



The Abdus Salam
International Centre
for Theoretical Physics



ESP internal Seminar on: Tropical Basin Interactions, a personal and biased perspective

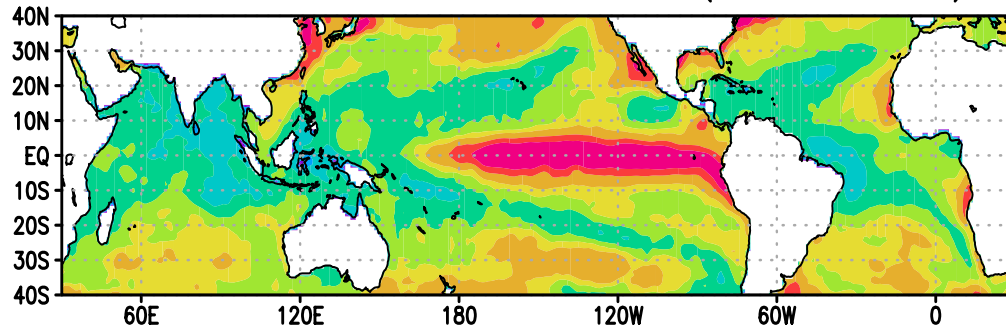
**Presenting Author: Fred Kucharski, ESP Section, Abdus
Salam ICTP, Trieste, Italy;
Thanks to all collaborators**

Topics covered (historical order):

- 1. Some basic considerations on Teleconnections and analysis methods**
- 2. Tropical Atlantic influence on South Asian Summer Monsoon**
- 3. Tropical Atlantic impact on Pacific and ENSO**
- 4. Some current interests**

Interannual SST standard deviation (HadISST)

SST DJF Standard Deviation (1980–2020)

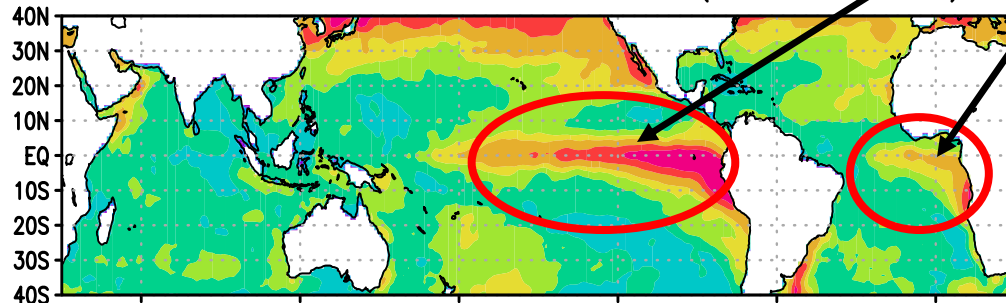


DJF



**In JJA, two distinct
Maxima in STDEV**

SST JJA Standard Deviation (1980–2020)



JJA

~1K

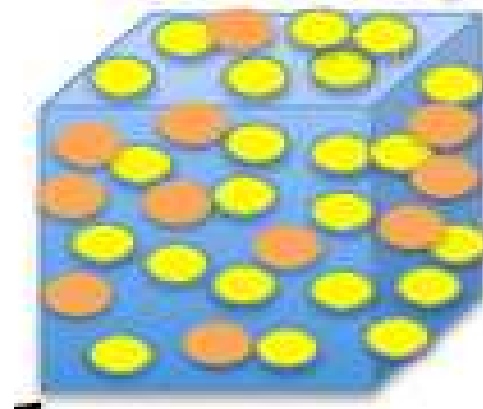
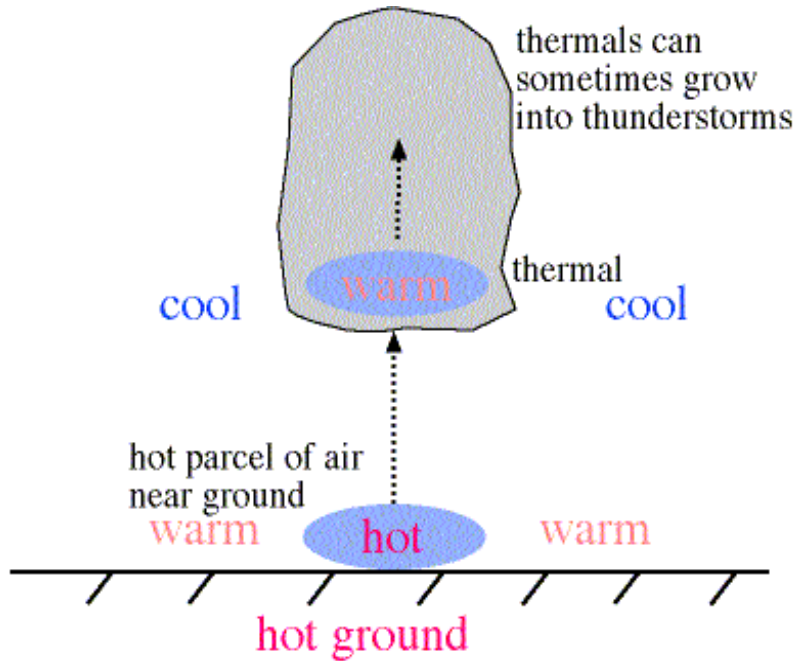
~0.7 K

Goliath

David

Evaluate parcel properties with respect to its environment

ρ, p, T



$\rho_{\text{env}}, p_{\text{env}}, T_{\text{env}}$

Buoyancy forces:

$$\frac{\partial w}{\partial t} = -\frac{\rho'}{\bar{\rho}}g \quad \rho' = \rho - \rho_{\text{env}}$$

Environment Criterion for instability of moist (saturated) air:

(Environment quantities indicates with a bar)

$$\frac{\partial \bar{T}}{\partial z} < \equiv - \frac{g}{c_p} \frac{\left(1 + \frac{L_{lv} \bar{m}_{vs}}{RT} \right)}{\left(1 + \frac{L_{lv}^2 \bar{m}_{vs}}{c_p \bar{T}^2 R_v} \right)} \sim -0.6 \text{ k/100m}$$

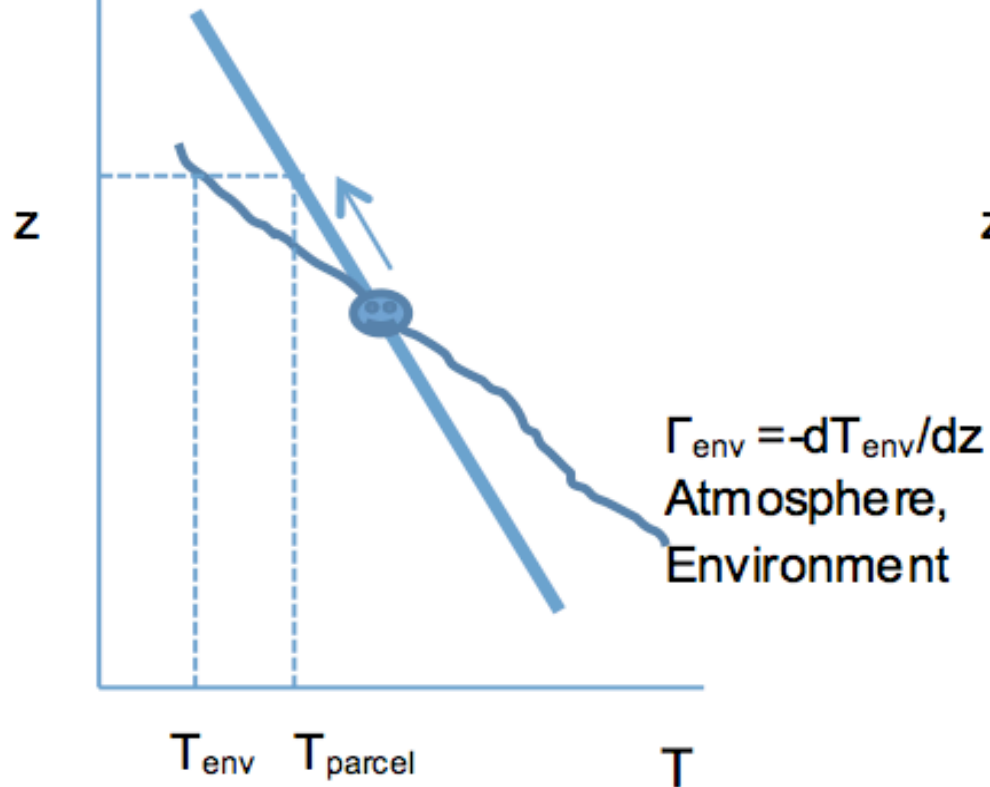
for dry air:
-1K/100m

Temperature has to decrease with height faster than the critical limit.
Such a situation may be favored by high surface temperatures!

Unstable condition – negative static stability,

$$\Gamma_d < \Gamma_{env}$$

Γ_d , DALR (parcel T follows this profile)



$$T_{env} < T_{parcel}, \rho_{env} > \rho_{parcel},$$

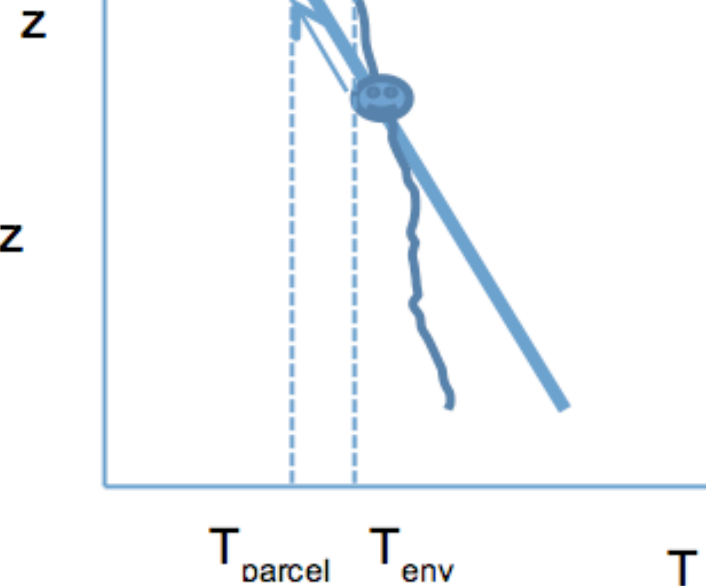
Parcel continues to rise

Stable condition – positive static stability

$$\Gamma_d > \Gamma_{env}$$

DALR

$\Gamma_{env} = -dT_{env}/dz$
Atmosphere,
Environment



$$T_{parcel} < T_{env}, \rho_{parcel} > \rho_{env}$$

Parcel sinks to original position



For small-scale air parcel scale motions ($\sim 1\text{km}$): A parcel of rising air always cools

$$\frac{dT}{dt} = -w \frac{g}{c_p} \frac{\left(1 + \frac{L_{lv} m_{vs}}{RT}\right)}{\left(1 + \frac{L_{lv}^2 m_{vs}}{c_p T^2 R_v}\right)}$$

Assuming **adiabatic** ascent; no heat exchange with its environment while rising

Note that as long as water vapor in parcel is not saturated we have $m_{sv}=0$, and therefore the parcel cools as $-wg/c_p$.

Further, it can be shown that due to the decreasing temperature as a parcel rises the relative humidity increases until condensation occurs (Clausius-Clapeyron):

$$RH = \frac{p_v}{p_{vs}} = \frac{m_v}{m_{vs}}$$

$$\frac{dRH}{dt} = -\frac{m_v}{m_{vs}^2} \frac{dm_{vs}}{dt} > 0$$

Note that there is a huge **asymmetry** between a rising and a sinking parcel:

A rising parcel loses all its water vapor (to rainwater that fall out) if rising high enough, whereas a sinking parcel will evaporate the little cloud water it may hold.

Therefore, the net effect of these rising and sinking parcels induced by static instability will be an **increase** of atmospheric heating!

Reflection: The process of a rising parcel with condensation heating and following sinking would be reversible (i.e. entropy conserving) if no rain is falling out! It's the rain falling out that make is irreversible and entropy producing (just as luv-lee effect, see below)!



For large-scale motions ($\sim 100\text{-}1000\text{km}$) this means:

$$c_p \frac{dT}{dt} - \frac{RT}{p} \frac{dp}{dt} = -L_{lv} \frac{dm_v}{dt} > 0$$

First law of thermodynamics
Heat release by condensation
of rising parcels

$$\left(\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right)_p - S_p \omega = \frac{Q}{cp}, \quad \text{Re-formulated in pressure coordinates}$$

Stability parameter:

$$S_p = (\Gamma_d - \Gamma) / (\rho g)$$

Always positive
in large scales

Lapse-rate definition:

$$-dT/dz = \Gamma$$

$$\Gamma_d = \bar{g} / \bar{c}_p$$

Note that the thermodynamic equation can also be used to derive the powerful concept of moist static energy conservation

In tropical regions, horizontal gradients and local time changes are small compared to the other terms in the Thermodynamic Equation, therefore we have approximately:

$$\left(\cancel{\frac{\partial T}{\partial t}} + u \cancel{\frac{\partial T}{\partial x}} + v \cancel{\frac{\partial T}{\partial y}} \right)_p \overset{\sim 0}{-} S_p \omega = \frac{Q}{c_p} ,$$

$$-S_p \omega \approx S_p \rho g w \approx \frac{Q}{c_p}$$

$$w \approx \frac{Q}{c_p} \frac{1}{S_p \rho g} . \quad \text{Also anomalous:}$$

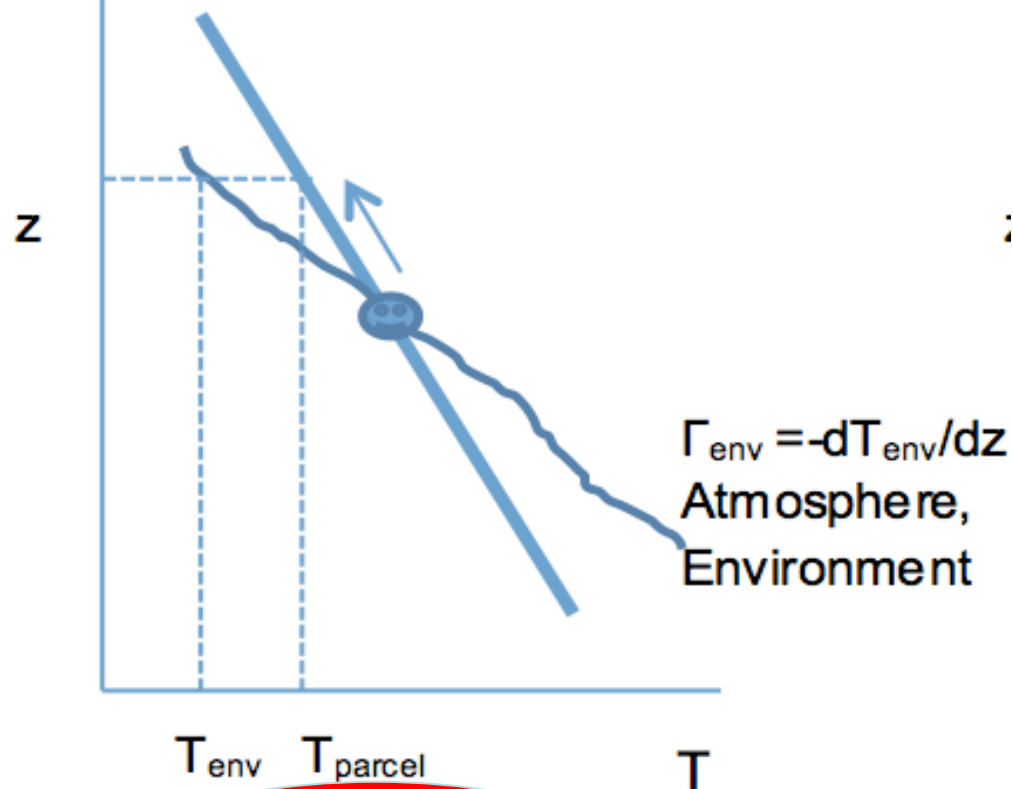
$$\Delta w \approx \frac{\Delta Q}{c_p} \frac{1}{S_p \rho g}$$

This means whenever there is convective heat release, we can expect that this heating is compensated by large-scale rising motion!

