Towards Sustained Autonomous Measurements of Coral Reef Metabolism and Health

Yui Takeshita[1] (yui@mbari.org), Wade McGillis[2], Ellen Briggs[3], Amanda Carter[3], Emily Donham[4], Todd Martz[3], Nichole Price[5], Jennifer Smith[3]

1. Monterey Bay Aquarium Research Institute, 2. Lamont Doherty Earth Observatory, 3. Scripps Institution of Oceanography, 4. University of California Santa Cruz, 5. Bigelow Laboratory for Ocean Sciences.

Abstract

Coral reefs are a highly dynamic system, where large variability in environmental conditions (e.g. pH, light) occurs on timescales of minutes to hours. Yet, techniques that are capable of monitoring reef calcification rates without artificial confinement on the same frequency are scarce. We have developed the Benthic Ecosystem and Acidification Measurement System (BEAMS) which is capable of simultaneously measuring benthic net community production (NCP) and net community calcification (NCC) under natural conditions without any alteration to the environment. BEAMS measures the chemical gradient and the current velocity profile in the benthic boundary layer using autonomous sensors to calculate the chemical flux (thus metabolism) from the benthos. We have successfully deployed BEAMS in multiple reefs around the world, and currently is capable of continuously measuring metabolic rates at 15 minute intervals for a month. Here, we highlight a deployment from Palmyra Atoll [1], and the potential use of BEAMS to monitor reef health as they transition from a healthy coral dominated state to a degraded algae-dominated state.

BEAMS: Benthic Ecosystem and Acidification Measurement System

BEAMS is based on the gradient flux approach, where vertical gradients in velocity and chemical constituents in the benthic boundary layer (BBL) are used to calculate chemical fluxes from the benthos [1]. Gradients of O_2 are directly measured, whereas the gradient in TA is calculated using simultaneous measurements of pH and O_2 using [2]:

$$-\Delta TA = \frac{\Delta O_2 * Q + (K - K')TA' - K(BA + HA) + K'(BA' + HA')}{(K - 1/2)}$$

The flux of O_2 and TA are directly proportional to benthic net community production (NCP) and net community calcification (NCC), respectively. The metabolic rates are calculated as:

$$NCP \text{ or } NCC = \rho u_* \kappa \frac{(C_{z=2} - C_{z=1})}{\ln(z_2/z_1)}$$

Where C represents O_2 or TA, ρ is density, u_* is friction velocity, κ is the Von Karman constant, and z is the height above the benthos. Subscripts represent values at different heights above the benthos.

