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Reef Currents: Coral Reef Watch's Latest Products

NOAA Coral Reef Watch's 5km Satellite Coral Bleaching Heat Stress Monitoring Product Suite Version 3 and Four-Month Outlook Version 4

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In May 2017, the U.S. National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch (CRW) program launched version 3 of its near-real-time daily global 5km Satellite Coral Bleaching Heat Stress Monitoring Product Suite and version 4 of its global Four-Month Coral Bleaching Heat Stress Outlook. New products provide significant improvements over previous versions (Liu et al. 2014a; Eakin et al. 2012) in pinpointing and predicting areas around the globe where reefs are, or soon will be, at risk of coral bleaching (https://coralreefwatch.noaa.gov).

1. Daily Global 5km Satellite Monitoring Product Suite Version 3

As with prior versions of the satellite monitoring products, the version 3 (v3) daily global ~5km (exactly 0.05°) satellite coral bleaching heat stress monitoring product suite (released on May 4, 2017) includes sea surface temperature (SST), SST Anomaly, Coral Bleaching HotSpot, Degree Heating Week (DHW), a 7-day maximum Bleaching Alert Area, and a 7-day SST Trend (Fig. 1). These near-real-time satellite products are available currently from March 12, 2013 to the present. Reprocessed data to 1985 will be added shortly.

The Coral Bleaching HotSpot product (Fig. 1c) measures the occurrence and magnitude of current heat stress that can lead to bleaching. It is calculated as the difference between the nighttime SST value and the average nighttime temperature of the warmest month of the year (the maximum of the monthly mean SST climatology, or MMM) at the same location. The Degree Heating Week (DHW) product (Fig. 1d), which measures accumulated heat stress experienced by corals, sums the HotSpots of 1°C or greater over a rolling 12-week period. The 7-day maximum Bleaching Alert Area product (Fig. 1e) identifies areas where bleaching heat stress meets or exceeds predefined levels, based on the HotSpot and DHW values during the most recent seven-day time period. The 7-day SST Trend (Fig. 1f) provides information on the near-term pace and direction of the SST variation and, hence, coral bleaching heat stress over the preceding seven days. All products are updated daily and posted on CRW's website and FTP site. Detailed descriptions are provided on CRW's website (https://coralreefwatch.noaa.gov/satellite/bleaching5km) and in Liu et al. (2014b). CRW's 5km satellite monitoring provides service at or near reef-scales, allowing direct monitoring of heat stress on at least 95% of the world's coral reefs. A set of enhanced color schemes, developed to improve graphic presentation of the data and implemented in the version 2 (v2) products after their official release in May 2014, continues to be used in v3.

The v3 5km satellite monitoring continues to use the NOAA/National Environmental Satellite, Data, and Information Service's (NESDIS) operational daily global 5km geostationary-polar-orbiting (Geo-Polar) Blended Night-only SST Analysis (Maturi et al., 2017) as the near-real-time input data. The products use the same algorithms as the v2 products (Liu et al., 2014b) but use a significantly improved climatology. The new climatology was derived from a combination of the recently completed NOAA/NESDIS 2002-2015 reprocessed daily global 5km Geo-Polar Blended Night-only SST Analysis, and the 1985-2002 portion of the daily global 5km SST reanalysis of the Operational SST and Sea Ice Analysis (OSTIA) system, produced by the United Kingdom Met Office. The near-real-time OSTIA SST was

