A photophysiological model of corals under thermal stress assessed by comparison of simulated and observed fluorescence.

Mark Baird, Monika Soja-Woźniak[1], Mathieu Mongin, Lesley Clementson

CSIRO Oceans and Atmosphere, GPO Box 1538 Hobart 7001, Australia

[1]presenting author

CSIRO OCEANS AND ATMOSPHERE
www.csiro.au

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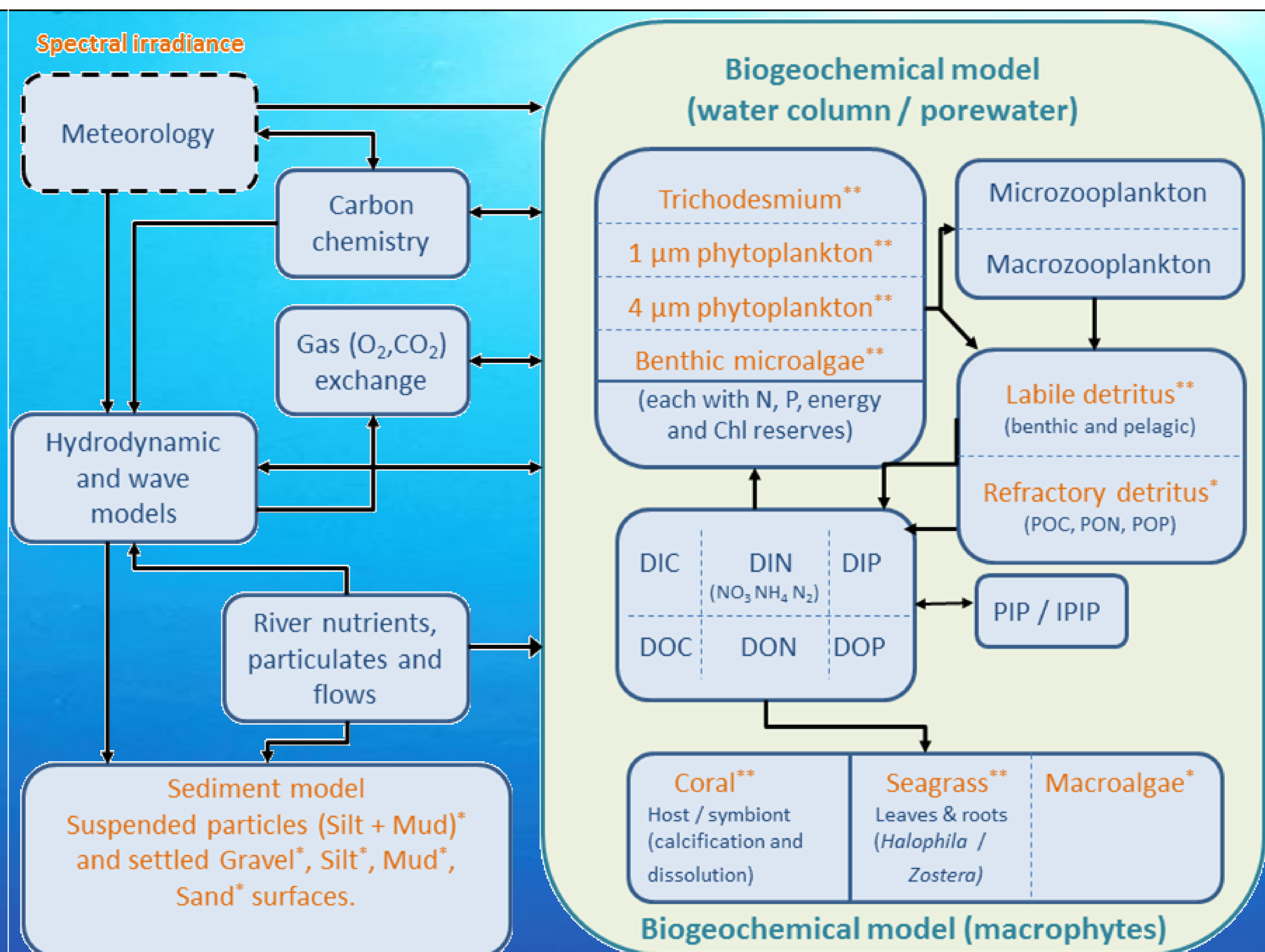
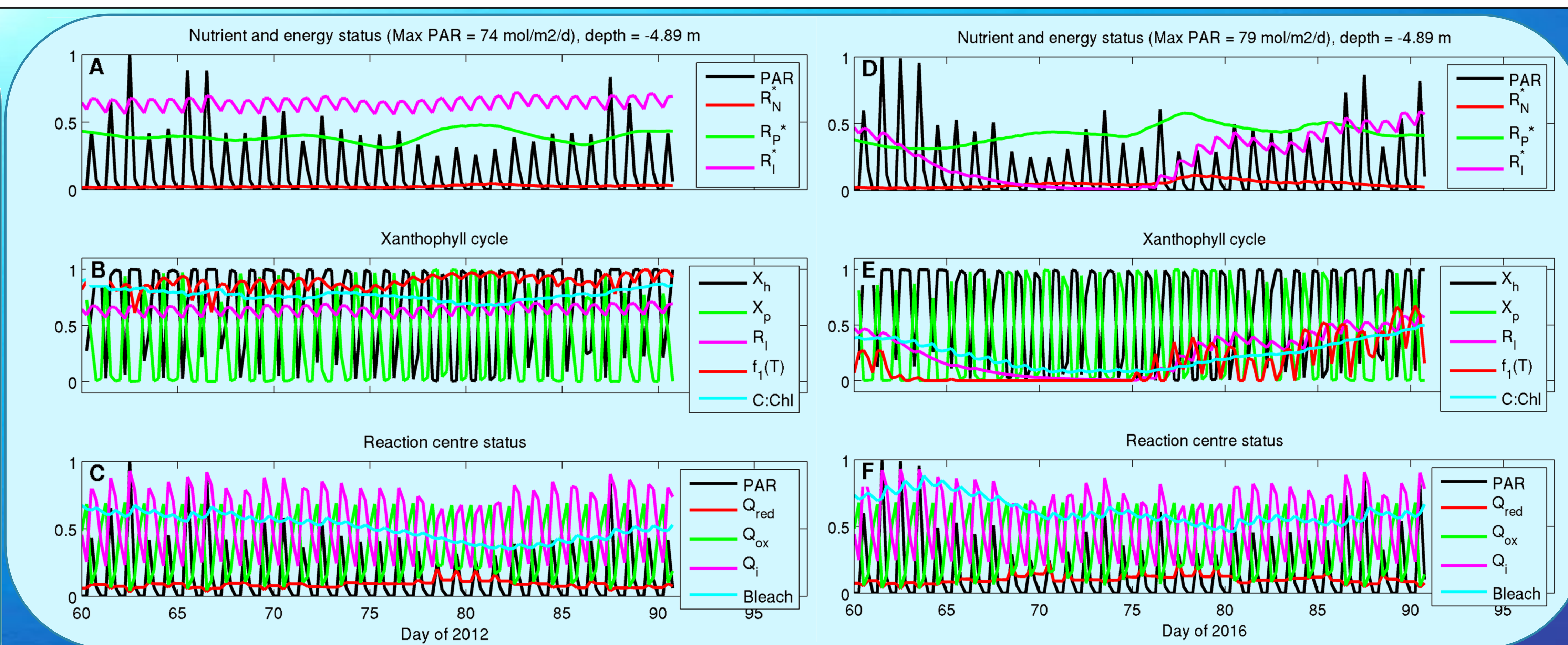
Abstract

