Northern Pacific Loggerhead Sea Turtle Movement and Sea Surface Temperature

Studying the Thermal Corridor Hypothesis

Anika Quon

ESS 141: Remote Sensing of the Oceans

Final Project

March 24, 2024

Abstract

Northern Pacific Loggerhead sea turtles make some of the greatest migrations of any animal, crossing the entire Pacific Ocean to find foraging habitat on the North American coast. However, little is known about the conditions of how and why they are able to make this journey. Briscoe et al. have hypothesized that oceanic temperature anomalies create a “thermal corridor” of warm water that allows turtles to pass through what is, in normal years, a strong barrier of cold water through the Eastern Pacific (2021). This study investigates the connection between sea surface temperature (SST) and turtle migratory habits in the 2023-2024 El Niño event—which is associated with elevated SST in the Eastern Pacific—to further understand how ocean sea surface temperature guides turtle migrations. Using remotely-sensed data on sea surface temperature, this study preliminarily found support for the thermal corridor hypothesis, showing that turtles follow temperature gradients in order to reach the Eastern Pacific during their migrations.

Introduction

Loggerhead turtles (*Caretta caretta*) are found in oceans worldwide and are vital members of their ecosystems, facilitating nutrient recycling and bioturbation in benthic communities across their range (Lazar et al., 2011). They hold important cultural significance to many communities, and can be found in many cultures’ traditional stories and mythologies. Loggerhead turtles are also listed as *vulnerable* by the IUCN (IUCN-SSC Marine Turtle Specialist Group, 2023). Despite this ecosystem and cultural relevance, and their vulnerability, little is known about the majority of turtles’ lives. The time between hatching and reproduction is termed the “lost years”, because so little is known about their behavior or life histories due to the inaccessibility and difficulty of monitoring in the open ocean (Carr, 1987). Understanding turtles' migratory patterns and behavior during the "lost years" will aid our understanding of how they are affected by climate change, and thus inform conservation efforts not only for loggerhead turtles but also the organisms and ecosystems that surround them.

North Pacific Loggerhead turtles are known to make some of the most vast migrations of any animal, traveling across the entire Northern Pacific Ocean. Through analysis of mitochondrial DNA, researchers have discovered that loggerhead turtles in Baja California, a healthy foraging habitat for them on the Eastern edge of the Northern Pacific ocean basin, actually originated from Japan, where they nest and hatch in the Western Pacific (Bowen et al., 1995; Matsuzawa et al., 2016). Through this genetic analysis and satellite tagging, the loggerheads on the eastern and western coasts of the Northern Pacific basin are now thought of as a single, widely-dispersed population (Uchida and Teruya, 1988; Resendiz et al., 1998; Nichols et al., 2000). Though not all loggerheads complete this whole coast-to-coast migration, this indicates a level of population connectivity previously believed not to be possible in many marine species, and has important implications for turtle and marine life conservation.

Typically, the California Coastal Current forms a barrier that marine life cannot cross, as cool waters from higher latitudes travel down the coast and create cold conditions that thwart marine life traveling from the west (Figure 1). Even Darwin deemed that the Eastern Pacific was "impassible" for marine life to cross, labeling the cold waters of the California coast as the "Eastern Pacific Barrier" (EPB) (Briscoe et al., 2016; Darwin, 1872). There have been exceptions to this trend, species that are able to cross this barrier despite the harsher conditions, including loggerhead turtles, as previously noted, however this is not the standard. While many turtles originating from Japan's nesting sites have been found to forage in the Central North Pacific, a select few have managed to cross the California Coastal Current and reach the Eastern

Pacific, typically only under variable and select conditions (Briscoe et al., 2016). The mechanisms of when and how the turtles are able to navigate this long journey remains largely a mystery.

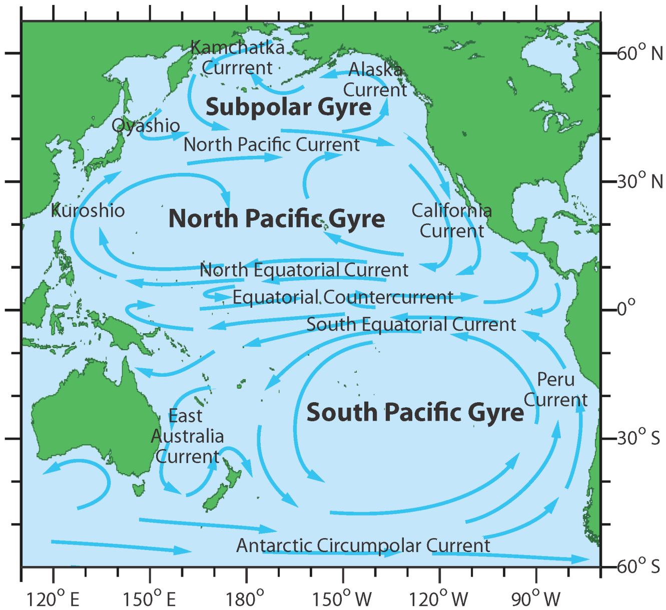

Figure 1: Ocean Currents in the Pacific Ocean. The California Current that typically brings cold water down the coast, creating an oceanographic barrier for marine life (Ocean Tracks).

