Title: Using on-line data sources to allow students to test hypotheses about river flow and effects on remotely sensed coastal ocean properties.

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Abstract:

This exercise shows students how to relate remotely sensible properties of coastal waters to variations in river discharge using on-line data resources. Students can then test hypotheses about the effects of climate changes (drought and wet periods), anthropogenic impacts (urbanized, agricultural, or undeveloped watersheds), or seasonality on river discharges and their consequences, if any, on coastal water quality as determined from remotely sensed properties. River flow has been measured for various periods of time, in some cases from almost the beginning of the 20th century, at many locations throughout the U.S. by the U.S. Geological Survey, with data on flow and, in some cases, other parameters available on-line. Data sets describing remotely sensible properties of coastal waters are available from SeaWiFS and MODIS-Aqua satellite platforms, and include several aspects of water color that can be related to water characteristics. Examples of simple hypotheses that can be tested using this approach include the predictions that high river discharges are associated with increases in coastal water absorption coefficients and scattering, and that low discharges are associated with low levels of absorption and scattering.

Instructions for accessing data sets are provided along with basic information about the nature of these data. Instructors may find portions of this resource useful as bases for separate exercises, as well as opportunities to address broader issues about hydrology and ecological impacts of anthropogenic and natural variations in hydrologic regimes.

Learning objectives:

1) Students will become familiar with river gaging data sets available from USGS, and learn to derive testable hypotheses from examination of river flow data sets and plots.

2) Students will become familiar with capabilities of remote sensing platforms, such as SeaWiFS, and learn to assess relationships between river flow and coastal ocean properties, particularly for periods of high and low flows.

3) Students will be able to plot river discharge vs. time and gain quantitative understanding of annual and inter-annual patterns, while exploring limitations of inferences derived from use of proxy measures, such as remotely sensed properties.

Timeframe: Instructors should plan to work through one or more full examples of the exercise to become familiar with the data sets, their access, and their manipulation. From a "cold" start this may require 3-4 hours of reading and on-line work. Instructors can walk a class through a model exercise in 20-30 minutes to familiarize students with the steps. This exercise works well as a homework assignment.

List of materials: This is largely a computer-based exercise requiring access to on-line data resources, plotting and statistical analysis capabilities. Ability to print graphs is highly desirable.

Procedure and general instructions (for instructor). REQUIRED.

Introduction

Rivers represent the principal connection between terrestrial ecosystems and oceans, although aeolian dust transport (Jickells et al., 2005) and submarine ground water discharge (SGWD; Simmons, 1992) are also recognized as important pathways of material transport to coastal oceanic ecosystems. Rivers deliver a complex mix of materials to coastal waters, including sediments, terrestrially derived organic matter, various dissolved materials, and, in several forms, plant nutrients. The interactions of these materials in the mixing zone along the river-ocean transition control the responses of coastal plankton communities. The concentrations of these materials in river discharges and their total loads (= concentration X volume) are functions of source strengths and river flow volumes, which are in turn a function of watershed size, land use, and precipitation patterns at short, seasonal, and longer time scales.

The annual appearance of a so-called "Dead Zone", a region in which the water column exhibits hypoxia and even anoxia, in the Gulf of Mexico off the mouth of the Mississippi River, highlights the effects that delivery of materials from rivers can have on coastal ocean ecosystems (Turner et al., 2005). The Mississippi River drains 42% of the continental U.S., including large portions of the extensively agricultural Midwest and several major metropolitan areas, with very large total inputs of nutrients, organic material, and sediments from point and non-point sources. As a result, the lower Mississippi has extremely high loads of turbidity and coloring materials, which limit light flux and the ability of aquatic plants to utilize the nutrient load in the river, allowing nutrient concentrations to reach levels ~100X those in offshore surface waters (Justić et al., 1993, 1995). As the river water enters the coastal ocean, it slows, losing much of its sediment load (hence forming its delta), mixes with sea water, and becomes much more transparent. Enhanced light penetration allows utilization of nutrients to support blooms of algae. Although this is a natural sequence of events (Osterman et al., 2008), anthropogenic nutrient loading has demonstrably strengthened the algal blooms, and they have in turn generated organic matter loads sufficient to consume essentially all the oxygen in the water column over larger areas and longer periods of time than ever before (Turner et al., 2006). The hypoxic zone off the Mississippi River mouth is actually only one of many now recognized in coastal waters, particularly those heavily impacted by anthropogenic inputs (Diaz, 2001; Diaz and Rosenberg, 2008).

Learning Opportunity:

The genesis, impacts and management implications of coastal hypoxic zones are important issues. Students can search and discuss the literature, consider trends, and argue different causes and responses.

