An Optimal Precursor of Northeast Pacific Marine Heatwaves and Central Pacific El Niño events

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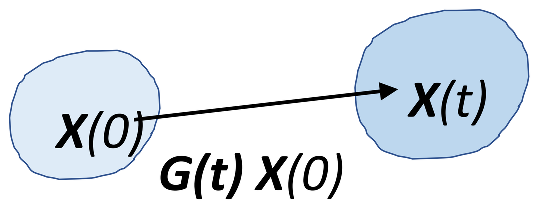
The intensity of Northeast Pacific marine heatwaves (MHWs) has been related to local stochastic atmospheric forcing with limited predictability, but their evolution and persistence may be controlled by large-scale climate influences. Here we use a Linear Inverse Model (LIM) to objectively determine the "optimal" initial conditions for MHW development two-to-four seasons later.

The Linear Inverse Model

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

x state vector including SST and SSH EOFs (data from ECMWF-ORAS4, 1958-2015)
L Dynamical Operator
ξ Stochastic forcing, white in time, but spatially coherent

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



We use LIM to determine the ***x*** (0) most conducive to a MHW at a later time *t*.

Composite Evolution of Northeast Pacific MHWs

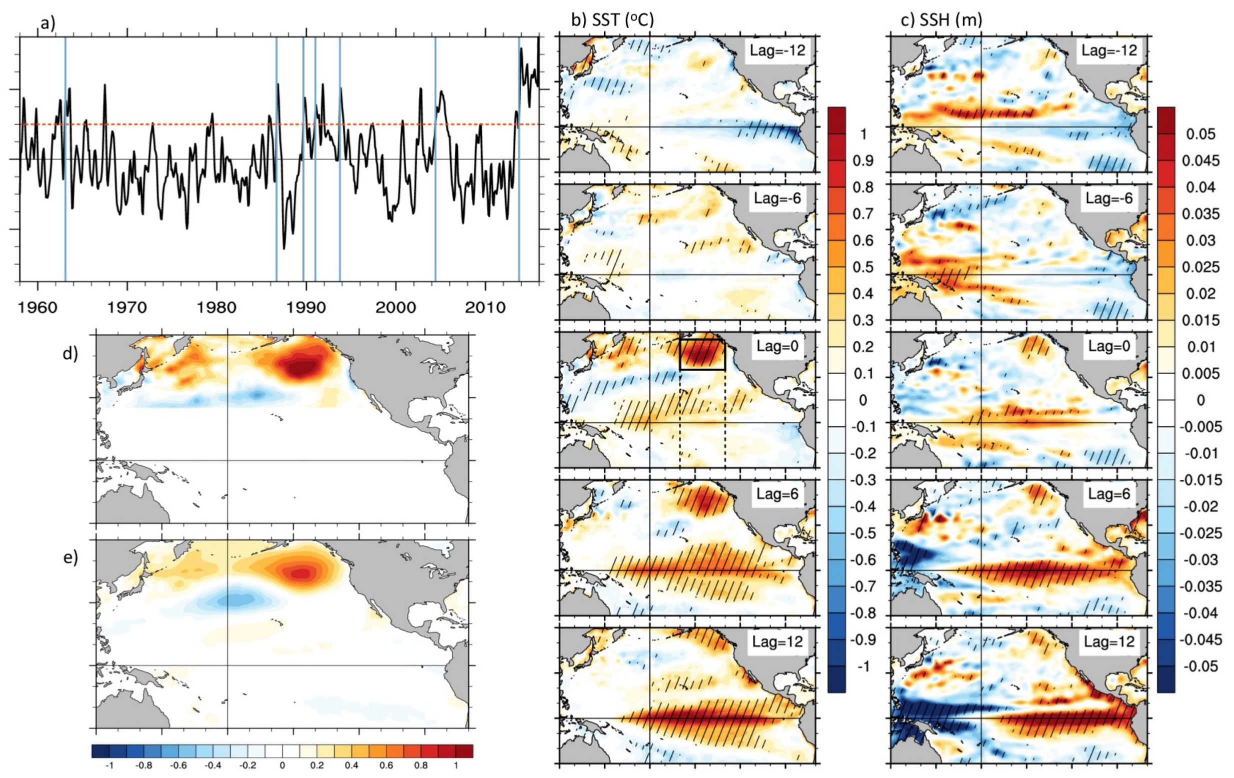


Figure 1. (a) "NEPac index", computed as the average SSTA in the box displayed in b (middle). Vertical light blue lines mark the times when the SSTAs first exceed the 1 standard deviation threshold, shown by the dotted orange line. (b) Composites of SSTAs for events exceeding 1 standard deviation of the NEPac index for at least 5 months, at lags -12, -6, 0, 6, and 12 months. (c) Same as in b), but for SSH. (d) Composite of SSTAs at lag 0, zeroed south of 25°N. (e) Representation of d) in the reduced SST space (20 EOFs) used to construct the LIM; i.e., the "MHW-norm".

