Global Forecasting of Coral Bleaching Events

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2

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

Coral Reef and Coral

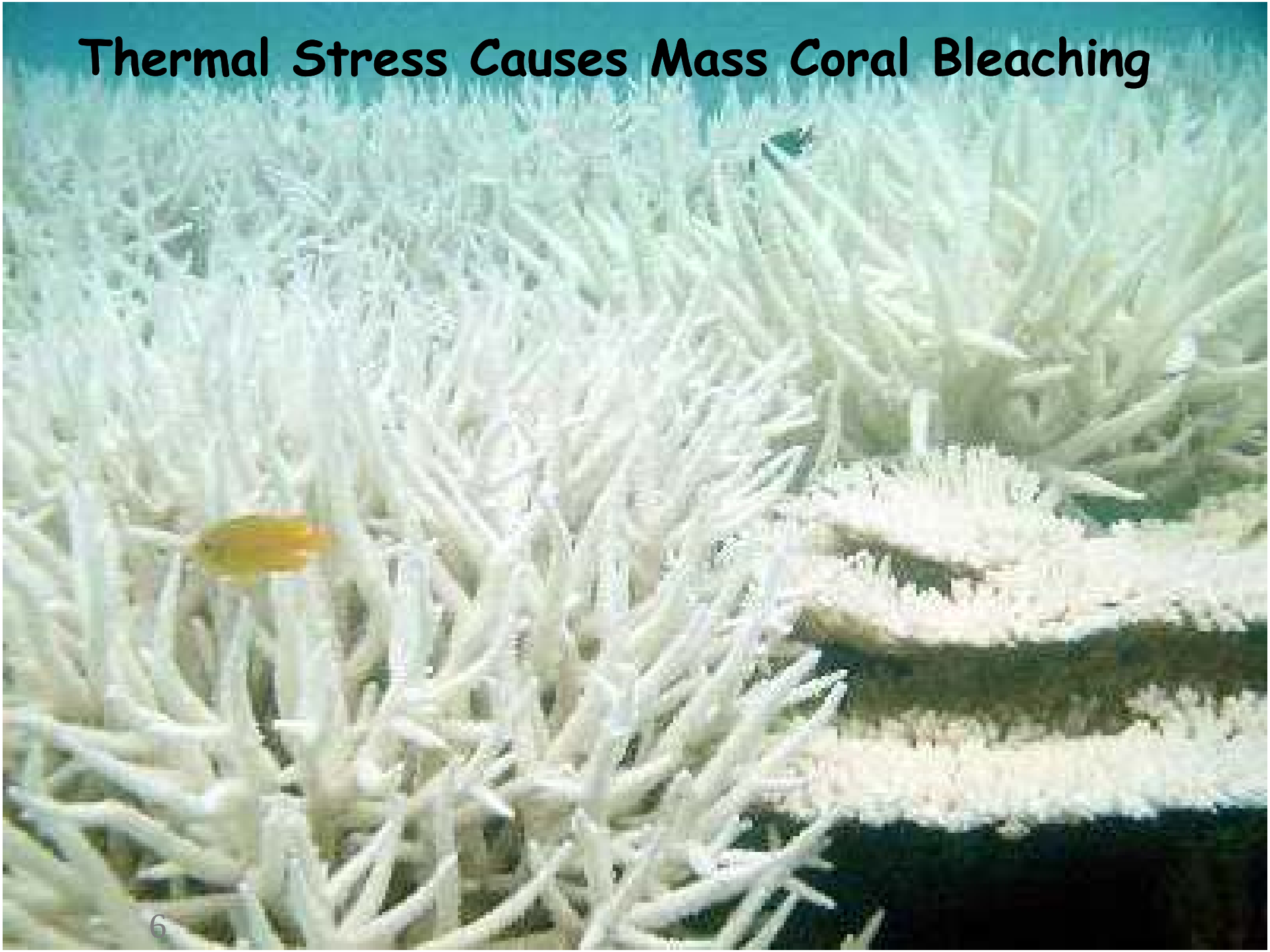
Well developed coral reef ecosystem takes hundreds to thousands of years to build.

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

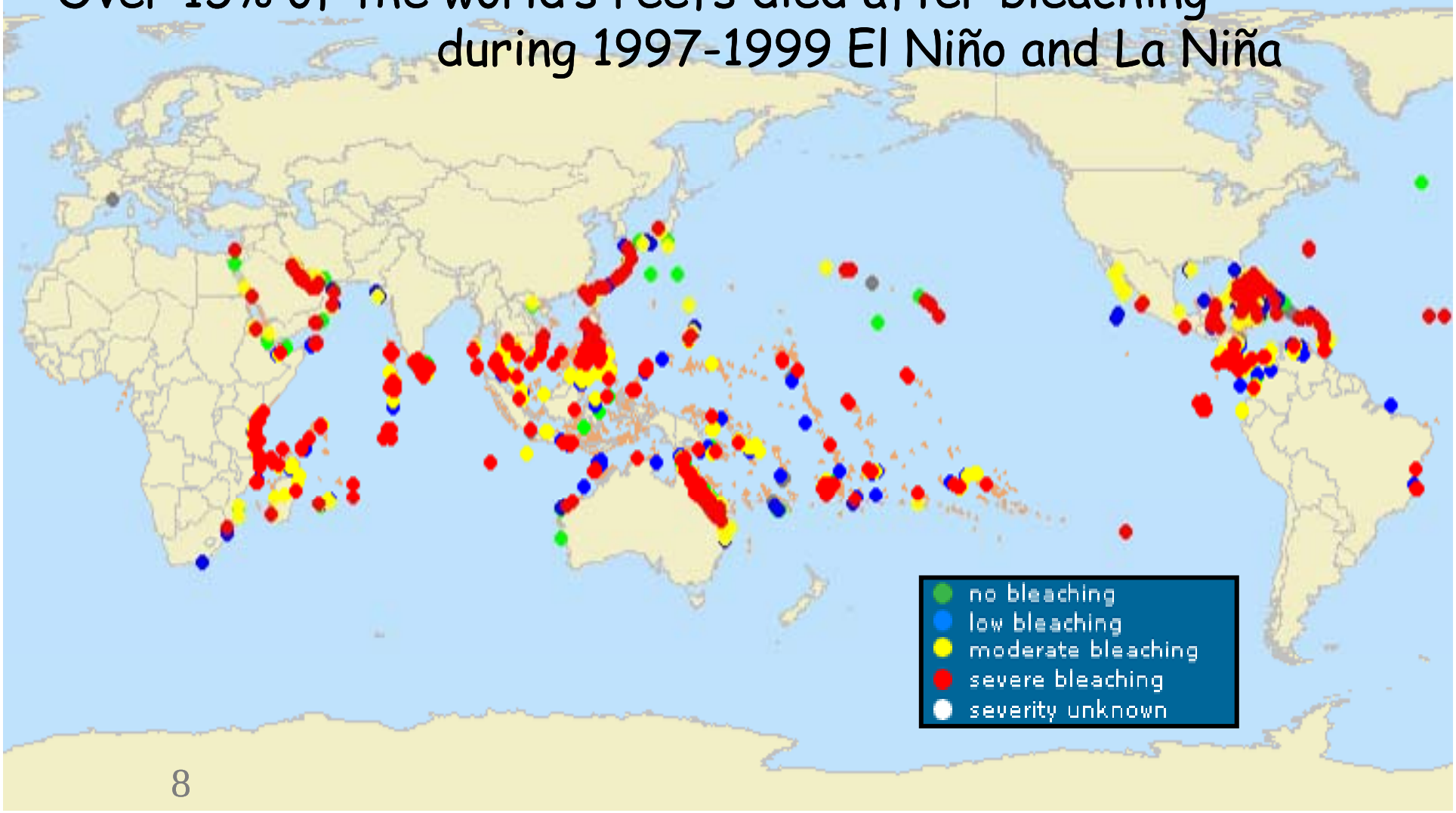
Thermal Stress Causes Mass Coral Bleaching



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

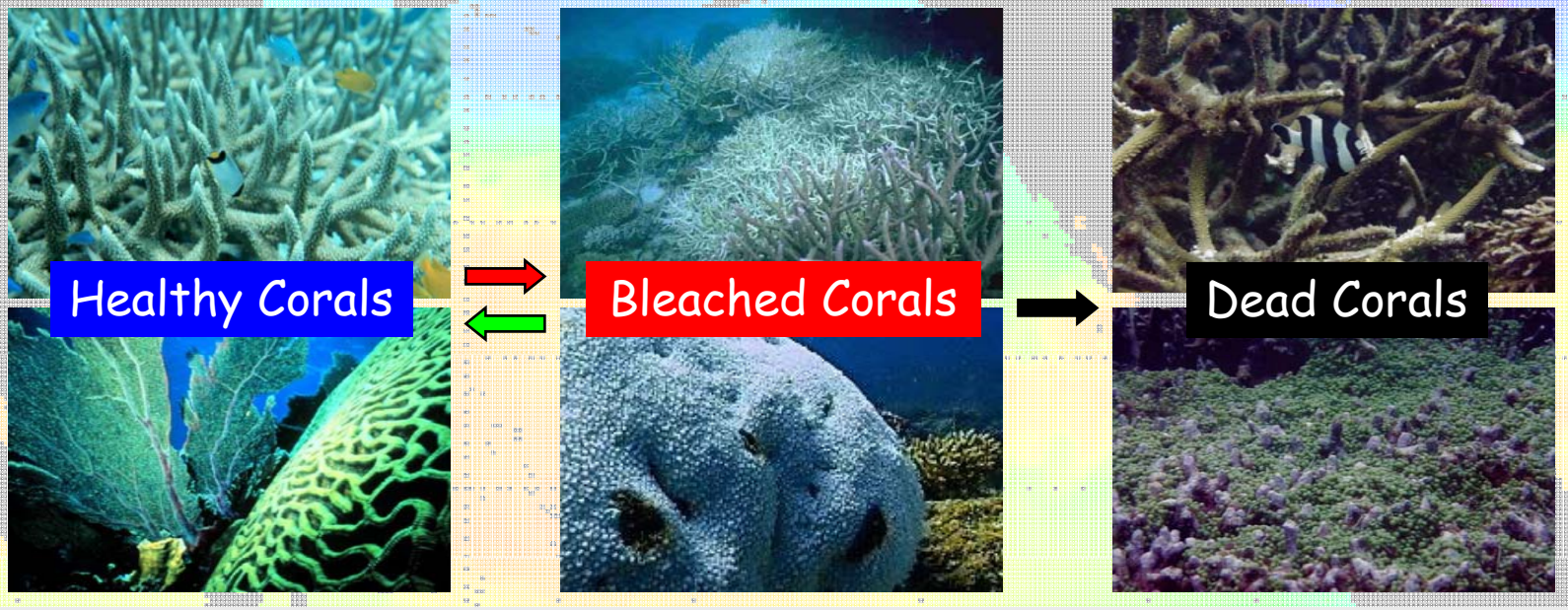


Wide Range of Coral Reef Threats

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

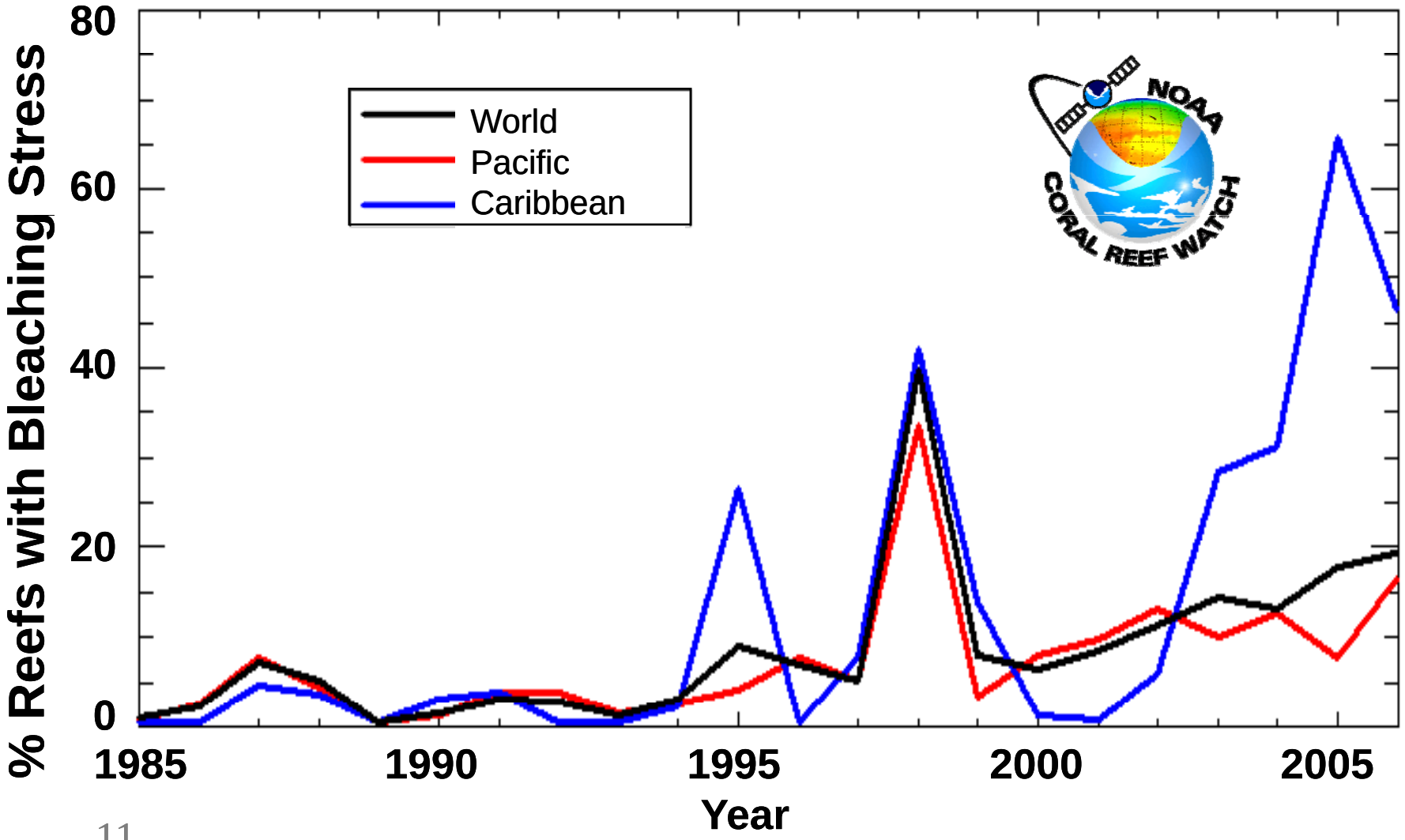
2004 Survey: 276 Coral Reef Scientists
Kleypas and Eakin (2007, Bull. Mar. Sci.)

