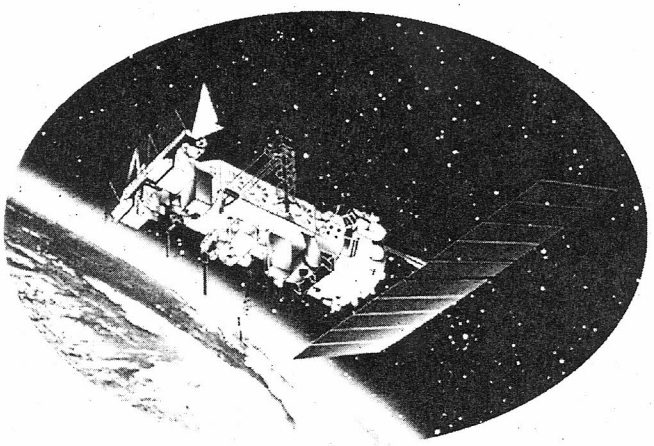


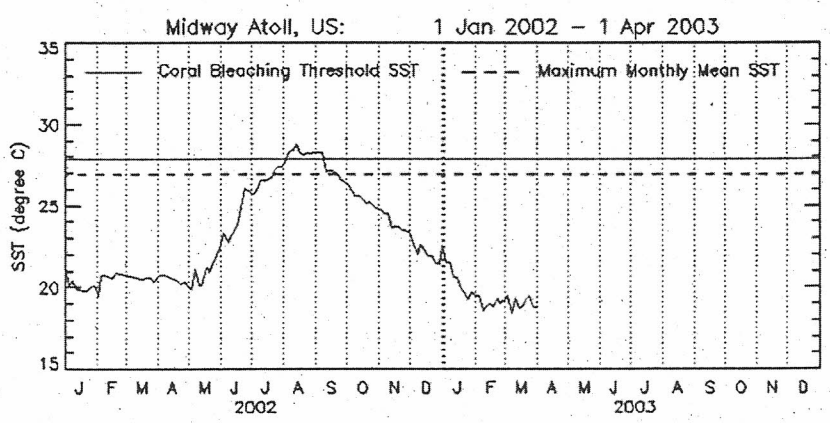
NOAA Satellites Give Early Warning For Coral Bleaching in Northwestern Hawaii Archipelago

Filter-feeding corals first evolved hundreds of millions of years ago, but modern reef-building forms have only evolved over the last 25 million years. Today, coral reefs are Earth's largest biological structures and have taken thousands of years to form. Coral reefs not only provide important habitat for many marine animals and plants, but they also provide people with food, jobs, chemicals, protection against storms, and life-saving pharmaceuticals. Native cultures often depend heavily on reefs for marine resources.

Most reef-forming corals contain symbiotic microscopic algae in their gastrodermal cells. The host coral provides the algae with protection from grazers and carbon dioxide for photosynthesis. In return, the algae supply the coral with oxygen and nutrients and remove wastes. Healthy corals come in a variety of colors, depending on the photosynthetic pigments of their symbiotic algae.

But under certain environmental stresses, the algae can be expelled by their hosts and the coral colony becomes stark white or pale in color, revealing the underlying white calcium carbonate skeleton. Coral bleaching is often caused by water temperatures that exceed the coral's tolerance level. This may be as little as 1 to 2 ^{o}C above the mean monthly summer values. High temperature not only contributes to bleaching, but also weakens coral's ability to fight diseases and grow. Reefs that are partly to totally bleached for long periods often die. Following coral death, the skeleton is colonized by algae and other encrusting organisms, often turning dirty brown in appearance. Dead reefs are vulnerable to waves and other reef organisms that bore into coral skeletons and as a result, the reefs soon break up and erode. Severe bleaching events have dramatic long-term ecological impacts, including loss of reef-building corals, changes in benthic habitat and, in some cases, changes in fish populations. Even under favorable conditions, it can take many years for severely bleached reefs to recover.

This is why reefs are being monitored extensively for elevated temperatures conducive to bleaching. During the summer of 2002, a major coral bleaching event was observed in the Northwestern Hawaiian Islands (NWHI). "To our amazement and horror, vast areas of the back reef were severely bleached," said Dr. Rusty Brainard, a scientist from NOAA's National Marine Fisheries Service (NMFS).



