2.2.7 Remotely sensing seasonal and interannual oceanic primary production for Western Australian waters

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Executive Summary

An algorithm was developed to estimate phytoplankton primary production from remotely sensed sea surface reflectance data (collected *in situ* or via space based platforms). MODIS-Aqua ocean colour data were input to the algorithm to obtain estimates of phytoplankton absorption, the light field within the water column and primary production at three SRFME field sites over the course of the SRFME field program (2002-2004). At the two deep validation sites (stations C, 100-m, and E, 1000-m), the outputs of the algorithm agree, within uncertainty, with observed co-located *in situ* measurements. Retrievals at shallow sites (<15-m) remain problematic.

Introduction

Our knowledge of phytoplankton production in the southeast Indian Ocean near Western Australia is limited by the very few measurements of carbon uptake made in this region during the last 50 years. This data set is not sufficient to form an understanding of the seasonal or interannual variability present in production, a key variable in current global biogeochemical models.

Space based remote sensing provides broad scale measurements of ocean properties with high spatial and temporal resolution, allowing the dynamic nature of the ocean surface and its properties to be observed. Figure 2.26 displays a typical June scene with the Leeuwin Current flowing along the edge of the continental shelf and meandering offshore south of 29°S. Figure 2.26 demonstrates the fine structure present in both sea surface temperature and surface chlorophyll-a (a proxy for phytoplankton biomass) and indicates the variability that may be found in primary production on both small and basin scales.

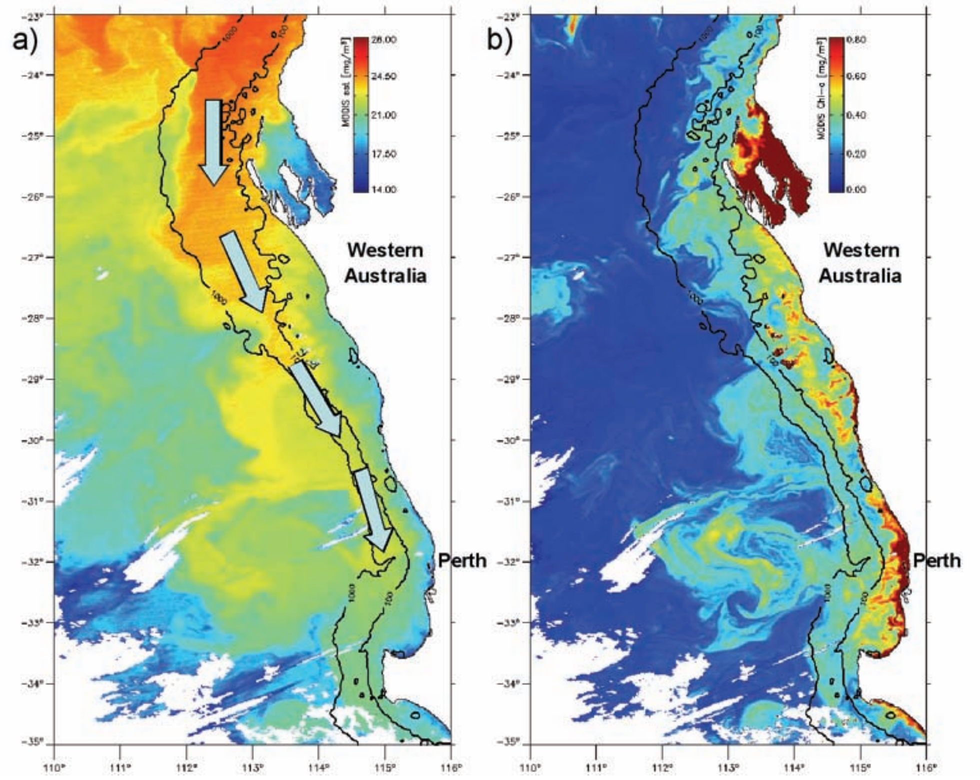
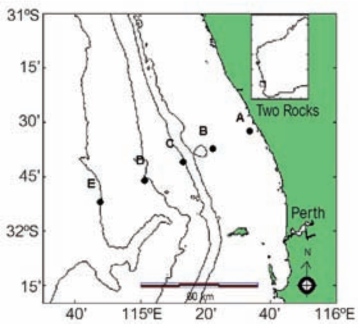


Figure 2.26: Remotely sensed data from MODIS-Aqua for the west coast of Australia on 19 June 2003; a) Sea surface temperature b) chlorophyll-*a* (phytoplankton proxy). The black lines indicate the 100 and 1000-m isobars. The path of the Leeuwin Current is denoted by the large blue arrows.

