Comparison of Measured SST & Fluorometer In-Situ to Remotes Sensing Products -

A Geospatial Information Systems Approach

OC3570

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Introduction

The purpose of this project is to compare and contrast the in-situ sea surface temperature and fluorometer data directly to remotely sensed satellite imagery. Although this type of project may seem rather ordinary and redundant given the projects and labs conducted in MR 3522 - Remote Sensing of the Atmosphere and Ocean, the emphasis will lie within the utilization of ArcGIS 8.3 as comparison and analysis tool.

This particular application of a geospatial information system has a very high relevance to future Naval Operations. The Chief of Naval Operations has tasked the Oceanographer of the Navy and the METOC community to provide all geospatial information within Forcenet under the SeaPower 21 concept. The Department of the Navy has recently created the Information Professional community to acquire, regulate, and administer the Navy's computer and network infrastructure. Since the METOC community has had years of experience displaying environmental information in stand alone type programs like GARP, TeraScan, and AWIPS, then it was a logical decision to appoint the community to take the next step take ownership of all geospatially referenced information for Forcenet. The IP community will simply provide the networking support.

For this project I chose ArcGIS 8.3 as the analysis tool because it is earmarked as the GIS program of choice for Forcenet. It is already established as the Unites States government GIS program standard by other agencies such as U.S. Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA), formally known as the National Imaging and Mapping Agency (NIMA). This was an excellent opportunity to utilize a computer program that should become an integral part of our community as GARP or TAWS has become in addition to introducing its display and analysis capabilities to my fellow METOC officers.

The majority of the cruise was overcast, which completely inhibits remotes sensing efforts. However, there were sufficient breaks in the weather to permit partial satellite coverage over the eight day period. Given that the measured data was collected every 20 seconds, I anticipated that there should be enough overlap to make a satisfactory comparison of the in-situ data to satellite imagery. I do anticipate a slight disparity between the measured values of sea surface temperature and fluorometer readings in comparison to the satellite images. The shipboard data was measured in the ship's sea chest which is several feet below the surface to the water. Since the satellites' instruments measure the environmental data at the skin of the water's surface, the comparison should be off slightly since the values of sea surface temperature and chlorophyll decrease with depth.

Data Analysis

As aforementioned, ArcGIS 8.3 was utilized as the analysis tool. The advantage of ArcGIS is to be able to display all data and images in a common display that is completely referenced to the same datum. If different datums or geospatial fields of view are used, the comparison to plotted data points to observed imagery will not match. Temperatures or sea color references will not spatially align and one would be compared to a different location than the other. This is displayed in Figure 1a Figure 1b. Figure 1a is view of the cruise legs traveled each day from January 27th to January 31st. These legs are ‘georeferenced’ to WCS 1984 datum. Figure 1b is a satellite image of chlorophyll concentration of the California coast with latitude and longitude line running straight up and down indicative of a mercator projection. The red circled areas clearly show where spatial alignment of the two sources is in error. Comparing a data point from one to the other would like be comparing a summertime temperature in downtown Monterey to downtown Salinas and claiming they were in the same spatial location. The georeferencing of the satellite imagery was uncomplicated since the latitude and longitude lines were displayed on the image. During the georeferencing process, those precise coordinates are manually entered to that visual point on the image. Once at least six points are entered into the program, the image has second order accuracy which is sufficient for analysis compared to the 275 kilometer diagonal length of the cruise perimeter.

The shipboard data in the UDAS files was plotted and the 20 second collection rate was too high of a display resolution to be useful when looking at the cruise perimeter in a single view. The data was time averaged every 10 minutes to provide a more visually useful resolution for comparison to the satellite imagery. Once the data was imported and plotted, satellite imagery was georeferenced and from there manual or “eyeball” procedures for comparison could be conducted. ArcGIS allows for zooming into the display at nearly any map scale. Visual comparison was done first with the cruise legs filling the display and viewed at larger scales (zoomed in) to reveal any subtle nuances between the data and the satellite image. Obviously, the finer the satellite image resolution, the better the comparison result at such higher scales. Since different color gradients were used for each satellite image, a color bar ‘Rosetta Stone’ was created to easily compare the SST values between the data plotted and the satellite image as shown in Figure 2.

The UDAS text files were imported to Microsoft Excel. From there, the latitude and longitude were converted from degree-minute-decimal minute format to degree-decimal degree format. The longitude had to be made negative to reflect western longitude for ArcGIS to properly plot in the correct hemisphere. All other columns were deleted except sea surface temperature and fluorometer. Those values were time averaged every 10 minutes and the file was copied into notepad and directly input into ArcGIS under the 'Add XY data' function. Assigning X to longitude and Y to latitude, the data set was then plotted as a series of points that I assigned to WGS 1984 datum.

Satellite imagery found online was CoastWatch SST [NOAA], CoastWatch Chlorophyll [MODIS], National Environmental Satellite, Data, and Information System (NESDIS) SST [NOAA], and NESDIS Chlorophyll [NOAA]. Also, a very useful product that I could only find from campus internet access (.mil access) displayed a POES orbiter non-linear sea surface (NLSST) temperature image. Failure to denote the internet source, only half of the cruise area was retrieved and said source could not be found again in future imagery search efforts. I labeled this image as POES NLSST Imagery. Lastly, Professor Collins conducted his own MATLAB plot of SST from the UDAS files. This plot was sent to me and I georeferenced the image since latitude and longitude marks were provided on the plot. This plot was very useful in conducting a quality check of my plotted 10 minute time averaged data of sea surface temperature as displayed in Figure 3. The MATLAB plot utilized a large variance in color making the subtle changes in SST very evident. The 10 minute averaged SST data was divided into

0.5 incremental bins. Although not the UDAS SST plot is not as variant in the color range, the values for both the 10 minute averaged data plots and the MATLAB plot do match at every point and thus pass the quality check.

Complications developed when attempting sea color comparisons. A fluorometer hits seawater with blue light, causing the chlorophyll pigments within phytoplankton to glow red. The instrument then measures this red fluorescence resulting in a voltage signal output. The shipboard fluorometer has three voltage output settings. Which ever setting that was used was not recorded and hence is unknown. This resulted in the inability to determine the direct proportionality of the fluorometer voltage output to a calculated chlorophyll level. There was no ability to determine a numerical comparison between the measured fluorometer value and a satellite image chlorophyll value. However, the procedure for visual comparison could still be conducted by looking at the rate of change in direct measurements to the rate of change of satellite imagery. This simplistic chlorophyll comparison method was done by assigning the fluorometer voltage output signals to a color code matching the satellite imagery. A green (lower), yellow (higher), orange (highest) direct measurement color code was used. So noticing a green-to-yellow or yellow-to-orange trend meant increasing chlorophyll concentrations and vice-versa. This same trend analysis could be applied to the satellite imagery as well.

Analysis

My analysis begins with comparing measured SST to SST satellite imagery. One observation was noted before beginning this analysis. By plotting the measured SST for the entire cruise, the data becomes overlapped in the Monterey Bay (Figure 4a). Starting

February 1st, the ship maintained position within Monterey Bay until pulling into Moss Landing on February 3rd. The measurements from January 27th and February 1st through February 3rd overlap spatially and confuse the analysis. Data points for those days were removed and saved under a separate file to alleviate the overlap for analysis comparison (Figure 4b).

Based on the satellite position during the cruise, CoastWatch SST imagery was available for January 27th through January 31st. Due to overcast conditions during these dates only January 31st imagery was useful for analysis. Partial coverage was available for January 29th – 30th, but the ship was not in position where non-overcast conditions existed. January 31st imagery contained the largest area of non-overcast imagery where the ship was actually in position over that same area. Even with this larger area for comparison, the CoastWatch SST imagery was not very useful for analysis (Figure 5). The color gradient varied very little for range of temperature change measured directly by the ship. Assuming little change from twenty-four hours prior, the ship measured 14.0 – 14.5°C starting on January 30th and lowered to 12.0 – 12.5°C by the time the ship reached Port San Luis. The satellite imagery displays the same light blue color for the entire area. This 2 degree variance with no ability to compare any change in the satellite imagery discounts this source of imagery from any analysis. By the end of January 31st, the measured SST dropped to 11.0 -11.5 (displayed in purple) where the Coastwatch image color darkened very slightly. This slight change in satellite imagery is still not useful for comparison.

Better results were obtained by looking at a three day averaged SST contour plot provided from the NESDIS website. The website did not have any links as to the process by which they obtain a fully detailed three day average plot when most of the area was obscured by cloud cover during that time frame. I can only assume that model data may provide resolution to the image when remotely sensed data is unavailable. The image obtained covered from January 30th through February 1st. The website did not provide a means to obtain any archived images from the list of current imagery. NESDIS contour imagery was available for January 27th through January 29th while the second group was out at sea, which included myself. I assume little to no change in daily sea surface temperatures in order to conduct the analysis from January 27 through January 30th (Figure 6).

Looking at the box for January 27th, the measured data lies within the 12.0 – 12.5°C range while the satellite image displays a region 13°C. This is close and could be accounted for the difference in depth from which the sea surface temperature is being measured. Half way through the box, the measured data changes to yellow (12.5-13°C) which closer to the satellite measurement and still within the difference due to depth of measurement also. On January 28th, the measured yellow trend (12.5-13°C) continues then rises slightly to 13.0-13.5°C (orange) then back down to yellow which maintains the satellite measurement of 13°C. A light blue 14°C warmer spot appears on this leg but no such conditions were measured by the ship and no other satellite imagery gives further indication of such a spot occurring. January 29th was of particular note. The temperature rose up to orange (13.0-13.5) and maintained that trend for most of the day. The location at which the temperature increased and maintained occurred very close to the contour line separating 13°C from 14°C. This indicated a strong visual correlation between the measured data and satellite imagery with only a slight disparity of a half a degree throughout the majority of the image. The measured data darkened to red (13.5-14°C) then hit a cooling trend down to yellow (12.5-13°C) before rising back up a matching 14°C measurement. This slight cooling condition lied spatially very near a 13°C plume 20 kilometers away, east by northeast. Starting January 30th, the visual correlation between measured data and satellite imagery is lost. As the ship approaches Port San Luis, the measured values dip down to 12.5-13.0°C (yellow) while the satellite image maintains a 14°C trend. At very near shore, the satellite image has not data while the direct measurement dips even cooler another half a degree (light blue). This lack of visual correlation continues on January 31st. Measured values remain in the low twelve's with satellite displaying no data, 13°C, and even a small spot back up to 14°C. By then end of the day, direct measurements are in the 11.0-11.5°C range which is a whole degree and a half to two degrees colder than the nearest satellite data point.

