Improved Predictability of the Indian Ocean Dipole Using Seasonally Modulated ENSO Forcing

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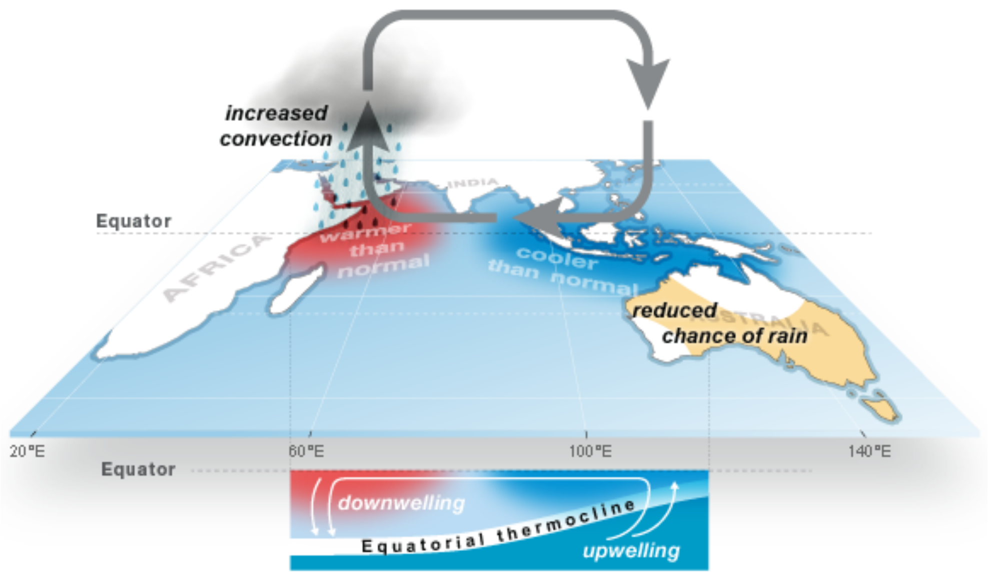
AOGS 06/05/2018

Introduction

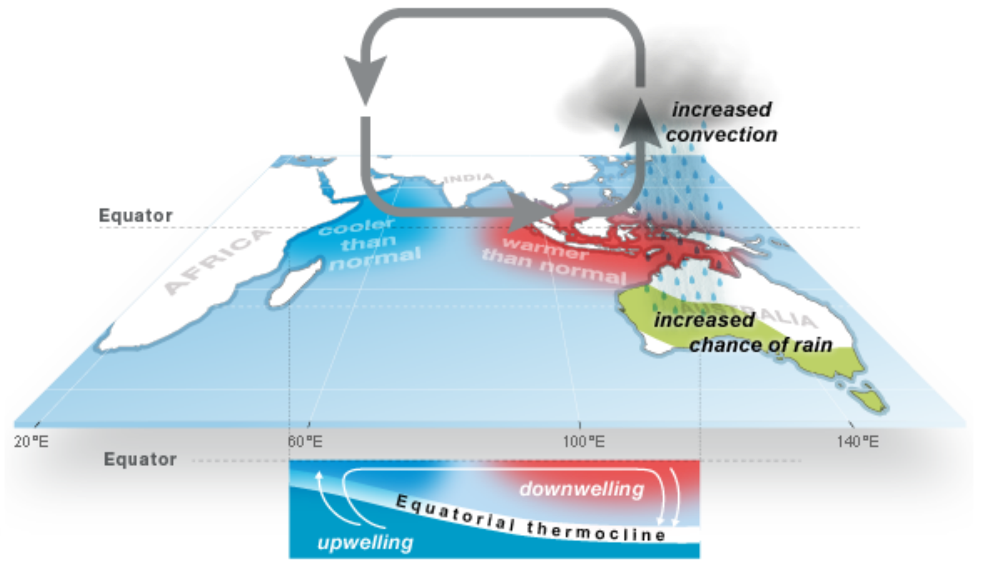
Indian Ocean Dipole (IOD)

- **Discovered in the late 20th century**
  (Saji et al. 1999; Webster et al. 1999)
- **A coupled ocean-atmosphere mode**
- **Develop in boreal summer, peak during autumn (SON), decay rapidly in winter**
- **Broad impacts on global climate**
  (Saji and Yamagata 2003; Guan and Yamagata 2003; Liu et al. 2007; Chan et al. 2008; Yuan et al. 2008; Cai et al. 2011; Cai et al. 2014; Luo et al. 2015)

Positive phase



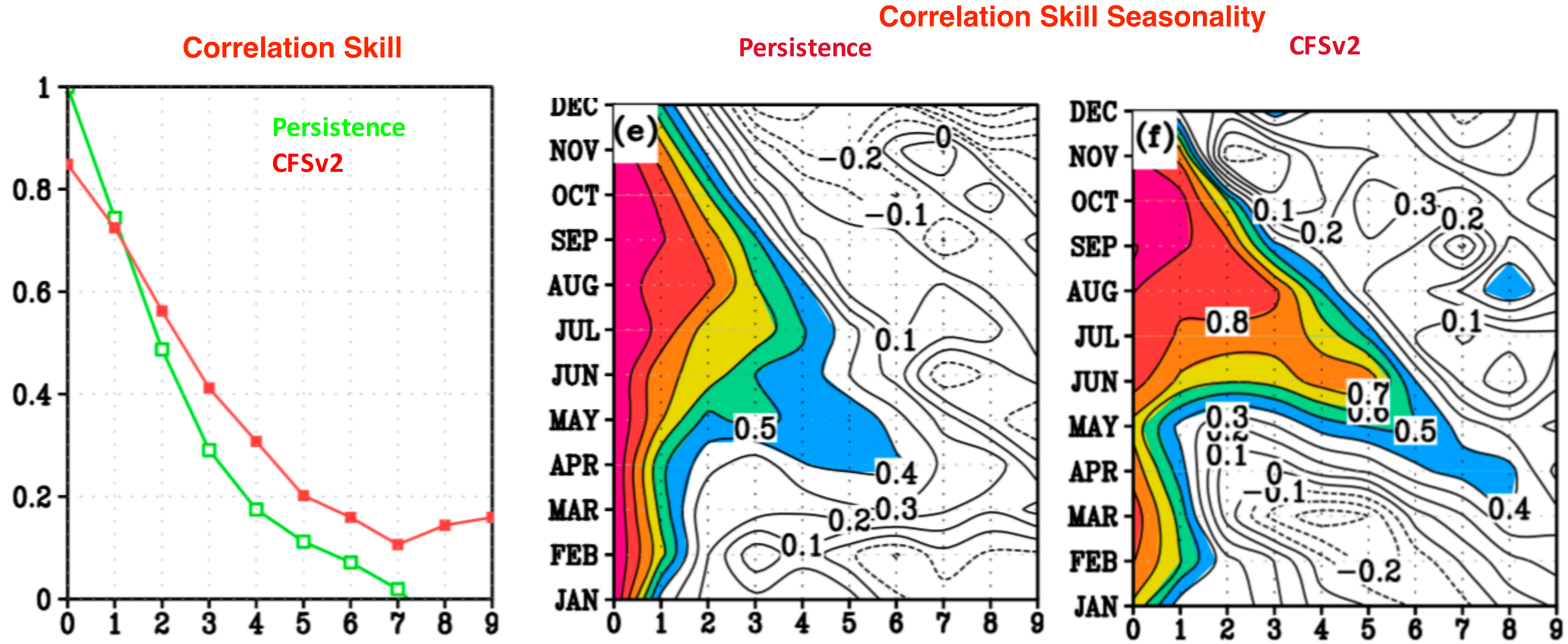
Negative phase



Images from [Bureau of Meteorology]

IOD Predictability

- **Only lead time of one season in current operational models** *(Shi et al. 2012; Liu et al. 2017)*
- **A strong winter-spring predictability barrier** *(Wajsowicz 2007; Wang et al. 2009; Feng et al. 2014)*



(Zhu et al. 2015)

CFSv2 did not have significantly better skill in predicting IOD than persistence

- **IOD events that co-occur with ENSO events appear to be more predictable** *(Song et al. 2008; Zhao and Hendon 2009)*

IOD -ENSO relationship is important in IOD prediction.

