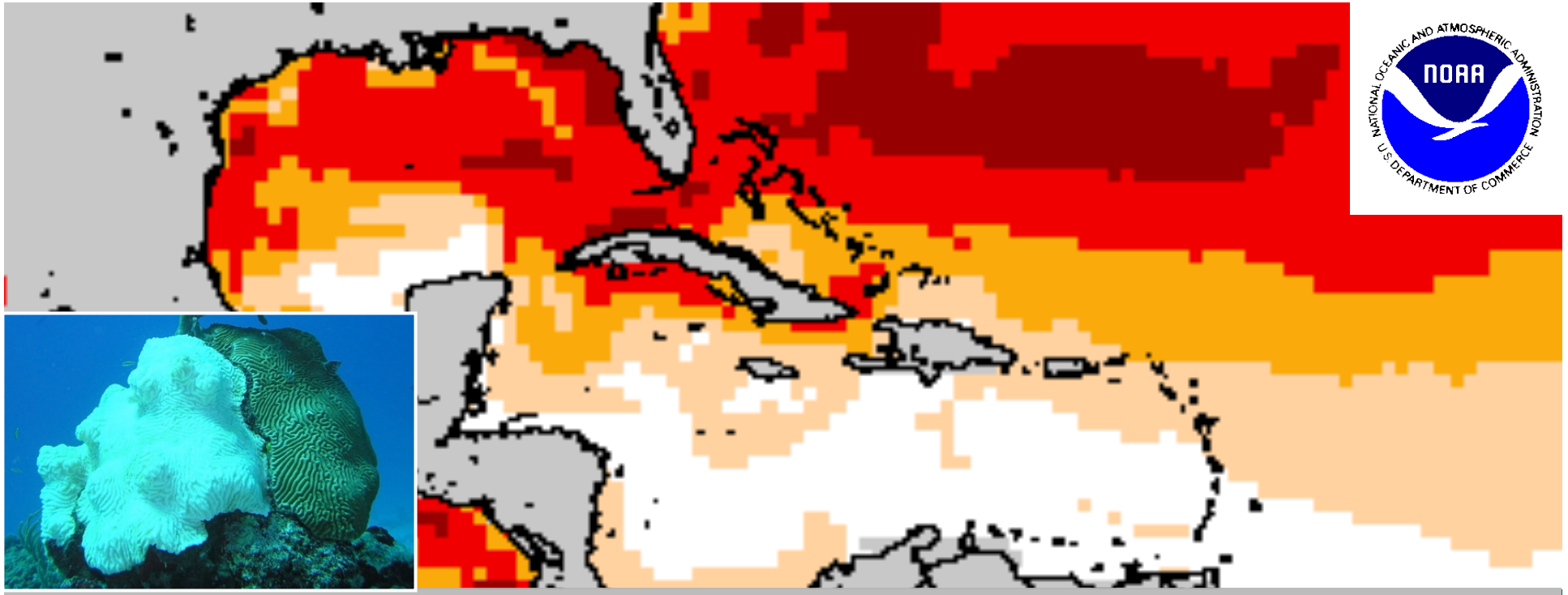


Seasonal to decadal modeling of coral bleaching thermal stress

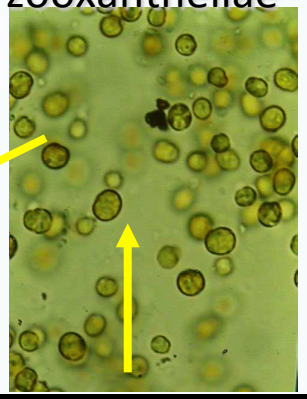
Dr. C. Mark Eakin
NOAA Coral Reef Watch

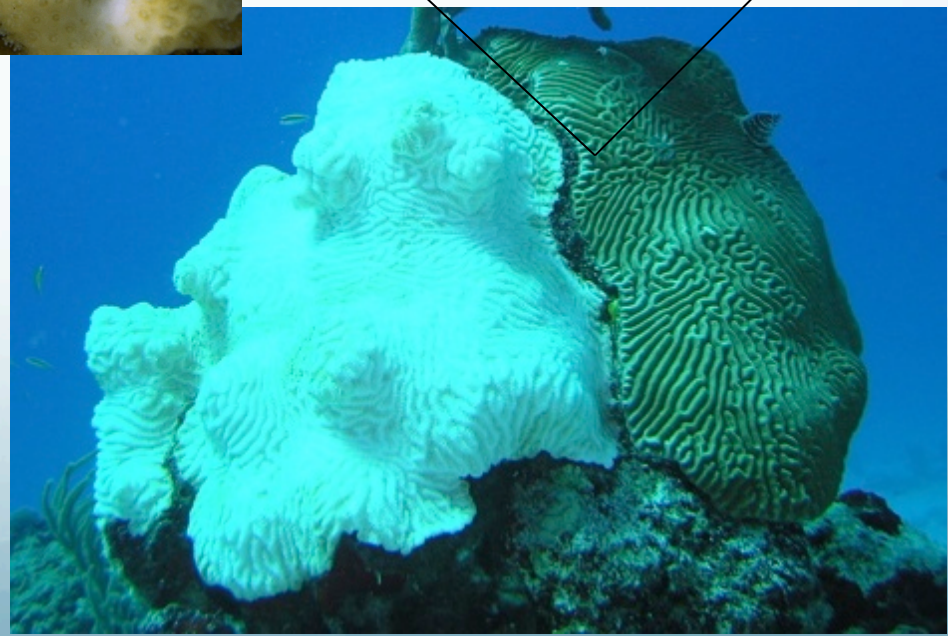
Coral Reefs are Important

Mass Coral Bleaching

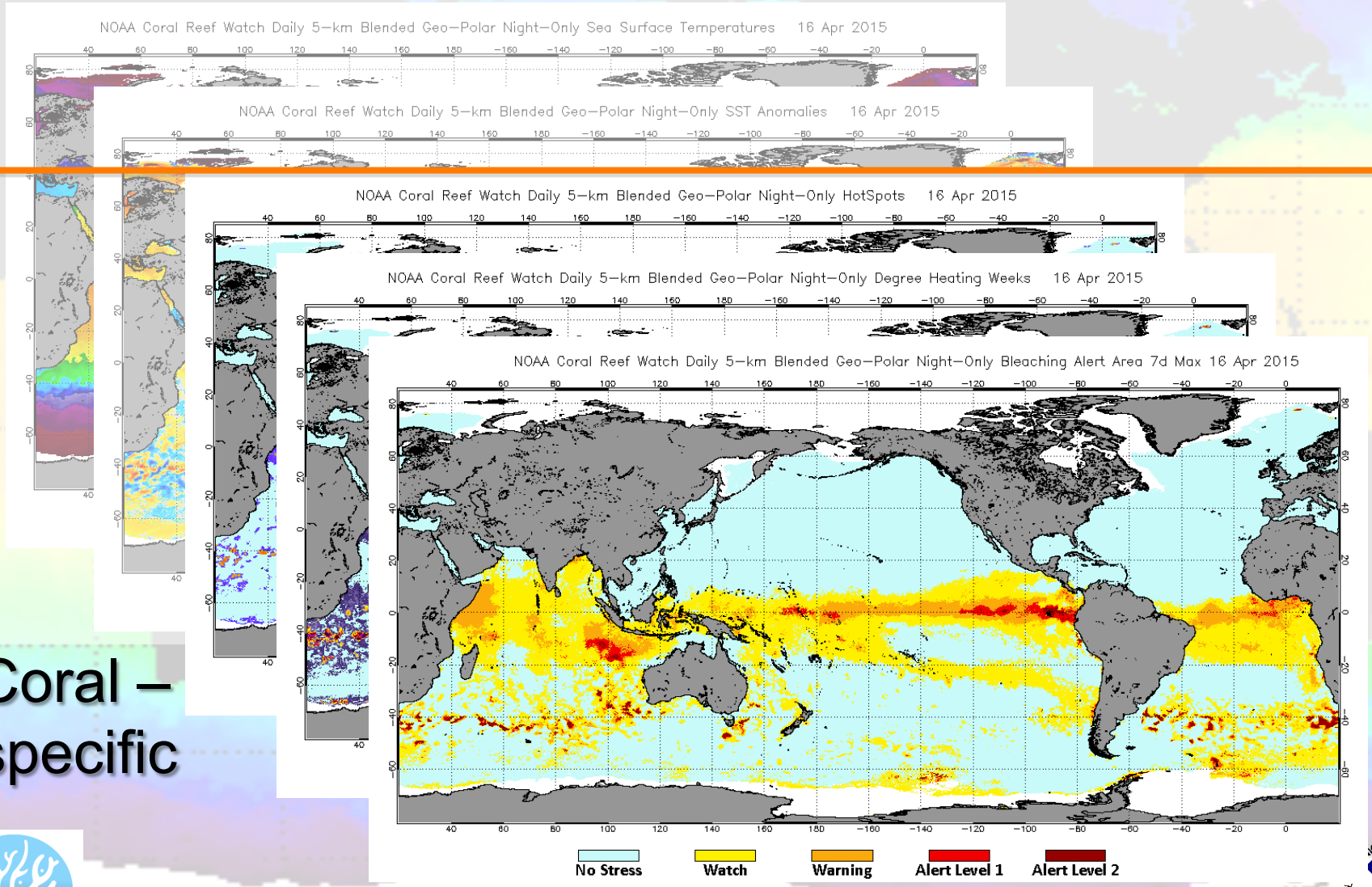
Impact of Climate Change

- Most of corals' food comes from photosynthesis
- Corals exposed to high temperatures and/or high light become stressed
- Corals eject their algae; corals appear "bleached"
- If stress is mild or brief, corals recover, otherwise they die
- Mass bleaching covers 100-1000km





Coral Reef Watch
5-km Satellite-Based Products

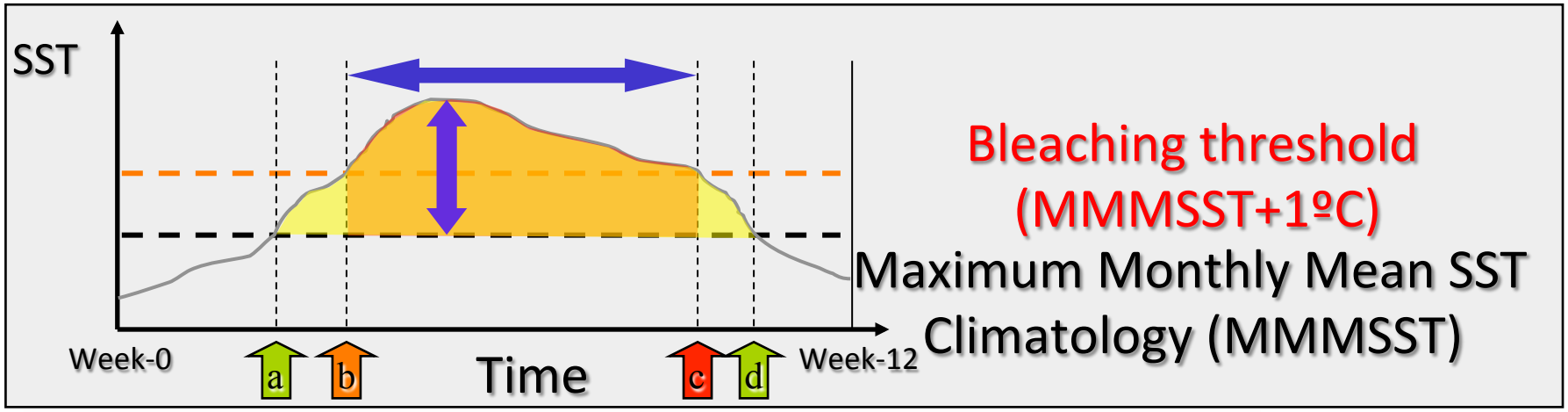


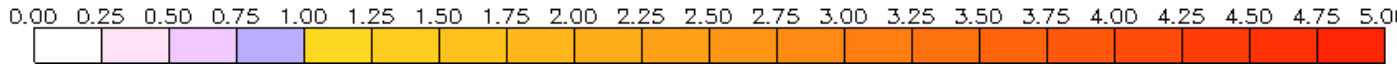
Coral – specific

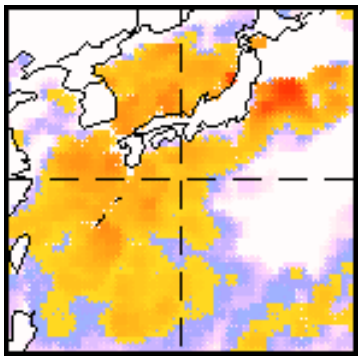
Bleaching Alert Area

http://coralreefwatch.noaa.gov

Degree Heating Week Product Algorithm

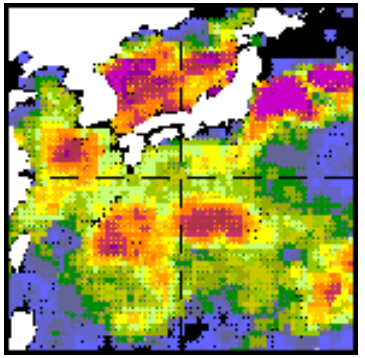




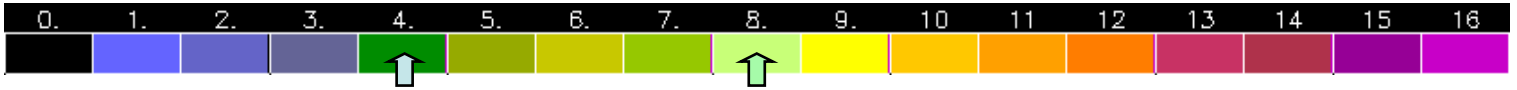


HotSpots

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



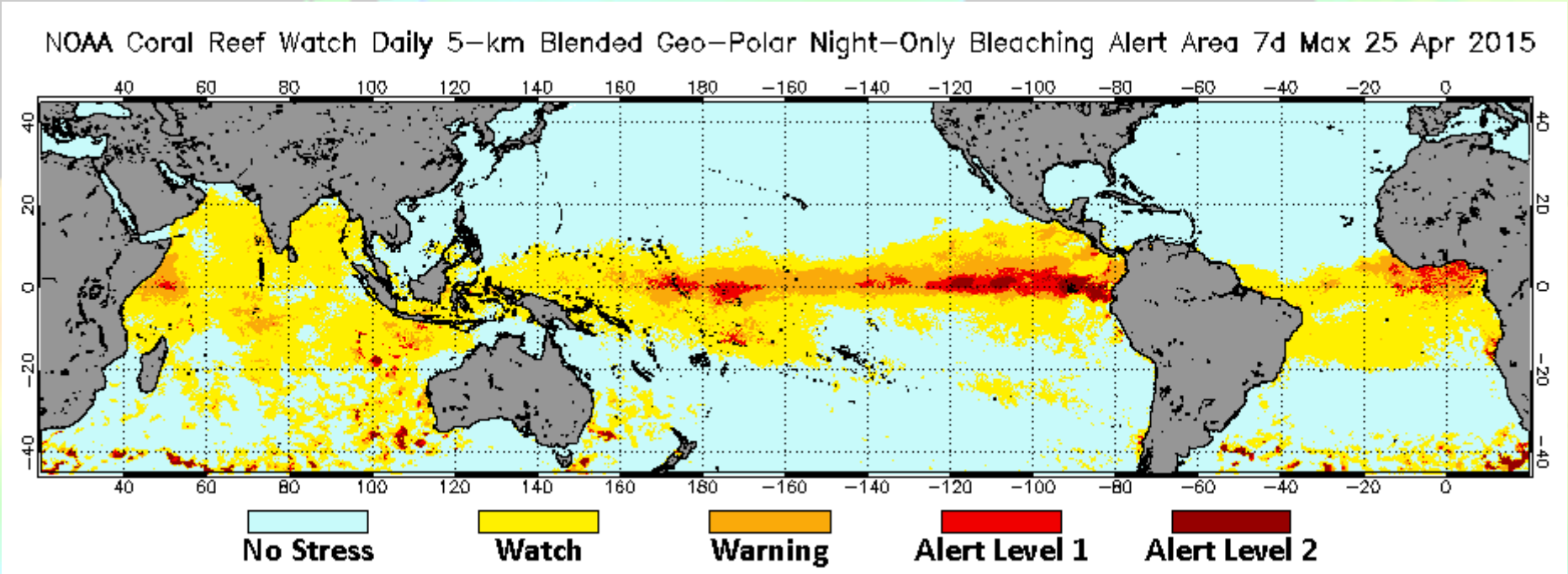
Degree Heating Weeks



≥ 4 DHWs coral bleaching is expected

≥ 8 DHWs mass bleaching and mortality are expected

Bottom Line for Managers

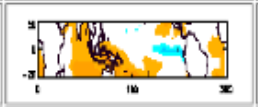
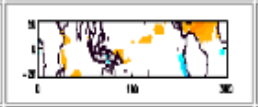
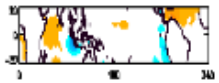
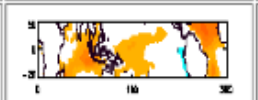
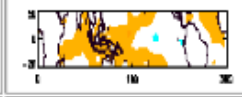
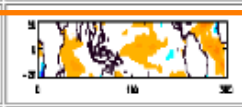
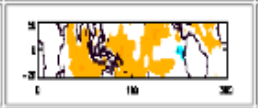
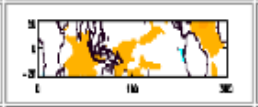
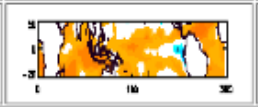


