

P2.11 IMPLEMENTATION OF THE OPERATIONAL AUTOMATED CORAL BLEACHING E-MAIL ALERT SYSTEM

J. Wemmer *
Science and Technology Corporation, Suitland, MD
K. Sprietzner
Science and Technology Corporation, Suitland, MD
L. Zhao
NOAA/NESDIS/OSDPD, Suitland, MD
J. Sapper
NOAA/NESDIS/OSDPD, Suitland, MD

1. INTRODUCTION

The Operational Automated Coral Bleaching E-mail Alert System is an enhancement of the Operational Tropical Ocean Coral Bleaching Indices, produced by NOAA's Office of Satellite Data Processing and Distribution (OSDPD). The original software was written by members of the Coral Reef Watch team at NOAA's Office of Research and Applications, and was improved and operationally implemented at OSDPD under Computer Sciences Corporation's Central Satellite Data Processing contract. The Automated Coral Bleaching E-mail Alert System is a user friendly method of providing useful information to scientists for monitoring the thermal stress that predisposes reefs to coral bleaching. While the Tropical Ocean Coral Bleaching Indices web page provides similar information, the Automated Coral Bleaching E-mail Alert System is tailored to the user. By using a web based form, users can subscribe to the Automated E-mail Alert System in order to receive coral bleaching alerts via e-mail for up to 24 coral reef sites around the world. E-mail alerts are issued to subscribers when a reef site experiences a change in its alert level. Alerts are divided into different categories based on whether coral bleaching indicators pass predefined thresholds. Therefore, alert levels reflect the intensity of the thermal stress that the reef site is undergoing. The possible alert levels include: no stress, a coral bleaching watch, a coral bleaching warning, a level 1 alert, and a level 2 alert.

2. SYSTEM DESIGN

Figure 1 shows how the Automated E-mail Alert System relates to the Satellite Coral Bleaching Monitoring Products System. The coral bleaching products data file, produced twice a week by the Satellite Coral Bleaching Monitoring Products System, is the primary input to the Automated Coral Bleaching E-mail Alert System. The data that is extracted from this file includes nighttime only sea surface temperature (SST), Hotspots, and Degree

Heating Weeks. Hotspots are the difference between the SST and the maximum monthly mean climatology. Degree Heating Weeks are the accumulation of Hotspots over the previous twelve weeks.

The Automated Coral Bleaching E-mail Alert System is comprised of the alert generation and distribution subsystem, and the web-based e-mail subscription subsystem. The alert generation and distribution software consists of an Interactive Data Language (IDL) program, and Perl and shell scripts. This software runs automatically on a production Linux machine, and in case of a system failure, a backup machine runs the software as well. The subscription software consists of HTML files, an interactive web-based form, and a Perl script which reside on a production web server. This software produces the e-mail subscription database which is transferred to the production machine where the alert generation and distribution subsystem resides. Figure 2 shows the system design of the Automated Coral Bleaching E-mail Alert System.

2.1 Subscription Subsystem

The user interface to the subscription subsystem is a web-based form linked from the Tropical Ocean Coral Bleaching Indices web page. A script was developed to process the users' input entered into the form. By entering an e-mail address, one may subscribe, view or change a preexisting subscription, or unsubscribe. A user may choose up to 24 coral reef sites around the world in which they have an interest. A confirmation e-mail is sent to the user as a security precaution, to verify that the user in fact initiated a request for a new account, a change in the subscription, or a request to unsubscribe. After verification from the user, the database of e-mail addresses is automatically updated. This database is used by the alert distribution script to send the alert messages to subscribers.

Users have the option to receive separate e-mails for each reef site they have selected, or a digest containing alerts for each selected reef site in one e-mail. In addition, users may choose to receive the last e-mail alerts to update them on the status of the coral reef sites in which they are interested. This option is useful for new users, or for users who wish to be reminded of a coral reef site's status if their chosen reef sites have not had a recent change in alert level.