We seek initial conditions that optimally grow into the pattern displayed in (e).

The Marine Heatwave Optimal (Optimization time τ =9 months)

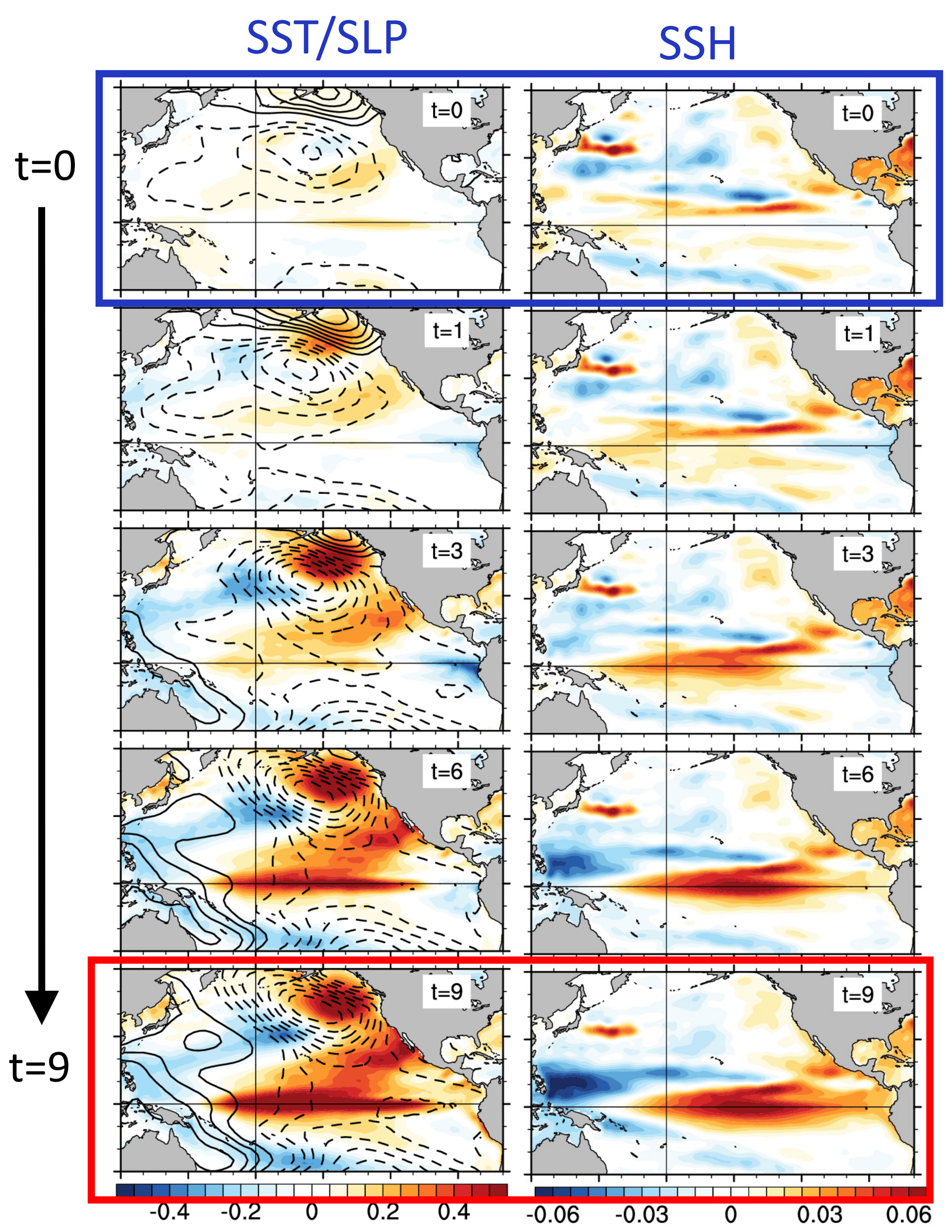
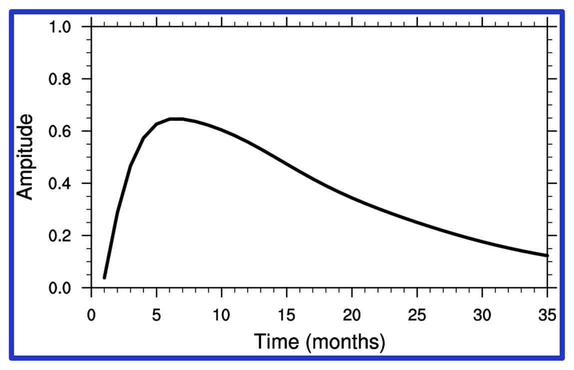
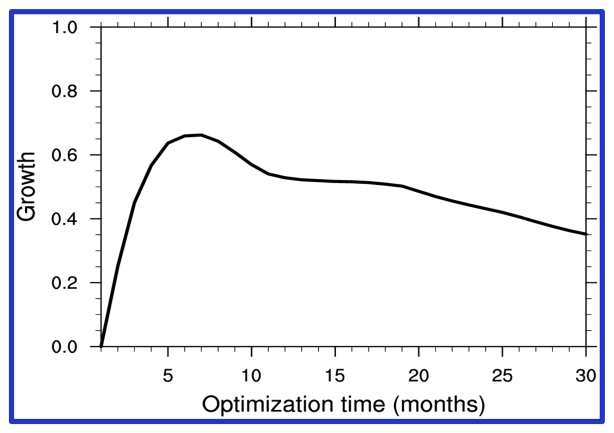


