Cal Linear Inverse Models (LIMs) Predict Ocean Biogeochemistry?

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Ocean biogeochemical quantities, such as Net Primary Production (NPP), Oxygen, CO_2 are fundamental to the ocean health and the dynamics of marine ecosystems, so that the ability to understand and predict their evolution in the context of climate variability and change is very important. Prediction systems based on Earth System Models (e.g., the NCAR Decadal Prediction Large Ensemble – DPLE) show the ability of successful near-term predictions of some biogeochemical quantities with higher prediction skill than for physical quantities. However, the complexity of Earth System Models and their computational cost may make it difficult to identify the climate-related sources of predictability. Linear Inverse Models provide an inexpensive alternative that may be also easier to diagnose, but they can only capture fast nonlinearities, so that their ability to adequately model ocean biogeochemistry and its potential nonlinearities is uncertain. Here we test the performance of the LIM approach for modeling and predicting NPP, using data from the Forced Ocean Sea Ice (FOSI) experiment over January 1948 – December 2017. FOSI is used to initialize the DPLE.

The Linear Inverse Model

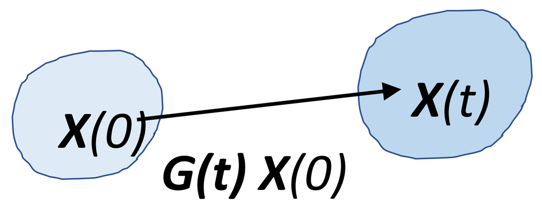
$$dx/dt = \boldsymbol{L}\boldsymbol{x} + \boldsymbol{\xi}$$

x state vector including 18 SST , SSH , and NPP EOFs, which account for 82% of SST and SSH variance and 72% of NPP variance

L Dynamical Operator

ξ Stochastic forcing, white in time, but spatially coherent

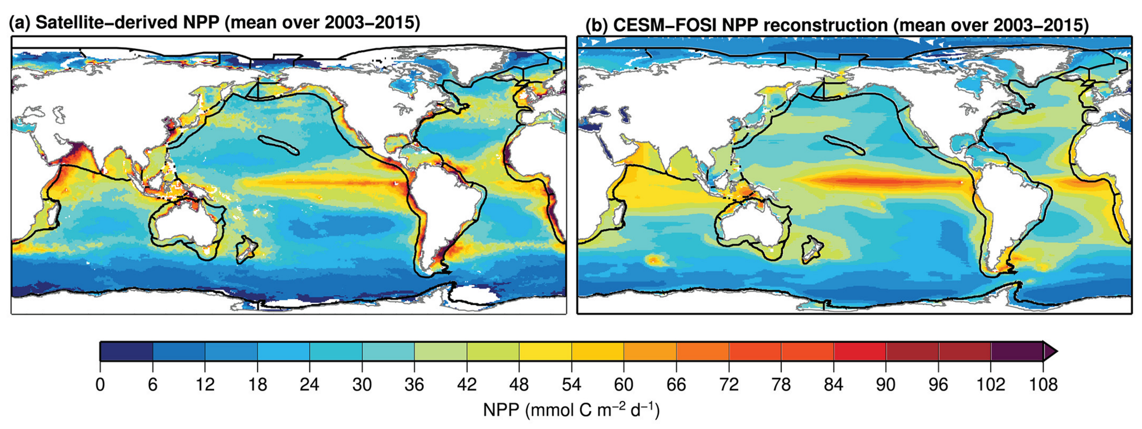
$$\boldsymbol{x}(t+\tau) = \boldsymbol{G}(\tau)\boldsymbol{x}(t) = \exp(\boldsymbol{L}\tau)\,\boldsymbol{x}(t)$$



