Exxon Valdez Oil Spill
Gulf Ecosystem Monitoring and Research Final Report

Visible remote sensing of the Gulf of Alaska

Gulf Ecosystem Monitoring and Research Project G030685
Final Report

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Study History

This project began in December 2002 and is not related to any previous project. This final report relies heavily on the material supplied in the annual report submitted in 2003.

Abstract

In this project we examined the utility of ocean color data for monitoring the Gulf of Alaska. Potential data users and providers were brought together to help define which products should be developed. For oceanic applications chlorophyll concentration and a measure of turbidity are of highest priority and within current sampling capabilities. Of the three satellites examined, SeaWiFS and MODIS Aqua data appeared to be of good quality, and MODIS Terra to be of poor quality. A comparison of SeaWiFS data to surface chlorophyll measurements showed good agreement until the chlorophyll maximum went below the surface. Standard processing flags were appropriate with the exception of the stray light flag that removed much of the nearshore data where the Alaska Coastal Current exists. Processing algorithms for SeaWiFS and a remapping algorithm for MODIS data are provided.

Key Words

Gulf of Alaska, Ocean Color, Phytoplankton, Remote Sensing

Project Data

Water samples were collected within 5 m of the surface and processed to determine the chlorophyll levels using fluoroscopic techniques. Most of the samples were collected during two GLOBEC mesoscale surveys in the Gulf of Alaska. The chlorophyll and phaeophyton values are provided in a tab delimited flat file with date, time, location, and depth. Date is in day-of-year with January 1 as day 1. Time is in GMT. The data is available from Scott Pegau at Kachemak Bay Research Reserve, 95 Sterling Hwy, Suite 2, Homer Alaska 99603, email: scott_pegau@fishgame.state.ak.us, ph: 907-235-4799, fax: 907-235-4794, www.kbayrr.org.

Sample processing routines for MODIS data are available as Matlab scripts, and SeaWiFS data as IDL scripts that run SeaDAS. These routines are available from Scott Pegau at the address above. Questions about the routines should be directed to Rachel Potter at the School of Fisheries and Ocean Science, University of Alaska Fairbanks.

No access limitations are placed on the data or routines. Modification to routines are the responsibility of users.

Citation Pegau and Potter, 2004, Visible remote sensing of the Gulf of Alaska, GEM project G030685 final report.

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- **Executive Summary**.

Satellite remote sensing provides the only means to provide synoptic views of the Gulf of Alaska. Ocean color data can be used to provide indications in changes of surface chlorophyll concentration. Such products can also be combined with sea surface temperature data to better understand the currents within the Gulf.

This project focused on three objectives.

1. To determine what are the appropriate products and how should they be delivered.
2. To determine the appropriate quality control flags and provide an initial measure of data quality.
3. To provide the tools to begin to develop a long-term data set of the appropriate products.

We addressed the first objective by holding a workshop that included potential data users and data providers. The second was addressed by examining images for obvious problems and providing the guidelines to prevent such problems. A small validation study was described that examined data quality from the SeaWiFS platform. Modifying or developing processing algorithms for the SeaWiFS and MODIS data addressed the third objective.

The workshop results showed that chlorophyll and turbidity measurements were the two oceanic products of interest and are within current processing capabilities. There was an expressed interest in increased temporal and spatial resolution of the satellite measurements. Standard processing flags were found to be appropriate for SeaWiFS data with the exception of the stray light flag. MODIS Terra data was found to be of poor quality compared to SeaWiFS and MODIS Aqua. The problem was manifested as striping in the data products that is most likely caused by calibration issues with that platform. A comparison of surface chlorophyll measurements to SeaWiFS chlorophyll estimates showed good agreement in the spring. The agreement was poorer in the summer when the chlorophyll maximum was subsurface. We provided algorithms with which to process SeaWiFS data and map MODIS data. Other sources of MODIS data may be easier to work with than that provided directly from NASA.

We conclude that ocean color does provide a good mechanism to observe changes in phytoplankton standing stock within the Gulf of Alaska. Currently seven years of data exists, allowing for a time series to be developed that can be used to examine interannual variability. The images provide a good description of the spatial distribution of the phytoplankton, but may not always be accurate in estimating surface chlorophyll. The best mechanism to distribute data products remains an unanswered question.

Introduction

The Gulf of Alaska is a vast region with high spatial and temporal variability in productivity and hydrodynamic structure. **The problem is how to economically monitor the Gulf of Alaska from the Subarctic Gyre to the coastal region in order to assess changes in productivity.** Remote sensing provides a tool that can be used to rapidly observe changes in the surface waters of the entire region. Ocean color is directly related to chlorophyll-a concentration, and changes in concentration measure the net primary productivity. Over short time scales the phytoplankton can be considered a passive tracer, and therefore the change in chlorophyll distribution an indication of the fluid flow (Pegau et al., 2002). Over longer time scales we can observe seasonal and annual variability within the region (Brickley and Thomas, submitted). Combining the OCTS, SeaWiFS, and MODIS sensors provides a data set of nearly continuous coverage from the fall of 1996 to present.

Using remote sensing to provide the information to understand changes in productivity is not without problems that need to be addressed. The data sets are large, requiring good computing resources, specialized software, and lots of time to process. This leads to the question of what products are necessary to have and how to make the data available. Once processed, there are questions about how accurate the algorithms are at high latitudes where the presence of glacial flour and different phytoplankton assemblages from those used to develop the ocean color algorithms may decrease the accuracy of the algorithms. This project addresses these questions by developing the routines needed to automate processing and/or mapping data from the SeaWiFS and MODIS satellites, meeting with potential data users to determine what products are needed and how to provide those products, analyzing of imagery to determine quality control flags, and measuring chlorophyll concentration to examine the accuracy of the algorithms.

The mapping algorithms are written to examine the Northern Gulf of Alaska (Figure 1). In particular, the region bounded by 56 to 62°N and 143 to 158°W. In this region the data is processed to 1 km resolution in order to retain data near the complex coastline and to fully resolve smaller spatial features like the ACC. A larger box encompassing all of the Gulf of Alaska is processed at 5 km resolution. The GLOBEC field measurements were conducted within the smaller box (Figure 2).

A workshop was held with scientists, resource managers, and educators to determine what were the appropriate products to produce. The primary oceanographic products were chlorophyll concentration, turbidity, and ice concentration. Areas of interest included determining how the timing of chlorophyll blooms affects higher trophic levels, and estimation of fluid flow based on temporal changes in chlorophyll and sediment distributions. The workshop examined how the data should be distributed and it was agreed that a clearinghouse location was desired, although the exact format was not clearly defined.

We adapted an IDL script to run SeaDAS to process SeaWiFS data, and a Matlab script for mapping MODIS images. These scripts map standard products only. We focused on these two satellites although there are currently 10 color sensors with high enough signal to noise characteristics to be of use in both terrestrial and marine systems. An additional 3 sensors have flown in the past, with full coverage of the Gulf beginning in 1996 with the OCTS satellite.

Shipboard discrete samples were collected and compared to SeaWiFS estimated chlorophyll values. We found differences in the linear regressions between the two variables from the May and July cruises. In both cases the SeaWiFS tended to provide higher estimates of chlorophyll than were found in the discrete samples and only about 60% of the variance was explained by a linear relationship.

Objectives

The objectives of this work were to:

1) determine the products and format of visible remote sensing that are most likely to be required by scientists and resource managers
2) develop a set of quality control measures to be added to each data set
3) develop a time series of the appropriate variables by developing the appropriate tools to process the remote sensing data in accordance with the needs identified within objective 1

An outreach plan was developed and is provided in Appendix 1.

Methods

To determine the remote sensing products that have the most applicability a workshop was held in Homer during the spring of 2003. Participants were invited to represent the interests of scientists, resource managers, commercial interests, and educators. A list of the participants is provided in Appendix 2. The participants were asked to address two questions.

1) What products should be produced?

2) How should those products be made available?

To help the participants answer the questions there were presentations on remote sensing basics by Scott Pegau and Dave Verbyla, and a presentation on data distribution by Buck Sharpton. While this project emphasizes ocean color products, the discussion was not limited to existing products, ocean products, or visible remote sensing. The purpose of opening the discussion was to identify other products that the GEM program may want to consider supporting. After a wish list (Appendix 3) was completed we revisited the list to determine the products that could be produced currently and the appropriate temporal and spatial scales.

To determine the quality control parameters that should be incorporated, we examined several images and collected data to validate the ocean color products. We examined images for factors causing quality degradation. It is through examining multiple images that we determined appropriate quality control measures to apply to the data sets. We also examined the differences between SeaWiFS and MODIS images. To provide an independent test of data quality, chlorophyll, water leaving radiance, and atmospheric transmittance measurements were made during two GLOBEC mesoscale surveys. Water samples were collected from the ship's inline water system every 4 hours with extra samples at the nominal satellite overpass times (2100, 2300, 0100 GMT). The intake to the inline system was at 5 m depth. At each sampling time water was collected, filtered, and stored in liquid nitrogen until they could be moved to a –70 °C freezer. The date, time, and volume filtered were logged to allow chlorophyll concentration to be determined and to allow the discrete measurements to be merged with continuous data. Throughout the cruise a Satlantic SeaWiFS Airborne Simulator (SAS) was operated on the bow of the ship. The SAS unit measured the downwelling irradiance, upwelling radiance and downwelling radiance at 45 degrees. These measurements were combined using SeaWiFS protocols to determine the water leaving radiance (Mueller et al., 2003). If the sky was clear during an overpass we collected atmospheric transmittance measurements using a MicroTops. These last two sets of measurements are needed to improve our understanding of potential sources of error in chlorophyll algorithms. Once back in Homer, the chlorophyll samples were analyzed using standard fluorometric techniques (Mueller et al., 2003).

Where possible we modified existing routines to improve our ability to process the existing ocean color imagery. An IDL script was developed that can batch process and map SeaWiFS images (Appendix 4). MODIS images come processed but need to be remapped to make them more useful. A Matlab script from OSU was modified to map the Gulf of Alaska region (Appendix 5). This algorithm has not been modified to allow batch processing. Both SeaWiFS and MODIS data can be ordered to be downloaded over the internet, however only a few images at a time can be collected. We chose to order a year of SeaWiFS data at a time to be delivered on CD-ROM. All data collected at the UAF HRPT site were ordered for each year.

Results

At the Homer workshop a commonly expressed desire was to have very high temporal and spatial resolution, especially for land resource management. Chlorophyll and total suspended sediment (TSS) measures were the two oceanographic products identified that can be most readily provided. These products were of interest because of their importance in the productivity of an area (chlorophyll) or indications of sediment transport (TSS), and both may provide an indication of circulation patterns and the position of fronts. Ice coverage was also desired, but has minimal applicability to the GEM study area. Land products included lake sediments and chlorophyll, land use patterns, and vegetation cover. These products represent the most obtainable and desirable of over 40 products that were discussed. For a complete list of desired products see Appendix 3.

We found the standard quality control flags were appropriate. Flags that should be applied are cloud coverage and scan angle >60°. At scan angles >60° the pixels are stretched enough to make interpretation more difficult (Figure 3). Errors in the atmospheric correction at large scan angles are also likely to increase. This is evident in Figure 3 as the increased chlorophyll values in the western portion of the 21:38 image (evident as more area in red). Based on the scan angle criteria the best SeaWiFS images are those collected at 23:00 GMT ± 45 minutes. Images collected up to 45 minutes before that time band have good quality in Prince William Sound, but poor quality west of there. Images collected up to 45 minutes after that period have good quality in Cook Inlet but poor quality east of there. With MODIS Terra the best imagery is collected at 21:30 GMT ± 45 minutes. And for MODIS Aqua one should focus on 00:30 GMT ± 45 minutes

Default SeaDAS processing has the stray light switch turned on. This switch is designed to remove potentially contaminated pixels near the coast. We found that this switch removed too much data around the complex coastline of the Northern Gulf of Alaska (Figure 4). While we recommend turning the switch off, people should note that the absolute values near the coast are likely to have higher errors than those farther offshore.

A difference in data quality between satellites is clearly evident (Figure 5). The three chlorophyll products of MODIS show some of the problems with the Terra satellite (Figure 6). The MODIS Terra images all show striping that is a consequence of calibration issue. The chlor_modis and chlor_a2 are both empirical algorithms with chlor_a2 being calculated in a manner similar to that of the algorithm used by SeaWiFS. The chlor_modis algorithm tends to predict higher chlorophyll values than the chlor_a2, particularly in regions of turbid water. The algorithm designed to function in turbid water is chlor_a3, but as stated earlier, calibration problems make the algorithm nonfunctional.

A comparison of shipboard and SeaWiFS chlorophyll estimates for samples collected in May and July show seasonal differences (Figure 7, Appendix 6). Our criterion for using a matchup is that the shipboard measurement be collected within 2.5 hours of a clear SeaWiFS image. Using this criterion, we had 13 match-up points in May and 8 in July/August. A linear regression between the shipboard and SeaWiFS chlorophyll estimates is able to explain approximately 60% of the variance in both periods. In both cases, SeaWiFS tends to provide higher estimates of chlorophyll than fluorometric analysis of discrete shipboard samples. In May the slope of the regression is 0.8, with intercept forced to 0, with shipboard values being the y variable and SeaWiFS the x. Without forcing the intercept to zero the slope is 0.7 and the intercept is 0.5 mg Chl m^{-3}. In July the intercept is found to be effectively 0 and the slope is 0.6. At the end of May when the chlorophyll maximum became subsurface the ratio of SeaWiFS estimated chlorophyll to shipboard estimates is similar to that found in July.

High chlorophyll values are associated with areas with high sediment loads. The effect is most evident in Upper Cook Inlet and near the mouth of the Copper River.

Discussion

The workshop provided useful interactions between potential remotes sensing data users and providers. Many of the desired products or sampling capabilities are not within the capabilities of the present ocean color sensors. The higher temporal and spatial resolution requests should be presented to NASA and NOAA/NESDIS to help plan future programs. The higher spatial resolution data is available to some extent through commercial satellites, such as Ikonos and may not be appropriate federal products. Since SeaWiFS is actually a commercial satellite, there are restrictions on data delivery that will impact some of the potential user groups. These restrictions do not exist with the MODIS platforms.