Not all effects of river discharges on the coastal ocean are necessarily harmful. The delivery of nutrients and other materials by rivers has always been a key factor supporting the productivity of coastal waters, so coastal fisheries production must be considered a “beneficial” consequence of river discharges. Similarly, the presence of beaches is partly a result of sediment delivery from upland areas by rivers. Finally, the delivery of fresh water by river discharges alters the salinity and physical characteristics of coastal ocean waters, including properties such as buoyancy and stratification, which have effects on circulation and the distribution of materials and organisms (Pietrafesa and Janowitz, 1979). Periods of high discharge may amplify these effects, while drought may weaken the land-ocean coupling.

The major aim of this exercise is to explore the consequences of river discharges on remotely sensible properties of coastal ocean ecosystems, particularly as they might affect phytoplankton populations. The exercise takes advantage of the availability of archived, publicly available data bases that can be used to examine possible effects of the coupling of terrestrial and oceanic ecosystems. It is also possible to examine the effects that human development, or lack of it, in a watershed can have on that coupling by examining river basins in different areas, as well as the effects of changing weather patterns over time. Recent analysis of watershed-scale land use and nutrient loading shows the strong effects of agricultural development on nitrogen export, for example (Broussard and Turner, 2009). As global climate change alters regional weather patterns (Christensen et al., 2007), we may predict that the nature of these links between land and ocean will change as well (Justić et al., 2005).

The U.S. Geological Survey maintains river gaging stations at thousands of locations in the U.S. These stations provide estimates of river flow based on water level and the known dimensions of each gaging station location. The gaging data sets extend in many cases back to the early 1900s, and are useful in analyzing flood probabilities, effects of drought, and derived effects of flow on other aspects of water quantity and quality. Most of the gaging data are freely available on the web, but one must learn to navigate the sites and work with the peculiarities of the data sets.

Learning Opportunity:

River gaging data extend well into the past for many rivers and streams. These data have been used for flood assessment and forecasting and as proxies for precipitation patterns. Separate exercises using these historical river gage data sets allow students to examine long-term patterns of flow, seasonality of flows from different precipitation regimes, e.g., direct rain runoff vs. snow-melt flows, effects of climate variability, and effects of human diversions of water, among others.

Similarly, data on coastal ocean properties have also been collected using satellite mounted sensors and archived for public access. In this exercise we will use Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data processed through the “Giovanni” portal, a relatively user-friendly web-based application for accessing remotely sensed ocean data available from September, 1997 to the present. Among these data sets are estimates of ocean color (“water-leaving irradiance”, or light reflected back into space, at several wavelengths), particulate backscatter, water clarity (“diffuse attenuation coefficient”, a measure of light attenuation in the water), and chlorophyll *a*. It is important to note that the algorithms that convert the sensible properties of surface waters into estimates of chlorophyll *a*, a phytoplankton biomass indicator, can be biased by turbidity and color in coastal waters (Hyde et al., 2007). Although these data may serve the purposes of this exercise, they must be interpreted with caution. Concurrent analysis of several parameters may provide a better assessment of coastal ocean responses to river discharges. There are excellent resources that provide much fuller descriptions of the theory and application of remote sensing for study of ocean ecosystems, e.g., Martin (2004), as well as specific situations in which river discharge is a factor, e.g., Pan et al., 2008; Kowalzcuk et al., 2006.

Learning Opportunity:

Remotely sensed chlorophyll *a* is relatively reliable for open ocean waters, and the Giovanni tool allows integration of space and time, as well as construction of time series, at least back to 1997. Students can learn quickly to examine large-scale variation in remotely-sensed chlorophyll *a* and can examine effects of phenomena, such as El Niño, on oceanic chlorophyll *a* patterns in time and space.

Exercise

Students will:

1) **Select a river** draining to the coastal ocean in the U.S., preferably one that drains directly into the sea, rather than flushing very slowly through a large estuary with long retention times, i.e., the coastal New River in North Carolina, whose estuary has a relatively slow 1.6 year flushing time. Very large rivers, e.g., the Mississippi, have more developed, complex watersheds, so interpretation of results for them may be similarly complex. Very small rivers have proportionally smaller effects on coastal ecosystems, and their discharges may be masked by discharges from any nearby larger rivers, which may vary in synchrony.

2) **Identify the most downstream gaging station**, i.e., nearest the ocean, to give the best measures of discharge, bearing in mind that gages are above tidally influenced portions of coastal rivers and the downstream watershed. You will use the USGS National Water Information System (NWIS) website: http://waterdata.usgs.gov/nc/nwis.