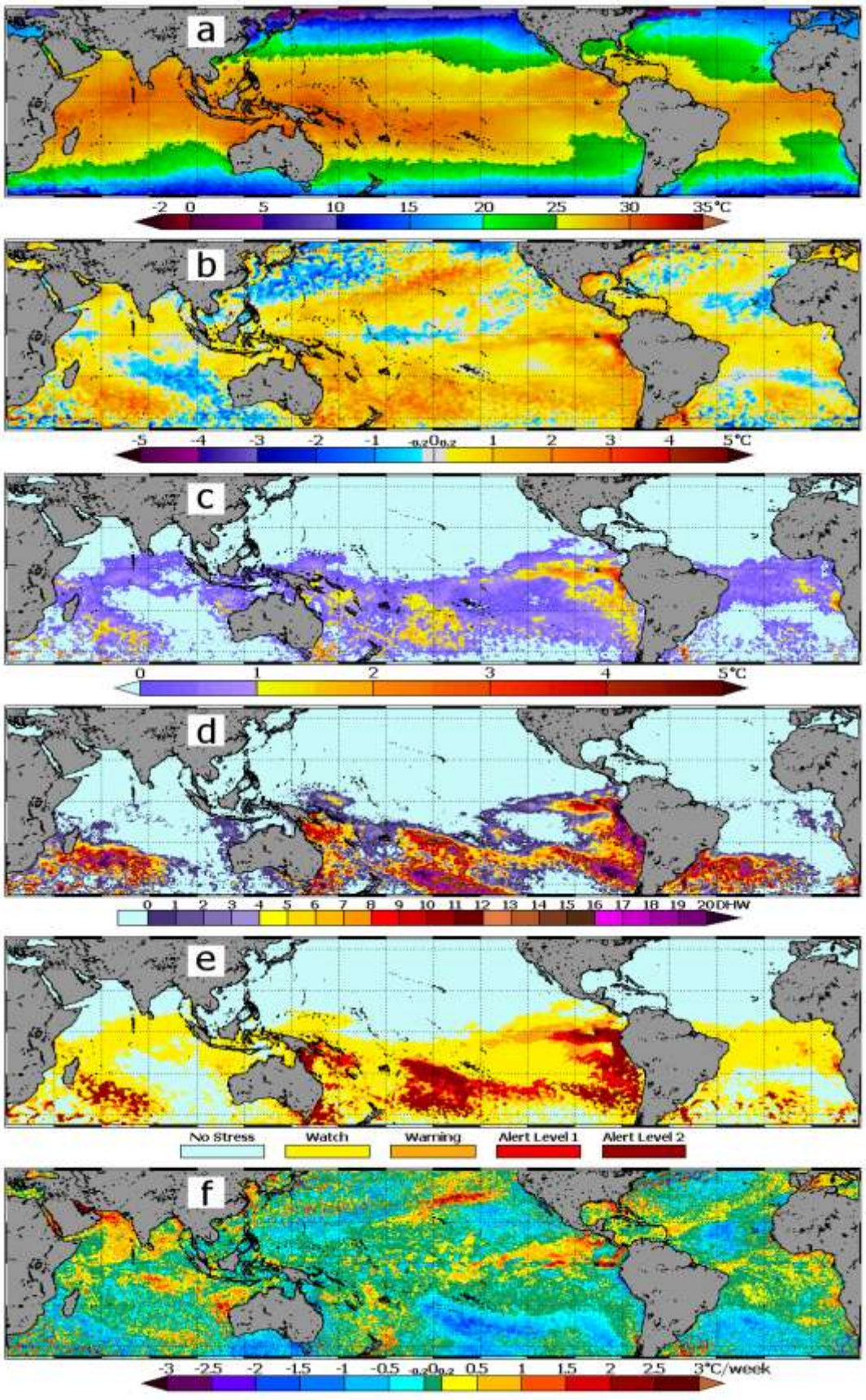

Figure 1. NOAA CRW's version 3 daily global 5km satellite (a) sea surface temperature (SST), (b) SST Anomaly, (c) Coral Bleaching HotSpot, (d) Degree Heating Week, (e) 7-day maximum Bleaching Alert Area, and (f) 7-day SST Trend maps issued on April 1, 2017. Note that the Bleaching Alert Area map (e) shows Alert Levels 1 and 2 heat stress in the Great Barrier Reef, Australia and in the region covering Samoa and American Samoa, where bleaching was being reported at that time.

recently (September 21, 2015) adopted by NESDIS to provide the bias correction in the latest generation of NESDIS' operational daily 5km Geo-Polar Blended Night-only SST Analysis, upon which CRW's 5km coral bleaching heat stress monitoring product suite is based. Hence, the combined 1985-2015 5km SST analysis has become the best historical global SST analysis available for deriving a climatology that is internally consistent with the near-real-time SST used in CRW's near-real-time 5km monitoring.