We found that the default SeaDAS processing flags are appropriate for the region with one exception. Because of the convoluted shoreline, it is nice to have the stray light flag turned off. This prevents masking the data within 5 pixels of the shore. When turning the flag off it must be remembered the chlorophyll estimates in the nearshore region are still suspect. But removing the flag helps to provide an intuitive feel for the connectivity of the rather narrow Alaska Coastal Current.

Using the standard flags also reduces the number of SeaWiFS images that must be processed. The overpasses with small enough scan angles fall into a narrow window. Unfortunately, to date there is no equivalent filter for MODIS data. In fact, we came across several small stumbling blocks that made working with MODIS data more difficult. One problem is that the standard search engine looks for MODIS granules (a block of MODIS data) that include even a single pixel within a region of interest. Thus, a large area of interest search provides a lot of data that is not of use. With MODIS Terra the overpass time filter does reduce the number of images that need to be processed. Another problem is that the geo-referencing data must be ordered separately from the data products. This is a small problem once a person knows where to find the appropriate data. The last real difficulty that we ran into was that the remapping routines that we used are slow. Many of these little annoying factors can be fixed by improved data distribution or processing. While SeaDAS has many of it's own quirks, it will soon be able to handle processing MODIS data as well as SeaWiFS. This may make it easier to set up batch processing algorithms for multiple satellite platforms. We expect that as new tools, such as the University of Alaska GINA project (www.gina.alaska.edu) come fully on-line, working with the satellite data will become easier.

How to store and serve data still remains an open question. The data sets still require large amounts of space to store and specific equipment or software to process. Most potential new users would most likely want the data in a georeferenced form that could easily be imported into a GIS database. An ideal distribution system would include a simple-to-use browse tool, allow a user to temporally or spatially average data, and allow for selecting a region of interest.

It is evident from the results that not all sensors are created equal. The problems observed with the MODIS Terra instrument are not unexpected. In the past year, NASA has been reviewing the quality of the data products by the various American satellites. They have decided to quit processing MODIS Terra data because of the calibration problems with the satellite. At the same time they have ordered an additional year of SeaWiFS data and are concentrating on ensuring the best quality of data is achieved from the MODIS Aqua platform. Of the several chlorophyll algorithms that are available, it appears that the SeaWiFS algorithm and its MODIS counterpart (chlor_a2) performed the best in the Gulf of Alaska. This statement is based on the fact that the other algorithms provided higher chlorophyll estimates, even though we found that the standard SeaWiFS algorithm estimated higher chlorophyll values than were observed. The semi-empirical algorithm has the most potential for Gulf of Alaska waters, but is also subject to larger errors caused by the increased number of wavelengths used.

Collecting satellite validation data in the Gulf of Alaska is very difficult due to the cloud cover and high spatial variability of the chlorophyll distribution. The two GLOBEC cruises provided very good validation match-up data. Out of 21 days in May, we had 7 satellite overpasses that could be used for validation work. The shipboard sampling provided 3 potential match-up points for each overpass. A few points were eliminated because of clouds and a few more because of large gradients in chlorophyll in the region. A linear regression with a zero intercept between shipboard and SeaWiFS chlorophyll estimates shows that the SeaWiFS estimate was generally 20% higher than shipboard estimates from water collected at 5 m depth. The overestimation increases as the chlorophyll maximum moves deeper in the water column. The differences between estimates can be attributed to several possible causes. The main ones are: 1) poor atmospheric correction at high latitude because of the long atmospheric pathlengths, 2) the mix of phytoplankton, detritus, and dissolved organics are different than assumed in the SeaWiFS chlorophyll algorithm, 3) the vertical distribution is not homogeneous as assumed by the satellite algorithms.

Poor atmospheric correction has been a long-standing problem for ocean color sensors. The water-leaving radiance, which is of interest, is only 5% of the radiance received at the satellite so that small errors in atmospheric correction can have a large effect on the chlorophyll algorithm. Indeed, it can be seen that at larger atmospheric pathlengths the chlorophyll estimate tends to be higher. We collected some atmospheric measurements that may be of use in quantifying the magnitude of this problem, but such analysis is outside the scope of the work being conducted for this program.

The satellite chlorophyll algorithm is based on an empirical relationship between measured surface chlorophyll values and water-leaving radiances. This approach assumes that all of the changes in optical properties that alter the water-leaving radiance are related to changes in the chlorophyll concentration. This is commonly referred to as the Case I assumption. The presence of high dissolved organics or sediment loads can also give the water a greener color which will be interpreted as higher chlorophyll loads. Regional changes in phytoplankton pigments and scattering properties can also affect the relationship. In the sediment laden waters of Cook Inlet and the Copper River, it is evident that the underlying assumption in the satellite chlorophyll algorithm has been violated and the satellite chlorophyll estimates are likely to be too high. At this point we do not have the data necessary to quantify this effect. The MODIS satellites have a semi-empirical algorithm that should work better in the coastal waters; however, the algorithm requires more wavelengths and other sources of error can make the algorithm unusable (Figure

6). It is quite likely that a regional algorithm for the Gulf of Alaska that would incorporate the local mix of optical materials would slightly improve the performance of the satellite algorithm in the area.

Another underlying assumption in the satellite algorithm may have had a larger impact on the agreement between shipboard and satellite estimates of chlorophyll. That assumption is that the chlorophyll is uniformly distributed in the water column, at least in the top optical depths that the satellite observes. The satellite does observe light that is scattered upward at depth of 10s of meters. When a chlorophyll bloom moves subsurface, as it commonly does in the summer, it may be observed by the satellite but not measured at the 5 m depth water sample. This seems to be a very plausible explanation for the disagreement between SeaWiFS and shipboard chlorophyll estimates in July and at the end of May. Vertical profiles of the chlorophyll distribution show that the chlorophyll maximum was below 5 m depth during these time periods. The vertical distribution problem affects the absolute value estimate of surface productivity as well as the horizontal distribution of chlorophyll. The horizontal patterns observed in an image are most likely to be accurate, but spatial changes in the vertical distribution may also provide a feeling of horizontal gradients. At this point, there is no possible way to correct for the vertical distribution problem.

Dave Musgrave's group at the University of Alaska Fairbanks has ordered and received the existing SeaWiFS data. The processing algorithms exist to allow products to be derived. Not all of the data has been processed since we are unsure how to deliver the products. We can provide the routines for remapping MODIS level 2 products; however, the GINA program is currently working to provide a better tool with which to deliver the data. Because of data quality issues, the MODIS Terra data is not currently being processed by NASA, which will impact the ability to develop a time series of data using that platform. The combination of SeaWiFS and MODIS Aqua data should allow a time series of chlorophyll and turbidity data to be developed.

In this work we have focused on the oceanographic products of the American satellites, SeaWiFS and MODIS. This leaves at least a few large questions open that will need to be addressed. One is the value and accuracy of the terrestrial products in the watersheds influencing the nearshore ocean. A second issue is the use of foreign satellites. Data is currently available from Indian, Chinese, and European platforms. If they have higher spatial resolution, should we be using them? We also need to address how multiple sensors can help extend our capabilities. During the workshop there were many questions of how to see through the clouds and whether synthetic aperture radar could be used to help address questions of interest.

Conclusions

Visible remote sensing provides a means to examine chlorophyll standing stocks and sediment distributions throughout the Gulf region. Other products, such as frontal positions, bloom timing, and estimates of primary productivity may also be developed. Thus remote sensing provides a useful tool with which questions of interest to GEM can be addressed. By combining sensors we can put together a time series that spans nearly seven years continuously, with the expectation being that ocean color products will continue to be available into the future. Not all of the sensors are created equal though. At this time we should develop a collection of all

SeaWiFS images and begin compiling a set of MODIS Aqua images. We recommend not using the MODIS Terra data until its calibration issues become better resolved. We should also be examining collecting data from other sensors to ensure a complete dataset remains available. An effort to characterize the differences between sensors will be needed. NASA or NOAA will most likely complete such a characterization. Some validation program would be useful in ensuring that there are not differences that only show up at high latitudes where the national programs don't have good sampling. Such validation programs will need to either piggyback on larger efforts or be able to rapidly respond to the appropriate weather conditions. In the validation work, it is important to understand the horizontal and vertical distributions. The presence of a strong horizontal gradient can make validation difficult because navigation errors can provide large errors. The vertical distribution may help explain differences between surface values and those estimated by the satellite.

For SeaWiFS data, the processing should occur with the standard flags with the exception that the stray light flag should be turned off. Processing of data should most likely be centralized with a single distribution point made available. The University of Alaska Geographic Information Network of Alaska is one such potential distribution center. It will be most useful if the distribution center does not add a large fee for providing data. Useful tools for such a distribution system include the capability to do temporal or spatial averaging, the capability to select regions of interest, and a simple-to-use image browser. The products should be made available mapped to a regular grid, and in a form that can easily be incorporated into a GIS product.

Acknowledgments

We thank the GLOBEC program and the crew of the R/V Wecoma for their assistance in collecting the chlorophyll samples used in this program. We thank the EVOS/GEM program for providing funding.

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Pegau, W. S., E. Boss, and A. Martinez, 2002, Ocean color observations of eddies during the summer in the Gulf of California, GRL, 2001GL014076

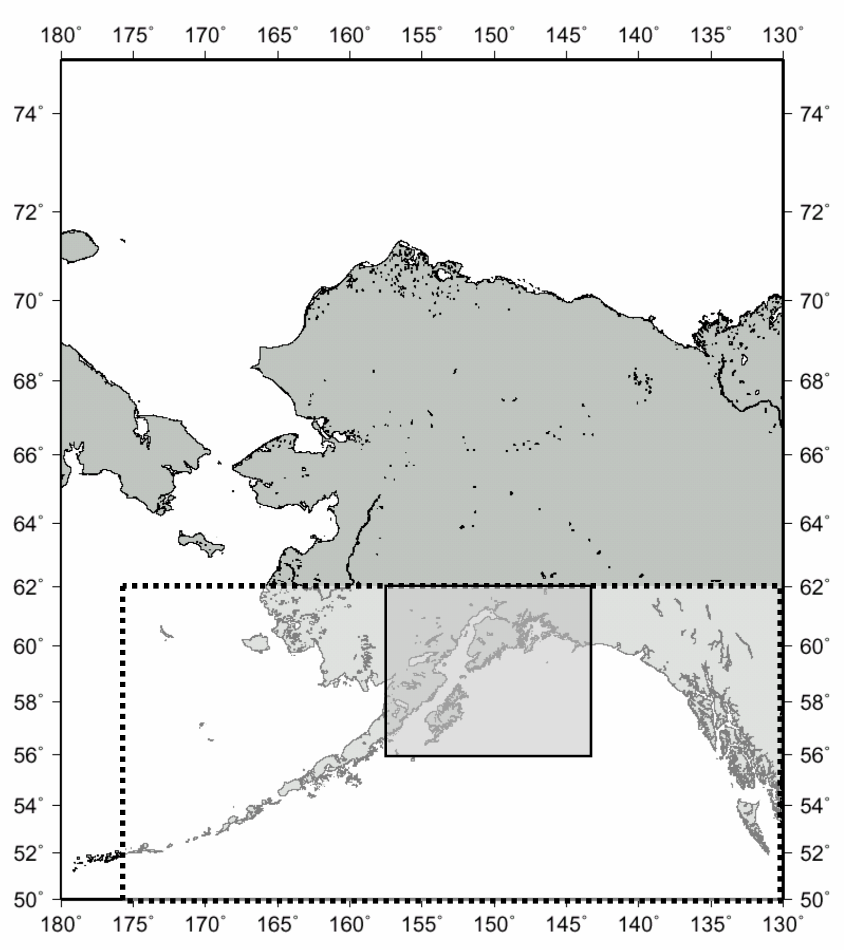

Figure 1. Data within the dashed box will be processed to 5 km resolution. Data within the gray box will be processed to full 1 km resolution in order to provide the highest detail of small current structures associated with the ACC and allow the data to extend as close as possible to the complex coastline.

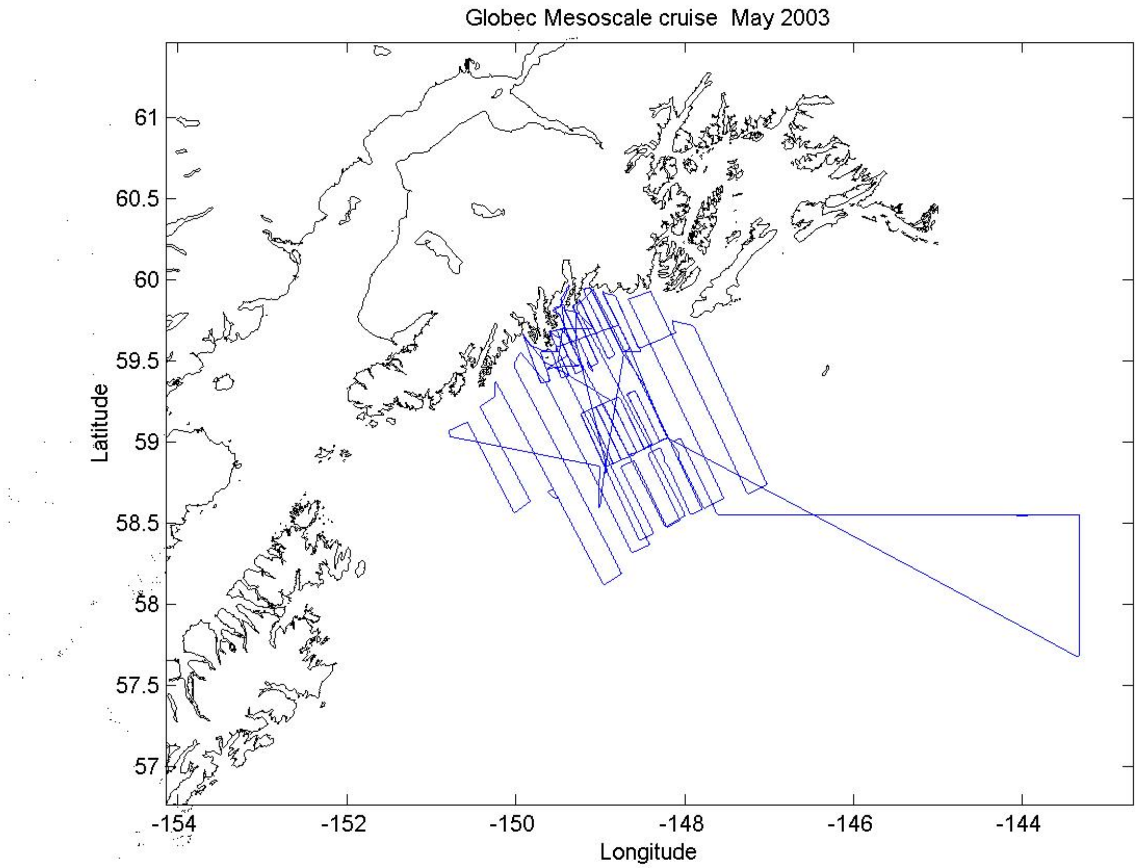

Figure 2. Cruise track of the May 2003 Globec cruise. The cruise track allowed sampling of both continental shelf and deep ocean water.