It is known that turtles navigate their migrations and orient themselves on the earth primarily according to geomagnetic fields (Lohmann et al., 2001), but much of their distribution is also determined by their surrounding temperature. Given that turtles are ectotherms, their core temperature and survival success is dependent on the temperature of their environment, making ocean temperature a particularly important factor in their ability to survive, and an important cue in their selection of habitat (Bentivegna, 2002; McMahon and Hays, 2006; Hawkes et al., 2007; Báez et al., 2011). Furthermore, beyond their own morphology, temperature has large effects on fishery distribution and the abundance of food for turtles. Sea surface temperature is thus hypothesized to have large influences on the distribution and migration of loggerhead turtles.

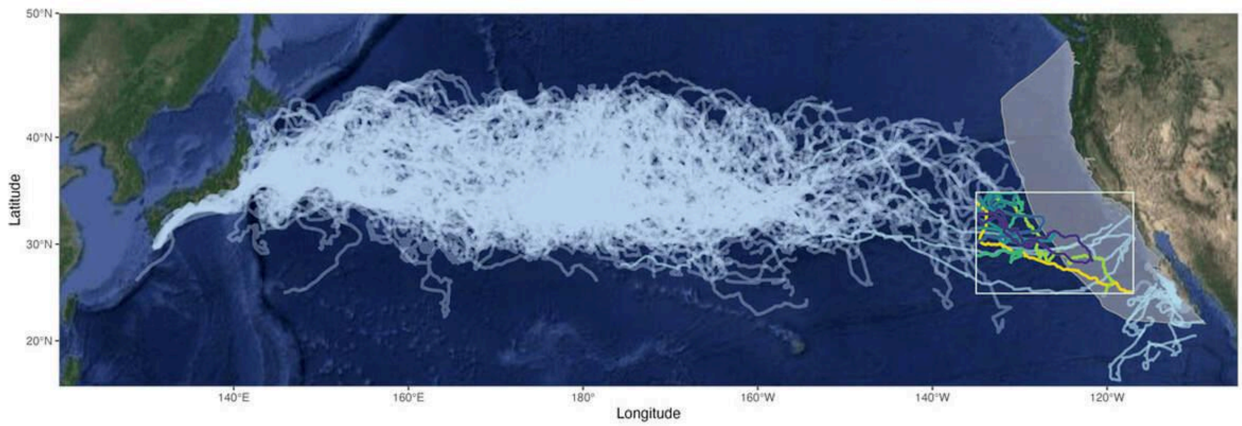

Figure 2: Modeled distribution of 231 electronically-tagged juvenile loggerhead sea turtles across the North Pacific Ocean between 1997 – 2013, deployed in Japan and in the Central North Pacific (Briscoe et al. 2021). The shaded gray region indicates the California Current Large Marine Ecosystem (CCLME). As seen, very few of the 231 turtles enter the CCLME.

In a landmark paper by Briscoe et al. (2021), they hypothesized that ocean temperature anomalies, such as El Niño, create dynamic corridors of warm waters within the Northern Pacific basin that allow loggerhead turtles to cross the California Coastal Current barrier under select conditions. In their meta-analysis of 231 satellite-tracked turtle migration routes in the Northern Pacific, only 6 routes crossed the EPB and migrated past the Central North Pacific region (Figure 2). Briscoe et al. analyzed the oceanographic conditions of these 6 “sentinel” loggerheads’ movements and noted a strong connection between anomalous sea surface temperature (SST) and migratory patterns (Figure 3), potentially facilitating the turtles’ atypical migrations. This hypothesis, named the “thermal corridor hypothesis”, has made the tangible connection between SST and turtle migratory behavior, and has implications on our understanding of the habitat and population connectivity, and recruitment of this species. Given that climate change is projected to create more intense and more frequent temperature and oceanographic anomalies, understanding this relationship more deeply is essential to appropriately managing and protecting this population of loggerhead turtles.

