

The anomalous 2014 warming of the California coastal ocean and San Francisco Bay: Observations and Model Simulations

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INTRODUCTION

During 2014 exceptionally warm ocean temperatures developed across a wide area off the California coast. This near-shore warming in California might be related to the region of positive sea surface temperature anomalies described by *Bond et al.* [2015] that developed to the northwest in the northeastern Pacific Ocean. *Bond et al.* [2015] found that these anomalies were the largest in the region since at least the 1980s and attributed the development of these warm waters during the winter of 2013-14 to higher than normal sea level pressures and weaker winds. They also reported that by May 2014 the warm waters had reached the Pacific NW coast and that anomalously warm sea surface temperatures (SSTs) persisted into March 2015. Interestingly, *Brown and Fu* [2000] also attributed the development of exceptionally warm SSTs in roughly the same offshore region during spring 1997 to weaker than normal winds. Concurrently, anomalously warm water temperatures also developed in the San Francisco Bay (SFB). SFB is a biological resource of substantial importance as it provides critical winter habitat for over a million migratory birds and is home to a vast diversity of plants and animals. The Bay ecosystems are sensitive to changes in environmental conditions such as temperature.

CALIFORNIA COASTAL WARMING

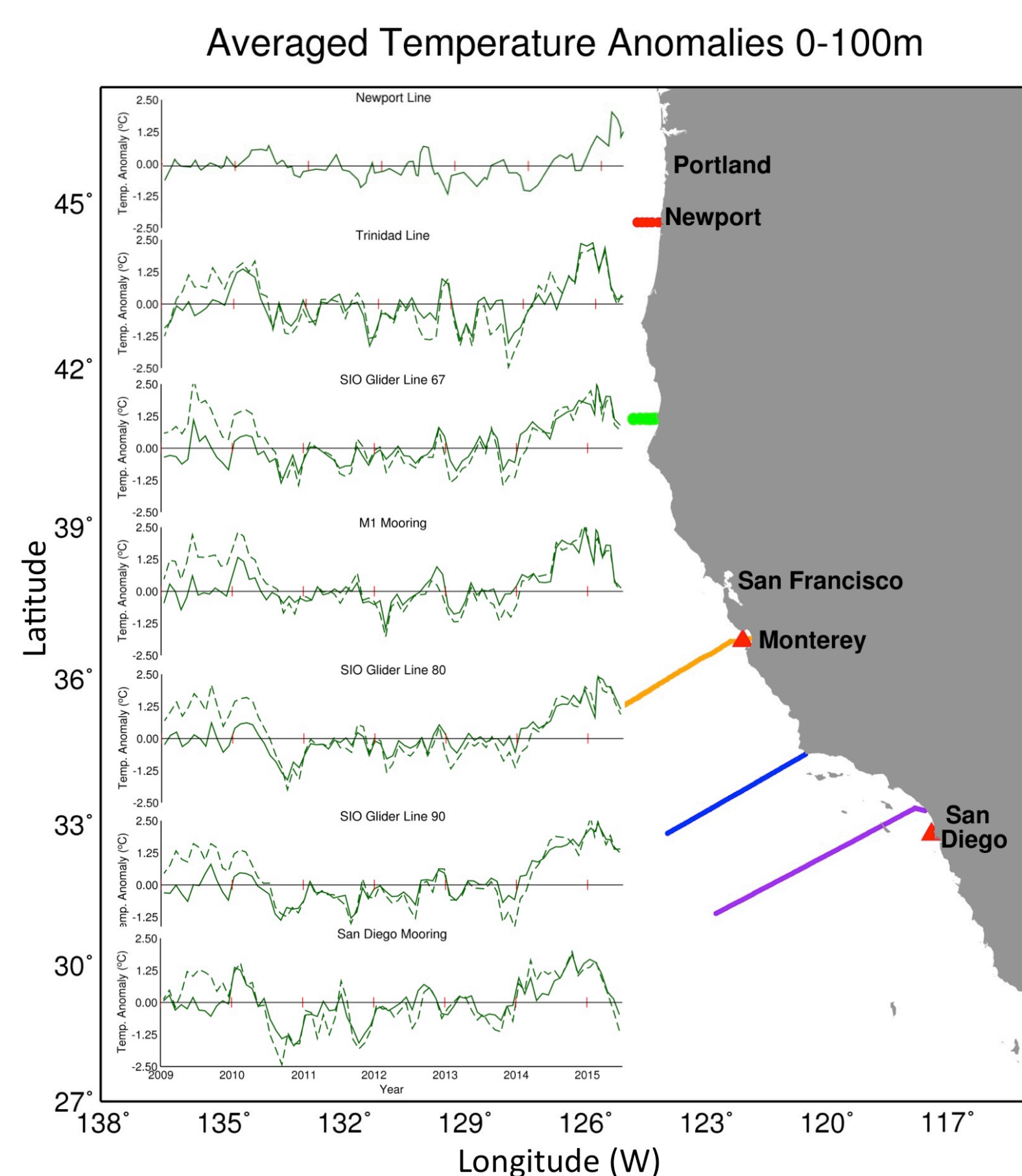


Figure 1. Monthly time series of depth-averaged (0-100m) temperature anomalies (°C; anomalies from the 2009 – 2014 means) for the period Jan 2009 – Apr 2015 from south to north: San Diego mooring (cyan triangle), Scripps glider transecting CalCOFI line 90 (purple line), Scripps glider transecting CalCOFI line 80 (blue line), M1 mooring (green triangle), Scripps glider transecting CalCOFI line 67 (orange line) and ship CTD observations near Trinidad, CA (green line) and near Newport, OR (red line). The dashed lines represent the anomalies from the CA ROMS hindcast run that includes data assimilation (see text for details).

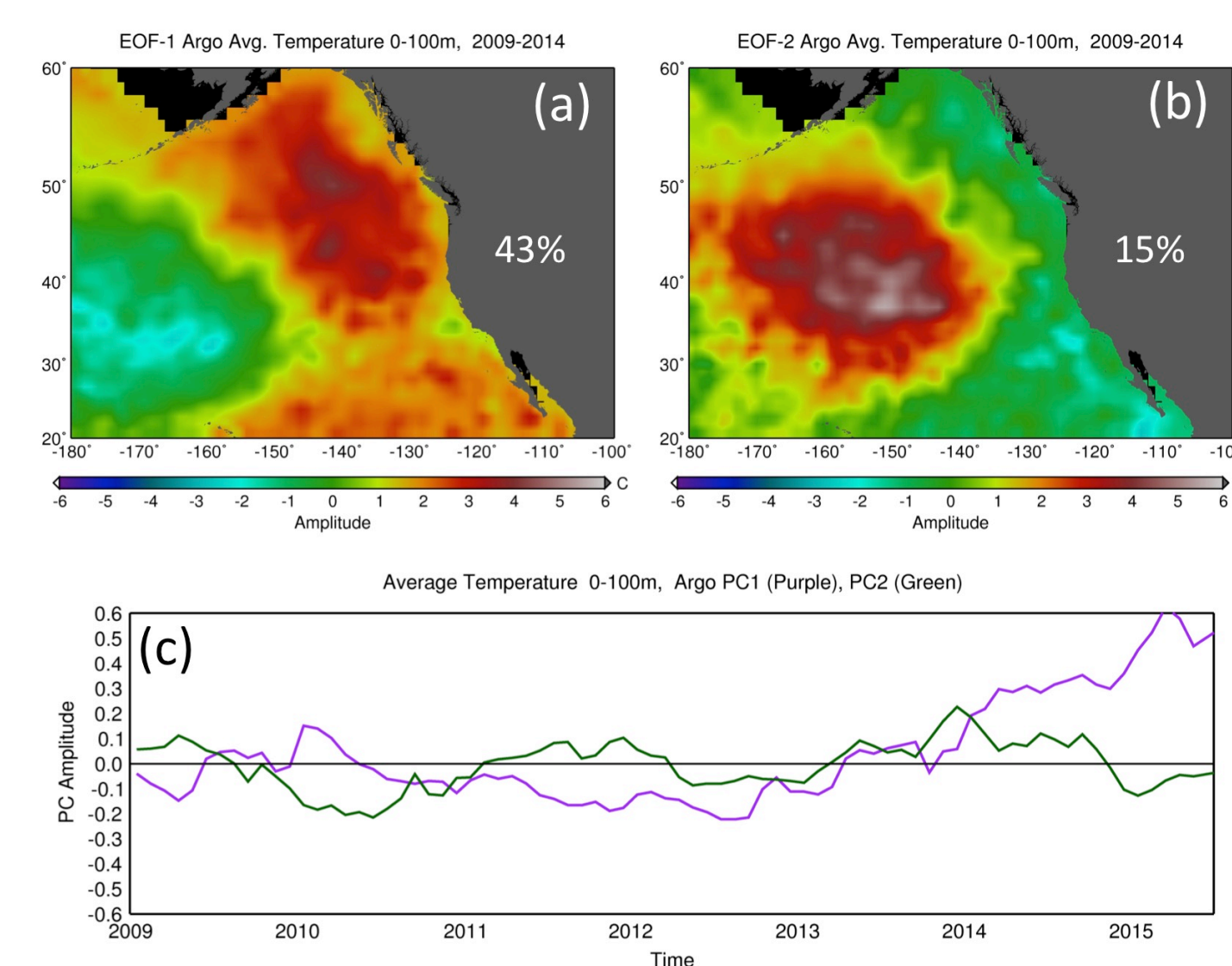


Figure 2. Empirical orthogonal functions (EOFs) 1 and 2 of the upper ocean (0-100 meters) average temperature (°C) from Argo float observations – (a) and (b). (c) Principal components (PCs) 1 and 2 (purple and green solid lines, respectively).

