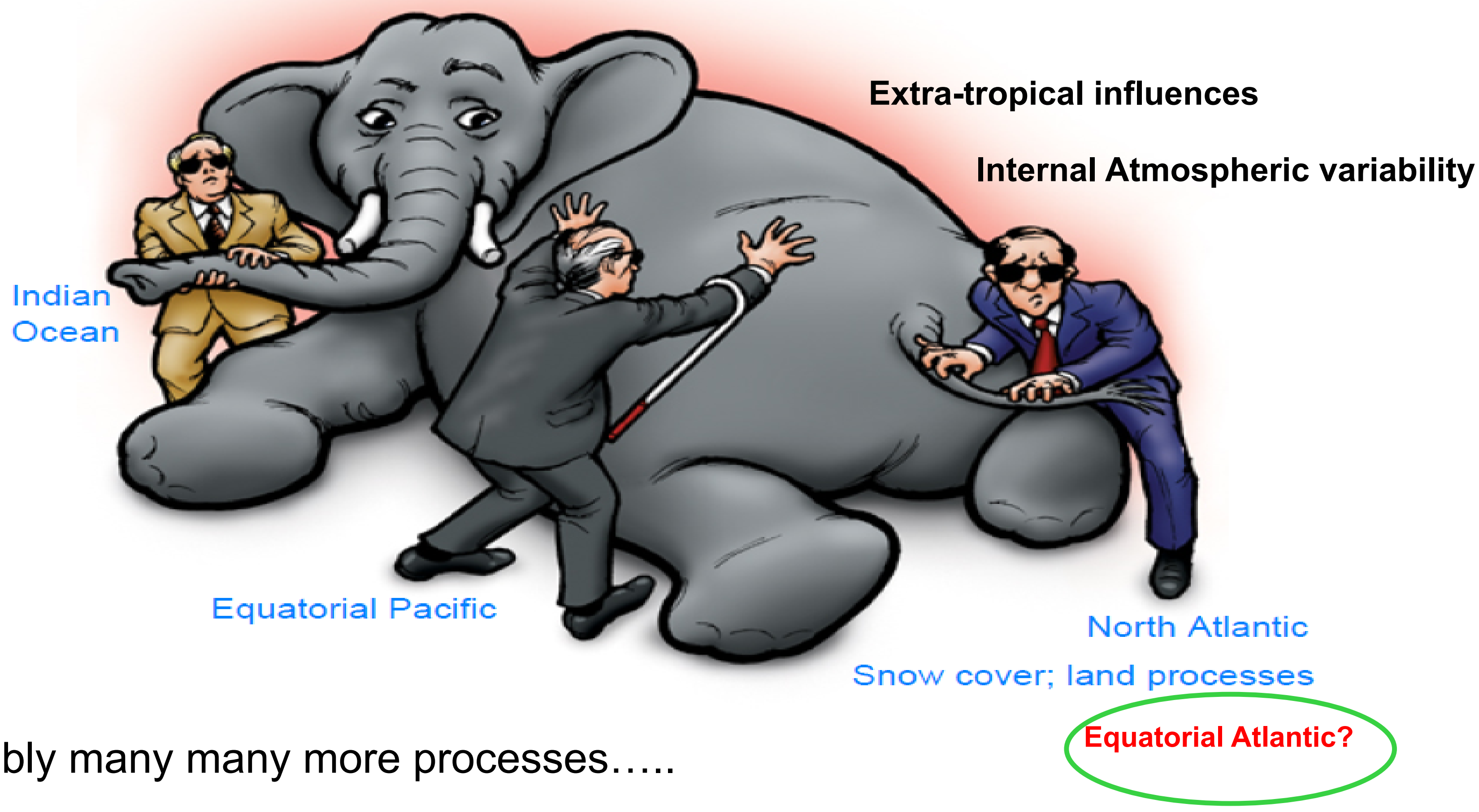
A) Influence of tropical Atlantic on South Asian Monsoon and Indian Ocean

Results published in: Kucharski et al., 2007, J Climate, 20, 4255-4266, Kucharski et al., 2008, GRL, 35, L04706, Kucharski et al, 2009, QJRMS, 135, 569-579, Wang et al., Meteorolog. Z., Aug, 2009, Barimalala et al., Clim Dyn, 2012, 38, 1147-1166, Barimalala et al., 2013, J Marine Sys., 117-118, 14-30

Sources of Monsoon Variability?



Probably many many more processes…..

Slide taken from presentation of Mark Cane at TTA 2008 at ICTP

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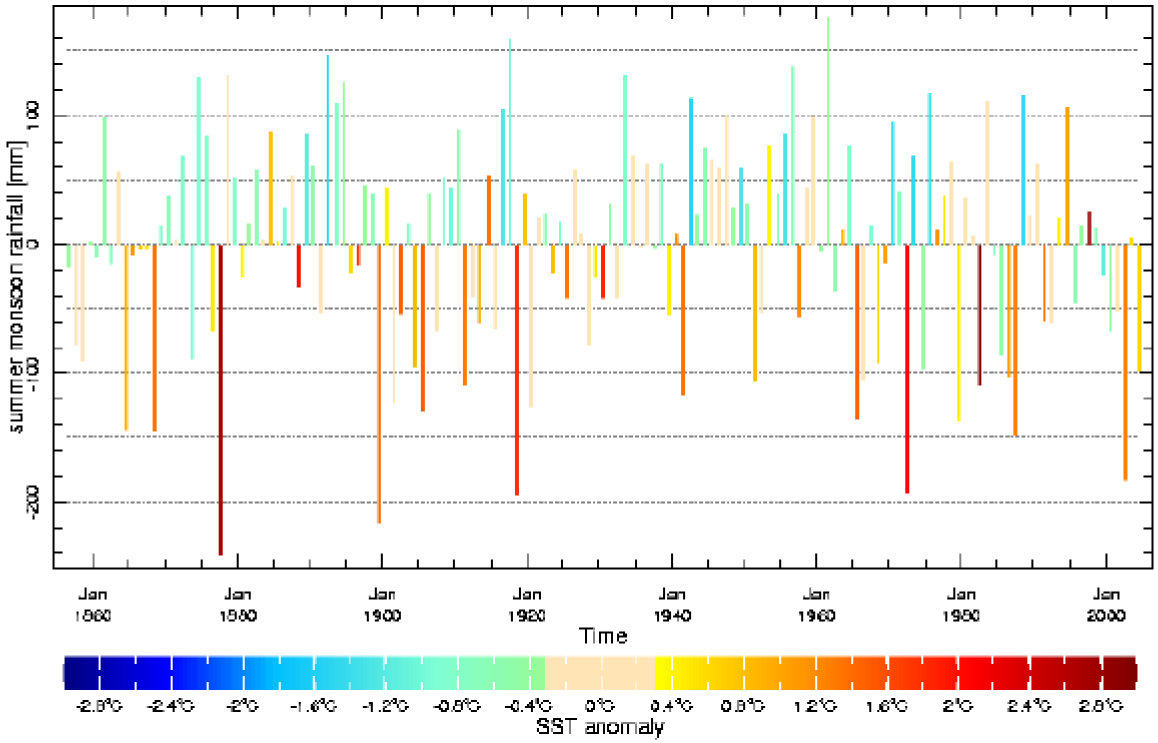
The India Rainfall - ENSO connection



Rainfall Data: Indian Institute of Tropical Meteorology (IITM).

SST Data: Kaplan NINO3 index from Optimal Smoother analysis of MOHSST5 monthly sea surface temperature anomalies.

Slide taken from presentation of Mark Cane at TTA 2008 at ICTP

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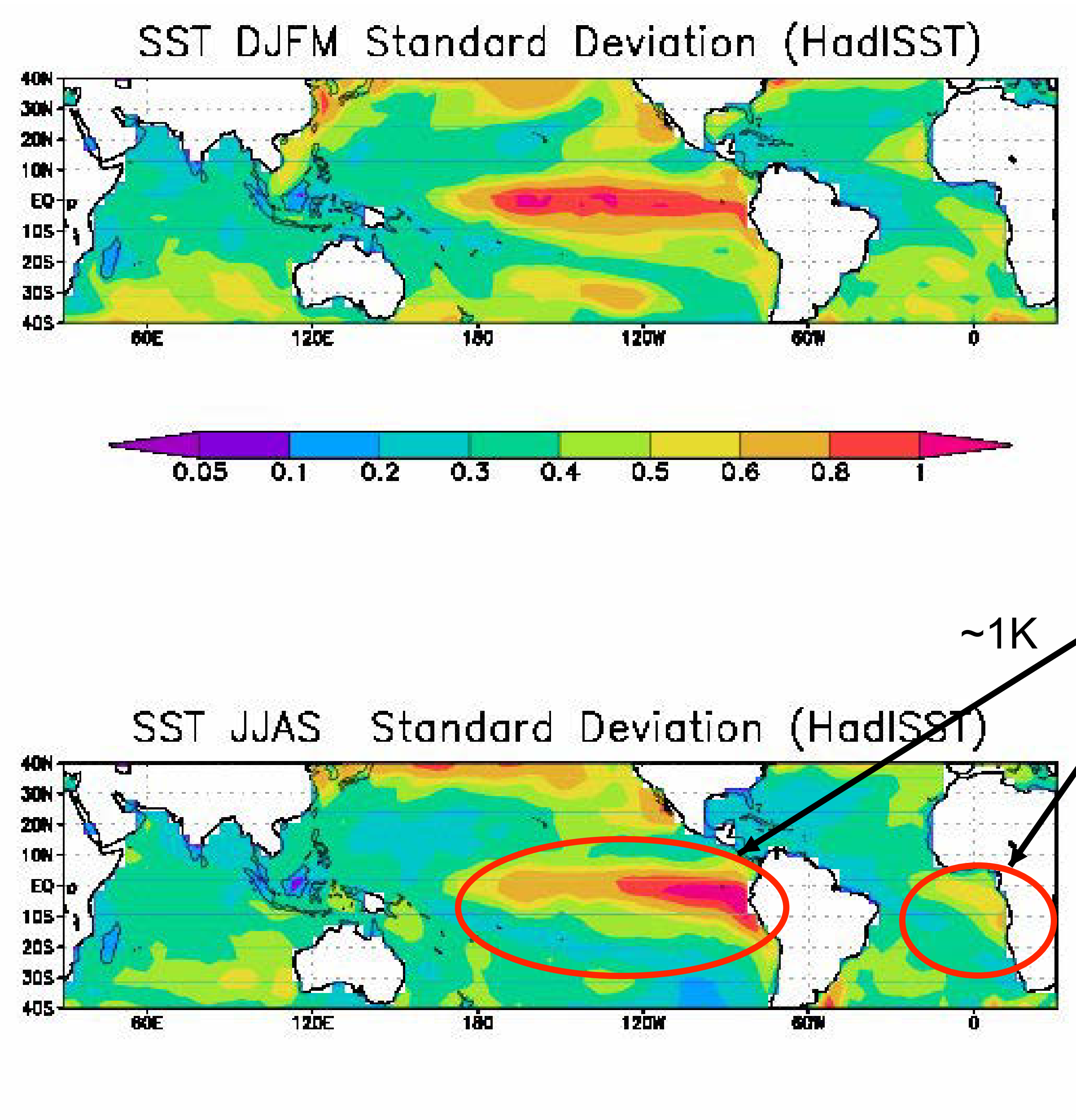
Interannual SST standard deviation



DJFM

In JJAS, two distinct Maxima in STDEV

~0.5 K

JJAS

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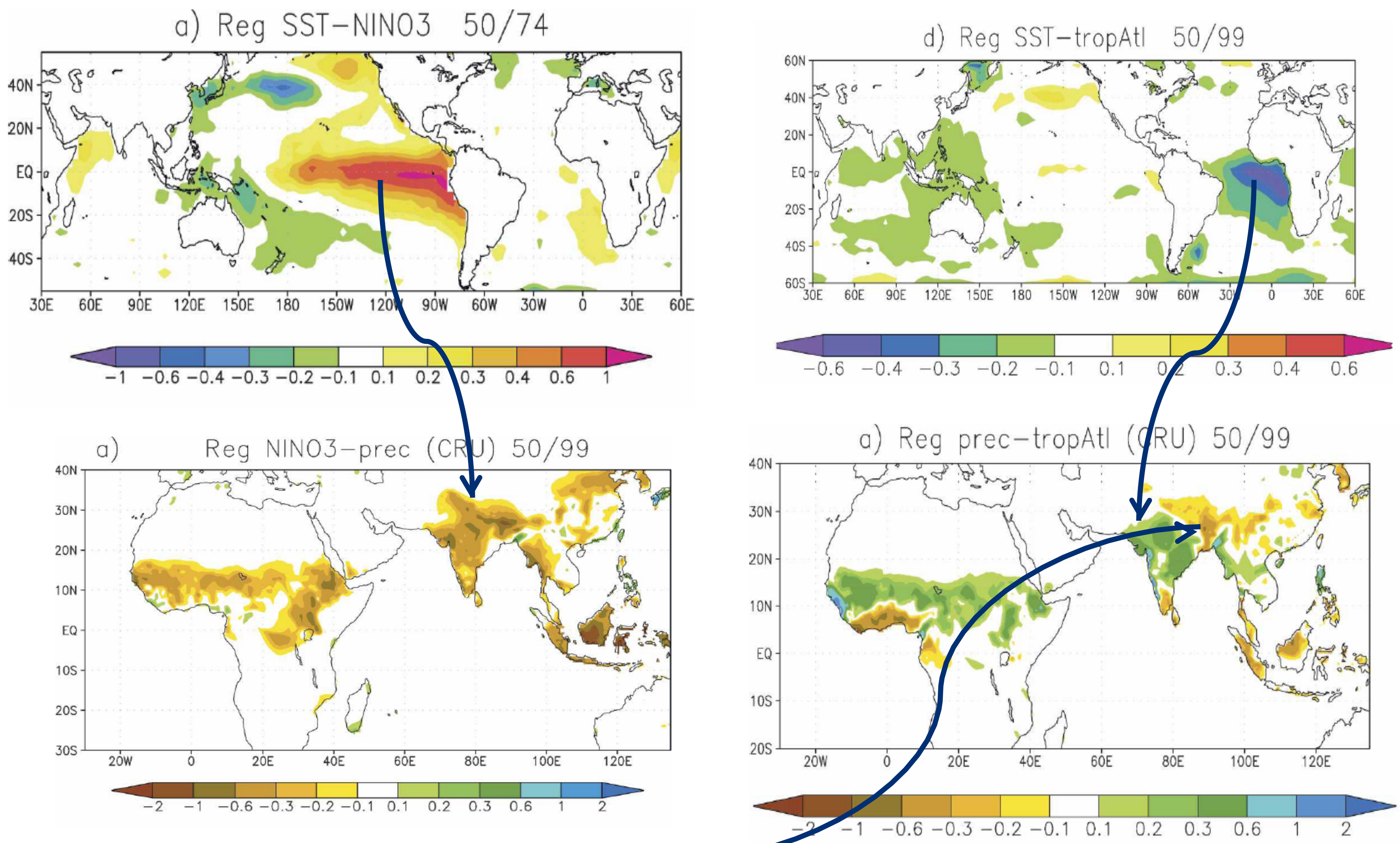
Contrasting Eastern Pacific and tropical Atlantic influences.



