Group on High Resolution Sea Surface Temperature (GHRSST) Coral Heat Stress Task Team (TT)

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Introduction

Coral reefs are among the most biologically diverse and economically important ecosystems on the planet. They provide ecosystem services that are vital to human societies and industries through fisheries, coastal protection, building materials, new biochemical compounds, and tourism.

Satellite-derived SST is therefore an important tool for researching the effects of and monitoring coral stress caused by anomalous SST. SST-based anomaly products that have been designed specifically for corals, such as those produced by the NOAA Coral Reef Watch (CRW) program are key to understanding and monitoring the effects of SST anomalies on coral health.

The GHRSST Coral Heat Stress Task Team (TT) has been set up to provide expert advice and recommendations to the GHRSST community on the satellite SST requirements for quantifying and monitoring the effects of heat stress on coral health. Following is a summary of the TT recommendations. This list is intended to be a comprehensive list of user requirements. The aim of this list is for the requirements to be achievable rather than being a wish list of impossible requirements. To this end, some of these requirements may have already been met, while others are yet to be achieved.

Whereas the vast majority of the use of satellite SST by coral reef managers, researchers and users is concerned with accumulated heat stress, there are other uses of satellite SST that often involve a slightly different set of requirements. It is intended that this document will eventually be updated to include these other uses, but for now, it is aimed at providing user requirements for the purpose of quantifying and monitoring heat stress in and around coral reefs.

Recommendations

Stability through time:

Mass coral bleaching has only been recorded since the early 1980s, ergo corals have adapted to a pre-1980 climate. Therefore, anomalies that are truly representative of the thermal stress of corals must be derived using temperature climatologies from as far back as possible. To achieve this, the satellite SST data sets need to extend back as far as they can go, which at the current time means to the early 1980s. Since these data will be used to derive anomaly products that are tuned to correlate with coral stress, the climatology and the SSTs used to calculate the anomaly need to have compatible error and sensitivity characteristics. In effect, this means that the data need to be as consistent as possible through the entire length of the dataset. To quantify this, we believe that ideally the temporal stability of the bias needs to be no worse than 0.05 deg C per decade, which is similar to the 0.03 deg C per decade requirement for the Global Climate Observing System (GCOS).

Accuracy of geo-location:

This is an important issue for coral reefs, since many of the coral reefs of the world are fringing reefs and therefore typically less than 1 km from the coast. So, having accurate geo-location and knowledge of footprint shape is critical since it is important to know exactly where an SST pixel is located so as to determine its relation to nearby land or exposed coral reef. This is equally important for small isolated oceanic reefs, since their existence often causes sharp changes in SST due to mechanisms such as upwelling. It is therefore important to know if the SST pixel being associated with an isolated reef is correctly located. It is the job of groups like CRW to determine the effect, if any, of islands and inter-tidal areas on the SST values and therefore the CRW products. Meaning that the coral reef users would prefer that a pixel be left as SST rather than masked out due to an island or islands, unless the land is a significant proportion of the pixel (e.g. > 25%, although this threshold will change depending on the location of the island and its vegetation type).

Level 3 vs Level 4 SST products:

Since coral stress is cumulative, it is important to have temporally and spatially gap-free data. Hence, Level 4 (L4) data are almost an imperative for the coral user community. So, regardless of the accuracy of Level 3 products, the coral reef community will always struggle to find a use for them due to their gappy nature.

A point to remember is that currently the L4 interpolation systems are likely to be set up primarily for the open ocean, it may be that other interpolation schemes might work better over coral reefs, e.g., for preserving fine scale SST variability, which is seen across some coral reefs, or for preserving relationships of SST at the coral reef compared to nearby SSTs (which may be dynamically distinct).

Daily average vs diurnal variability:

Currently daily average SST is the coral heat stress product of choice. When possible, a diurnally corrected daily average is good (e.g. ESA Climate Change Initiative, CCI, which is set to a 10am SST), and if not diurnally corrected then a night-only averaged SST is required. The aim of both of these requirements is to ensure that the heat stress products are based on SSTs that are close to the water temperature at coral depths (or at least has the same stability as the bulk temperature). A diurnally adjusted product is presumably the better of these two products because the day and night temperatures can be used, ensuring that there will be less interpolation in the L4 products due to increased data density. It would be worthwhile to test this in the context of SST anomalies for coral heat stress.

Radiometric accuracy and spatial/temporal resolution:

An accuracy (random error) of order 0.2 deg C per pixel (i.e. per actual retrieval) seems to work well, given what we have seen so far. The caveat is that this figure must be achieved at the high end of the observed temperature range (typically SSTs greater than 28°C) and of course over coral reefs, where waters are much shallower than the open ocean and have more complex oceanographic processes.

Spatial resolution needs are harder to define. In reality, the answer needs to contain an understanding of tidal excursions and the speed of relevant low frequency currents from prevailing boundary currents and any large-scale eddy generated currents, combined with an understanding of the observational frequency. For instance, currently CRW products are gridded at 0.05 degree (approx. 5 km) spatial resolution and are produced daily. If we compare that with a fast current (e.g. speeds indicative of tidal currents around northeast Queensland and the speed of the East Australian Current, EAC) of 1 ms^{-1}, the daily excursion for the EAC is approx. 17 pixels, and the GBR tidal excursion is around 4 pixels. Given that the true resolution of the CRW products is closer to 0.1 degrees and the currents on the GBR are stronger than most currents found on coral reefs around the world, having the CRW products at 0.05 degree and daily, seems to be a good compromise.

