3rd NPOCE webinar on Roles of western Pacific Ocean circulation variability in warm pool

ENSO, IOD, and the Indonesian Throughflow in CMIP Models

Agus Santoso

Climate Change Research Centre & ARC Centre of Excellence for Climate Extremes, University of New South Wales, Sydney, Australia

Email: a.santoso@unsw.edu.au

UNSW THE UNIVERSITY OF NEW SOUTH WALES | Climate Change Research Centre | climate extremes ARC centre of excellence | Climate Systems National Environmental Science Program

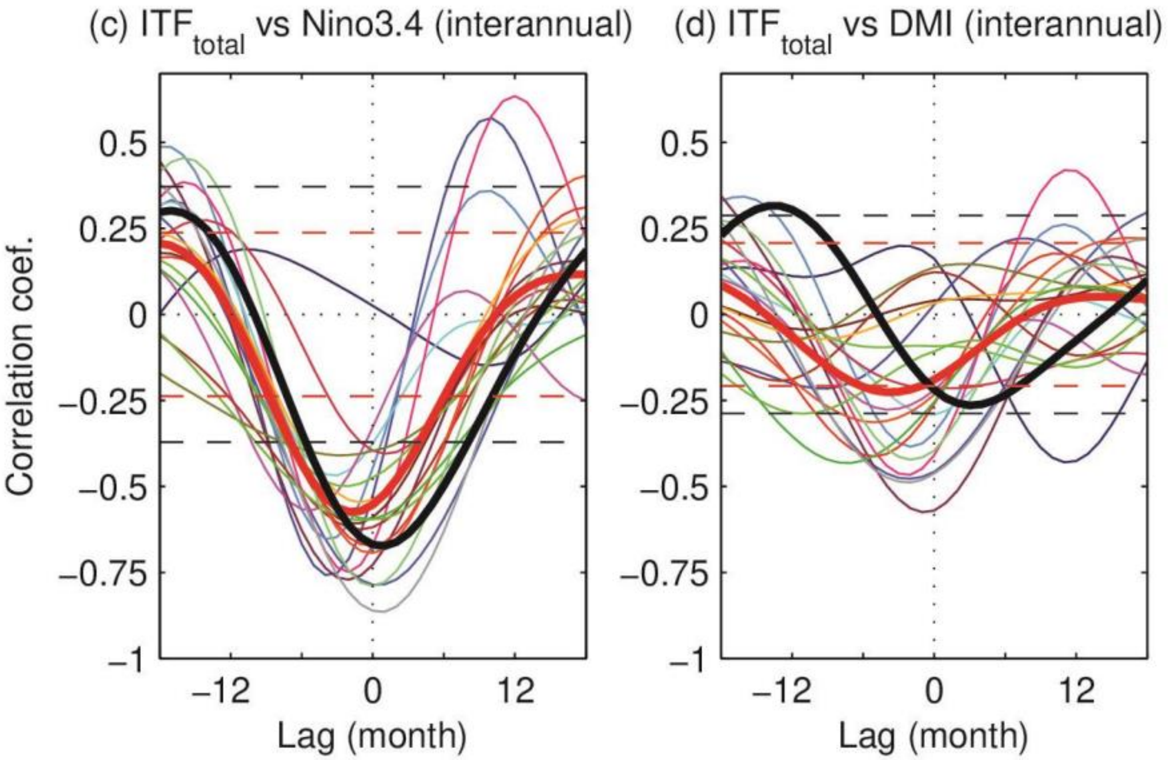
Journal of
Climate

Indonesian Throughflow Variability and Linkage to ENSO and IOD in an Ensemble of CMIP5 Models

Agus Santoso[1,2,3], Matthew H. England[1,2], Jules B. Kajtar[4,5], and Wenju Cai[3,6,7]

Published-online: 29 Apr 2022

Impact on ITF total transport

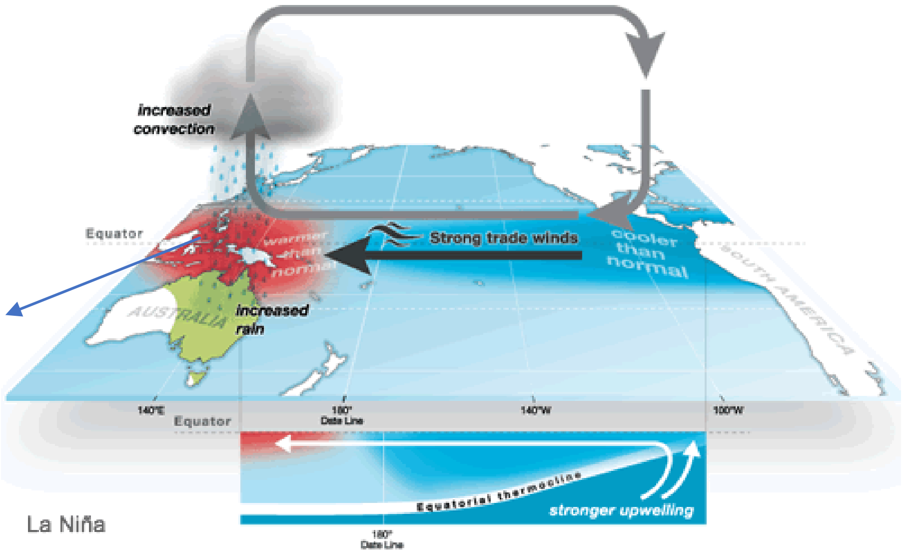


El Nino -> reduced transport
La Nina -> enhanced transport
IOD -> not clear

La Niña

stronger Walker Circulation

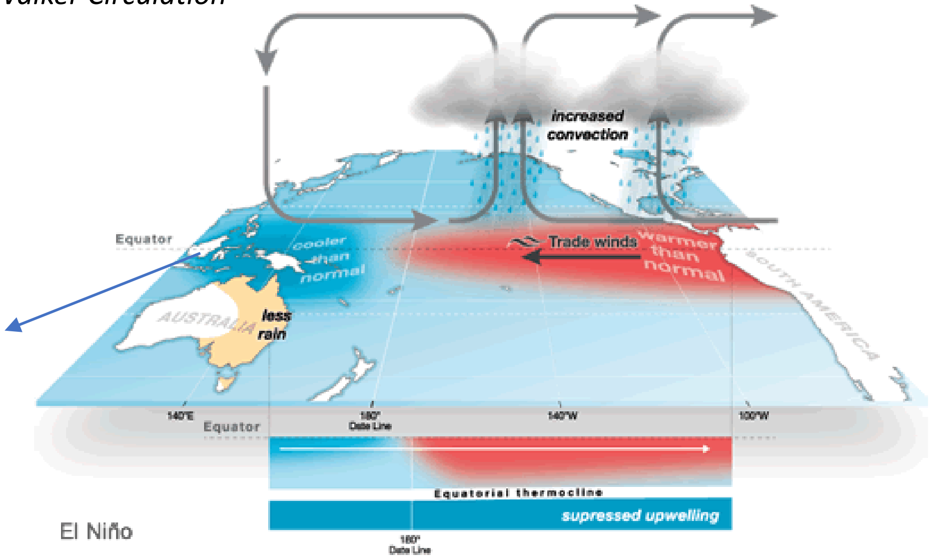
Higher sea level (Pacific side)
-> increased **Indonesian Throughflow (ITF)**

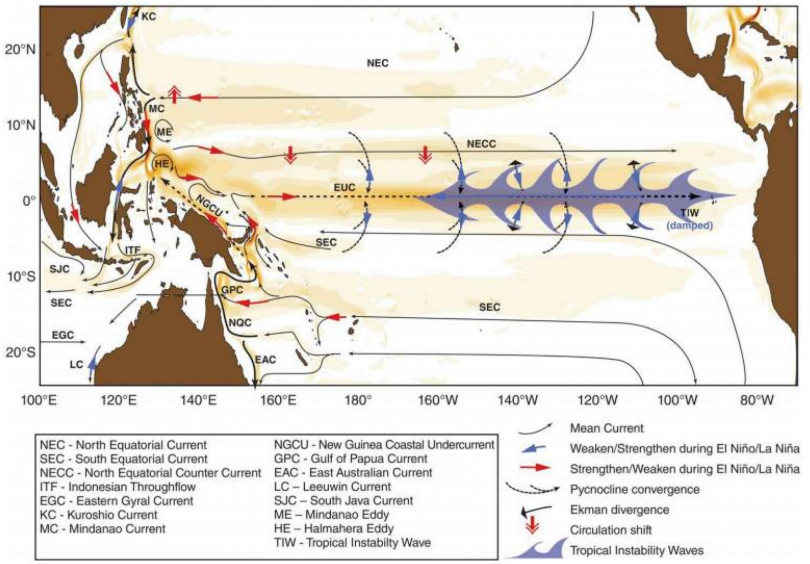


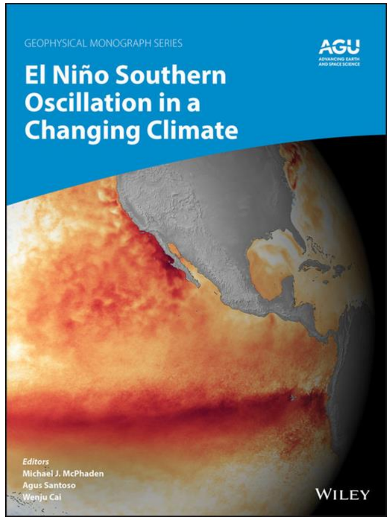
El Niño

weaker Walker Circulation

Lower sea level (Pacific side)
-> decreased **ITF**





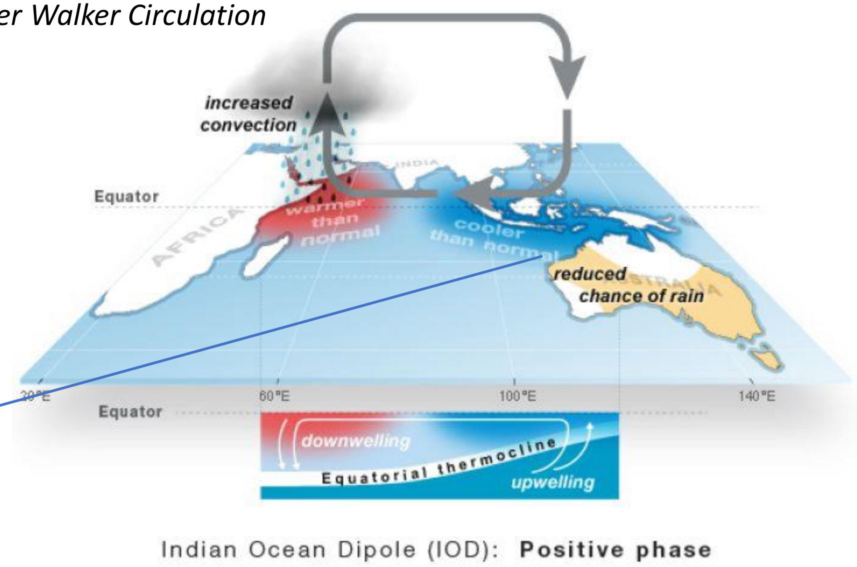


Chapter 15, Sprintall et al.

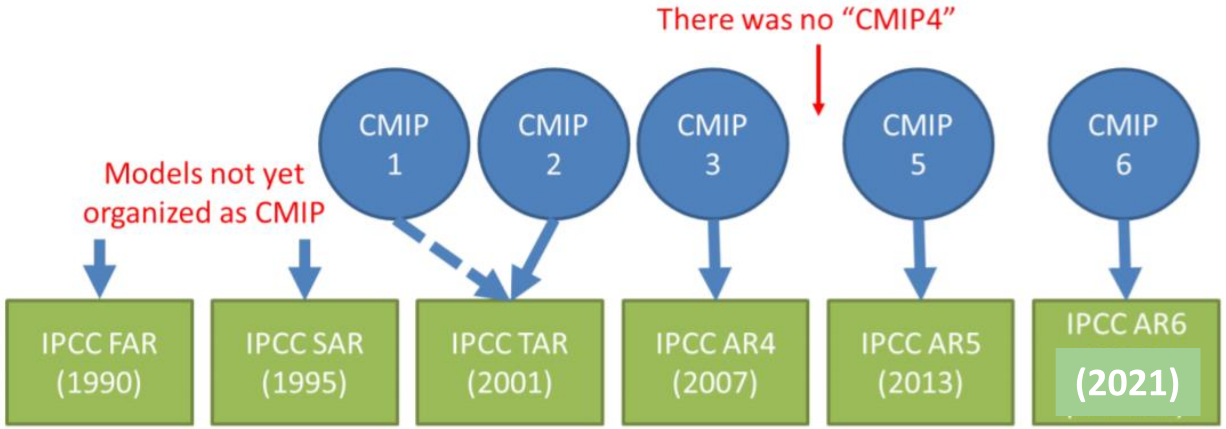
pIOD

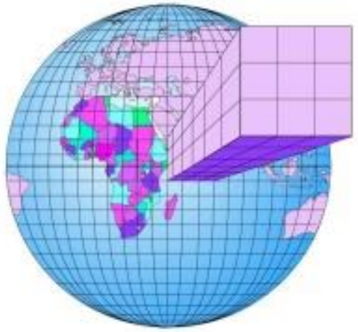
weaker Walker Circulation

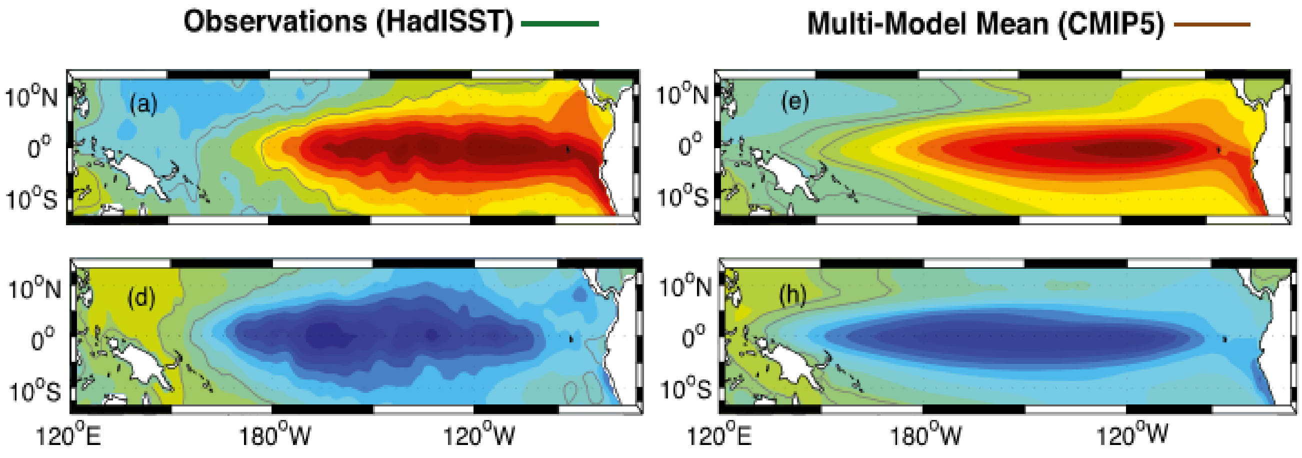
Lower sea level (Indian Ocean side)
-> increased **ITF**



Coupled Model Intercomparison Project (CMIP)







Taschetto et al. 2014, J. Climate

Chapter 9, Guilyardi et al.