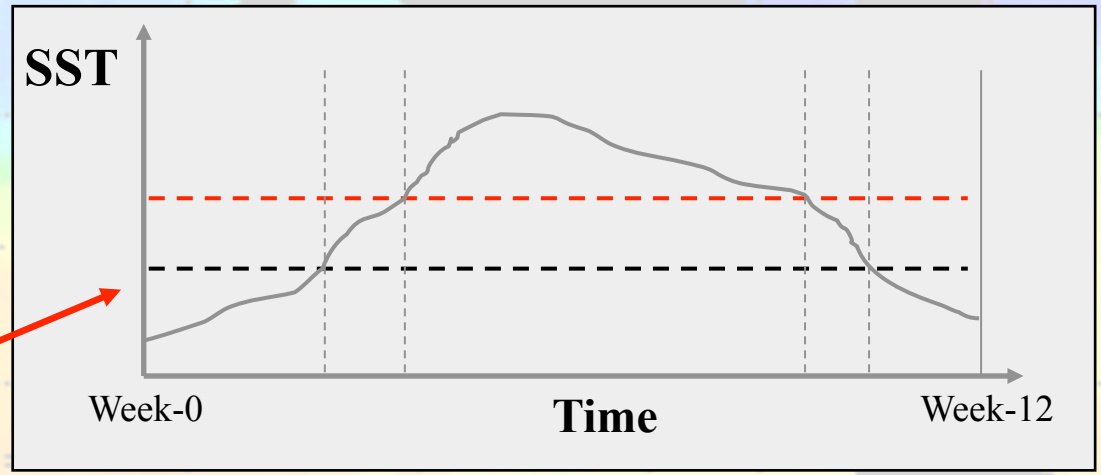
Is my reef currently at risk for bleaching?

http://coralreefwatch.noaa.gov

Proposed Bleaching HotSpots and Degree Heating Weeks (DHW) Forecasting

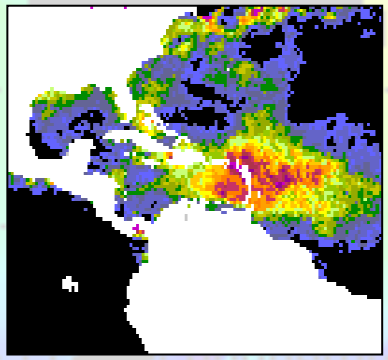
Forecasts made 1 April 2005

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

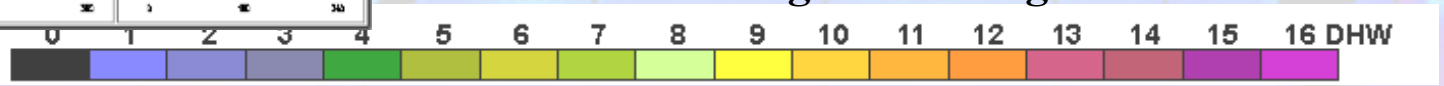


HotSpot from Forecasts

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



Degree Heating Weeks



≥ 4 DHWs → coral bleaching is expected

≥ 8 DHWs → mass bleaching and mortality are expected

http://coralreefwatch.noaa.gov

NOAA CRW Coral Bleaching Outlook System

LIM SST forecast model

- NOAA-ESRL Linear Inverse Model, 2x2° resolution
- Uses 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 used for training and are used as model input

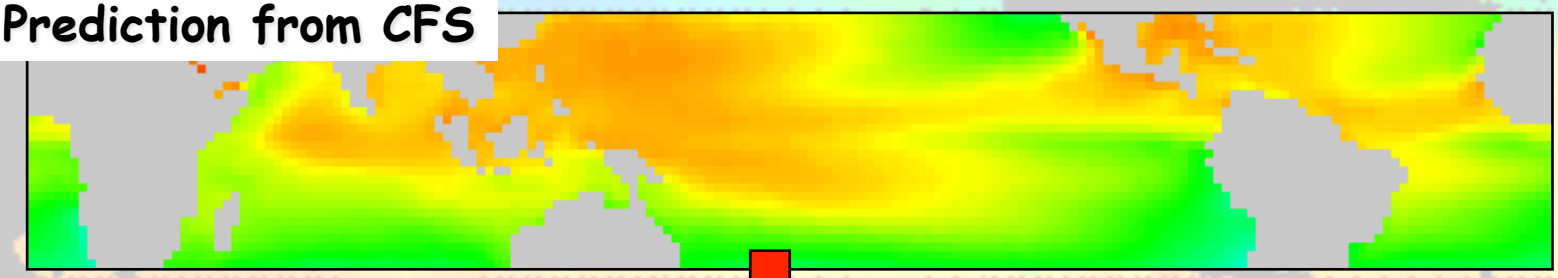
CFS SST forecast model

- NOAA-NCEP Climate Forecast System Model, 1x1° resolution
- Ensemble of 28 runs each week
- Thermal stress for each pixel arranged warmest to coolest, redistributed into 28 ensembles to determine probabilities
- Data assimilation based on Weekly Reynolds and Smith Optimum Interpolation SST (OISST) data are used as initial SST conditions

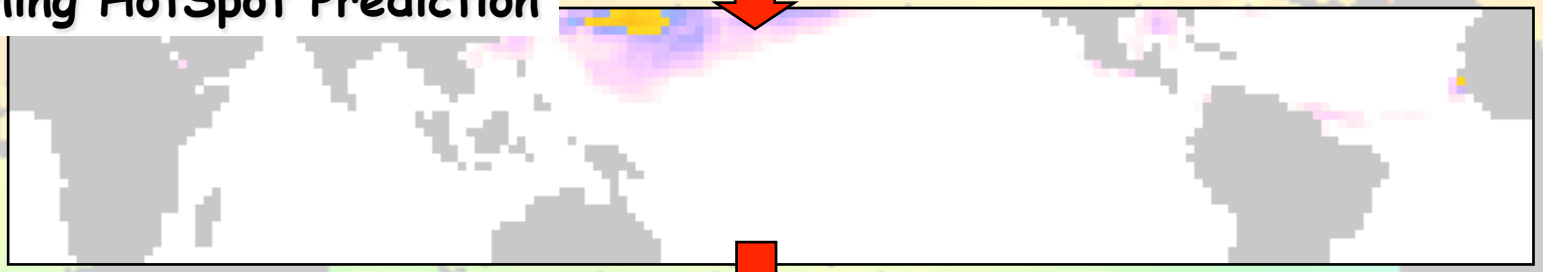
From SST to Bleaching Thermal Stress Forecast

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

SST Prediction from CFS



Bleaching HotSpot Prediction



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

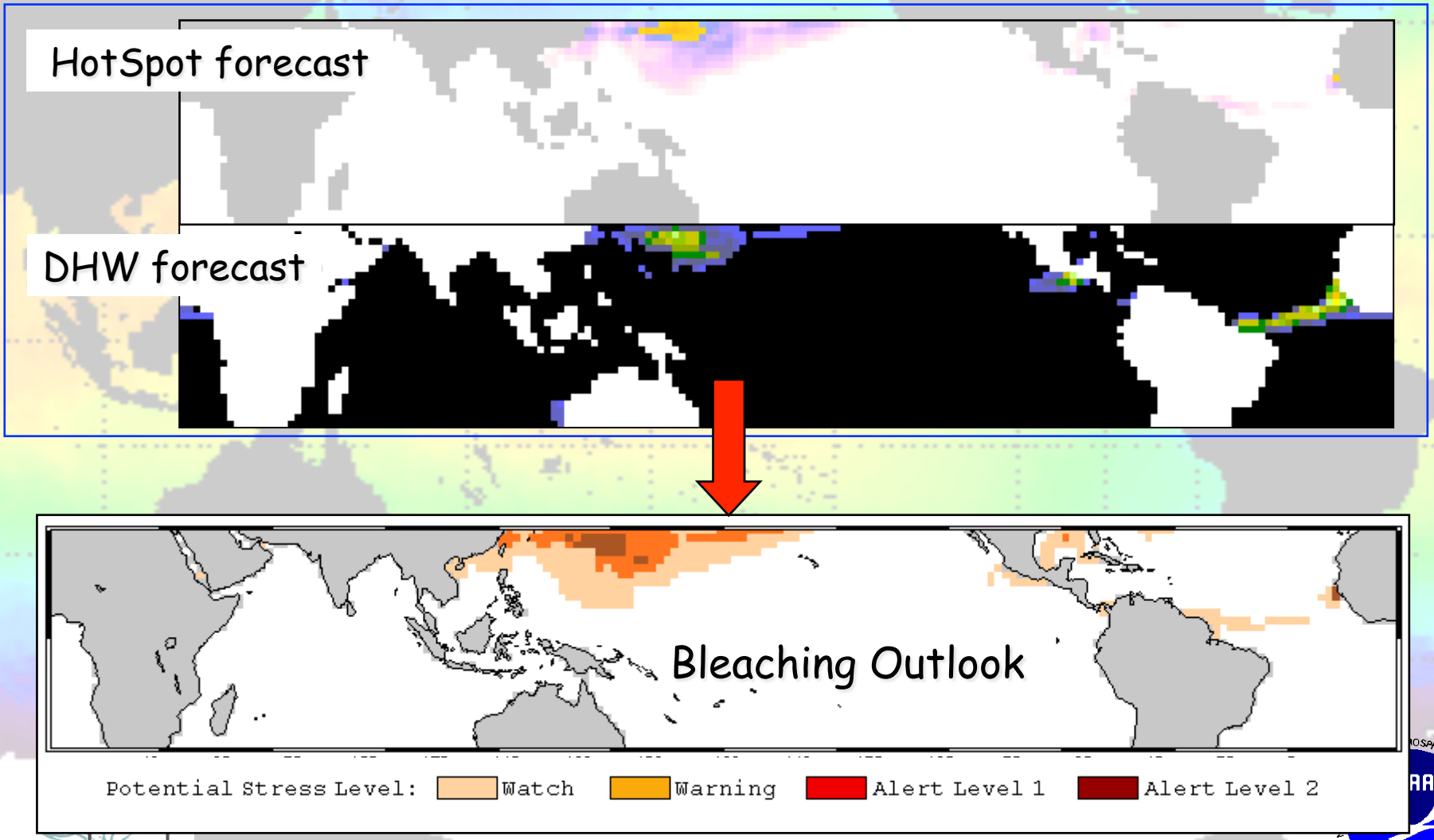
Bleaching Degree Heating Weeks

NOAA coral reef CONSERVATION PROGRAM

http://coralreefwatch.noaa.gov

From Bleaching Thermal Stress to Outlook

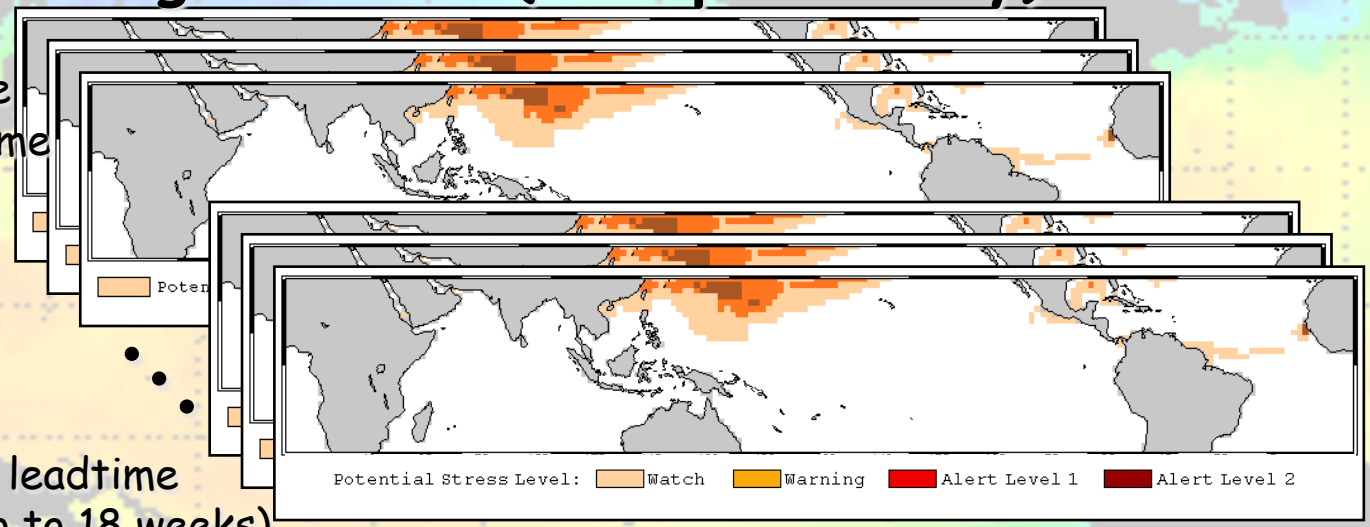
Prediction for July 17-23, 2008 (4-week lead-time)



