Journal of Applied Sciences and Archaeology

Research Article

WRJASA-26-011

Comparison of In-Situ and Satellite Measurements of Sea Surface Salinity in Coastal Southern California

James Halpern[1*] **and Reinhard Flick**[2]

[1]Torrey Pines High School, San Diego, United States of America
[2]Scripps Institution of Oceanography, La Jolla, United States of America

[*]**Correspondence:** James Halpern, Torrey Pines High School, San Diego, United States of America, E-mail: jameskhalpern@gmail.com;
DOI: https://doi.org/10.56147/jasa.1.1.011

Citation: Halpern J, Flick R (2026) Comparison of In-Situ and Satellite Measurements of Sea Surface Salinity in Coastal Southern California. J Appl Sci & Archeaol 1: 011.

Abstract

Our objective is to determine to what extent coastal Sea Surface Salinity (SSS) data represents offshore SSS measurements. Offshore time series of SSS from ships are sparse because of ship-related costs and now widely available global satellite measurements exclude the area within about 25 km of the coast. Our dataset will be used to evaluate satellite SSS measurements with the aim of guiding improvements of satellite instruments to measure coastal SSS.

SSS variations in the coastal ocean influence climate, fisheries and water quality, including pH. Increase in SSS causes surface water to sink with associated upwelling in adjacent regions. Upwelling of colder, nutrient rich water can offset some anthropogenic-generated atmospheric warming and enhance plankton production, boosting fisheries.

We use daily Shore Stations Program data from Scripps Institution of Oceanography (SIO/UCSD) pier and California Cooperative Oceanic Fisheries Investigations (CalCOFI) ship data from 1985-2020. CalCOFI data are seasonal from 3-4 cruises per year at 15 stations along Line 93.3 trending 240° True extending from about 3 km to 750 km offshore of Del Mar, CA, about 11 km north-northwest of SIO. Daily SSS measurements have been recorded at SIO pier since 1916. Beginning in 1950 CalCOFI operated ship surveys at 3-4 months intervals to monitor the coastal ecosystem off the west coast. Operations were intermittently reduced in frequency and geographic extent for lack of funding, becoming irregular after 2020.

The 35-year average SSS at SIO pier was 33.54 Practical Salinity Units (PSU). Within 200 km of the coast, average SSS salinity is 0.04 PSU lower (fresher) than SIO pier with high R^2 coherence of 0.81. Measurement uncertainty is about ±0.002 PSU. This area is the Southern California Bight that lies in the “shadow” of Point Conception with intermittent eddy-like northward counter flow to the farther offshore south-flowing California Current.

We contain our analysis within 200 km of the coast since coastal influences such as freshwater signatures from rivers and runoff don’t extend past 50 km offshore. Coastal fisheries and coastal ecosystems including kelp forests are generally contained within 200 km of the coast, including the Channel Islands. Beyond 200 km, satellite data is very representative of ocean conditions.

Keywords: Satellite; Sea surface; Coastal area; Southern California; Oceanography

Received date: April 08, 2026; **Accepted date:** April 20, 2026; **Published date:** April 30, 2026

Introduction

Sea Surface Salinity (SSS) is the saltiness of the ocean's surface layer. The average global sea surface salinity is approximately 35 Parts Per Thousand (PPT), which is equivalent to 35 grams of salt per kilogram of seawater. Globally, SSS varies from about 32-37 ppt. Changes in ocean salinity are driven by freshwater inputs like precipitation, river runoff and ice melt and by water loss due to evaporation and ice formation. Along with temperature and depth, salinity is a key factor governing seawater's density (mass per volume). Consequently, changes in density drive ocean circulation below the surface layer (which is tens to hundreds of meters deep), a process separate from wind-driven surface currents [1].

Historically, the absolute concentration of dissolved salts in seawater was difficult to measure directly using traditional methods like titration, resulting in sparse global salinity records. To overcome this, modern oceanography shifted away from mass-based methods and utilizes the Practical Salinity Scale (PSS), with measurements expressed in the dimensionless Practical Salinity Units (PSU). PSU is derived from measuring a seawater sample's electrical conductivity, temperature and pressure and is roughly equivalent to ppt. The measurements utilized in this research are expressed in PSU [1].

