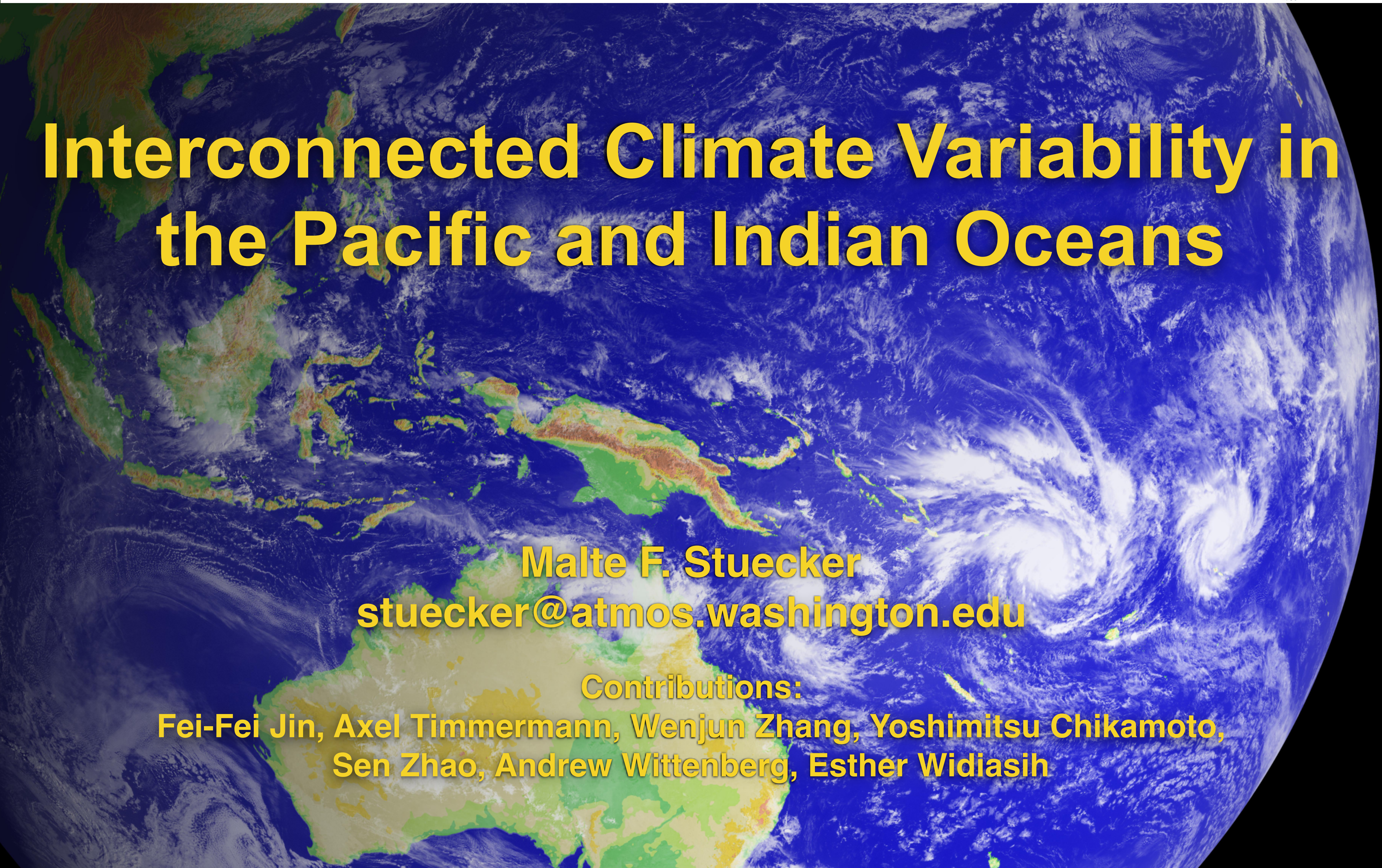

Interconnected Climate Variability in the Pacific and Indian Oceans

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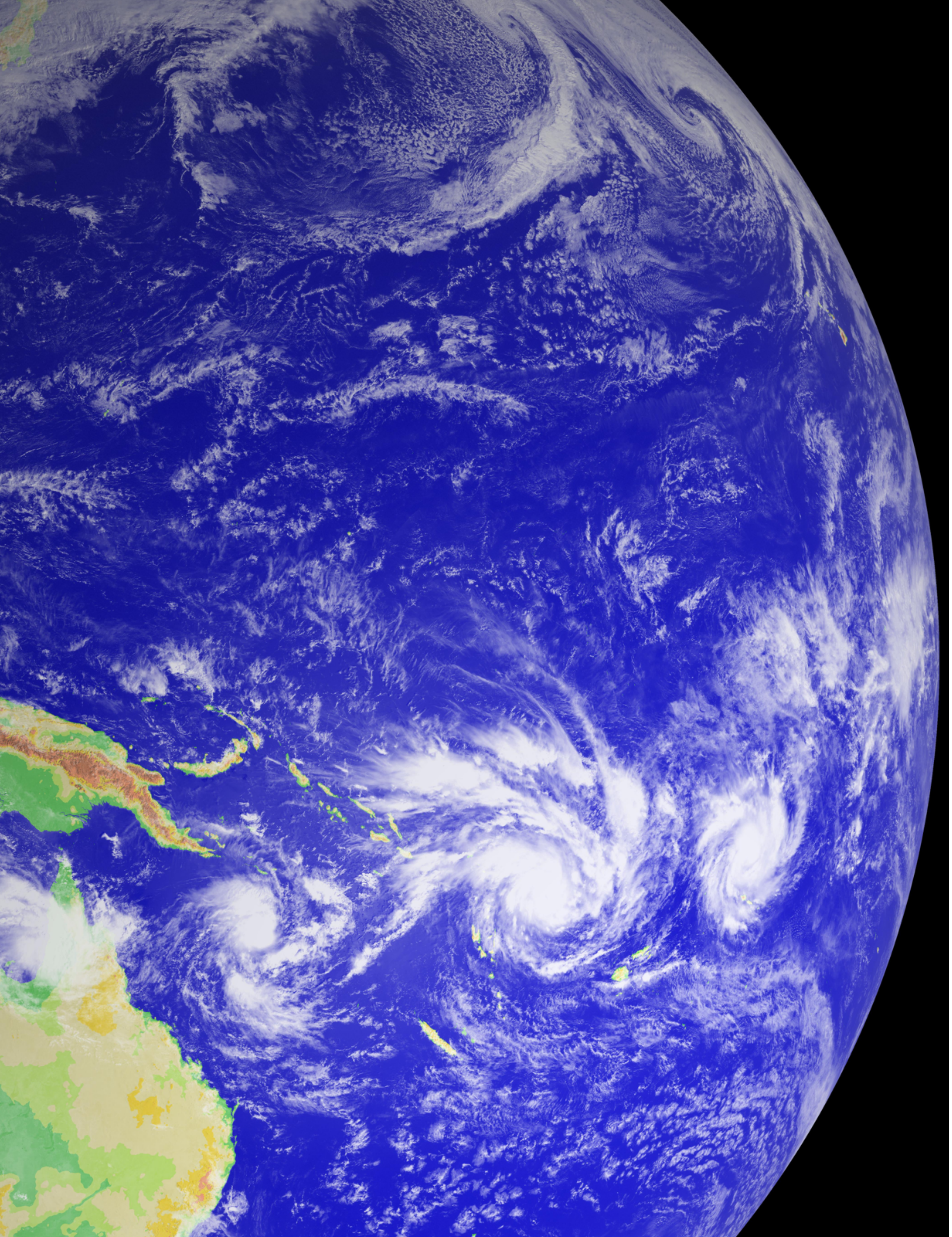
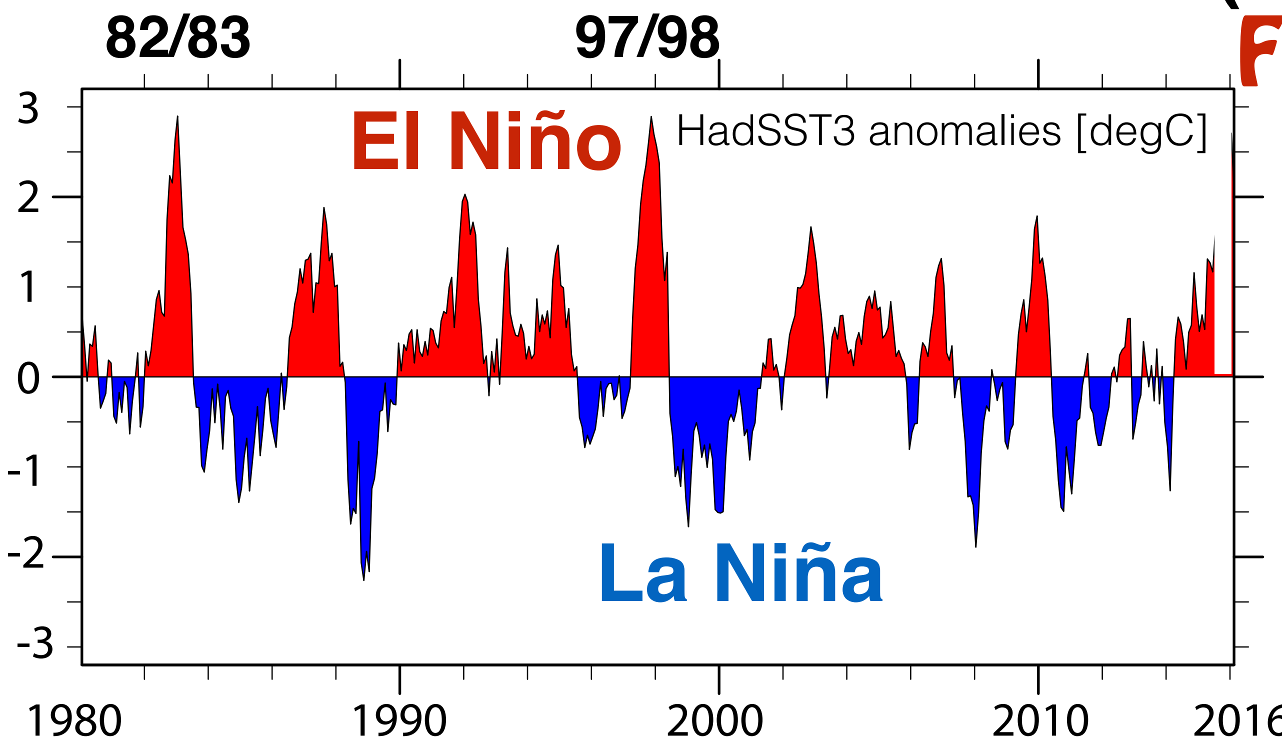
Contributions:
Fei-Fei Jin, Axel Timmermann, Wenjun Zhang, Yoshimitsu Chikamoto, Sen Zhao, Andrew Wittenberg, Esther Widiasih

