Computation of primary production from remote sensing: Operational mode

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ABSTRACT

Estimation of primary production from remotely-sensed data on ocean colour is a problem with two principal parts: construction of a local algorithm and definition of a protocol for extrapolating the local algorithm to large scales. By "local algorithm", we mean an algorithm that can be implemented at a fixed point provided that all necessary information (forcing variables, physiological parameters, chlorophyll profile parameters) is available. Such algorithms already exist. The remaining challenge is to define an extrapolation protocol that will lead to best estimates of the necessary parameters on all pixels in the image, that is on pixels for which we have no direct knowledge of the parameters.

Here, the extrapolation protocol under development for the Canadian Atlantic Coast is presented and discussed.

INTRODUCTION

In Canada, one of the applications of remote sensing is to produce bi-weekly information on the state of the marine ecosystem for the Atlantic Zone, with the continental shelves put into their oceanographic context. The intended uses are first, for research (establish a time series that can be exploited to address various scientific questions); and second, development of information and conceptual bases for coastal-zone management, including fisheries management. The time series is based on ocean-colour data and on sea-surface temperature data, which can both be received through the same dish and analysed to produce images at the same time and space scales (Figure 1). The images comprise some 1.8×10^6 ocean pixels each. The total area covered (land and ocean) is some $5 \times 10^6 \text{ km}^2$.
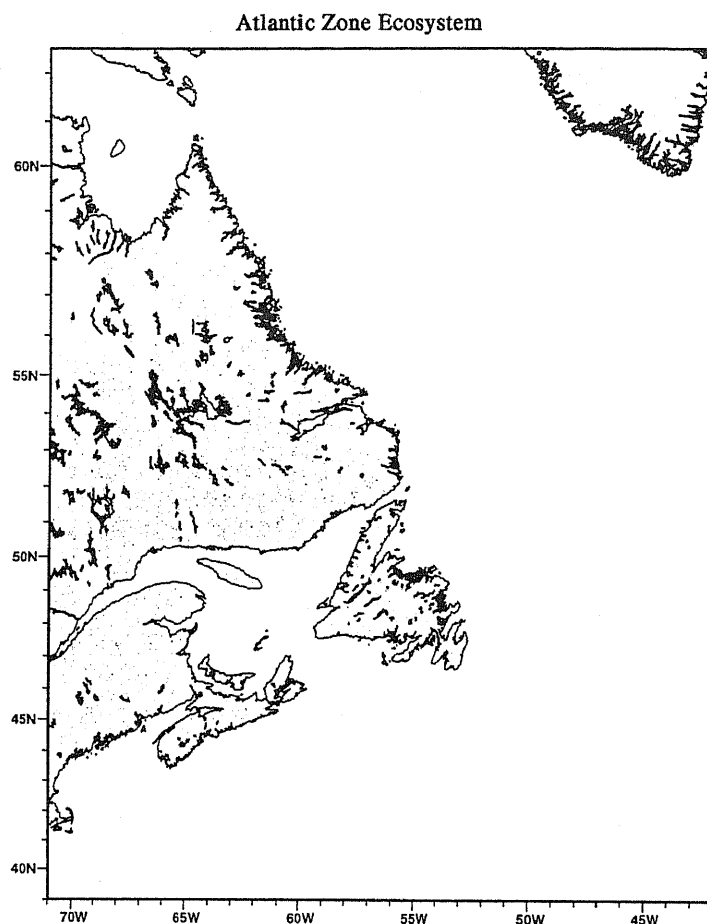
Atlantic Zone Ecosystem

Figure 1.

It was considered that the value of the project would be enhanced if it could include bi-weekly images of primary production computed, on the same spatial scales, using the remotely-sensed fields as inputs. Whereas several authors have computed primary production from remotely-sensed data on ocean colour, to our knowledge the routine calculation for a particular area, with a view to production of a time series, has not been attempted.