Debate on IOD-ENSO Relationship

- **IOD is an intrinsic climate mode largely independent from ENSO** *(Saji et al. 1999; Webster et al. 1999; Behera et al. 2006)*
- **IOD may trigger or modulate ENSO events** *(Izumo et al. 2010; Luo et al. 2010; Behera and Yamagata 2003)*
- **IOD events can be externally initiated by ENSO** *(Annamalai et al., 2003; Yang et al., 2015; Zhang et al., 2015; Kajtar et al., 2017)*

- **Only about one-third of IOD events occur independently of ENSO events** *(Loschnigg et al., 2003; Stuecker et al., 2017)*
- **IOD still exists without ENSO, but with weak amplitude and reduced Bjerknes feedback** *(Crétat et al. 2017)*

IOD Predictability Sources/Drivers?

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IOD predictability

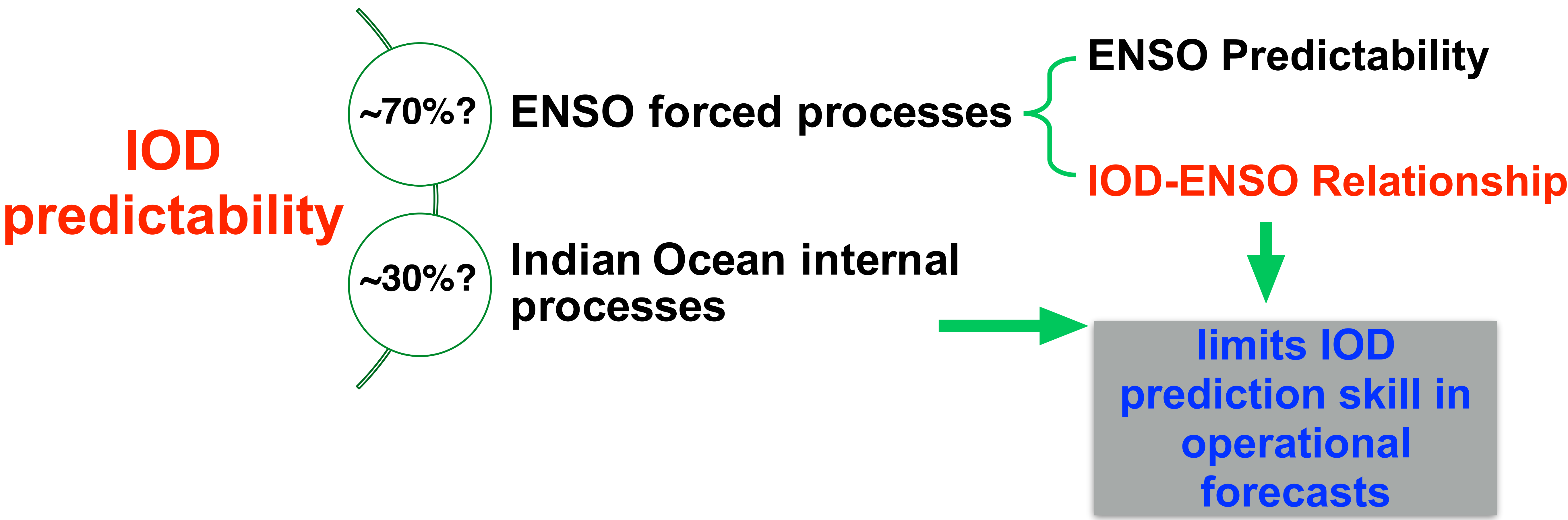
- **~70%?** ENSO forced processes
- **~30%?** Indian Ocean internal processes

IOD Predictability Sources/Drivers?

IOD predictability

- ~70%? **ENSO forced processes**
  - ENSO Predictability
  - IOD-ENSO Relationship
- ~30%? **Indian Ocean internal processes**

IOD Predictability Sources/Drivers?



Stochastic-Dynamical Model (SDM) for IOD Index

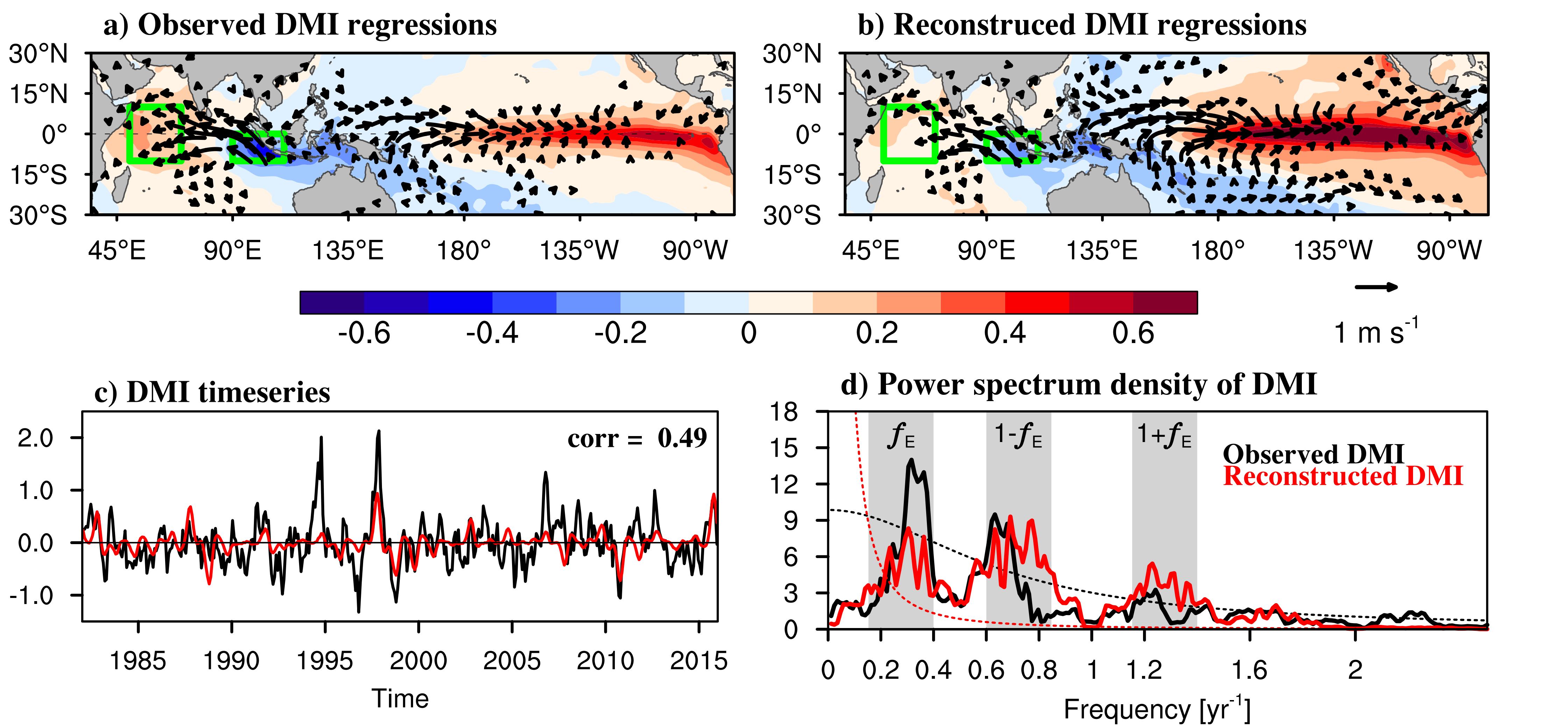
$$\frac{dT}{dt} = \left[-\lambda_0 + \lambda_a \cos\varpi_a t\right]\cdot T + \boxed{\left[\alpha_0 + \alpha_a \cos\varpi_a t\right]\cdot \mathrm{N3.4}(t)} + \xi(t)$$

