# SeaWiFS and MODIS Analysis for CCLEAN

<u>1. Overview</u>: As part of CCLEAN's routine measurements, nutrient and pathogen data are collected from several streams in the Monterey Bay region. CCLEAN compared SeaWIFS chlorophyll (n=11, 4 sites, N=44) and normalized water leaving radiance at 555 nm (nLw555; n=4, 4 sites, N=16) for reference and "impact" stations near Scott Creek and Pajaro River. Using paired t-tests, CCLEAN found that Pajaro River was significantly different from its reference site, and from Scott Creek. Based on this initial analysis, we proposed to provide a more detailed spatial correlation between river flow and SeaWiFS data.

For the analysis, data from 2001-2005 were obtained from the NASA Goddard Distributed Active Archive Center (DAAC), processed using SeaDAS version 4, following the general methods for NASA reprocessing 4. Riverflow data were obtained from the USGS. As previously (CCLEAN), both chlorophyll a (calculated using OC4v4; O'Reilly et al., 2000) and normalized water-leaving radiance at 555 nm (nLw555), a proxy for suspended materials, were compared to river discharge (reported as cubic feet per second). Statistical analyses were conducted using USGS gage stations at Chittenden (Pajaro River) and Spreckles (Salinas River). River flow data was also compared for the San Lorenzo River, Soquel Creek, and Carmel River gage stations. Data analysis was restricted to 2001-2005 based on existing CCLEAN data and the availability of QA/QC'd data from the USGS website.

Two methods were used to identify the spatial correlations and zones of impact related to river flow in the Monterey Bay region. First, simple correlations (not adjusted for autocorrelation of the time series) were calculated for the river flow versus satellite data. Second, those data were filtered to remove all pixels that had correlations with p-values less than 0.05, to produce maps of statistically significant impact. Further analyses involved temporal binning of the data to remove interannual variability.

<u>2. Methods</u>: The analysis was conducted in two stages. An initial analysis was conducted with data from January-September 2004. No river data were available at that time for October-December 2004. We first tested 8-day and 1-day averages for the satellite data; however, it was apparent that 8-day averages were too coarse, so all subsequent results are for 1-day averages. Zero-values (no flow) were left in the river flow data, but were removed (since zero values correspond to clouds or other problems) from the satellite data. Based on preliminary analysis of 2004 data from January-September, which showed poor correlations (see Appendix A), a narrower time window was chosen. For all years (2001-2004) yearday 1-91 (January-March) was used for statistical analysis. For 2003, additional tests were done using yearday 1-151 (January-May). All analyses were performed using Matlab and IDL.

*2.1 Satellite data:*

SeaWiFS data were obtained at (nominal) 1 km resolution from the Goddard DAAC, and spatially projected onto a uniform grid (36.13 – 37.17° N, 121.7 - 122.5° W). Data were assumed to be correct after processing with SeaDAS using the standard (global) flags for quality assurance, and no further modifications were made. For analysis at the event-scale, a series of images from 2005 were also obtained, using MODIS Terra (morning) and Aqua (afternoon) satellite passes. These data include a pseudo-250 m chlorophyll product (the data are mapped to 250 m, using a combination of 250, 500, and 1000 m bands), and a true, 250 m resolution band at 667 nm, which can be used as an estimate of turbidity (or suspended sediment). Data were also processed using algorithms that provide values as total suspended sediment (mg/m3), but the spatial patterns were essentially identical to the 667 nm band. MODIS data were processed following the description of Franz et al. (2006). The 250 m resolution data provide 16x more spatial resolution than SeaWiFS.

*2.2 River flow data:*
Mean daily river flow data were obtained from USGS (http://waterdata.usgs.gov/ca/nwis/) for the Chittenden (1115900; Pajaro River) and Spreckles (11152500; Salinas River) gage stations (Figure 1). Data were also obtained for the San Lorenzo (11161000), Soquel (11160000), and Carmel 11143250) stations. Data were assumed correct as reported by USGS and were not modified.

*2.3 Statistical analysis:*
Prior to analysis, both the satellite and the river flow data were log-transformed. Chlorophyll and other bio-optical data are generally assumed to be lognormal (Campbell, 1995). Analysis of the 2004 Salinas River data similarly showed a lognormal distribution (Figure 2). Simple correlations were determined for the time-series at each pixel, with the satellite data compared to the corresponding gage data. No corrections were made for autocorrelation (which can result in inflated assumptions of degrees of freedom), since we were primarily interested in the spatial patterns. Similar comparisons were made for gage data correlated to other gage data to determine the degree of coherence between gage sites. For this report, correlations were considered significant at the $p<0.05$ level. Correlation analysis was also performed using satellite-data lagged by 0, 1, and 2 days relative to the river flow data.

## 3. Results

*3.1 Choice of gage stations* Based on the initial (2004) analysis, we subsequently expanded to include 2001-2005. For 2004, there were poor correlations between the Salinas River and satellite data for January-September, and additional tests were conducted using February-March data. After examining the river flow data for the gage stations listed in the methods, we expanded this window to include January-March, to capture the majority of the high-flow events. To determine which gage stations to compare with the satellite data, we also ran a correlation analysis for the 5 USGS gage stations chosen. There was generally good correspondence between all of the flow data (i.e. the discharge into Monterey Bay follows similar temporal patterns for all stations; Figure 3). Based on a qualitative analysis of the flow data, and the correlations (Table 1), we chose to test the river flow-satellite correlations using the Pajaro River and Salinas River stations.

*3.2 Correlation with suspended material* The preliminary analyses for 2004 conducted previously suggested that the sediment data (nLw555) was better correlated than chlorophyll, and that the sediment data were positively correlated, while the chlorophyll data were negative. This implied that river discharge had a positive impact on total suspended material, but was inhibitory to phytoplankton biomass.

This expanded analysis confirms that there this a positive correlation between suspended material and river flow. We again tested time lags of 0, 1, and 2 days. Across years, the maximum correlation (determined by counting the number of pixels with significant correlations for each year) varied, with 2001 and 2002 exhibiting the best fit with lag 0, 2003 with lag 2, and 2004-2005 with lag 1. Visual inspection of the longer lag periods (not shown) suggest that the increasing correlations were due to waters advecting past the outer part of the Monterey Bay; the increasing correlation was thus likely due to the time lag in water transport. Based on this assumption, we focused on lag 0 data for nLw555, assuming that suspended sediments within the bay are best correlated with river flow form the same day.

There was considerable interannual variability between years (Figures 4, 5). Generally, the Pajaro River exhibited more spatially coherent correlations (Figure 4) than the Salinas River (Figure 5). Across all years and both gage stations, maximum correlations were found nearshore and predominantly in the north bay. The area offshore of the Carmel River (and possibly the Big Sur River) also stands out as significant. Note that in 2004, there was a strong correlation off Davenport to the Pajoro river flow, likely due to alongshore oceanic transport from further north.

As another way of visualizing the data, the correlation coefficients (r-values) for those pixels with significant correlations ($p<0.05$; Figure 4, 5) were summed for 2001-2005 (Figure 6). This again shows that for the Pajaro River data, the mean (2001-2005) pattern exhibited strong correlations in the north bay (roughly from Moss Landing to Santa Cruz) with weaker correlations off Davenport, in the south bay, and off the Monterey Peninsula. The correlation coefficients were generally higher and more variable for individual years (Figure 6, lower panel) as expected.

Although it was assumed that a lag of zero days was most reasonable for these data, Figure 7 shows the spatial patterns for 2001-2005 at lag 0, 1, and 2 days for both Pajaro and Salinas flow data. While the Pajaro patterns are similar, with a trend towards increasing noise with increasing lag, the Salinas data show a southward spatial trend, such that at 0 lag, the maximum correlations are in the north bay, while at lags of 1 and 2 days, the correlations increase in the south bay, with a corresponding decrease to the north. This suggests that the Salinas flow data is associated with time periods where southern Monterey Bay is exhibiting a clockwise rotation in flow (alternatively, the Salinas River flow may precede flow in the south bay by a few days; however, it’s not clear what the forcing mechanism would be for this pattern).

*3.3 Correlation with chlorophyll* In the preliminary analysis (Appendix A), statistical correlations for chlorophyll were weaker, with a negative relationship at 0-day lag. Using the larger dataset (2001-2005, two gage stations) the chlorophyll relationship is still less robust than for suspended material. Using the same analysis methods as for nLw555, it is apparent that significant ($p<0.05$) correlations are less uniform between years and between lag periods, as shown in Figures 8 and 9.

As with nLw555, there was substantial interannual variability in spatial patterns. There was no obvious trend in any given year as a function of lag, but the average spatial maps (bottom row) generally showed the most coherent (qualitative) patterns at lag 2, indicating that biomass responds to river flow after some period of time (2 days in this case).

While the spatial patterns were not as strong for chlorophyll compared to nLw555, there were obvious differences between Pajaro and Salinas data. The results from the Pajaro correlations show a strong spatial correlation in the south bay, with a weaker pattern around Santa Cruz Wharf. In contrast, the Salinas data are noisier, but show the strongest spatial correlations at mid-bay, approximately over the mouth of the Monterey Canyon.

When the r-values of the correlations are mapped (Figure 10), it is again apparent that individual years (2001 in this case) show higher correlations, with varying patterns compared to the 2001-2005 average. Across all years, the dominant pattern for the Pajaro River data is a positive correlation in the south bay with weak positive correlations off Santa Cruz, and extending across the mouth of the Bay. The offshore correlations are likely due to advection of water southwards from Davenport. 2001 shows much stronger correlations around Moss Landing, the Carmel River, and Santa Cruz. For reference, the correlations for all years at lag 2 are provided in Figure 11.

In the preliminary analysis, there appeared to be a pattern of negative anomalies at lag 0 for chlorophyll (i.e. river flow had a negative impact on biomass). From the expanded analysis, the lag-2 data show positive correlations to river flow, suggesting that biomass is enhanced during high-flow events. To address this, Figure 12 provides the average (2001-2005) correlation maps for lag-0 days chlorophyll. Although noisy, the pattern generally shows negative correlations (decreases in biomass) nearshore for both the Pajaro and Salinas, suggesting that the immediate response to river flow is noisier, and may result in decreases in chlorophyll, but that the longer-term (2 days) response is to enhance biomass.

*3.4 Effect of integration window* To determine whether the time period year day 1-91 is reasonable, we also ran the analyses for 2003 with a time period of 1-151 days. 2003 exhibited slightly more regular flow later into the spring (Figures 1, 2), providing a longer period of high flow data to correlate. Figures 13 and 14 show the results at lag 0, 1, and 2 for nLw555, and the sum of the chlorophyll correlations for lags 0-2. With the extended time window, the regions of positive correlation for suspended material expand to cover most of the Bay, as well as offshore and northward (past Davenport). Interestingly, the correlations do not improve off Big Sur, and there is a pronounced spatial separation between the Pajaro and Salinas rivers in the interior of the Bay, with the Salinas correlating to the nearshore pixels and the Pajaro correlating primarily in the north bay extending up the coast. The chlorophyll maps show a qualitatively similar pattern as for the other analyses (year day 1-91), but with a much more pronounced "ring" around the inner bay.

*3.5 Event-scale processes from 250 m data* For 2005, a series of images were processed at 250 m to compare the spatial extent of individual flow events, rather than using a multi-year statistical analysis. As with the multi-year analysis, there is a much weaker association between the spatial chlorophyll patterns and river flow. For the turbidity data, however, the 250 m resolution clearly delineates the occurrence of two major plumes, roughly situated at the Salinas River (Elkhorn Slough) and the Pajaro River. During low flow periods, the Salinas plume is still evident (possibly associated with tidal flushing of Elkhorn Slough), while a broad, nearshore sediment pattern manifests along much of the northern bay. Of note is that there are not obvious sediment-rich plumes associated with the Carmel, San Lorenzo, Scott Creek, or Waddell Creek gage stations.

More generally, the patterns observed from the 250 m data closely match the multi-year patterns, with enhanced chlorophyll and sediments apparent from roughly mid-bay to Santa Cruz. The 250 m data also show that river flow events likely influence surface water quality tens of kilometers offshore. Note that satellite imagery is generally cloudy during the peak flow events, so these event-scale patterns are likely not the greatest offshore extent of the river plumes.

## 4. Summary

The data analyses demonstrate that there is a statistically significant correlation between USGS gage data and spatial/temporal patterns of both chlorophyll (biology) and turbidity (a proxy for particles and particle-associated materials). Based on the 5 year statistical analysis, the best correlations (overall) were for zero-lagged turbidity, and 2-day lagged chlorophyll. Some general conclusions and inferences can be drawn:

• There is considerable interannual variability in both river flow and satellite data; despite this, consistent patterns are observed within and between years. Highest correlations with both sediments and chlorophyll are observed in the northern part of the Bay (Figure 16).

• While statistical correlations exist between remotely sensed data and river flow, the correlations are relatively weak (r values of 0.4-0.5) suggesting that, even for the Jan-Feb-Mar period, substantial variability is evident. This is also apparent from a multi-year average (1998-2006, year day 1-91) from SeaWiFS (Figure 17). There is good correspondence between sediment correlations (compare Figure 16 and 17), while the variability in chlorophyll (Figure 17) overwhelms the weak correlation to river flow.

• The CCLEAN monitoring stations are well situated to capture the region influenced by coastal runoff (Figure 16).

• Although there are broad regions of positive correlation, the Salinas (Elkhorn Slough) and Pajaro Rivers dominate at the event-scale (Figure 15), and appear to be much more important than the smaller rivers and creeks in the Monterey Bay region, at least for chlorophyll and sediments.

**References**

Campbell, J.W., 1995: The lognormal distribution as a model for bio-optical variability in the sea. J. Geophys. Res. 100: 13237-13254.

Franz, B.A., P.J. Werdell, G. Meister, E.J. Kwiatkowska, S.W. Bailey, Z. Ahmad, and C.R. McClain, 2006: MODIS Land Bands for Ocean Remote Sensing Applications, Proc. Ocean Optics XVIII, Montreal, Canada, 9-13 October 2006.

O'Reilly, J.E. and 21 co-authors, 2000: Ocean color chlorophyll *a* algorithms for SeaWiFS, OC2, and OC4: Version 4. In: O'Reilly, J.E. and 24 co-authors, 2000: SeaWiFS postlaunch calibration and validation analyses, part 3. *NASA Tech. Memo. 2000-206892, Vol. 11*, S.B. Hooker and E.R. Firestone, Eds., NASA Goddard Space Flight Center, Greenbelt, Maryland, 9-23.

Table 1. Correlation coefficients for mean daily discharge from USGS gage stations. Upper table provides all data from 2001-2005, lower table provides correlations for year day 1-91.

| | *San Lorenzo* | *Soquel* | *Pajaro* | *Salinas* | *Carmel* |
|---|---|---|---|---|---|
| San Lorenzo | 1.00 | | | | |
| Soquel | 0.95 | 1.00 | | | |
| Pajaro | 0.56 | 0.52 | 1.00 | | |
| Salinas | 0.16 | 0.16 | 0.29 | 1.00 | |
| Carmel | 0.58 | 0.55 | 0.81 | 0.51 | 1.00 |

| | *San Lorenzo* | *Soquel* | *Pajaro* | *Salinas* | *Carmel* |
|---|---|---|---|---|---|
| San Lorenzo | 1.00 | | | | |
| Soquel | 0.98 | 1.00 | | | |
| Pajaro | 0.57 | 0.51 | 1.00 | | |
| Salinas | 0.17 | 0.17 | 0.25 | 1.00 | |
| Carmel | 0.58 | 0.54 | 0.76 | 0.53 | 1.00 |

Figure 1. A map of the study region is provided, with the locations of the USGS gage stations annotated. For each gage station, the corresponding daily mean discharge is plotted for 2001-2005.

Figure 2. An example of the Salinas River discharge for 2004 is plotted. The data are lognormally distributed.

Figure 3. The USGS gage stations are mapped (top) with the corresponding flow data for 2001-2005 (bottom) for all stations. The flow data follow similar patterns for all stations except the Salinas River.

Figure 4. Maps show pixels with significant temporal correlations ($p<0.05$) as white regions compared to the Pajaro River gage data. The bottom right panel shows the same data averaged for all years; white pixels indicate regions where correlations were significant for all years, while increasingly dark shades of grey correspond to regions significant for less than 5 years. Black indicates land, dark grey indicates non-significant pixels.

Figure 5. Maps show pixels with significant temporal correlations ($p<0.05$) as white regions compared to the Salinas River gage data. The bottom right panel shows the same data averaged for all years; white pixels indicate regions where correlations were significant for all years, while increasingly dark shades of grey correspond to regions significant for less than 5 years. Black indicates land, dark grey indicates non-significant pixels.