BACKGROUND

Estimation of primary production from ocean-colour data is a problem with two components. First, we must construct a local algorithm that will make reliable estimates of primary production, given biomass, provided that all necessary information (forcing variables, physiological parameters, chlorophyll profile parameters) is available. Next, we must establish a protocol for extrapolation of the local algorithm to large horizontal scale, that is a protocol for applying the local algorithm on all pixels in the target image, where, typically, we have no direct knowledge of the parameters required.

In our view, the construction of a local algorithm is a solved problem. An array of models is available according to the degree of approximation that can be tolerated and the computing time that is acceptable.

EXTRAPOLATION PROTOCOL

The extrapolation protocol, however, is a different matter, especially for implementation in the routine mode. One of the factors that must be weighed is the existing knowledge about the phytoplankton (vertical profile of chlorophyll, photosynthetic performance) for the region under consideration. In the case of the Atlantic Zone of Canada, some 835 stations are available in the archive for photosynthesis parameters, and some 495 for the vertical structure of chlorophyll.

In deciding on a protocol for assignment of parameters, the following options may be considered.

1 According to some objective function of a continuous variable such as depth, latitude or SST.

2 According to partition of region into dynamic domains wherein parameters are piecewise constant or piecewise continuous (suite of biogeochemical provinces).

3 According to a match between given remotely-sensed fields (chlorophyll, SST) and information in archive of ship observations for the same region.

In choosing between these options, we must acknowledge that the region is complex and dynamic, with cold water from the Labrador Current and warm water from the Gulf Stream in close proximity. No suitable objective function yet exists that will assign the parameters we need. We have not yet succeeded in finding a suitable dynamic partition into provinces, where the qualifier "dynamic" implies that the boundaries of the provinces are free to vary from image to image.

Thus, we resort to the third option, assigning the parameters according to matches between the image data and the archived station data. For any pixel in the images (Figure 2), we know the biomass and the SST.
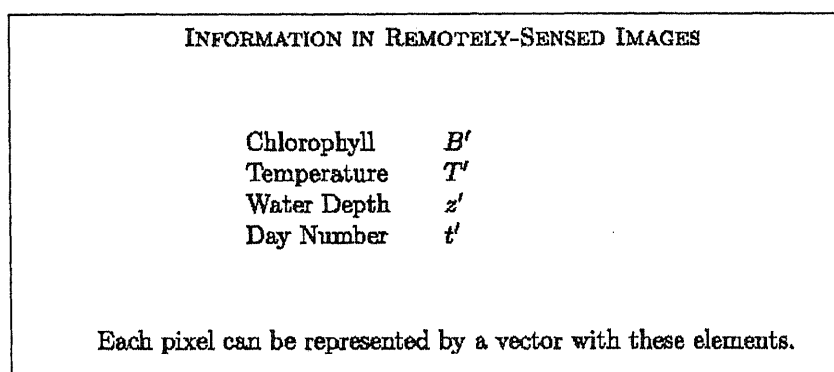
INFORMATION IN REMOTELY-SENSED IMAGES	
Chlorophyll	B'
Temperature	T'
Water Depth	z'
Day Number	t'

Each pixel can be represented by a vector with these elements.

Figure 2.