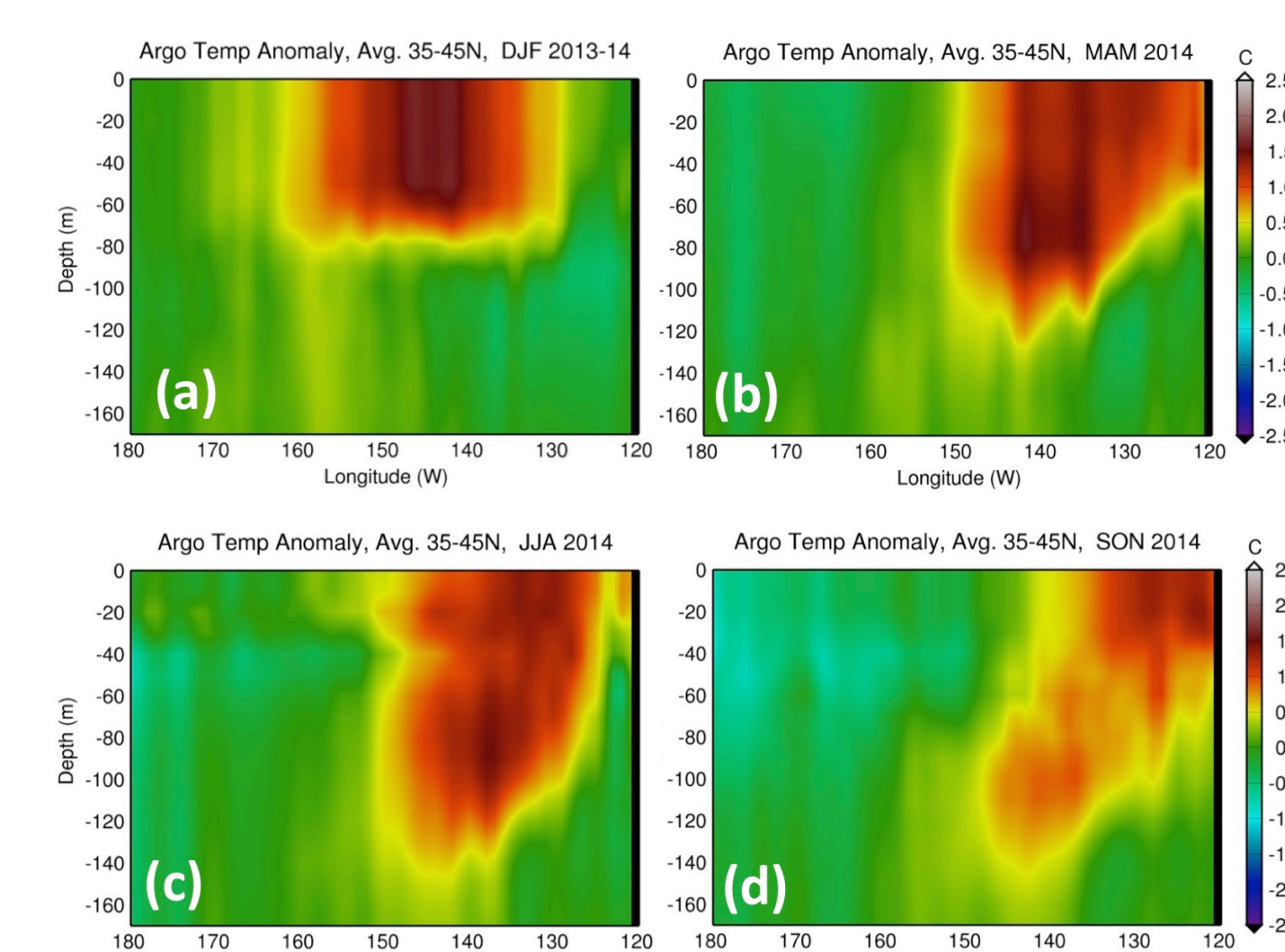


Figure 3. Depth-longitude plots of the vertically averaged (0-100m) Argo temperature anomalies (°C), defined as the departure from the climatological mean annual cycle for the period 2009-2014, averaged over a latitudinal band from 35°N to 45°N during (a) December-January-February (DJF) 2013-2014, (b) March-April-May (MAM) 2014, (c) June-July-August (JJA) 2014 and (d) September-October-November (SON) 2014.