Figure 2



MHW Amplitude: Projection of the anomaly evolution from the Initial Optimal onto the MHW-norm.

Maximum potential growth of a MHW for a given optimization time τ: Change in MHW amplitude from the initial to the maximum value



The optimal initial condition is associated with a SLP pattern (black contours) characterized by a meridional dipole typical of the NPO. SLP anomalies evolve to a deepened Aleutian Low, as a CP El Niño event develops in the equatorial Pacific.

What are the characteristics of MHW optimals for different optimization times?

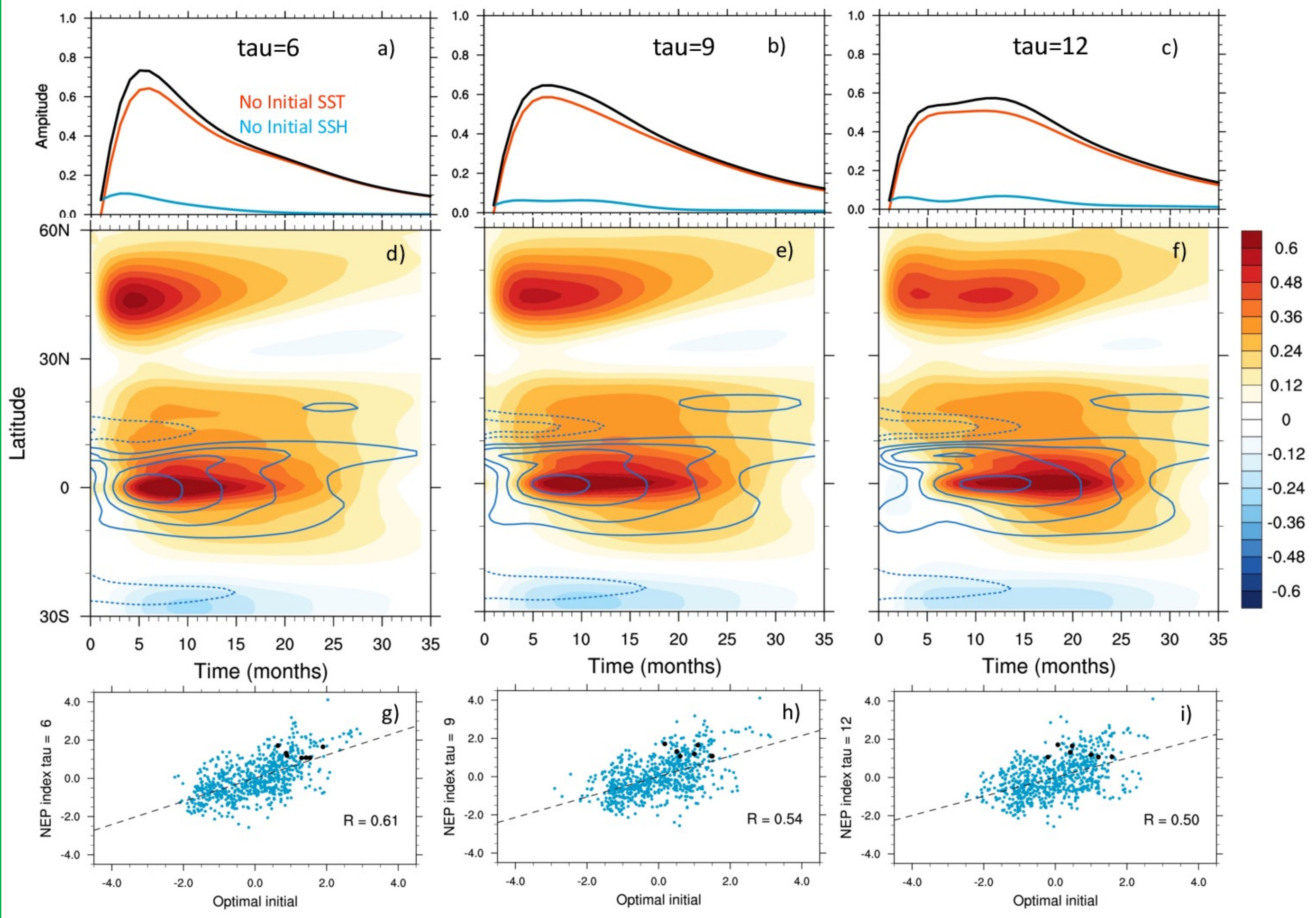


Figure 3. a-c) MHW amplitude as a function of time for different optimization time intervals. d-f) The evolution of the optimals averaged zonally over the 160°-130°W longitude strip (dashed meridional lines