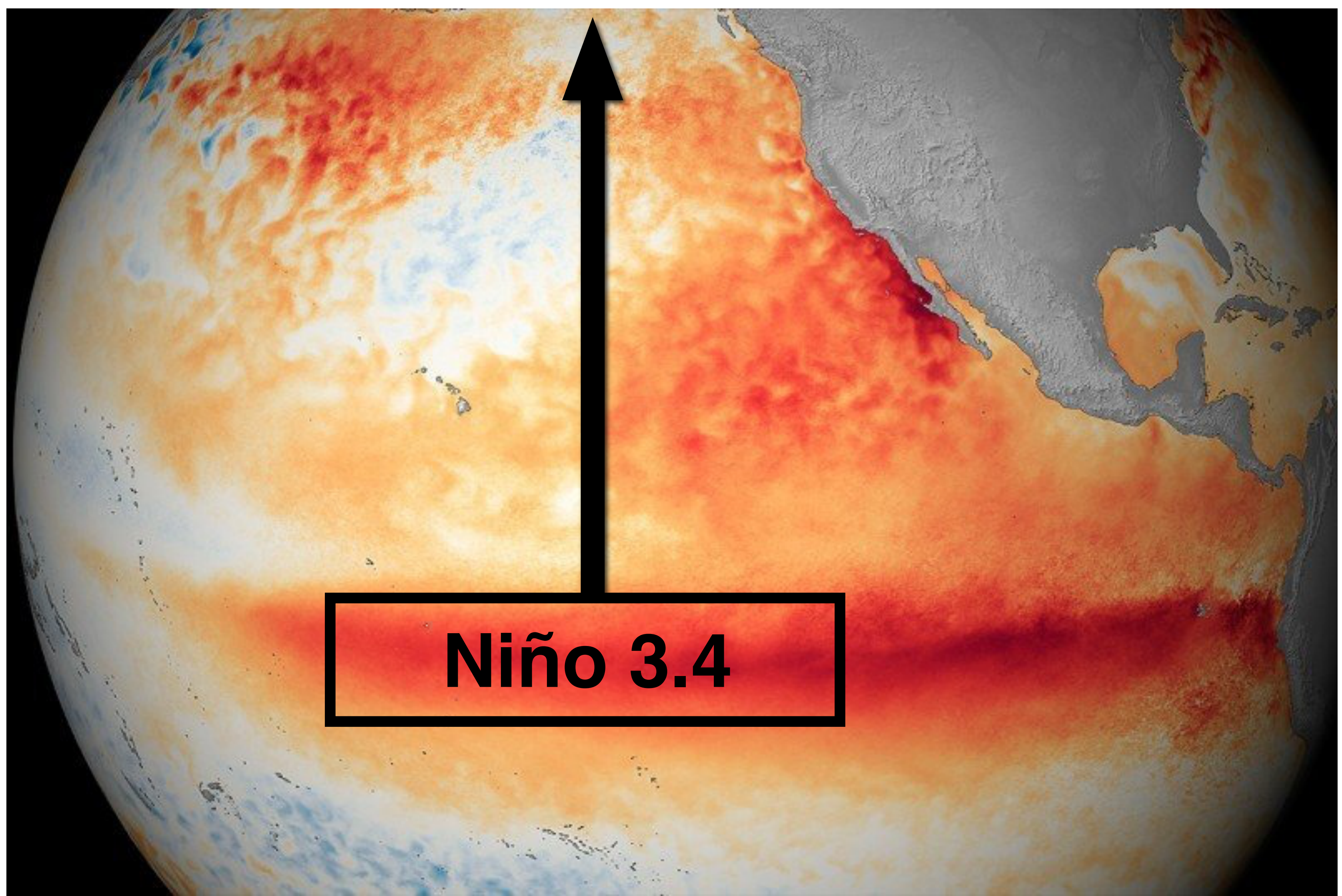


Climate variability in the Pacific Ocean

The largest variability in the tropical Pacific: The El Niño-Southern Oscillation (ENSO)



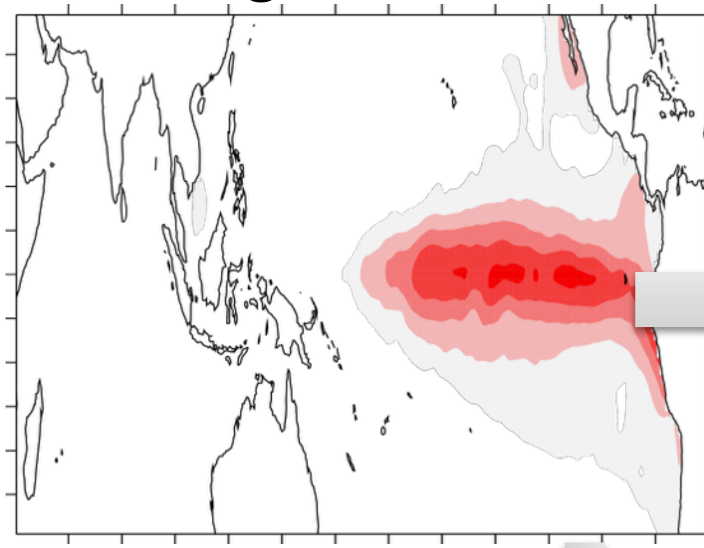
February 2016



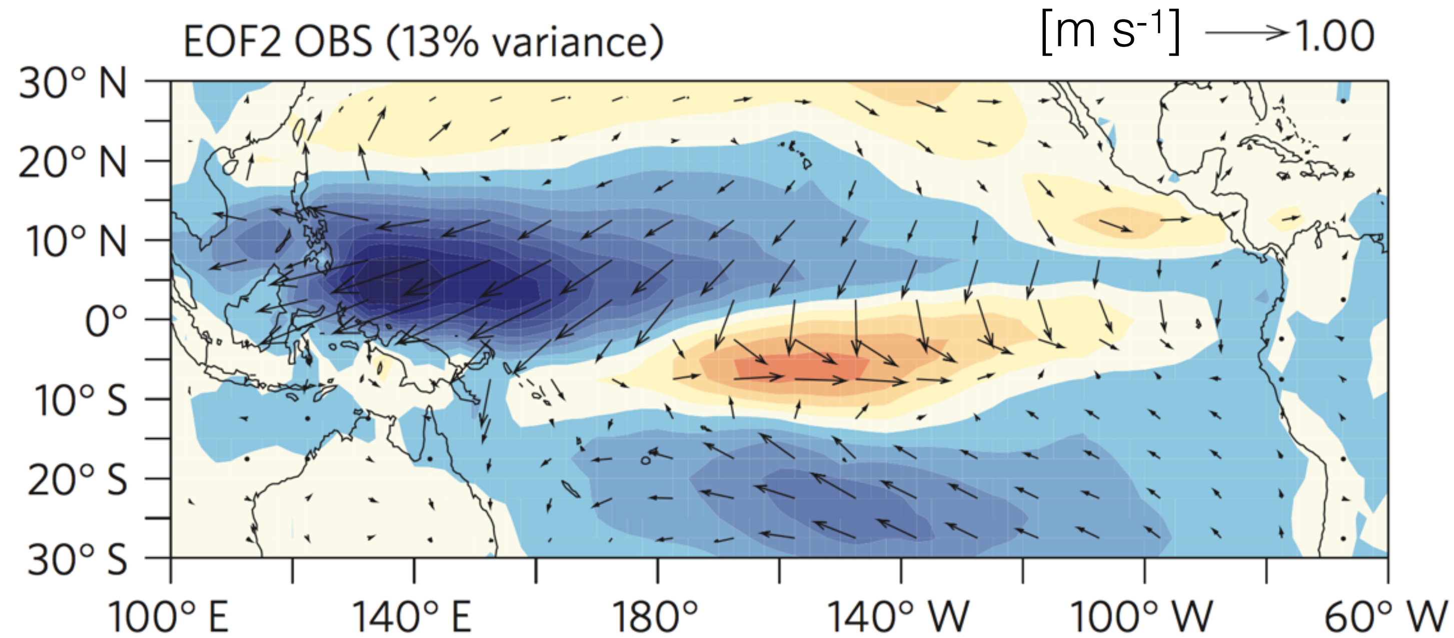
Sea surface temperature anomalies October 2015 (NOAA)

However, one index (Niño3.4) is not sufficient to describe ENSO variability under a seasonally varying background state, instead we need at least 2 degrees of freedom…