9

ENSO Modeling: History, Progress, and Challenges

Eric Guilyardi[1], Antonietta Capotondi[2], Matthieu Lengaigne[3], Sulian Thual[4], and Andrew T. Wittenberg[5]

[1] *LOCEAN-IPSL, CNRS/Sorbonne University/IRD/MNHN, Paris, France; and NCAS-Climate, University of Reading, Reading, UK*

[2] *University of Colorado, CIRES, Boulder, CO, USA; and NOAA Physical Sciences Laboratory, Boulder, CO, USA*

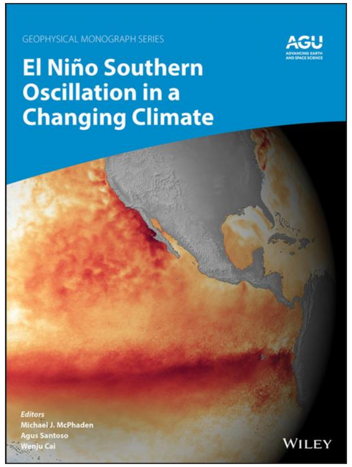
[3] *LOCEAN-IPSL, Sorbonne Universités/UPMC-CNRS-IRD-MNHN, Paris, France; and MARBEC, University of Montpellier, CNRS, IFREMER, IRD, Sète, France*

[4] *Institute of Atmospheric Sciences/Department of Atmospheric and Oceanic Sciences, Fudan University, Shanghai, China*

[5] *NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA*

ABSTRACT

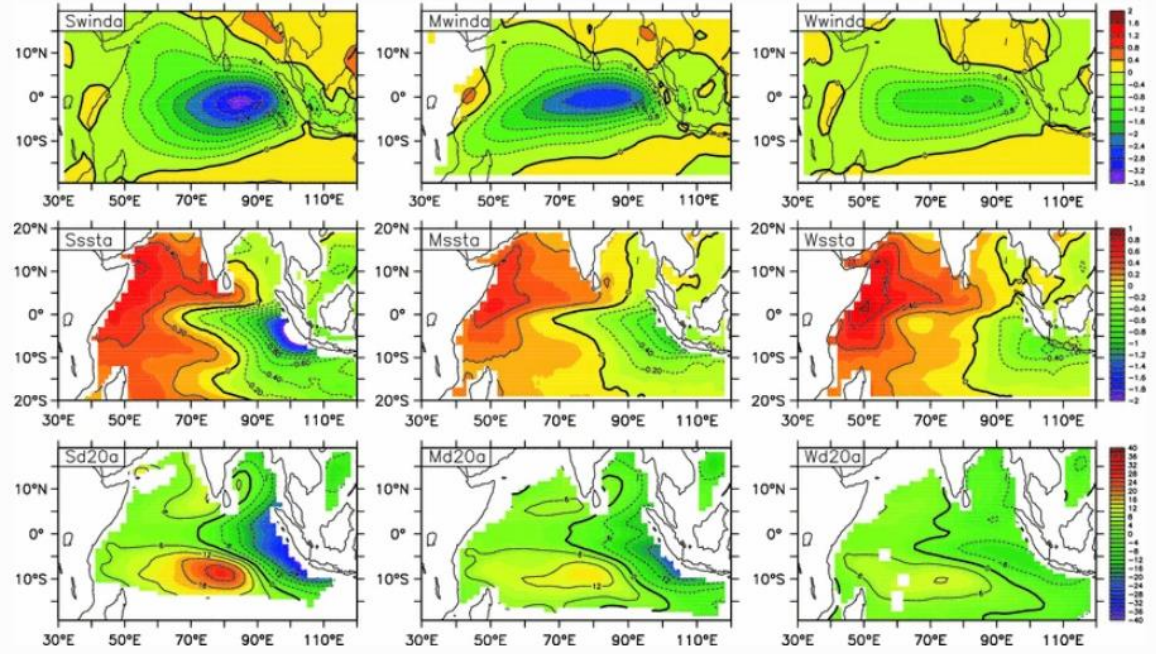
Climate models are essential tools for understanding ENSO mechanisms and exploring the future, either via seasonal-to-decadal forecasting or climate projections. Because so few events are well observed, models are also needed to help reconstruct past variability, explore ENSO diversity, and understand the



Indian Ocean variability in the CMIP5 multi-model ensemble: the zonal dipole mode

Clim Dyn (2014) 43:1715–1730
DOI 10.1007/s00382-013-2000-9

Lin Liu · Shang-Ping Xie · Xiao-Tong Zheng ·
Tim Li · Yan Du · Gang Huang · Wei-Dong Yu



Tropical Indian Ocean Variability in the IPCC Twentieth-Century Climate Simulations

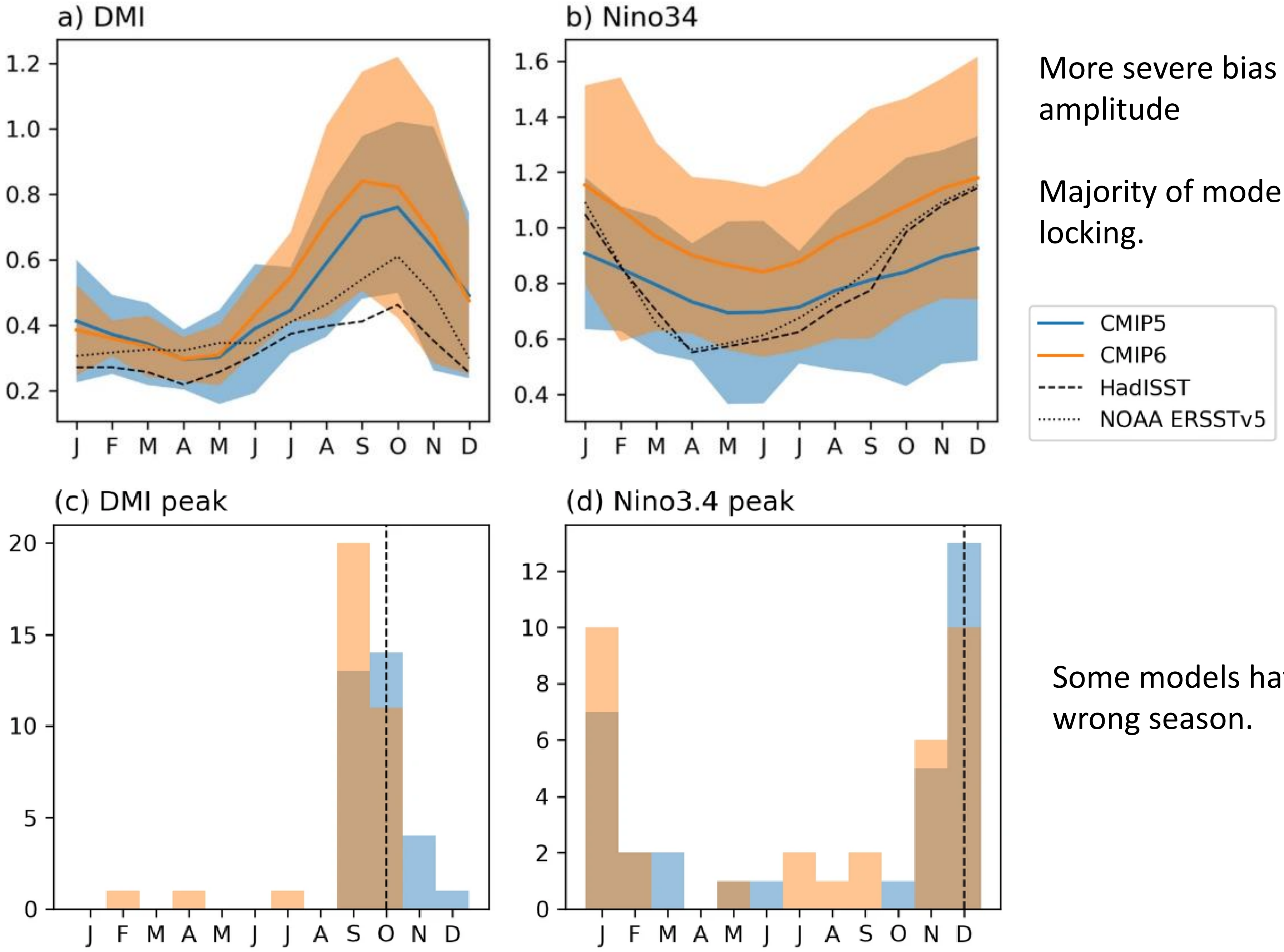
N. H. Saji[1], S-P. Xie[1], and T. Yamagata[2]

J. Climate (2006)

Why is the amplitude of the Indian Ocean Dipole overly large in CMIP3 and CMIP5 climate models?

Wenju Cai[1,2] and Tim Cowan[1,2]

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 1200–1205, doi:10.1002/grl.50208, 2013



More severe bias in IOD amplitude than ENSO amplitude

Majority of models show good seasonal phase locking.

32 CMIP5, 34 CMIP6 (1850-2005)

Some models have ENSO and IOD peak in the wrong season.

McKenna et al. 2020, Sci. Rep.

Geophysical Research Letters

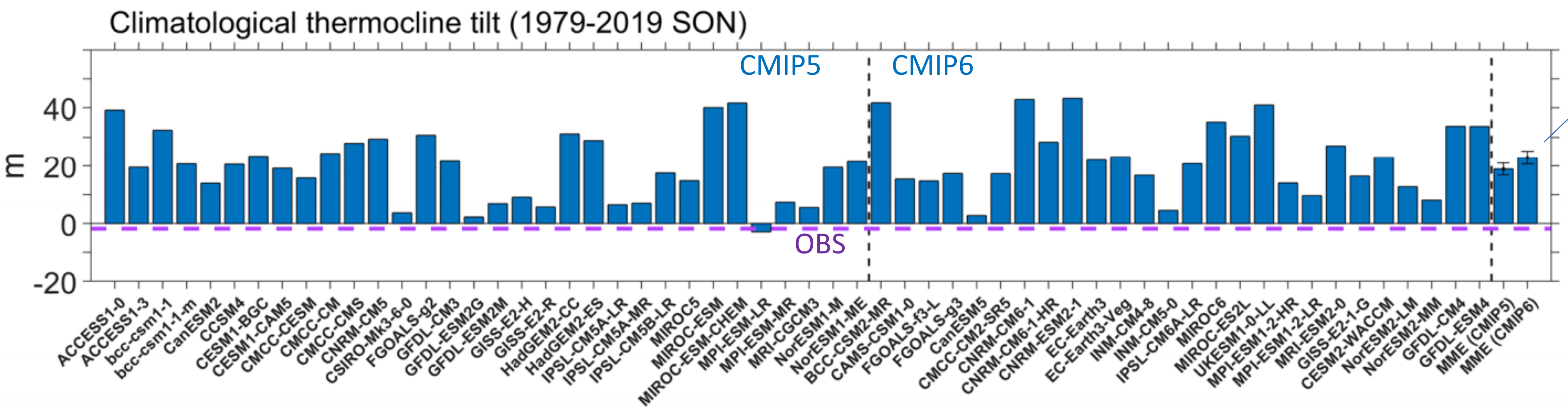
RESEARCH LETTER
10.1029/2020GL091902

Simulated Thermocline Tilt Over the Tropical Indian Ocean and Its Influence on Future Sea Surface Temperature Variability

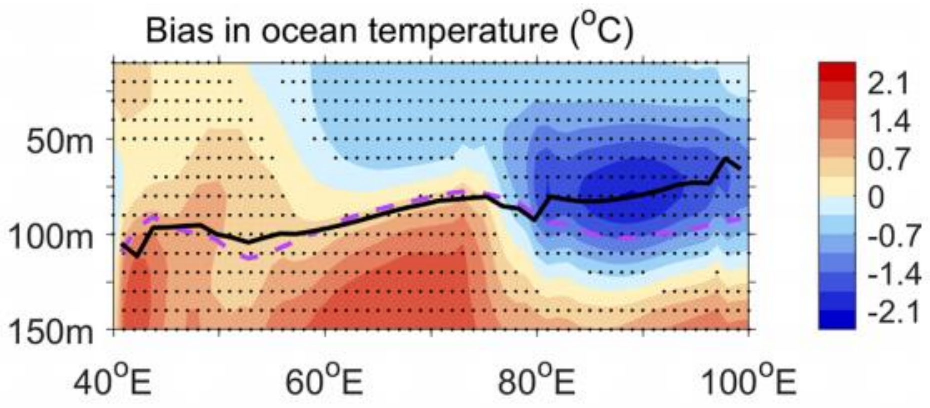
Guojian Wang[1,2], Wenju Cai[1,2], and Agus Santoso[2,3]

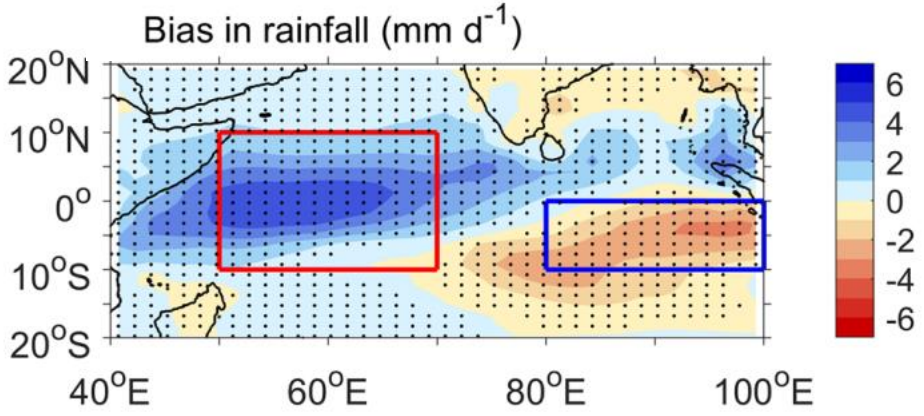
Key Points:

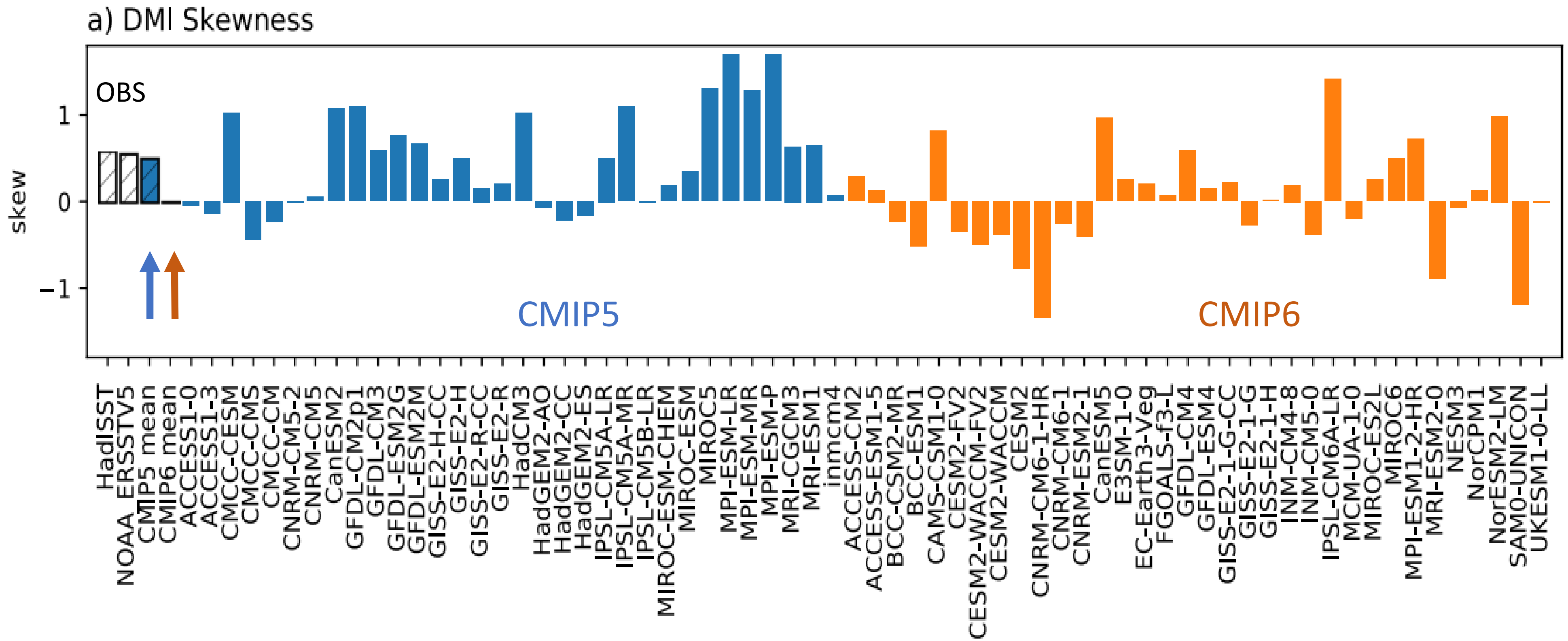
- An overly steep west-to-east upward tilt in the climatological thermocline of the tropical Indian Ocean persists



