

Quantitative Marine Science



Thesis Abstract

A heat balance of the Great Barrier Reef with particular emphasis on recent sea surface temperature trends

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This study estimates a surface heat budget of the Great Barrier Reef (GBR) and Coral Sea off the Queensland coast in Australia (10° S to 26° S, 142° E to 155° E). The ocean-atmosphere heat fluxes and ocean advective heat transport are examined for the present and future so as to determine the relative roles of the atmosphere and ocean in creating anomalies in oceanic heat content and sea surface temperature.

Schemes are developed to estimate a reliable high-resolution climatology of the total ocean-atmosphere heat exchange, comprising radiation and turbulent heat flux components. These were based on satellite data for the study area over the period 1995 to 2005. The climatology was based on satellite data obtained from the SSM/I, AVHRR and VISSR (GMS and GOES) spacecrafts and applied to selected algorithms and techniques detailed throughout the thesis. These satellite-based ocean-atmosphere heat fluxes were validated with measurements collected over the study area, therefore providing an accurate and reliable heat flux dataset with which to examine recent sea surface temperature changes in the region and its impact on biological processes such as mass coral bleaching.

Estimates of monthly average shortwave radiation fluxes had the highest radiation component errors, with root-mean-square differences/errors (RMSE) of approximately 14.8 W m⁻². Errors in monthly downward and upward longwave radiation fluxes were smaller, with RMSE differences of 8.5 and 2.2 W m⁻², respectively. Monthly averaged latent and sensible heat flux estimates show RMSE of approximately 25.2 W m⁻² and 3.4 W m⁻², respectively. These improved estimates allow a higher confidence in studies which examine recent sea surface temperature trends and observed mass coral bleaching for the region.

It is proposed that the greatest uptake of heat occurs over the austral spring/summer period in the central and southern regions of the GBR. This agrees well with areas where anomalously high sea surface temperatures are observed and where the most significant coral bleaching occurred, and not in the most northern more tropical region as one may expect. The surface heat budget climatology was used to examine the mass bleaching episode that occurred in 2002. Results show that areas of maximum and minimum bleaching are better discriminated by the anomaly from mean seasonal values in the net surface heat flux, with accuracy of 86 and 79 percent, respectively, as apposed to using the absolute net surface heat flux, or absolute or anomalous sea surface temperature. It was postulated that the relationship results from a combination of direct stress due to higher solar radiation, plus indirect stress due to local heat uptake by ocean waters.

This study also conducts detailed examinations of the relationships between the net surface heat flux, oceanic heat fluxes, and the changes in sea surface temperature to gain an understanding into the dominant processes of the surface heat budget in influencing the variability of water temperatures in the GBR and Coral Sea region. It is shown that the highest variability of sea surface temperature of the GBR and Coral Sea region is located in the reef system and related to the shallowest mixed layer. In such a region of shallow mixed layers and strong net surface heat fluxes, sea surface temperature is consequently very

sensitive to small changes in ocean-atmosphere heat fluxes, ultimately resulting in an environment with high sensitivity to surface temperature. The highest correlation between the net surface heat flux and changes and sea surface temperature is shown to exist in the southern area of the GBR (below about 18° S), suggesting that accurate estimates of net surface heat fluxes and mixed layer depths could be used as a good prediction tool for the estimation of sea surface temperature, which is vital in understanding the processes that initiate localised coral bleaching.

Overall, the study shows net surface heat flux is the dominant mechanism controlling sea surface temperature in the GBR and Coral Sea region. Advection by currents also has a measureable impact on sea surface temperatures, more so offshore in the Coral Sea than inshore in the GBR. Other oceanic processes such as vertical advection, mixing processes and seasonal upwelling (downwelling) along the outer GBR appear to have enough forcing to reduce the seasonal cycle of the sea surface temperatures but are not directly quantified in this study. It is also suggested that some infrequent large-scale intrusions of cooler waters into the GBR may offer some relief from extensive localised heating from ocean-atmosphere heat fluxes.

The findings from the high spatial and temporal resolution estimates are extended over a longer time period to ascertain the likely future climate for the GBR and Coral Sea region. Numerous coupled ocean-atmosphere general circulation models (GCMs) output that supports the Working Group 1 component of the IPCC's 4th Assessment Report, a downscaled GCM over the Australasian region (CCAM-MK3.0) and also a blended observational dataset of sea surface temperature (HADISST) are used to assess 20th century, current (1995-2005) and projected 21st B1 (least extreme) and A2 (most extreme) climate conditions, the factors responsible for maintaining these conditions and the factors driving changes in climate.

Although the IPCC model and HADISST provide low resolution outputs, they are shown to represent the general patterns of the past and current climate conditions well. This study shows that sea surface temperatures, and to a lesser extent net surface heat fluxes display changes during the 20th century of 0.7° C and 1.4 W m⁻² in annual means. The change in the net surface heat fluxes has not been enough to force all the warming observed suggesting that there has been a major change in oceanic dynamical mechanisms. Future climate simulations show that they are very likely to continue to increase in the 21st century, with rates during the 21st century of 2 to 4 times higher for sea surface temperature and 2.5 times higher for net surface heat fluxes. Similar to the 20th century however, the output from the models used in this study suggest that future changes in the net surface heat fluxes once again are not enough to force all of the predicted warming in sea surface temperatures. Possible changes in the oceanic dynamical mechanisms are discussed to provide insight into the causes of the future warming trend. This will certainly increase thermal stress on the ecosystems of the region such as coral bleaching, leaving cooling by oceanic dynamical mechanism as a possible process to ameliorate these effects.