SUMMARY – CALIFORNIA COASTAL WARMING

During 2014 exceptionally warm ocean temperatures developed across a wide area off the California coast. Temperature anomalies in the upper 100 meters of the ocean were used to characterize the warming. Positive anomalies approaching 2.5°C were found at a number of locations along the coast for much of the latter half of 2014 and early 2015. The magnitude and evolution of these positive anomalies is accurately reproduced in a ROMS model hindcast simulation. Spatially, this warming manifested itself strongly in the two leading modes of upper ocean temperature variability in the extra-tropical eastern Pacific in Argo observations. The second mode, whose pattern resembles that of a region of strongly positive sea surface temperature anomalies described by *Bond et al.* [2015], peaks first in late 2013 / early 2014 and was followed by a stronger peak in the first mode, which resembles the PDO, in 2014. In the vertical, gridded Argo temperature data reveal that the maximum depth covered by strong positive anomalies expands from around 80 meters to 140 meters as the anomalies moved eastward toward the coast.

References

Bond, N. A., M. F. Cronin, H. Freeland and N. Mantua (2015), Causes and impacts of the 2014 warm anomaly in the northeast Pacific, *Geophys. Res. Lett.*, doi: 10.1002/2015GL063306.
Brown, R. G., and L.-L. Fu (2000), An examination of the spring 1997 mid-latitude east Pacific sea surface temperature anomaly. *Atmosphere-Ocean*, **38**(4), 577-599.