Figure 6. Correlation coefficients for Pajaro River data, where spatial pixels with p-values $<0.05$ are mapped. The upper panel shows the sum of 2001-2005 (significant pixels were averaged for all 5 years, using the individual correlation values from each year). The lower panel shows 2001 only. Note the change in color scales. A time lag of 0 days was used.

Figure 7. Correlation coefficients for Pajaro River (left column) and Salinas River (right column) showing the sum (2001-2005) of r-values for significant pixels at lag 0, lag 1, and lag 2 days.

Figure 8. Maps show pixels with significant temporal correlations ($p<0.05$) between chlorophyll and river flow as white regions compared to the Pajaro River gage data. Columns are from left: 0, 1, and 2 day lags. Rows are from top: 2001, 2002, 2003, 2004, 2005. The bottom row shows the same data averaged for all years; white pixels indicate regions where correlations were significant for all years, while increasingly dark shades of grey correspond to regions significant for less than 5 years. Black indicates land, dark grey indicates non-significant pixels.

Figure 9. Maps show pixels with significant temporal correlations ($p<0.05$) between chlorophyll and river flow as white regions compared to the Salinas River gage data. Columns are from left: 0, 1, and 2 day lags. Rows are from top: 2001, 2002, 2003, 2004,

2005. The bottom row shows the same data averaged for all years; white pixels indicate regions where correlations were significant for all years, while increasingly dark shades of grey correspond to regions significant for less than 5 years. Black indicates land, dark grey indicates non-significant pixels. The black pixels offshore are an artifact of the processing (bad/missing data matchups).

Figure 10. Correlation coefficients for Pajaro River data, where spatial pixels with p-values $<0.05$ are mapped, using Chlorophyll with a 2-day lag. The upper panel shows the sum of 2001-2005 (significant pixels were averaged for all 4 years, using the individual correlation values from each year). The lower panel shows 2001 only. Note the change in color scales.

Figure 11. Correlation coefficients (p-value $< 0.05$) for all years and the average of 2001-2005 for both the Pajaro and Salinas rivers. Chlorophyll at lag-2 days is shown.

Figure 12. Correlation coefficients (p-value $< 0.05$) for the average of 2001-2005 at lag 0 for chlorophyll.

Figure 13. Maps of pixels with significant correlations ($p<0.05$) at lag 0, 1, 2 days (top to bottom) for nLw555 compared to the Pajaro River gage data (shown in the upper left) for year day 1-151, 2003. The map at lower left shows the corresponding correlation map for chlorophyll, averaged for lags 0, 1, 2 from year day 1-151, 2003.

Figure 14. Maps of pixels with significant correlations ($p<0.05$) at lag 0, 1, 2 days (top to bottom) for nLw555 compared to the Salinas River gage data (shown in the upper left) for year day 1-151, 2003. The map at lower left shows the corresponding correlation map for chlorophyll, averaged for lags 0, 1, 2 from year day 1-151, 2003.

Figure 15. Maps of chlorophyll and nLw(667), used here as a proxy for total suspended material, are provided for several dates during 2005. In each set of images, chlorophyll is on the left, nLw(667) is on the right, and the river flow data from the Pajaro gage station is plotted in the bottom panel. On the river flow data, the date of the satellite images is denoted with a dashed line. Dates were year days 14, 16, 19, 20, 22, 29, 33, 59, and 84.

Figure 16. Maps of pixels with significant correlations ($p<0.05$) at lag 0 (sediment) and 2 (chlorophyll) are provided for the Salinas and Pajaro gage data. The color corresponds to the r-value at each pixel. Pixels that were not significant ($p>0.05$) were set to an r-value of zero. Superimposed are some of the gage station locations, and the CCLEAN sampling sites.

Figure 17. Climatological (1998-2006, year day 1-91) chlorophyll and nLw(555) data from SeaWiFS are plotted in the upper panels. The lower panels provide the variance for the same time period. Superimposed are some of the gage station locations, and the CCLEAN sampling sites.

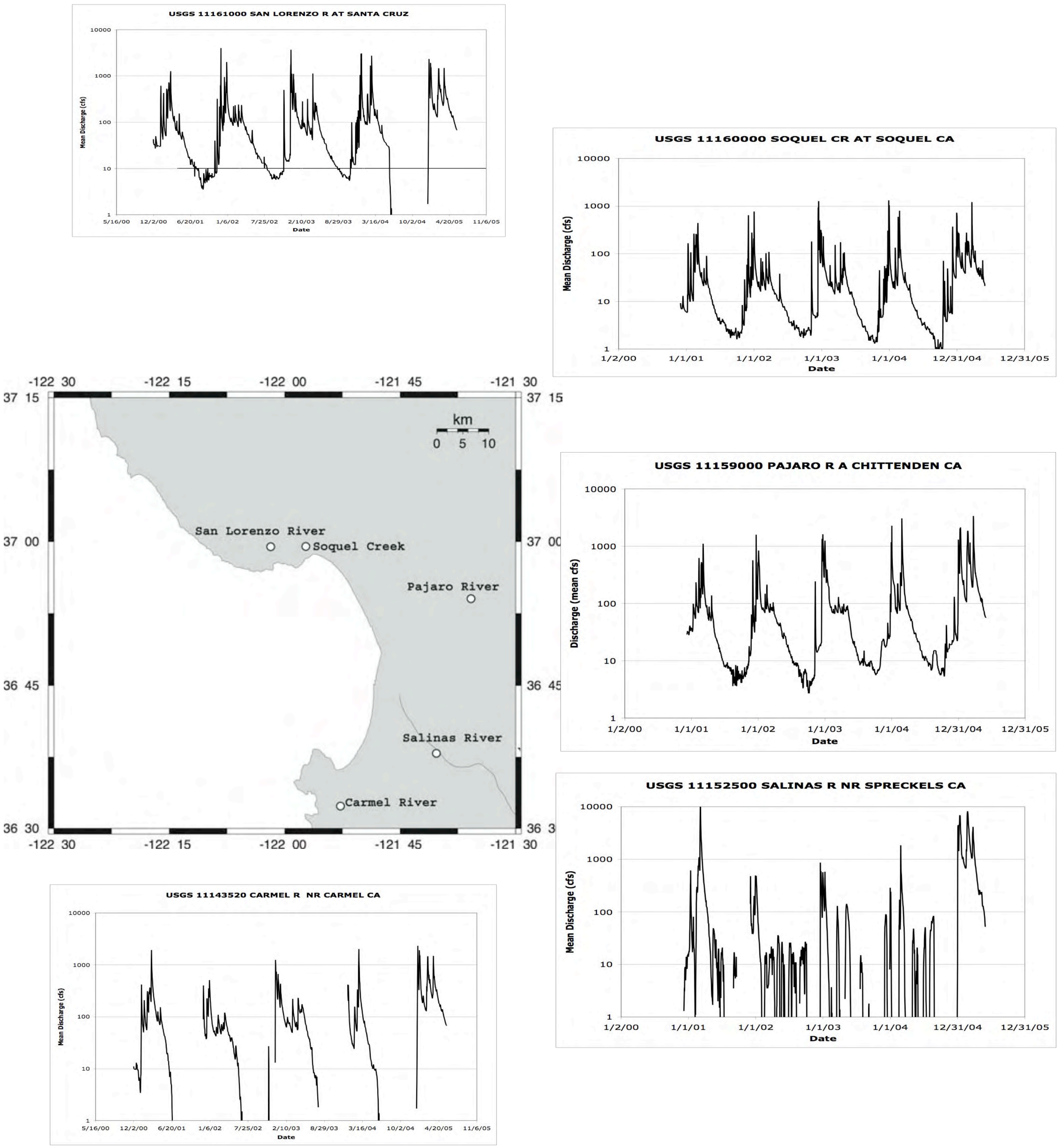
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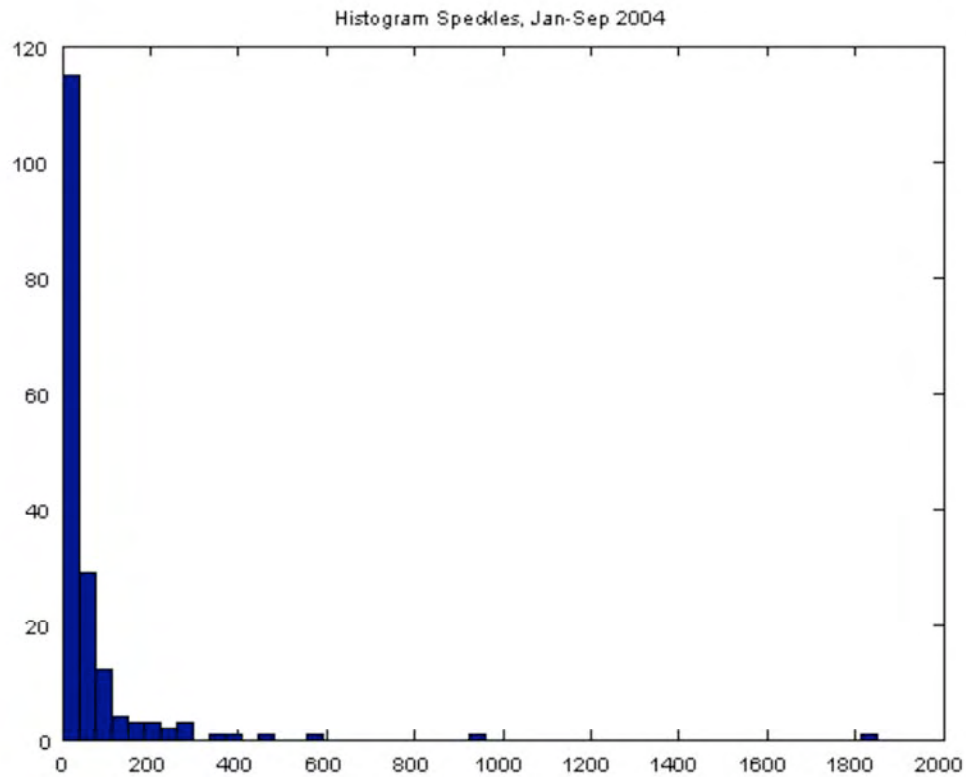
Figure 1.



Histogram Speckles, Jan-Sep 2004
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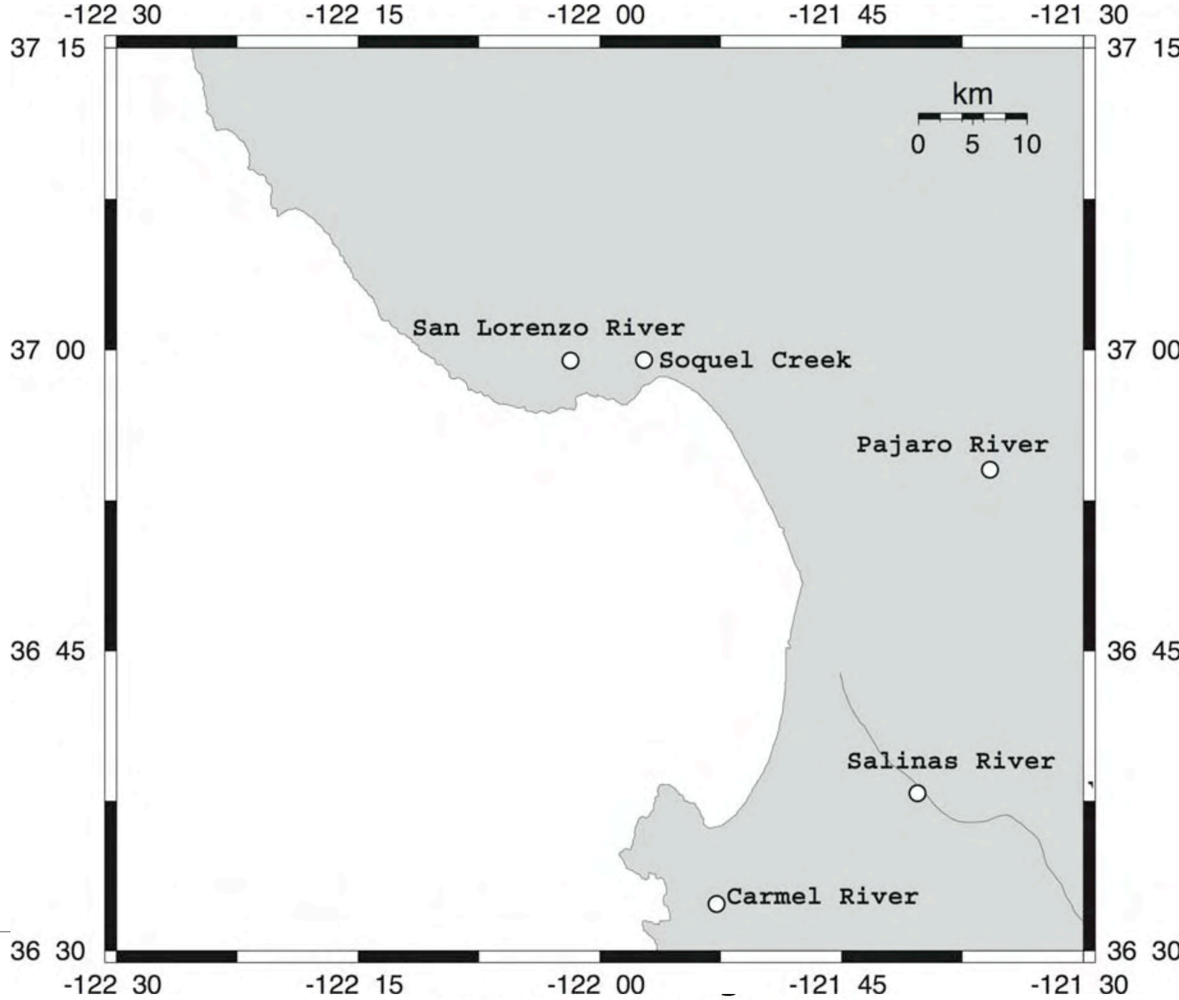
Figure 2.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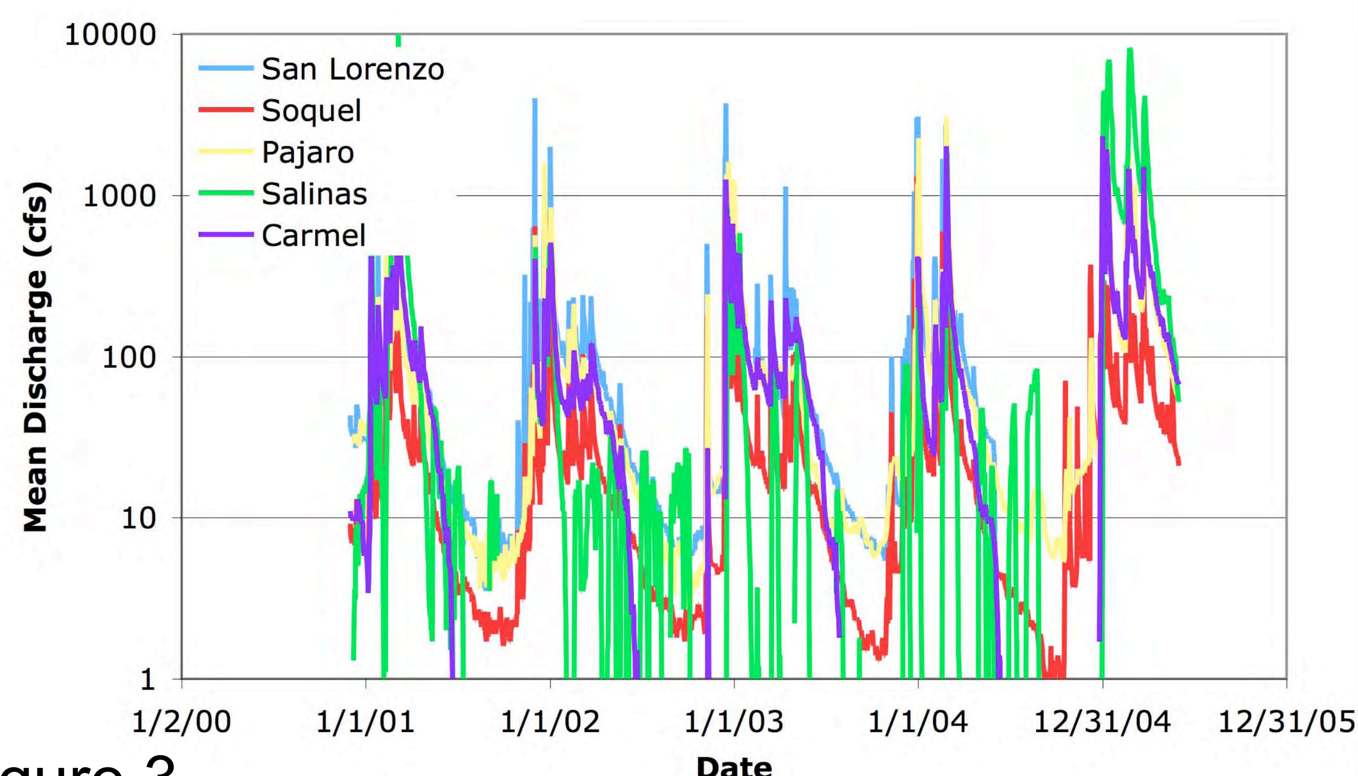
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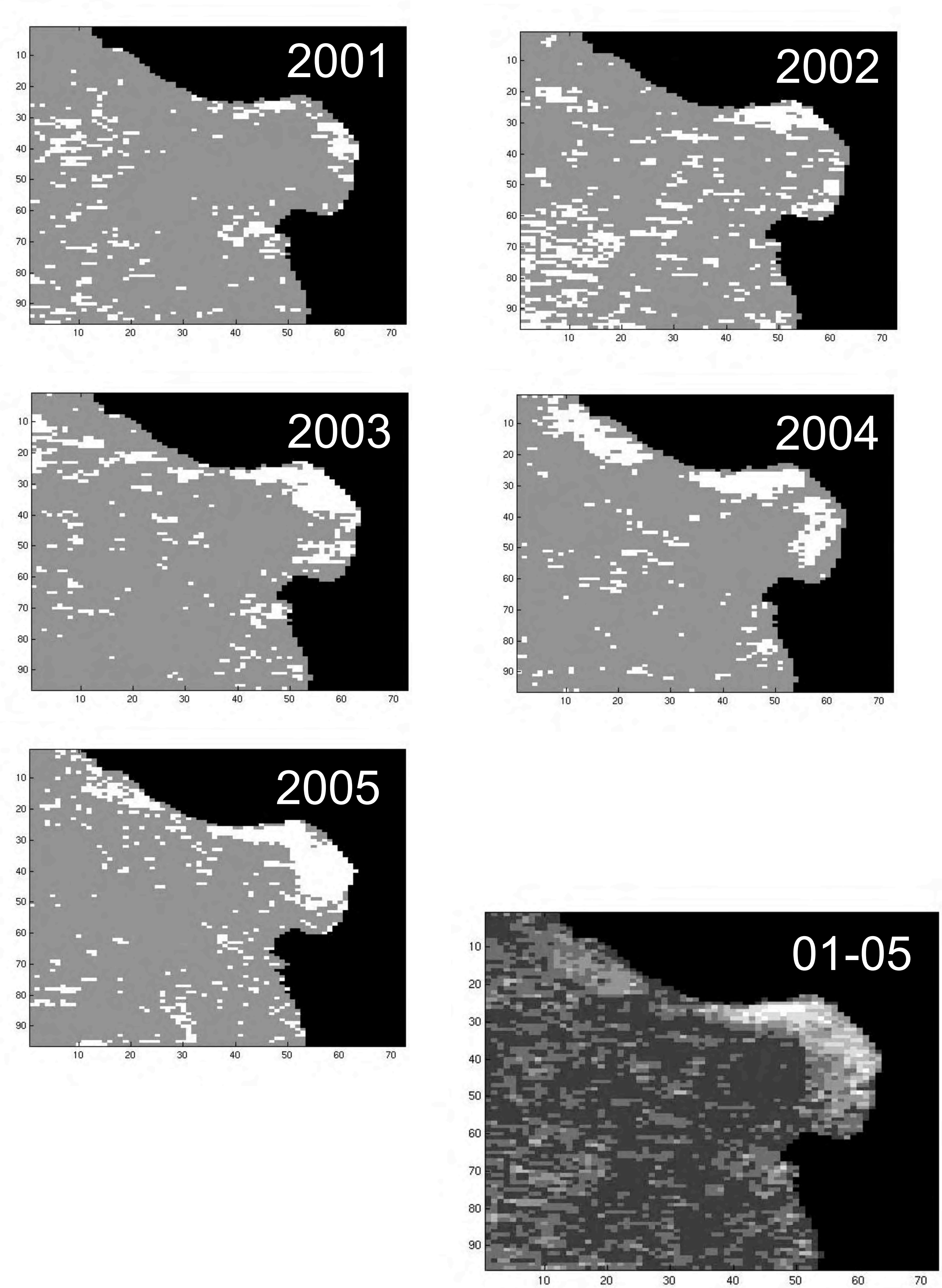
Figure 3.