The comparison between measured SST and the higher resolution POES SST image for January 31st was next (Figure 7). A noticeable difference between this image and the NESDIS contour image is the more accurate visual comparison of the two data sets along the coast. This higher resolution image utilized an even larger color gradient to display the temperature reading. Additionally the satellite imagery displays data right up to the coastline. Utilizing the color bar 'Rosetta Stone' (Figure 2), it is visually clear the measured and satellite temperature values are nearly identical. As the satellite colors darken from greenish-yellow (12.6°C) to light blue (12.3°C) to a darker blue (11.7°C), the measured values are within the same range and drop with the satellite values.

The five-night averaged POES SST image has similar visual correlation especially from January 27th to January 28th (Figure 8). Where the NESDIS SST contour image displayed poor correlation between the two data sets at the beginning of the cruise, the opposite is seen in Figure 8. The measured temperature starts at darker blue (11.5-12.0°C) and changes to light blue (12.0-12.5°C) and then to yellow (12.5-13.0°C) as the satellite image starts at darker green (12.3°C) and changes to light green (12.5°C) and then to yellow (12.8°C). On January 31st, the comparison looses visual correlation on the second half of the day. Where the directly measured temperature was 11.5-12.0°C (blue), the satellite displayed 12.8 (yellow) and further down track they both cool a half of a degree yet the comparison still holds a degree and a half difference.

Next is the sea color analysis using a simplified chlorophyll comparison method mentioned earlier. The MODIS imagery for January 29th was plotted with the 10 minute averaged fluorometer measurements (Figure 9). Even though image is for January 29th, assume little change in 24 hours compare to the cruise let on January 39th. The values start from lower (darker green) to higher values (light green then yellow) as ship closes to Port San Luis on both the measured and satellite imagery. The ship headed due south for a stretch and both set of data visually correlate as the color darkens more greener.

The January 30th MODIS image confirmed even better correlations that can be seen on Figure 10. The same trends seen in Figure 9 are still present. Upon examining the data sets by zooming in on Port San Luis (Figure 11), the satellite and measure changes match even further as both sets of data change from green to yellow. This is illustrated even more clearly by looking at the January 31st MODAS image and similar focus on Port San Luis (Figures 12, 13, & 14 respectfully). Better image detail reveals an even larger increase in chlorophyll within the bay of Port San Luis with the increase in yellow data points the visualization of practically overlying orange data points, despite the difference in spatial resolution from the satellite imagery.

The last useful sea color image to review was a NESDIS sea color satellite image from January 31st (Figure 14 & 15). Despite the slight color offset between these data sets, they display the visual change in chlorophyll along the entire January 31st leg, with the exception the very end.

The most ideal method to compare satellite to measured data is to import the satellite data directly similarly to how the UDAS data was imported and plotted. I sought the assistance of Mr. Kurt Neilson in the NPS Meteorology Department. He was able to extract brightness temperatures from TeraScan using a script. I provided him with the latitude and longitudes derived from the 10 minute averaged points with the UDAS data and I received a table that could be directly imported into ArcGIS and plotted exactly like the SST or fluorometer readings. This would be the ideal method to compare satellite data to measured data. January 21st was selected for the satellite data extraction. Even though this was not during our cruise, it was a very clear day prior to the cruise and would provide the least broken image possible. Despite the success of procuring the data, the plot comparison was extremely unsuccessful (Figure 17). The extracted data was way to high compared to other higher resolution SST imagery. There was little SST variation throughout extracted data set, mostly dark brown (15.0-15.5°C) while the satellite image clearly illustrates largely varied and cooler SST conditions.

Conclusions

Concerning the analysis, direct comparison of SST from daily imagery showed numerous disparities. The averaged SST data (NESDIS SST, POES) displayed greater correlation with most discrepancies occuring at the very near coast. Despite lack of numerical comparison in fluorometer/chlorophyll, changes in measured data and satellite imagery were visually noticeable.

Considering the data itself, data availability was hampered by excessive cloud cover during the cruise. This extremely hindered this process. Different satellite imagery displayed better spatial coverage and resolution than other imagery from same sources (NOAA) or the same satellite. The imagery color gradients need to have enough variance to be informative (i.e. CoastWatch SST). There was difficulty in obtaining satellite imagery very near shore.

Recommendations

As a look to future utilization of this product within our community and to support Forcenet, the ability to import satellite data itself and not the imagery would increase ability to maximize ArcGIS as an analytical tool. The process to georeference the imagery was too slow and less accurate than the ability to directly import raw satellite data itself. A great number of tools and functions within ArcGIS deal with manipulation and greater display options of numerical values over locations than just images similar to utilizing Microsoft Excel. In order to do that, assurances need to be in place that the satellite data imported is accurate. The old adage of 'Garbage in is garbage out' would still apply as it did in my attempt to display raw satellite data. Lastly, as a METOC officer, ArcGIS display would obviously involve importing model data as well. Mission planning utilizing a geospatial tool will need a forecasting element in the display. Weather models, sea state and wave height model data input would inevitably be a necessary function of a Forcenet GIS support officer.

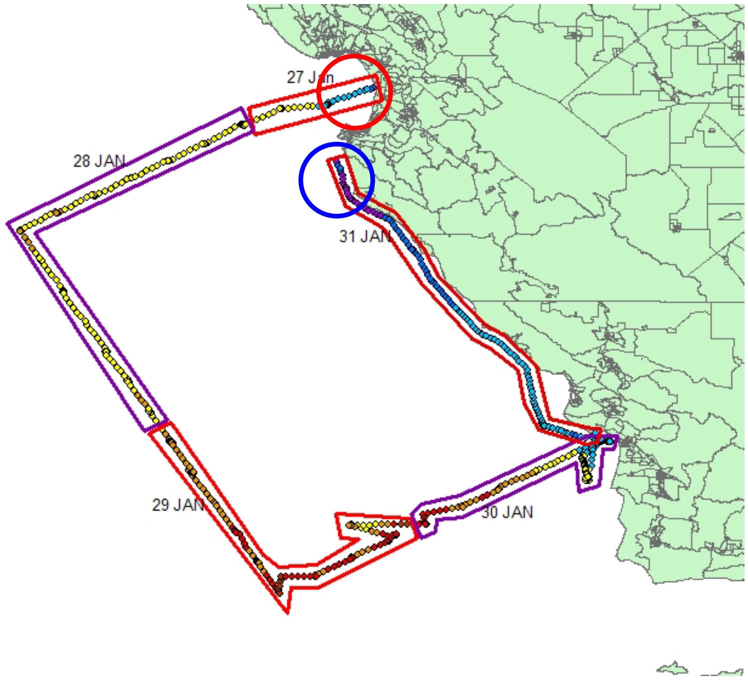

Figure 1a : ArcGIS 8.3 plot of cruise legs from January 27th to January 29th
(WCS 1984 datum)

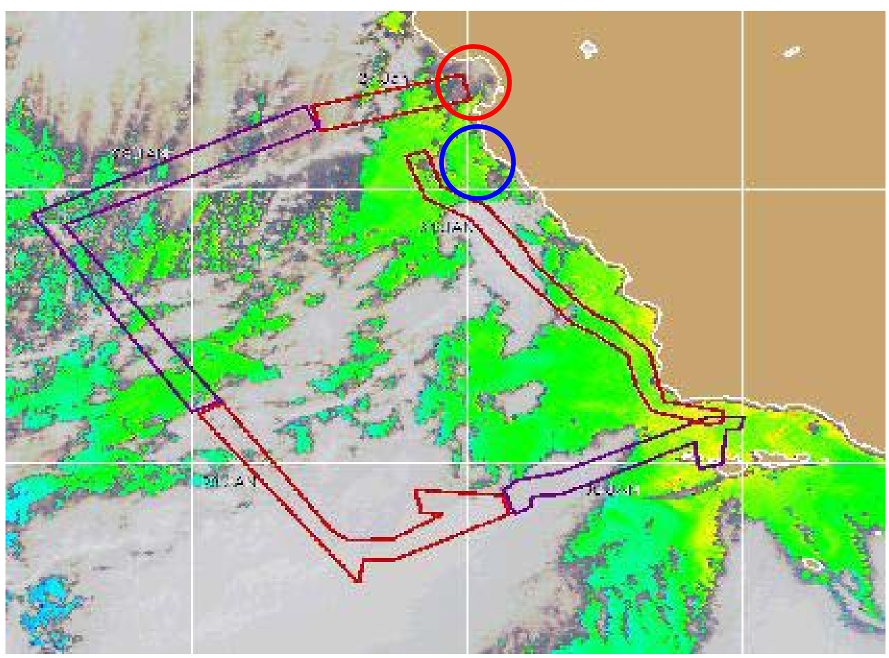

Figure 1b : NESDIS Chlorophyll concentration for January 31st (mercator projection)

