The South Pacific Meridional Mode and Its Role in Tropical Pacific Climate Variability

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INTRODUCTION

- The El Niño-Southern Oscillation (ENSO) phenomenon is a key player in seasonal-to-decadal Pacific climate variability.
- Precursor patterns to ENSO events like the **North Pacific Meridional Mode (NPMM)**, a coupled mode of variability which links extratropical Pacific climate variability to the tropical Pacific, have been explored for enhanced predictability [e.g., *Chiang and Vimont* 2004; *Alexander et al.* 2010]. However**,** the NPMM alone has little skill in predicting ENSO and its flavors [e.g., *Larson and Kirtman* 2014, 2015].
- ***What about the South Pacific?*** Recent studies point to the South Pacific atmospheric and oceanic variability as key determinants for explaining a portion of tropical Pacific climate variability, including the **South Pacific Meridional Model (SPMM)** [e.g., *Zhang et al.* 2014; *Ding et al.* 2015; *Min et al.* 2017]. But, the mechanics of the SPMM and how it interacts with the NPMM and the tropical Pacific on seasonal-to-longer timescales remain to be quantified, both in observations and in coupled climate models.

RESEARCH OBJECTIVES

- Explore potential enhancements to ENSO prediction by incorporating South Pacific extratropical climate variability into our Pacific interannual-to-decadal climate framework.
- Provide a benchmark by which to test coupled climate models in simulating Pacific multi-scale variability.

DATA AND METHODS

- ***Atmospheric and Oceanic Reanalyses:*** Monthly-mean NCEP-NCAR reanalysis (SLP/10-m winds), Hadley Centre SST, and ECMWF ORA-S4 (subsurface fields). **Period:** 1948 – 2016. Robust results when using ERA-20C and ERA-interim.
- ***Methods:*** Linear regression, EOF analysis, and maximum covariance analysis (MCA).
- **Definition of the SPMM:** Leading MCA mode of SST and 10-m wind anomalies (after linearly removing the *Cold Tongue Index*) in the region 35°S-10°S, 180°-70°W. Corresponding time series are the $\mathbf{EC\text{-}1_{SST}}$ and $\mathbf{EC\text{-}1_{Wind}}$ indices.

The SPMM – STRUCTURE AND SEASONALITY

South Pacific Oscillation (SPO)
[*You and Furtado*, 2017]