Study Site

To support the development of a remotely sensed primary production algorithm, measurements of primary production (24 hour ^{14}C incubations) and bio-optical properties were obtained during the multidisciplinary SRFME field experiments conducted along the SRFME Two Rocks Transect (TRT, Figure 2.27) between early 2002 and late 2004. Primary production was routinely measured at stations A, C and E, while optical profiles were conducted at these sites opportunistically.



Station	Longitude (°E)	Latitude (°S)	Depth (m)
A	115.598	31.520	15
B	115.463	31.577	40
C	115.296	31.648	100
D	115.123	31.722	300
E	114.909	31.812	1000

Figure 2.27: Map and table indicating the location of SRFME field sites (A-E). Primary production measurements (24 hour ^{14}C incubations) were carried out at stations A, C and E.

Algorithm Development

A model was developed to estimate phytoplankton production from remotely sensed variables. The model is applicable to both *in situ* and space based measurements of sea surface reflectance (SSR). The conceptual framework is shown in Figure 2.28 and detailed below.

The measured reflectance is used to retrieve the in-water inherent optical properties (IOPS; including backscattering, b_b, absorption by coloured dissolved organic matter, a_g, and phytoplankton, a_j) through the inversion of an appropriate optical model. The Semi-Analytical model (SAM, Lee *et. al.*, 1999) is employed for *in situ* measurements of SSR, while the Quasi-Analytic Algorithm (QAA, Lee *et al*, 2002) is used for space based SSR measurements. The QAA was developed to retrieve IOPs within the constraints of multi-spectral sensors, while the SAM can take advantage of the additional information within hyperspectral data sets. The retrieved IOPs are combined with the sub-surface irradiance, $E_d(0^-)$, and an optical model to propagate the surface light field through the water column.

These light field statistics and IOPs are then used to estimate photoinhibition and the quantum efficiency of photosynthesis, Φ_m. Photoinhibition occurs when phytoplankton are exposed to intense light fields; the photo-systems necessary for photosynthesis are degraded/destroyed and photosynthesis decreases. The quantum efficiency of photosynthesis, Φ_m, is used to link energy absorption by phytoplankton with primary production. The model of Finenko *et. al*. (2002) was employed to form an estimate of Φ_m. While the model was developed for the Black Sea it was found to be applicable in the Atlantic (Finenko *et. al*. 2002), thus it has been assumed that the model is generally applicable. It should be noted that no measurements of photoinhibition or Φ_m were carried out during the SRFME field experiments.