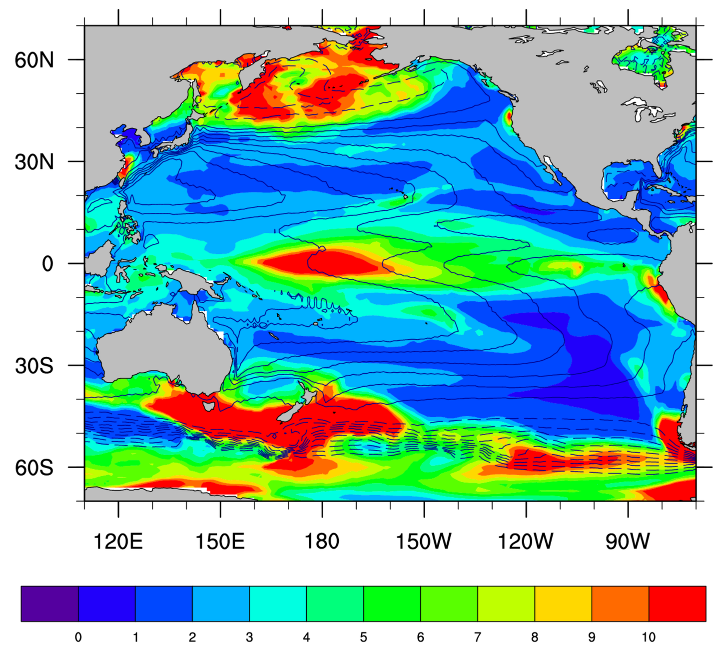
The LIM can be used to determine optimal initial conditions for growth, and for making predictions.

Net Primary Production

Net Primary Production (NPP) by ocean phytoplankton provides energy to marine ecosystems, and plays a key role in the global carbon cycle. It can be affected by climate variations, which can provide sources of predictability.



Mean NPP in observations (left) and FOSI (right). From Krumhardt et al. (2017)

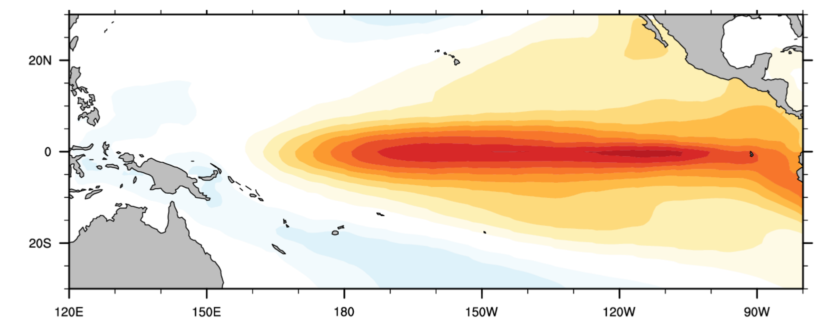


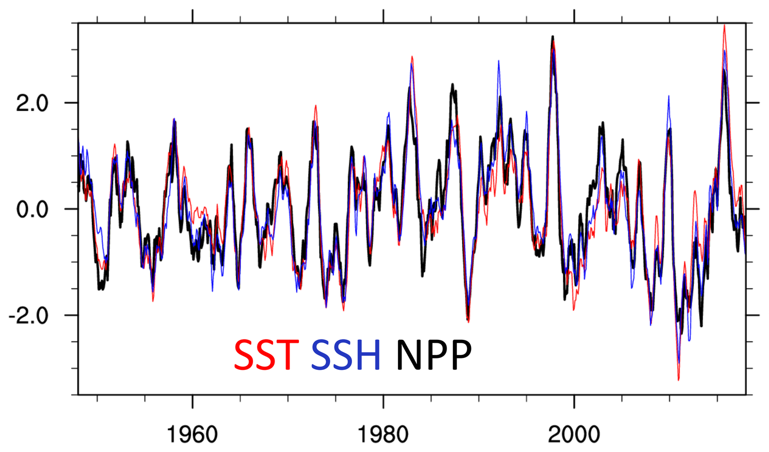
FOSI NPP variance (shading) and mean SSH (contours).

NPP has an important tropical signature and the largest variability appears to be near fronts.