The launch of satellite missions to measure global SSS was revolutionary by utilizing highly sensitive radiometers capable of detecting minute changes in the ocean's microwave emissions caused by variations in salinity [1].

When analyzing SSS measurements done by satellites, there are some important definitions. The base mission refers to the satellite itself and is the physical platform carrying the instruments that take the raw measurements.

The product is the final, usable dataset derived from the satellite's raw measurements. It's the end result of extensive data processing, calibration and quality control [2].

In-Situ Measurements

Our analysis utilizes the in-situ measurements from CalCOFI's bottle database and the Shore Stations Program's station at Scripps Institute of Oceanography (SIO) [3]. In-situ (Latin for on-site") refers to any¨ measurement taken directly in the water, as opposed to measurements taken remotely by satellite.

CalCOFI data

The California Cooperative Oceanic Fisheries Investigation (CalCOFI) collects data on water properties are measured along linear tracks approximately perpendicular to shore through regular offshore sampling cruises [3]. During these cruises, water properties are measured using a CTD instrument, which stands for Conductivity, Temperature and Depth. The CTD measures the electrical conductivity of the seawater, which is then used to calculate salinity. This monitoring effort is supported in part by the SCCOOS (Southern California Coastal Ocean Observing System) program [4].

Shore stations program data

The Shore Stations Program (SSP) provides long-term, daily observations of coastal ocean properties. The SSP collects daily water samples at specific shore stations, including the one at Scripps Pier near CalCOFI Line 93.3. The salinity of these collected samples is determined in a lab using an inductive salinometer. This instrument measures salinity very precisely by inducing an electrical current in the water sample, eliminating common errors associated with traditional conductivity sensors [5].

Satellite Measurements

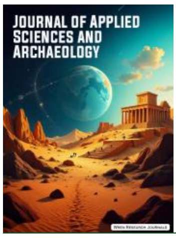
The data for some products comes from direct satellite measurements. This is the SSS data that comes directly from a single satellite and is high-resolution but often noisy and less accurate near the coast because of land and radio contamination. Multi-mission merged products are created by taking data from several different base missions, filling in gaps and smoothing out noise. The data is much more accurate and consistent but slightly less detailed.

Our analysis compares the in-situ measurements from CalCOFI's bottle database, the Shore Stations Program's station at SIO and the SSS measurements from NASA's Multi-mission Optimum Interpolation SSS (NASA OISSS) product [4].

Another multi-mission merged SSS product is the ESA Climate Change Initiative SSS (ESA CCI SSS). While another viable multi-mission merged product, the ESA CCI SSS product will not be included in this analysis and should be assessed in further research. Additionally, measurements from ESA's SMOS satellite are used to fill in gaps when SMAP is unable to deliver scientific data [2].

Other prevalent products for near-coast SSS measurements include the single-mission products Jet Propulsion Laboratory Soil Moisture Active Passive (JPL SMAP) and Remote Sensing Systems Soil Moisture Active Passive (REMSS SMAP) from NASA's base mission SMAP, as well as the Laboratory of Oceanography and Climate: Experiments and Numerical Approaches Soil Moisture Ocean Salinity (LOCEAN SMOS) product of the European Space Agency's (ESA) SMOS base mission [6].

These direct satellite measurements will not be the



Journal of Applied Sciences and Archaeology

primary focus of this research, as they are noisier and more prone to error in the critical coastal region. Our SSS dataset focuses on multi-mission merged products because they represent the best choice for this research, as they have already undergone data cleaning and bias correction *via* a bias-correction algorithm, resulting in the most accurate available dataset. The data record is cleaner, more consistent and minimizes the time and effort required for post-processing and filtering. With further time, research could compare in situ measurements with both multi-mission merged products and direct satellite measurements.

Explaining the OISSS product grid

The OISSS product is a Level 4 product, which means it has been processed and interpolated onto a fixed, uniform grid of 0.25° by 0.25°. This means every single point where a salinity value exists is separated from its neighbors by exactly 0.25 degrees of latitude and 0.25 degrees of longitude. Each pixel in our dataset has hundreds of SSS measurements from 2011-2022, with each measurement being the average SSS over that 0.25 degree by 0.25-degree area.

