Early results from Seawifs observations of the NE Pacific and BC coast

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Abstract

Seawifs satellite images of the BC coast and Gulf of Alaska have been collected at the Institute of Ocean Sciences since the first transmissions began in September 1997. Image data are received and stored, and are later de-crypted using delayed (research) keys. Quick-look images are then used to select sections of passes for processing with the NASA Seadas software to geometrically corrected (level 3) products. This paper presents a first assessment of the resulting series of images, which show water-leaving radiance and chlorophyll distributions on about 140 dates between September 1997 and May 1999. Image coverage is greatly reduced by the heavy cloud cover of this area, but the data should be extremely useful for showing the spatial patterns of surface phytoplankton presently being monitored by ship samples and buoy time series as part of on-going research. Problems in the Seadas output are evident from the large number of negative radiance values computed at shorter wavelengths, which cause overestimates in the derived chlorophyll values. Examples are shown of significant images, and of comparisons of the chlorophyll values with ship measurements. The effects of the negative radiances and the results of a simple ad-hoc compensation are also discussed. Future plans for collection of surface and satellite data are presented.

Introduction

The importance of satellite images of coastal and offshore water colour patterns for showing the spatial and temporal variability of primary productivity is now widely recognised. After the initial demonstration by NASA's CZCS imager, data were first provided by Japan's OCTS imager and are now being regularly provided by the Seawifs instrument. Improved satellite-born imagers (MODIS and MERIS) will soon be launched by both NASA and ESA.

Seawifs image data are available as global mosaiced products with about 10 km spatial resolution. Higher resolution (1 km) imagery can also be received directly using local tracking antennas. Seawifs satellite images of the BC coast and Gulf of Alaska have been collected at IOS since the first transmissions began in September 1997. Images are received and stored using low-cost hardware, and are de-crypted using delayed (research) keys provided over the internet as part of NASA's support to international research. Data are converted to level 0 and a copy is sent to NASA. A simple processing of the data gives quick-look images of an individual band (usually band 3, 490 nm) with a first-order atmospheric correction that shows water colour features in cloud-free areas. Images selected from these quick-looks are then processed to geometrically corrected (level 3) products using the Seadas software.

This paper reports on a first assessment of the resulting series of images, which show water-leaving radiance and chlorophyll distributions on about 140 dates (though with significant cloud cover) between September 1997 and May 1999.

Seadas results

The Seadas software produces Level 1 and Level 2 data of complete Seawifs passes, and also produces mapped (Level 3) products of specified areas. Level 2 and 3 data show derived products for each pixel, including normalised water-leaving radiances in the first 5 spectral bands (centered at 412, 443, 490, 510, and 555 nm) and chlorophyll concentrations. 16 flags for each pixel indicate conditions based on Seawifs data (blooms, turbidity and other anomalies), geometry (sun and satellite angles, sun glint) other data bases (land, shallow water), see table 1, below. These flags provide much of the diagnostic information useful in interpreting the images, and include one flag, for coccolithophores, that attempts an identification through the spectral signature measured by Seawifs.

Figure 1 shows four images (Level 3 data) derived from the Seawifs pass on 28 May 1998 of the Vancouver Island area, which was especially cloud-free at the time. The area is defined by 512 X 512 pixels each covering 1100 m square, centered at 49 N, 126 W (cylindrical projection with equal x and y scale at the image centre). The images show computed normalised water-leaving radiances at 443 nm (top left), 490 nm (top right) and 555 nm (bottom left). The chlorophyll concentration image, derived from the ratio of the 490 to

the 555 nm radiance, is shown at bottom right. Scales at the top of each image show the radiance or chlorophyll values corresponding to each colour. The radiance scale includes negative values, which are common in Seadas output in this geographic area.

A significant bloom of a strongly-scattering phytoplankton is in progress off the west coast of Vancouver Island. Land is masked (to dark blue) from a database included in Seadas. Cloud is masked to black using a Seawifs radiance threshold. A coastline and latitude/longitude grid has been added. The radiance images show high values between 49 and 50 degrees north latitude, indicating the presence of scattering material, presumably phytoplankton or its decay products. The chlorophyll image, in contrast, shows high values in areas where low radiance at 490 nm (top left image) is assumed to indicate strong absorption by high concentrations of chlorophyll a pigments. Off the north-west tip of Vancouver Island and in a strip along the west coast of Washington State (bottom right of the images) the high chlorophyll is associated with increased scatter at 555 nm (lower left image).