Unstable condition – negative static stability

$$\Gamma_d < \Gamma_{env}$$

Γ_d , DALR (parcel T follows this profile)



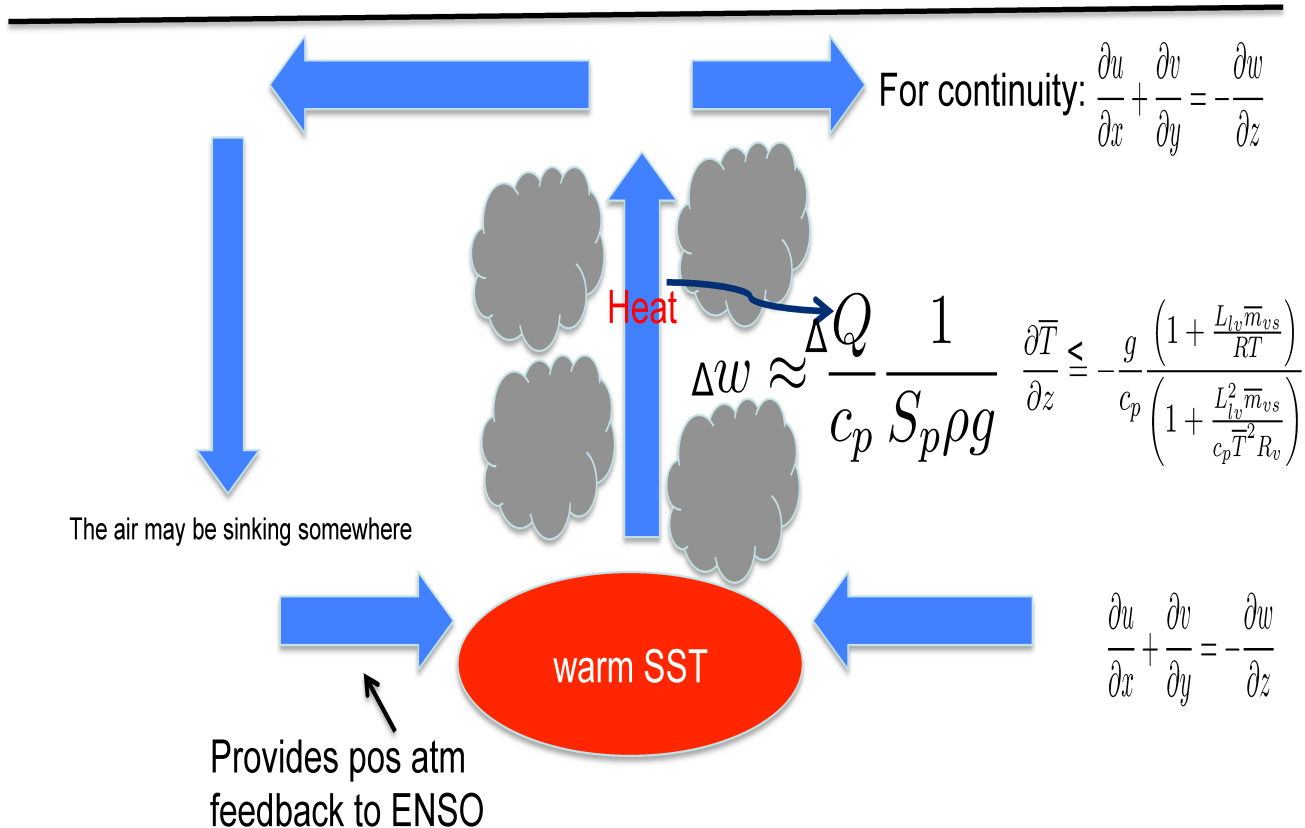
warm SST

Atmospheric response to Equatorial heating

In Stratosphere: $\Delta w \approx \frac{\Delta Q}{c_p} \frac{1}{S_p \rho g}$ small, because $S_p = (\Gamma_d - \Gamma)/(\rho g)$ Large!

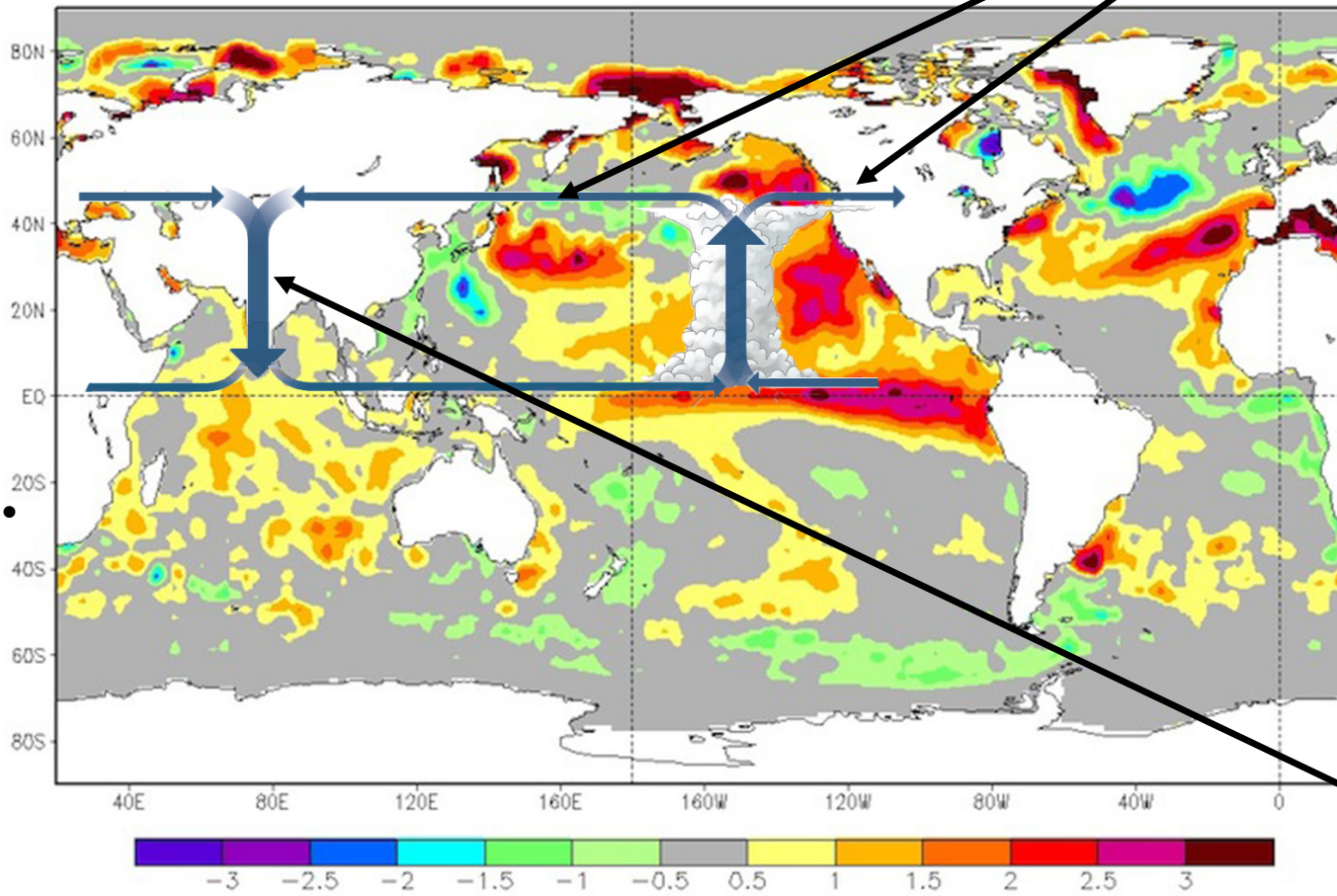
$$-dT/dz = \Gamma = 0$$

Tropopause ~ 10km



Example: Atmospheric teleconnection between ENSO and ISMR

Sea Surface Temperature Anomaly ($^{\circ}\text{C}$), Base Period 1971-2000
Week of 22 JUL 2015



Equatorial Rossby and Kelvin waves transport this signal

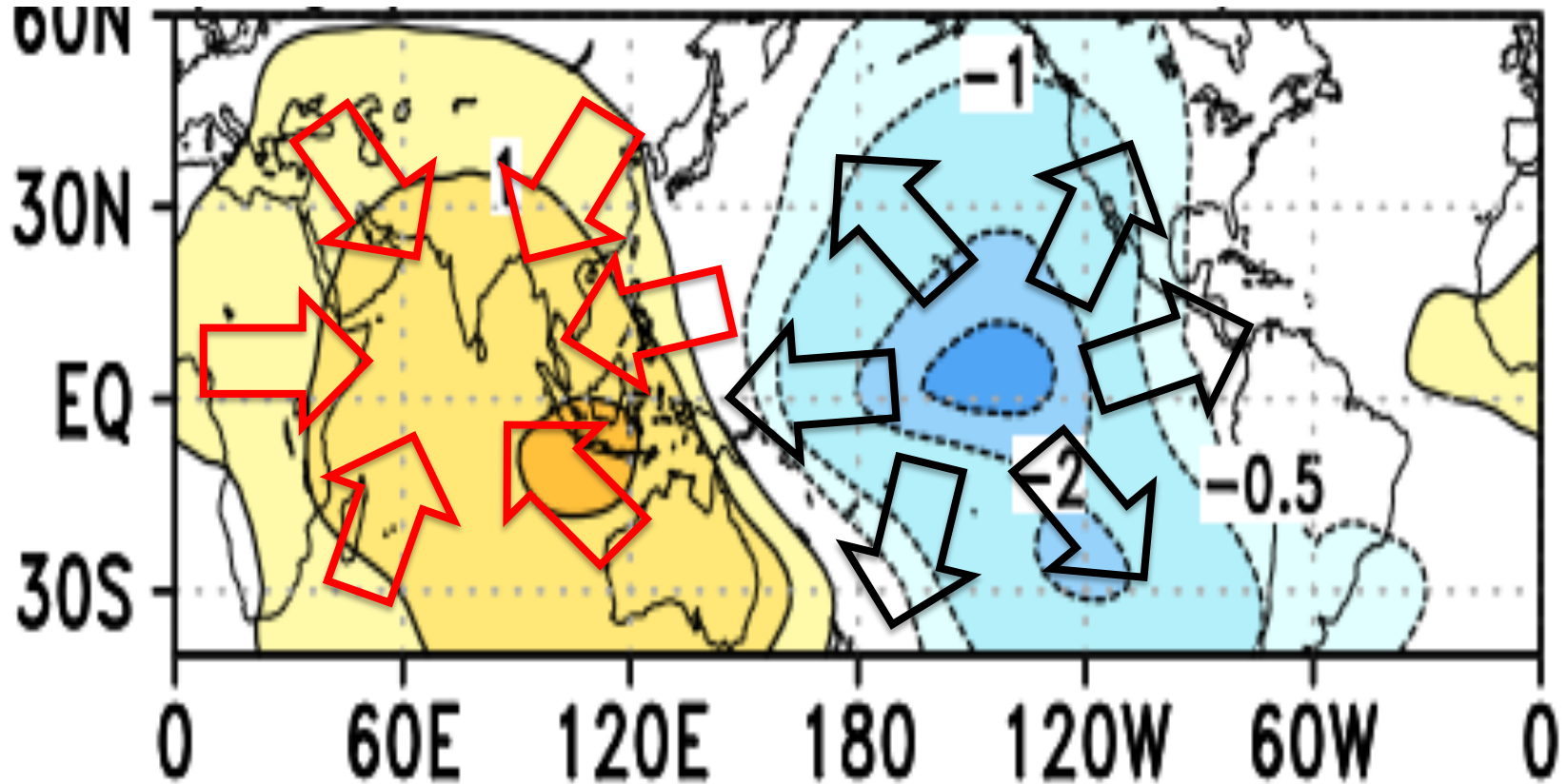
In principle:

warmer SST
more instability
more rainfall
more heating
in atmosphere
more upward
motion to
compensate
heating

explain this:
what comes up
must come down....
more sinking motion,
less moisture,
suppressed rainfall

Slide from Fabio Di Sante

Regression maps (OBS) of Niño3.4 (JJAS) onto 200 hPa velocity potential



Note, however, that there are also other more complicated adjustment processes.

Many mechanisms (perhaps order of several hundred publications) have been proposed for the ENSO-monsoon relationship:

I. Dynamic:

- a) Walker circulation adjustment sets up a local hadley cell adjustment in Indian Ocean [e.g. Goswami (1998) and Krishnamurthy and Goswami (2000)]
- b) Gill-type rossby wave response to sinking motion in maritime continent could induce sinking motion over India [e.g. Wang et al. (2003)]

II. Thermodynamic:

- a) A warm ENSO event warms the equatorial regions, including Indian Ocean (through fast equatorial wave propagation; equatorial Rossby and Kelvin waves). This reduces the tropospheric temperature gradient between relatively cool Indian Ocean and warmer South Asian [e.g. Goswami and Xavier (2005)]

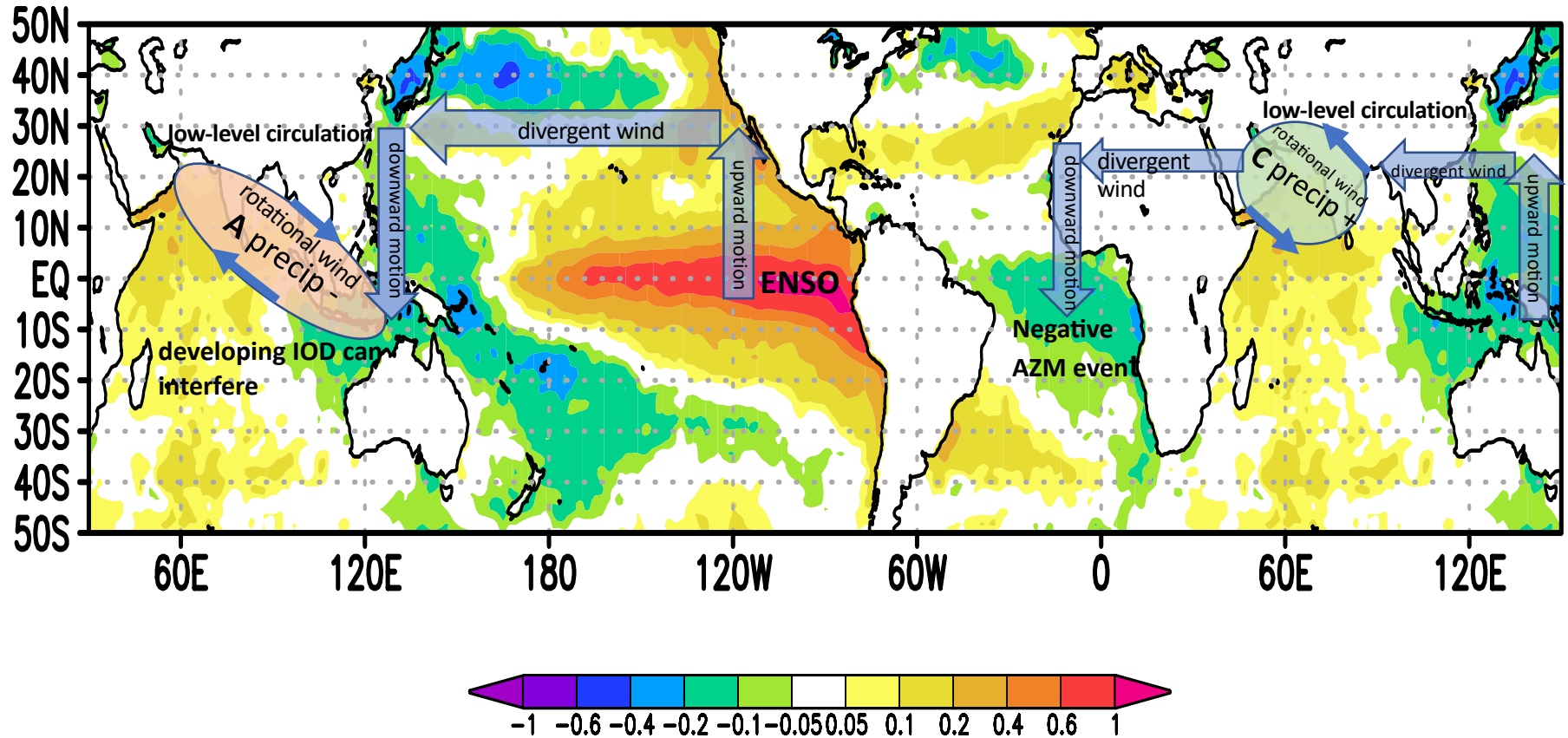
Focus on dynamic mechanisms

HadISST Nino3 regression Aug 1980-2020

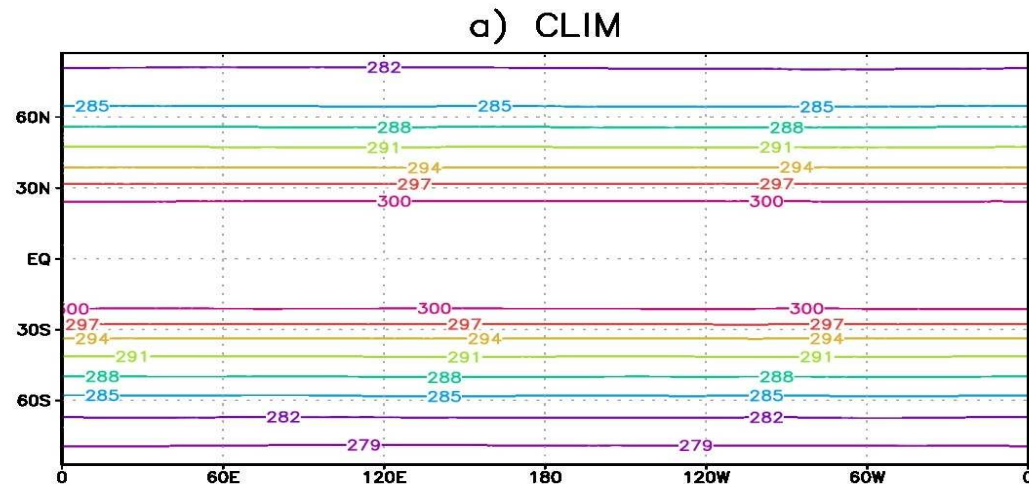
South Asian summer monsoon:

