Supplemental Material

Title

Forcing of Multiyear Extreme Ocean Temperatures that Impacted California Current Living Marine Resources in 2016

Author Information

Michael G. Jacox[1,2], Michael A. Alexander[3], Nathan J. Mantua[4], James D. Scott[3,5], Gaelle Hervieux[3,5], Robert S. Webb[3], Francisco E. Werner[6]

[1]Institute of Marine Sciences, University of California, Santa Cruz, CA
[2]NOAA Southwest Fisheries Science Center, Environmental Research Division, Monterey, CA
[3]NOAA Earth System Research Laboratory, Physical Sciences Division, 325 Broadway R/PSD1, Boulder, CO 80305-3328
[4]NOAA Southwest Fisheries Science Center, Fisheries Ecology Division, Santa Cruz, CA
[5]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309
[6]NOAA Fisheries, 1315 East West Highway, Silver Spring, MD 20910

Correlation of CCLME SST and US west coast salmon

Links between CCLME-SST and west coast salmon cannot be easily evaluated with correlations between salmon abundance (or catch) and SST time series because abundance has been highly influenced by other factors that include varying salmon hatchery operations and freshwater habitat changes (due to massive habitat loss and degradation, precipitation and water temperature variations that may be uncorrelated with SST, and highly managed streamflows because of dams, diversions, hydropower operations, etc.). Salmon catch has been especially impacted by time and space varying harvest policies since the early 1990s when many U.S. west coast population units were listed as either threatened or endangered under the US Endangered Species Act. Concern for "weak stocks" has led to widespread salmon fishery closures or restrictions along different parts of the U.S. west coast in many seasons since the early 1990s, such that ocean catch is not a good measure of salmon abundance. Finally, coast-wide data on total salmon abundance (catch+escapement) is unfortunately not available.

Supplemental Figures

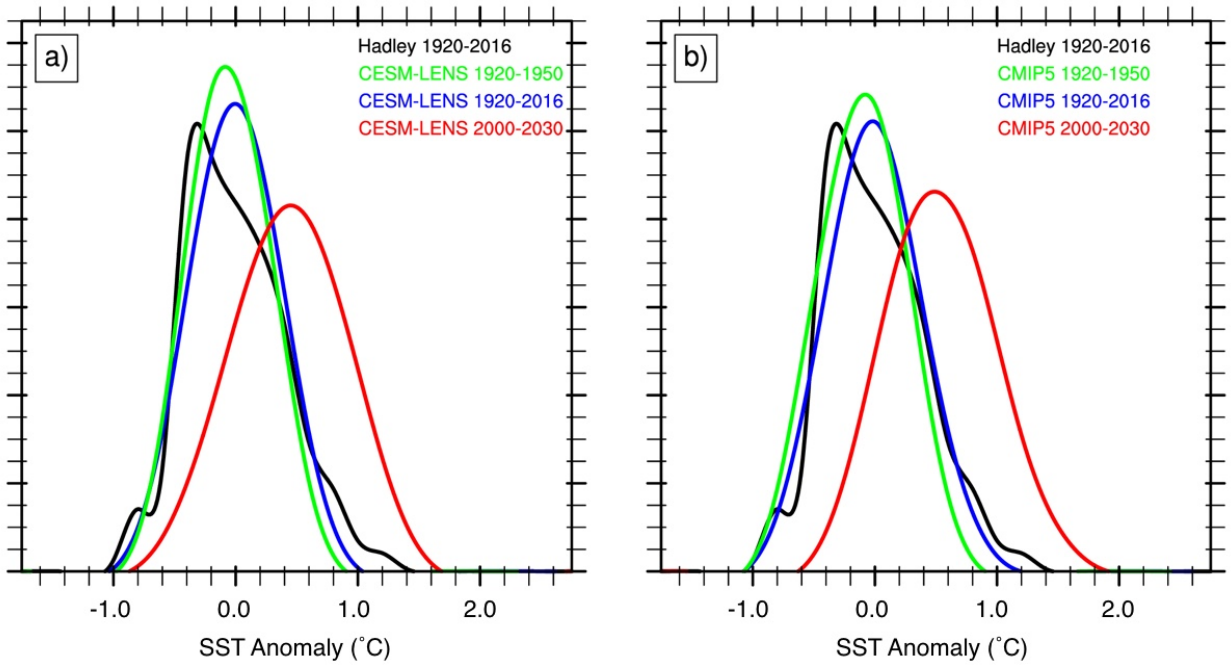

Figure S1: As in bottom panels of Fig. 1, but for three-year mean SSTa instead of annual mean SSTa, using (a) CESM-LENS and (b) CMIP5. The thee-year period 2014-2016 was the warmest in the 1920-2016 record, with mean SSTa of 1.27˚C, 3.1σ above the mean for all three-year periods.