This can be viewed in **figure 18**. The white markers represent the center of OISSS pixels and the markers that are shades of blue and red represent CalCOFI stations along the 093.3 line The black markers represent the center of pixels that do not have data, since they are contaminated by areas of land that disrupt the satellites' average SSS measurement.

Methods

This research uses the OISSS data product's Multi-Mission Optimally Interpolated Sea Surface Salinity 7-Day Global Dataset V1.0. For more information on this product, see the "Satellite Measurements" section of this poster. It was accessed through the Environmental Research Division Data Access Program (ERDDAP), a visualization and data conversion tool that was developed by the National Oceanic and Atmospheric Administration's (NOAA) at the former Environment Research Division of NOAA's Southwest Fisheries Science Center [7].

Grid dap, a protocol that enables use of the OPeNDAP hyper slab protocol to request data subsets, graphs and maps from gridded datasets, was used to get data with the specific temporal and spatial parameters necessary for this research [7]. CalCOFI data was accessed through their publicly available bottle database, which contains a large variety of oceanographic data collected from chemical analyses of seawater samples from 1949 to present. For more information, see the "In Situ Measurements" section of this poster. Data from the Shore Stations Program is available in Excel and .csv spreadsheet formats through the UC San Diego Library Digital Collections. There is more information in the "In-Situ Measurements" section of this poster.

These datasets were compared through a variety of plots and statistical measures. A 90-day running average calculation was performed on the OISSS product to reduce noise before any further statistical analysis. CalCOFI and OISSS measurements are compared in time series and scatter plots, to visualize correlation. Then, a variety of statistical measures, such as least squares regression and mean difference, were calculated to numerically compare the two measurements of SSS. CalCOFI and Shore Stations Program datasets are compared by calculating R^2 between CalCOFI SSS measurements and the Shore Stations program SSS measurements for that day for all 15 of the stations on the 093.3 line. SSS measurements by the OISSS product and Shore Stations Program are not able to be compared because the OISSS product grid does not cover near-shore regions and SSP measurements are strictly near-shore.

For visualization purposes, the relevant CalCOFI points, OISSS grid datapoints and SSP station in La Jolla were programmed to overlay satellite imagery using Google Earth Engine. This is shown in the" Findings and Discussion section of this poster. These points were plotted manually and one at a time, so only relevant points for this research and extra points to demonstrate the resolution of the OISSS data product grid, are included in the consideration of time.

Data Points

The caption of each plot indicates the CalCOFI station that is being compared with the nearest OISSS grid datapoint (**Figure 18** in" Findings and Discussion section for visualization).

OISSS 90-day running average and CalCOFI SSS measurements *vs.* time.

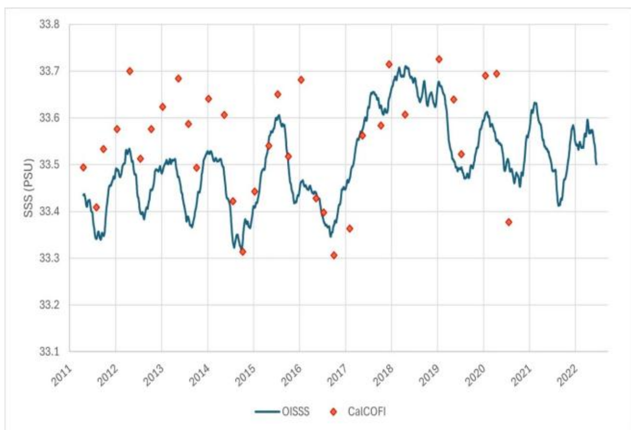


Figure 1: 093.3 035.0.

Journal of Applied Sciences and Archaeology

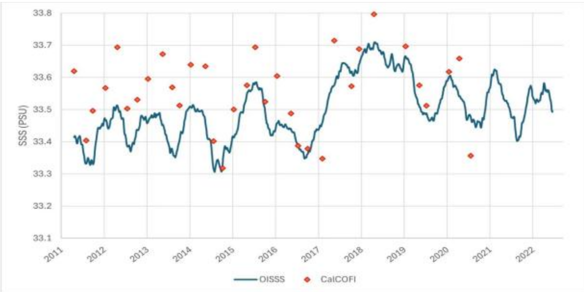


Figure 2: 093.3 040.0.