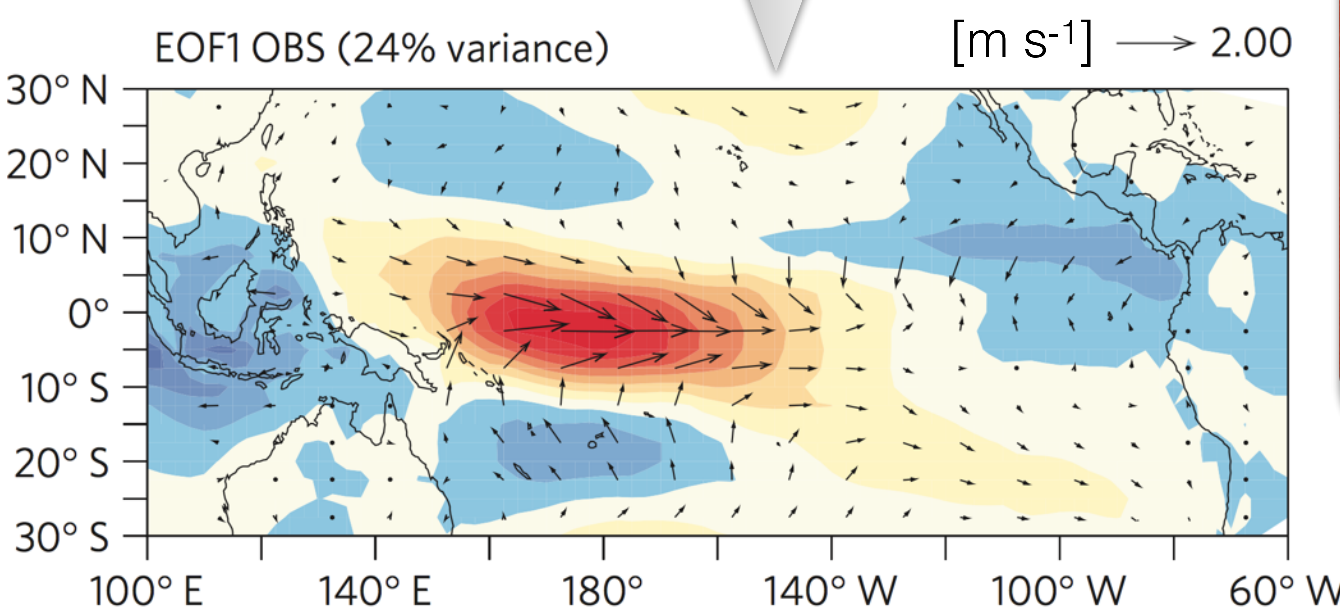
ENSO forcing under seasonally varying background state



ENSO combination mode



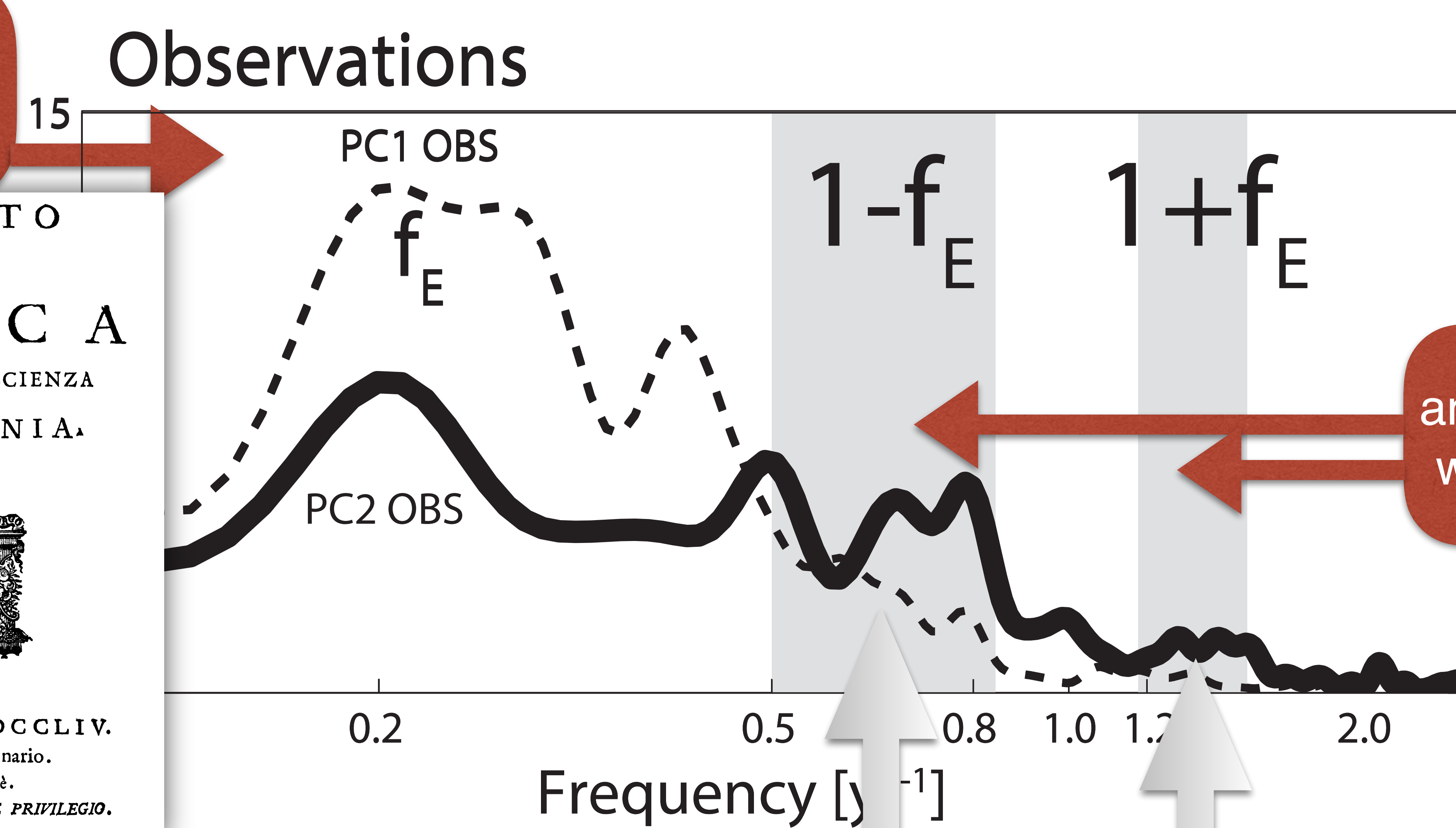
seasonally modulated wind response, meridionally **antisymmetric**, atmospheric response on **different timescales** than the forcing (**PC2 ~ Niño3.4 x cos(ω_a t)**)

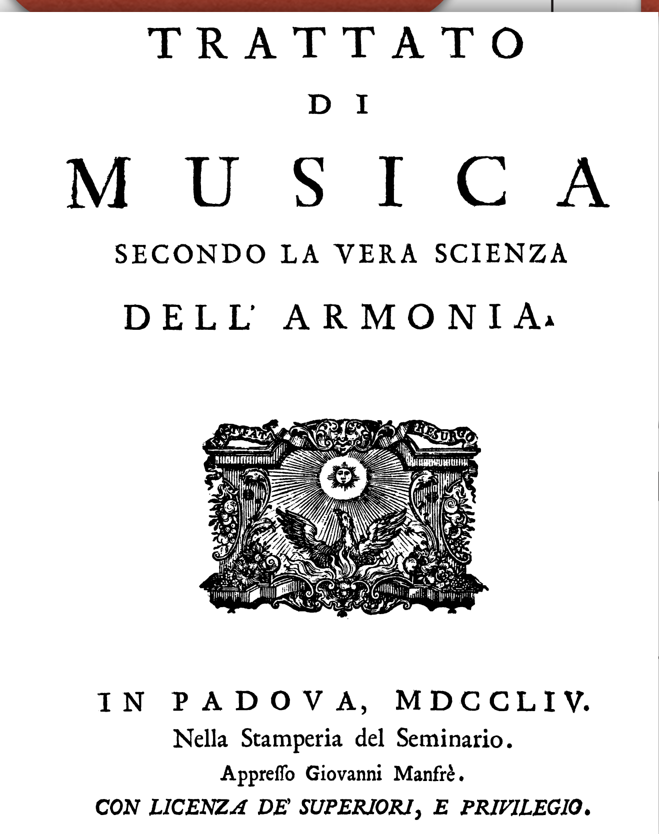


linear wind response, meridionally **symmetric**, atmospheric response on **same timescale** as the forcing (**PC1 ~ Niño3.4**)

Stuecker et al. 2013, Nature Geoscience

interannual ENSO timescale




TRATTATO
DI
MUSICA
SECONDO LA VERA SCIENZA
DELL' ARMONIA.