*Corresponding author's address: Jillian E. Wemmer,
Science and Technology Corporation,
E/SP1, Rm 3045, FB4
NOAA/NESDIS/IPD
5200 Auth Rd
Suitland MD 20746-4304
e-mail: Jill.Wemmer@noaa.gov

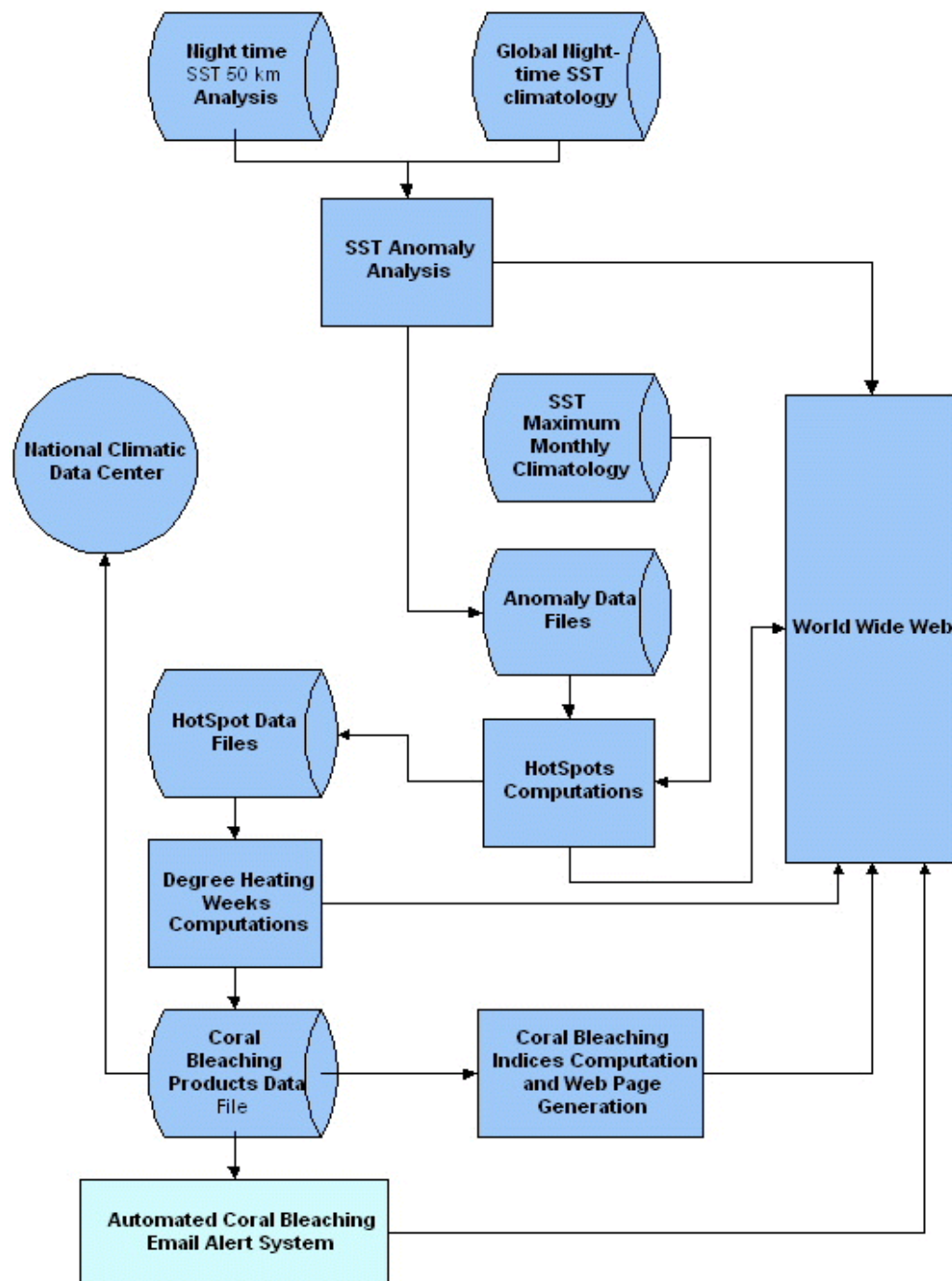


Figure 1. NOAA/NESDIS/OSDPD Satellite Coral Bleaching Monitoring Products System

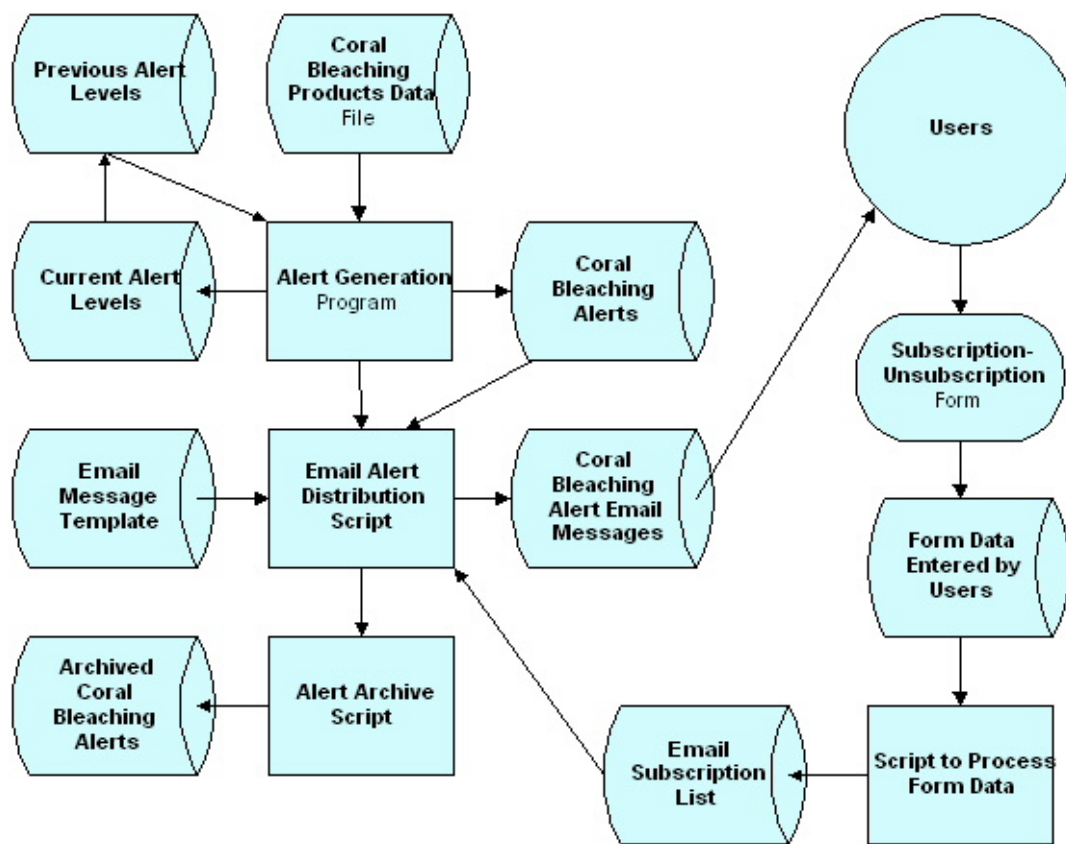


Figure 2. System Design of the Operational Automatic Coral Bleaching E-mail Alert System

2.2 Alert Generation and Distribution Subsystem

A Perl script acts as the main driver of the alert generation and distribution subsystem. First, the current coral bleaching products data file is retrieved. The previous three alert levels for each reef site are also used as input to the IDL program. Other data defined in the program includes latitudes and longitudes of the reef sites, and the maximum monthly mean SST climatology values for each reef site.

The program then extracts the current sea surface temperature, Hotspot, and Degree Heating Weeks values for each reef site from the coral bleaching products data file. These values are compared to thresholds to determine the current alert levels. See Table 1 for the definitions of the alert levels. The current alert level for each reef site is compared to the previous alert level, in order to determine whether a reef site experienced a change in its alert status. If there was a change in a reef site's alert status, a message is produced that lists the current SST, Hotspot, and Degree Heating Weeks values, and the maximum monthly mean climatology value for that reef site. In addition, the previous three alerts and their dates are listed, as well as a link to a SST time series chart for that reef site.