This one is for North Carolina, but there is a pull down menu of states in the upper right hand corner from which you can select any state. Once you've picked a state, select "GO" to get to that state's site, then select the "Surface Water" bar. In the next screen, look under the blue bar, "Statistics", and select "Monthly". The next screen lets you select site criteria. You really only need to leave it set at "Site Type"; more restricted criteria will eliminate selections before you really need to do that, so click on "Submit". In the next screen, under "Site type", select "Stream", then under "Available Parameters", select

"Streamflow, ft^3/s" (note how many sites are available for this category as opposed to all the other options. This number will be found in parentheses adjacent to each parameter). Then scroll down and under "Choose Output Format", click the button for "List of sites with links available for Monthly Statistics", just above the "Submit" button, which you now click as well. The next screen (if you have done right so far) is a large table listing site numbers, stream names, and locations. When you have found a location that fits your need (you only need one for the exercise here) check the box and proceed to the next step. You should choose a gaging station nearest the river mouth (Google Earth can be helpful here, unless you can do Latitude and Longitude in your head). You will want to display data for discharge at that station by clicking the box labeled "00060".

3) **Download the flow data** (= discharge, ft^3/s) for the period Sept., 1997-most recent. These data will be flows for each month; ideally the record for the selected gaging station covers the period of interest without gaps. If not, move along to another station or pick a better gaged river. For example, choose the "Cape Fear R at Lock #1, N(ea)R Kelly" site number 02105769. If you click in the box (00060) for discharge, then scroll to the bottom, select "Tab-separated data", then select date format (Excel will like MM/DD/YYYY) and select "Display in browser". Then click on "Submit". You should eventually get a text file with a big header, then various data columns, including dates and flow data. If during this whole process you find the data are not what you wanted, use the "back arrow" key in your web browser to go backwards until you can select a new site, new state, etc. Note that sometimes the download can take a while, and every now and then the overall site crashes (what else is new?), so just keep trying. Also, some states simply have better gaging programs than others, notably South Carolina, which has lots of temporal and spatial gaps in coverage. Once you have a good, usable file, save the whole file to your computer as a text file (*.txt) and rename it with some more descriptive file name than the number code you get first, such as "river name at location". Reopen that saved text file, delete the header lines, and resave it. Import the data into an Excel spreadsheet using the "Import data" function, and "tab-delimited" as a file format. You can then delete columns with unneeded information from the Excel spreadsheet. (Warning: if you missed seeing a data gap, you'll need to check one more time to see if all months and years are really there. They don't put in dashes or other codes for missing data.) All you really need are month, year, and flow data. Numerical codes for missing data, i.e., "9999", should be deleted to leave a blank cell.

4) **Identify the geographical coordinates** of the mouth of the river in question and identify a 1^o x 1^o area (or appropriately larger or smaller area depending on if you choose a big river like the Hudson, or a smaller stream) centered offshore of it. **Google Earth** is very good for doing this and for preparing

images of the watershed and coastal ocean region selected for this exercise using the option to select grid lines (found under the View tab) so you can get coordinates.

5) **Download the satellite data**, which can be obtained as monthly area-averaged values, for the selected area. Go to: http://reason.gsfc.nasa.gov/Giovanni/. Scroll down and click on: **OBPG SeaWiFS Monthly Global 9-km Products**. First, you will need to specify a latitude-longitude box 1^o x 1^o (or other appropriate size) centered offshore of the selected river mouth. For example, you could pick a box with dimensions 77-78 degrees W longitude and 32-33 degrees N latitude, in which case 77 is east of 78 but still west longitude (so, you type it as -78.0 W and -77.0 W) and 32 is south of 33 but still north latitude. The map graphic yields a box to show the lat/long selection you have made. If it looks wrong, you did something wrong; check your coordinate values and signs. A correct box should be a square in the right location. For "Parameters" select "Data Product Info". Under "Analysis Options" pick "Parameter". Next, select among the parameters available from SeaWiFS sensors. One may also look at MODIS and GSM data (somewhat different sets of data products from more recently launched satellites and sensors), but those time series are shorter, starting in early 2000s). In the "Parameter" box, one may select one or more parameters that describe aspects of ocean color; "Chlorophyll *a* concentration" is a derived estimate, and may be problematic in coastal waters, but one can examine other parameters (see examples in Tables 1 and 2). Next, choose the period of interest under "Temporal"; for "Begin Date", choose Sept., 1997, and for "End Date", choose a reasonable later date; bear in mind these data are processed, not real time data, so there is a time lag between the latest data posted here and the current date. Then go to "Select Visualization", scroll to select "time series", and click on "Generate Visualization". You will see a regularly updated table ("Execution Status") showing the steps in the process (have patience!) and then get a graphic of the data you wished to view, which can be saved or printed. You can then select "Download Data", which will cause a listing of data files. Scroll down to "Time Series Rendering"; under "Input Files" click on the "ASC" icon (for ascii form data), and you will get a table with month/year date, and values of the SeaWiFS parameter(s) you selected above (note "99999" indicating missing data). You may save these data as a text file (*.txt) and import the data into Excel, as above, noting that these files have "fixed width" format.