There are some interesting regional features, too!

Warm anomalies in Eq. Pacific and Atlantic have broadly very similar influences on Asian (and African) Monsoon!

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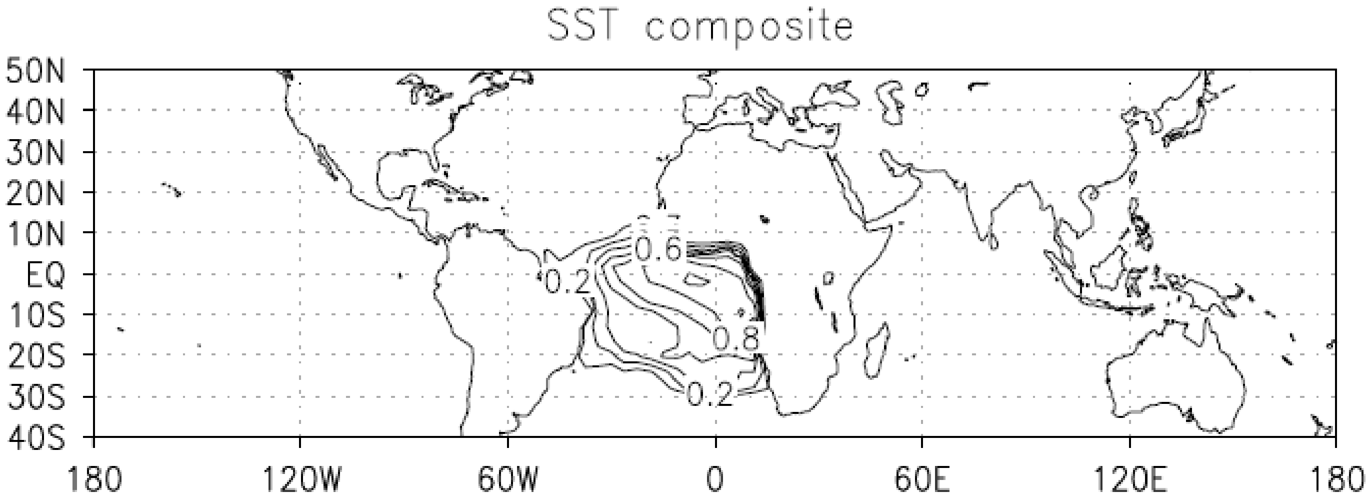
Atlantic El Nino?



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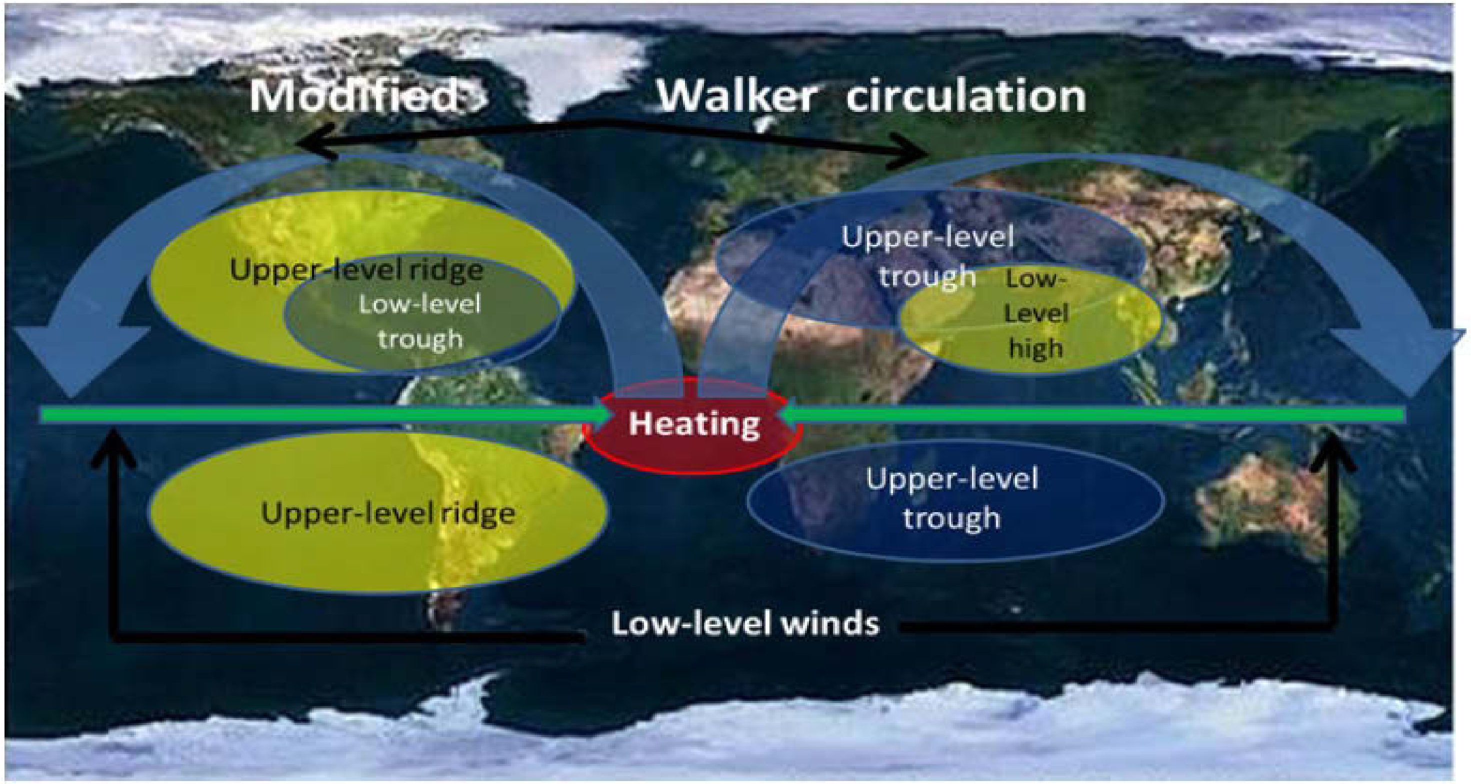
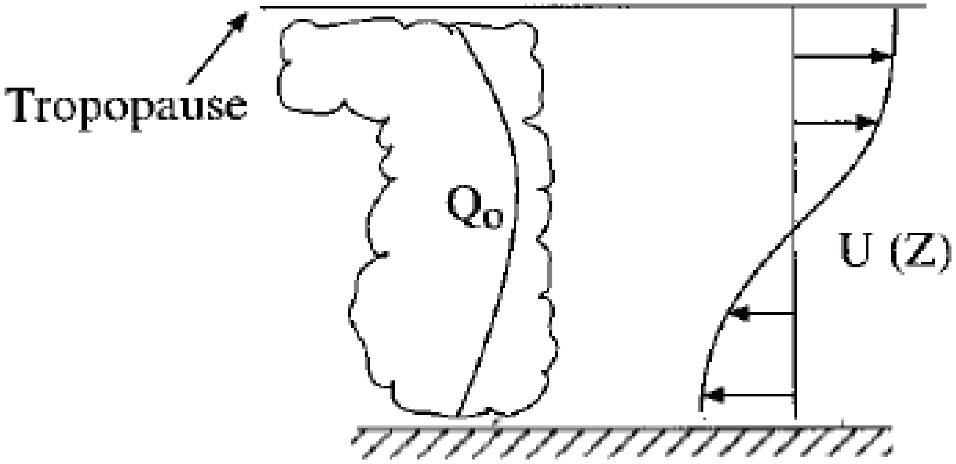
Tropical Atlantic link has been noticed in Yadav, Clim Dyn, (2008), Rajeevan and Sridhar, GRL, (2009), Li et al., GRL, (2008), Losada et al. (2009)



Gill-type response (explain!) leads to upper-level cyclonic and low-level anticyclonic response over South Asia, leading to low-level divergence and reduced rainfall. Response is locally enhanced by diabatic heating in monsoon region. Similar mechanism has been proposed by Xie et al. (2009), J Climate, to a similar mechanism to physically describe the influence of the Indian Ocean SST on the subtropical western Pacific.

From paper: Barimalala et al., Clim Dyn, 2012, 38, 1147-1166

Gill (1980) response to heating Q_o



$Q_o = Q_{evap} + Q_{conv}$

A. E. GILL

: the buoyancy equation.
ponse to steady forcing, dissipative processes must be included
ent is the so-called 'Rayleigh friction' and 'Newtonian cooling'
:rator $\partial/\partial t$ by $\partial/\partial t + \varepsilon$. The mathematics is simplest when the
ne as the one for cooling, so the steady-state versions of Eqs.

$$\varepsilon u - \tfrac{1}{2} y v = -\frac{\partial p}{\partial x}, \qquad (2.6)$$

$$\varepsilon v + \tfrac{1}{2} y u = -\frac{\partial p}{\partial y}, \qquad (2.7)$$

$$\varepsilon p + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = -Q, \qquad (2.8)$$

$$w = \varepsilon p + Q. \qquad (2.9)$$

This model was used by Matsuno (1966).

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Gill (1980) response to heating Q_c

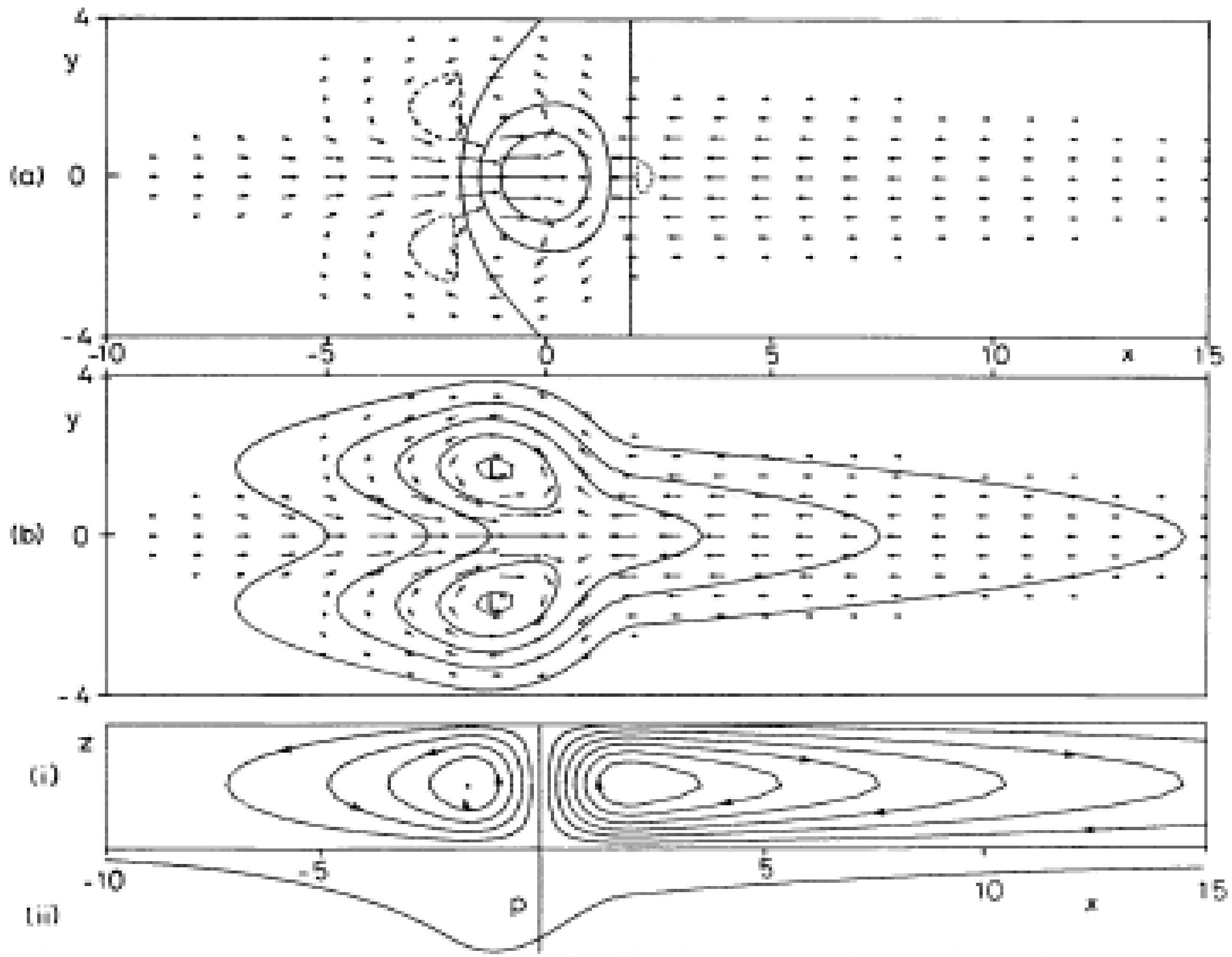

Figure 1. Solution for heating symmetric about the equator in the region $|x| < 2$ for decay factor $\varepsilon = 0{\cdot}1$.
(a) Contours of vertical velocity w (solid contours are 0, 0·3, 0·6, broken contour is −0·1) superimposed on the velocity field for the lower layer. The field is dominated by the upward motion in the heating region where it has approximately the same shape as the heating function. Elsewhere there is subsidence with the same pattern as the pressure field.