If an alert message is produced, a file for that reef site is

appended with the current alert level, date, SST, Hotspot, and Degree Heating Weeks values, as a record of the reef site's alert history. As a method of ensuring that the system is running smoothly twice a week, an e-mail message is produced and sent to monitoring personnel that summarizes the current alert levels for all of the reef sites, and indicates for which reef sites a new alert was issued.

Table 1. Definitions of Alert Levels

No Stress:	No thermal stress (HotSpot <= 0)
Watch:	Low-level thermal stress (0 < HotSpot < 1)
Warning:	Thermal stress is accumulating (HotSpot >= 1 and 0 < DHW < 4)
Alert Level 1:	Bleaching expected (HotSpot >= 1 and 4 <= DHW < 8)
Alert Level 2:	Significant bleaching expected (HotSpot >= 1 and DHW >= 8)

At the end of the IDL program, the system is prepared for its next run, which occurs after the coral bleaching products data file has been updated. If there was a change in the alert level for a reef site, the current alert level is saved as the previous alert level, and the second to last alert level is saved to the third to last alert level, and so on. If a reef site did not experience a change in its status, the original previous three alert levels are retained. This information is written to files, which are read during the next run of the system.

A shell script then saves the alert messages to an archive directory. Finally, a Perl script runs that distributes e-mail messages to the appropriate subscribers, if any alerts had been generated. Depending on the user's preference, the alert messages are sent either as individual e-mails for each reef site, or as one e-mail composed of the alert information for all of the user's selected reef sites.

3. SAMPLE BLEACHING ALERT

Table 2 lists the 24 coral reef sites that are monitored by the Automated Coral Bleaching E-mail Alert System.

Table 2. Monitored Coral Reef Sites

<u>Atlantic Ocean</u>	<u>Pacific Ocean</u>	<u>Indian Ocean</u>
Bermuda	Midway Atoll	Oman-Muscat
Sombrero Reef	Oahu-Maui	Maldives-Muscat
Bahamas	Palmyra	Seychelles
Puerto Rico	Galapagos	Cobourg Park
Virgin Islands	American Samoa	Scott Reef
Glovers, Belize	Tahiti	Ningaloo
	Guam	
	Enewetok	
	Palau	
	Davies Reef	
	Heron Island	
	Fiji-Beqa	

A change in alert status that occurred for the Bermuda reef site in August of 2004 has been chosen as an example, to demonstrate how the Automated E-mail Alert System operates. Bermuda's location is shown in local and regional maps in Figures 3 and 4, respectively. The yellow box in Figure 3 indicates the data grid at a resolution of 50 km, which is closest to Bermuda.