NOAA CRW Seasonal Bleaching Outlook

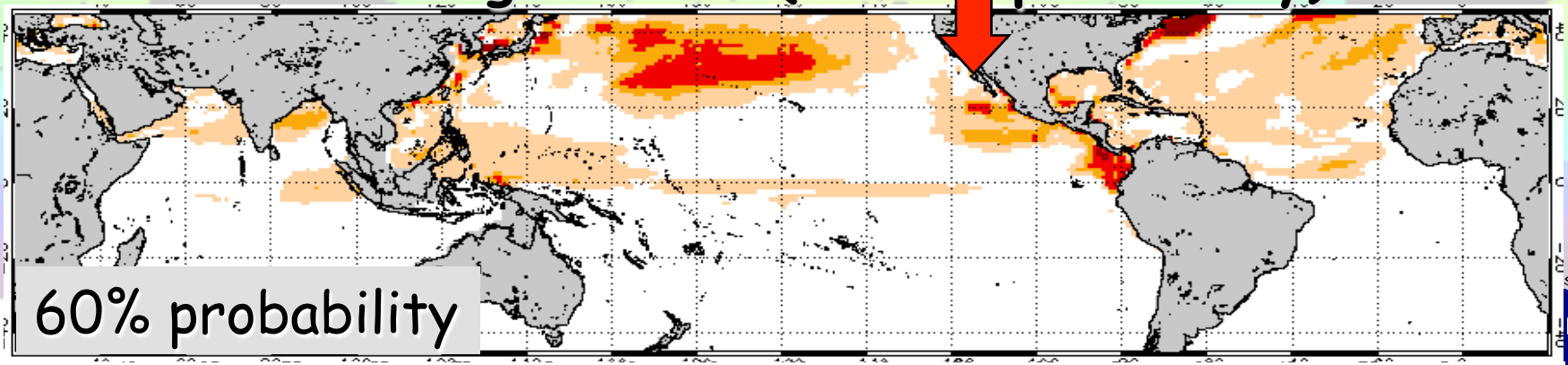
Weekly Bleaching Outlooks (xx% probability)

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



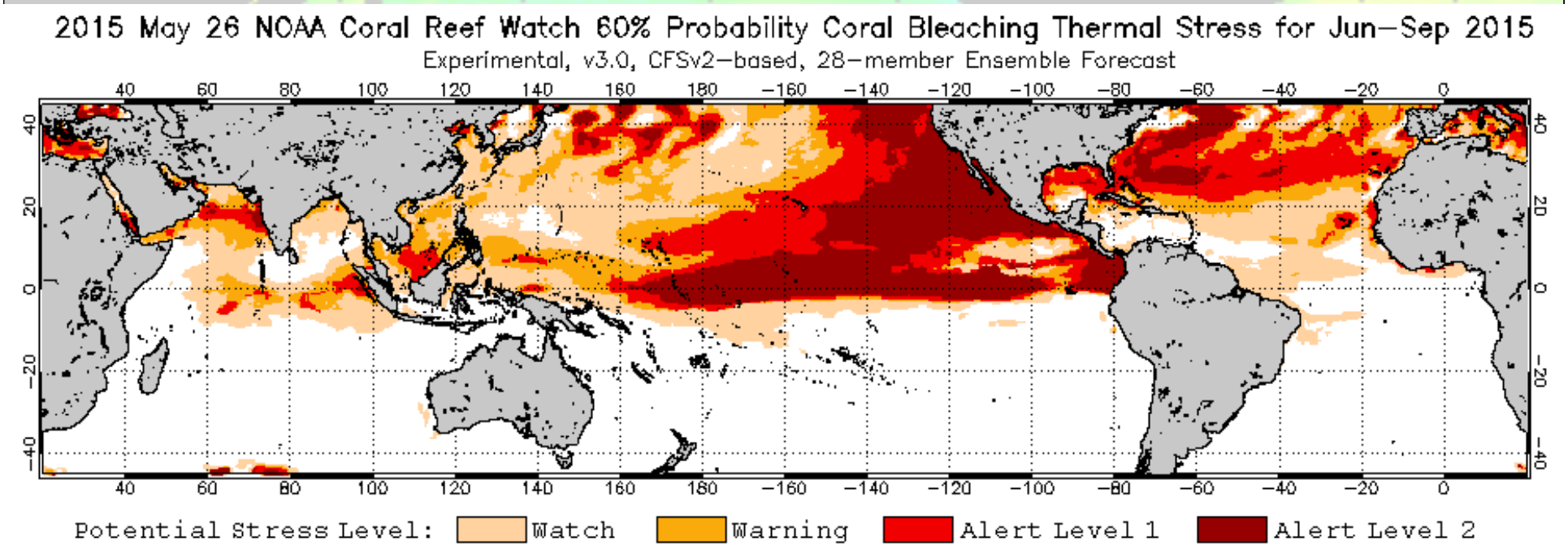
N-week leadtime
(currently up to 18 weeks)

Seasonal Bleaching Outlook (xx% probability)



Potential Stress Level: Watch Warning Alert Level 1 Alert Level 2

Bottom Line for Managers

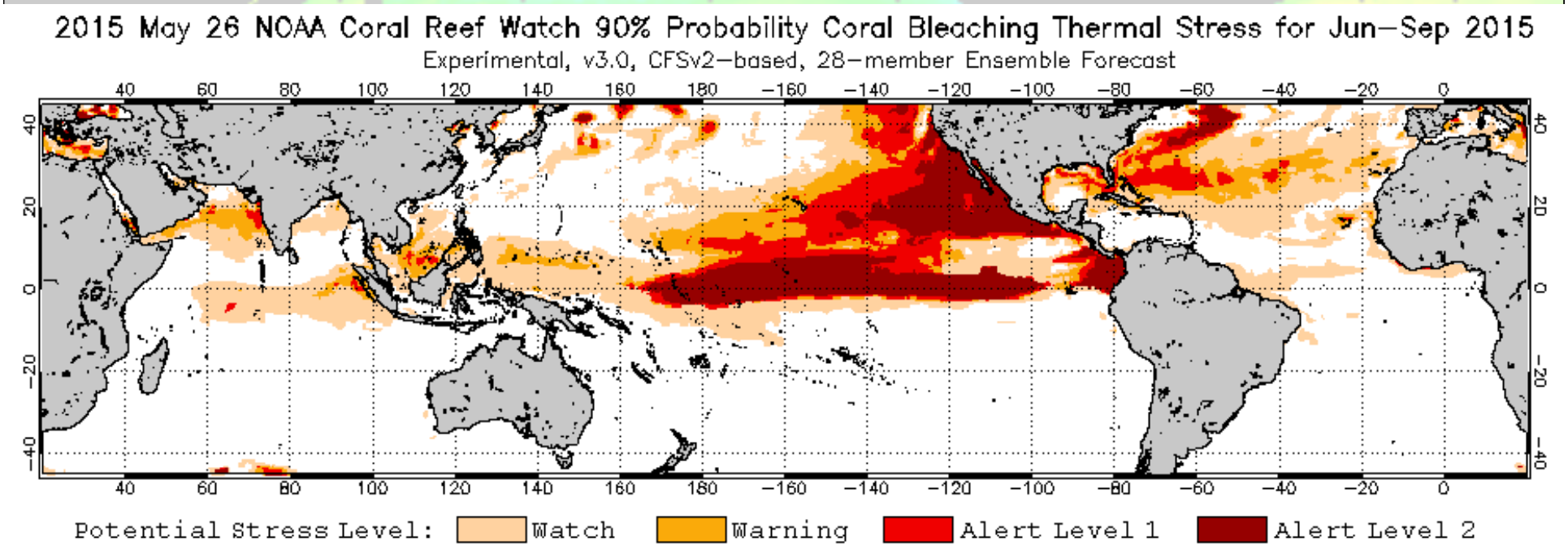


Will my reef be at risk for bleaching soon?

NOAA coral reef CONSERVATION PROGRAM

http://coralreefwatch.noaa.gov

4-Month Coral Bleaching Thermal Stress Outlook (90%)



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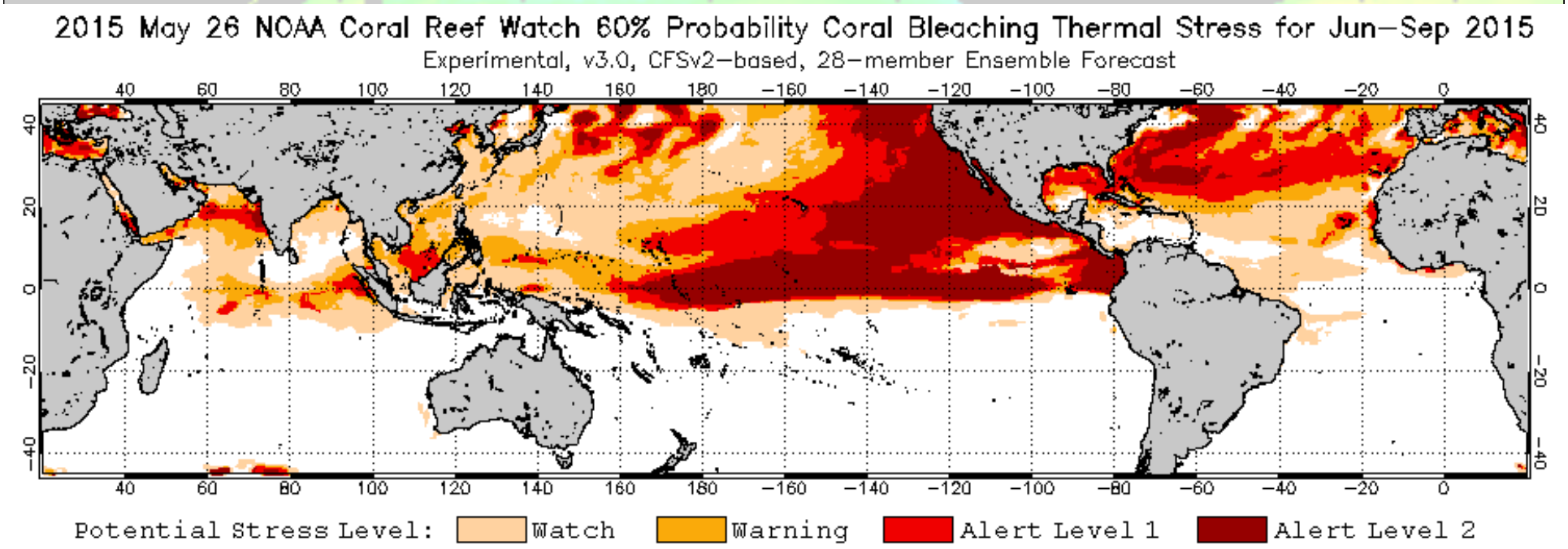
4-Month Coral Bleaching Thermal Stress Outlook (60%)



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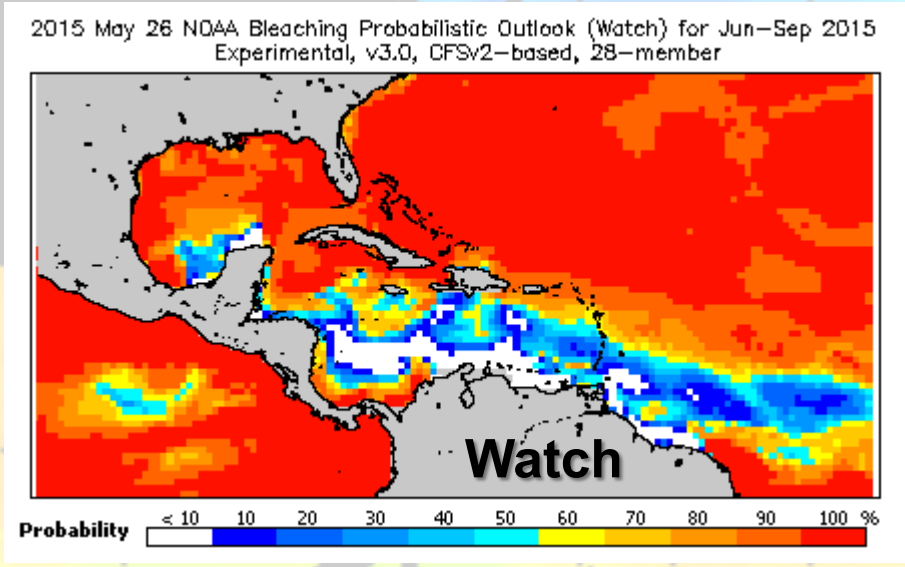
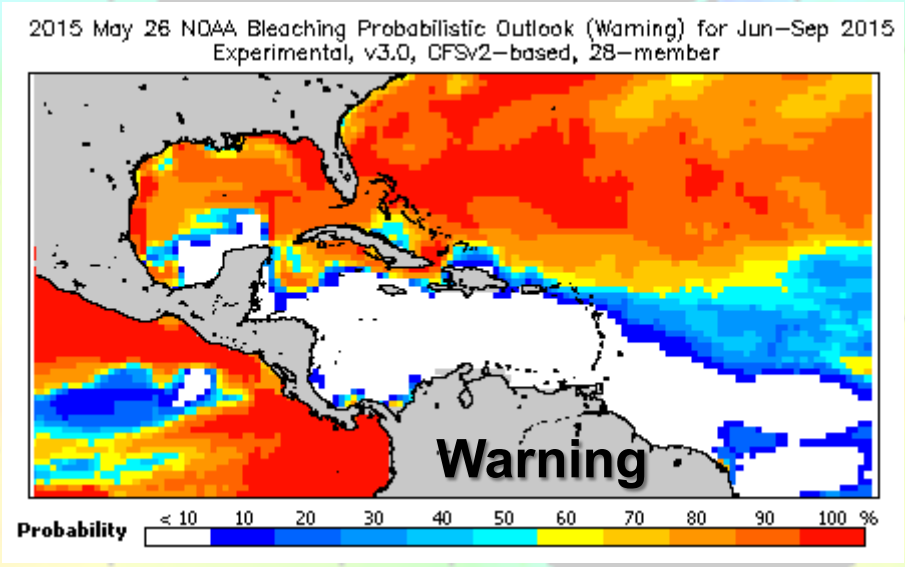
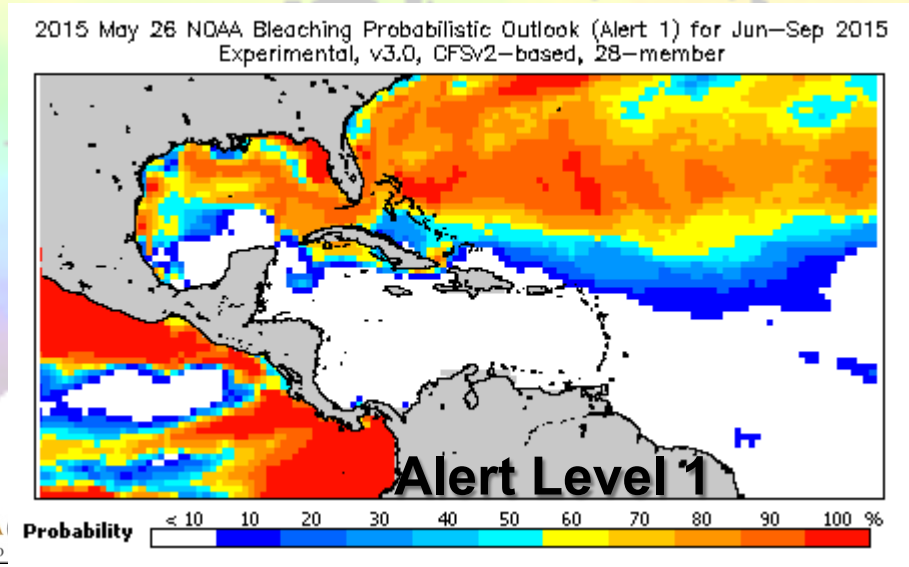
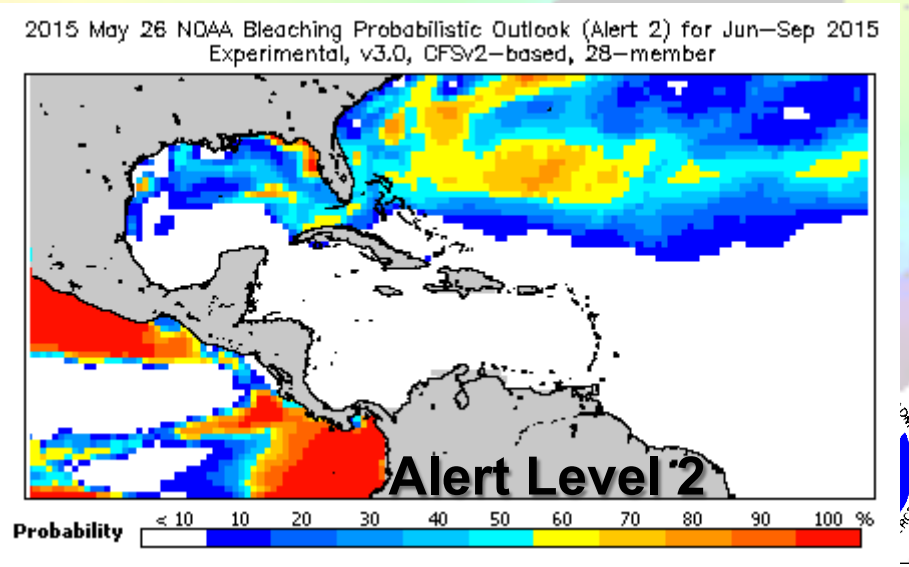
4-Month Coral Bleaching Thermal Stress Outlook