The methodology employed to create the v3 climatology followed the relevant algorithms applied in deriving the v2 climatology and is described in Heron et al. (2015). The 2002-2015 reprocessed Blended SST became available in October 2016 and led to the development of the v3 products presented in this article. The long-lasting 2014-2017 global coral bleaching event (Eakin et al., 2017), which started in June 2014 right after the launch of the v2 products and has continued into 2017, provided a unique opportunity for testing CRW's v2 satellite products on a global scale in a relatively short time period. Discrepancies between the v2 monitoring products and reported bleaching in some reef regions provided by CRW's partners and collaborators helped to confirm some of the problems CRW anticipated in the climatology of the v2 satellite monitoring products, further necessitating the improved climatology in the v3 products. Further analysis is ongoing, but the v3 products appear to have resolved most of the discrepancies between the v2 products and bleaching observations.

A reanalysis of the CRW 5km product suite spanning 1985-2015 will soon be produced, based on the combined 5km reprocessed Blended SST and OSTIA SST Reanalysis, and posted on CRW's website. This will be merged with our near-real-time products to provide a single dataset spanning 1985-date.

2. Four-Month Outlook Version 4

CRW released a new version (v4) of its subseasonal-to-seasonal-scale global ~50km (exactly 0.5°) probabilistic Four-Month Coral Bleaching Heat Stress Outlook on May 16, 2017. The Outlook predicts the likelihood of coral bleaching heat stress up to four months into the future. The predictions are derived using the daily SST forecast from the NOAA/National Weather Service/National Centers for Environmental Prediction's (NCEP) Climate Forecast System Version 2 (CFSv2), an operational, global, fully coupled, atmosphere-ocean-sea ice-land, dynamical, seasonal climate prediction system. The Outlooks are generated by applying the detection algorithm used in CRW's global 5km satellite coral bleaching heat stress monitoring (described in the last section; Liu et al., 2014b), with slight modifications (Eakin et al., 2012; Liu et al., 2017), to the SST predictions from the CFSv2.

The CFSv2 system provides sixteen forecast runs per day: nine runs out to 45-days, three runs out to three months, and four runs out to nine months. Each week, CRW probabilistic outputs from the v4 Outlook use between 28 and 112 ensemble members for each predicted week (112 members for Weeks 1-5 in the future, 49 members for Weeks 6-12, and 28 members for Week 13 and longer). The v4 Outlook utilizes all daily CFSv2 runs, with various predicted temporal lengths, to maximize the number of ensemble members for shorter lead-times (one to 12 weeks in the future); the v3 Outlook used only 28 members to provide predictions out to nine months. Initial analysis indicates that the v4 Outlook has a more robust dataset; however, the accuracy does not seem to be significantly different from the v3.

The v4 Outlook updates once a week, usually on Tuesday morning, U.S. Eastern Time. The Four-Month Outlooks, predicting Bleaching Alert Areas with 90% and 60% probabilities (Fig. 2), can be found at https://coralreefwatch.noaa.gov. Each probability has a four-month composite Outlook map (Fig. 2a-b) and a weekly Outlook map (not shown) for each week of the four-month time period. Taking the 60% probability as an example, at any given data grid, for a specified lead-time (i.e., a predicted week), the heat stress level depicted is the stress level predicted by at least 60% of the forecast ensemble members that correspond to that lead-time. Global probability distribution maps, one for each of the four specified stress ranges (Bleaching Watch and higher, Bleaching Warning and higher, Alert Level 1 and higher, and Alert Level 2), are also provided so that the probability of the occurrence of corresponding stress ranges can be identified for any reef location (Fig. 2c-f). A detailed description of CRW's CFS-based Bleaching Outlook product is provided in Liu et al. (2017) and Eakin et al. (2012), and online at https://coralreefwatch.noaa.gov/satellite/bleachingoutlook_cfs/outlook_cfs.php.