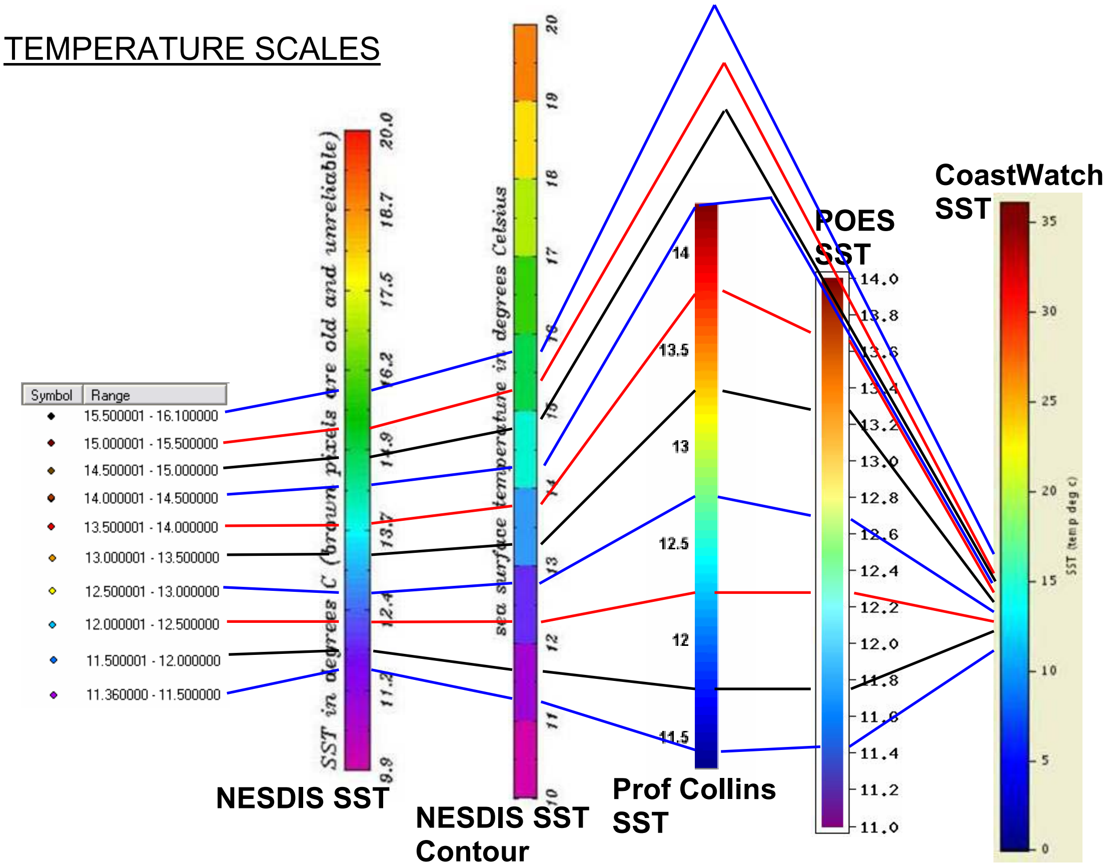

Figure 2: Color Bar reference chart to compare SST values between data plotted & various satellite images.

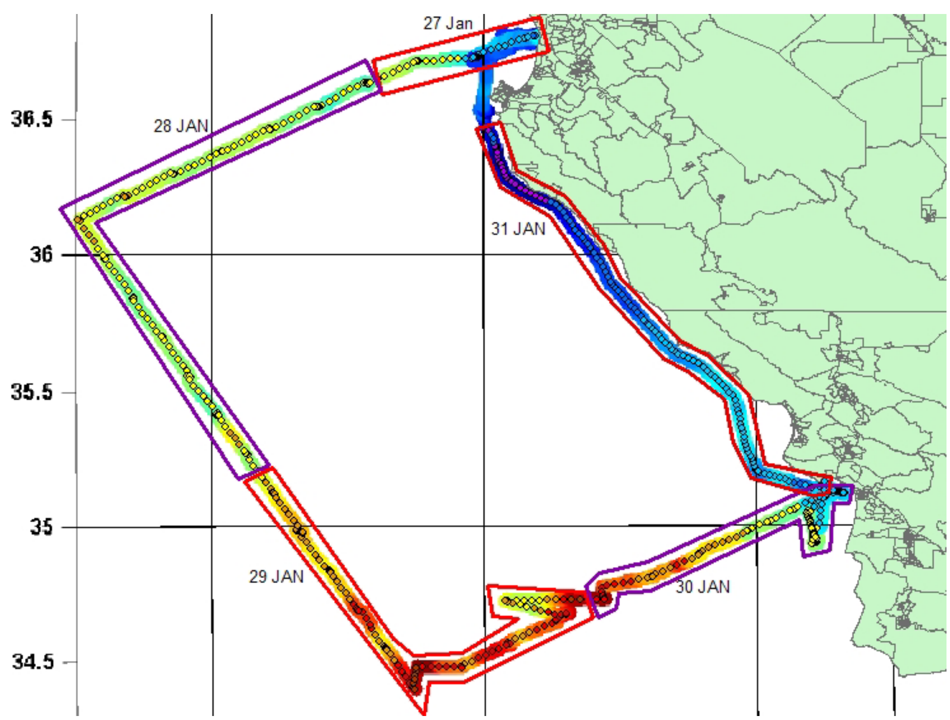

Figure 2: Quality check comparison of 10 minute averaged UDAS SST data to MATLAB plot of UDAS SST data provided by Professor Collins.

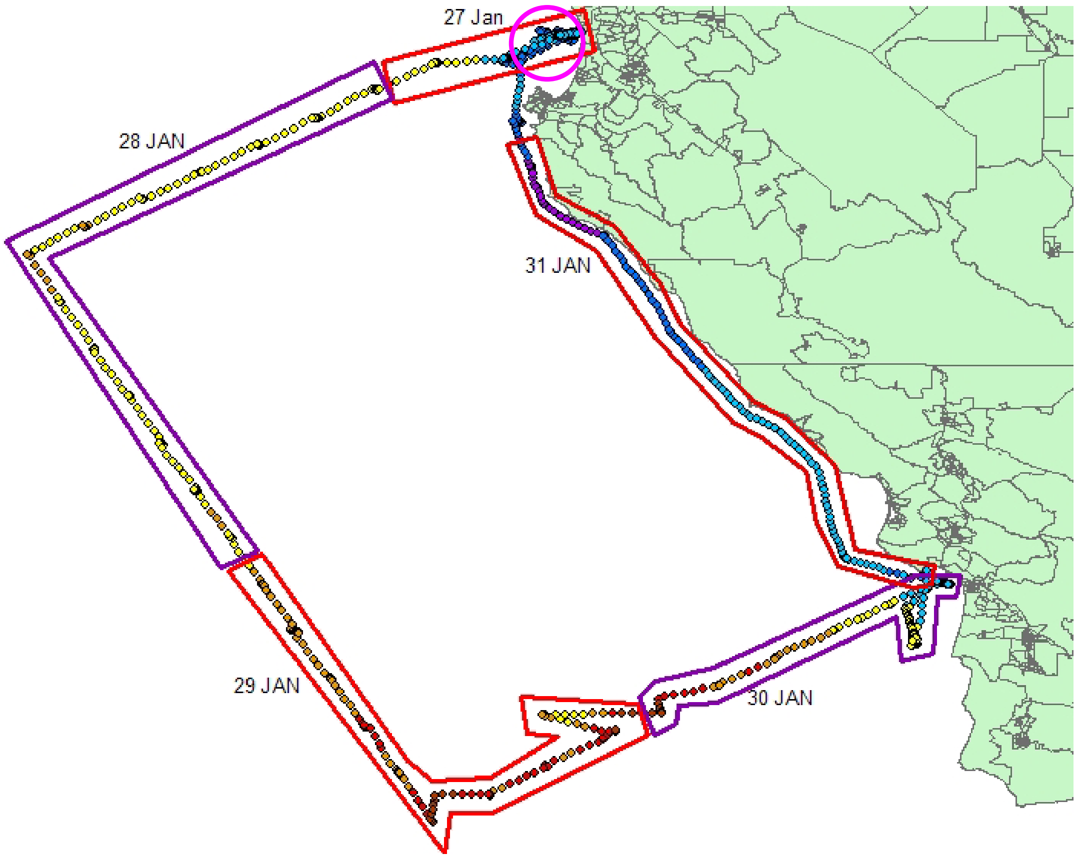

Figure 4a: Measure SST plot over entire cruise.

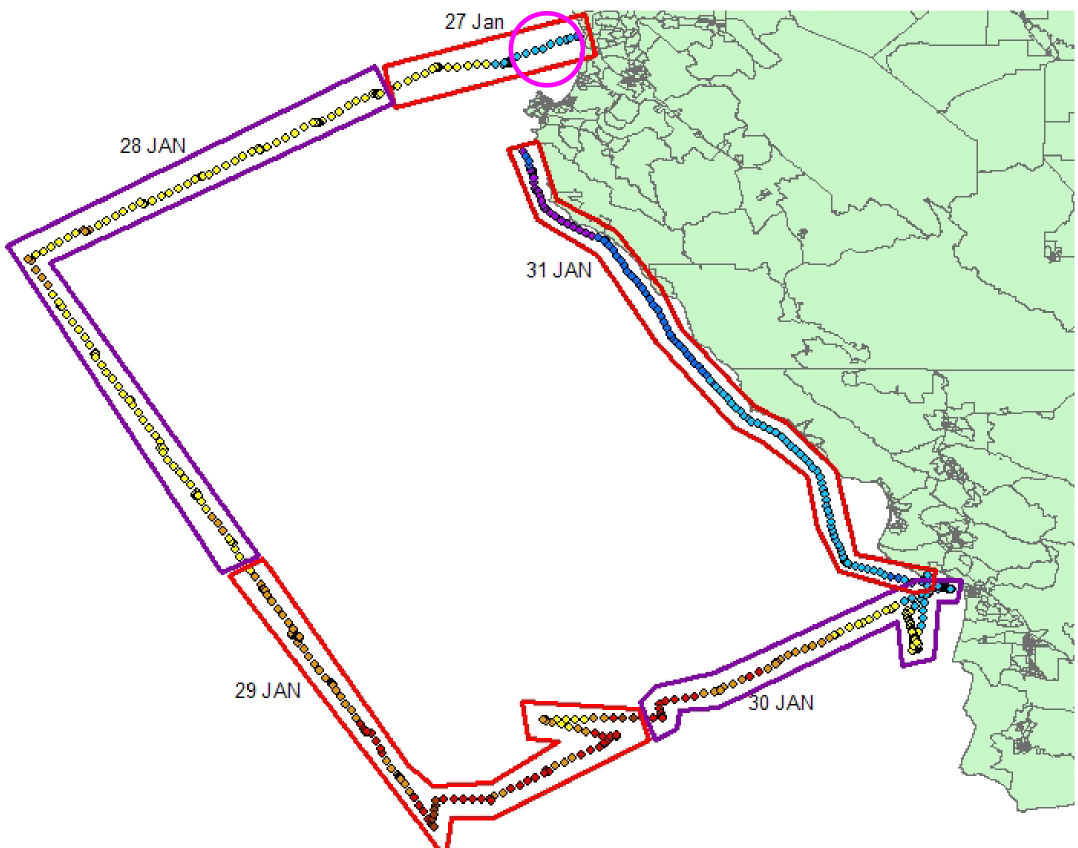

Figure 4a: Measure SST plot over January 27th through January 31st.