6) **Plot the two data sets (flow and parameter)** against each other and create two plots: 1) parameter against flow and 2) each parameter against time. The first plot lends itself to regression analysis (how Y is driven by X) and both allow you to see how temporal variation in flow may or may not drive parameter responses.

7) **Test the hypothesis** that river flow (= "discharge") drives sensible properties of the ocean surface by regression analysis (fitting a line to the plot of parameter vs. flow) and by (informal) time series analysis (examination of the plots of flow and chlorophyll *a* vs. time). Formal time series analysis is not a trivial undertaking and requires a thorough grounding in statistical analysis.

Questions:

1) **How do river discharge patterns vary through time?** Is there a seasonal pattern within each year? Is there noticeable inter-annual variability? Is there any longer-term trend that corresponds to regional drought or rainy periods? Are there any major event signals in the discharge data, such as the flooding from Hurricane Floyd in parts of the southeast US in 1999, rainy periods associated with El Niño, or extensive drought in the southern US in 2007?
2) **How does coastal ocean color vary with time?** Is there a seasonal pattern within each year? Is there noticeable inter-annual variability?
3) **How do ocean color values respond to river discharges?** Is there a positive, negative, or insignificant effect of discharge on ocean color in the coastal ocean area off the selected river mouth? What elements in river discharges might account for a positive effect? What elements in river discharges might account for a negative effect? If there is no significant relationship, why might that occur? Are there other relevant data or factors that might obscure or uncouple river discharge effects on coastal ocean phytoplankton?

Procedure and general instructions (for students).

Instructions provided above should suffice for students as well, with some guidance from instructors.

OPTIONAL SECTIONS (other sections you can add if applicable)

Suggestions and materials for assessing student learning: Dependent on student level and familiarity with data analysis tools. Assignments could include preparation of seasonal and inter-annual hydrographs, plots of coastal ocean properties vs. flow, regression analyses, and written interpretations, as appropriate to level.

Student data: Two fully developed example exercises are provided below.

Reference list:

Broussard, W., and R.E. Turner. 2009. A century of changing land-use and water-quality relationships in the continental US. Frontiers in Ecology 7:302-307.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Diaz, R.J. 2001. Overview of hypoxia around the world. J. Env. Qual. 30: 275–281

Diaz, R.J., and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. Science 321: 926-929.

Hyde, K.J.W., J.E. O'Reilly and C.A. Oviatt. 2007. Validation of SeaWiFS chlorophyll a in Massachusetts Bay. Cont. Shelf Res. 27: 1677-1691.

Jickells, T.D., Z.S. An, K.K. Andersen, A.R. Baker, C. Bergametts, N. Brooks et al. 2005. Global iron connections between desert dust, ocean biogeochemistry, and climate. Science 308: 67-71.

Justić, D., N.N. Rabalais, R.E. Turner and Q. Dortch. 1993. Changes in nutrient structure of river-dominated coastal waters: stoichiometric nutrient balance and its consequences. Est. Coastal Shelf Sci. 40: 339-356.

Justić, D., N.N. Rabalais, R.E. Turner and W.J. Wiseman, Jr. 1995.

Seasonal coupling between riverborne nutrients, net productivity and hypoxia.
Mar. Poll. Bull. 26:184-189.

Justić, D., N.N. Rabalais and R.E. Turner. 2005. Coupling between climate variability and coastal eutrophication: Evidence and outlook for the northern Gulf of Mexico.
J. Sea Res. 54: 25-35.

Kowalczuk, P., Durako, M.J., and Cooper, W.J., 2006. Comparison of radiometric quantities measured in water and above water and derived from SeaWiFS imagery in Onslow Bay and Cape Fear River plume area. Cont. Shelf Res. 26: 2433-2453.

Martin, S. 2004. An introduction to ocean remote sensing. Cambridge University Press, New York.

Osterman, L.E., R.Z. Poore and P.W. Swarzenski. 2008. The last 1000 years of natural and anthropogenic low-oxygen bottom-water on the Louisiana shelf, Gulf of Mexico.
Mar. Micropaleontol. 66: 291-303.