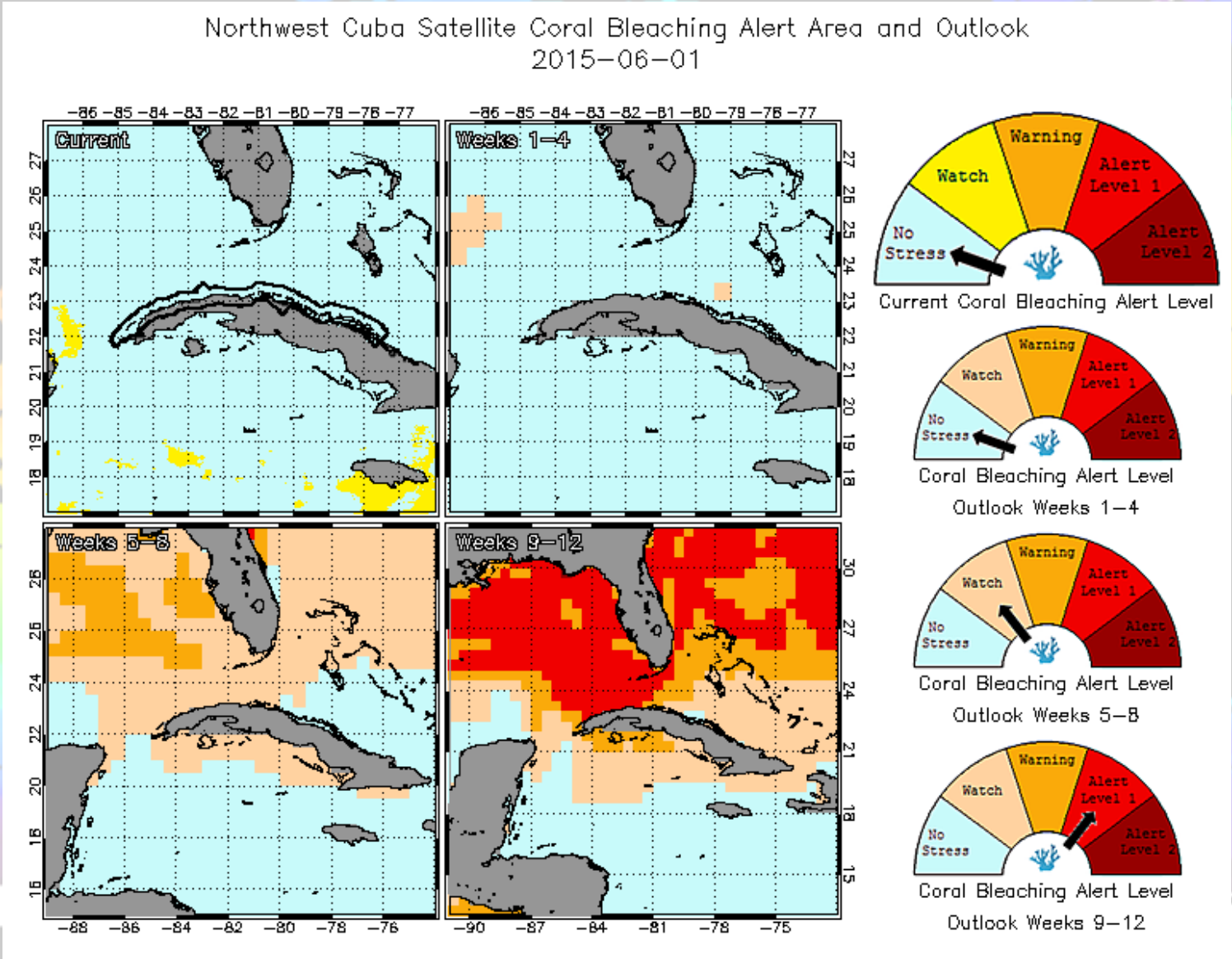








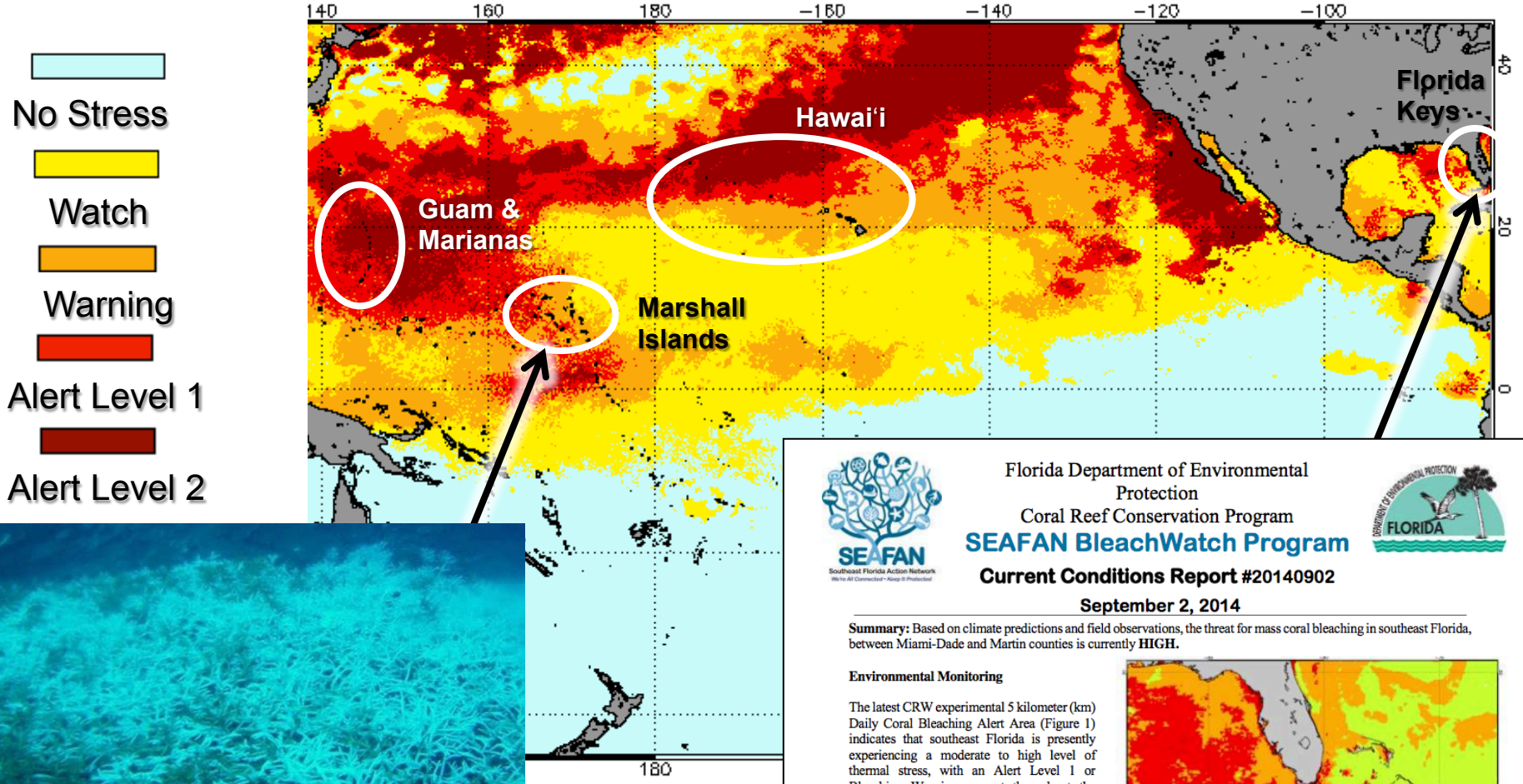
5-km Regional Thermal Stress Gauges



http://coralreefwatch.noaa.gov

2014 Severe Bleaching

NOAA Coral Reef Watch Annual Maximum Satellite Coral Bleaching Alert Area 2014



Florida Department of Environmental Protection
Coral Reef Conservation Program

SEAFAN BleachWatch Program

Current Conditions Report #20140902

September 2, 2014

Summary: Based on climate predictions and field observations, the threat for mass coral bleaching in southeast Florida, between Miami-Dade and Martin counties is currently **HIGH.**

Environmental Monitoring

The latest CRW experimental 5 kilometer (km) Daily Coral Bleaching Alert Area (Figure 1) indicates that southeast Florida is presently experiencing a moderate to high level of thermal stress, with an Alert Level 1 or Bleaching Warning present throughout the region. This indicates that bleaching is likely in southeast Florida and additional alerts are possible if current conditions continue or worsen.

- NOAA's Bleaching Hotspot Map compares current SST to the maximum monthly mean, which is the average temperature during the

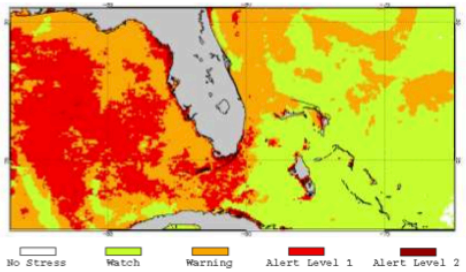
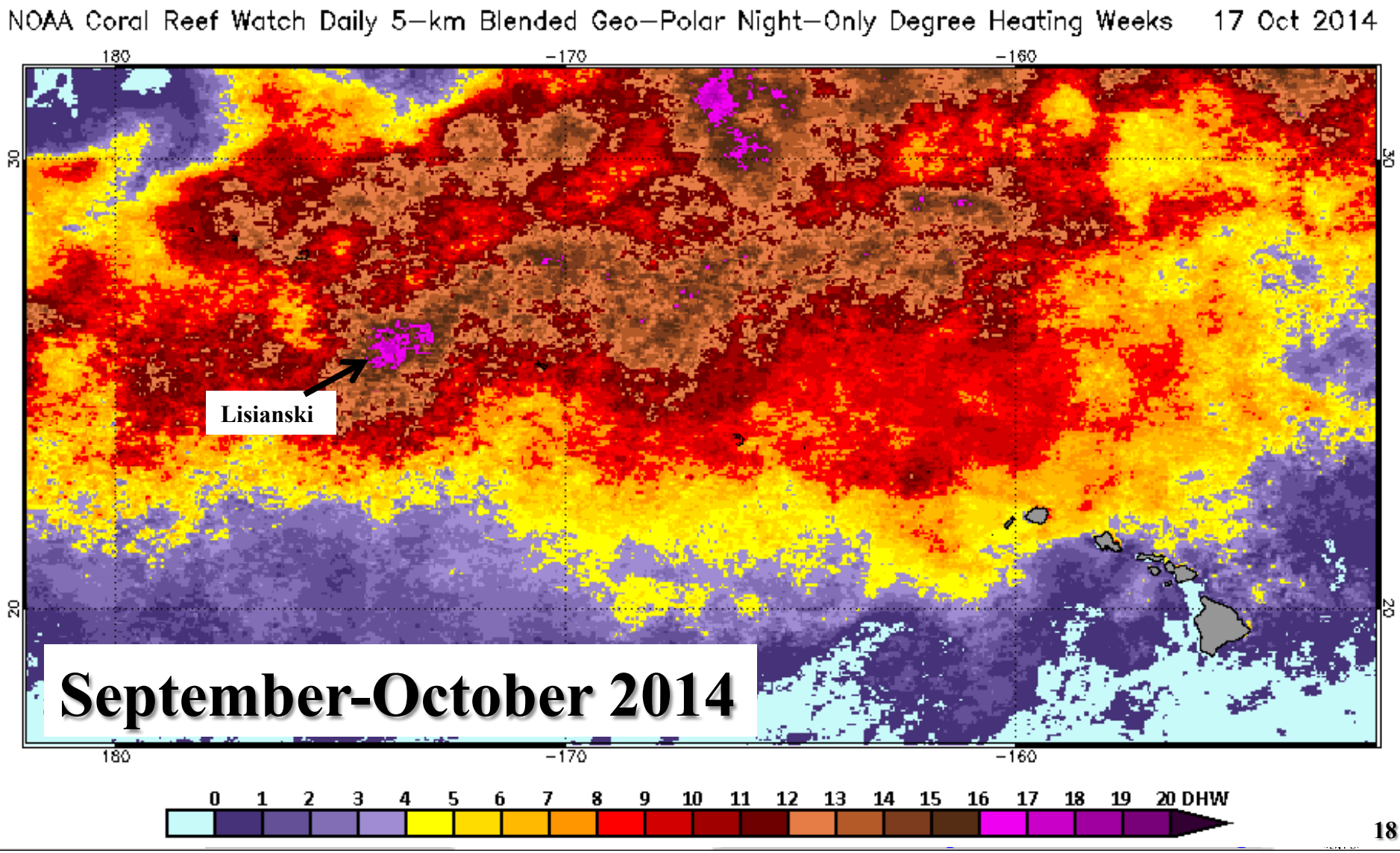
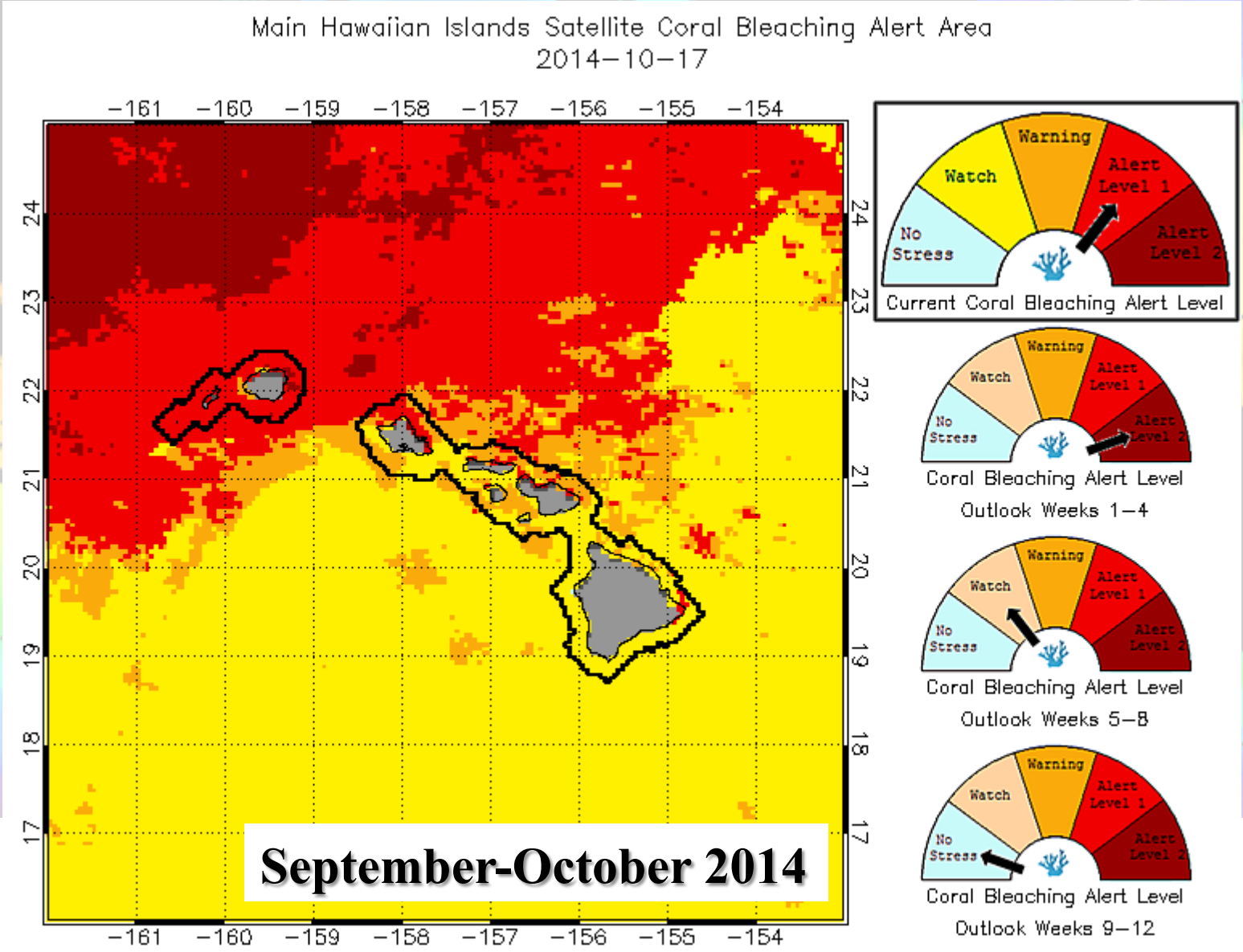