We also know the water depth and the date (day number). In the archived data (Figure 3), over and above the properties already mentioned for the images, we know the parameters of the photosynthesis-light curve and the parameters of the chlorophyll profile, when it is fitted to a standard shape. We must then consider the intersection between these data sets (Figure 4).
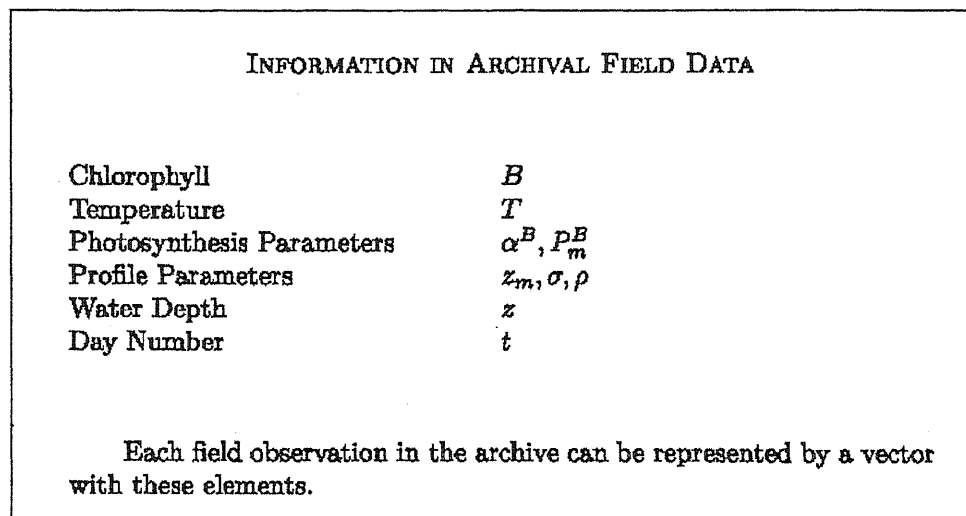

INFORMATION IN ARCHIVAL FIELD DATA

Chlorophyll	B
Temperature	T
Photosynthesis Parameters	α^B, P_m^B
Profile Parameters	z_m, σ, ρ
Water Depth	z
Day Number	t

Each field observation in the archive can be represented by a vector with these elements.

Figure 3.

INTERSECTION OF REMOTELY-SENSED AND SHIP DATA

$$\begin{pmatrix} B' \\ T' \\ z' \\ t' \end{pmatrix}$$

Image Pixel

$$\begin{pmatrix} B \\ T \\ \alpha^B \\ P_m^B \\ z_m \\ \sigma \\ \rho \\ z \\ t \end{pmatrix}$$
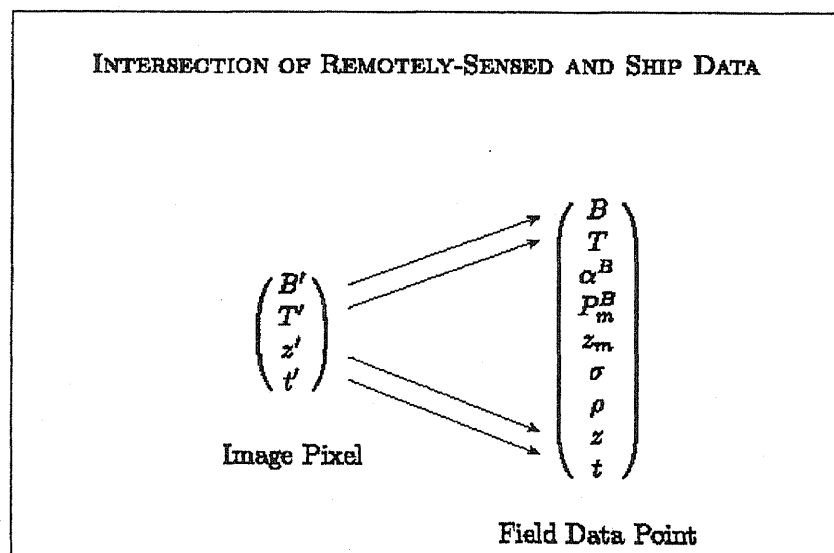
Field Data Point

Figure 4.