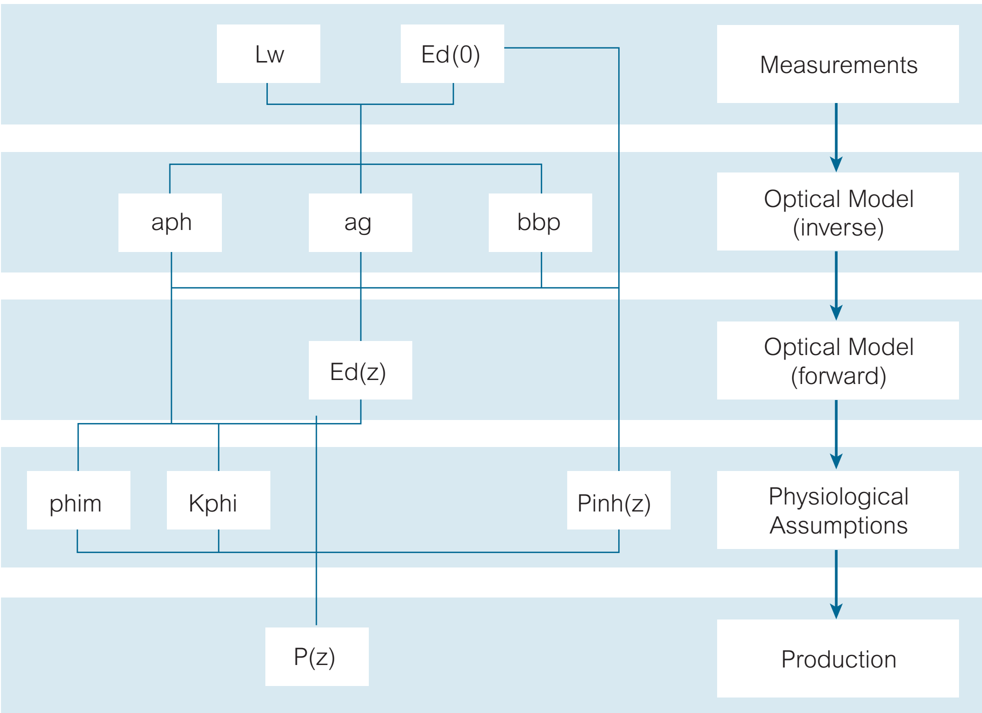


Figure 2.28: Conceptual framework of the algorithm. Optical measurements are inverted to obtain in-water properties. These in-water properties are then propagated through the water column and combined with physiological parameters to obtain an estimate of production at depth.

The final stage of the algorithm computes integrated primary production. This is achieved by calculating production at depth and then integrating over the region where production is possible (the euphotic zone). Production at depth is computed through,

$$P(z) = \frac{k_\phi \exp(-vQ(z))}{k_\phi + Q(z)} \int_{400}^{700} \Phi_m a_\varphi(\lambda, z) E(\lambda, z) d\lambda$$

where k_f is a constant that represents the change in Φ_m with depth (Kiefer and Mitchell, 1983) and v accounts for photoinhibition (Lee et. al., 1996), Φ_m is obtained from the model of Finenko et. al. (2002) and a_f is retrieved from SSR through SA or QAA.

$$Q(z) = \int_{400}^{700} E(\lambda, z) d\lambda \text{ and } E(\lambda, z) = E_d(\lambda, 0^-) \exp(-k(\lambda) z),$$

where $E_d(\lambda,0^-)$ is the downwelling irradiance just below the sea surface and $k(\lambda)$ is the diffuse attenuation coefficient. Integrated production is simply

$$P = \int_0^{Z_{eu}} P(z) dz,$$

where Z_{eu} is the depth of the euphotic zone, estimated as the depth where Photosynthetically Available Radiation (PAR) is diminished to 0.1% of the surface value.

Results

The *in-situ* model was applied to data collected using a hyperspectral profiling radiometer (HydroRad-2) and compared to co-located measurements of primary production. An example of the output for the three SRFME production sites (A, C and E) from the January 2004 field experiment aboard the Southern Surveyor (SS2004/01) is displayed in Figure 2.29. In general, retrievals at sites C and E fall within 25% of collocated measurements. Retrievals at station A are problematic, with consistent underestimation of production in the shallow (< 15-m) coastal waters.

