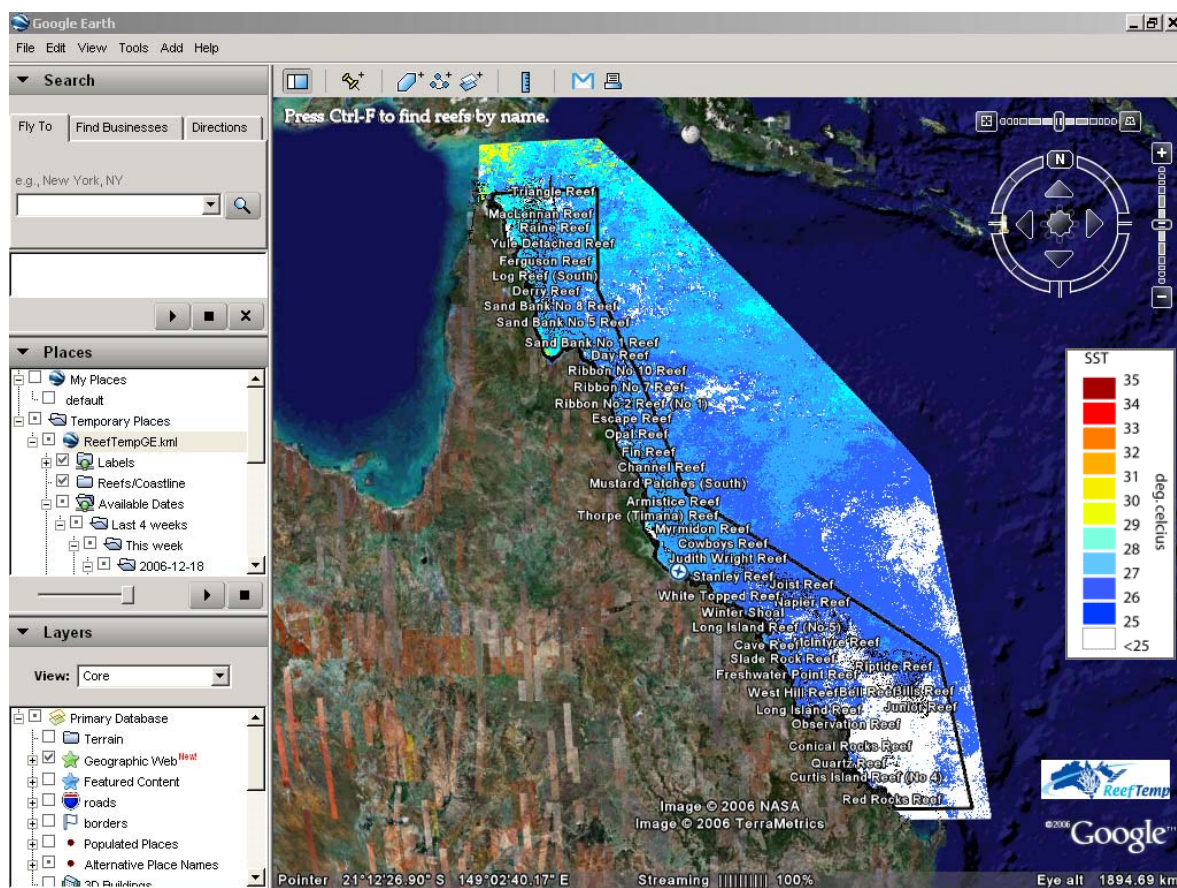




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New and improved tools to forecast and monitor coral bleaching in the Great Barrier Reef and Coral Sea

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Australian Government

Great Barrier Reef
Marine Park Authority

Bureau of Meteorology

Department of the
Environment and Heritage
Australian Greenhouse Office

Introduction to Mass-Bleaching Events and the Coral Bleaching Response Plan

The Great Barrier Reef Marine Park has experienced two mass coral bleaching events in recent years: 1998 and 2002. In 2006 severe bleaching also occurred and was confined to the southern GBR. The spatial extent of these events, combined with the high level of mortality seen at the most severely affected sites, has led to widespread concern about the future of the Great Barrier Reef in the face of global climate change. For this reason, a Coral Bleaching Response Plan has been developed, enabling the Great Barrier Reef Marine Park Authority (GBRMPA) to provide early warnings of a major bleaching event, measure the spatial extent and severity of events, and assess the ecological impacts.