SAN FRANCISCO BAY WARMING

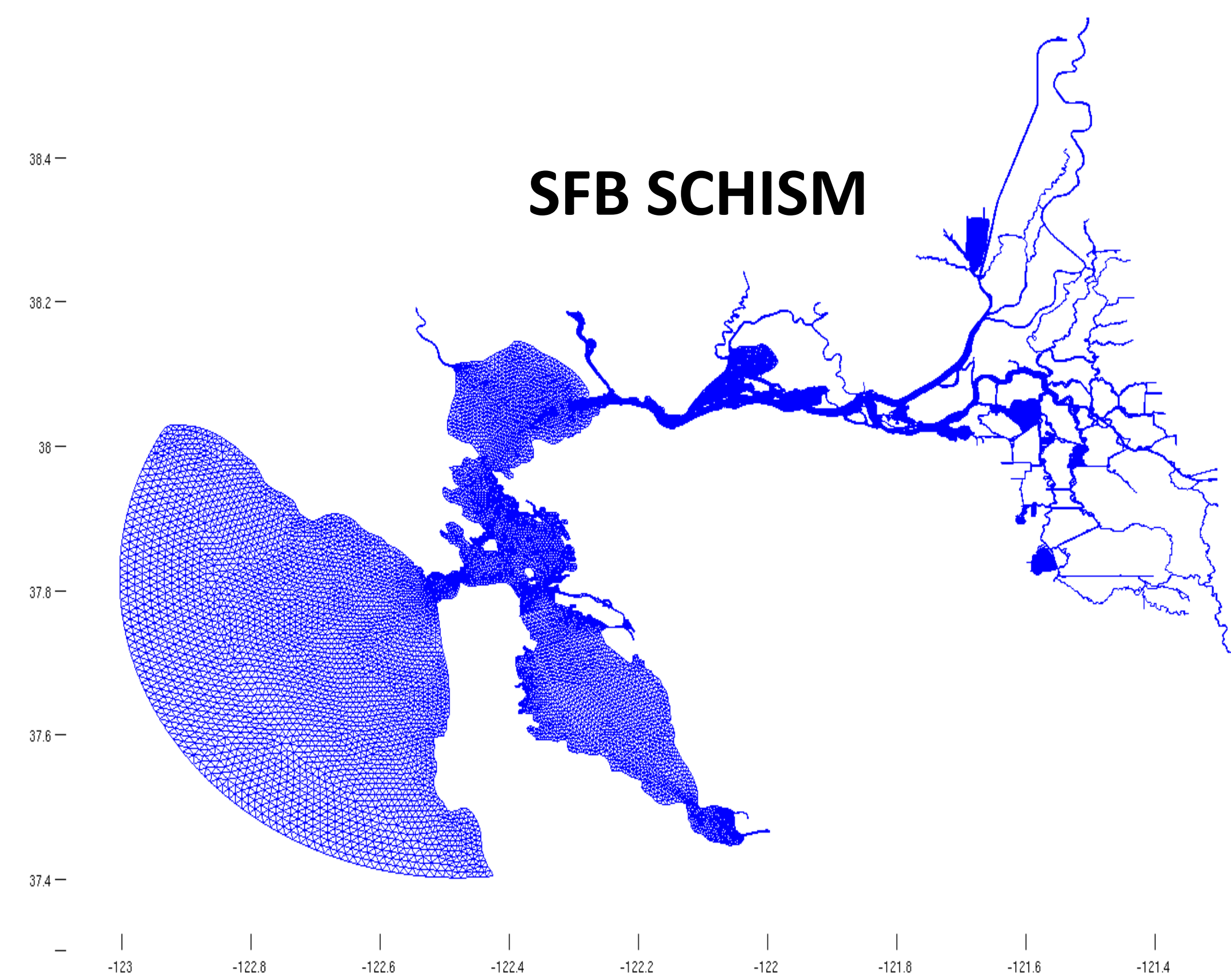


Figure 4. San Francisco Bay model domain for the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM), an open-source community-supported modeling system with unstructured grids, designed for seamless simulation of three-dimensional baroclinic circulations across creek-lake-river-estuary-shelf-ocean scales.