REANALYSIS

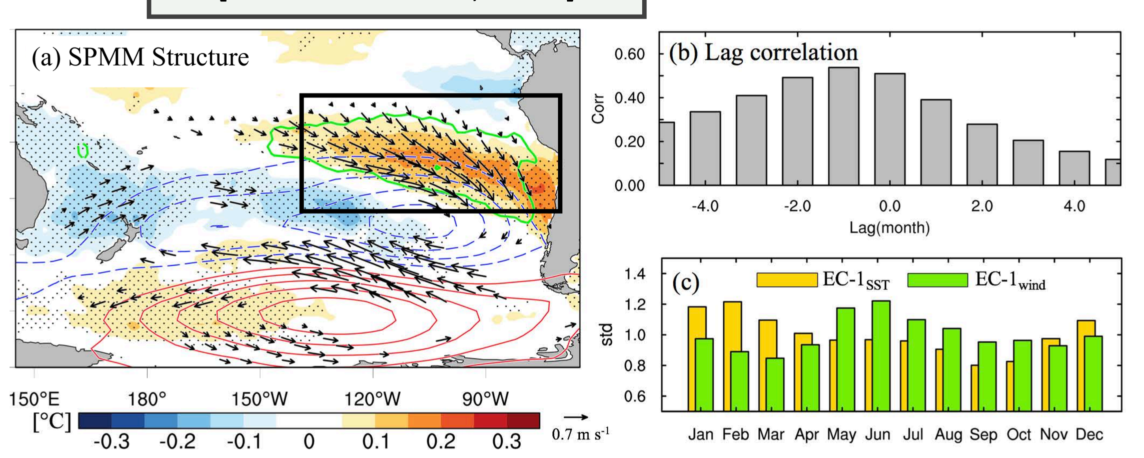


FIG. 1. (a) Regression of monthly-mean SSTA (shading, °C), SLPA (blue/red contours, hPa), 10-m wind anomalies (vector, m/s) and net surface latent heat flux (LHF) anomalies (green contours, W/m²) onto the standardized monthly-mean SPMM index. Contour intervals 0.4 hPa and 5 W/m². Stippled areas indicate significance of SSTA (p < 0.05). (b) Lag correlation between $EC\text{-}1_{wind}$ and $EC\text{-}1_{SST}$ indices. Negative (positive) lags indicate that $EC\text{-}1_{wind}$ leads (lags) $EC\text{-}1_{SST}$. (c) Monthly standard deviation of the $EC\text{-}1_{wind}$ (green) and $EC\text{-}1_{SST}$ (yellow) indices.

MONTH-BY-MONTH CORRELATION (EC_{SST},EC_{WIND})

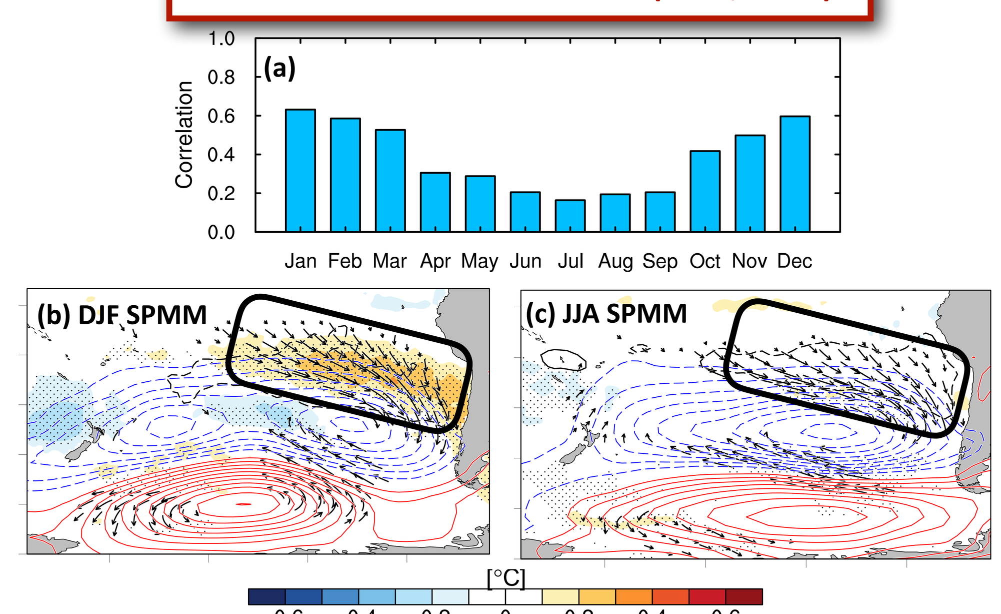


FIG. 2. (a) Month-to-month correlation between the $EC\text{-}1_{wind}$ and $EC\text{-}1_{SST}$ indices from reanalysis; i.e., a measure of the air-sea coupling strength of the SPMM. **(b)** As in Fig. 1a, except for December-February (DJF). Line contour interval 0.4 hPa (blue/red contours) and 5 W/m² (green contours). **(c)** As in **(b)** but for June – August (JJA).