Study Site

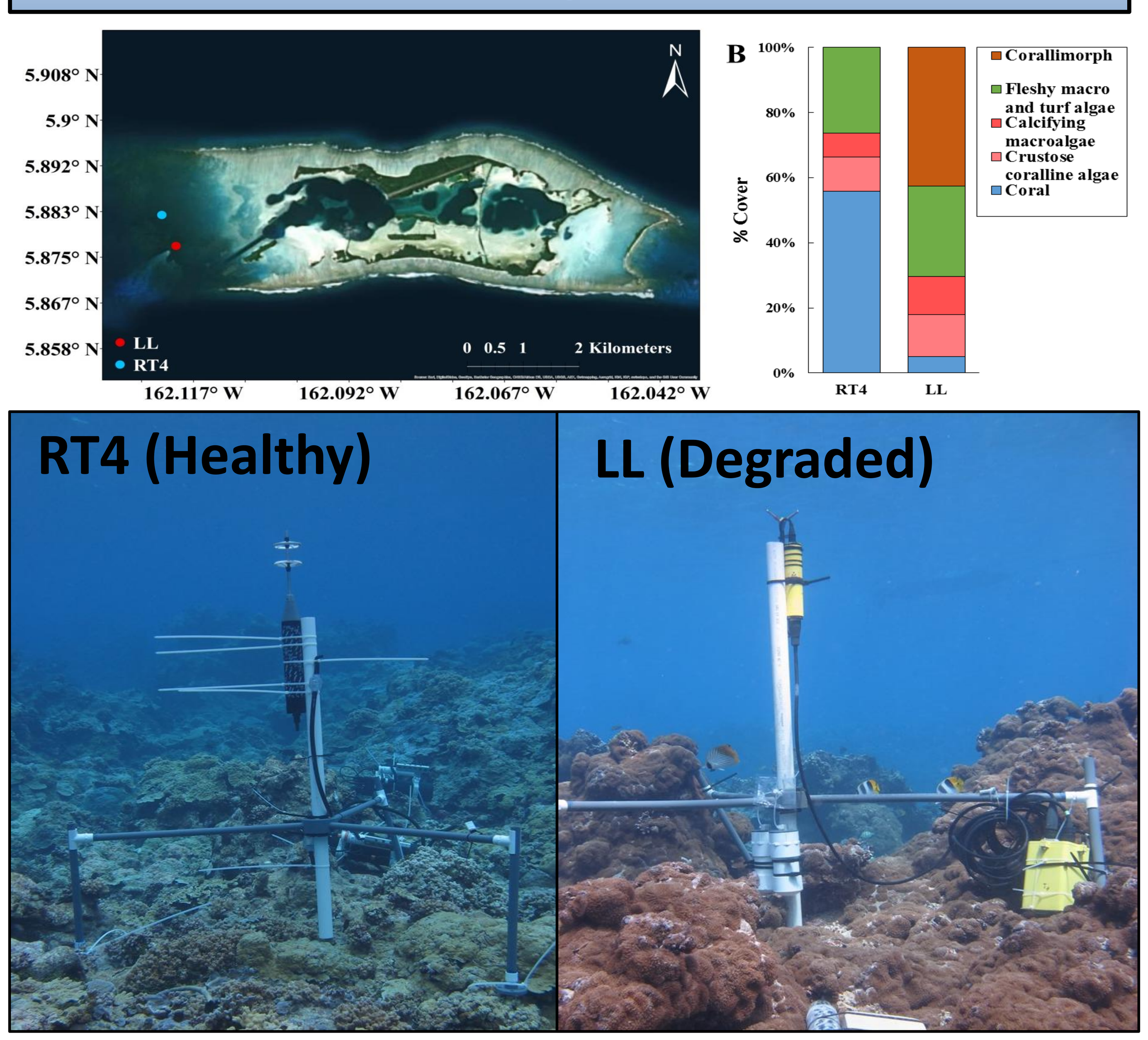

Figure 1: Map of Palmyra Atoll (top left). The two deployment sites (RT4; blue, LL; red) are located within 1 km, and have significantly different benthic community composition (top right) reflecting a healthy reef (RT4) and a degraded reef (LL). Pictures from each site is shown.

References

[1] Takeshita , Y., McGillis, W., Briggs, E. M., Carter, A. L., Donham, E. M., Martz, T. R., Price, N. N, and Smith, J. E. (2016) Assessment of net community production and calcification of a coral reef using a boundary layer approach. *Journal of Geophysical Research: Oceans*, 1-17, doi:10.1002/2016JC011886.

[2] Barnes, D. J. (1983). Profiling coral reef productivity and calcification using pH and oxygen electrodes. *J. Experimental Marine Biology and Ecology*,*66*(2), 149-161.