Pan, X., A. Mannino, M.E. Russ, and S.B. Hooker. 2008. Remote sensing of the absorption coefficients and chlorophyll a concentration in the United States southern Middle Atlantic Bight from SeaWiFS and MODIS-Aqua. J. Geophys. Res. 113: C11022, doi:10.1029/2008JC004852

Pietrafesa, L.J. and G.S. Janowitz. 1979. On the effects of buoyancy flux on continental shelf circulation.
J. Phys. Oceanogr. 9: 911-918.

Simmons, G.M., Jr. 1992. Importance of submarine groundwater discharge (SGWD) and seawater cycling to material flux across the sediment/water interfaces in marine environments. Mar. Ecol. Prog. Ser. 84: 173-184.

Turner, R.E., N.N. Rabalais, E.M. Swenson, M. Kasprzak and T. Romaire. 2005. Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. Mar. Env. Res. 59: 65-77.

Turner, R.E., N.N. Rabalais and D. Justić. 2006. Predicting summer hypoxia in the northern Gulf of Mexico: Riverine N, P, and Si loading. Mar. Poll. Bull. 52: 139-148.

Student assignments related to the activity: Suggestions offered within text.

Any other appendices appropriate for your particular activity:

Sample data sets

Data sets developed by students are presented here to illustrate the kinds of results one may obtain. One example illustrates a positive relationship and the other a negative relationship between remotely sensed coastal ocean chlorophyll *a* and river discharge. In each case additional remote sensing data sets were examined to explore further the effects of river discharge on coastal ocean properties. Those relationships and the temporal patterns of remotely sensed coastal ocean chlorophyll *a* suggest that different mechanisms may act to control coastal ocean phytoplankton populations, as well as additional hypotheses that can be addressed by appropriate extension of this exercise.

Remotely sensed chlorophyll *a* in the coastal ocean off the mouth of the Satilla River, a small coastal stream in Georgia, varied six-fold in a ten year period (Fig. 1). A notable spike coinciding with the 1997-1998 El Niño, which brought heavy rains and high river discharges to the southeastern U.S., suggests a stimulatory effect of river discharge on coastal ocean chlorophyll *a*. A significant positive regression of remotely sensed coastal ocean chlorophyll *a* against Satilla river discharge was also found (Fig. 2; Table 1). One plausible explanation for this effect is increased nutrient loading when discharges rise, similar to the situation with the Mississippi River Dead Zone, although without actual dead zone formation. Estimates of chlorophyll *a* derived from remotely sensed properties in this situation were also positively related to more directly sensed properties, the diffuse attenuation coefficient at 490 nm (DAC490), a measure of yellowing substance concentration in the water, and water-leaving irradiance at

670 nm (WLI670), a measure of reflection by particulate material. These properties were positively related to flow as well, suggesting significant co-variation of coastal ocean properties with river discharge in general. However, one must consider that chlorophyll *a* algorithms can be biased upward by coloring materials and particulate matter (Kowalczuk et al., 2006) in coastal waters, so interpretation requires caution. Another note of caution here requires consideration of the possibility that effects of discharges from the Satilla River, a relatively small, coastal plain drainage, might be aliased by discharges from larger rivers in the vicinity, such as the Altamaha River, although a similar coupling of discharge and chlorophyll *a* might be hypothesized for those rivers as well. The precautions advised here with regard to interpretation of these results serve as another “teachable moment” – ground-truthing and the nature of proxy data sets are important considerations in science.

Fig. 1. Remotely sensed chlorophyll *a* (mg m^{-3}) in the coastal ocean at the mouth of the Satilla River (30.5^o – 31.5^o N., 81.5^o – 80.5^o W) from Sept., 1997 (month 1) to Jan., 2007.