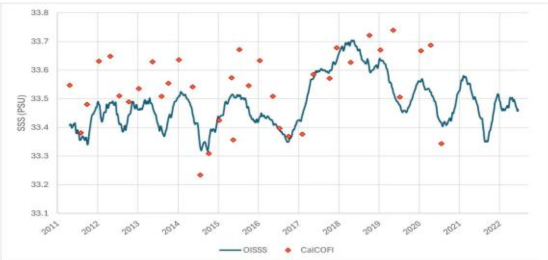


Figure 3: 093.3 045.0.

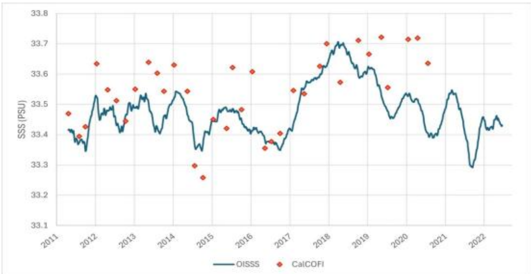


Figure 4: 093.3 050.0.

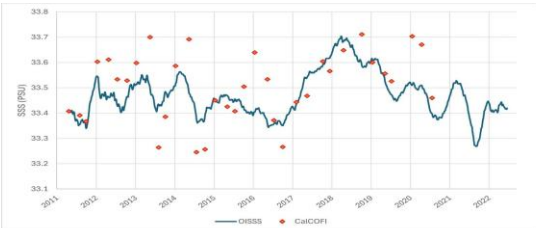


Figure 5: 093.3 055.0.

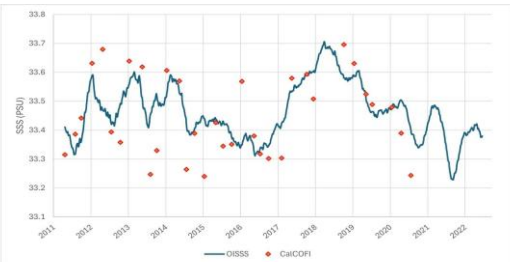


Figure 6: 093.3 060.0.

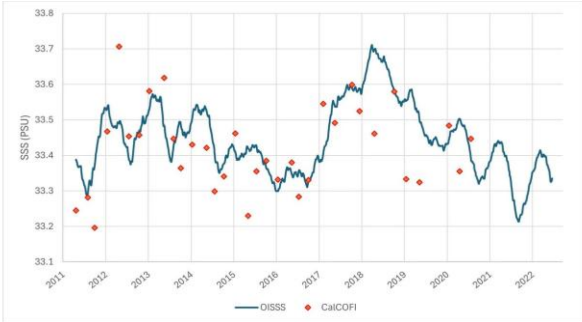


Figure 7: 093.3 070.0.

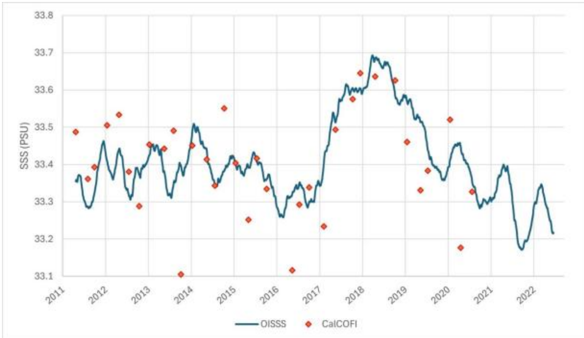


Figure 8: 093.3 080.0.

OISSS *vs.* CalCOFI SSS measurements

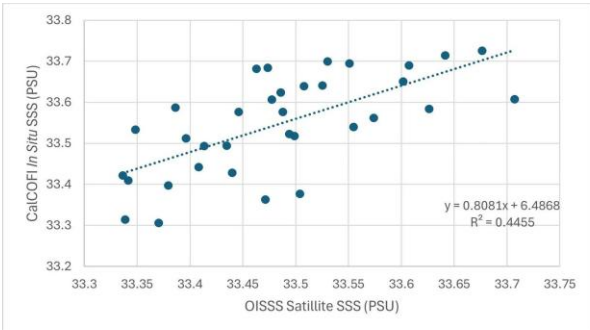


Figure 9: 093.3 035.0.