Leading EOFs of LIM variables

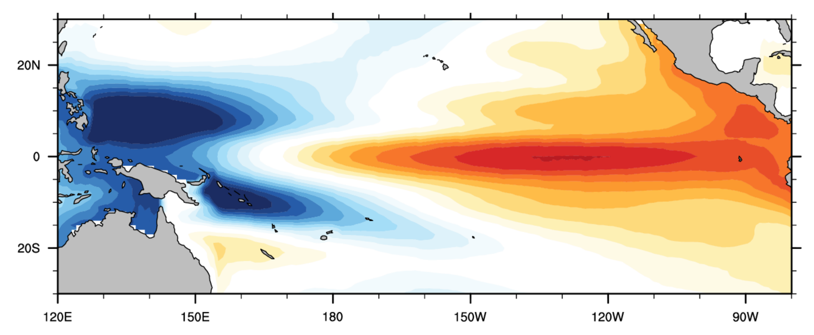
SST EOF1 44.8%





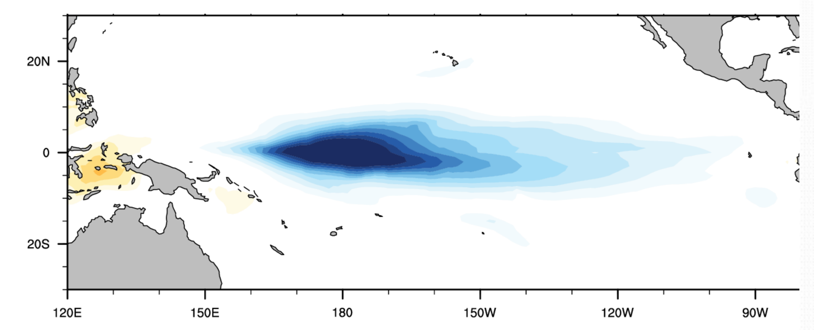
Leading Principal Components (time series) of SST, SSH, and NPP, describing the evolution of the EOF patterns.

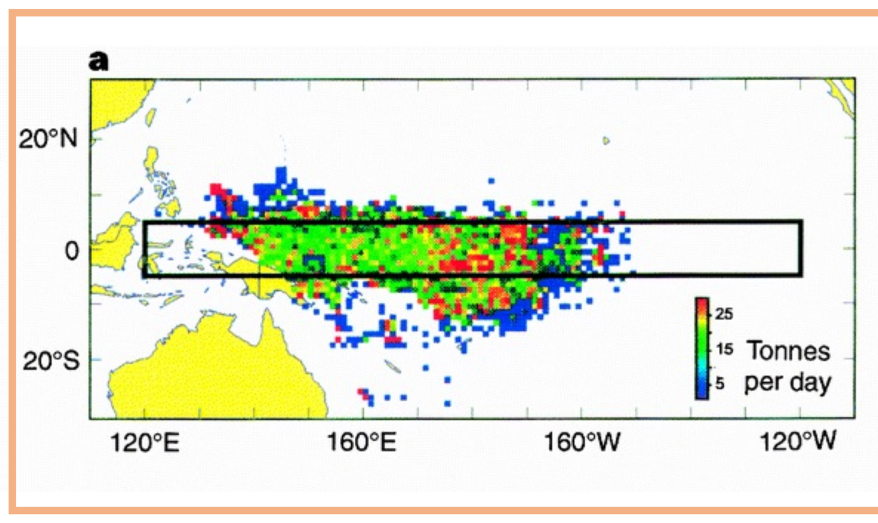
SSH EOF1 37.7%



The leading EOFs of SST and SSH describe the mature ENSO phase. The dominant mode of variability of NPP appears to be strongly related to ENSO. The largest NPP loading is found near the front at the eastern edge of the Warm Pool, where predators like tuna are also found.