Mass coral bleaching is preceded by a series of stages, beginning with the build-up of climate conditions that warm the air and sea (Stage 1), followed by above-average sea temperatures (Stage 2), which in turn can lead to bleaching of more vulnerable species of corals (Stage 3). If stressful conditions persist, there can be widespread bleaching of a range of coral species and mortality of some corals, resulting in a mass bleaching event. Mass bleaching events have caused widespread degradation to many reefs worldwide, with up to 16% of the world's reef seriously damaged by coral bleaching in 1998 (Wilkinson 2004).

The onset of each of the main stages can be used to provide an early warning of a mass bleaching event. Stage 3, when corals in many locations already show signs of bleaching, is detected by a community monitoring initiative, BleachWatch, and intensive ecological surveys. Previously, Stage 2 was monitored using the Hotspot and Accumulated Heat Indices products available from the National Oceanographic and Atmospheric Administration (NOAA), along with local weather station data. This suite of global products provides near real-time estimates of sea surface temperatures (SST), and has improved understanding of the relationship between thermal stress and bleaching response patterns (<http://www.osdpd.noaa.gov/PSB/EPS/SST/climohot.html>).

Recently, however, CSIRO Marine and Atmospheric Research (CMAR) have been working with the GBRMPA and the Bureau of Meteorology to develop an improved SST product for the Great Barrier Reef region. This product, *ReefTemp*, has been tailored specifically to the needs of users of the Great Barrier Reef Marine Park including research scientists, tourism operators and the public. *ReefTemp*, described below, will improve the GBRMPA's ability to monitor thermal stress, and allow for the now-casting of bleaching risk at the scale of an individual reef.

Project Components

Aspects of the development of *ReefTemp* include: 1) data acquisition, 2) calculation of climatologies, 3) calculation of thermal stress indices, 4) representation of bleaching risk, 5) data and image processing, and 6) Google Earth application development and automation.

1. Data Acquisition

The Bureau of Meteorology processes the latest NOAA environmental satellite Advanced Very High Resolution Radiometer (AVHRR) thermal imagery for Australia through rigorous algorithms to produce a 15-day composite image of SST (currently from NOAA AVHRR satellites 15, 17, and 18) at a resolution of 0.017995° (~2 km) (Figure 1). Data from the resulting Australian Mercator Projection SST Mosaic is sent to the GBRMPA for the Queensland region along with an age-of-data grid file. In cases where SST cannot be

calculated due to cloud cover, the most recent temperature calculated for a grid cell is inserted unless over 15 days old. In *ReefTemp*, data over 10 days old are not used to estimate bleaching risk. Generally though, temperatures are updated every 1 to 4 days. In cases where cloud cover obscures data collection, it is important to note that dense cloud cover is not conducive to further ocean warming and therefore the missing data is not critical for estimating bleaching risk. Backfilling the data allows for continuity in the estimation of bleaching risk and is conservative because, if temperatures have decreased, the result is a slight overestimate of bleaching risk.