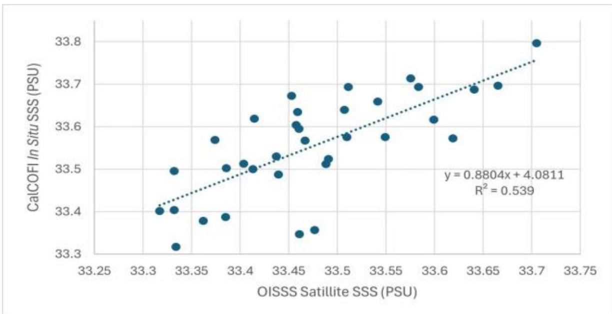
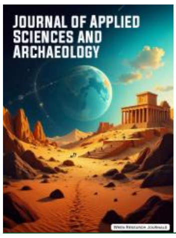


Figure 10: 093.3 040.



Journal of Applied Sciences and Archaeology

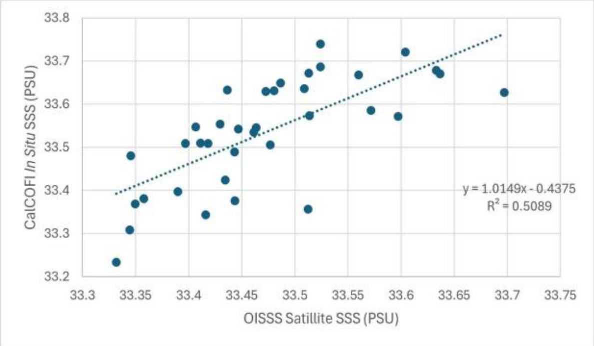


Figure 11: 093.3 045.0.

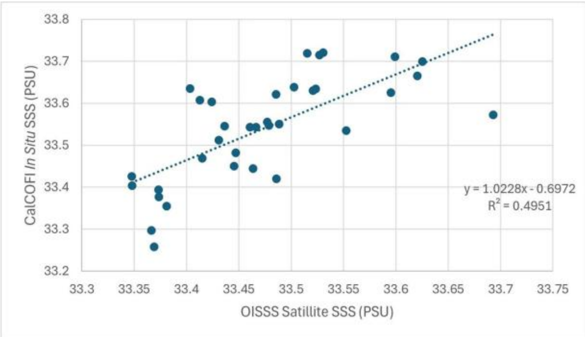


Figure 12: 093.3 050.0.

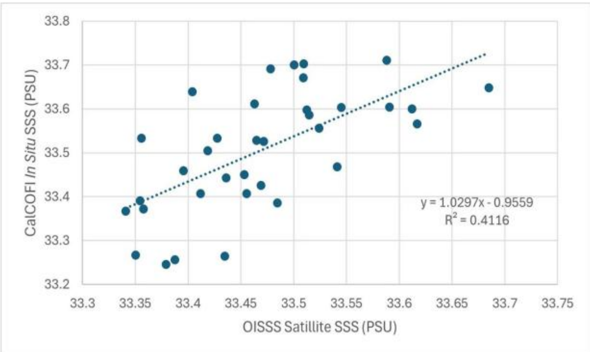


Figure 13: 093.3 055.0.

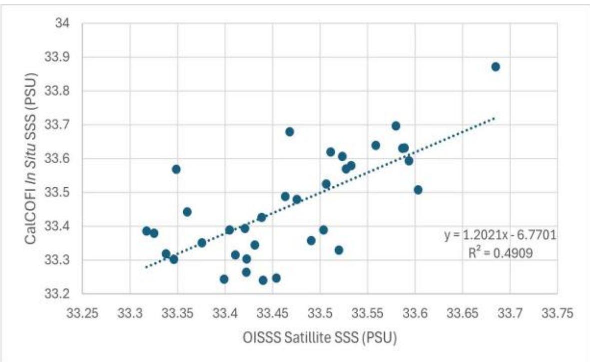


Figure 14: 093.3 060.0.