ENSO impacts

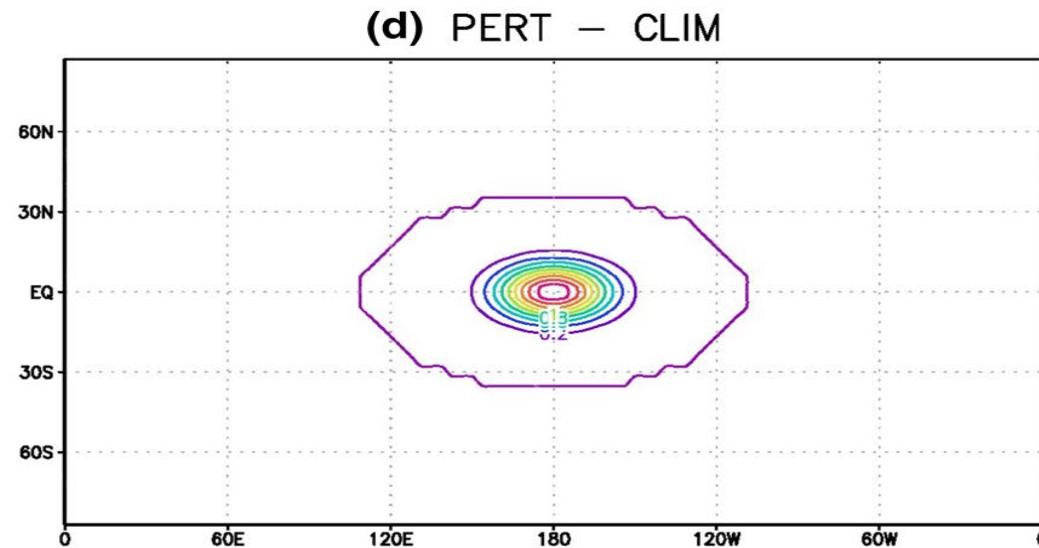
tropical Atlantic impacts



Many AGCM simulations have confirmed the tropical Atlantic Indian monsoon teleconnection; here results from a very idealised setting: Aquaplanet



A zonally symmetric world made of water, no mountains!



AGCM aquaplanet simulations; 2 K SST perturbation added to symmetric mean state SSTs

SST

Understanding the upper-level response (note response is baroclinic and changes sign in lower levels)

$$\xi_g = \frac{\partial v_g}{\partial x} - \frac{\partial u_g}{\partial y} \quad \frac{d_g \xi_g}{dt} = -f \left(\frac{\partial u_a}{\partial x} + \frac{\partial v_a}{\partial y} \right) - \beta v_g$$

approximate vorticity equation; again gradients are small in tropics

$$\xi_g = \nabla^2 \psi$$

$$\beta v_\psi = -f_0 \left(\frac{\partial u_\chi}{\partial x} + \frac{\partial v_\chi}{\partial y} \right)$$

Sverdrup balance in tropics (Rodwell & Hoskins)

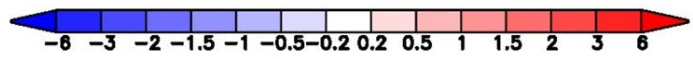
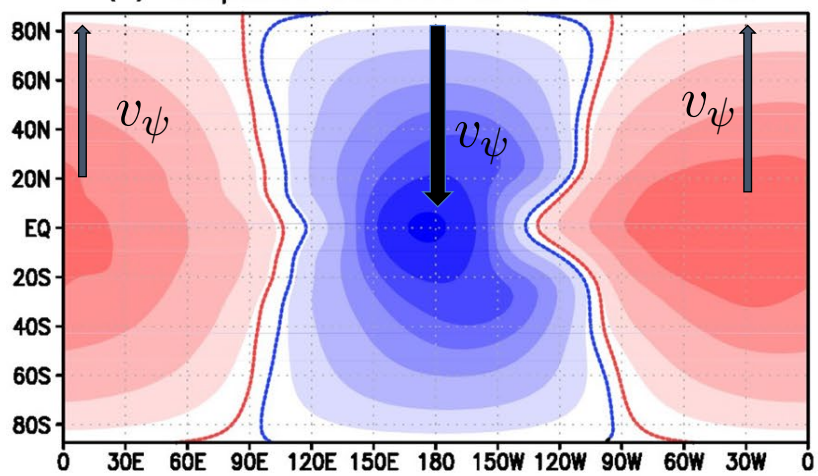
$$\mathbf{v}_\chi = \nabla \chi$$

Note that responses are baroclinic; i.e. change sign with height

$$\mathbf{v}_\psi = \mathbf{k} \times \nabla \psi$$

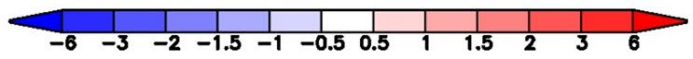
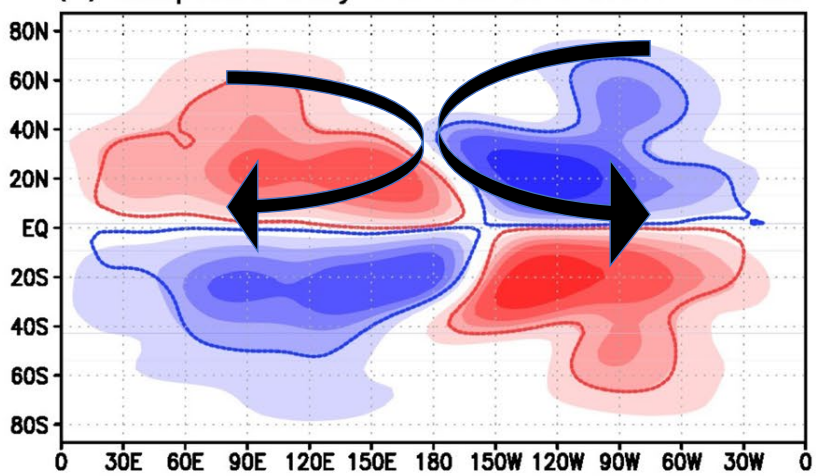
200 hPa Velocity Potential χ

(c) Response Chi 200 hPa PERT - CLIM

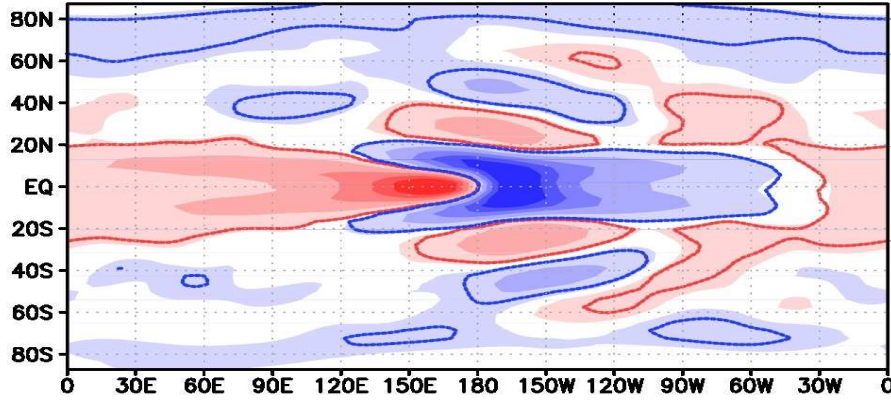


200 hPa Eddy Streamfunction ψ

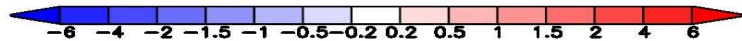
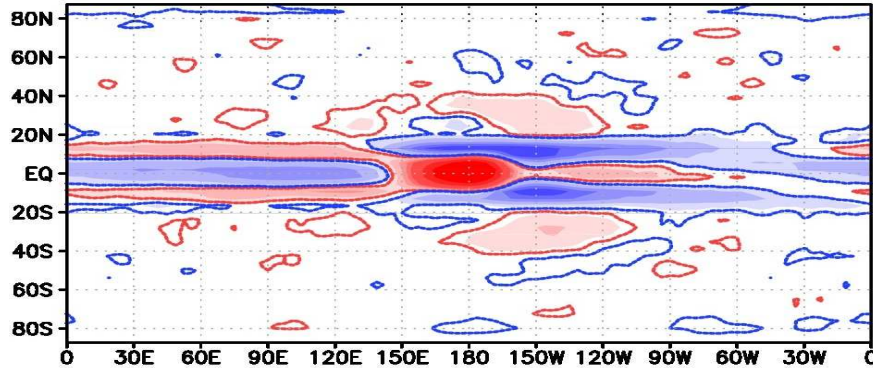
(d) Response eddy Psi 200 hPa PERT - CLIM



Surface zonal wind
b) Response SFC U PERT – CLIM



e) Response Prec. PERT – CLIM



Note that also:
$$\Delta w \approx \frac{\Delta Q}{c_p} \frac{1}{S_p \rho g}$$

Always holds! But sometimes ΔQ or rainfall is not the cause for the results of vertical motions!

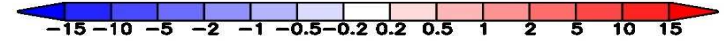
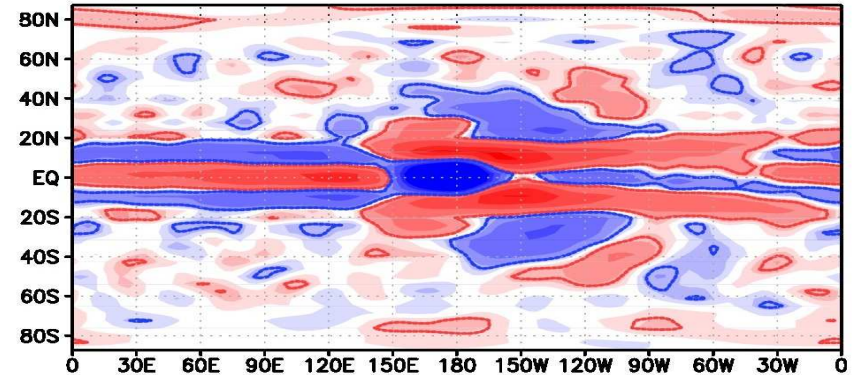
The low-level response

$$\xi_g = \frac{\partial v_g}{\partial x} - \frac{\partial u_g}{\partial y} \quad \text{Note: } -S_p \omega \approx S_p \rho g w$$

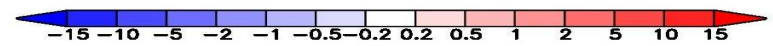
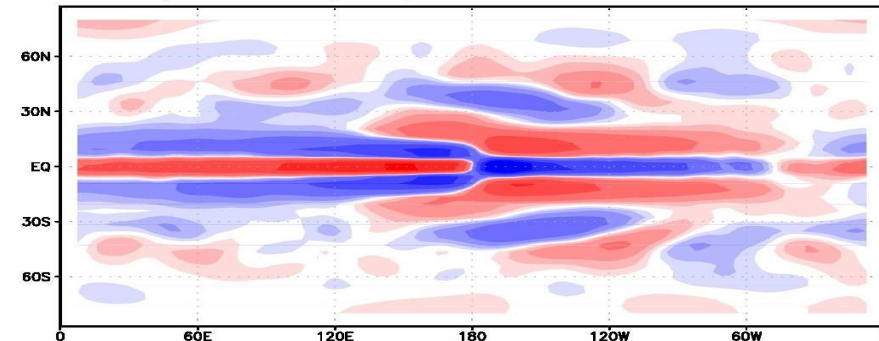
Ekman pumping

$$w(De) = \xi_g \sqrt{\frac{K_m}{2f}} \quad \text{Omega}$$

f) Response 850 hPa Omega PERT – CLIM



a) Ekman pump 850 hPa PERT-CLIM



Indexes used:

Nino3.4 : 190E to 240E, 5S to 5N

Nino3 : 210E to 270E, 5S to 5N

ATL3 : 20W to 0, 5S to 5N

STA : 30W to 10E, 20S to Eq.

We will often use composite analysis (e.g. ENSO) based on linear regression. These will be calculated as follows:

$$\hat{\beta}(x, y) = \frac{1}{N} \sum_{i=1}^N \left(\frac{X(t_i)}{\sigma_X} \right) \times F(x, y, t_i)$$

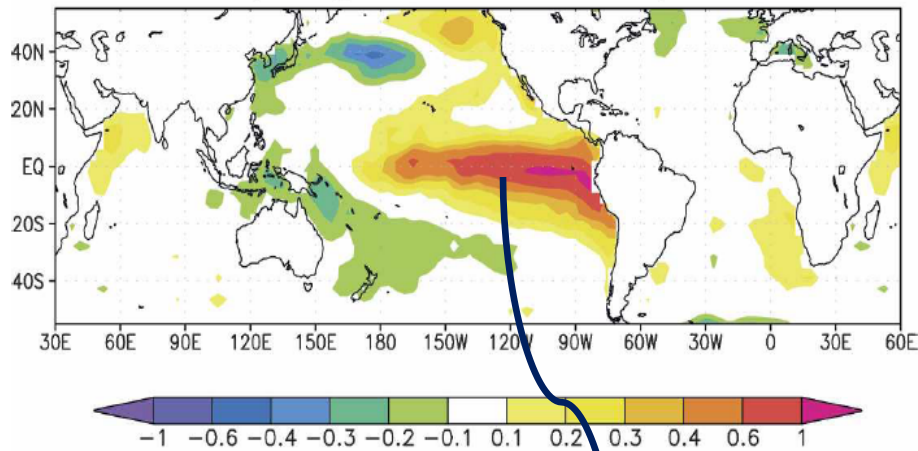
That is the covariance of a normalized index (e.g. Nino3.4 or ATL3) with a field of interest. This gives us an idea of how much of a typical (1 standard deviation) anomaly of the index is related to a field (e.g. rainfall); sometimes also a residual index is used from which the impact of another index has been linearly removed:

$$X_{res}(t) = X(t) - b \times X_{rem}(t)$$

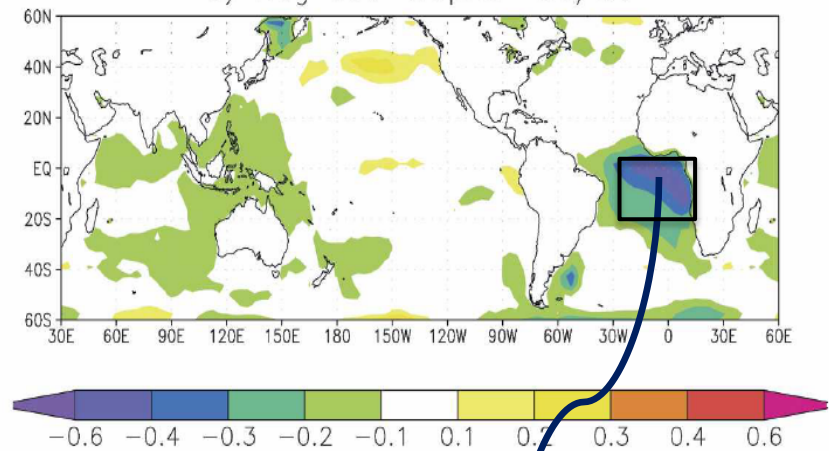
Here : $X_{rem}(t)$ is the index whose impact is removed (e.g. Nino3.4), while $X_{res}(t)$ is the index independent of Nino3.4 (e.g. 'pure' ATL3 impact).