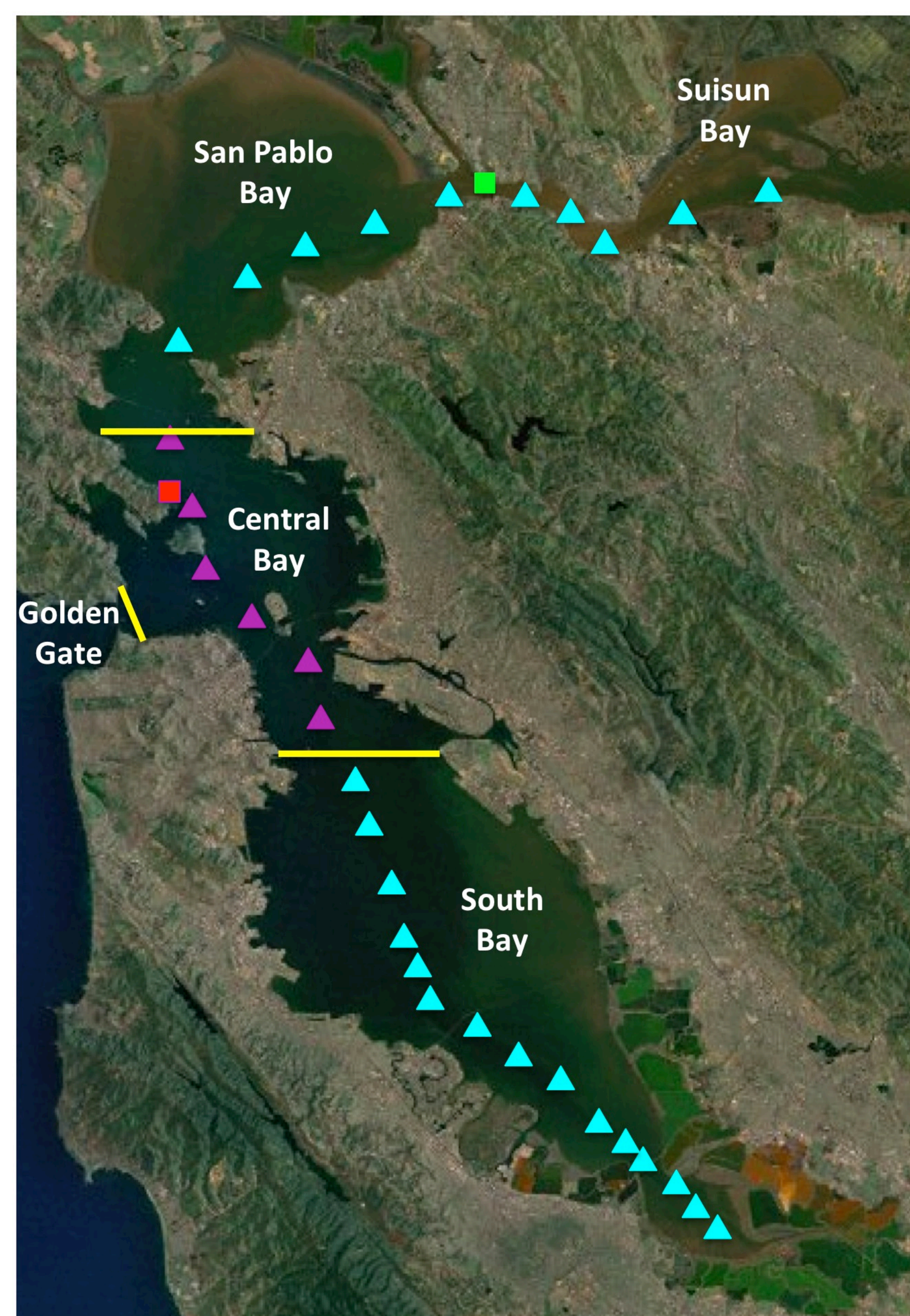


Figure 5. Map of the San Francisco Bay (SFB) region showing the locations of the 31 USGS observation stations used as triangles (purple for locations within the Central SFB and cyan for all others), and the locations of the Tiburon and Carquinez stations as red and green squares, respectively. The yellow lines delineate the horizontal area used to define the control volume for the heat budget calculations presented in the text.