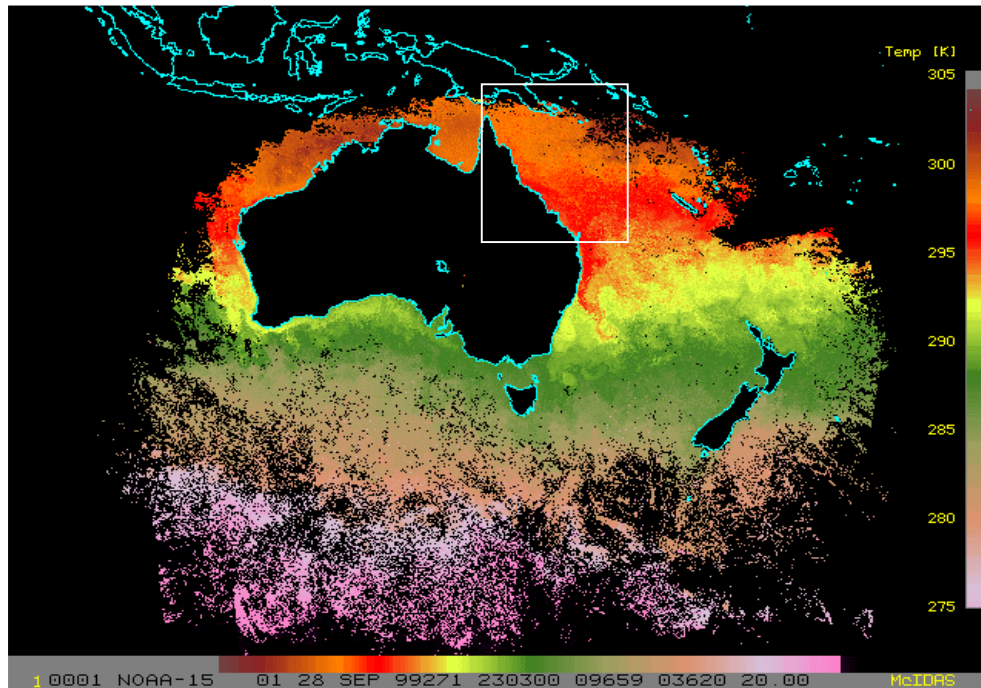


Figure 1: Bureau of Meteorology 15-day composite SST mosaic in mercator projection (http://www.bom.gov.au/sat/SST/SST_AUST.gif). The white box denotes the data field sent to the GBRMPA as a daily update.

2. Calculating long-term climatologies

Dataset

In 2003, the National Oceans Office contracted CMAR to provide a dataset of SST for the Australasian region to cover 1993 to 2003 (<http://www.marine.csiro.au/DIY.htm>). The dataset has been derived from the analysis of NOAA environmental satellite AVHRR thermal imagery and extends from 10N to 65S and 80E to 170W, including composite images formed over intervals of 1, 3, 6, 10 and 15 days (http://www.cmar.csiro.au/remotesensing/oceancurrents/ten_years_of_SST.doc). The data have been calibrated against ships and drift buoys. The composite images have been mapped onto an equal angle grid of 0.042 degrees of latitude (4 km) and 0.036 degrees of longitude (2 to 4.5 km). The representative SST for each grid cell is determined by taking the SST value at the 65th percentile of the cumulative frequency distribution within each group of data. Both night and afternoon satellite passes have been included. The dataset starts on 6 October 1993 and ends on 13 June 2003. This is the best dataset available for this project as

it captures short-term variation, has high-resolution, and there are quality control measures for both the SST estimates and image shifting.

Calculation and Resampling

Average monthly temperatures have been calculated from the 3-day composite for the entire year. The climatology grids were then resampled to the resolution and extent of the daily update grid by taking the weighted average. Climatologies are automatically updated by recalculating the long-term average at the end of each month.

3. Calculation of thermal stress indices

Relating temperature characteristics to measures of bleaching severity on the Great Barrier Reef has revealed that multiple temperature variables or indices of cumulative heat stress allow for a better estimate of bleaching risk than any single one (Maynard 2004). This evidence highlights the value of using more than two heat stress indices in *ReefTemp*. The following indices have been selected based on research demonstrating that when combined they can provide for a consistent and effective estimate of bleaching risk at a site: a) SST anomaly, b) Degree-Heating Days, and the c) Heating Rate (Maynard 2004).

a) SST anomaly (+SST): Calculated as the number of degrees above the long-term average temperature observed for that month. The temperature anomalies visualized range from +0.1°C to +5°C.

