

NOAA Coral Reef Watch Coral Bleaching Outlook System

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Abstract. A new NOAA tropical coral bleaching outlook system has just been developed. The system includes a sea surface temperature (SST) prediction model based on NOAA's Linear Inverse Model (LIM) and a bleaching thermal stress model based on the coral bleaching HotSpot and Degree Heating Week (DHW) algorithms used in NOAA Coral Reef Watch (CRW) operational near-real-time satellite bleaching monitoring. The system forecasts regions of potential thermal stress conducive to coral bleaching ranging from one week to 18 weeks in advance.

Key words: Coral bleaching, Thermal stress, Prediction, Forecast, Outlook.

Introduction

Mass bleaching of coral reefs has occurred with increasing frequency in recent decades. The US National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Watch (CRW) provides critical information to reef managers and scientists based on near-real-time satellite monitoring of thermal stress conducive to coral bleaching (Liu et al. 2006). However, many managers and scientists have requested information on the likelihood of coral bleaching months in the future.

NOAA CRW, in collaboration with the Physical Sciences Division of the NOAA Earth System Research Laboratory (ESRL), has just developed a bleaching prediction tool capable of forecasting weeks to months in the future. Using global sea surface temperature (SST) forecast models, NOAA CRW now provides outlooks of potential bleaching thermal stress, to significantly improve strategic planning and management of coral reef ecosystems. Here we introduce this bleaching outlook system and evaluate its performance by comparison with CRW operational near-real-time observations.

Bleaching Outlook System

The NOAA bleaching outlook system covers the tropical latitudes between 30°S and 30°N. The outlook comprises three integrated parts: sea surface temperature (SST) prediction model, coral bleaching thermal stress prediction, and coral bleaching outlook. The SST model results are currently available at 2°×2°×weekly resolution and for lead times of 1 to 24 weeks. The seasonal bleaching outlook is created

from the maximum thermal stress forecast up to 18 weeks into the future.

Sea Surface Temperature Prediction Model

The system uses the SSTs predicted by the NOAA Linear Inverse Modeling (LIM) developed by NOAA/ESRL Physical Sciences Division (Penland and Matrosova 1998; Penland and Magorian 1993; Penland 1989). LIM is a statistical derivation of the best dynamical description from the observations of a linear system and prediction are made from the derived statistical model. Penland and Sardeshmukh (1995a) and Penland and Matrosova (1998) found that the evolution of tropical SST anomalies (SSTAs) can in large part be represented as a stable, multivariate linear dynamical system maintained by stochastic forcing. From this, NOAA developed the NOAA LIM prediction model for forecasting tropical SSTAs.

Weekly 1°×1° Reynolds and Smith Optimum Interpolation SST (OISST) data (Reynolds et al. 2002 and 1994) between 30°N and 30°S during the years 1982-2006 were consolidated onto 2°×2° grids to train our model. This minor reduction in spatial resolution reduces the number of degrees of freedom one must diagnose from a fairly short data set. Then, weekly climatologies were derived and weekly SSTAs were calculated. The resulting anomalies were cast in terms of Empirical Orthogonal Functions (EOFs). Most of the variability and almost all of the predictable variability were compressed into a basis having a much smaller dimensionality than the original data. The leading 30 EOFs that contain 75% of the data are retained in the model. Using this compressed

description of the data, LIM was applied to estimate the linear operators giving the best forecast of SSTA.

Prediction of global tropical SSTAs is made by applying the statistical model described above to the observed initial SSTAs as represented by EOFs from weekly OISST. The prediction in the EOF domain is then cast back to SSTA in the geospatial domain. Both initial conditions and forecasts have smaller amplitude than the original data because, on average, only 75% of the variance was retained. To account for this reduction, predicted anomaly at a location is inflated by a factor reflecting the amount of variance retained at that location. For example, SSTAs in a location where only half the variance is retained are inflated by the square root of 2, while very little is inflated in a region that retained nearly 100% of the variance. The climatology is added to the adjusted prediction of the SST anomaly to give the SST forecast.

Bleaching Thermal Stress Prediction Model

The stress forecast methodology is similar to the CRW operational near-real-time satellite coral bleaching monitoring. In the near-real-time monitoring, the HotSpot measures the intensity of bleaching thermal stress as the difference between the observed SST at a grid point and the climatologically averaged temperature for the warmest month. Since both intensity and duration of thermal stress are important in causing bleaching, the Degree Heating Week (DHW) accumulates HotSpot values ≥ 1.0 °C during the prior 12 weeks (Liu et al. 2006). DHWs of 4 °C-weeks is likely to cause significant coral bleaching, and 8 °C-weeks or above is likely to cause widespread severe bleaching and significant mortality (Liu et al. 2006).