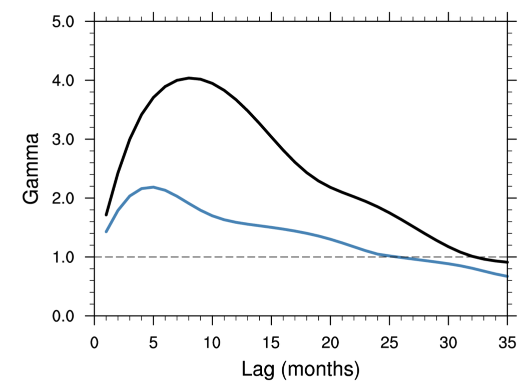
NPP EOF1 33.0%



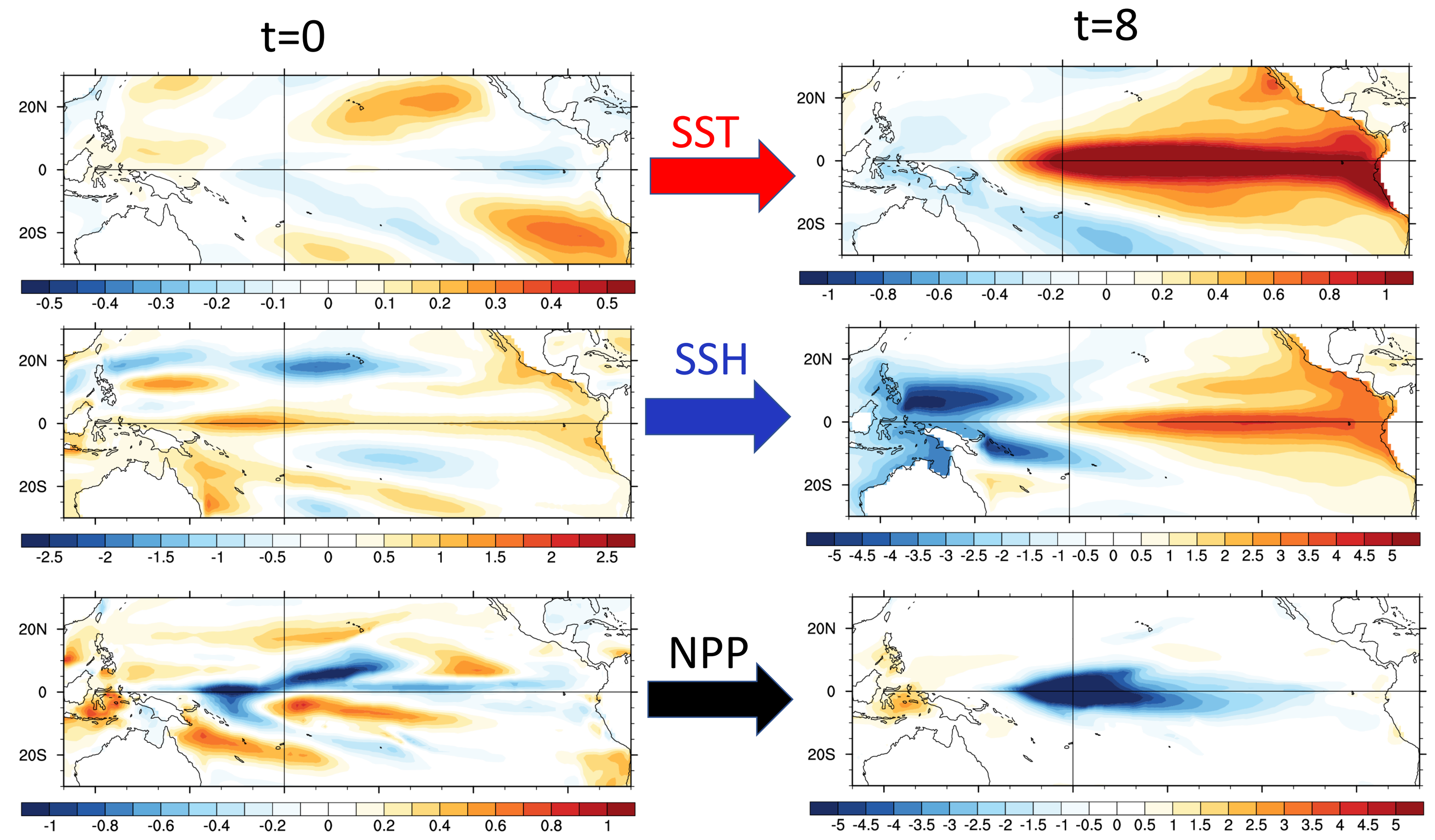


Average catch per unit effort (CPUE) of skipjack tuna during 1988-1995 (Lehodey et al., 1997, Nature)