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

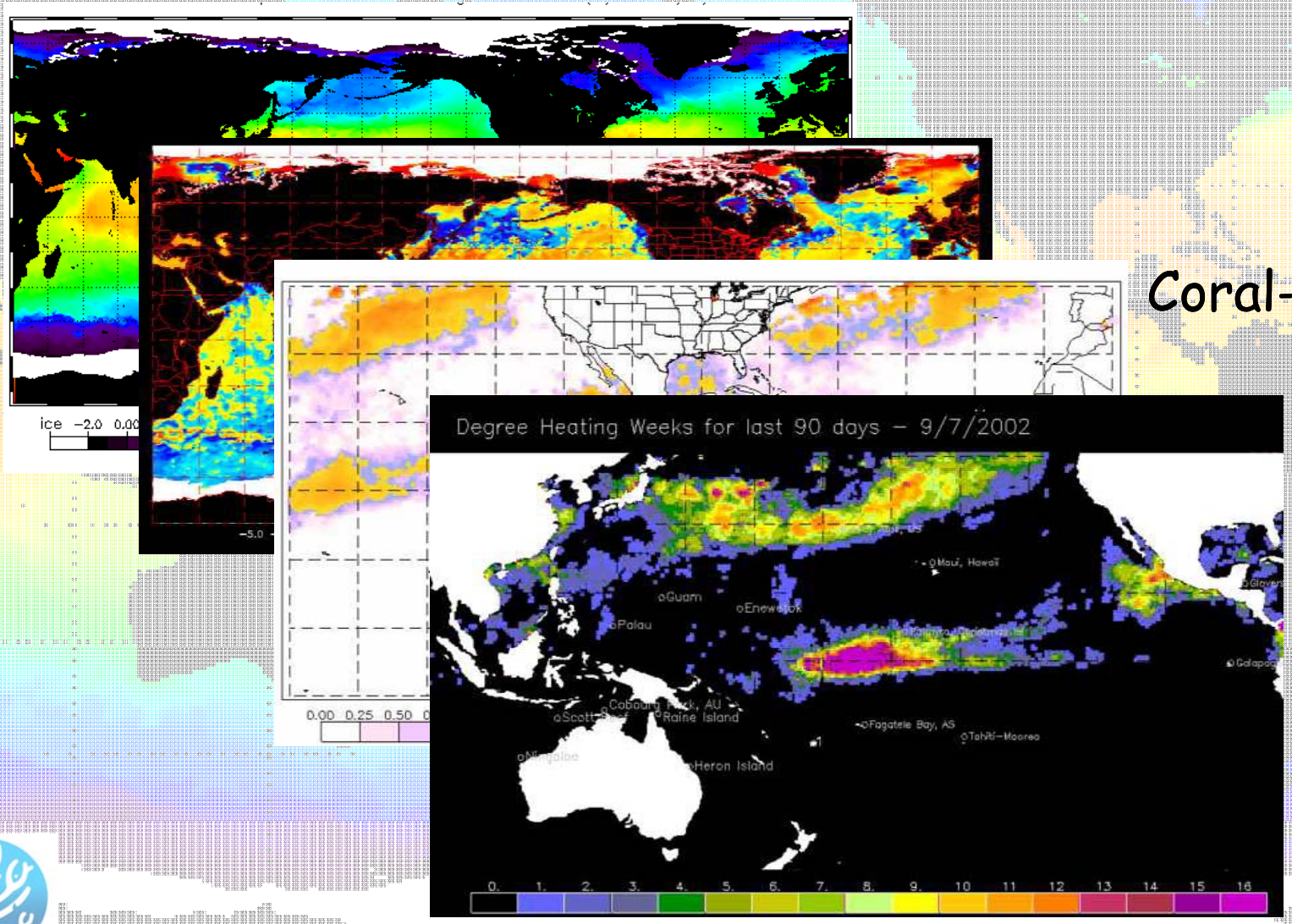
Highest Thermal Stress Recorded?



Overview

- Structure of existing bleaching products
- SST forecast model
- Building the bleaching outlook
- Testing the bleaching outlook

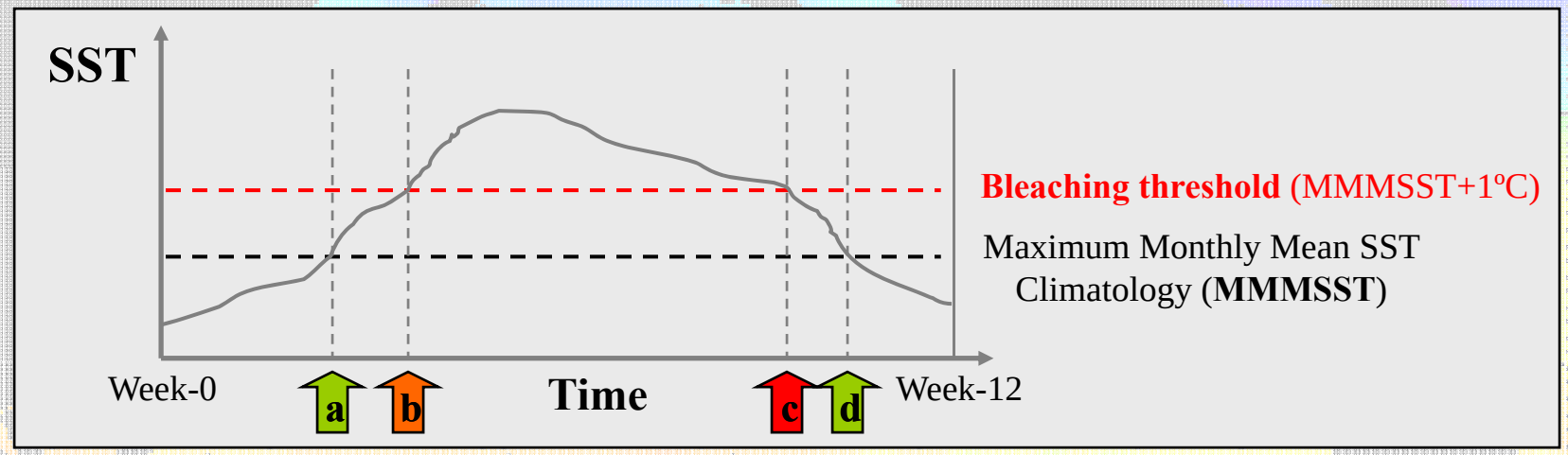
NOAA Coral Reef Watch
Satellite-based Products

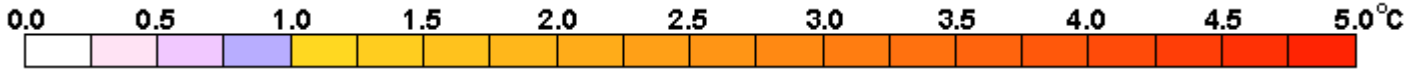


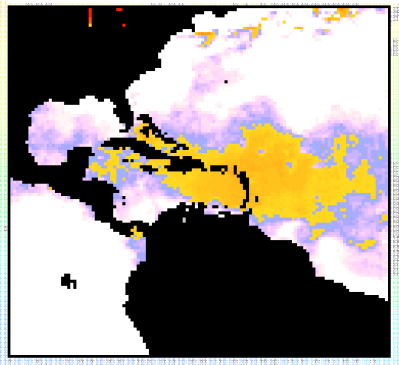
Coral-specific

Thermal Stress -- Degree Heating Weeks

CRW Operational Bleaching HotSpots and Degree Heating Weeks (DHW) Nowcasting



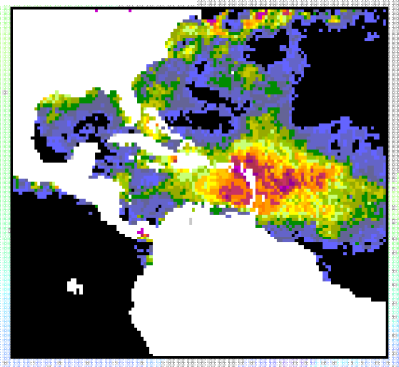




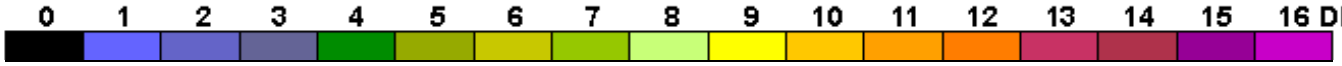
HotSpots

12 weeks

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



Degree Heating Weeks



≥ 4 DHWs → coral bleaching is expected

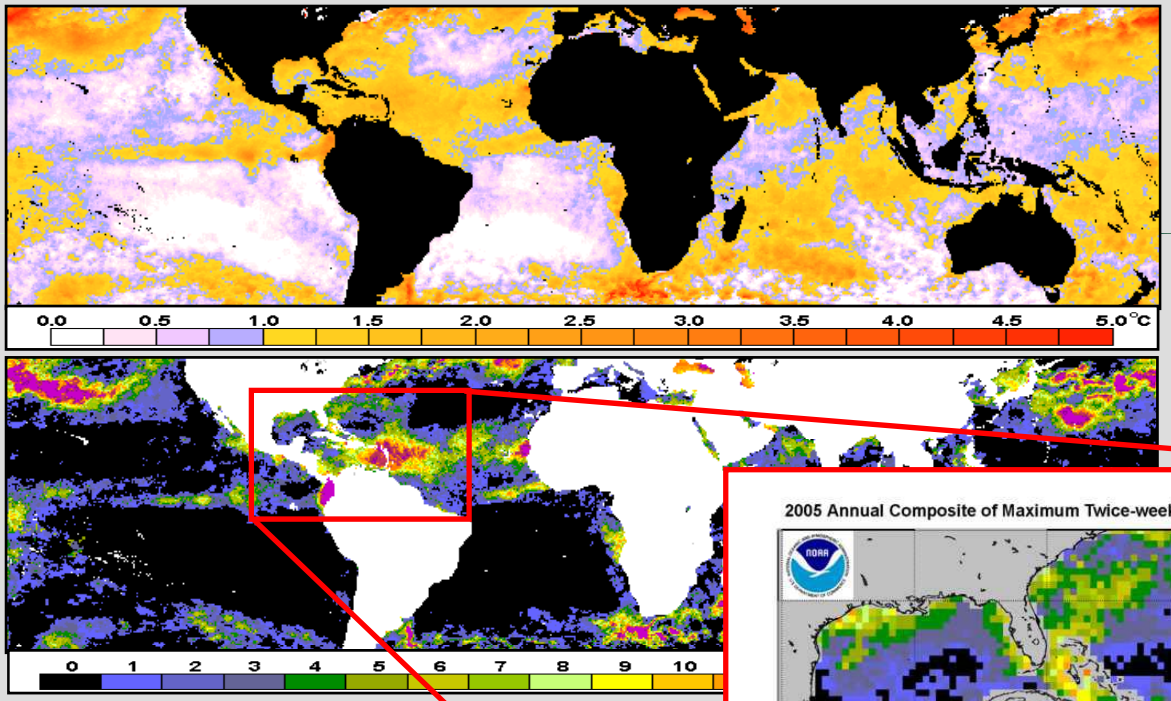
≥ 8 DHWs → mass bleaching and mortality are expected

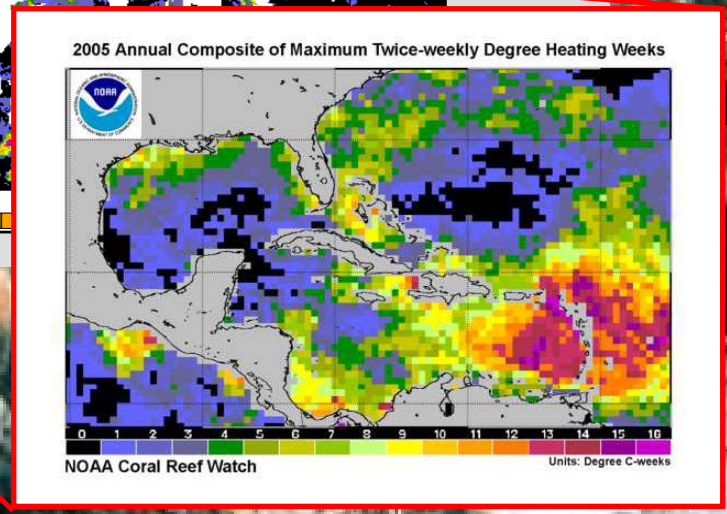
http://coralreefwatch.noaa.gov

2005 Mass Coral Bleaching in the Caribbean

(A record-breaking event)

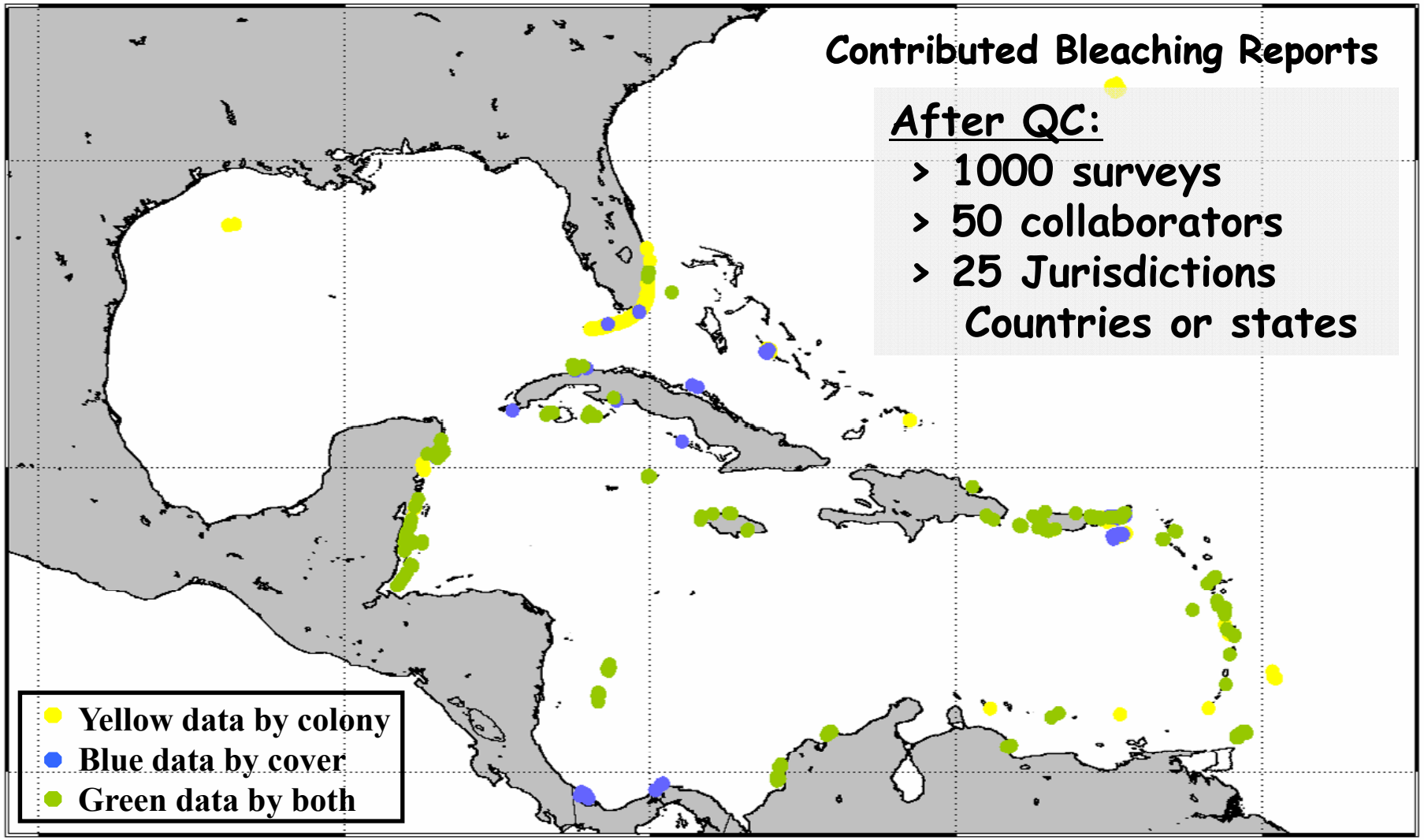
Coral Reef Watch's 2005 Annual Maximum HotSpot and Degree Heating Weeks