(b) Contours of perturbation pressure p (contour interval 0·3) which is everywhere negative. There is a trough at the equator in the easterly régime to the east of the forcing region. On the other hand, the pressure in the westerlies to the west of the forcing region, though depressed, is high relative to its value off the equator.
Two cyclones are found on the north-west and south-west flanks of the forcing region.

(c) The meridionally integrated flow showing (i) stream function contours, and (ii) perturbation pressure. Note the rising motion in the heating region (where there is a trough) and subsidence elsewhere. The circulation in the right-hand (Walker) cell is five times that in each of the Hadley cells shown in (c).

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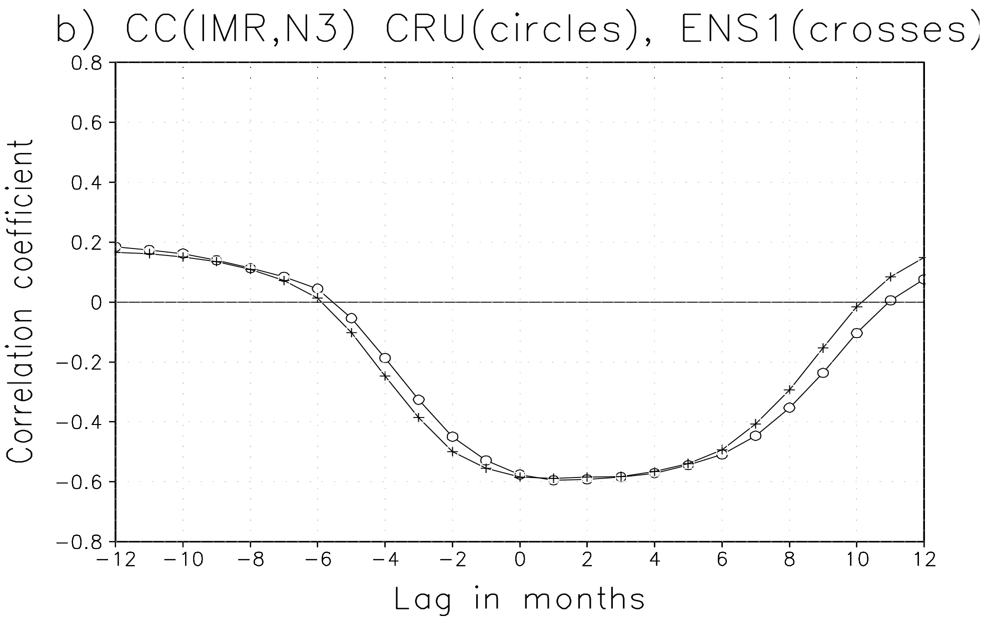
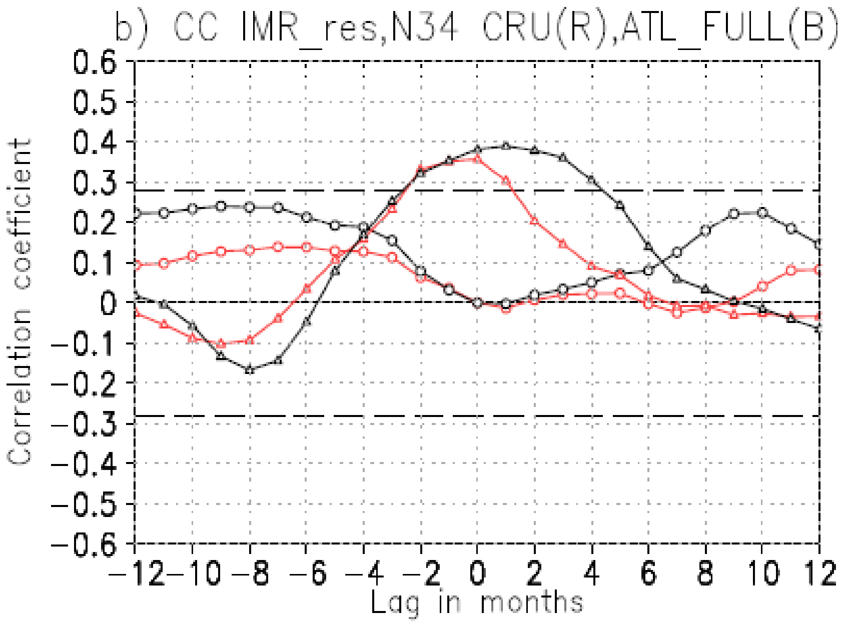
Lead-lag correlations between an IMR index (CRU-based) and Nino3 and a south tropical Atlantic Index (period: 1950 to 2000)





From Kucharski et al. J Clim., (2007) and Kucharski et al. GRL, (2008)

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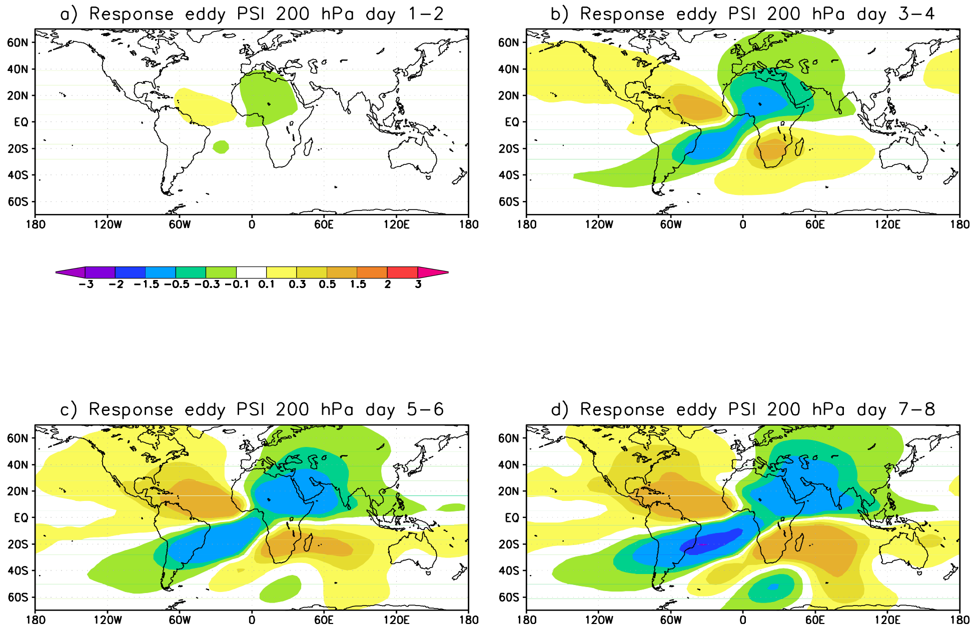
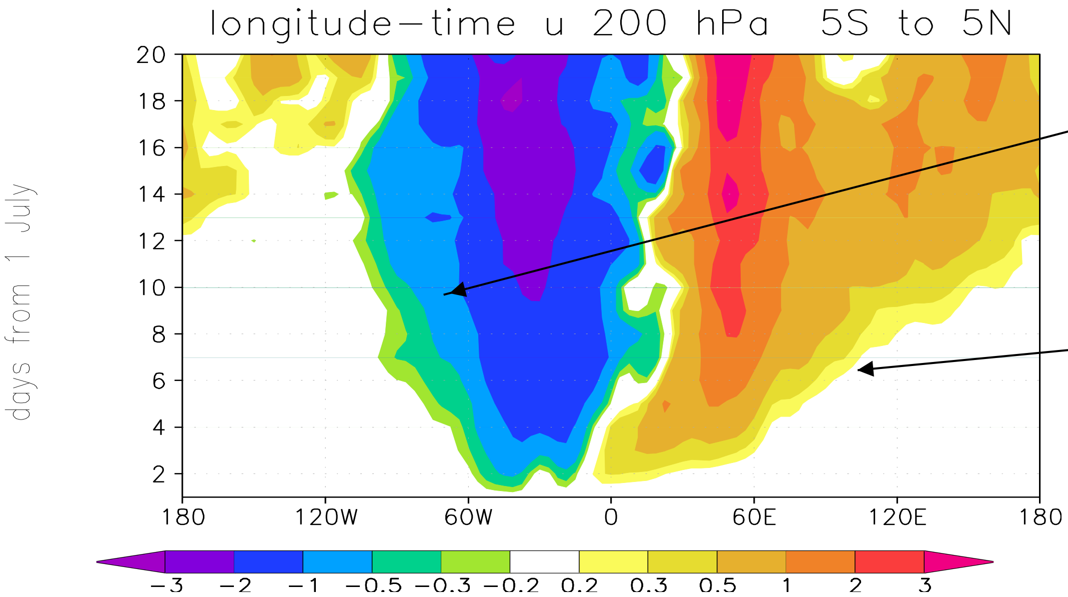
Time-evolution of Response (equatorial wave dynamics relevant also here). Results from paper Kucharski et al., QJRMS, 2009



Initial 200 hPa Streamfunction Response to a warm tropical Atlantic (switch-on)

Everything consistent with Gill-Matsuno-type quadrupole Response as in Jin and Hoskins (1995), JAS



Equatorial Rossby waves (speed: 6 m/s)

Convectively coupled Kelvin waves (speed: 20 m/s)

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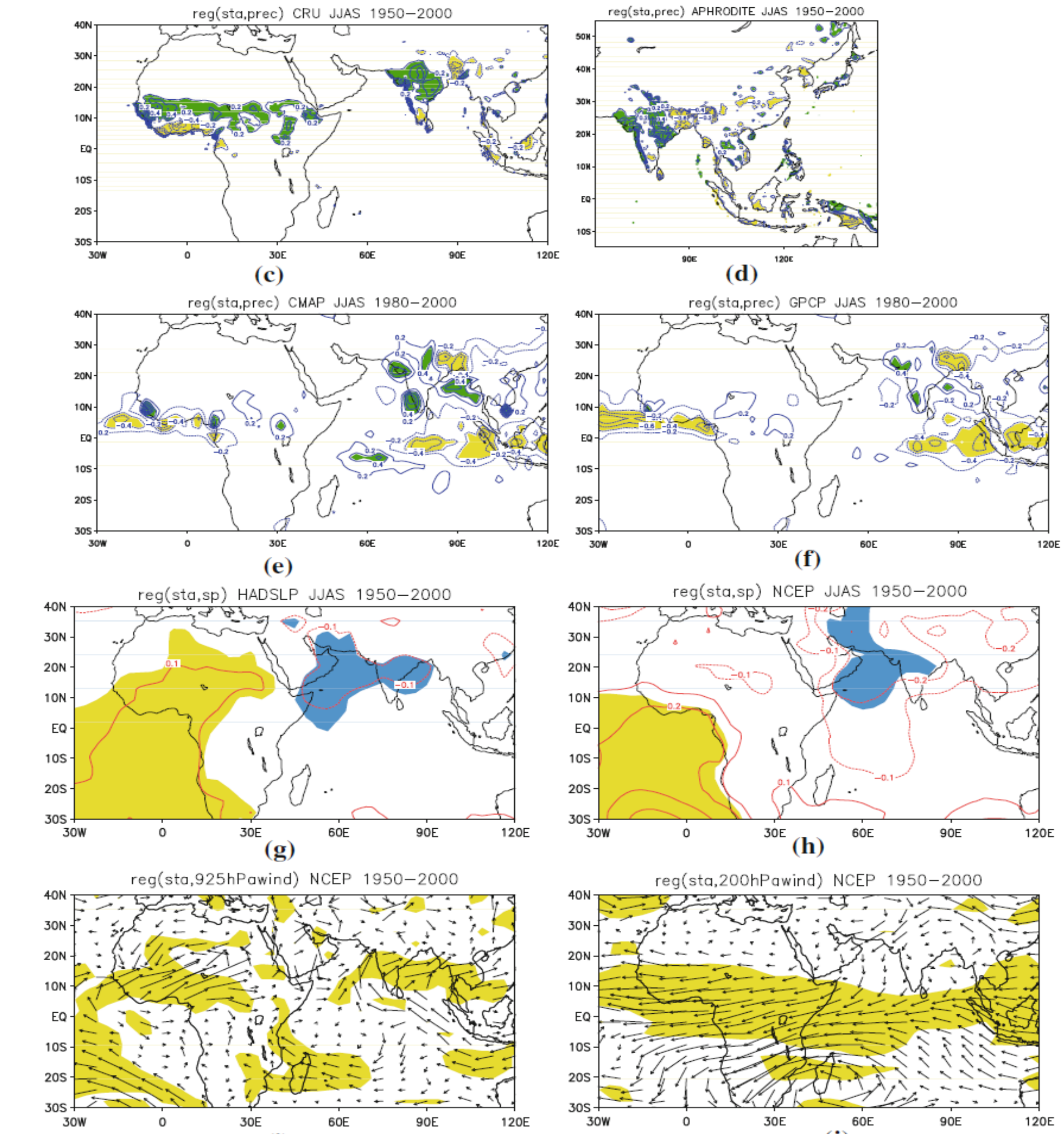

