Time Evolution of a Pelagic Ecosystem Along the Tasman Front off Southeast Australia in a Coupled Physical-biological Model

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Abstract

A coupled physical-biological model of the circulation off the southeast coast of Australia has been developed. The physical and biological properties of the Tasman Front as a warm-core eddy forms are analysed. In particular, the biological terms are analysed to estimate the relative magnitude of different processes that determine the phytoplankton biomass at the front. A diagnostic tracer age, a measure of how long water has resided in the euphotic zone, is used to further establish the links between spatial scales and time scales. Model results are compared to measurements taken from transects across the front in September 2004.

Model description

The physical model is a configuration of the sigma-coordinate, primitive equation Princeton Ocean Model (Blumberg and Mellor, 1987), forced with a 0.1 Pa northerly wind, and constant inflow on the northern boundary. The biological model is an nitrogen/phytoplankton/zooplankton model, with internal reserves of nitrogen and energy in the phytoplankton, and is based on a combination of physical and physiological descriptions of biological processes (Baird et al., 2004). The biological model starts from a quasi steady-state obtained from 2D simulations.

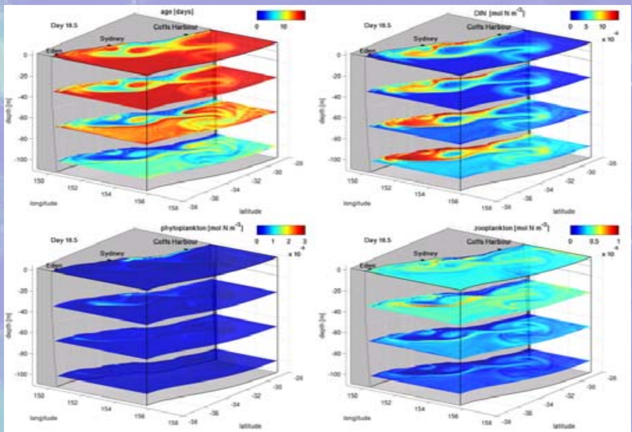

Fig. 1. The age, dissolved inorganic nitrogen, phytoplankton and zooplankton biomass on Day 18.5. Age in this application is the average time parcels of water within a volume have been above the 90 m depth level since the beginning of the simulation, and is subject to mixing and advective processes.

Model results

Fig. 1 shows that on Day 18.5, upwelled water which has been above the 90 m depth level for ~5 days is associated with high nutrients. The nutrients drive a phytoplankton bloom, which is advected downstream and becomes consumed by zooplankton. A large eddy has formed, the edge of which will be analysed in the next section.

Analysis of the biological model at the Tasman Front

An analysis of the individual terms affecting the biological state variables gives a powerful analysis tool of model behaviour. Fig. 2 shows a cross front vertical slice of the Tasman Front on Day 6.5 as the Front develops. Deep water is being brought to the surface at the Front through advection as shown by the uplift of age contours towards the surface (Fig. 2G and M).

Uplift results in a high nutrient concentrations penetrating to the surface below the 21^0C contour (Fig. 2A), and can be seen to result from a strongly positive N advective term (Fig. 2C). Uptake of nutrients by phytoplankton is relatively small, and is centred at the highest phytoplankton biomass (Fig. 2E) .

High nutrient concentrations, co-incident with high phytoplankton biomass and light availability, drives strong primary productivity (Fig. 2K). Note the role 'age' plays. Phytoplankton biomass peaks at an 'age' of between 3 and 3.5 days, and is found at a depth of ~40 m in 19^{O}C water (Fig. 2G). In water of an age of 4 to 4.5 days, there is a strong negative grazing term (Fig. 2L), resulting in reduced biomass of phytoplankton (Fig. 2G).

The source of the high grazing pressure is a larger zooplankton biomass, which has a maximum in slightly 'older' water (Fig. 2M). The extra day provides time for a zooplankton growth response (Fig. 2Q) to the elevated phytoplankton biomass.