b) Degree-Heating Days (DHDs): Degree-Heating Days are a measure of the accumulation of heat stress. One DHD is calculated as one degree above the local long-term average temperature for one day. The Degree-Heating Days index within *ReefTemp* displays the number of DHDs accumulated within the last 120 days.

c) Heating Rate: Degree-Heating Days can represent a broad range of heat stress in that three weeks at 1°C above the local long-term average results in the same number of DHDs as one week at 3°C, the latter representing more severe stress to corals. For this reason, *ReefTemp* also displays the Heating Rate, calculated as the number of Degree Heating Days divided by the number of days in which temperatures have exceeded the long-term average. This index is initiated after temperatures have been above the long-term average for a minimum of five days. During the 1998 and 2002 mass bleaching events on the GBR the Heating Rate ranged from 2.0 to 3.5 at severely bleached sites.

4. Representation of Bleaching Risk

These indices were back calculated for all of the 1998 and 2002 survey sites for which temperature data was available, and related to the severity of bleaching responses at those sites (Maynard 2004). The strength of each index that related to bleaching responses are shown within *ReefTemp* as blue/purple (no bleaching), yellow (minor bleaching), orange (moderate bleaching) and red (severe bleaching) respectively (Figure 2).

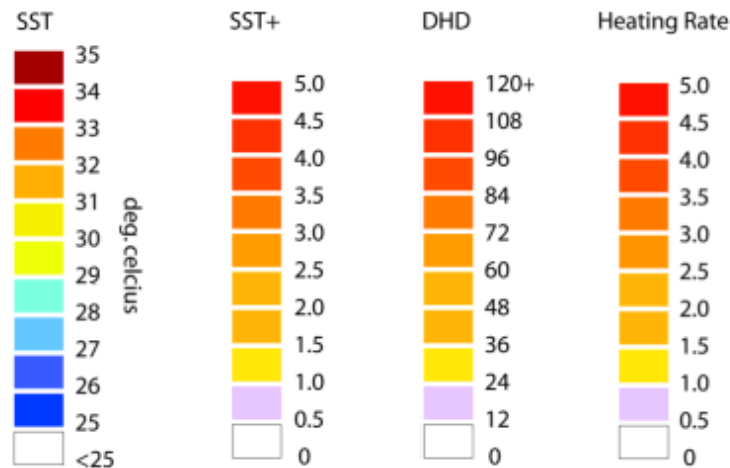


Figure 2: Legends for the stress indices calculated by *ReefTemp*. The colour gradations shown represent the best knowledge of the correlation between levels of thermal stress and bleaching response severity in the Great Barrier Reef.

5. Data and Image Processing

The creation of daily images depicting values for the thermal stress indices in the Great Barrier Reef region is automated via a myriad of technologies that span the three partner agencies. Once the daily SST data is received from the Bureau of Meteorology by GBRMPA, the data is entered into an Oracle Enterprise Database and then further manipulated via Oracle Packages (containing stored procedures & functions) into a tabular grid representation of the four thermal stress indices. The tabular grid representation is then spatially enabled into a “spatial view” with the assistance of ArcSDE, and run through a series of ArcInfo Workstation commands to finally produce a high-resolution TIF image file (Figure 3).

These four TIF image files are then downloaded by CMAR to be an overlay in the ReefTemp Google application. Scripts at CMAR compress the images into a PNG format and adds a transparent background to the images. Lastly, the new images, along with the respective legends and date stamps, are packaged into a compressed Keyhole Markup Language (KML) file- a KMZ file, suitable for viewing in Google Earth (Figure 3).

6. Google Earth Application Development

The *ReefTemp* application designed for use with Google Earth has built on recent advancements in technology. It provides users with a fast, efficient, user-friendly application for viewing the thermal stress indices.

The Google Earth application allows the user to see any one of the four thermal stress indices for a selected summer day (1st December to 31st March), overlaid on a 3D globe that is easy to navigate and traverse. Google Earth functions include the ability to change resolution, change viewing angle, search for reefs and bookmark favourite places.