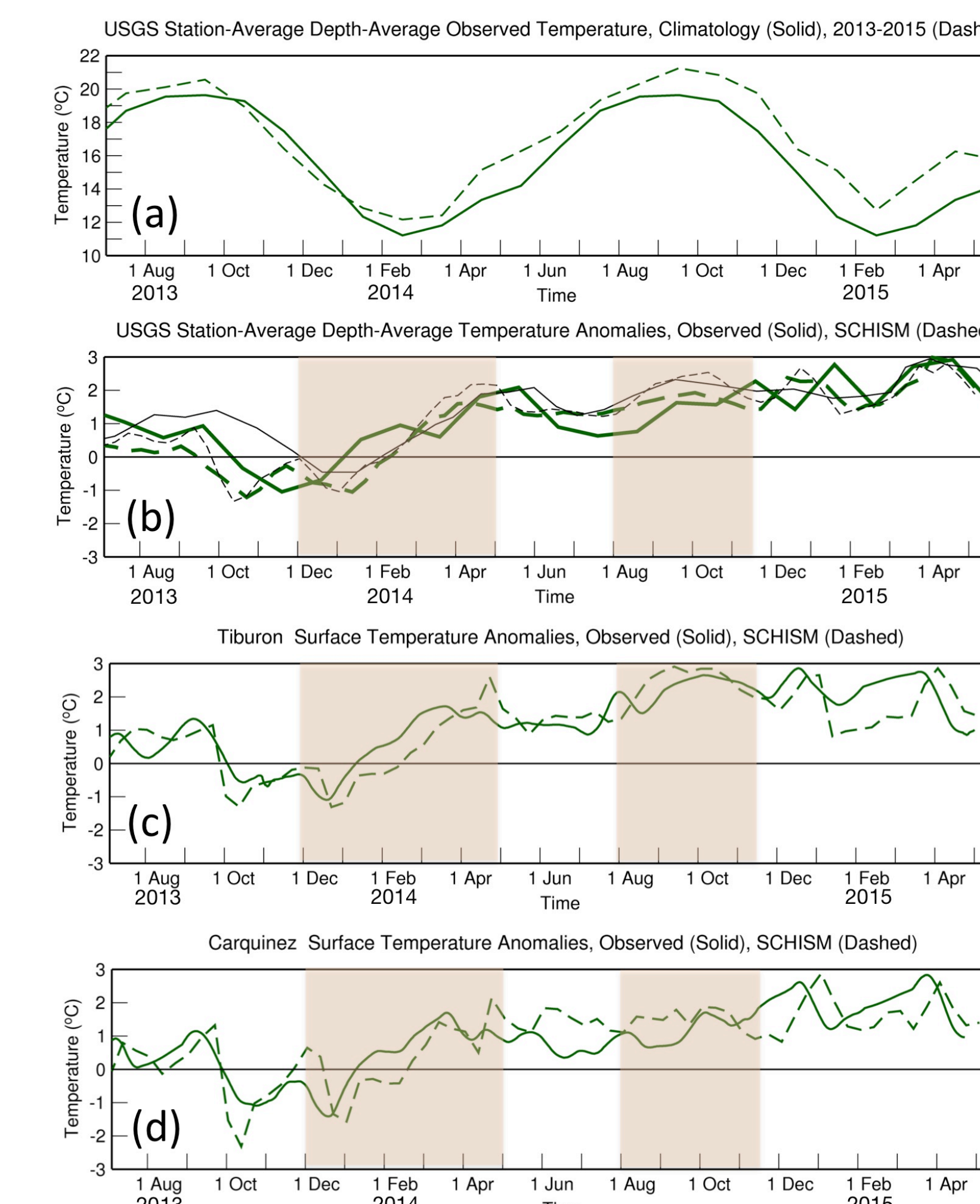


Figure 6. (a) Time series of depth-average mean temperature (°C, dashed line) at the 31 USGS stations used (see text and Figure 1 for details) for the period 1 July 2013 – 31 May 2015. Also shown is the climatological mean seasonal cycle in temperature (solid line). Time series for the period 1 July 2013 – 31 May 2015 of temperature anomalies (°C; anomalies from the 2005 – 2014 mean climatology), solid green lines are observed and dashed green lines the co-located SCHISM model values for: (b) depth-average mean anomalies from the 31 USGS water quality monitoring stations within San Francisco Bay (the thin solid and dashed lines show the observed and SCHISM model anomalies, respectively, for the Central Bay only, see purple triangles in Figure 5 for stations in the Central Bay), (c) the Romberg Tiburon Center pier station surface anomalies, (d) Carquinez California Maritime Pier station surface anomalies. The light brown shading denotes the periods during which the two primary warming pulses discussed in the text develop.

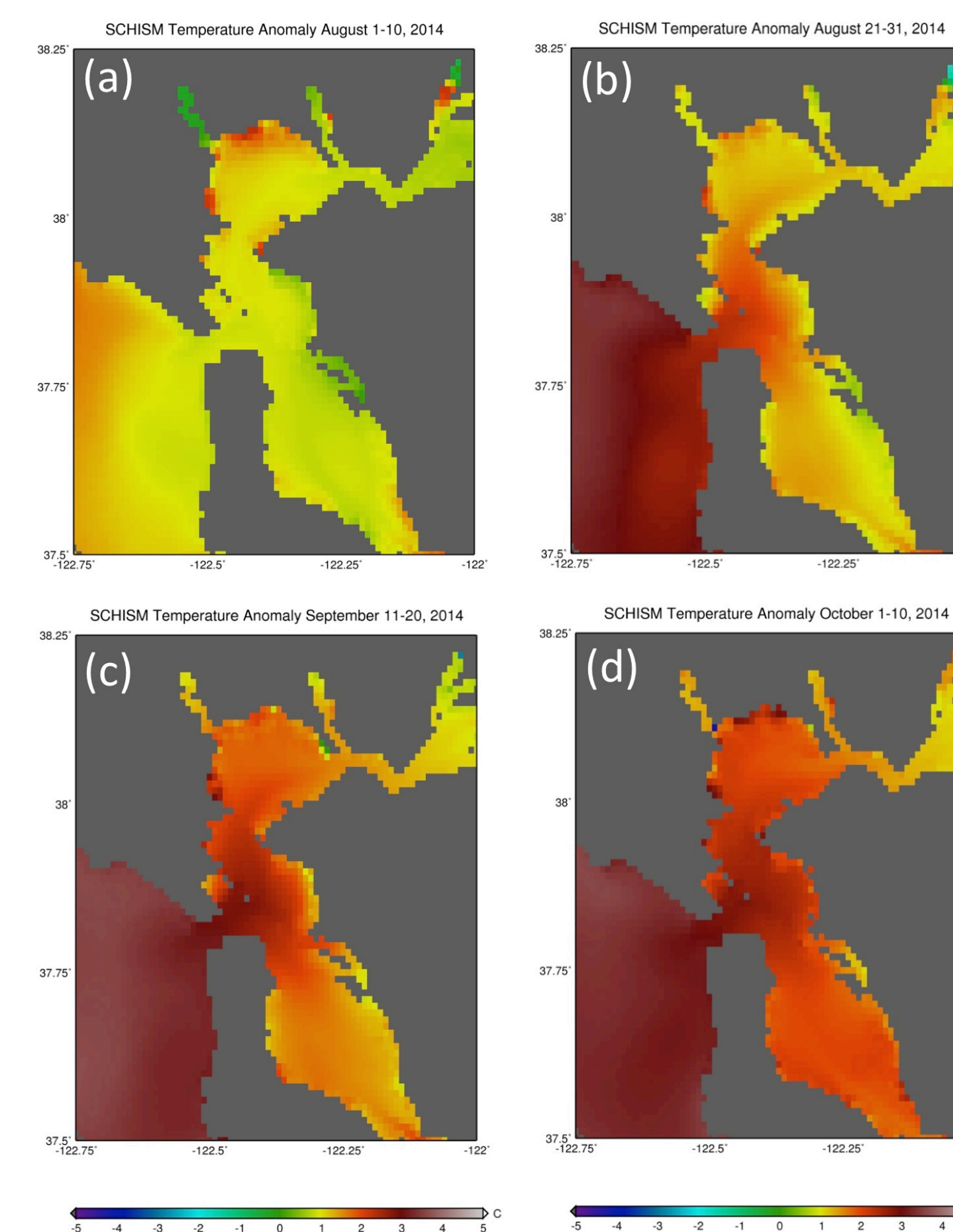


Figure 7. Ten-day average surface water temperature anomalies (°C) as simulated by the SCHISM model (see text for details). (a) Mean for the period 1 – 10 August 2014, (b) 21 – 30 August 2014, (c) 11 – 20 September 2014 and (d) 1 – 10 October 2014.