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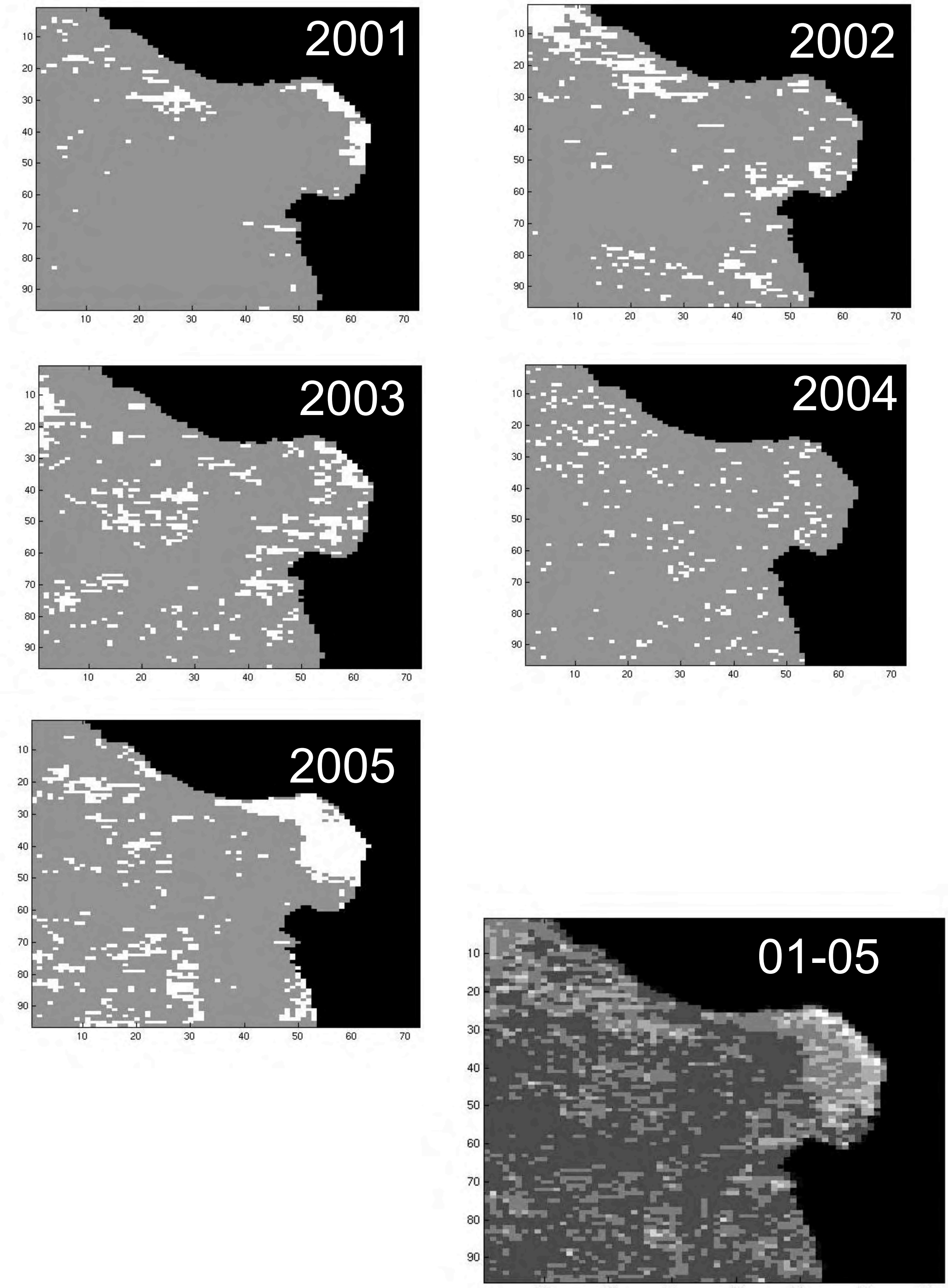


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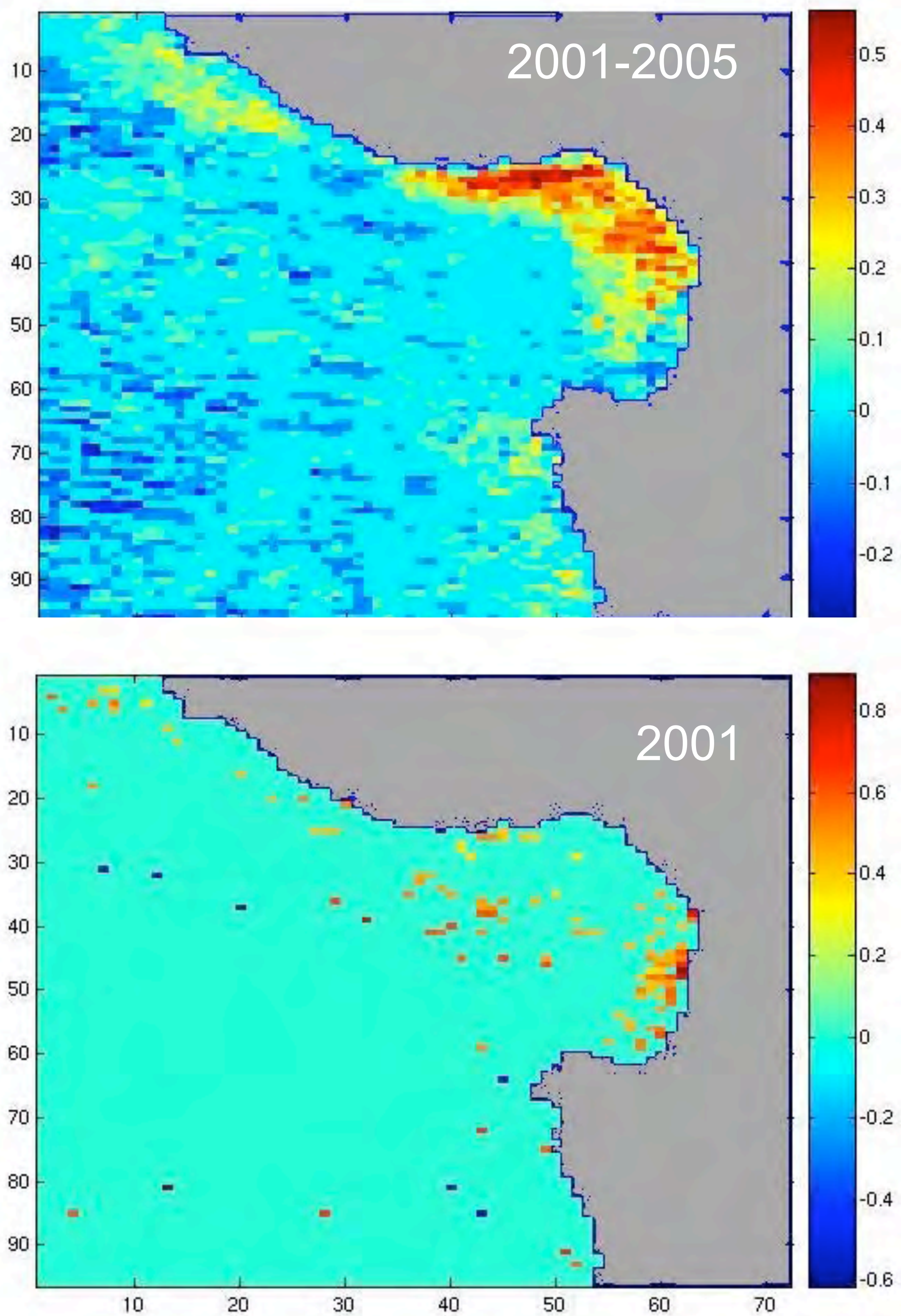


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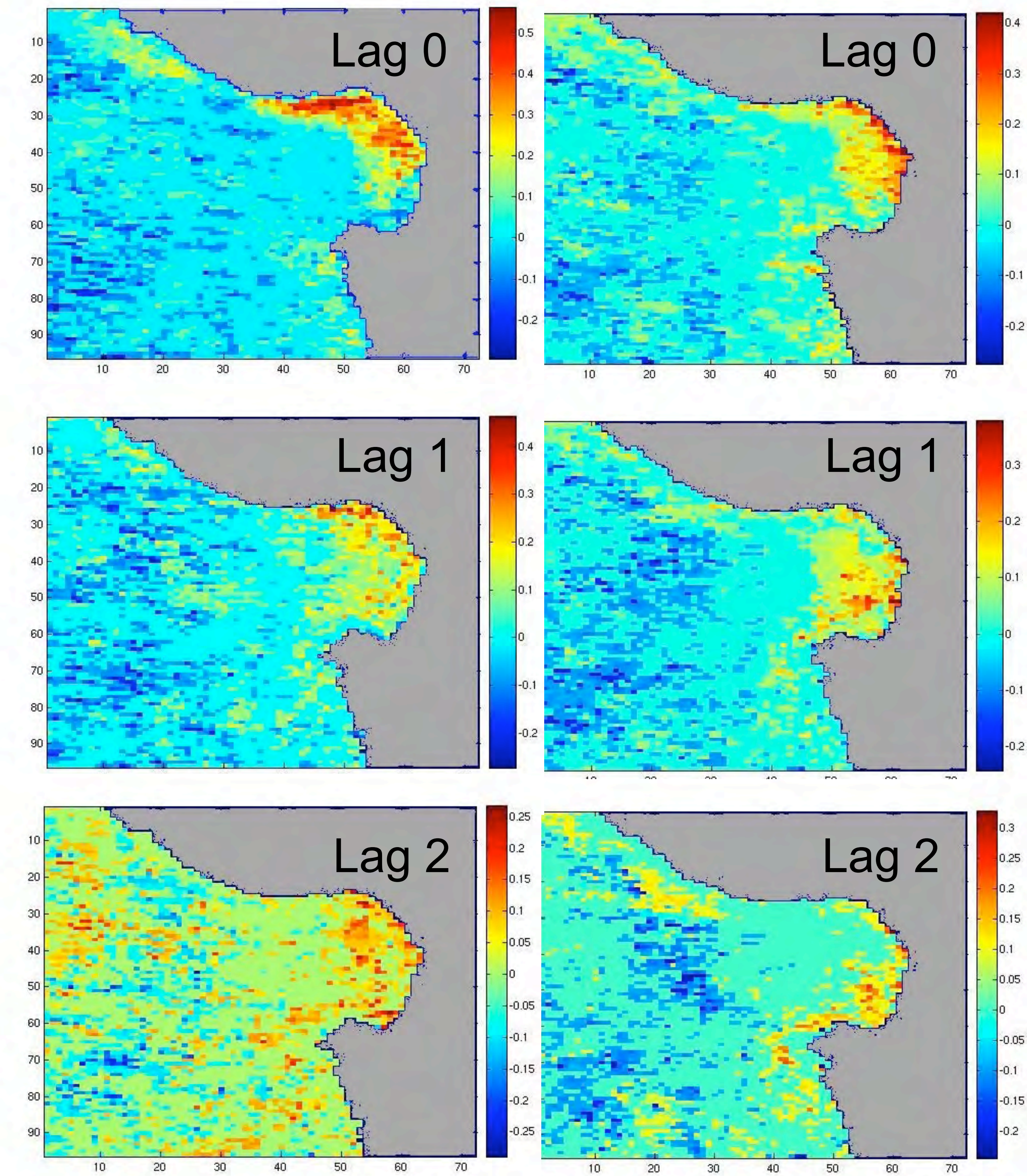