Details of Teleconnection Response to Eq. Atlantic cooling

CRU, APHRODITE

CMAP, GPCP (1980-2000)

HADSLP, NCEP SP

925 and 200 hPa NCEP winds

From paper: Barimalala et al., Clim Dyn, 2012, 38, 1147-1166

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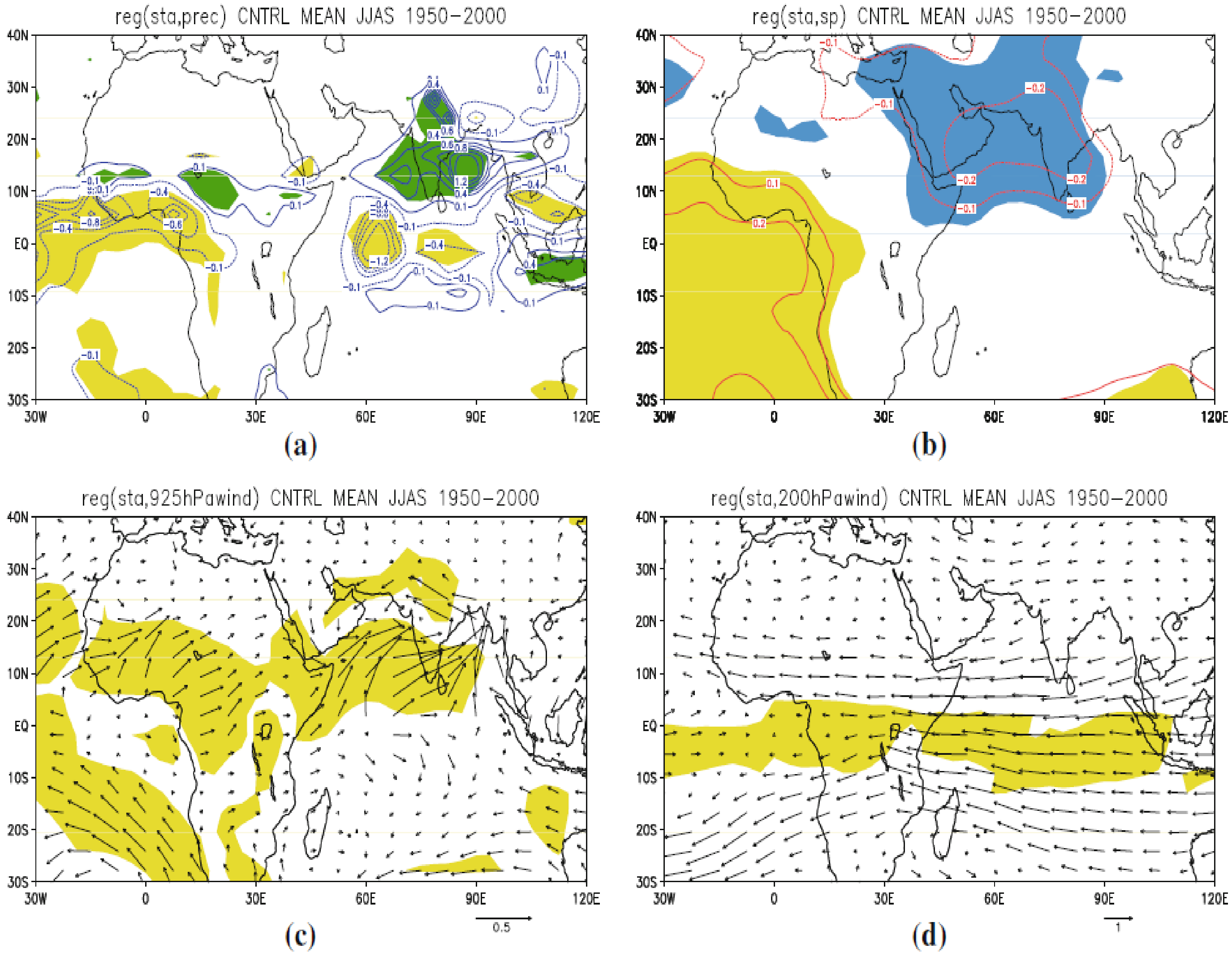
Results from an AGCM (ICTPAGCM)

Prec

SLP



925 and 200 hPa winds

From paper: Barimalala et al., Clim Dyn, 2012, 38, 1147-1166

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We take a look at how coupled models (CMIP3) models represent this teleconnection

Why is it interesting to test this teleconnection in state-of-the-art models?
Because even though the Atlantic influence is not the dominant impact,
it is still important that models capture this teleconnection for predictability!

Selection of CMIP3 models with good monsoon Climatology according to Annamalai, Clim Dyn, 2007

Model	# of Members	Resolution	References
GFDL-CM2.1	3	$2.5° \times 2°L24$	Delworth et al. (2006)
MPI-ECHAM5	3	T63L31	Jungclaus et al. (2006)
MRI	5	T42	Yukimoto et al. (2001)
UKMO-HadCM3	1	$3.75° \times 2.5°L19$	Gordon et al. (2000)
NCAR-PCM1	4	T42L18	Washington et al. (2000)

From paper: Barimalala et al., Clim Dyn, 2012, 38, 1147-116

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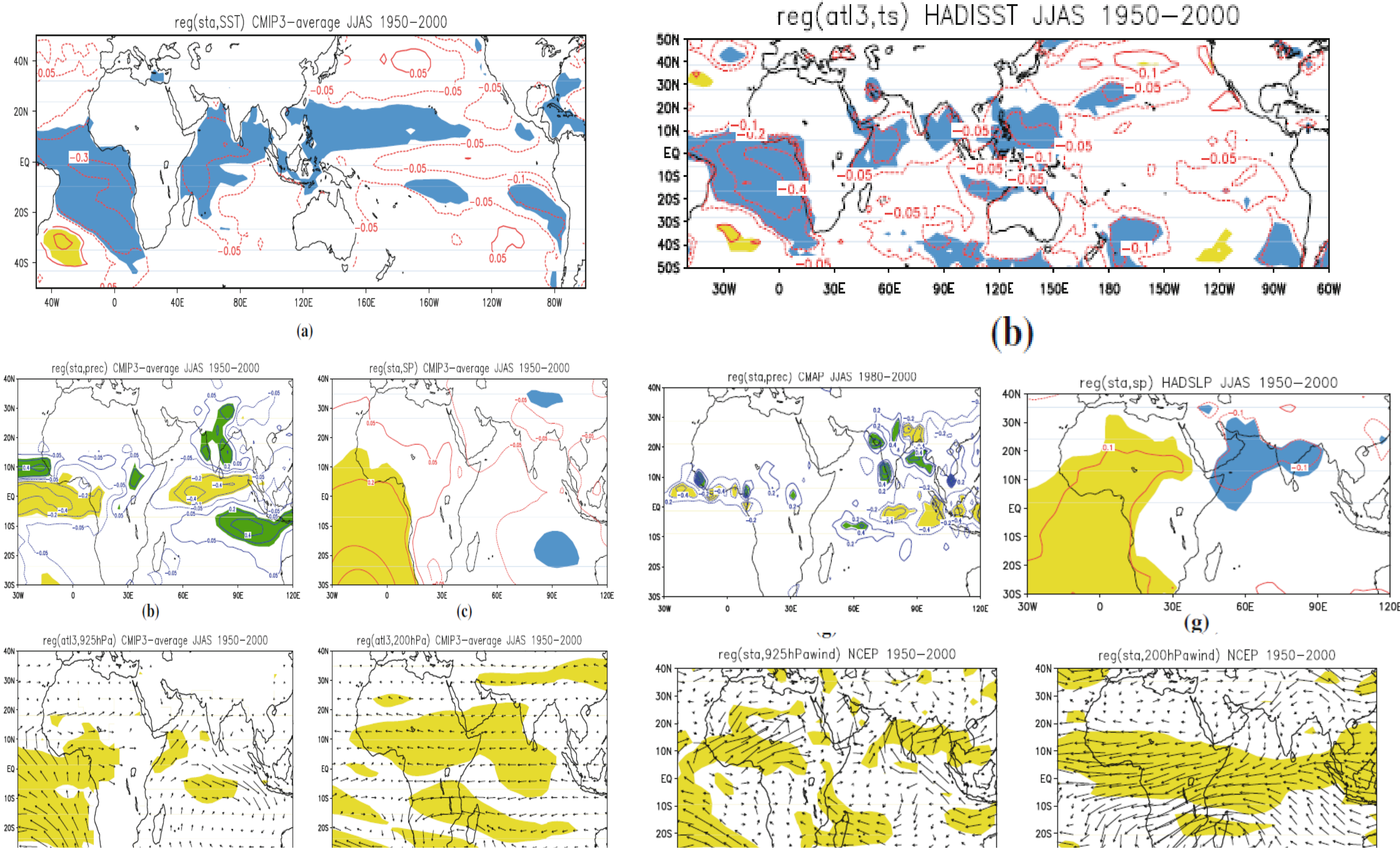
How is teleconnection captured in Ensemble mean of 5 cmip3 models? Overall weak, but not bad!

Ensemble mean **OBS**



Would be interesting what happens in CMIP5 with this Teleconnection?

From paper: Barimalala et al., Clim Dyn, 2012, 38, 1147-116

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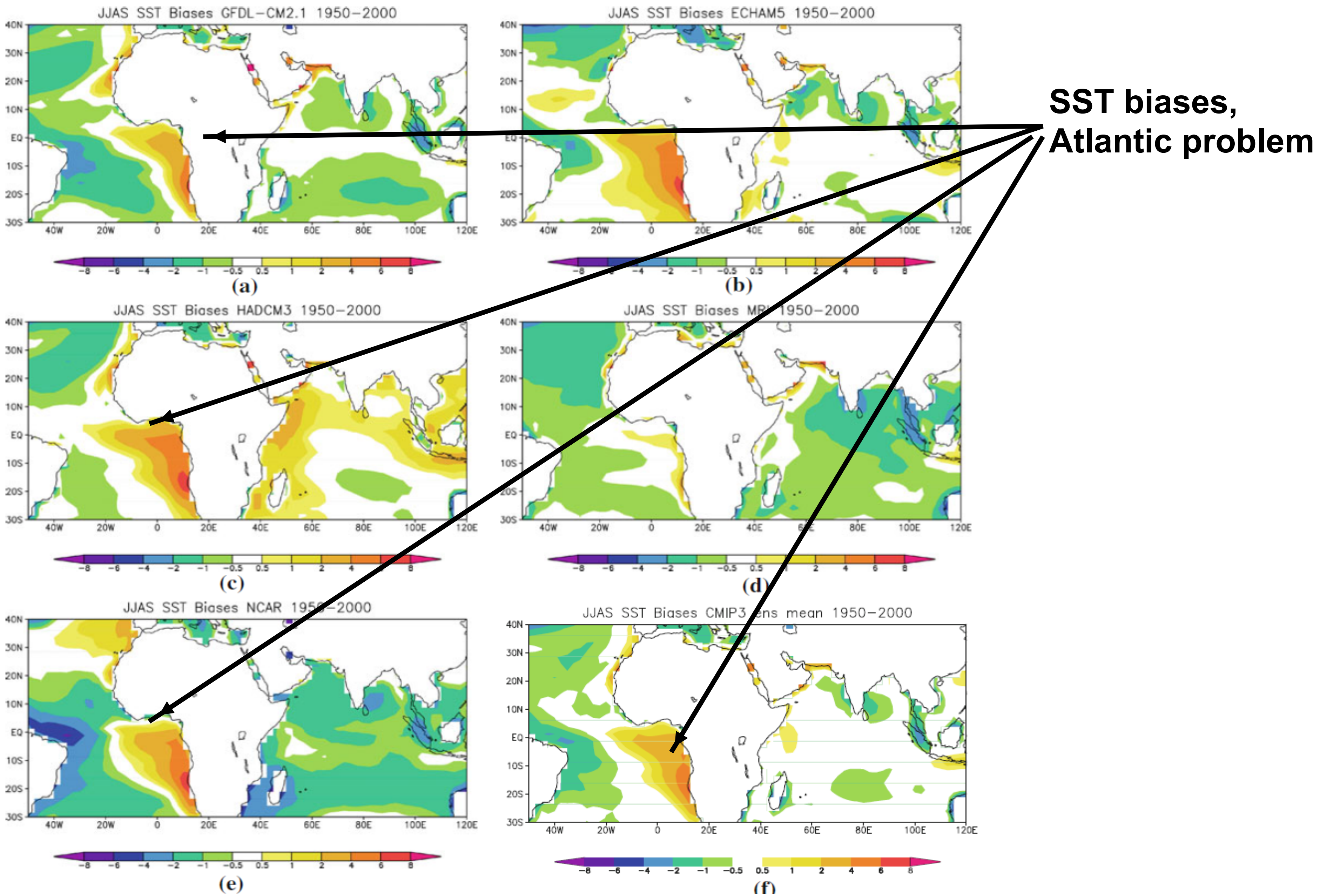
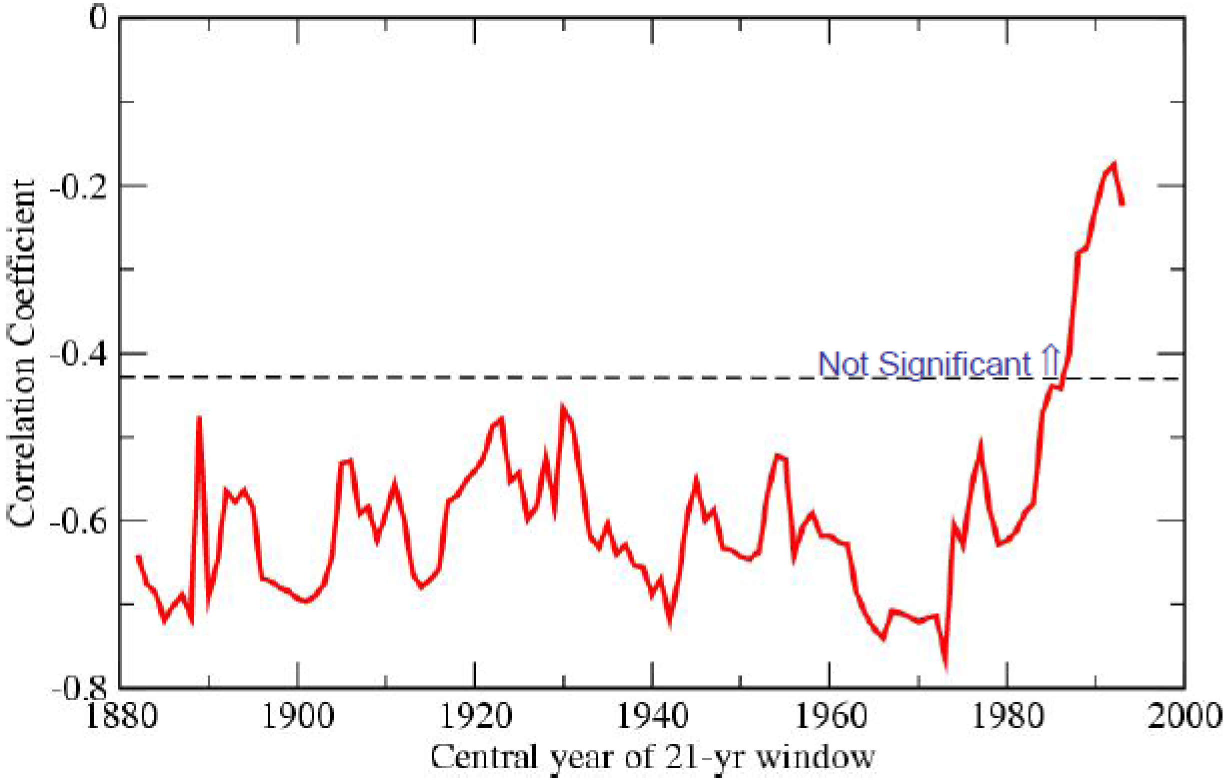
We have shown in that paper that the Atlantic warm bias has a role in weakening the teleconnection (i.e. more Hadley cell like response compare to Walker circ. Type)