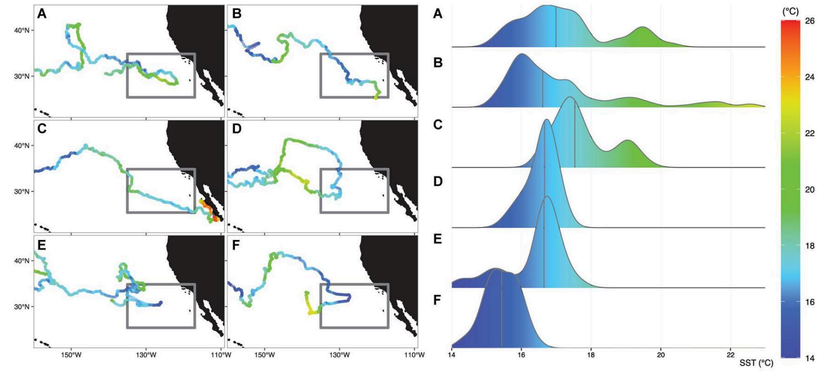

Figure 3: Daily SST trends (right panel) of the 6 "sentinel" loggerhead turtles (Briscoe et al. 2021). Data extracted was from a subset of the turtles' movements, shown by the gray box (left panel).

In this paper, I combine recent data on sea turtle migration and SST from the 2023-2024 El Niño event. El Niño events create above-average SST in the central and eastern tropical Pacific Ocean (NOAA), thus, we hypothesize that under these conditions, loggerheads are able to cross the EPB and reach the North American coast around Baja California. I investigate if turtles were able to cross the cold California Coast Current during this season and, by combining these two datasets, further analyze the thermal corridor hypothesis, understanding how turtles react to anomalies in sea surface temperature.

Methods

This paper combines two datasets: satellite-tracked sea turtle location data and remotely-sensed SST. Data on sea turtle migratory patterns was gathered from the ongoing *Sea Turtle Research Experiment of the Thermal Corridor Hypothesis* (hereafter referred to as the STRETCH project), a collaboration between Japanese, Mexican, and US researchers to understand the thermal corridor hypothesis. This project releases 100 juvenile loggerhead turtles in the Central Northern Pacific, equipped with satellite tags, and then tracks their location for as long as the batteries allow (for most trackers, approximately six months). The juvenile loggerheads are raised from hatchlings at the Port of Nagoya Public Aquarium (PNPA) in Japan, for about two years prior to deployment, and then 25 are released each year over the course of four years. The project aims to understand turtle movement patterns in a variety of different oceanographic and climate conditions. The STRETCH project began in 2023, which was during an El Niño event with anomalous warm waters in the Eastern Pacific Ocean—the ideal conditions under which the turtles are able to reach Baja California, according to the Thermal Corridor Hypothesis (Briscoe et al., 2021). On July 10, 2023, 25 juveniles were deployed in the Central North Pacific Ocean somewhere between 140 and 160 degrees west longitude. Exact deployment locations were determined by weather and SST conditions, and their locations have been tracked since.

For the scope of this study, sea turtle location data from the STRETCH project was extracted on 14 dates at two-week intervals between July 25, 2023 and January 23, 2024 (inclusive). Although turtle locations were transmitted at different times on each date depending on when they surfaced, I only gathered and analyzed the first transmitted location on each date, for consistency. I did not analyze data before July 25 in order to allow time for the turtles to adjust and respond to their surrounding SST, meaning that the results are more indicative of the turtles' response to SST cues rather than their deployment locations. I chose to collect data at two-week intervals because it shows change in both sea turtle location and SST, while still making overall patterns of movement and temperature clear. For my study, the study period ended January 23, 2024 due to the timing and the availability of the data at that point in time. In this vein, it is important to note that this dataset is inherently incomplete. Further data has since been made available, and more data on turtle migration patterns will continue to be collected and made available across the next three years and under different oceanic conditions, as the STRETCH project researchers deploy more cohorts of turtles.

SST data was collected via a remotely-sensed dataset available on the Ocean Color web database from NASA. The data was level 3, 8-day SST averages (11 μ nighttime) from the Aqua-MODIS satellite, with 4 km resolution. While 8-day average data is not ideal given that the sea turtles' locations changed daily, it provided the most complete image of sea surface temperature over the shortest period of time. Given the two-week intervals between turtle location data, using 8-day averages avoided overlapping SST data points (i.e. no two images used the same SST 8-day average).

The two datasets were combined and analyzed on the SeaDAS program version 8.4.1. SST data was loaded and cropped to the coordinates 57.417°N, -171.125°W, 13.375°S, -110.875°E, which adequately fit all turtle location coordinates across the 14 dates. Black land masks were laid over any land within that region and the turtle location dataset was cleaned and uploaded as a .txt file with the latitude and longitude of each of the 25 turtles on each date. This yielded 14 images that overlay the locations of the loggerhead turtles with the SST data across the 14 different dates (Appendix 1). Using the SeaDAS program, I extracted the mean SST across all turtles' transmitted locations for each date (Table 1).

Note: This study is not part of the STRETCH project, though I collaborated with its principal investigators to get the turtle location data. The STRETCH project researchers are actively working on conducting their own analysis connecting SST and other oceanographic conditions to turtle behavior. Results from this study aim to show general trends, but remain preliminary and are not an official part of the project.