The strategy for the protocol (Figure 5) is, for any given pixel, to enter the archive with the values of biomass and SST for that pixel and find the archive station with the closest coordinates of biomass and SST (Figure 6). The chlorophyll profile and photosynthesis parameters for that archive station are the first-order estimates of the parameters for that pixel.
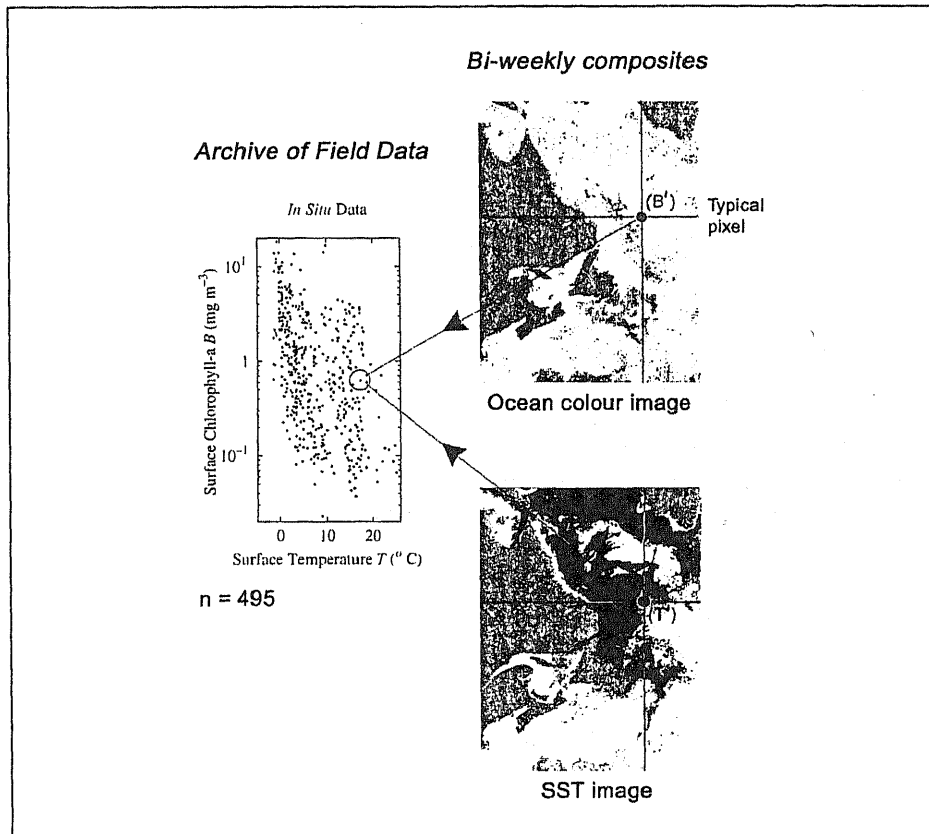
Figure 5.

Figure 6.

Certain refinements can now be made. Instead of taking the parameters from only the single archive point with the closest coordinates, we can use also a number (ten, say) of its nearest neighbours, and calculate the average parameter values over this set (Figure 7). Then, we take into consideration that the archive station and the image may have been taken in different seasons, so we can weight the utility of the archived station according to the difference in day number between it and the image, constructing a weighted average of the parameters over the nearest neighbour set (Figure 8). This is the procedure that is in use

in our laboratory. Further refinements may be possible based on water depth, but these have not yet been explored.
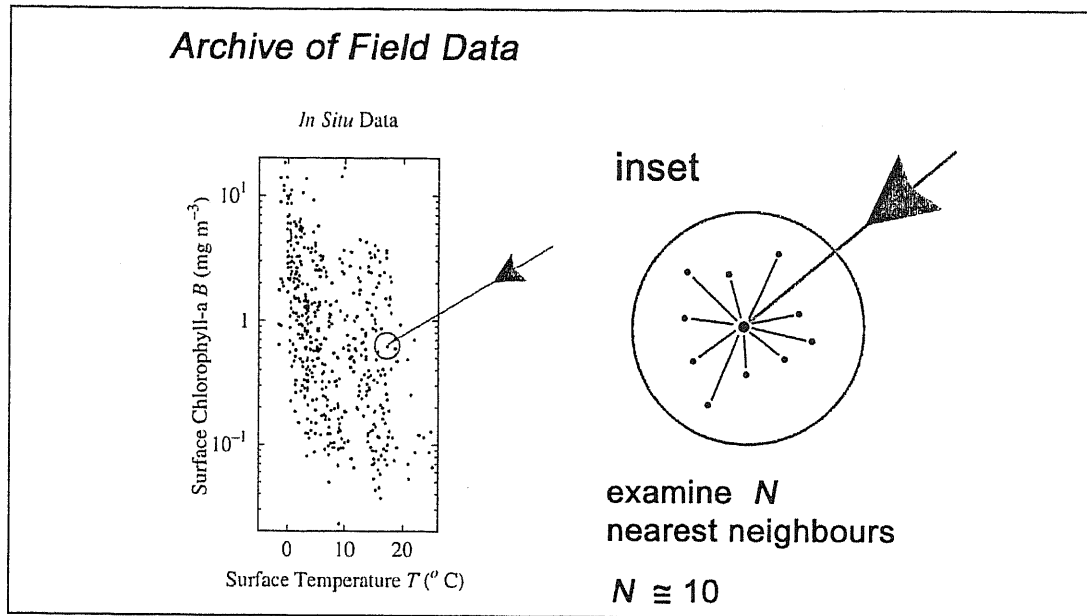