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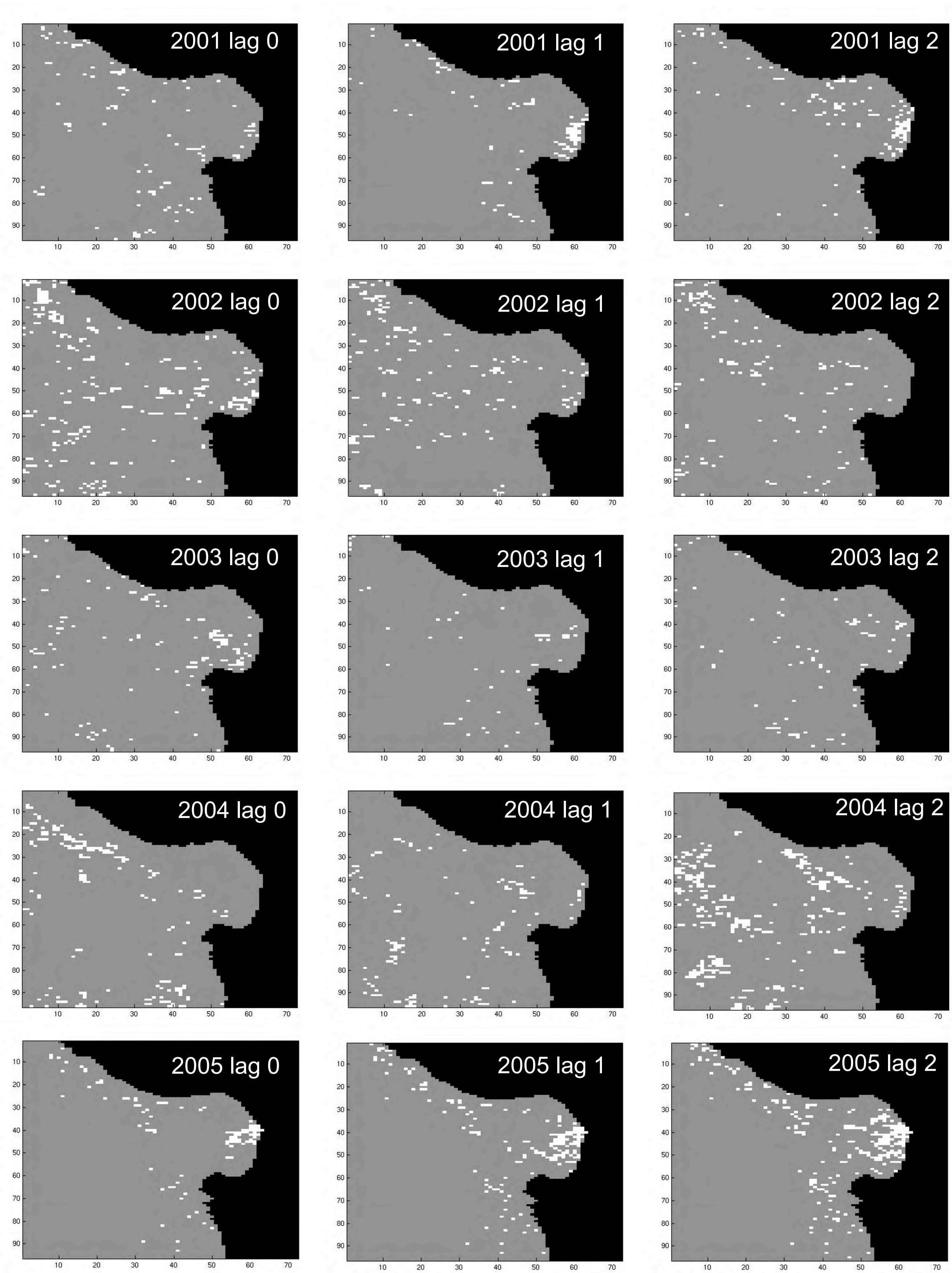
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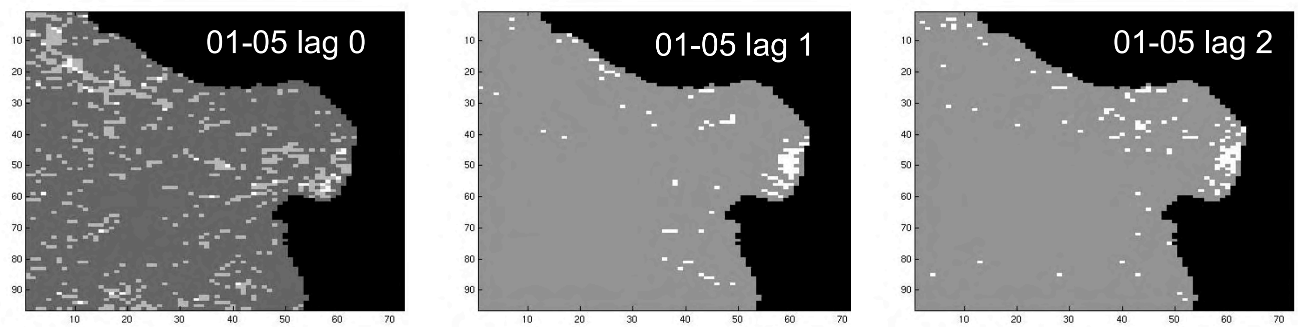
Figure 8.

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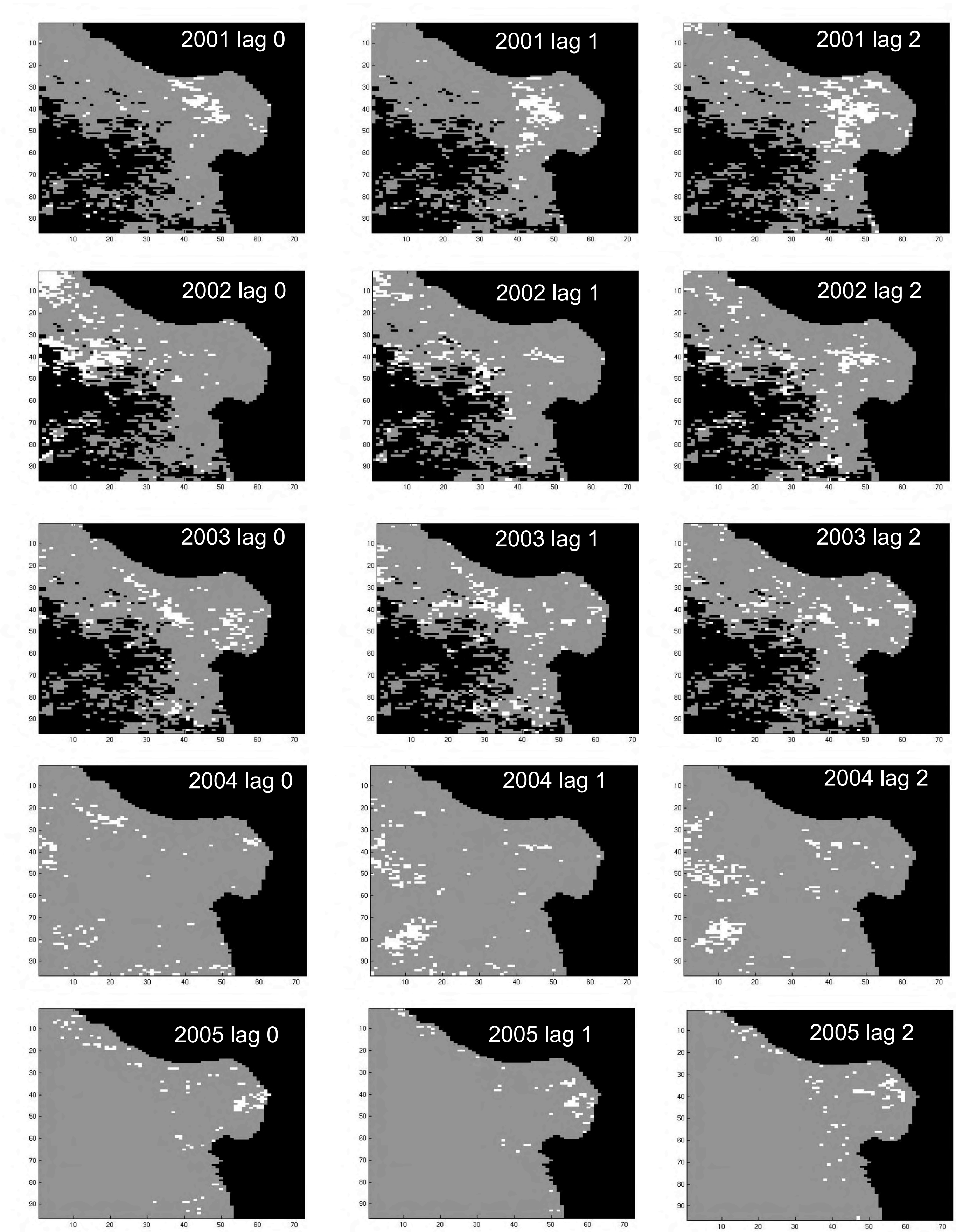

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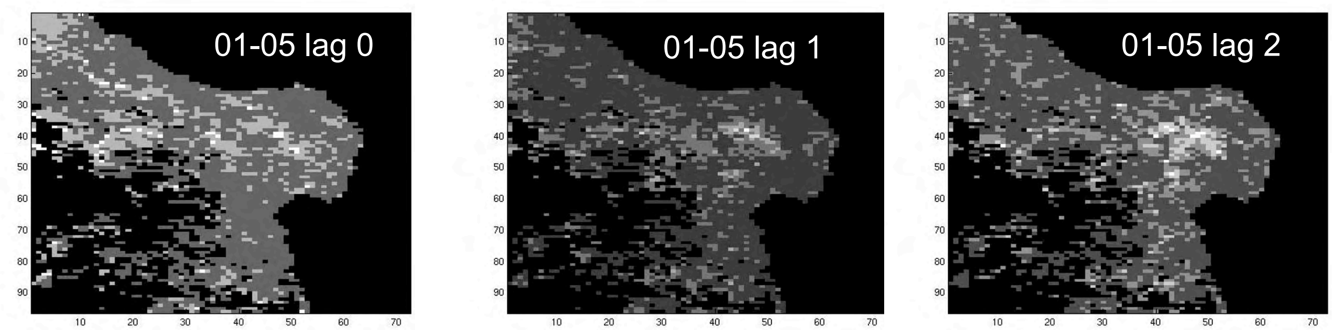
Figure 9.

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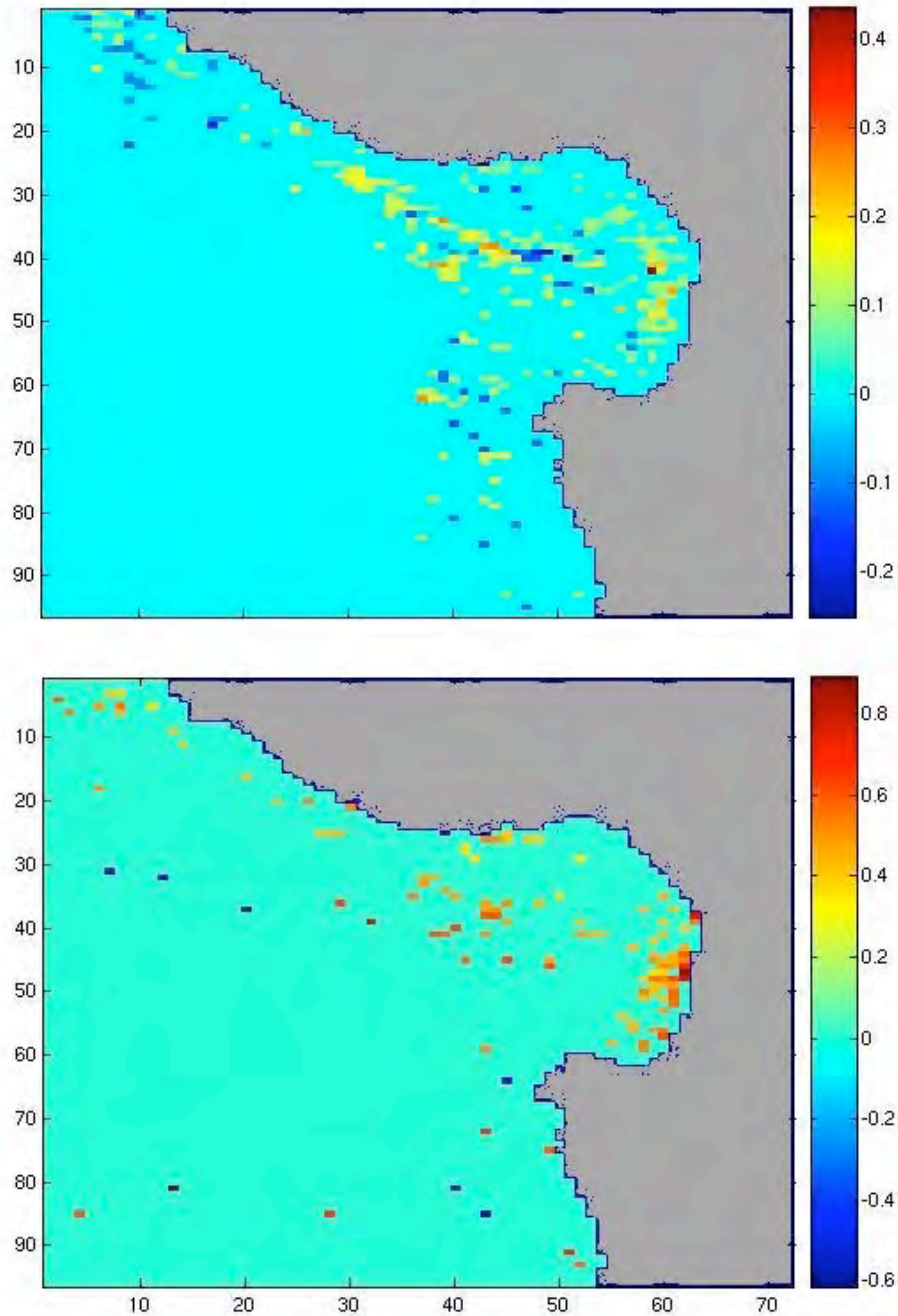
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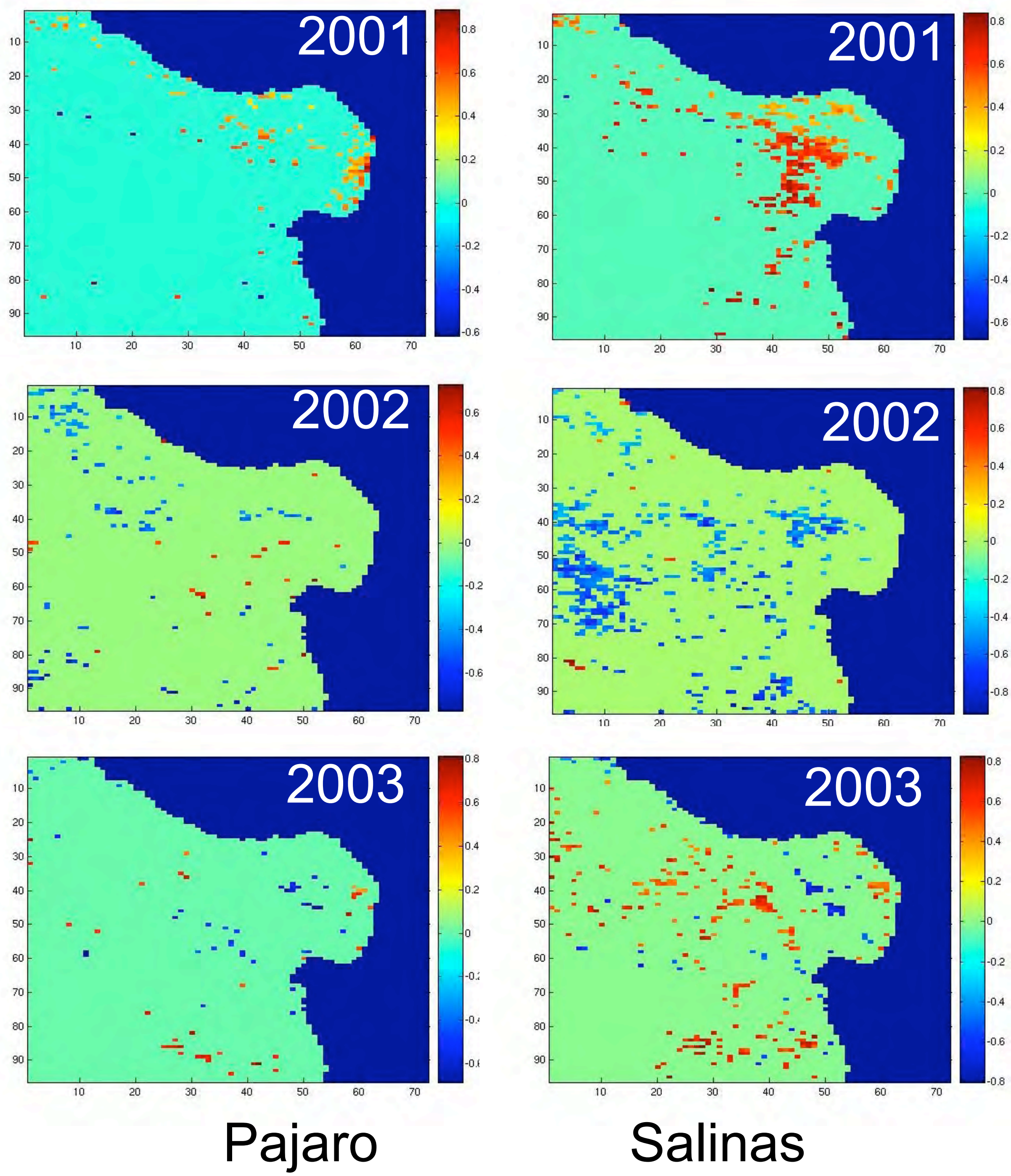
Figure 10.