Reef outlines, Marine Park boundaries and coastline data are also visible within Google Earth by using compressed images (with transparent backgrounds) at different resolutions to optimise performance. These layers accurately display the real-world location of geographical features such as towns and rivers. The compressed images were further split using a grid to enable the streaming and “smart” loading of the data as users navigate through

the images. Reef names are available, enabling the user to search for a reef by name and zoom into that reef.

KML, an XML grammar and file format for modelling and storing geographic features and images, was used to construct and format the presentation of the thermal stress indices and reef data. Recent advancements with KML 2.1 and Google Earth allows packaging of all the KML files and images into KMZ files. This way, initially, the user only downloads a single KMZ file (approx 380k) containing all the necessary data. This file then calls another KMZ file created daily that downloads the stress index images as you request them. Date stamp and legend images also appear on the Google Earth interface to assist with the interpretation of the images.

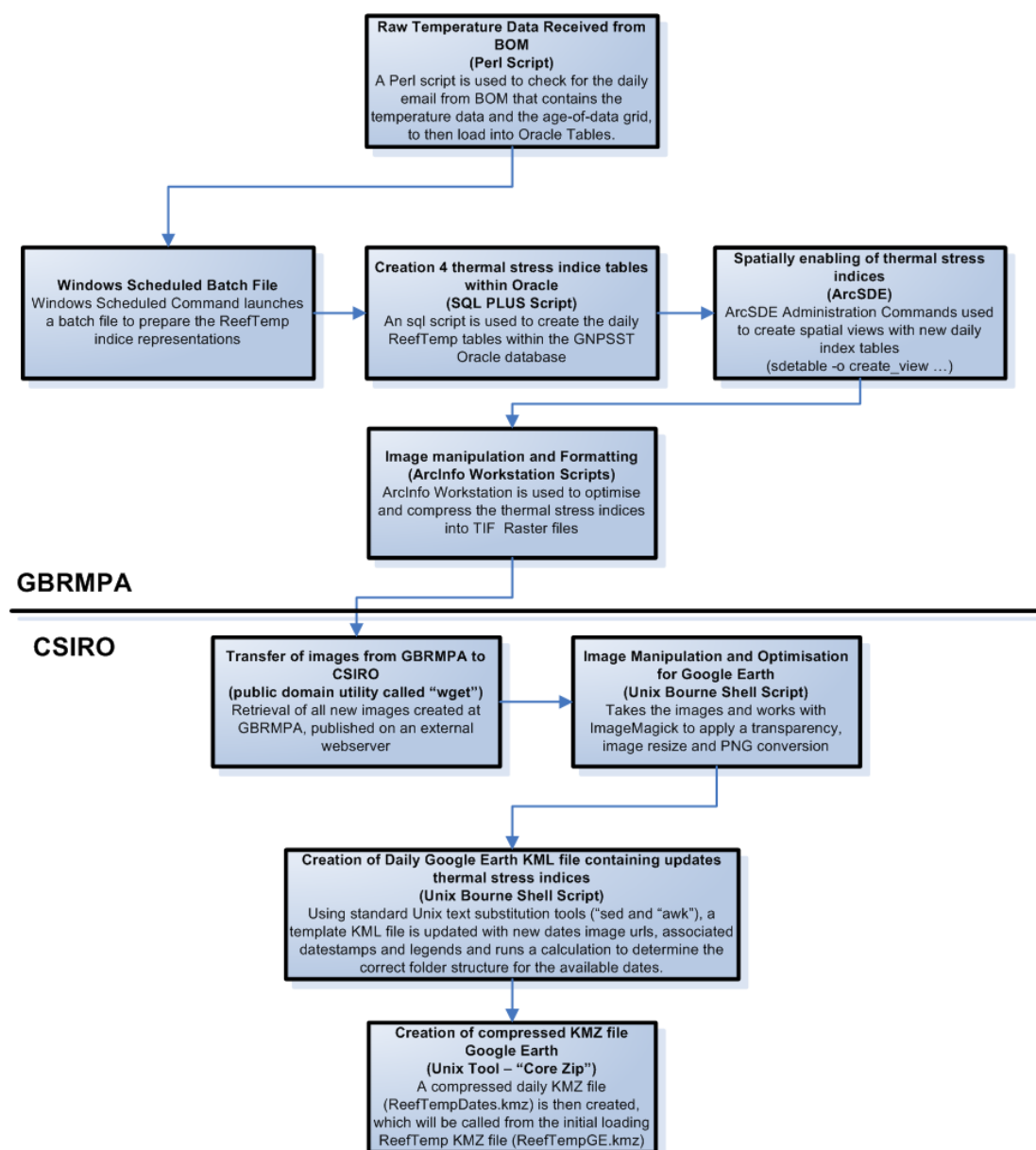


Figure 3: Creating *ReefTemp*: process for data automation and processing, and image creation by the GBRMPA and CMAR.

POAMA Forecasts of SST

The Predictive Ocean and Atmosphere Model Australia (POAMA) group at the Bureau of Meteorology Research Centre have been working with the GBRMPA to adapt outputs of their climate model to provide forecasts of anomalous SST in the Great Barrier Reef and Coral Sea. Statistical downscaling techniques have been used to produce contour plots of anomalous SST based on the primary model drivers of ENSO and the Madden-Julian Oscillation. Currently, intraseasonal forecasts with lead times of 0 – 3 months are being produced (see Figure 4).