Results

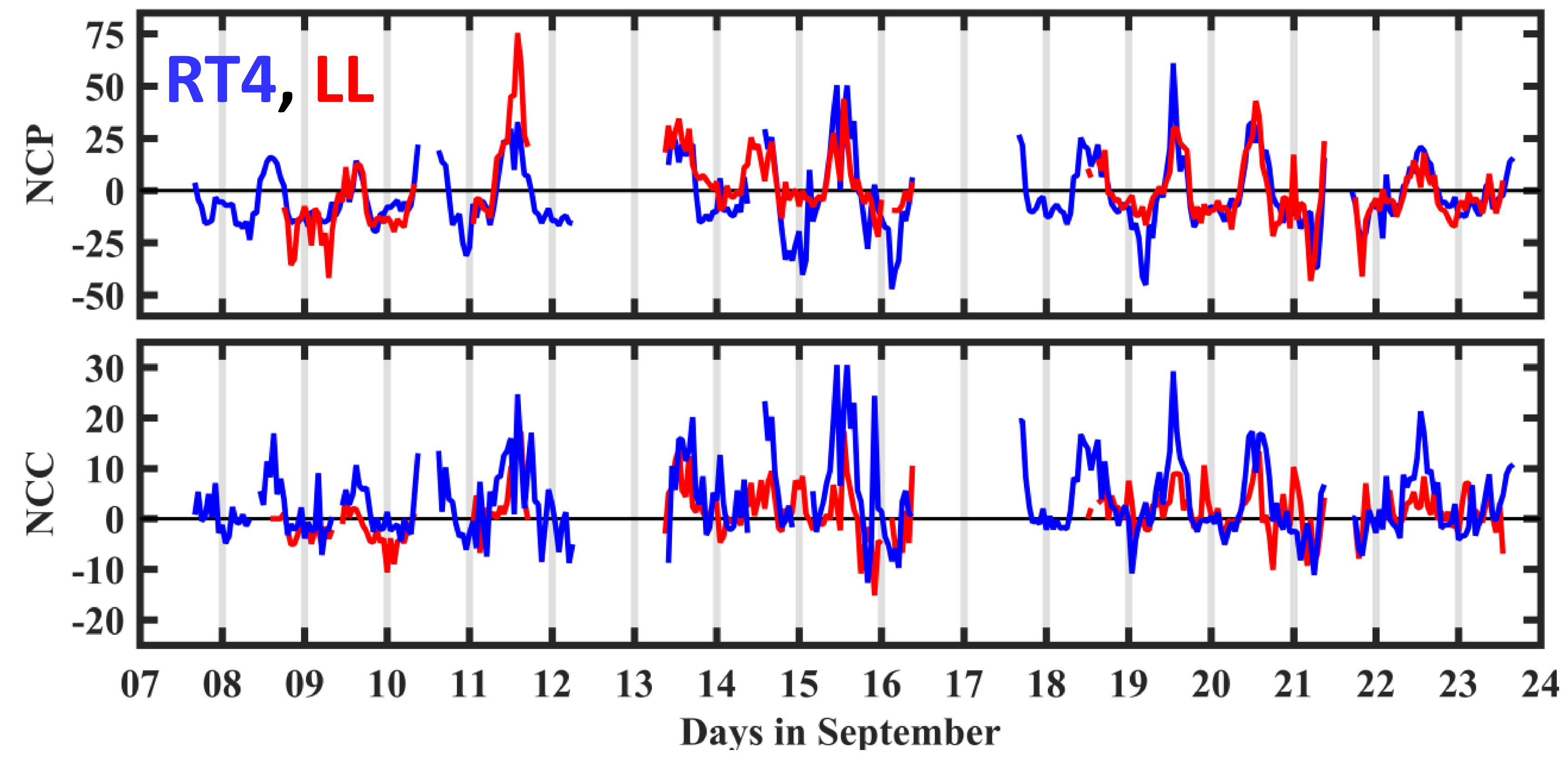

Figure 2: Time series of hourly binned NCP (mmol O_2 m^{-2} h^{-1}), and NCC (mmol $CaCO_3$ m^{-2} h^{-1}) from RT4 (blue; healthy reef) and LL (red; degraded reef). Vertical gray lines represent midnight. A clear diel cycle of NCP and NCC is observed at both sites. Gaps in data are due to sensor maintenance or unfavorable flow conditions.

