In situ and remote monitoring for conditions conducive to **coral bleaching** in **American Samoa**

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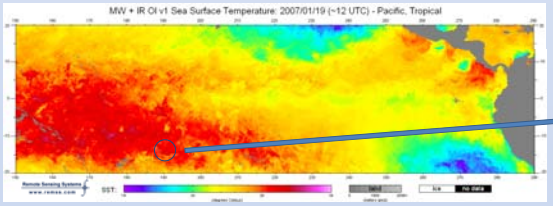
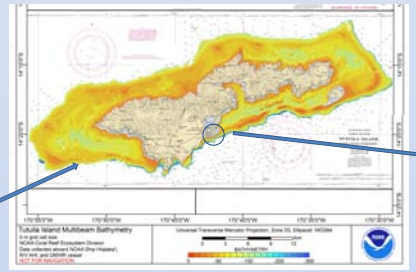
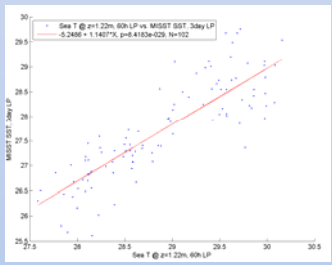
American Samoa is a natural laboratory for studying physical antecedents to coral bleaching: it is a small group of islands lying near the SE edge of the Pacific Warm Pool. In shallow back-reef pools, branching corals (*Acropora muricata*, *A. nobilis*, *A. pulchra*) bleach **annually** in the austral summer months of Oct-Apr (Fenner and Heron, 2009); Tutuila is the first place in the world where annual bleaching is documented, making it a unique location for studies like this one. Mass multi-species bleaching of hard corals in pools, or bleaching of branching coral on reef slops, is a rarer event, having been recorded in only three of the past twenty (20) years: 1994, 2002, 2003.



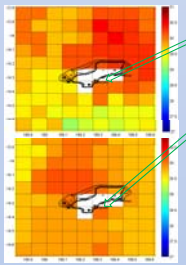
The island of Tutuila is home to the most of the population of American Samoa: reefs near the Airport and one other back-reef site here have been continually monitored for bleaching by Fenner since 2004.

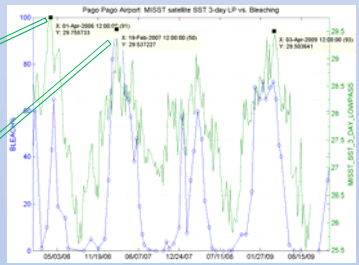


Multi-sensor Improved Sea Surface Temperature or MISST is a new global data product developed to monitor sea temperatures below the ocean surface using satellite SST, winds and other data (Gentemann et al. 2009). This product interpolated to a 9km square grid is now being applied to monitoring of coral reef ecosystems with promising results, including annual bleaching monitoring in American Samoa. Figures below compare MISST daily sea temperature time series with data from near- and sub-surface thermistors placed by NOAA Fisheries / JIMAR around Tutuila.

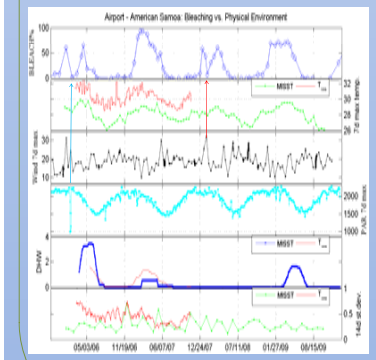


Satellite data predicting timing of *local* coral bleaching: Fenner's observations of % bleached *Acropora spp.* for the Airport are superimposed on 3-day low-pass filtered MISST data: these lower-frequency MISST variations match the observed bleaching linearly: R^2=0.5, 95% CI p<0.0001, dof=59, response lag of six (6) days.

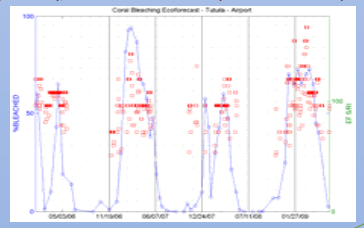




Several indicators or *indices* based on sea temperature time series have been suggested as correlates for coral bleaching, including either high- or low-frequency variability, and cumulative anomaly. See Strong et al. (2004) and Manzello et al. (2007) for reviews. The figure ***below left*** shows many of these indices with Fenner's % bleached observations. The figure suggests that sea temperature alone does not adequately explain the observed pattern of annual bleaching at this site, e.g., when MISST temperature and incident solar radiation (as measured at the NOAA ESRL American Samoa Observatory) were essentially stable in austral summer 2007-2008, coral bleaching actually reduced in the Airport pool. High wind speeds during this episode appear to explain the discrepancy (red arrow). This pattern recurs in 2006-2007, but in 2005-2006 a rapid bleaching recovery corresponds with both high wind and low incident light (cyan arrow).



To model the combined effects of thermal/photo-stress and high winds, we define a set of fuzzy logic rules. This non-deterministic model, also called an ***ecoforecast*** (Hendee et al. 2009), quantifies severity of an ecological response (bleaching), to multiple stimuli (here, 7-day maxima for MISST, PAR and wind speed) by means of a stimulus / response index (S/RI). S/RI accumulates severity and persistence of each stimulus, as well as combined effects. The figure below compares Fenner's Airport % *Acropora* bleached for 2006-2009, with this model S/RI: R^2=0.72, p<0.0001, dof=37. Significantly, the ecoforecast model produced no false positives.



Conclusions

1. **Sub-surface sea temperature** on remote coral reefs can be monitored via satellite, e.g., MISST. This daily gridded (9km x 9km) product characterizes a significant part of low-frequency variability and cumulative **benthic thermal stress**, as measured by benthic thermistors in American Samoa.
2. Six years of bleaching observations in shallow branching corals of Tutuila, American Samoa were analyzed. Results suggest **bleaching is a response to multiple environmental factors**, including incident light and local winds, as well as high sea temperature. Other factors such as water-column light attenuation (e.g., Houk et al. 2005), not considered in this study, may also contribute.
3. While the authors hesitate to claim a *synergistic* response to all of these factors (see, e.g., Dunne 2010), **heuristic ecoforecasting using integrated data** from available satellite and *in situ* sensors was **a useful predictor for bleaching** time and severity in back-reef pools in American Samoa, 2005-2010.

References and Acknowledgments

NOAA Earth System Research Laboratory (ESRL) provided hourly global radiation data from Samoa Observatory on Tutuila

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