Global Forecasting of Coral Bleaching Events

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Acknowledgements

Collaboration between

- NOAA Coral Reef Watch in Silver Spring, Maryland
- NOAA Earth Science Research Laboratory's Physical Science Division in Boulder, Colorado

Funding from

- NOAA Climate Program Office’s Sectoral Applications Research Program
- NOAA Coral Reef Conservation Program

http://coralreefwatch.noaa.gov
Well developed coral reef ecosystem takes hundreds to thousands of years to build.
What is Coral Bleaching?

- Most of corals’ food comes from photosynthesis
- Corals can “bleach” due to stress
- Corals exposed to high temperatures and/or high light become stressed
- Corals eject their algae; coral appears “bleached”
- If stress is mild or brief, corals recover, otherwise they die
Thermal Stress Causes Mass Coral Bleaching
Thermal Stress Causes Mass Coral Bleaching
Thermal Stress Causes Mass Coral Bleaching and Mortality
1998 Global Bleaching

Over 15% of the world's reefs died after bleaching during 1997-1999 El Niño and La Niña
Wide Range of Coral Reef Threats

1. Human Population Growth
2. Overfishing
3. Coastal Development
4. Lack of Laws / Enforcement
5. Sedimentation (unnatural)
6. Lack of Education
7. Nutrient Enrichment
8. Algal Competition
9. Climate Change / Bleaching
10. Habitat Destruction
11. Tourism
36. Ocean Acidification


http://coralreefwatch.noaa.gov
Climate Change and Coral Bleaching

- Bleaching has increased in frequency & intensity
- Significant long-term social, cultural, economic, and ecological impacts
- >25% of the world’s coral reefs have been destroyed by warming and pollution in recent decades

Healthy Corals → Bleached Corals → Dead Corals

http://coralreefwatch.noaa.gov
Highest Thermal Stress Recorded?

![Graph showing thermal stress levels from 1985 to 2005 for World, Pacific, and Caribbean regions.](http://coralreefwatch.noaa.gov)
Overview

• Structure of existing bleaching products
• SST forecast model
• Building the bleaching outlook
• Testing the bleaching outlook
NOAA Coral Reef Watch
Satellite-based Products

Coral-specific

Thermal Stress -- Degree Heating Weeks

http://coralreefwatch.noaa.gov
CRW Operational Bleaching HotSpots and Degree Heating Weeks (DHW) Nowcasting

**SST**

**Bleaching threshold** (MMMSST+1°C)

Maximum Monthly Mean SST Climatology (MMMSST)

**Time**

**Week-0**  **Week-12**

- 0.0  0.5  1.0  1.5  2.0  2.5  3.0  3.5  4.0  4.5  5.0°C

**HotSpots**

12 weeks

\[ \sum (\text{HotSpot value} \times \text{duration}) \geq 1°C \]

**Degree Heating Weeks**

\[ \geq 4 \text{ DHWs} \rightarrow \text{coral bleaching is expected} \]

\[ \geq 8 \text{ DHWs} \rightarrow \text{mass bleaching and mortality are expected} \]

http://coralreefwatch.noaa.gov
2005 Mass Coral Bleaching in the Caribbean
(A record-breaking event)

Coral Reef Watch's 2005 Annual Maximum HotSpot and Degree Heating Weeks

http://coralreefwatch.noaa.gov
2005 Mass Coral Bleaching in the Caribbean

Contributed Bleaching Reports

After QC:
> 1000 surveys
> 50 collaborators
> 25 Jurisdictions
Countries or states

- Yellow data by colony
- Blue data by cover
- Green data by both

http://coralreefwatch.noaa.gov
2005 Coral Bleaching Surveys - Virgin Islands N.P.

6 sites

>90% coral cover bleached

>60% coral cover dead

South Florida/Caribbean Network I&M Program

J. Miller (unpublished)
CRW Operational Bleaching HotSpots and Degree Heating Weeks (DHW) Nowcasting

**SST**

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- Maximum Monthly Mean SST Climatology (MMMSST)

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**HotSpots**

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http://coralreefwatch.noaa.gov
### Proposed Bleaching HotSpots and Degree Heating Weeks (DHW) Forecasting

Forecasts made 1 April 2005

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**SST**

![Graph](image17.png)

**Time**

Week-0 → Week-12

**HotSpot from Forecasts**

\[ \sum (\text{HotSpot value} \times \text{duration}) \geq 1^\circ \text{C} \]