The SPMM AND ENSO EVENTS

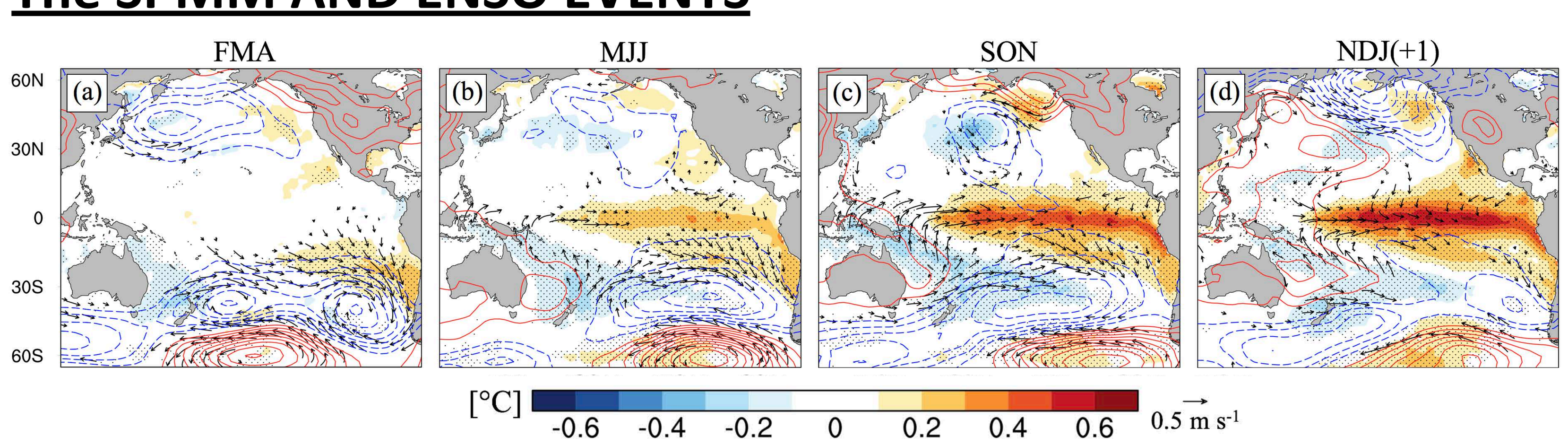


FIG. 3. Lag-regression of **(a)** February-April (FMA), **(b)** May-July (MJJ), **(c)** August-October (ASO), and **(d)** November-January (NDJ(+1)) SSTA (shading, °C), SLPA (line contour, hPa) and surface wind anomalies (vector, m/s) from reanalysis onto the $SPMM_{FMA}$ index. Line contour interval 0.2 hPa. Stippling indicates where the SSTA regression coefficients are considered significant (i.e., p < 0.05).

UNIFYING THE NPMM AND SPMM IN TROPICAL PACIFIC VARIABILITY

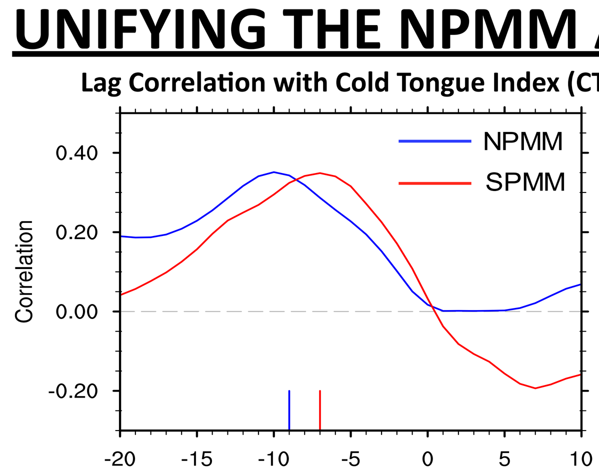


FIG. 4. Lag correlation of the monthly NPMM (blue) and SPMM (red) indices with the CTI. Positive (negative) lags indicate that the meridional mode leads (lags) the CTI.