IN PADOVA, MDCCLIV.
Nella Stamperia del Seminario.
Appresso Giovanni Manfrè.
CON LICENZA DE' SUPERIORI, E PRIVILEGIO.

antisymmetric wind pattern

PC2 spectrum shows combination tones (Tartini, 1754) between ENSO ($f_E \approx 0.2$ yr^{-1}) and the annual cycle (1 yr^{-1}) in the near-annual band

~15 months **~10 months**

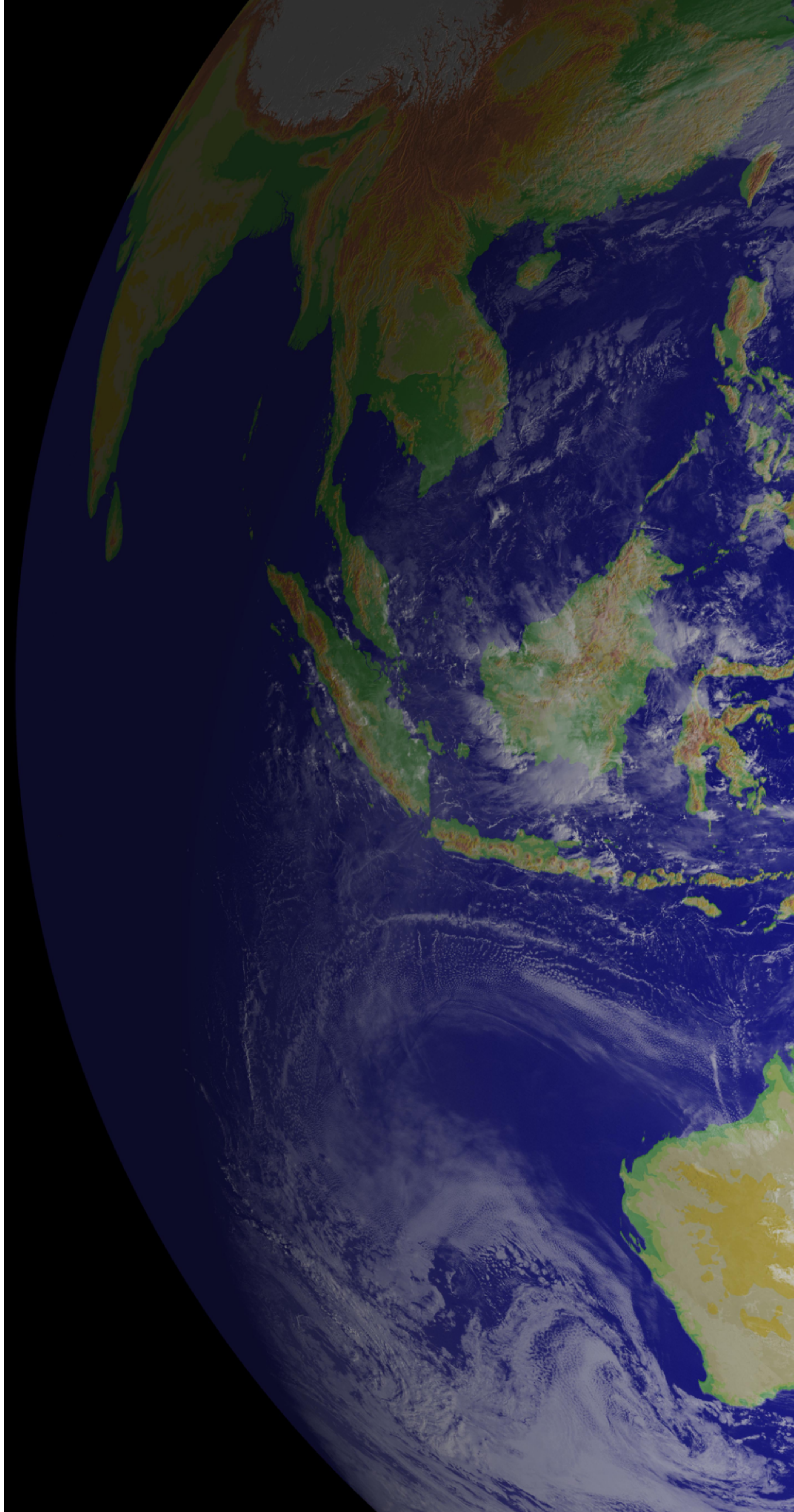
$$A_A \cos(\omega_A t)\, A_E \cos(\omega_E t) = \frac{1}{2} A_A A_E \left\{ \cos([\omega_A - \omega_E]\, t) + \cos([\omega_A + \omega_E]\, t) \right\}$$

$1-f_E$ **$1+f_E$**

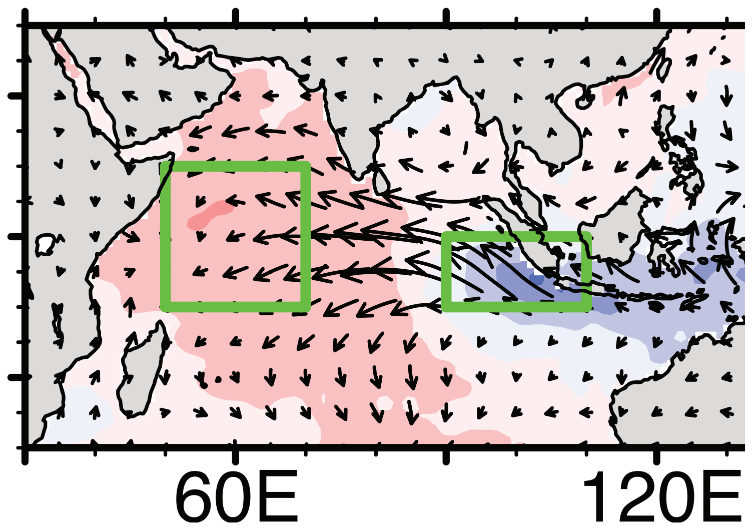
er et al. 2013,
Geoscience

ENSO's interaction with the annual cycle creates variability on a wide range of timescales (e.g., Stuecker et al. 2015 PNAS) that can be temporally un-correlated with traditional ENSO indices (such as Niño3.4)

What is the dominant mode of climate variability in the Indian Ocean?



Indian Ocean Dipole (IOD)



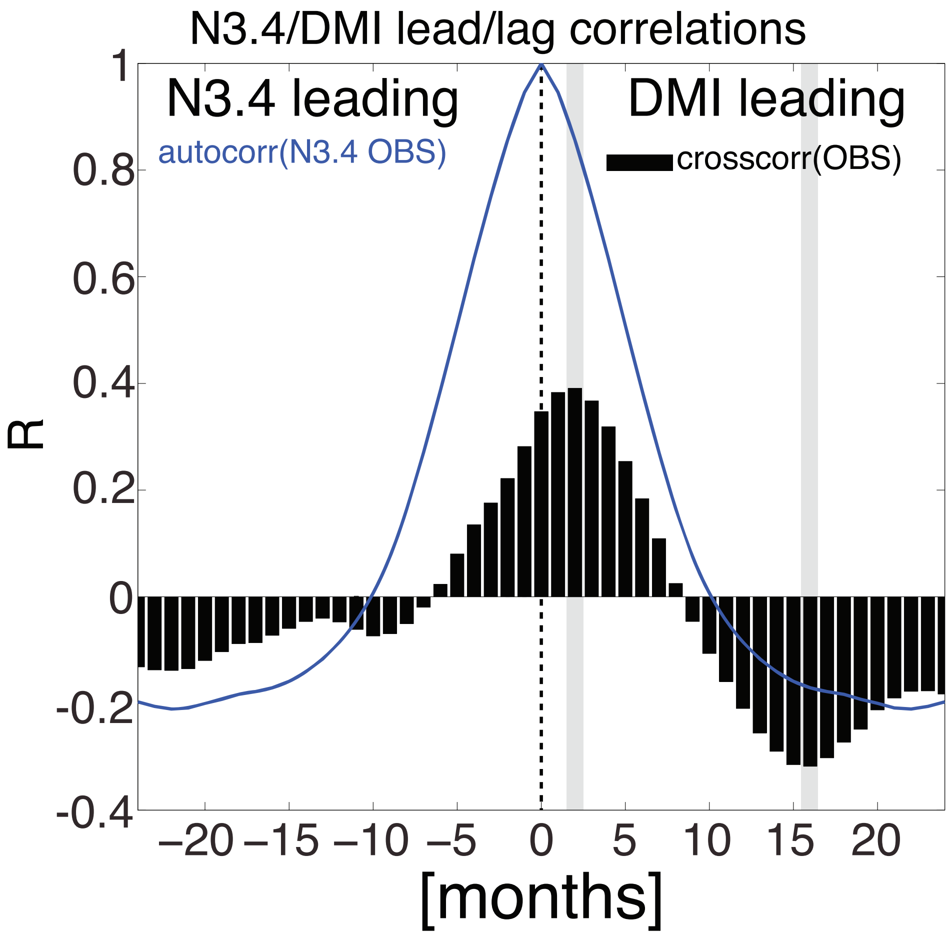
- zonal SSTA dipole mode in the Indian Ocean
- **Dipole Mode Index (DMI)** = Western IO SSTA - Eastern IO SSTA

- air/sea coupled mode that peaks during SON season

- most IOD events are forced by ENSO

Stuecker et al. 2017, GRL

ENSO and the Indian Ocean Dipole



- DMI is leading N3.4 by 2 and 16 months —> has been interpreted that IOD forces ENSO in the same year and in the following year (negative correlation at ~16 months)