Contrasting Eastern Pacific and tropical Atlantic influences on rainfall.

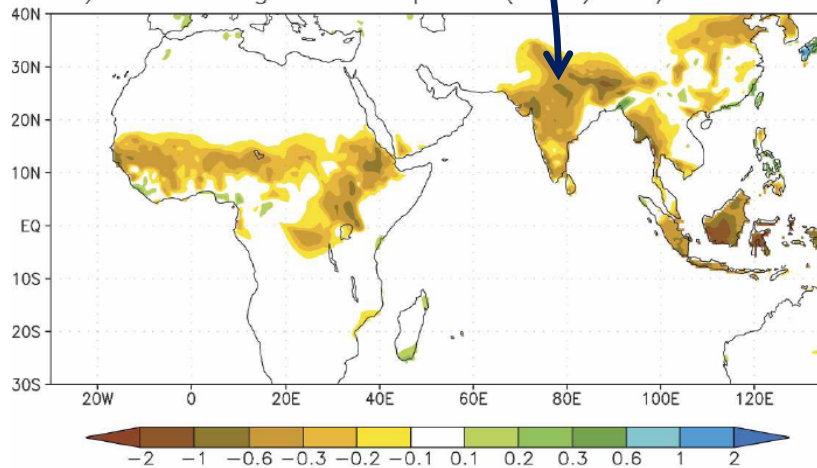
a) Reg SST-NINO3 50/74



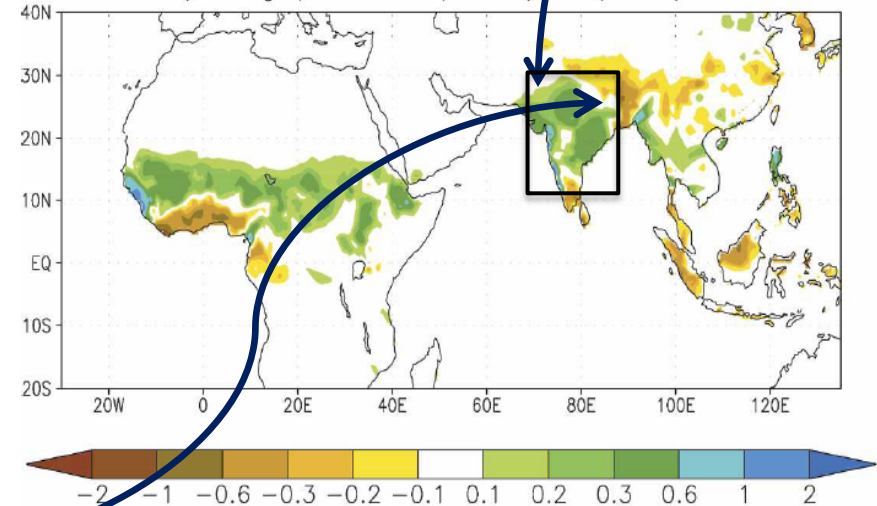
d) Reg SST-tropAtl 50/99



a) Reg NINO3-prec (CRU) 50/99



a) Reg prec-tropAtl (CRU) 50/99



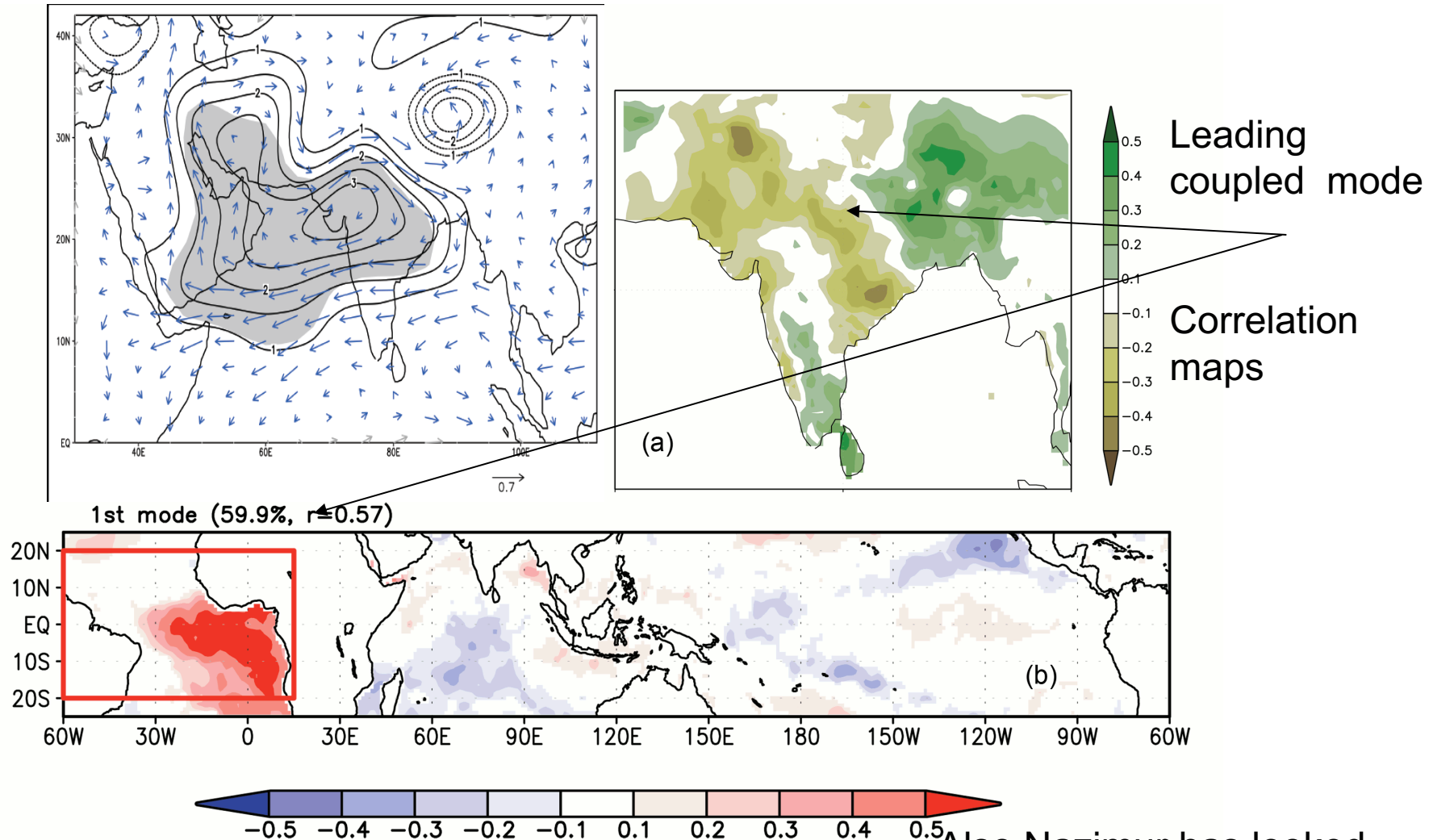
There are some interesting regional features, too!
Warm anomalies in Eq. Pacific and Atlantic have broadly
very similar influences on Asian (and African) Monsoon!

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

Results from a Maximum Covariance Analysis between observed (Aphrodite) Rainfall and tropical Atlantic SSTs (HadISST), leading mode

Figure from Syed and Kucharski (2016), published in Atmos. Sci. Lett. 17: 183-189

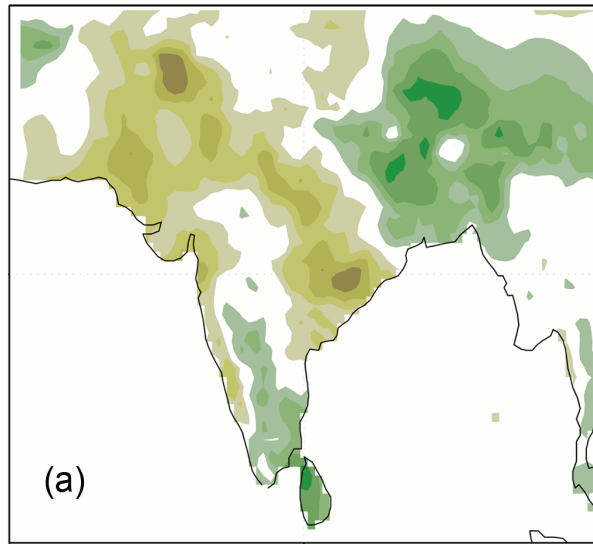
PC Regression (slp, low-level winds)



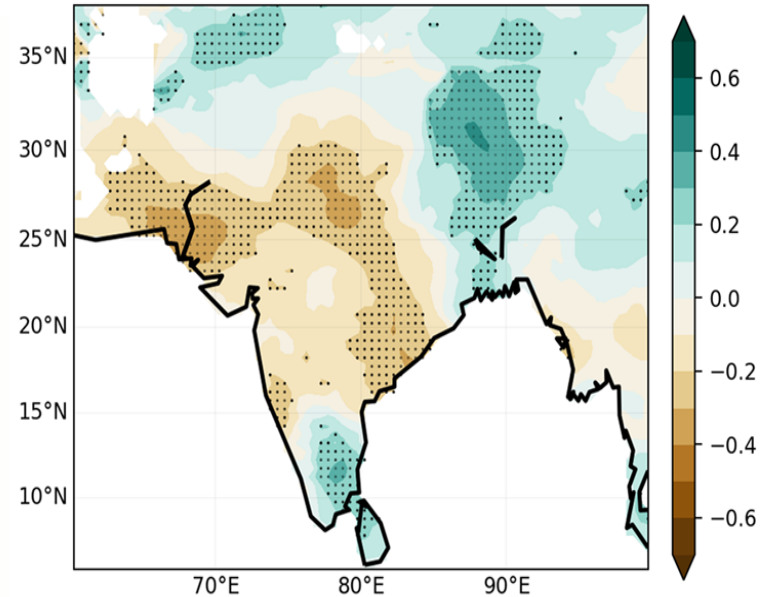
Also Nazimur has looked at this in Diploma thesis!

As we can see the result is a dipole structure!

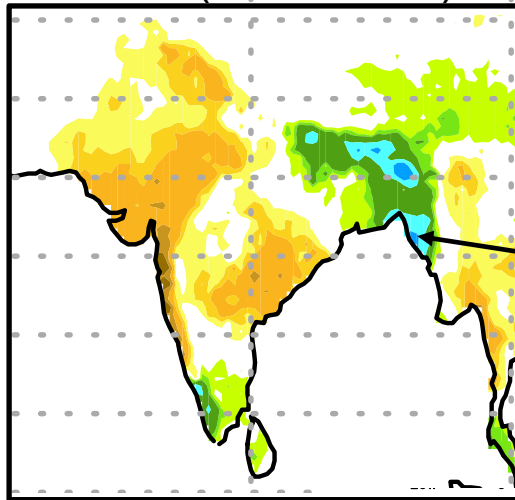
Aphrodite (1951-2007)



(c) CRU (1951-2017)



CRU (1951-2023)



nature climate change

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Letter | Published: 03 March 2013

Malaria epidemics and the influence of the tropical South Atlantic on the Indian monsoon

[B. A. Cash](#), [X. Rodó](#), [J. Ballester](#), [M. J. Bouma](#), [A. Baeza](#), [R. Dhiman](#) & [M. Pascual](#) [✉](#)

[Nature Climate Change](#) **3**, 502–507 (2013) | [Cite this article](#)

Hari, V., Pathak, A. & Koppa, A. Dual response of Arabian Sea cyclones and strength of Indian monsoon to Southern Atlantic Ocean. *Clim Dyn* **56**, 2149–2161 (2021). <https://doi.org/10.1007/s00382-020-05577-9>

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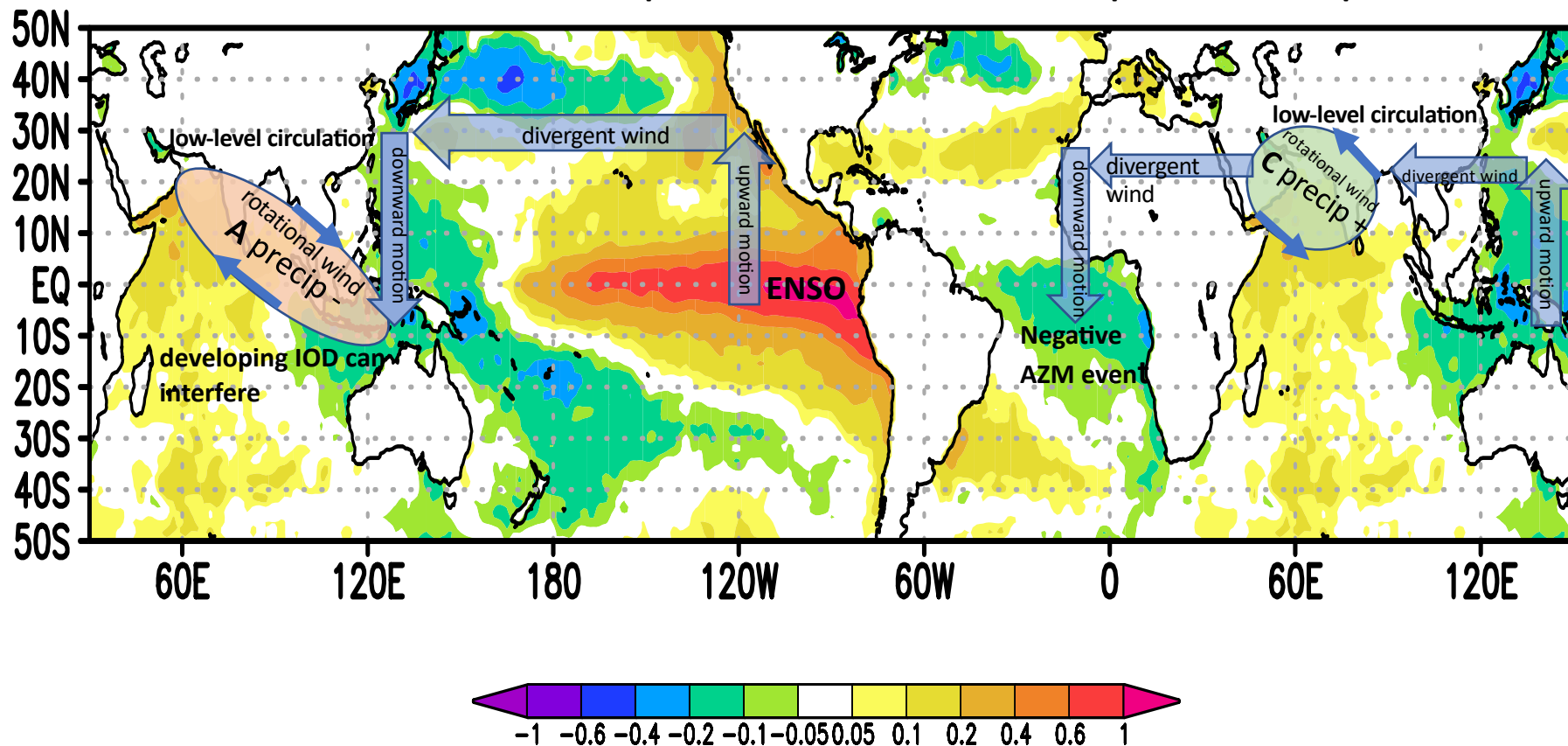
Focus on dynamic mechanisms