Figure 1. NOAA CRW Experimental Daily 5 km Blended Geo-Polar Nighttime Blended Bleaching Alert Area; August 31, 2014
http://coralreefwatch.noaa.gov/satellite/bleaching5km/index.php

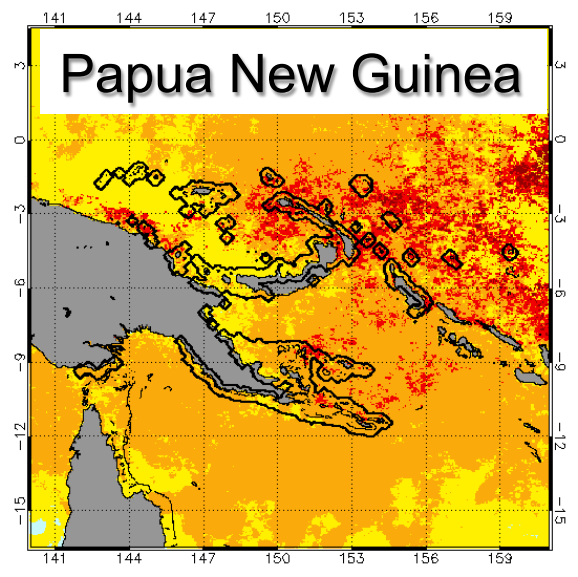
2014 NWHI Bleaching

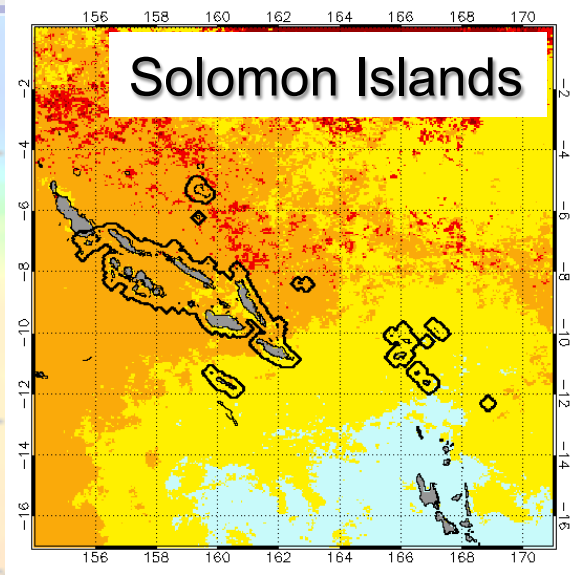


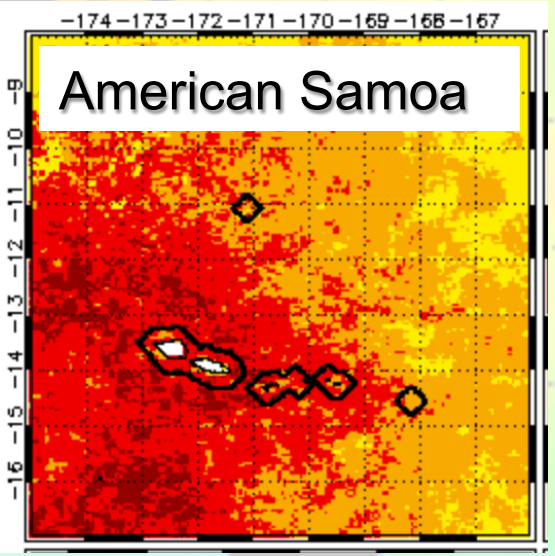
2014 Main Hawaiian Islands Bleaching

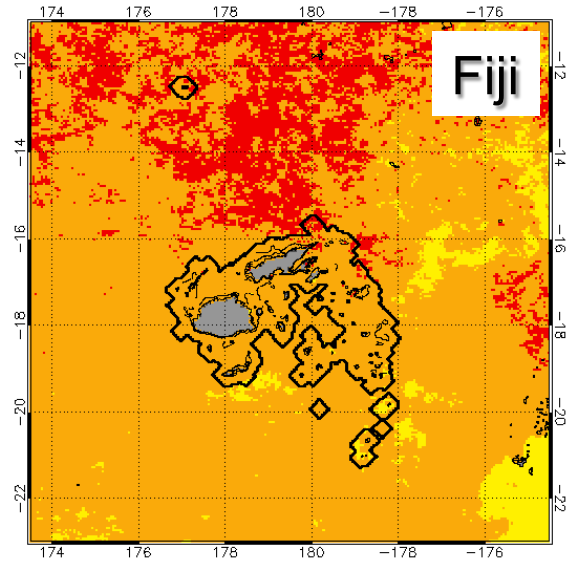


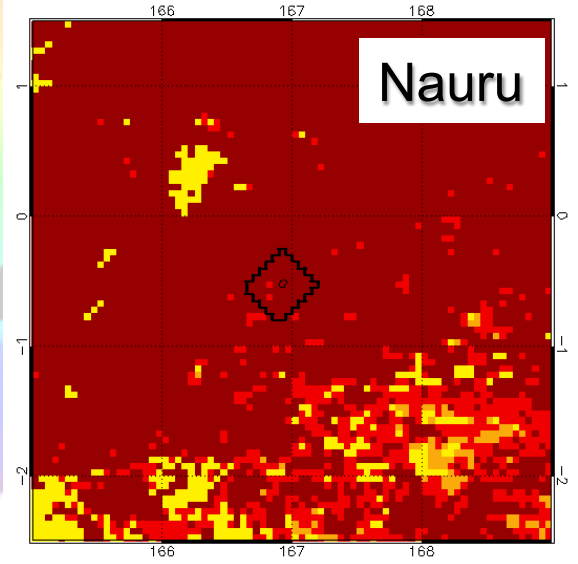
2015 Bleaching – South Pacific











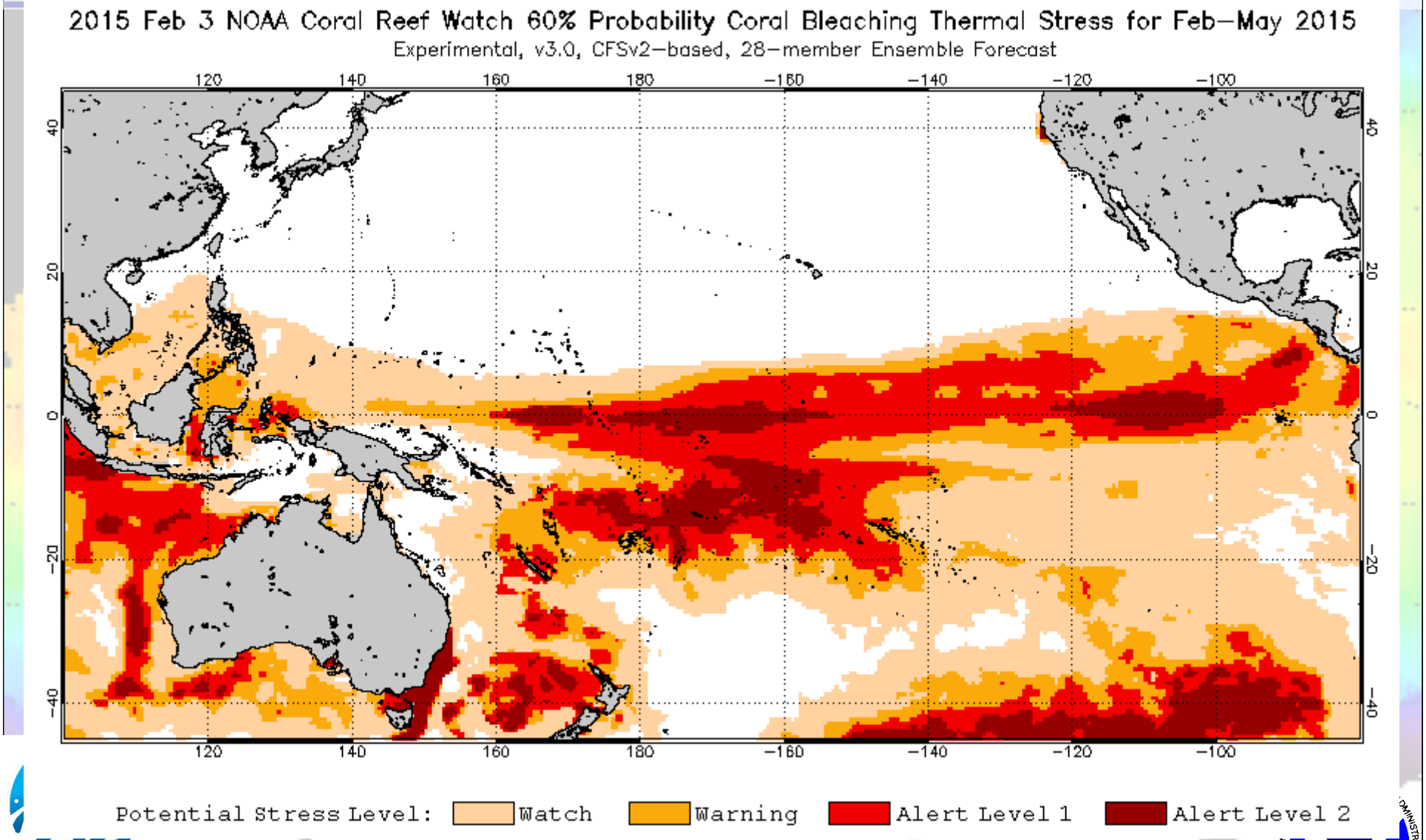
NOAA CORAL REEF CONSERVATION PROGRAM

http://coralreefwatch.noaa.gov

2015: American Samoa before and after: Flower Pot Island in Dec. 2014 & Feb. 2015