Results

While not all turtles completed the journey eastward after their deployment in the Central North Pacific, approximately 7 of the 25 turtles were able to pass the EPB and migrate to the Baja California coast (Figure 4). Approximately 8 of the other turtles headed directly back west towards Japan after deployment. 2 of the turtles stopped transmitting their location early in the monitoring period (August and September), likely due to technology malfunctions, and the remaining 8 headed south, their destination and ability to pass the EPB remain unclear. Overall, the 7 successful migrators in the 25 turtle cohort demonstrate that oceanographic conditions during the 2023-2024 season did indeed allow for select loggerhead turtles to overcome the barriers that typically deter their migration to the Eastern Pacific. Further analysis of the SST and other oceanographic conditions allows us to understand if this was due to the existence of a thermal corridor.

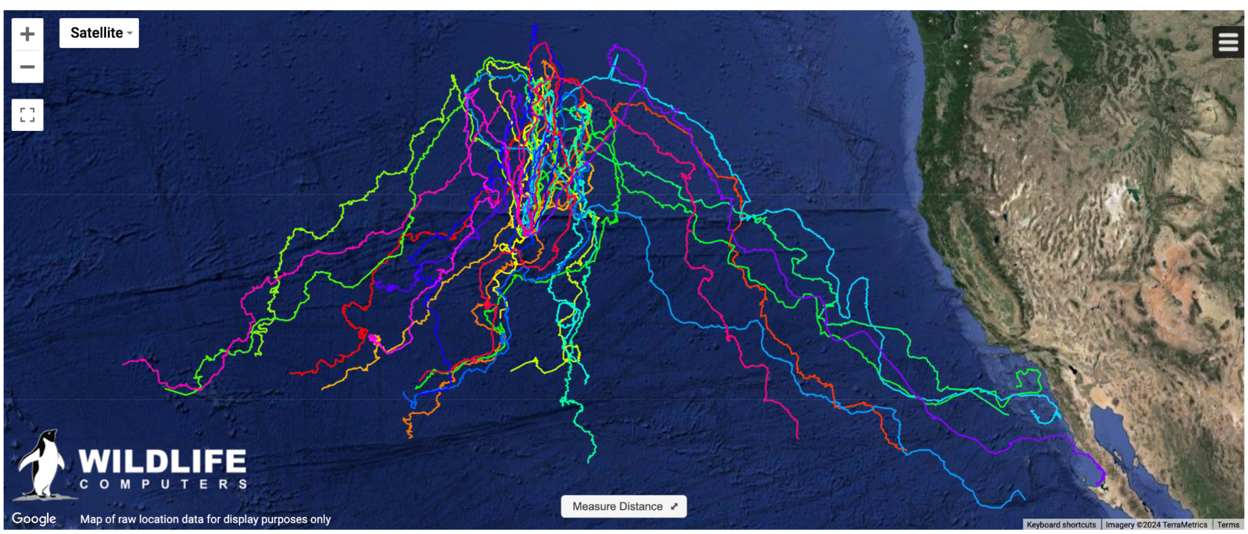

Figure 4: Loggerhead turtle migration routes from the STRETCH project, from July 25, 2023 - March 21, 2024. While the dataset used for my study does not show the turtles actually reaching the North American coast, they do, as shown by this most recent data from the STRETCH website.

Images created in SeaDAS, showing the turtles' locations laid over SST satellite data, are in Appendix 1. Looking qualitatively at the images, the turtles appear to follow along the gradient of temperatures between ~15°C to 23°C, shown by their frequent appearance along the border of light blue and green shaded areas in the images. Throughout the six-month monitoring period of this study, whether traveling east or west, turtles continued to be found along this blue-green border (i.e. they are found in a constant temperature range) in all images. This dynamic temperature border extends from the turtles' deployment area in the Central Northern Pacific both westward towards Japan and southeast towards Baja California, forming a visual and qualitative "thermal corridor" of ideal temperatures for turtles to follow, as hypothesized (Briscoe et al., 2021). The existence of this dynamic corridor becomes particularly apparent in November 2023. This qualitative finding of the thermal corridor is supported by the extracted data on mean SST (Table 1).

The mean SST for turtles' transmitted locations fell within a range of ~15.9°C to 20.6°C, with a median of 17.14°C. All turtles were found in similar temperature ranges throughout their monitored time, regardless of whether they moved east, west, or south. This suggests that temperature is in fact an important environmental cue guiding turtle habitat selection. As seen in Figure 5, the mean SST at turtle locations decreased throughout the course of the monitoring period, however, this is most likely due to seasonality affecting overall regional SST, as there is a corresponding trend in regional mean SST (Figure 5) as the monitoring season moves from summer to winter. The mean regional SST was consistently above the mean SST at turtle locations. Changes in overall regional SST can be seen qualitatively by the images in Appendix 1, as less space is occupied by warm orange/red shading and more blue shading takes over as time passes. Because the turtles were always found at SST values within the expected range and below the regional mean across all dates, and because turtle movement patterns appear to follow a predictable warm corridor through qualitative analysis, this decrease in mean SST at turtle locations over time is not thought to be a significant trend signaling turtles' response to temperature cues.