HadISST Nino3 regression Aug 1980-2020

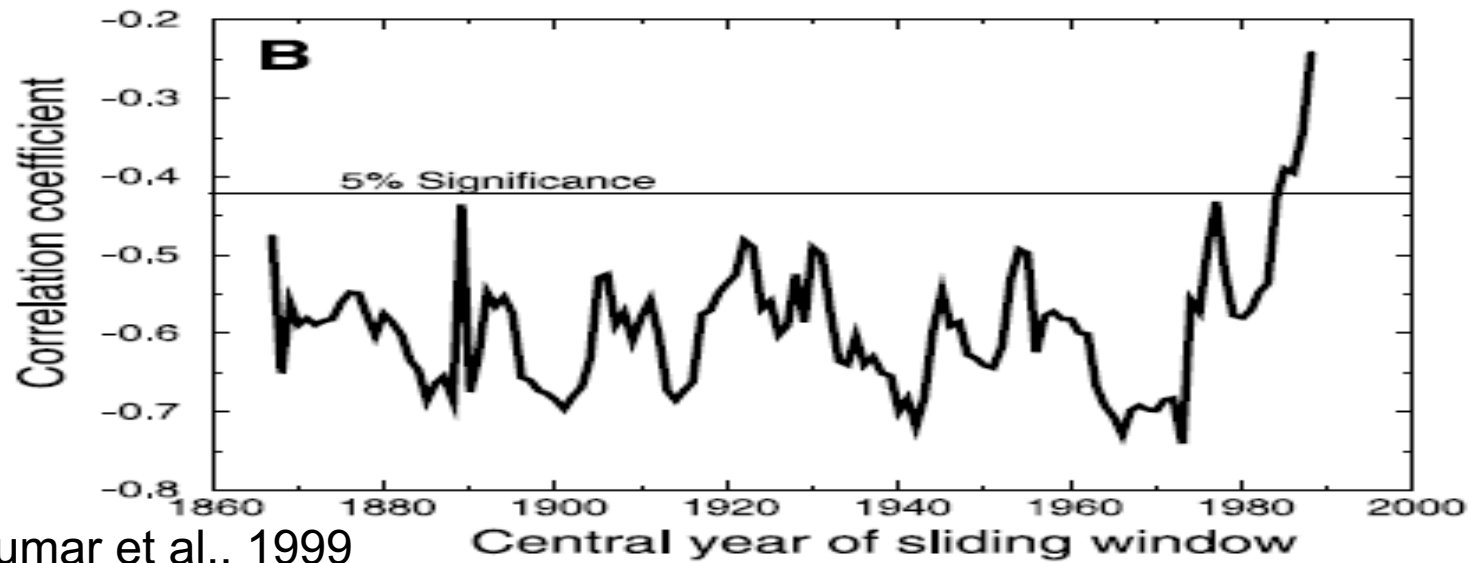
South Asian summer monsoon:

ENSO impacts

tropical Atlantic impacts

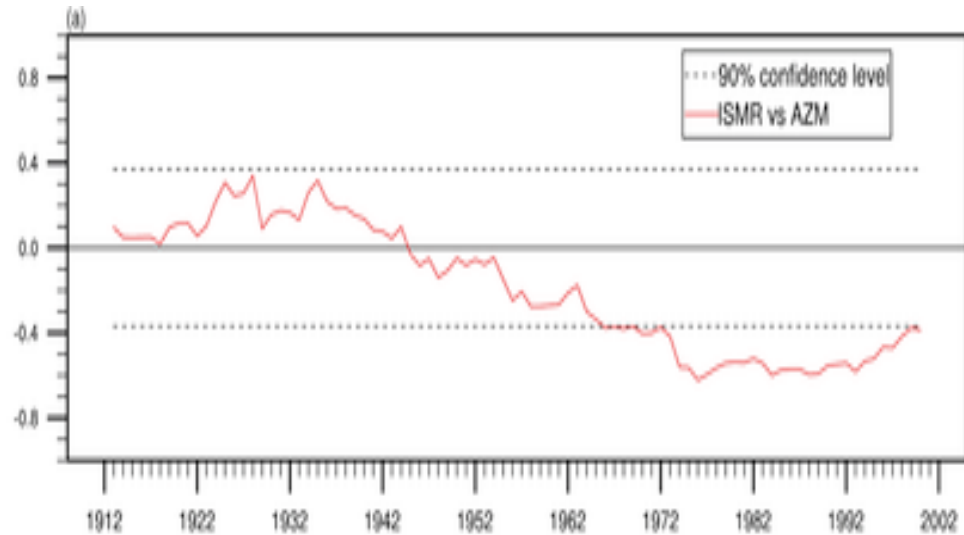


Sliding correlation between Nino3 index and ISMR



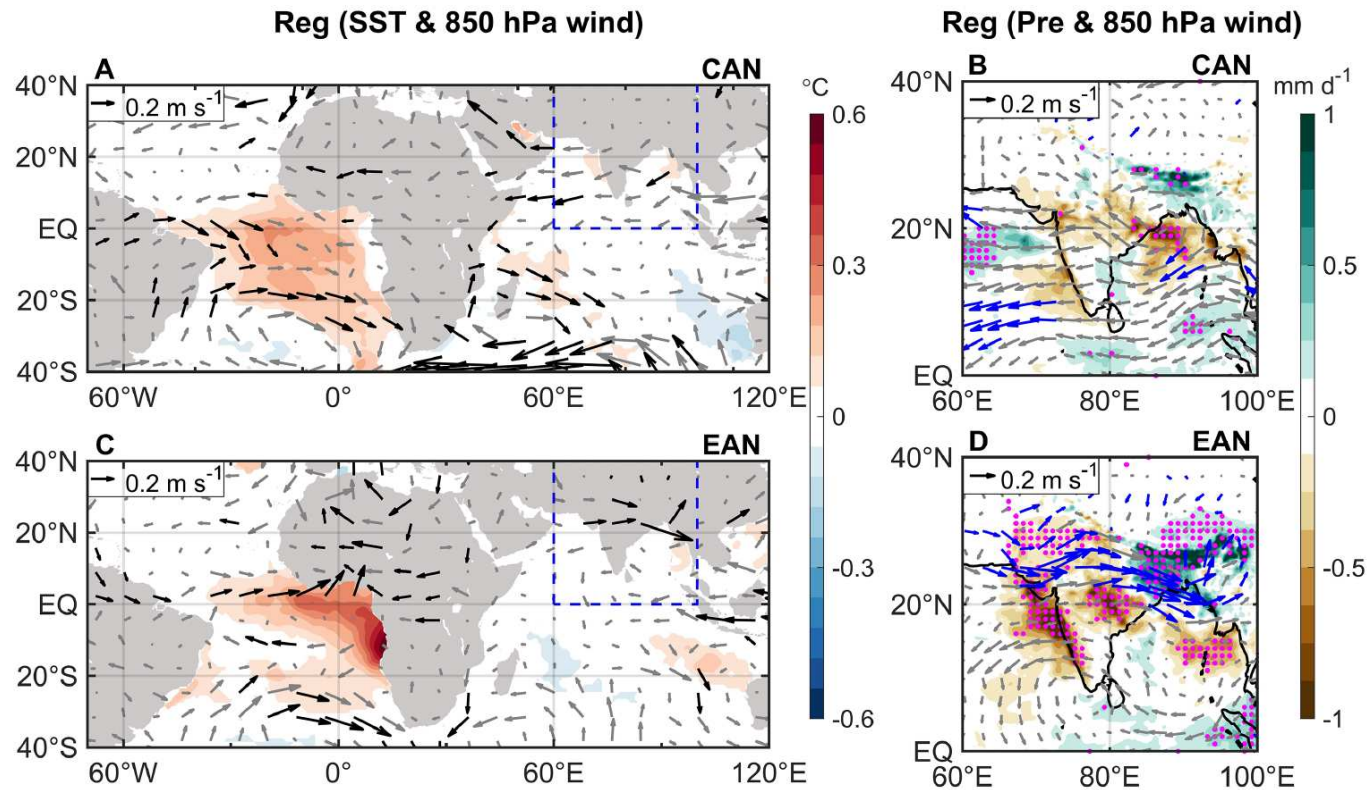
From: Kumar et al., 1999

Sliding correlation between Atl3 index and ISMR

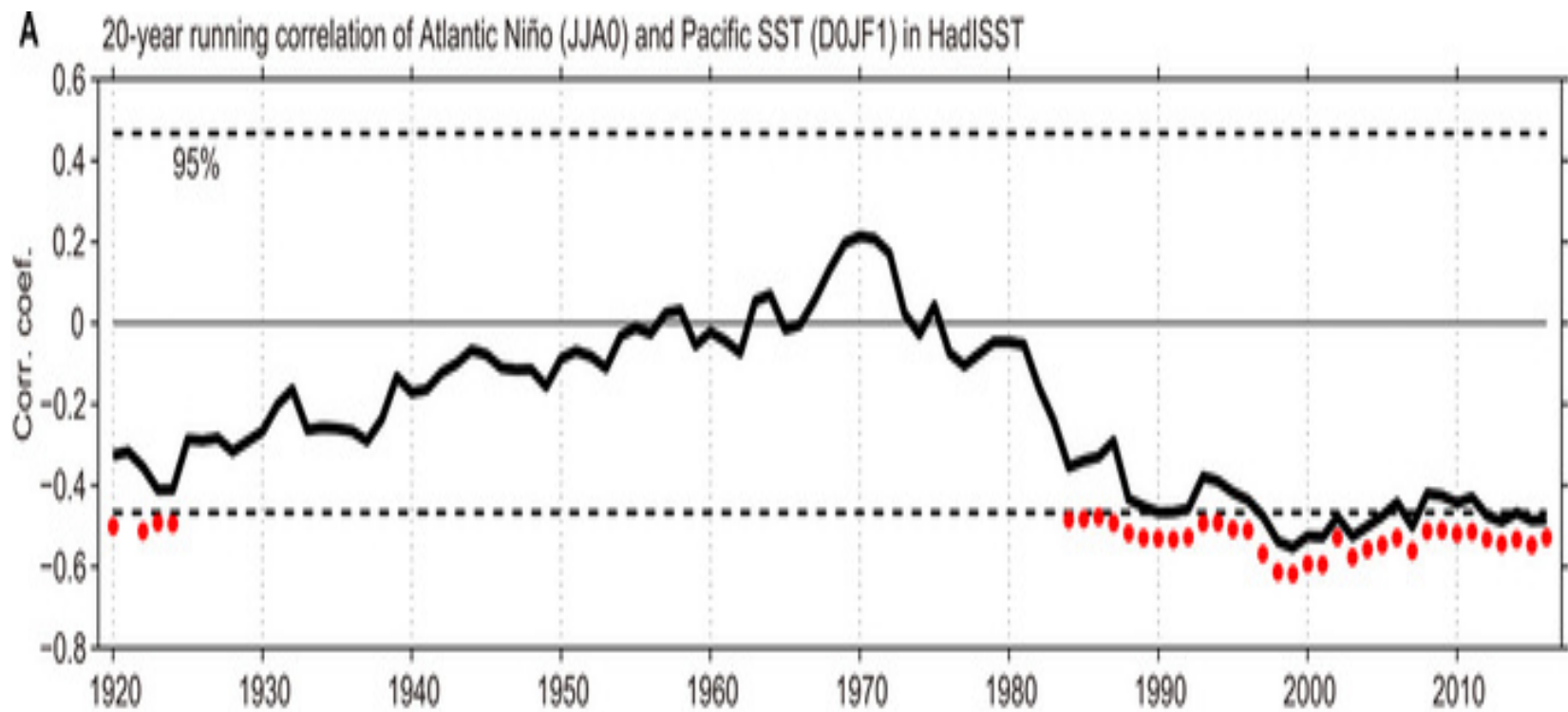


From: Sabeerali et al., GRL, 2019

Recently different impacts of 2 types of Atlantic Niño on South Asia have been discussed



Jin et al., 2026, Roles of central and eastern Atlantic Niño in the interannual variability of Indian summer monsoon, Sci. China Earth Sciences, doi.org/10.1007/s11430-025-1841-9



Jia et al., 2019, Weakening Atlantic Niño–Pacific connection under greenhouse warming, *Science Advances*, DOI:10.1126/sciadv.aax4111

Barimalala R, Bracco A, Kucharski F. 2011. The representation of the south tropical Atlantic teleconnection to the Indian Ocean in the AR4 coupled models. *Clim. Dyn.* **38**: 1147–1166, doi: 10.1007/s00382-011-1082-5.

Hari, V., Pathak, A. & Koppa, A. 2020. Dual response of Arabian Sea cyclones and strength of Indian monsoon to Southern Atlantic Ocean. *Clim Dyn.* <https://doi.org/10.1007/s00382-020-05577-9>

Kucharski F, Bracco A, Yoo JH, Molteni F. 2007. Low-frequency variability of the Indian monsoon – ENSO relationship and the tropical Atlantic: The ‘weakening’ of the 1980s and 1990s. *J. Clim.* **20**: 4255–4266, doi: 10.1175/JCLI4254.1.

Kucharski F, Bracco A, Yoo JH, Molteni F. 2008. Atlantic forced component of the Indian monsoon interannual variability. *Geophys. Res. Lett.* **35**: L04706, doi: 10.1029/2007GL033037.

Kucharski F, Bracco A, Yoo JH, Tompkins AM, Feudale L, Ruti P, Dell’Aquila A. 2009. A Gill – Matsuno-type mechanism explains the tropical Atlantic influence on African and Indian monsoon rainfall. *Q. J. R. Meteorol. Soc.* **135**: 569–579, doi: 10.1002/qj.406.

Losada T, Rodriguez-Fonseca B, Polo I, Janicot S, Gervois S, Chauvin F, Ruti P. 2010. Tropical response to the Atlantic Equatorial mode: AGCM multimodel approach. *Clim. Dyn.* **35**: 45 – 52, doi 10.1007/s00382-009- 0624-6.

Pottapinjara V, Girishkumar MS, Ravichandran M, Murtugudde R. 2014. Influence of the Atlantic zonal mode on monsoon depressions in the Bay of Bengal during boreal summer. *J. Geophys. Res. Atmos.* **119**: 6456 – 6469, doi: 10.1002/2014JD021494.

Pottapinjara V, Girishkumar MS, Sivareddy S, Ravichandran M MR. 2015. Relation between the upper ocean heat content in the equatorial Atlantic during boreal spring and the Indian monsoon rainfall during June–September. *Int. J. Climatol.* **36**: 2469–2480, doi: 10.1002/joc.4506.

Syed FS, Kucharski F. 2016. Statistically related coupled modes of South Asian summer monsoon interannual variability in the tropics. *Atmos. Sci. Lett.* **17**: 183–189, doi: 10.1002/asl.641.

Yadav RK. 2009. Role of equatorial central Pacific and northwest of North Atlantic 2-metre surface temperatures in modulating Indian summer monsoon variability. *Clim. Dyn.* **32**: 549–563.