Three potential sources of error in the data are:

- overcompensation for atmospheric radiance (computed radiances at 490 nm are then too low)
- degradation of the Seawifs instrument leading to calibration errors, which are expected to have a greater effect at shorter wavelengths
- presence of other dissolved organic material in the water near the coast contributed by fresh water run-off from land (another cause of low radiance at 490 nm, but not indicating chlorophyll)

Errors in computed water-leaving radiances are clearly demonstrated by negative values. Seawifs measures radiance at a wavelength of 412 nm, where the atmospheric radiance contribution is extremely high, so that a small error can result in negative derived water-leaving radiances. If the negative values are due to an overestimate in the atmospheric correction, then this implies errors at longer wavelengths, most importantly in the 490 nm values used in calculation of chlorophyll concentrations.

The third source of error due to dissolved organic material, is known to be significant in all the areas showing high chlorophyll in the south-east of the imaged area. Surface water along the west coast of Washington State contains water from the Columbia and local coastal rivers. Sheltered water to the east of Vancouver Island is strongly affected by outflow from the Fraser River. The fresh water from the Fraser river contains very high concentrations of dissolved organic and suspended material. The suspended material causes a strong increase in water-leaving radiance, typically over an area 10 km by 10 km near the river mouth. This is masked in Seadas output, and is visible as the black area in the chlorophyll image. Dissolved organic material reduces water leaving radiance at short wavelengths over a much larger area.

Table 1: Flags provided for each pixel of Seawifs data by the Seadas software

1	Atmos. Correction failure
2	Land
3	Missing ancillary data
4	Sun glint
5	Radiance > knee
6	Large s/c zenith angle
7	Shallow water
8	Negative nLw
9	Stray light
10	Cloud or ice
11	Coccolithophores
12	Turbid case 2 waters
13	Large solar zenith Angle
14	High aerosol concn.
15	Low nLw at 555 nm
16	Chloro. Algorithm failure

Figure 2 shows the 16 masks computed by the Seadas software for the data shown in Figure 1. Masks are shown in the order listed in table 1. One interesting result is the identification of coccolithophores as being responsible for the area of elevated chlorophyll noted above off the north tip of Vancouver Island. A significant flag is that for negative radiances, showing that most other areas of high chlorophyll are affected by this error. This and other flags indicate small areas near edges of cloud and land where various problems occur. The only extended area where atmospheric correction failure is flagged is over the Fraser River plume where the high water-leaving radiance levels would be expected to cause problems. The shallow water flag is based on data with low spatial resolution and is not useful in the steep topography of this area.

Comparison with surface data

A series of chlorophyll measurements have been made during the Seawifs time period to provide data for Canadian studies of coastal productivity as part of the international JGOFS program. Cruises were undertaken in October 1997, May, July and October 1998 and May 1999. A program to provide time series of surface chlorophyll from surface meteorological buoys is underway at IOS, but the only test mooring so far instrumented is in sheltered water in an inlet too narrow to be imaged by Seawifs.

For this first comparison we consider ship measurements made near the location of the meteorological buoy on La Perouse Bank at 48° 50' North, 126° West, close to the edge of the area of highest chlorophyll on Figure 1. The value indicated for this location in the Figure 1 data is 6.2 $mg.m^{-3}$. These data

show a very low radiance at 443 at this location and a negative value at 412 nm, indicating that this chlorophyll concentration is probably overestimated.

Figure 3 shows the frequency distribution of chlorophyll values taken from Seadas output at this location for the 70 images at which the software indicated the area to be cloud-free. This is compared to a similar distribution derived from ship measurements over the shallow water of the continental shelf within 15 nautical miles of this buoy location over all available cruises. The distribution derived from satellite data shows a large number of high chlorophyll values, which do not appear in the ship data. Poor atmospheric correction or Seawifs calibration errors, as indicated by the presence of negative radiances, may explain this discrepancy.

Figure 4 shows the frequency distribution of radiances at 412 nm at this location. It can be seen that the vast majority are negative. In the absence of other information, a more accurate value of the negative radiance values at 412 nm can be taken as zero. One simple ad-hoc correction procedure is to then assume an error in the Rayleigh (λ^{-4} power) correction for atmospheric scattering, and apply a scaled additive correction to all Seawifs bands. If the error is in fact only in the 412 band (due to sensor degradation or a calibration change) then such a correction may over-compensate other bands. Inspection of the data shows negative values at 443 nm and occasional very low positive values at 490 nm, showing some link between bands.