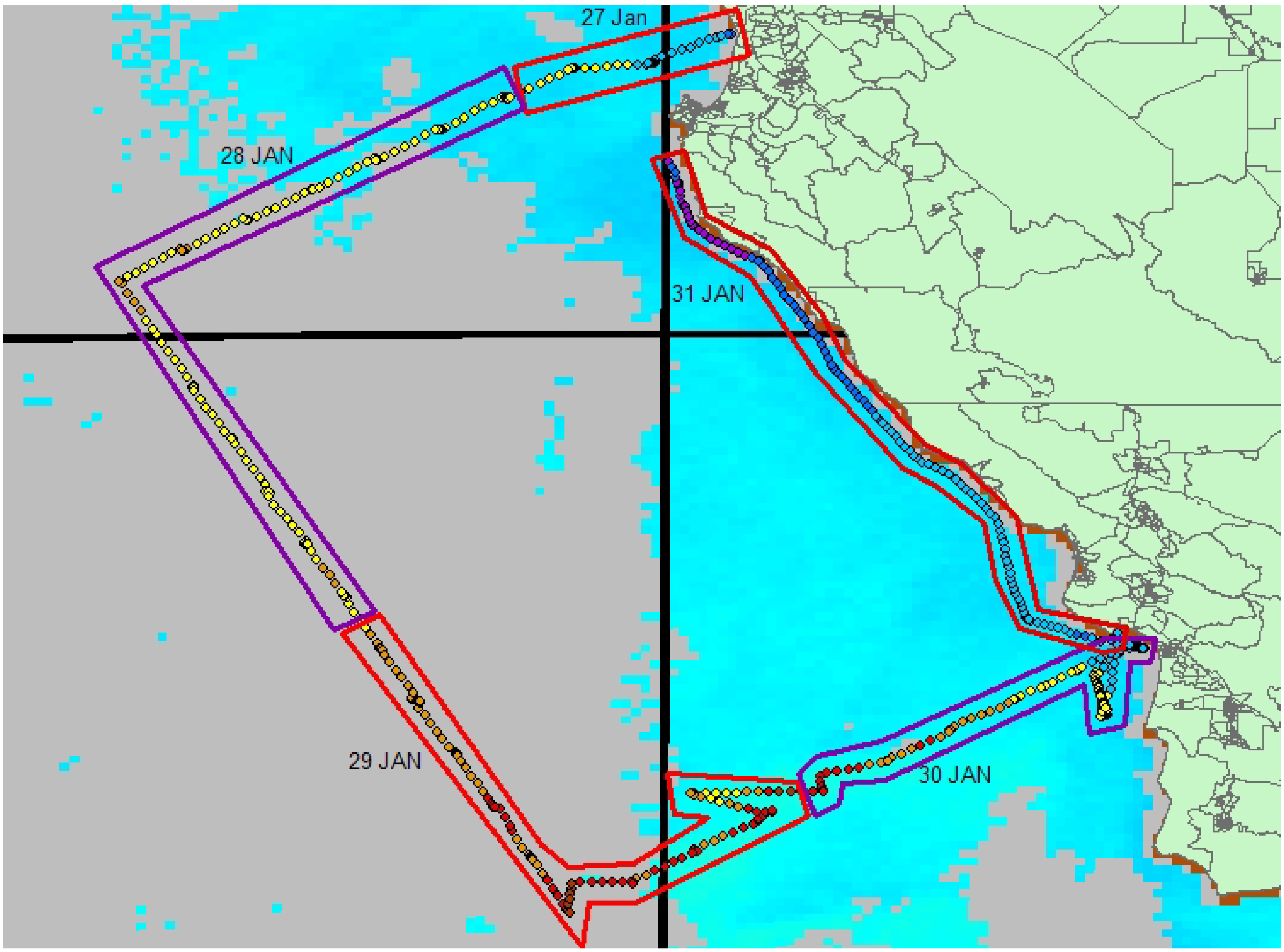

Figure 5: Measured SST compared to CoastWatch SST satellite image for January 31st.

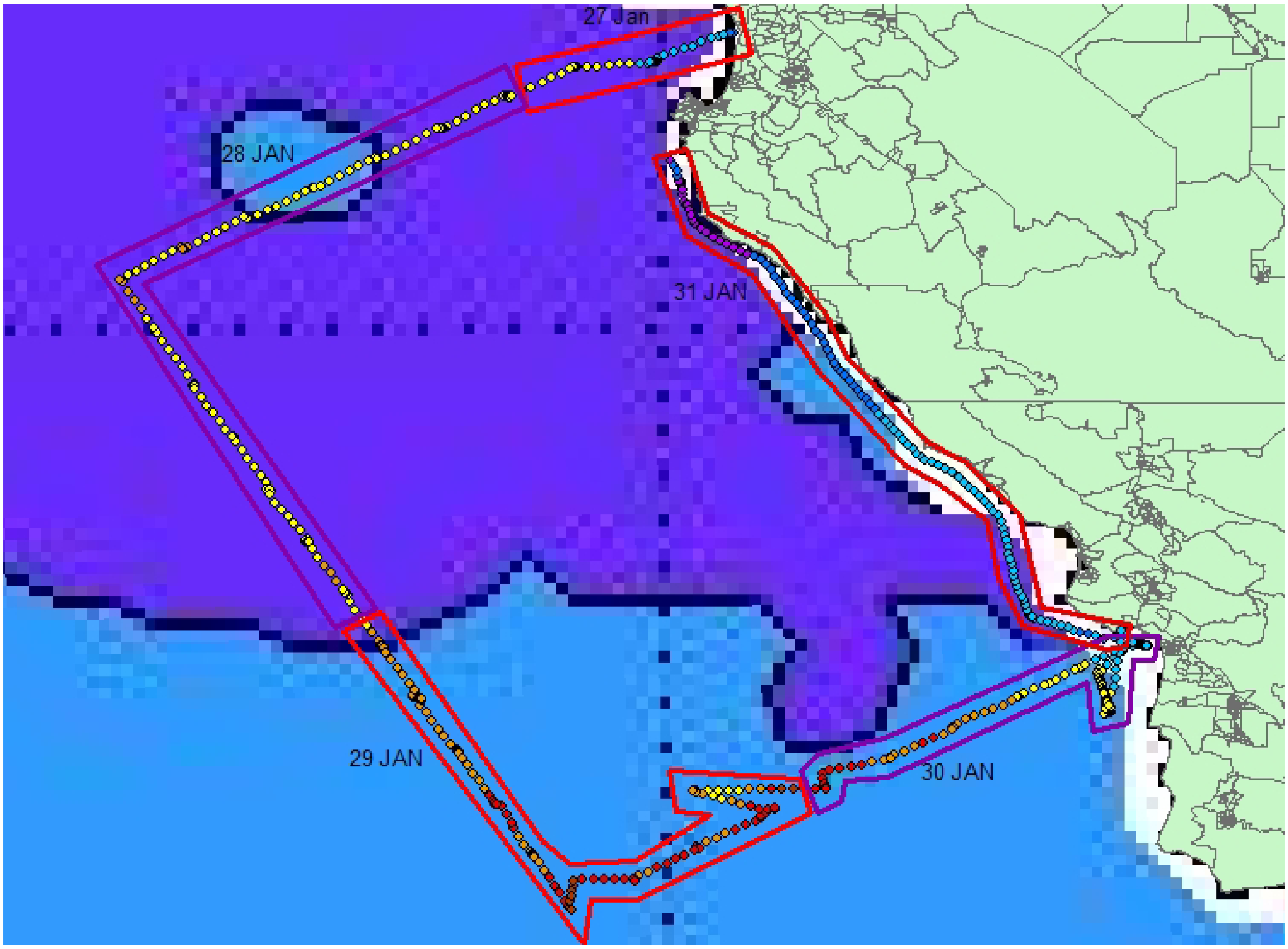

Figure 6: Measured SST compared to NESID SST contour satellite image for January 30th through 01 February.

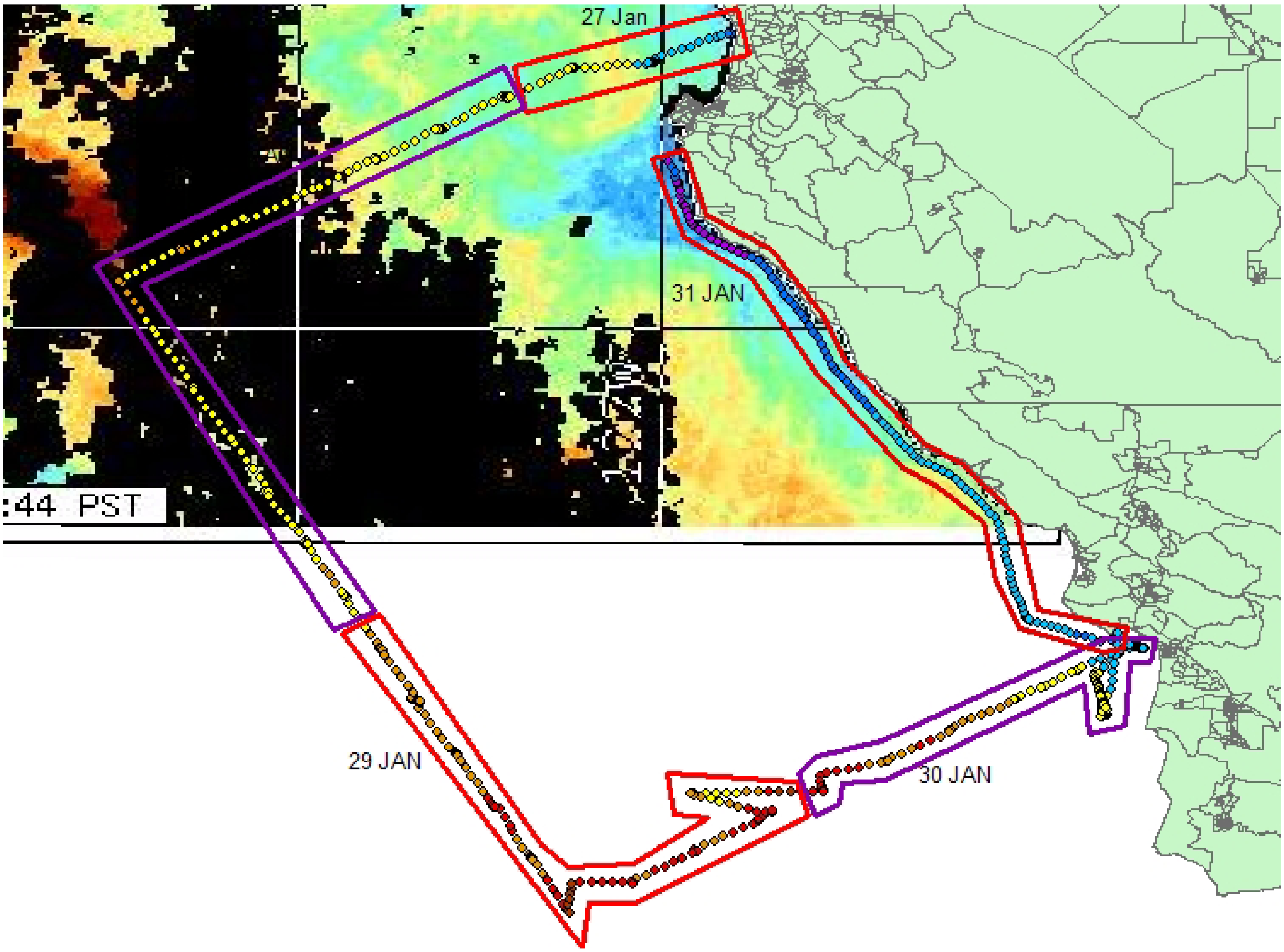

Figure 7: Measured SST compared to higher resolution POES SST satellite image for January 31st.