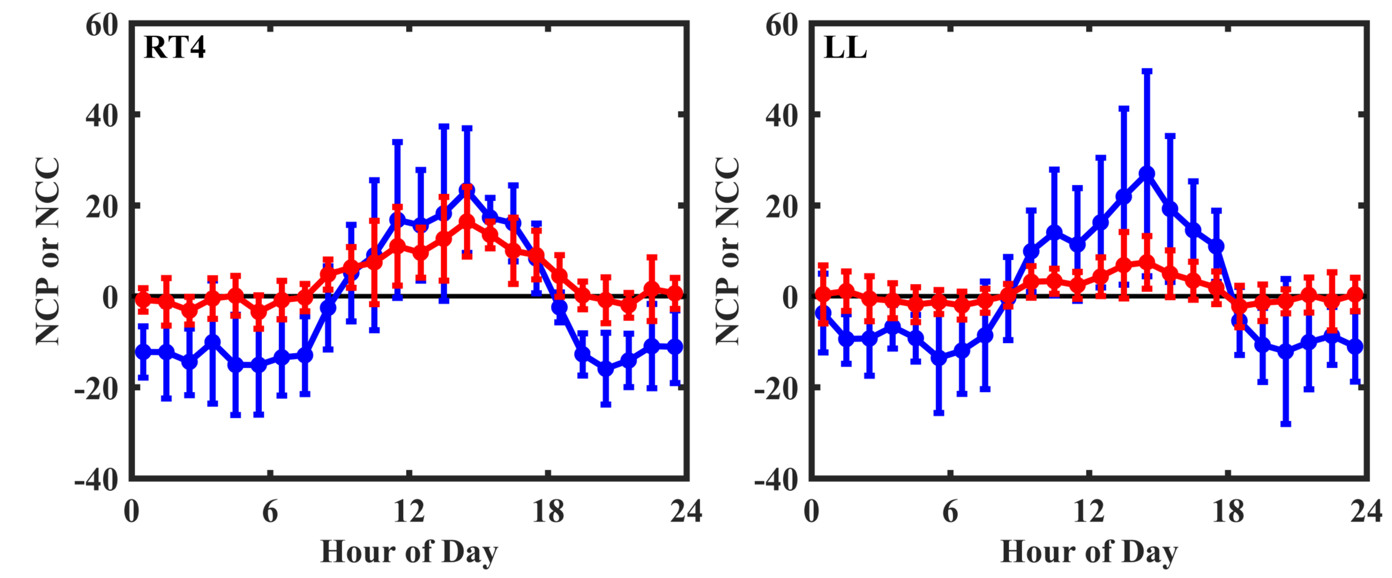

Figure 3: Diel composite plot of hourly NCP (blue) and NCC(red) for RT4 and LL. Error bars are 1 SD, and reflect day-to-day variability. Significantly lower NCC was observed at LL due to lower abundance of calcifying organisms.