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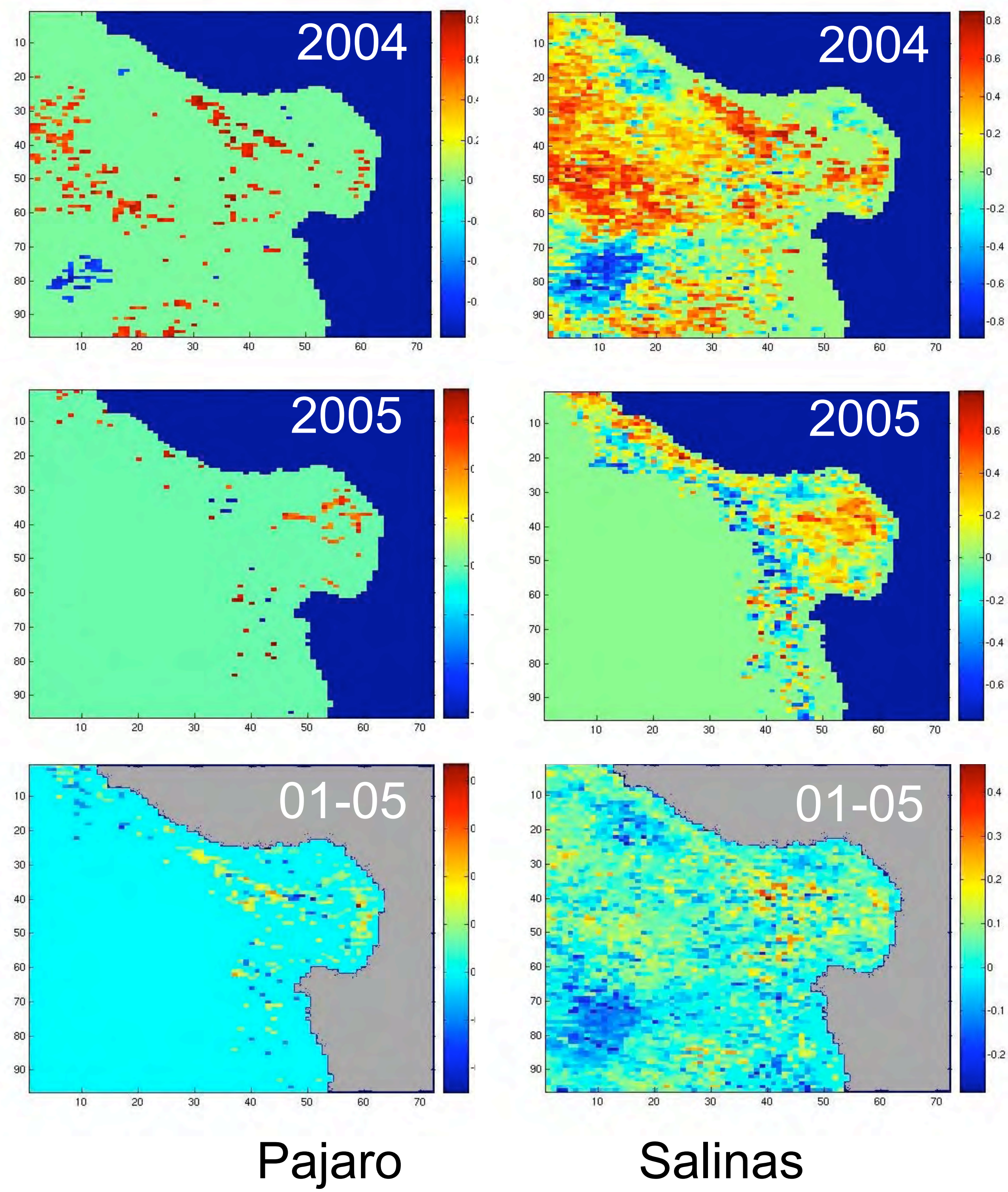


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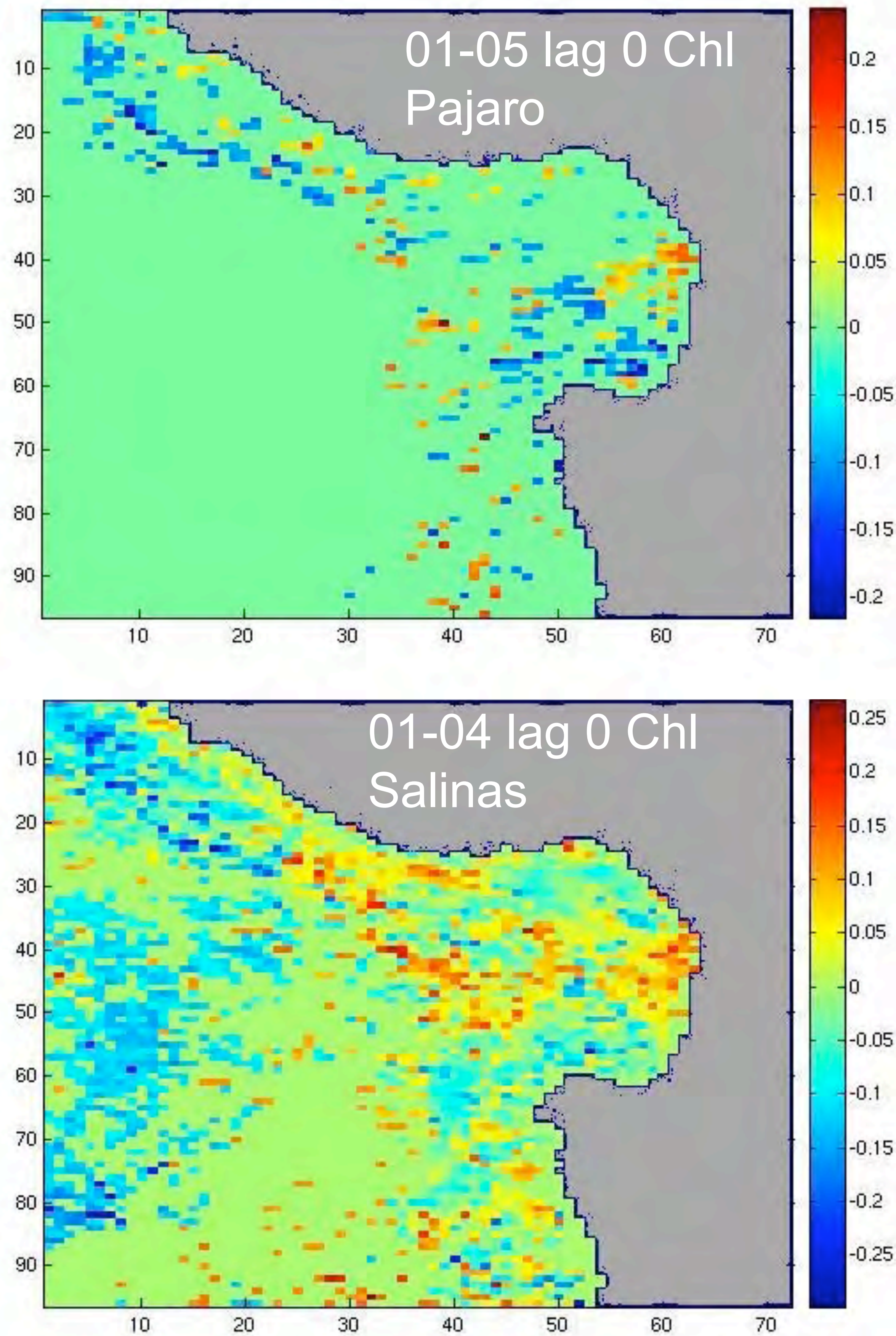
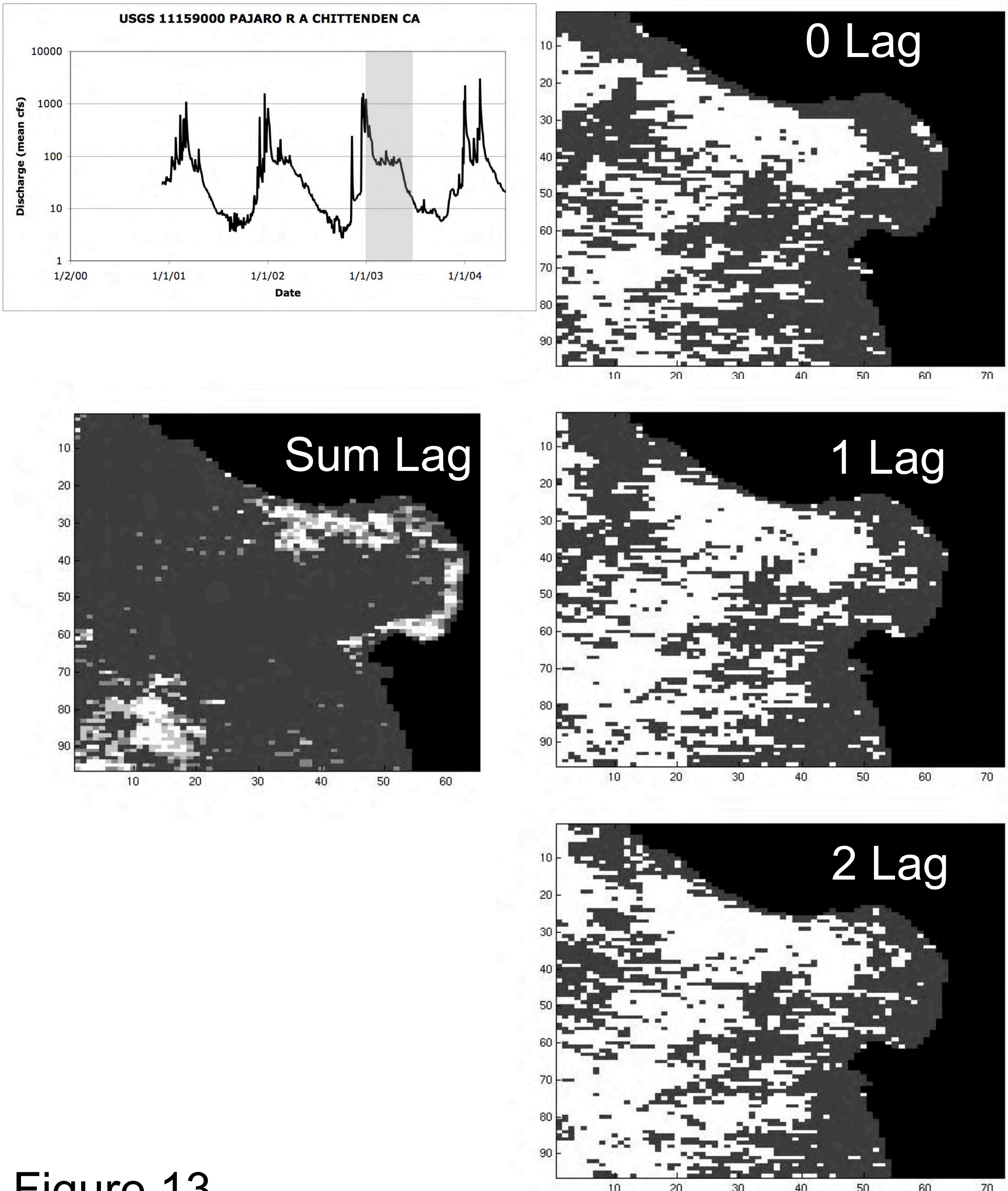



Figure 12.


USGS 11159000 PAJARO R A CHITTENDEN CA
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2 Lag

Figure 13.

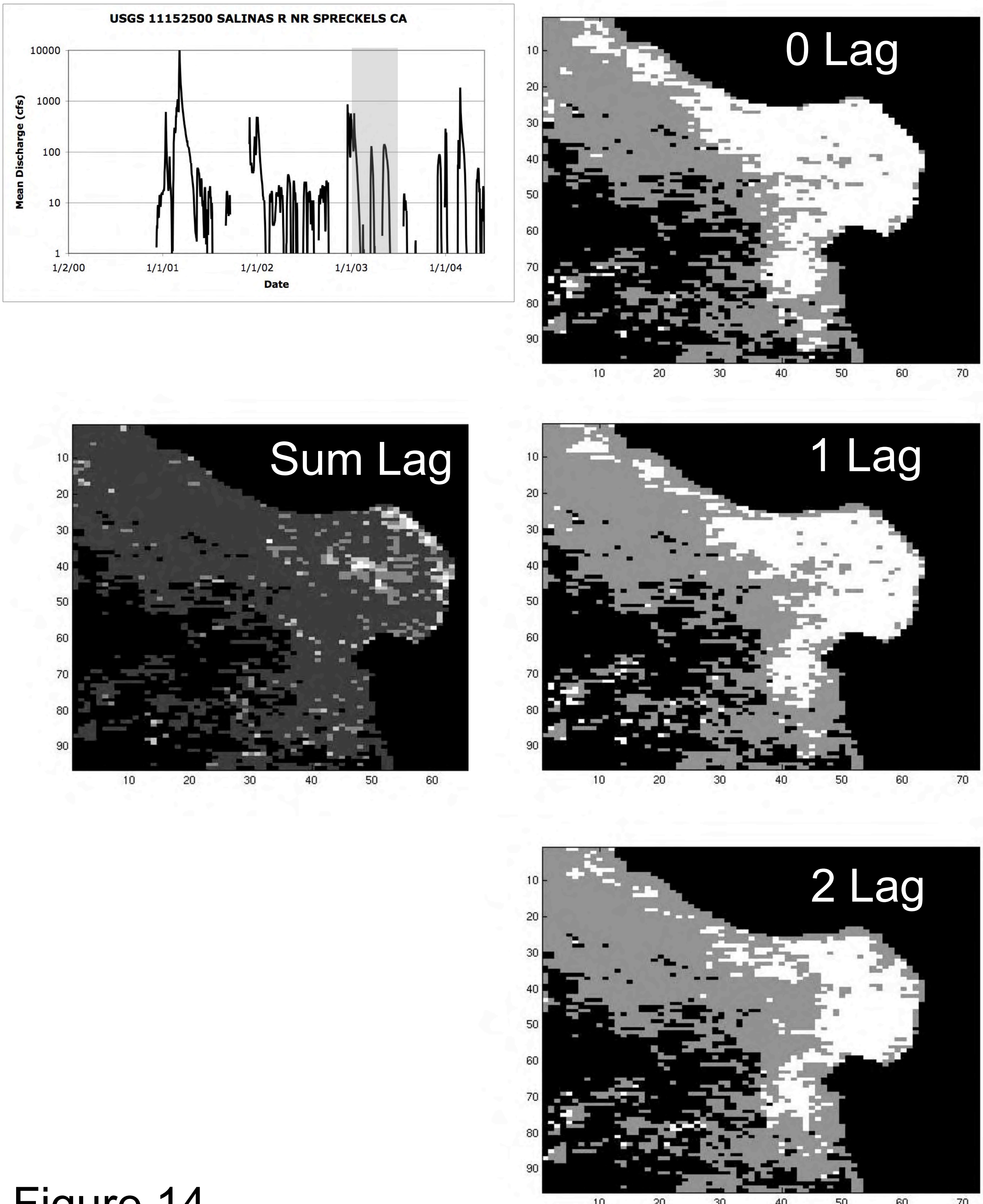
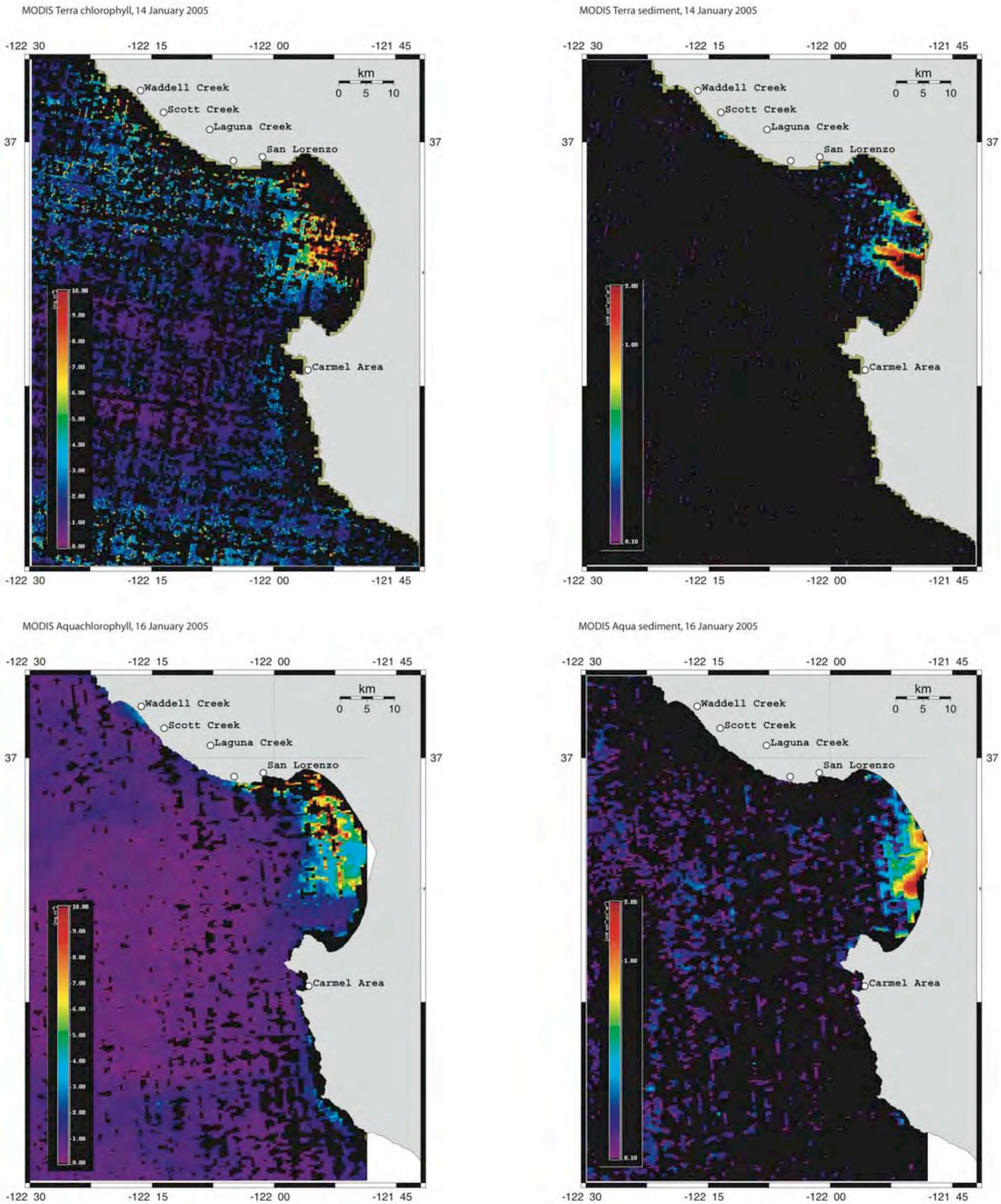