Seasonally modulated damping ✚ **ENSO C-mode forcing + stochastic forcing**

(Stuecker et al., 2017; Zhao et al. 2018)

- **Net effect of coupled air-sea Indian Ocean feedbacks**
  - positive Bjerknes feedback (Annamalai et al. 2003; Saji et al. 2006; Hong et al. 2008; Zhang et al. 2015)
  - negative SST-cloud-radiation feedback (Li et al. 2003; Cai and Qiu 2013; Ng et al. 2014)
- **Stochastic forcing** is neglected and the IOD is treated as a purely deterministic process

IOD Observation & Reconstruction (1982-2015)



- The SSTA and 10 m wind regression patterns exhibit similar spatial structures between observation and reconstruction.
- IOD C-mode* reconstruction well captures the observed monthly DMI for the period 1982-2015.

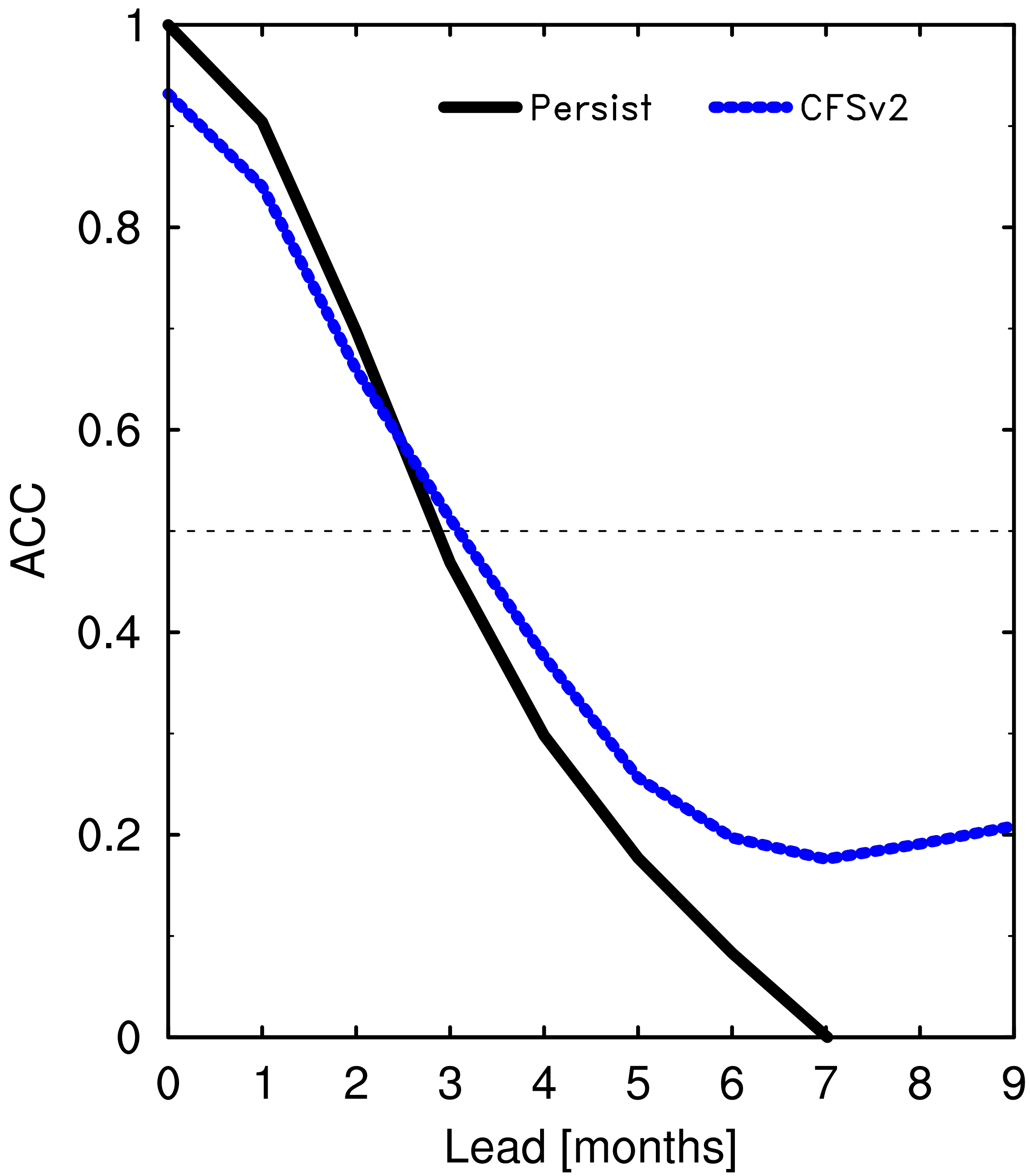
SDM Hindcast experiments

Table S1. Lists of hindcasts experiments with the SDM.

Experiment Name	ENSO forcing	Initial DMI condition
SDM-Z	Zero	Perfect
SDM-P	Perfect ENSO	Perfect
SDM-F	Forecast ENSO	Perfect
SDM-Z-F	Zero	Forecast
SDM-P-F	Perfect ENSO	Forecast
SDM-F-F	Forecast ENSO	Forecast

- **Perfect forcing / DMI condition were derived from observations (OISST v2)**
- **Forecast forcing / DMI condition were derived from CFSv2 ensemble mean forecasts**
- **SDM-P is a measure of the upper IOD predictability limit provided by ENSO**
- **SDM-F-F can be used in an operation forecast setting**