Stuecker et al. 2017, GRL

Physical null hypothesis for independent IOD

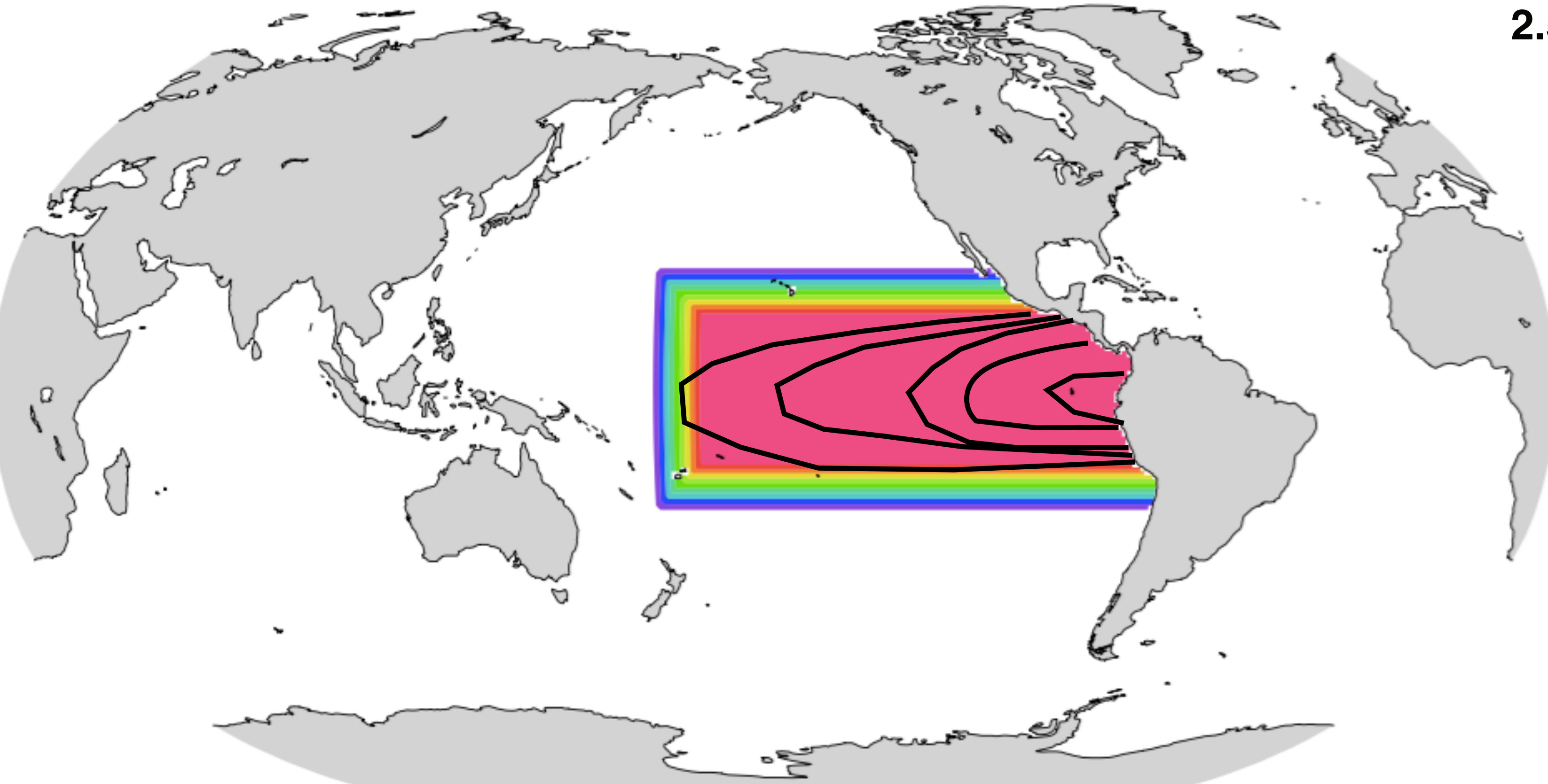
(1) Model for ENSO-independent IOD events:

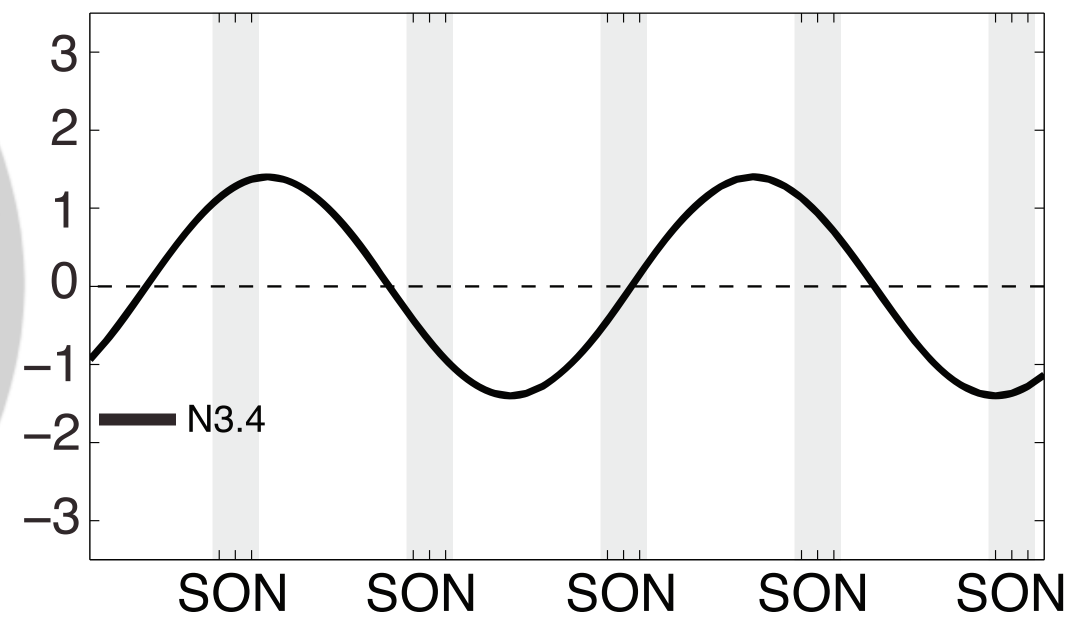
$$\frac{\mathrm{d}T}{\mathrm{d}t} = \left[-\lambda_0 + \lambda_a \cos\left(\omega_a t + \varphi_I\right)\right] T(t) + \xi(t)$$

- Noise forced SST equation with a seasonally modulated damping rate (Hasselmann 1976; de Elvira & Lemke 1982)
- Air/sea coupling (Bjerknes feedback) has a strong annual cycle in the Indian Ocean (Eastern Equatorial IO convection, ocean barrier layer thickness, thermocline depth, and Indonesian Throughflow transport -> Annamalai et al. 2003)
- Describes stochastically occurring IOD events peaking in the SON season (no ocean memory required)

Stuecker et al. 2017, GRL

ENSO and the Indian Ocean Dipole



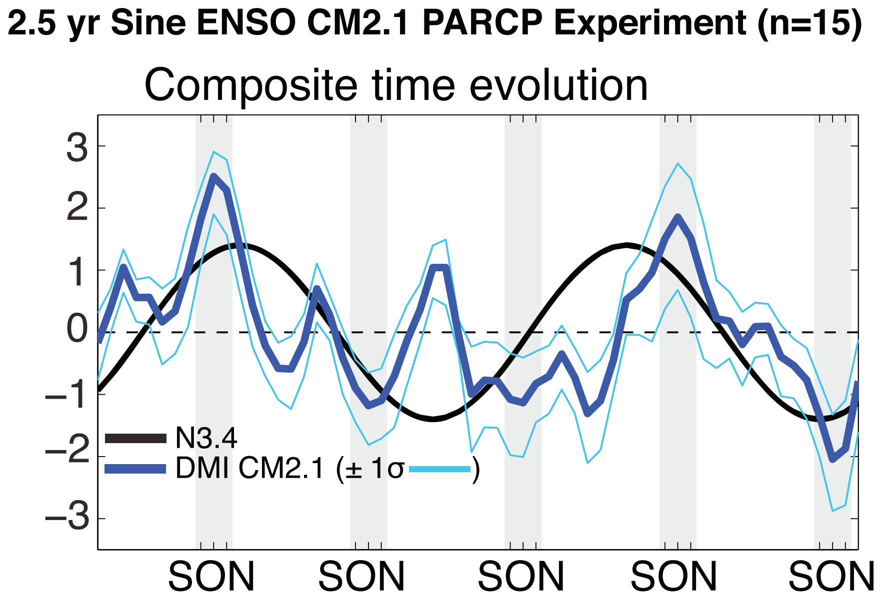


- Motivation: Investigate the ENSO-forced IOD events next
- CM2.1 partially coupled (PARCP) experiment: prescribed sinusoidal ENSO SSTA forcing in the eastern equatorial Pacific (contours) with **fully coupled dynamical ocean** everywhere else (including Indian Ocean)
- Using model experiments with sinusoidal ENSO forcing allows us to clearly identify the timescales and patterns of the climate system response to ENSO

Stuecker et al. 2017, GRL

ENSO and the Indian Ocean Dipole

- DMI shows clear C-mode signature (correlation with ENSO x cos(ωa t); higher frequency variability)



Physical null hypothesis for the ENSO/IOD relationship

(2) Model for ENSO-forced IOD events:

ensemble mean

$$\frac{dT}{dt} = \left[-\lambda_0 + \lambda_a \cos\left(\omega_a t + \varphi_l\right)\right] T(t)$$

- adding a seasonally-modulated ENSO forcing (C-mode) on the right hand side (dominant signal in the CM2.1 model experiment)
- as in the stochastic model, Indian Ocean air/sea coupling is included and has an annual cycle
- Solution T will be referred to as **C-mode***

