Modelling Sub-Reef Thermodynamics to Predict Coral Bleaching: A Case Study at Scott Reef, WA

by

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Appendix 2

STATEMENT OF ACCESS

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Appendix 3

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DECLARATION

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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Statement of Contribution

Fees: Waived by James Cook University

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Use of infrastructure internal to JCU: *Hydra* supercomputer used for numerical simulations.

This thesis research forms part of a three-year project between AIMS and Woodside Energy Ltd. The overall design and goals of the project were developed by my advisors at AIMS prior to my involvement. Additionally, all field measurements were collected by AIMS before I began the project. My contributions were to develop the methodology to achieve the overall design and goals, process and analyse the field data, develop appropriate forcings for the numerical models, and analyse the results.

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Abstract

Coral bleaching occurs when corals become stressed, which typically occurs during periods of elevated water temperatures. If water temperatures remain elevated for a sufficient length of time, the corals often die. Coral bleaching affects reefs around the world and the recent increase in the frequency and severity of bleaching episodes has raised considerable concern.

A clear understanding of the physics that elevate water temperatures may improve coral bleaching predictions and lead to more effective reef management. Currently, the best method to detect bleaching-like conditions is through a time integration of sea surface temperatures observed by satellite. Unfortunately, these observations only reveal the thermal structure for the top millimetre of water averaged over large areas (presently 2500 km^2). The aim of this study is to use environmental physics to predict water temperatures at the reef and sub-reef scales. The study then goes a step further and translates these thermodynamic models into bleaching predictions.

Simulations are run using atmospheric and oceanographic data from Scott Reef, a 40 km-wide atoll 300 km off the northwest coast of Australia. Scott Reef presents an ideal test site as it experienced a severe bleaching event in 1998 that was well documented. Averaged coral cover in exposed sites dropped from 54% to less than 10% over the top 30 metres. Additionally, the bathymetry around Scott Reef has been thoroughly surveyed and in 2003 an extensive array of oceanographic instruments was deployed for three months at strategic locations.

A one-dimensional turbulence model is used to determine the vertical temperature structure of the water column around Scott Reef. Scott Reef is in a data-sparse region so that all of the heat fluxes have to be estimated from atmospheric conditions recorded at distant weather stations. The model results are verified with the 2003 field data. By driving the model with the appropriate atmospheric conditions, the simulated temperature profiles match the field observations. The model is next used to hindcast the temperature profiles during the 1998 bleaching event. Simulations indicate that anomalously-warm water most likely reached depths of 30 metres, a result that supports the claim that the deep bleaching was due to thermal stress.

Field observations confirm that water currents around Scott Reef are predominantly tidal. Additionally, the observations demonstrate that the upper layers of certain regions within Scott Reef cool during strong tides. This finding is characteristic of tidal cooling, a common phenomenon where tides mix cooler, deeper water with warmer surface water.

A map of sub-reef regions at Scott Reef that might experience tidal cooling is revealed by the numerical modelling. In a novel approach, stratified waters from the vertical model can be well-mixed in zones identified by a two-dimensional hydrodynamic model. There is a strong correlation between areas where bleached corals survived and locations that are predicted to have access to cooler well-mixed deep waters.

The techniques used in this work are applicable to other reef systems. Therefore the results in this thesis are significant as they improve two aspects of coral bleaching prediction. First, the methods can determine if coral at different depths are at risk of bleaching. Second, the methods can distinguish regions within individual reefs that are more susceptible to coral bleaching.

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Preface

This thesis describes how a combination of thermodynamic and hydrodynamic models can be used to improve coral bleaching prediction. The model results have been compared to extensive field observations at Scott Reef, an isolated reef off the coast of northwest Australia. That said, the techniques presented within this thesis are not restricted to a particular geographic location and it is the author's hope that they might one day improve coral bleaching predictions worldwide.

In the introduction I discuss coral bleaching and why it is becoming an increasingly important issue. The spatial patterns that have been observed during bleaching events are mentioned with particular emphasis on how they may be caused. I describe two methods that are used to predict where coral bleaching is most likely to occur. I then identify the limitations of these techniques and outline how the work carried out in this project addresses these issues.

The second chapter focuses on the local oceanography around the test site, Scott Reef. I review what is currently known about the oceanography in the area and describe the 2003 field campaign, which was completed prior to my involvement in the project. Almost half of the work in the thesis involved compiling and analysing the field data; therefore considerable attention is given in explaining all the required steps. Finally, the noteworthy oceanographic characteristics are discussed; the results form a foundation that is referred to often in later chapters.

The third chapter describes the techniques used to estimate the heat transfer across the air-sea interface. The heat transfer depends on atmospheric conditions and the methods used to approximate these conditions are described. Finally, I discuss how the atmospheric conditions are applied to approximate the heat fluxes.

The fourth chapter explains how a numerical model was used to calculate the water temperature at various depths around Scott Reef. Simulations are first performed to calibrate and validate the model with the field data collected in 2003. The model is then run to calculate the temperature profiles which may have been present during the 1998 bleaching episode at Scott Reef. The impact of these temperature profiles on coral bleaching is discussed.

The fifth chapter investigates whether certain regions around Scott Reef are persistently cooler than other regions. Coral records at Scott Reef demonstrate that the coral mortality in 1998 differed among the sites sampled. Under the assumption that the spatial variability may be due to tidal mixing, a hydrodynamic model is used to calculate the tidal currents around the reef. Tidal currents and local bathymetry are combined to estimate mixing and potential cooling around the reef. Finally, the results are related to coral records as well as to temperature data.

The sixth and final chapter summarizes the techniques and results precented in this thesis. The two key objectives of the thesis are reiterated: first the investigation of water temperature at various depths, and second the examination of whether certain spatial locations are more susceptible to coral bleaching. I summarize the results of the numerical simulations and describe how these simulations are helpful in predicting coral bleaching. Finally, future research initiatives are identified and briefly discussed.