in Fig. 1b) as a function of time (x-axis) and latitude (y-axis). Shading indicates SSTA (C.I. 0.05), while contours indicate SSHA (C.I. 0.015, negative values dashed). Units are arbitrary, but normalization is consistent among panels.

g-i) The projection coefficients of observed anomalies on the corresponding optimal patterns, versus the observed NEPac index τ -months later. The dashed lines is the linear fit using a least squares approach. Correlations (insets) are significant at the 99% level. Black dots indicate the onset times (y-axis) of the seven identified MHWs vs. the projection coefficients τ months earlier (x-axis).

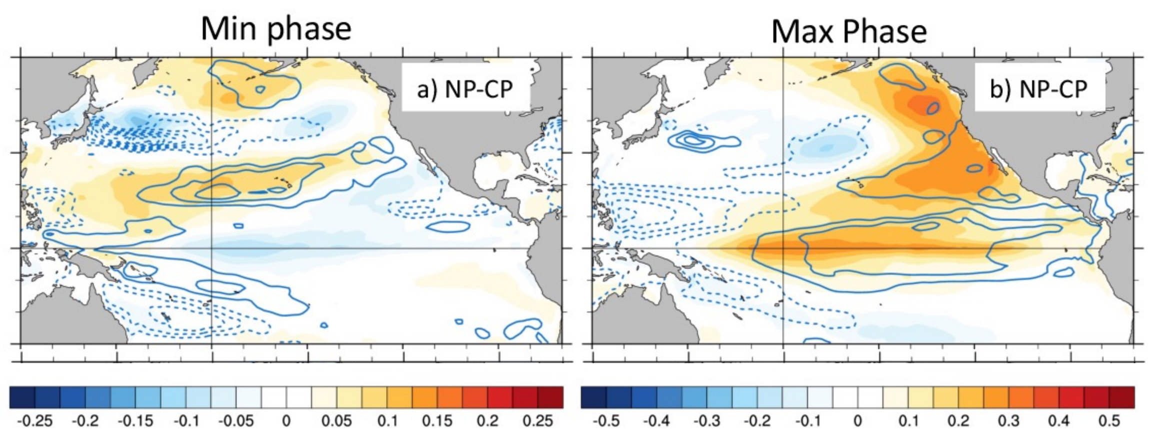
These optimal precursors can help us anticipate observed events

Which basin-scale dynamics is associated with Northeast Pacific MHWs?