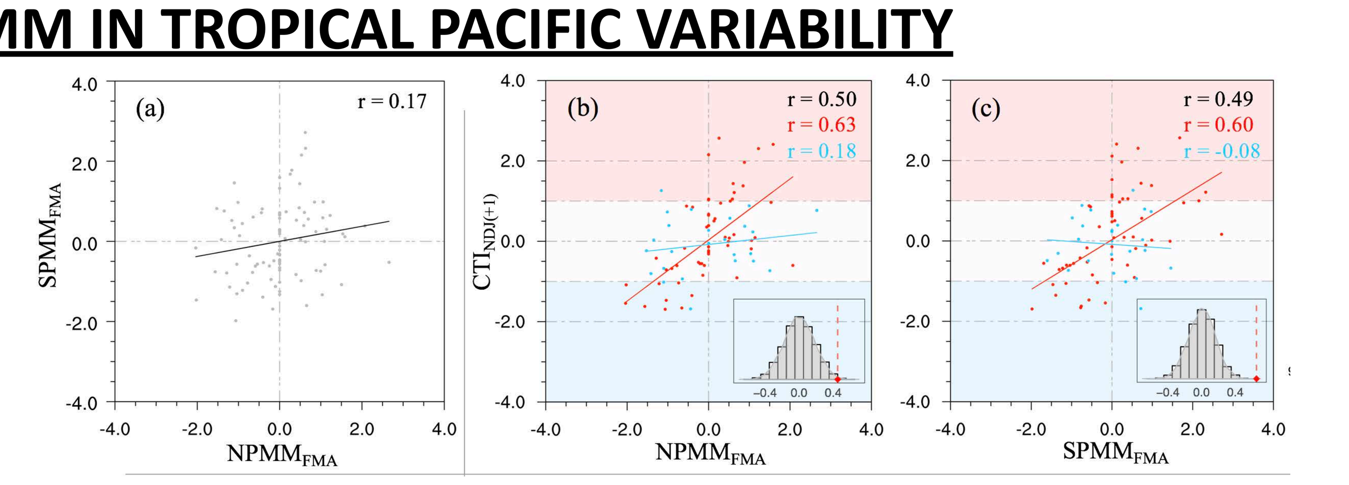
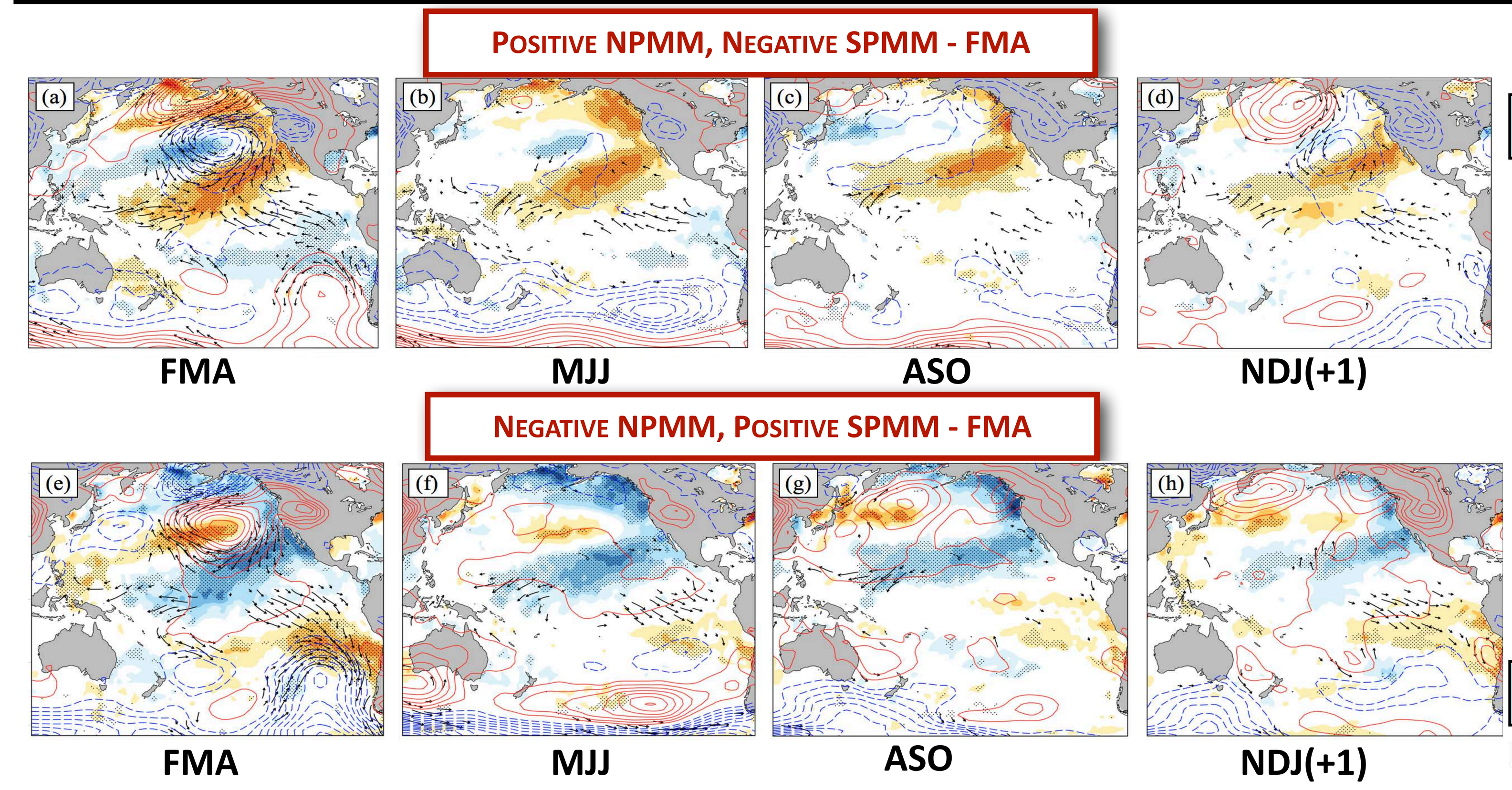


