THE INFLUENCE OF WAVE ENERGY ON SPATIAL VARIATION IN CORAL REEF MORPHOLOGY: MIDWAY ATOLL

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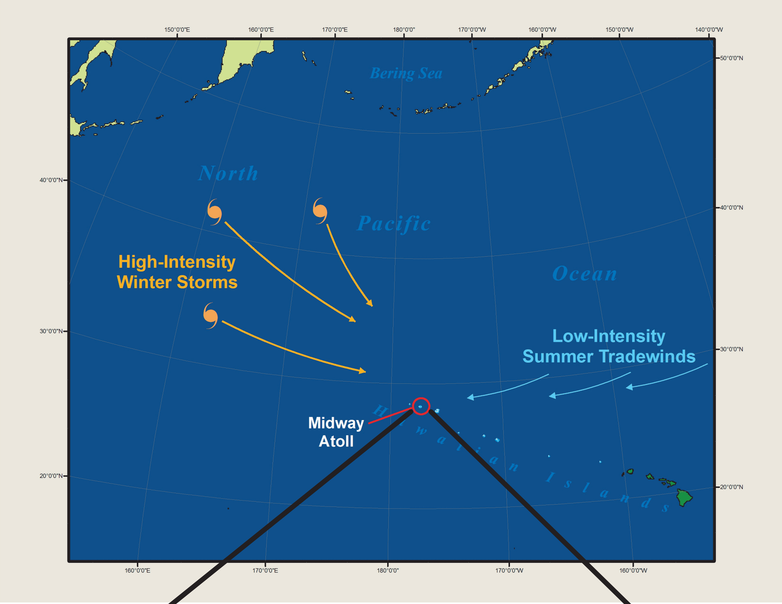
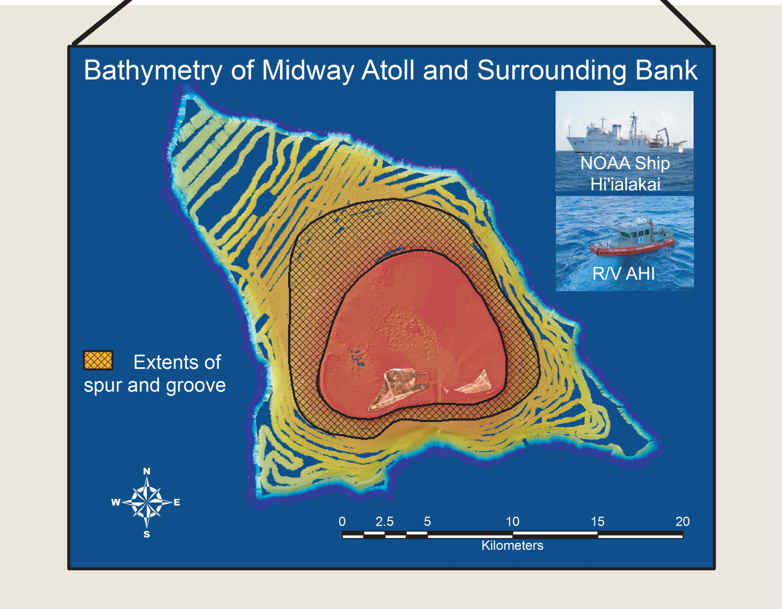
Joseph D. Chojnacki, John J. Rooney and J. Scott Ferguson
Joint Institute for Marine and Atmospheric Research, University of Hawaii, and the Coral Reef Ecosystem Division - Pacific Islands Fisheries Science Center - National Marine Fisheries Service
1125B Ala Moana Blvd., Honolulu, Hawaii 96814
Joe.Chojnacki@noaa.gov