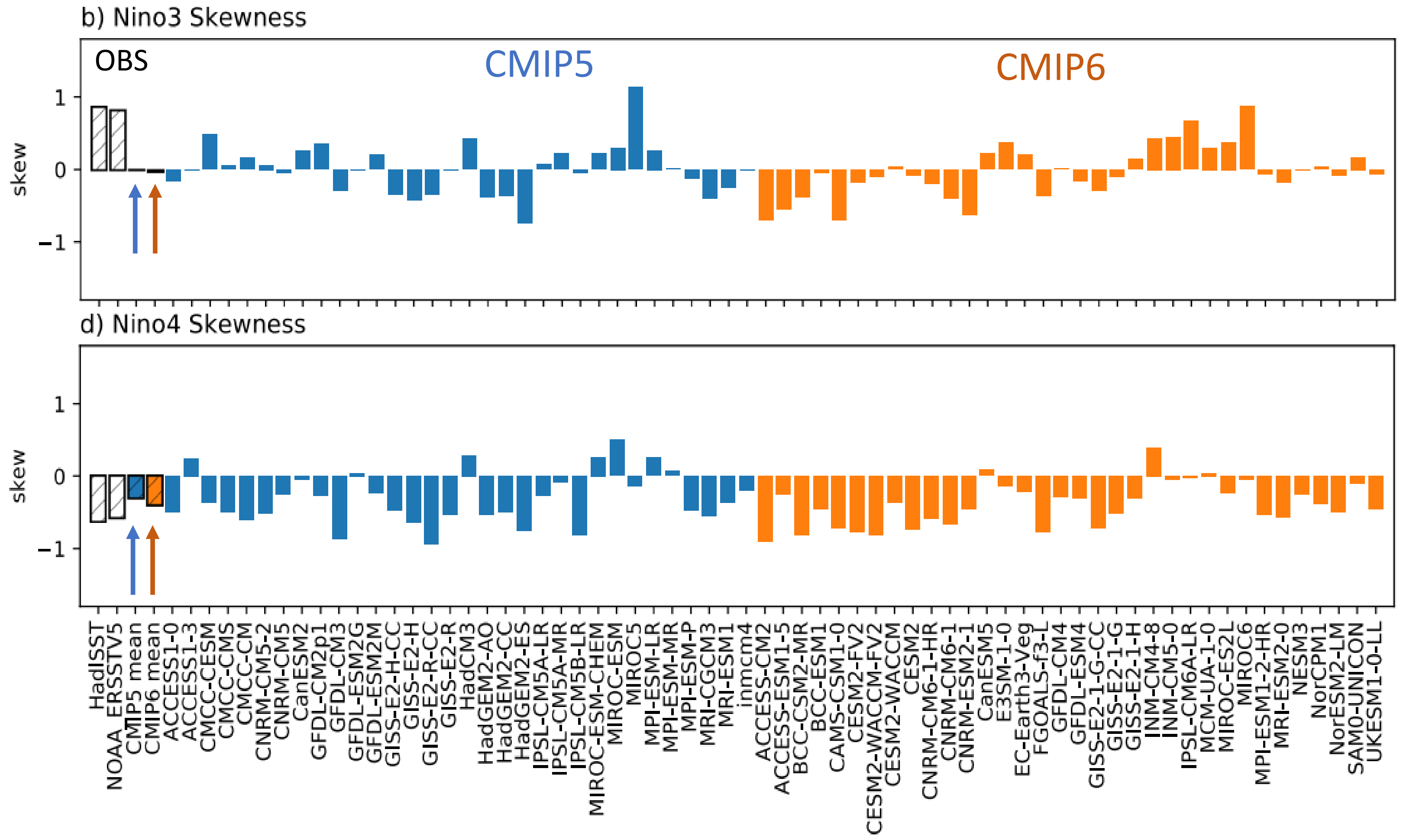
slightly worse in CMIP6







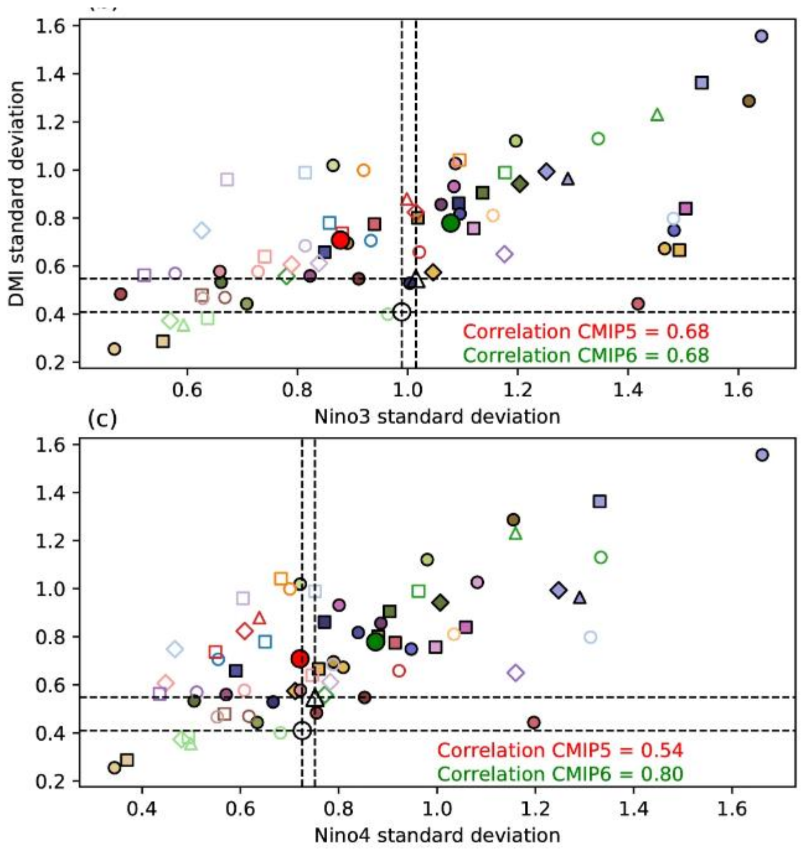
McKenna et al. 2020, Sci. Rep.



- Both CMIP5 and CMIP6 models severely underestimate skewness in equatorial Eastern Pacific (Nino3) SST anomalies

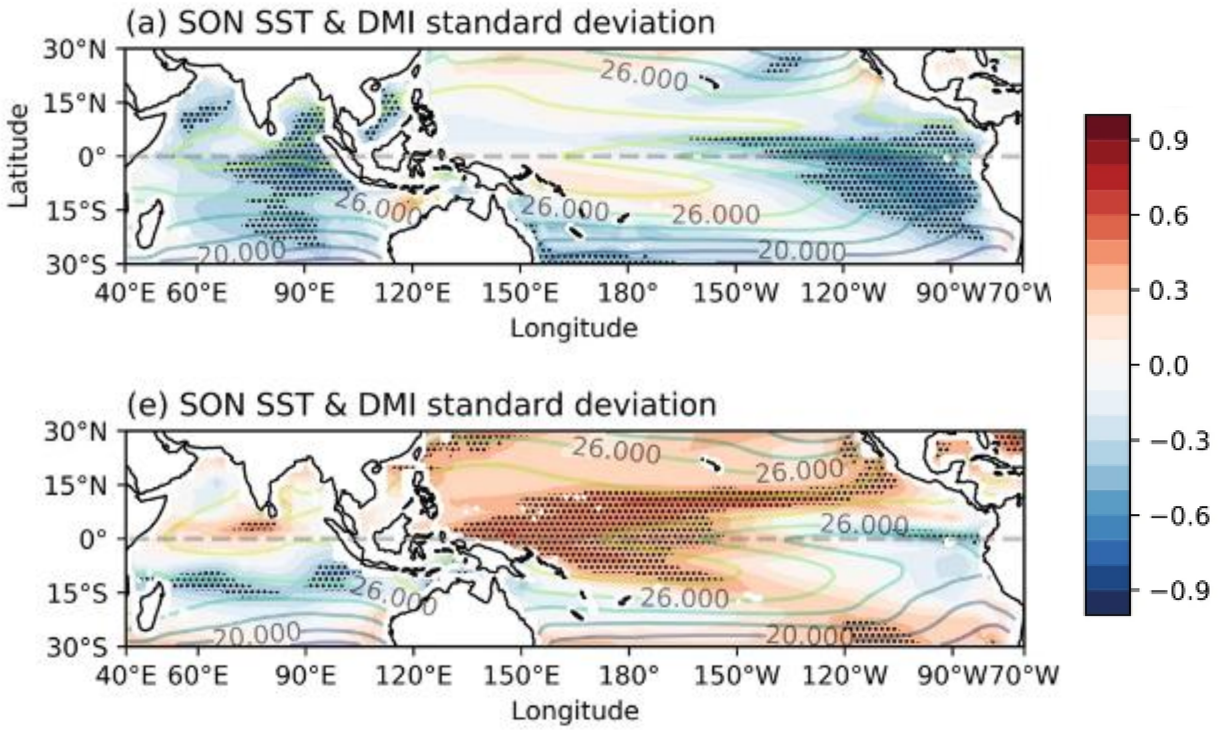
- Slightly underestimate in Central Pacific (Nino4)

McKenna et al. 2020, Sci. Rep.



IOD amplitude linked to ENSO amplitude

The relationship with Central Pacific variability increases in CMIP6. This is accompanied by inter-model correlation between IOD amplitude and Central Pacific climatological SSTs.

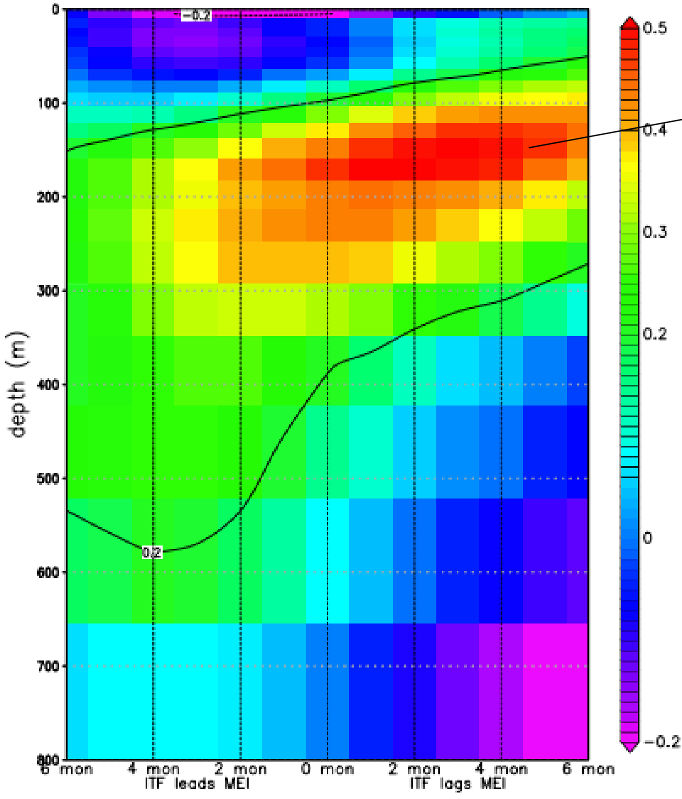


McKenna et al. 2020, Sci. Rep.

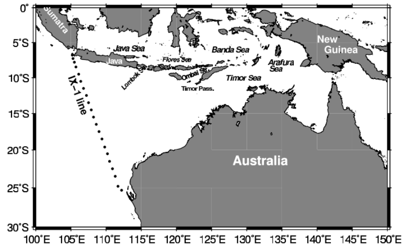
Many existing studies on ITF variability based on limited observations and models: *Clarke & Liu 1994, Meyers 1996, Molcard et al., Murtugudde et al. 1998, Sprintall et al., Gordon et al., Lee et al. papers, England & Huang 2005, Susanto et al., Liu et al. 2015, Feng et al. 2018, Pujiana et al. 2019, Hu & Sprintall 2016, etc.*

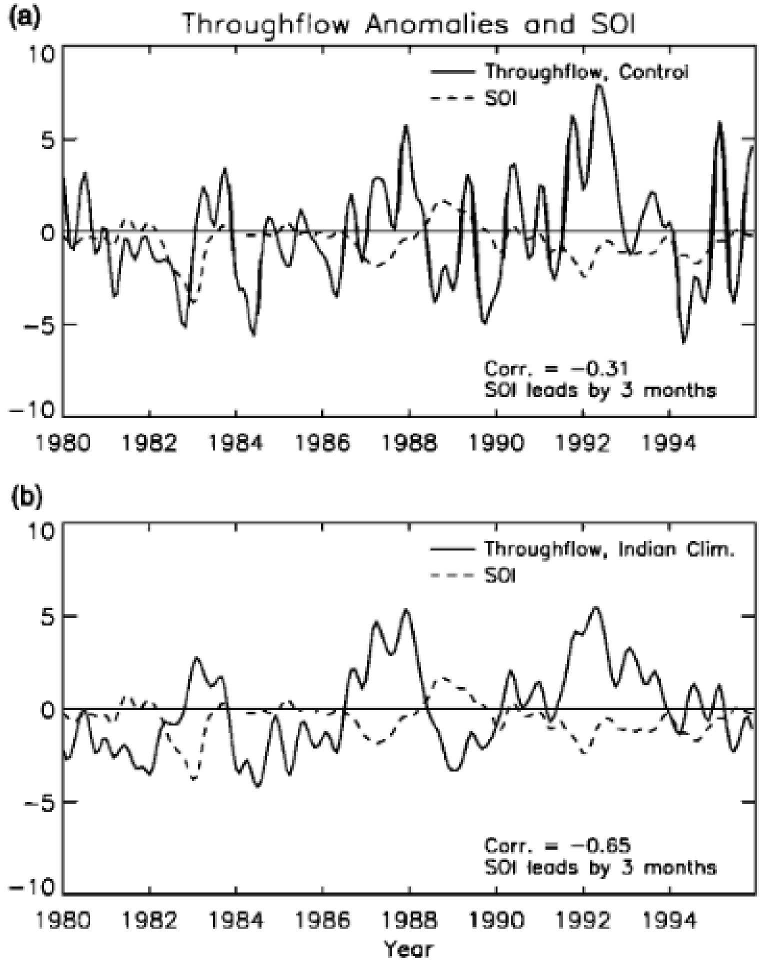
Potemra & Schneider (2007)

Lag correlation: transport vs ENSO index (SODA reanalysis version 1)



