Glider Observations of the 2014-2015 Warming Anomaly in the Southern California Current System

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Overview

During 2014-2015, basin-wide patterns of oceanic and atmospheric anomalies affected surface waters throughout the North Pacific Ocean. We present coastal physical and biological effects of the warming, as measured by our autonomous underwater gliders in the southern California Current System (Fig 1).

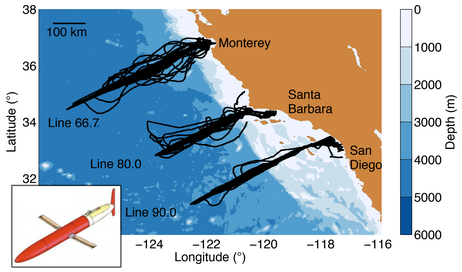

Figure 1: Glider profile locations along CalCOFI lines 66.7, 80, and 90 in black. Blue and tan contours show bathymetry and land, respectively.

Established in 2006, the California Underwater Glider Network (Fig 1) provides sustained subsurface observations for monitoring the regional effects of large-scale climate variability. Along CalCOFI lines 66.7, 80, and 90 (Fig 1), Spray gliders repeat sections that extend to 350-500 km in offshore distance and 500 m in depth. Measured variables include pressure, temperature, salinity, chlorophyll fluorescence, and velocity.

Warm, downwelling conditions characterized the SCCS during 2014-2015. Upper ocean anomalies included: high temperatures, high stratification, a depressed thermocline, freshening, and a depressed subsurface chl-*a* fluorescence maximum. Contemporaneous surface heat flux and wind strength perturbations from the NCEP North American Mesoscale (NAM) model suggest that local anomalous atmospheric forcing caused the unusual oceanic conditions.

2014-2015 Warming Anomaly

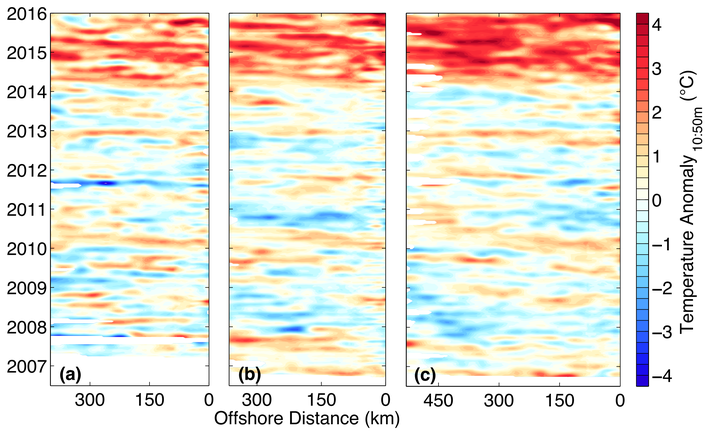

Figure 2: Hovmöller plots of temperature anomalies depth-averaged over 10-50 m along (a) Line 66.7, (b) Line 80, and (c) Line 90. Positive upper ocean temperature anomalies began in early 2014 and remained through the end of 2015. The warming signal occurred simultaneously along all three glider lines. Its duration and amplitude were unprecedented in the nine-year glider timeseries.

Oceanic Conditions

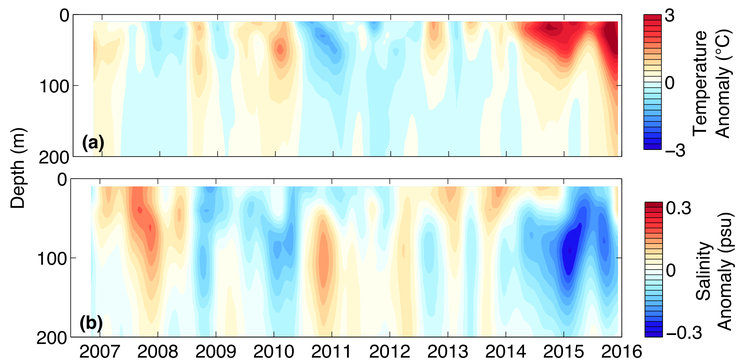

Figure 3: Depth-dependent (a) temperature and (b) salinity anomalies averaged over the inshore 200 km along Line 90 and filtered with a 3-month running mean. A surface-intensified warming and subsurface freshening persisted from early-2014 through mid-2015. Subsequently, a subsurface warming and freshening, likely caused by ongoing El Niño dynamics, developed during the latter half of 2015.