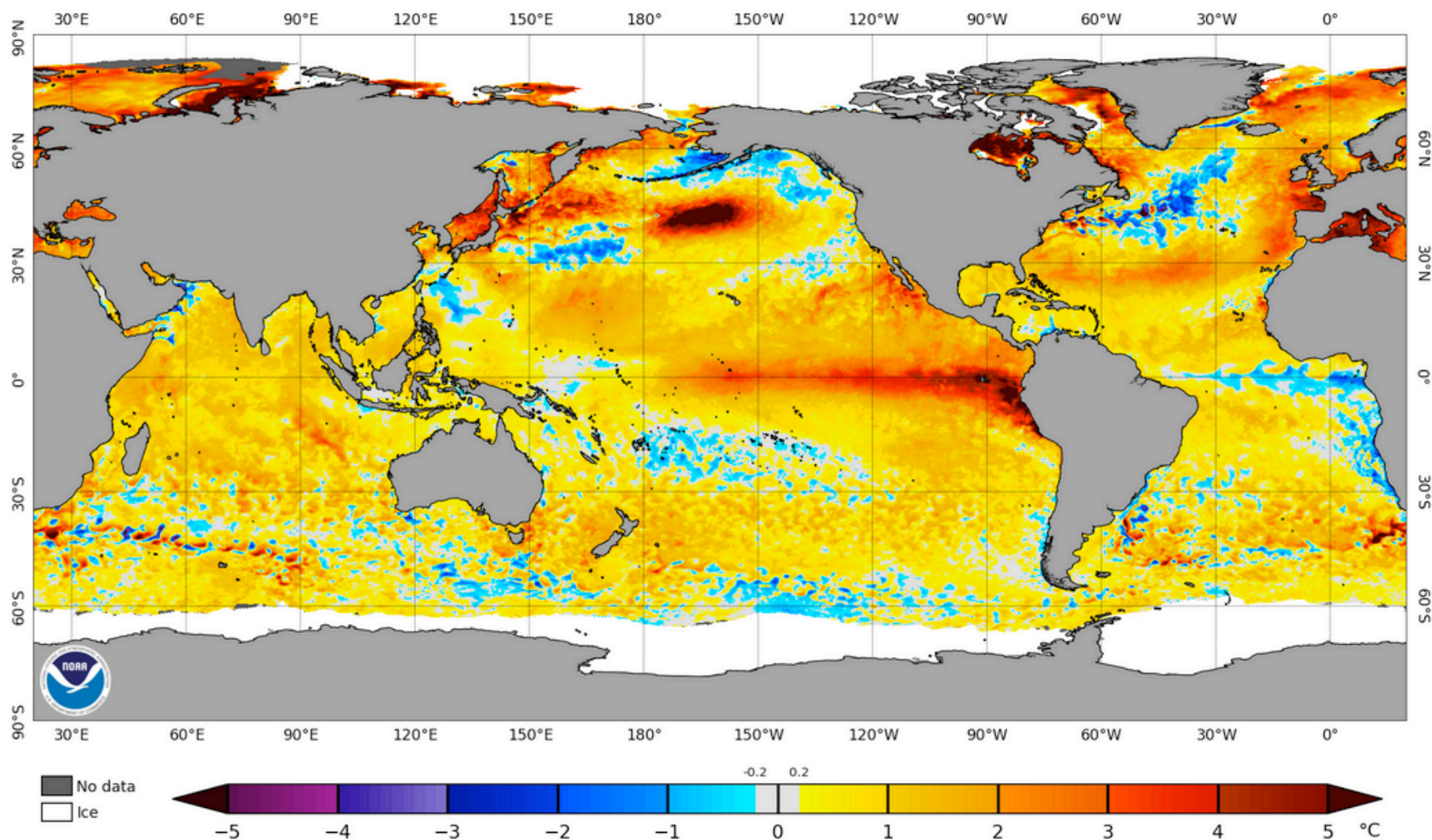
Yadav RK. 2017. On the relationship between east equatorial Atlantic SST and ISM through Eurasian wave. *Clim. Dyn.* **48**: 281–295, doi: 10.1007/s00382- 016-3074-y

Yadav, R.K., Srinivas, G. & Chowdary, J.S. 2018. Atlantic Niño modulation of the Indian summer monsoon through Asian jet. *npj Clim Atmos Sci* **1**, 23. <https://doi.org/10.1038/s41612-018-0029-5>.

and many more

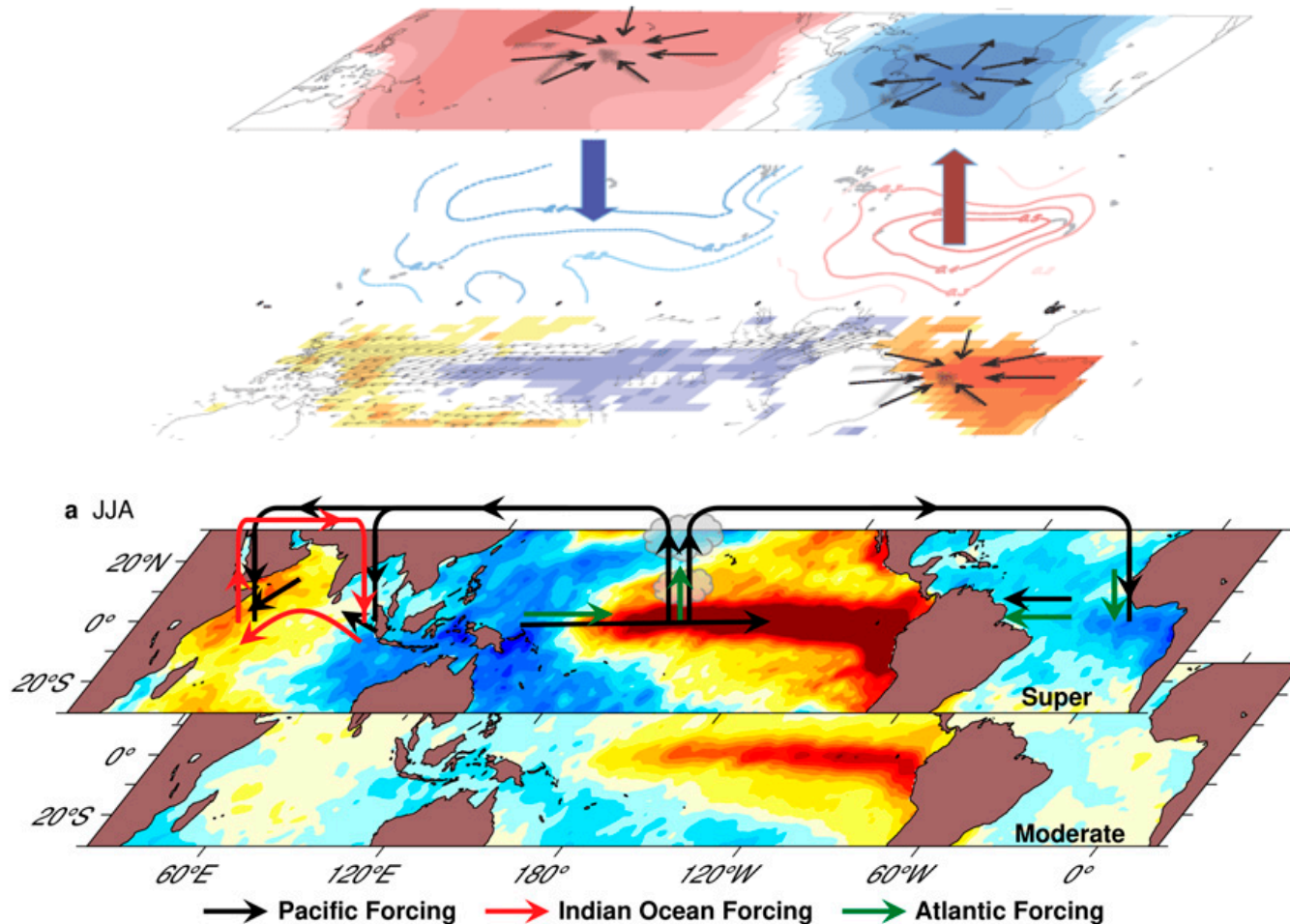
Current SST anomaly

NOAA Coral Reef Watch Daily 5km SST Anomalies (v3.1) 18 Jul 2026

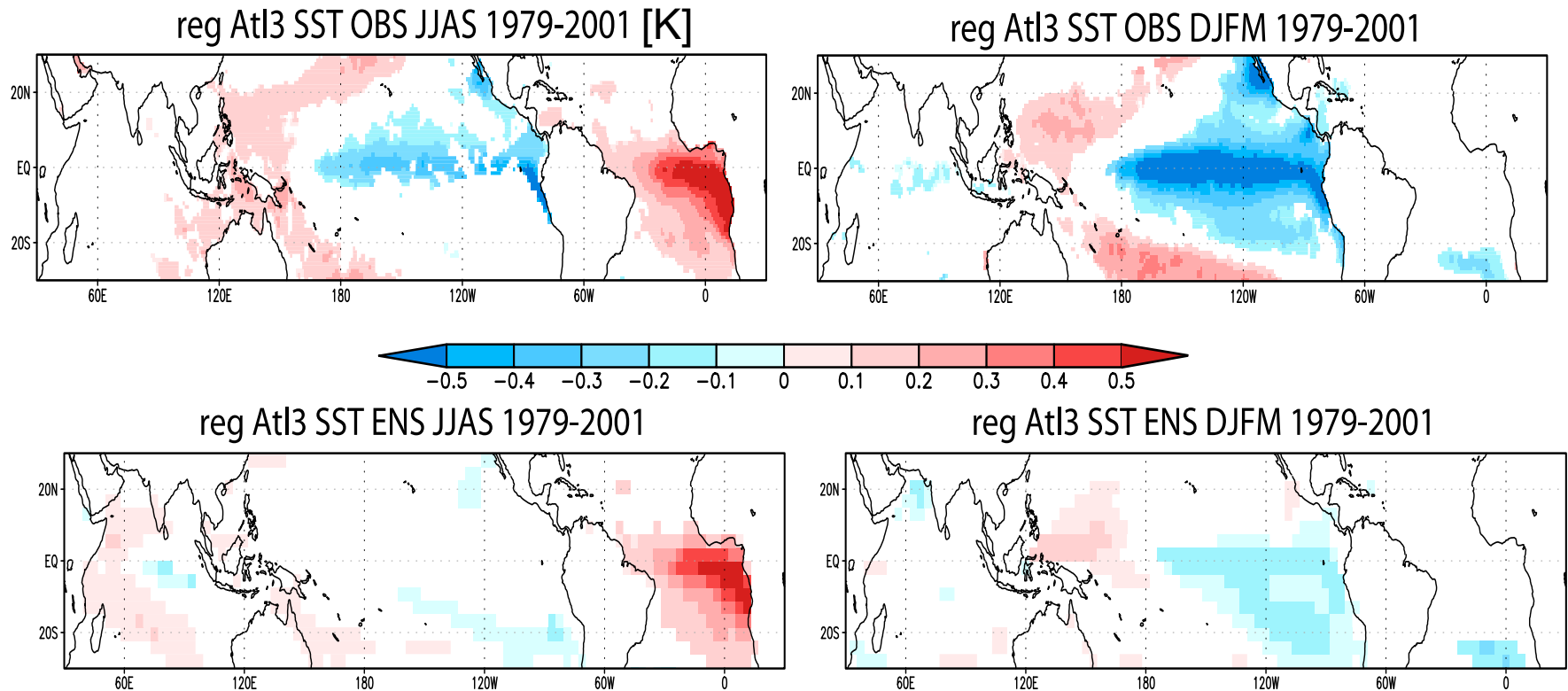


Next topic: Tropical Atlantic impact on Pacific; Probably something like 200 papers on this topic in the period 2008-2026

How can the 'small' Atlantic Ocean impact variability in the 'big' Pacific Ocean? Probably the Atlantic Ocean can provide some initial persistent forcing that is amplified in the Pacific through positive feedback (e.g. Bjerknes feedback and others). Some catalytic effect.



a) Atlantic zonal mode impact on ENSO

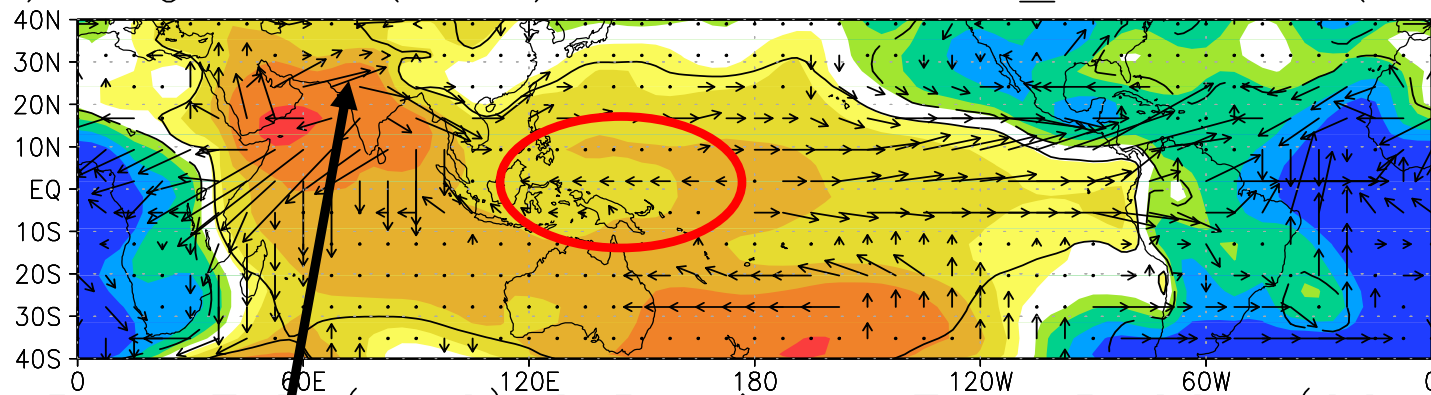


From Rodriguez-Fonseca et al. (2009) for period 1979 to 2001
'Pacemaker' Experiments done with SPEEDY coupled to an Reduced Gravity Ocean model for the equatorial thermocline.

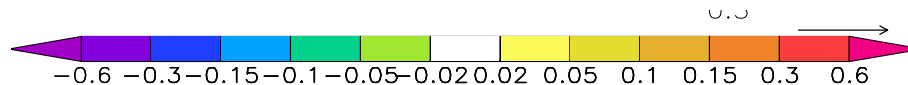
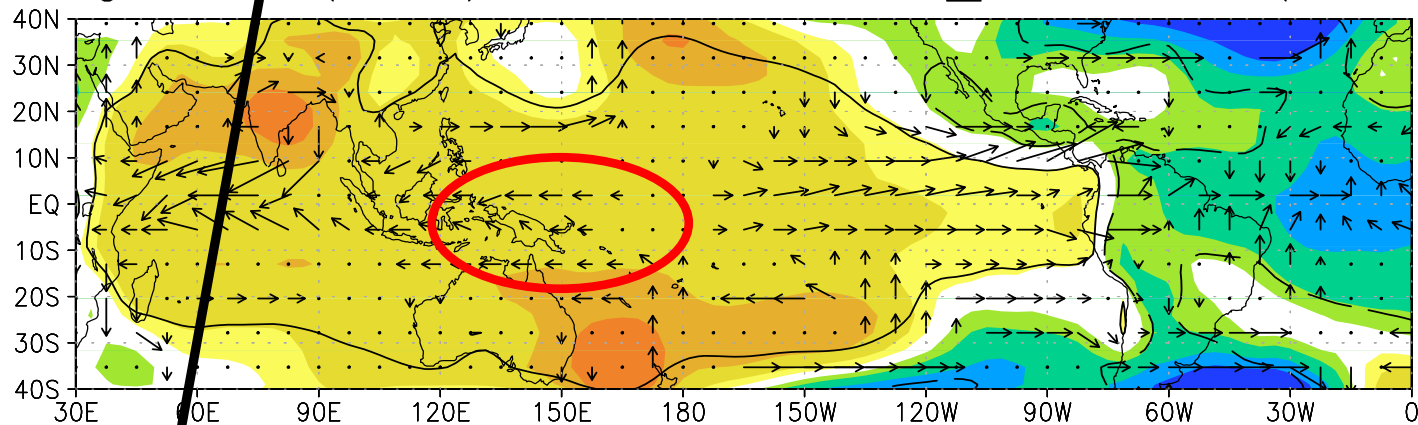
a) Atlantic zonal mode impact on ENSO; SPEEDY AGCM Atlantic Pacemaker simulations

Period: 1900-2010

a) Reg ATL3 (JJAS) SLP, winds ATL_VARAGCM (JJAS)



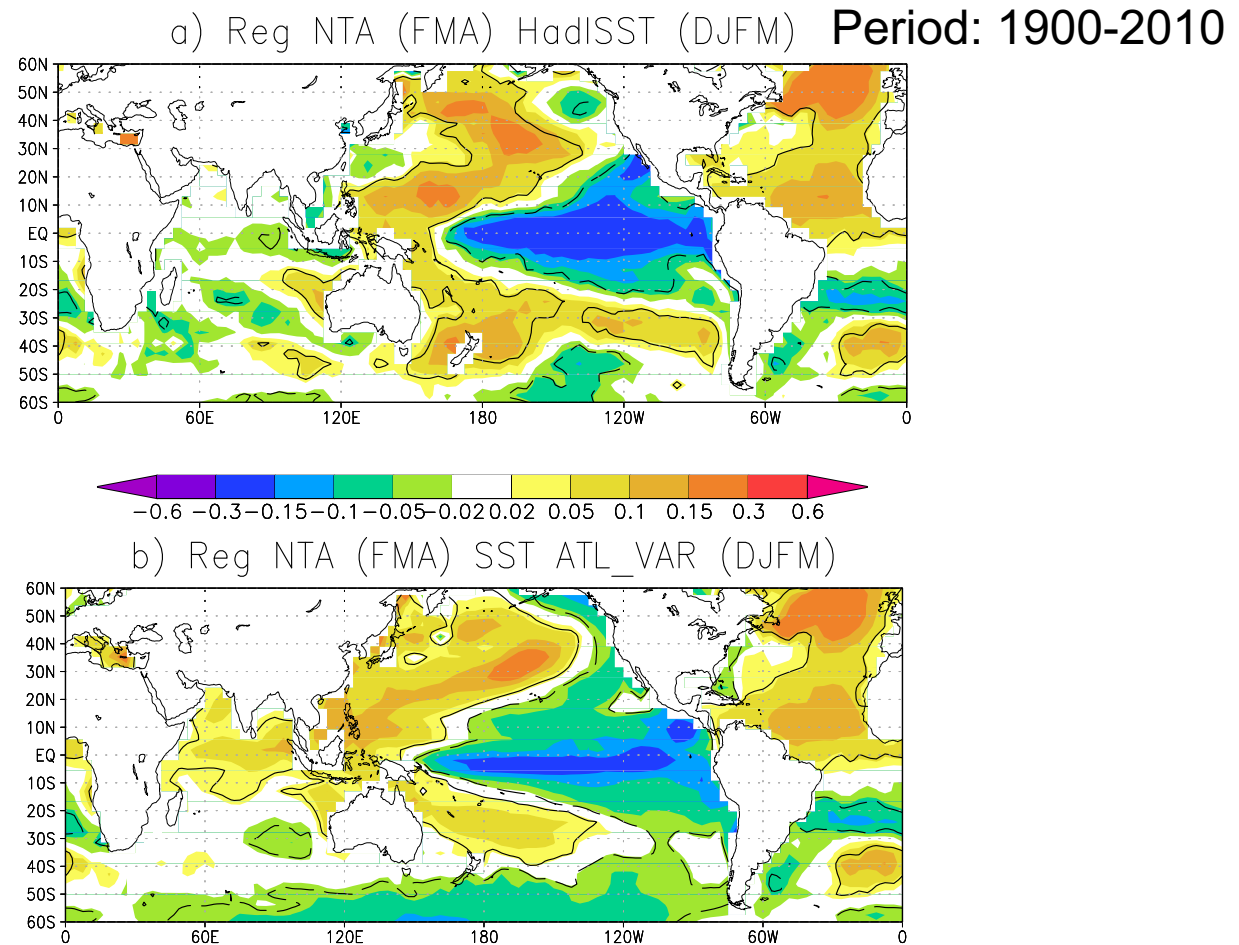
Reg ATL3 (JJAS) SLP, winds ATL_VARAGCM (SOND)