Based on satellite observations of anomalously warm sea surface temperatures (SSTs), NOAA Coral Reef Watch (CRW) Program sent a warning of potential bleaching in early August, 2002, to coral reef scientists and managers in the area. The *in situ* Coral Reef Early Warning System (CREWS) buoys, operated by NMFS Honolulu Laboratory, also

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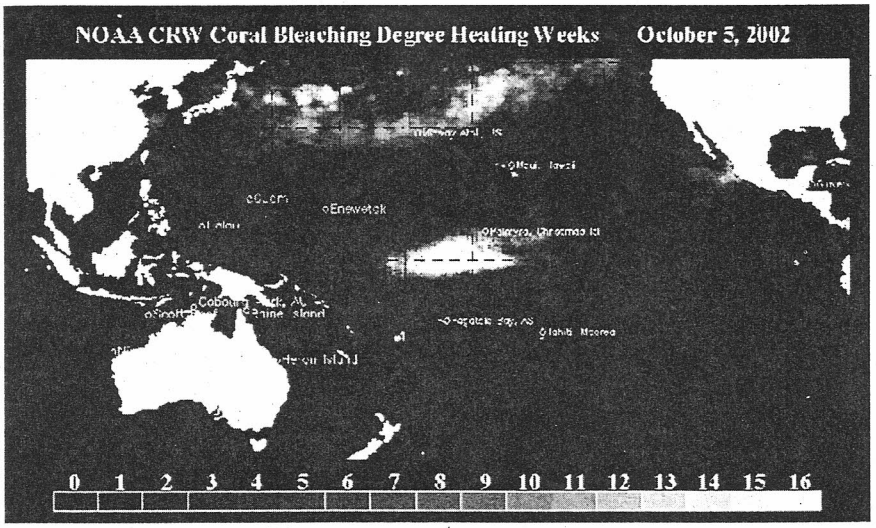

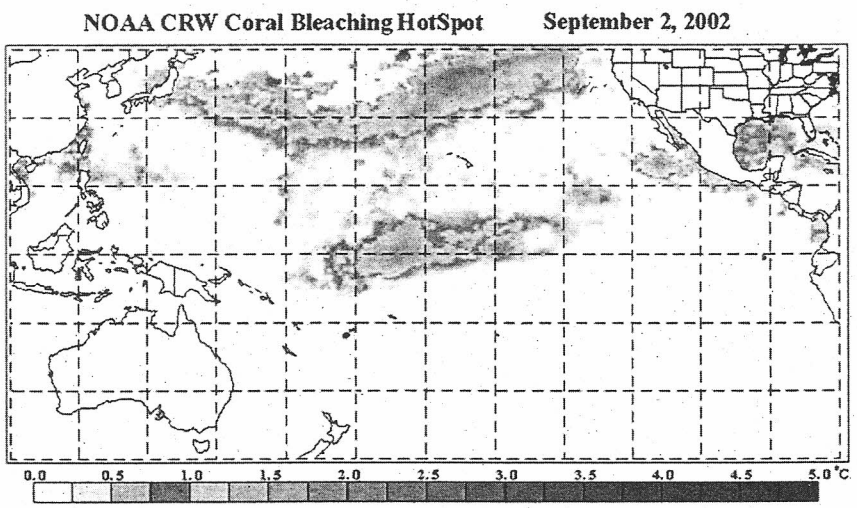

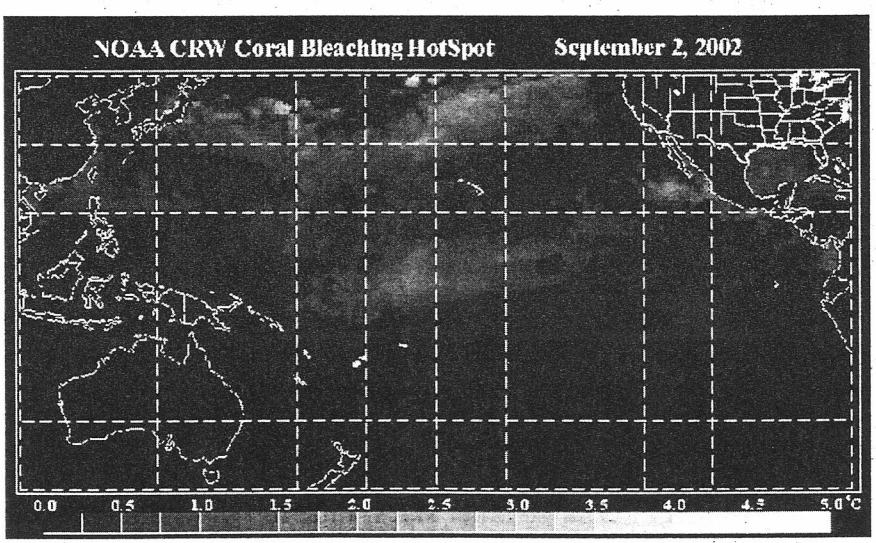

(The above HotSpot and DHW charts were modified from original color charts accessible at http://orbitnet.nesdis.noaa.gov/orad/sub/coastlines/figures_2002.html)