FIG. 5. (a) Scatterplot of the $NPMM_{FMA}$ vs. $SPMM_{FMA}$ indices from reanalysis. **(b)** Scatterplot of $NPMM_{FMA}$ vs $CTI_{NDJ(+1)}$ values from reanalysis. Red (blue) dots represent years when the $NPMM_{FMA}$ and $SPMM_{FMA}$ are of same (opposite) sign. Inset PDF denotes correlation differences (red - blue) from a Monte Carlo simulation. **(c)** As in **(b)** but for the $SPMM_{FMA}$ vs. $CTI_{NDJ(+1)}$ values.

WHAT HAPPENS WHEN THE NPMM AND SPMM ARE OUT OF PHASE?



Weak "Central Pacific" ENSO Event

FIG. 6. (a)-(d) Lag-regression of observed **(a)** FMA, **(b)** MJJ, **(c)** ASO, and **(d)** NDJ(+1) SST anomalies (shading, °C), SLP anomalies (line contours, hPa) and surface wind anomalies (vector, m/s) onto the standardized $NPMM_{FMA}$ index under the condition that the $NPMM_{FMA}$ and $SPMM_{FMA}$ indices are of opposite sign. **(e)-(h)** As in **(a)-(d)** but regressed onto the standardized $SPMM_{FMA}$ index. Line contour interval 0.2 hPa. Stippling indicates where the SST regression coefficients are considered significant (p < 0.05).