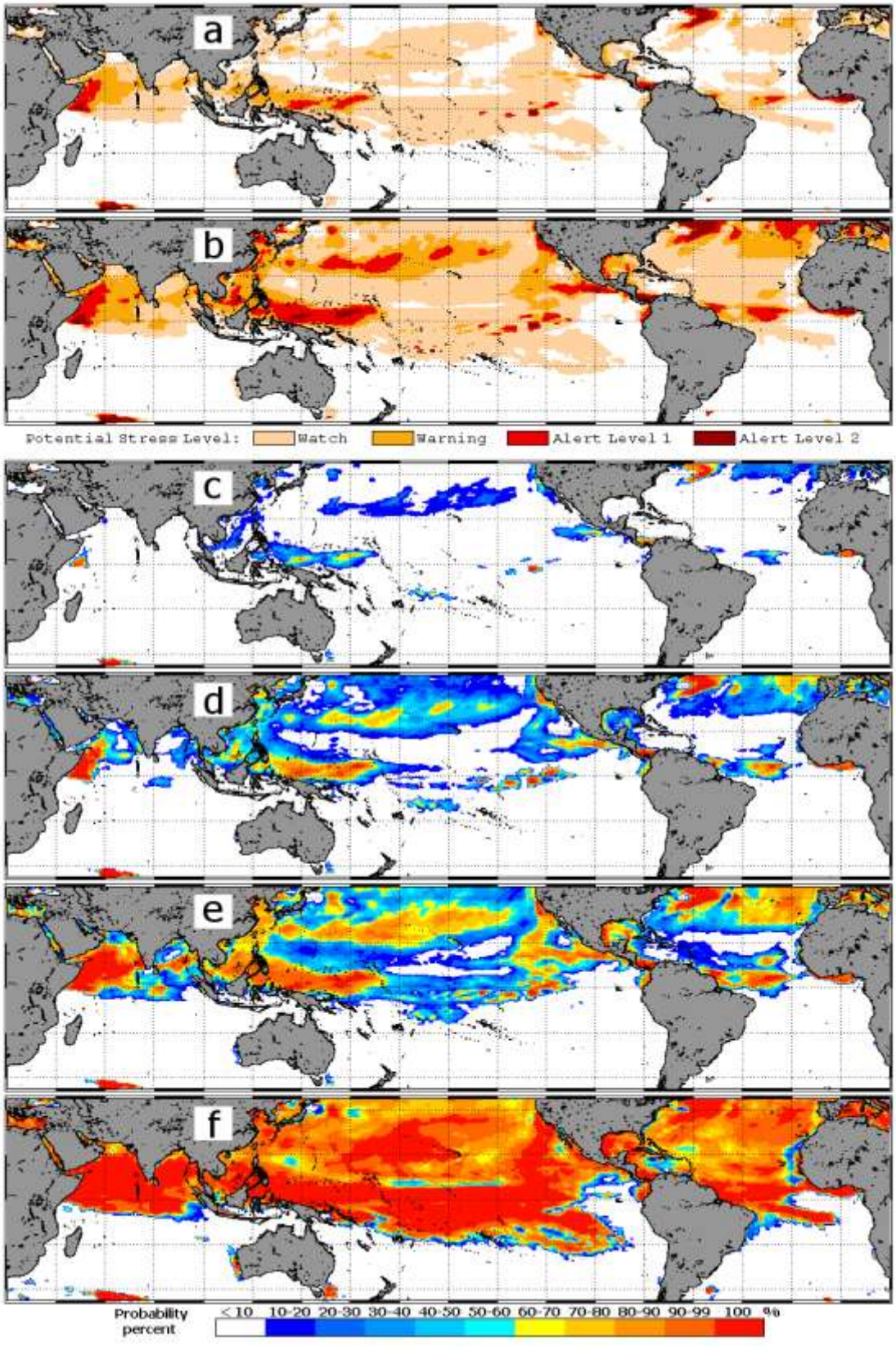

Figure 2. NOAA CRW's version 4 (a) 90% and (b) 60% probabilistic Four-Month Coral Bleaching Heat Stress Outlook maps, and probabilistic maps for the four predicted heat stress ranges: (c) Alert Level 2, (d) Alert Level 1 and higher, (e) Warning and higher, and (f) Watch and higher, issued on May 9, 2017 for May-August 2017.

3. Regional Virtual Stations and Bleaching Alert Email System

With the release of new versions of CRW's 5km global satellite monitoring and modeled Outlook described above, CRW updated its 5km satellite Regional Virtual Stations and Regional Bleaching Heat Stress Gauges product as well, as that product is based on the 5km global satellite monitoring products and associated climatology. The 5km satellite Regional Virtual Stations and Regional Bleaching Heat Stress Gauges product (https://coralreefwatch.noaa.gov/vs) includes 212 Stations intended to cover most coral reefs globally (Fig. 3). The free, automated Bleaching Alert Email System associated with the Regional Stations was also updated (http://coralreefwatch-satops.noaa.gov/).