Anomaly correlation coefficient (ACC) skill of DMI prediction



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

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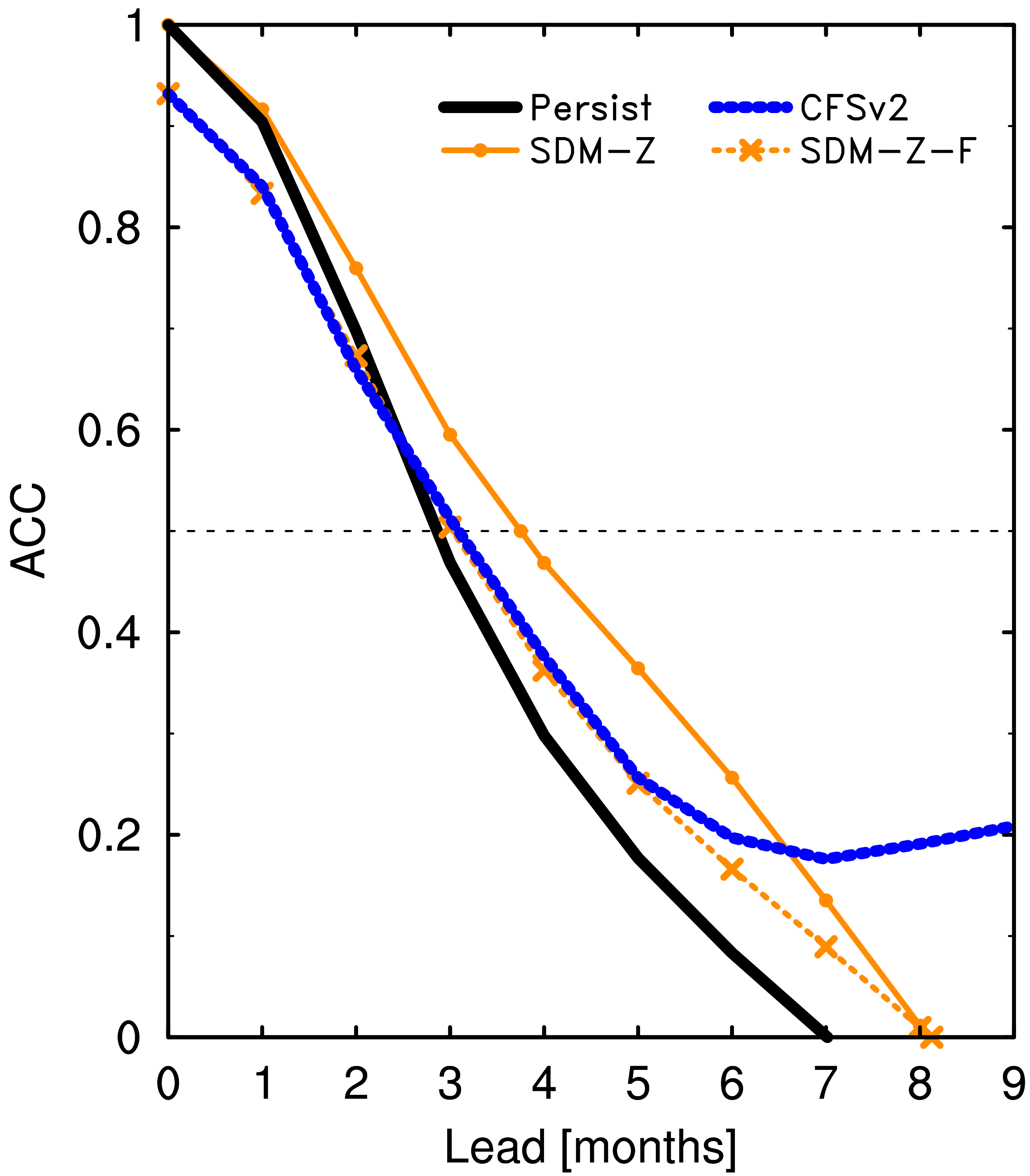

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- **SDM-Z**: Stochastic-Dynamical model with **zero (Z) ENSO** information with observed and CFSv2 initial conditions

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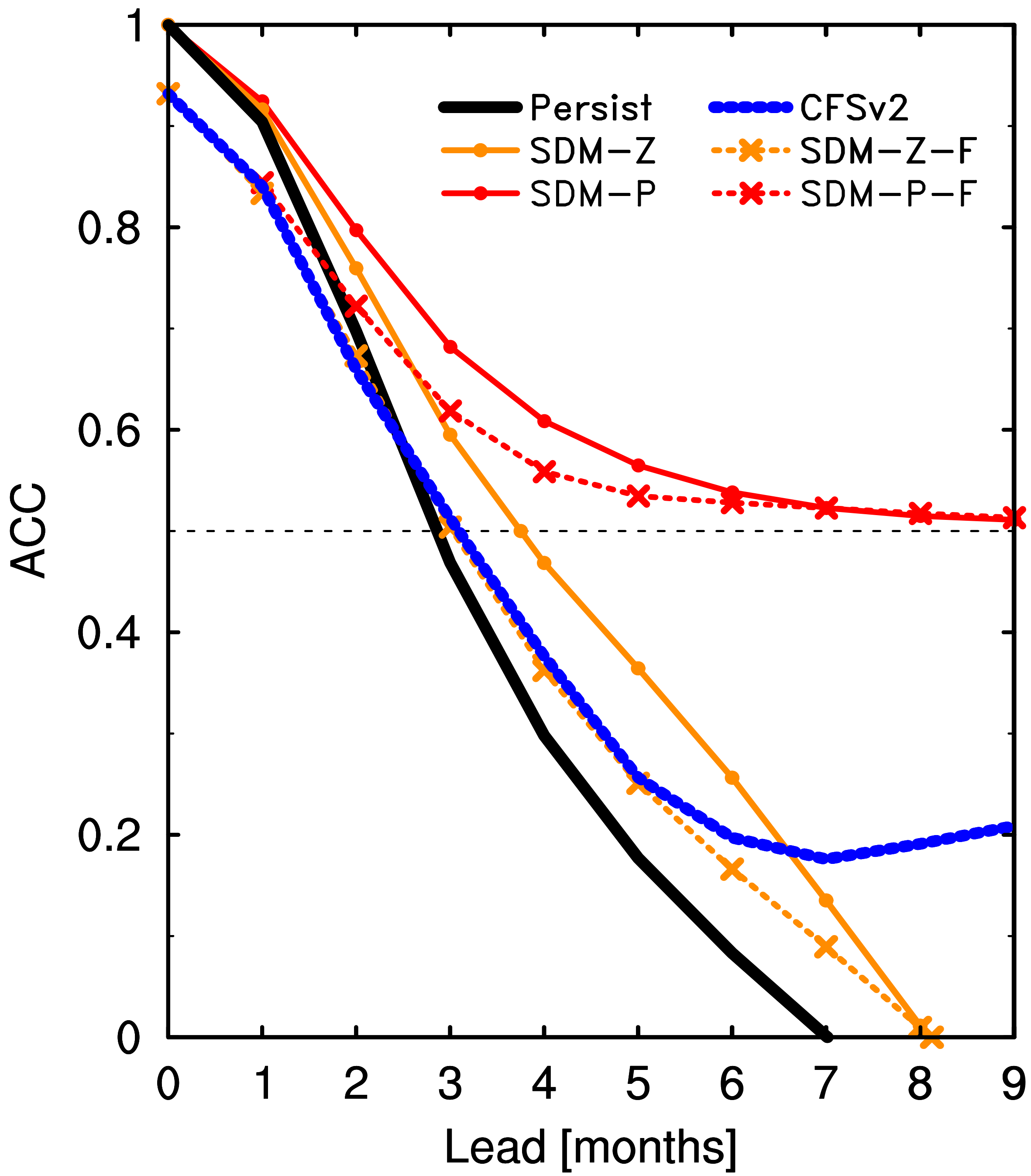