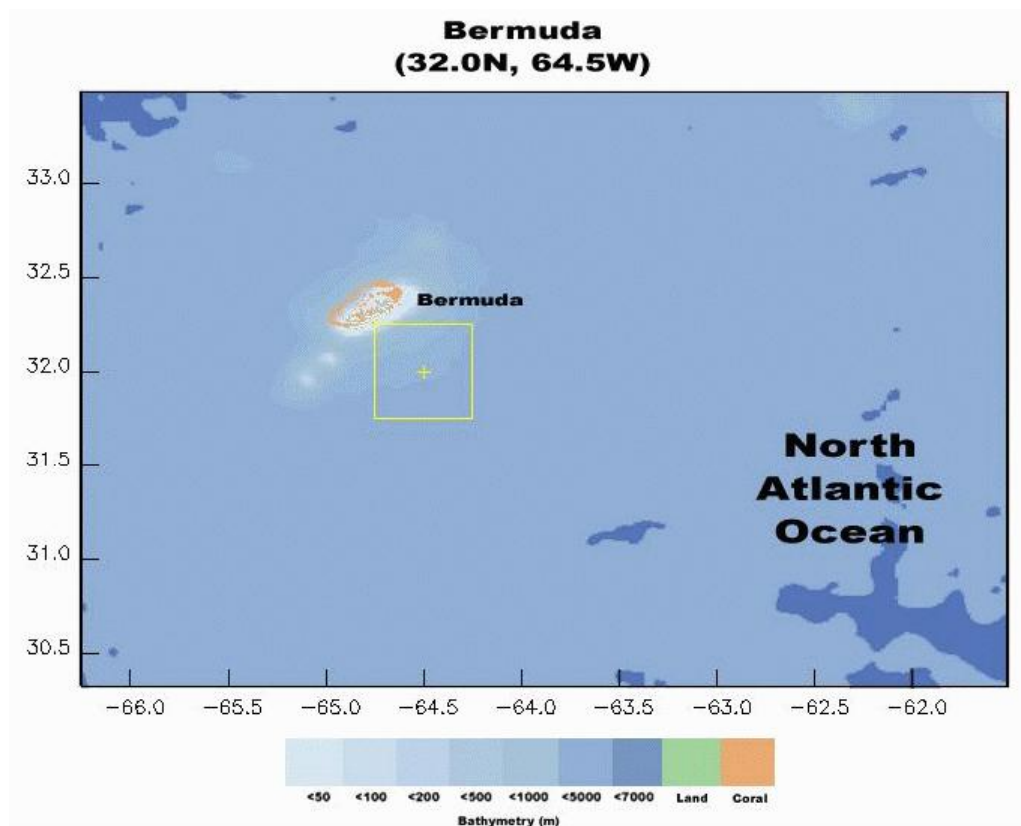


Figure 3. Local Map of Bermuda



Figure 4. Regional Map of Bermuda

In order to find the three previous alerts for each reef site for inclusion in the e-mail alert messages, it was necessary to run the Automated E-mail Alert System on older coral bleaching products data files, since some reef sites had not had three recent changes in their alert levels. Therefore, processing was done on all available coral bleaching data files. This processing enabled a history

to be generated for each reef site dating back to the beginning of 2003. The history of Bermuda's coral bleaching indicators from the beginning of 2003 to the last part of 2004 is shown in Table 3. The two highlighted entries show that thermal stress at Bermuda intensified from a Coral Bleaching Watch on August 17, 2004 to a Coral Bleaching Warning on August 24, 2004.

Table 3. History of Bermuda's Sea Surface Temperature, Hotspots, Degree Heating Weeks, and Alert Levels

Bermuda				
Date	SST	HotSpot	DHW	Alert
02/08/2003	20.2000	-7.00000	0.00000	No Stress
07/15/2003	27.5000	0.300000	0.00000	Bleaching Watch
08/05/2003	28.2000	1.00000	0.500000	Bleaching Warning
09/09/2003	26.6000	-0.600000	3.40000	No Stress
07/24/2004	27.4000	0.200000	0.00000	Bleaching Watch
08/14/2004	26.5000	-0.700000	0.00000	No Stress
08/17/2004	27.5000	0.300000	0.00000	Bleaching Watch
08/24/2004	28.3000	1.10000	0.500000	Bleaching Warning
09/25/2004	26.4000	-0.800000	1.50000	No Stress

The Bermuda SST time series chart in Figure 5 shows that the SST was 27.5 degrees Celsius on August 17, 2004 and increased to 28.3 degrees Celsius on August 24, 2004. The dashed line shows the maximum monthly mean sea surface temperature value, which is 27.2 degrees Celsius for Bermuda. The red line in the figure is one degree greater than the maximum monthly mean SST, or the threshold at which bleaching becomes more probable.

Hotspots are equal to the maximum monthly mean

SST subtracted from the SST. On August 17, 2004 the Hotspot value was 0.3 degrees Celsius and the DHW value was 0 degree-weeks, which resulted in a Bleaching Watch. On August 24, 2004 the Hotspot value for Bermuda was 1.1 degrees Celsius and the DHW value was 0.5 degree-weeks. Because the HotSpot value was greater than or equal to 1, and the DHW value was between 0 and 4, a Bleaching Warning was generated for Bermuda on August 24, 2004, since this was a change in Bermuda's alert level.