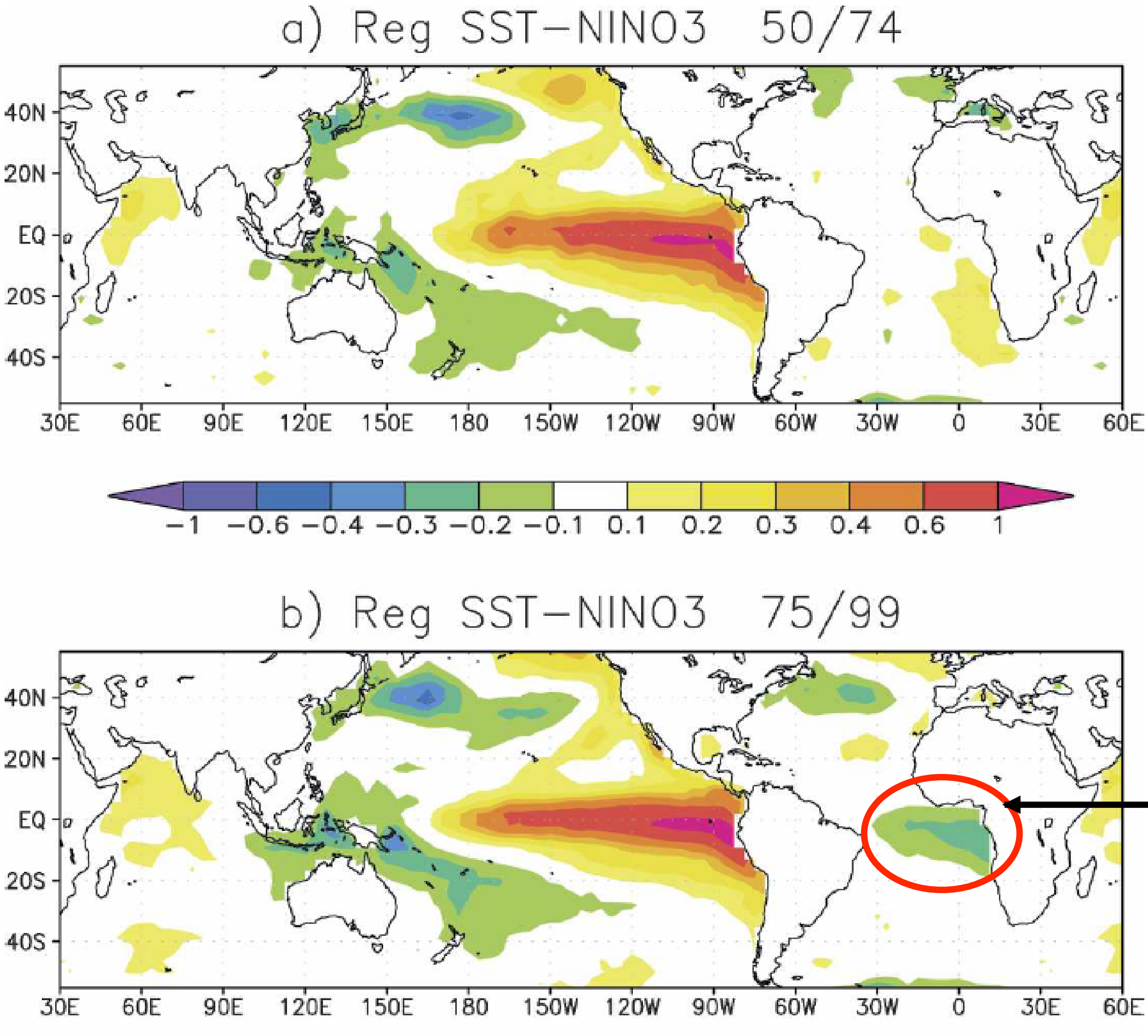
Did the equatorial Atlantic teleconnection also reduce the ENSO-South Asian monsoon relation?

21-Yr Sliding Correlation between Indian Monsoon Rainfall and NINO3 (JJAS)1871-2002



from K. Kumar, Rajagopalan & Cane
Science, 1999

Did the equatorial Atlantic teleconnection also reduce the ENSO-South Asian monsoon relation?



There is indeed an anticorrelation Between Pac and Atl SSTs that would favor a cancellation!

From: Kucharski et al., 2007, J Climate, 20, 4255-4266

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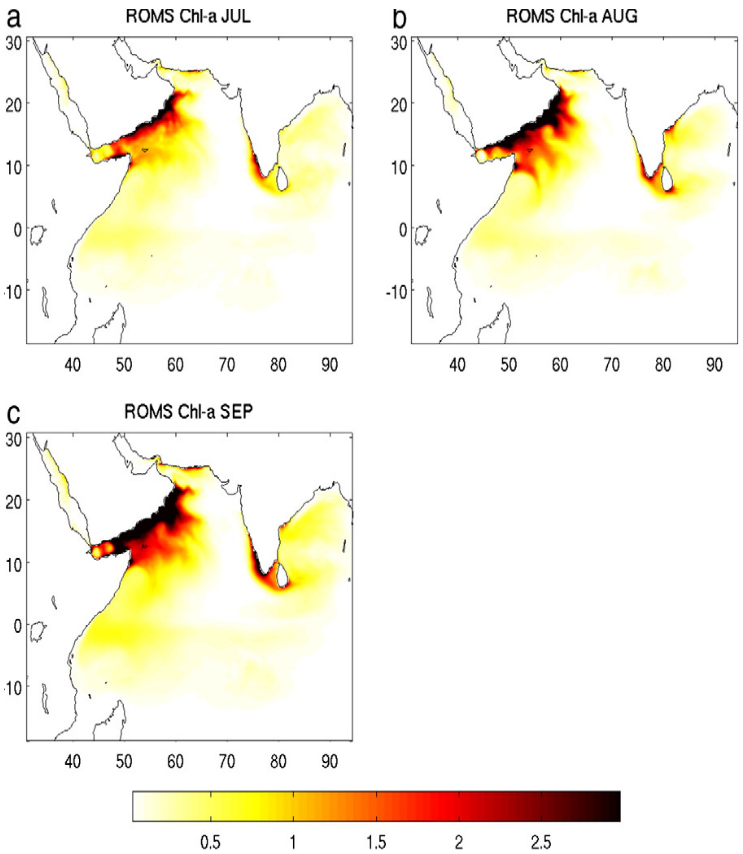
We can model the decline in ENSO-monsoon anticorrelation given that Atlantic SST variability is included in the simulations

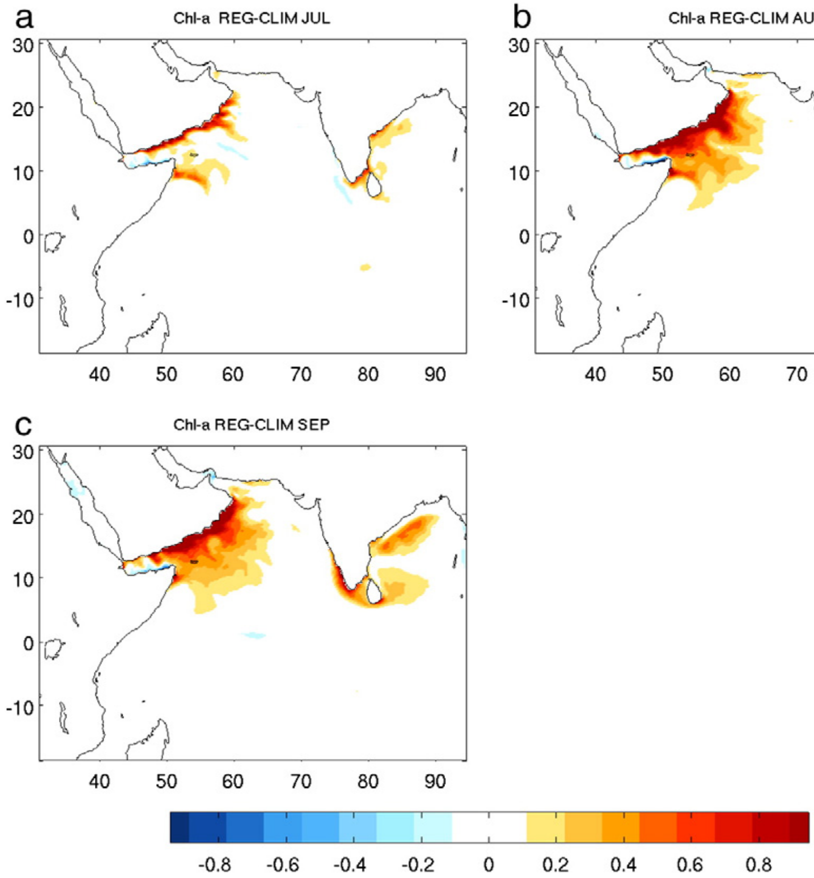
	1950–90	1950–74	1975–99	1975–99 − 1950–74
CC (CRU, Niño-3)	−0.59	−0.69	−0.45	0.24
CC ($\mathrm{ENS1}_{\mathrm{ENSM}}$, Niño-3)	−0.63	−0.79	−0.51	0.28
Mean CC (ENS1, Niño-3)	−0.42	−0.49	−0.33	0.16
CC ($\mathrm{ENS2}_{\mathrm{ENSM}}$, Niño-3)	−0.73	−0.74	−0.72	0.013
Mean CC (ENS2, Niño-3)	−0.49	−0.47	−0.48	−0.01
		1950–69	1980–99	1980–99 − 1950–69
CC (CRU, Niño-3)		−0.55	−0.41	0.15
CC ($\mathrm{ENS1}_{\mathrm{ENSM}}$, Niño-3)		−0.73	−0.56	0.17

Table from: Kucharski et al., 2007, J Climate, 20, 4255-4266

Indian Ocean Ecosystem is also influenced by tropical Atlantic Teleconnection

Mean Chlorophyll production | **Change for 1K tropical Atlantic cooling**





In summer, this impact is as larger as the one from ENSO
And larger than the IOD impacts!!!