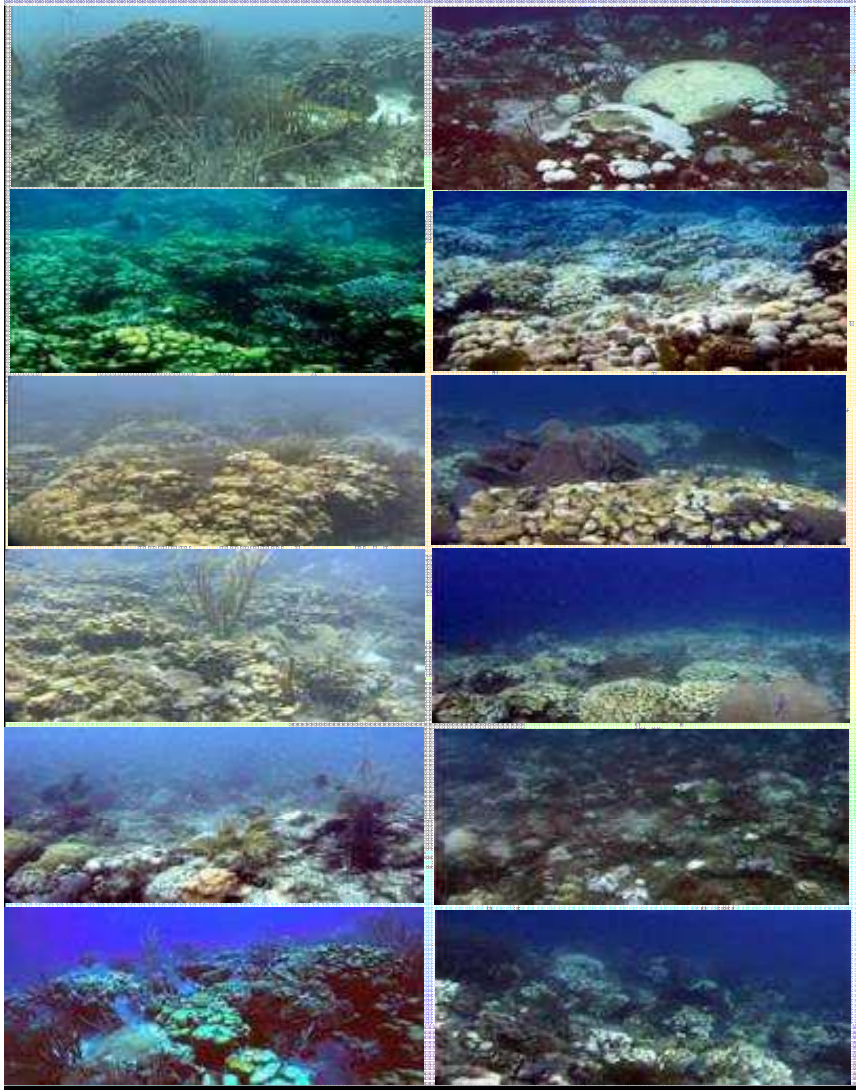


NOAA CORAL REEF CONSERVATION PROGRAM

2005 Mass Coral Bleaching in the Caribbean



2005 Coral Bleaching Surveys -Virgin Islands N.P.



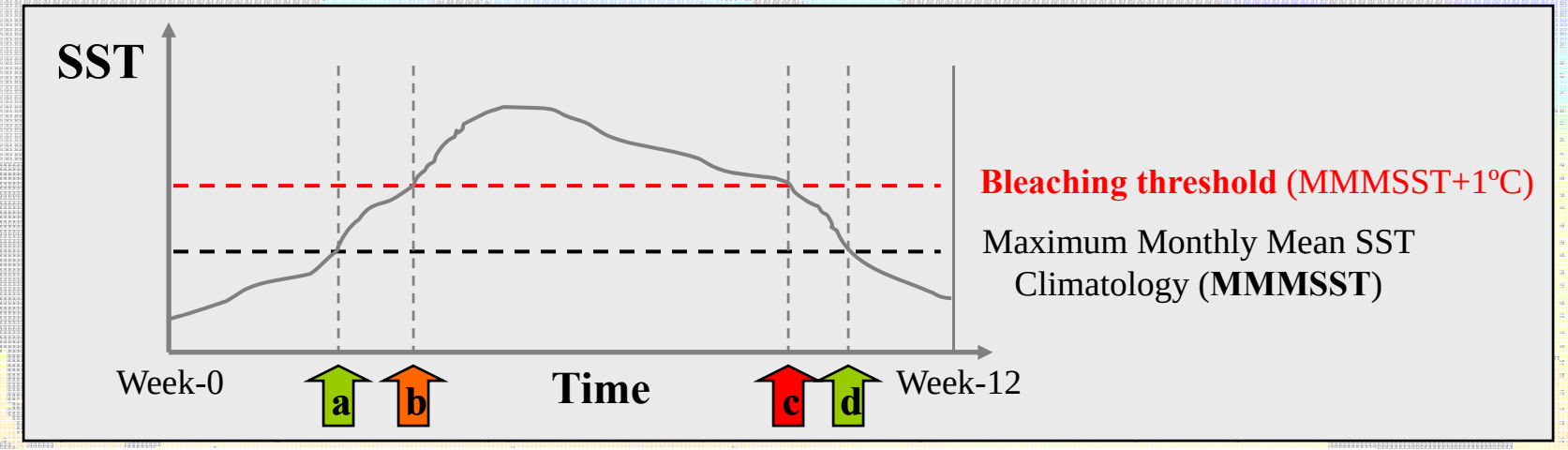
6 sites

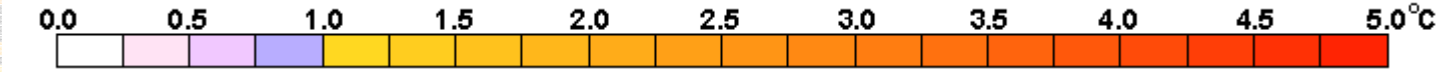
>90% coral cover bleached

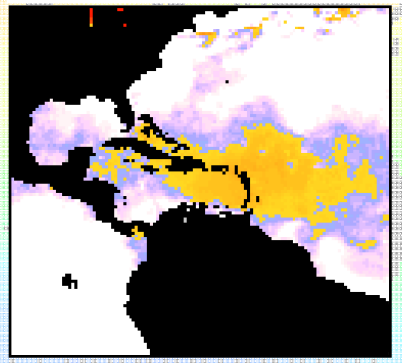
>60% coral cover dead

J. Miller (unpublished)

CRW Operational Bleaching HotSpots and Degree Heating Weeks (DHW) Nowcasting

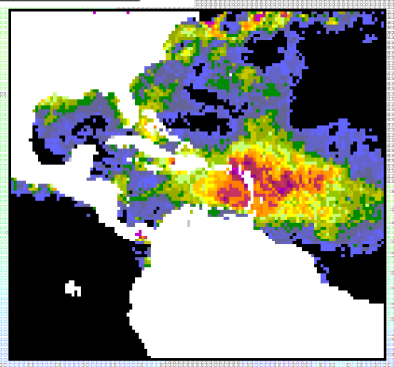




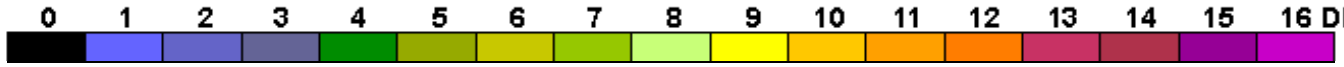


HotSpots

12 weeks
Σ (HotSpot value × duration)
≥ 1°C



Degree Heating Weeks



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≥ 8 DHWs → mass bleaching and mortality are expected

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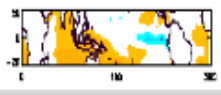
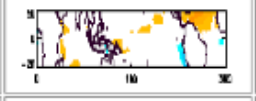
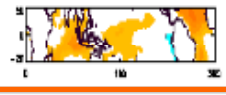
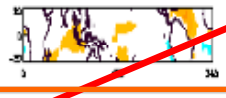
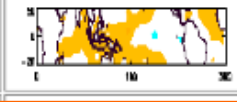
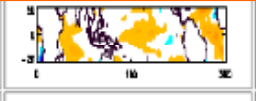
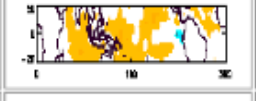
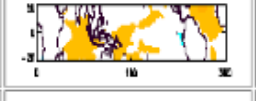
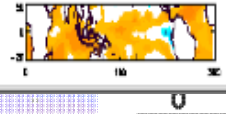
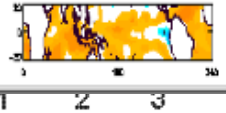
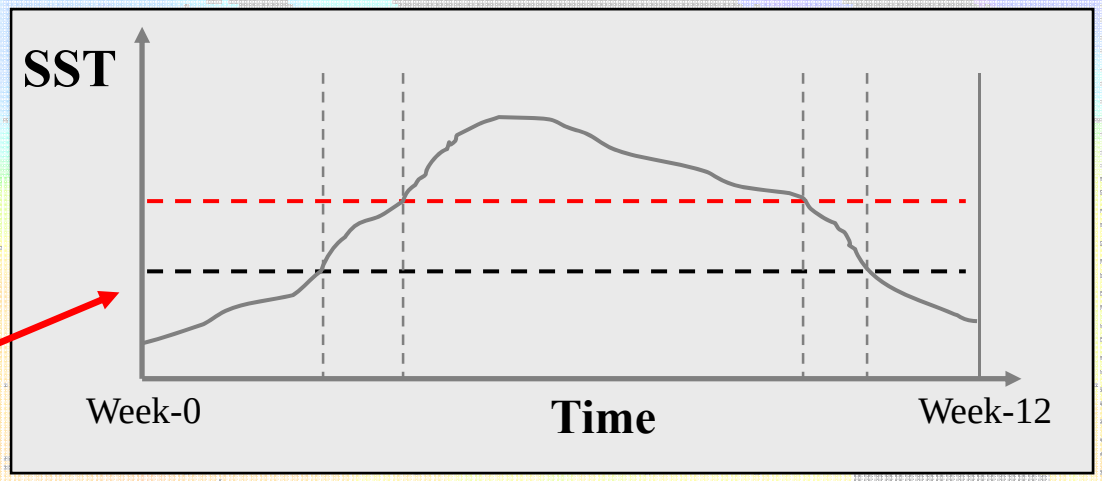
Proposed Bleaching HotSpots and Degree Heating Weeks (DHW) Forecasting

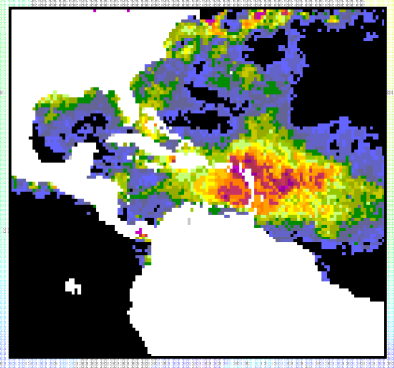
Forecasts made 1 April 2005

SST Forecast	MJJ	ASO
CCA Method		
NCEP Model		
IRI Model		
Linear Model		
NSIPP Model		
CPC Constructed Analog		
Average of 6 Forecasts		
Persistence		

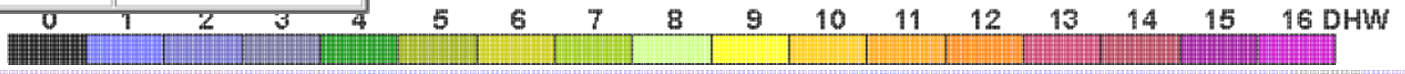


HotSpot from Forecasts

$$\sum_{12\ \text{weeks}} (\text{HotSpot value} \times \text{duration}) \quad \geq 1^{\circ}\text{C}$$



Degree Heating Weeks



≥ 4 DHWs → coral bleaching is expected

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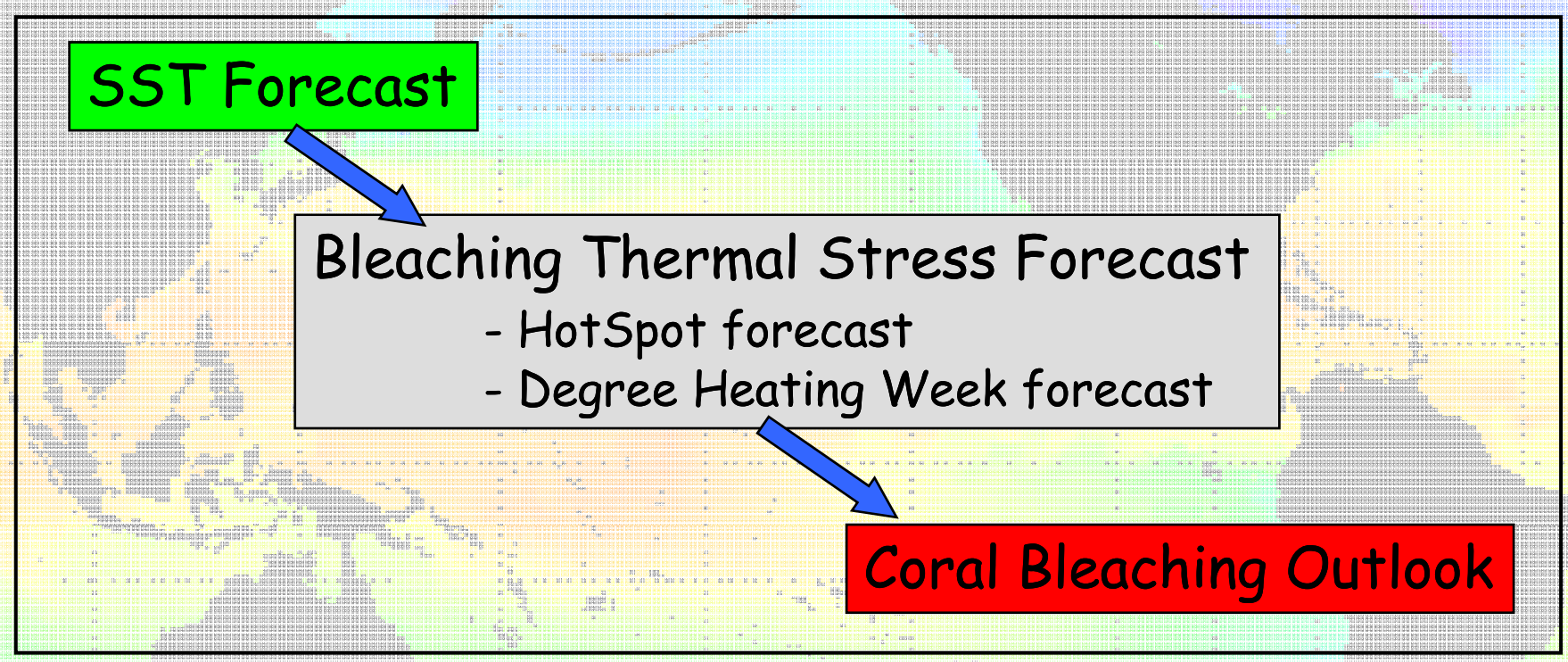
NOAA CRW Coral Bleaching Outlook System



Collaboration between

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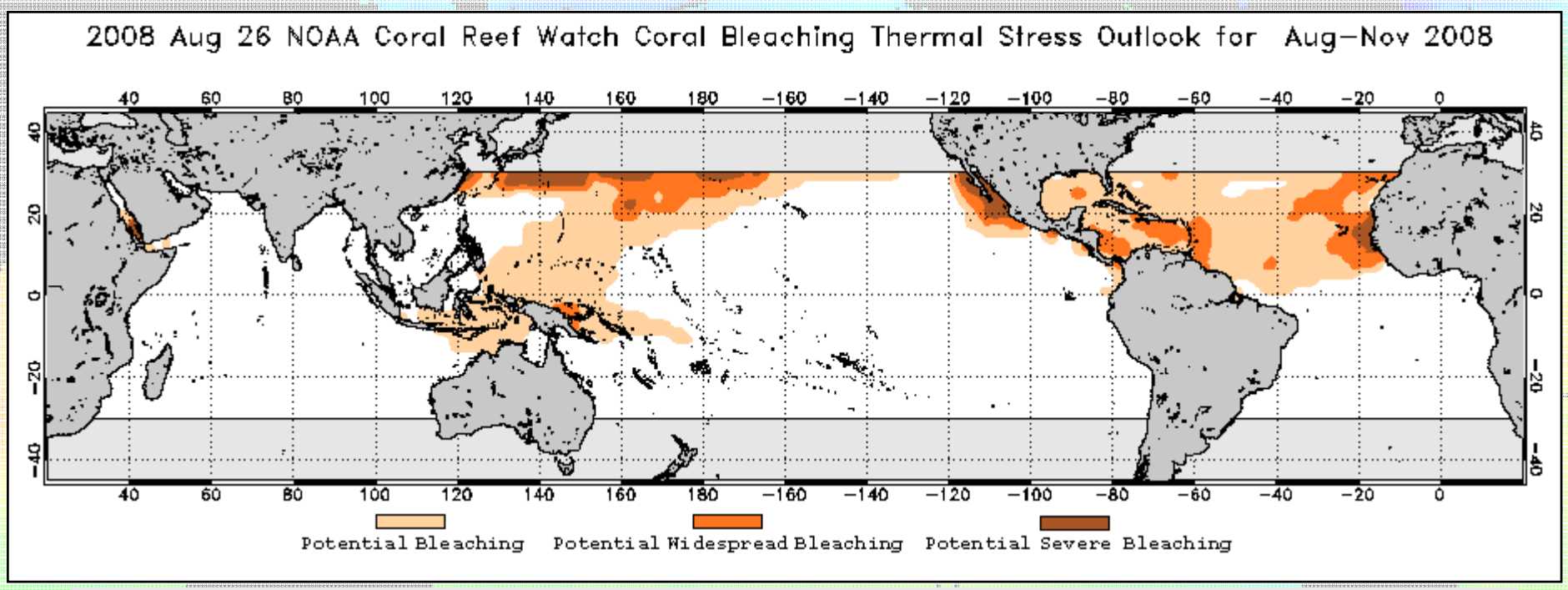


A global tropical ocean prediction system (Released in July 2008)

- 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)

$$dX/dt = \mathbf{B}X + \xi$$

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.