The effect of this correction is indicated by the dotted frequency distribution in Figure 4, in which all values greater than 30 mg.m-3 are now removed and values between 10 and 30 are greatly reduced. However, the mean value is now shifted significantly below the mean of the ship observations, suggesting that a different method of propagating errors between bands may be more appropriate.

Figure 5 shows the data comparison as a time series. The original Seawifs data values are high in summer and also indicate a possible "spring bloom" peak in March. Average values computed for the months in which ship cruises occurred show much less contrast. The July 1998 cruise does not confirm the high summer values seen by Seawifs, but the Seawifs time series suggests that timing of the cruises may explain some of the lack of high values in Figure 4. Applying the same correction to Seawifs data as in Figure 4 results in the dotted time series in which summer values are reduced to better average agreement with ship data, but data at other months appears too low. The "spring bloom" observation in March 1998 has now disappeared, showing a strong effect of the "negative radiance" error on this observation.

Seawifs data internal consistency.

On 7 dates, usable data was collected as Seawifs observed the La Perouse site twice, once on the western edge of the swath (low pixel number) and once an orbit later, on the eastern edge of the swath (high pixel number). Since little or no change is expected in chlorophyll concentration in such a

short time (about 100 minutes) comparison of the two computed values provides a test of the accuracy of the Seadas results.

Table 2: Data from dates on which the La Perouse site was observed twice by Seawifs (on consecutive orbits). The table shows the two pixels numbers at which the site was imaged (in the range 1 to 1285), the two radiance values at 412 nm in units of $mw.cm^{-2}.\mu m^{-1}.sr^{-1}$, the two chlorophyll values computed by Seadas, and the two values after correction as above.

Date	Pixel 1	Pixel 2	L 412 1	L 412 2	Chl 1	Chl 2	Corr C1	Corr C2
980318	196	1185	-.32	-.80	4.4	54.0	2.5	2.8
980331	128	1141	-.52	-.83	1.1	1.7	0.9	0.9
980512	160	1160	-.31	-.74	1.2	1.0	1.0	0.8
980612	182	1170	-.46	-.53	46.1	30.0	6.4	6.0
980713	207	1182	+.03	-.59	3.9	21.6	4.1	3.2
980804	178	1179	-.25	-.58	10.1	15.0	6.4	5.2
990331	150	1157	-.42	-1.00	2.6	4.5	2.2	2.3

Table 2 shows that all but one of the radiance values are negative. There is a consistent bias in that radiances measured on the later pass are considerably more negative (they include the most negative value observed at this site of –1.0). Seadas chlorophyll output shows some high values with large inconsistency in the pairs. Corrected values are considerably more consistent, suggesting that some correction as proposed here should be able to improve the data at this site and at similar coastal sites round the world.

Future plans.

Seawifs data will continue to be received at IOS, and we anticipate improvements in data processing software which will correct the problems noted above. New data from MODIS and MERIS will be applied as they come available.

A program is underway at IOS to add optical sensors (including fluorometers) to some of the 17 surface meteorological buoys along and off the west coast of Canada. These buoys provide weather and ocean data for the Environment and the Fisheries departments of the Canadian federal government. The standard buoys measure wind speed and direction, wave height and spectrum, surface water and air temperature and atmospheric pressure and transmit the data hourly by satellite. The new sensors, installed on two buoys so far, measure insolation, water colour and fluorescence. This data is also transmitted hourly. A salinometer and acoustic profiler has been added to one package. The first time series from the prototype mooring started at the end of 1997 in Saanich Inlet, near the Institute of Ocean Sciences. This location is in too narrow an inlet to be imaged by Seawifs. Some data has also been collected from a second buoy off the Fraser River.

Fouling by marine growth is a major problem, but time series of data are available. Data from the prototype buoy can be viewed at http://www-sci.pac.dfo-mpo.gc.ca/ecobuoys.