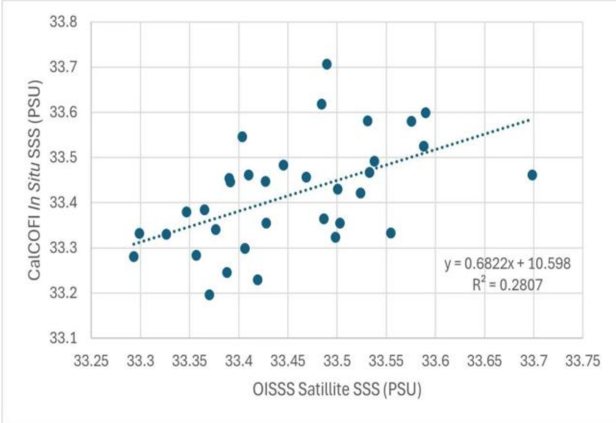


Figure 15: 093.3 070.0.

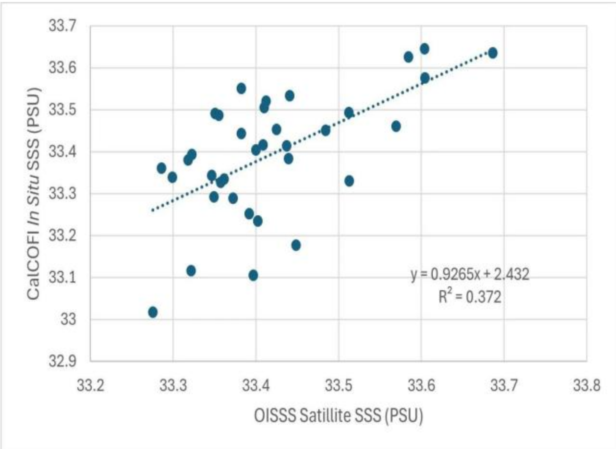


Figure 16: 093.3 080.0.

R2 of CalCOFI and shore stations program SSS measurements relative to shore

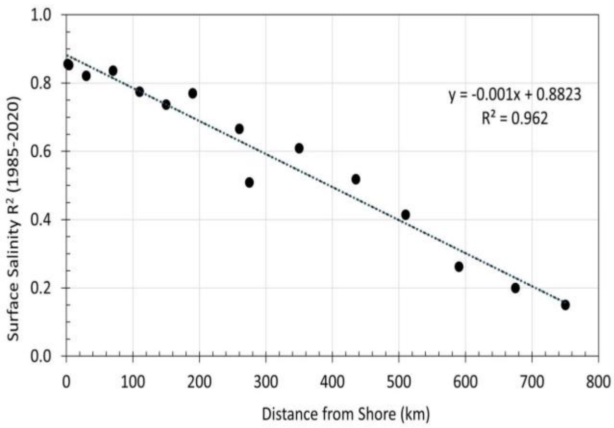


Figure 17: Correlation squared between CalCOFI in situ SSS measurements and Shore Stations Program (SSP) SSS time series as a function of distance from the shore.

Journal of Applied Sciences and Archaeology

Findings and Discussion

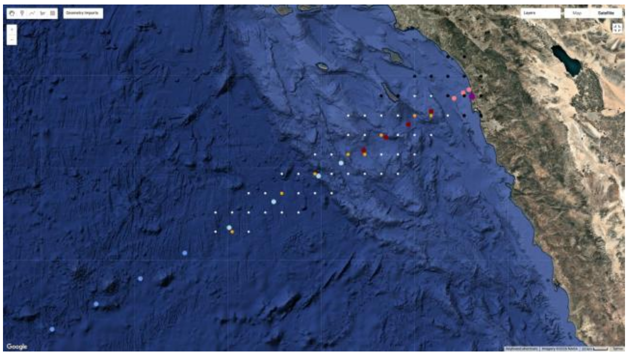


Figure 18: Interactive map of CalCOFI Line 93.3, SIO Pier and OISSS salinity measurement sites (key in appendix). The live, interactive version of this tool is available *via* Google Earth Engine at: https://line-andoisss-grid.projects.earthengine.app/view/calcofi-line-933-vs-oisss-grid-vs-sio-pier-map

Statistical Findings

Our statistical analysis finds that the OISSS product demonstrates a moderate positive correlation with in situ CalCOFI measurements across all stations (Average R [?] 0.66, Average R2 [?] 0.44). This suggests that OISSS successfully captures the overall low-frequency variability of SSS in the region. It exhibits a small, statistically significant negative bias relative to CalCOFI, with an average mean difference of -0.030 PSU, indicating that OISSS generally reports SSS values slightly lower than the in-situ measurements. The overall precision (standard deviation of the difference) between the two datasets is approximately 0.099 PSU. This is essentially equivalent to the mission requirement for satellite SSS accuracy, which is cited at 0.1 PSU [8,9].

