stuecker@hawaii.edu

El Niño–Southern Oscillation frequency cascade

Malte F. Stuecker, Fei-Fei Jin, and Axel Timmermann

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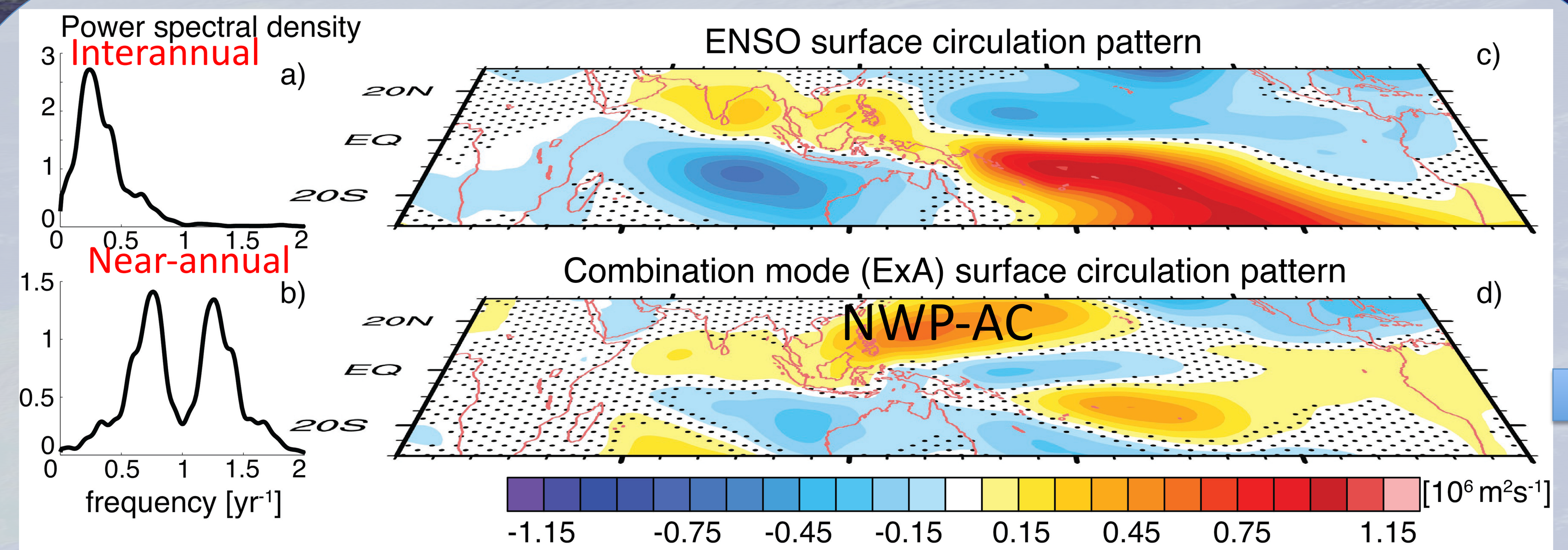
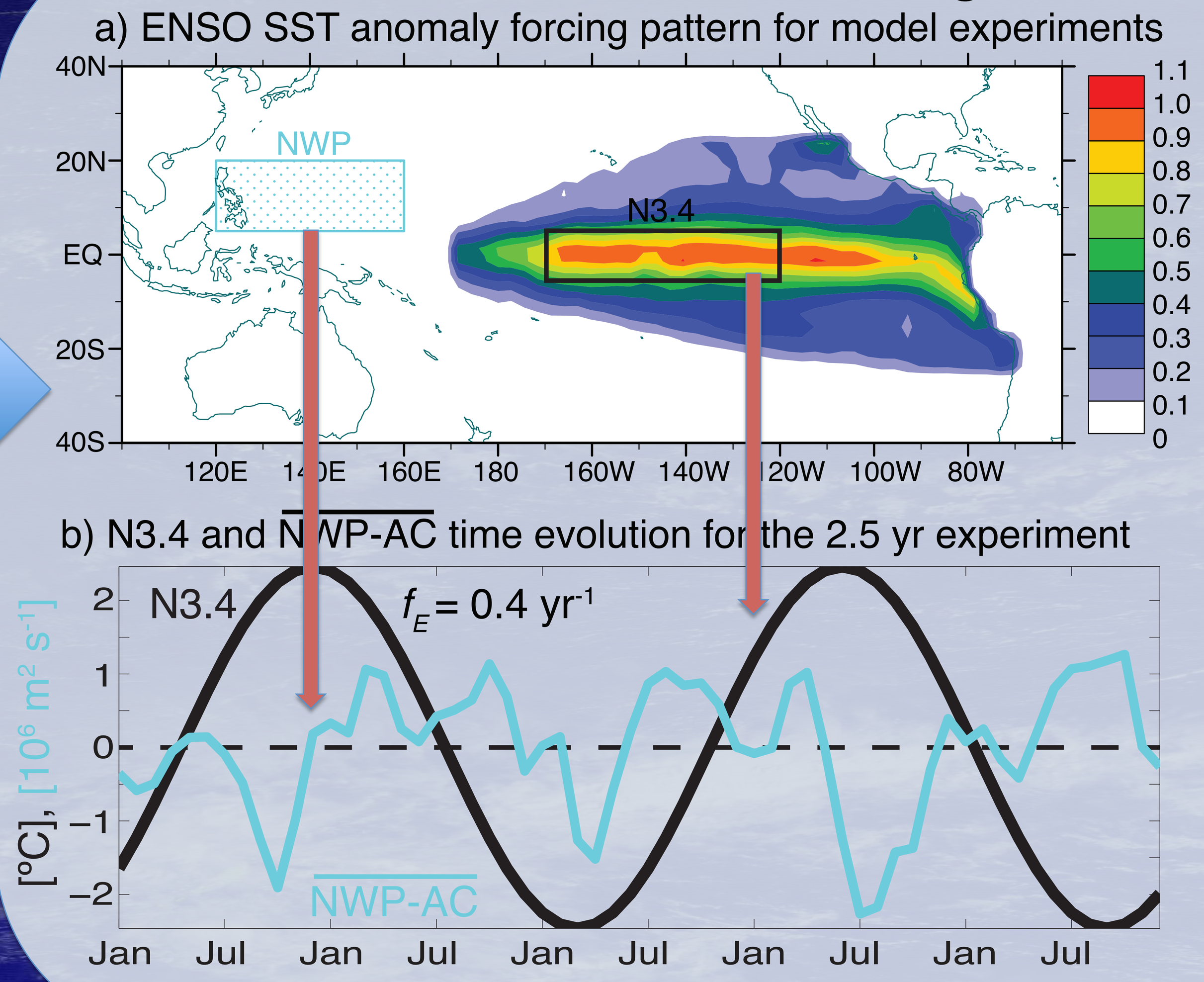