Also note impact on South Asian monsoon seen here!

b) North tropical Atlantic impact on ENSO;

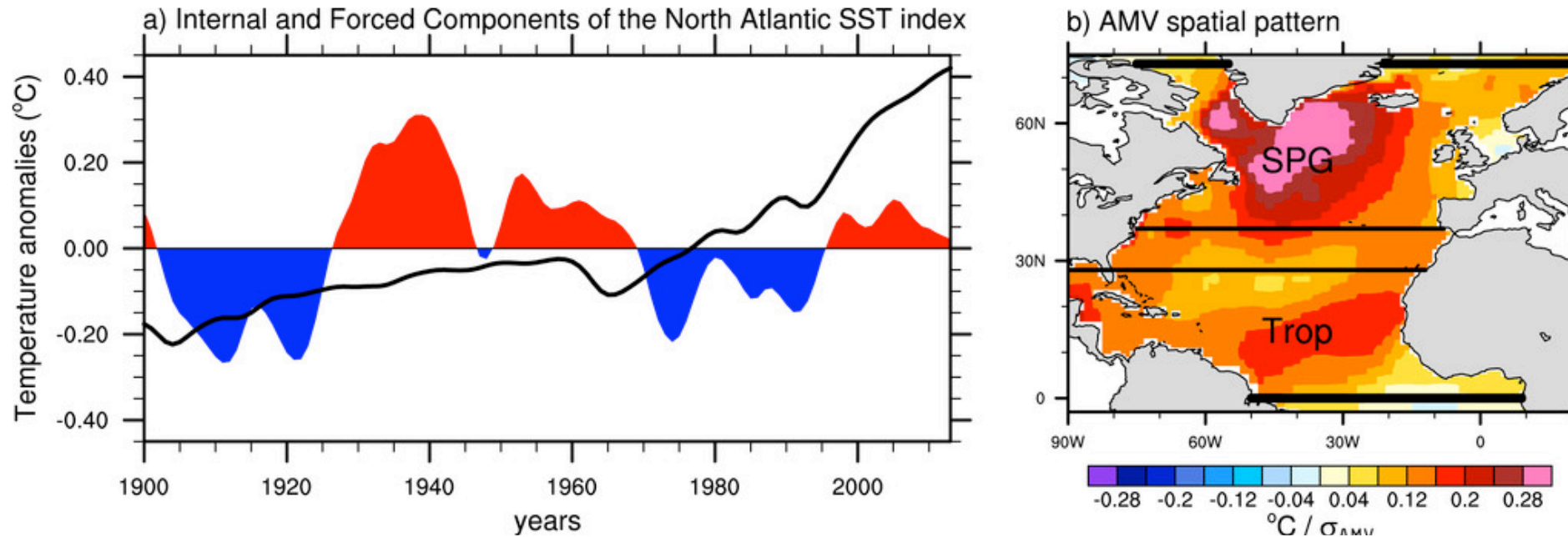
SPEEDY-NEMO Atlantic Pacemaker simulations



Originally proposed by:

Ham, Y.-Y.; Kug, J.-S.; Park, J. Y.; Jin, F.-F. Sea surface temperature in the north tropical Atlantic as a trigger for El Nino/Southern Oscillation events. *Nat. Geosci.* **2013**, 6, doi:10.1038/NGEO1686.

c) Atlantic Multidecadal Variability impact on Indo-Pacific



Topic still under investigation!

Nature Communications

<https://doi.org/10.1038/s41467-026-73763-0>

Article in Press

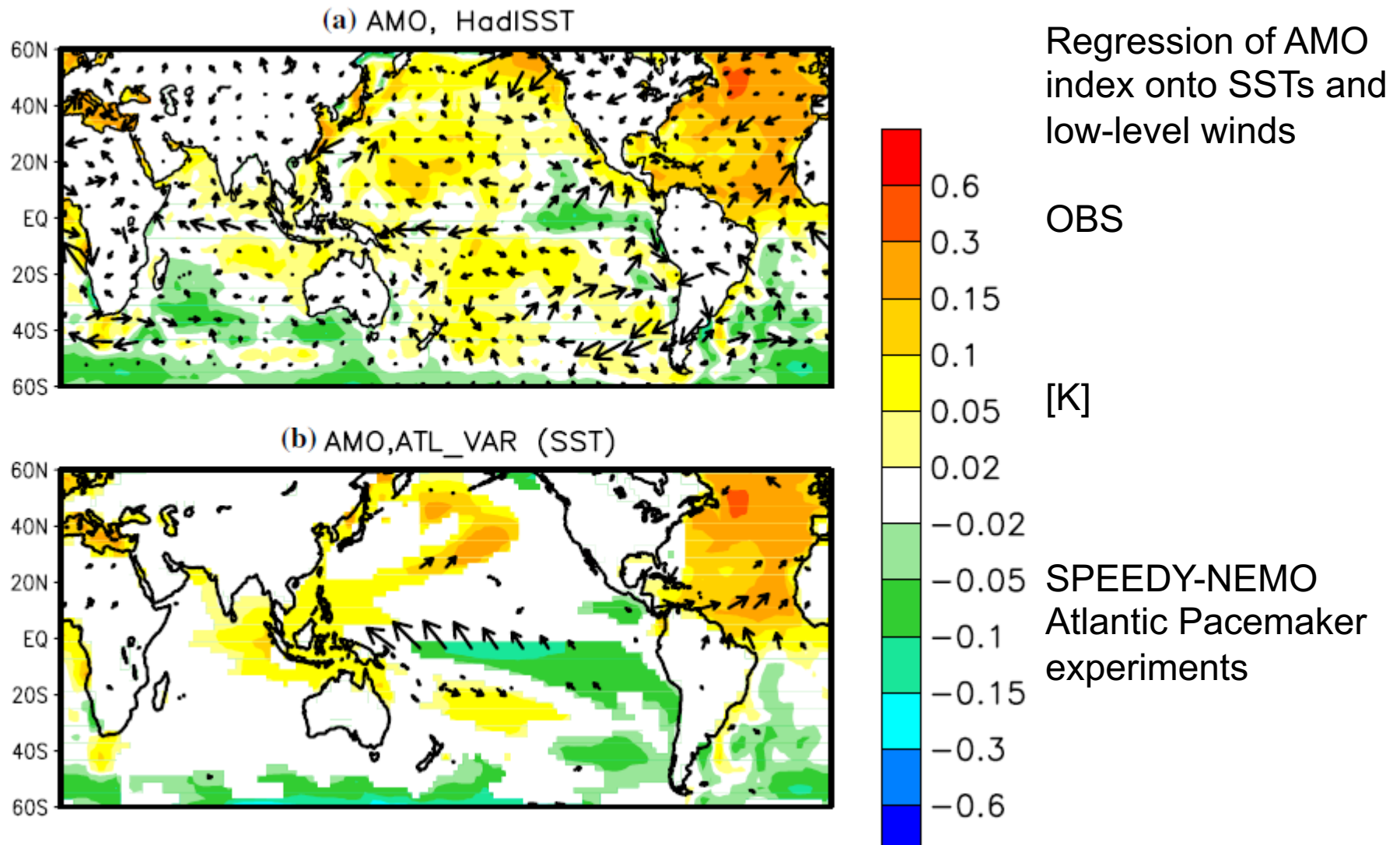
North Atlantic influence reconciling model-observation discrepancy in the tropical Pacific warming pattern

Received: 21 July 2025

Yueh-Chi Lin & Masahiro Watanabe

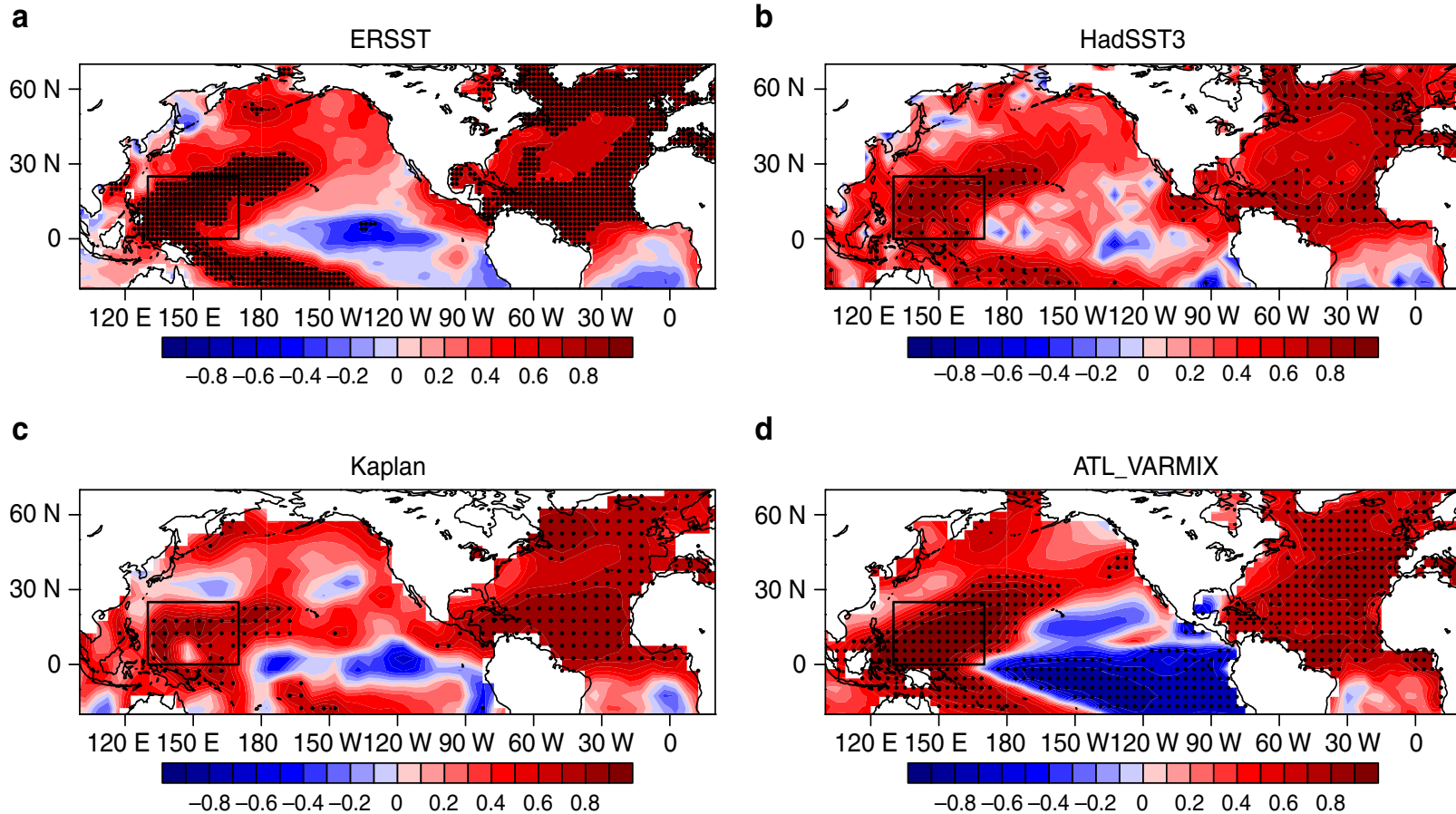
Accepted: 18 May 2026

c) Atlantic Multidecadal Variability impact on Indo-Pacific



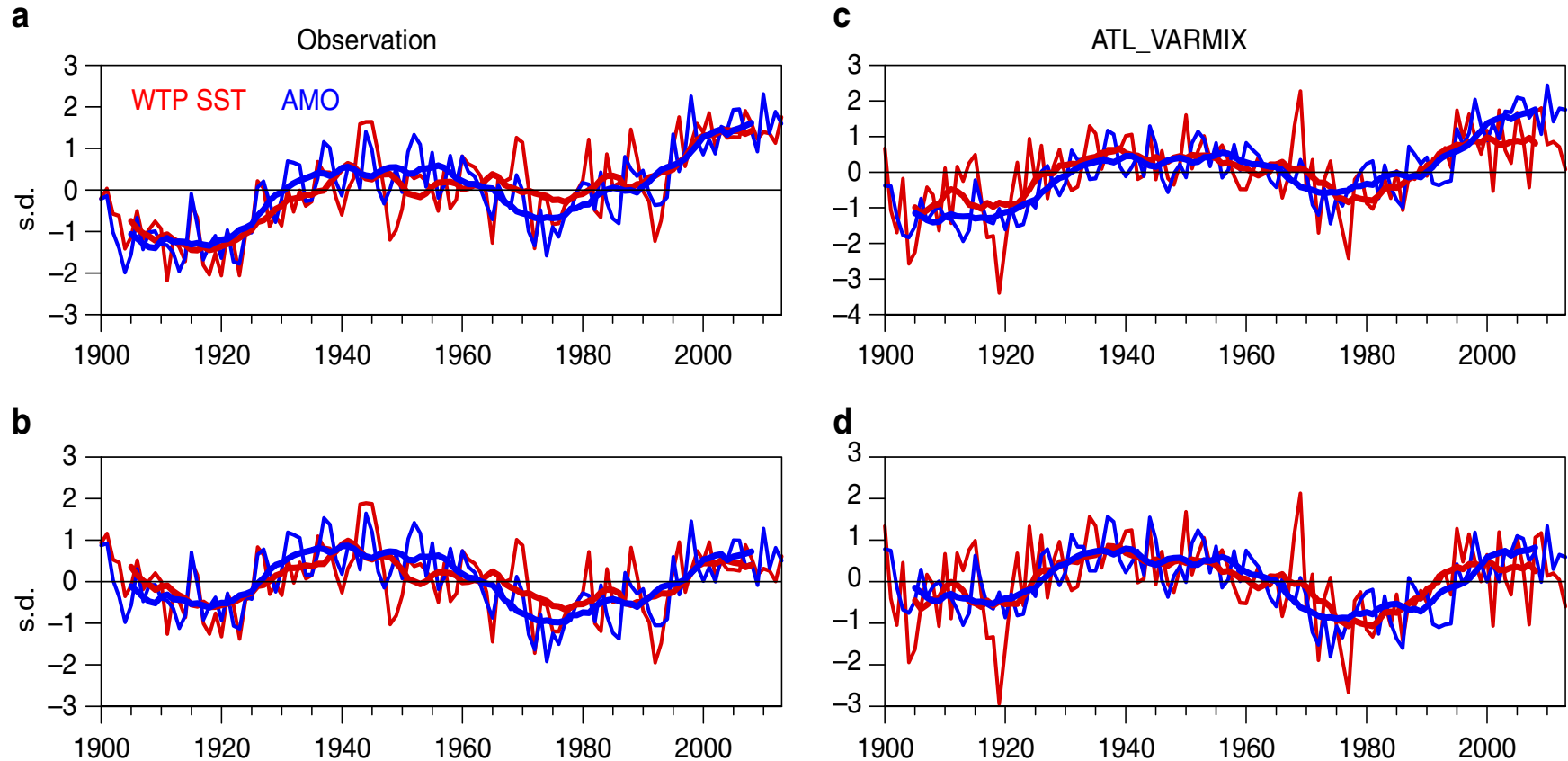
From Kucharski, F., et al. (2015), Climate Dynamics

c) Atlantic Multidecadal Variability impact on Indo-Pacific;
here correlations of AMO index with SSTs