Table 1: Mean SST at turtle locations and for the region as a whole on each date.

Date	Turtle Location Mean SST (°C)	Regional Mean SST (°C)	Difference in regional and turtle mean SST
July 25, 2023	20.58	21.68	1.10
Aug 8, 2023	19.08	22.73	3.65
Aug 22, 2023	19.26	22.86	3.60
Sep 5, 2023	18.71	22.33	3.62
Sep 19, 2023	17.81	21.99	4.18
Oct 3, 2023	17.19	21.64	4.45
Oct 17, 2023	17.05	20.95	3.90
Oct 31, 2023	17.12	20.61	3.48
Nov 14, 2023	17.15	19.34	2.19
Nov 28, 2023	16.21	18.43	2.22
Dec 12, 2023	15.77	18.33	2.56
Dec 26, 2023	16.11	17.60	1.49
Jan 9, 2024	15.77	16.81	1.05
Jan 23, 2024	15.94	16.56	0.62

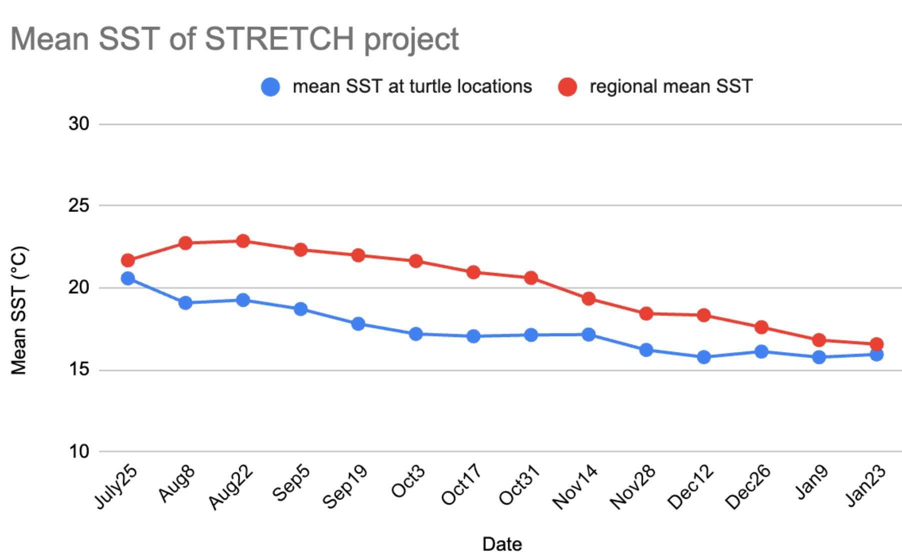

Figure 5: Graph comparing mean SST at turtle locations to regional mean SST across all dates.

Discussion

The findings of this study align with previous analysis done by Briscoe et al. on the six previously-known cases of eastward turtle migrators, and preliminarily support the thermal corridor hypothesis. The successful migrators analyzed in Briscoe et al. were found in a range from 15.1 to 22.6 °C water (2021), which encompasses the range of mean SST values found in this study of 25 loggerheads deployed in 2023. Briscoe et al. found that turtles that migrated east stayed within habitats with a median SST of 17.1°C, which aligns with the median SST value found in this study. Thus, when placed in the context of the larger body of literature, this study agrees with existing data on sea turtle temperature preferences, and continues to support the hypothesis that temperature is a primary indicator of turtle migratory habits. This study is preliminary support for the thermal corridor hypothesis that anomalous warm conditions in the Northern Pacific (such as the El Niño event of 2023-2024) allow for increased recruitment of loggerhead turtles on the North American coast.

The largest difficulty in analyzing this study is that this dataset represents only one season's worth of oceanographic and climatic conditions. In order to truly understand how temperature anomalies affect loggerhead turtle migratory behavior, this year must be compared to other years of both normal and anomalously cold conditions. In other words, we lack a standard control group, being able only to resort to satellite-tracking data collected by other research groups as a baseline, as was analyzed by Briscoe et al. (2021). This is due to the nature of this field, as there is so little research done on sea turtles in the open ocean during their "lost years." With more cohorts of juvenile turtles being released over the next three years as part of the STRETCH project, it will be possible to compare turtle movements as it relates to year-to-year changes in mean SST. This should fill in some of the lingering questions about turtles' responses to temperature, and shed light on this underfunded, under-researched topic. This study shows support for the fundamental concepts behind the thermal corridor hypothesis, but due to the ongoing nature of this project, all results of this study can only be considered to be preliminary due to their limited sample size.