**Degree Heating Weeks**

- \( \geq 4 \text{ DHWs} \) → coral bleaching is expected
- \( \geq 8 \text{ DHWs} \) → mass bleaching and mortality are expected

http://coralreefwatch.noaa.gov
NOAA CRW Coral Bleaching Outlook System

- SST Forecast
- Bleaching Thermal Stress Forecast
  - HotSpot forecast
  - Degree Heating Week forecast
- Coral Bleaching Outlook

Collaboration between

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http://coralreefwatch.noaa.gov
A global tropical ocean prediction system (Released in July 2008)
- Covering 30°S to 30°N (the global tropical coral reef areas)
- 2x2 degree spatial resolution
- Weekly temporal resolution
- 1- to 24-week lead-times
- Updates once a week

http://coralreefwatch.noaa.gov
NOAA CRW Coral Bleaching Outlook System

CRW SST forecast model

• NOAA ESRL Linear Inverse Modeling (LIM)

• Evolution of tropical SST anomalies (SSTAs) can in large part be represented as a stable, multivariate linear dynamical system maintained by stochastic forcing.
  - Penland and Sardeshmukh (1995)
  - Penland and Matrosova (1998)

\[
\frac{dX}{dt} = BX + \xi
\]

- \(X\): sea surface temperature anomaly

• 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.
ESRL LIM forecast model

Best prediction at time $t + \tau$ is

$$X(t + \tau) = G(\tau) X(t),$$

where

$$G(\tau) = \exp(B\tau) = \langle X(t + \tau)X^\top(t) \rangle \cdot \langle X(t)X^\top(t) \rangle^{-1}$$

- SST anomalies were cast in terms of Empirical Orthogonal Functions (EOFs).
- The leading EOFs are retained in the model and contain most of the observed data.
- Using this compressed description of the data in EOF, LIM was applied to estimate the linear operators giving the best forecast of SSTA.
- Prediction of global tropical SSTAs is made by applying the derived statistical model to the observed initial SSTAs as represented by EOFs from weekly OISST.
ESRL LIM forecast model

- NOAA LIM prediction model for forecasting tropical SSTAs was developed by the Physical Sciences Division (PSD) of NOAA Earth System Research Laboratory.

NOAA/ESRL PSD and CIRES/CDC Forecast in Global Tropics Domain based on January-February-March 2009 initial conditions.

http://www.cdc.noaa.gov/forecasts/sstlim/Frcst.html
CRW SST forecast model

- NOAA ESRL Linear Inverse Model (LIM)
- Based on Principal Components/EOF Analysis
- The leading 30 EOFs are retained for prediction, explaining average 75% of the total variance in the SST time series data
- Weekly Reynolds and Smith Optimum Interpolation SST (OISST) data were used for training the model and are used as model input
NOAA CRW Coral Bleaching Outlook System

30 Leading EOFs

Fig. 1 Range of the SST anomaly for the years 1981-2007. Contour interval 0.3.
Skill Analysis for SST Prediction

Correlation Coefficients between actual SST anomalies and their predictions.

1982-2007 (26 years)

Only values significant at 95% level are shown.

http://coralreefwatch.noaa.gov
CRW Operational Bleaching HotSpots and Degree Heating Weeks (DHW) Nowcasting

Bleaching threshold (MMMSST+1°C) Maximum Monthly Mean SST Climatology (MMMSST)

Based on Glynn and D’Croz (1990)

1 DHW = 1°C above maximum monthly mean for 1 week

≥ 4 DHWs → wide-spread coral bleaching is expected

≥ 8 DHWs → wide-spread severe bleaching is expected

http://coralreefwatch.noaa.gov
SST and Bleaching Thermal Stress Forecast

Prediction for July 17-23, 2008 (4-week lead-time)

SST Prediction

Bleaching HotSpot Prediction

DHW = 12-week accumulation of HotSpots (≥ threshold)

Bleaching Degree Heating Weeks

http://coralreefwatch.noaa.gov
SST and Bleaching Thermal Stress Forecast

Prediction for July 17-23, 2008 (4-week lead-time)

HotSpot forecast

DHW forecast

Bleaching Outlook

Potential Bleaching  Potential Widespread Bleaching  Potential Severe Bleaching

http://coralreefwatch.noaa.gov
Weekly Bleaching Outlook

1-week leadtime
2-week leadtime
3-week leadtime

N-week leadtime (currently up to 18 weeks)