detected elevated water temperatures. Following the warning, NMFS conducted diver surveys to assess conditions along 135 kilometers of prime reef habitat in the shallow back reefs and lagoons of Pearl, Hermes, Midway, and Kure Atolls.
The key CRW satellite coral bleaching monitoring and prediction tools include the near-real-time satellite SST "HotSpot" anomaly detector, which detects thermal stress conducive to bleaching and "Degree Heating Weeks" (DHW), which measures cumulative thermal stress. The Coral Reef Early Warning System (CREWS) buoys also provide *in situ* data for these products.

The satellites are operated by NOAA's National Environmental Satellite, Data, and Information Service (NESDIS, now also known as Satellite and Information Services). The coral bleaching satellite products are produced by NESDIS' CRW program, while the Pacific CREWS buoys are operated by the NOAA NMFS laboratory at Honolulu.

CRW's satellite SST observations showed that Midway Atoll, in the far northwest of the Hawaiian Islands, experienced significantly high SSTs from early August through early September, 2002, reaching 28.9 ºC in August. This was 1 ºC above the local SST bleaching threshold. HotSpot charts showed that maximum thermal stress developed around early September as DHWs peaked at 9.6 at Midway Atoll during the late-summer months (July-September).

(The charts were modified from the original color charts accessible at http://orbit-net.nesdis.noaa.gov/orad/sub/coastlines/figures_1998.html)

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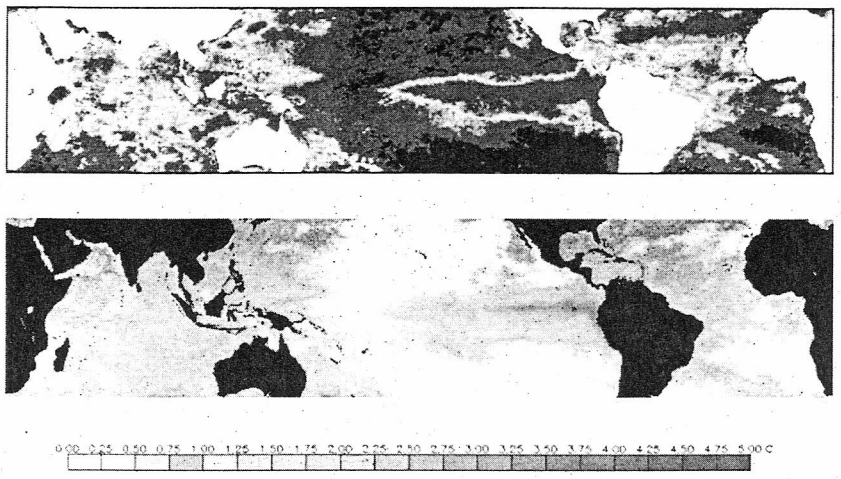
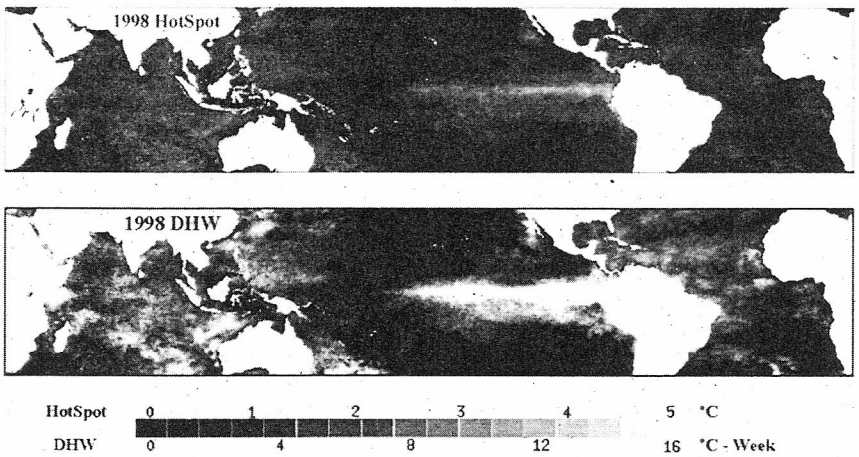
Coral mortality exceeded 50% in many areas, and approached 75% in places. Bleaching was blamed on sustained high water temperatures resulting from lack of wind and clear sunny skies. "This was a major event for the NWHI, where widespread coral bleaching had never been observed before," Dr. Brainard concluded. But the CRW early warning system worked well by accurately monitoring and predicting the bleaching event.