This study primarily relied on looking at overall trends, without rigorous statistical analysis. Using statistical testing would improve the confidence in our conclusions. Further research would also need to be done to understand what factors drove the cohort of 25 turtles to diverge, with some turtles moving east and others moving west. Factors such as chlorophyll-*a* concentrations, wind speeds, or turbidity should also be examined in connection with this dataset to understand what other oceanographic and/or geomagnetic cues turtles may follow to guide their migrations.

Conclusion

Both qualitatively and quantitatively, loggerhead sea turtles have been found to follow temperature gradients when migrating in the North Pacific. This study has shown that this species has a preferred temperature range of ~15.9°C to 20.6°C, which they stay in throughout their migration, regardless of final destination. While sea turtle migration data under other oceanic conditions is limited, this shows preliminary support for the thermal corridor hypothesis, suggesting that temperature is a key factor in predicting the viability of sea turtle migration pathways. Anomalous temperatures, as created by El Niño during the monitoring period of this study, allow for the passage of turtles through regions that are typically barriered off by cold currents. However, this is based on a limited data set and limited statistical analysis, so further research is needed to validate this hypothesis.

With climate change making ocean warming a more frequent and extreme occurrence, the thermal corridor will likely widen and be more readily available for turtles to utilize in crossing the EPB in future years. We can expect higher recruitment of loggerheads in North American waters, and increased connectivity between North American and Western Pacific loggerhead populations. Continuing to learn about this population dynamic over the coming years via the STRETCH project will help the multiple countries that house native loggerhead populations to prepare and put protective measures in place regarding the conservation of these creatures in a changing world.

Acknowledgements

Thank you to Professor Arrigo for guiding me through SeaDAS and remote sensing. Thank you to Dana Briscoe, Larry Crowder, George Balazs, and the rest of the Loggerhead STRETCH research team for sharing their preliminary data with me. Visit https://www.loggerheadstretch.org/ to learn more about the project and to follow along the course of this experiment.