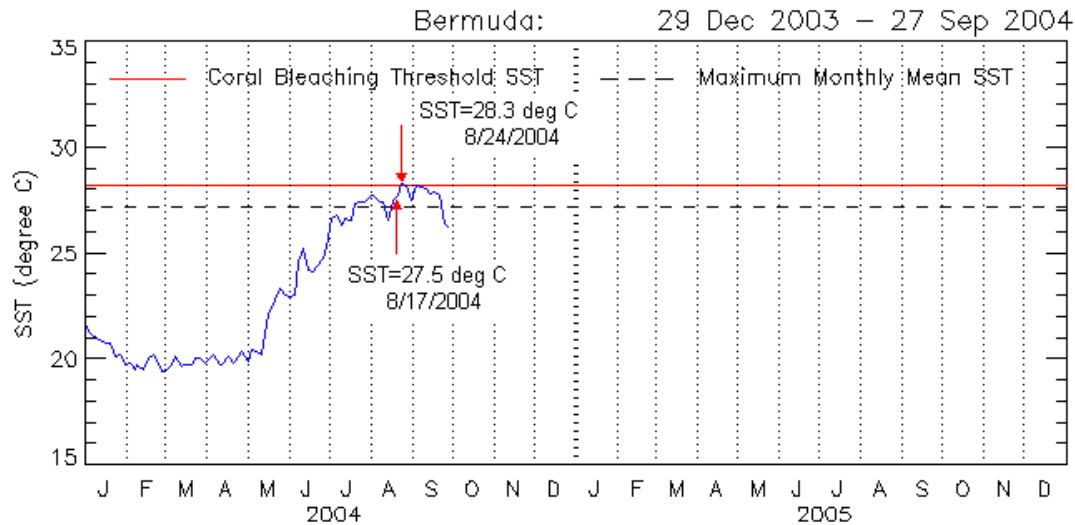


Figure 5. Bermuda Sea Surface Temperature Time Series Chart

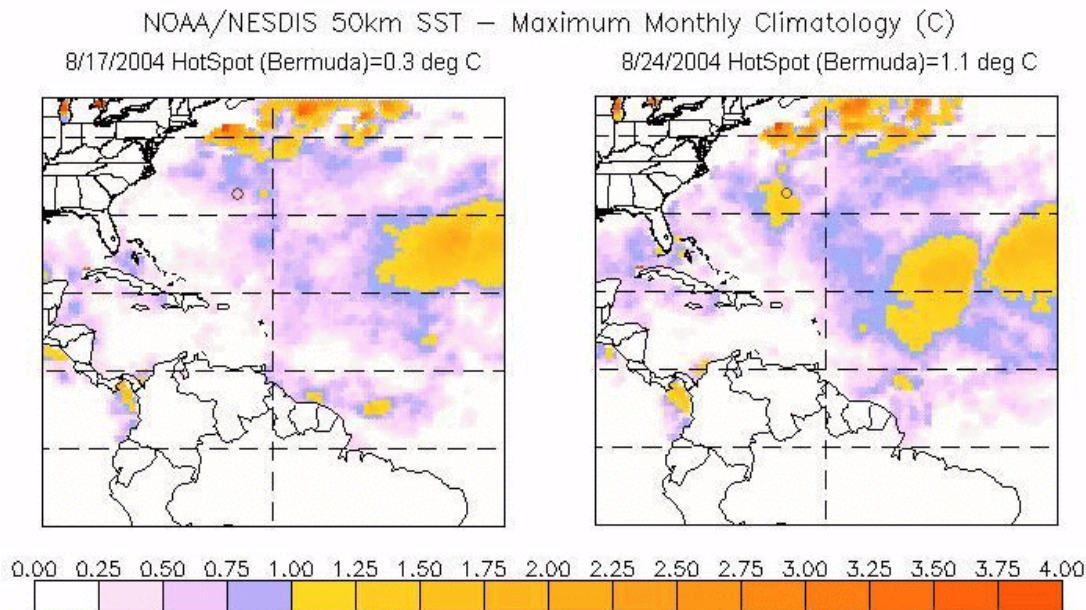


Figure 6. Hotspots at Bermuda on August 17th and 24th, 2004

The Hotspot charts for August 17th and 24th are shown in Figure 6 with the location of Bermuda circled. The change in color from pink to yellow is evident, which corresponds to an increase in SST. The Degree Heating Week charts for August 17th and 24th are shown in Figure

7, with Bermuda's location labeled. The blue area surrounding Bermuda had expanded by August 24th, as the Degree Heating Weeks value increased slightly. The Coral Bleaching Warning e-mail message that was generated on August 24, 2004 is shown in Figure 8.