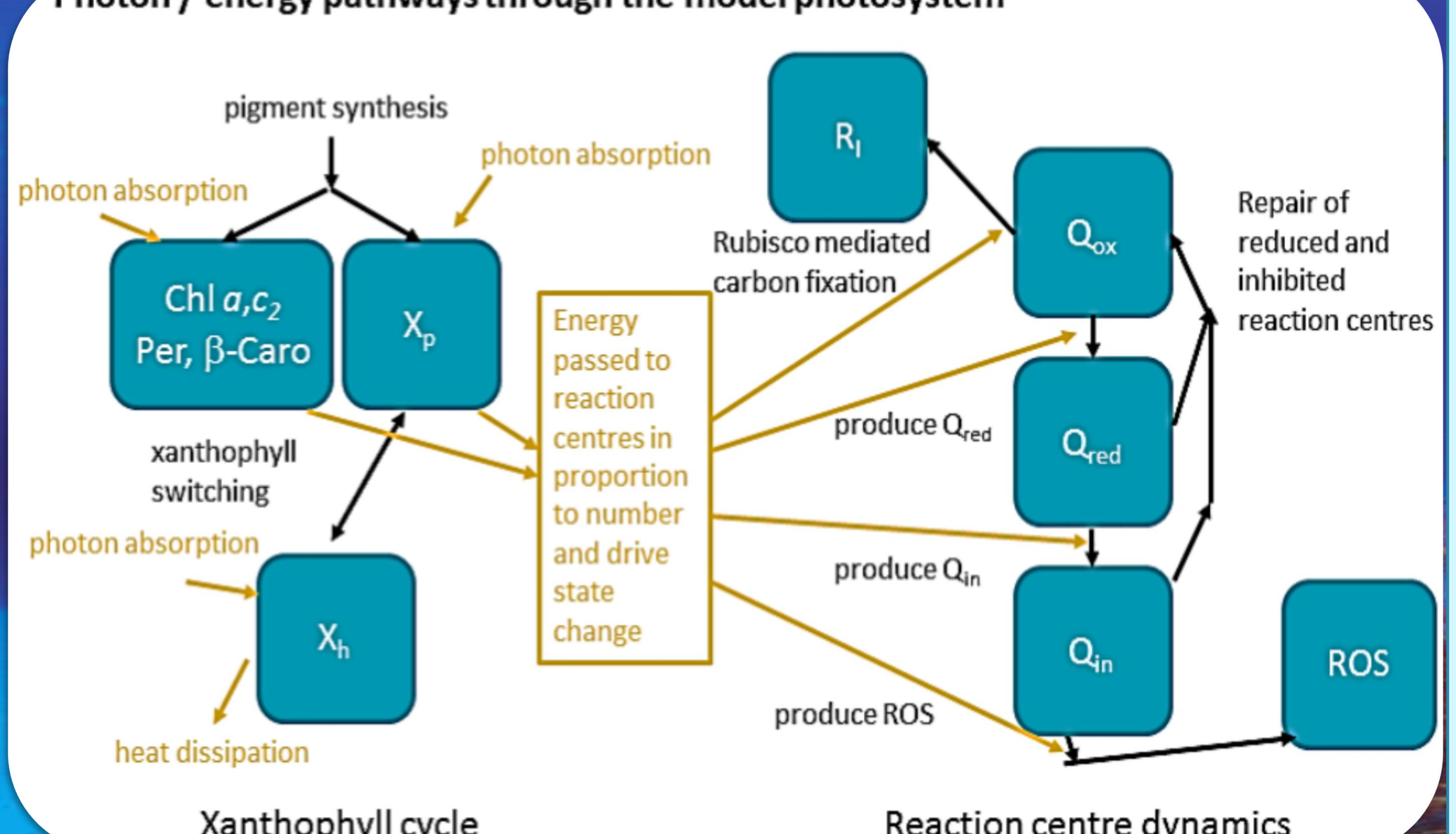
In the last few years the understanding of the physiological processes leading to thermal coral bleaching have improved, and highlights the link between photoinhibition and oxidative stress as critical in this process. We present a numerical model of coral bleaching forced by thermal stress, irradiance, and the concentrations of dissolved and particulate nutrients. The coral polyp model quantifies the coral by a host biomass (biomass of polyps in the coral community with a constant stoichiometry), and by zooxanthellae abundance containing a variable C, N, P and chlorophyll content. Further, the model represents the processes of host and zooxanthellae growth and mortality, and the photophysiological zooxanthellae processes of photoacclimation, xanthophyll pigment transformation, reaction centre inhibition, and the production of reactive oxygen species. By considering the fraction of reaction centres open, we are able to simulate the fluorescent response of the corals. The direct comparison of observed and simulated fluorescence provides a more direct measure of performance of the model than simple correlations.