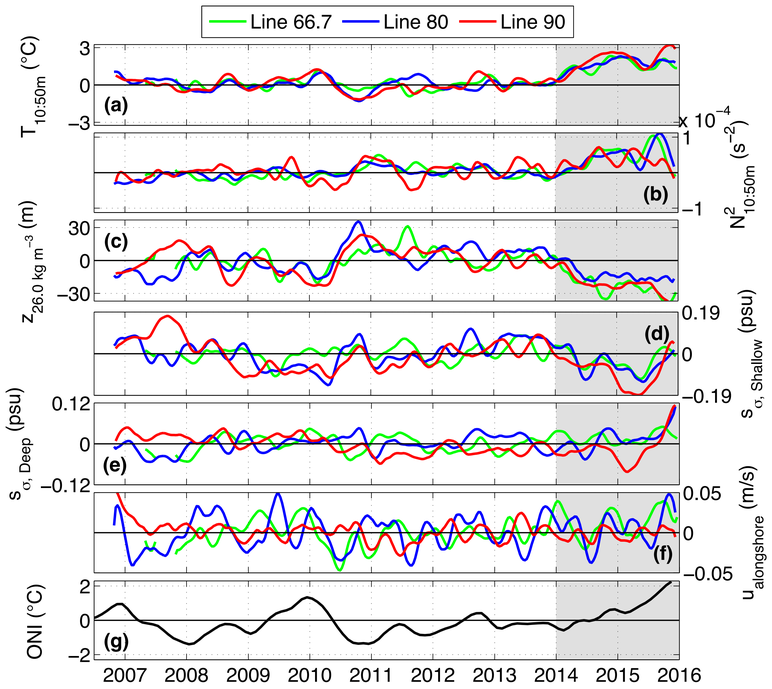

Figure 4: Timeseries of oceanic property anomalies. Glider-measured (a) temperature in the upper 50 m, (b) buoyancy frequency in the upper 50 m, (c) depth of the 26.0 kg/m^3 isopycnal (negative indicates deep), (d) salinity along relatively shallow isopycnals: 25.8 (Line 66.7), 25.5 (Line 80), 25.2 (Line 90) kg/m^3 , (e) salinity along relatively deep isopycnals: 26.5 (Line 66.7), 26.5 (Line 80), 26.0 (Line 90) kg/m^3 , (f) alongshore velocity depth-averaged over the upper 500 m. The glider-measured anomalies are averaged along the inshore 200 km of Lines 66.7 (green), 80 (blue), and 90 (red). (g) Oceanic Niño Index (ONI) shows equatorial SST anomalies averaged over the Niño 3.4 region. All spatially averaged anomalies (a-g) are filtered with a 3-month running mean. The temporal range of the recent anomalous period is shaded in grey.

Atmospheric Conditions

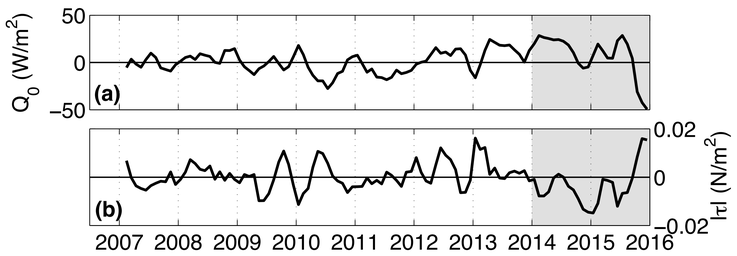

Figure 5: Timeseries of atmospheric property anomalies. NAM model (a) net surface heat flux (positive indicates downward) and (b) wind stress magnitude are averaged over the oceanic domain of Fig. 1 ([-128°,-116°W]x[30°x38°N]), i.e. data above land are excluded from the spatial average. From early-2014 through mid-2015, downward surface heat flux was anomalously high, consistent with the surface-intensification of the warm pool (Fig. 3a), and wind stress magnitude was anomalously low, consistent with the downwelling anomalies (Fig. 4c).

Effects on Biology

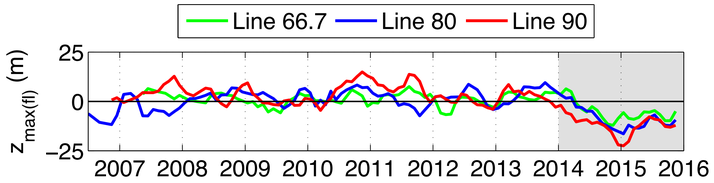

Figure 6: Timeseries of subsurface chl-*a* fluorescence maximum depth anomalies. The anomalies are averaged over the inshore 200 km of Lines 66.7 (green), 80 (blue), 90 (red) and filtered with a 3-month running mean. Like the thermocline depth (Fig. 4c), the depth of the chl-*a* fluorescence maximum was anomalously deep during 2014-2015 along all lines but particularly along Line 90.

Conclusion

Early-2014 through Mid-2015:

- Anomalous surface-intensified warming
- Downwelling anomaly (depressed thermocline, freshening, deepening of subsurface chl-*a* fluorescence max); high stratification
- Freshening along shallow isopycnals
- Atmospheric anomalies: high downward surface heat flux, low wind stress magnitude
- Neutral ONI

Mid-2015 through Present:

- Anomalous subsurface warming
- Positive salinity anomaly along deep isopycnals
- Positive ONI

References

Zaba, K. D., and D. L. Rudnick (*in press*), The 2014-2015 warming anomaly in the southern California Current System observed by underwater gliders, *Geophysical Research Letters*.