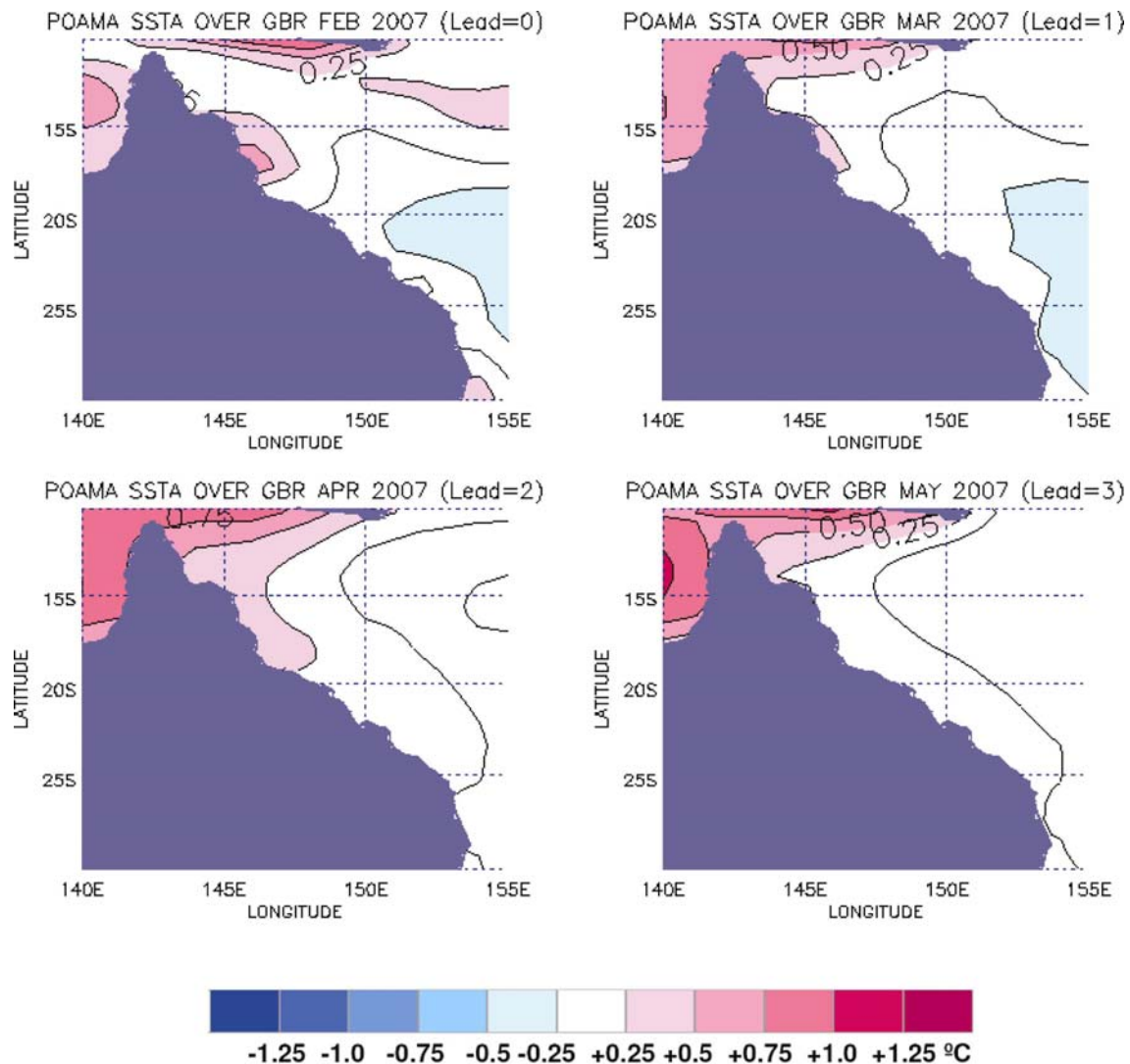


Figure 4: POAMA-1 intraseasonal forecasts of anomalous SST for the Great Barrier Reef and Coral Sea February to May 2007.

Skill plots for the POAMA GBR forecasts show high skill values for these intraseasonal forecasts (see Figure 5). Testing of the skill in the coupled model POAMA V1.0 employs the so-called "hindcast-test". This method initialises a prediction on, for example, 1 March 1987 using only information available before that date. The test of the model is then based on comparing prediction to information collected during the remainder of 1987. Hindcast tests initialised at many past dates can be combined into a statistic to evaluate the accuracy of forecasts and provide a measure of "skill" of the model.