Similarly, in the stress forecast, the HotSpot prediction is calculated as the difference between the model-predicted SST and the climatologically

averaged OISST temperature for the warmest month. In deriving DHW prediction, we found that a threshold of 0.5 °C of predicted HotSpot for accumulating DHW prediction yielded the best agreement between the predicted DHW and CRW's near-real-time DHW observation. This lower threshold is a consequence of reduced amplitude of SST variation intrinsic to the LIM model and a reduced spatial and temporal resolution in the outlook relative to CRW near-real-time observations. Weekly bleaching thermal stress predictions are produced for the upcoming 18 weeks.

Coral Bleaching Outlook Model

A coral bleaching outlook algorithm was developed to derive a bleaching risk level from the predicted thermal stress. Three levels of bleaching risk are defined based on the relationship between the hindcast HotSpot and DHW for 2001-2007 and the HotSpot and DHW observations from archived 2001-2007 near-real-time satellite data. The three levels are color-coded on an outlook map (Fig. 1) and defined as:

Potential Bleaching (light-orange):

$$HS_{pred} > 0$$

Potential Widespread Bleaching (orange):

$$HS_{pred} > 0.5$$

Potential Severe Bleaching (brown):

$$HS_{pred} > 0.5 \text{ and } DHW_{pred} > 4$$

where, HS_{pred} and DHW_{pred} are HotSpot and DHW predictions, respectively. A seasonal outlook of bleaching potential for the upcoming 3 to 4 months is based on the maximum composite of weekly outlooks in the predicted seasonal time period.

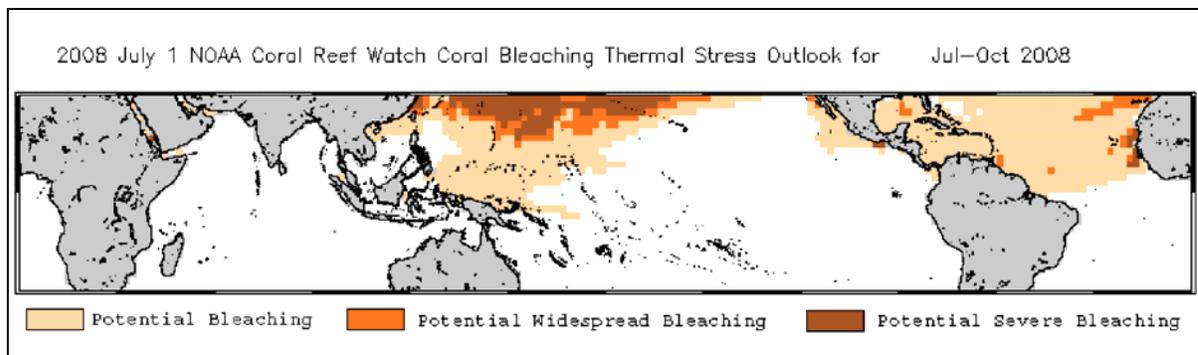


Figure 1: Seasonal bleaching outlook for July-October 2008 produced on July 1, 2008