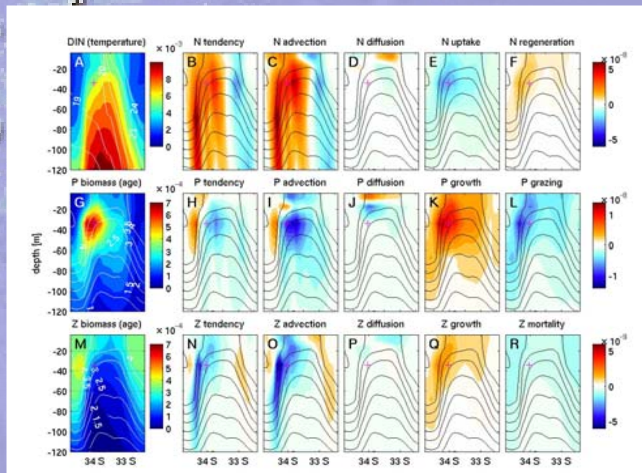

Fig 2. A north-south slice across the Tasman Front on Day 6.5. Panels A, G, and M give the DIN, phytoplankton and zooplankton biomass respectively. Panels B-F, H-L and N-R give the DIN, phytoplankton and zooplankton terms respectively, with red colouring signifying positive, blue negative, and white zero. Temperature [^{0}C] contours are shown on Panel A. The contours of the diagnostic tracer age [d], the average time since the water was below 90 m since the beginning of the simulation, are shown in Panels G and M with labels, and without labels in Panels B-F, H-L and N-R. Note that the units of terms is mmol N m^{-3} d^{-1}, and of concentration are mol N m^{-3}. For reference, a pink cross locates the phytoplankton biomass maximum on all plots.

Field Observations

Measurements of physical and biological properties across the Tasman Front (the interface of Coral Sea and Tasman Sea waters) were undertaken in September 2004 from the R/V Southern Surveyor. The observations from a section along the 153.5 E line of longitude using the CTD and a towed optical plankton counter are shown in Figs. 3 and 4 respectively. High fluorescence is seen in the surface waters south of the Front, and is associated with low nutrients and high zooplankton biomass.

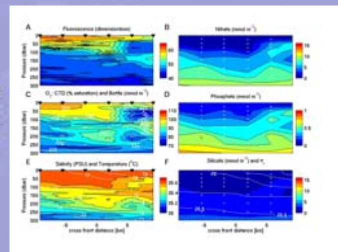

Fig 3. CTD transect along 153.5 E. North-South transect with South to the left. Panels show (A) Fluorescence, (B) Nitrate, (C) Oxygen from the CTD (greyscale) and bottle oxygen (contours), (D) Phosphate, (E) Salinity (greyscale) and temperature (contours), (F) Silicate (greyscale) and σ_t (contours). Fluorescence and CTD oxygen are 2 m depth averages from a dropping CTD instrument. Black triangles indicate CTD stations and white dots bottle samples.

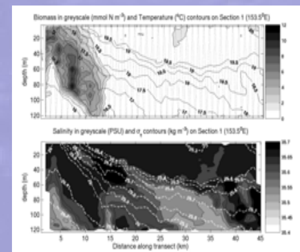

Fig. 4. The biomass of particulate matter in greyscale with temperature contours (top) and the salinity in greyscale with potential density contours (bottom). The small dotted black lines in the top panel shows the path of the optical plankton counter, and the points at which measurements were averaged. The transect was undertaken in a southerly direction from 2155 on the 3rd September to 0050 on the 4th eastern Standard Time.

Conclusion

A coarse-resolution coupled physical-biological model of the waters off the south east Australian coast demonstrates the mechanisms by which upwelling at a thermal front can result in a phytoplankton and zooplankton concentration maximum. A diagnostic variable 'age' provides a link between time and spatial scales in the development of the ecosystem. Observations from the Tasman Front show a co-incident phytoplankton and zooplankton maximum, and are probably dominated by the surface spring bloom dynamics and complex interleaving of water bodies. A higher resolution model may be required to capture these processes.

References

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Baird, M. E., P. G. Timko, I. M. Suthers and J. H. Middleton (Feb, 2006) Coupled physical-biological modelling study of the East Australian Current with idealised wind forcing. Part I: Biological model intercomparison. *J. Mar. Sys.*

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