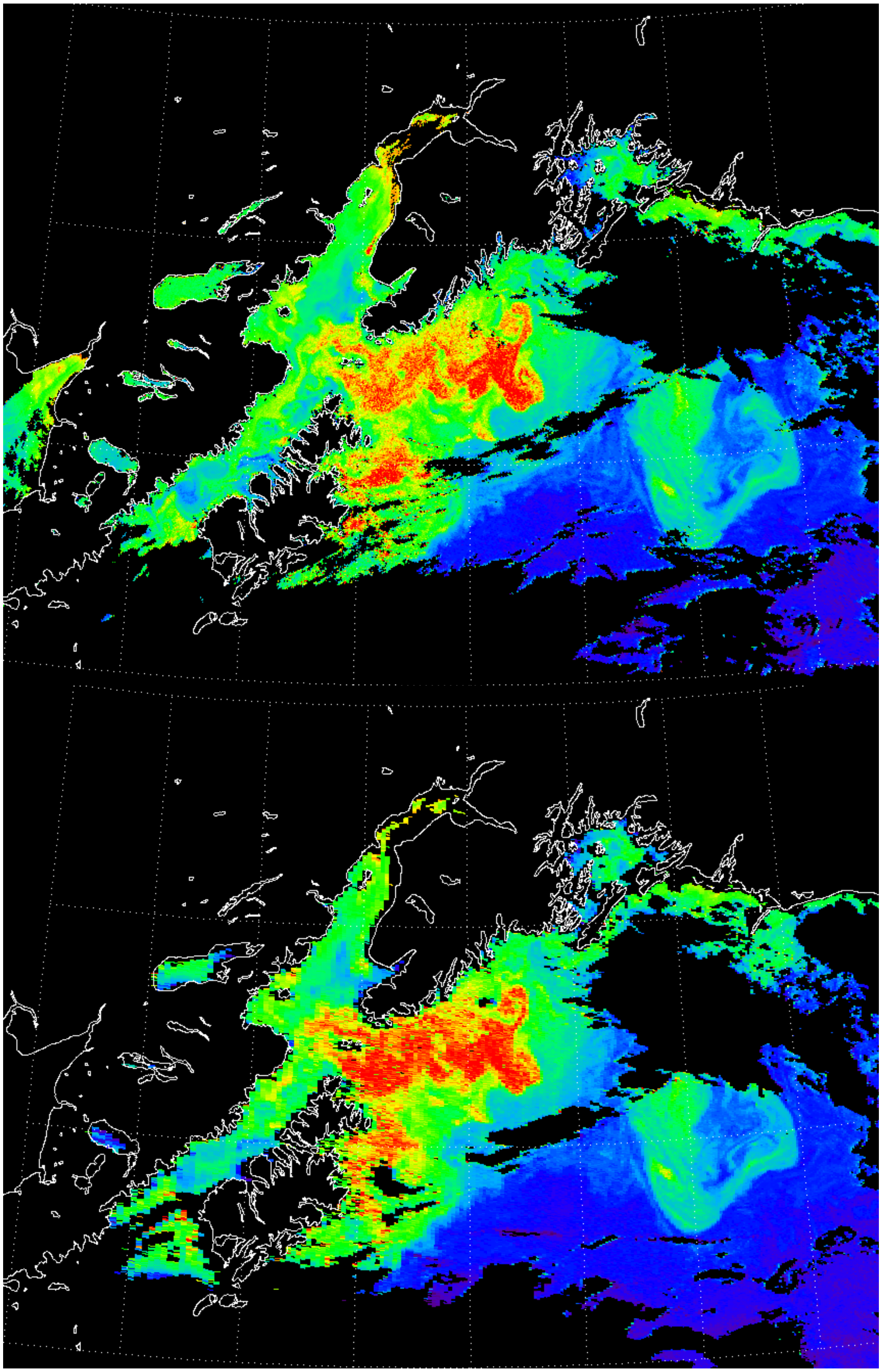

Figure 3. Chlorophyll images collected using SeaWiFS on day 139 of 2001 at 23:15 (top) and 21:38 (bottom). The 23:15 image has good quality throughout the region, however the 21:38 overpass has stretched pixels on the western boundary.

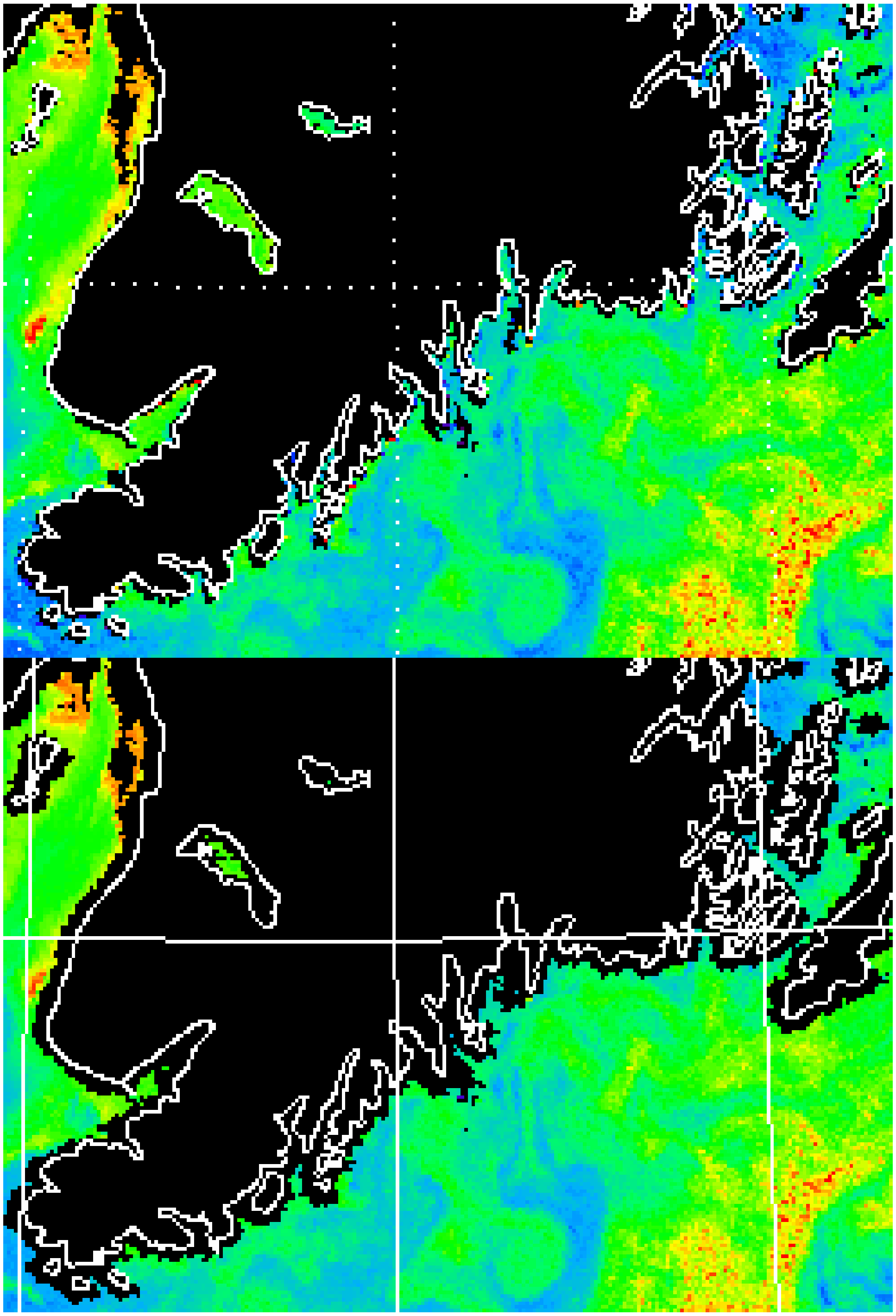

Figure 4. SeaWiFS images without (top) and with (bottom) the stray light switch turned on. The stray light switch masks pixels within 5 km of land. This in effect smoothes the complex coastline of the Gulf of Alaska.

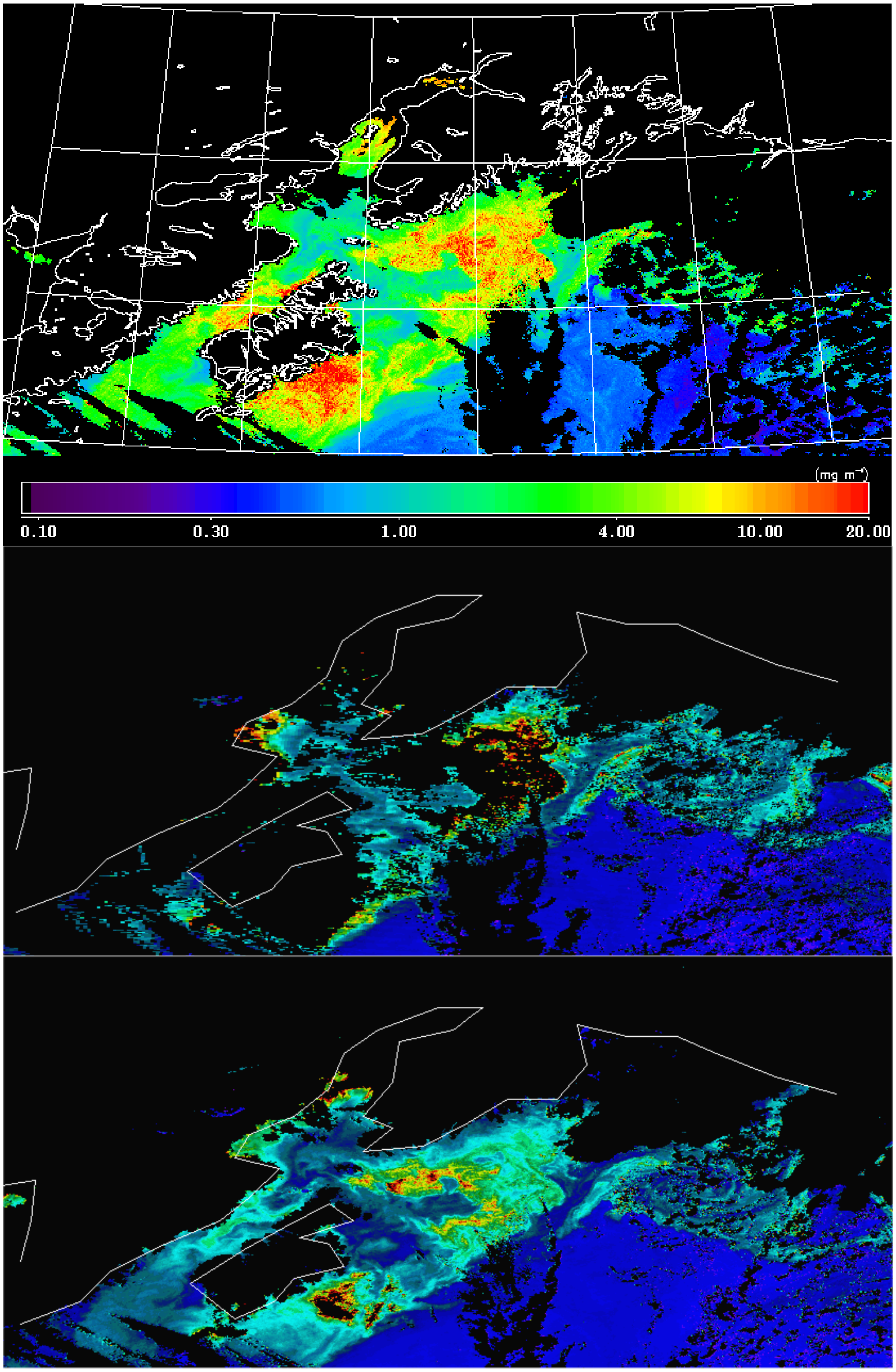

Figure 5. Chlorophyll images collected on day 135, 2003 using SeaWiFS (top), MODIS Terra (middle), and MODIS Aqua (bottom). Much of the high chlorophyll region is masked in the MODIS Terra image. Striping is also evident in the Terra image. The colorbar of the MODIS images is different than that used in the SeaWiFS image.