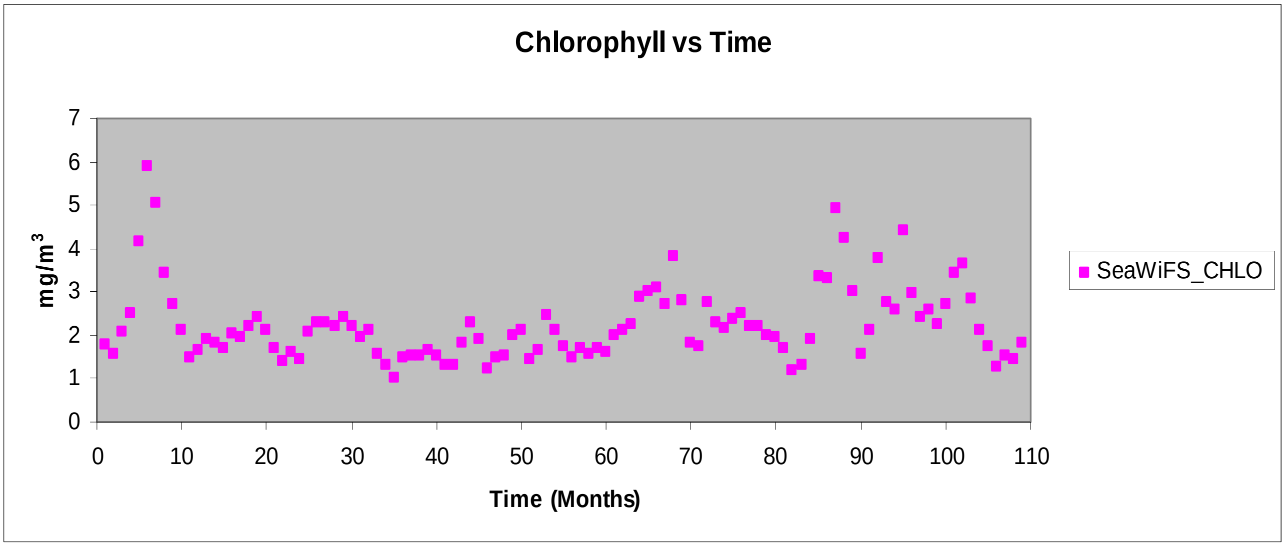
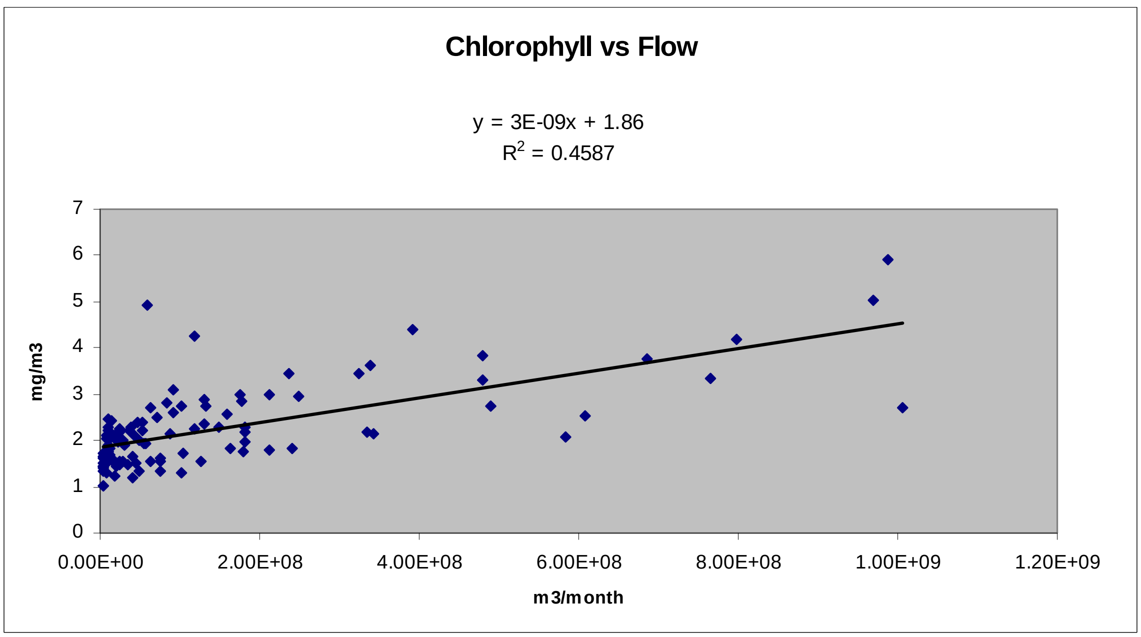


Fig. 2. Relationship between remotely sensed chlorophyll *a* (mg m^{-3}) in the coastal ocean at the mouth of the Satilla River and river discharge gaged at Atkinson, GA (USGS # 2228000),1997-2007.



The Chetco River is a small coastal river in southern Oregon that drains an essentially undeveloped watershed rising in the Coast Range mountains. In this case remotely sensed coastal ocean chlorophyll *a* (Fig. 3) varied by over an order of magnitude annually between 1997 and 2006, but was temporally offset from river discharges. Not surprisingly, there was a strongly negative relationship between the two variables (Fig. 4; Table 2), in contrast to the Satilla River's effects. In addition, chlorophyll *a* was positively related to DAC490, which was also negatively related to discharge. Neither chlorophyll *a* nor DAC 490 was related significantly to variation in WLI670 (Table 2). WLI670, a measure of particle back-scatter, was positively related to river discharge. River discharge peaked in the winter and remotely sensed chlorophyll *a* peaked in summer months, suggesting at least one mechanistic interpretation: river discharges might have had a high turbidity:nutrient loading ratio, causing light limitation rather than nutrient stimulation. The Chetco River drains a rugged watershed, driving relatively more erosion of sediments with a very small human population as nutrient sources. Reduction of discharge and accompanying sediment load might permit enhanced light penetration and phytoplankton blooms in the summer months. Again, these ideas are hypotheses that require further elaboration, not firm conclusions, but the data sets and their analyses provide interesting predictions and comparisons.