USGS 11152500 SALINAS R NR SPRECKELS CA
Mean Discharge (cfs)
10000
1000
100
10
1
1/2/00
1/1/01
1/1/02
1/1/03
1/1/04
Date
0 Lag
Sum Lag
1 Lag
2 Lag

Figure 14.


MODIS Terra chlorophyll, 14 January 2005
MODIS Terra sediment, 14 January 2005
MODIS Aquachlorophyll, 16 January 2005
MODIS Aqua sediment, 16 January 2005
-122 30
-122 15
-122 00
-121 45
37
km
0 5 10
Waddell Creek
Scott Creek
Laguna Creek
San Lorenzo
Carmel Area

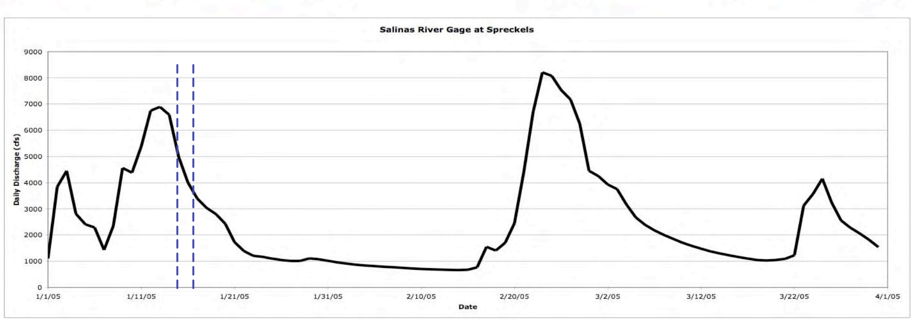

Salinas River Gage at Spreckels
Daily Discharge (cfs)
Date
1/1/05
1/11/05
1/21/05
1/31/05
2/10/05
2/20/05
3/2/05
3/12/05
3/22/05
4/1/05

Figure 15-A

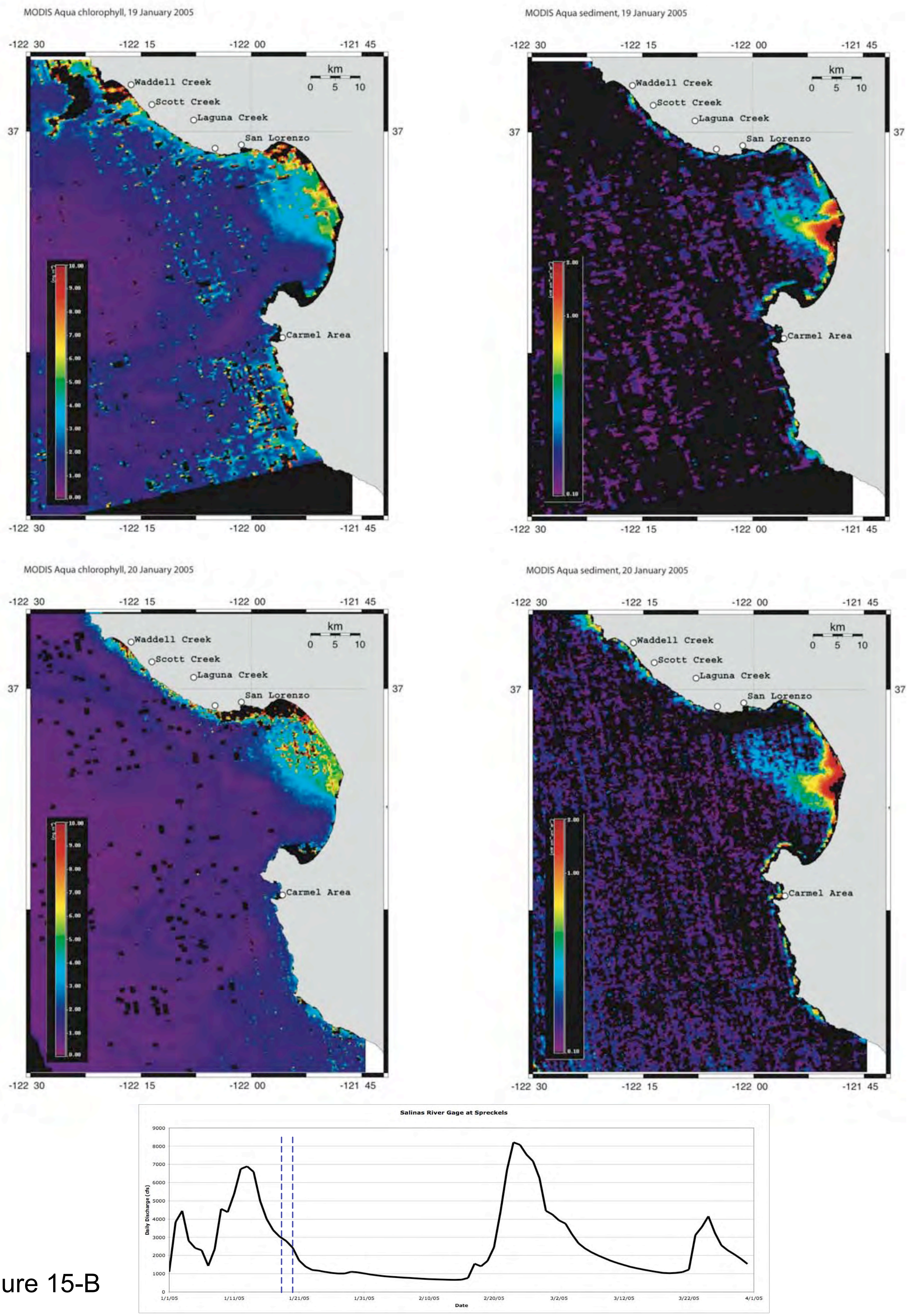
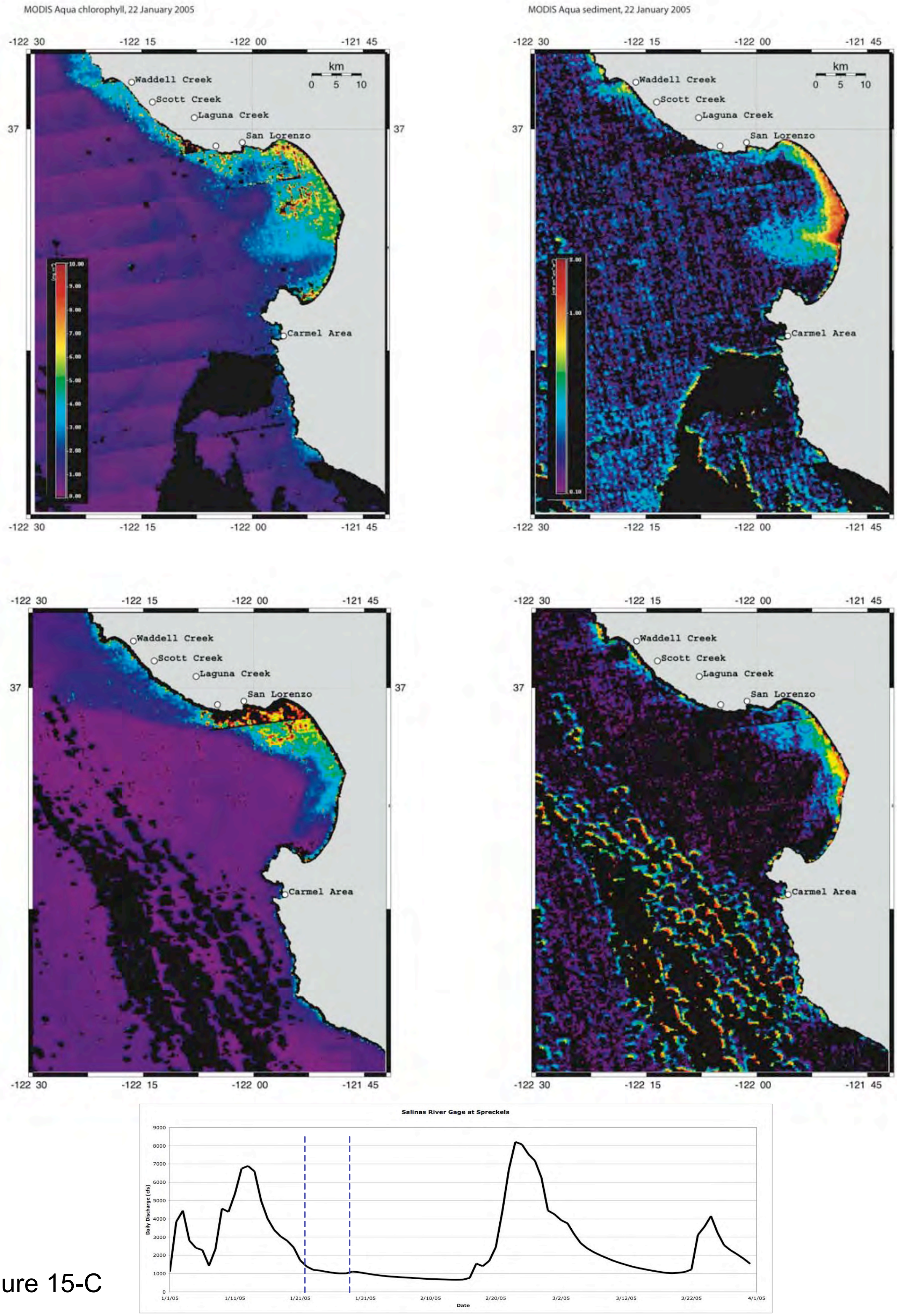

MODIS Aqua chlorophyll, 19 January 2005
MODIS Aqua sediment, 19 January 2005
MODIS Aqua chlorophyll, 20 January 2005
MODIS Aqua sediment, 20 January 2005
-122 30
-122 15
-122 00
-121 45
37
km
0 5 10
Waddell Creek
Scott Creek
Laguna Creek
San Lorenzo
Carmel Area
Salinas River Gage at Spreckels
Daily Discharge (cfs)
Date
1/1/05
1/11/05
1/21/05
1/31/05
2/10/05
2/20/05
3/2/05
3/12/05
3/22/05
4/1/05

Figure 15-B



MODIS Aqua chlorophyll, 22 January 2005
MODIS Aqua sediment, 22 January 2005
-122 30
-122 15
-122 00
-121 45
37
km
0 5 10
Waddell Creek
Scott Creek
Laguna Creek
San Lorenzo
Carmel Area
Salinas River Gage at Spreckels
Daily Discharge (cfs)
Date
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1/1/05
1/11/05
1/21/05
1/31/05
2/10/05
2/20/05
3/2/05
3/12/05
3/22/05
4/1/05


Figure 15-C

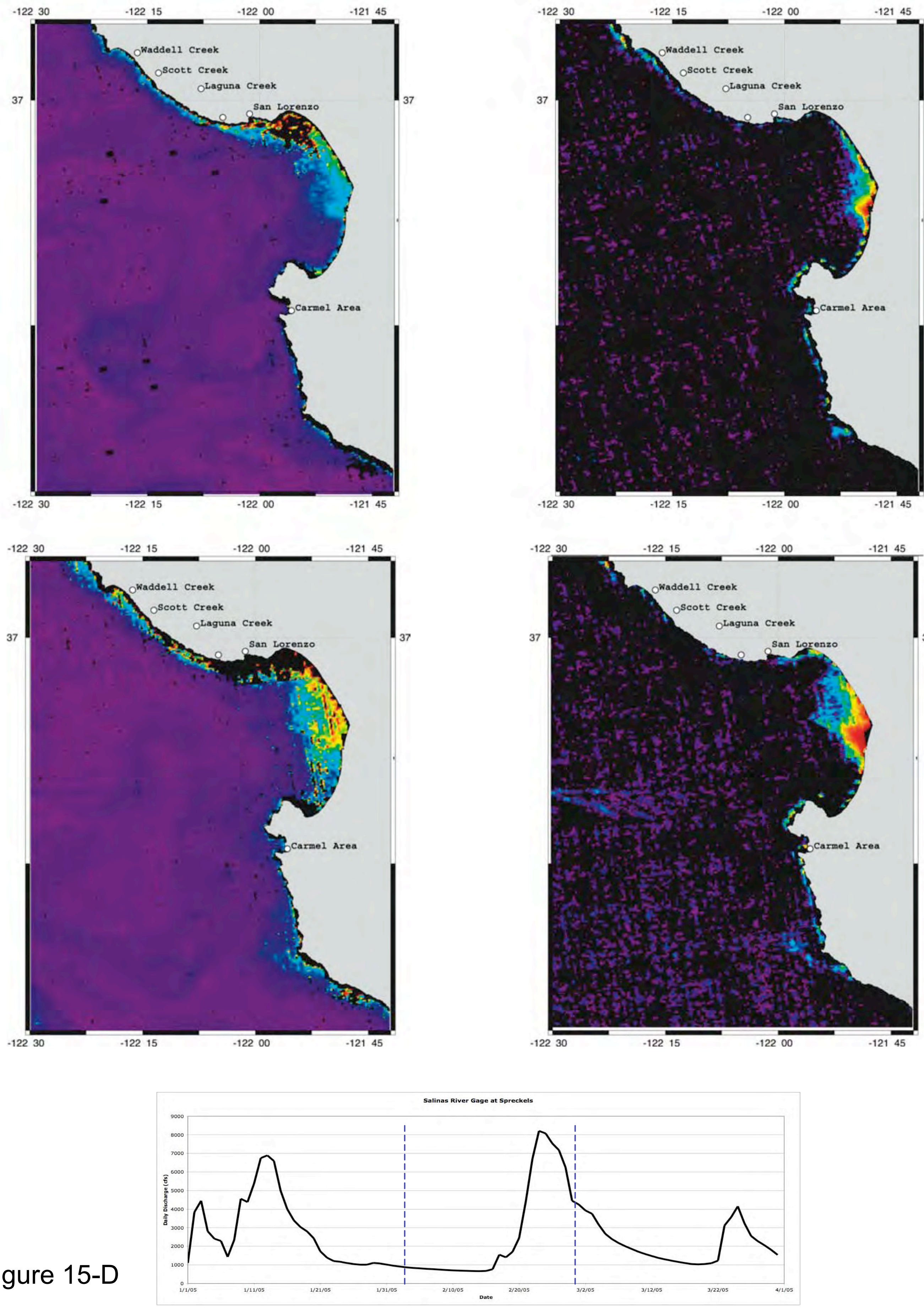
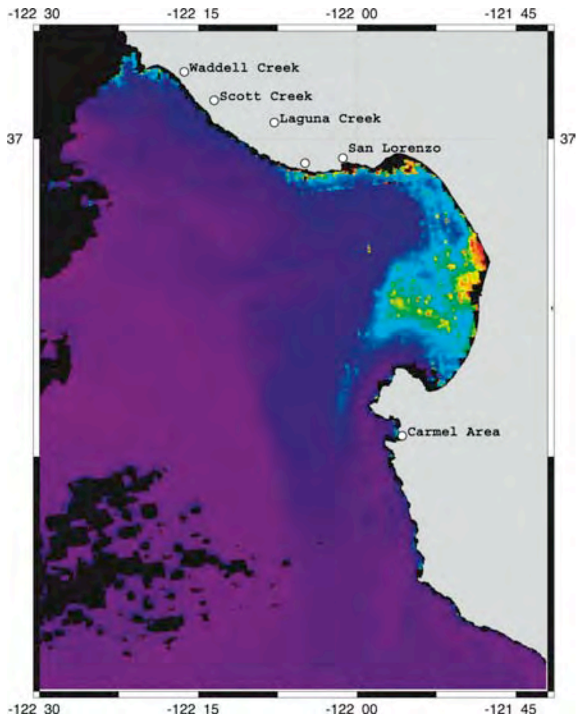