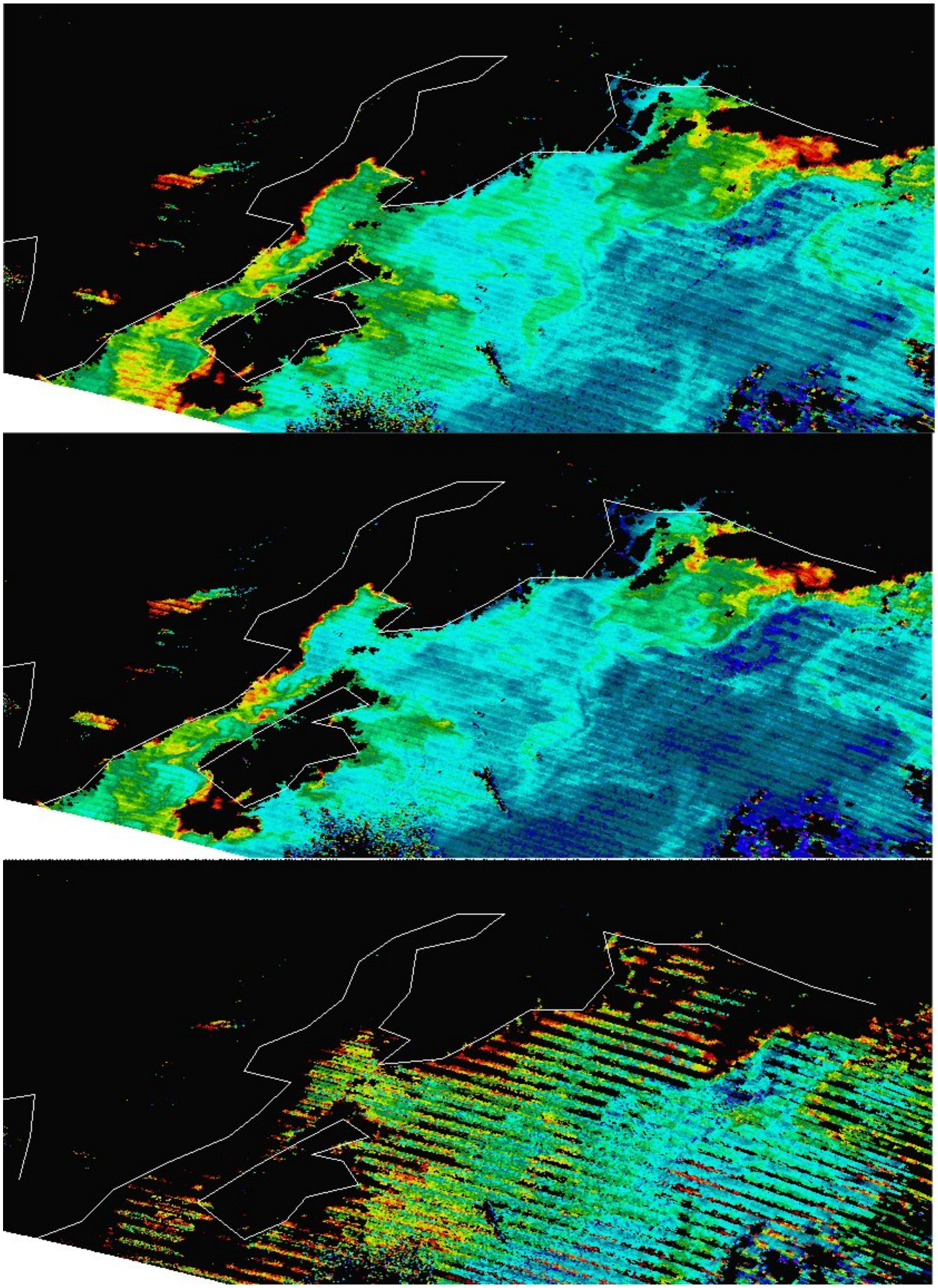

Figure 6. MODIS has three chlorophyll products. The three images above are from MODIS Terra taken on day 140 in 2002. The products are chlor_modis (top) an empirical algorithm, chlor_a2 (middle) a SeaWiFS equivalent routine, and chlor_a3 (bottom) a semi-analytic algorithm. The white lines are a low resolution coastline.

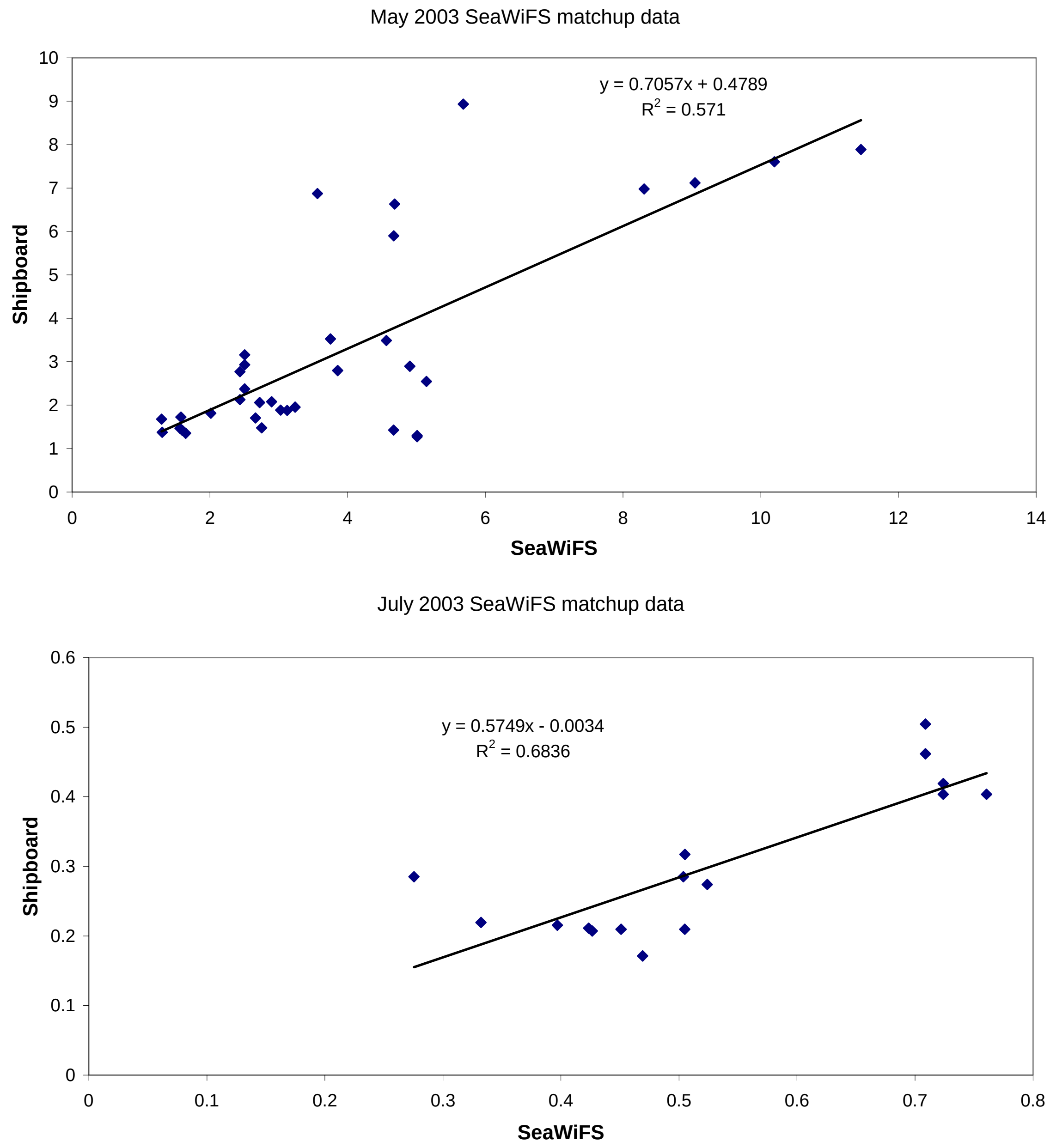

Figure 7. A comparison of shipboard and SeaWiFS chlorophyll estimates from samples collected in May (top panel) and July/August (bottom panel). Comparisons are made using shipboard samples collected within 2.5 hours of a SeaWiFS overpass that viewed the ship's track.

Appendix 1. Outreach plan developed by Dr. Rick Foster at KBRR

Remote Sensing Educational Outreach Design

The purpose of this Remote Sensing Education and Outreach Design is to provide suggested guidelines to bring remote sensing imagery and data to potential users. It offers ideas for products and services as well as techniques to deliver these that will meet the identified needs of resource managers, policy makers, resource users, and educators.

INTRODUCTION

There has been an expressed need to make remote sensing accessible to people who are not remote sensing experts. Resource managers, policy makers, various resource user groups, the general public and educators have a need for a variety of information about the characteristics and condition of the ecosystem with which they are dealing. The availability of multispectral scanner and radar data obtained from satellites, photos, radar from aircraft, shipboard acoustic sensors, coastal radar, along with a multitude of quantitative computer-aided analysis techniques for processing such data, have created a tremendous increase in the array of data. Recent and very significant developments in GIS (geographic information systems) technology, and the interrelationships between remote sensing and digital mapping, have created additional dimensions of complexity as well as opportunities to use various data sources and analysis techniques to provide the information needed by the resource managers, planners and policy makers, coastal resource users, and educators.

When one considers that Landsat 1 was launched just over 30 years ago (1972), it is clear that tremendous progress has been made in a relatively short time in the development of effective methods for processing and analyzing remote sensing data. In the early years, there was concern that there would be a limited amount of processed data. That is not the case today. Earth and Oceanic Remote Sensing can be promoted by providing full access to a wide range of remotely sensed data, near real-time imagery, and geospatial thematic data, in a user-friendly fashion. The customers should include policy makers (managers, planners, elected/volunteer officials) environmental scientists, resource users, and schools (grades 9-12), colleges and universities.

The Challenge

There currently is an abundance and continually increasing amount of remote sensing imagery—archived and in near real-time. There are also numerous data products (i.e., processed archives of analyzed data from multiple sources, in some cases, organized into a GIS format). Developing such products requires correction, analysis and processing of satellite imagery, converting raster data to vector, developed into geospatial thematic data for further analyses and mapping. Therein lies the challenge-- to make these *imagery* data and *products* available and used by various professions and the general public to help them make decisions.

Throughout the remote sensing needs assessment process, the resource managers, policy makers, and educators acknowledged that remote sensing visualizations have tremendous power. Imagery is one of the most essential tools our brains use to make sense of the world. Spatial representations enable us to visualize large volumes of data, and perceive and understand complex concepts, create mental models of systems and comprehend the interactions among data elements. A picture is worth a thousand words, and a map of a place is worth a thousand data points.

Resource managers, planners, policymakers resource users and educators had 10 requests regarding remote sensing imagery and products.

1. Alaskan imagery should be collected into a clearinghouse.
2. It must be easy to find and obtain the images
3. Clearinghouse should provide information from multiple sources
4. Clearinghouse should provide information in a variety data formats and resolutions
5. Images should be searchable based on topic of interest (e.g., physical or biological process or feature
6. Images and data should be of high resolution
7. There should be access to image archives
8. Images should be able to show time series and/or composed as animations
9. Assistance should be provided
10. Provide examples of how data can be applied
11. Provide processed images for use with GIS

At present, there are a score of government, private sector, and university web based clearinghouses for near-real-time and archived images, as well as processed data (in the form of product data). The data for Alaska is limited and most of these sites are designed for the scientist/technician skilled in remote sensing. These websites can be overwhelming and not readily useful for the majority of policy makers, educators or the public resource users. Because of this need, specific website service and support as well as products should be developed for these audiences.

While websites services require maintenance, processed data imagery products can be placed on a CD (compact disk) for use by resource managers, planners, and policymakers. Classroom lessons can be developed into products that utilize remote sensing images to enhance science, geography, and mathematics educational programs. Interpretive exhibitory products can be constructed to demonstrate how resource decisions are made as well as to explain how remote sensing is used to enhance scientific studies.

Possible Solutions

This *Remote Sensing Educational Outreach Design* provides suggestions along with examples of services and products for each of these audiences: Resource Manager, Planners and Policy Maker; Resource User-General Public; and Educator. Some *services* are appropriate for combinations of these audiences, while some should be customized. Sites or specific products should be customized for an identified audience. A few of the example sites focus on a definite audience while others have special sections on their site for an identified audience. Some of the sites provide customized services, either on-line or that can be ordered and sent in a CD product. Where applicable, the services and products are categorized by the specific targeted audience.

1. Combined Audiences

Many of the needs expressed at the Remote Sensing Needs Assessment were agreed upon by the various audience user groups. These challenges are combined in the following section.

Challenge: Alaska imagery should be collected into a clearinghouse

Websites could provide images and project data for various users, but designed for the needs of the identified audiences. Based on the information received from participants at the workshop, it is clear that potential users need to know what useful Alaskan images are available and, how they can obtain them. Therefore, remote sensing data must be easy to find—in a clearinghouse. Providers of the site must complete a pre-selection of appropriate material. Currently, there are two Alaskan sites which act as a clearing house of remote sensing and/or processed geo reference data—GINA (Geographic Information Network of Alaska) and ASGSC (Alaska State Geo-Spatial Clearinghouse).

GINA http://www.gina.alaska.edu/ is the University of Alaska's framework for organizing and sharing its diverse data and technological capabilities among the Alaskan, Arctic and world communities. GINA is housed within the International Observatory of the North (ION), which offers real-time reception, processing, and delivery of imagery and information products from a variety of polar-orbiting satellites. Currently, ION receives real-time data from NASA's EOS Terra and Aqua Moderate Resolution Imaging Spectroradiometer; MODIS (since August 2001) and NOAA's operational satellites carrying the Advanced Very High Resolution Radiometer; AVHRR (since August 1993). The GINA is committed to being an active partner with K-12 education. There is a wealth of resources available for teachers, classes, and students. GINA is also dedicated to advancing communication in the geospatial sciences among the university, local, state, and federal agencies, Native Alaskan organizations, private businesses, and individuals.

The Alaska State Geo-Spatial Data Clearinghouse (ASGDC) http://www.asgdc.state.ak.us/ is a user-friendly collection of some geo-spatial data as well as providing access to state and local nodes housing geo-spatial maps and data. It does not include imagery except as a component of GIS project themes. It is searchable by topic area.