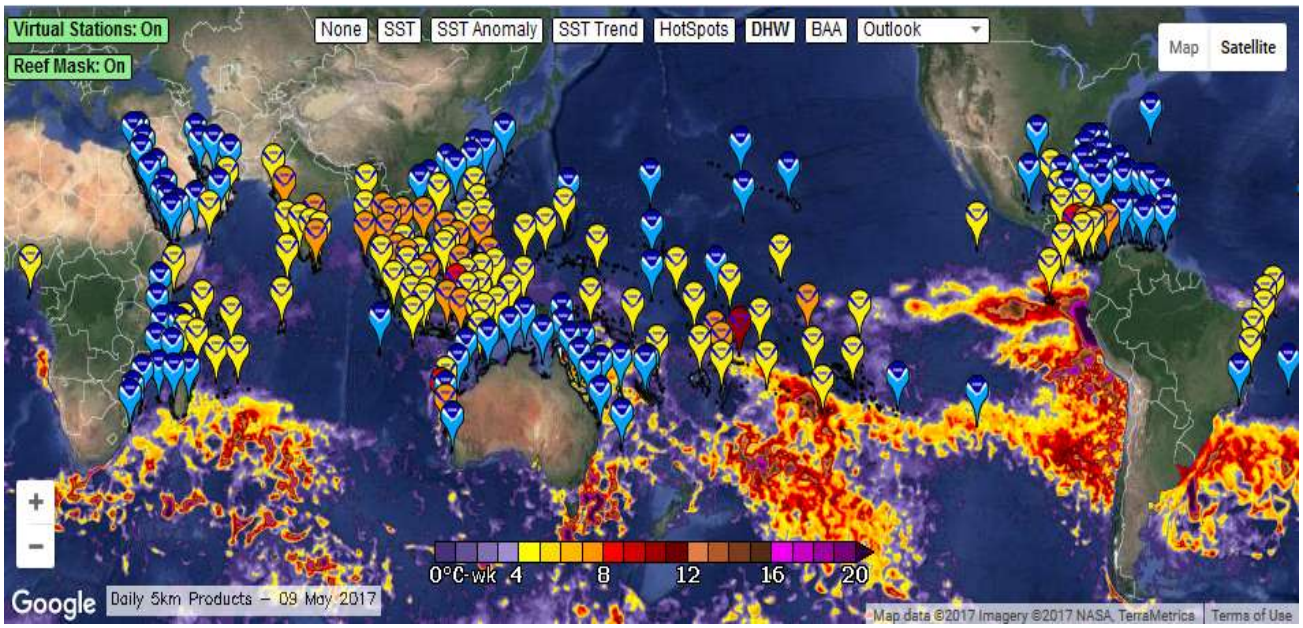

Figure 3. NOAA CRW's 5km Regional Virtual Stations (212 Stations across the global tropical oceans) presented in Google Maps and overlaid on CRW's 5km Degree Heating Week product of May 9, 2017. The color of each Station balloon indicates the level of heat stress experienced on that day (see the Bleaching Alert Area color legend of Fig. 1e).

A Regional Virtual Station includes all coral reefs in a jurisdiction or predetermined sub-region, providing local bleaching heat stress maps and analyses of 5km SST, SST Anomaly, HotSpot, DHW, and Bleaching Alert Area values. When a user receives an email alert for a pre-selected reef region, it indicates that there is change in the status of heat stress within the Station's boundary and guides the user to CRW's online information pertaining to the Station.

Daily-updated Coral Bleaching Heat Stress Gauges (Fig. 4) and time series data and graphs (Fig. 5) are provided for each 5km Regional Virtual Station. While the time series data and graphs contain temporal heat stress information based only on the 5km satellite monitoring, the Gauges provide both the current Station warning level and spatial distribution of heat stress, using the 5km satellite products, and the 60% probability Outlook for the upcoming 1-4, 5-8, and 9-12 weeks. Their detailed description and algorithm can be found at the Regional Virtual Stations website.

The global 5km satellite monitoring and Four-Month Outlook, along with the 5km satellite Regional Virtual Stations and Regional Bleaching Heat Stress Gauges, form the core components of CRW's next-generation decision support system (DSS) informing management and communication about the status of tropical coral reef ecosystems and other coastal marine ecosystems worldwide. These products will undergo continuous improvements as they are tested and ultimately transitioned to full operational support. The 5km satellite Regional Virtual Stations product was developed to help facilitate timely and effective jurisdiction-level management actions pertaining to mass coral bleaching.