CATLIN SEAVIEW SURVEY

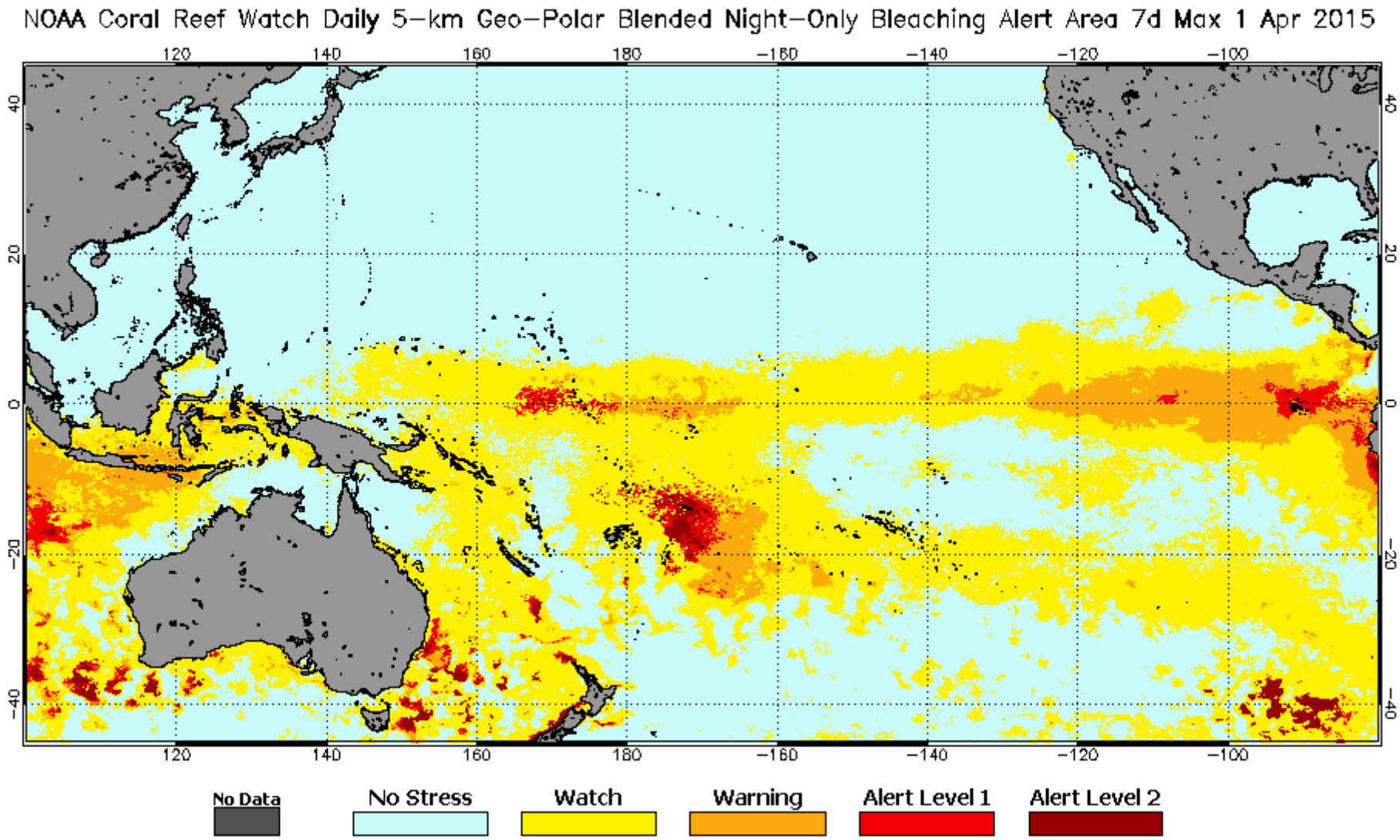
Four-Month Outlook verification



NOAA CORAL REEF CONSERVATION PROGRAM

http://coralreefwatch.noaa.gov

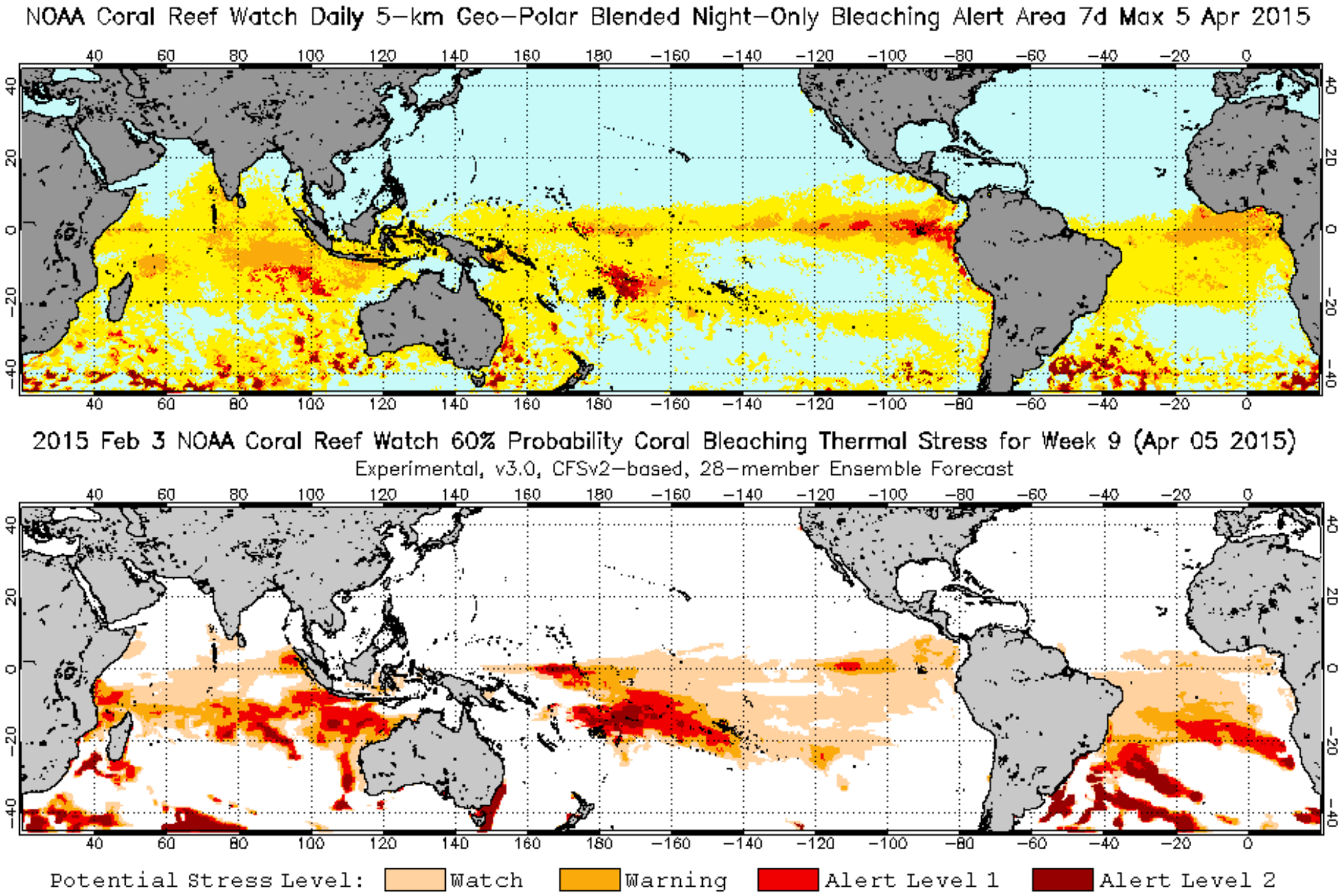
Four-Month Outlook verification



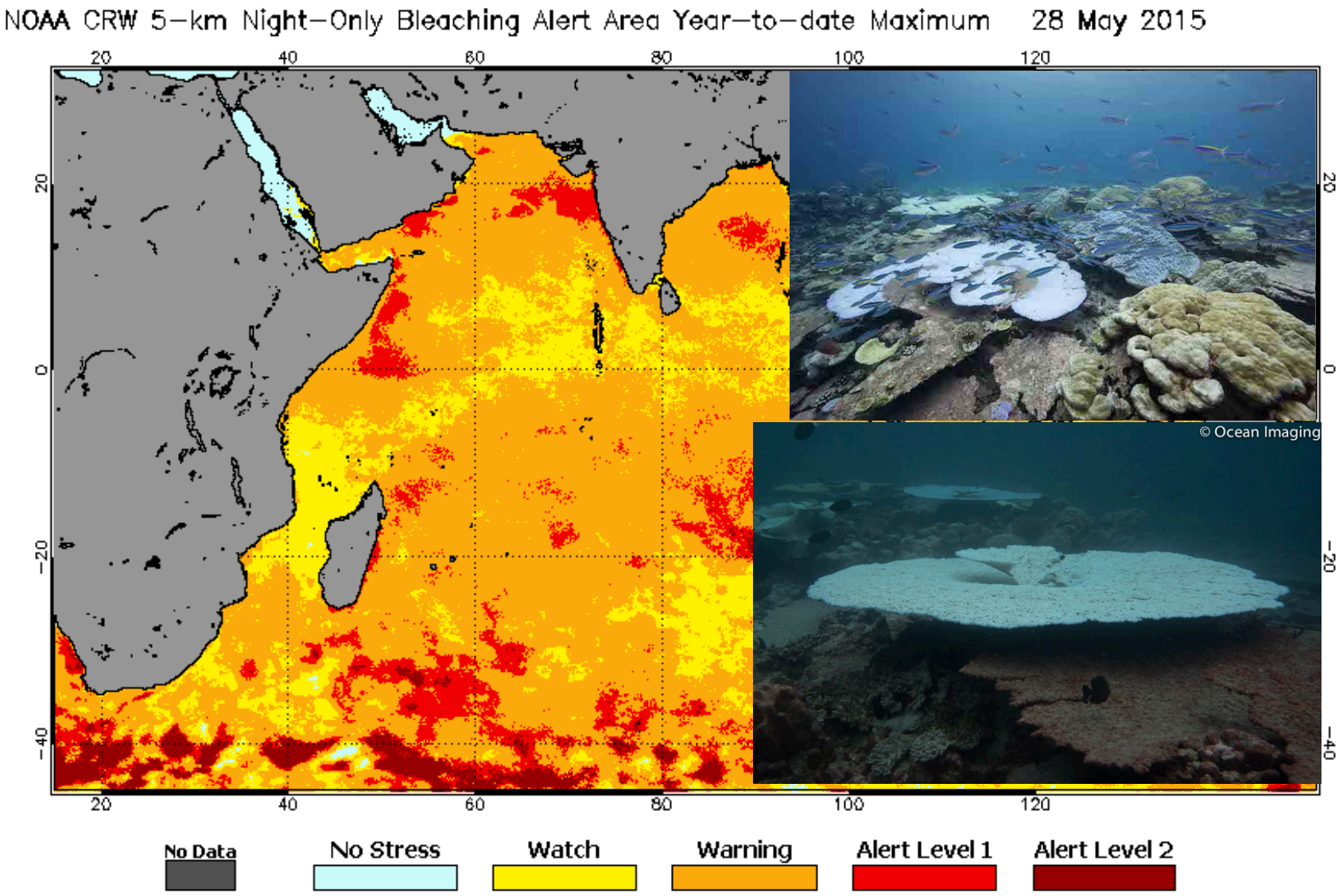
NOAA CORAL REEF CONSERVATION PROGRAM

http://coralreefwatch.noaa.gov

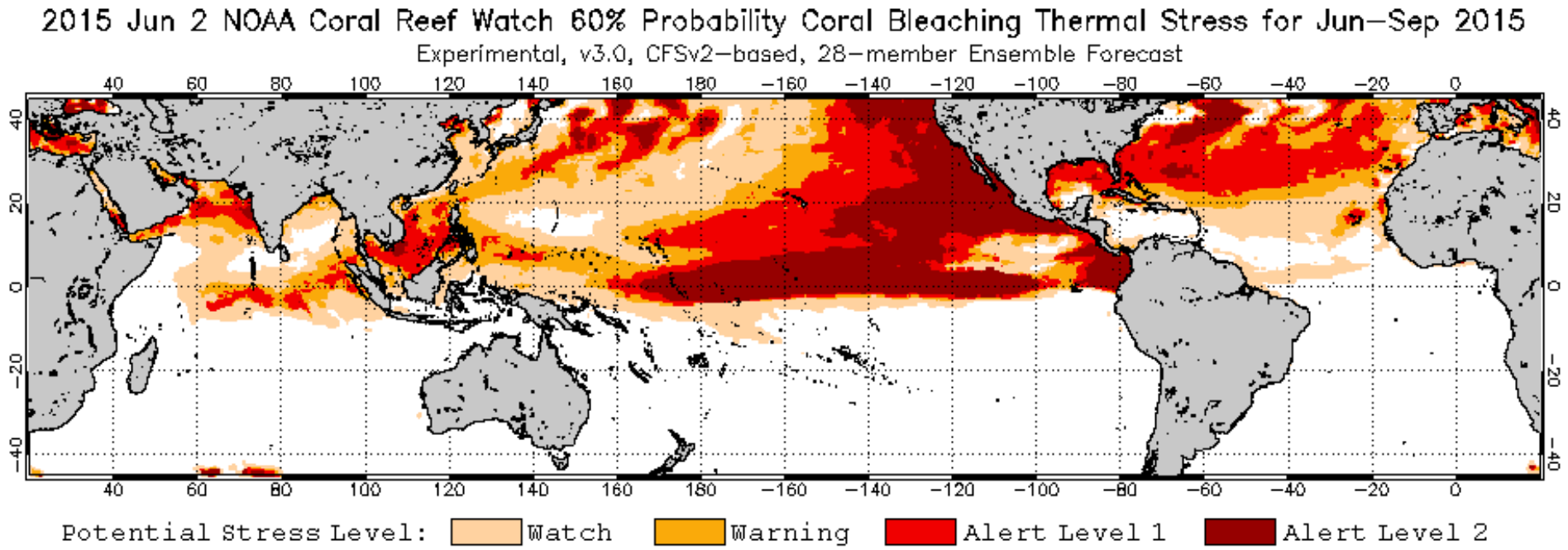
Four-Month Outlook verification



2015 Indian Ocean Bleaching



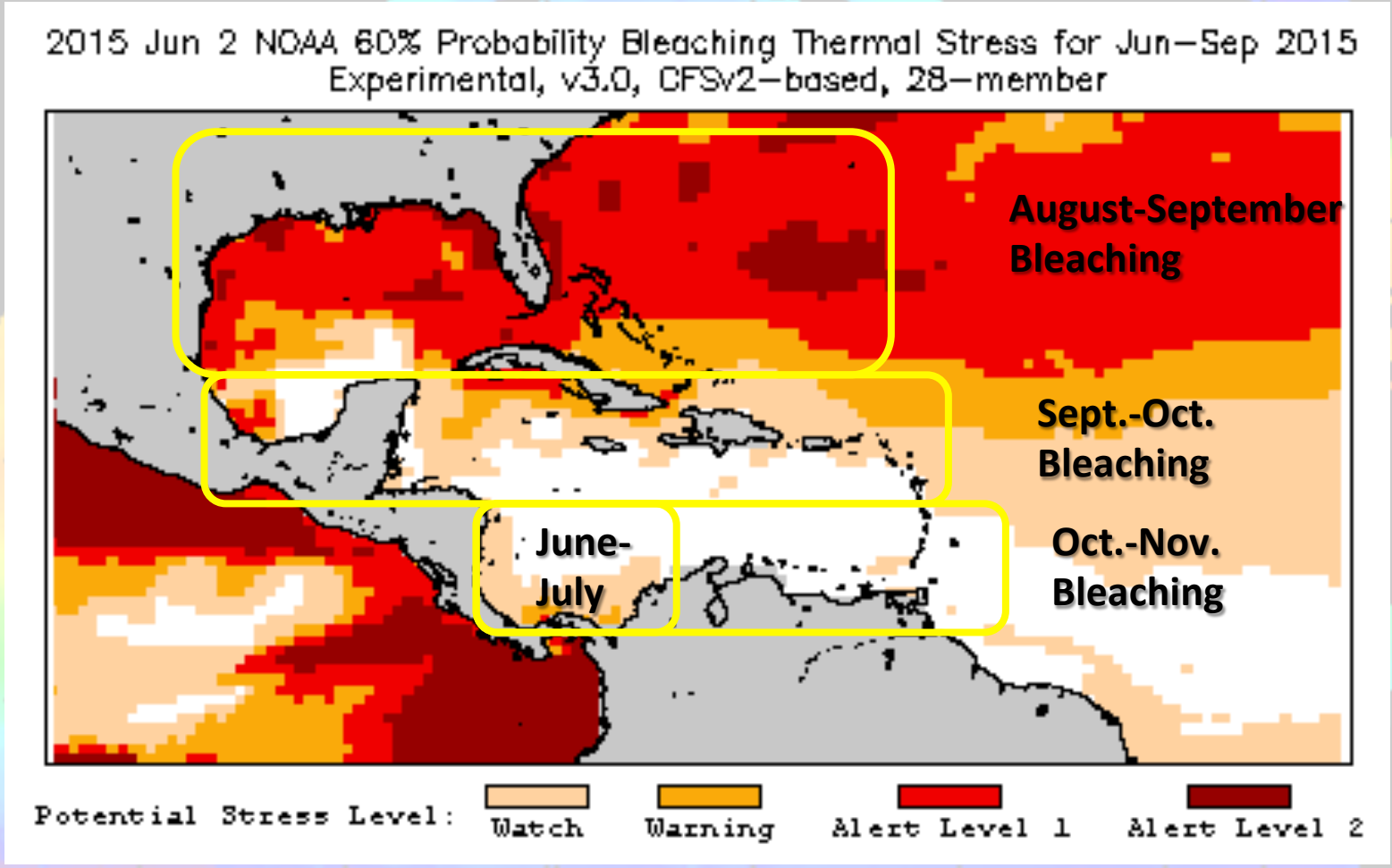
4-Month Bleaching Outlook



Ongoing predictions: Best test for a model

http://coralreefwatch.noaa.gov

Current Caribbean Outlook, May-August:



http://coralreefwatch.noaa.gov

Florida BleachWatch Programs

Mote Marine Laboratory / Florida Keys National Marine Sanctuary

Coral Bleaching Early Warning Network

Current Conditions Report #20150602

Updated June 2, 2015

Summary: Based on climate predictions, current conditions, and field observations, the threat for mass coral bleaching within the FKNMS is currently **LOW.**

NOAA Coral Reef Watch 60% Probability Coral Bleaching Thermal Stress Outlook June 2015-Sept. 2015 (experimental)

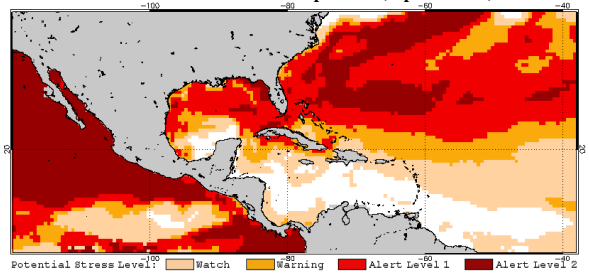


Figure 1. NOAA's Experimental Coral Bleaching Thermal Stress Outlook for June 2015– Sept. 2015
http://coralreefwatch.noaa.gov/satellite/bleachingoutlook_cfs/outlook_cfs.php

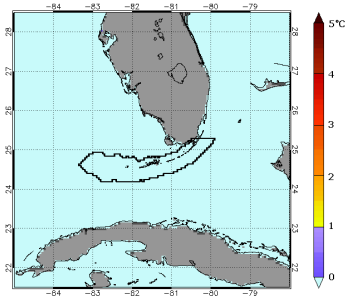


Figure 2. NOAA's Experimental 5km Coral Bleaching HotSpot Map for Florida May 31, 2015.
http://coralreefwatch.noaa.gov/regions/florida.php

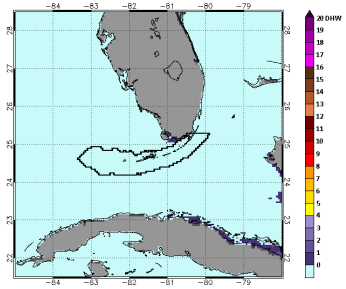


Figure 3. NOAA's Experimental 5km Degree Heating Weeks Map for Florida May 31, 2015.
http://coralreefwatch.noaa.gov/regions/florida.php

Weather and Sea Temperatures

According to the newly released NOAA Coral Reef Watch (CRW) experimental Coral Bleaching Thermal Stress Outlook, there is potential for coral bleaching throughout the Florida Keys region in the coming months, as well as the rest of Caribbean for the remainder of the summer of 2015 (Fig.1).