ABSTRACT

It has been recognized for some time that the ability of coral reefs in the Hawaiian archipelago to successfully accumulate and maintain new carbonate material is largely dependent on whether or not they are directly exposed to incident wave energy. More recent work has provided a finer resolution to our understanding how exposure to varying levels of wave energy is correlated with specific reef geomorphology. Both conceptual and quantitative models have been presented that predict characteristics of spur and groove morphology on Hawaiian reefs exposed to specific wave climates. To the best of our knowledge however, it has not yet been tested or applied to an area outside of the fringing reef along the south shore of Molokai, where the models were developed. The ongoing study discussed here aims to characterize the present day wave climate around the perimeter of Midway Atoll, compare measured and predicted changes in reef morphology, and to investigate the feasibility of comparing changes in morphology across the entire surface of a reef rather than along discrete isobaths. By comparing bathymetric and wave data across a spatially continuous surface, the opportunity exists to define threshold values of spur and groove development and identify trends in spur and groove dimensions with changes in wave power. Using gridded 5m multibeam-derived bathymetry of Midway Atoll's fore reef, automated measurements of spur and groove dimensions will be made on a cell-by-cell basis. Full-spectrum wave data from the last 40 years will be modeled across a second 20m raster grid covering Midway's bank and mean annual bed-shear stress values will be derived for each cell. Correlation analysis between wave and morphology values in each raster cell will determine how well they are related, and crosscovariance will determine the spatial pattern of correspondence between the two variables. Developing an improved understanding of the relationship between wave energy and reef development may enable resource managers to predict the location of specific reef morphologies, and their reef-associated communities, using modeled results of insular wave dynamics.





The Hypothesis:
- The intensity of wave energy controls the dimensions of developing spur and groove structures.

- Sustained spatial variation in wave energy distributed across Midway's fore reef have yielded reef tracts of variable spur and groove dimensions over time.

- Correlation analysis will support this relationship and enable development of an equation describing the distribution of spur and groove dimensions around Midway's fore slope.

Midway Bathymetry:
- Multibeam echosound data collected by NOAA Ship Hi'ialakai, R/V AHI, and bathymetry derived from Ikonos satellite imagery

- The atoll lagoon is 10km in diameter, and the bank is 35km in length at its longest point

- Spur and groove features cover an area of roughly 74 sq.km.

WAVE ENERGY

Forty years of modeled global wave data has been derived from wind measurements by the European Centre for Medium-Range Weather Forecasts (ECMWF). This data will be used to calculate 480 monthly averages of significant wave height, period and direction (below) for the open ocean around Midway.