Stuecker et al. 2017, GRL

ENSO and the Indian Ocean Dipole

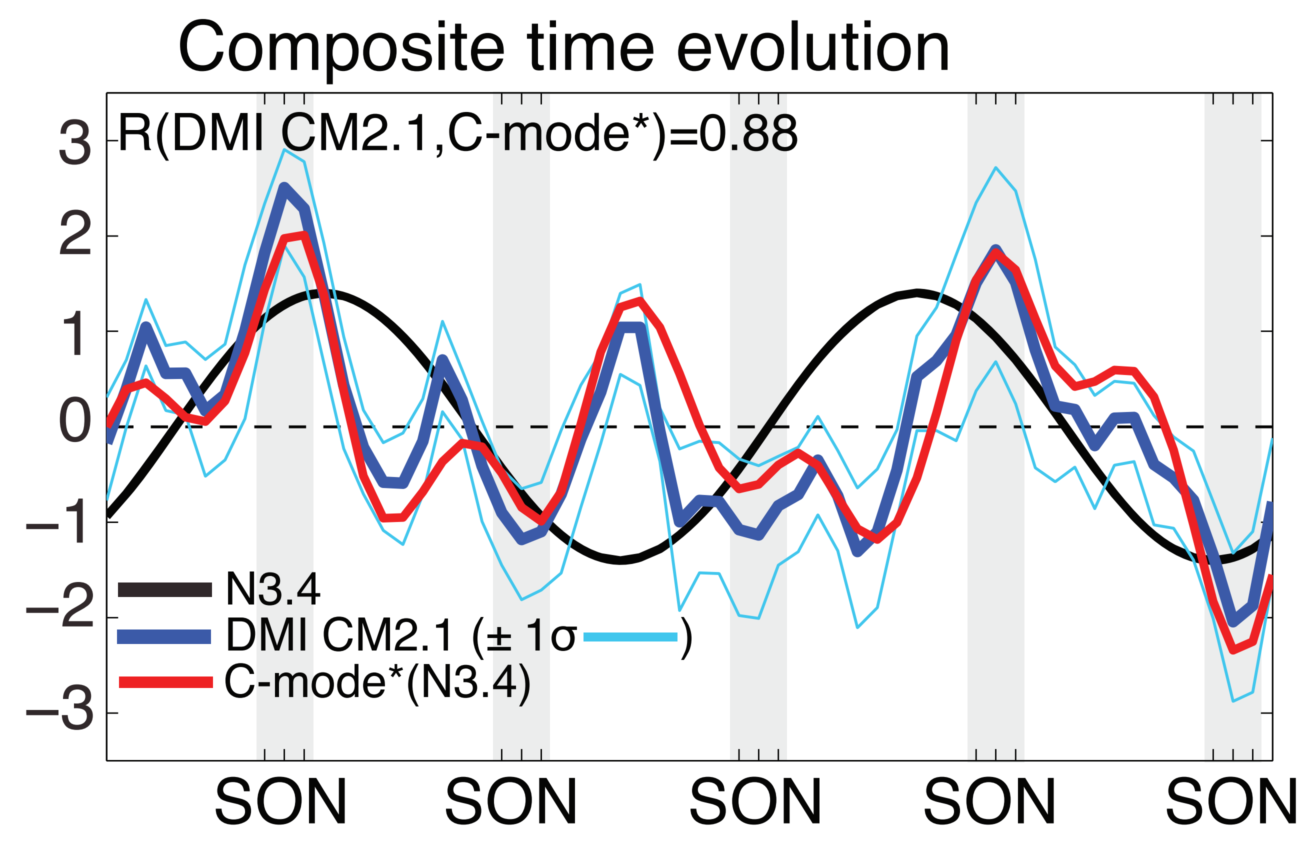
- We can obtain the approximate analytical solution of our model and gather terms with same timescale:

$$\tilde{T}(t) = -\overbrace{\frac{1}{\sqrt{\lambda_0^2 + \omega_a^2}} \left[\cos\left(\omega_a t - \theta_0^{\#} + \varphi_a\right) \cos\left(\omega_0 t + \varphi_0\right)\right]}^{1 \pm f_E}$$

- dominant term in the IOD response has the same timescale as the seasonally modulated ENSO forcing

ENSO and the Indian Ocean Dipole

2.5 yr Sine ENSO CM2.1 PARCP Experiment (n=15)



- our simple model (C-mode*) captures the ENSO-forced IOD in the partially coupled model experiment

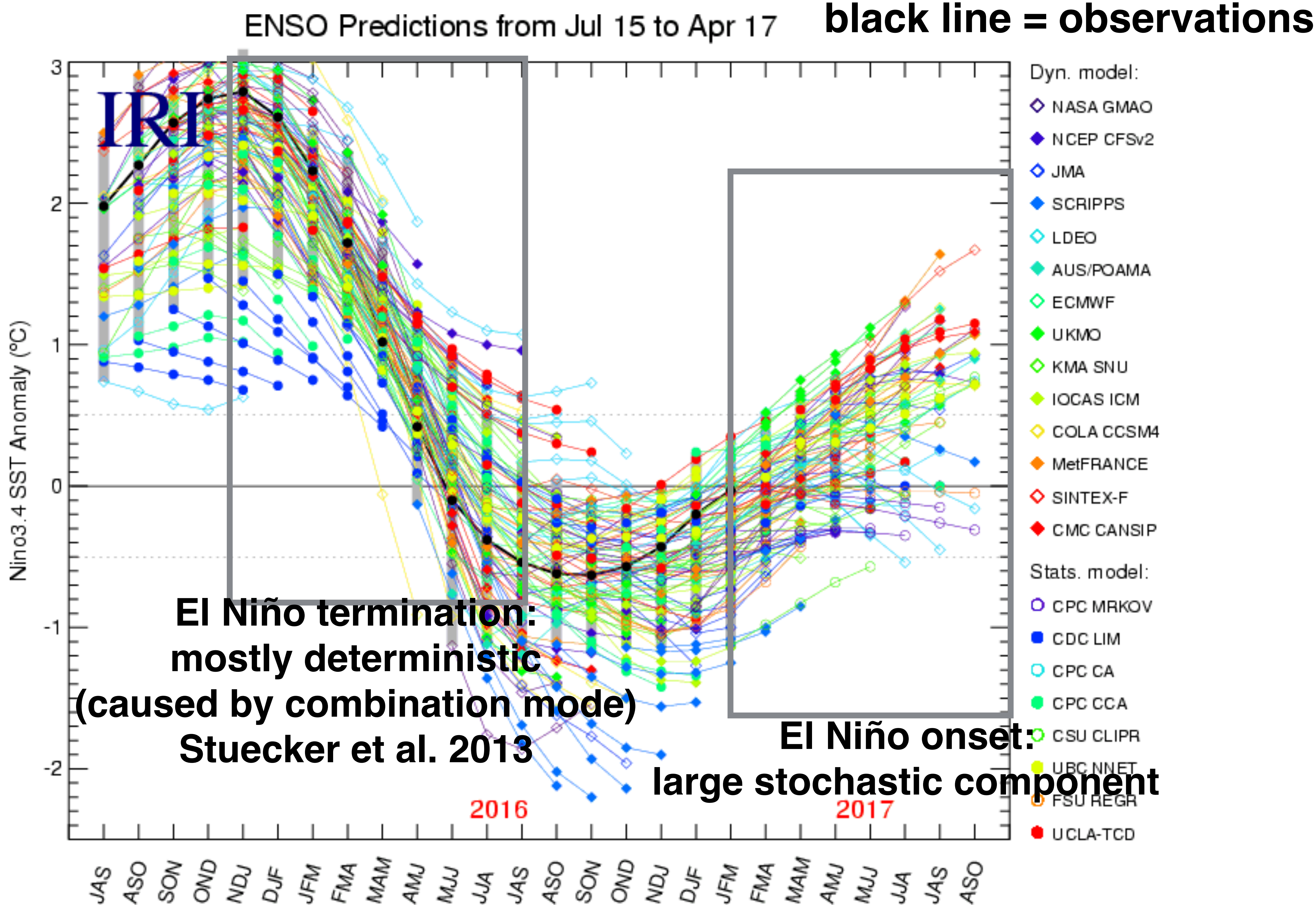
Stuecker et al. 2017, GRL

ENSO and the Indian Ocean Dipole

Conclusions so far…

- a simple low-order model captures the observed ENSO/IOD relationship (time evolution, lead/lag correlations, and power spectrum)
- no ocean memory (besides ENSO) is required for the IOD
- the observed 2 month lead time of IOD with regard to ENSO can be explained by the different annual cycle phases of the coupled air/sea system in the Pacific and Indian Ocean respectively
- the observed 15 month lead time of IOD with regard to ENSO can be explained by ENSO forcing the IOD (El Niño forces a positive IOD, El Niño terminates, following La Niña forces a negative IOD)

ENSO predictability



IOD predictability

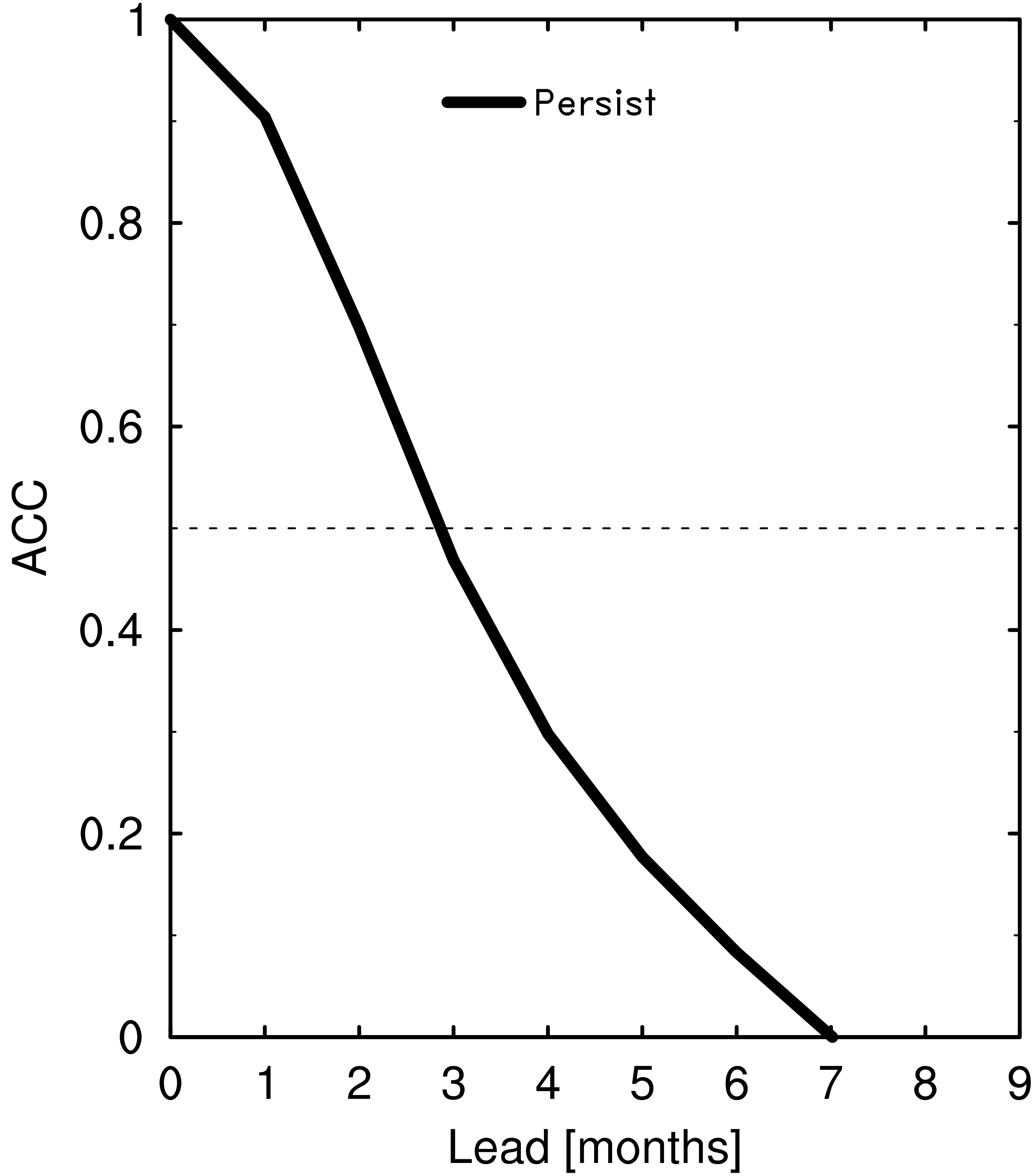
Q: How much of IOD predictability originates from ENSO predictability?