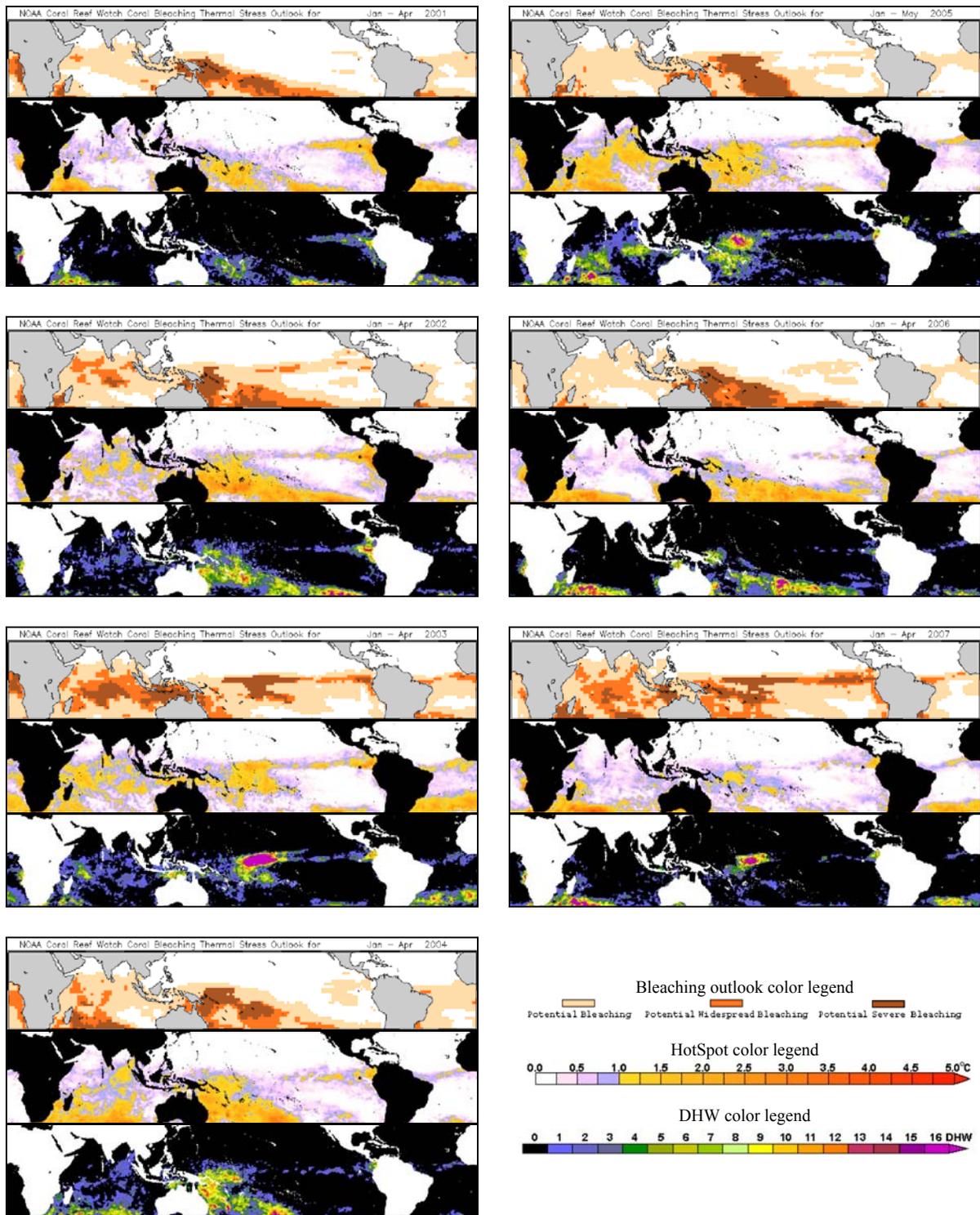


Figure 2: Hindcast austral bleaching season (January-April) seasonal bleaching outlooks for 2001-2007 (top panel of each three-panel set one for each year) and the maximum composites of the CRW near-real-time twice-weekly satellite HotSpot and DHW observations for the corresponding time periods (middle and bottom panel of each three-panel set).