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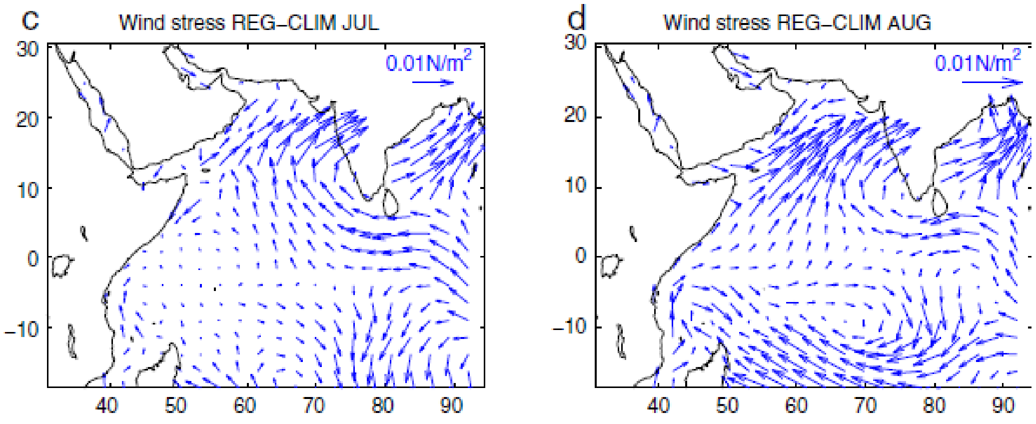
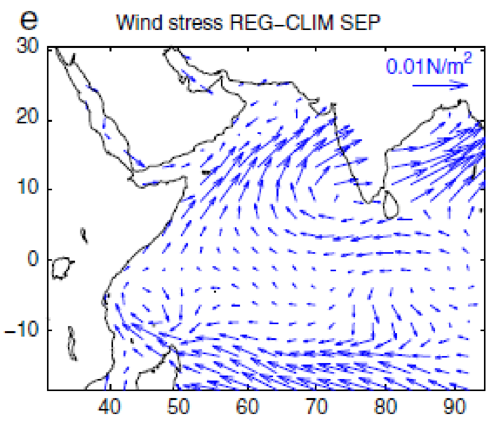
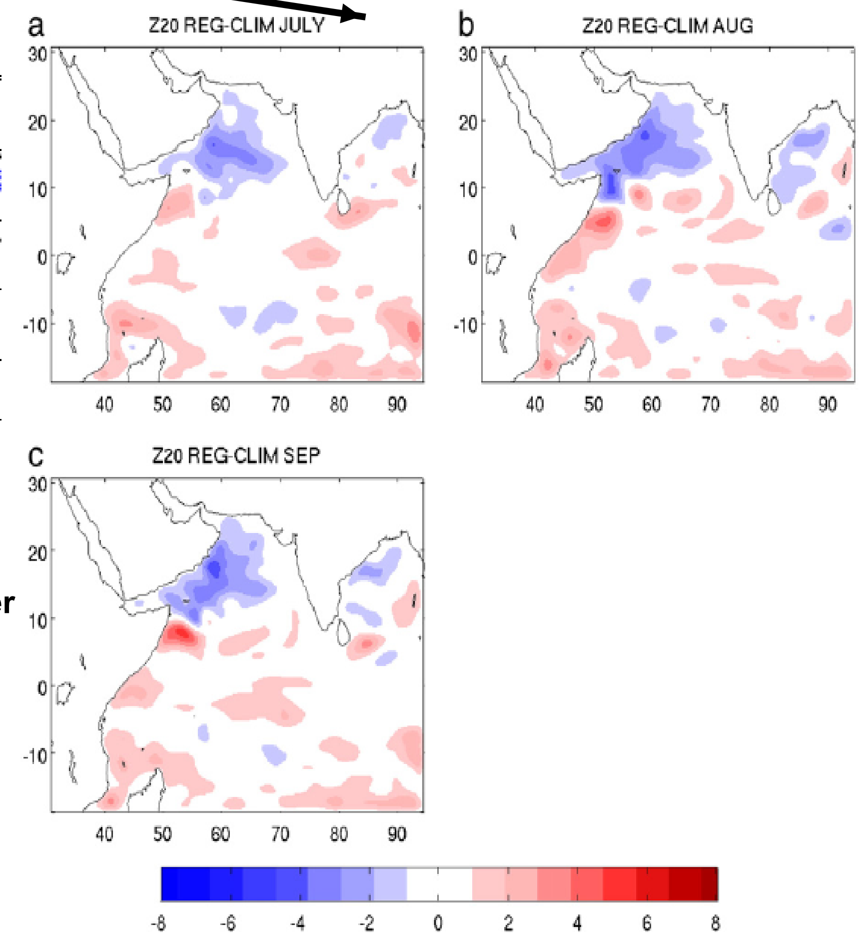
Physical Mechanism for Ecosystem changes

Wind stress and thermocline change for 1K tropical Atlantic cooling





Atlantic cool -> somaly jet stronger -> upwelling in Arabian sea -> Nutrient rich water at surface



From paper: Barimalala et al., 2013, J Marine Sys., 117-118, 14-30

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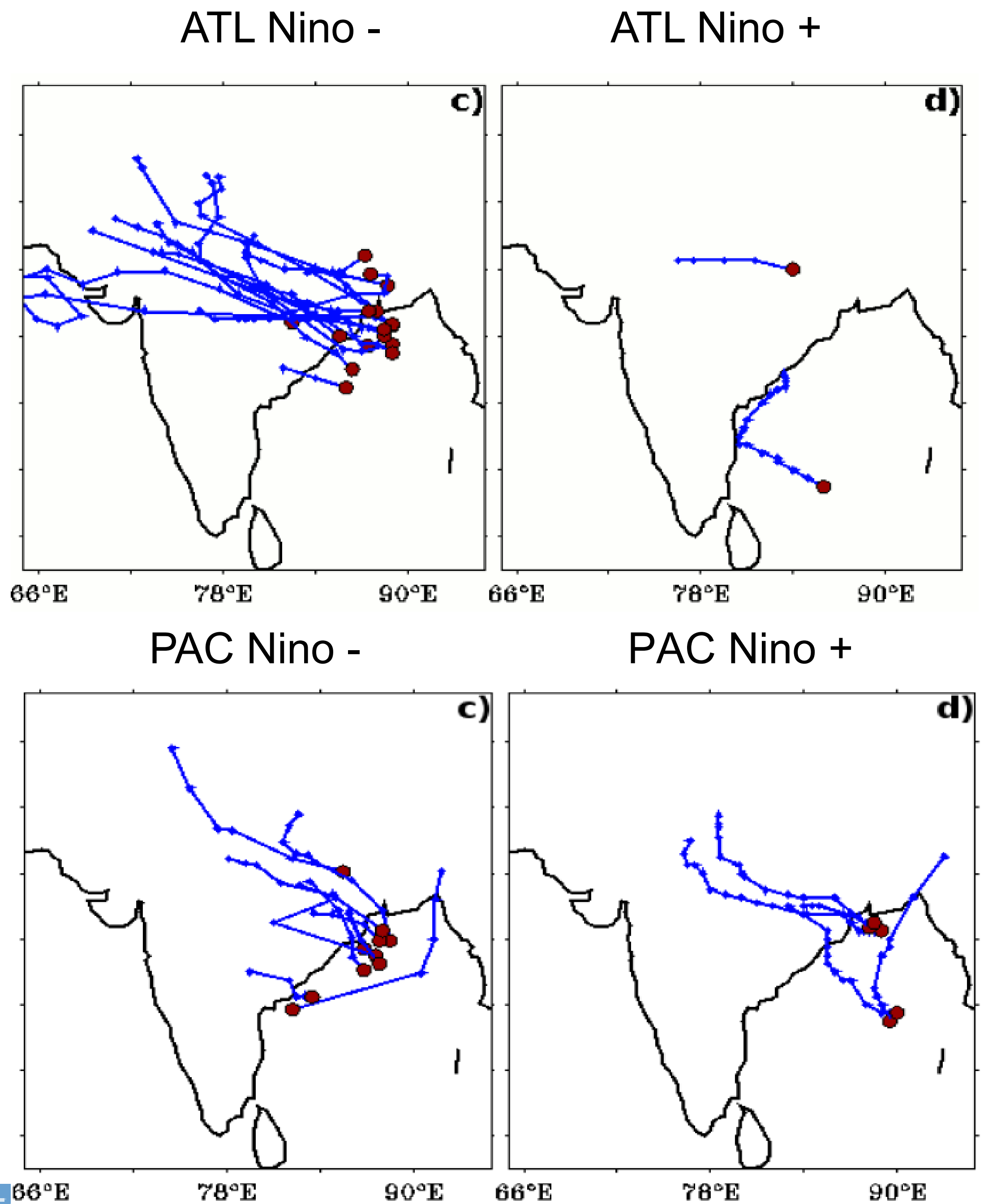
Influence on IO tropical cyclones: Pottapinjara et al. JGR, 2014



The genesis locations (red circle) and tracks of monsoon depressions (blue line)

	AZM cold (Pure AZM cold)	AZM warm (Pure AZM warm)	La Niña (Pure La Niña)	El Niño (Pure El Niño)	Normal years
No of years	8 (6)	9 (4)	7 (3)	7 (4)	14
Total depressions	26 (15)	12 (2)	17 (10)	18 (5)	43
Depressions per season	**3.3 (2.5)**	**1.3 (0.5)**	2.5 (3.3)	2.6 (1.25)	3.1
Average life of a depression in days	4 (4.4)	3 (4)	2.9 (3.3)	3.1 (3.2)	2.9

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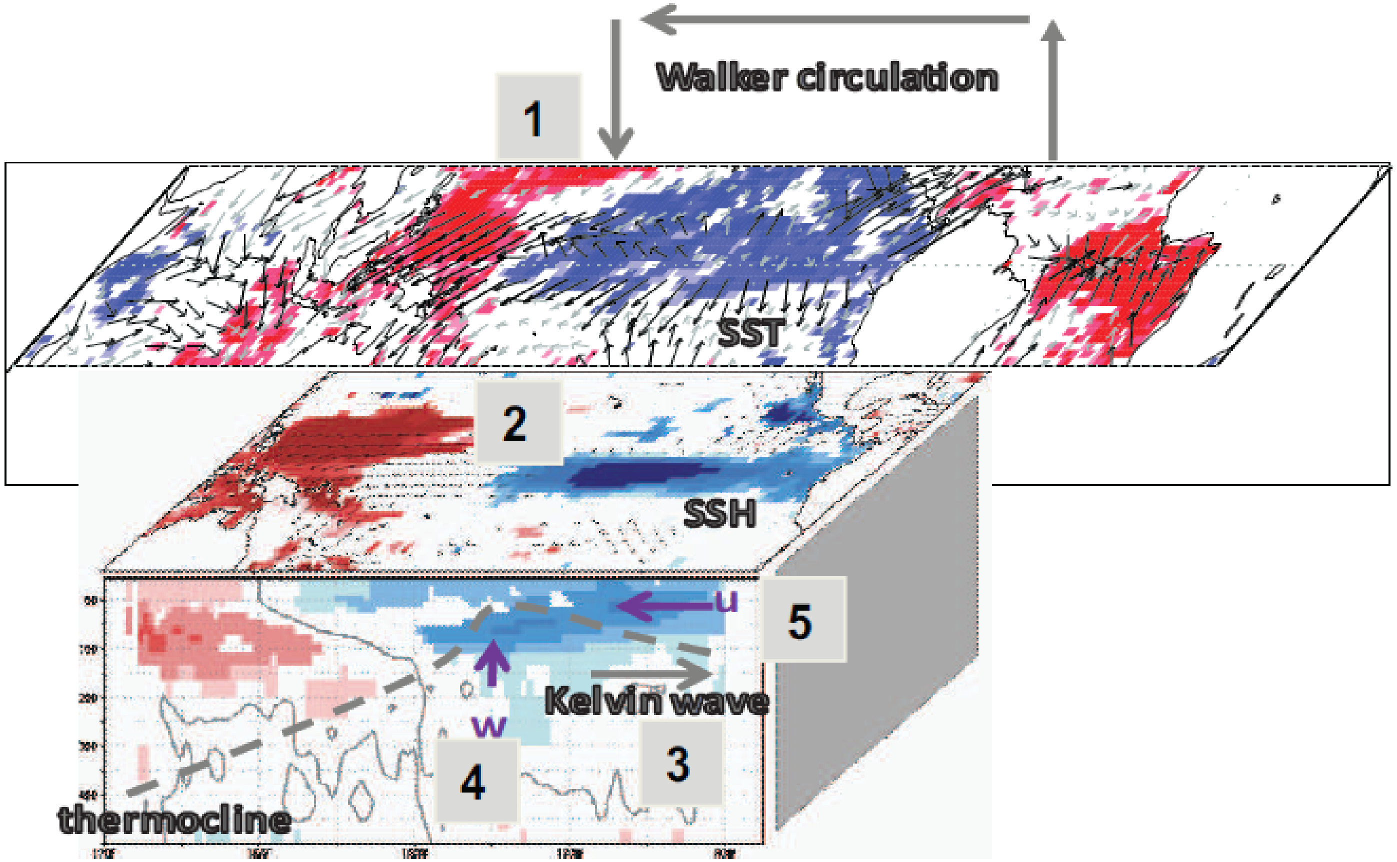
B) Influence of tropical Atlantic on Pacific

Results published in: Rodriguez-Fonseca et al., 2009, GRL, 36, L20705, Kucharski et al., 2011, GRL, 38, L03702, Kucharski et al., 2014, Clim Dyn, in press., Polo et al., Climate Dynamics, in review