Stochastic-dynamical model (SDM):

$$\frac{dT}{dt} = \left[-\lambda_0 + \lambda_a \cos\left(\omega_a t + \varphi_l\right)\right] T(t) - \beta \mathrm{N3.4}(t) \cos\left(\omega_a t + \varphi_a\right) + \xi(t)$$

IOD predictability

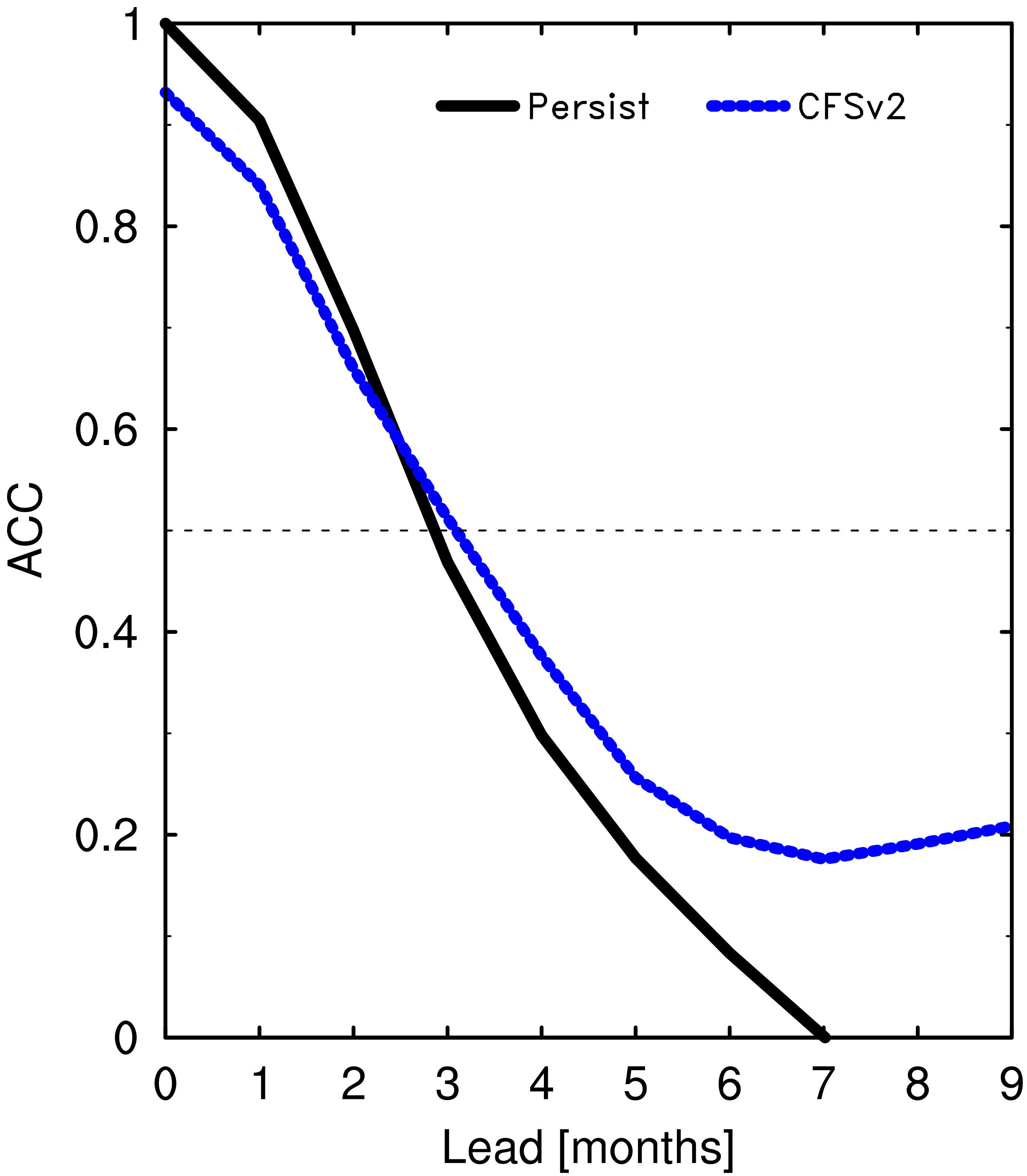
Anomaly correlation coefficient (ACC) skill of DMI prediction



Zhao et al. 2017,
In Review

IOD predictability

Anomaly correlation coefficient (ACC) skill of DMI prediction

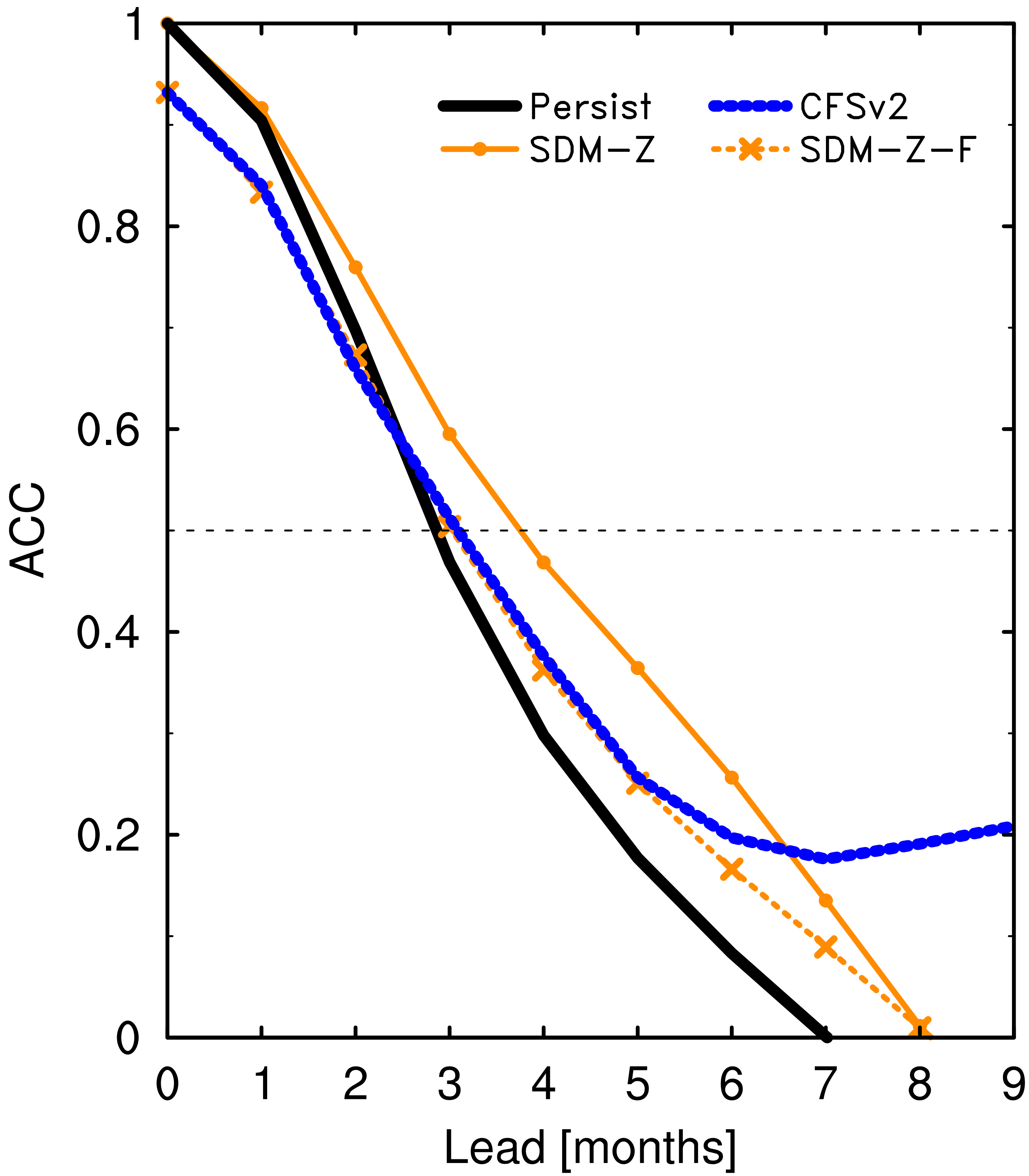


Operational dynamical forecasts only slightly better than persistence forecast (note the different initial conditions)