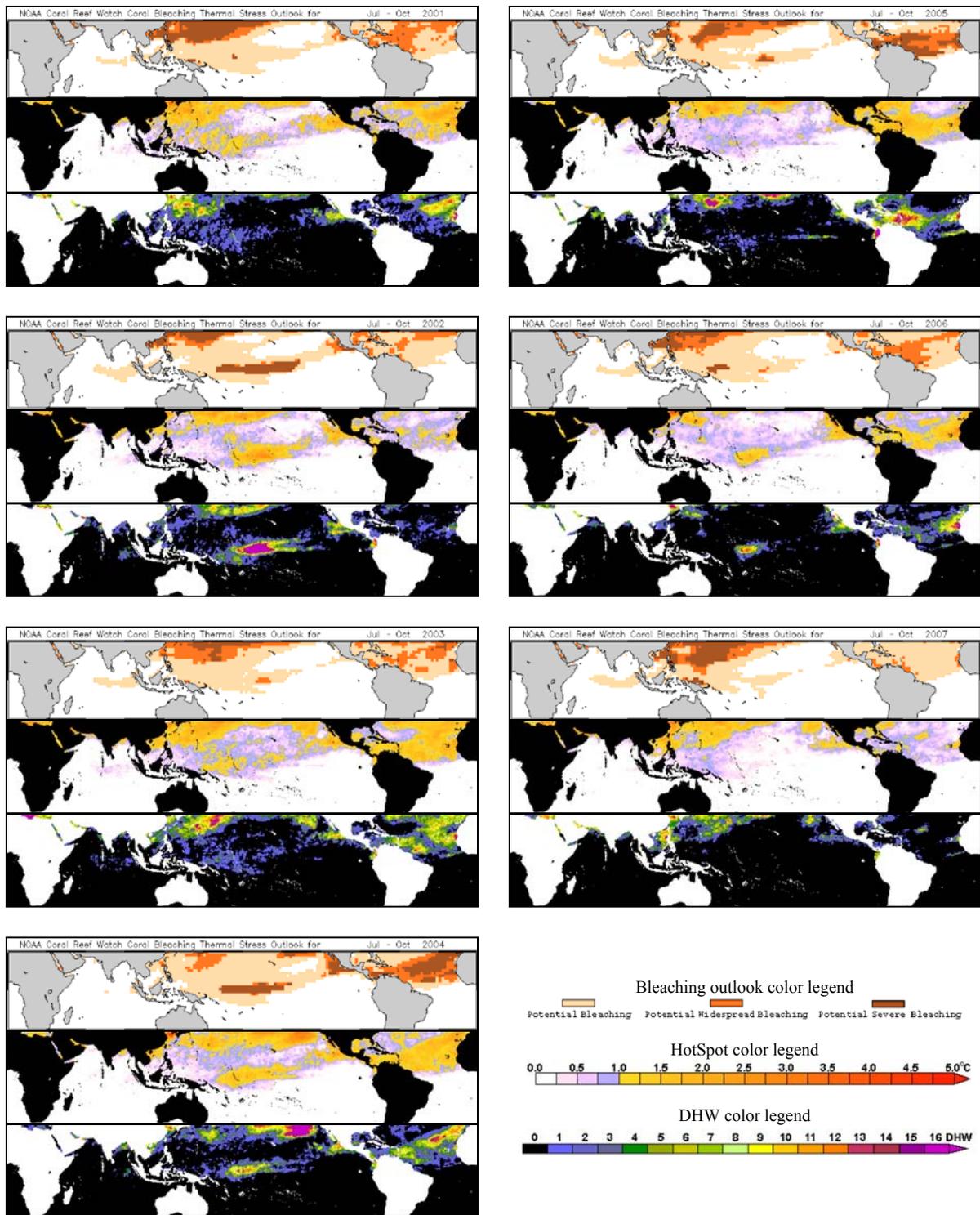


Figure 3: Hindcast boreal bleaching season (July-October) seasonal bleaching outlooks for 2001-2007 (top panel of each three-panel set one for each year) and the maximum composites of the CRW near-real-time twice-weekly satellite HotSpot and DHW observations for the corresponding time periods (middle and bottom panel of each three-panel set).

Analysis of Seasonal Bleaching Outlook Products
 We have examined the accuracy of the seasonal bleaching outlook product during a 7-year set of

boreal and austral bleaching season predictions. Seasonal bleaching outlook maps for January-April and July-October of 2001-2007 are shown (Fig. 2-3)

together with the maximum composites of the CRW operational near-real-time twice-weekly HotSpot and DHW observations for the corresponding time periods. This corresponds to seven full years during which has operated its Here we compare the outlook and monitoring data for the Caribbean, Great Barrier Reef (GBR), and Northwestern Hawaiian Islands (NWHI) during known large-scale bleaching events.

The general pattern and intensity of the seasonal bleaching outlooks match well with the HotSpot and DHW observations. For the GBR region (Fig. 2), the 2002 mass bleaching event (Oliver *et al.* 2008) is well captured in the seasonal outlook. The outlook correctly predicts low to mild stress years at the GBR for 2001, 2003, 2005, and 2007, but over-estimates the thermal stress in the GBR for the 2006. For the Caribbean region (Fig. 3), the outlook performs well for all seven years, including the 2005 mass coral bleaching event (Wilkinson and Souter 2008). HotSpot and DHW observations show that in all years, high thermal stress was seen in the northwestern Pacific Ocean near the NWHI (Fig. 3). Mass coral bleaching occurred in the NWHI 2002 (Aeby *et al.* 2003) and 2004 (Kenyon and Brainard 2006), suggesting the outlook underestimated the stress for these two events. However, the outlook tended to overestimate for other years where thermal stress was comparatively low.

Discussion

The comparison for 2001-2007 shows that the seasonal bleaching outlooks generally match the HotSpot and DHW observations. The outlook performs best in the Caribbean and GBR regions, but does not perform as well in the NWHI. This may be caused by relatively low variance explained by the leading 30 EOFs around the NWHI, but we are continuing to investigate. Also, unlike the Caribbean and GBR, masses of warm water are not constrained by land-masses and may easily miss these small islands. Examination of weekly predictions (not shown) also indicates that these are able to predict the development and dissipation of thermal stress during mass coral bleaching events, including the record-breaking 2005 bleaching in the Caribbean.

As with any forecast model, both the variance and accuracy decline with longer lead times. In the case of this outlook product, it tends to increasingly underestimate the thermal stress at longer lead times. It also seems to develop unrealistically high thermal stress at short lead times near the end of the bleaching season. These suggest that predicted HotSpot values may need to be calibrated as a function of lead time.

NOAA CRW will continue to evaluate this new prediction system to improve the accuracy for coral reefs globally.

This new NOAA bleaching outlook system has been available at CRW's website, <http://coralreefwatch.noaa.gov>, since July 2008. It is updated weekly to provide coral reef managers and researchers critical information on large-scale bleaching thermal stress events weeks to months in advance. Similar to seasonal hurricane outlooks, the outlook product does not to provide exact predictions at any particular reef locations, but provides general patterns of potential bleaching, enabling managers and scientists to prepare in advance.

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