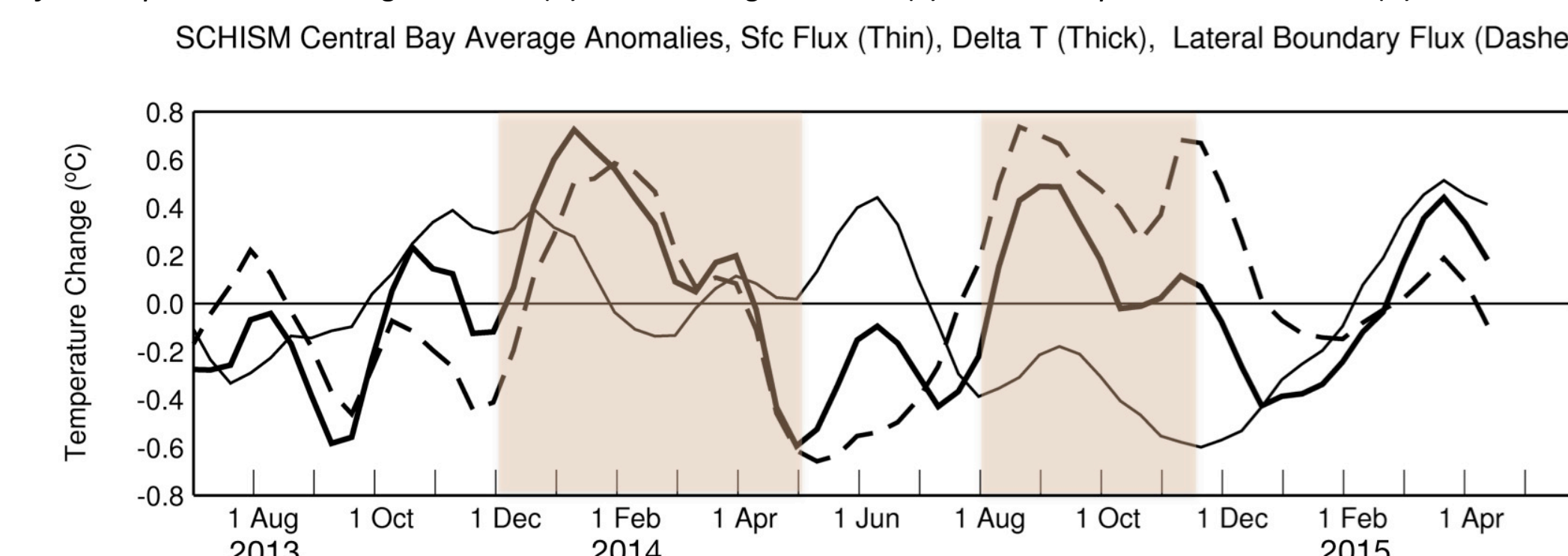


Figure 8. For the period mid-2013 to mid-2015, anomalies in 10-day vertically averaged temperature changes (thick solid line) in the central Bay region delineated by the white lines in Figure 1 and anomalies in selected terms in the heat budget for this box contributing to these changes. The thin solid line curve shows anomalies in the fluxes from the atmosphere and the dashed line the anomalies in the heat flux at the lateral western boundary of the box (the Golden Gate).

SUMMARY – SAN FRANCISCO BAY WARMING

Results presented here document the exceptionally warm temperatures that developed in the SFB during 2014 and early 2015. Observations and simulations using an unstructured-grid numerical model were used to quantify this anomalous warming and study its origins. It was shown that the warming in the Bay occurred primarily during two pulses, the first one early in 2014, followed by a strong reinforcing pulse during the second half of 2014. An analysis of the spatial evolution of the temperature anomalies during the warming pulse in the second half of 2014 suggested that it originates in the adjacent Pacific Ocean. An examination of the heat budget in the SCHISM model for a control volume in the Central Bay supported this conjecture. To what extent these anomalous and persistent warm water temperatures in SFB during 2014 and early 2015 impact the ecosystems would be a logical next step in the study of this warming.