Waddell Creek
Scott Creek
Laguna Creek
San Lorenzo
Carmel Area
-122 30
-122 15
-122 00
-121 45
37
Salinas River Gage at Spreckels
Daily Discharge (cfs)
Date
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1/1/05
1/11/05
1/21/05
1/31/05
2/10/05
2/20/05
3/2/05
3/12/05
3/22/05
4/1/05

Figure 15-D


-122 30
-122 15
-122 00
-121 45
37
Waddell Creek
Scott Creek
Laguna Creek
San Lorenzo
Carmel Area

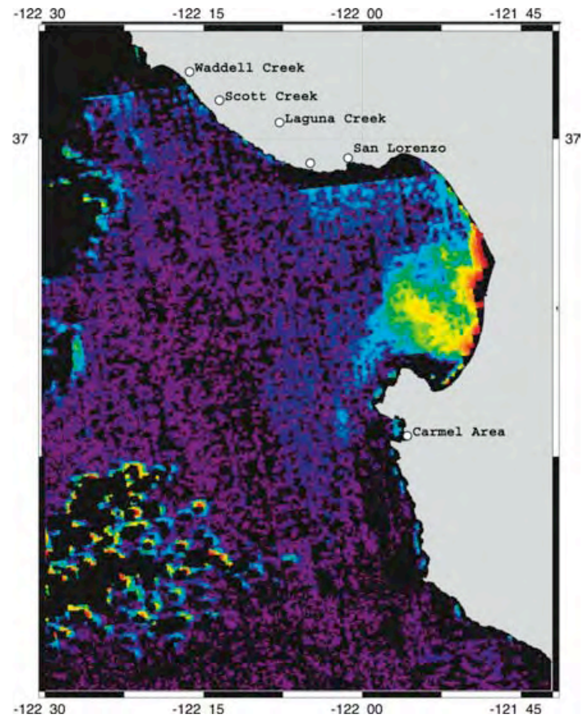
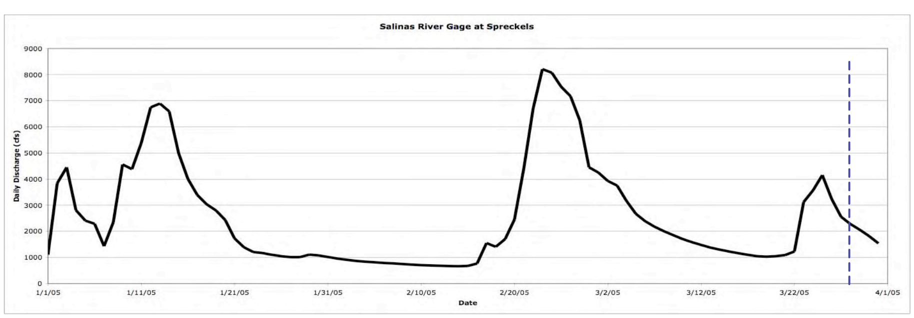

-122 30
-122 15
-122 00
-121 45
37
Waddell Creek
Scott Creek
Laguna Creek
San Lorenzo
Carmel Area

Figure 15-E


Salinas River Gage at Spreckels
Daily Discharge (cfs)
Date
1/1/05
1/11/05
1/21/05
1/31/05
2/10/05
2/20/05
3/2/05
3/12/05
3/22/05
4/1/05

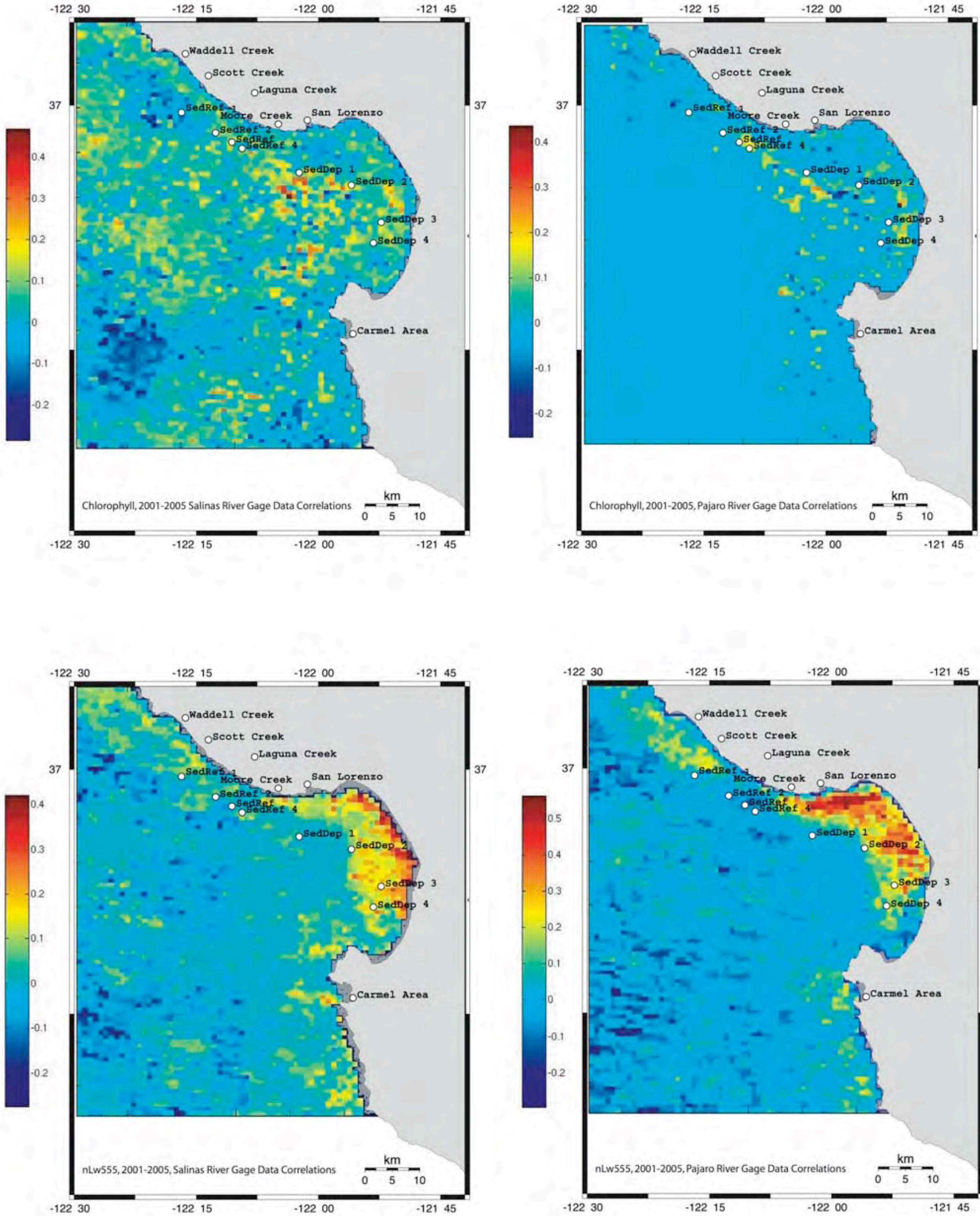
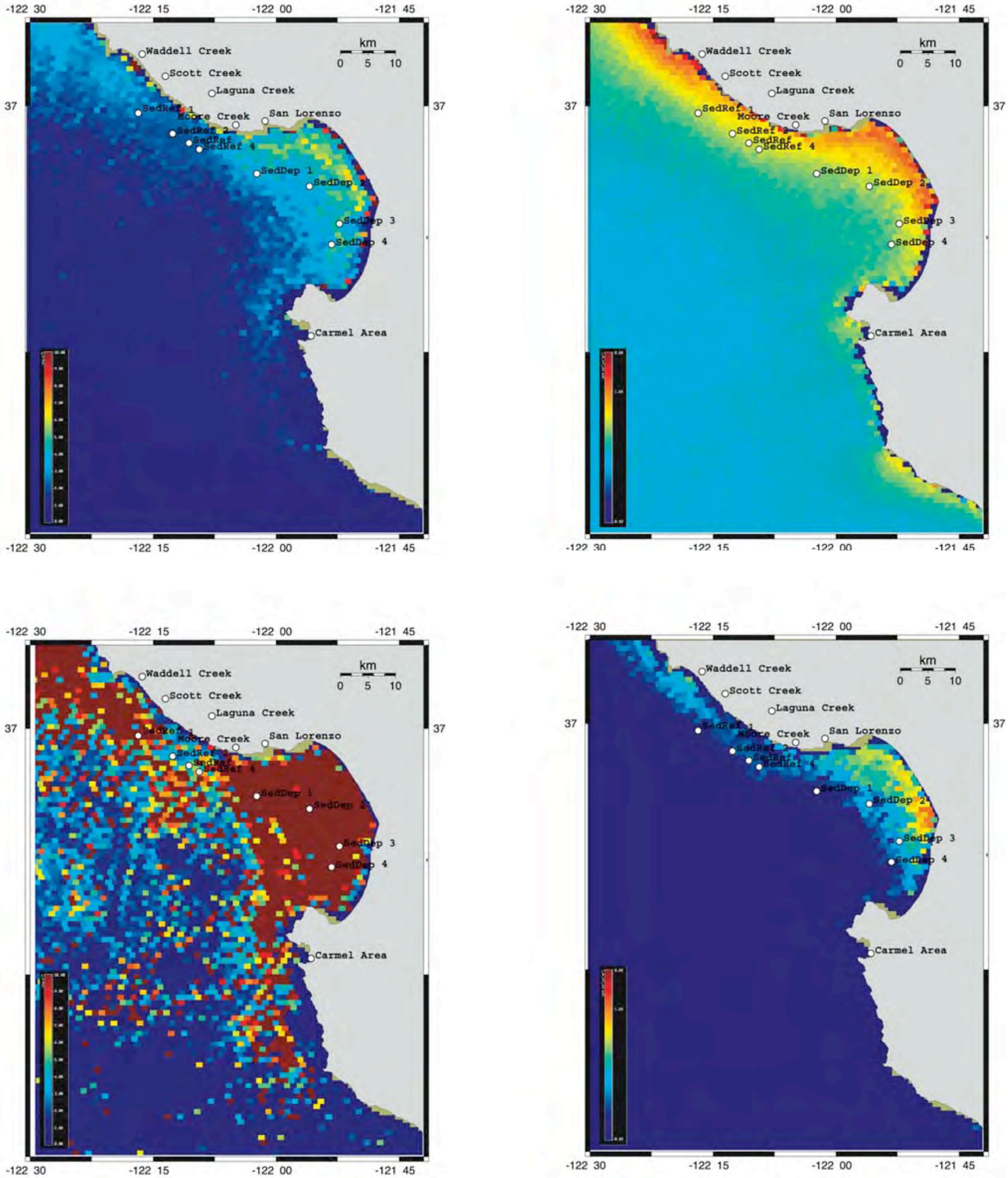

Chlorophyll, 2001-2005 Salinas River Gage Data Correlations
Chlorophyll, 2001-2005, Pajaro River Gage Data Correlations
nLw555, 2001-2005, Salinas River Gage Data Correlations
nLw555, 2001-2005, Pajaro River Gage Data Correlations
Waddell Creek
Scott Creek
Laguna Creek
SedRef 1
Moore Creek
San Lorenzo
SedRef 2
SedRef
SedRef 4
SedDep 1
SedDep 2
SedDep 3
SedDep 4
Carmel Area
-122 30
-122 15
-122 00
-121 45
37
km
0 5 10

Figure 16.



-122 30
-122 15
-122 00
-121 45
37
km
0
5
10
Waddell Creek
Scott Creek
Laguna Creek
SedRef 1
Moore Creek
San Lorenzo
SedRef 2
SedRef
SedRef 4
SedDep 1
SedDep 2
SedDep 3
SedDep 4
Carmel Area


Figure 17.

## Appendix A
## SeaWiFS Analysis for CCLEAN: Preliminary Results

Overview: As part of CCLEAN's routine measurements, nutrient and pathogen data are collected from several streams in the Monterey Bay region. CCLEAN compared SeaWIFS chlorophyll (n=11, 4 sites, N=44) and normalized water leaving radiance at 551 nm (nLw555; n=4, 4 sites, N=16) for reference and "impact" stations near Scott Creek and Pajaro River. Using paired t-tests, CCLEAN found that Pajaro River was significantly different from its reference site, and from Scott Creek. Based on this initial analysis, we proposed to provide a more detailed spatial correlation between river flow and SeaWiFS data.

Methods: For this initial analysis, we focused on January-September 2004. No river data were available at this time for October-December 2004. SeaWiFS data were obtained at (nominal) 1 km resolution from the Goddard DAAC, and spatially projected onto a uniform grid (36.13 – 37.17° N, 121.7 - 122.5° W) using both 8-day average and 1-day average images. River flow data were obtained from USGS for the Spreckles (Salinas River) gage station. Statistical comparisons were done using cross-correlation, with zero-values (no flow) left in the river data (Figure 1), but removed from the satellite data. Both data sets were log-transformed prior to analysis. For correlation analysis, data were lagged (SeaWiFS lagging the river flow data) for 0, 1, and 2 days.

Preliminary results: The first processing utilized 8-day average imagery for the entire time period (Jan-Dec 2004). This method was determined to be too coarse to identify patterns of interest (Figure 2), and subsequent analyses utilized 1-day satellite imagery.

Based on the 8-day data, higher temporal resolution imagery was used. Analysis of the entire time period (Jan-Dec) again showed poor correlation (data not shown), so a smaller time period during peak river flow was chosen, February-March 2004 (see Figure 1).

Using this time window, a significant ($p<0.05$) negative relationship was found between river flow and chlorophyll at zero-lag (Figure 3). It was not persistent with 1 and 2 day lags, although qualitatively, the same pattern was present. There is also high correlation with offshore regions, presumably because river flow is associated with a mesoscale restructuring of the region (i.e. the oceanography is correlated to the conditions associated with heavy rainfall).

In contrast with the chlorophyll data, the nLw555 data showed a significant positive relationship (i.e. more sediment and other reflective material), with much greater spatial extent (Figure 4). Again, the 1- and 2-day lags were not significant, and again, there was mesoscale structure presumably unrelated to river flow in the outer domain.

Current Status: Based on these preliminary observations, it is suggested that the river flow has an immediate (1-day) impact on nearshore chlorophyll and suspended sediments, which is largely dissipated after about a day. The impact of suspended sediment is spatially greater than the (negative) impact on chlorophyll. The river flow has negligible impact on the oceanographic patterns during periods of low/no flow, as expected.