El Nino –> reduced transport

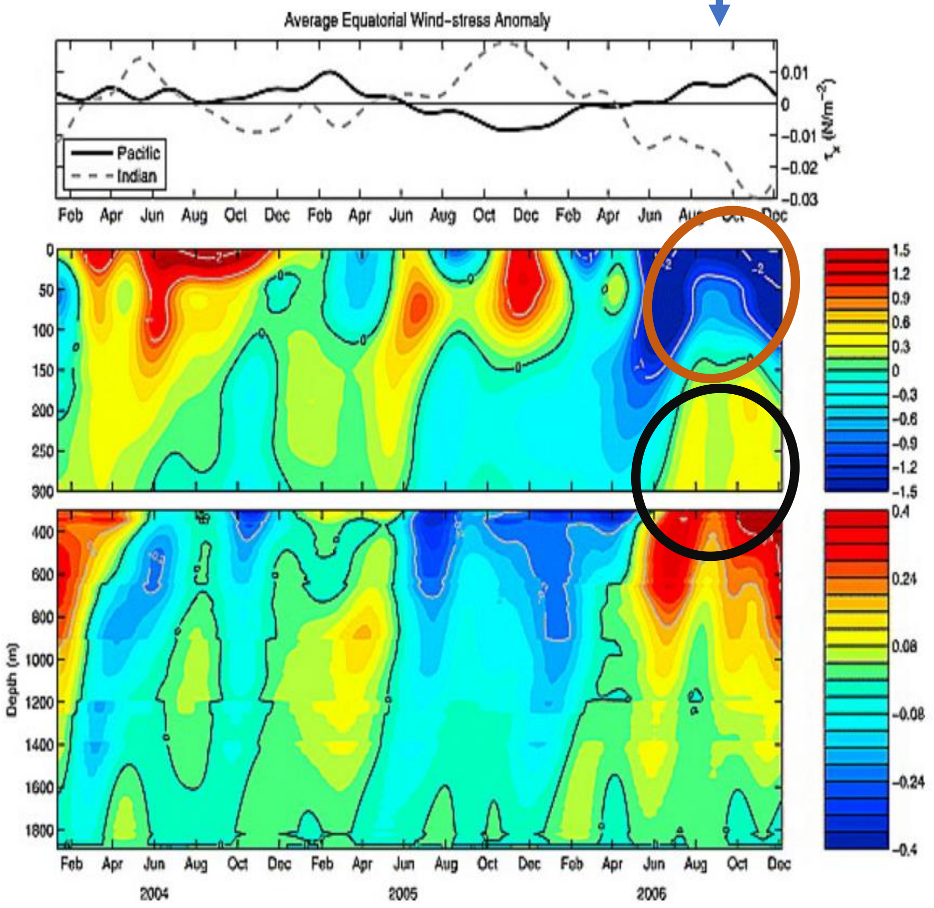




Murtugudde et al. (1998, JGR)

Divergent wind anomalies

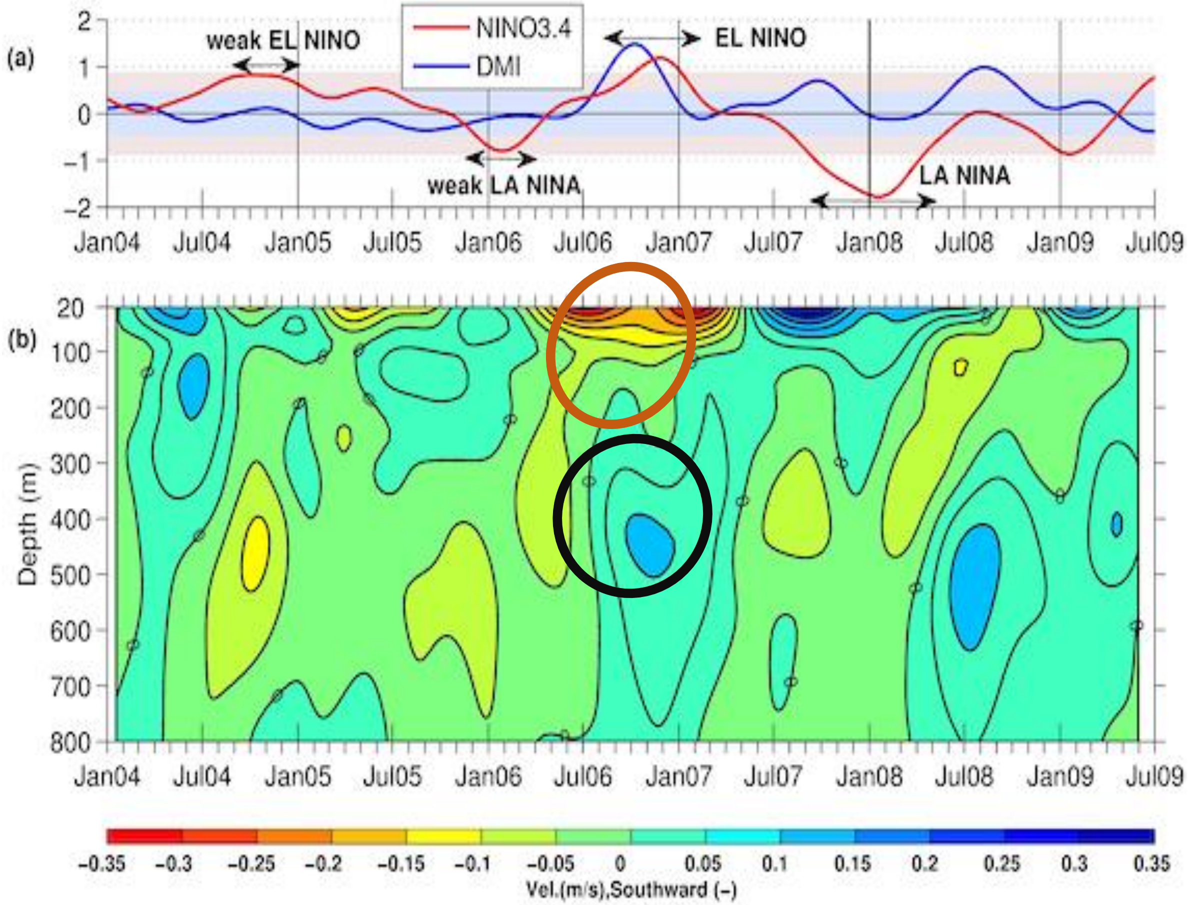
Outflow passages (total)



Opposing surface-subsurface anomalies

Sprintall et al. (2009, JGR)

Makassar Strait



Susanto et al. (2012, JGR)

Upward propagation is also evident in Makassar Strait current observation 2004-2017 (Gordon et al. 2019): transport 300-760 m leading 0-300 m transport.

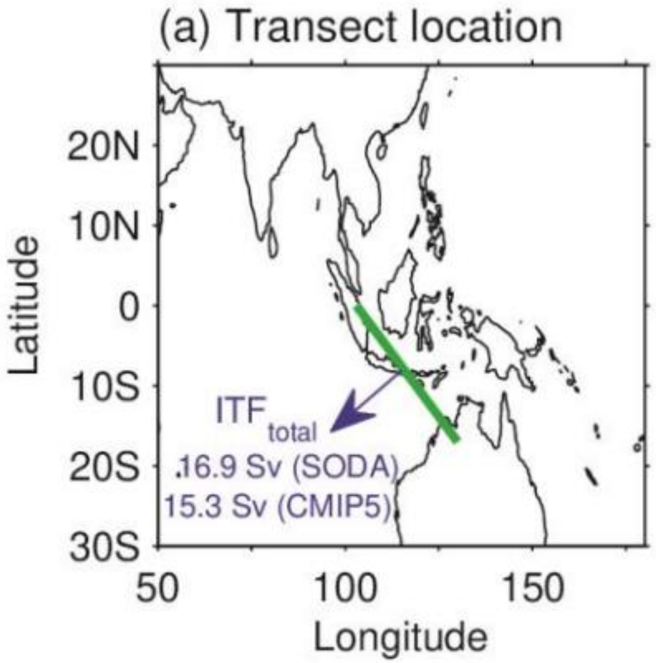
Clear impact of IOD is highlighted by Pujiana et al. (2019) who found ~ 40% reduction in ITF transport during the weak 2016 La Niña due to the concurrent negative IOD.

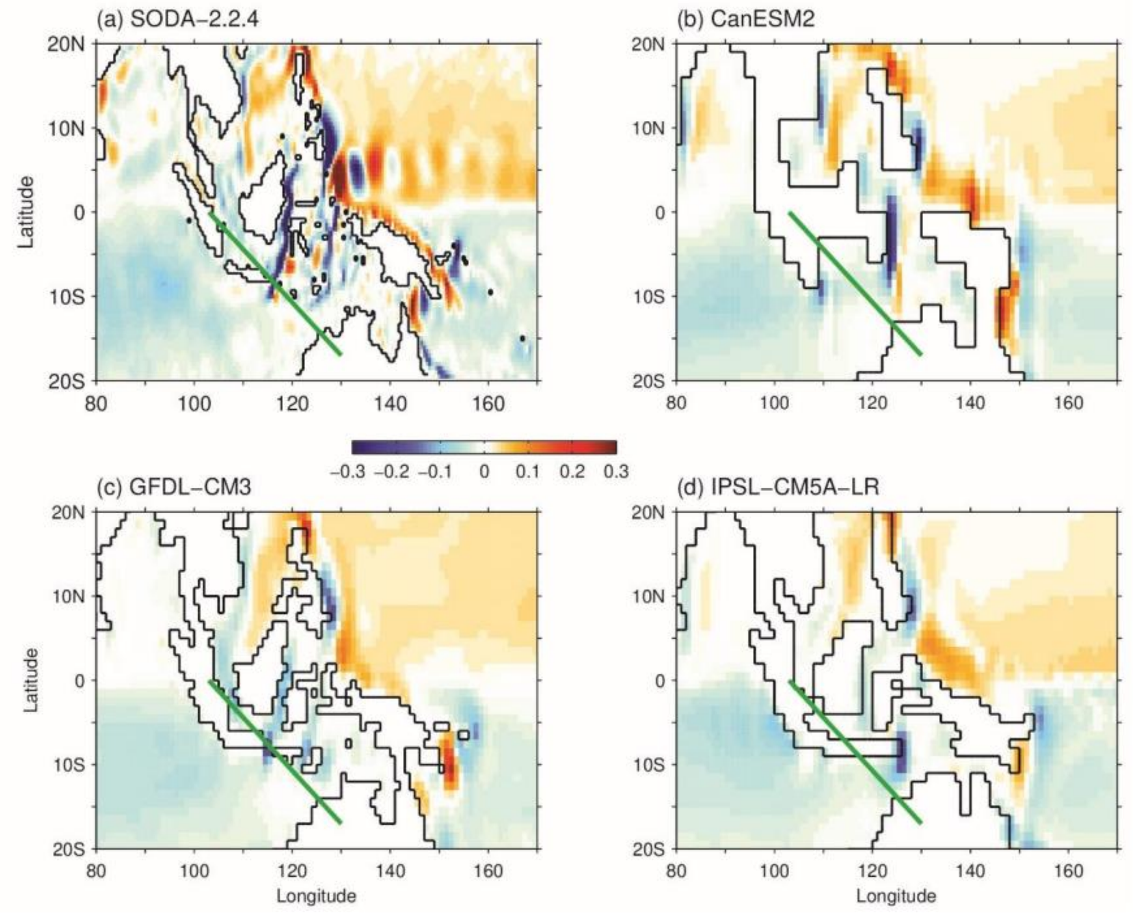
Data and methods

Santoso A., M. H. England, J. B. Kajtar, W. Cai, 2022: Indonesian Throughflow Variability and Linkage to ENSO and IOD in an Ensemble of CMIP5 Models. *J. Climate*, https://doi.org/10.1175/JCLI-D-21-0485.1

CMIP5 historical period (1907-1999)

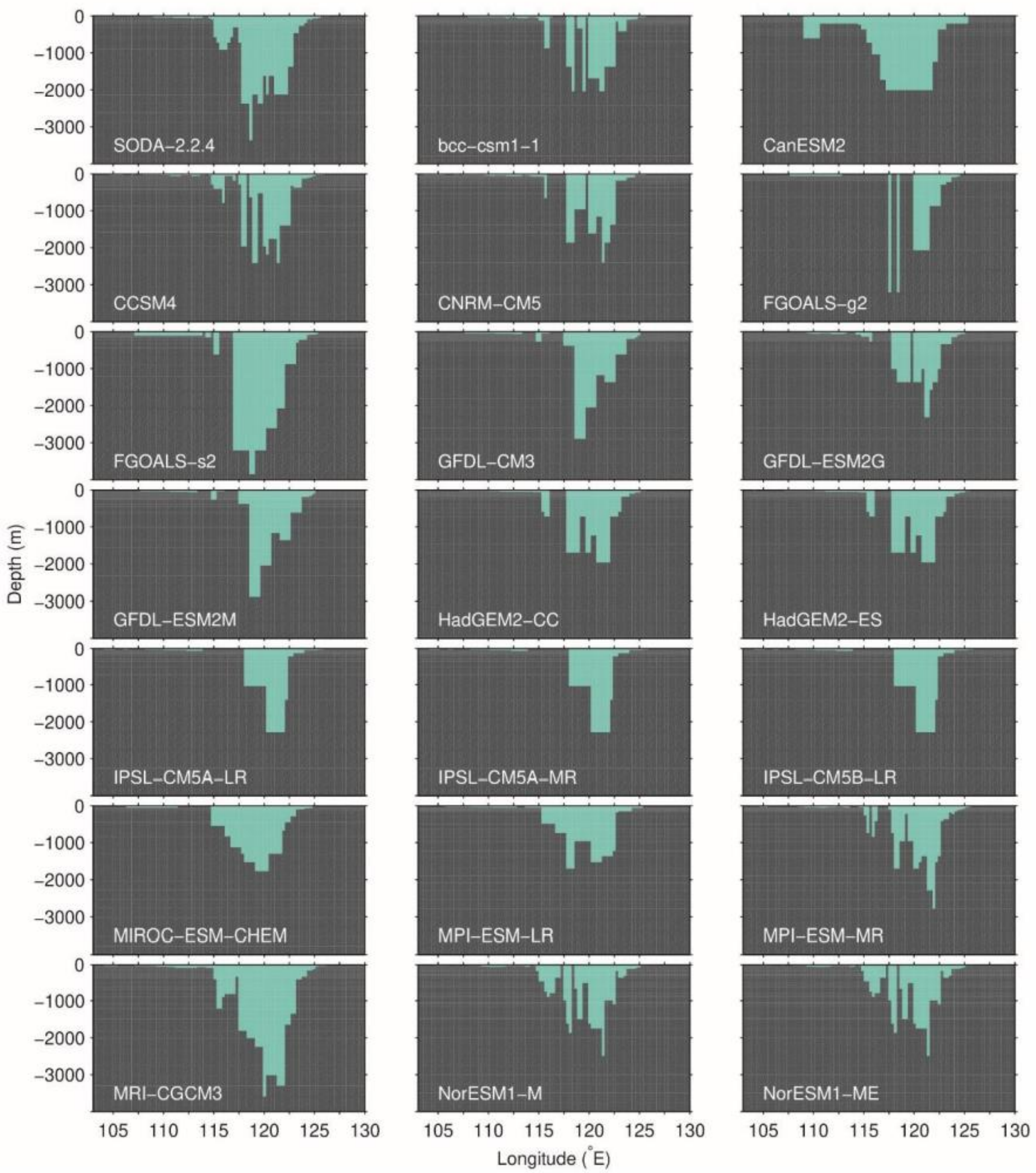
NorESM1–ME
NorESM1–M
MRI–CGCM3
MPI–ESM–MR
MPI–ESM–LR
MIROC–ESM–CHEM
IPSL–CM5B–LR
IPSL–CM5A–MR
IPSL–CM5A–LR
HadGEM2–ES
HadGEM2–CC
GFDL–ESM2M
GFDL–ESM2G
GFDL–CM3
FGOALS–s2
FGOALS–g2
CNRM–CM5
CCSM4
CanESM2
bcc–csm1–1