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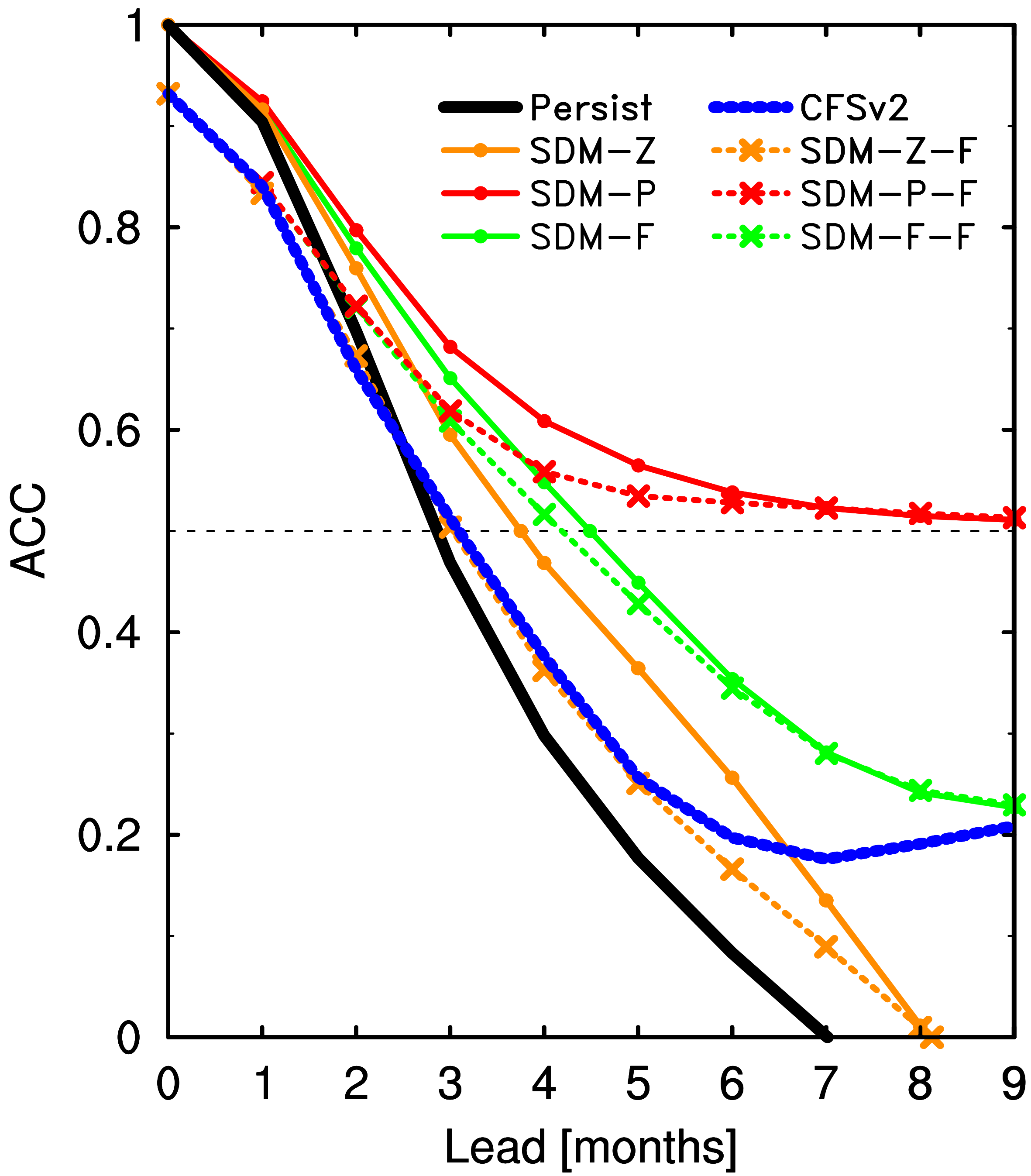

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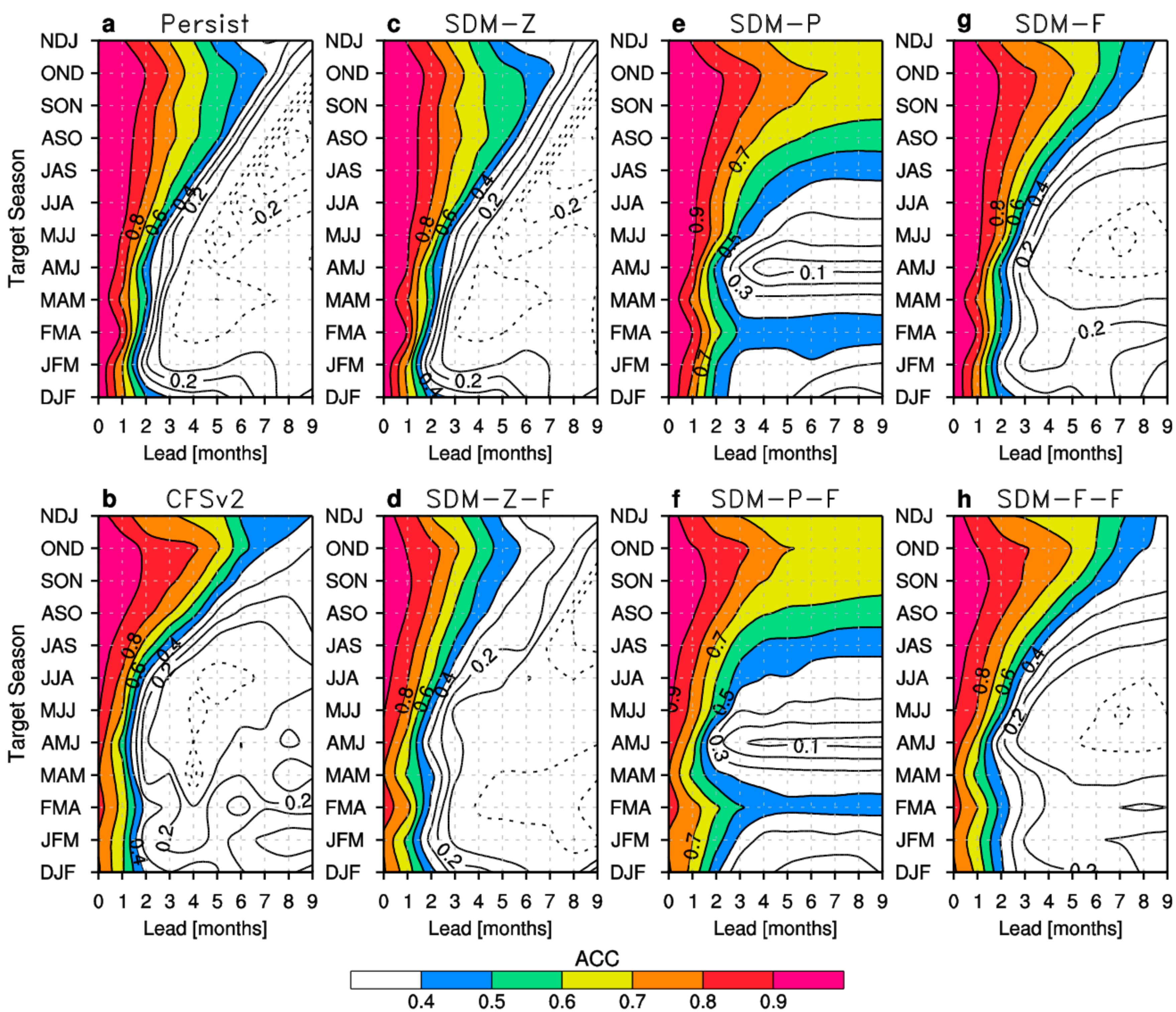
- **SDM-P**: Stochastic-Dynamical model with **Perfect (P) ENSO** information with observed and CFSv2 initial conditions
- **SDM-F**: Stochastic-Dynamical model with **CFSv2 forecasted (F) ENSO** information with observed and CFSv2 initial conditions