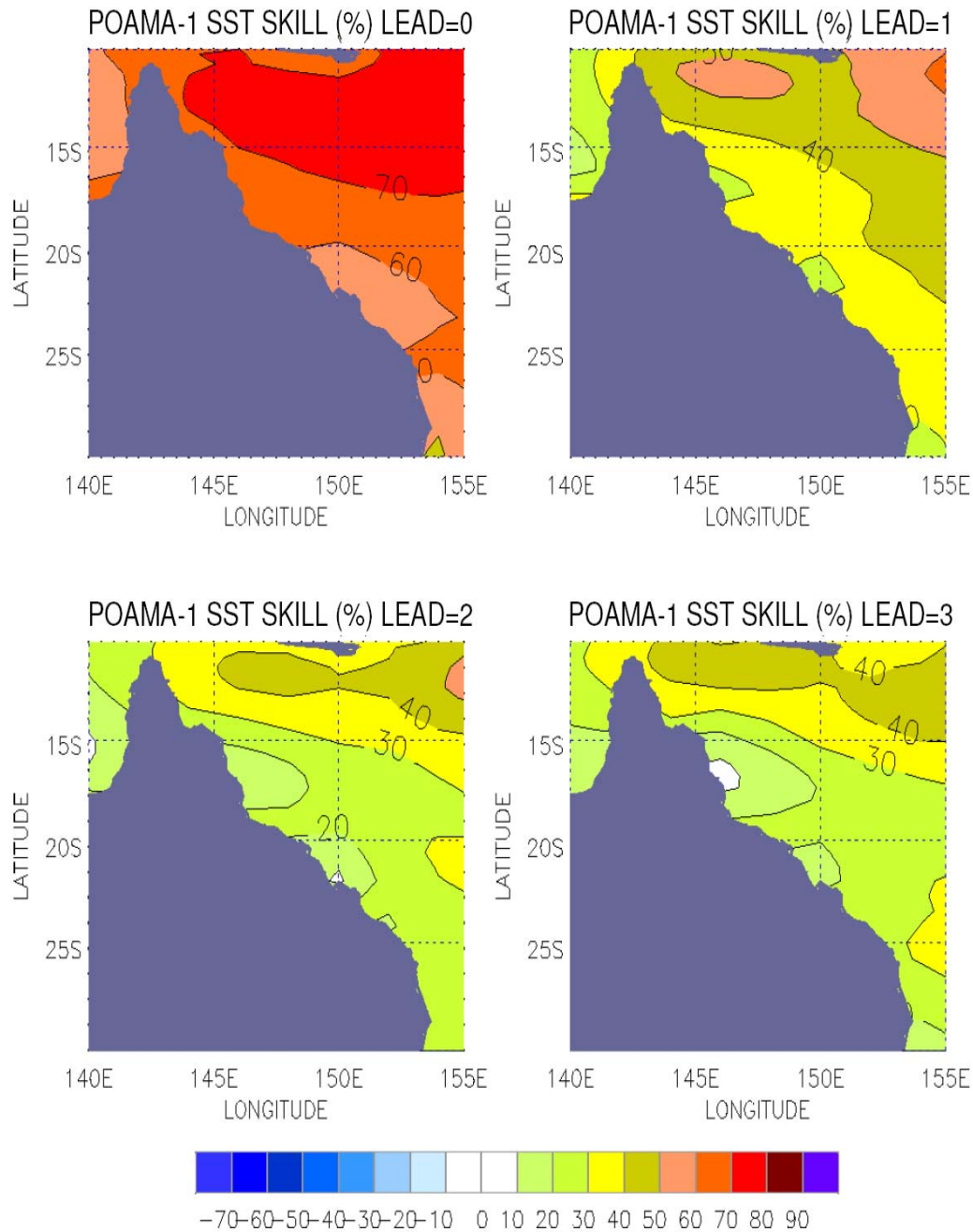


Figure 5: Skill plots from the POAMA-1 SST forecasts. ‘Skill’ here represents the mean percent accuracy of the forecasts from 15 years of hindcast testing (1987 – 2001).

In the coming months the SST forecasts will be produced from POAMA 1.5 and POAMA 2. Skill improvements are expected following transitions to the improved climate models, giving managers and researchers more confidence in decisions involving resource allocation and reports to the media on current conditions. The POAMA forecasts have already dramatically improved the capacity to manage human and financial resources during the 2006 – 2007 summer.

Stakeholders and Applications

Significant increases in the frequency and severity of bleaching events may render, from a management perspective, presence-absence bleaching predictions less meaningful in the near future. The products described here give managers and researchers the opportunity to refine knowledge of the relationship between measures of thermal stress and bleaching response severity by developing new thresholds and reassessing existing bleaching thresholds for critical sites.

When responding to future events, the GBRMPA, partner agencies, researchers and tourism operators will use these tools to focus research and monitoring efforts, increase the effectiveness of impact assessment programs, and heighten awareness within the community.

Related products are being developed as a result of collaborations between the GBRMPA, CSIRO Marine and Atmospheric Research and the Bureau of Meteorology. Importantly, these are dynamic products. The presentation and usability of *ReefTemp* and the POAMA forecasts will continually be improved in response to stakeholder feedback, and data processing may evolve in upcoming summers.

References

Maynard, J. A. (2004) Spatial and temporal variation in bleaching susceptibility and the ability of SST variables to describe patterns in bleaching response, 1998 and 2002 events, central GBR. Thesis, James Cook University.

Wilkinson, C. (2004) *Status of Coral Reefs of the World: 2004*. Australian Institute of Marine Science.

Links

ReefTemp: <http://www.cmar.csiro.au/remotesensing/gbrmpa/ReefTemp.htm>

POAMA GBR SST Forecasts:

http://www.bom.gov.au/bmrc/ocean/JAFOOS/POAMA/exproducts/poama_v10/gbr_rt.htm