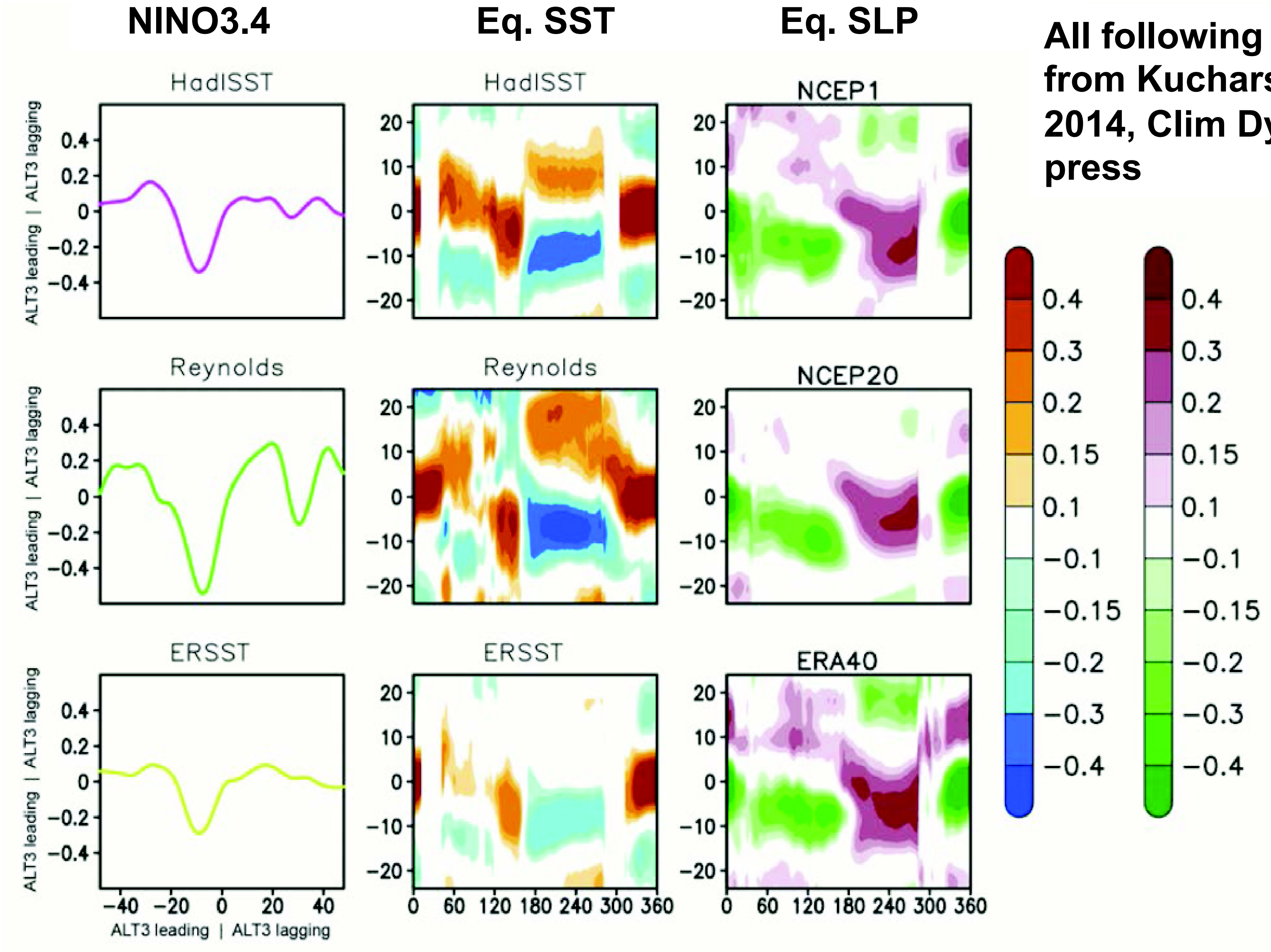
What is known from obs and idealized Atlantic pacemaker experiments (e.g. Rodriguez-Fonseca et al., 2009, GRL, 36, L20705, Polo et al., Clim Dyn, in rev



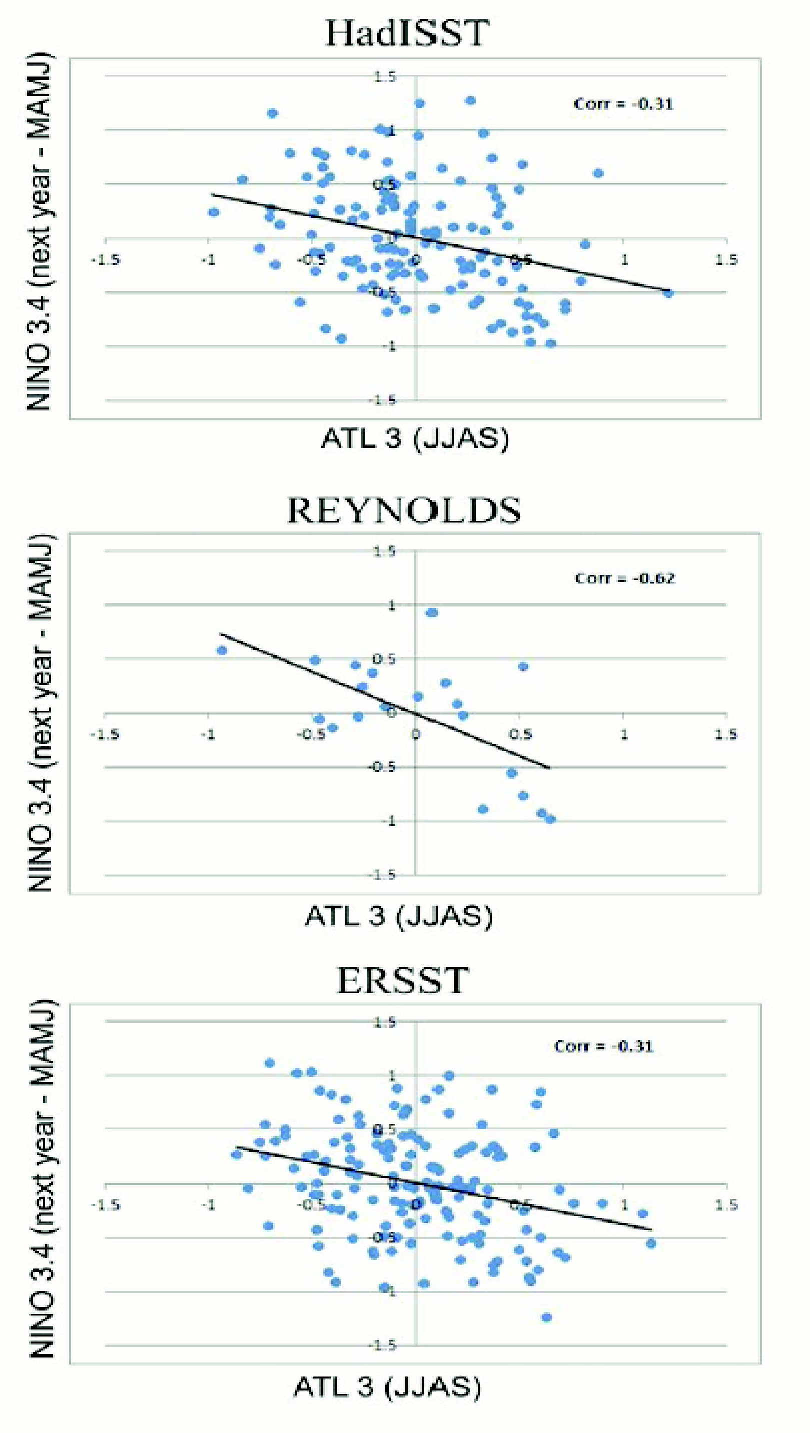
Mechanism: Atl Nino -> modif. Walker circ. -> sinking motion in central Pac. -> easterly wind stress in central-west Pac. -> triggers upwelling Kelvin waves, propagation to east Pac. -> Pac. La Nina

Observations: Lead-Lag correlations between ATL3 and

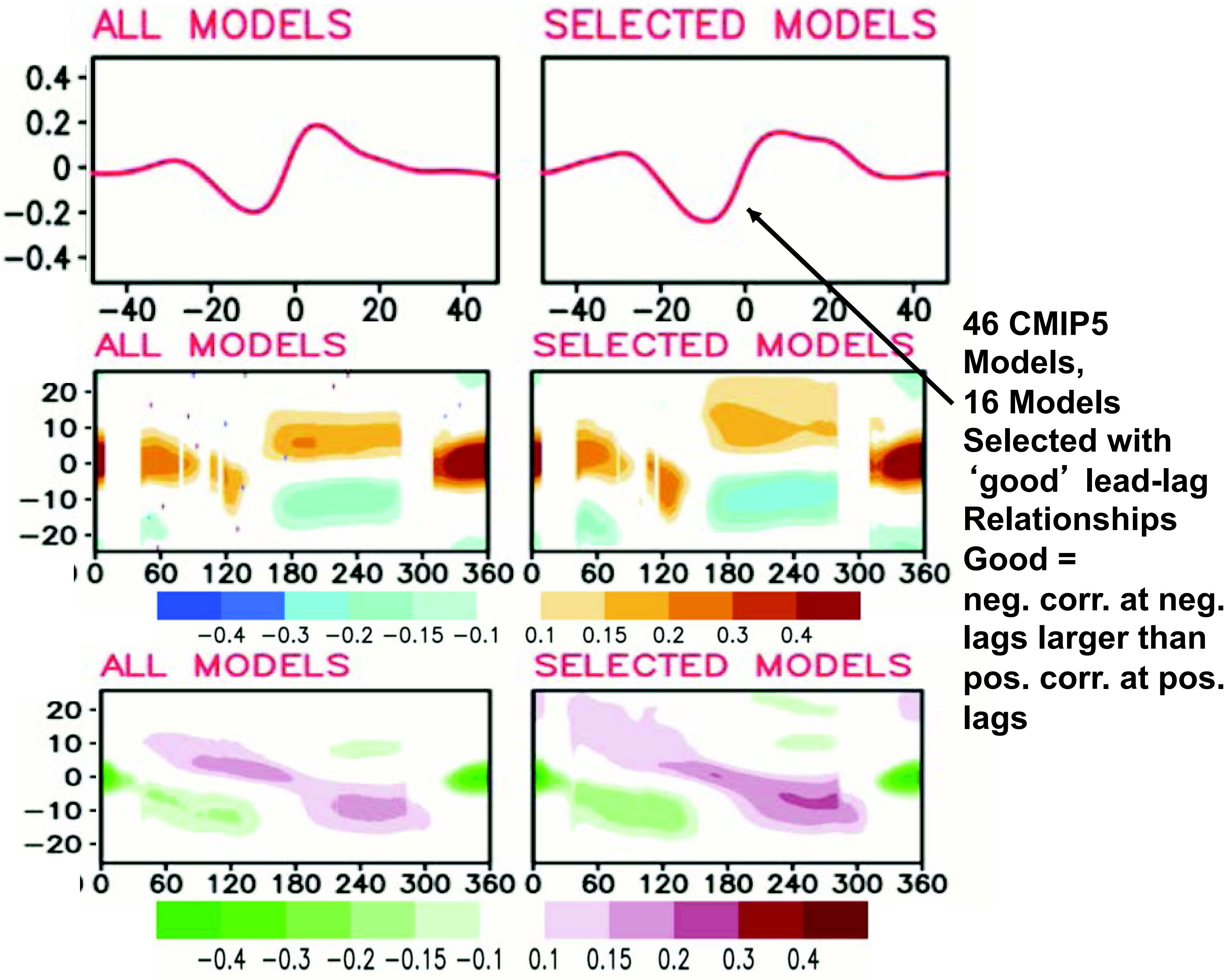
(Negative lags mean ATL3 leads)



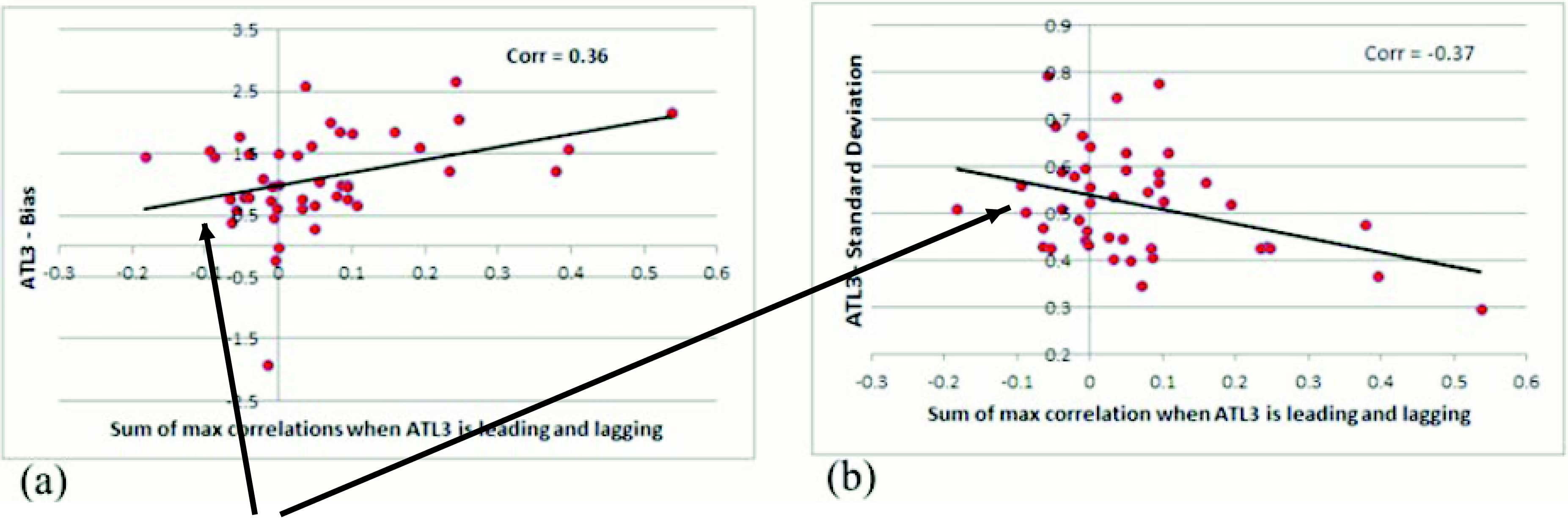
All following results from Kucharski et al., 2014, Clim Dyn, in press