Conclusions

Many projects with global implications such as JGOFS depend on research carried out in coastal areas. It is therefore important that Seawifs data should be calibrated and corrected adequately to provide good data near shore where water properties are complex and short wavelength radiances may be relatively low. Full resolution (1 km) Seawifs data are needed to resolve patterns in these areas. Future sensors such as MODIS and MERIS will provide higher spatial resolution and the spectral bands needed to detect solar-stimulated chlorophyll fluorescence and to better characterise intense plankton blooms (red tides).

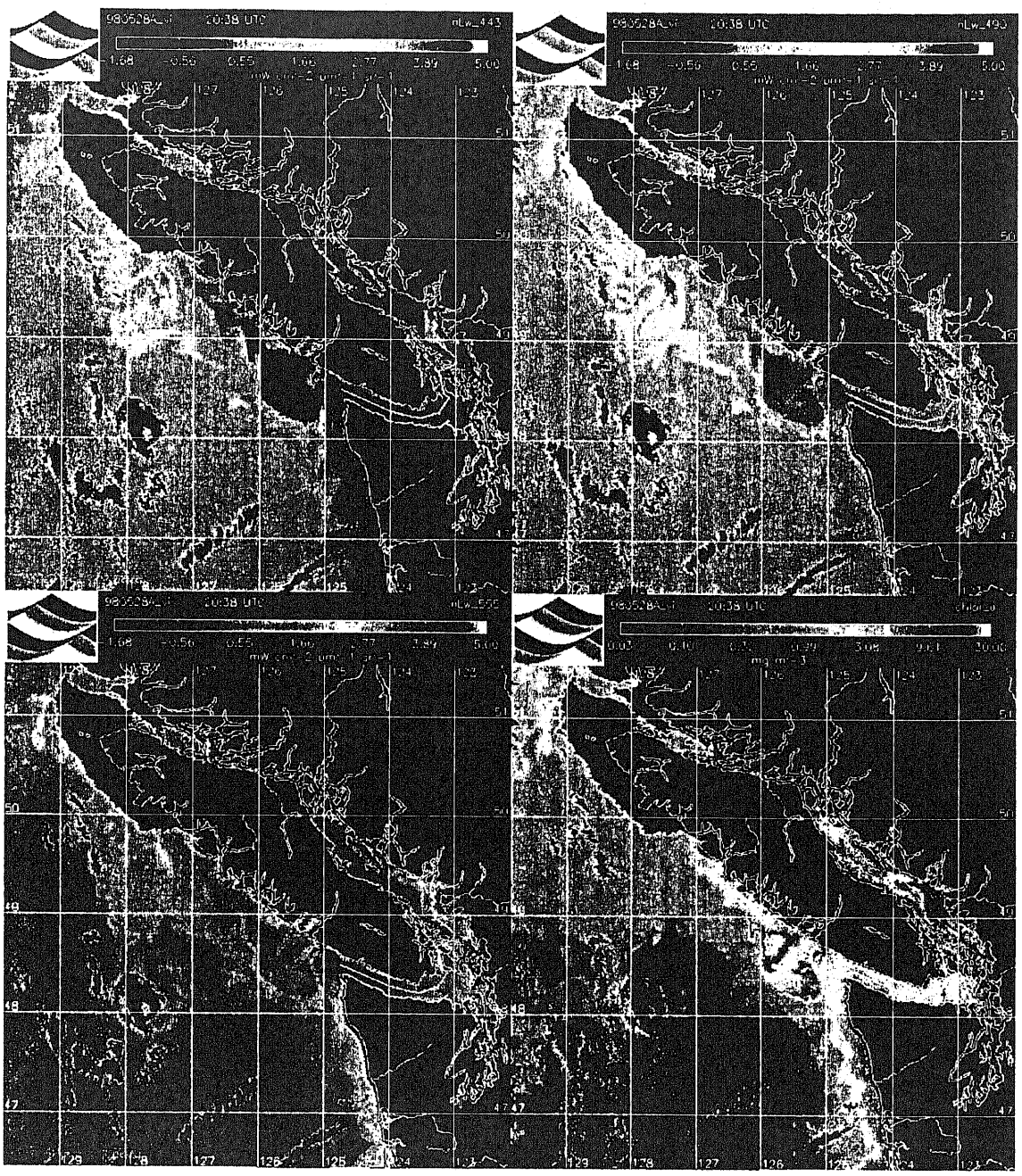

Figure 1. Seadas mapped output images (level3) showing normalised water-leaving radiances at 443, 490 and 555 nm (top left, right and bottom left),and computed chlorophyll concentrations (bottom right). Colour bars show the scales, which include negative radiances.