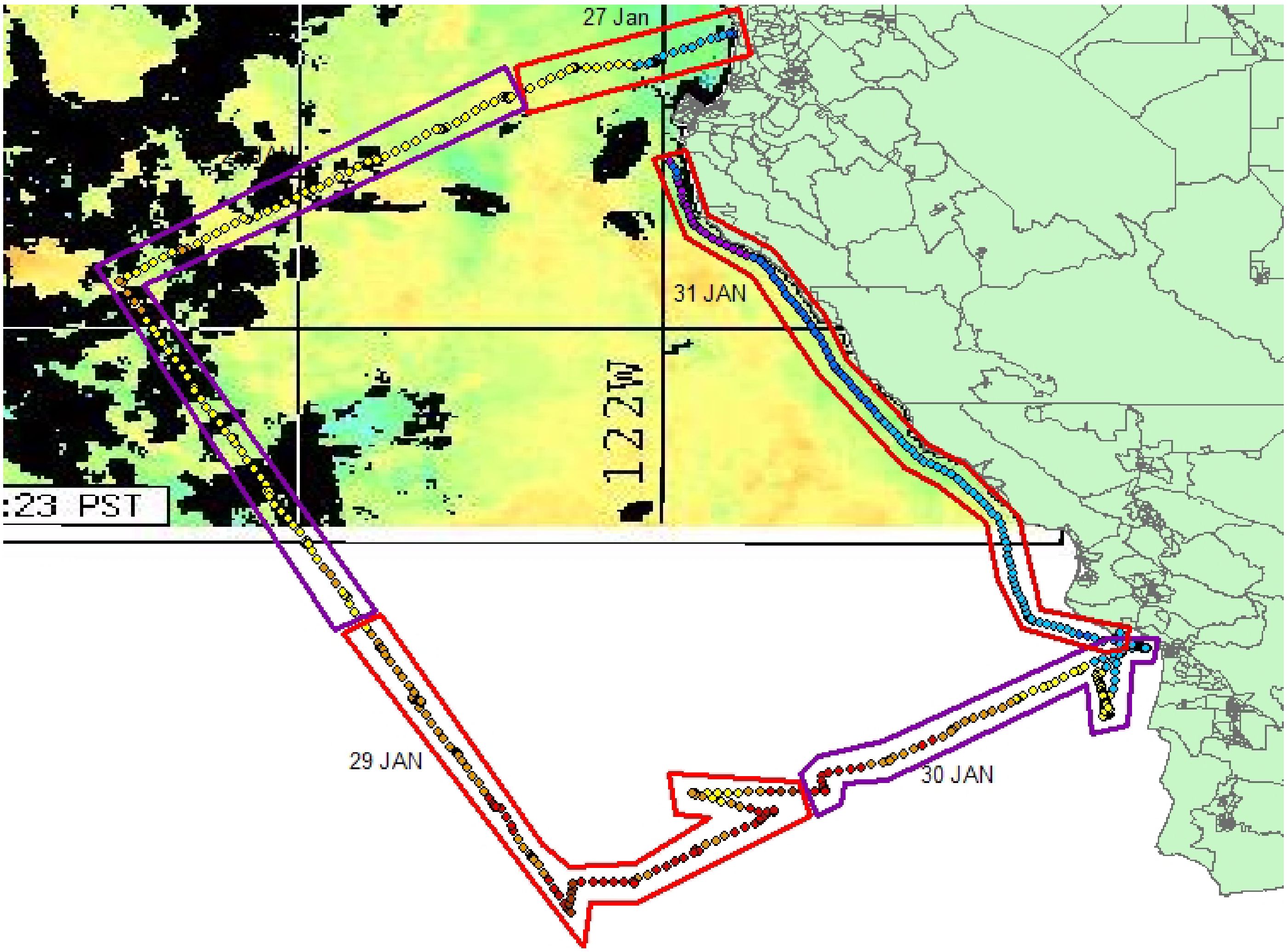

Figure 8: Measured SST compared to higher resolution 5 night averaged POES SST satellite image for January 27th through February 1st.

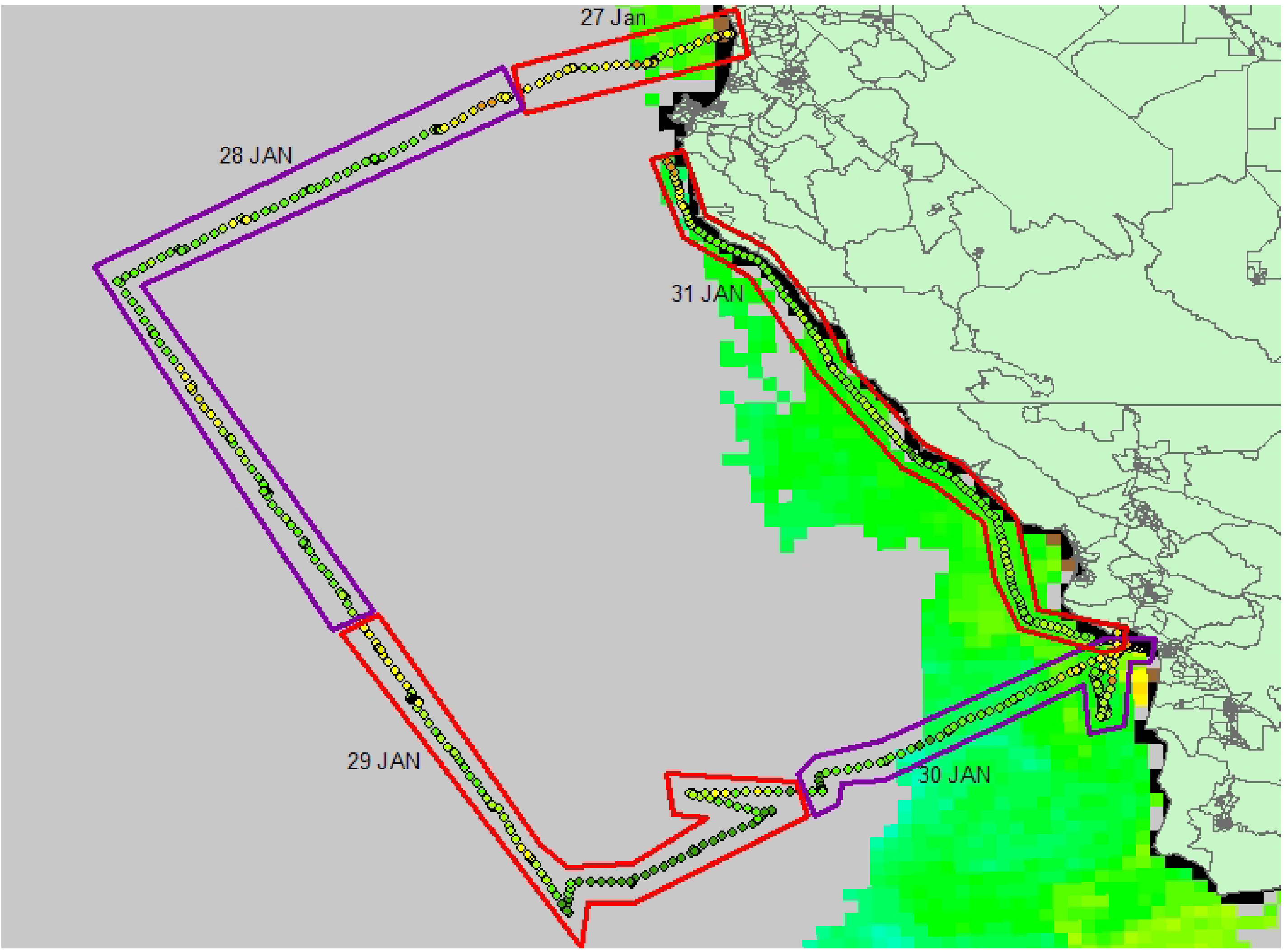

Figure 9: Measured fluorometer measurements compared to MODIS satellite imagery for January 29th.