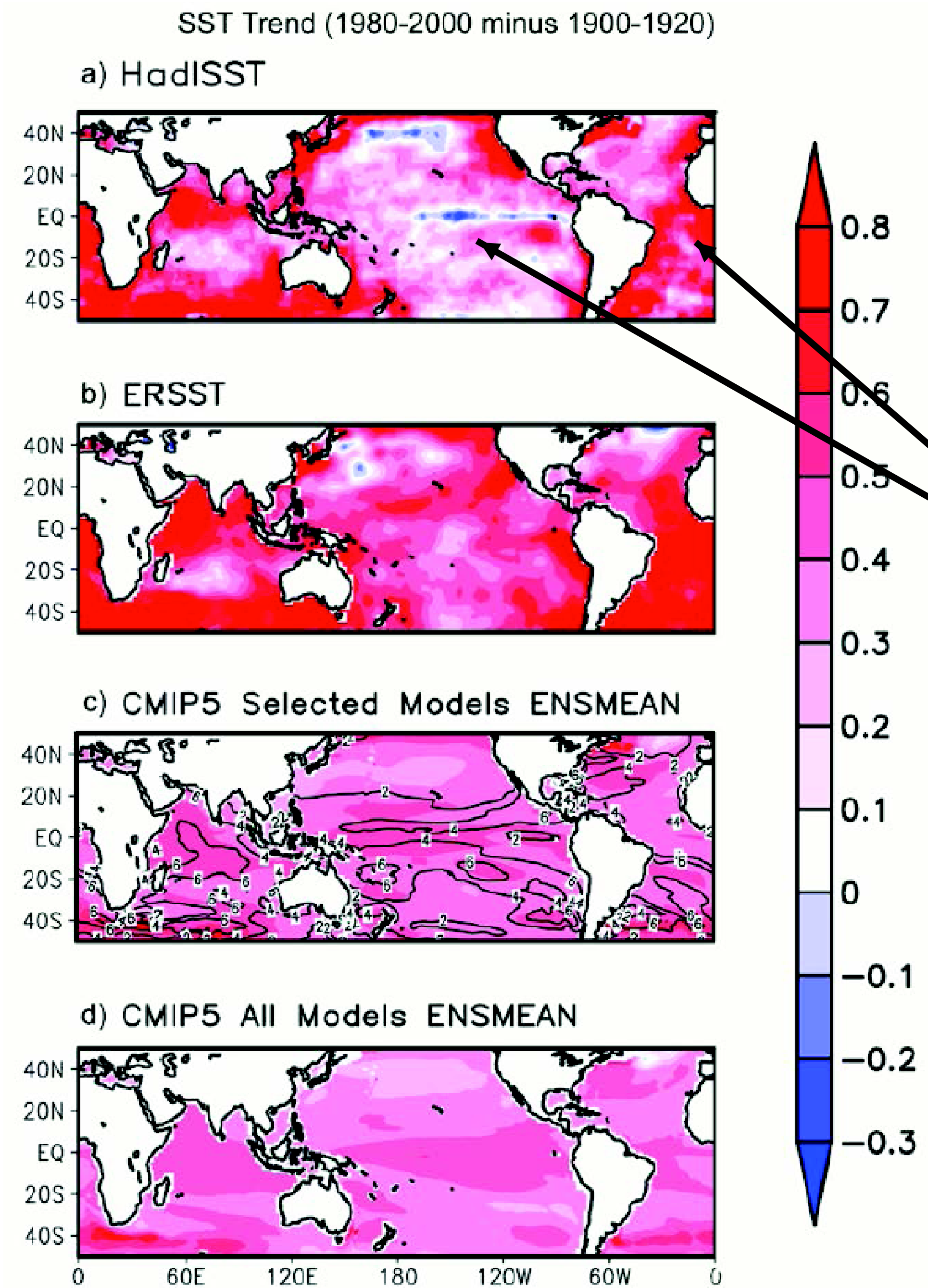
JJAS (year 0) ATL3 index versus MAMJ (year +1) NINO3.4 index.


ALL MODELS
SELECTED MODELS
0.4
0.2
0
−0.2
−0.4
−40 −20 0 20 40
ALL MODELS
SELECTED MODELS
20
10
0
−10
−20
0 60 120 180 240 300 360
−0.4 −0.3 −0.2 −0.15 −0.1 0.1 0.15 0.2 0.3 0.4
ALL MODELS
SELECTED MODELS
−0.4 −0.3 −0.2 −0.15 −0.1 0.1 0.15 0.2 0.3 0.4
46 CMIP5 Models,
16 Models Selected with 'good' lead-lag Relationships
Good = neg. corr. at neg. lags larger than pos. corr. at pos. lags

Influence of Atlantic warm bias and ATL3 stdev on connection



"Good" lead-lag correlations are negative on x-axis



Consequences for tropical Pacific mean state changes?

What about ‘trends’ in SST in OBS and CMIP5?

We have learned that Eq. Atlantic warming leads to Eastern Pacific cooling.

Hypothesis: A stronger than global mean tropical Atlantic warming may lead to reduced warming in eastern Pacific

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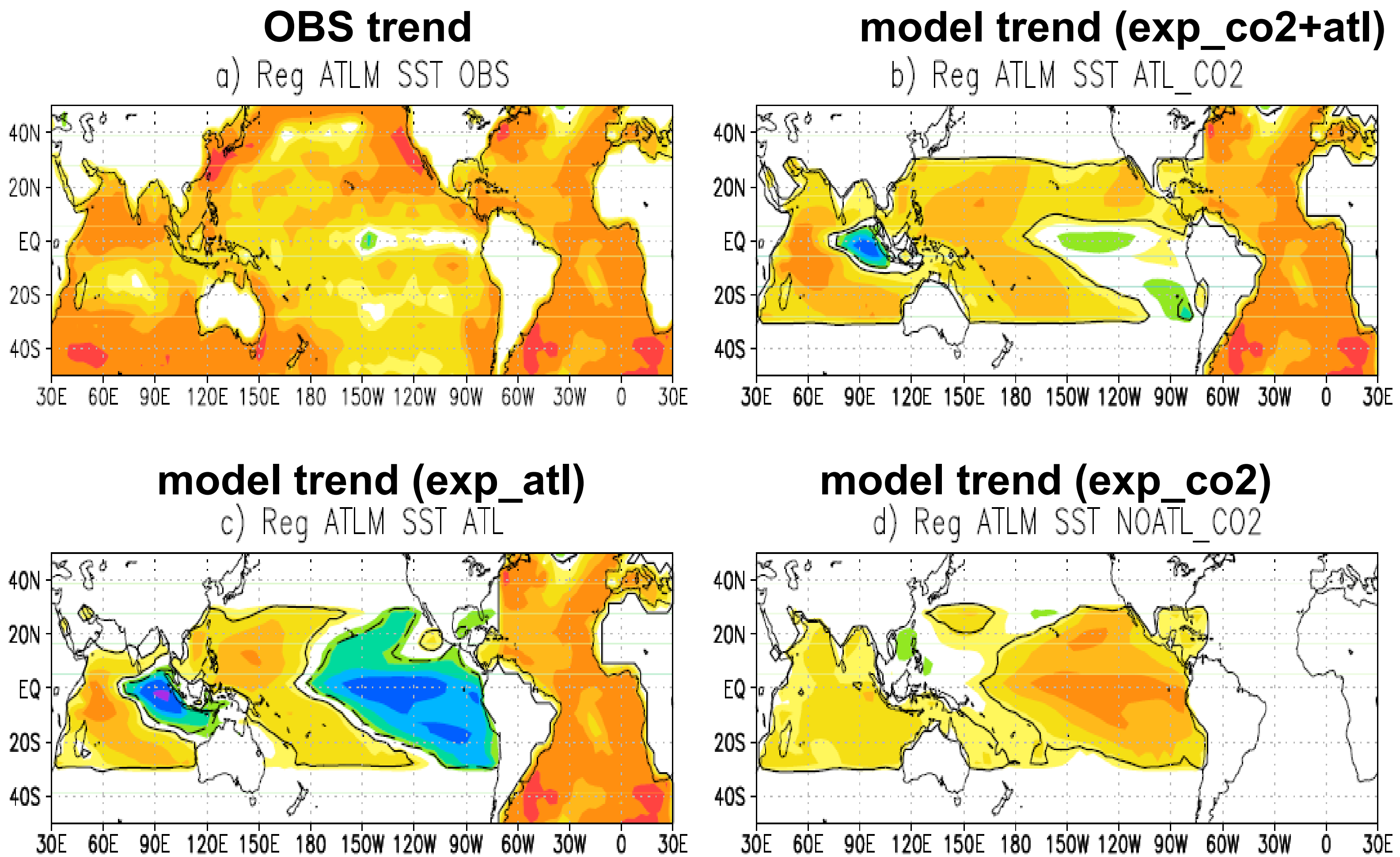
This has been shown to be the case in idealized Atlantic Pacemaker experiments (e.g. Kucharski et al., 2011, GRL, 38, L03702)



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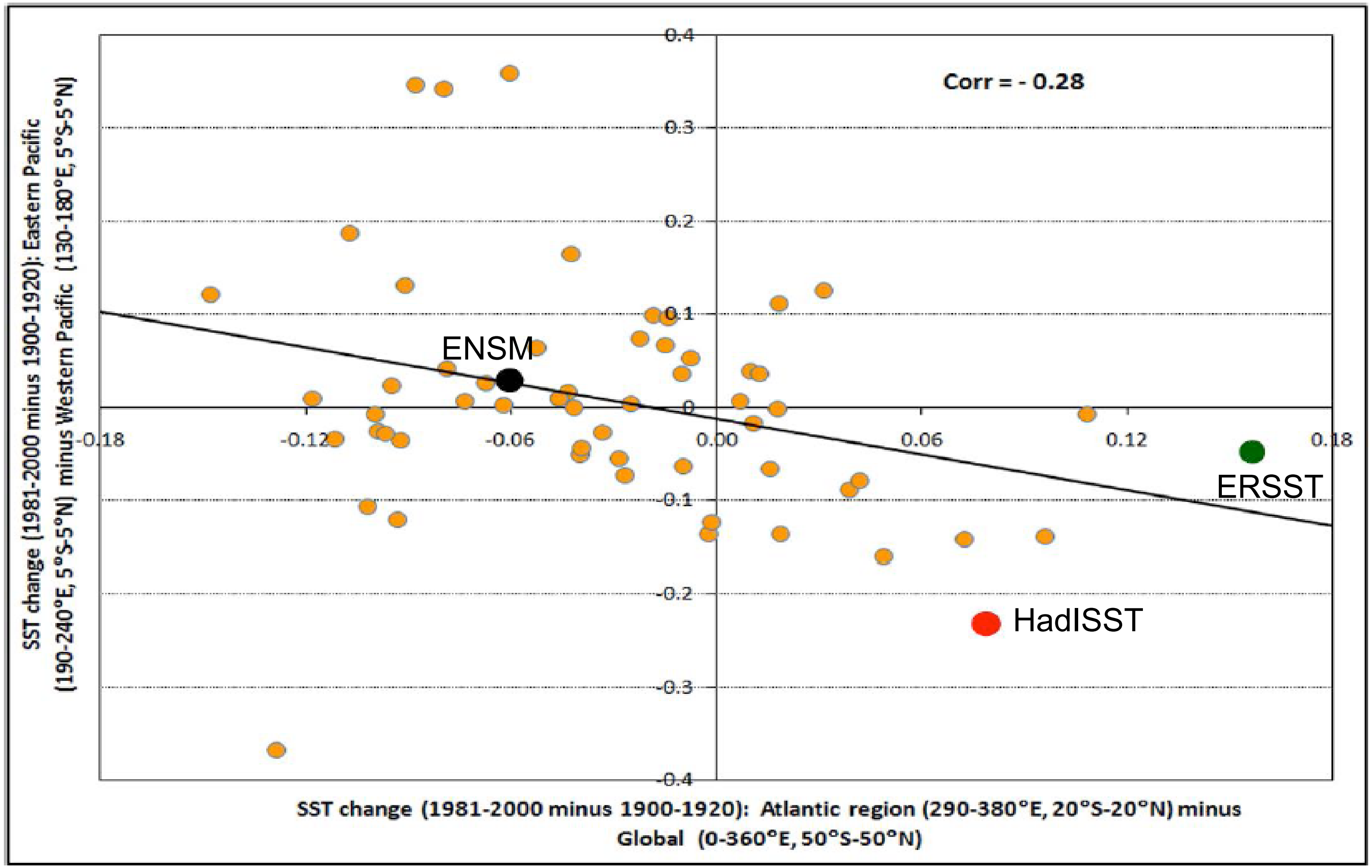

Corr = - 0.28
ENSM
ERSST
HadISST
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.18
-0.12
-0.06
0.00
0.06
0.12
0.18
SST change (1981-2000 minus 1900-1920): Eastern Pacific (190-240°E, 5°S-5°N) minus Western Pacific (130-180°E, 5°S-5°N)
SST change (1981-2000 minus 1900-1920): Atlantic region (290-380°E, 20°S-20°N) minus Global (0-360°E, 50°S-50°N)

Summary:

- The tropical Atlantic has a secondary (compared to ENSO), but relevant Impact on the Asian Monsoon.

- A tropical Atlantic warm anomaly leads to drying in most parts of South Asia, (but to increased rainfall in some others).

- Physical mechanism related to modification of Walker Circulation and Gill-type response.

- Many AGCMs are able to reproduce this teleconnection reasonably well, CGCMs (CMIP3) have difficulties because of Atlantic warm bias.

- Also Indian Ocean ecosystem is influenced by the tropical Atlantic teleconnection.

-Tropical Atlantic SST anomalies also influence ENSO. Mechanism is also through walker circulation modification, and leads to anticorrelation of the Atlantic and the Pacific basins.

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