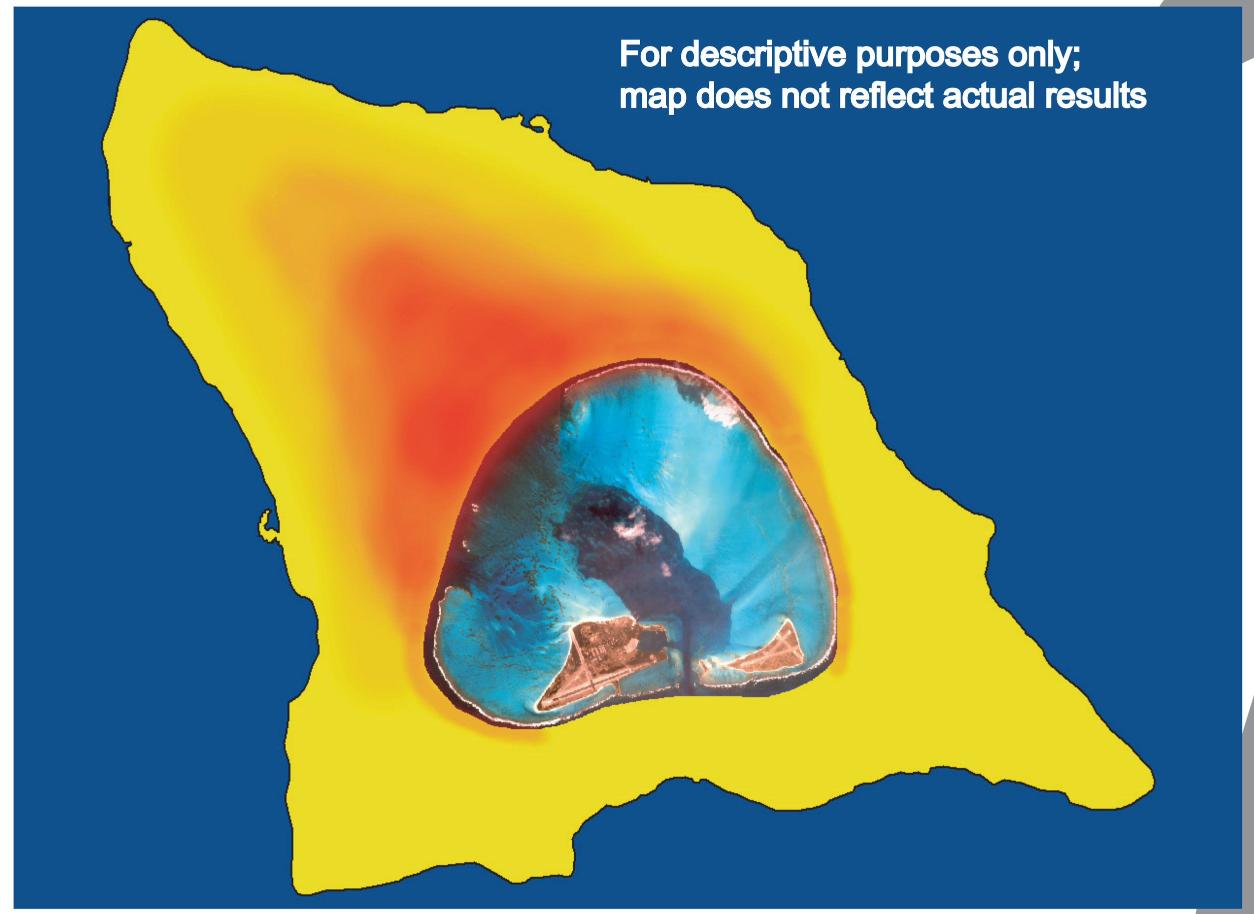
Using a 20m bathymetric grid of Midway's bank, the modeled deep-water values will be input to the Simulating WAves Nearshore (SWAN) model to simulate the shoaling of deep-water waves as they encounter Midway's bank. Output values of SWAN will be the modified significant wave height, period and direction of the waves at each cell in the raster grid.

The insular wave parameters of each grid cell will then be used to to calculate the force exerted against the reef by the wave energy at that location, taking into account the depth of the water column. This value is termed peak bed shear stress (BSS), and it is calculated using the following equations:

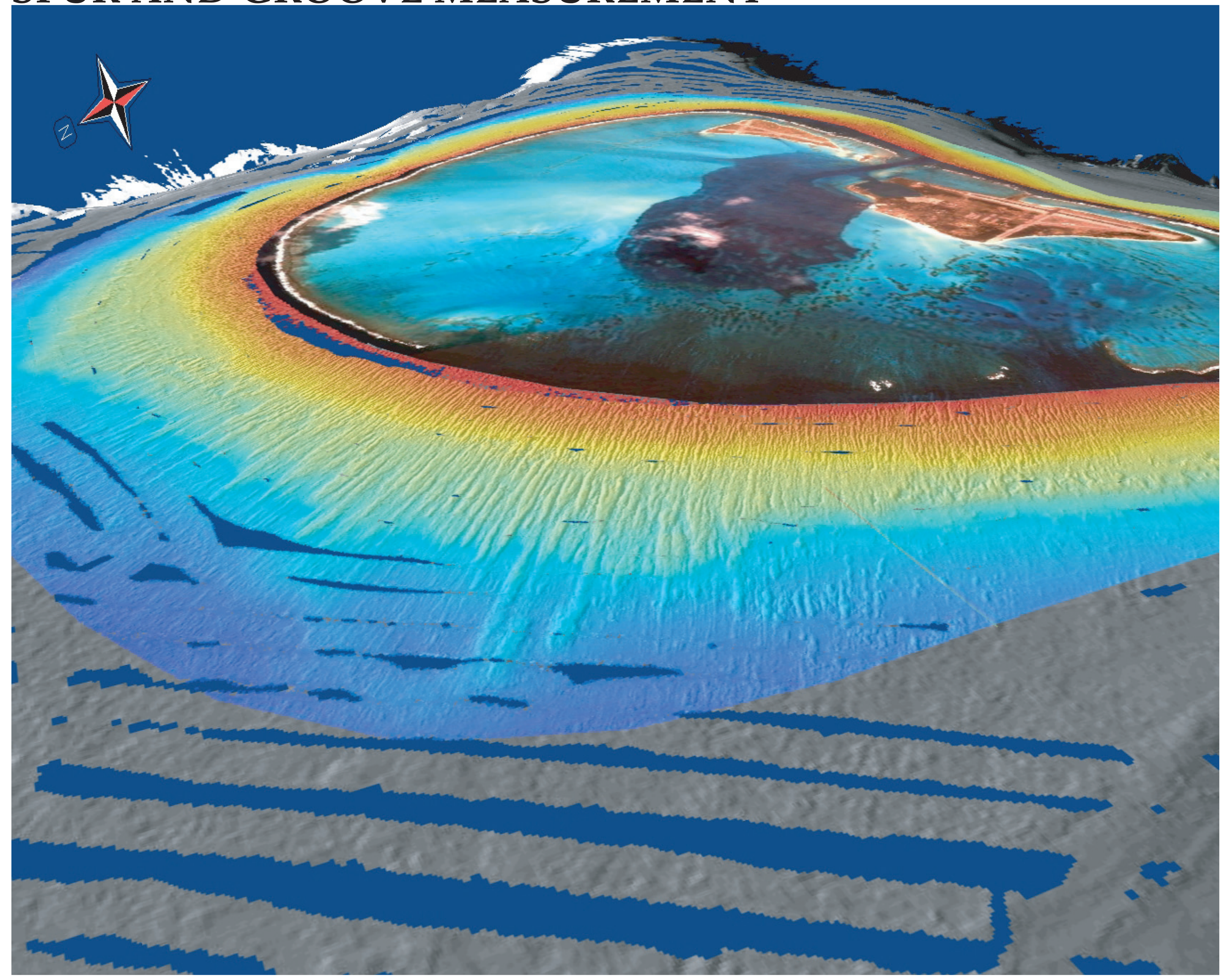
$$f_w = 0.04\left[\left(\frac{A_e}{0.0025}\right)^{-0.25}\right]$$

$$\hat{\tau}_b = \frac{1}{2}\rho_f f_w (A_e\omega)^2$$

With peak BSS calculated for each cell, it will then be possible map the distribution of wave energy as experienced by Midway's reefs (below). Once spur and groove measurements have been made, it will be possible to do a correlation analysis between the two.