Fig. 3. Remotely sensed chlorophyll *a* (mg m^{-3}) in the coastal ocean at the mouth of the Chetco River (125.16-124.16 W, 42.02-41.02 N) from Sept., 1997 to Sept., 2006.

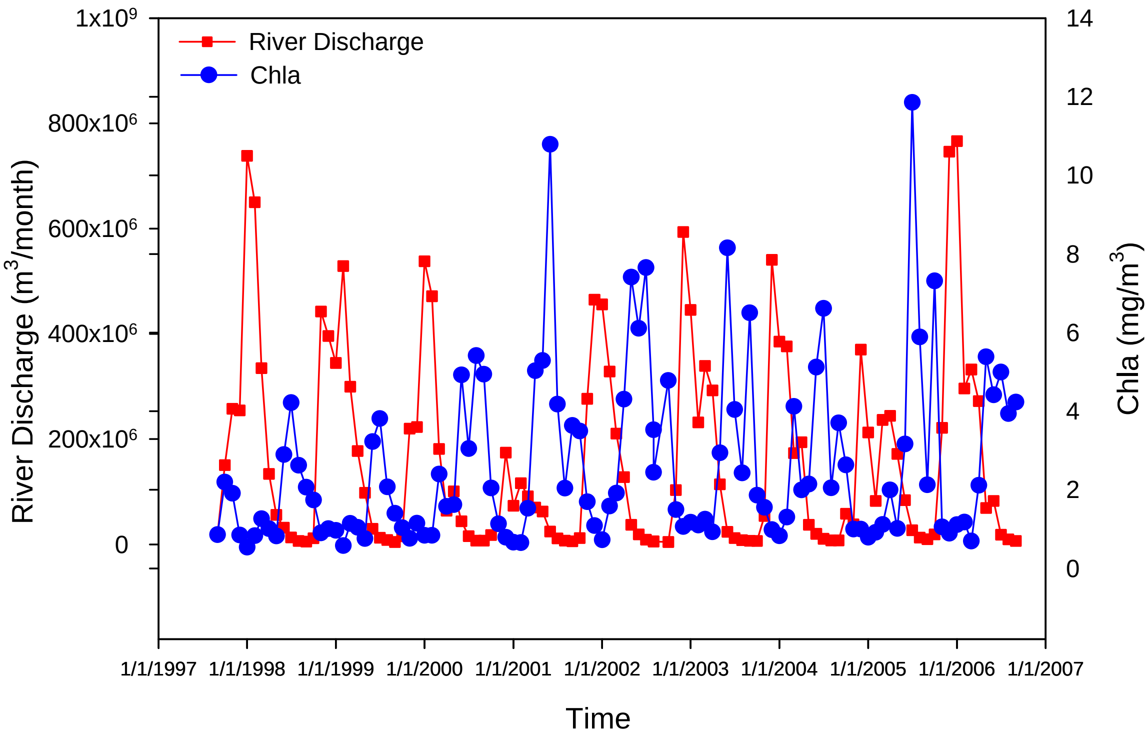


Fig. 4. Relationship between remotely sensed chlorophyll *a* (mg m^{-3}) in the coastal ocean at the mouth of the Chetco River and river discharge gaged at Brookings, OR, 1997-2006 (USGS # 14400000). Equation is Log[Chl *a*] = 1.08 – 2.488x10^{-9} (Discharge), $p<0.0001$.