NOAA CRW Coral Bleaching Outlook System

ESRL LIM forecast model

Best prediction at time $t + \tau$ is

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

where

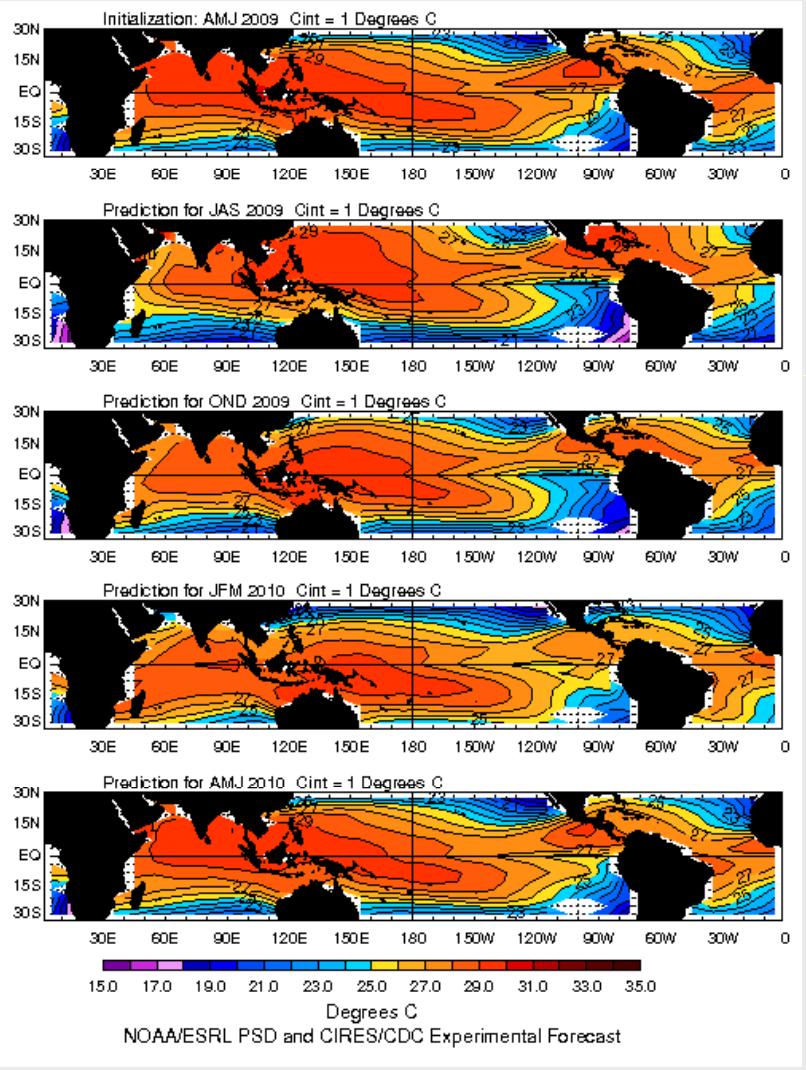
$$G(\tau) = \exp(B\tau)$$
$$= \langle X(t+\tau)X^{\top}(t)\rangle \langle X(t)X^{\top}(t)\rangle^{-1}$$

- 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.

NOAA CRW Coral Bleaching Outlook System

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



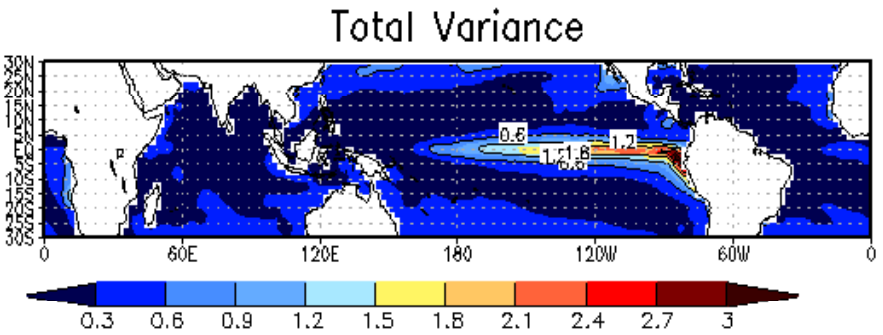
NOAA/ESRL PSD and CIRES/CDC Forecast in Global Tropics Domain based on January-February-March 2009 initial conditions.

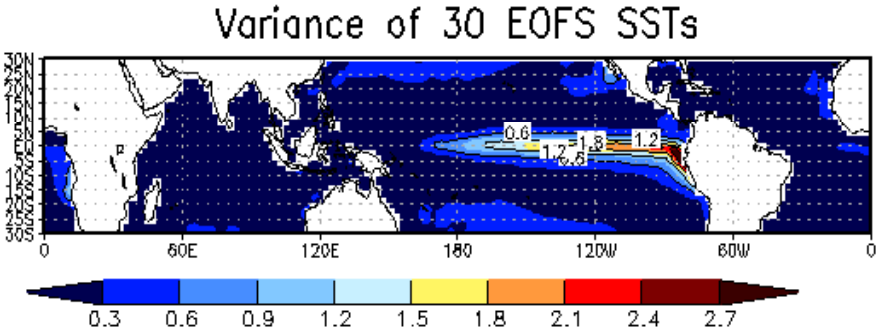
http://www.cdc.noaa.gov/forecasts/sstlim/Frcst.html

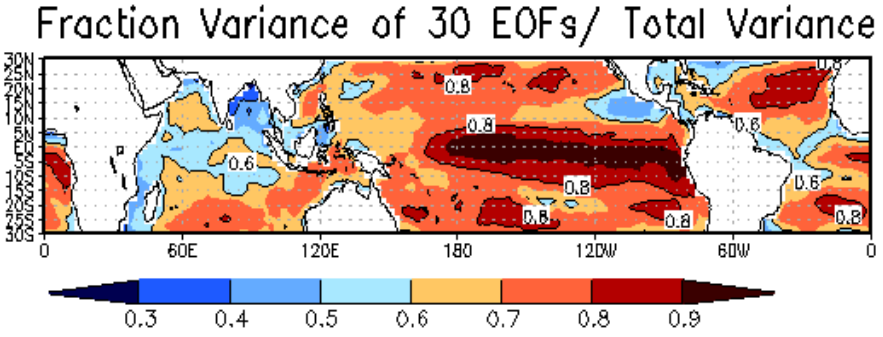
NOAA CRW Coral Bleaching Outlook System

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

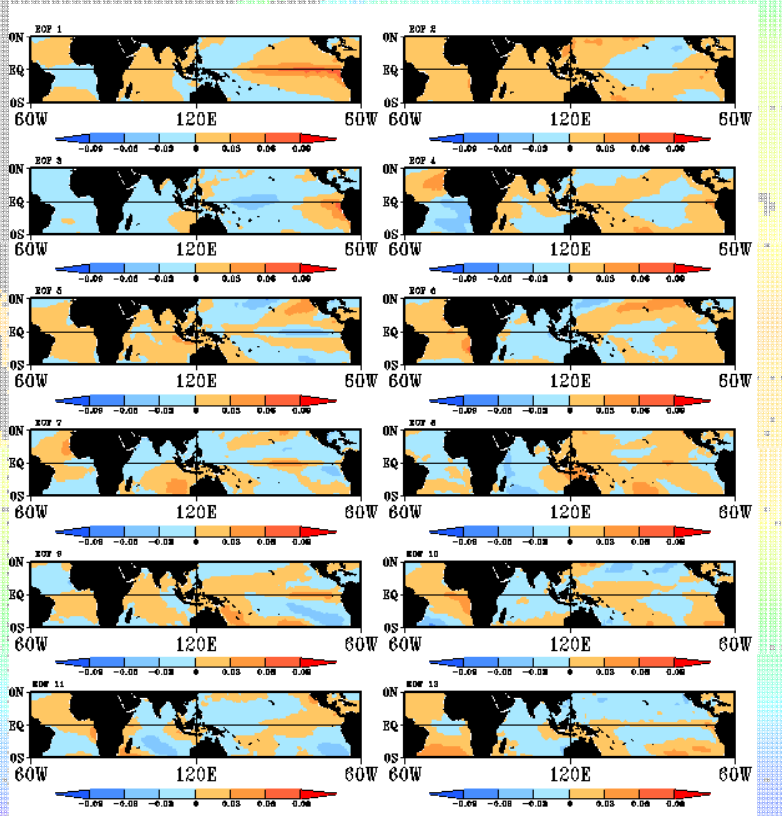
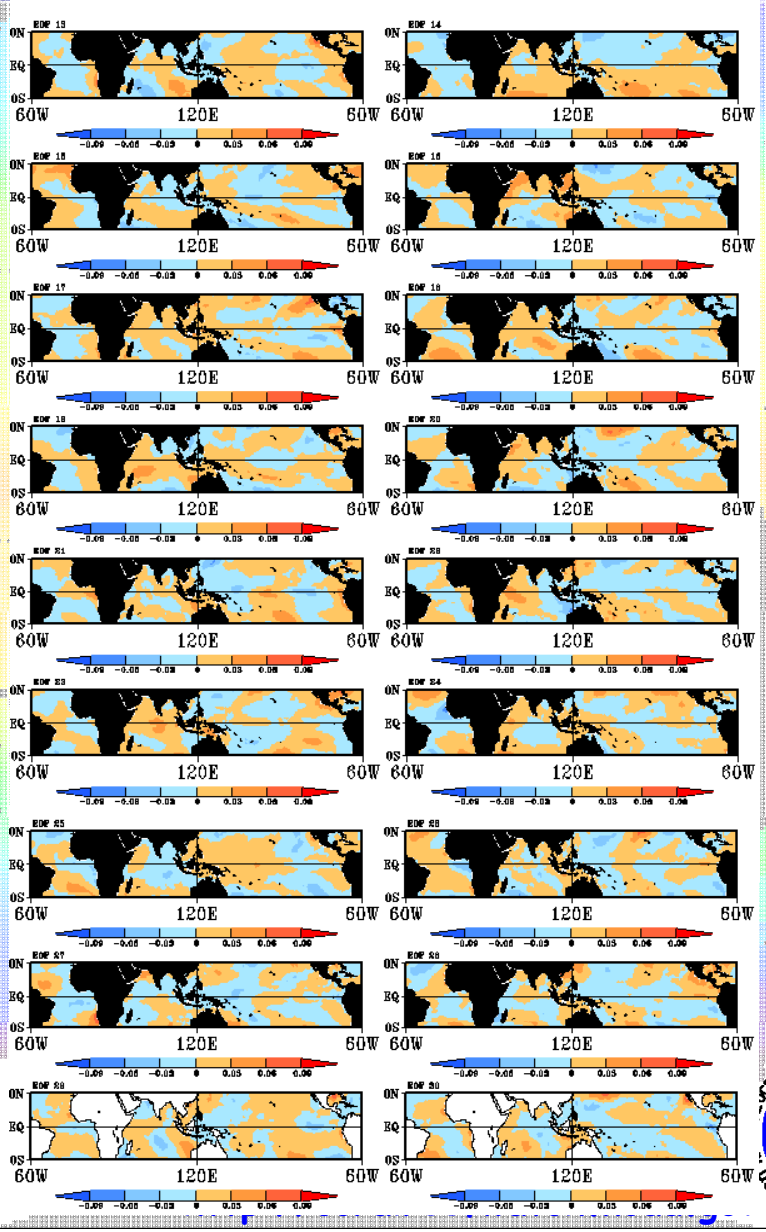
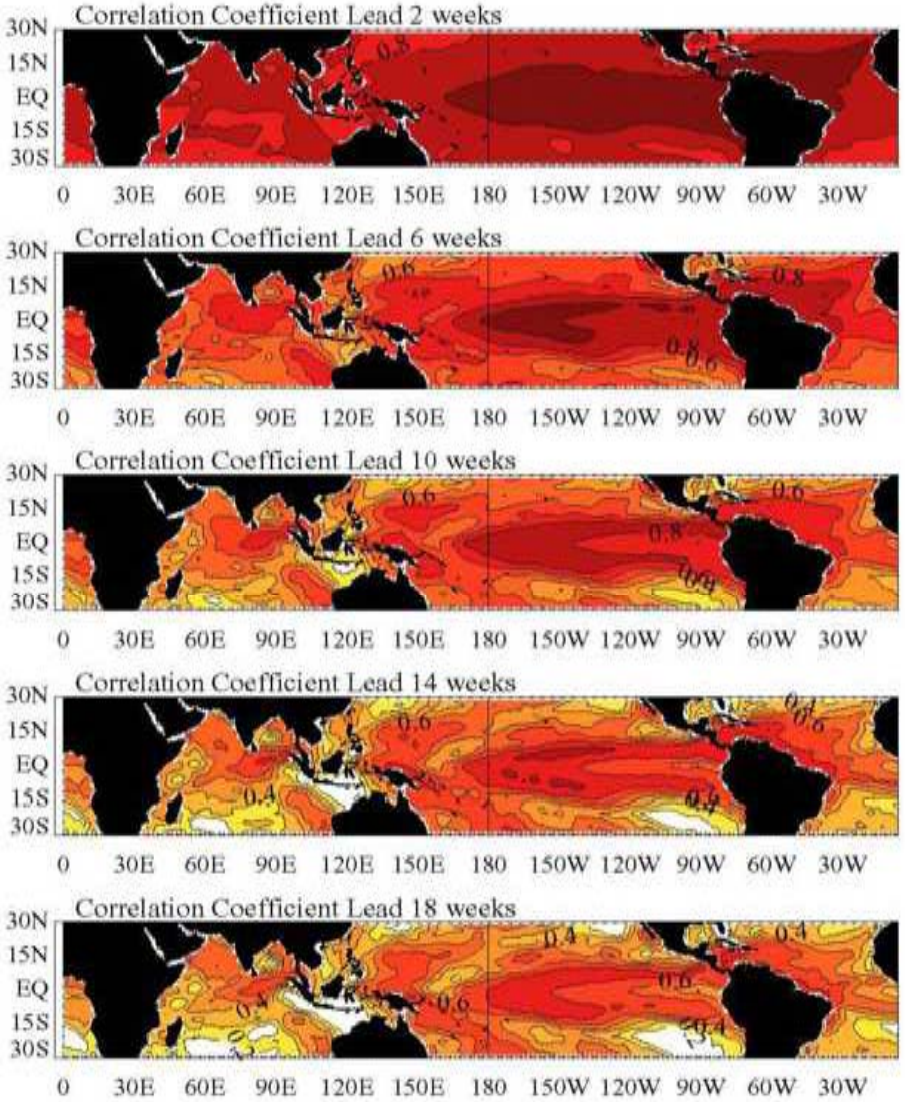


Fig.1 EOFs of the SSTA weekly (OI 1981-2007). Contour interval: 0.03.



Skill Analysis for SST Prediction



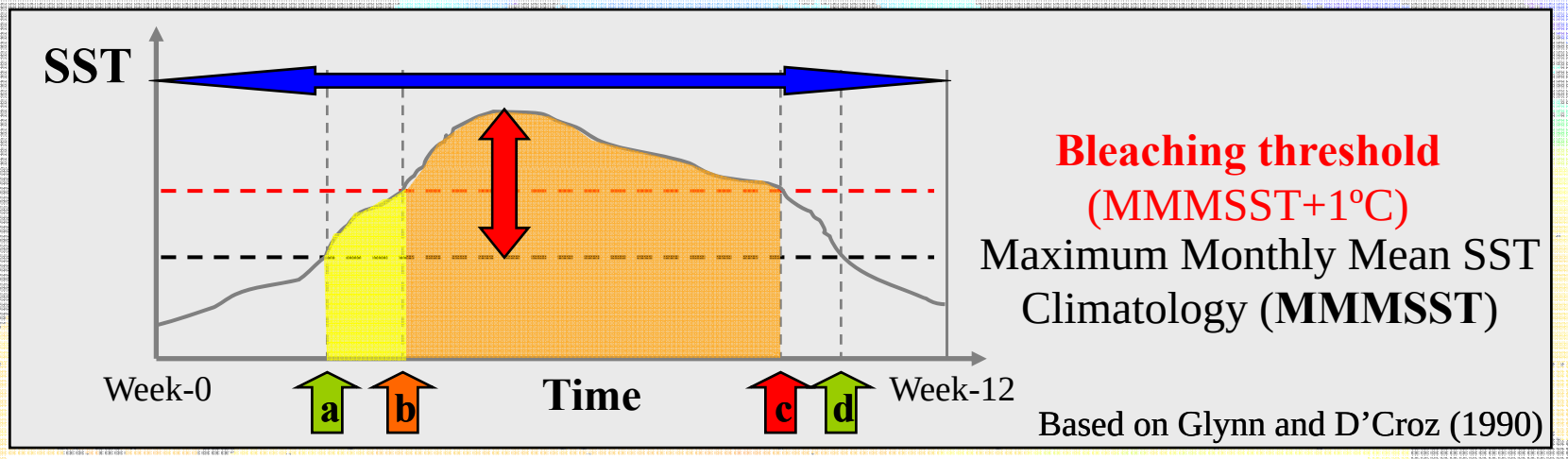
Correlation Coefficients between actual SST anomalies and their predictions.

1982-2007 (26 years)

Only values significant at 95% level are shown.