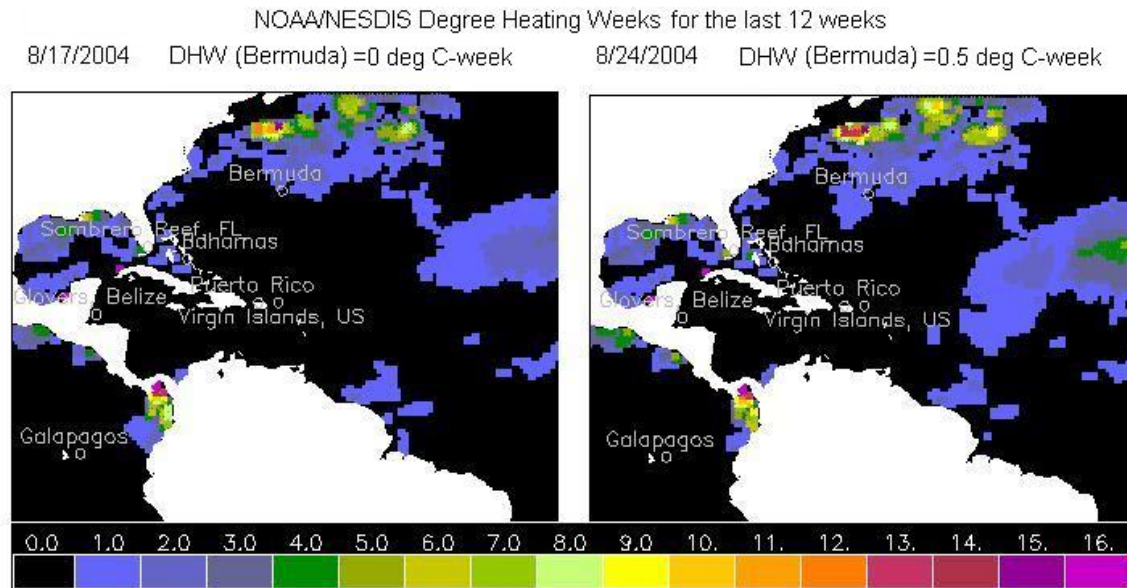


Figure 7. Degree Heating Weeks at Bermuda on August 17th and 24th, 2004

** [CRW Alert] Bermuda: Bleaching Warning	
Satellite observations: 8/21/2004 - 8/24/2004	
-- Sea surface temperature	: 28.3000 Deg C
-- Coral bleaching HotSpot	: 1.10000 Deg C
-- Bleaching Degree Heating Weeks	: 0.500000 Deg C-week
-- Maximum Monthly Mean SST at site	: 27.2000 Deg C
For more information, please visit the coral bleaching indices web site:	
http://www.osdpd.noaa.gov/PSB/EPS/CB_indices/coral_bleaching_indices.html	
Previous Three Alerts for Bermuda:	
--08/17/2004 Bleaching Watch	
--08/14/2004 No Stress	
--07/24/2004 Bleaching Watch	
SST Time Series:	
http://coralreefwatch.noaa.gov/satellite/images/current/SST_Bermuda.png	
Reef site name:	Bermuda
SST Pixel latitude:	32.0000
SST Pixel longitude:	-64.5000