Coupled hydrodynamic, sediment, optical and biogeochemical model – orange variables scatter or absorb light – for more information see ereefs.info. A 4 km resolution configuration of the entire Great Barrier Reef for 2011-2016 has been run as part of the eReefs project.

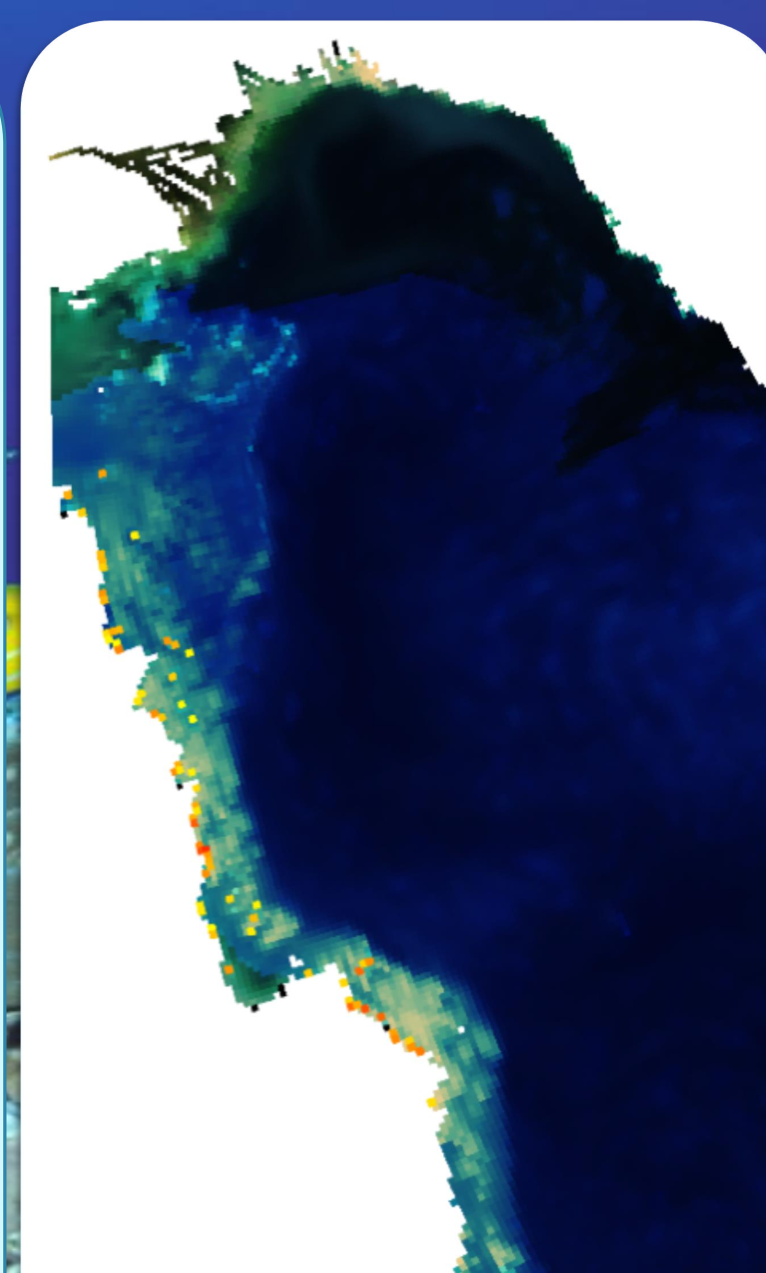


Photon / energy pathways through the model photosystem



Zoothanallae photophysiological model, showing pathway of photons through the xanthophyll to the reaction centres, where they change the state of oxidized, reduced or inhibited reaction centres (Q_{ox}, Q_{red}, Q_{in} respectively).

Zooxanthallae growth is a function of the maximum growth rate, and the reserves of nitrogen, phosphorus and energy (Fig. A). Each normalised reserve, R^*, is a value between zero and one. The normalised reserved increases when the supply of the nutrient exceeds the consumption for growth, and decreases when consumption for growth exceeds the nutrient supply. In coral reef environments, nutrients are strongly limiting in the surface waters. One exception to this rule is if Rubisco becomes inactive at high temperatures ($f_1(T) \rightarrow 0$), and then light absorption does not add to energy reserves and growth can become limited by fixed carbon. In 2012 at the shallow reef (Fig. A) energy reserves are high (~0.6), phosphorus reserves intermediate (~0.4), and nitrogen reserves very low. Thus growth is strongly N limited. High energy reserves can be maintained in part because Rubisco is highly active (0.7 < f_1(T) < 1, Fig. B). In 2016, when Rubisco became inactive at this site (Fig. E), especially in the first two weeks of March, energy reserves drop to less than even the nitrogen reserves. The reaction centres are mostly inactive during the day, with some recovery over night (Fig. C,G). As a result, the xanthophyll cycle is primarily in the heat dissipating state during the day, and light absorbing in the early morning. The photoacclimation processes are able to keep the energy reserves, under the moderate temperatures of 2012. In 2016 photoacclimation processes have little control over energy reserves due to the inactivity of Rubisco. The rate of ROS build up, which is greater in 2016, depends on both the fraction of inhibited reaction centres, and the flux of photons to the reaction centres.



Simulated true colour in the 4 km eReefs model, with grid cells containing reefs with high ROS levels overlayed in yellows through to reds.

Conclusions: A numerical model has been develop that realistically represents the processes of photoacclimation, xanthophyll pigment transformation, reaction centre inhibition, and the production of reactive oxygen species. Simulations show ROS stress in the northern half of the GBR during the stress year. These results are promising, but further work is required to assess model predictions against observations. In particular, it should be possible to the assess the photosynthetic state of corals (Q_{ox} /Q_T) against measurements of efficiency of photochemistry (F_V / F_m).

FOR FURTHER INFORMATION

e *monika.wozniak@csiro.au

w www.research.csiro.au/eReefs

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