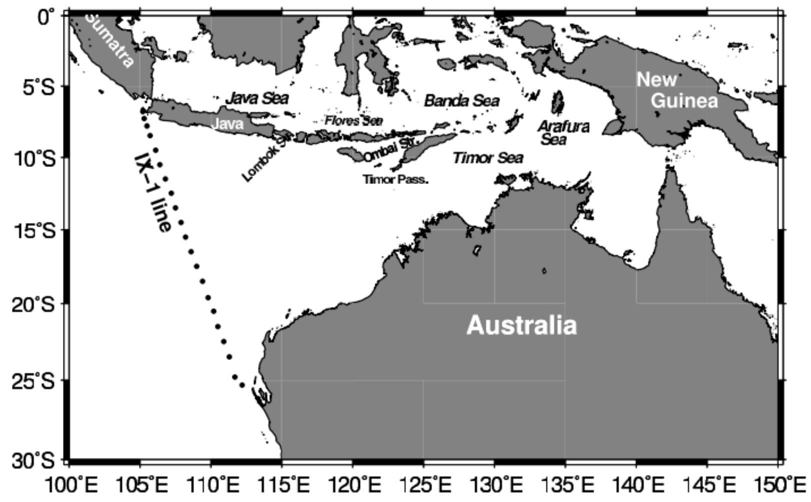
SODA-2.2.4 reanalysis (1970-2008)

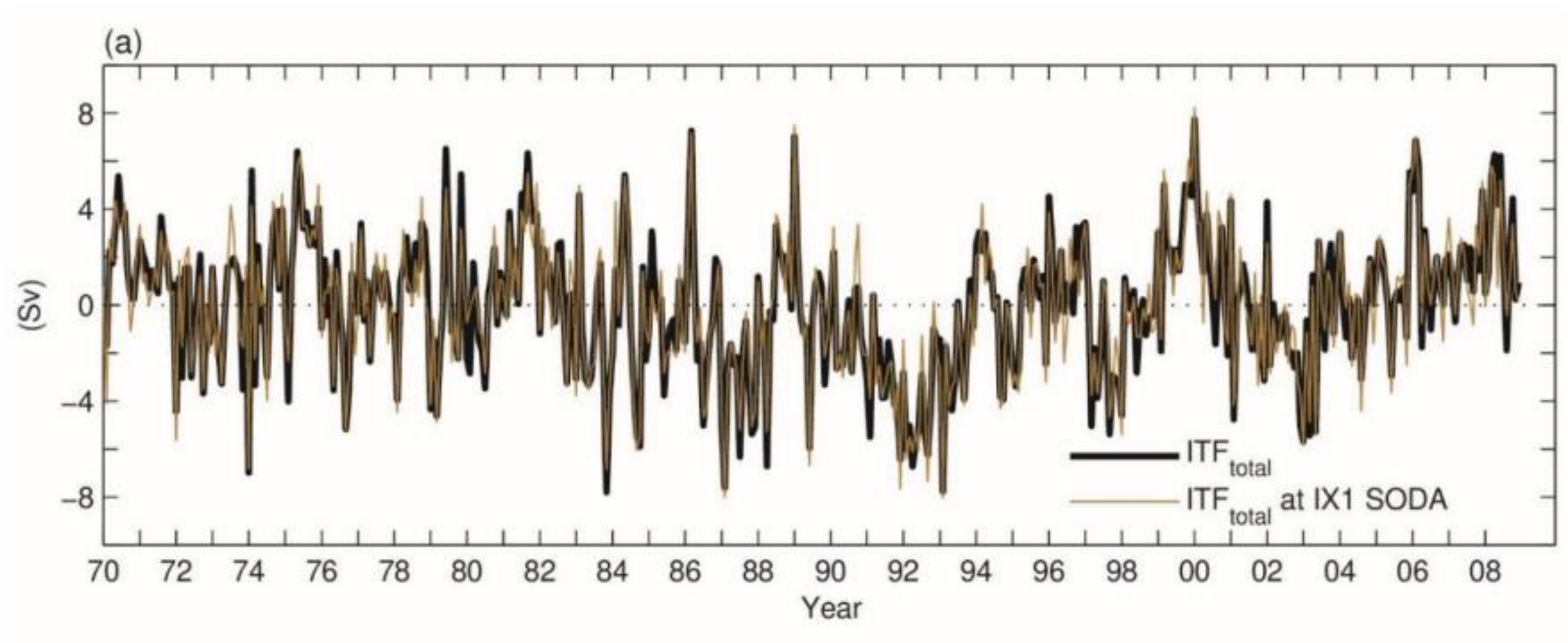
Sign convention: +ve transport, southward, Pacific to Indian Ocean



Model name	Mean ITF transport (Sv)	Ocean resolution (°lon x °lat x no. vertical levels)	Reference
bcc-csm1-1	8.55	1° x 0.3° x 40	Wu et al. (2014)
CanESM2	16.98	1.9° x 1.9° x 40	Arora et al. (2011)
CCSM4	12.44	1.1° x 0.3-0.6° x 60	Gent et al. (2011)
CNRM-CM5	11.39	1° x 0.3-0.8° x 42	Voldoire et al. (2013)
FGOALS-g2	19.12	1° x 0.5-1° x 30	Li et al. (2013)
FGOALS-s2	16.41	1° x 0.5-1° x 30	Bao et al. (2010)
GFDL-CM3	13.98	1° x 0.4-1° x 50	Donner et al. (2011)
GFDL-ESM2G	27.22	1° x 0.4-1° x 63	Dunne et al. (2013)
GFDL-ESM2M	15.90	1° x 0.4-1° x 50	Dunne et al. (2013)
HadGEM2-CC	12.91	1° x 0.3-1° x 40	Martin et al. (2011)
HadGEM2-ES	12.25	1° x 0.3-1° x 40	Martin et al. (2011)
IPSL-CM5A-LR	12.60	2.0° x 0.5-2° x 31	Dufresne et al. (2013)
IPSL-CM5A-MR	13.23	2.0° x 0.5-2° x 31	Dufresne et al. (2013)
IPSL-CM5B-LR	10.16	2.0° x 0.5-2° x 31	Dufresne et al. (2013)
MIROC-ESM-CHEM	17.20	1.4° x 0.5-1.4° x 44	Watanabe et al. (2011)
MPI-ESM-LR	16.32	1.5° x 1.5° x 40	Raddatz et al. (2007)
MPI-ESM-MR	14.48	0.4° x 0.4° x 40	Raddatz et al. (2007)
MRI-CGCM3	12.70	1° x 0.5° x 51	Yukimoto et al. (2012)
NorESM1-M	20.78	1.1° x 0.3-0.6° x 53	Iversen et al. (2013)
NorESM1-ME	20.55	1.1° x 0.3-0.6° x 53	Tjiputra et al. (2013)
SODA-2.2.4	16.90	0.25° x 0.4° x 40	Giese and Ray (2011)

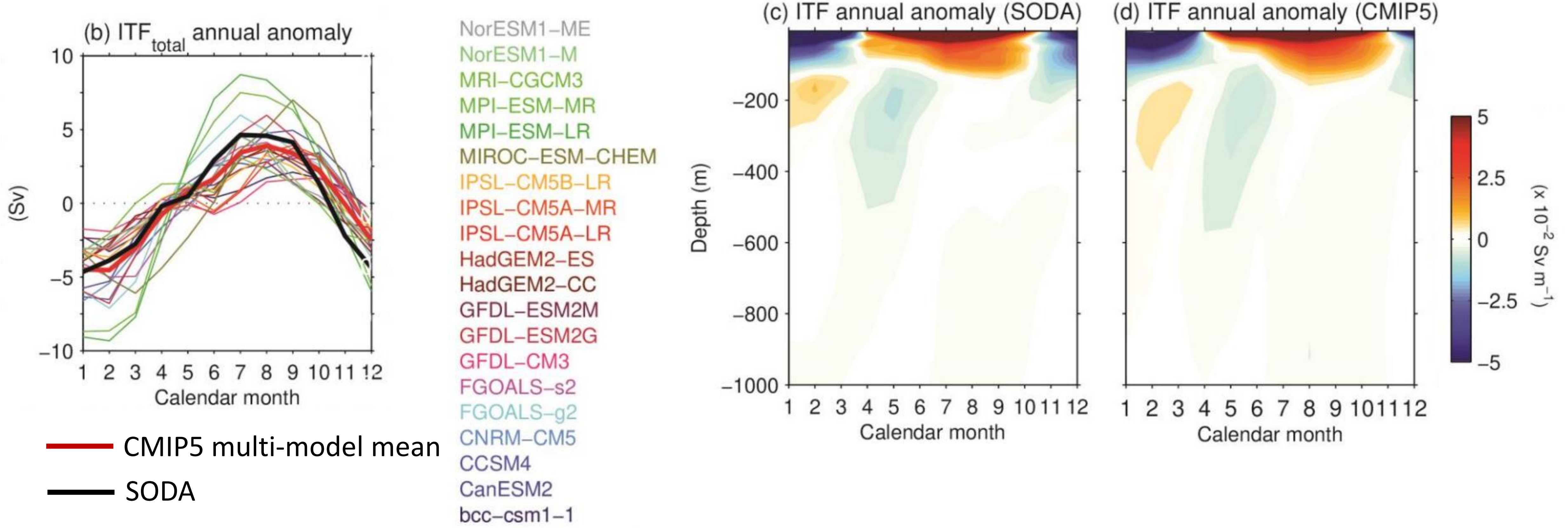
The adopted transect is closest to the IX1 observation line that provides geostrophic transport estimate based on expendable bathythermograph (XBT) temperature records (Meyers 1996; Liu et al. 2015; Feng et al. 2018).





The transport time series calculated at the two transects in SODA are correlated at *r*=0.95. There is notable agreement between the ITF total transport in SODA and the geostrophic transport timeseries across the IX1 transect (Fig. 2 of Feng et al. 2018).

ITF annual cycle

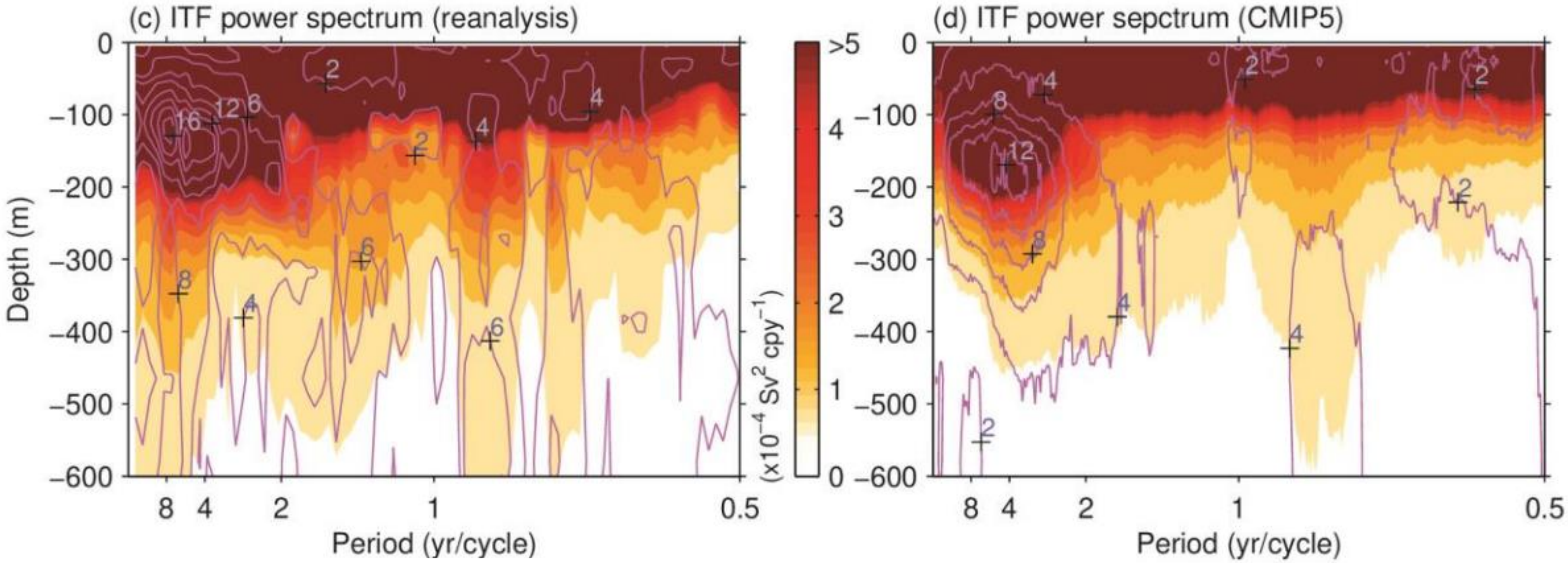


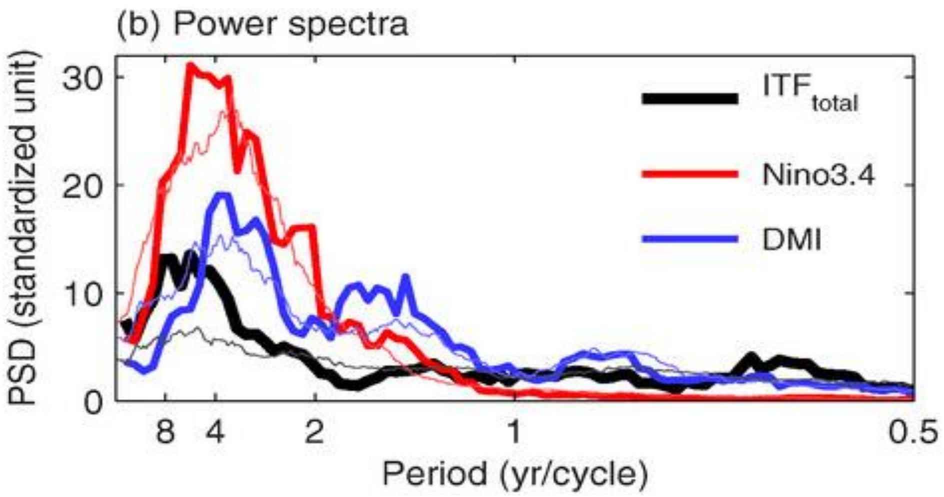
The CMIP5 multi-model mean and the SODA reanalysis are remarkably consistent: maximum ITF in austral winter and a minimum in austral summer consistent with previous studies (e.g., Masumoto & Yamagata 1996, Lee et al. 2010, Shinoda et al. 2012, Liu et al. 2015, Gordon et al. 2019).

Peak-to-trough amplitude ranges from 3.6 to 18 Sv with MMM of 9 Sv similar to SODA.