Seasonality of DMI forecast skill (1982-2015)

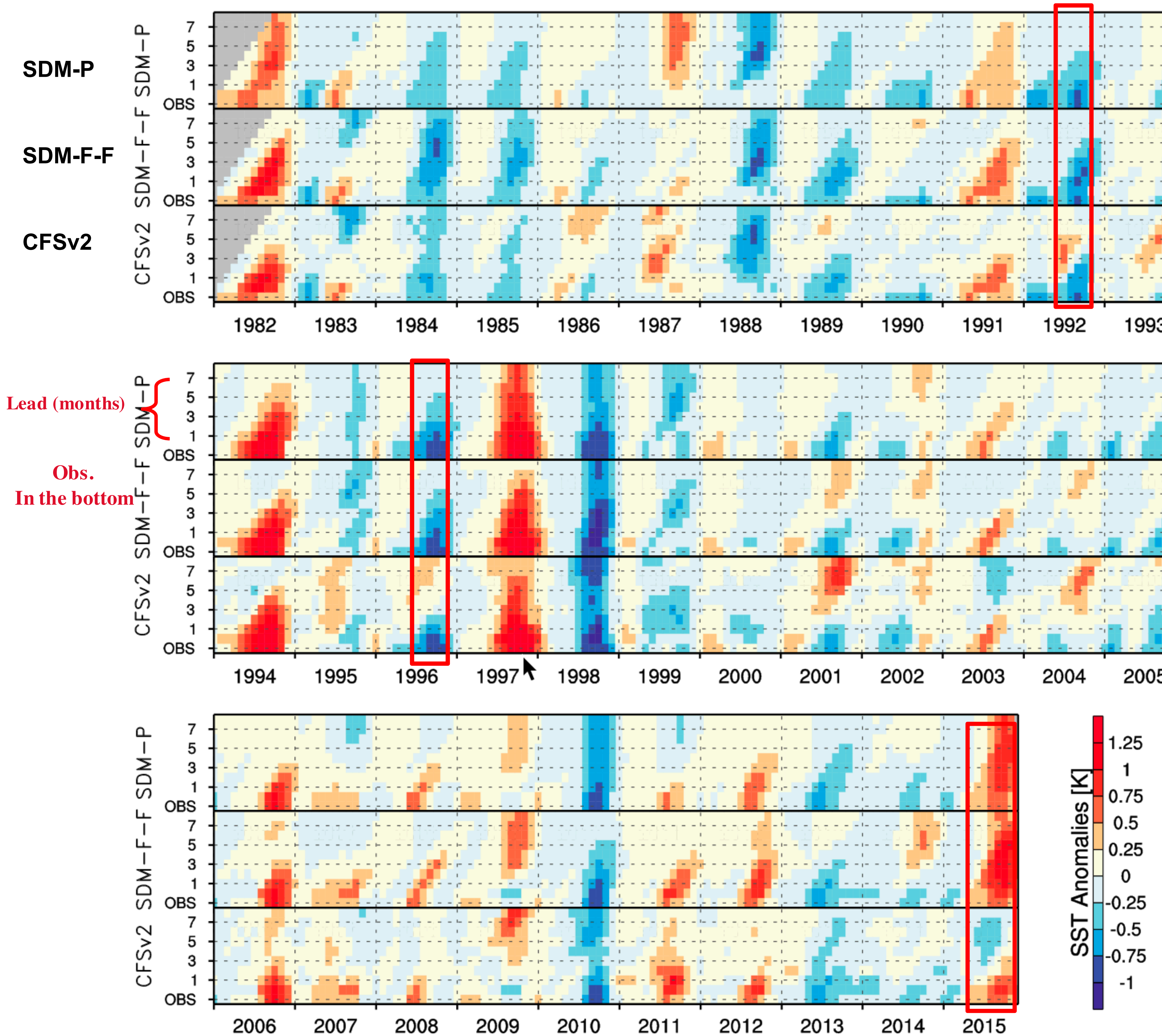


DMI Prediction Skill at SON From June Initialization

Table S2. ACCs and NRMSEs for the DMI at SON between observation and model predictions (persistence, CFSv2 and SDM-F-F) from the June initialization for the period of 1982-2015. The SINTEX ACCs and NRMSEs in last three rows were adopted from Table 2 and 3, respectively, in Doi et al. [2017] for the period of 1983-2015.

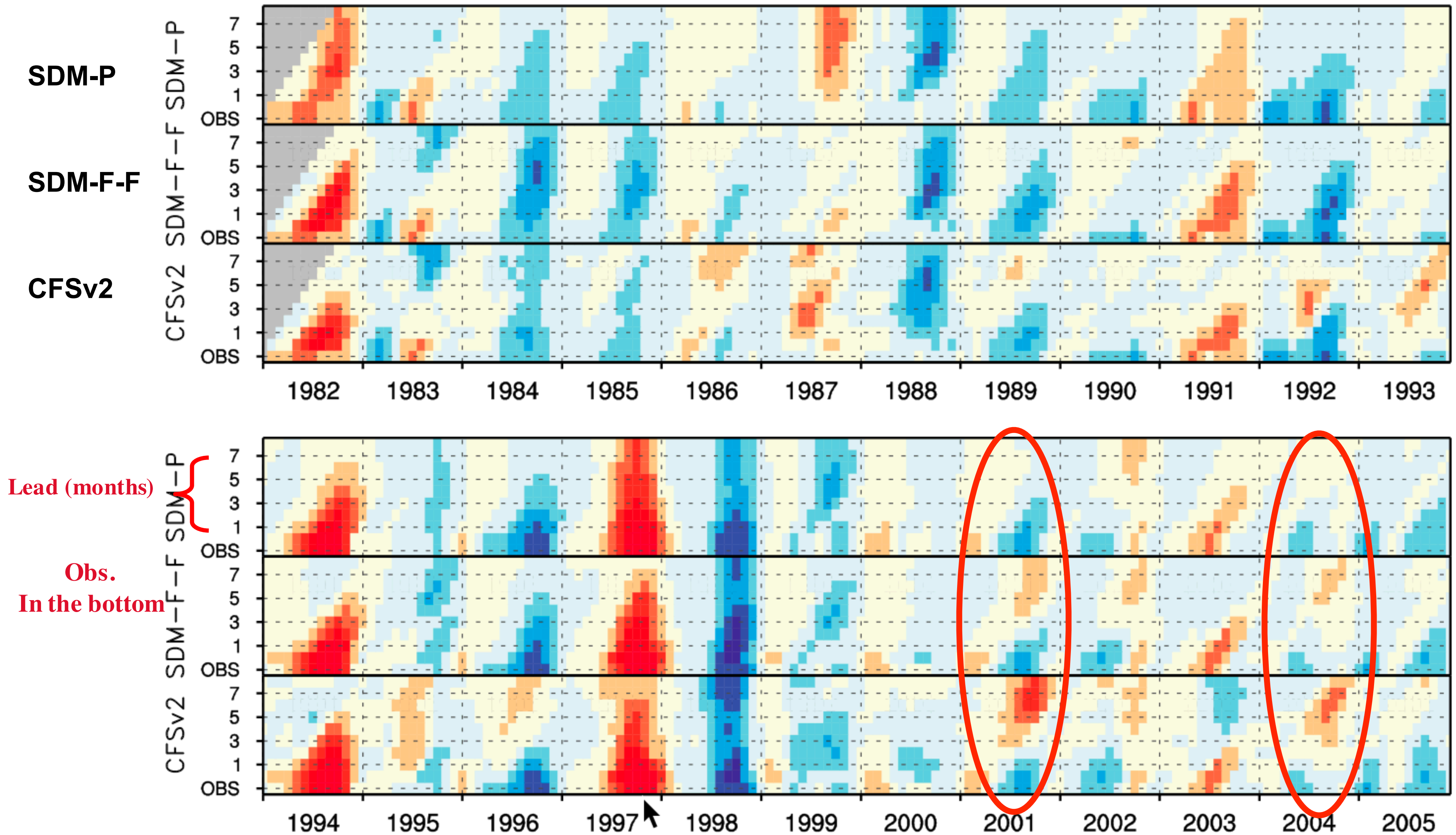
Experiment Name	ACC	NRMSE
Persistence forecast	0.46	0.89
CFSv2	0.74	0.68
SDM-F-F	0.72	0.71
SINTEX-F1	0.47	1.03
SINTEX-F2	0.34	1.31
SINTEX-F2-3DVAR	0.53	0.97