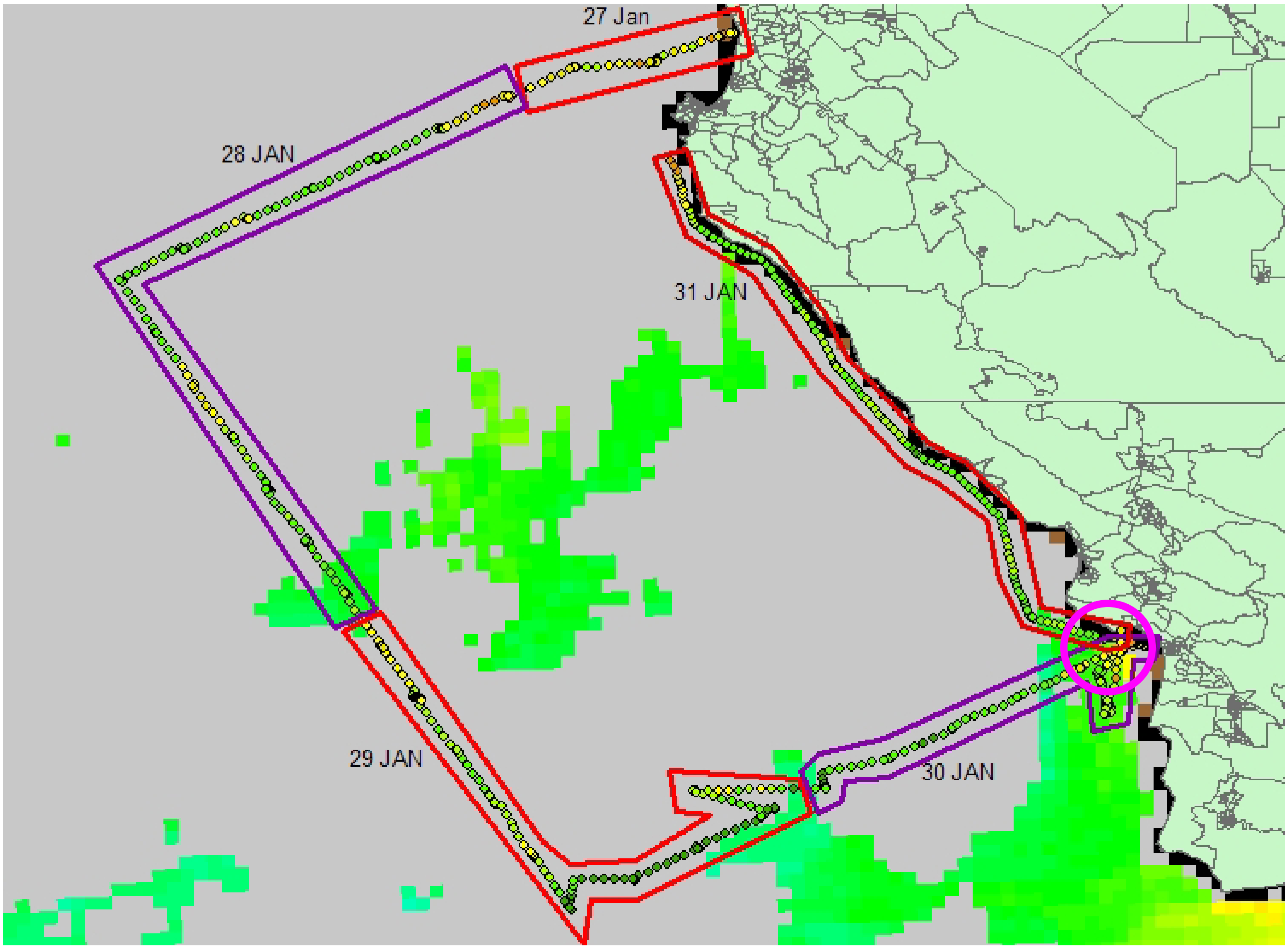

Figure 10: Measured fluorometer measurements compared to MODIS satellite imagery for January 30th.

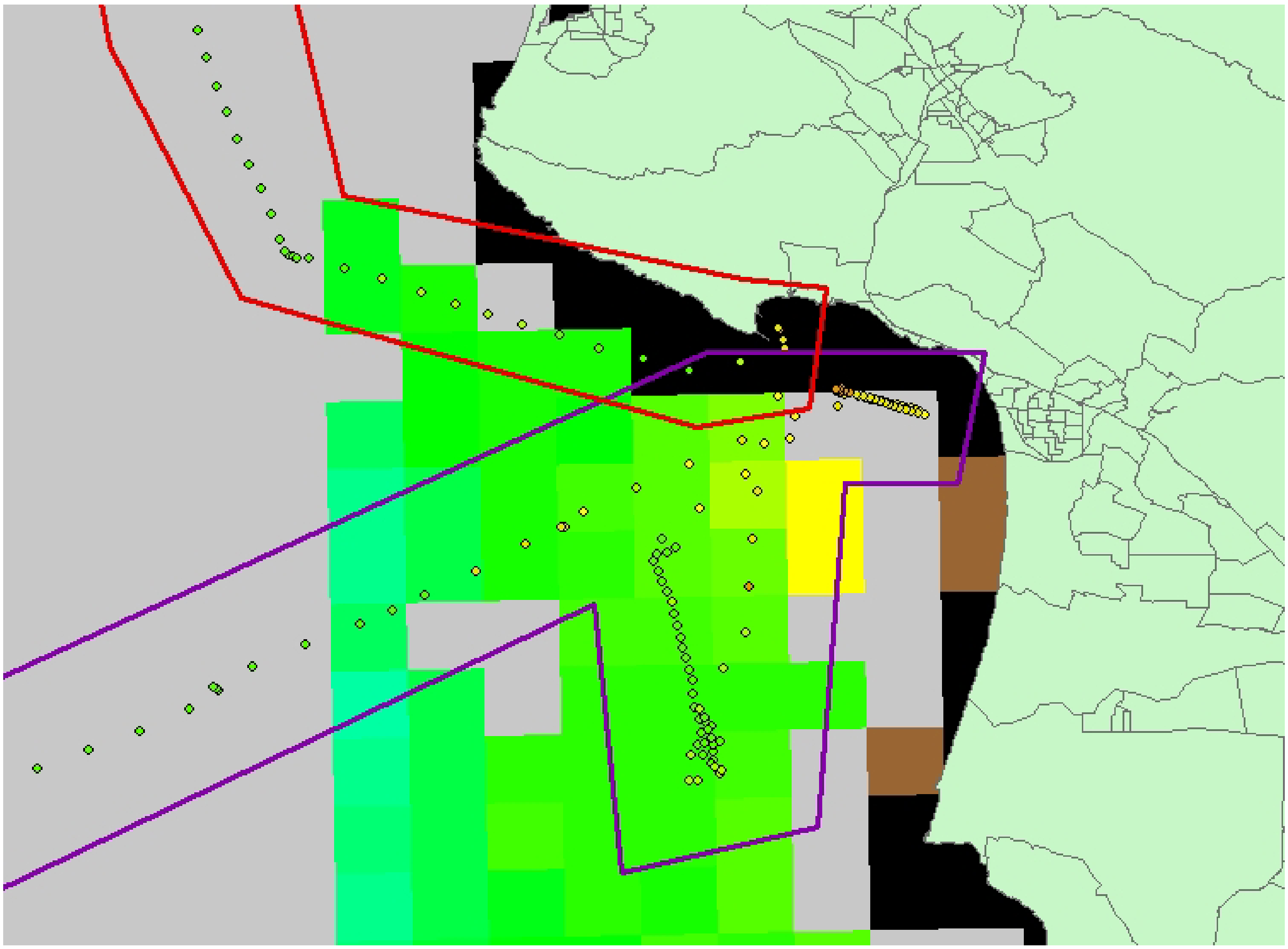

Figure 11: (Close up of Figure 10) Measured fluorometer measurements compared to MODIS satellite imagery for January 30th.

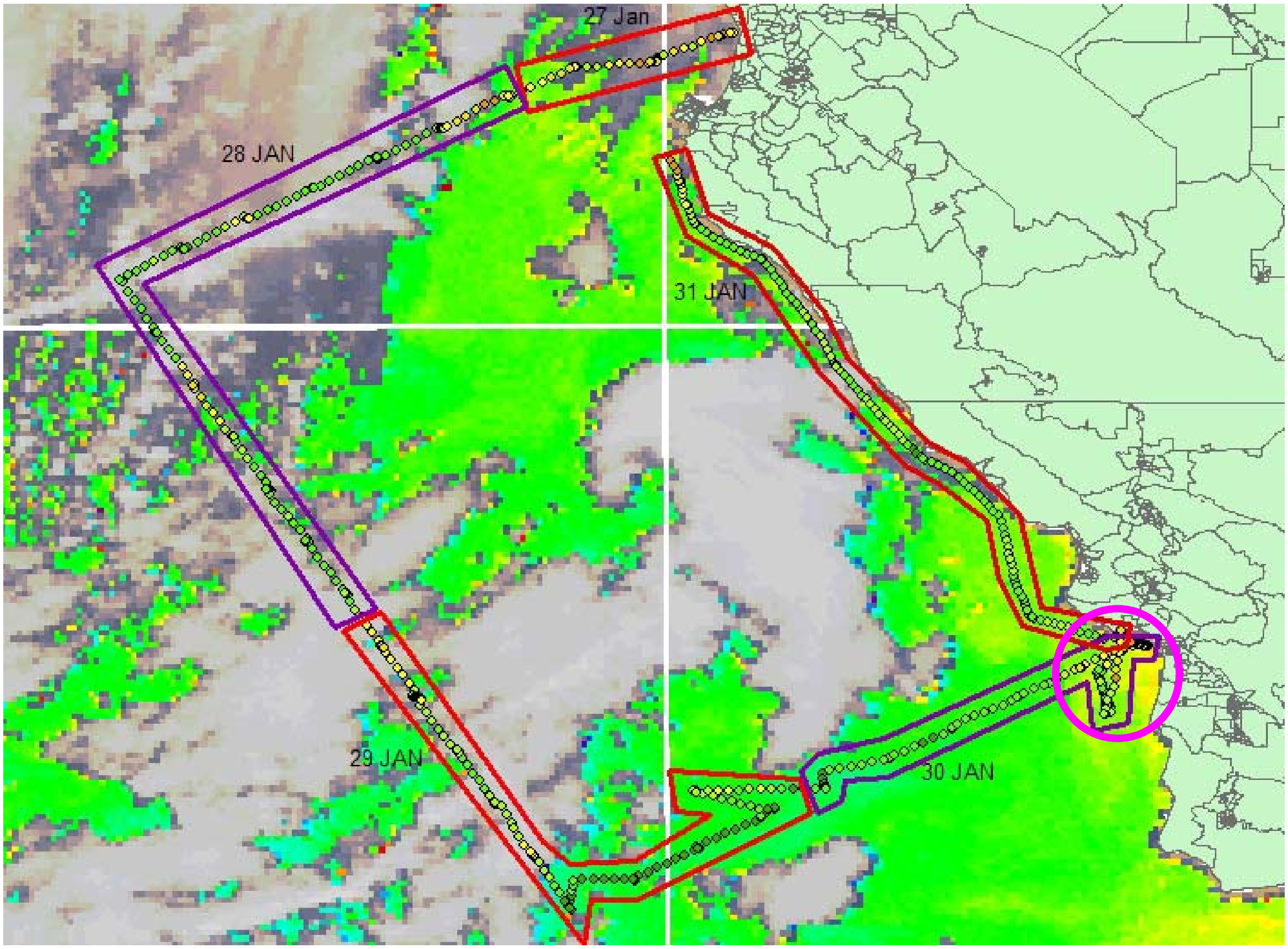

Figure 12: Measured fluorometer measurements compared to MODIS satellite imagery for January 31st