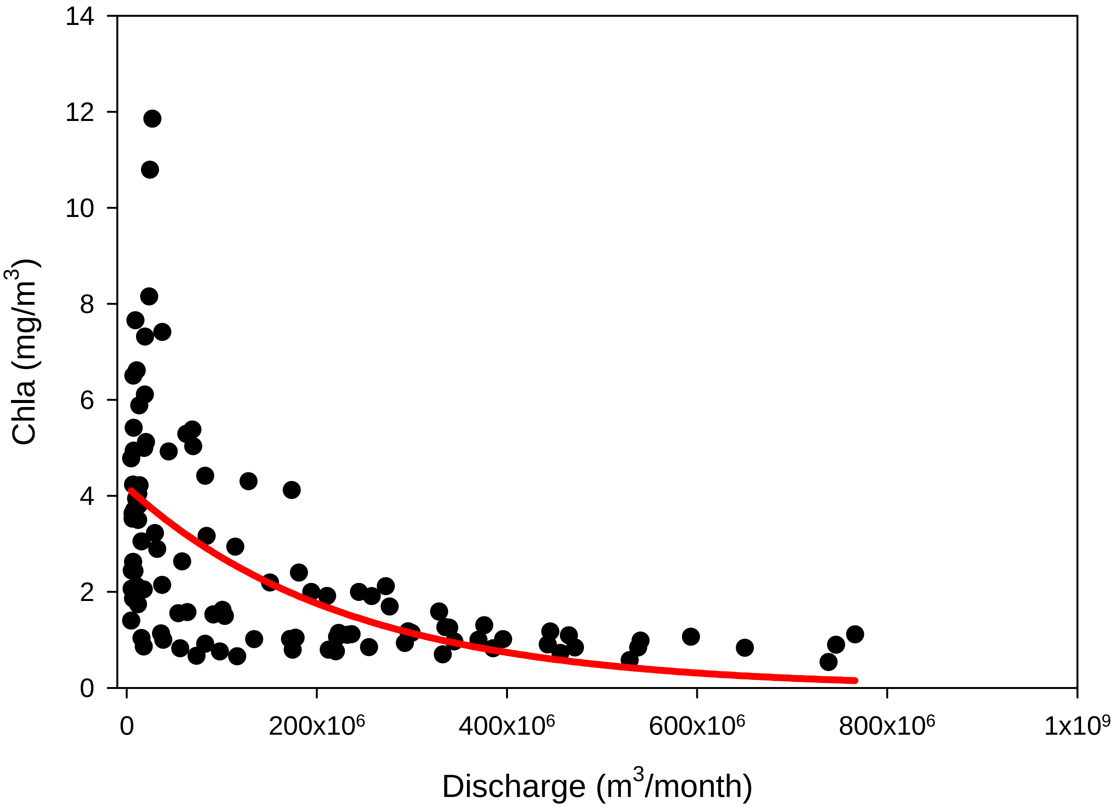


Table 1. Analyses of flow data for the Satilla River (at Atkinson, GA, USGS#2228000) and SeaWiFS data for adjoining coastal ocean (30.5-31.5^{o} N, 81.5-80.5^{o} W), Sept., 1997-Jan. 2007. Degrees of freedom (df) for all regressions = 1, 111.

Parameter:	Flow[1]	Chl*a*[2]	DAC490[3]	WLI670[4]
Range:	25.8-13710	1.13-7.11	0.108-0.342	0.097-0.394

Comparison	F	p	r^2	Response
	Regression Statistics			
Chl*a* v. Flow	91.7	<0.0001	0.45	positive
DAC490 v. Flow	68.9	<0.0001	0.38	positive
WLI670 v. Flow	27.5	<0.0001	0.20	positive
Chl*a* v. DAC490	3384	<0.0001	0.97	positive
Chl*a* v. WLI670	33.8	<0.0001	0.23	positive
WLI670 v. DAC490	31.5	<0.0001	0.22	positive

[1] – River discharge, cu ft sec^{-1}, monthly average

[2] – Chlorophyll *a*, mg m^{-3}, SeaWiFS-derived monthly average

[3] - Diffuse Attenuation Coefficient @ 490 nm, m^{-1}, SeaWiFS-derived monthly average

[4] - Water Leaving Irradiance @ 670 nm, mW cm^{-2} um^{-1} sr^{-1}, SeaWiFS-derived monthly average

Table 2. Analyses of flow data for the Chetco River (at Brookings, OR USGS#14400000) and SeaWiFS data for adjoining coastal ocean (41.02-42.02°N, 125.16-124.16° W), Sept., 1997- Sept. 2006. Abbreviations and units as in Table 1. Degrees of freedom (df) for all regressions = 1, 107.

Parameter:	Flow	Chl*a*	DAC490	WLI670
Range:	63.5-10290	0.62-12.4	0.073-0.368	0.031-0.169

	Regression Statistics			
Comparison	F	p	r^2	Response
Chl*a* v. Flow	38.0	<0.0001	0.26	negative
DAC490 v. Flow	39.2	<0.0001	0.27	negative
WLI670 v. Flow	70.5	<0.0001	0.40	positive
Chl*a* v. DAC490	1681	<0.0001	0.94	positive
Chl*a* v. WLI670	0.0093	0.92	0.00008	none
WLI670 v. DAC490	0.01	0.916	0.0001	none