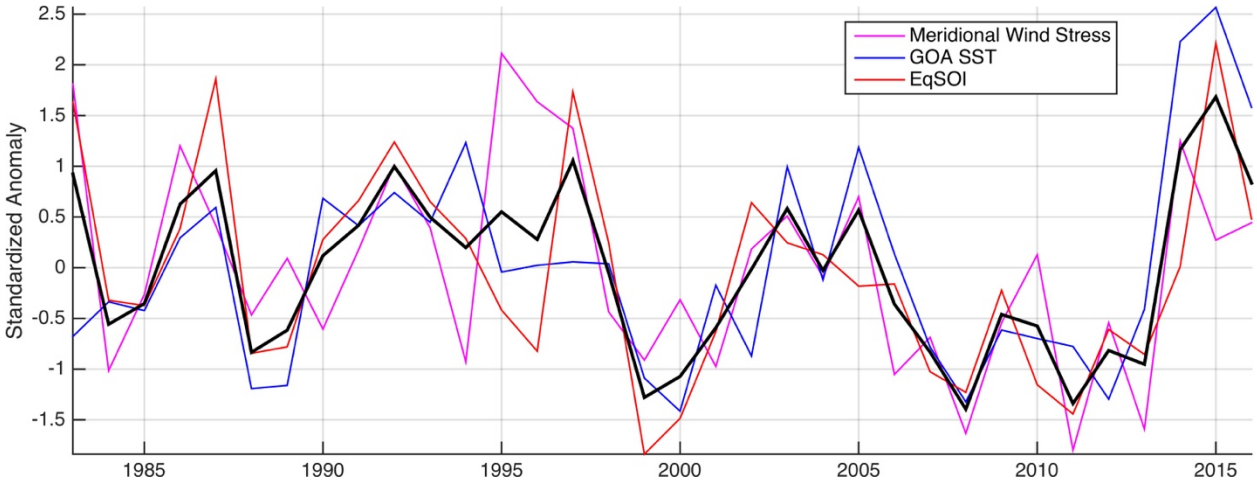

Figure S2: Time series of the three forcing patterns used to construct the AR1 model in Fig. 2 (note GOA SST is calculated at 6-month lead). There is considerable shared variance, with correlation coefficients of 0.4-0.6 between individual time series. However, when considering all three (the black line is the mean of the three time series), 2014-2016 was a notable period of strong and sustained forcing, with three straight years at a level comparable to or greater than that observed during the strong El Niño of 1997-98.

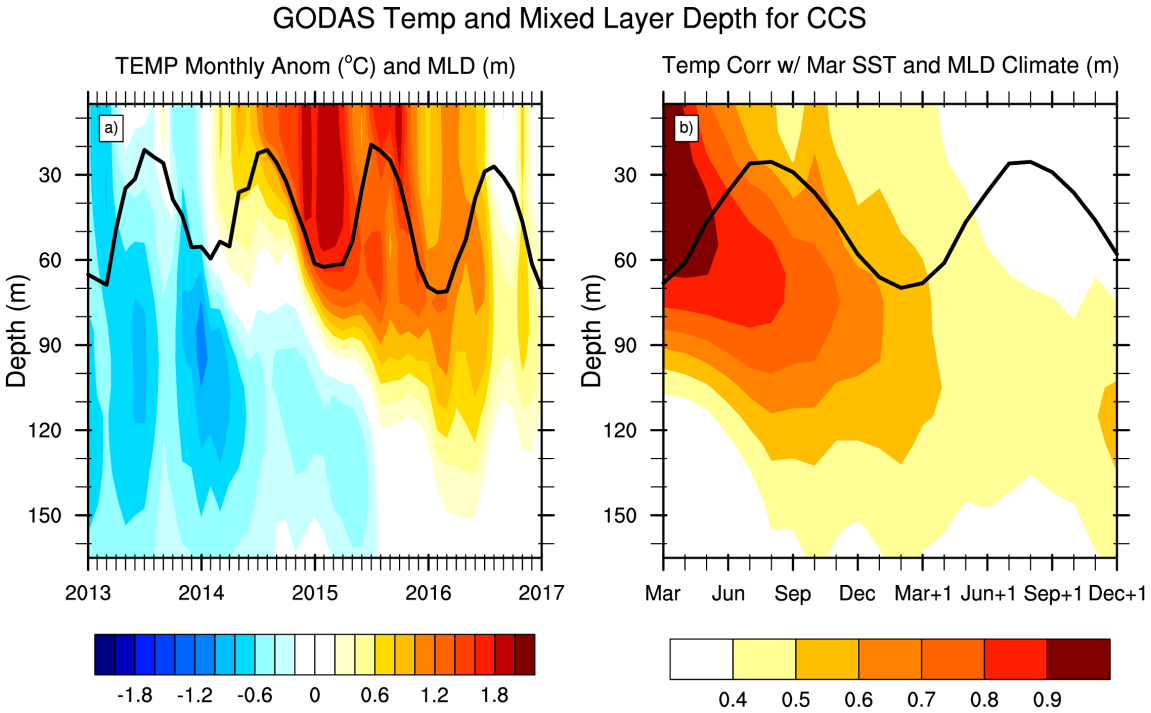

Figure S3: (a) Monthly temperature anomalies (°C shading) as a function of depth (with mixed layer depth (MLD) in black) averaged over the entire CCLME during 2013-2016. (b) Correlations of monthly temperature anomalies with SSTA in March as a function of lag, out to 21 months, and depth. Black line indicates the climatological MLD. Based on Global Ocean Data Assimilation System (GODAS; see Saha et al. 2006) data from 1980-2016.

			CESM-LENS			CMIP5		
Averaging Period	SSTa (˚C)	SSTa (σ)	Historical Probability	Present Probability	FAR	Historical Probability	Present Probability	FAR
2014	1.15	2.2	0.002	0.147	0.984	0.005	0.192	0.972
2015	1.71	3.3	0	0.021	1	0	0.038	1
2016	0.95	1.8	0.014	0.250	0.941	0.011	0.287	0.959
2014-2016	1.27	3.1	0	0.074	1	0	0.088	1

Table S1: CCLME SSTa averaged over calendar years 2014, 2015, 2016, and the three-year period 2014-2016 (in absolute units, ˚C, and standardized units, σ), their probabilities in historical (1920-1950) and present (2000-2030) periods of the CESM-LENS and CMIP5 ensembles, and the fraction of attributable risk (FAR) for each period, calculated from each ensemble.

Additional Reference

Saha, S.S., et al., 2006: The NCEP Climate Forecast System. J. Climate, 19, 3483–3517, doi: 10.1175/JCLI3812.1.