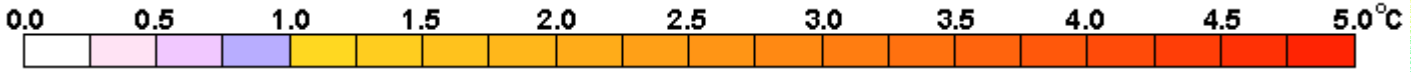
http://coralreefwatch.noaa.gov

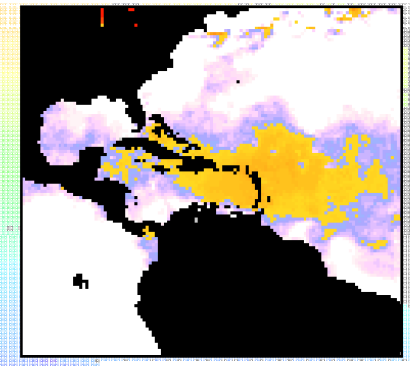
CRW Operational Bleaching HotSpots and Degree Heating Weeks (DHW) Nowcasting



Bleaching threshold
(MMMSST+1ºC)
Maximum Monthly Mean SST Climatology (**MMMSST**)

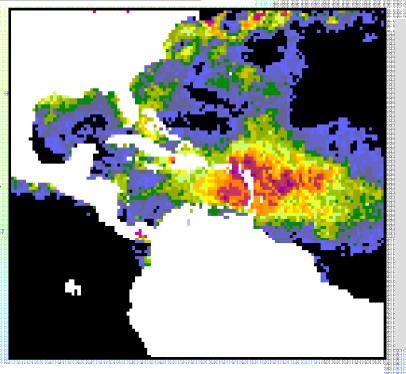
Based on Glynn and D'Croz (1990)



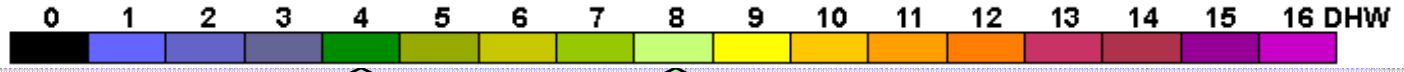


HotSpots **Degree Heating Weeks**

12 weeks
Σ (HotSpot value **x** duration)
≥ 1°C



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



≥ 4 DHWs → wide-spread coral bleaching is expected

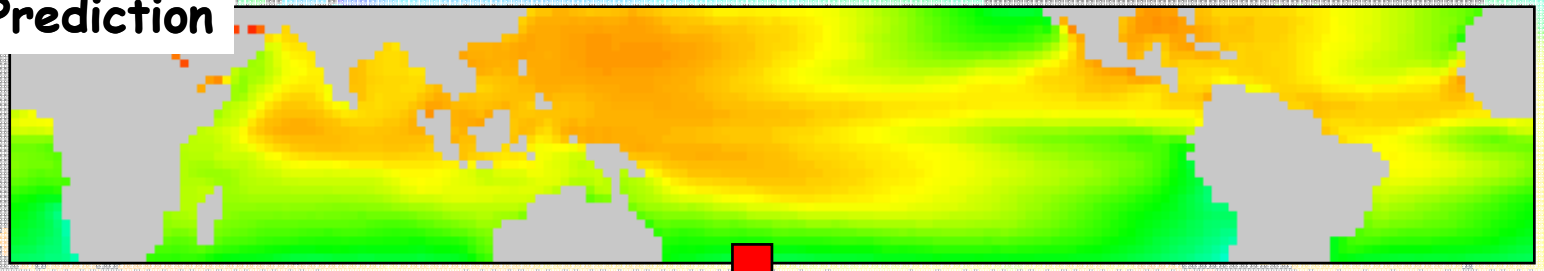
≥ 8 DHWs → wide-spread severe bleaching is expected

http://coralreefwatch.noaa.gov

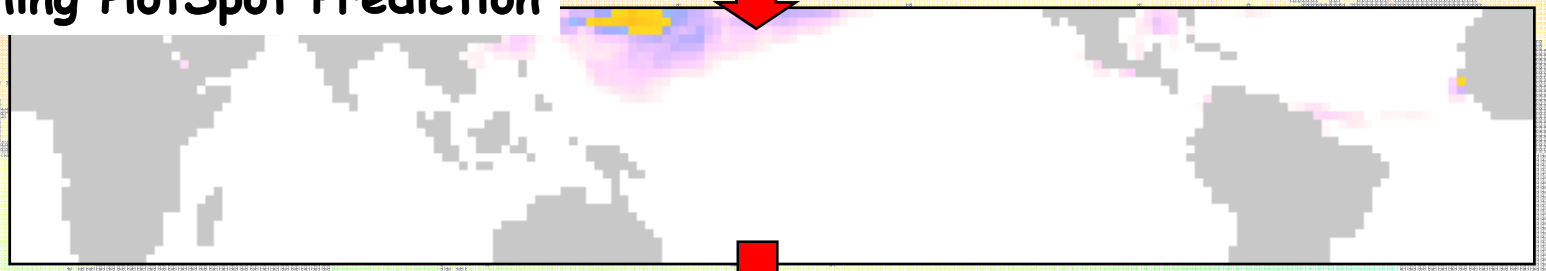
SST and Bleaching Thermal Stress Forecast

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

SST Prediction



Bleaching HotSpot Prediction



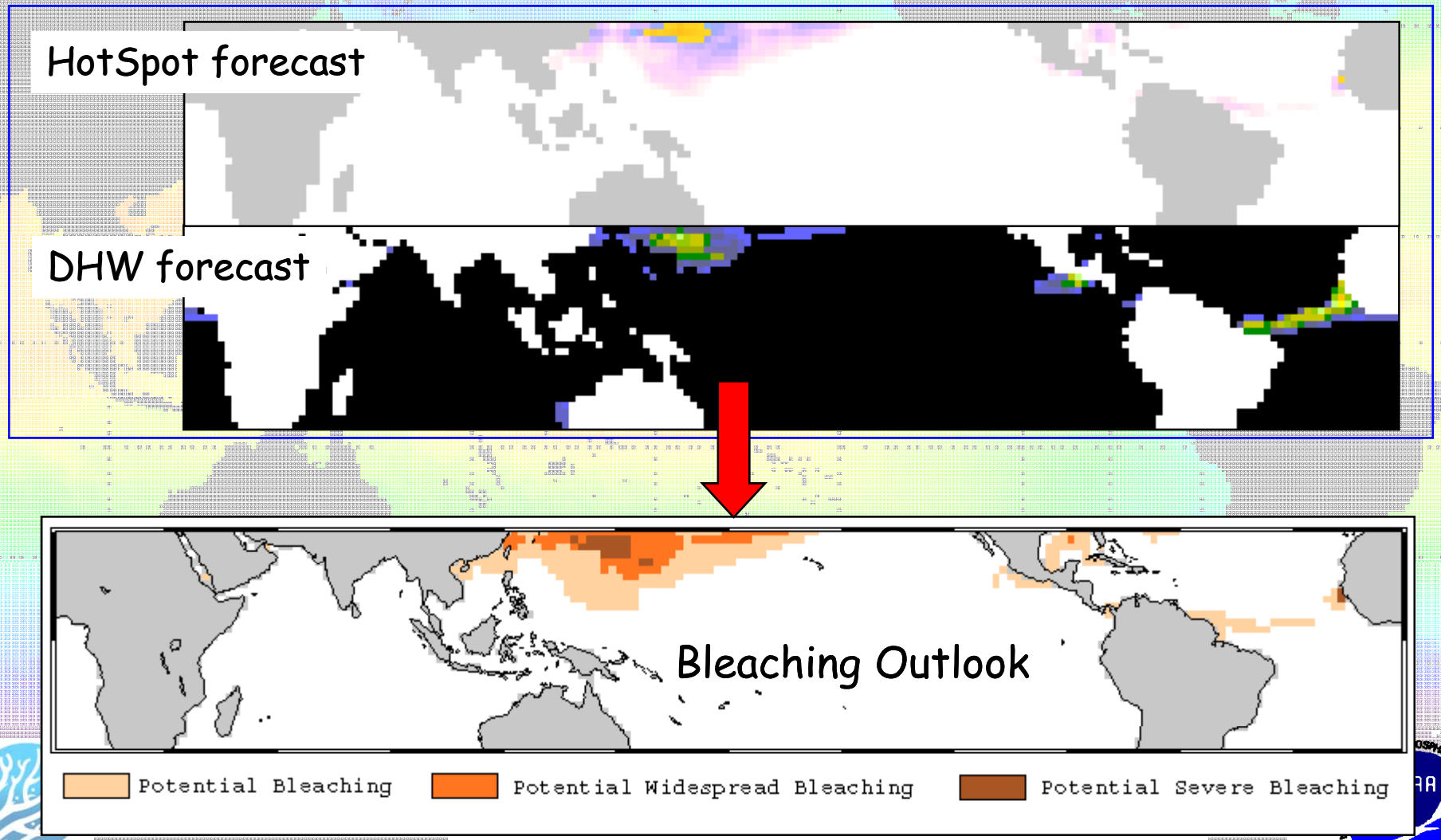
DHW = 12-week accumulation of HotSpots (≥ threshold)

Bleaching Degree Heating Weeks

http://coralreefwatch.noaa.gov

SST and Bleaching Thermal Stress Forecast

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

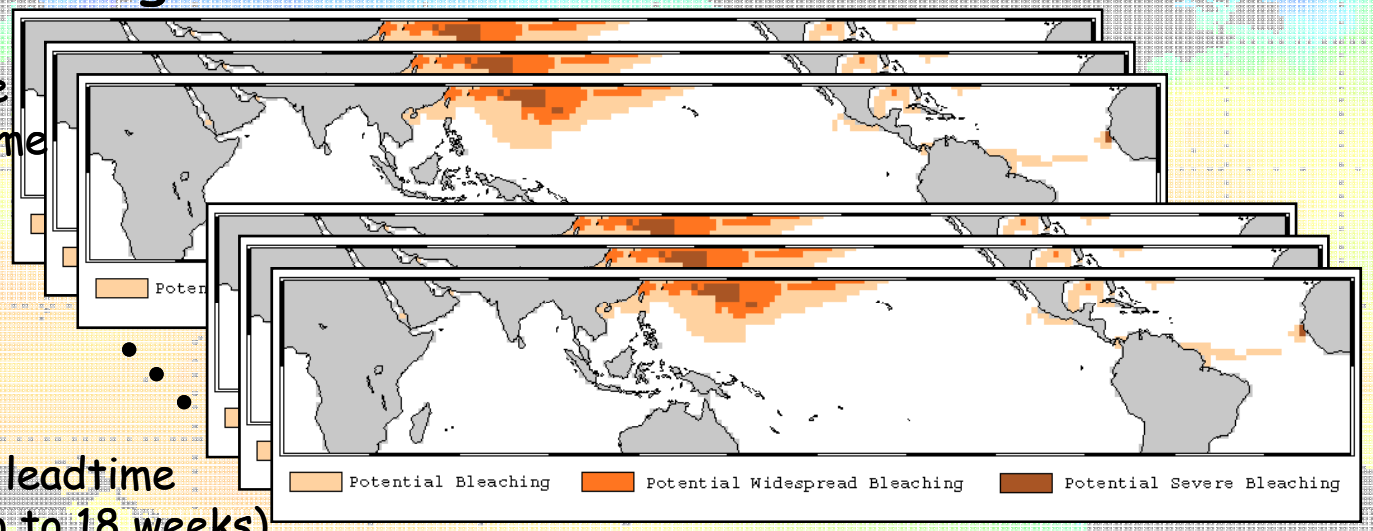


http://coralreefwatch.noaa.gov

NOAA CRW Seasonal Bleaching Outlook

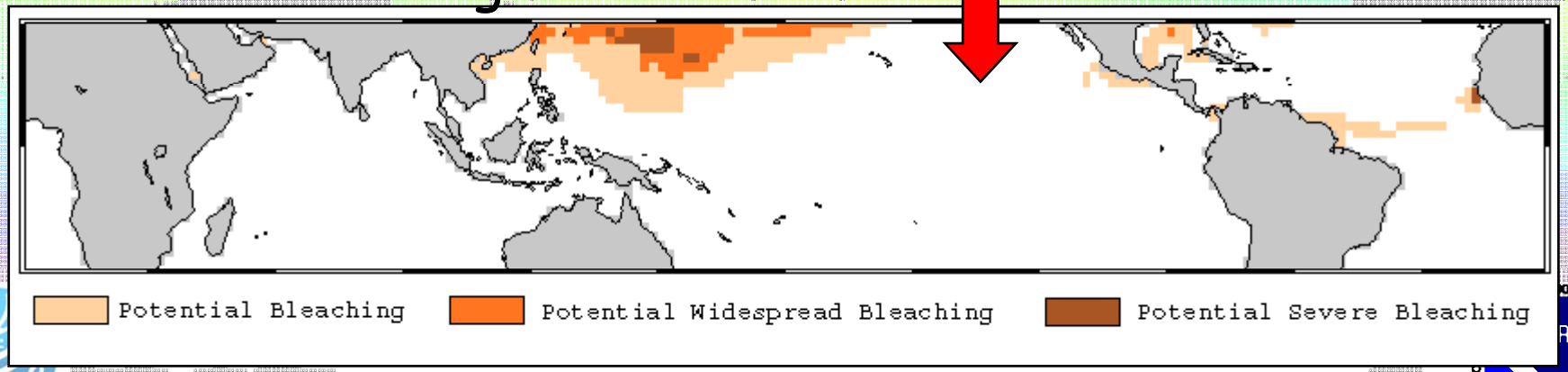
Weekly Bleaching Outlook

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



N-week leadtime
(currently up to 18 weeks)