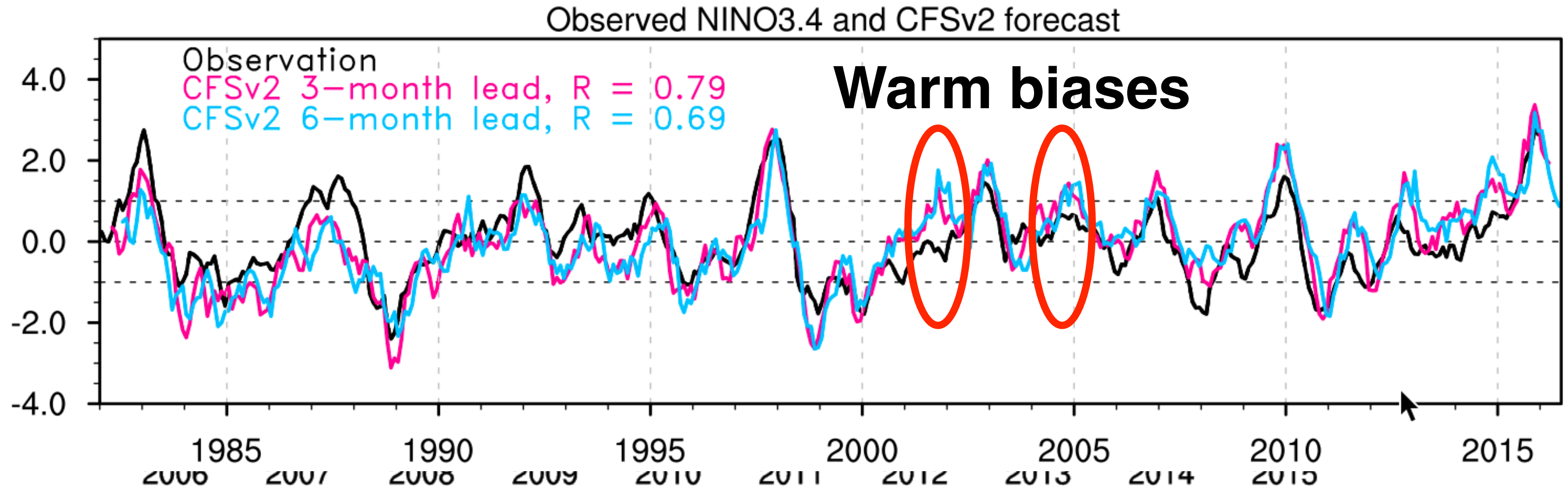
Individual IOD Events: DMI Seasonal Mean Forecast



SDM demonstrably better forecast skill than CFSv2: 1992, 1996, 2015.

Individual IOD Events: DMI Seasonal Mean Forecast





False alarms in CFSv2 for positive IOD events (2001, 2004)

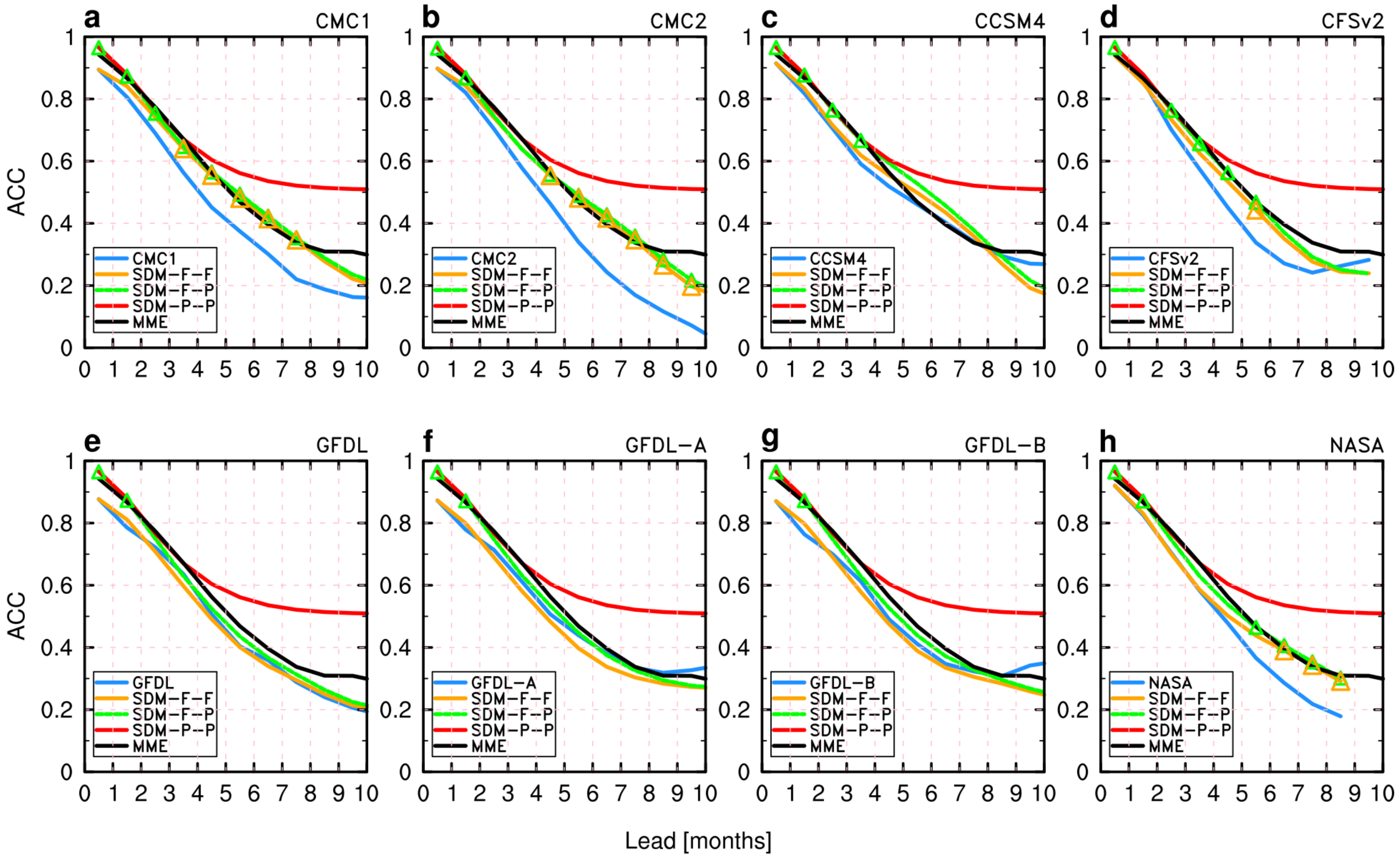
may related to warm biases of the predicted ENSO

Compared With NMME Operational Models

Table 1. Basic information for the eight NMME climate models.