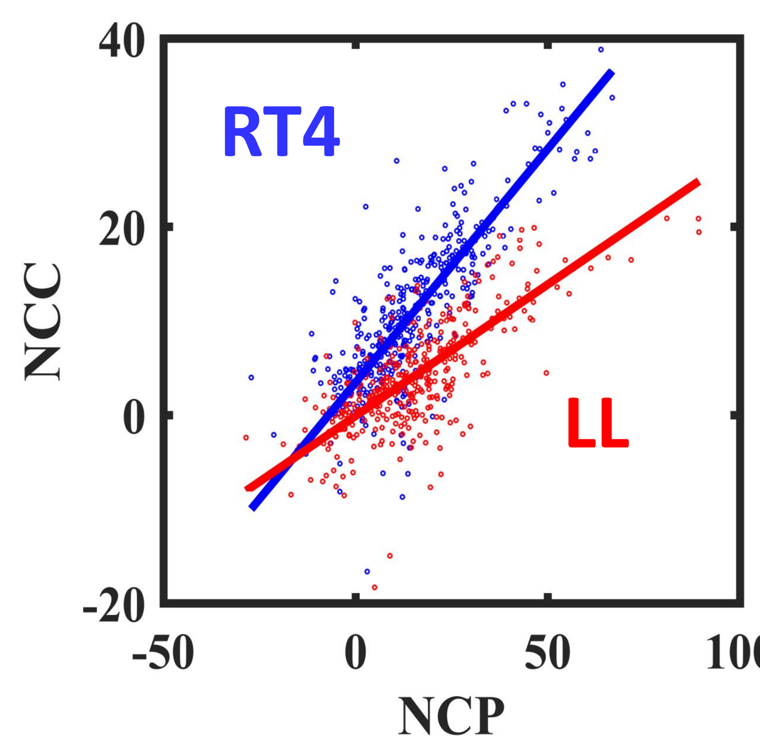

Figure 4: Daytime NCP and NCC at RT4 (Blue) and LL (red). Lines represent model II regression. Slope at RT4 and LL were 0.50 ± 0.02 and 0.27 ± 0.01, respectively. Significantly different ratio of NCC:NCP was observed between the two sites reflecting their respective reef health

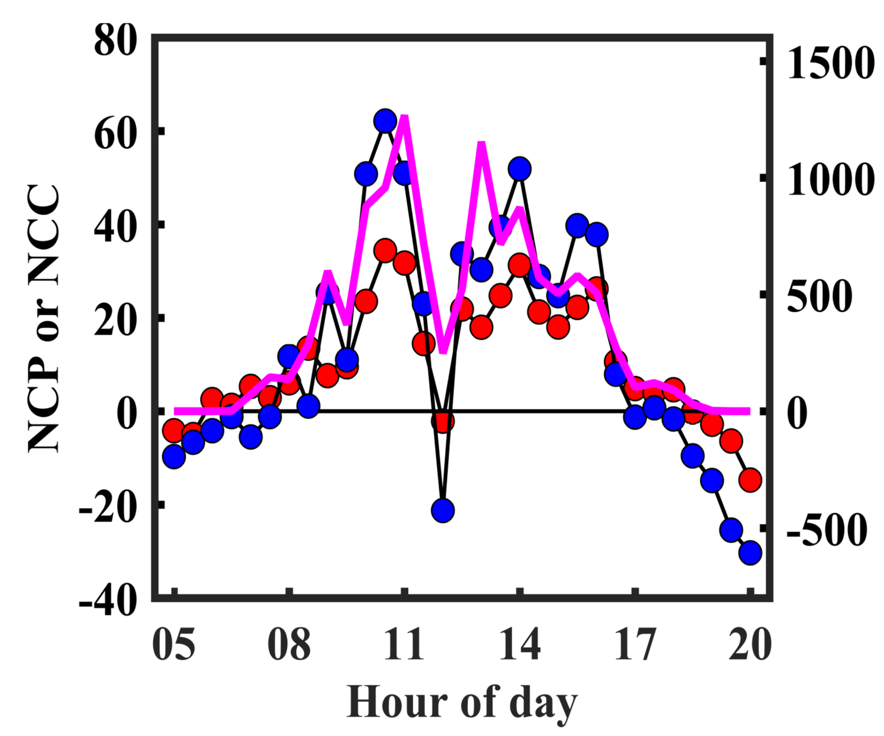

Figure 5: Daytime NCP (blue) and NCC (red) on 15 September at RT4. PAR (μmol photons m^{-2} s^{-1}) is shown in the solid pink line, demonstrating the tight coupling between PAR and reef metabolism on time scales of tens of minutes. .