- Nonlinear interactions between the El Niño-Southern Oscillation (ENSO) and the Western Pacific warm pool annual cycle generate an atmospheric combination mode (C-mode) of atmospheric circulation variability.
- C-mode dynamics are responsible for the development of an anomalous low-level North-West Pacific anticyclone (NWP-AC) during El Niño events.
- The NWP-AC is embedded in a large-scale meridionally anti-symmetric Indo-Pacific atmospheric circulation response, which exhibits large impacts on the East Asian Monsoon system.

Q: How are deterministic timescales generated in the NWP region?



AGCM experiments using CESM.

ENSO SSTA forcing is sinusoidal (→ clearly identifiable combination tones) and only prescribed in the eastern equatorial Pacific.

Experiments with different ENSO forcing frequencies f_E, thereby discretizing ENSO!

Large ensemble (overbar) to filter out internal atmospheric variability in each experiment!

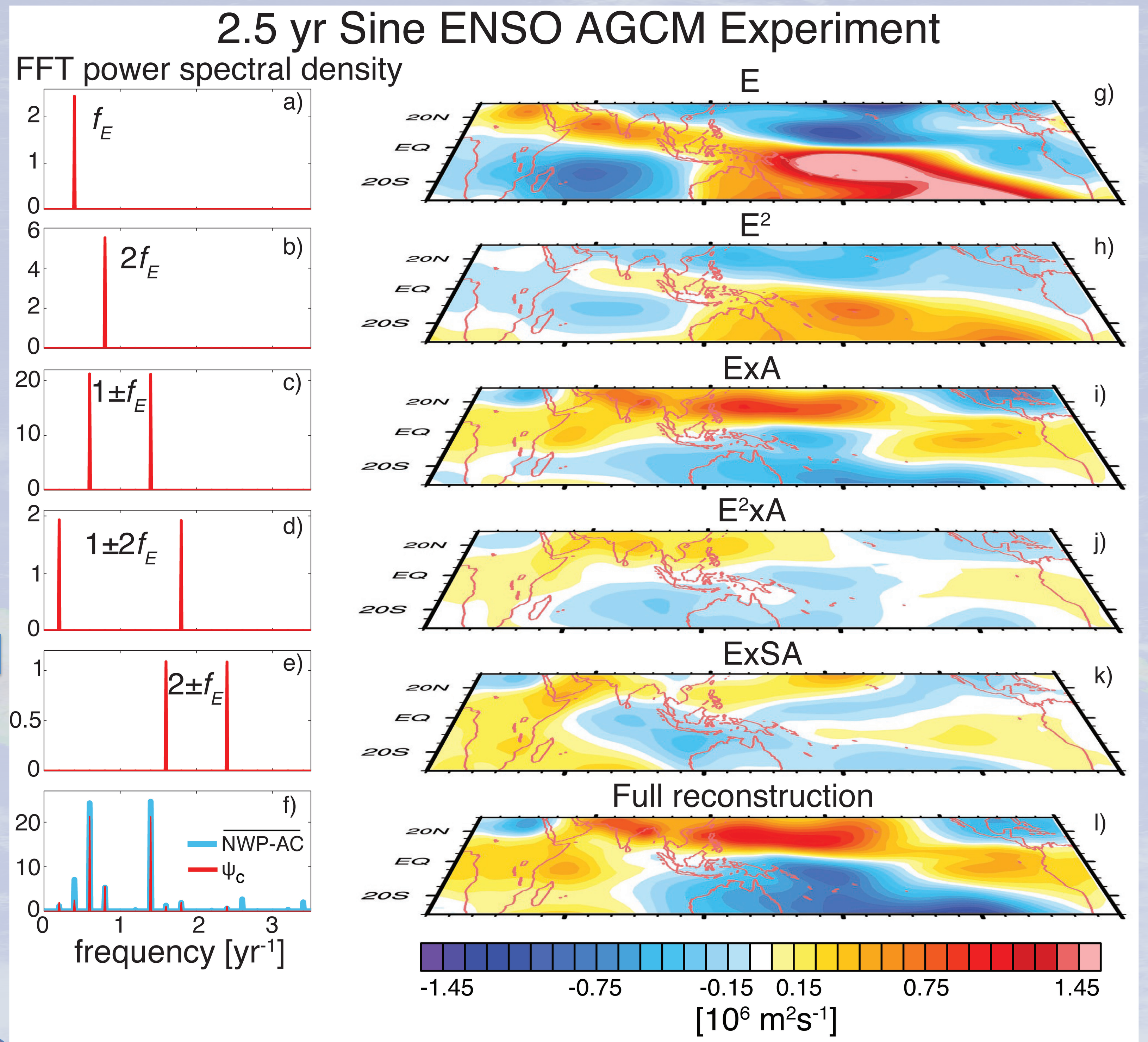
$$\Psi_c(t) = \overbrace{\alpha_{10}\times E(t)}^{f_E} + \overbrace{\alpha_{20}\times \hat{E}(t)^2}^{2f_E} + \overbrace{\alpha_{11}\times E(t)\times\cos(\omega_A t - 2\pi\phi_1)}^{1\pm f_E}$$
$$+ \underbrace{\alpha_{21}\times \hat{E}(t)^2\times\cos(\omega_A t - 2\pi\phi_1)}_{1\pm 2f_E}$$
$$+ \underbrace{\alpha_{12}\times E(t)\times\cos(\omega_{SA} t - 2\pi\phi_2)}_{2\pm f_E},$$