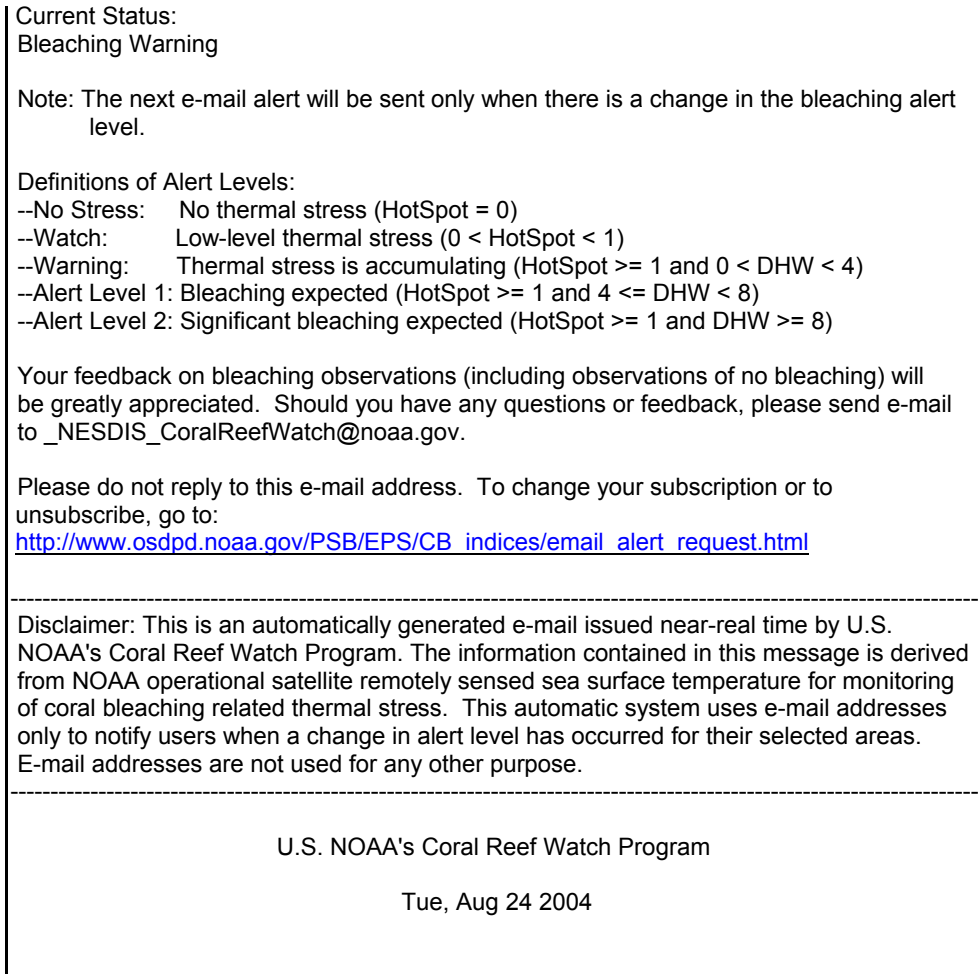


Figure 8. Coral Bleaching Warning E-mail Message for Bermuda on August 24, 2004

4. CONCLUSION

Tropical coral reefs are one of the world's most important ecosystems, yet they are threatened by bleaching. Thermal stress is one factor that leads to coral bleaching, and can be detected by the use of satellite derived monitoring products. The Operational Automated Coral Bleaching E-mail Alert System enables marine scientists and reef managers to keep a closer vigilance over the coral bleaching status of reef sites around the world. This new system is an instrument for remotely gauging the health of coral reefs. The system has been running automatically on production machines since the end of 2004, and will soon become officially operational. With the help of feedback from those who have first hand observations of bleaching, it can be confirmed that the system is accurately indicating bleaching conditions. In addition, feedback from subscribers will also allow improvements to be made to the system in the future.

5. REFERENCES

- Tropical Ocean Coral Bleaching Indices. NOAA/NESDIS. 14 Oct 2004
<http://www.osdpd.noaa.gov/PSB/EPS/CB_indices/coral_bleaching_indices.html>.
- Operational Satellite Coral Bleaching Monitoring Products Methodology. NOAA/NESDIS. 14 Oct 2004
<<http://www.osdpd.noaa.gov/PSB/EPS/SST/methodology.html>>.