Optimal growth structures determined with the LIM



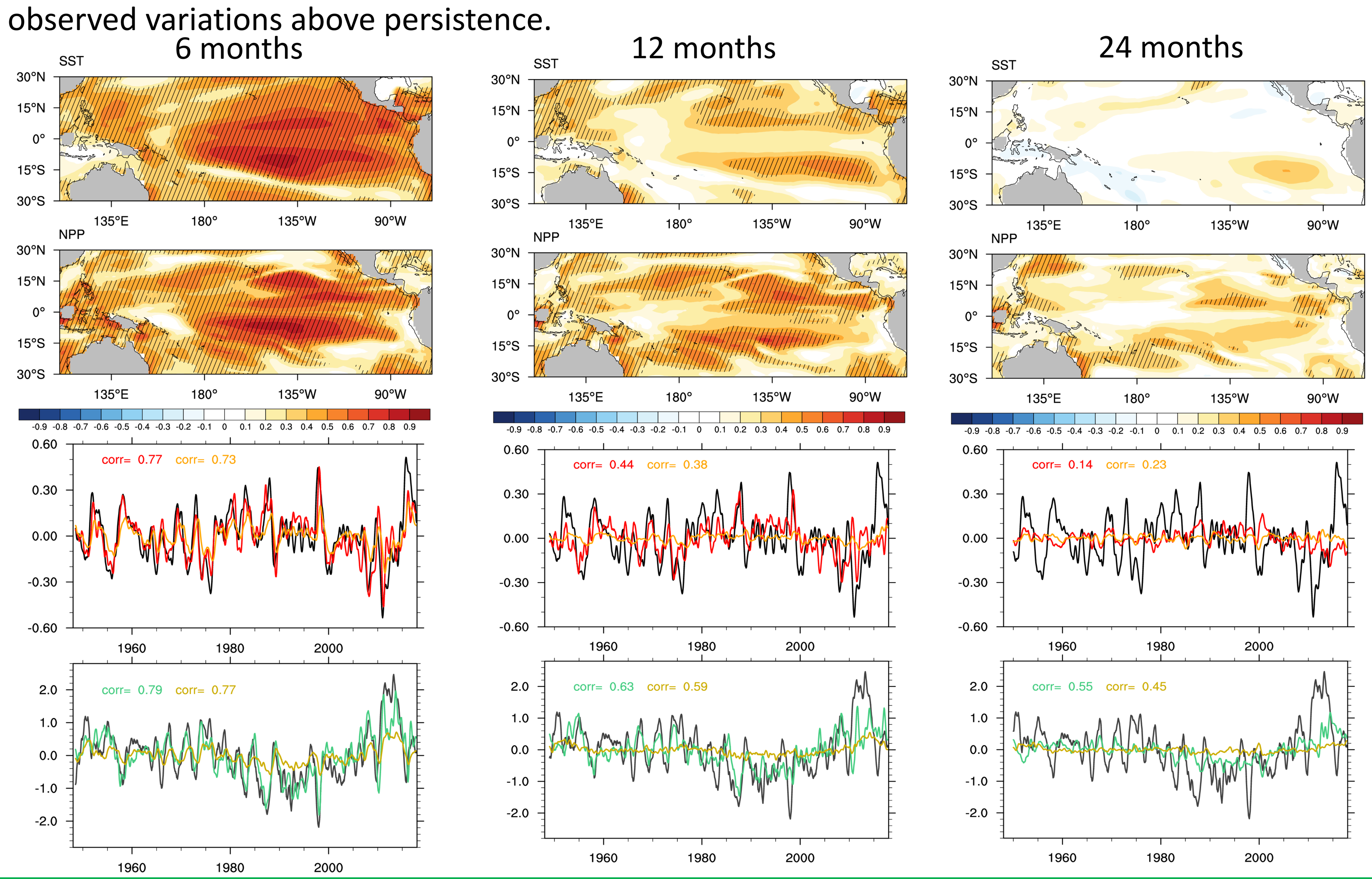
The eigenvectors of the dynamical operators are not orthogonal, and their superposition can result in transient growth. The optimal initial conditions for growth can be computed as the leading right singular vectors of the operator G. Here we find two optimal structures: the leading optimal is associated with canonical ENSO growth, while the second optimal describes CP ENSO events (not shown).



The leading optimal describes the growth of canonical (EP) events and their associated NPP anomalies, from an initial precursor state to their mature state. The initial state is the most conducive to growth toward the final mature state.

How well can LIM predict NPP?

Cross-validated anomaly correlations show significant skill for NPP prediction at lead times up to 24 months, exceeding SST skill at 12 and 24 months. Predicted time series over the domain capture observed variations above persistence.



Conclusions

In the tropical Pacific, LIM can capture the dynamics linking NPP variability with the physical variability associated with ENSO, and produce skillful predictions. Next steps include:

- Diagnose the relative influence of SST and SSH on NPP
- Consider probabilistic forecasts
- Compare the LIM forecasts with the NCAR CESM Seasonal-to-MultiYear Large Ensemble (SMYLE) forecasts