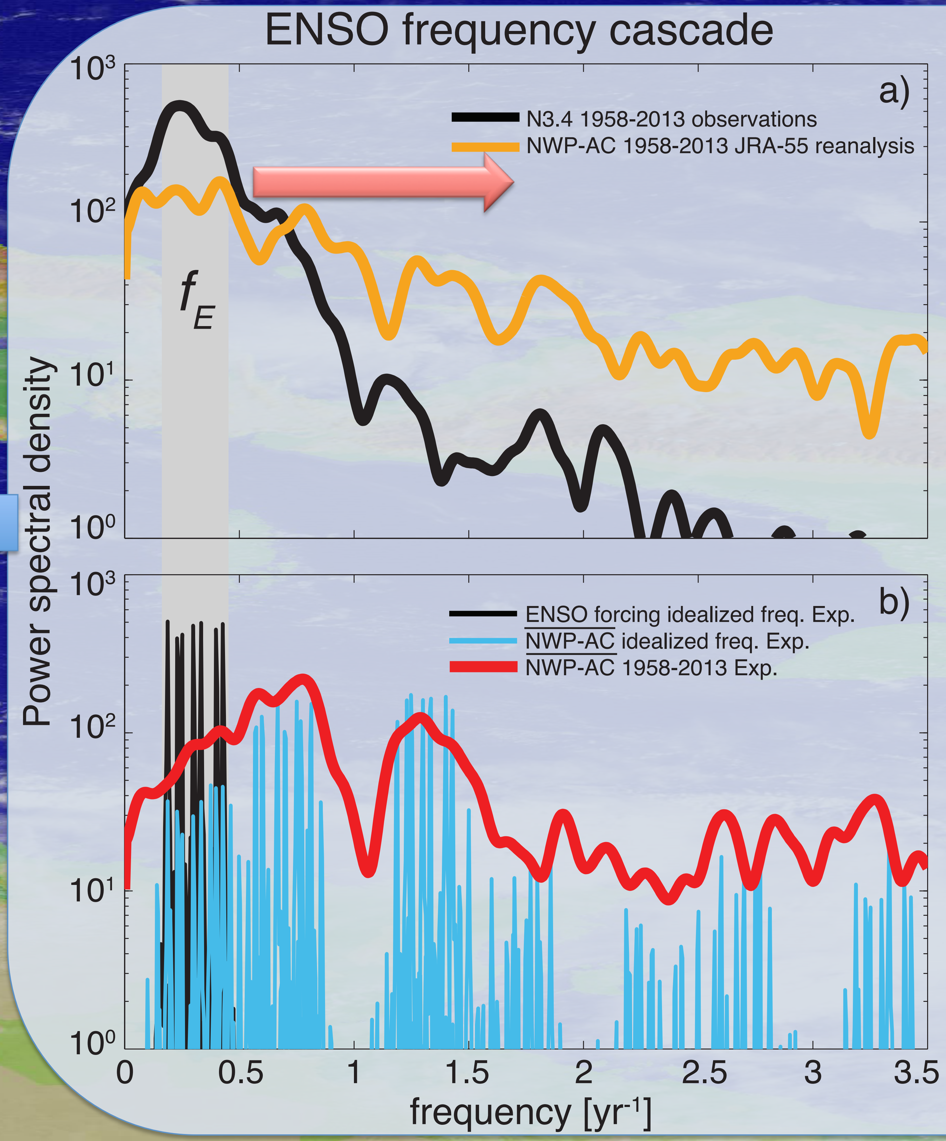
ENSO-induced NWP variability can be understood in terms of a nonlinear interaction between **ENSO (E)** and the **annual cycle ($\cos(\omega_A t)$)**.

We reconstruct the anomalous NWP circulation for each experiment with linear fitting of the amplitude and phase parameters of the ENSO (E) and annual cycle interaction terms!

Each term has a different timescale and and a different corresponding spatial pattern!

Estimated parameters are stable for each experiment (no overfitting)!