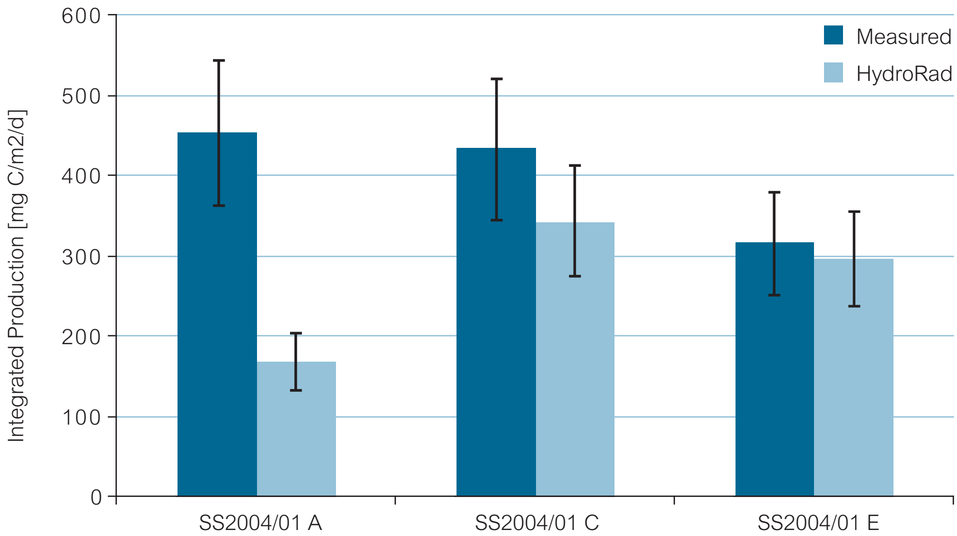


Figure 2.29: Comparison of measured and modelled primary production at three SRFME stations (A, C and E) during SS2004/01. The dark bars represent 24 hour ^{14}C incubations (courtesy of S. Pesant), while light bars indicate results from the model using *in situ* HydroRad profiles. Agreement (within uncertainty) is not achieved at the shallow, coastal site (depth of 15m).

The model to estimate production from space-based platforms (using QAA rather than SA) was applied to MODIS-Aqua data over the course of the SRFME field experiments. As an initial check of the algorithm, the reconstructed light field was compared to a series of measurements. Depth dependence of PAR is of primary importance to many ecological studies. Figure 2.30 displays the measured and modelled PAR at Station C over the course of the SRFME field experiments. It should be noted that 1) measurement time varied, 2) the instrument was sometimes shaded, 3) the instrument cannot provide accurate measurements below 0.05 μE/m^2/s and 4) retrievals are obtained for clear sky conditions only. Bearing these limitations in mind, PAR retrievals yield temporal patterns at Stations C and E (not shown) similar to those observed during the field program.

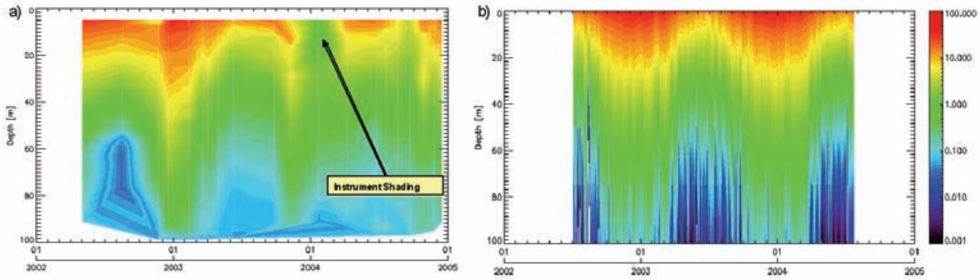


Figure 2.30: Photosynthetically available radiation (PAR, units of μE/m^2/s) at Station C as a function of time and depth a) measured on CTD and b) as output by the model using remotely sensed data (MODIS-Aqua). Near surface values from the CTD are rejected due to poor data quality and are affected by instrument/ship shading. Note the logarithmic scale.