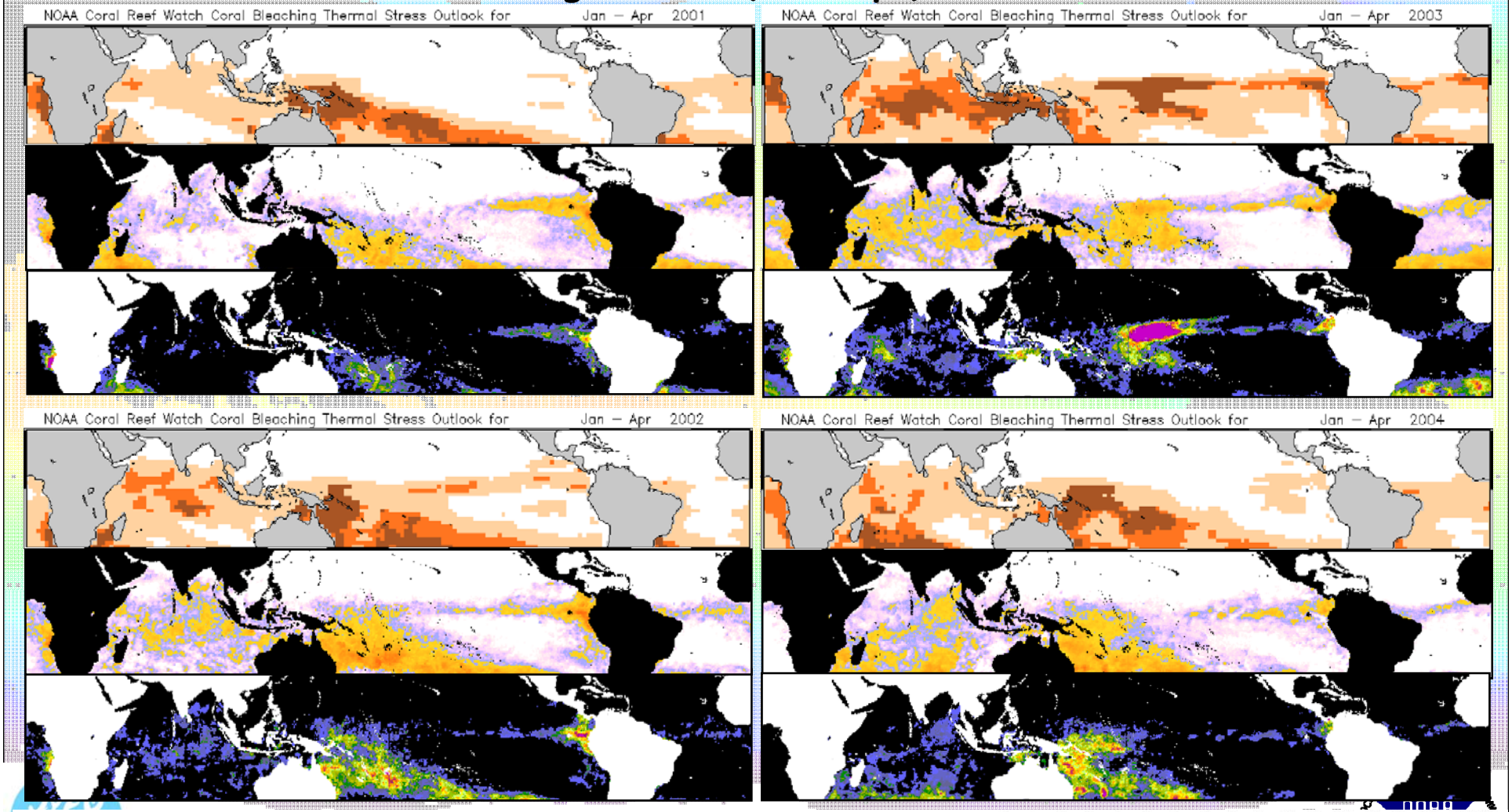
Seasonal Bleaching Outlook



http://coralreefwatch.noaa.gov

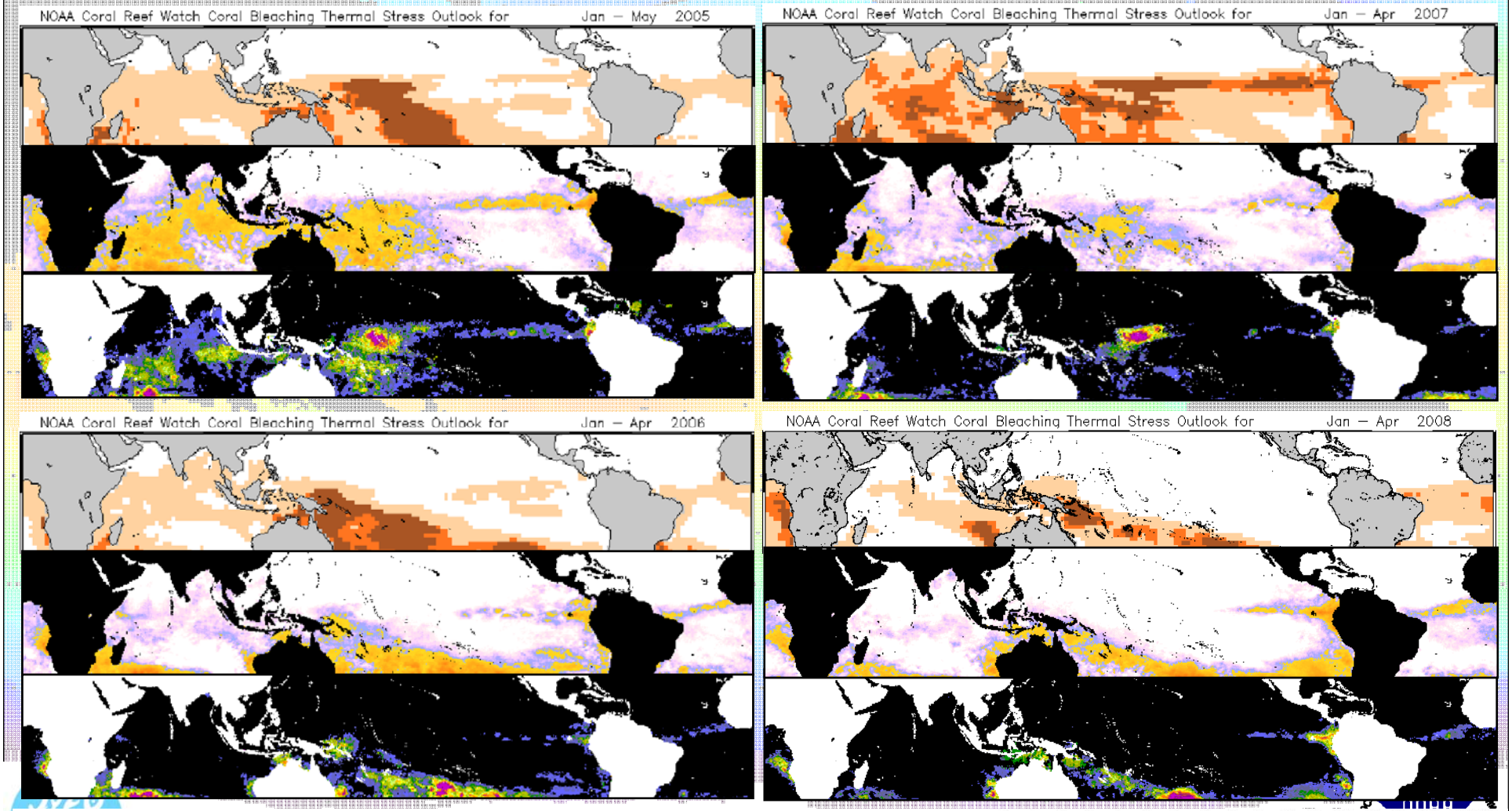
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2001-2004 Austral Bleaching Season (Jan-Apr)



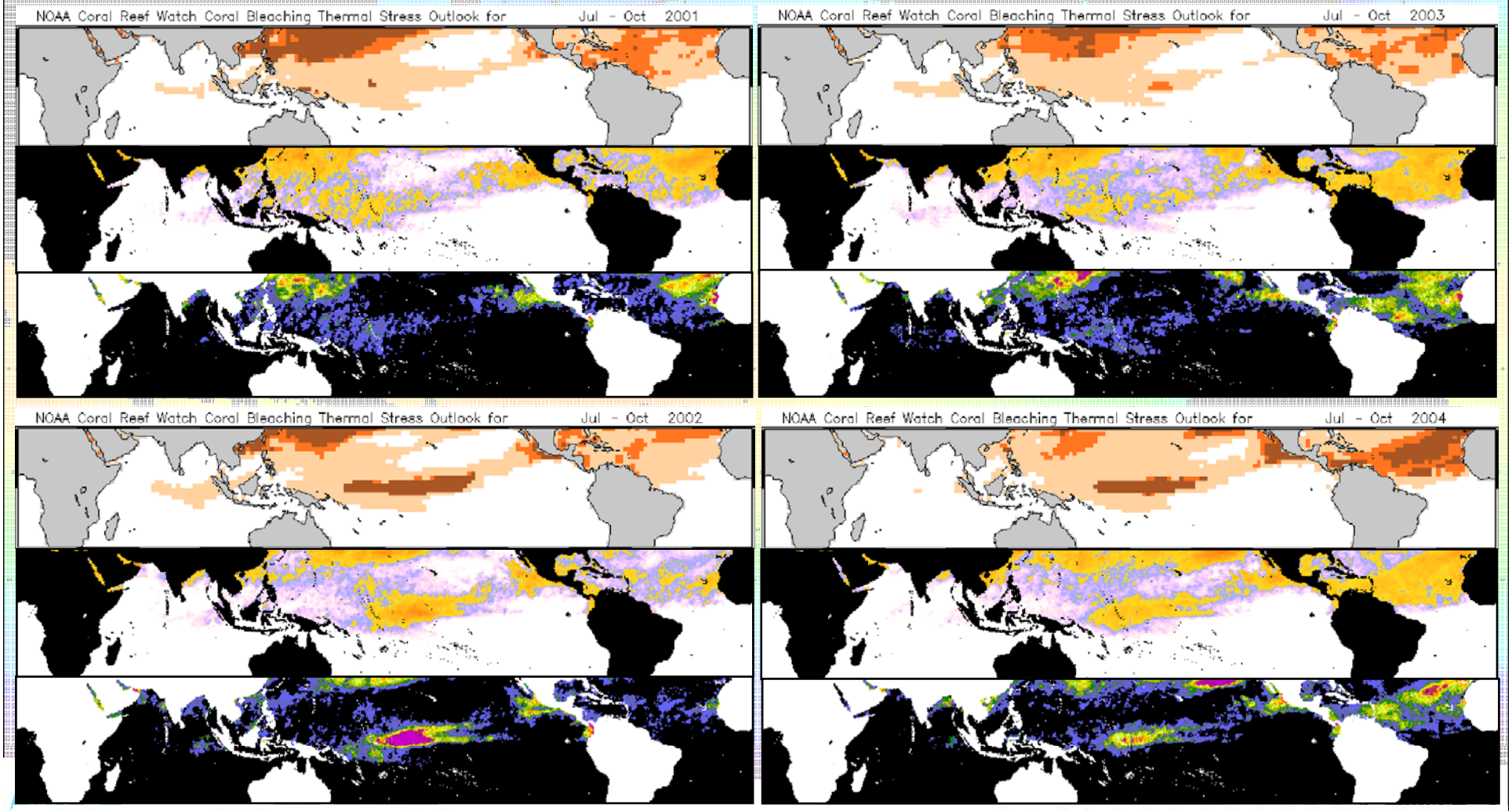
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2005-2008 Austral Bleaching Season (Jan-Apr)



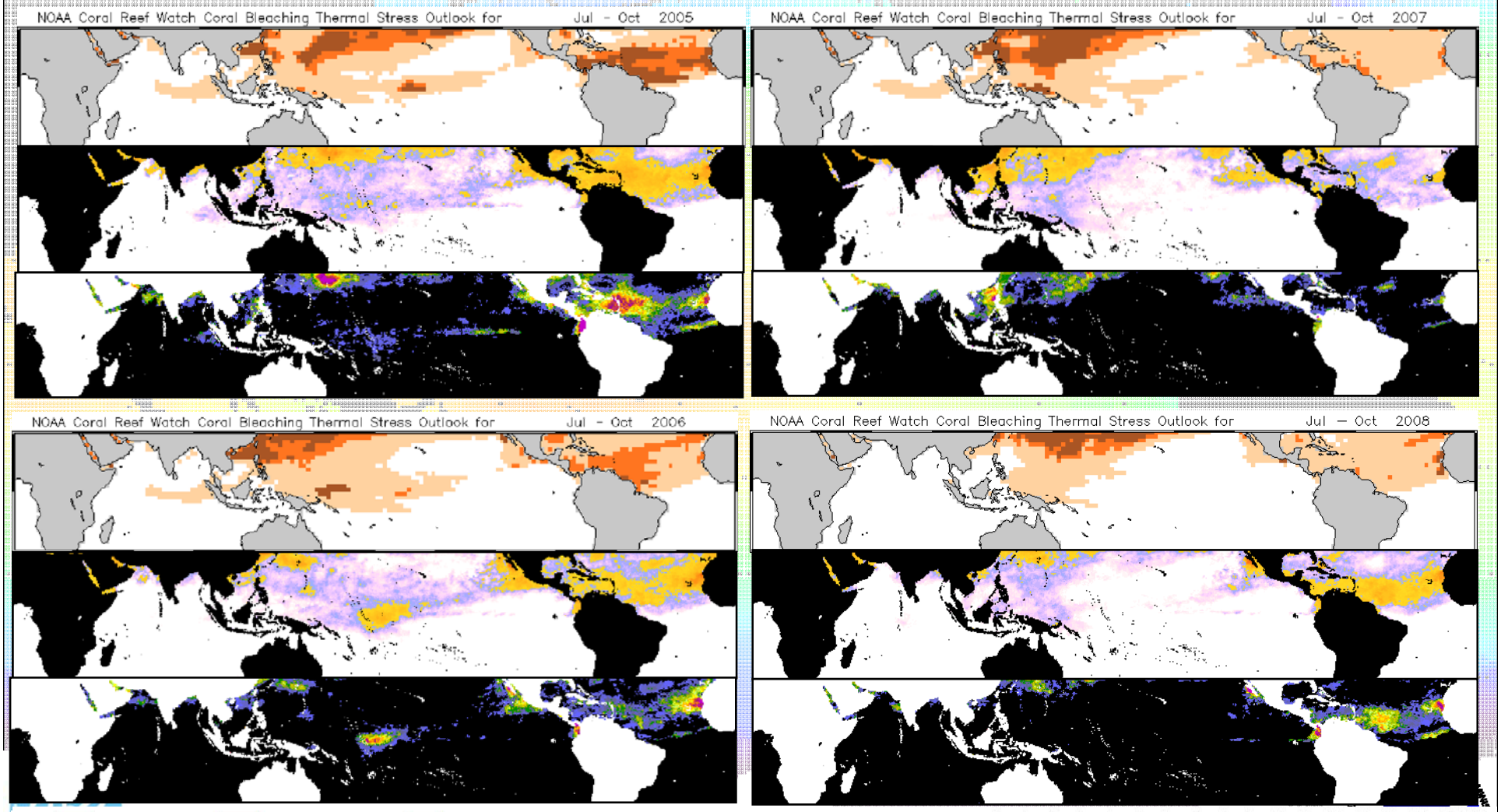
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2001-2004 Boreal Bleaching Season (July-Oct)



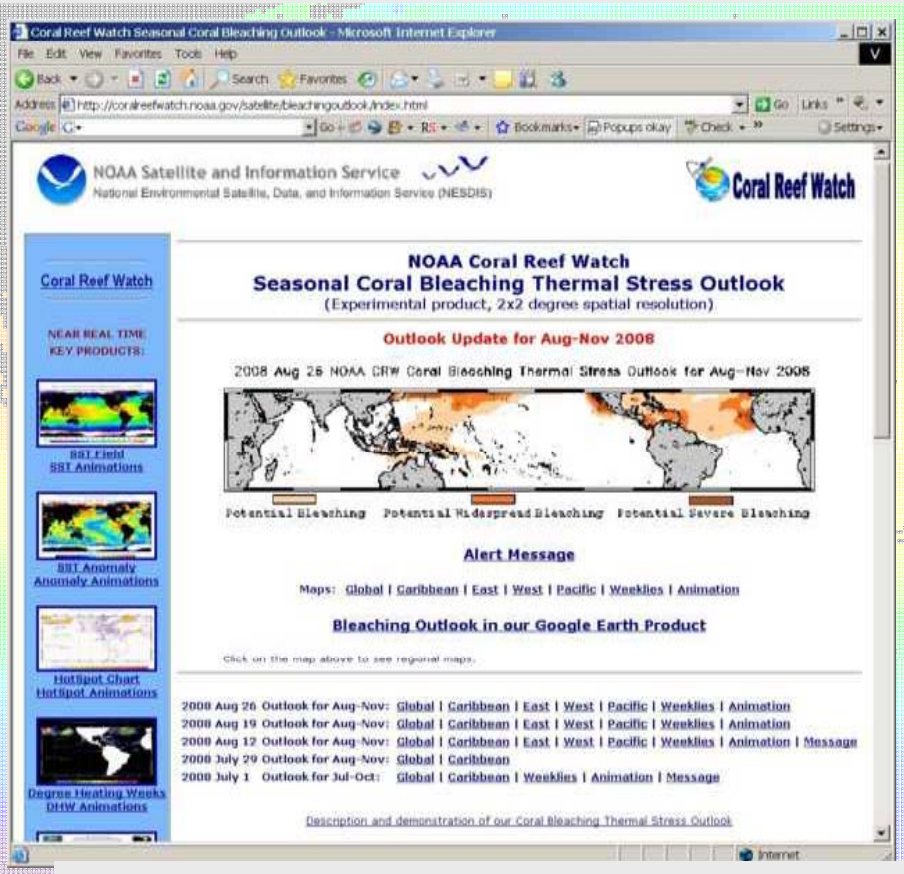
Hindcast Seasonal Bleaching Outlooks vs CRW HotSpot/DHW Observations

2005-2008 Boreal Bleaching Season (July-Oct)