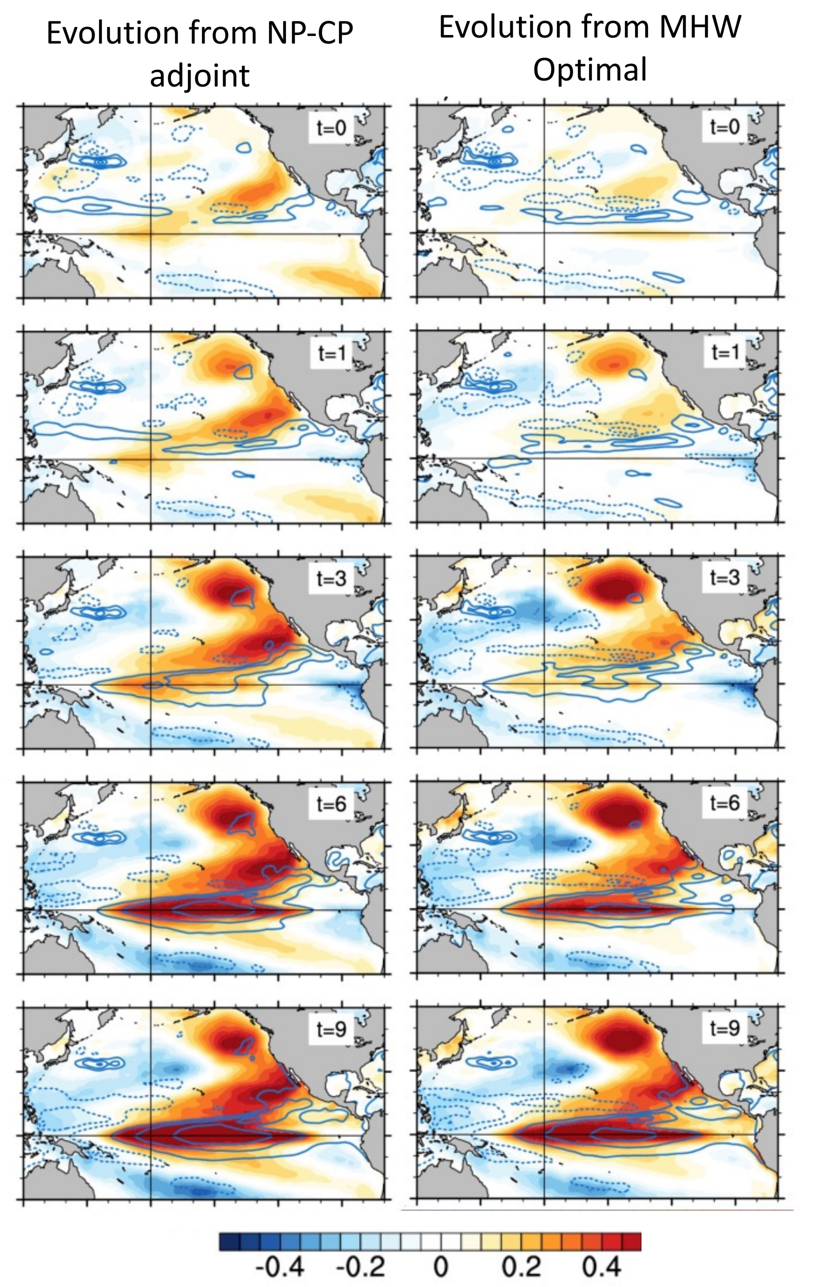
We decompose the initial MHW optimal into the eigenmodes of the LIM dynamical operator ***L***, and check which eigenmodes are most influential on MHW growth:

$$\boldsymbol{x_{MHW}}(\boldsymbol{0}) = \sum_{i=1}^{i=N} \boldsymbol{\alpha_i}\,\boldsymbol{u_i}$$

The key dynamical eigenmode for MHW growth is the "NP-CP" eigenmode (period ~10 years):



The optimal forcing for the eigenvectors of ***L*** is provided by their "adjoints", i.e., the eigenvectors of $L^{\dagger}$. The adjoint of the NP-CP eigenmode is very similar to the MHW optimal. Thus, the initial condition leading to optimal development of Northeast Pacific MHW is the same initial condition leading to optimal development of the NP-CP eigenmode.



Conclusions

- A large-scale precursors of Northeast Pacific MHWs with anomalies in both the North Pacific and the Central equatorial Pacific is identified.
- The initial condition leading to optimal development of Northeast Pacific MHWs can also lead to subsequent Central Pacific El Niño events, which can lengthen MHW duration.

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