SPUR AND GROOVE MEASUREMENT

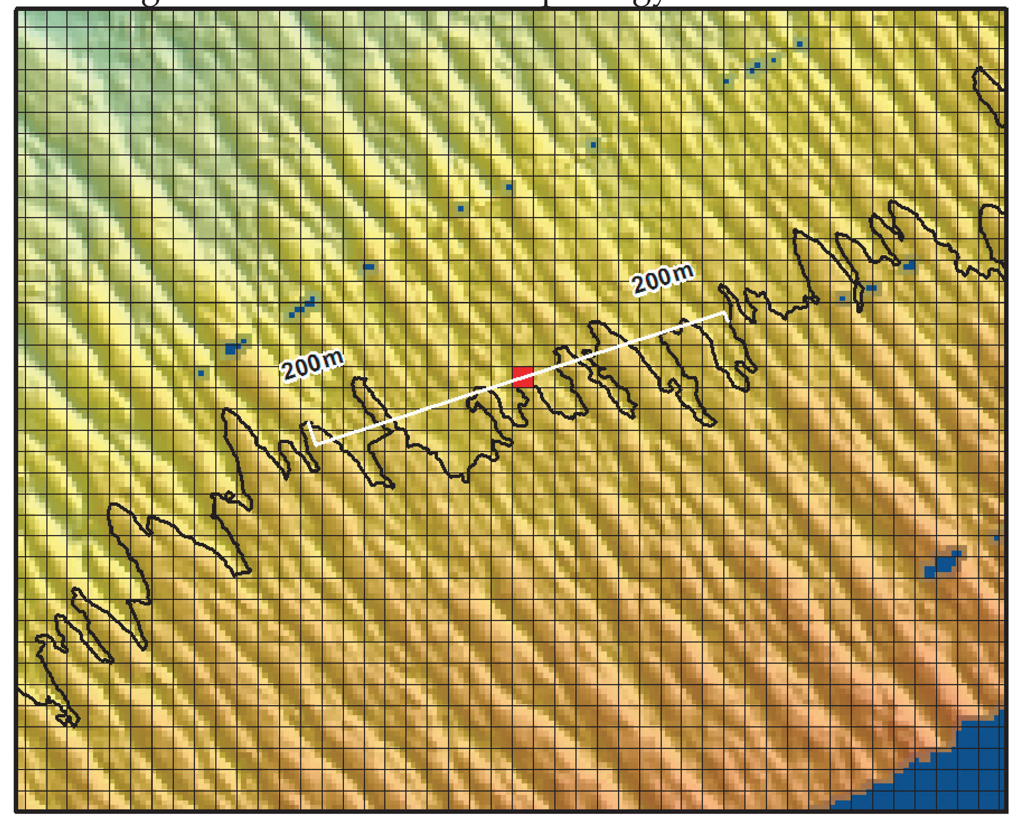


The measurement of spur and groove features will be automated to accomodate the high volume of bathymetric data. For each grid cell in the spur and groove zone (left), the cell's depth value will be used to create a depth contour for 200m in either direction (right).

Fourier Analysis, the technique of separating a complex cyclical signal into its constituent sine waves, will be applied to the analysis of the contours. Fourier Analysis of a contour will provide the values of the dominant frequencies reflected in the undulating spur and groove structure.

Several additional measurements will be taken of this contour: the ratio of the total length to the 400 linear meters, the mean spacing between spurs, and the mean contour length between spurs. Finally, a profile will be drawn along the 400m tract to calculate mean spur height.

This automated process will be repeated until each grid cell's neighborhood has been measured. Each of these values - including the Fourier-derived frequencies - represents a unique character of the reef surrounding one grid cell.
With these values assigned to each cell, it will be possible to produce maps displaying the spatial variation in spur and groove dimensions. Adjacent cells will have slightly different values, reflecting subtle shifts in reef morphology.



DATA ANALYSIS & CONCLUSIONS

Once BSS values and spur and groove measurements have been determined for each cell in the spur and groove zone, a crosscovariance analysis will be conducted to establish spatial patterns of correlation between the variables. Rather that a traditional correlation analysis, which provides a single correlation coefficient for an entire dataset, crosscovariance provides correlation values at each grid cell. This enables us to create a cross-covariance map showing which portions of the study area have good correlation between variables, and which ones have poor correlation. Crucially, if poor correlation appears on the crosscovariance map, its spatial arrangement may help identify the processes not accounted for in our hypothesis, allowing us to refine it.

If BSS and spur and groove prove to be tightly correlated, it should be possible to define threshold BSS values for spur and groove formation and derive an equation explaining how spur and groove dimensions change with BSS values.

If successful in establishing a predictive link between wave energy and reef morphology this research could have important implications for management and further research. For example, if known reef morphology can be used to estimate oceanographic conditions during winter months, it will give researchers a more complete picture of reef ecology in the NWHI.

FUTURE RESEARCH

If research shows a strong link between wave energy and spur and groove morphology, the relationship will need to be tested at other sites, both in Hawaii and beyond. Comparing the wave energy/spur and groove relationship could offer crucial insights to oceanographic differences between islands.

Other research would include:

A study of benthic species distribution compared with BSS values. In particular, identifying BSS threshold values for different coral species and calcareous algae would be an important step in refining estimates of reef accretion and the relative importances of coral and algae in Hawaii.

Performing an analysis of historical swell activity at Midway: seasonal trends, differences between 40 years ago and today, and El Nino vs. normal years.