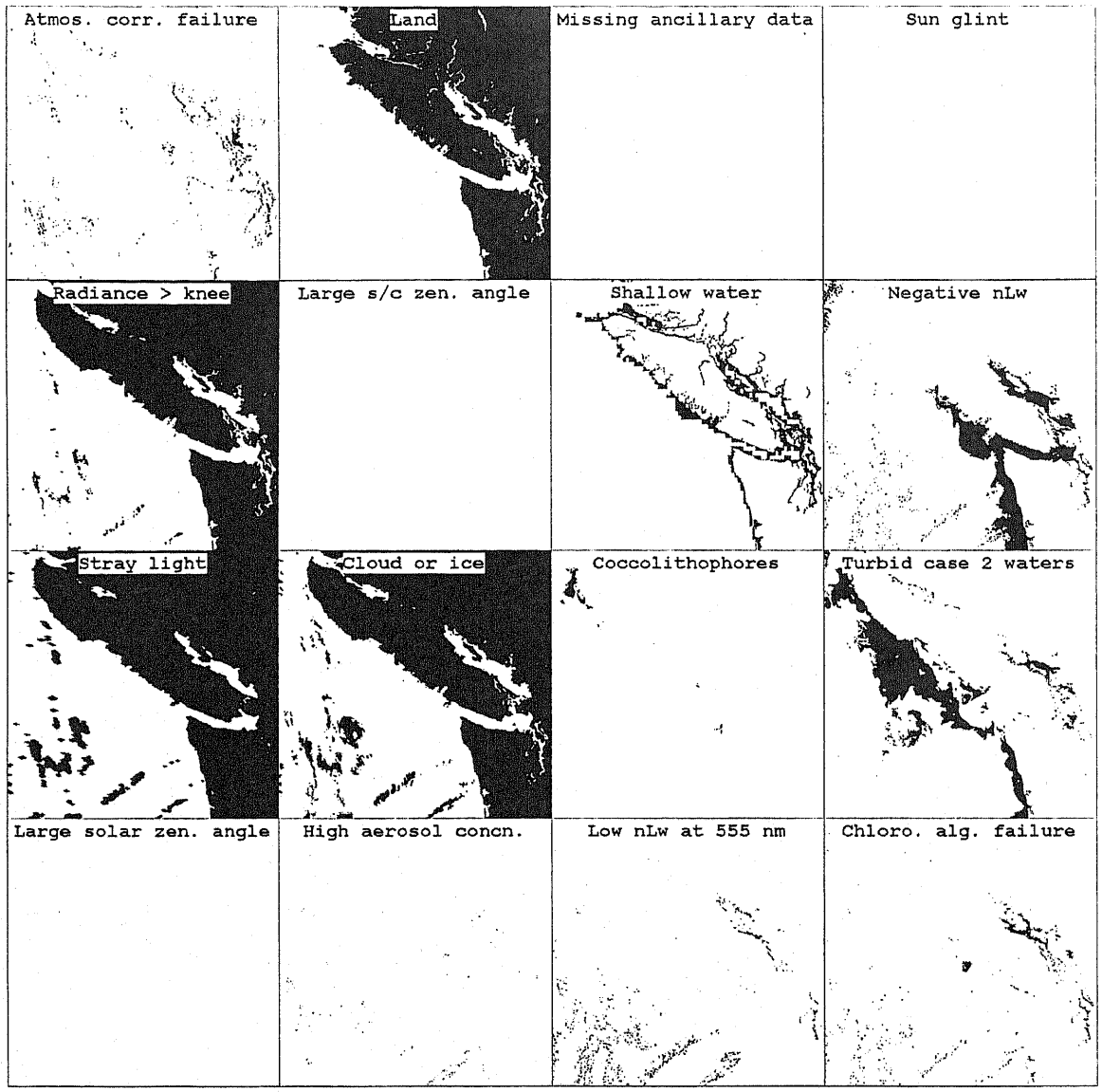

Figure 2. Binary (bitmap) images of all 16 flags in the order given in Table 1. Negative water-leaving radiances are flagged in coastal waters. The atmospheric correction algorithm fails over the bright water of the Fraser plume. Some high chlorophyll values are flagged as "algorithm failure."