We have thus far only examined 2004, and only used Salinas River data. However, there is good correspondence between the Salinas and Pajaro flows for 2004 (Figure 5), and we expect that the spatial correlations observed are really spatial correlations to total river flow, not just the Salinas River. The next steps that we are following up on include:

1) Extending the temporal domain from 2000-2005; there was substantial variability in the river flow data during this period, so different years may exhibit different patterns.
2) Creation of a "climatological" spatial correlation, by calculating the same statistics for multiple seasons (i.e. December-March for multiple years)
3) Comparing the spatial correlations with river flow data from other gage stations
4) After #1, we will focus on the most interesting year and run the same analysis with higher spatial data (e.g. MODIS 250 or 500 m data)

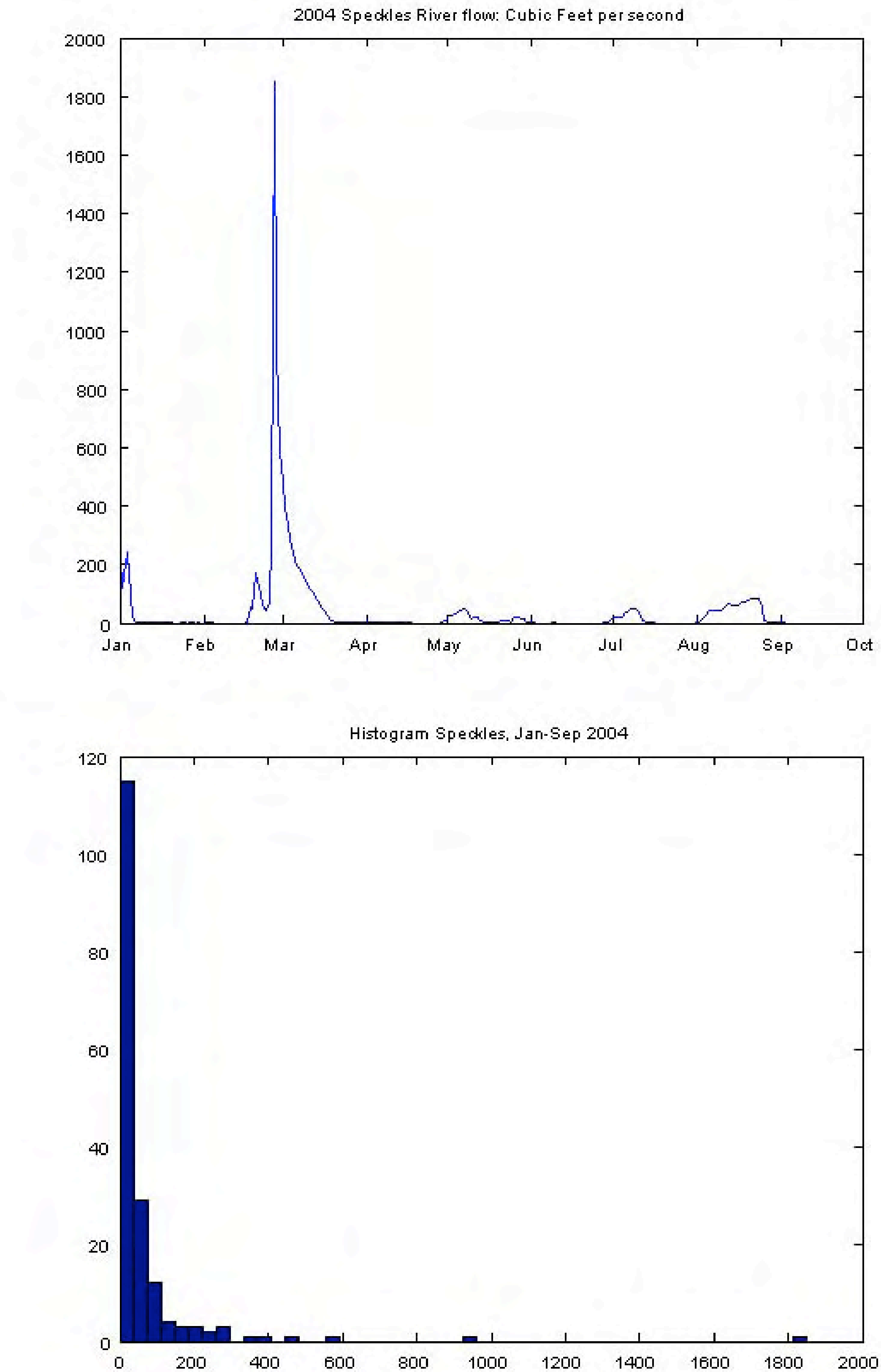



Figure 1. Salinas River data (Spreckles) prior to being log-transformed.

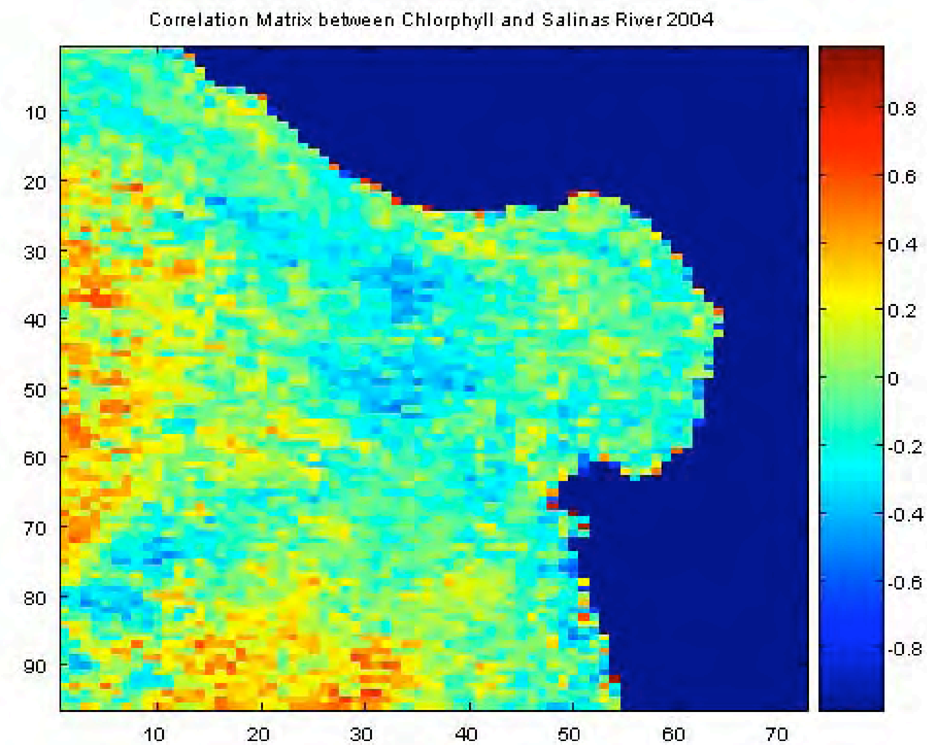



Figure 2. Correlation matrix for SeaWiFS chlorophyll using an 8-day average and Jan-Sep 2004.

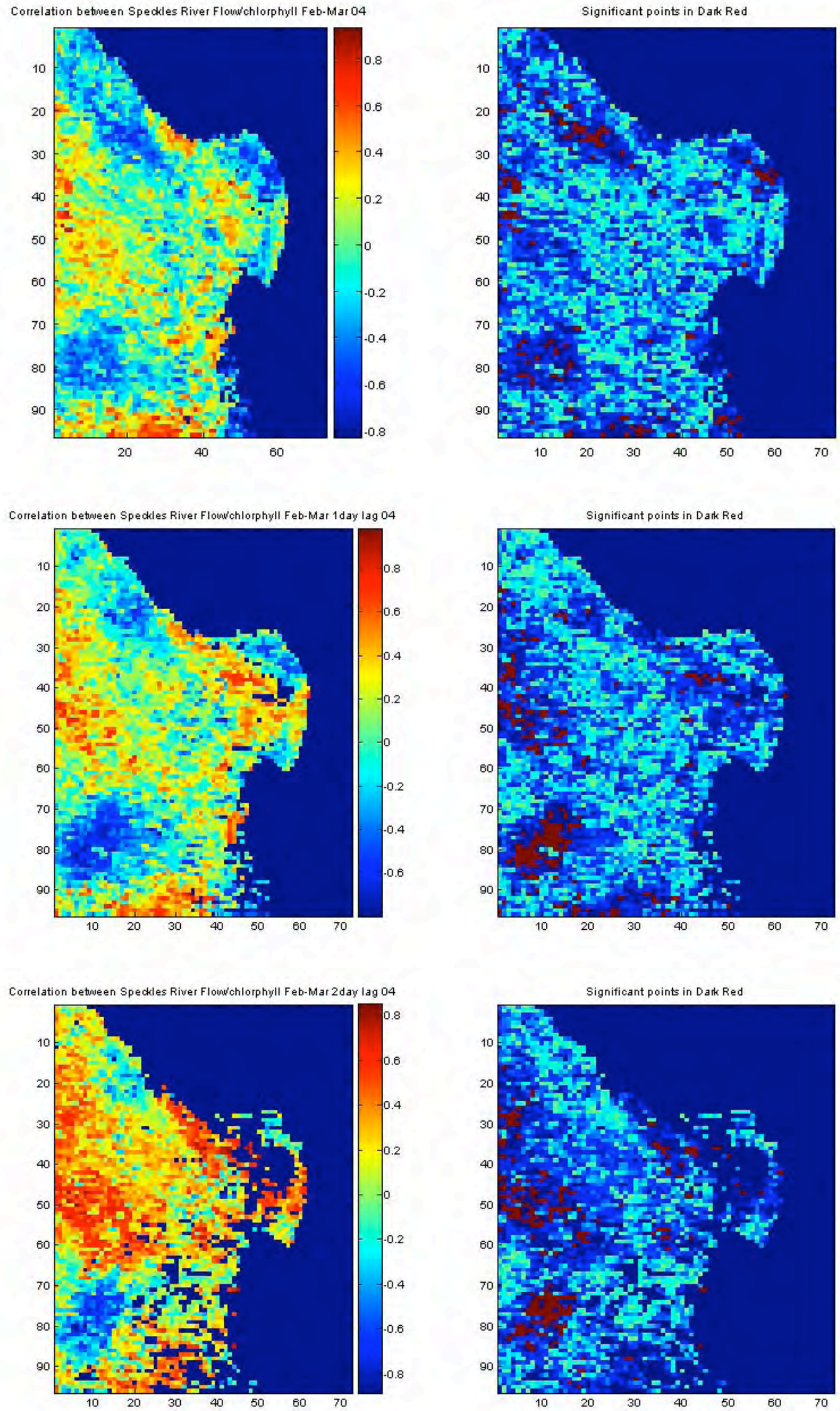



Figure 3. Spatial correlation between chlorophyll and river flow at 0, 1, and 2 day lags (top to bottom) showing the correlation (left) and p-value (right; dark red pixels are significant at $p<0.05$). At zero days, a significant negative correlation was obtained at mid-Bay. At 1- and 2-day lag this correlation largely disappeared.

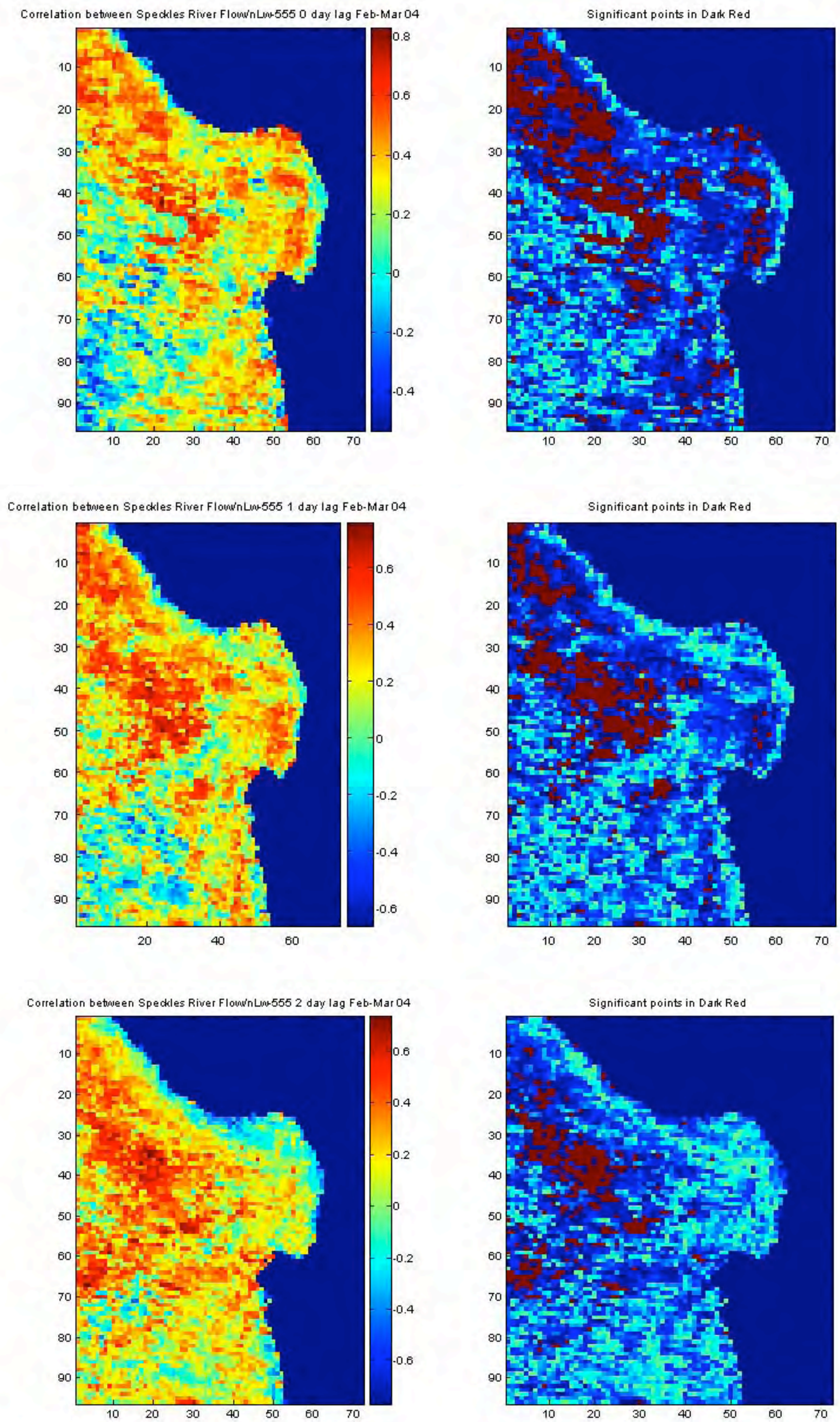



Figure 4. Spatial correlation between nLw555 and river flow at 0, 1, and 2 day lags (top to bottom) showing the correlation (left) and p-value (right). At zero days, a significant positive correlation was obtained over large sections of the inner Bay. At 1- and 2-day lag this correlation largely disappeared.

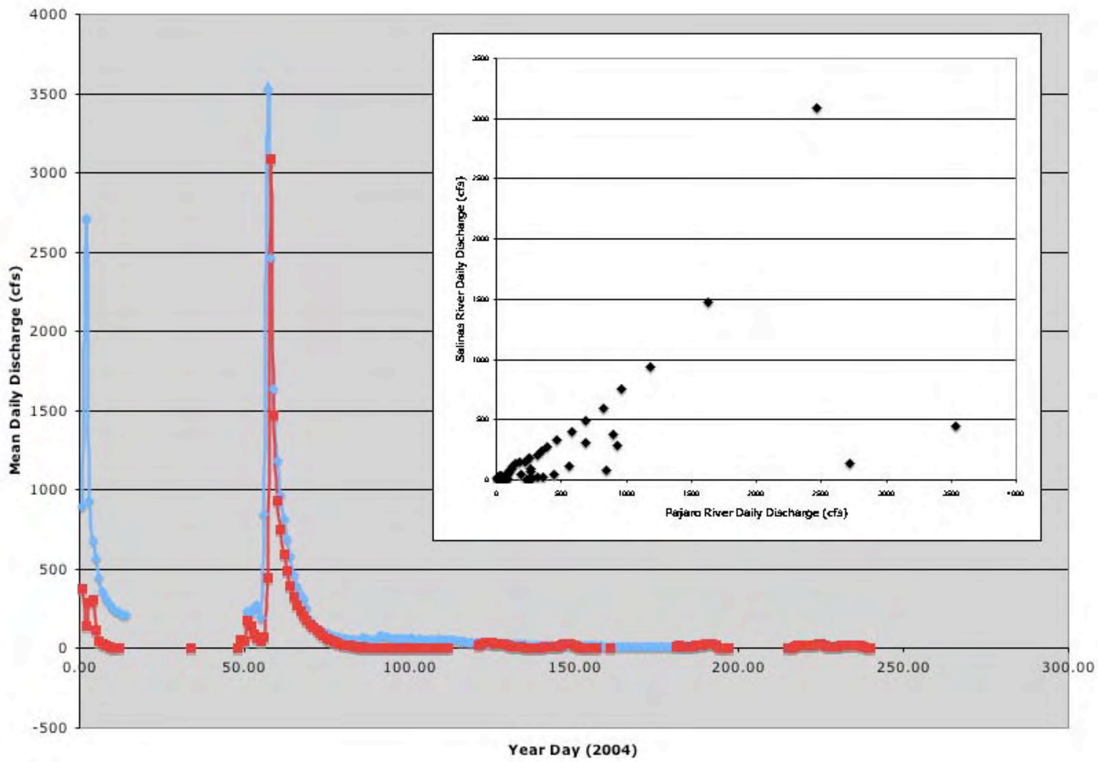



Figure 5. Mean daily discharge for Pajaro River (red) and Salinas River (blue) for 2004. The inset graph shows the data plotted as a property-property plot.