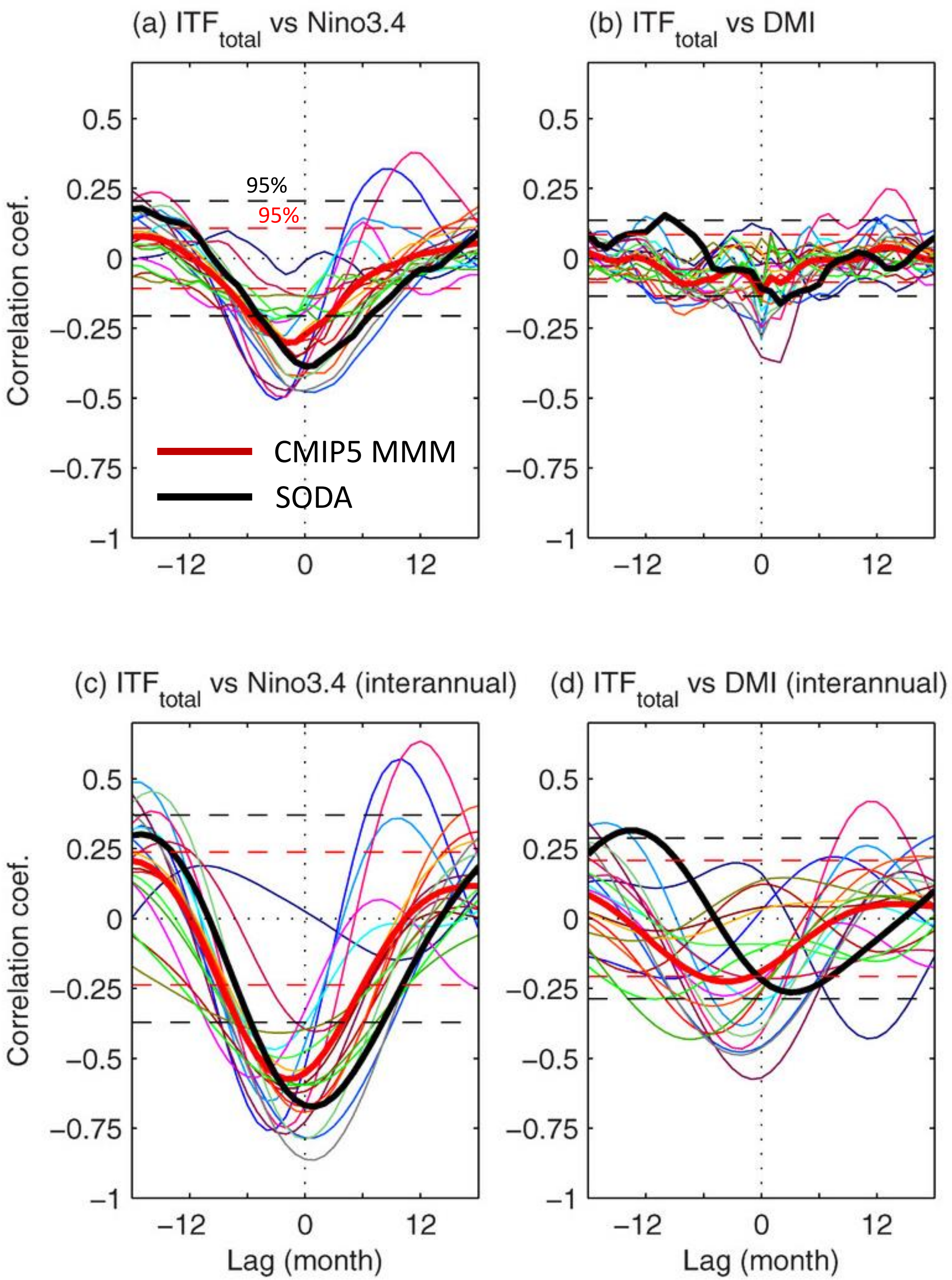
The vertical profile is also consistent with each other.

Most transport variability is contained in the upper 100-m across a diverse range of time scales, with interannual variability becoming more dominant with depth.





The total ITF transport variability in the SODA reanalysis (thick curves) exhibits peak variability of 4–8 years per cycle, coinciding more with ENSO (3–5 years per cycle) than IOD (2–4 years per cycle) - similar in the CMIP5 multi-model (thin curves).



Tendency for a weaker and stronger ITF total transport to occur with El Niño and La Niña, respectively – both in SODA and CMIP5, in raw and filtered data to focus on interannual time scales.

The relationship is not statistically significant for IOD.

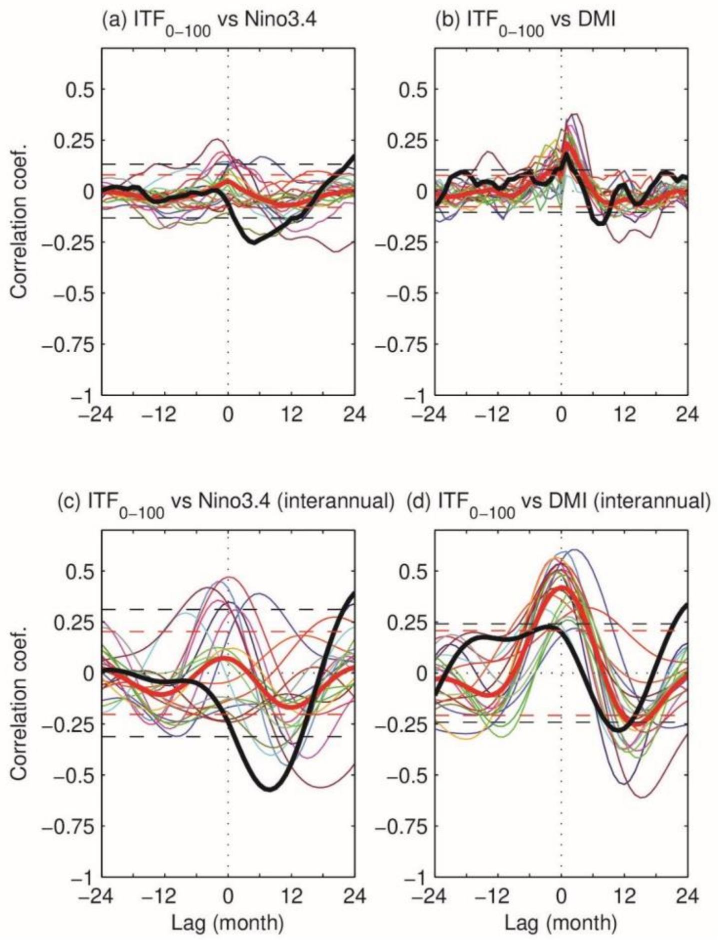
Why does the ITF total tend to lead ENSO in the CMIP5 models?

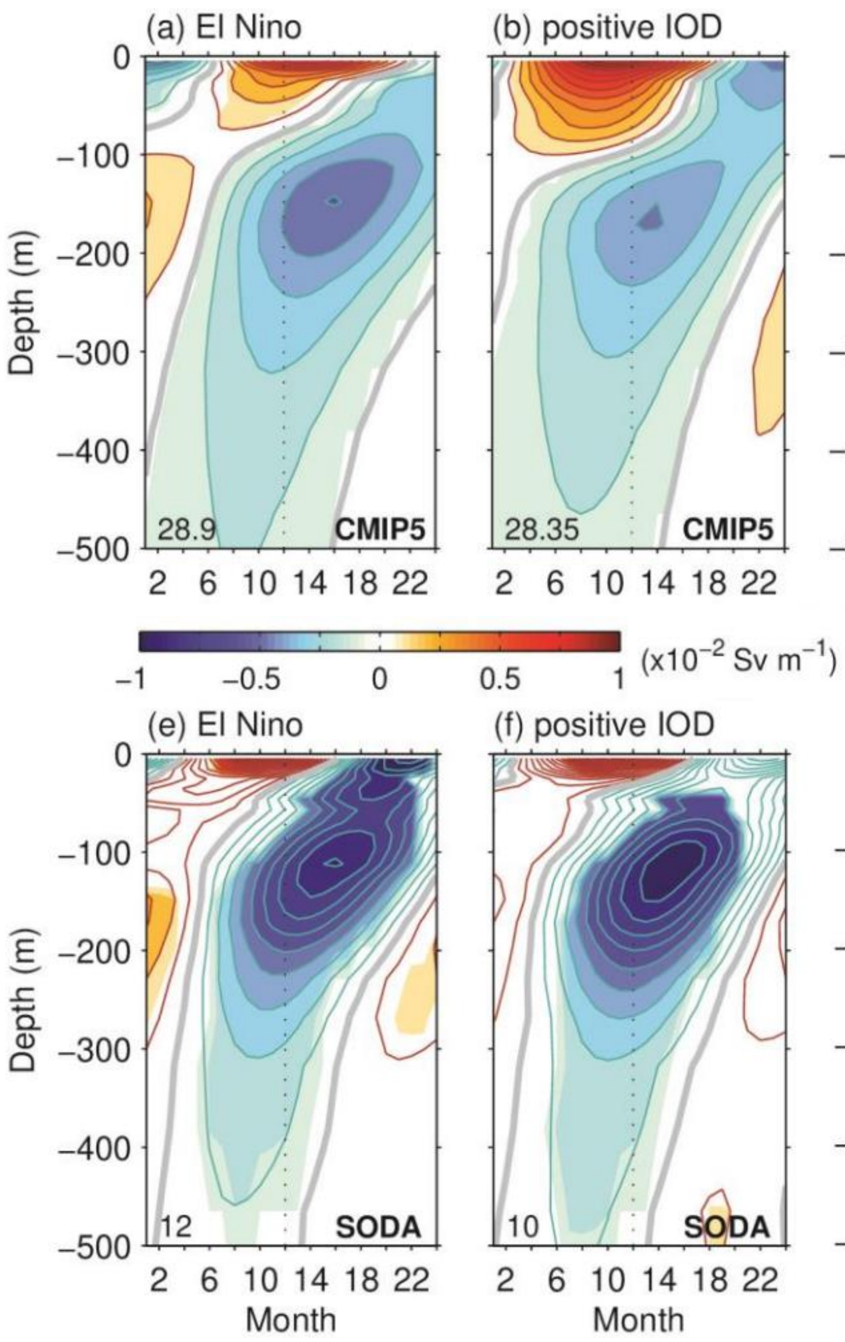
First look at the correlations for the surface layer.

Now we can see that in SODA, ENSO leads ITF.

There is also clear relationship with the IOD, especially in the CMIP5 models (and SODA in raw data).

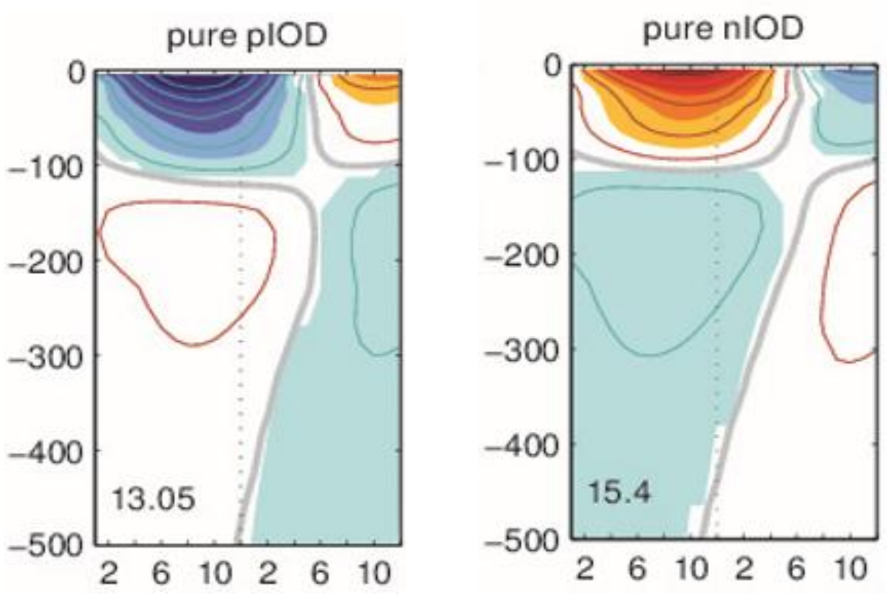
More next slide….





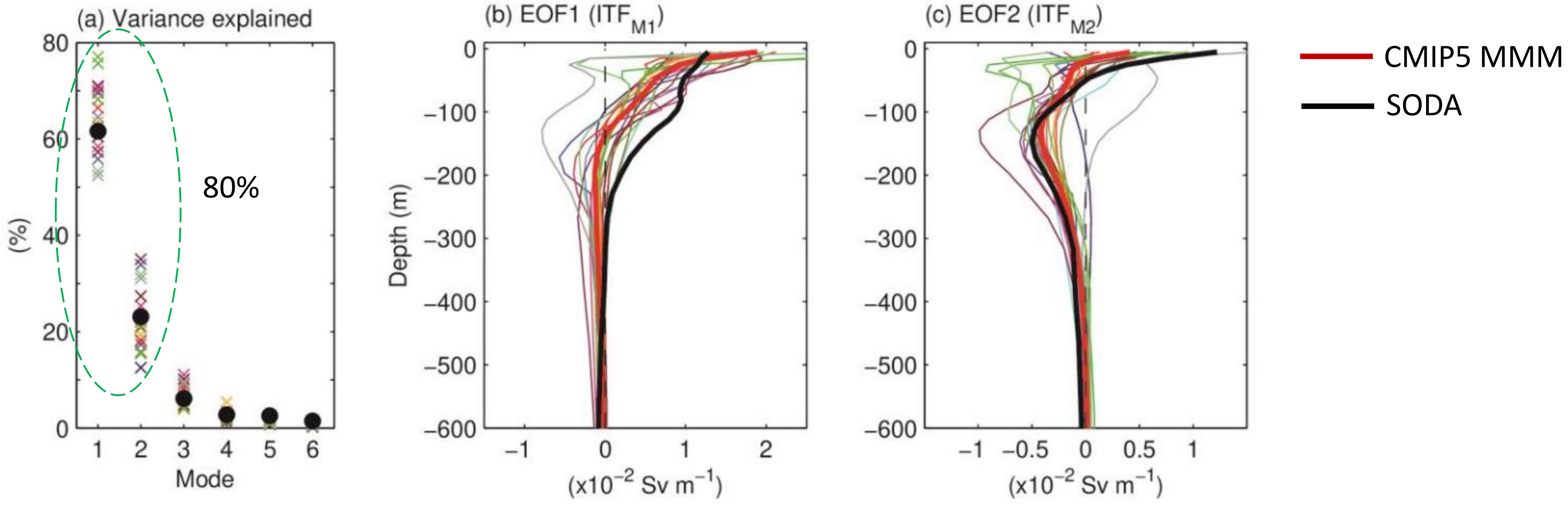
Transport anomaly composites

- El Nino and pIOD: Anomalously weak subsurface transport (100-300 m), surface intensification (0-100 m).
- Surface anomaly is more prevalent and deeper during IOD, particularly so in the CMIP5 models.
- Similar but opposite patterns for La Nina and nIOD. Stronger asymmetry seen in SODA reanalysis.
- Prolonged surface transport anomaly in the CMIP5 models, in the ENSO composites in particular.
- Upward propagation, contributing to a tendency for ITF lagged response to ENSO.
- ENSO has stronger impact on subsurface transport, IOD on surface transport.



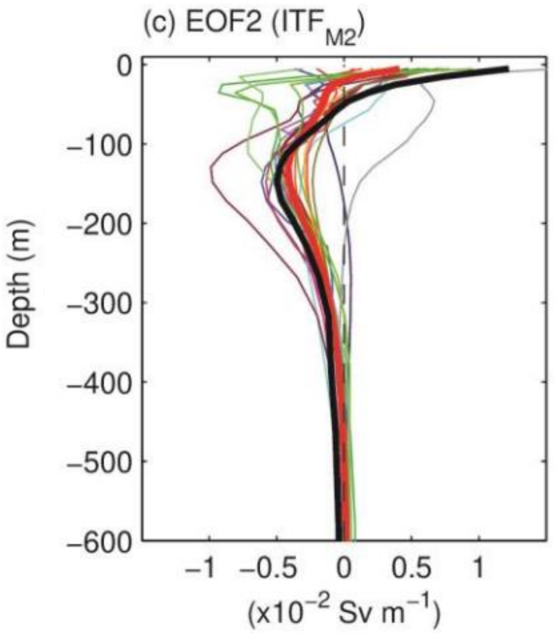
Composites of ENSO-independent IOD events in the CMIP5 models further highlight the point that the IOD has stronger impact in the surface layer.