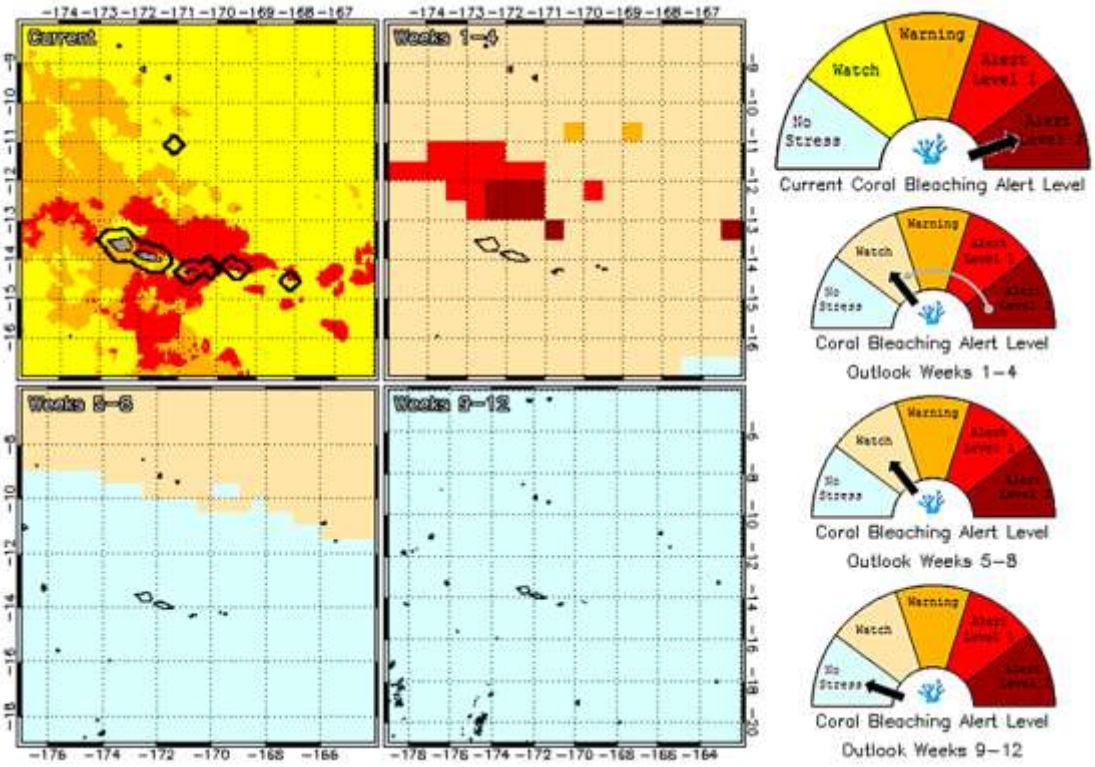

Figure 4. Example NOAA CRW Bleaching Heat Stress Gauge for the 5km Regional Virtual Station at the Samoas, issued on May 12, 2017. The top dial (gauge) and the top left map provide the current Station warning level and spatial distribution of heat stress in the Samoas, as monitored by CRW's 5km satellite products. The other three pairs of maps and corresponding dials (gauges) provide CRW's model-projected bleaching heat stress conditions (Outlook) with 60% probability at the Samoas Station for the upcoming 1-4, 5-8, and 9-12 weeks.