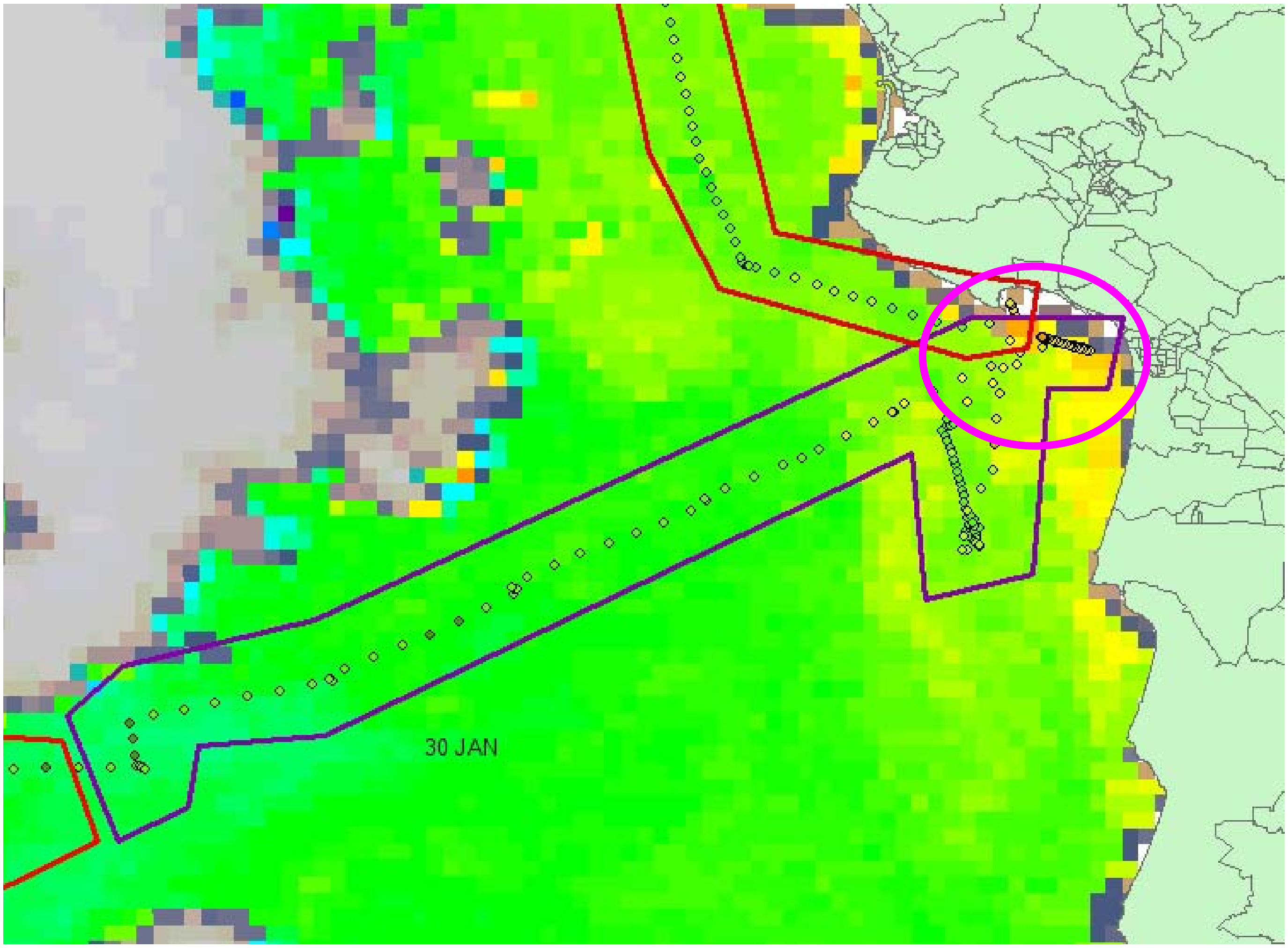

Figure 13: (Close up of Figure 12) Measured fluorometer measurements compared to MODIS satellite imagery for January 31st.

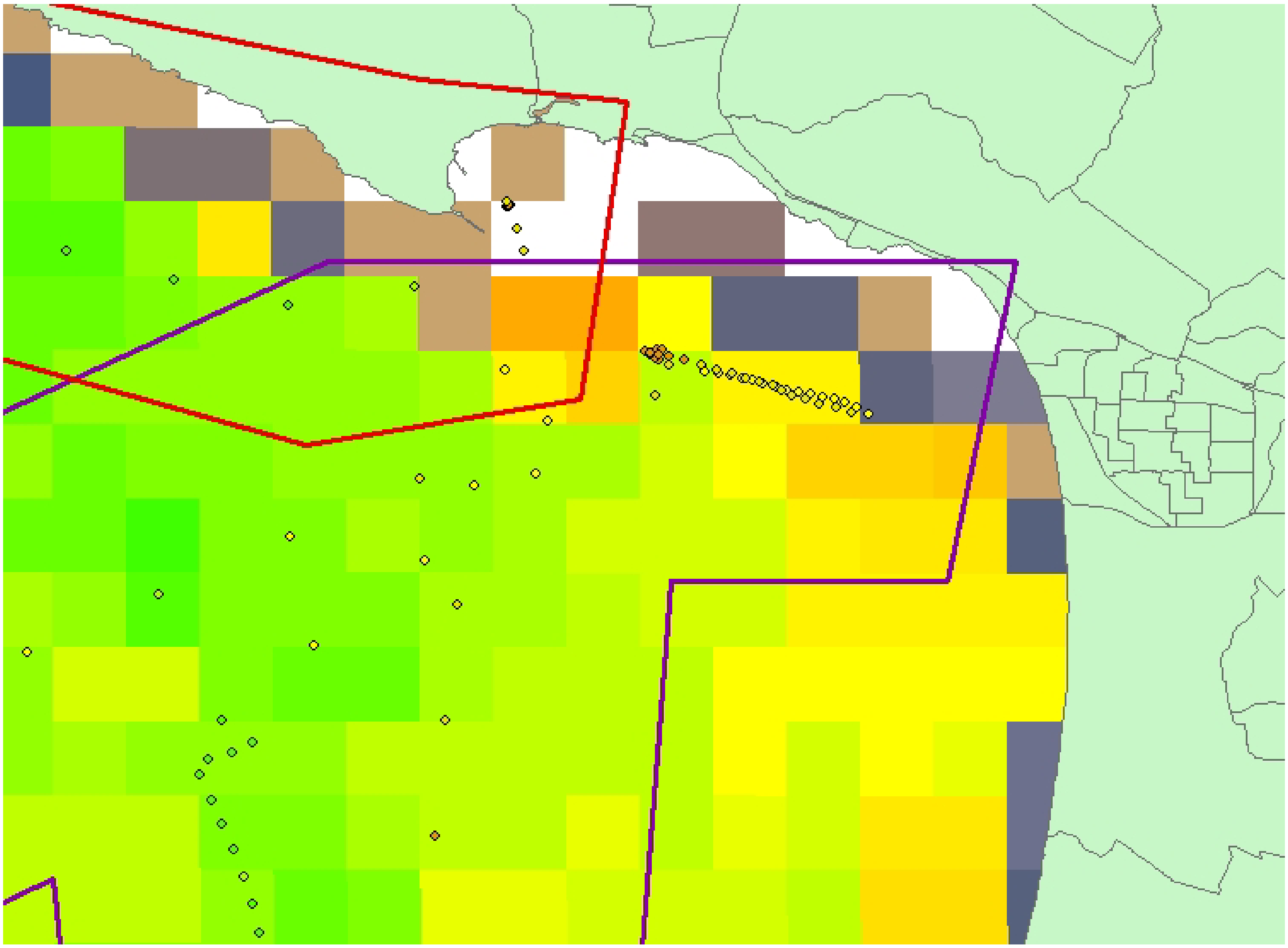

Figure 14: (Close up of Figure 13) Measured fluorometer measurements compared to MODIS satellite imagery for January 31st.