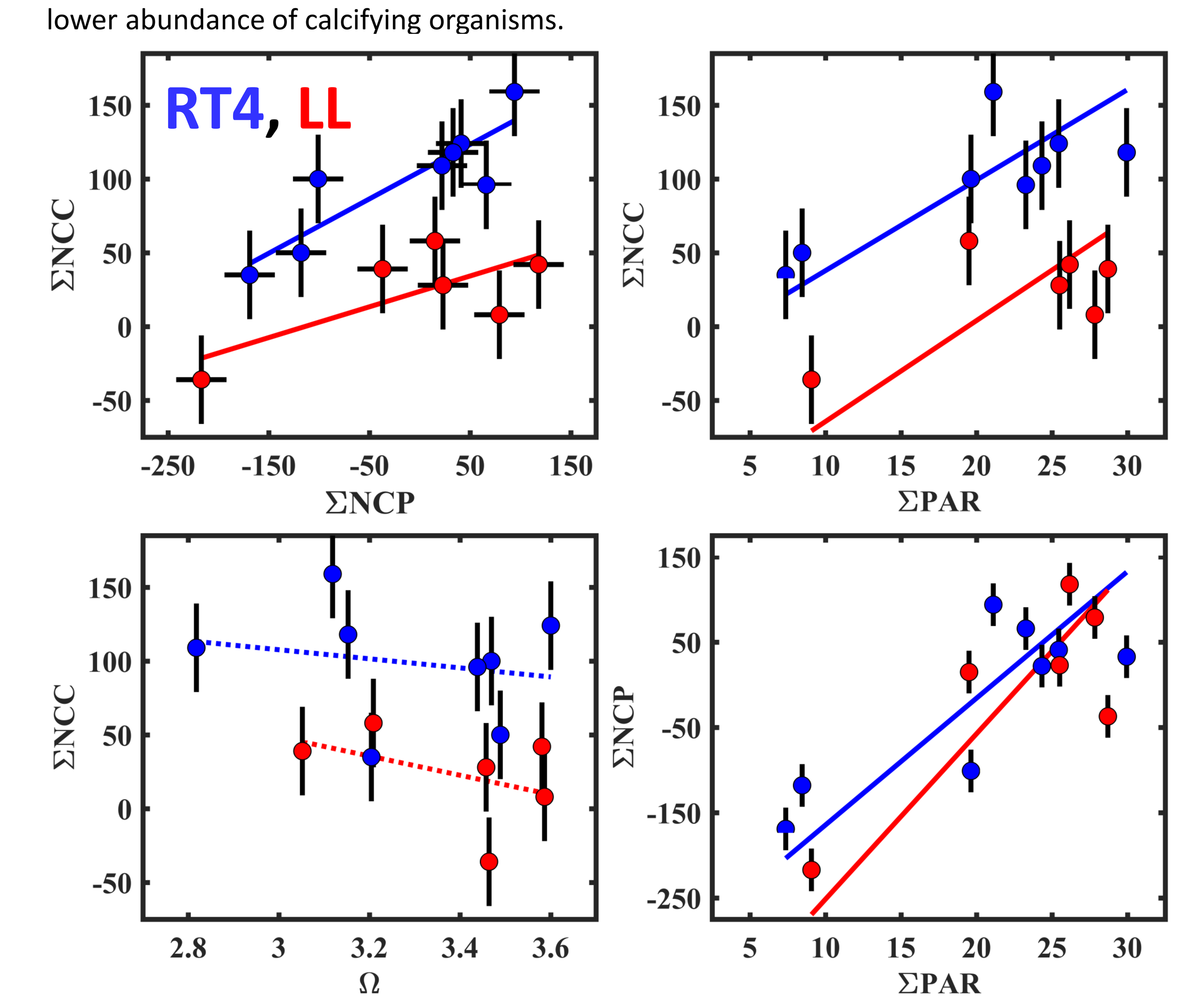

Figure 6: Relationship between ΣNCP (mmol O_2 m^{-2} d^{-1}), ΣNCC (mmol $CaCO_3$ m^{-2} d^{-1}), ΣPAR (mol photons m^{-2} d^{-1}), and daily average Ω at both sites. Data from RT4 and LL are shown in blue and red, respectively. Error bars represent uncertainty in the daily integrated metabolic rates. Solid lines represent model II regression results where the slope was significant at the 0.05 level. Dashed lines indicate a nonsignificant slope.

Conclusions and Future Directions

- Successfully demonstrated BEAMS, a novel system which autonomously measures coral reef metabolic rates (NCP and NCC) every 15 minutes for weeks.
- Reef metabolism was highly dynamic and responded to changes in environmental conditions within minutes
- Detected significantly different ratio of NCC:NCP between a healthy and degraded reef site, demonstrating potential for monitoring reef health
- No correlation was observed between daily mean Ω and daily integrated NCC.
- BEAMS deployed in 6 different reefs worldwide. Potential for providing a snapshot of coral reef metabolism using a single method.