Challenge: It must be easy to find and obtain images

The website also must be intuitive to navigate. People are spatial, and need to have a way to identify the place via a map but also with the name of a place. It is essential that the users can select images using a spatial browser—being able to identify the locations for the desired imagery on a map, using their mouse (or latitude and longitude). This could be in various formats. One service provides a map that when the user points to the desired location, the latitude and longitude appear below the map. The user can then input this into the search. Users may also use the postal zip code or community name to locate the coordinates. One “Alaskan” example of spatial browser is called “AlaskaView”—an Alaska visualization viewer tool for LANDSAT Images. It was developed by the USGS EROS (Earth Resource Observing System Data Center). *AlaskaView* is available on a few websites such as University of Alaska Fairbanks’ International Observatory of the North (ION) website http://www.ion.gina.alaska.edu/, to browse, order, or download LANDSAT scenes of Alaska. Although designed for professionals in the field, it is fairly intuitive to use. *AlaskaView* is the Alaska version of the USGS Global Visualization Viewer http://glovis.usgs.gov/-- which has a useful *Help* section to help the non-professional.

Imagery websites could use a simple but fully capable web-based user interface. The images should be available as a thumbnail as well as a text description, so the user does not have to download the entire image. NOAA’s CoastWatch website http://coastwatch.noaa.gov/index.html uses this technique. Their focus is to make environmental satellite data project and in-situ data available to Federal, state and local marine scientists, coastal resource managers, and the public. When applicable, the images in close proximity, both spatially should be easily accessed by zooming and scrolling. The California Coastal Records Project (http://www.californiacoastline.org/) also uses this technique with almost 13,000 aerial photos ranging from the Oregon state line to the Mexican border.

Challenge: Clearinghouse should provide information from multiple sources

The *Imagery* could be available from multiple sources—satellite imagery, aerial photographs, acoustic data, and radar imagery. The processed imagery data (e.g., LANDSAT, SeaWifs, or MODIS--Terra and Aqua satellites) and should be categorized by *how* they could be applied (e.g., sea surface temperature, ocean surface winds, ocean color), as well as by the name of the instrument or satellite. NOAA’s CoastWatch website offers this feature. The CoastWatch search interface provides access to multiple satellite ocean remote sensing data and products for a selected geographic region. Multiple products, sensors and satellites may be selected/highlighted by using "[shift]-click" and dates may be entered manually into the text fields or by using the pop-up calendars.

Challenge: There should be access to image archives

The website collection could include an archive of past, as well as near real-time data—of regional images. In order to demonstrate change over time, images of the same location should be available over extended time periods—daily, monthly, seasonally and, annually. It therefore, should be easy for the user to navigate to the selected data (scrolling through time) for temporal studies. A good example of archived data can be seen at Oregon State University’s website (http://picasso.oce.orst.edu/ORSOO) for its Remote Sensing Ocean Optics program. This site offers MODIS (moderate resolution imaging spectroradiometer) images from NASA’s Terra, and Aqua satellites. They offer real-time and achieved satellite images of the west coast of the United States. Their image gallery contains an achieve of processed images “from fires to oil spills.” Their complete collection of data is searchable however, the format is not designed for the lay public.

Challenge: Images should be able to show time series and/or composed as animations

Users asked that *imagery* might be available in time series and as animations, where appropriate. A good working example of a site that provide animations is NASA's Visible Earth NASA's Visible Earth (http://visibleearth.nasa.gov/). Visible Earth provides a consistently updated, central point of access to the superset of NASA's Earth science-related images, animations, and data visualizations. These images are considered to be public domain and, as such, are freely available to the interested public-at-large, the media, scientists, and educators for re-use and/or re-publication. Visible earth offers processed MODIS images. These can be browsed, or searched using keywords with simple Boolean operators. An advanced search option is available using key words and by adding the desired "location," "sensor," "parameter," and/or "dates." It is not very easy for a novice to obtain Alaska data using the advanced search option.

An excellent Alaskan example of the use of applying remote sensing animations is University of Alaska's Sea Air Land Modeling Observation Network (SALMON) http://halibut.ims.uaf.edu:8000/~salmon/index.html. SALMON is providing continuous real-time or near real-time observations of ocean circulation and ecosystems. Their application strives to link these data with models to provide ocean forecasts in much the same way that weather forecasts are made.

Challenge: Clearinghouse should provide information in a variety data formats

Imagery could be supplied (downloaded) in a variety of data formats depending on file size, source (sensor), and use (scientific analysis, GIS). Example data formats used by CoastWatch are: IMG (imagemap) for analysis of sea surface temperature, HDF (hierchical data format) for scientific analysis of ocean color, GEOTIFF for GIS application of sea surface temperature and ocean color; GIF/PNG/JPEG/TIF for general use graphics; Binary Raster (FLT, HDR for scientific modeling GIS; and Binary (raw) for image processing for GIS. The general use graphics (e.g., JPEG) should be available in various resolutions. The chooser should identify the format, dimensions, and the approximate time to download (with both dial-up and broadband).

The user should only need an Internet connection and a web browser to access the data. It could include web-based data location, manipulation, viewing and downloading capabilities.

- **Example**: The Remote Sensing On-Line Laboratory (RSOL) at the NASA/Goddard Space Flight Center, (http://carstad.gsfc.nasa.gov/Topics/rsoldmvd.htm) is proposing such a website feature. Their plans are for a three stage website that would allow a lay user to choose images from a variety of sensors, manipulate the images and then download and print the images. A link would explain each instrument (e.g., MODIS, AVHRR, ASTER, TRMM, LANDSAT, MISR).. The user would be able to drag a square to identify their selected location, choose a date they desire, the size of the image window—four choices from 100 X 100 to 1000 X 1000, and save the location of the image for future reference. The user could then manipulate their image—for example, identify which bands will be attributed to which color (RGB), and download a false color image. Or, they might choose a specific product (pre programmed supervised classification) such as: NDVI (normalized digital vegetative index), soil moisture, biomass, chlorophyll, sea surface temperature, surface currents, or choose unsupervised classification. The data product could then be saved for future manipulation, or downloaded to the user.

- **Example**: NOAA’s Coast Watch is developing a “one-stop shopping” site for both raw remote sensing data and processed images. NOAA's CoastWatch Program makes data and imagery available from a variety of sensors and satellites. Deciding which satellite data to view or download depends on the type of information that is needed. The three most common data types are those that show sea surface temperature, ocean surface winds, or ocean color. These products can be browsed online at the NOAA CoastWatch Ocean Products Server or at the NOAA CoastWatch web site.

  The images displayed on the NOAA CoastWatch websites are created from satellite datasets. These datasets are self-contained, meaning they hold more than just the information required to produce an image. NOAA CoastWatch data products are not viewable by Internet browsers and may require specialized software to view, manipulate, and extract the information from the dataset. For many uses, NOAA CoastWatch images provide enough information and are easily viewed over the Internet.

  There are many uses for each type of image. Temperature images for instance, are used to locate fishing spots and for forecasting weather. Ocean color images help scientists track changes in the ocean, and sea surface wind images are used primarily by meteorologists and boaters. Each image and dataset will be available in near real-time, which means the image is just a few hours old. NOAA CoastWatch will provide software utilities and data primers to assist in using the data products. A node to link to Alaskan images is in the works.

Challenge: Examples of application

In addition to imagery data, users requested examples of products that explain how various remotes sensing data might be applied to answer specific scientific and resource management questions. It would be an advantage if the clearinghouse website also include short reports of research that highlights the various approaches (products) scientists are using to answer research questions with remote sensing data. A good example of this is in NASA’s Earth Observatory Website. (http://earthobservatory.nasa.gov/Observatory/).

Challenge: Assistance should be provided

Since the imagery websites will be used by a variety of users, with a range of remote sensing experience, simple instructions for “quick start” of novices might be offered in the form of on-line instructions, and quick tutorials. In addition, links to complete remote sensing tutorial programs could be available. An on-line “help” feature would be a useful component. Some of these features are available with NOAA’s CoastWatch site, or are planned for NASA/Goddard’s RSOL.

Challenge: Provide processed images in the form of GIS

Resource management and education users suggested that website clearinghouse include products that might be called *Project Data*—imagery and analyzed data, converted into thematic, that may be in the form of raster/vector integrated digital data, large-scale color maps, or enhanced/unenhanced digital data. Remote sensing provides data and information that can be incorporated into scientific studies and applied to management strategies. Maps made from remotely sensed data are the most efficient way to document land cover over a large area. Various audiences can use remote sensing from a multitude of activities, from mapping shorelines to monitoring water quality. Educators can use this same information to address science, mathematics and geography standards as well as to make learning more exciting. Images, combined with other geospatial information in a GIS application make remote sensing data an aid to decision-making, discovery and problem solving. The default *project data* set may be small, but customizable; there should be access to large data sets for experienced users.

The best example of combined imagery and product data, for a general audience is a local Alaska example—the Barrow Area Info Database Internet Map Server (BAID-IMS) (http://ims.arcticscience.org/). The BAID-IMS is a clearinghouse of achieved regional-based processed imagery and project data. It is a prototype project developed by the Barrow Arctic Science Consortium (BASC). As well as remote sensing products, topographic maps and current research information, BAID-IMS contains information about historical research conducted in the Barrow area in northern Alaska dating back to the 1940's. This information is designed to be used freely by researchers, land managers, educators and the local community to access spatial data and information on terrestrial, marine, freshwater and atmospheric research in the Barrow area.

Working Example

Example: One of the best working examples that meets many of the requests that the Remote Sensing Needs Assessment Audience identified is provided by the Remote Sensing Data Analysis Service (RSDAS) website (http://www.npm.ac.uk/rsdas/), at the Plymouth Marine Laboratory in England. This website provides processed SeaWiFS and AVHRR data of Great Britain and Northwest Europe. Both archived and near real-time data are available. It is designed for use by environmental scientists, resource managers, and educators who are not specialists in remote sensing, or do not have access to image analysis hardware or software. Images are supplied in a variety of formats and resolution, and can be used without further processing. Searches are accomplished via spatial browser (map). There are quite a few existing products that may be of interest to remote sensing scientists and land managers wishing to avoid processing long sequences of data. After registering, an approved researcher/ user can obtain all available data.

2. Resource Managers and Policy-Maker Audiences

Websites can be organized for a specific audience, with an explicit project application, to accomplish an objective. Or, they can be designed so users can choose the topical application. The planners and manager audience might want specific project data such as impermeable surfaces and watershed impact modeling, weather forecasting, primary production assessment, oil spill remediation, or coastal sediment transport modeling.

Remote sensing images, when combined with thematic data, can be an important tool for management planning and policy-making because of the importance of large spatial scales. It can offer an excellent means of preparing information on management modeling and display alternatives for elected and appointed officials to choose from whose time and perhaps attention span is short.

An example of how remote sensing images can be applied to be used to address specific concerns, is the STORM Project (The Science center for Teaching, Outreach, and Research on Meteorology), at the University of Northern Iowa—a cooperative program between the National Oceanic and Atmospheric Administration and UNI (http://www.uni.edu/storm/). STORM is a model of how remote sensing data can be combined to support decision-making in a regional context. The site provides weather information and conceptual models of the atmosphere to relevant user communities in Iowa and the Midwest. The outreach component involves the collection and preparation of remotely-sensed imagery and the distribution of this data via the Internet. The majority of the data is satellite imagery—LANDSAT, EOS, and AVIRIS.

The Chesapeake Bay from Space Infomart http://www.chesapeakebayfromspace.netis a similar remote sensing resource for local, state, and regional policy makers. Contained in the Infomart are a wide variety of data and tools designed to introduce decision makers to the use and interpretation of LANDSAT 7 ETM+ imagery, with a primary focus on imagery used to measure the extent of impervious surfaces in the Chesapeake Bay and Maryland Coastal Bays Watersheds. The Infomart provides the LANDSAT data as well as a variety of background information and educational tools designed for users outside the research-oriented community.

Nonpoint Education for Municipal Officials, or NEMO, NEMO, http://nemo.uconn.edu/, is an educational program for local resource managers, planners, and policymakers. NEMO uses remote sensing-derived images of land cover, in a GIS format, to help educate local officials about the impacts of non-point source pollution in their towns and how to address them.

The Lighthouse Geospatial Data Gateway http://lighthouse.nrcs.usda.gov/lighthouse/index.html is an example of a site that allows a specific audience (Natural Resource Conservation Service, Soil Conservation Districts and user public) to customize their application (related to soil data). The Gateway allows the user to choose his or her area of interest, browse and select remotely-sensed images and geospatial themes coverage data from their catalog, customize its the format, and have it downloaded or shipped on CD.

Apparently both of the above models are effective and meet the needs of the audience.. Since the latter is more expensive to maintain, an Alaska application should use the Chesapeake Bay model with links to the Lighthouse Gateway.

Challenge: Provide high resolution images

High resolution data was identified as a need by this audience. In order to make land use decisions, a high resolution digital elevation model map products are needed. With an accurate, high resolution DEM map a product can be produced to assist managers, planners and policymakers model water flow in the region.

Although the best way to obtain this is via Light Detection and Ranging (LIDAR) technology, which is effective (accuracy up to 20 centimeters, but is very expensive and thus, may be cost prohibitive for a large area such as the Kenai Peninsula. Another other option available is use of Interferometric Synthetic Aperture Radar (IfSAR) that uses two SAR images of the same area taken from slightly different positions. Comparison of the images generates relative height differences that can be calibrated with known ground elevations to create three-dimensional images (spatial resolution of three meters and vertical accuracy of one meters).

A local system, known as STAR-3i, developed by Intermap Technologies Inc., consists of a dual-channel SAR, an inertial motion measurement unit (IMU) and a Global Positioning System (GPS) unit housed in a Learjet 36A. This combination of hardware and software makes it possible to compute very high accuracy results in the Digital Elevation Model map products. This map data could be incorporated into very many very usable products for the identified audiences in the GEM region.