Development of the CRW satellite-based coral bleaching monitoring tools began in 1997 at NOAA NESDIS. The Advanced Very High Resolution Radiometers (AVHRR) on NOAA's Polar-Orbiting Operational Environmental Satellites are used to measure SST. These SST data are used to derive global coral bleaching HotSpot and DHW charts twice-weekly in near-real time. Charts and explanations are Web-accessible at: http://orbitnet.nesdis.noaa.gov/orad/coral_bleaching_index.html.



The Bleaching HotSpot chart is an anomaly product based on the coral bleaching threshold for a region. While HotSpot measures intensity of thermal stress, it does not measure accumulation of the thermal stress experienced by corals. For this, a thermal stress index called DHW was developed. DHW is the sum of HotSpots for a given location, over a rolling 12-week period. Visible coral stress is usually not apparent until DHW reaches values of 2 - 4, and by the time DHW reaches 8 - 10, widespread bleaching is likely and some mortality can be expected. CRW uses these DHW thresholds when generating satellite bleaching alerts.

In February, 2003, these monitoring tools became operational products. "Coral reef managers and stakeholders will now have up-to-date, accurate, and reliable information on the status of their reefs and may be able to take active measures to prevent further damage if their sites are approaching higher DHW levels," said Dr. Alan Strong, CRW coordinator at NOAA Satellite and Information Services.

Satellite SSTs have been used to successfully monitor major coral bleaching episodes around the globe. In recent years, abnormally high water temperatures, often linked to climate change and El Niño/La Niña weather patterns, have been one of the major causes of massive coral reef bleaching. "Coral bleaching is the result of a weather event," says Dr. William Skirving, a visiting scientist with the CRW team. "It is almost always a result of clear summer skies, little to no wind and neap (weak) tides. This allows the sun to heat the water to extraordinary temperatures. These weather events are most likely modulated by climatic events such as El Niño."

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During the very strong 1997-1998 El Niño, some of the most extensive and severe coral bleaching in modern history occurred, destroying approximately 16% of the world's remaining coral reefs. HotSpot and DHW charts (below) show that coral bleaching was associated with unprecedented high SSTs.

In 2002, yet another wave of bleaching swept coral reefs worldwide, possibly again related to another El Niño event, making 2002 the second worst year for bleaching after 1998.

During previous bleaching events, once water conditions returned to normal, most coral species were able to re-establish their symbiotic algae and their color and health returned to normal in weeks to months. But because prolonged or repeated bleaching can kill entire coral reefs, the increasing frequency of warm-water events is cause for concern. Global warming, sea level rise and bleaching of coral reefs are seen as "major, yet largely unmanageable threats" to coral reefs by reef managers from Florida, the Marshall Islands, and Palau in the Western Pacific.

Coral bleaching poses major economic and social concerns because of impacts on fisheries and coastal tourism. In the U.S., more than 10.5 million people live near shallow coral reefs, and some 45 million tourists annually visit these areas, according to "The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2002". The U.S. has jurisdiction over approximately 7,607 square miles of coral reefs in the tropical-subtropical belt. The Pacific Freely Associated States (the countries of the Republic of Palau, the Republic of the Marshall Islands, and the Federated States of Micronesia) have coral reefs covering 4,479 to 31,470 square miles. Tourism in U.S. coral reef areas generates more than $17 billion annually, while commercial fishing generates an additional $246.9 million annually. Worldwide, coral reef habitats provide estimated annual benefits of $375 billion in fish, seafood, tourism and coastal protection.

Coral reefs face many natural stresses, such as storms, floods, diseases, and natural climate change. Today, these natural stresses are compounded by impacts from human activities such as pollution, sedimentation, over-fishing, vessel groundings, anchor damages, and marine debris. Coral habitats worldwide are declining rapidly. An estimated 27 percent of the world's shallow coral reefs may be past recovery and an estimated 66 percent are severely degraded, according to the 2002 Report. Although some U.S. reefs are in good to excellent health, every U.S. reef system is suffering from both human and natural disturbances.

Using satellites to measure SST provides coral reef managers and scientists with a valuable tool to measure, predict and understand coral bleaching and to protect and preserve these "rainforests of the sea." NOAA's CRW program welcomes field observations on coral bleaching. An online report system is available at http://www.reefbase.org/input/bleachingreport/index.asp.

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