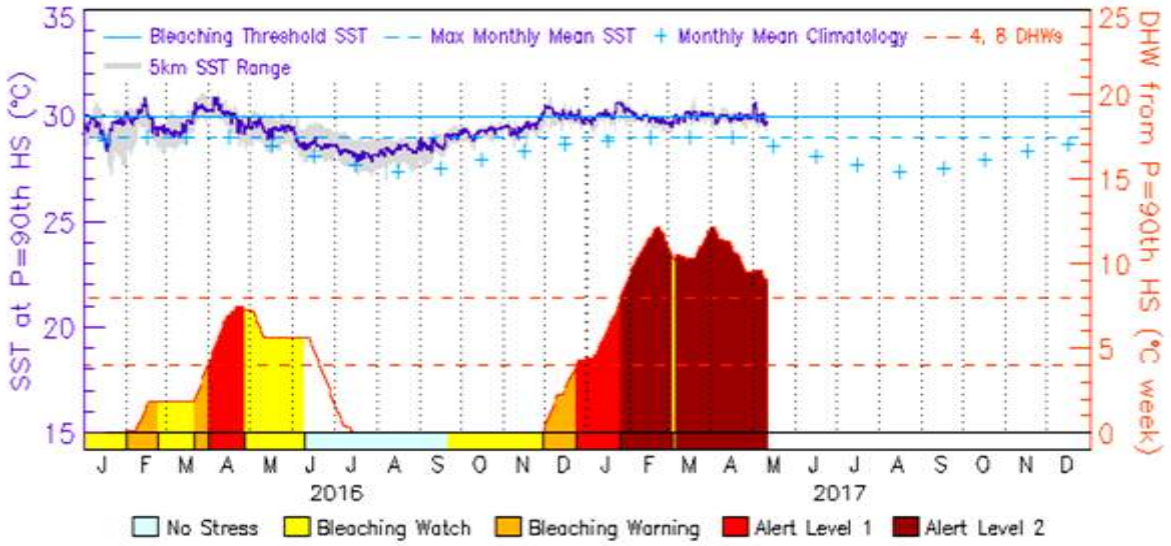

Figure 5. NOAA CRW's 2016-2017 coral bleaching heat stress time series (SST, DHW, and Bleaching Alert Level) for the 5km Regional Virtual Station at the Samoas, issued on May 12, 2017.

We encourage users worldwide to report episodes of coral bleaching and non-bleaching to help us calibrate and validate the new DSS products. Please email observations to coralreefwatch@noaa.gov and/or enter them online at https://coralreefwatch.noaa.gov/satellite/research/coral_bleaching_report.php. Your feedback is important for us to improve our products. Please send your comments and suggestions to coralreefwatch@noaa.gov.

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References:

Eakin CM, Liu G, Gomez AM, De La Cour JL, Heron SF, Skirving WJ, Geiger EF, Marsh BL, Tirak KV, Strong AE (2017) Ding, Dong, The Witch is Dead (?) – Three Tears of Global Bleaching 2014-17. Reef Encounter (this issue)

Eakin CM, Liu G, Chen M, Kumar A (2012) Ghost of bleaching future: Seasonal Outlooks from NOAA's Operational Climate Forecast System. Proc 12th Int Coral Reef Symp

Heron SF, Liu G, Eakin CM, Skirving WJ, Muller-Karger FE, Vega-Rodriguez M, De La Cour JL, Burgess TFR, Strong AE, Geiger EF, Guild LS, Lynds S (2015) Climatology Development for NOAA Coral Reef Watch's 5-km Product Suite. NOAA Technical Report NESDIS 145. NOAA/NESDIS. College Park, MD. 21pp

Liu G, Eakin CM, Chen M, Kumar A, De La Cour JL, Heron SF, Geiger EF, Skirving WJ, Tirak KV, Strong AE (2017) Predicting Coral Bleaching Heat Stress to Inform Reef Management: NOAA Coral Reef Watch's Four-Month Outlook. Front Mar Sci (in review)

Liu G, Heron SF, Eakin CM, Rauenzahn JL, Geiger EF, Skirving WJ, Burgess TFR, Strong AE (2014a) NOAA Coral Reef Watch's Next-Generation 5 km Satellite Coral Bleaching Thermal Stress Monitoring. Reef Encounter 29(2): 27-29

Liu G, Heron SF, Eakin CM, Muller-Karger FE, Vega-Rodriguez M, Guild LS, De La Cour JL, Geiger EF, Skirving WJ, Burgess TFR, Strong AE, Harris A, Maturi E, Ignatov A, Sapper J, Li J, Lynds S (2014b) Reef-scale Thermal Stress Monitoring of Coral Ecosystems: New 5-km Global Products from NOAA Coral Reef Watch. Remote Sensing 6(11): 11579-11606 [doi: 10.3390/rs61111579]

Maturi E, Harris A, Mittaz J, Sapper J, Wick G, Zhu X, Dash P, Koner P (2017) A New High-Resolution Sea Surface Temperature Blended Analysis. Bull Amer Meteor Soc 98(5): 1015-1026 [doi: 10.1175/BAMS-D-15-00002.1]

Coral bleaching in New Caledonia (Photo credit - courtesy of The Ocean Agency / XL Catlin Seaview Survey / Richard Vevers).