Challenge: Provide examples of how data can be applied

Resource managers and policy makers desire examples of how they can use the remote sensing in their work. NOAA's Coastal Services Center, developed an excellent model in a CD format, that could be developed for Alaska. *Using Remote Sensing to Address Coastal Management Issues: The Maine Project* integrates multiple satellite-derived data sets with vector data in a multi-platform environment for use by coastal resource managers. This CD-ROM approaches different audiences with multiple ways to access the data: a Web browser for viewing static maps; an ArcView® project file for ArcView GIS users; ArcExplorer®, a free data browser for those users who do not have GIS software; and Adobe Acrobat's® Portable Document Format (PDF) files to view technical reports. Its case studies offer the following titles: *A Land Cover and Habitat Analysis of Casco Bay; Using Eelgrass Data to Improve Oil Spill Response; Restoring Atlantic Salmon; and Satellite Data and Coastal Management in Penobscot Bay*. An Alaska version of this product could demonstrate how various agencies and organizations in Alaska use remote sensing data and GIS technologies to aid in addressing issues.

The Alaska model could focus on various proposed uses of remote sensing for coastal resource management in five categories such as: *coastal development, habitats, water quality management, mapping and monitoring living resources,* and *managing watersheds*. Managers and policy makers could be provided specific topics (see below) along with descriptions of how and where the information can be obtained, analyzed, and applied for their purposes. If provided in a CD ROM, active links to NOAA's CoastWatch site, or an Alaskan site, would provide necessary images. Examples of topics might include the following:

Coastal Development

- *Mapping Wetlands*, *Mapping Flood Plains*, and *Identifying At-Risk Properties* with Light Detection and Ranging (LIDAR) technology or Interferometric Synthetic Aperture Radar (IfSAR) to develop high resolution digital elevation models for modeling and planning.

- *Mapping Coastal Sediment Transport* with Light Detection and Ranging (LIDAR) technology, ARGOS camera array, and digital aerial photography.

Habitats

- *Mapping Submerged Reefs and Submerged Vegetation,* with high-resolution, multi-spectral imagery (e.g., IKONOS, oblique aerial photography, or digital aerial imagery.
- *Mapping Seafloors* with multbeam sonar, side-scan sonar, and sub-bottom sonar. Images can be mosaicked together to create a complete three-dimensional bathymetric picture of the seafloor.
- *Identifying Changes in Turbidity in Ocean,* Turbidity and Chlorophyll-a products are generated using NOAA developed algorithms from ocean color sensors. At present, data products produced using SeaWiFS data are restricted due to limitations associated with these commercial data however NOAA plans to use MODIS data in the near future and these products will be open to the public.
- *Identifying Changes in Sea Surface Temperature,* available from NOAA’s CoastWatch are provided from three sources.
    - NOAA's Geostationary Operational Environmental Satellites (GOES) are updated 8 times per day (every 3 hours) and are available in near real-time.
    - NOAA Polar Operational Environmental Satellites (POES), produced from Advanced Very High Resolution Radiometer (AVHRR) data, are available four times daily for the coastal waters of the United States.
    - NOAA CoastWatch is planning to provide near real-time MODIS sea surface temperature products from the NASA Terra and Aqua spacecraft. Currently, only daytime imagery is supported within 24 hours of observation.
- *Ocean Chlorophyll* and *Ocean Primary Productivity,* with MODIS, making localized maps of ocean color. NOAA CoastWatch is planning to provide near real-time MODIS ocean color products from the NASA Terra and Aqua spacecraft. Currently, imagery is supported within 24 hours of observation.
- *Mapping Ice Coverage* in the ocean with MODIS, measuring the albedo.

Water Quality:

- *Monitoring Water Quality* with Oceanographic Light Detection and Ranging (LIDAR)
- *Monitoring Sewage Outfall Impacts* with ocean color ultispectraul satellite sensor (e.g., Sea-viewing Wide Field-of View—SeaWIFS), to identify elevated nutrient levels via increased chlorophyll in the water.

3. Educators

Technology that provides accessing, displaying and manipulating of both images and data can dramatically extend the educational power of the remote sensing images. Given an appropriate set of tools and local "real world" data, students can directly observe, explore and investigate fundamental concepts in Alaska's earth and ocean science in ways that have never before been possible in a school environment.

Currently, innovative educators successfully use remote sensing images, combined with GIS to teach science, geography, and mathematics content. What they have found to be particularly effective are activities that involve students in collecting and analyzing data of local significance. KBRR educators found this phenomena to be true in the Spring of 2003 when they field-tested an educational program to local high school students that introduced remotely-sensed LANDSAT images of ocean, waterways and land cover and data from satellite-tracked Beluga whales in Cook Inlet, along with observed sightings of marine mammals and fisheries in a GIS format. This type of lesson could be enhanced with animations of sea surface currents, ocean color, and sea surface temperatures.

Another potential application might be a lesson using animations of sea surface currents and surface winds in the Nanwalek area. This would be coordinated with stories, using Traditional Ecological Knowledge about currents winds and their subsistence resources.

Alaska might follow an excellent example of an educational outreach of remote and in situ coastal data provided by Rutgers University Marine & Coastal Sciences' COOL Laboratory (Coastal Ocean Observatory Laboratory) Classroom (http://www.coolclassroom.org/home.html). This is an excellent example of how real-time remote sensing data might be used in Alaska to augment the school curriculum.

The COOL Classroom is a series of Internet-based instructional modules that link middle and high school classrooms with active research investigations at the COOL Room, a collaboration of oceanographers studying the coastal ocean off the coast of New Jersey. An Educational component of an Alaskan Remote Sensing Clearinghouse site might provide processed imagery as described above for Policy-Makers, based on topics, linked to Alaska State Science and Geography Standards. It would also offer a similar project as the COOL Classroom. It would provide interdisciplinary products, using real-time or near real time data animations (current and continuous data from the coastal ocean) to support learning of important science concepts. Example programs might include:

a. *Discrete Versus Continuous Data* where students learn about data collection and the difference between discrete (snapshots), continuous, and real-time data.
b. *Oceanography Through Time*: students use an interactive time line to learn about the history of the exploration and study of the ocean.
c. *What is the Remote Sensing Oceanography?* In this lesson, students explore how and why oceanographers collect data
d. *Using Remote Sensing Technology* allows students to use the tutorials to learn about the instrumentation used to collect data.

University of Alaska's SALMON program is developing curricula and programs for K-12, undergraduate, graduate and continuing science education in coastal and interior communities with special emphasis on Native Alaskans. This model could be supported to provide curricula designed to bring the real-time atmospheric and marine observations into classroom environments. They could be offered through venues such as the Prince William Sound Science Center, Campbell Creek Science Center, The Alaska SeaLife Center, and the Alaska Islands and Oceans Visitor Center.

The Kachemak Bay Research Reserve is developing a framework for a classroom computer laboratory program called "Exploring Kachemak Bay" that uses remote sensing data with GIS to educate high schools students about their region. The model might be used for other communities within the GEM region. The specifics of Exploring Kachemak Bay are described below. Because of what was learned in the Remote Sensing Needs Assessment Workshop, KBRR plans to incorporate remote sensing imagery into their soon to be developed educational programs *High Seas Drifters, Oceans in Motion, Watershed Explorations, Mapping the Beach, Taking the Pulse of the Bay,* and *Undersea Forests.*

Exploring the Kachemak Bay Community-- (a proposal)

With this exciting new KBRR program students learn about the "digital geography" of the Kachemak Bay community by using air photos, satellite imagery, satellite tracking of sea mammals, CODAR animations, and other remote sensing data and GIS data to study the basic physical and human geographic elements of the region. While a majority of the information is available via the Kachemak Bay Ecological Characterization (KBEC) CD and Website, additional datasets and imagery will be made available for the units. These elements are consistent with the 1994 Geography for Life Standards, include atmosphere, lithosphere, biosphere, hydrosphere, movement & settlement, cultural mosaic, economic activities, and political divisions as well as the Alaska State Science, Geography, and Math Standards.

The first core track allows students to become familiar with the tools that are used to study the environment. Students begin by studying a view of their local school area as seen via remote sensing aerial photograph imagery. Association is made between the less familiar plan view perspective and the more familiar ground views of their region with actual ground view photographs taken around their community. Students also explore use of map and compass and GPS (geographic positioning system) to locate various objects found in the photos. Then, they are introduced to the concepts of vector-based mapping using point, line and polygon with respect to landscape features, such as school, roads and forested areas, identified in the aerial photograph.

Students then move on to examine satellite images through the use of a raster-based image viewer and processor. A three-band LANDSAT TM image of their community is viewed (using MultiSpec software) and studied to find geographic features that students and teachers can recognize. They then move on to work with a single-band grayscale image and color, or classify, it according to identified land uses and geographic features. This gives students and teachers an opportunity to actually jump into the image to interact with it beyond basic visual interpretation. They can practice both classified and unclassified identification of features found in the imagery. Students use MultiSpec software to group pixels with similar spectral patterns in a LANDSAT TM data set. They classify the land cover type of each spectral group as well as use their local expertise of their community and if applicable, their sample site measurements, to assess the accuracy of their maps.

Students and teachers can use these tools and other remote sensing images and animations to study physical and human elements in their local community, within the surrounding watershed and coastal marine environment. The physical elements include atmosphere, lithosphere, biosphere and hydrosphere. The human elements are movement and settlement, cultural mosaic, economic activities and political divisions. Each local element is presented and studied through the use of digital geographic data viewed in map form on the computer screen. An example investigation might include identifying good fishing or shell fish production areas predictions based on sea surface temperatures, sea color, and currents.

The final module provides a context for students and teachers to partner with KBRR to study real scientific investigations. The module will take the users through a series of interactive screens and queries to load data collected by KBRR's remote and in-situ sensors as well as other regionally relevant data . These data can then be viewed and studied along with the data studied in earlier modules. This enables the user to put these new data in a locally-based GIS context for analysis.

3. Resource Users/General Public

Providing near real-time remote sensing information can be a wonderful service for natural resource users and the general public to help them make better decisions prior to their activities.

One of the best model for Alaska is one provided by a research and educational organization in Australia—CSIRO (Commonwealth Scientific Industrial Resource Organization) Marine Research Program. The Remote Sensing group of CSIRO Marine Research provides custom built sea surface temperature (SST) products for the commercial fishing community, boaters, specifically yacht racers, and for the marine shipping community.

An Alaskan site might provide clients with their own web page of custom prepared SST images. The images could be tailored to meet the client's needs with respect to scaling and region shown. Clients should be able to access their page at any time by using their username and password. To be useful, the images could be updated to show different scaling or regions within 24 hours notice. New images could be uploaded many times during the day to the web pages and images for at least the last seven days available at any time. Detailed cloud cover estimates or thumbnail images should be available. Geographic information such as; land mask, coastline, 200m depth contour and latitude-longitude grid could be superimposed on the images. Color would be used in the images to describe surface temperature. Although a scale bar shows the relationship between color and temperature, a “point and click” feature would identify the temperature, accurate to about one degree. Other services that might be offered are surface currents, surface winds and “On-line” assistance.

Another good example of how remote sensing needs might be addressed for other audiences can be seen with Rutgers University's Coastal Ocean Observing Laboratory (COOL) http://www.thecoolroom.org/ program that gathers data from satellites, coastal radars and underwater weather stations.

An Alaskan site could coordinate undersea weather (temperature, currents, waves) customized to resource user groups such as: boaters or sailors; fishers; or kayakers, divers, or wind surfers
An example for Alaskan resource users might include:

A. Fishers want to know where the fish may be. This is available via
    - Sea surface temperature to find fronts
    - Ocean surface currents from coastal radar use current fields to find fronts
B. Boaters and Sailors want to know where the currents are—to best plot their course. Use to help navigate
    - Surface temperatures to avoid bad areas
    - Ocean surface currents from coastal radar—use current fields to plot their course
    - Wave heights at selected beaches—CODAR data is used to predict off shore waves
C. Kayakers, Windsurfers, Divers want to know the ocean temperature and want to know—will it be a good day for paddling, surfing, or diving?
    - Sea surface temperature: find out water temp on the coast
    - The wave heights—what type or style of kayak to bring, the best way to dress
    - Coastal Weather: air winds and temperature; undersea temperature and wave heights
    - Upwelling Index: provides a quick look at the ocean's potential to upwell cold water from the sea floor. This is calculated from data obtained from Satellites sea temperatures, CODAR currents, and meteorological data.

Resource users and the general public can be provided products, via interpretive exhibits at visitor centers and museums. The exhibits should include interactive displays about *what* remote sensing images are, *how* they are obtained, and *how* they can be useful to scientists, but most important, to themselves—the public.

As stated above, providing real-time remote sensing information can be a wonderful exhibit at a visitor center. It can be an exciting addition to assist natural resource users and the general public makes better decisions prior to their outdoor activities. University and research organizations might partner to gather and provide data from satellites, coastal radars and land and underwater weather stations. This would be targeted to fishers, sailors, and kayakers/wind surfers, and mariculturists.

Other visitor center exhibits might provide an explanation of coastal dynamics—winds, currents, or sediment transport. Exhibits might explain what remote sensing is and how it works.

1. The GLOBE (Global Learning and Observations to Benefit the Environment) classroom lesson called *Odyssey of the Eyes* might be adapted to demonstrate *how* and *why* digital images are made and how satellites communicate the data to earth.
2. Another example is to use an electronic stud sensor to remotely sense a pattern that is Hidden under a sheet of plywood. What is the pattern? Using different cell sizes, what is the tradeoff in detail versus "scanning time?"

To demonstrate how remote sensing can be useful to the general public, visitor centers and museums can incorporate photographs or video screens with images that the public can manipulate. Following are a few examples of investigations that might be made by the general public.

1. Use high resolution satellite imagery of a community during a simulated emergency response to wildfire. Visitors identify locate the locations of the houses that must be evacuated first.
2. Views of Arctic Ocean—visitors locate best shipping lanes related to sea ice.
3. Views of the Trans Alaska Pipeline to demonstrate how to monitor for changes.