Recent remote sensing analysis by NOAA's CRW program indicates that the Florida Keys region is presently experiencing minimal thermal stress. NOAA's new experimental 5 km Coral Bleaching HotSpot Map (Fig.2), which illustrates current sea surface temperatures compared to the average temperature for the warmest month, shows that sea surface temperatures are not elevated above normal in the Florida Keys. Similarly, NOAA's experimental 5 km Degree Heating Weeks (DHW) map, which illustrates how much heat stress has built up over the past 12 weeks (Fig.3), indicates no accumulated temperature stress is currently evident in the Florida Keys region. NOAA's Integrated Coral Observing Network (ICON) monitoring stations, which provide near real time *in-situ* sea temperature data along the outer reef tract throughout the Florida Keys, confirm that temperatures are still below 30°C over the past four weeks (Fig.4), likely due in part to breezy conditions observed during this time frame (Fig. 5). *In-situ* sea temperature data is currently only available at Molasses Reef. Fowey Rocks is not recording any data at this time. Mote Marine Laboratory will continue to monitor the NOAA HotSpot maps, DHW maps, and ICON sea temperature data from NOAA monitoring stations on a weekly basis for the remainder of the bleaching season.

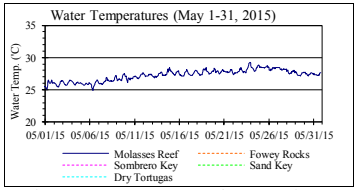


Figure 4. *in-situ* sea temperature from NOAA/ICON monitoring stations (May 1-31, 2015).

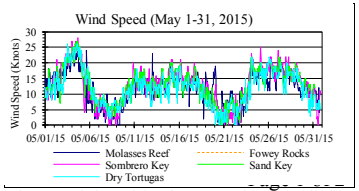


Figure 5. Wind speed data from NOAA/ICON monitoring stations (May 1-31, 2015).

CariCOF Coral Bleaching Bulletins:

- Monthly
- Start: May/June
- End: December

- High Bleaching Potential:
  1-2 page with analysis
- Low Bleaching Potential:
  1 page

Headline Impacts

WARM PACIFIC WATERS HAVE CAUSED SIGNIFICANT BLEACHING IN MANY JURISDICTIONS

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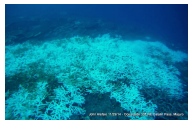
NUNC UT LECTUS

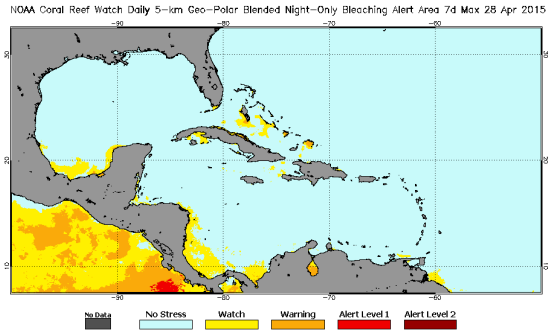


MORBI CONGUE MAGNA NON LACUS
VIVAMUS NEC NUNC

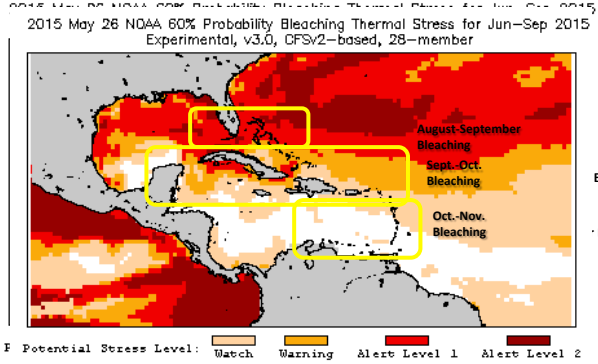
CARIBBEAN CORAL BLEACHING BULLETIN

Notable Observations

- El niño has been declared
- Any major Caribbean bleaching has been preceded by warm May sea surface temperatures (SSTs) around Colombia-Panama
- Southwestern Caribbean bellwether region already warm with early bleaching watches and warnings



Current Model Outlook (Jun-Sept)

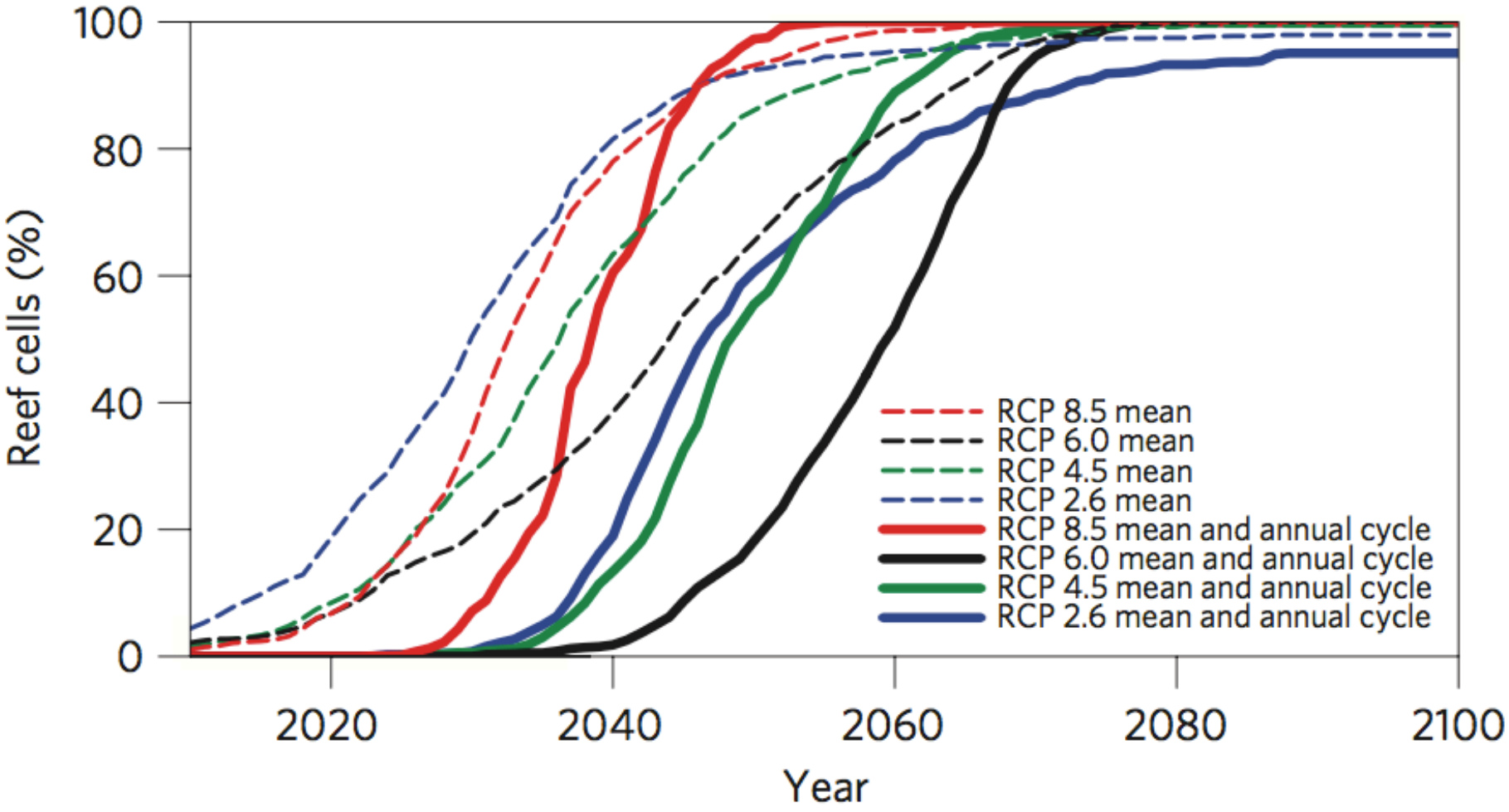


Bleaching

Bleaching

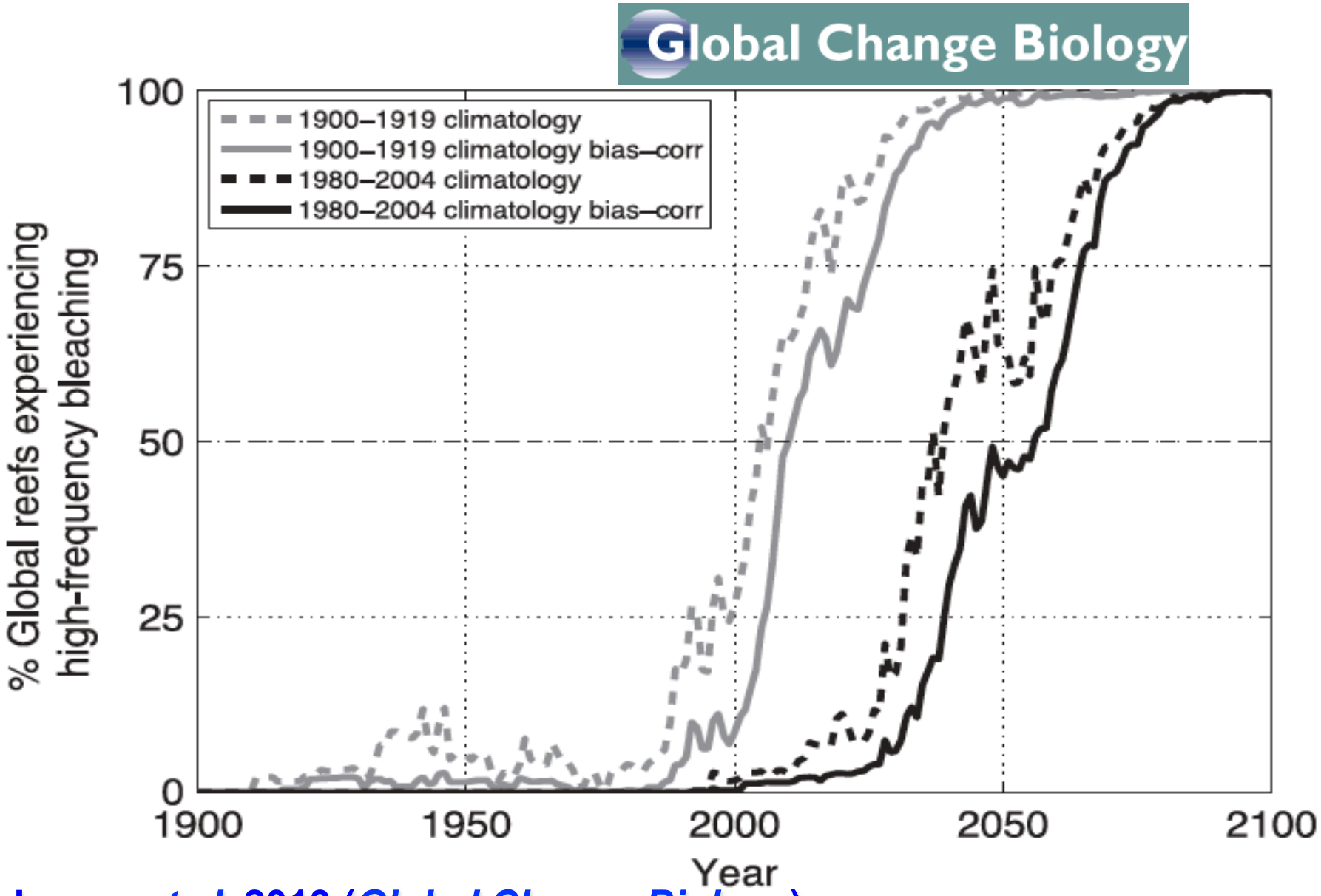
Significant risk of moderate bleaching in Gulf to northern Bahamas

Decadal Modeling of Bleaching



Van Hooidonk *et al*. 2013 (*Nature Climate Change*)

Can Corals Adapt to Climate Change?

