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DOCTORAL THESIS OUTLINE

Student: Lawrence Patrick Cases Bernardo **Date:** February 20, 2018
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Thesis Title: Computational model analyses and field observations of hydrodynamic and larval dispersal processes in coral reef areas
（サンゴ礁域における水理ならびに幼生分散過程に関する数値モデル解析と現地観測）

Synopsis

Motivation: Coral reef ecosystems are marine ecosystems of great significance. They are sites of high marine biodiversity and provide a wide variety of ecosystem services. However, it is now widely known that coral reef ecosystems are at great risk due to various stressors, such as thermal stress, typhoon damage, and excessive terrestrial sediment and nutrient discharges. There is a continuing need to study the coral reef ecosystem especially during this recent period of alarming environmental changes. This research aims to address this need and contribute to the body of work on coral reefs by putting together data collected from various field survey activities, analyzing the data using various techniques, and the development of modelling approaches to supplement the observations and provide further insights. Many gaps in understanding the relevant processes in coral reefs still exist, and this research is an attempt to make the best use of the available field survey data, modeling techniques, and computational resources in order to generate some possibly new insights into the processes at work in coral reef ecosystems.

Objectives: The overall aim of this research is to use a variety of approaches to study hydrodynamic processes in coral reef areas, utilizing sites found within and around the Yaeyama Islands as the “natural laboratories” for specific numerical modeling and data analysis experiments. The specific objectives are:

i. To contribute to the development of a nested hydrodynamic modeling system to study coral reef-related processes in Sekisei Lagoon, Okinawa, Japan
ii. To investigate the effects of typhoon passages in the Yaeyama Islands and surrounding waters
iii. To support the investigation of the massive coral bleaching in Sekisei Lagoon in 2016 through numerical modeling approaches
iv. To analyze long term continuous monitoring data in Shiraho Reef, Okinawa, Japan to elucidate factors affecting temperature trends
v. To assess marine connectivity in Seksei Lagoon under normal and typhoon conditions through larval dispersal simulations

Contents and Highlights

Chapter 1: An introductory overview on the background and motivation for this research is given. The rationale and objectives of the study are also explained.

Chapter 2: This chapter documents the development of the nested modeling configuration used to investigate hydrodynamics around the Yaeyama Islands and in the Sekisei Lagoon area. The Regional Ocean Modelling System (ROMS) was adapted for the study site and the configuration used in this study consisted of a 1.5 km grid resolution Yaeyama1 model

which included the eastern side of Taiwan and ocean waters surrounding the Yaeyama Island. A 300 m grid resolution Yaeyama2 was nested on the Yaeyama1 model and was used to more closely investigate hydrodynamics in Sekisei Lagoon. Oceanographic sensor deployments provided a means to validate results generated by the model, and model performance was found to be satisfactory upon evaluation using a widely used skill index.

Chapter 3: While widely known to be destructive, typhoon events can benefit coral reef ecosystems through typhoon-induced cooling, which can mitigate against thermally stressful conditions causing coral bleaching. Sensor deployments in Sekisei Lagoon, Japan's largest coral reef area, during the summer months of 2013, 2014, and 2015 were able to capture local hydrodynamic features of numerous typhoon passages. Through an analysis of the field data and jointly investigated using Regional Ocean Modeling System (ROMS) numerical simulations conducted for the summer of 2015, the presence of an island-enhanced cooling mechanism in typhoon events was discovered. Local cooling events may have been initiated by the Yaeyama Islands acting as an obstacle to a strong typhoon-generated flow which was modulated and led to prominent cooling of waters on the leeward sides. Such cooled waters could then enter the inner Sekisei Lagoon area likely through density-driven flow.

Chapter 4: The modeling configuration featured in the previous chapters was used to simulate hydrodynamics in Sekisei Lagoon for April to November 2016, during which massive coral bleaching occurred. Temperature sensor deployments and coral bleaching surveys were also meticulously conducted by the Ministry of the Environment during this period. The model exhibited relatively good skill at reproducing the general temperature trends in the sensor data. Model results were also used to calculate accumulated heating and cooling based on specified threshold temperatures, and the resulting outputs may aid in the interpretation of spot check field survey results which looked at the spatial trend in the percentages of bleached and dead corals. Unlike the observed temperature data which were at specific points and relatively shallow depths, the model was able to show a more complete spatial picture of which areas potentially experienced the most heat stress as well as those which were cooled effectively by the passage of typhoons.

Chapter 5: Water temperature at different locations within and just offshore of Shiraho Reef, Okinawa, Japan, as well as offshore bottom current and wave height have been continuously monitored since 2010 using standalone sensors. This chapter attempts to closely examine trends in the long-term dataset to more gain insight into the mechanisms that may be causing them through various analyses methods. While inner reef temperatures were strongly affected by the diurnal cycle, offshore temperatures were shown to be significantly affected by regional circulation trends. A particularly notable transition between lower and higher temperatures generally occurring in the month April, characterized by pulses of cooling and warming over a span of 2 to 3 weeks. This feature was investigated using Regional Ocean Modeling System (ROMS) numerical simulations and was found to be possibly linked to regional flow patterns, particularly changes in the Kuroshio flow characteristics and subsequent eddy formation in the vicinity of the Yaeyama Islands. Simulations for other times of the year were also conducted and further supported the potential influence of regional eddy activity on the local temperatures in Shiraho Reef.

Chapter 6: The nested hydrodynamic model used in previous chapters was also used to run particle tracking scenarios to simulate potential larval dispersal within the Sekisei Lagoon domain and the coastal areas of the Yaeyama Islands. Particle tracking experiments were focused on attempting to characterize the differences in larval dispersal trajectories between relatively "normal" hydrodynamic conditions and hydrodynamics during the passage of a strong

typhoon. In 2015, 3 strong typhoons with relatively distinct tracks struck the area, and model-generated hydrodynamics during the passage of these typhoons was used as the basis to run typhoon track dispersal cases. Particle release locations were then organized into more distinct numbered sites around the coastal areas and parts of Sekisei Lagoon to generate connectivity matrices which quantitatively describes the marine interconnectivity between the different locations.

Chapter 7: The outcomes from this PhD research are synthesized and prospects for future investigations are given.

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