The strength of the correlation varied significantly along the CalCOFI line, ranging from a high of R^2=0.539 at station 093.3 040.0, to a low of R^2=0.281 at the further offshore station 093.3 070.0. This suggests satellite data performance is not uniform across the spatial gradient, requiring cautious application depending on location. Overall, these statistics indicate that The OISSS product is a reliable indicator for regional SSS trends, although there is an apparent small, negative bias and a reduction in correlation at specific offshore locations.

To further determine the statistical significance of our findings, p-values were calculated between each assessed CalCOFI station and the nearest OISSS grid datapoint. The average of the observed positive correlations (R [?] 0.66) was found to be highly statistically significant, with an average p-value of 1.78×10^{-4} ($p<0.001$), confirming a true relationship between the datasets that is extremely unlikely to have occurred by chance and is therefore statistically significant.

Table 1: Statistical measures for each CalCOFI station and corresponding point on OISSS product grid. The averages of each measure across all 8 analyzed stations are included in the bottom row.

Station	R	R^2	Mean OISSS	SD OISSS	Mean CalCOFI	SD CalCOFI	P-value	Mean difference	Precision (SD of difference)
93.3 35.0	0.67	0.45	33.49	0.1	33.55	0.12	1.62E05	-0.06	0.09
93.3 40.0	0.73	0.54	33.47	0.1	33.55	0.12	7.74E07	-0.08	0.08
93.3 45.0	0.71	0.51	33.47	0.09	33.54	0.13	1.04E06	-0.06	0.09
93.3 50.0	0.7	0.5	33.47	0.08	33.54	0.12	2.42E06	-0.07	0.09
93.3 55.0	0.64	0.41	33.47	0.08	33.51	0.14	3.27E05	-0.04	0.1
93.3 60.0	0.7	0.49	33.47	0.09	33.46	0.16	2.78E06	0.01	0.11
93.3 70.0	0.53	0.28	33.45	0.09	33.42	0.12	0.0	0.04	0.11
93.3 80.0	0.61	0.37	33.42	0.1	33.39	0.15	0.0	0.03	0.12
Average	0.66	0.44	33.46	0.09	33.49	0.13	0.0	-0.03	0.1

Shore stations program *vs.* CalCOFI stations

The relationship between SSS measurements by CalCOFI's bottle database and coastal Shore Stations Program stations demonstrates a decaying trend in R2 with increasing distance from the coast. This trend indicates that as distance from shore increases, SSS variability measured close to the shore by the SSP shares an increasingly small amount of its total variation with SSS measurements taken offshore by CalCOFI missions. This rapid decrease in correlation suggests that the processes driving SSS variability are highly localized and coastal-bound in this context (*e.g.,* river runoff, coastal upwelling) and become rapidly less influential on the SSS signals observed in the open-ocean environment, which are instead dominated by larger-scale oceanic dynamics such as eddies and large-scale upwelling events [10,11].

Discussion

The satellite data and the in-situ data have some significant variation of up to a couple of tenths of a unit, which is a large number in SSS measurements. Visually, comparisons between SSS measurements from the OISSS product and CalCOFI missions show the same large changes in salinity from 2011 to 2022 and the statistical analysis from the prior section reaches the same conclusion. Long term variability is reflected in both means of measurement, but with significant noise from CalCOFI data when compared with the running average of the OISSS data product.

While the calculated R and R^2 values are moderately high, it would be expected that these two-time series would be more strongly correlated as they are measured roughly in the same spatial and temporal range. This naturally brings the question: Why are they so different? Could it be that temporal specificity is extremely important and measurements need to be made almost simultaneously to be accurately correlated? Or could it be that spatial variation is very significant as a result of eddy flows? Are there acute inaccuracies in SSS measuring instruments?