Archive of Field Data

In Situ Data

inset

examine *N*
nearest neighbours

N ≅ 10

Figure 7.

SEARCHING IN A NEIGHBOURHOOD OF (B,T)

Consider N nearest neighbours, $(B,T)_i$ of (B,T) and produce corresponding N parameter vectors x_i.

Over the N vectors, construct the weighted average, $\bar{x} = \sum x_i w_i / \sum w_i$, where the weight, w_i, is chosen according to the proximity in time (day number) of the image and the archival station data, using a function of the form:

weight

$N \cong 10$

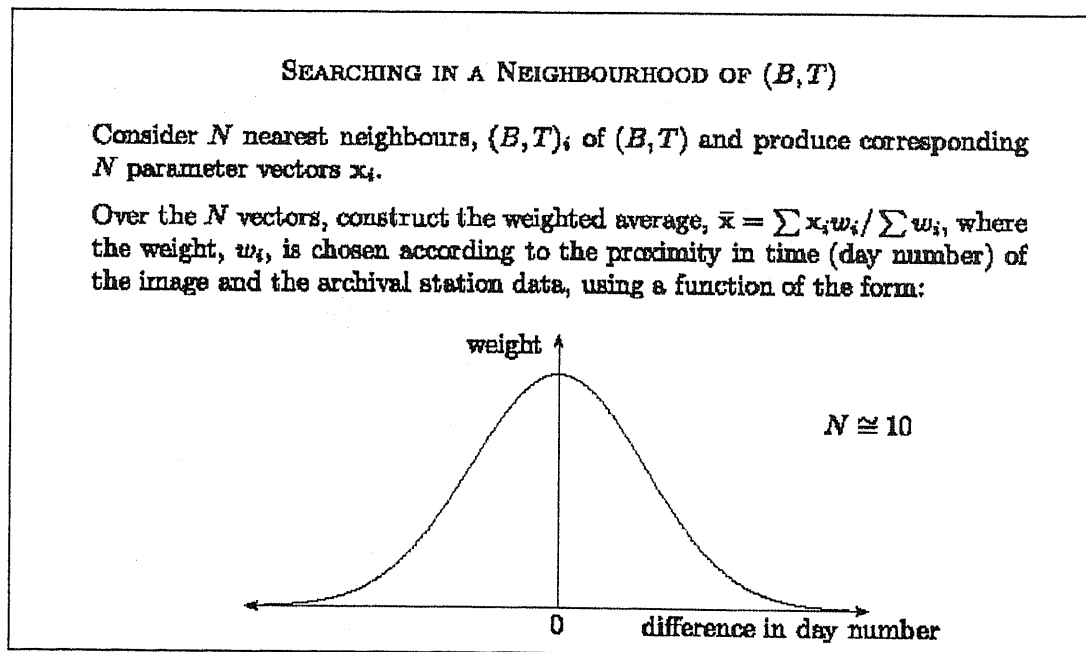0   difference in day number

Figure 8.

The advantage of the method is that it exploits fully the intersection between the image data and the archive data, using information from both the ocean-colour and the SST images. It is also an objective procedure. It is now being evaluated for computing efficiency. At the earliest opportunity it will be tested against independent field data.