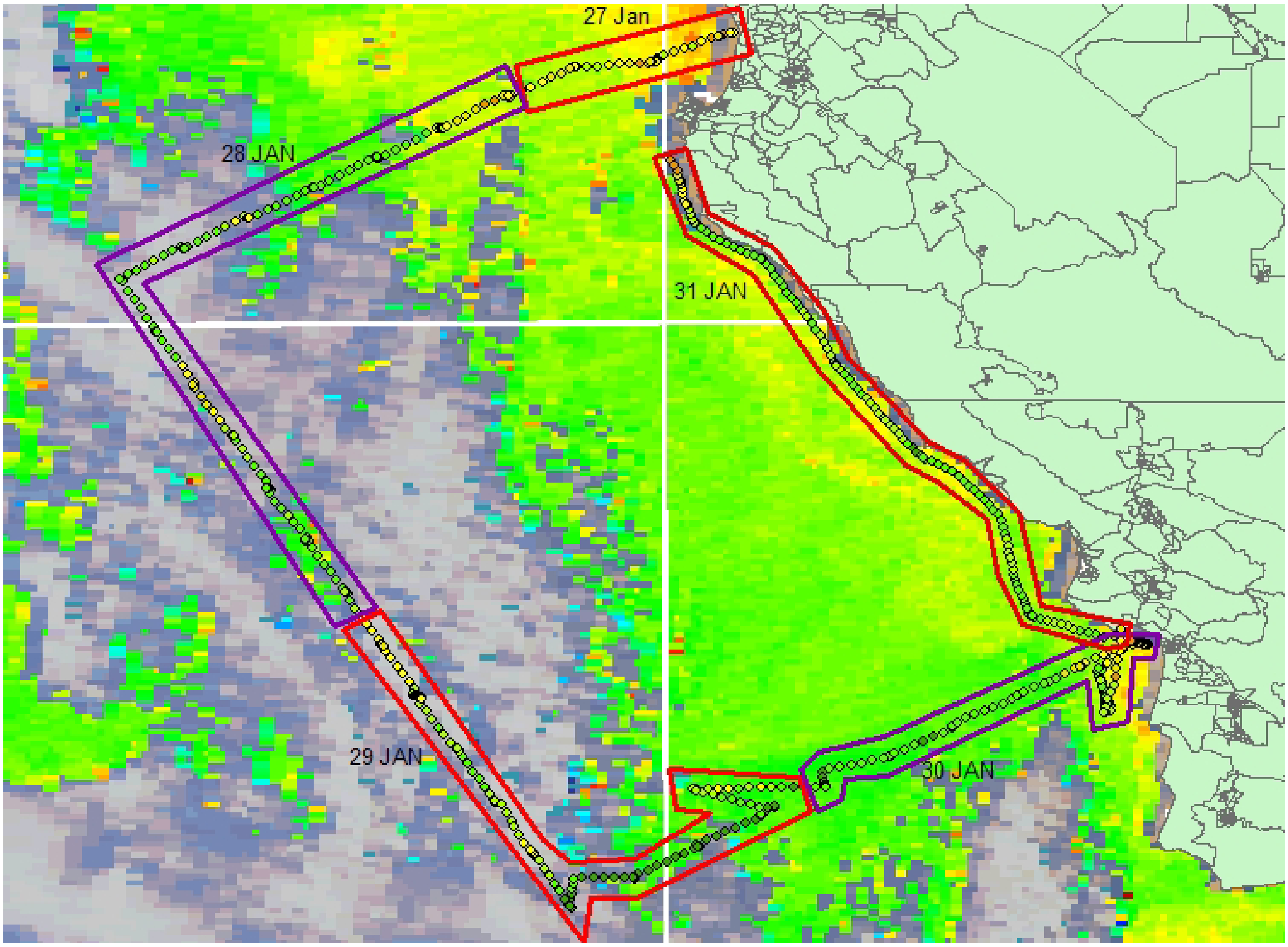

Figure 15: Measured fluorometer measurements compared to NESDIS sea color image for January 31st.

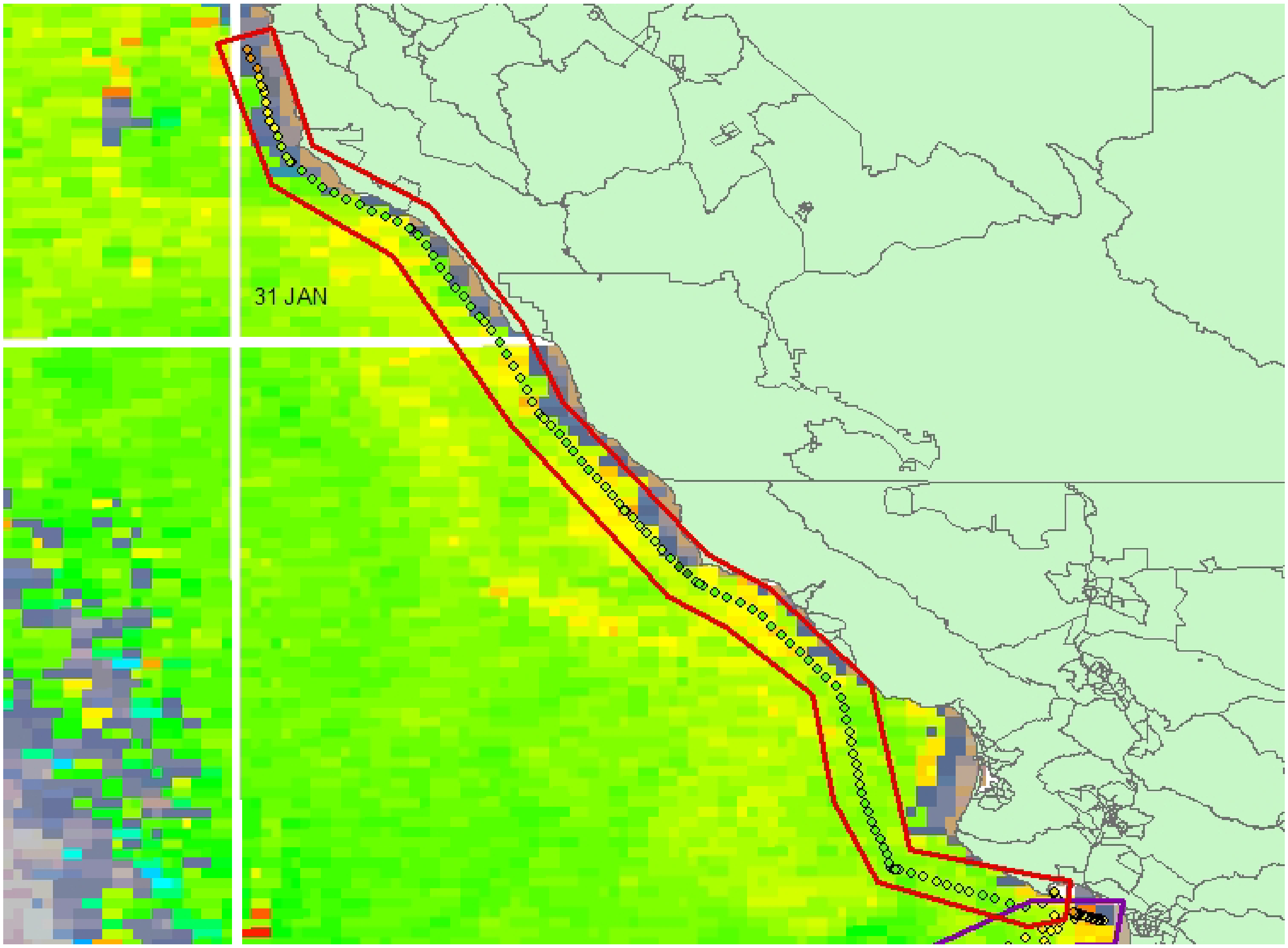

Figure 16: (Close up of Figure 15) Measured fluorometer measurements compared to NESDIS sea color image for January 31st.

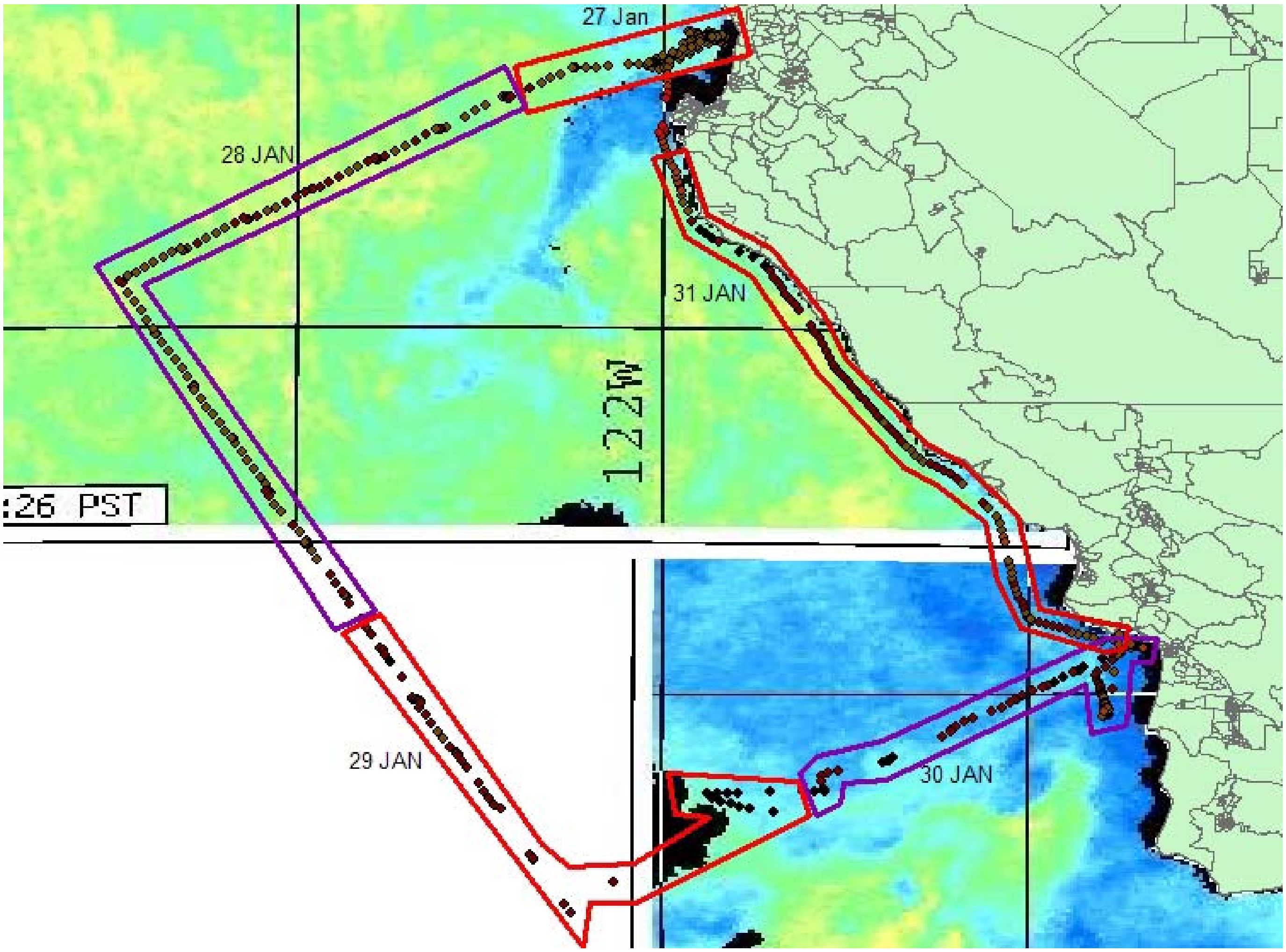

Figure 17: Extracted satellite SST compared to higher resolution POES SST image for January 21st.

References

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http://coastwatch.noaa.gov

Coastwatch product search
http://coastwatch.noaa.gov/interface/interface.html

NOAA Office of Satellite Data Processing and Distribution,
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http://www.osdpd.noaa.gov/PSB/

NESIDS Sea Surface Temperature (SST) Contour Charts
http://www.osdpd.noaa.gov/PSB/EPS/SST/contourthumb.html

NOAA CoastWatch Ocean Product Server
http://wwwo2c.nesdis.noaa.gov

NASA SEAWIFS SITE
http://seawifs.gsfc.nasa.gov/cgi/browse.pl?typ=GAC

MODIS (Moderate Resolution Imaging Radio Spectrometer)
http://modis.gsfc.nasa.gov/

Primer on the Estimation of Sea Surface Temperature Using TeraScan Processing of NOAA AVHRR Satellite Data
http://fermi.jhuapl.edu/avhrr/primer/primer_html.html