Model	Name used here	Available Period	Ensemble size	Lead times (months)
CMC1-CanCM3	CMC1	January 1981–December 2017	10	0.5–11.5
CMC2-CanCM4	CMC2	January 1981–December 2017	10	0.5–11.5
COLA-RSMAS-CCSM4	CCSM4	January 1982–December 2017	10	0.5–11.5
NCEP-CFSv2	CFSv2	January 1982–December 2017	24	0.5–9.5
GFDL-CM2p1-aer04	GFDL	January 1982–December 2017	10	0.5–11.5
GFDL-CM2p5-FLOR-A06	GFDL-A	March 1980–December 2017	12	0.5–11.5
GFDL-CM2p5-FLOR-B01	GFDL-B	March 1980–December 2017	12	0.5–11.5
NASA-GMAO-062012	NASA	January 1981–December 2017	12	0.5–8.5

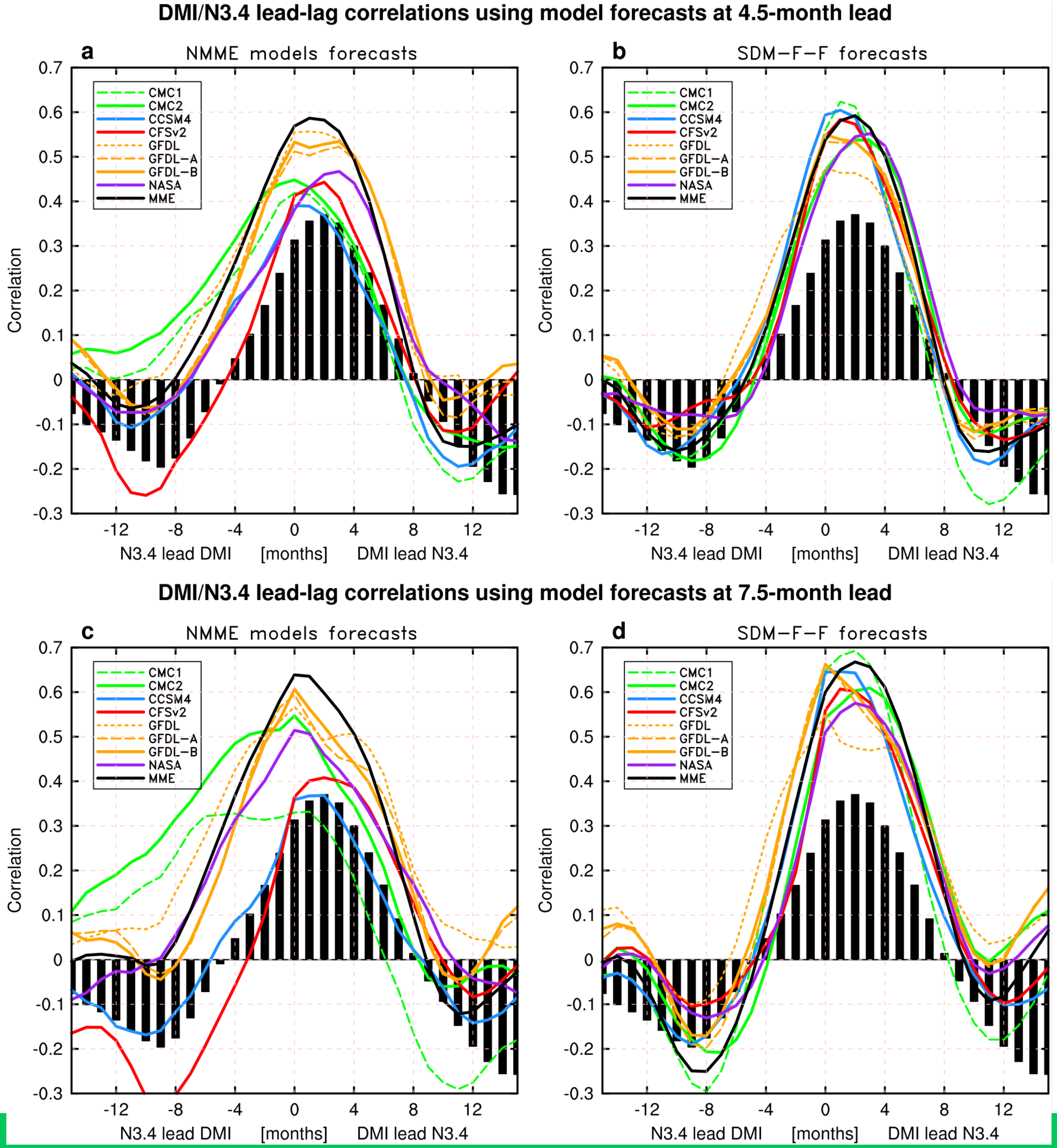
Anomaly correlation coefficient (ACC) skill of DMI prediction for NMME models and SDM



Failure Representation of IOD-ENSO Relationship

4-months lead

7-months lead



Summary and Implications

- **The stochastic-dynamical model using seasonally modulated ENSO forcing has higher skill in predicting the IOD than CFSv2 and SINTEX**

- **Operational IOD predictability beyond persistence is mostly controlled by ENSO predictability and the signal-to-noise ratio of the system**

- **Potential future ENSO improvements in GCMs could directly translate to more skillful IOD predictions using the stochastic-dynamical model**

- Stuecker, M. F., A. Timmermann, F.-F. Jin, Y. Chikamoto, W. Zhang, A. T. Wittenberg, E. Widiasih, and **Sen Zhao** (2017), Revisiting ENSO/Indian Ocean Dipole phase relationships, Geophys. Res. Lett., 44(5), 2481–2492, doi:10.1002/2016GL072308
- **Zhao, S.**, F.-F. Jin, and M. F. Stuecker (2018), Improved predictability of the Indian Ocean Dipole using seasonally modulated ENSO forcing, Geophys. Res. Lett., in second round of review

Thank You For Your Attention!

Future Work

Clim Dyn (2014) 42:1569–1586
DOI 10.1007/s00382-013-1765-1

Indian Ocean dipole interpreted in terms of recharge oscillator theory

Michael J. McPhaden · Motoki Nagura

IOD predictability

~70%? ENSO forced processes
- ENSO Predictability
- IOD-ENSO Relationship

SDM

~30%? Indian Ocean internal processes

not included in present SDM

Differences With Dommenget and Jansen (2009)

$$T_i(t+1) = r_T T_i(t) + r_{Tp} T_p(t), \qquad (1)$$

$$T_p^f(t_0+l) = a_{Tp}^l T_p(t_0+l) + \sqrt{1-a_{Tp}^{2l}}\,\xi(t_0), \qquad (2)$$

The SDM is different from the regression models developed in previous studies [Dommenget and Jansen, 2009; Shi et al., 2012], as the crucial parameters in the SDM were determined based on the physical processes that control the net coupled air-sea feedbacks [e.g., Annamalai et al., 2003; Li et al., 2003; Stuecker et al., 2017].