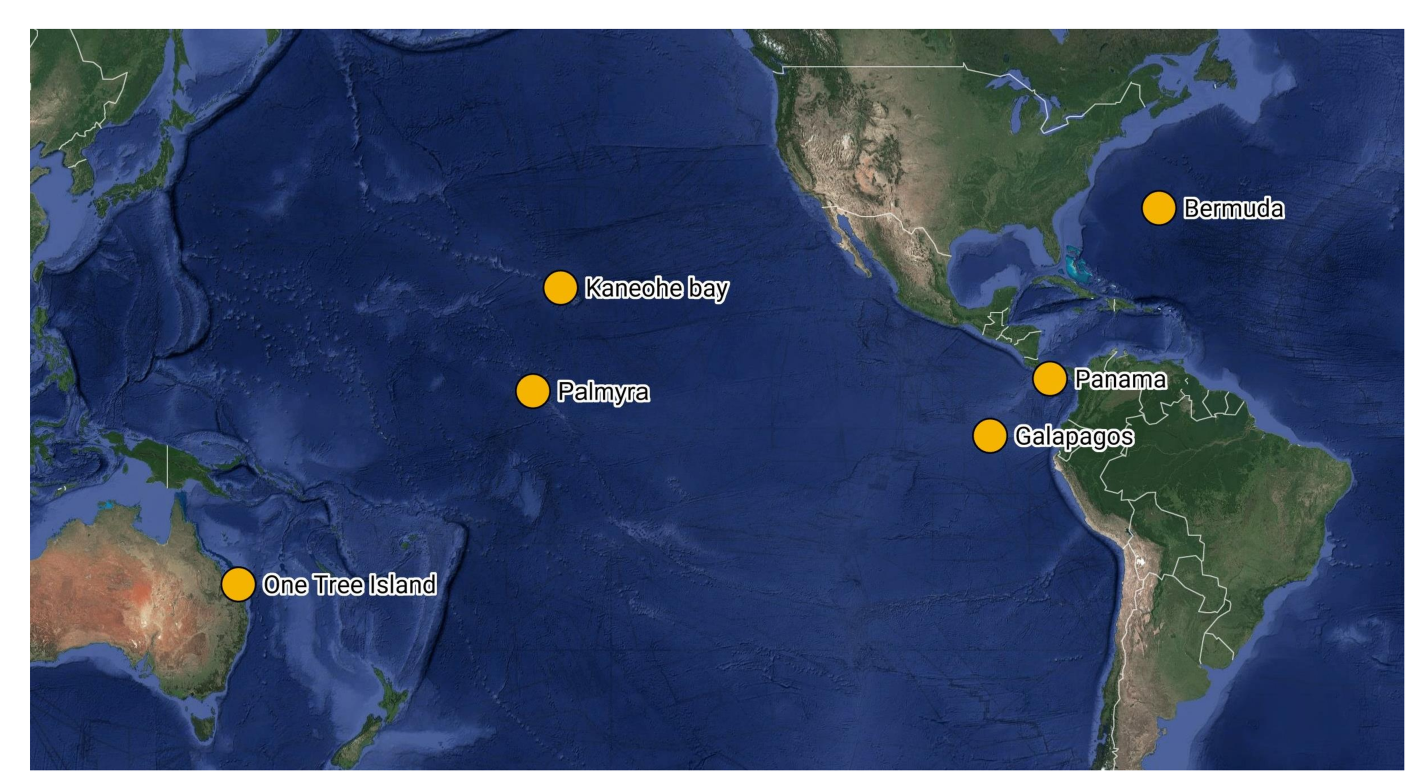

Figure 7: Sites where BEAMS has been deployed over coral reefs. Most recently, BEAMS was deployed for 6 weeks on the fore reef at One Tree Island, representing one of the longest time series for reef metabolism. Metabolic rates of fore reefs have traditionally been understudied due to difficult conditions and deeper water columns.

Acknowledgements

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