Additionally, when examining the time series plots of OISSS product data, two things are visually eye catching: A clearly defined and substantial increase in SSS from 2017 through 2018 and a subsequent decrease throughout 2019. What might have caused this? Was it a combination of factors?

Limitations

Our in-situ analysis is limited spatially, confined to: CalCOFI line 093.3, which is a single line of measurements that begins offshore of Del Mar, CA, spanning from about 3 km to 750 km at 240° true and the single point of Scripps Pier at Scripps Institute of Oceanography (SIO) in La Jolla, CA.

Additionally, we only conduct a statistical analysis between CalCOFI and OISSS product SSS measurements for points 4 through 11 of the 15 points on the CalCOFI 093.3 line. Ideally, we would analyze OISSS versus CalCOFI measurements for all of the first seven points on the CalCOFI 093.3 line, since these are within 200 km of the coast (the farthest of these from the coast is station 093.3 050.0, which is 176km away from the coast along the CalCOFI 093.3 line, see the" Findings and Discussion section). Beyond 200 km, satellite data is very representative of ocean conditions. However, satellite data is not available for the first three points on the CalCOFI 093.3 line due to land contamination from proximity to the coast, which is a core reason for this research. Therefore, the next four points along the line are included in our statistical analysis (093.3 055.0, 093.3 060.0, 093.3 070.0 and 093.3 080.0). Future research should compare the data from remaining sites with satellite measurements, potentially using more advanced programming resources.

As mentioned in the “Satellite Measurements” section, this analysis only uses satellite SSS data from NASA’s OISSS data product. Further research should compare in situ measurements with both multi-mission merged products and direct satellite measurements.

With more programming resources, a program could be made to take all 113 CalCOFI stations (Southern California stations are shown in the” Findings and Discussion section), determine the ones that have corresponding satellite data with the aforementioned products and perform a statistical analysis to compare the two forms of SSS measurement in the available spatial and temporal range. This program could also compare data from all 10 of the active Shore Stations Program sampling sites with the nearest CalCOFI stations, ultimately creating a comprehensive analysis of the relative accuracy of SSS measurements, both in situ through the Shore Stations Program and CalCOFI nearshore sampling and with satellite observations.

Disclosures

All raw in situ data were sourced from the CalCOFI Bottle Database (https://calcofi.org/ data/oceanographic-data/bottle-database/) and the Shore Stations Program Data Archive (DOI: 10.6075/J0S75GHD). Satellite data were obtained from the PO. DAAC archive (DOI: 10.5067/SMP104U7CS) using ERDDAP’s grid dap tool.

An LLM (Gemini 2.5 Pro) was used for editing and refining language in some sections of this poster. The authors are solely responsible for all scientific content and accuracy.

The authors declare no conflicts of interest related to this research.

References

1. NASA (2011) Salinity: Overview.
2. NASA (2026) SSS retrieval-it’s complicated.
3. CalCOFI (2026) Bottle database.
4. SCCOOS (2023) Strategic plan.
5. Shore Stations Program (2022) Program & methods.
6. Jarugula S, Fournier S, Reager JT, Pascolini-Campbell M (2025) Intercomparison of in situ and satellite sea surface salinity products for global coastal ocean studies. Journal of Atmospheric and Oceanic Technology 42: 3-16. [Crossref] [Google Scholar]

7. National Centers for Environmental Information (2026) Using ERDDAP.

8. Kerr YH, Font J, Waldteufel P, Berger M (2005) The soil moisture and ocean salinity mission-SMOS. European Space Agency.

9. Lagerloef G, Colomb FR, Le Vine D, Wentz F, Yueh S, et al. (2008) The Aquarius/SAC-D mission: Designed to meet the salinity remote-sensing challenge. Oceanography 21: 68-81. [Crossref] [Google Scholar]

10. Melnichenko O (2021) Multi-mission L4 optimally interpolated sea surface salinity (Ver. 1.0). [Crosssref] [Google Scholar]

11. Carter ML, Flick RE, Terrill E, Beckhaus EC, Martin K, et al. (2022) Shore stations program data archive: Current and historical coastal ocean temperature and salinity measurements from California stations. UC San Diego Library Digital Collections. [Crossref] [Google Scholar]