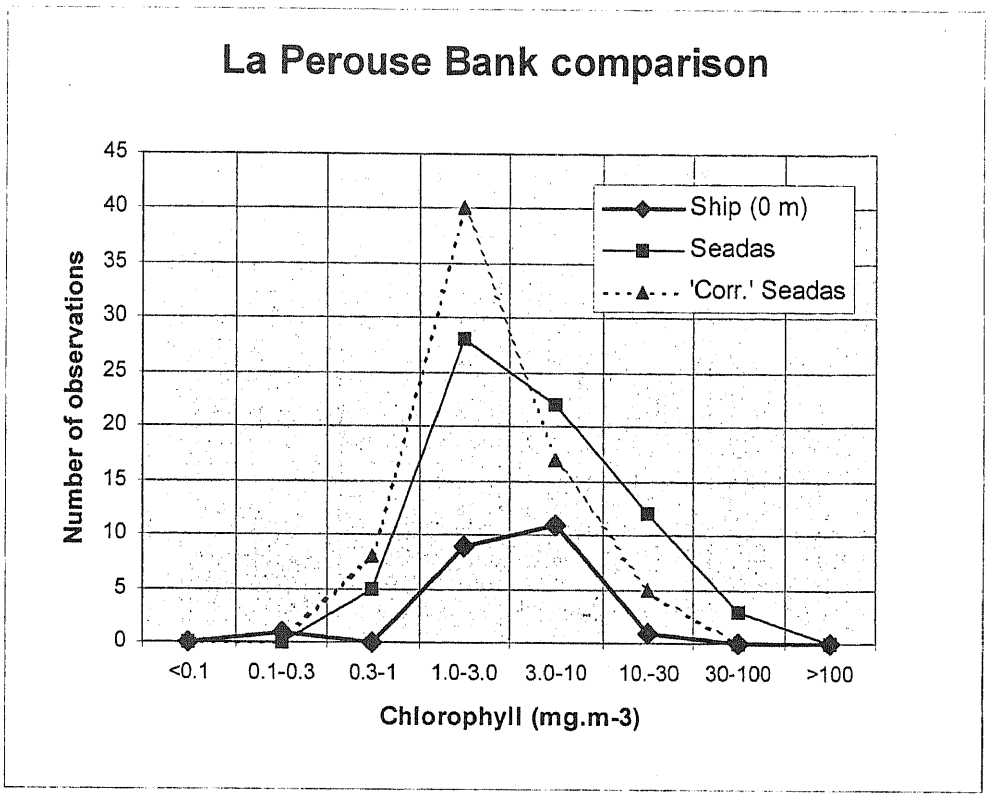

Figure 3. Frequency distributions of measured chlorophylls at the La Perouse Bank location at 49° 50' N, 126° W on the continental shelf off south west Vancouver Island. Data from Seawifs are compared with the limited ship data available. The effect of an ad-hoc correction for negative radiances is shown (dotted).