Weak "Eastern Pacific" ENSO Event

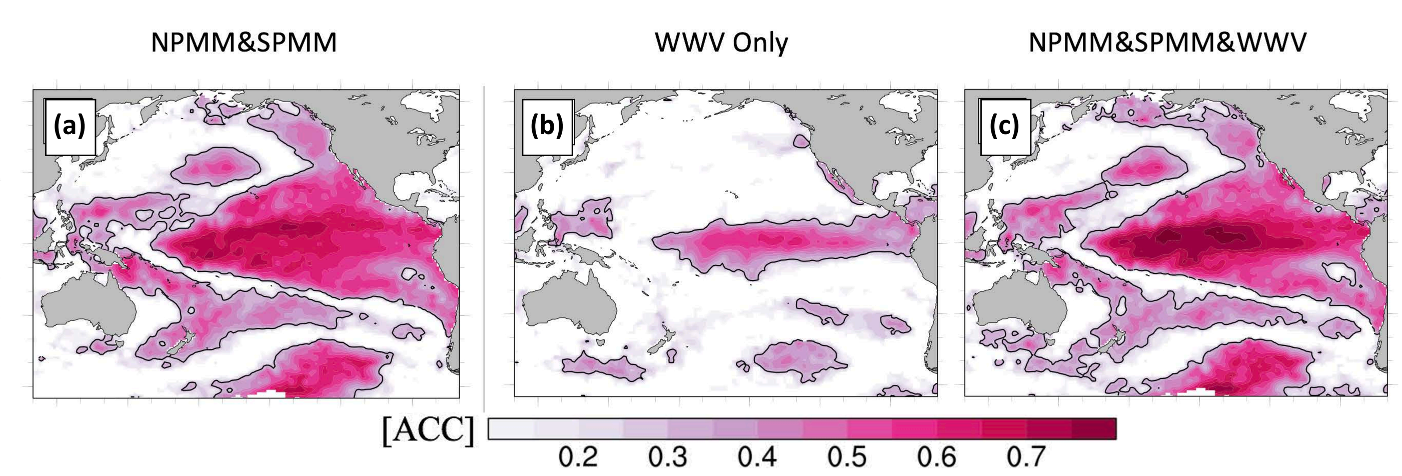
[°C] -0.6 -0.4 -0.2 0 0.2 0.4 0.6

TESTING A SIMPLE ENSO PREDICTION MODEL

$$\mathrm{SSTa}_{\mathrm{NDJ(+1)}} = \alpha \times \mathrm{NPMM}_{\mathrm{FMA}} + \beta \times \mathrm{SPMM}_{\mathrm{FMA}} + \gamma \times \mathrm{WWV}_{\mathrm{FMA}} + \varepsilon$$

- WWV = **W**arm **W**ater **V**olume - Proxy for ocean heat content
- r(WWV,NPMM) = 0.32 (**TRADE WIND CHARGING**)
- r(WWV, SPMM) = 0.08

FIG. 7. Anomaly correlation coefficient (ACC) of observed $SSTA_{NDJ(+1)}$ predicted by **(a)** the $NPMM_{FMA}$ and $SPMM_{FMA}$ indices, **(b)** the WWV_{FMA} index, and **(c)** the $NPMM_{FMA}$, $SPMM_{FMA}$, and WWV_{FMA}. Hindcasts use reanalysis data from 1950–2016. The "leave-out-method" is used for cross-validation. Black contour outlines significant ACC values (p < 0.05) per a Monte Carlo test.



A LOOK AT THE SPMM IN THE CMIP5 MODELS

CMIP5 ENSEMBLE-MEAN

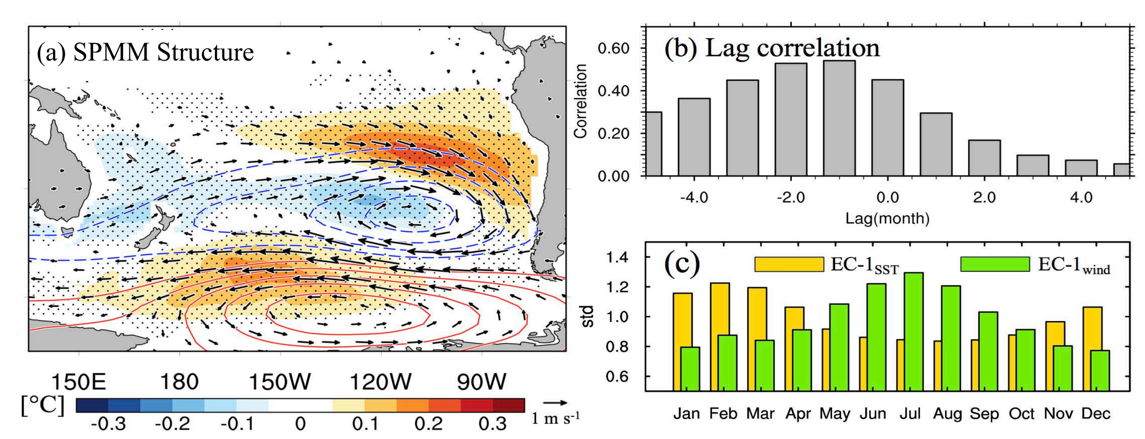


FIG. 8. As in **FIG. 1** except for the CMIP5 ensemble-mean fields.