Zhao et al. 2017,
In Review

IOD predictability

Anomaly correlation coefficient (ACC) skill of DMI prediction



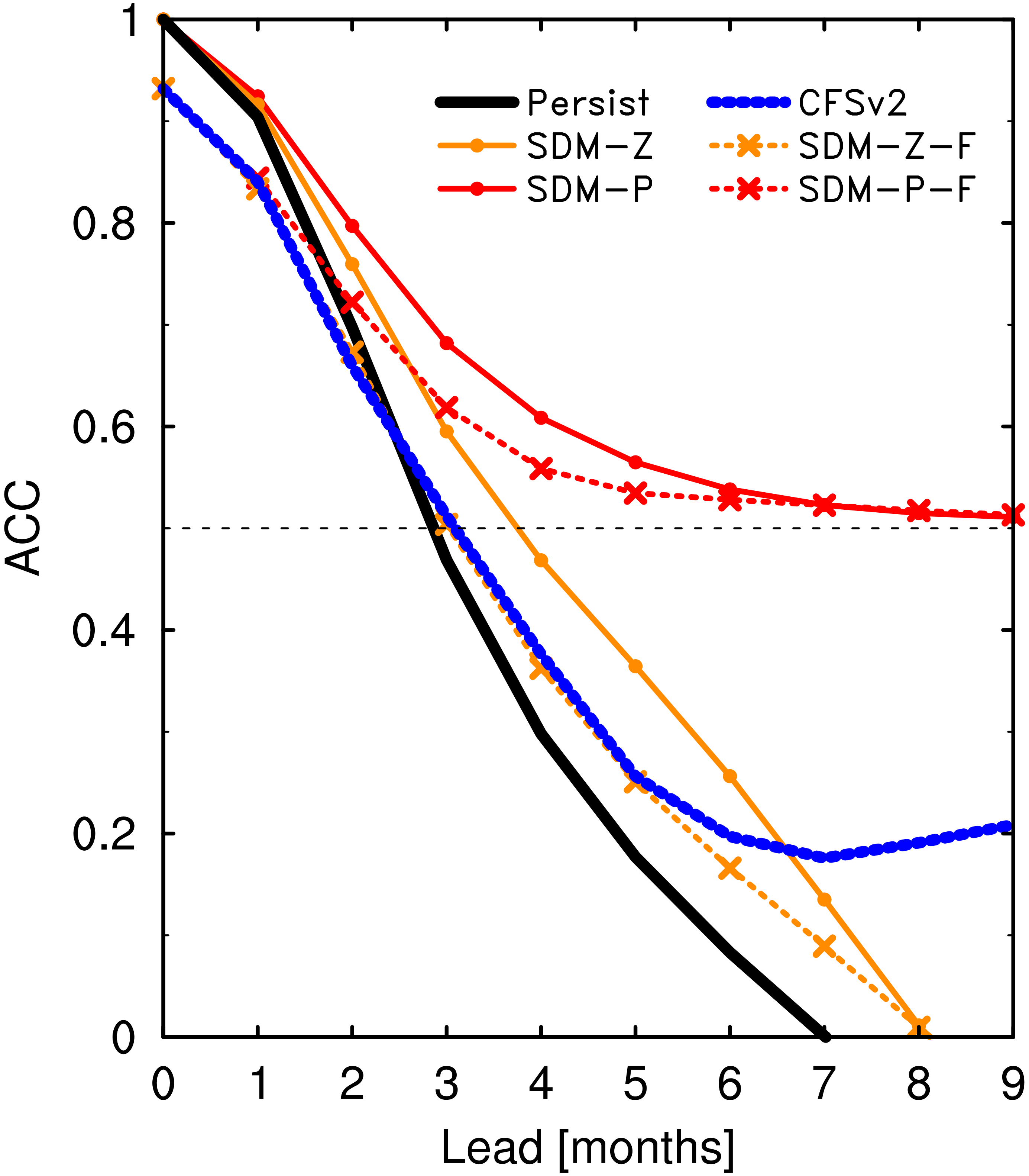
Operational dynamical forecasts only slightly better than persistence forecast (note the different initial conditions)

SDM-Z: Stochastic-Dynamical model with **zero (Z) ENSO** information with observed and CFSv2 initial conditions

Zhao et al. 2017,
In Review

IOD predictability

Anomaly correlation coefficient (ACC) skill of DMI prediction



Operational dynamical forecasts only slightly better than persistence forecast (note the different initial conditions)

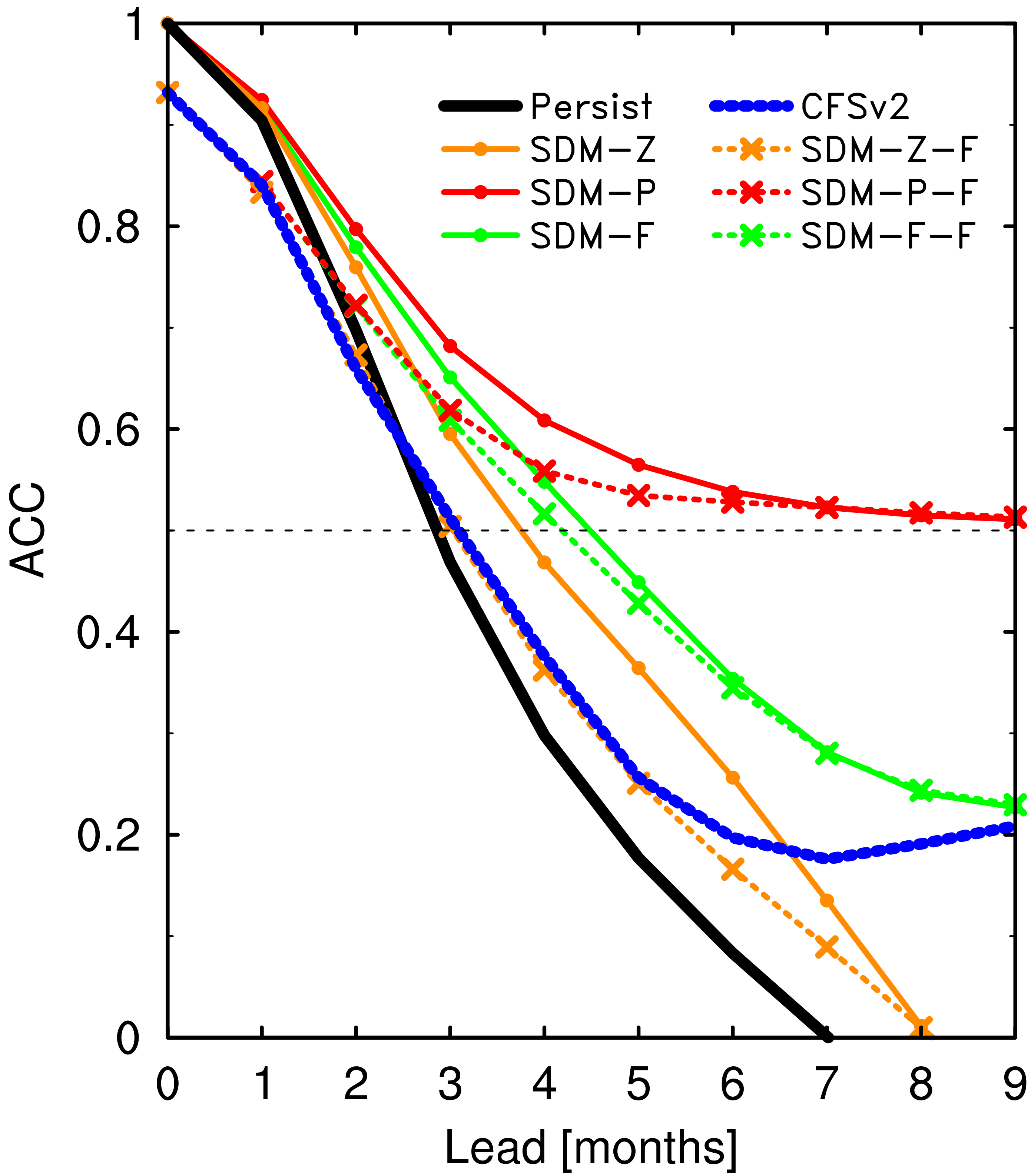
SDM-Z: Stochastic-Dynamical model with **zero (Z) ENSO** information with observed and CFSv2 initial conditions

SDM-P: Stochastic-Dynamical model with **perfect (P) ENSO** information with observed and CFSv2 initial conditions

Zhao et al. 2017,
In Review

IOD predictability

Anomaly correlation coefficient (ACC) skill of DMI prediction



Operational dynamical forecasts only slightly better than persistence forecast (note the different initial conditions)

SDM-Z: Stochastic-Dynamical model with **zero (Z) ENSO** information with observed and CFSv2 initial conditions

SDM-P: Stochastic-Dynamical model with **perfect (P) ENSO** information with observed and CFSv2 initial conditions

SDM-F: Stochastic-Dynamical model with **CFSv2 forecasted (F) ENSO** information with observed and CFSv2 initial conditions

Zhao et al. 2017,
In Review

IOD predictability

Q: How much of IOD predictability originates from ENSO predictability?

A: Pretty much all of it

ENSO and the Indian Ocean Dipole

Implications

- IOD predictability is determined by (i) ENSO predictability and (ii) the signal-to-noise ration of the system
- our simple ENSO-forced IOD model has better skill in predicting IOD events compared to operational IOD forecast systems (full dynamical GCMs)

$$\frac{dT}{dt} = \left[-\lambda_0 + \lambda_a \cos\left(\omega_a t + \varphi_I\right)\right] T(t) - \beta \mathrm{N3.4}(t) \cos\left(\omega_a t + \varphi_a\right) + \xi(t)$$

- CFSv2 has some skill in predicting ENSO, but no skill in predicting IOD
- CFSv2 ENSO prediction skill can be translated to IOD prediction skill via our simple SDM

Summary

- Combination mode framework is a powerful tool to study interactions between modes of climate variability, specifically seasonally modulated climate phenomena
- ENSO controls many regions of the world, however coupled local processes might need to be taken into account to see ENSO's local climate manifestations (e.g., IOD, East Asian Monsoon)
- Seasonal climate predictions should improve significantly (even in remote regions beyond the tropical Pacific) once ENSO and annual cycle biases are reduced in climate models

Questions?

paper references:
www.maltestuecker.com