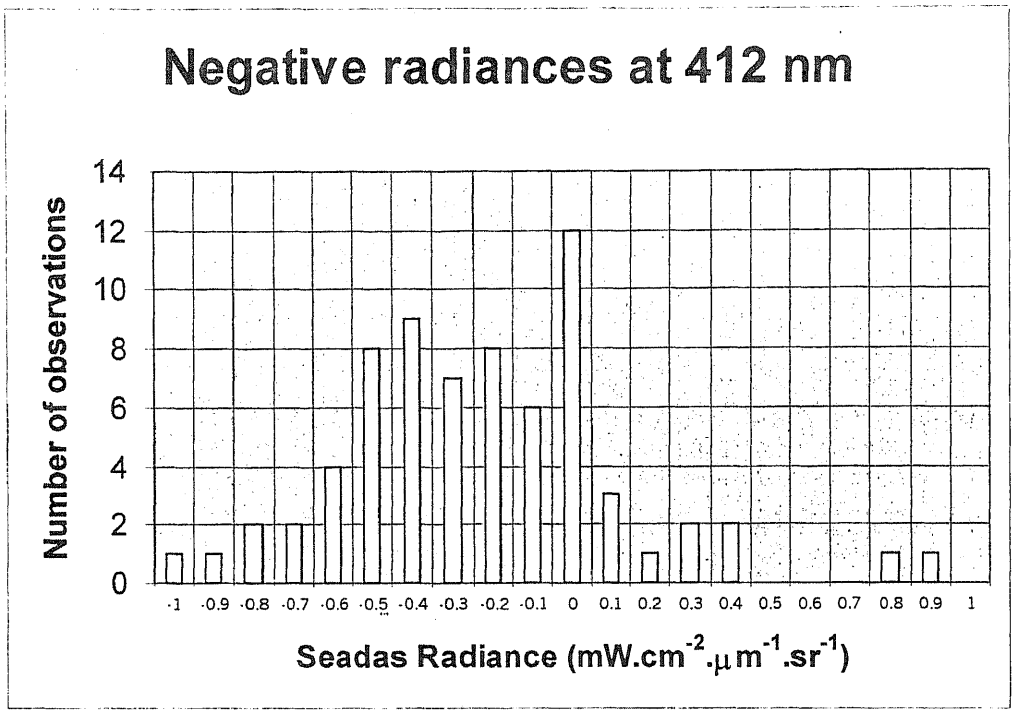

Figure 4. The frequency distribution of radiances measured by Seawifs at the La Perouse Bank location. Numbers on the x-axis are the maximum of each segment of the radiance range. Most computed radiances at 412 nm at this location are negative.

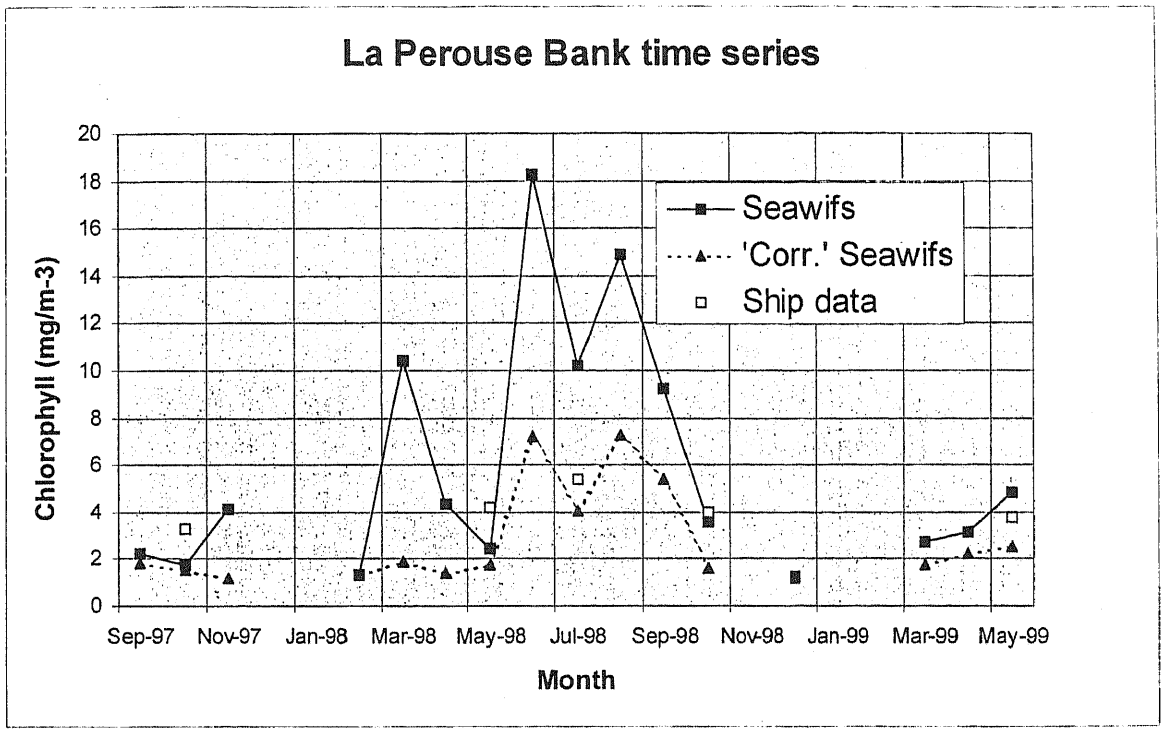

Figure 5. Time series (month average) of chlorophyll values deduced from Seawifs data at the la Perouse Bank location. Average ship measurements are shown for comparison. The effect of an ad-hoc correction for negative radiances is shown (dotted).