- **Examined piControl runs of 12 CMIP5 models** (CCSM4, CanESM2, CNRM-CM5, CSIRO-Mk-3-6-0, GFDL-ESM2G, GISS-E2-R, HadGEM2-CC, INMCM4, MIROC5, IPSL-CM5A-MR, MPI-ESM-P, NorESM1-ME)
- **SPMM structure and seasonal statistics are quite similar to those derived from reanalysis.**
- **However, models are <u>overly dependent</u> on WWV / tropical Pacific dynamics for ENSO predictions and less so on the extratropical precursors.**

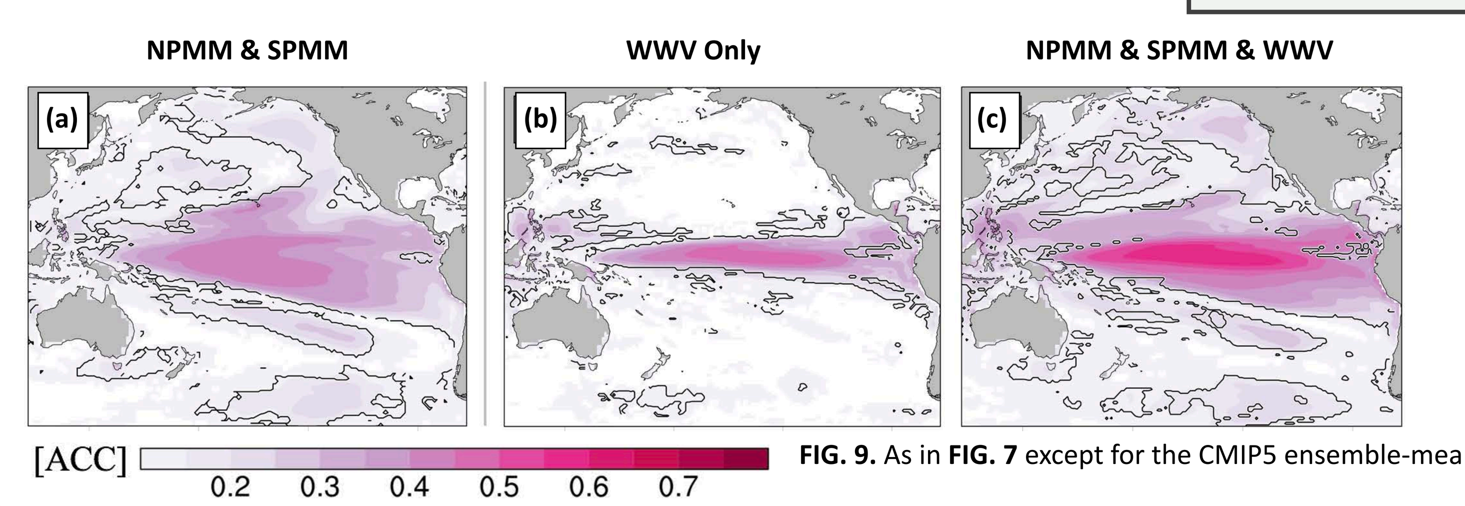


FIG. 9. As in **FIG. 7** except for the CMIP5 ensemble-mean.

SUMMARY & CONCLUSIONS

- The **South Pacific Oscillation (SPO)** is a (largely) intrinsic mode of variability that is analogous to the **North Pacific Oscillation (NPO)** and is a driver of the **South Pacific Meridional Mode (SPMM).**
- The **NPMM** "primes" the tropical Pacific during the boreal spring for a potential ENSO event. The **SPO/SPMM** can then influence the flavor/type of ENSO event. There is higher predictability when the two modes are the same sign.
- The CMIP5 models replicate the **SPMM** and its seasonality well. However, when it comes to ENSO predictability, the models are over reliant on WWV / tropical Pacific dynamics, not enough on the PMMs.
- <u>**FUTURE WORK:**</u> The SPO and the meridional modes show significant low-frequency variability [*You and Furtado*, 2017; 2018]. We seek to explore this variability further in long-record reanalyses and in climate models.

READ MORE ABOUT THIS IN AN UPCOMING *JOURNAL OF CLIMATE* ARTICLE

You, Y. and J. C. Furtado, 2018: The South Pacific Meridional Mode and its role in tropical Pacific climate variability. *J. Climate*, accepted pending minor revisions.