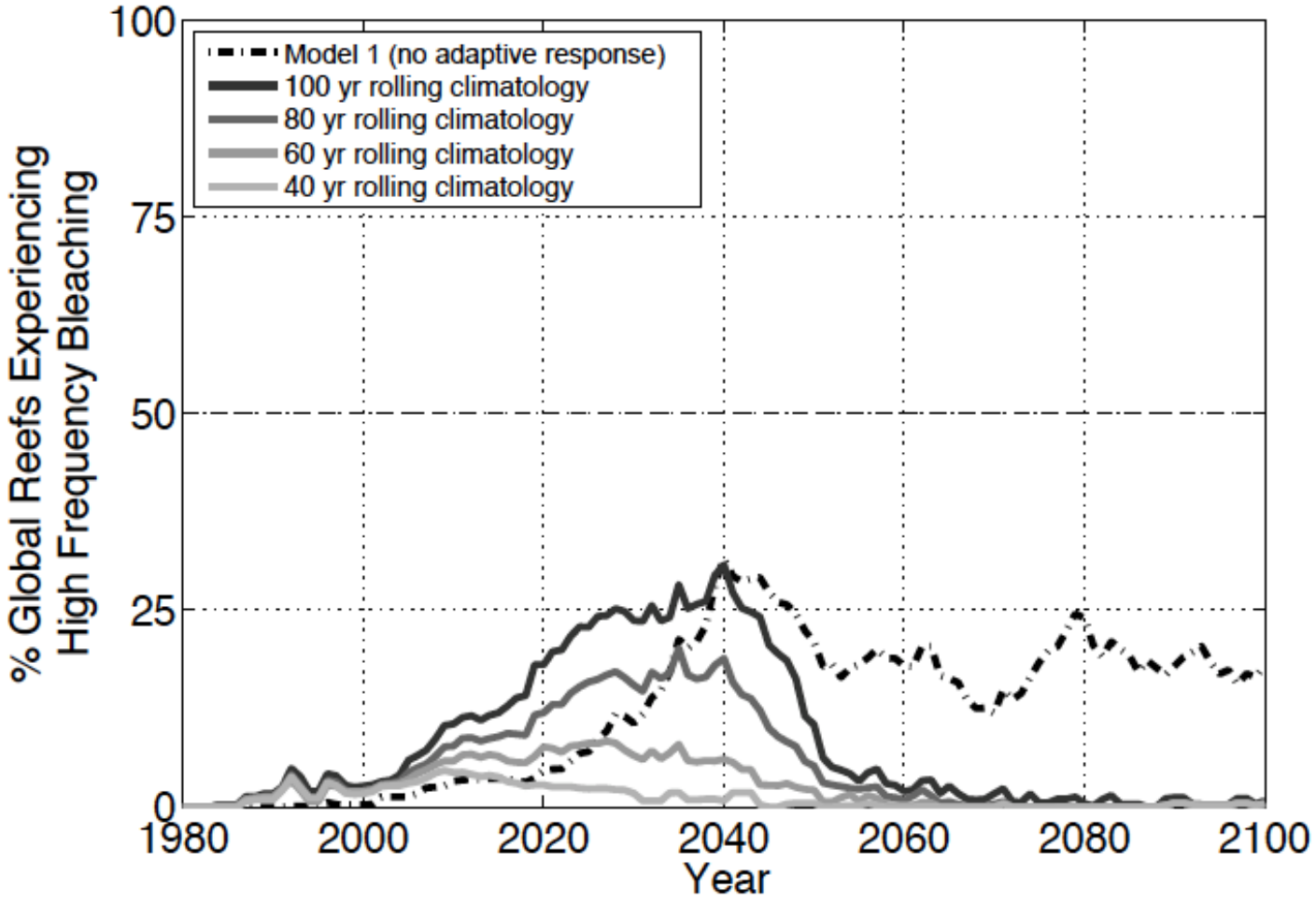


Logan *et al*. 2013 (*Global Change Biology*)

Can Corals Adapt to Climate Change?

Global Change Biology

(a) RCP 2.6 – Model 2



Logan *et al*. 2013 (*Global Change Biology*)

Two Part Solution:
1) Reduce Global CO_2

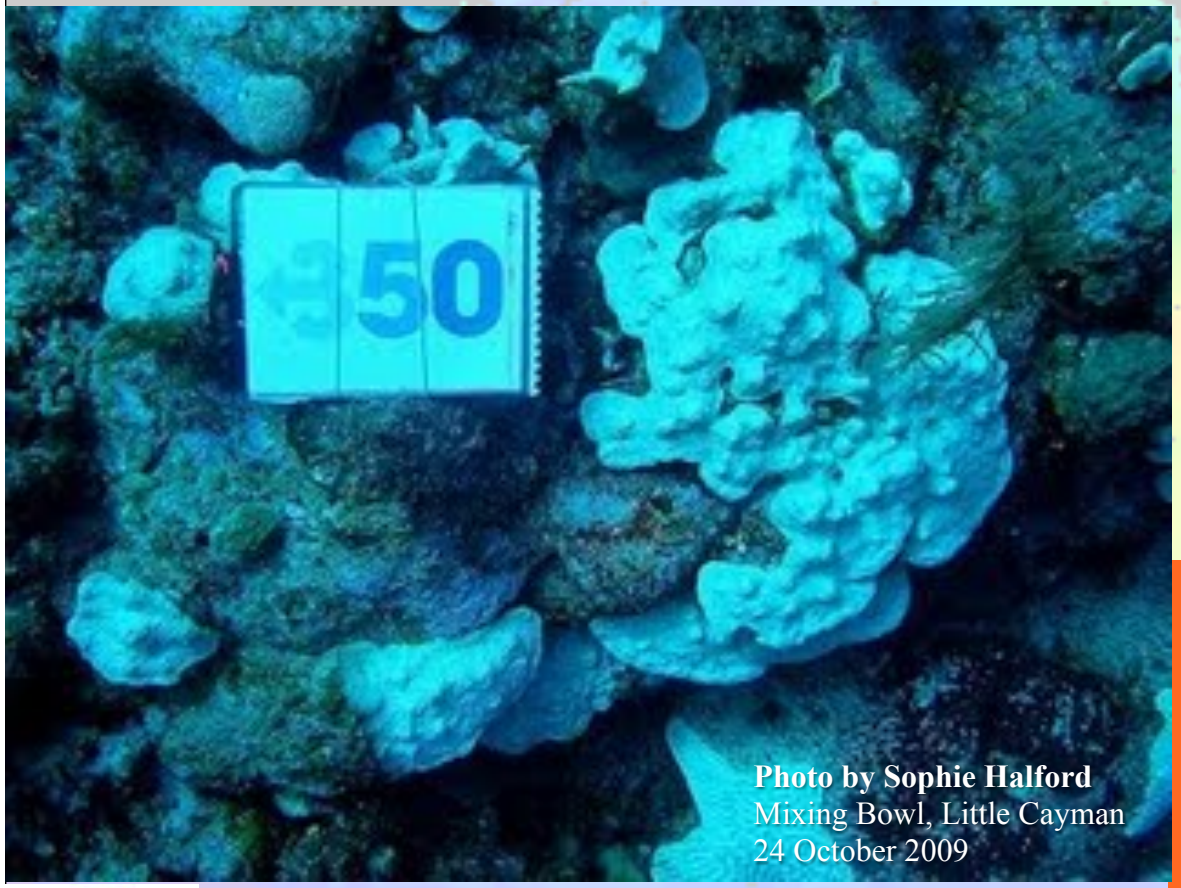
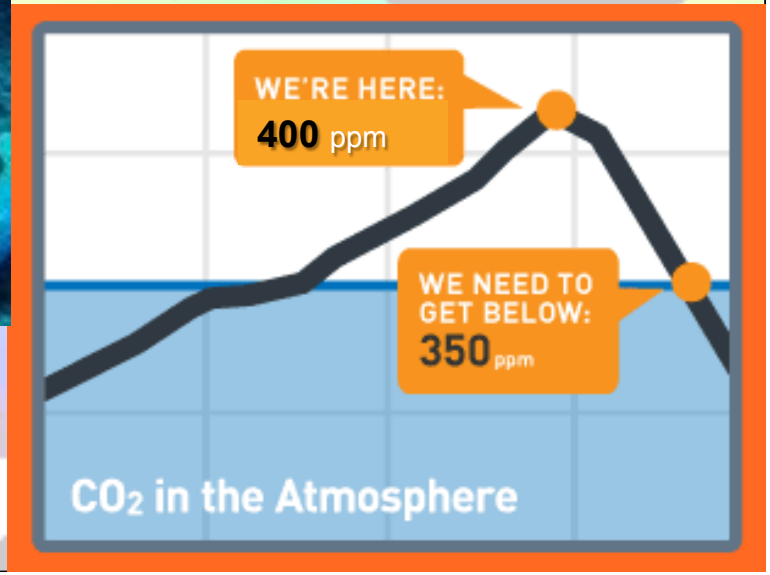
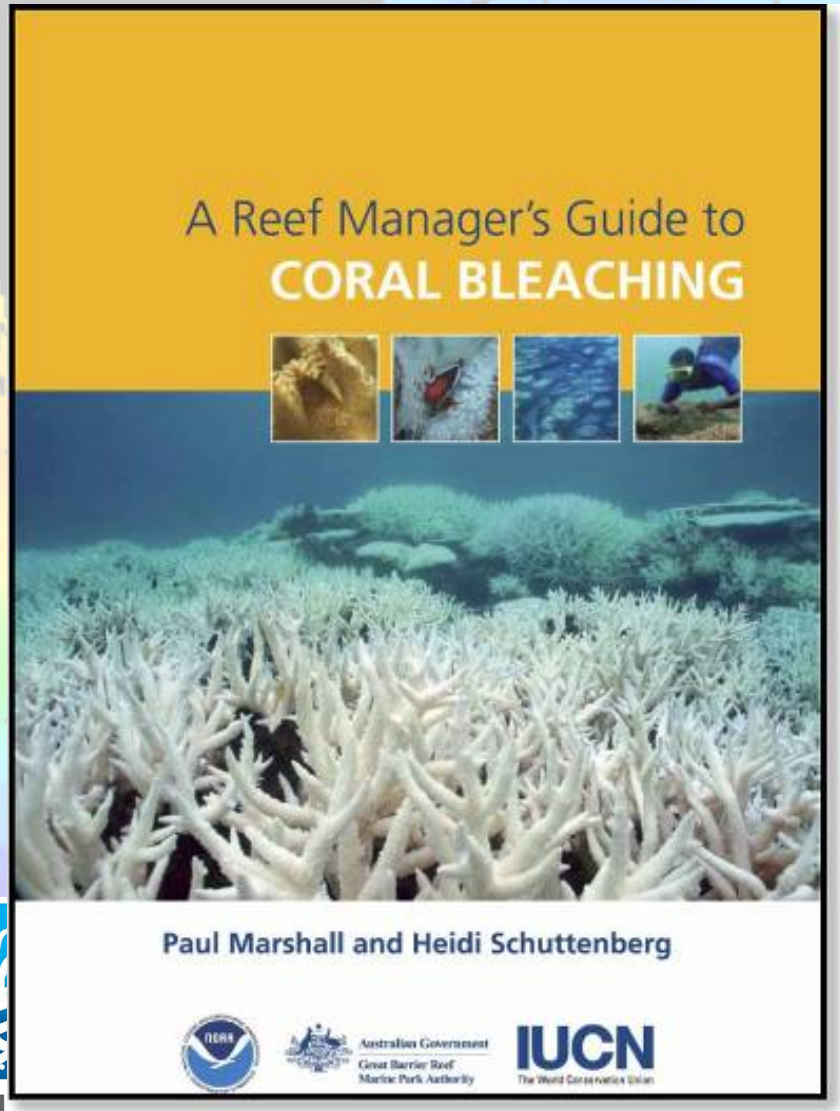


Photo by Sophie Halford
Mixing Bowl, Little Cayman
24 October 2009

See 350.org for why we need to get back to 350 ppm in the atmosphere



Two Part Solution:
2) Reduce Local Stressors



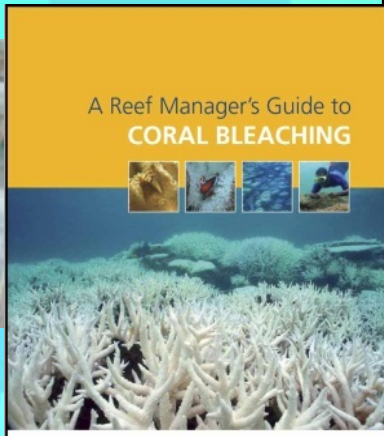
- Result of international workshop, research, and planning
- Addresses local reef management in light of changing climate

Available at coralreef.noaa.gov

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)
- Enhance Marine Protected Areas
  - Planning for climate change

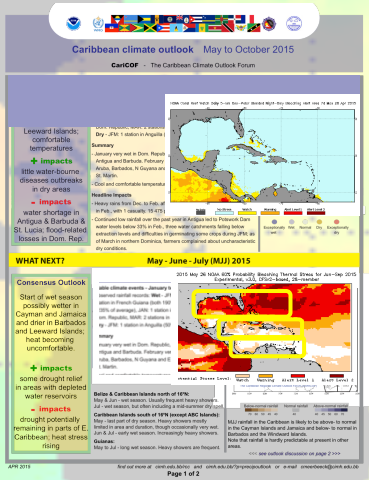


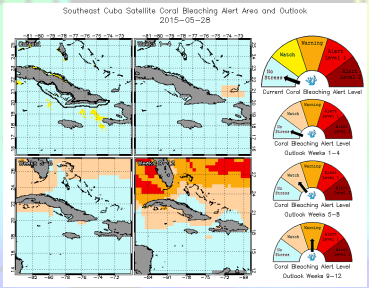
NOAA CORAL REEF CONSERVATION PROGRAM

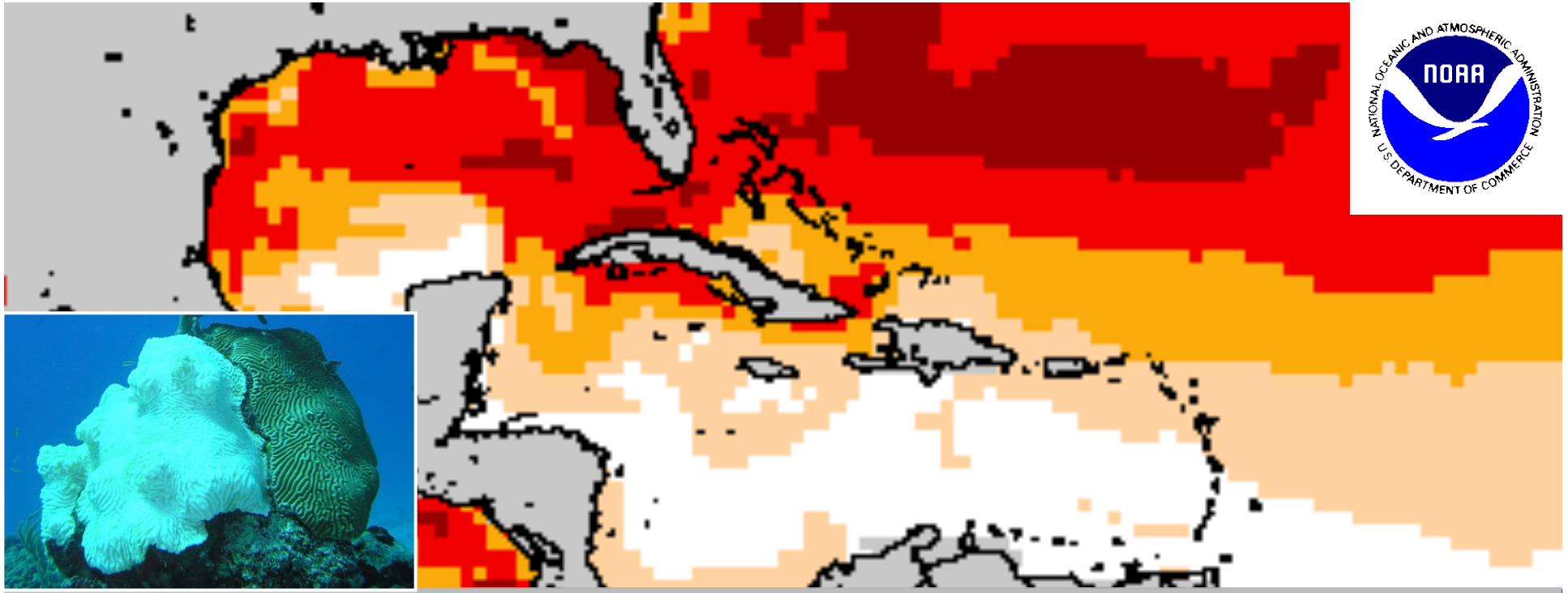
http://coralreefwat

Next Steps

- Add 25 km, large CFS ensemble for days 1-45
- Develop appropriate statistics to analyze skill and predictability
- Apply model to coral disease
- Compare CFS-based Outlook with Outlook from multi-model ensemble?







Questions?

Seasonal to decadal modeling of coral bleaching thermal stress

Dr. C. Mark Eakin
NOAA Coral Reef Watch