Seasonal Bleaching Outlook

http://coralreefwatch.noaa.gov
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2001-2004 Austral Bleaching Season (Jan-Apr)

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - Apr 2001

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - Apr 2003

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - Apr 2002

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - Apr 2004

Potential Bleaching  | Potential Widespread Bleaching  | Potential Severe Bleaching

Bleaching Outlook  | HotSpot  | DHW

http://coralreefwatch.noaa.gov
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2005-2008 Austral Bleaching Season (Jan-Apr)

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - May 2005

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - Apr 2007

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - Apr 2008

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jan - Apr 2009

Bleaching Outlook vs HotSpot/DHW Observations

Temperature Scale: 0.0 - 56.0°C

Potential Bleaching: 0.0 - 2.0
Potential Widespread Bleaching: 2.5 - 5.0
Potential Severe Bleaching: 5.5 - 8.0

HotSpot/DHW Observations: 0 - 16
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2001-2004 Boreal Bleaching Season (July-Oct)
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2005-2008 Boreal Bleaching Season (July-Oct)

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jul - Oct 2005

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jul - Oct 2007

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jul - Oct 2006

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook for Jul - Oct 2008

Bleaching Outlook

HotSpot

DHW
Noaa CRW Coral Bleaching Outlook System

http://coralreefwatch.noaa.gov/satellite/bleachingoutlook
http://coralreefwatch.noaa.gov

Announced July 2008

- Outlook message will usually be updated once a month
- Outlook maps will usually be updated once a week
Bleaching Outlook for Jul-Oct 2008

NOAA/NESDIS Degree Heating Weeks for last 12 Weeks – 11/13/2008

http://coralreefwatch.noaa.gov
Current Bleaching Outlook for Jun-Sept 2009

Animation

NOAA Coral Reef Watch Coral Bleaching Thermal Stress Outlook: 2–Week forecast for Jul 05 2009

Potential Bleaching
Potential Widespread Bleaching
Potential Severe Bleaching

http://coralreefwatch.noaa.gov
Thermal Stress Causes Mass Coral Bleaching and Mortality

What can bleaching outlook help?

[Image: Coral reef with bleached and healthy corals]
Reduce Local Stressors

- Driven by US Coral Reef Task Force
- Result of international workshop, research, and planning
- Addresses local reef management in light of changing climate

Availabe at coralreef.noaa.gov

http://coralreefwatch.noaa.gov
Short-term Opportunities for Coral Bleaching Management

Local managers can:

- Reduce bleaching
  - Reduce light stress
  - Cool reefs, increase mixing

[http://coralreefwatch.noaa.gov]
Short-term Opportunities for Coral Bleaching Management

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Small yet economically important effect

Quicksilver Connections

http://coralreefwatch.noaa.gov
Short-term Opportunities for Coral Bleaching Management

Local managers can:

• Reduce bleaching
  • Reduce light stress
  • Cool reefs, increase mixing

• Increase survival
  • Improve water quality
  • Reduce disease prevalence

http://coralreefwatch.noaa.gov
Short-term Opportunities for Coral Bleaching Management

Local managers can:

- Reduce bleaching
  - Reduce light stress
  - Cool reefs, increase mixing

- Increase survival
  - Improve water quality
  - Reduce disease prevalence

- Aid recovery
  - Coral fragmentation
  - Encourage recruitment
  - Protect ecosystem functions (herbivory)

http://coralreefwatch.noaa.gov
Conclusions and Future Work

First-ever bleaching forecast tool

SST prediction skill highest in central and eastern Pacific Ocean and Caribbean

Performs best in the Caribbean and Great Barrier Reef

Provides general patterns of potential bleaching
- enables managers and scientists to prepare

Further evaluate and analyze skill and improve accuracy

Next: Application of NOAA operational Climate Forecast System

http://coralreefwatch.noaa.gov
Tropical SST Outlooks - Multiple Models

- NOAA and other groups produce dynamical and empirical SST outlooks for the global tropics from weeks to seasons in the future.

- These tropical SST outlooks are critical for the operational seasonal forecast guidance products for US Temperature and Precipitation.

- Goal is to transform this multidecadal investment to improve SST prediction into a decision support resources for coral reef management.

Forecasts made June 2009

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