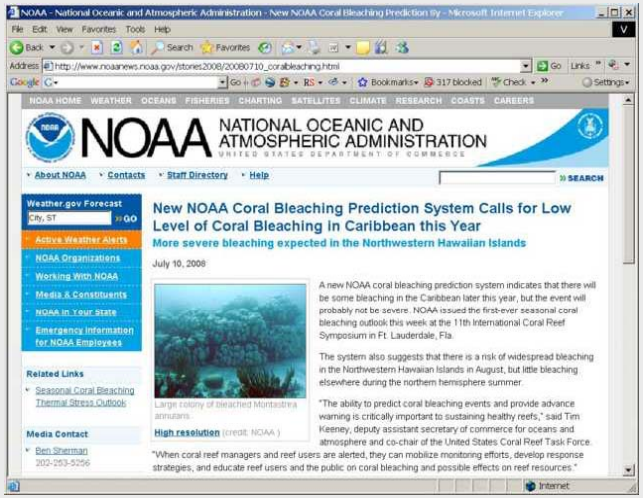


NOAA CRW Coral Bleaching Outlook System

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

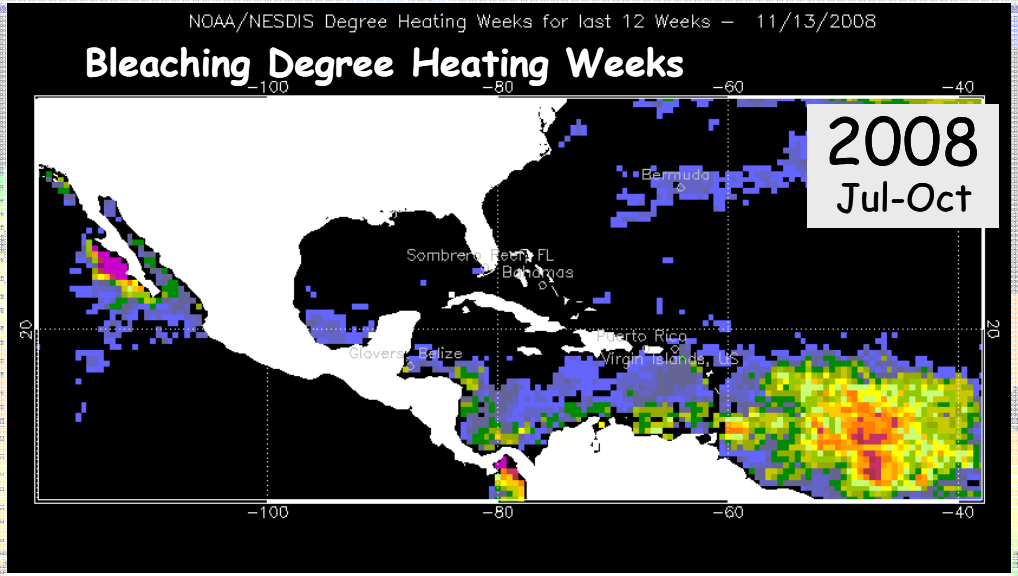


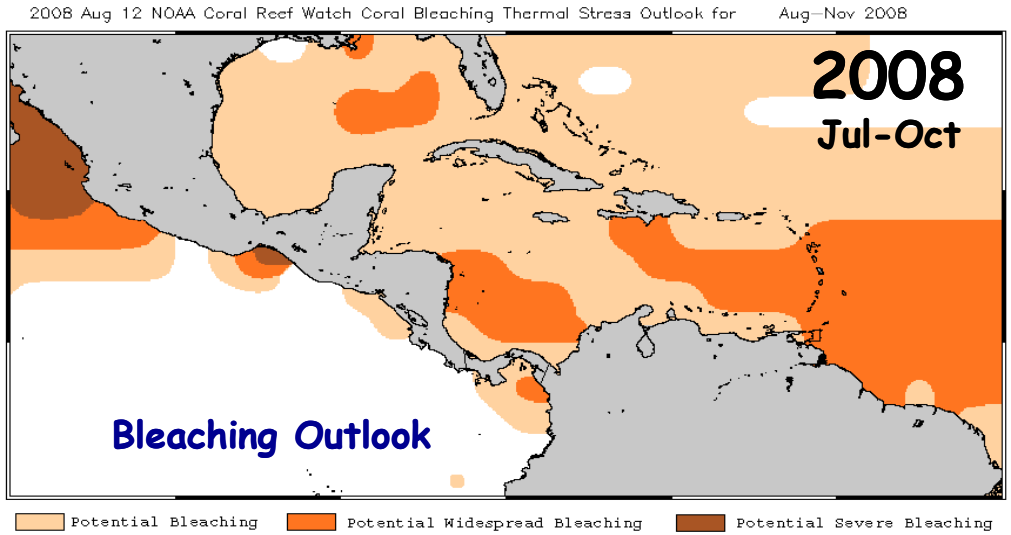
Announced July 2008



- Outlook message will usually be updated once a month
- Outlook maps will usually be updated once a week

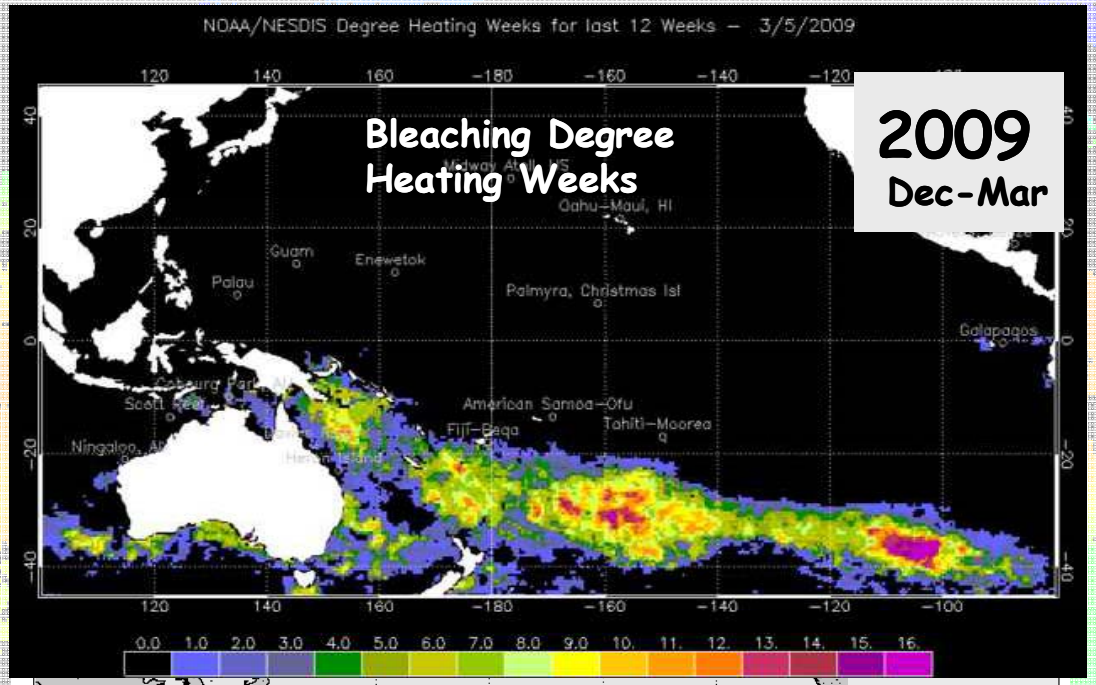
Bleaching Outlook for Jul-Oct 2008

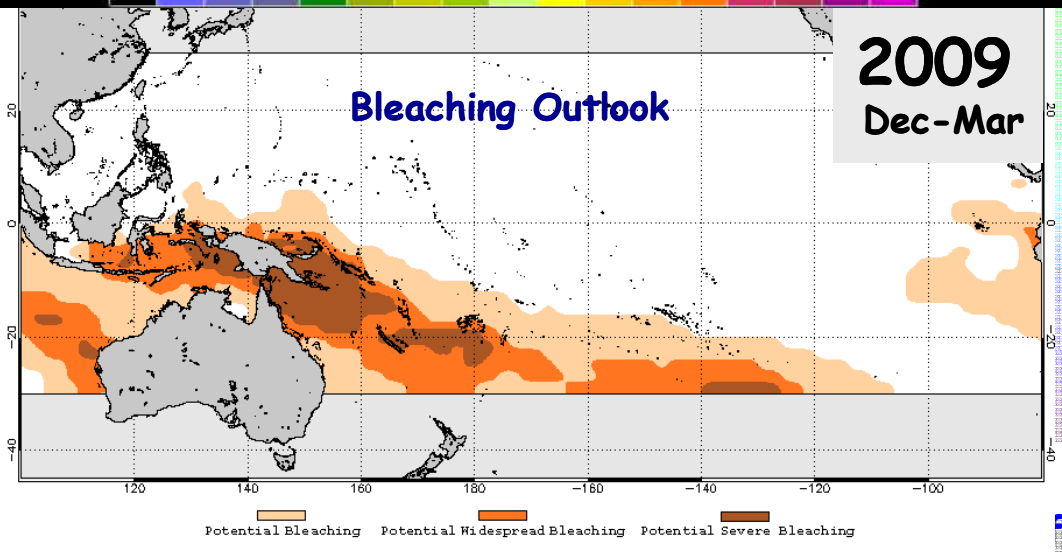




http://coralreefwatch.noaa.gov

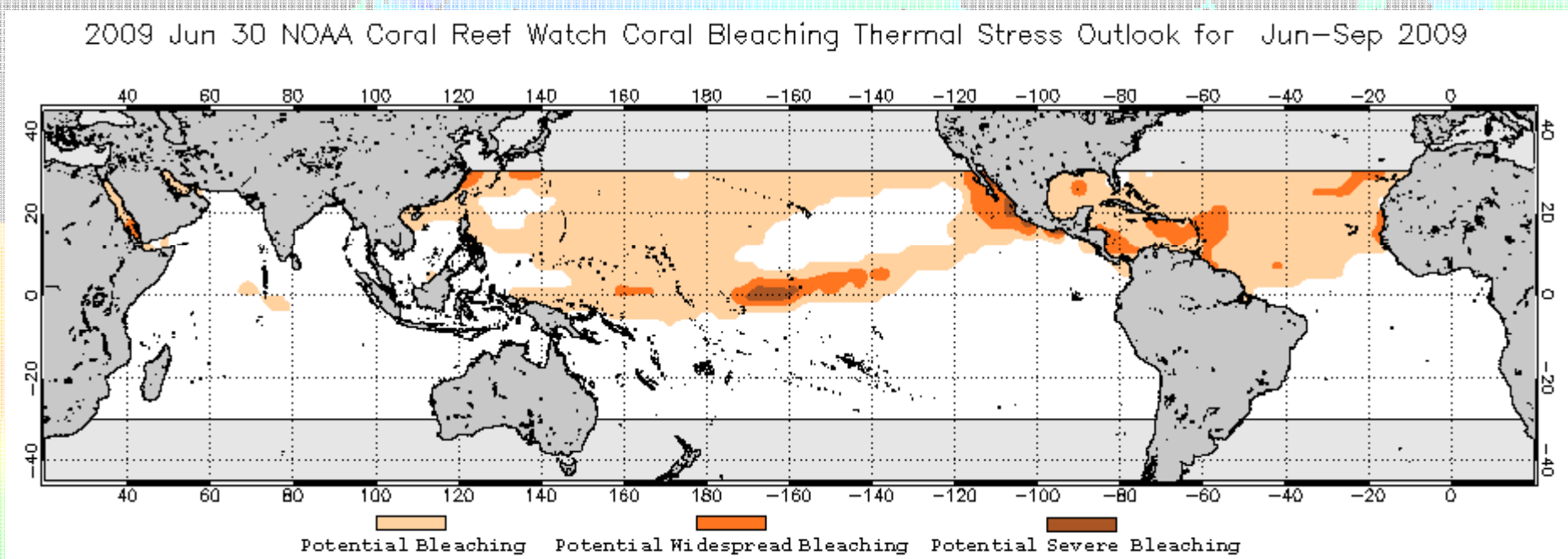
Bleaching Outlook for Dec 2008-Mar 2009





coralreefwatch.noaa.gov

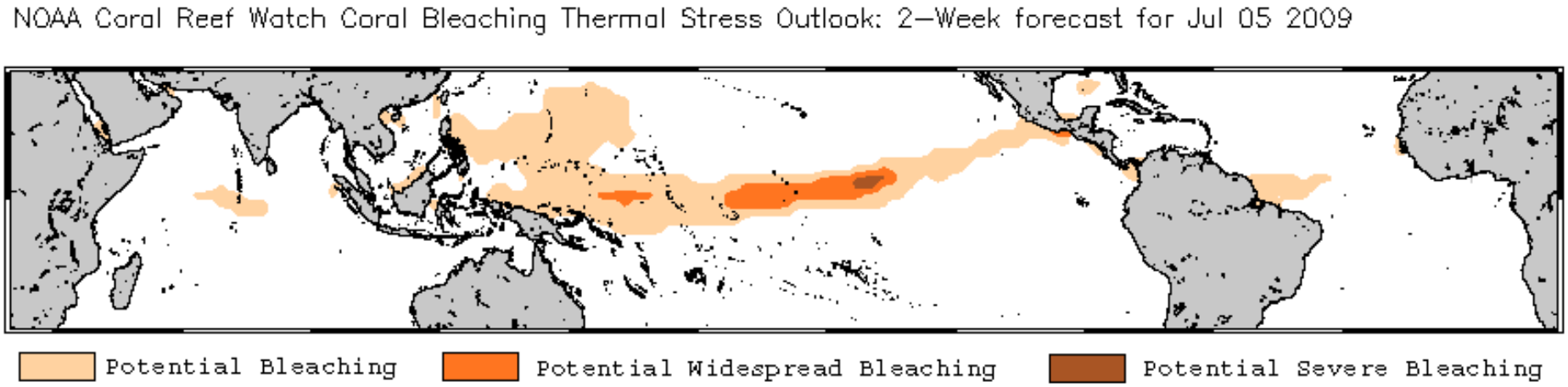
Current Bleaching Outlook for Jun-Sept 2009



http://coralreefwatch.noaa.gov

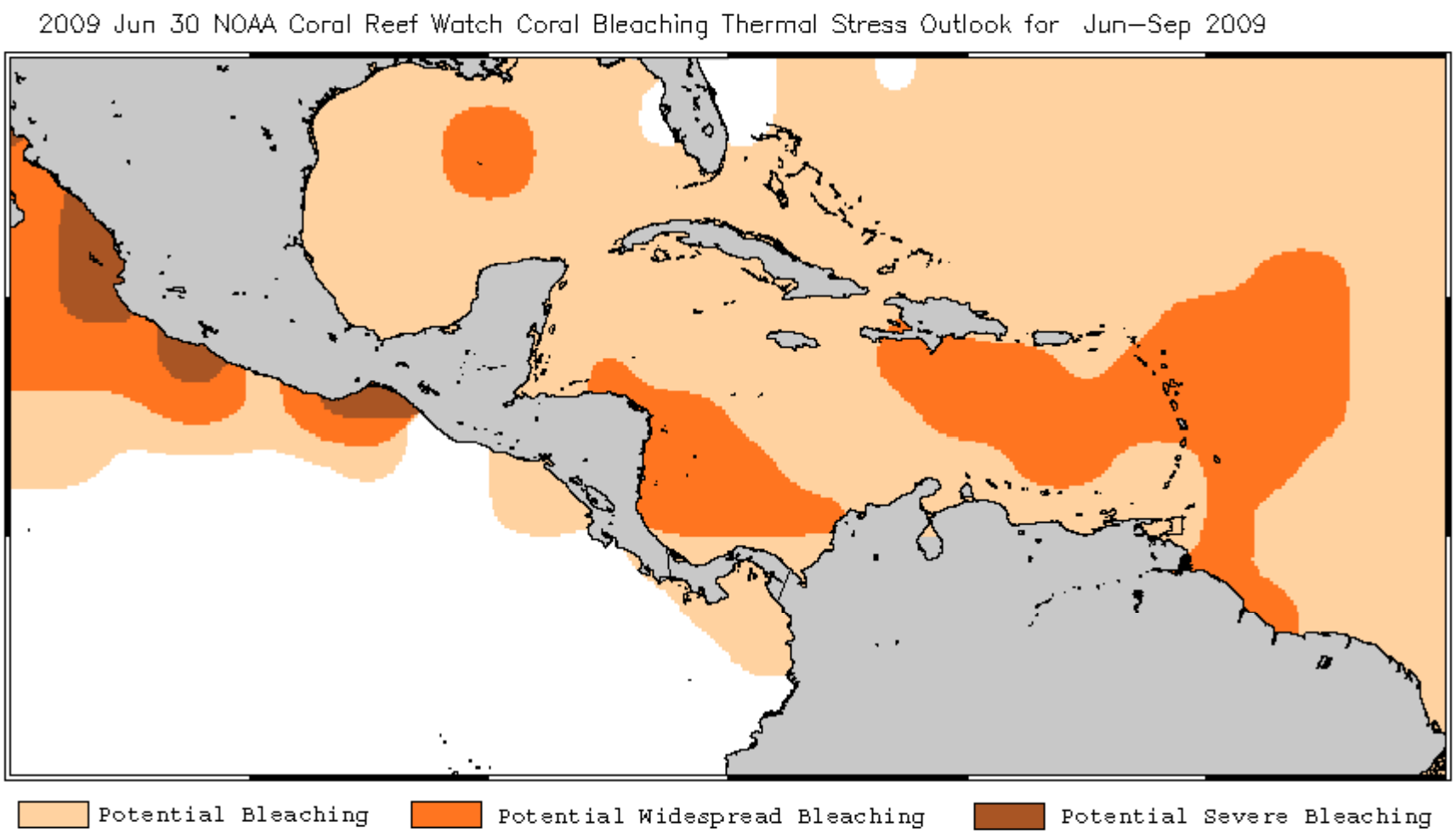
Current Bleaching Outlook for Jun-Sept 2009