IV CONCLUSION

Remote Sensing images and project data should be made available to the identified audiences in an easy to use format. They must be of the highest resolution possible, and if applicable, in a time series so that changes can be observed. Users should be able to locate images and data via a spatial browser—being able to identify the locations for the desired imagery on a map. Availability of both achieved and near real time data would be optimum. Support services should be provided to assist application and so it does not overwhelm the user. There are numerous examples of *services* and *products* that exist.

Resource managers and planners could use high resolution relief models to help them make decisions on a landscape scale. With these, they can add aerial photos, vegetation and development data, to plan for future growth.

Educators can use images of their community and region at various scales (to zoom in and out); this technique can assist students gain a sense of place. Besides learning what remote sensing is and how it works, images combined with other data in a GIS database can help students make discoveries about their place and make decisions about what should be done.

Resource users and the general public should learn about what remote sensing is and how it works. The data should be available for specific audiences (fishers, boaters, and others) to help them make decisions prior to using the resource. It also can be used to demonstrate how remote sensing data is vital for their safety, or in helping make their life more efficient and comfortable.

To this end, we recommend that GEM works to make satellite data more accessible and to fill the knowledge gap in education about the uses of data. This might be accomplished with a collaboration of agencies, nonprofit organizations and university partners. The following suggested goals might be incorporated:

- Create a prototype of a State public access system for geospatial data from the US Government—collaborate with existing sites such as University of Alaska’s ION (GINA), the Alaska State Geo-Spatial Data Clearinghouse, and NOAA’s CoastWatch
- Promote the use of satellite and geospatial data in education
- Facilitate the use of satellite data to monitor a wide variety of environmental issues, such as identifying at risk properties, ice and navigational risks, search and rescue planning, mitigating oil spills, monitoring storm water, monitoring submerged aquatic vegetation, flood risk, urban planning, and loss of wetlands.
- Facilitate cooperation between education, the State and local governments to obtain remote sensing and digital mapping needs through cost sharing.
- Facilitate research and development in the applications of satellite data.
- Establish "virtual" centers for satellite and geospatial data synthesis and dissemination.
- Establish a high-speed network to provide satellite data to the public, educators, scientists, and community leaders in Alaska.

Appendix 2. Workshop participants

Rachel Potter (UAF – data processing collaborator)
Gary Hufford (Coastwatch)
Buck Sharpton (UAF)
Marin Montes (UAF)
Mia Jackson (Imaginarium)
Neil Folcik (Corp of Engineers)
Carol Compton (DNR)
Susan Saupe (CIRCAC)
Julieanne Fogde (UAF extension service)
Dave Verbyla (UAF)
Bob Mikol (Ocean logic)
Rob Bochenek (GEM)
Kevin Williams (Kenai Borough)
Ted Otis (ADFG)
Dave Roseneau (USFW)
Debby Burwen (ADFG)
Mark Willette (ADFG)

Appendix 3. Workshop wish list

WISH LIST:

- 1-stop shop
- DEAs
- History of sediments – annual data
- Chlorophyll
- Surface currents
- Total suspended solids (TSS)
- Density via salinity…?
- Digitized coastline CIT?
- LID bathymetry & terrain
- Major herring spawning events
- Monitor veg changes – riparian, watershed @ 12”/pixel resolution (spatial), Aug/May every 3-5 years (temporal), Aeromap-compatible
- Area pictures – sediment monitoring, river train changes
- Seabird perspective: SST and chlorophyll archives, changes throughout the year (temporal)
- Sea ice coverage, break-up timing (temporal) in Chuckchi Sea, and ice movement (spatial)
- Better ability to sense remote nearshore data
- Hydrocarbon/oil detection
- Toxic blooms
- Sediment type (relationship w/oil) – particle size distribution
- Good soil moisture
- Relationship between chlorophyll & PAR
- 2km resolution every 6 hours
- Good nearshore data
- Ocean circulation velocity and direction
- Surface current
- Wave ht and period
- Ocean color
- Sea surface temperature
- Fronts & eddies
- Impervious surfaces
- Wetland classifications – vegetation type, classifications, land types
- Separate nearshore photosynthesizers – zone types
- LAI
- Turbidity of LCI
- Relationship to salmon migration, migration patterns, factors
- Insular upwelling
- Time series thru time of development and extent of coastal water masses (seabirds) – salinity, temperature
- June/july daily data for salmon

- Turbidity and chlorophyll in lakes – 1km pixel resolution too small for some lakes
- Late-season plankton bloom timing, location
- Monitor events (plankton blooms, river flooding)
- Ground-water dynamics
- Predict where too find precious minerals (non-renewable resources); hydrothermal activity
- Ice extent and condition (width, breaks, compression) of ice front (seabirds)
- Subsurface ice
- Local photos, current & historical, from Alaskan communities available on web (Imaginarium) – highlighted images
- Shoreline changes over time
- Yearly comparisons ---LUNCH BREAK----
- Salmon swimming upstream, herring balling – visual
- Ground-truth
- Counting sea lions & other marine mammals, beluga whales LCI
- Ground-truthing
- River temperatures
- Historical land-use, human activity
- Remote cabin location
- Elevation, slope, vegetation cover – human watershed use issues
- ATV use in Anchor R. watershed, history
- Fine resolution (4m)
- Community project-planning tools; link existing databases
- Temporal data -- monitor every 2 weeks?
- Industrial waste monitoring, fisheries waste
- Fishing fleet identification and tracking
- Lost driftnets, “ghost nets” and plastic pellets – tracking by identifying convergence zones, fronts, etc.
- Currents resolution: 10 m pixels, not 100 m pixels

Appendix 4. SeaWiFS IDL Script

readme.txt for remap_gulf.pro (IDL Programming Language written for use with SeaDAS the SeaWiFS Data Analysis System)
Written for use with l1a2l2_batch.pro

This program is called for in 'l1a2l2_batch' and maps the products of your choice to the map projection of your choice using SeaDAS. The 'outfile' should be specified by path in order to easily find the .png that is created by this script.

For further assistance on the projection properties, the user is referred to:

http://seadas.gsfc.nasa.gov/doc/sds_command.html

readme.txt for l1a2l2_batch.pro (IDL Programming Language written for use with SeaDAS the SeaWiFS Data Analysis System)

Originally written by Tim Moore (UNH) 10/97
Modified by Rachel Potter (UAF) 9/03

This program inputs a Level 1A SeaWiFS .hdf file (Hierarchical Data Format), which we acquired from the Goddard DAAC along with ancillary (meteorological and ozone) data, and processes it to a Level 2 .hdf file. After processing, another 'remap_gulf.pro' is called to make a projection of the data from user preferences.

In order for the programs to compile and run properly, the user must create a simple ascii/text file (huaf_l1a.list) containing the Level 1A filenames to be processed and place it in the same directory with the Level 1A files. This brings up the subject of directory structure. The first input within 'l1a2l2_batch.pro' is your level 1a directory. This is where the user should specify a basic SeaWiFS path where all of the SeaWiFS data/information is stored. Within this directory, it is assumed that the path structure is as follows:

$seawifs_path/hrpt_name – hrpt_name being the hrpt station that received the data
$seawifs_path/hrpt_name /l1a – location for level 1a input files
$seawifs_path/hrpt_name /l2 – location for level 2 output files
$seawifs_path/hrpt_name/ncep – location for metorological files
$seawifs_path/hrpt_name/eptoms – location for ozone files
$seawifs_path/remaps/region – region is user specified to identify geographic area

If you are not comfortable with this directory structure, you will have to change the paths in the code, but as is, the program is set up to follow these paths so that all you have to change is the ‘l1adir’ variable.