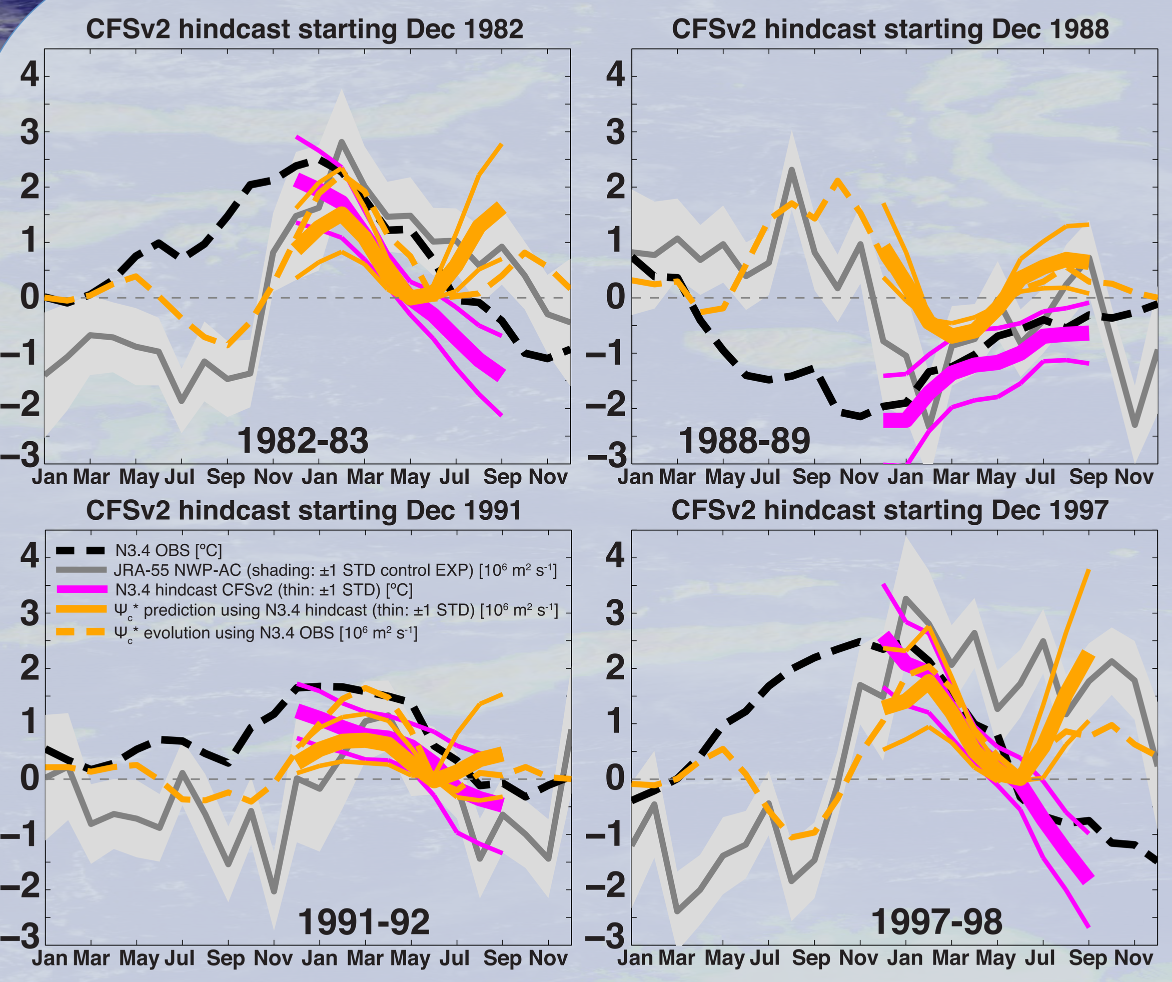




The ENSO frequency cascade

Putting together the anomalous ensemble mean NWP circulation response for each sinusoidal experiment (thin blue lines) – the discretized ENSO response – produces a spectrum very similar to an experiment forced with a realistic ENSO with a broad interannual spectral peak (red line).

Thus, we have a deterministic transfer of power from interannual (black line) to higher frequencies (orange line)!



ENSO predictions (magenta lines) can be used to predict (orange lines) the NWP-AC evolution (grey line)!

Grey shading is a conservative estimate of the large internal unforced NWP-AC variability.

Conclusions

- **Combination mode (C-mode) dynamics are responsible for the extension of ENSO impacts beyond the inter-annual timescale through a frequency cascade mechanism**
- **It provides a simple but powerful concept to study seasonally modulated climate phenomena**
- **A large fraction of the atmospheric background spectrum during ENSO-active periods in the tropics is deterministic on timescales down to several months**
- **The framework can for instance be utilized for predictions of the East Asian Monsoon**

References

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