EOF analysis



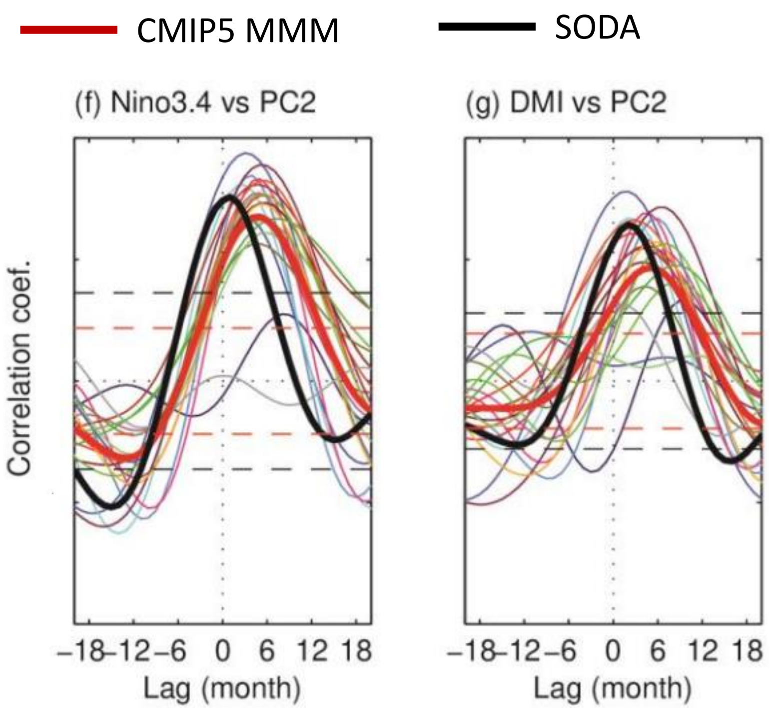
ITF$_{M1}$: Surface intensified transport anomaly

ITF$_{M2}$: Dipole anomaly



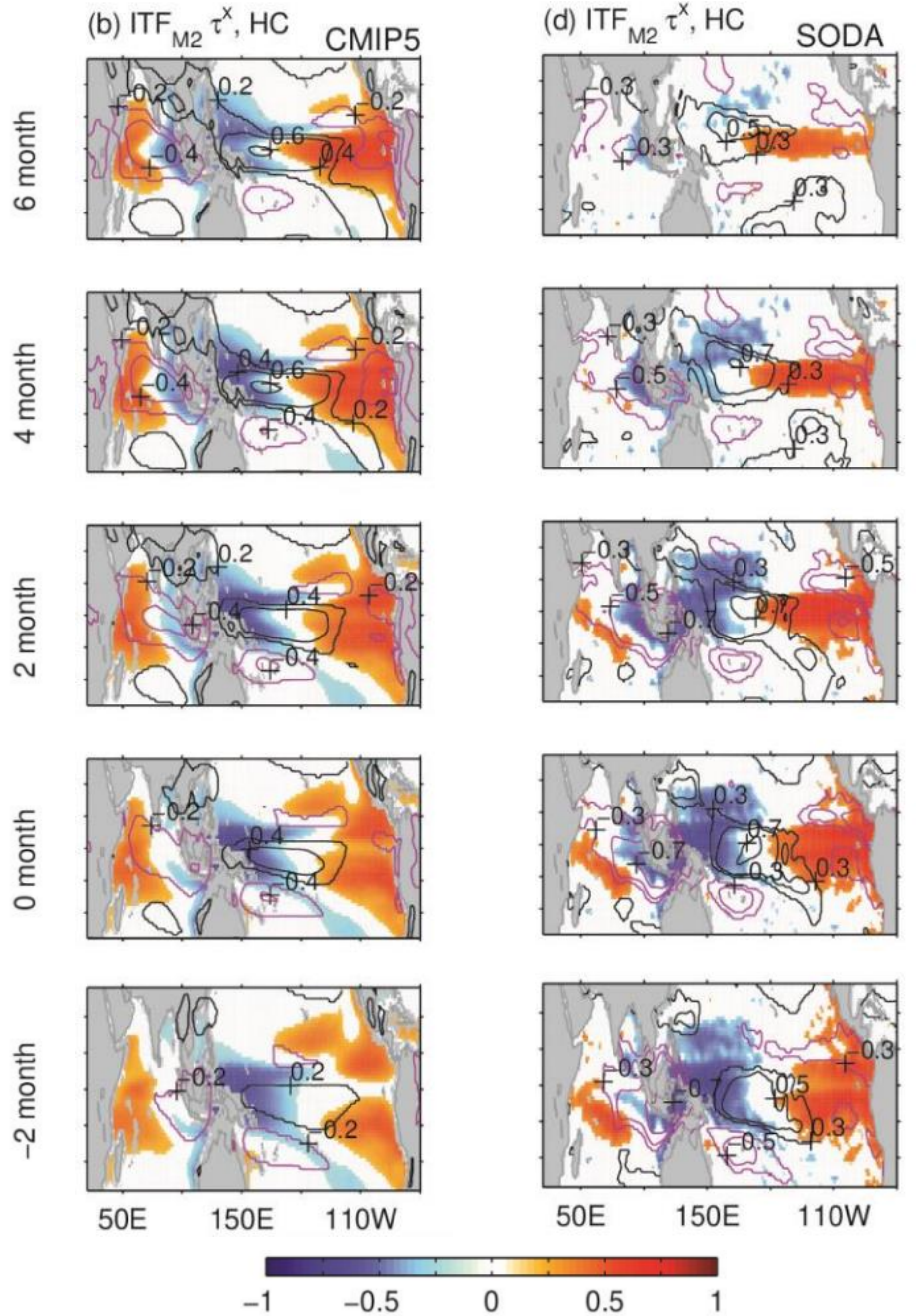
ITF$_{M2}$: Dipole anomaly is associated with ENSO and IOD, both in CMIP5 and SODA.

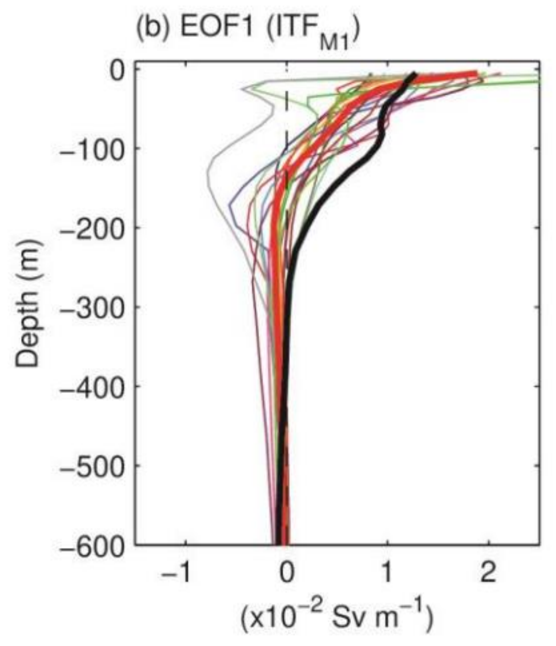
Reduced transport at subsurface, enhanced transport at surface associated with El Nino and pIOD.



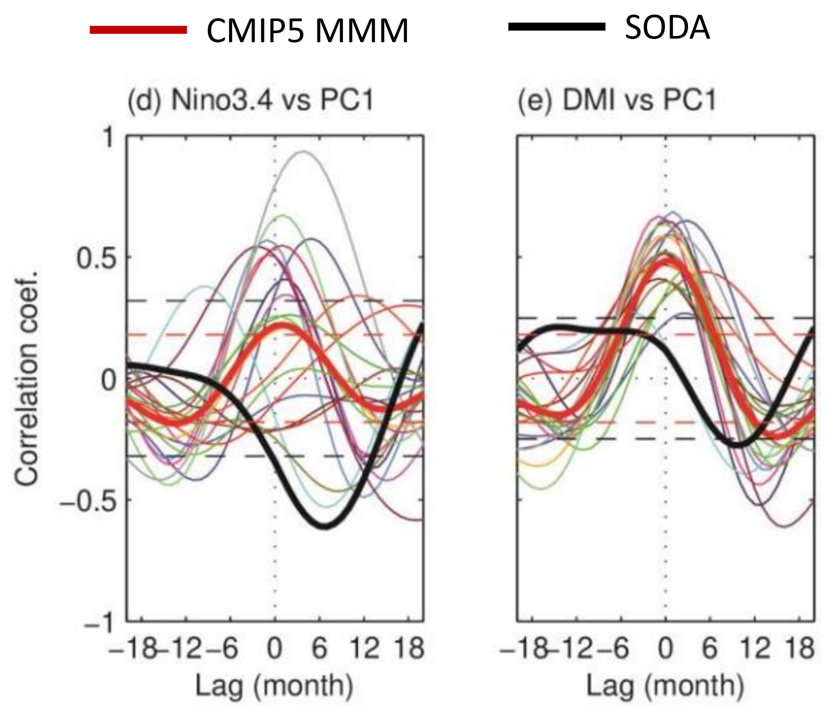
Lowered upper ocean heat content (color shading) in the western Pacific and eastern Indian Ocean.

Westerly wind anomaly (contours) in the Pacific, easterly in the Indian Ocean (i.e., large-scale divergence; weakened Walker Circulation).



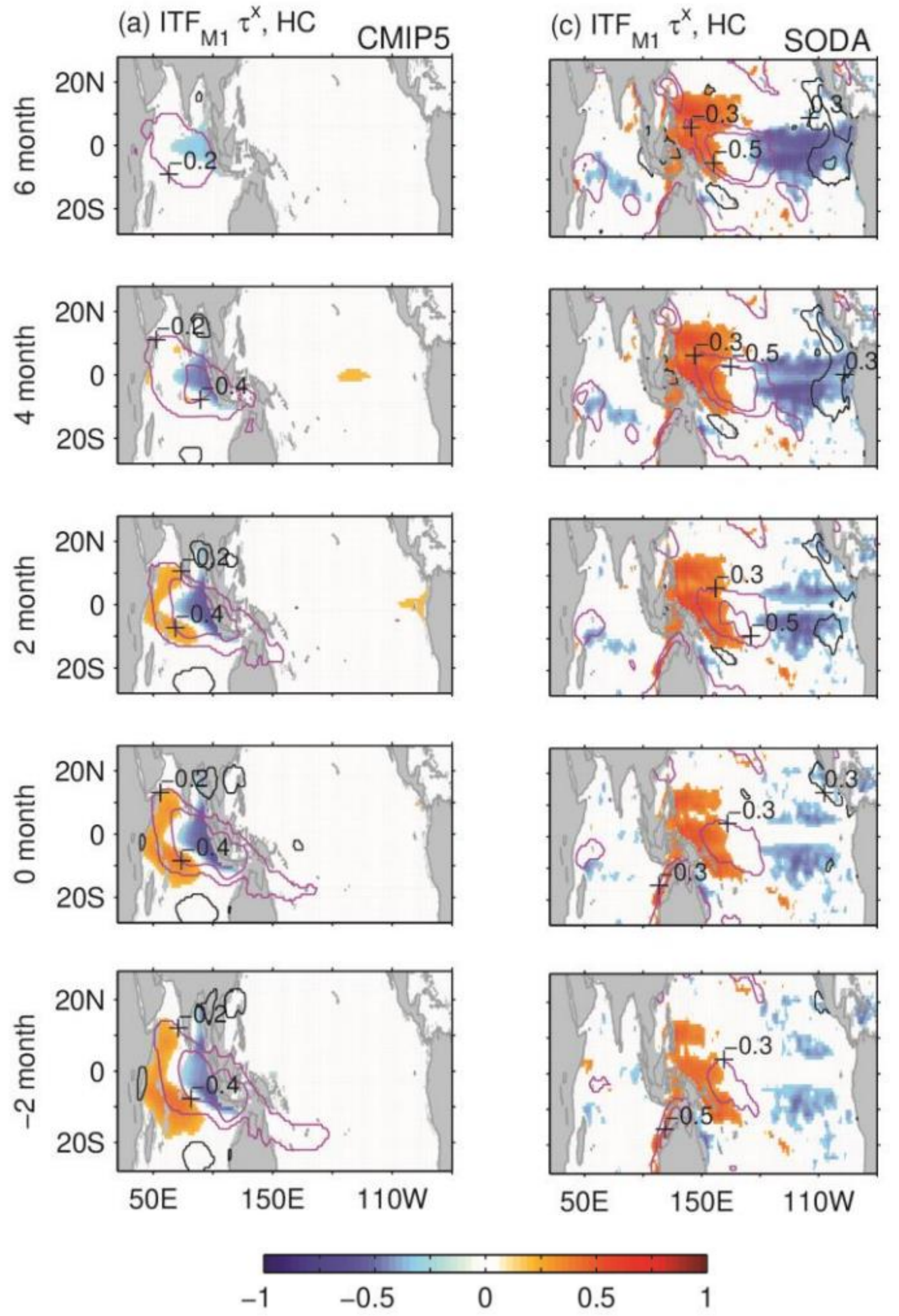


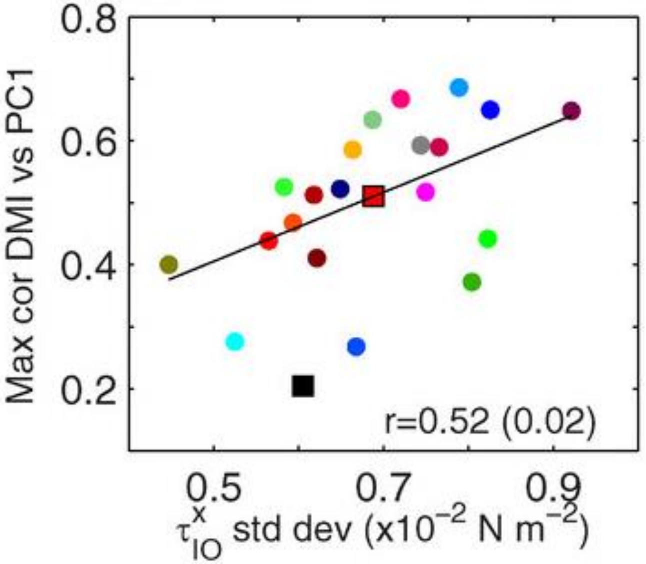
ITF$_{M1}$: Surface intensified anomaly is associated with ENSO in SODA, but IOD in CMIP5.