Currently, all satellite stress products are based on daily averages (i.e. daily average for diurnally corrected products, night-only average for all other products. The latter is the most common at present). Coral scientists are beginning to study the effects of diurnal variation on coral stress, which will enable groups like CRW to develop heat stress products that include this new knowledge. Therefore, a diurnal variation product would be useful for research and will soon be able to be used in an operational heat stress monitoring product.

Until we have the ability to utilize diurnal variation in heat stress products, there is little advantage to increasing the spatial resolution of current products due to the need to also increase the temporal resolution so as to avoid tidal aliasing. For instance, if we increase the spatial resolution to 0.01 degrees, an observational frequency of ten minutes will result in a tidal excursion of 600 m, which is sub pixel in scale and hence should avoid aliasing. It must be noted that Reef Managers have always desired higher resolution heat stress satellite products than we have been able to provide, so any advancements that take the above into consideration, and result in improved spatial resolution are welcome.

Level 4 data density:

Given that L4 is the product of choice for the coral reef community, it makes sense that as many satellites are used as possible for the production of SSTs. It is also necessary to have a measure of the number of observations in each L4 pixel as a way to compare one product against another and to determine metrics such as the average number of retrievals that contributed to a measure of accumulated heat stress. Data density is especially important in the Coral Triangle region, which happens to also be the most clouded maritime region in the world. This request makes more sense when considering products that have a global coverage, but deliberately have a greater data density near the country of origin, but is also of importance when understanding other accuracy metrics in persistently cloudy regions.

Level 4 analysis uncertainty:

A measure of analysis uncertainty is an important consideration for the development of coral heat stress products. Users (of coral heat stress products, e.g. coral reef managers) should be provided with some index of pixel by pixel confidence that they should place in the products being provided to them. This analysis uncertainty, should be able to be accumulated along with the heat stress accumulations. Currently, every GHRSST format L4 product contains a mandatory field for each grid cell called "analysis error", however there is no standard method for calculating this metric and the provided uncertainties also need to be fully validated and ideally traced back to references sources. The coral reef SST user community have not adequately investigated this aspect of satellite SST products and should do so prior to providing feedback to the GHRSST community.

Use of in situ data in the derivation of SSTs:

Whereas the inclusion of near-real-time in situ data and even the inclusion of microwave data into SST analyses is often attractive for improving aspects of the retrieval, neither of these data exist over most coral reefs. Therefore, if they are to be included in an analysis, it would be necessary to check that they don't bias SSTs over reefs.

It is also noteworthy that the coral SST user community have access to a significant network of in situ coral reef SST instrumentation, which can provide short term and long term historic in situ SST data. We would be happy to facilitate access to these data for satellite SST algorithm development and validation.

Modern SST retrievals vs historic retrievals:

If improvements are made to the near-real-time SST products, and these improvements alter the characteristics of the product, then this may cause a change in the consistency of the bias through time, which is undesirable for use over coral reefs. It is unrealistic to expect L4 products derived from early sensors to match the quality achievable in today's data-rich environment. Equally, we must expect and encourage further developments in the modern-day products. Thus, while it is fair to say that better (resolution, accuracy, etc.) is always desirable, the data need to be interpreted with care with respect to the baseline reference. In that regard, the improved products of today should be used to better characterize uncertainties of the historical data in order to permit optimum continuity.

Near-real-time SST vs Reprocessed SST:

It would be helpful to the coral users if the reprocessed SST product were to be updated in such a way as to lag behind the near-real-time (NRT) SST by an appropriate, but short amount of time. This will enable small hiccups in NRT processing to be corrected, ensuring a high quality and consistent reprocessed product. An example of a hiccup might be a missing day. In NRT, the heat stress products can use persistence to gap fill, then during the update to the reprocessed SST product, an interpolation can gap fill more accurately. Another example would be to eliminate a problem satellite from the analysis of a L4 product after it is known to have erroneous SST retrievals.

Importance of temperatures above 25°C:

When analyzing SST accuracy, developers need to keep an eye on the high end of the SST range (i.e. above 25°C and definitely above 28°C, which is the lower end of the thermal stress threshold for most corals). Developers often ignore deviations at the ends of the temperature distributions as they concentrate on the bulk of their validation data, which usually has better accuracy than at the high temperature end. When analyzing accuracy, the coral community would be better served if a separate analysis of accuracy were performed on those temperatures above 25°C.

Regional analyses:

While accuracies and uncertainties are derived from global statistics, regional studies concentrating on coral reef locations are necessary to ascertain whether the SSTs satisfy the requirements for quantifying coral heat stress. These could be conducted using the vast array of in situ and modelled SST data that exist throughout the world's coral reefs. If after these studies, it is deemed necessary, regional coral reef-only SST retrievals may need to be developed, or possibly the development of a global shallow water retrieval may be desirable.