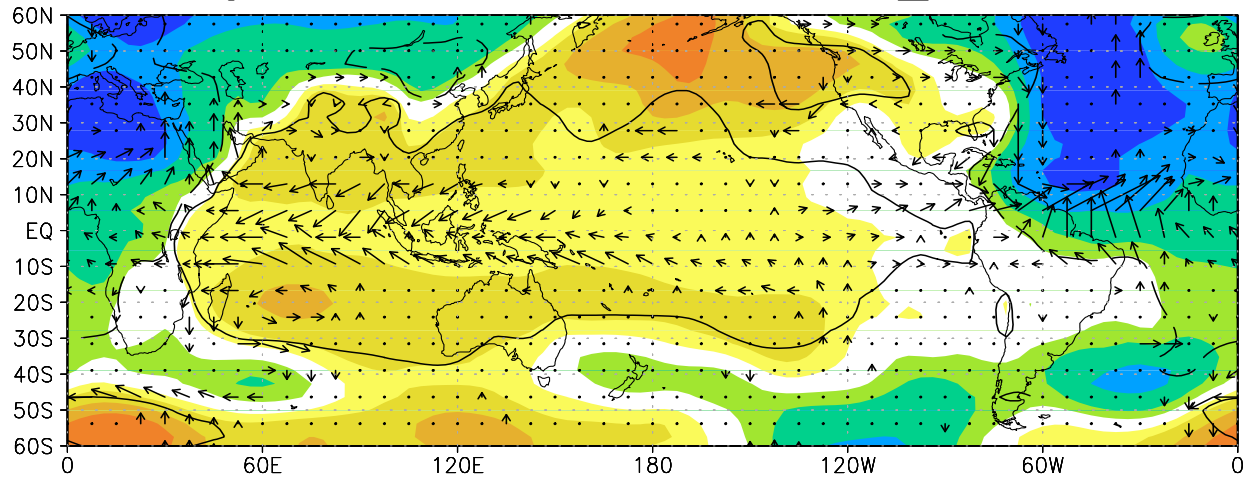
Sun, C., Kucharski, F., Li, J. *et al.* Western tropical Pacific multidecadal variability forced by the Atlantic multidecadal oscillation. *Nat Commun* **8**, 15998 (2017). <https://doi.org/10.1038/ncomms15998>

b) Atlantic Multidecadal Variability impact on Indo-Pacific; concentrating on Western North Pacific

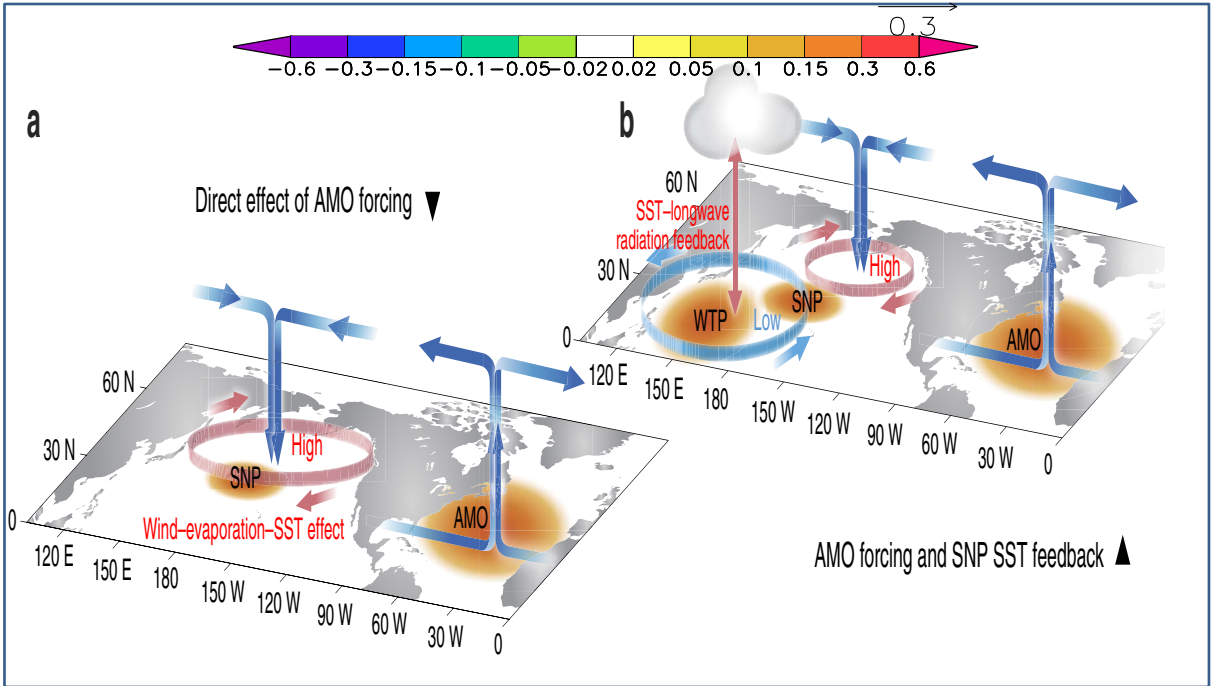


b) Atlantic Multidecadal Variability impact on Indo-Pacific; focus on Western Pacific

Reg AMO SLP, surf winds ATL_VARAGCM



SPEEDY Atlantic Pacemaker experiment; climatological SST elsewhere



c) Atlantic Multidecadal Variability impact on Indo-Pacific; concentrating on Western North Pacific

Studies have confirmed this result in the meantime, even if the AMO signal could be partially forced by Aerosol forcing.



Geophysical Research Letters®



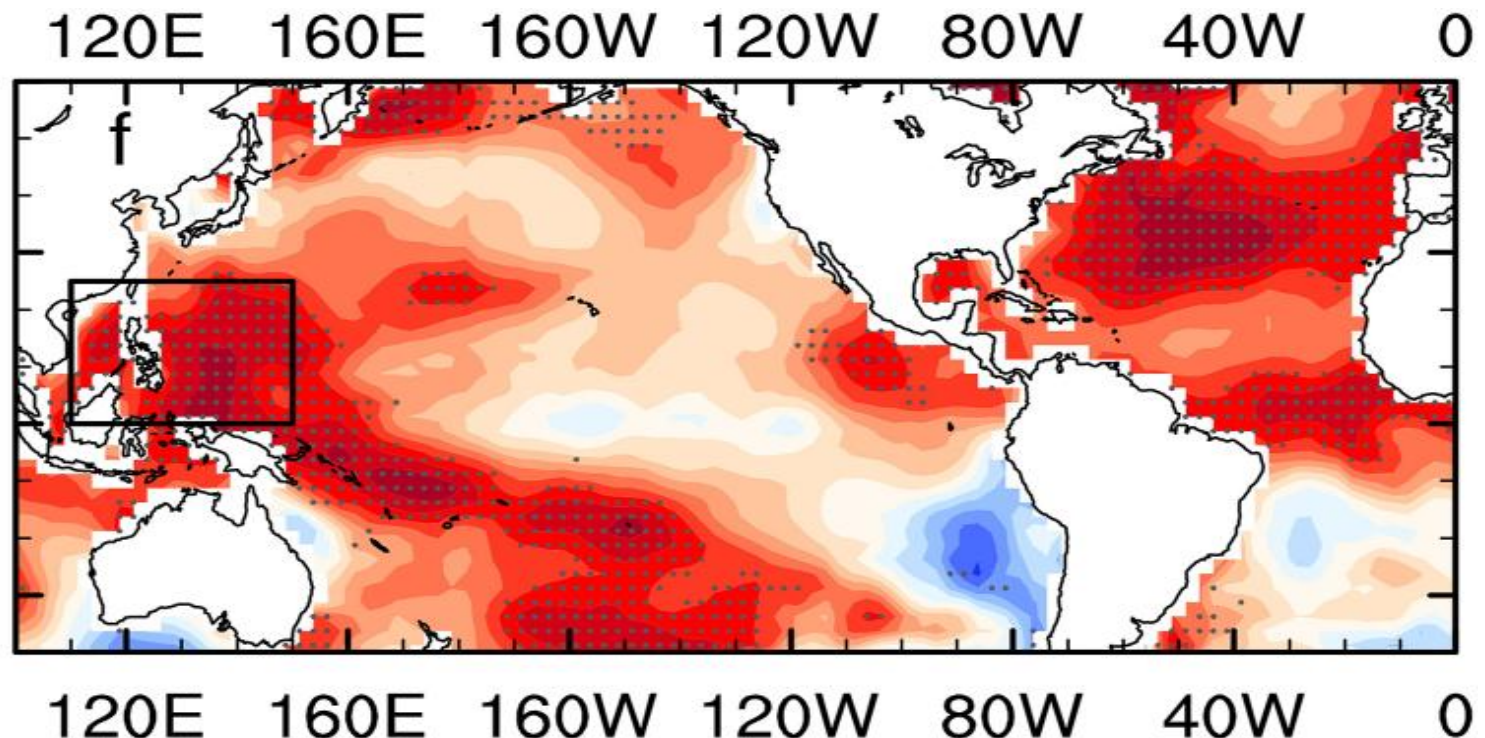
RESEARCH LETTER

10.1029/2023GL106795

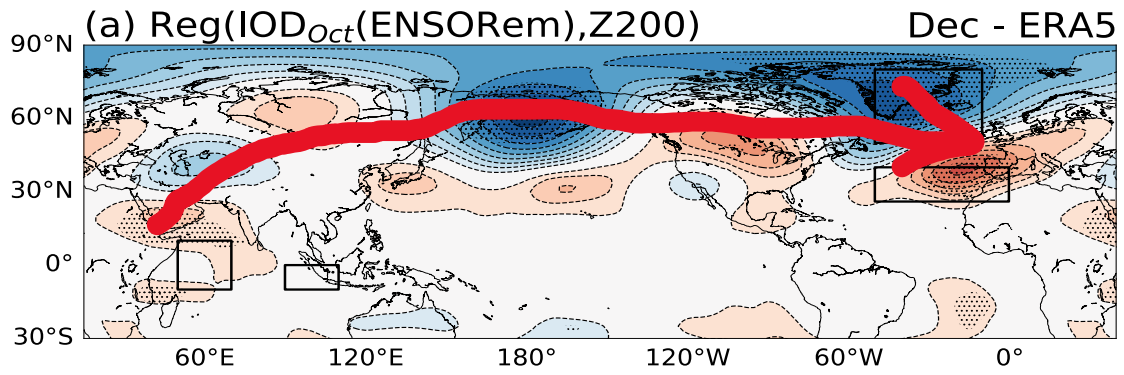
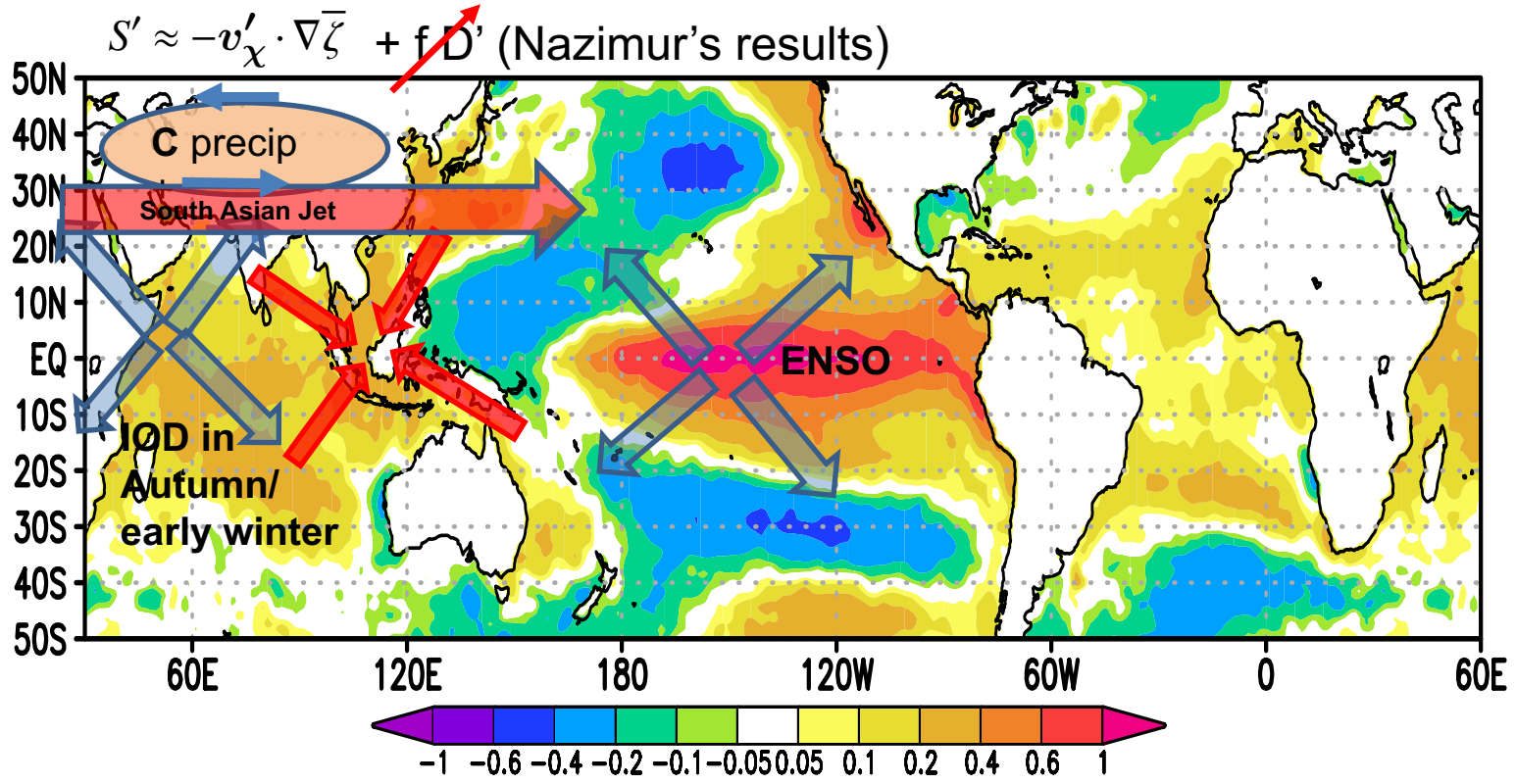
Multidecadal Variations in the Tropical Western Pacific Driven by Externally-Forced AMV-Like Changes

Key Points:

Minhua Qin^{1,2,3} , Renhe Zhang^{1,3} , Aiguo Dai⁴ , and Wenjian Hua²



Recent research interest with involvements of Adnan, Adrian, Nazimur, Marco and Alessandro: Indian Ocean mediation of ENSO impacts or pure IOD
fD too simple, interactions of divergent wind with South Asian jet very important here to generate RWS!
ENSO and Indian Ocean impacts on Northwest South Asia winter precipitation



The ICTP/IPCC/IAP Chapter Scientist Support Programme

Funded by: Wellcome



ICTP-IAP Team:

Giulia Gennari (Programme manager)

Petra Krizmancic (Administrative focal point)

Peter McGrath (IAP)

and all ICTP admin

Why was this programme created?

IPCC AR7 assessment report to be delivered around 2028-2029

3 Working Groups and ~15-25 chapters per report

Each chapter coordinated by Coordinating Lead Authors (CLAs)

CLAs often rely on Chapter Scientists for research and technical support

In developing countries this support has historically been harder to access

What does the programme aim to achieve?

3 main objectives!

Capacity building
Training and
experience for
early-career scientists
from DC/EITs

Strengthening
participation
Support CLAs from
developing countries

Supporting AR7
delivery
Increase operational
capacity of IPCC
chapter teams

ICTP Support to Chapter Scientists: How does the programme support CSs?

Scientific contract until
2029
Monthly allowance

Contribution for Health
Insurance

LAM meeting participation
Travel support

IT equipment grant
Incidentals grant

Research expenses
APC publication support

Training activities
Supervision framework
ICTP Global Science Portal

Programme data so far

>5,000
Expressions of
interest

2,603
Complete
applications

171
Interviews with CLAs

57
Chapter Scientists
selected

53%
Women

28
Countries
represented