Actually Compiling and Running the Program

Entering: 'do_full_remap1' at the prompt should compile and run 'l1a2l2_batch.pro.' 'do_full_remap1' calls 'do_full_remap2,' which in turn calls 'do_full_remap3.' In 'do_full_remap3,' the number of files in your 'huaf_l1a.list' to be processed should be an input variable as well as the name of the hrpt station that the files were retrieved from.

```
pro l1a2l2_batch,numimg,hrpt_name
;script to process L1A files to L2 files using the seadas program l2gen.
;All the L1A present in chosen directory are processed.
;TSM 10/2/97.
;Modified by RAP 09/03

l1adir='/space1/part3/seawifs/'

l1a_list=strarr(numimg)
openr,99,l1adir+STRLOWCASE(hrpt_name)+'/l1a/'+STRLOWCASE(hrpt_name)+'_l1a.lis
t'
readf,99,l1a_list
close,99

indir=l1adir+STRLOWCASE(hrpt_name)+'/l1a/'
metdir=l1adir+STRLOWCASE(hrpt_name)+'/ncep/'
ozonedir=l1adir+STRLOWCASE(hrpt_name)+'/eptoms/'
outdir=l1adir+STRLOWCASE(hrpt_name)+'/l2/'
remap_flag=1

print,'Beginning batch l1a conversion to l2...'
print,'numimg =',numimg

for i=0,numimg-1 do begin

      fname1=indir+strmid(l1a_list(i),0,14)+'.L1A_'+STRUPCASE(hrpt_name)+'.Z'
      fname2=indir+strmid(l1a_list(i),0,14)+'.L1A_'+STRUPCASE(hrpt_name)

      fname3=indir+strmid(l1a_list(i),0,14)+'.L1A_'+STRUPCASE(hrpt_name)+'.gz
'

       result1=findfile(fname1,COUNT=exist_flag1)
       result2=findfile(fname2,COUNT=exist_flag2)
       result3=findfile(fname3,COUNT=exist_flag3)
        if ((exist_flag1) or (exist_flag2) or (exist_flag3)) then begin

         if ((exist_flag1) and (exist_flag2 ne 1)) then begin
              command='uncompress '+fname1
              spawn,command
              print,'Uncompressing File ',fname1
         endif else if (exist_flag3) then begin
              command='gunzip '+fname3
              spawn,command
              print,'gunzipping File ',fname3
         endif

           infile=indir+strmid(l1a_list(i),0,14)+'.L1A_'+STRUPCASE(hrpt_name)
```

```
;
outfile=outdir+strmid(l1a_list(i),0,14)+'.L2_'+STRUPCASE(hrpt_name)

         hour=strmid(l1a_list(i),8,2)
           day=strmid(l1a_list(i),5,3)
         day2=fix(day)+1
         valid_hour_flag=1

   if (valid_hour_flag) then begin
;  Determine what meterological and ozone files are needed

           fname=strmid(l1a_list(i),1,7)

     if ((STRLOWCASE(hrpt_name) eq 'huaf') and ( hour ne 00 )) then begin
      metone=metdir+'S'+fname+'18_NCEP.MET'
        mettwo=metdir+'S'+strtrim(long(fname)+1,2)+'00_NCEP.MET'
      metthree=metdir+'S'+strtrim(long(fname)+1,2)+'06_NCEP.MET'
        oz=ozonedir+'S'+fname+'12_EPTOMS.OZONE'
     endif else if ((STRLOWCASE(hrpt_name) eq 'huaf') and ( hour eq 00 ))
then begin
        metone=metdir+'S'+strtrim(long(fname)-1,2)+'18_NCEP.MET'
        mettwo=metdir+'S'+fname+'00_NCEP.MET'
      metthree=metdir+'S'+fname+'06_NCEP.MET'
        oz=ozonedir+'S'+fname+'12_EPTOMS.OZONE'
     endif

      print,'metone = ',metone
      print,'mettwo = ',mettwo
      print,'metthree = ',metthree
      print,'ozone = ',oz

; get first met file

           result1=findfile(metone+'.Z',COUNT=exist_met1_z)
           result2=findfile(metone,COUNT=exist_met1)
           result3=findfile(metone+'.gz',COUNT=exist_met1_gz)
         if ((exist_met1_z) and (exist_met1 ne 1)) then begin
              command='uncompress '+metone+'.Z'
              spawn,command
              print,'Uncompressing File ',metone
              exist_met1=1
           endif else if ((exist_met1_gz) and (exist_met1 ne 1)) then begin
              command='gunzip '+metone+'.gz'
              spawn,command
              print,'gunzipping File ',metone
              exist_met1=1
         endif else if ((exist_met1_z ne 1) and (exist_met1 ne 1) $
         and (exist_met1_gz ne 1)) then metone =
'$SEADAS/data/common/S19461993_COADS_GEOS1.MET_noon'

; get second met file

           result1=findfile(mettwo+'.Z',COUNT=exist_met2_z)
           result2=findfile(mettwo,COUNT=exist_met2)
           result3=findfile(mettwo+'.gz',COUNT=exist_met2_gz)
         if ((exist_met2_z) and (exist_met2 ne 1)) then begin
              command='uncompress '+mettwo+'.Z'
```

```
              spawn,command
              print,'Uncompressing File ',mettwo
              exist_met2=1
           endif else if ((exist_met2_gz) and (exist_met2 ne 1)) then begin
              command='gunzip '+mettwo+'.gz'
              spawn,command
              print,'gunzipping File ',mettwo
              exist_met2=1
         endif else if ((exist_met2_z ne 1) and (exist_met2 ne 1) $
         and (exist_met2_gz ne 1)) then begin
            if (metone ne
'$SEADAS/data/common/S19461993_COADS_GEOS1.MET_noon') then mettwo = metone $
            else mettwo=''
         endif

         if ((metone eq
'$SEADAS/data/common/S19461993_COADS_GEOS1.MET_noon') and (mettwo ne ''))
then begin
             metone = mettwo
         endif

; get third met file

           result1=findfile(metthree+'.Z',COUNT=exist_met3_z)
           result2=findfile(metthree,COUNT=exist_met3)
           result3=findfile(metthree+'.gz',COUNT=exist_met3_gz)
         if ((exist_met3_z) and (exist_met3 ne 1)) then begin
              command='uncompress '+metthree+'.Z'
              spawn,command
              print,'Uncompressing File ',metthree
              exist_met3=1
           endif else if ((exist_met3_gz) and (exist_met3 ne 1)) then begin
              command='gunzip '+metthree+'.gz'
              spawn,command
              print,'gunzipping File ',metthree
              exist_met3=1
         endif else if ((exist_met3_z ne 1) and (exist_met3 ne 1) $
         and (exist_met3_gz ne 1)) then begin
            if (metone ne
'$SEADAS/data/common/S19461993_COADS_GEOS1.MET_noon') then metthree = mettwo
$
            else metthree=''
         endif

; get ozone file

           result1=findfile(oz+'.Z',COUNT=exist_oz_z)
           result2=findfile(oz,COUNT=exist_oz)
           result3=findfile(oz+'.gz',COUNT=exist_oz_gz)
         if ((exist_oz_z) and (exist_oz ne 1)) then begin
              command='uncompress '+oz+'.Z'
              spawn,command
              print,'Uncompressing File ',oz
            oz1 = oz
            oz2=oz1
            oz3=oz2
                exist_oz=1
```

```
          endif else if ((exist_oz_gz) and (exist_oz ne 1)) then begin
              command='gunzip '+oz+'.gz'
              spawn,command
              print,'gunzipping File ',oz
              exist_oz=1
            oz1 = oz
            oz2=oz1
            oz3=oz2

         endif else if ((exist_oz_z ne 1) and (exist_oz)) then begin
            oz1 = oz
            oz2=oz1
            oz3=oz2

         endif else if ((exist_oz_z ne 1) and (exist_oz ne 1)) then begin
;check to see if TOVS file is available
            oz=ozonedir+'S'+fname+'*_TOVS.OZONE'
            tovs_exist_Z=findfile(oz + '.Z')
            tovs_exist_gz=findfile(oz + '.gz')
              if (tovs_exist_Z) then begin
               command='uncompress '+oz+'.Z'
                   spawn,command
                   print,'uncompressing File ',oz
                   exist_oz=1
               oz1 = oz
               oz2=oz1
               oz3=oz2
            endif else if (tovs_exist_gz) then begin
               command='gunzip '+oz+'.gz'
                   spawn,command
                   print,'gunzipping File ',oz
                   exist_oz=1
               oz1 = oz
               oz2=oz1
               oz3=oz2
; else, use default ozone file
            endif else oz1='$SEADAS/data/common/S19891991_TOMS.OZONE'
         endif

; Print out Met results
        print,'Got meteorological files'
        print,'met1= ',metone
        print,'met2= ',mettwo
        print,'met3= ',metthree
        print,'oz= ',oz1
          print, 'In= ',infile


;************* generate Level2 file *****************
        print,'Creating L2 file...'

; Running msl12 to create l2 file

      result=findfile(infile,COUNT=l1a_exist_flag)

      if (l1a_exist_flag) then begin $
```

```
          outfile=outdir+strmid(l1a_list(i),0,14)+'.L2_'+STRUPCASE(hrpt_name)
        infile=indir+strmid(l1a_list(i),0,14)+'.L1A_'+STRUPCASE(hrpt_name)

        print,'infile = ',infile

        msl12,0,ifile=infile, $
        ofile1=outfile, $

l2prod1="chl_oc2,chl_oc4,chl_octsc,chl_nn,chl_ndpi,chlor_a,pig_oc2,pig_oc4,pi
g_octsc,pig_nn,pig_ndpi,l2_flags,aer_model_min,aer_model_max,aer_model_ratio,
aer_num_iter,epsilon,eps_78,solz,sola,senz,sena,K_490,evi,ndvi,par,glint_coef
,aerindex,ozone,windspeed,windangle,mwind,zwind,water_vapor,pressure,humidity
,cloud_albedo,fsol,sst,chl_gsm01,acdm_gsm01,bbp_gsm01,calcite,height", $
        met1=metone, $
        met2=mettwo, $
        met3=metthree, $
        ozone1=oz1 , $
        ozone2=oz2 , $
        ozone3=oz3 , $
        maskstlight=0, $
        wait="wait"
;
      fname=strmid(l1a_list(i),0,14)
        result=findfile(outfile,COUNT=l2_exist_flag)

;       if level2 file exists, remove level1a files and remap l2 file

        if (l2_exist_flag) then begin

         l1afile=infile

;     gzip met files
          if (metone ne
'$SEADAS/seadas/data/common/S19461993_COADS_GEOS1.MET_noon') then begin
               command='gzip '+metone
               spawn,command
               print,'gzipping met1 File ',metone

             if (mettwo ne metone) then begin
                  command='gzip '+mettwo
                  spawn,command
                  print,'gzipping met2 File ',mettwo
             endif

             if (metthree ne mettwo) then begin
                  command='gzip '+metthree
                  spawn,command
                  print,'gzipping met3 File ',metthree
             endif
          endif

          if (oz1 ne '$SEADAS/seadas/data/common/S19891991_TOMS.OZONE') then
begin
               command='gzip '+oz1
               spawn,command
               print,'gzipping ozone File ',oz1
          endif
```

```
;     remap to Gulf of Alaska 1km and 5km projections

          outfile=outdir+strmid(l1a_list(i),0,14)+'.L2_'+STRUPCASE(hrpt_name)

      if (remap_flag eq 1) then remap_gulf,outfile,hrpt_name,rm_flag $
      else rm_flag=0

;     remove the l2 file
rm_flag=0
gzip_flag=1

         if (rm_flag eq 1) then begin $
              command='rm '+l1afile
              spawn,command
              print,'removed L1a File ',l1afile

              command='rm '+outfile
              spawn,command
              print,'removed L2 File ',outfile

           endif else if (gzip_flag eq 1) then begin
              command='gzip '+l1afile
              spawn,command
              print,'gzipped L1a File ',l1afile

              command='gzip '+outfile
              spawn,command
              print,'gzipped L2 File ',outfile

         endif

      endif else begin

        print,'No L2 file ',outfile

      endelse

      endif else begin
         print,'L1a file ',fname2,' Not Found'
            endelse
   endif
   endif
endfor
end



pro remap_gulf,infile,hrpt_name,exist_flag

print, 'Beginning l2 remapping'

inmapfile=infile

swfs_fname=strmid(infile,STRPOS(infile,'S'),14)
```

```
str1='_1km_map.L2_'
str2='_5km_map.L2_'

if (STRUPCASE(hrpt_name) eq 'HUAF') then begin

; remap 1k gulf of alaska projection

      outfile='/space1/part3/seawifs/remaps/gulf/'+swfs_fname+str1+STRUPCASE(
hrpt_name)

      bl2map, inmapfile, outfile, $
      ['chl_oc4'],$
      xsize=858, ysize=668,$
      /albers,$
      limit=[56,-158,62,-143],$
      POSITION=[0.0, 0.0, 1.0, 1.0],$
      rot=0

print,'loading 1km mapped image'
      seadisp
      load,outfile,ftype='MAPPED',prod_name=['chl_oc4']
      loadpal,'/home/potter/rach_color.lut'
      display

print,'applying coastline...'
      qt='''
      coast,color=7,hires=1
      grid,grdcol=7,glinestyle=1,latdel=2,londel=2,label=1,lblcol=7
      cbar,vals=[0.1, 0.3, 1.0, 4.0, 10.0, 20.0]
      out,outfile_chl,ftype='PNG'
      print,'*******'


; remap 5km gulf of alaska projection

      outfile='/space1/part3/seawifs/remaps/gulf/'+swfs_fname+str2+STRUPCASE(
hrpt_name)

      bl2map, inmapfile, outfile, $
      ['chl_oc4'],$
      xsize=550, ysize=267,$
      /albers,$
      limit=[50,-175,62,-130],$
      POSITION=[0.0, 0.0, 1.0, 1.0],$
      rot=0

print,'loading 5km mapped image'
      seadisp
      load,outfile,ftype='MAPPED',prod_name=['chl_oc4']
      loadpal,'/home/potter/rach_color.lut'
      display

print,'applying coastline...'
      qt='''
      coast,color=7,hires=1
      grid,grdcol=7,glinestyle=1,latdel=2,londel=2,label=1,lblcol=7
      cbar,vals=[0.1, 0.3, 1.0, 4.0, 10.0, 20.0]
```

```
      out,outfile_chl,ftype='PNG'
      print,'*******'


      result=findfile(outfile,COUNT=exist_flag)

endif

end
```

Appendix 5. MODIS Matlab script

readme file for display_modis.m (Matlab programming language)

Originally created by Jasmine Nahorniak, COAS/OSU

This Matlab script is used to display and then to project or map a MODIS image.

You will need to provide the path to the directory where all of your .hdf MODIS data files are located. In the beginning of the .m file you will need to define: 'mypath', 'fname', and 'prod_name.' Which are, respectively, the path where your MODIS files are located, the name of the data file you wish to load, and the variable name of the product that you want to display.

Half of the way through the script (on line 45), you will find another input, which is the MODIS geolocation file for use when you're mapping an area. If it seems more conveninent and useful for you, this line can be moved to the top of the document near the other inputs. It is simply in this location to help the commenting and flow of the program for initial users.

If you desire, you may change the projection of the image on line 60, and the latitude and longitude limits are defined on lines 68 and 69.

You may use any color map that you would like, but there is one included here 'rainbob' that was created by Bob Evans, RSMAS/MPO.

```
%Loading and Displaying MODIS level 2 data
fprintf(1,'%s','Example 1: Loading and displaying MODIS level 2 data')

% define the path and filename
mypath='/space2/part1/modis/';
fname= 'MODOCL2B.A2003135.2035.004.2003147230854.hdf';
prod_name= 'chlor_a_2';

% load the individual product data
product=hdfread([mypath fname],prod_name);

% get the scaling equation from the HDF file
% to convert the data from raw counts to appropriate units
[name, units, slope, int, eq]=get_hdfmeta([mypath fname],prod_name);

% convert the data from raw counts to appropriate units
% IMPORTANT NOTE!!!
% NOT ALL PARAMETERS HAVE LINEAR SCALING EQUATIONS
% - check the contents of  the variable eq before proceeding
product=double(product)*double(slope)+double(int);
```

```
% open a figure window
figure

% load the rainbob color palette and set the colormap to it
load rainbob
colormap(rainbob)

% display the image with a colorbar
imagesc(product)
colorbar

% change the range of data plotted by the colormap and redraw the colorbar
imagesc(product,[0.01 10])
colorbar

%Map level 2 data
%(The script below requires the Mapping Toolbox)
fprintf(1,'%s','Mapping level 2 data')

% First, we will load the two parameters:Latitude and Longitude from the MODOCQC or MOD03 file
% by using hdfread twice.  If using the MODOCQC file, the lat and lon data will need to be converted
% from raw counts to appropriate units, as in example 1.  The code should look like:

fname='MOD03.A2003135.2035.004.2003136042536.hdf';

 % load the chlor_a_2 data
lat=hdfread([mypath fname],'Latitude');
lon=hdfread([mypath fname],'Longitude');

% change the lat/lon data to double precision
lat=double(lat);
lon=double(lon);

% open a new figure window
figure

% set the projection to equidistant cylindrical
% (available projections can be seen by typing getm mapprojection)
axesm eqdcylin

% set the colormap
colormap(rainbob)

% set the map lat/lon limits
```

```
%setm(gca,'maplatlimit',[min(min(lat)) max(max(lat))]);
%setm(gca,'maplonlimit',[min(min(lon)) max(max(lon))]);
setm(gca,'maplatlimit',[56 62]);
setm(gca,'maplonlimit',[-143 -158]);

% plot the data and add a colorbar
surfm(lat,lon,product)  % this takes a long time!
set(gca,'CLim',[0.01 10])
colorbar('horiz')

% add coastline data to the figure
hold on  % this allows you to plot more than one thing on the same figure
plotm(coast,'Color','white','Clipping','on')
```

Appendix 6. Chlorophyll data

Day	time	seawifs	discrete
123	21:11	1.30696	1.374748
123	21:11	1.29872	1.67482
123	22:57	3.7509	3.524101
123	22:57	4.56286	3.489209
124	0:57	3.56203	6.873741
124	0:57	5.68063	8.932374
124	0:57	4.67015	5.896763
126	21:01	2.5049	3.157734
126	22:01	2.5049	2.372662
126	23:01	2.5049	2.930935
126	23:03	9.04545	7.117986
126	23:03	11.454	7.885612
126	23:03	10.1972	7.606475
135	21:03	2.75117	1.475935
135	21:03	2.01441	1.814388
135	21:03	2.66294	1.702734
135	23:04	2.72373	2.058633
135	23:04	3.02621	1.884173
135	23:04	3.23699	1.953957
136	1:10	3.12225	1.877194
136	1:10	2.89542	2.076079
136	1:10	1.57942	1.723669
136	21:13	4.68409	6.629496
136	21:13	8.30648	6.978417
137	1:00	3.85453	2.794856
137	1:00	2.43721	2.128417
137	1:00	2.43721	2.770432
139	21:05	1.56495	1.465468
139	21:05	1.60098	1.416619
139	21:05	1.64876	1.353813
140	23:11	5.00964	1.297986
140	23:11	4.66774	1.427086
140	23:11	5.00964	1.270072
141	1:00	5.14525	2.547122
141	1:00	4.90432	2.896043
212	23:00	0.72392	0.40352
212	23:00	0.72392	0.41904
212	23:00	0.760609	0.40352
213	0:50	1.45638	0.56454
214	22:58	0.45101	0.20952
214	22:58	0.396995	0.21534
214	22:58	0.504869	0.20952
215	0:58	0.503803	0.28518

215	23:00	0.708811	0.5044
215	23:00	0.708811	0.46172
216	23:08	0.423491	0.211118
216	23:08	0.332213	0.219269
217	0:48	0.46923	0.171176
217	22:52	0.523924	0.273882
217	22:52	0.504998	0.317084
218	0:15	0.275471	0.48306
218	0:15	0.275471	0.4559
218	0:15	0.275471	0.28518
220	23:00	0.426553	0.207042