Animation



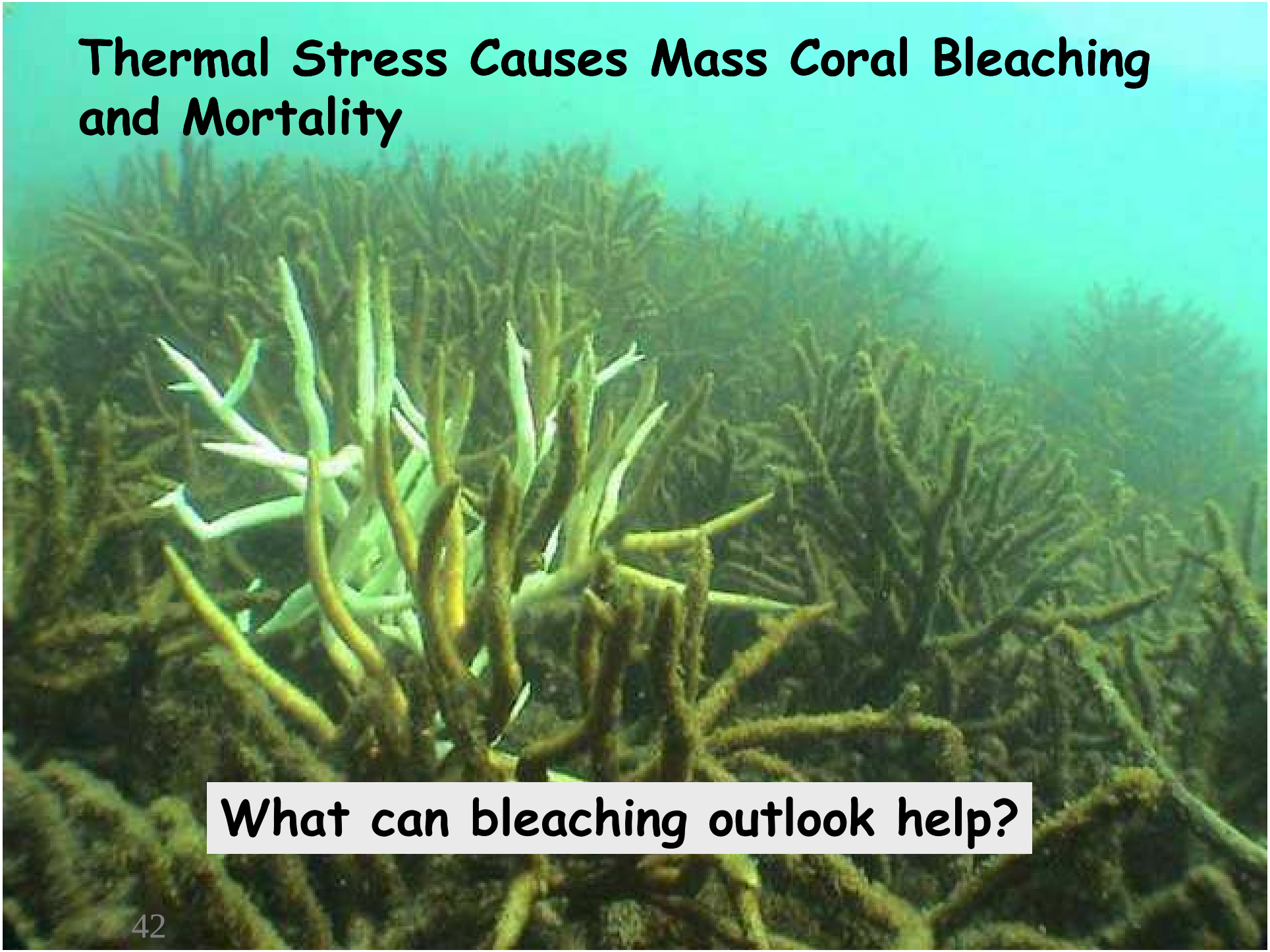
http://coralreefwatch.noaa.gov

Current Bleaching Outlook for Jun-Sept 2009



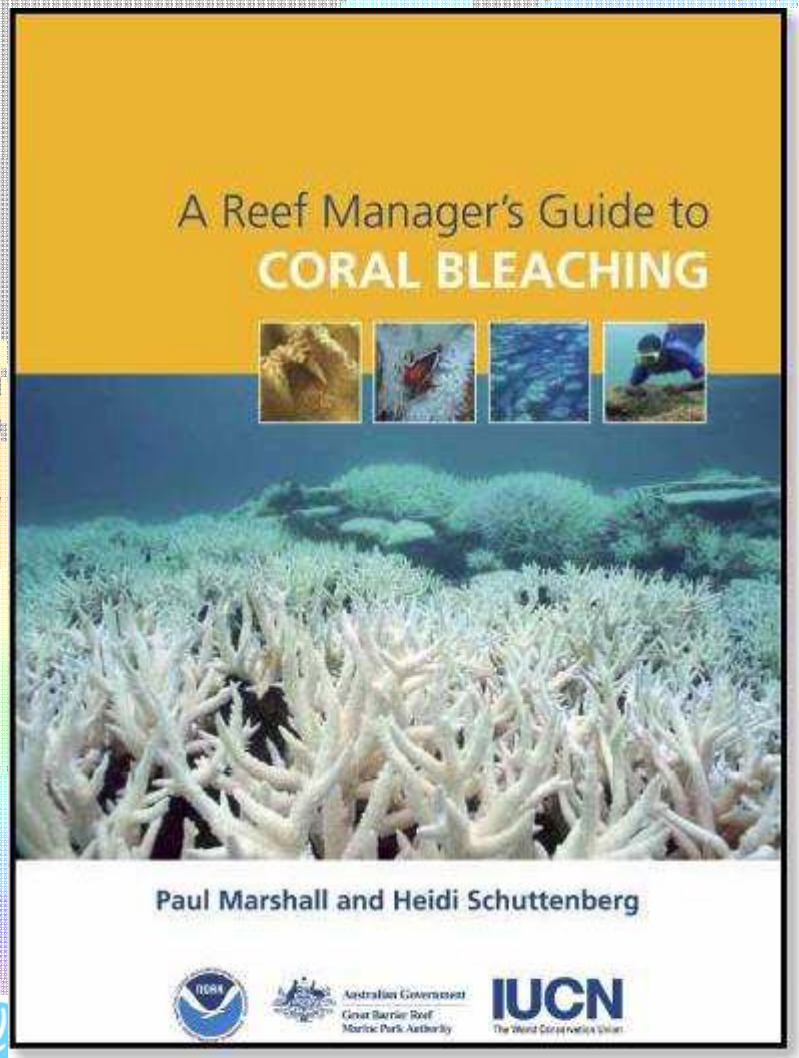
http://coralreefwatch.noaa.gov

Thermal Stress Causes Mass Coral Bleaching and Mortality



What can bleaching outlook help?

Reduce Local Stressors



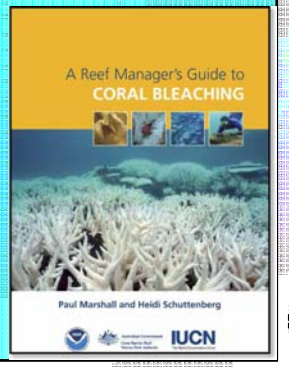
- Driven by US Coral Reef Task Force
- Result of international workshop, research, and planning
- Addresses local reef management in light of changing climate

Available at coralreef.noaa.gov

Short-term Opportunities for Coral Bleaching Management

Local managers can:

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



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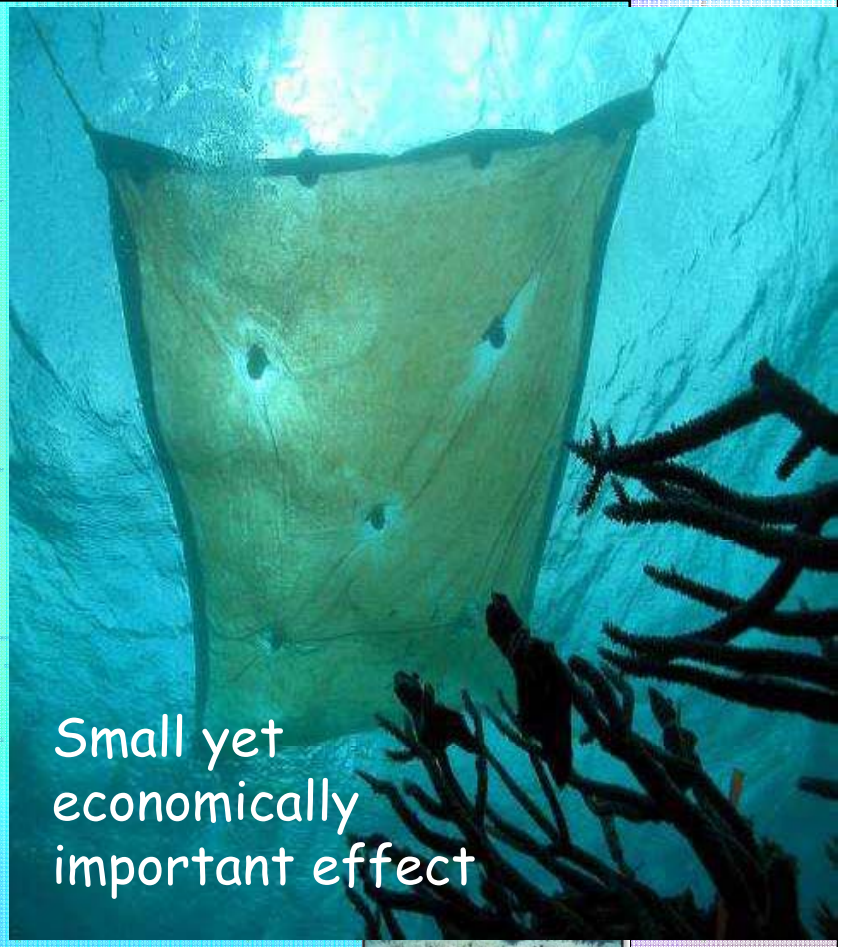
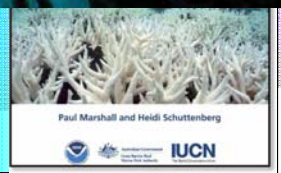
Quicksilver Connections



Small yet economically important effect



Paul Marshall and Heidi Schuttenberg

IUCN

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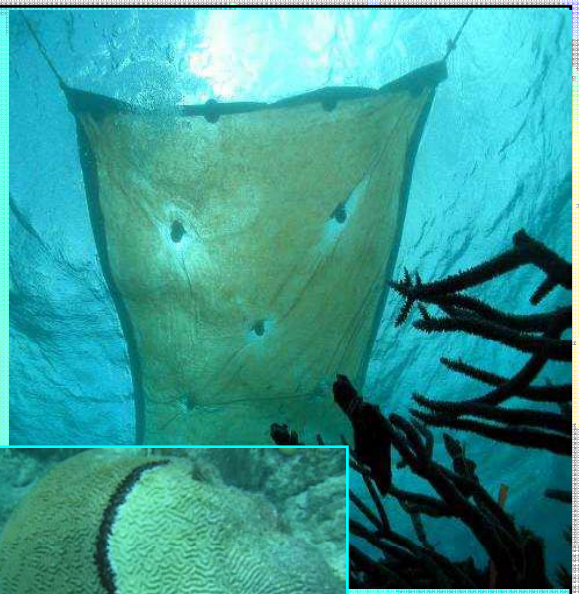
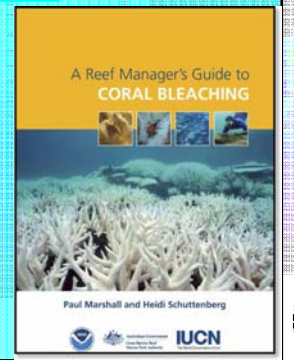
  - Improve water quality
  - Reduce disease prevalence





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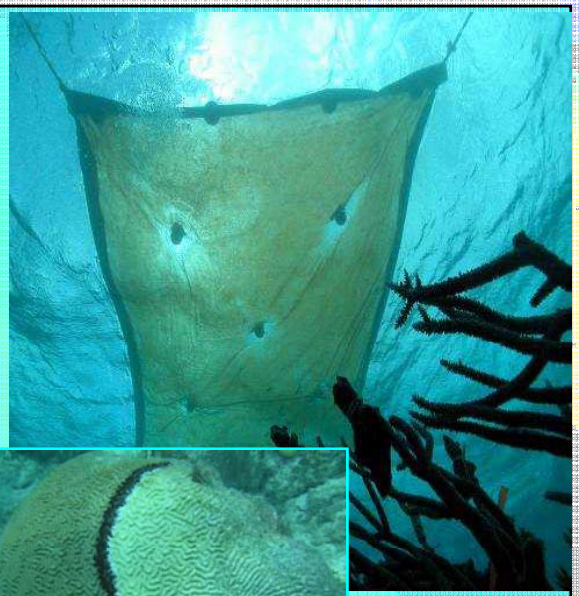
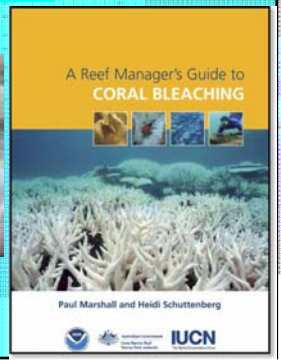
- Increase survival
  - Improve water quality
  - Reduce disease prevalence
- Aid recovery
  - Coral fragmentation
  - Encourage recruitment
  - Protect ecosystem functions (herbivory)





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

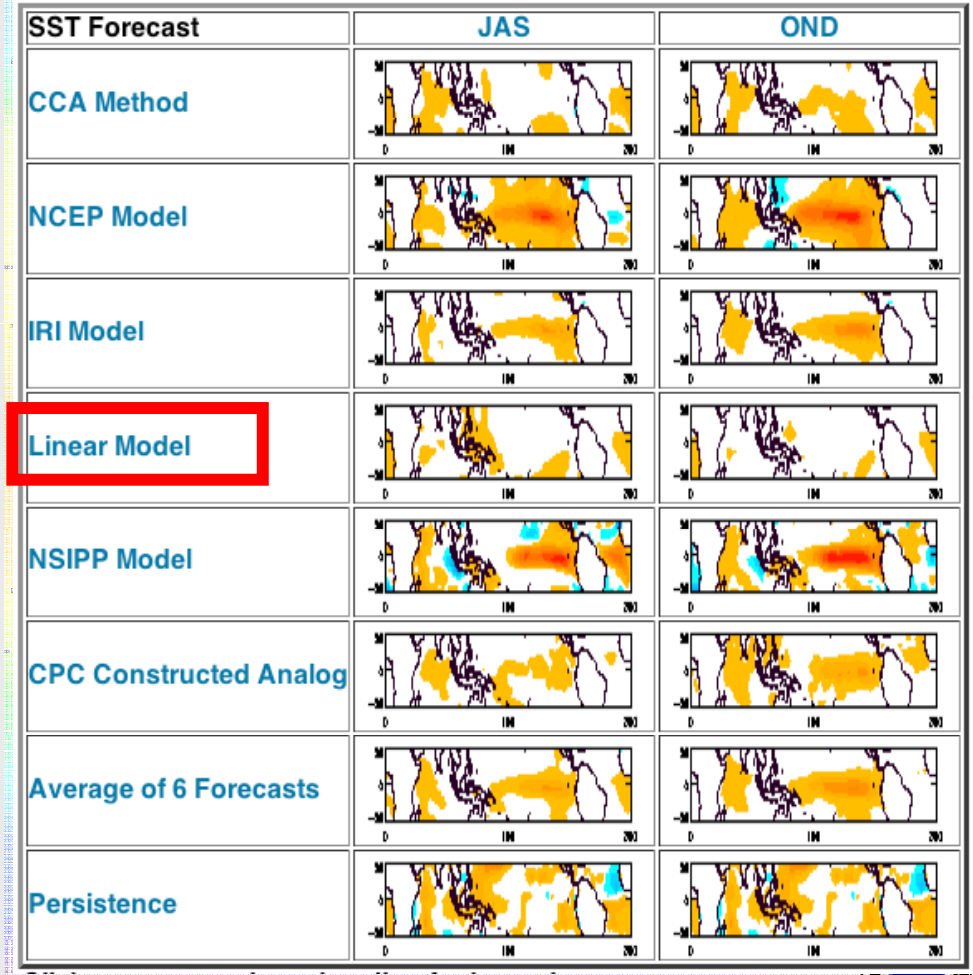
Provides general patterns of potential bleaching
- enables managers and scientists to prepare

Further evaluate and analyze skill and improve accuracy

Next: Application of NOAA operational Climate Forecast System

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

http://coralreefwatch.noaa.gov

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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

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