SODA: Enhanced transport is a response to La Nina (high Western Pacific heat content)

CMIP5: Enhanced transport is a response to pIOD (low eastern IO heat content linked to local wind variability τ_{IO}^{x})

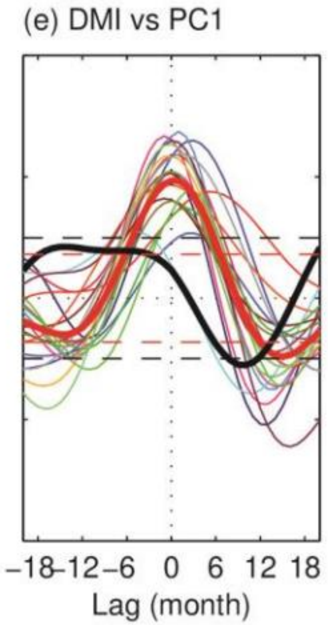


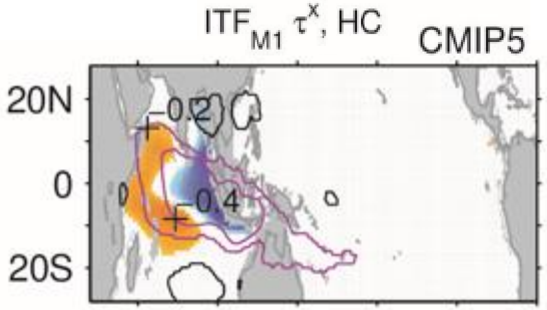


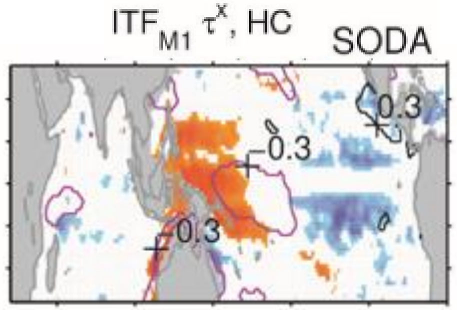
The prevalence of the IOD in driving ITF_{M1} in the CMIP5 models is linked to the magnitude of τ_{IO}^{x} variability, which is notably stronger than the reanalysis

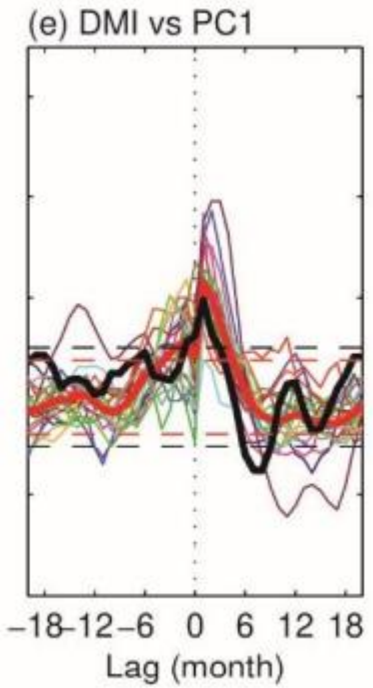
■ CMIP5 MMM
■ SODA

Interannual



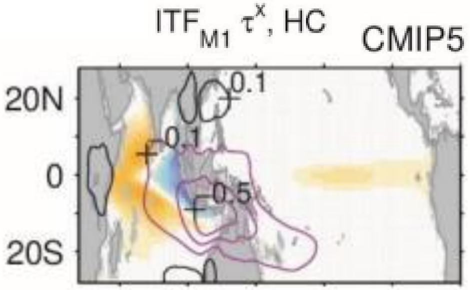


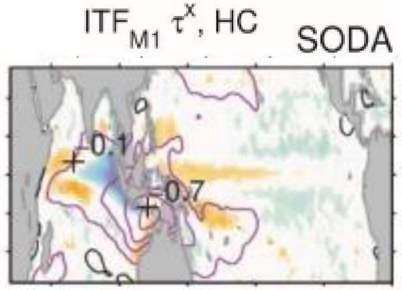




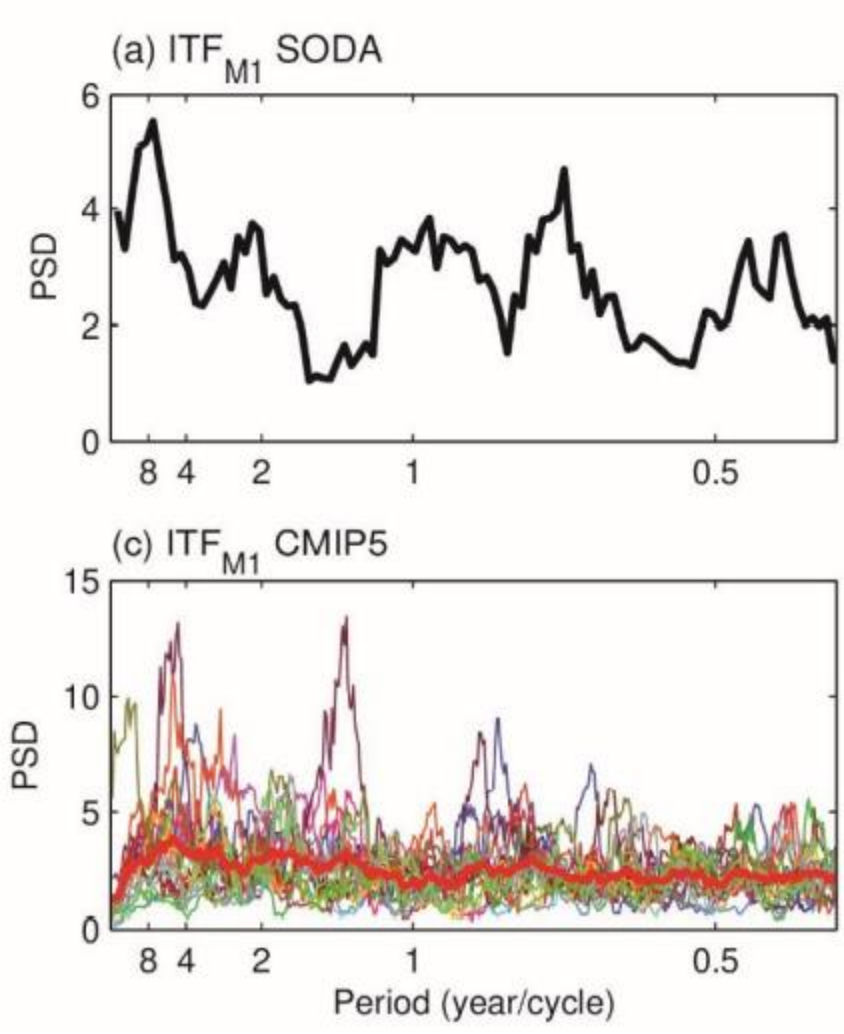
Raw

Role of τ_{IO}^{x} variability appears in both CMIP5 and SODA. Local winds contain frequency at sub annual time scales.

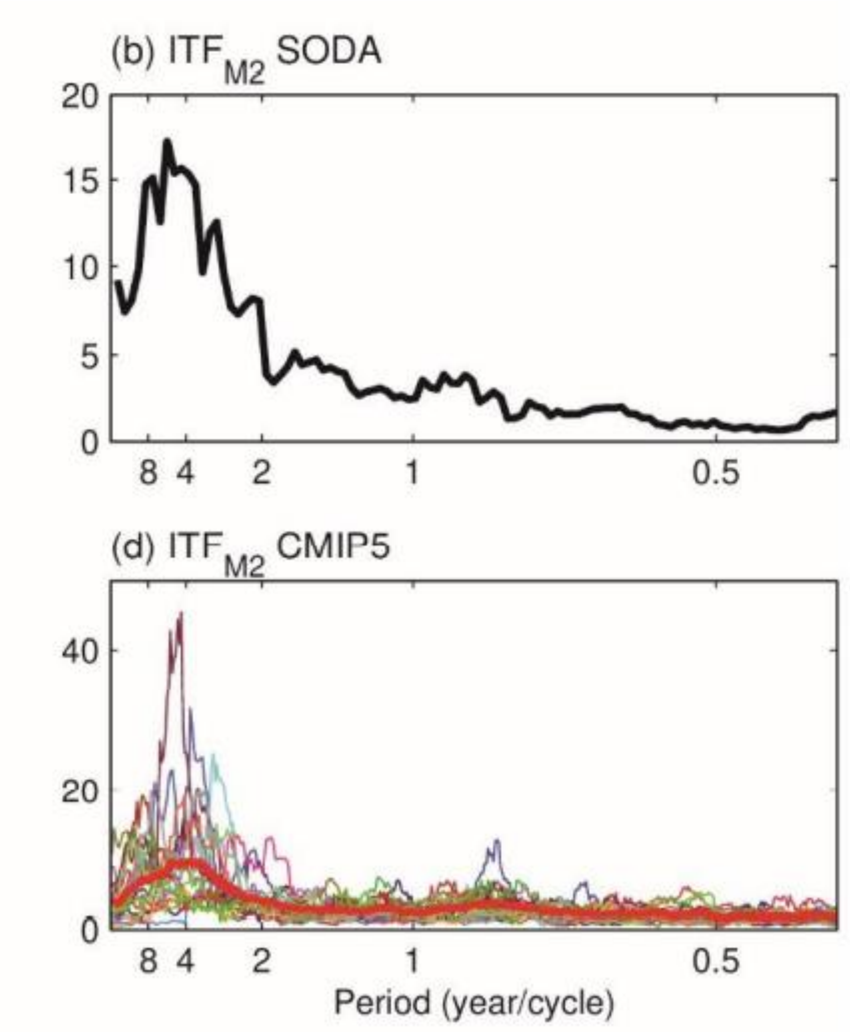


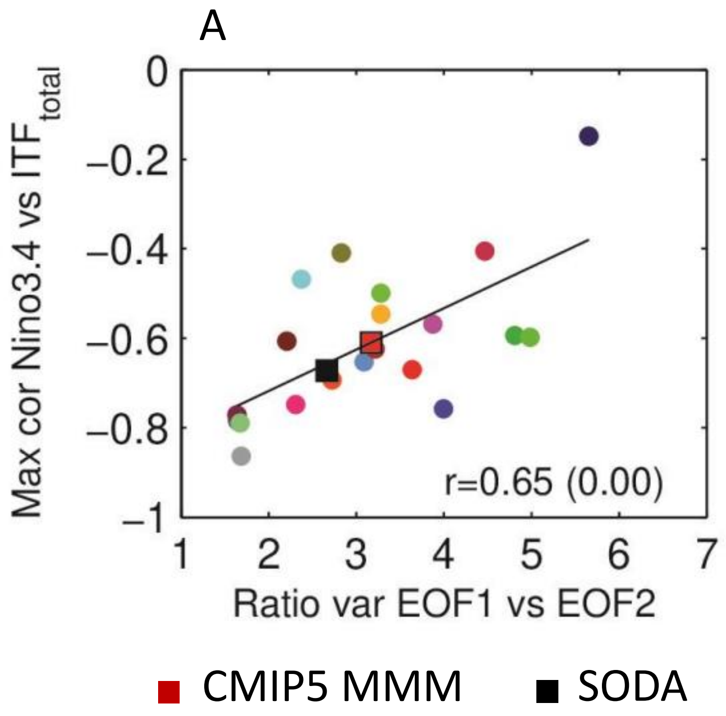


First mode is rich of sub-annual variabilities.



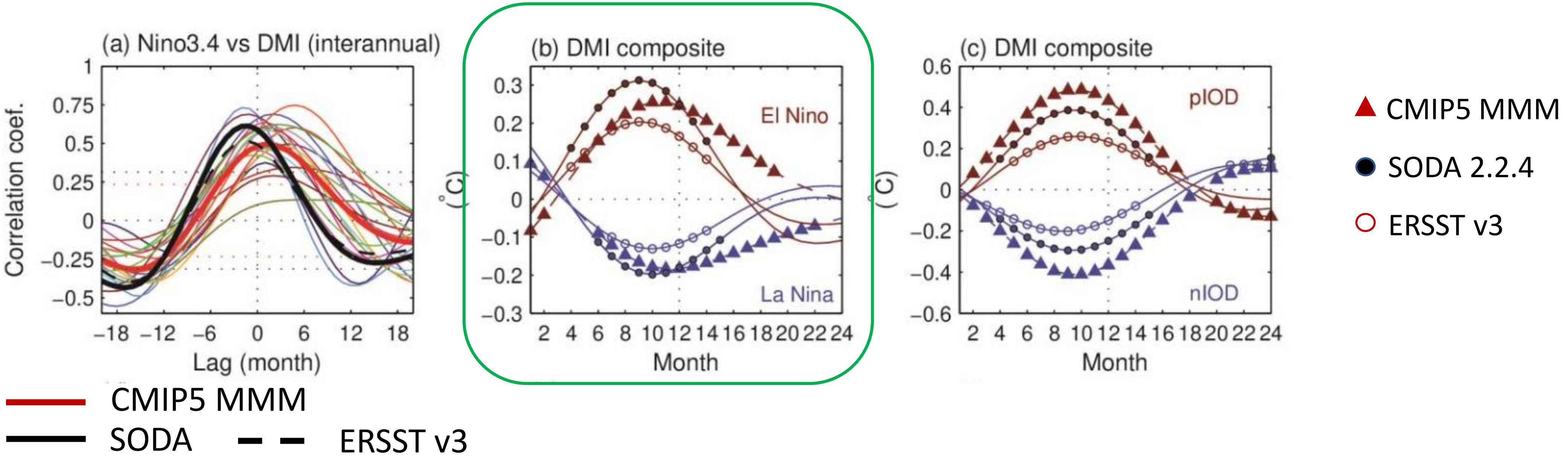
Second mode is largely interannual





There is a tendency for models with more prevalent $\mathbf{ITF_{M1}}$ relative to $\mathbf{ITF_{M2}}$ to exhibit a weaker link between ENSO and ITF_{total} variability.

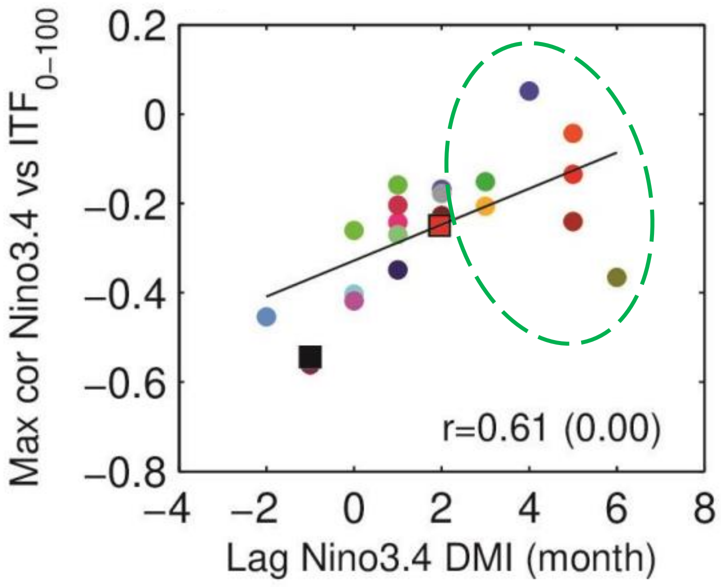
Delayed IOD response to ENSO



IOD tends to lead ENSO by about a season as IOD peaks in boreal autumn and ENSO peaks in winter. But in 15 out of 20 CMIP5 models, the converse occurs, with El Niño and La Niña respectively leading pIOD and nIOD.

This bias is related to the simulated ENSO teleconnection, as the delayed bias is much more apparent in the DMI composite according to El Niño and La Niña phases (b) than the composite based on IOD events (c).

The longer the IOD lags ENSO, the weaker the ENSO influence is on the ensuing surface ITF.



Summary

- Current generation of climate models still exhibit biases in ENSO and IOD: too strong IOD amplitude, weak ENSO and IOD event asymmetry/nonlinearity.
- Using 20 CMIP5 models and SODA-2.2.4 reanalysis to provide a systematic multi-model study on ITF variability linked to ENSO and IOD.
- The CMIP5 models capture many ITF properties that are qualitatively consistent with the SODA reanalysis, although with significant inter-model spread.
- The ITF total transport is found to weaken during El Niño and strengthen during La Niña, but not significant during the IOD, due to compensating effects between surface and subsurface transport anomalies.
- Separating variability into ITF_{M1} (surface intensified) and ITF_{M2} (dipole) structures reveals discrepancy between CMIP5 and reanalysis: agreement in ITF_{M2} associated with ENSO and IOD; disagreement in ITF_{M1} associated with ENSO in SODA but IOD in CMIP5 due to overly strong IOD magnitude and delayed IOD response to ENSO.

Santoso A., M. H. England, J. B. Kajtar, W. Cai, 2022: Indonesian Throughflow Variability and Linkage to ENSO and IOD in an Ensemble of CMIP5 Models. *J. Climate*, https://doi.org/10.1175/JCLI-D-21-0485.1

UNSW THE UNIVERSITY OF NEW SOUTH WALES

Climate Change Research Centre

climate extremes ARC centre of excellence

Climate Systems National Environmental Science Program