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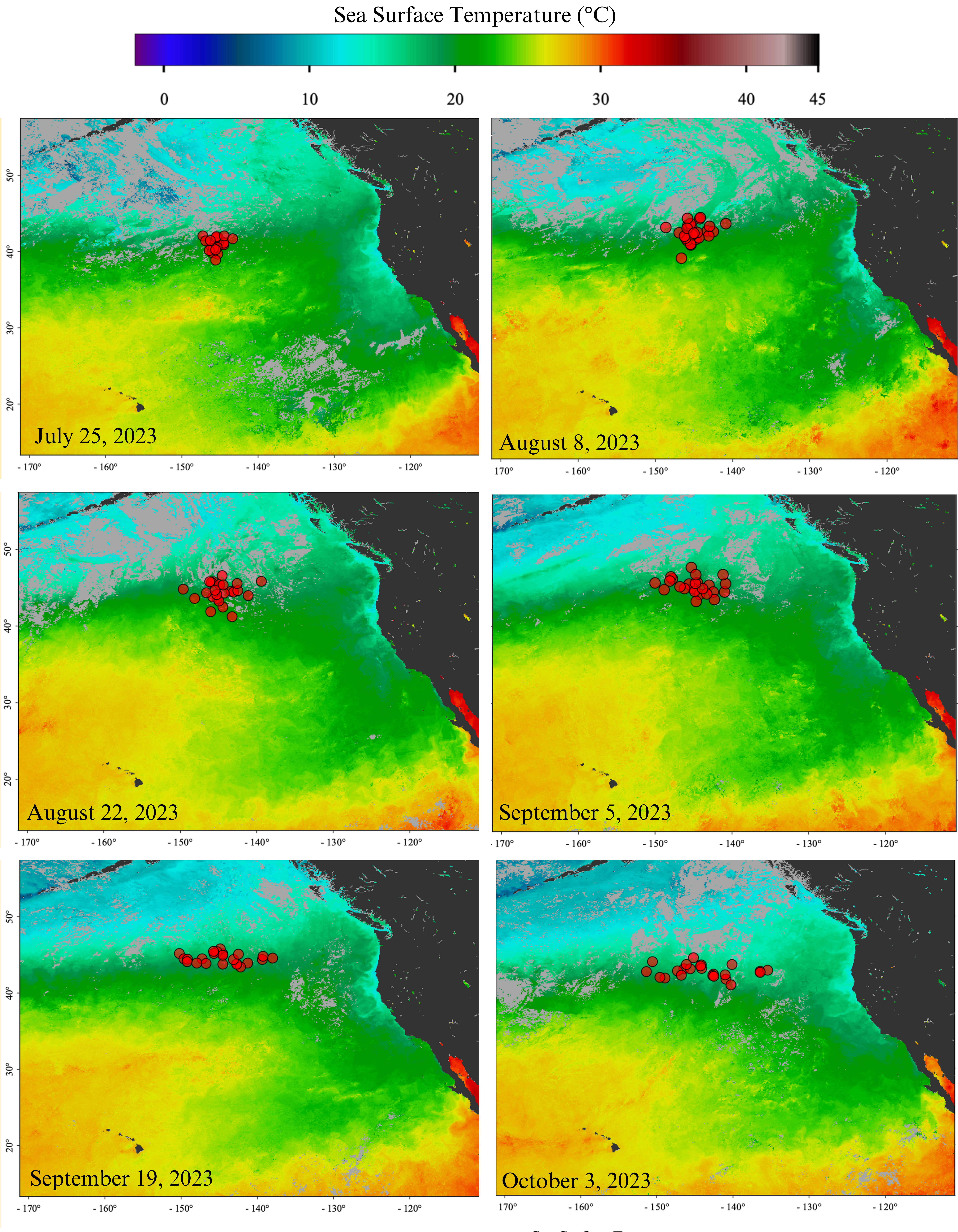
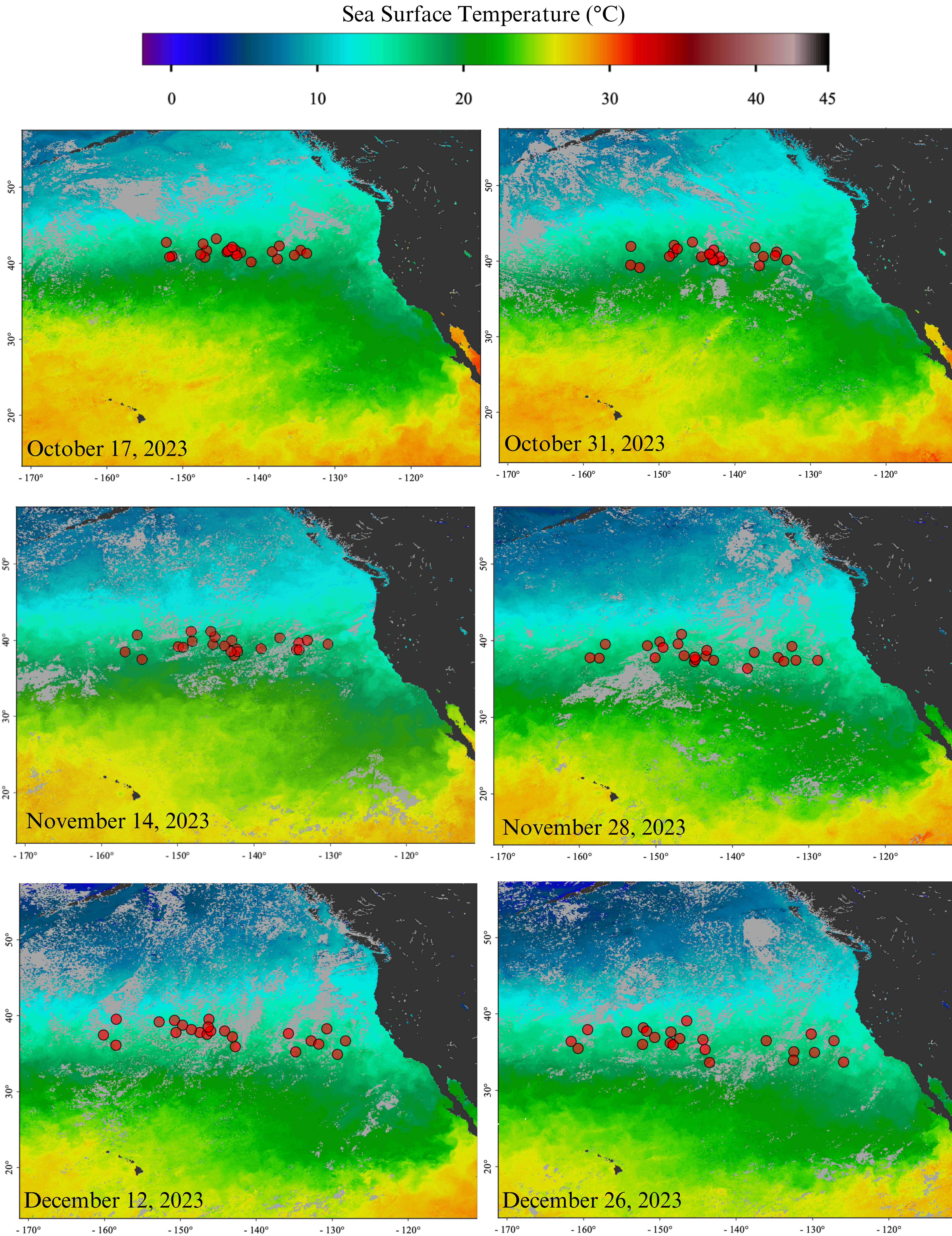
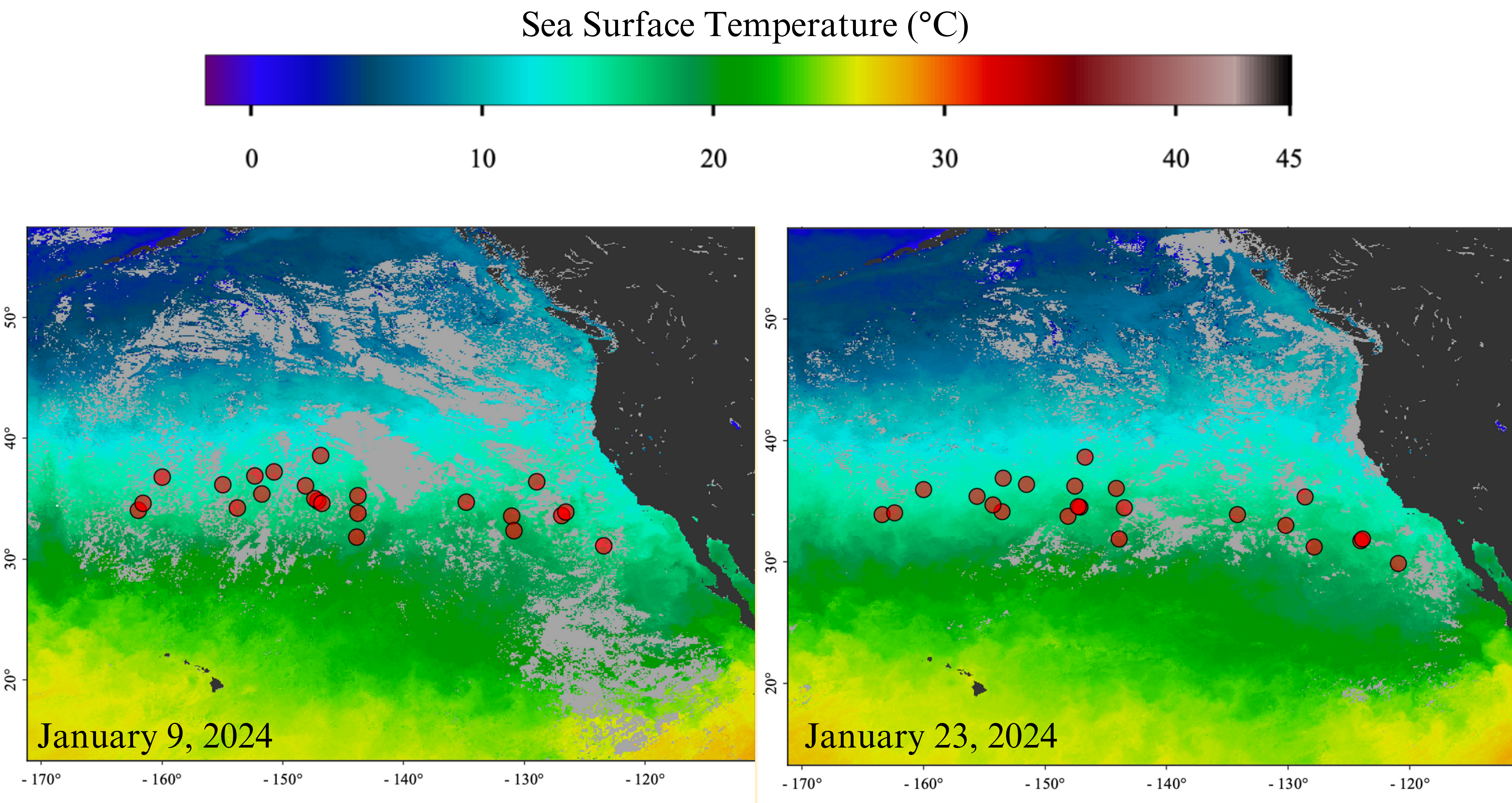
Appendix 1: Images from SeaDAS of SST and Turtle Locations across dates 2023-2024




Sea Surface Temperature (°C)
0
10
20
30
40
45
October 17, 2023
October 31, 2023
November 14, 2023
November 28, 2023
December 12, 2023
December 26, 2023
20°
30°
40°
50°
- 170°
- 160°
- 150°
- 140°
- 130°
- 120°


Sea Surface Temperature (°C)
0
10
20
30
40
45
January 9, 2024
January 23, 2024
50°
40°
30°
20°
- 170°
- 160°
- 150°
- 140°
- 130°
- 120°