Deconvolving and Improving the Spatial Resolution of Satellite Data Using the Maximum Entropy Method

by

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A dissertation submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in the CSIRO-UTAS PhD Program in Quantitative Marine Science

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July 2013

Declaration

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

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Statement of Co-authorship

The following publication contributed to the work undertaken as part of this thesis:

Jackett, C. J., Turner, P. J., Lovell, J. L., Williams, R. N., 'Deconvolution of MODIS imagery using multiscale maximum entropy', Remote Sensing Letters, Volume 2, No. 3, September 2011, Pages 179-187

C. J. Jackett was the primary author (70%). He performed the majority of the experimental work and subsequent analysis. P. J. Turner (12%) and J. L. Lovell (12%) helped guide the development and assisted in the analysis. R. N. Williams (6%) provided general support and advice. All authors provided feedback and suggestions on the manuscript.

We the undersigned agree with the above stated proportion of work undertaken for the above published manuscript contributing to this thesis.

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Abstract

Remote sensing satellite imagery provides information about the surface of the Earth at a range of spectral bands and spatial resolutions. This information is a valuable resource for the management of terrestrial and marine environments. During the capturing process, incoming light is reflected or refracted by the instrument optics which causes a small amount of blurring. This effect is described by a mathematical operation called convolution in which the satellite input radiance field is convolved with the instrument Point Spread Function (PSF). This form of instrumental distortion has the largest impact on high-contrast scenes where bright land or clouds are adjacent to dark surfaces such as water.

This thesis investigates three mechanisms for improving the quality of recorded satellite data. An efficient convolution method was developed to minimise boundary effects, a deconvolution algorithm was used to remove instrumental distortion, and a resolution enhancement algorithm was developed to improve the spatial resolution of input images. The latter two of these problems are underdetermined and require appropriately selected constraints in order to find unique and stable solutions. An entropy-based method was chosen as the constraint element due to its heavy grounding in statistical mechanics and information theory. MODerate resolution Imaging Spectroradiometer (MODIS) Aqua images were used to quantify the improvement of these algorithms, with a focus on coastal marine and open-ocean environments.

Deconvolution is an algorithm-based process designed to reverse convolution effects with a known PSF. Multiscale Entropy deconvolution was applied to MODIS level 1A imagery to remove instrumental distortion from top-of-atmosphere radiance counts. Removing these effects at the beginning of the satellite image processing

chain reduces the propagation and amplification of errors in subsequent processing stages. Wavelet transforms were implemented to decompose images into a range of resolution levels that represent different spatial frequencies. This allows both large-scale and small-scale features to be resolved simultaneously. Multiresolution Support images were used to accurately define and target important areas within the imagery. The combination of these techniques includes two-dimensional structural information in the Multiscale Entropy calculation which results in accurate deconvolution. Validation of the Multiscale Entropy deconvolution algorithm was undertaken using in-situ measurements from the Baltic Sea and a QuickBird image of a high-contrast Antarctic ice edge.

A novel approach to the spatial resolution enhancement of MODIS imagery uses information about the optical PSF, along with the result of Multiscale Entropy deconvolution. With this information, a system of linear equations was constructed that models how high-resolution PSF convolution redistributes information over a finite area. A new method termed Multiresolution Entropy was developed to constrain the linear system and retrieve an optimal solution. The algorithm successfully improved the spatial resolution of input images and compared favourably to other interpolation-based methods. The key requirement of this technique is to obtain high-resolution PSF measurements at the same sampling frequency as the desired final output resolution.

The techniques developed and presented in this thesis contain a range of important research contributions. The combination of Fast Fourier Transform convolution with a boundary renormalisation approach produces an efficient and accurate convolution method with minimal boundary effects. A multi-detector convolution process accurately simulates the MODIS Aqua instrumentation and allows for successful deconvolution. A detector saturated estimation technique for ocean colour bands ensures the correct quantity of instrumental distortion is removed during deconvolution. The formulation of a linear system consisting of high-resolution PSF modelling and appropriate physical constraints defines the spatial resolution enhancement problem. The development of Multiresolution Entropy targets high-frequency content, constrains the linear system and results in a unique and stable resolution-enhanced solution. The techniques developed throughout this thesis provide considerable benefit to the quality of remote sensing imagery and can substantially improve the monitoring and management of coastal zones and other marine environments.

Acknowledgements

I would like to thank Jenny Lovell and Robert Ollington for supervising this thesis. Their dedicated guidance and support was gratefully appreciated. Ray Williams and Peter Turner are also acknowledged for their supervision efforts in the early stages of this research. I would particularly like to thank Peter Turner for providing the initial inspiration for this work and outlining a worthwhile and rewarding research topic.

My gratitude extends to Thomas Schroeder, Young Je Park, Ian Grant and Edward King for reading draft manuscripts and providing useful feedback. Edward King also receives my appreciation for processing a range of MODIS scenes. Gerhard Meister, Jack Xiong and Brian Wenny generously provided the MODIS Aqua characterisation models that underpin many of the research components in this thesis. I would like to thank Susanne Kratzer for providing in-situ Baltic Sea validation measurements and making suggestions regarding the deconvolution algorithm validation. Selima Ben Mustapha and Gerald More helped facilitate the direct comparison of in-situ Baltic Sea and MODIS measurements. Petra Heil also provided high-resolution QuickBird validation data.

Finally, a special thank you to my wife Amy Jackett for always listening to my current problems, suggesting alternative strategies and being incredibly supportive.

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