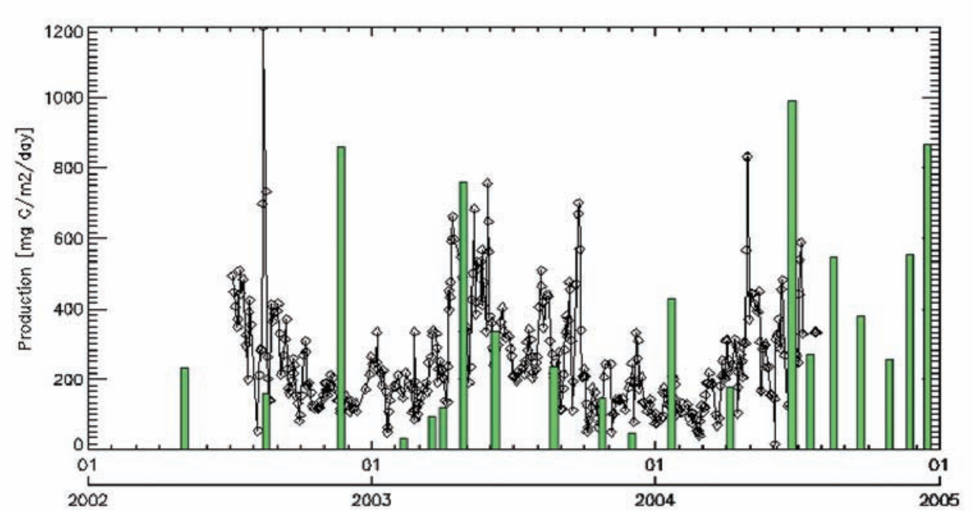


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Figure 2.31: Integrated phytoplankton primary production at station C for the period of the SRFME field experiments. Green bars indicate the results of 24 hour ^{14}C incubations (courtesy of S. Pesant), connected black diamonds are remotely sensed estimates (MODIS-Aqua).

Discussion

To achieve the goals of this research, aspects of the biological and bio-optical oceanography of the southeast Indian Ocean have been investigated using data from SRFME field experiments and space based platforms. The field data were used to validate the remotely sensed ocean products (including the water-leaving radiance, surface chlorophyll a concentration and column-integrated phytoplankton biomass).

A spectral, depth resolved, model of primary production was developed, independent of field data, for use with *in situ* and remotely sensed SSR data. The outputs of the model have been compared to field measurements and display general agreement at sites with depths greater than 15-m.

Acknowledgements

I would like to thank my supervisors and Curtin colleagues for their invaluable assistance; Tony Koslow for the opportunity to participate in a number of field experiments; Stephane Pesant for access to primary production data; Lesley Clementson, Christine Hanson and Tim Harriden for laboratory analysis; the masters, crew and science staff aboard the *R/V Southern Surveyor*, *Naturaliste*, and *Maritime Image* for their assistance during SRFME field experiments.

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Planned date for thesis submission: January 2007

Publications

Feng, M., L. Majewski, C. Fandry and A. Waite (submitted). Characteristics of two counter-rotating eddies in the Leeuwin Current system off the Western Australian coast. (Resubmitted after review to *Deep-Sea Research II*)

Majewski, L.J. (in prep.). Remote sensing of phytoplankton production at the Abrolhos Islands, Western Australia.

Majewski, L.J. and S. Pesant (in prep.). Structure and dynamics of the pelagic ecosystem along an onshore-offshore transect off southwestern Western Australia, 2002-2004: primary production models and validation of remote sensing algorithms.

2.2.8 Ichthyoplankton assemblage structure in coastal, shelf and slope waters off south-western Australia

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Executive summary

Spatial and temporal variation in larval fish assemblages collected from the Two Rocks transect has been characterized, and related to available environmental variables. Assemblages were shown to vary primarily with water depth, with different families dominating inshore, shelf, and offshore assemblages, and with season. Correlation of larval fish assemblages from summer, and from winter, with environmental variables highlighted the strong influence of water depth, and water mass on broadly structuring assemblages. In winter, microzooplankton cell densities and water temperature had a further structuring influence on assemblages, while in summer, water mixing rates for the five days prior to sampling, and surface salinities were also correlated to assemblage structure.

Introduction

Project aims

This project aimed to document the seasonal and spatial variability in ichthyoplankton (larval fish) assemblages in inshore, shelf and offshore waters off Western Australia, and to relate this variability to environmental (physical, biological and meteorological) parameters.

Methods

Sample collection

Sampling for this study was carried out along an 84km transect, located off the town of Two Rocks (Figure 2.32). Five sampling stations (A - 18m depth, B - 40m, C - 100m, D - 300m,