Ensemble Dust Detection Techniques Utilising a Web-Based Workflow Environment Linked to a High Performance Computing System

M. Broomhall[a,*], H. Chedzey[a], R. Garcia[a], M. Lynch[a], P. Fearns[a], E. King[b], Z. Wang[b], G. Smith[c], D. Schibeci[d]

[a]Remote Sensing and Satellite Research Group, Department of Imaging and Applied Physics, Curtin University, Perth, W.A., Australia – (mark.broomhall, helen.chedzey, p.fearns, m.lynch)@curtin.edu.au
[b]CSIRO Marine and Atmospheric Research, Canberra, ACT, Australia – (edward.king, ziyuan.wang)@csiro.au
[c] CSIRO Marine and Atmospheric Research, Hobart, Tasmania, Australia – glenelg.smith@csiro.au
[d]Centre for Comparative Genomics, Murdoch University, Perth, W.A., Australia – dschibeci@ccg.murdoch.edu.au

Abstract – The advection of mineral dust has implications for crop lands, radiative forcing and public health. Satellite imagery is the only effective way to monitor dust storm events in remote regions and on a national or international basis. The MODerate resolution Imaging Spectroradiometer (MODIS) has attributes that make it ideal for such monitoring. This case study investigates the implementation of dust detection algorithms for the MODIS instrument within a workflow system combined with a High Performance Computer (HPC) environment. This new remote sensing workflow system provides a powerful tool to researchers without the requirement to have any knowledge of remote sensing data processing techniques.

Keywords: Remote Sensing, Workflow, HPC, Dust Detection

1. INTRODUCTION

Advection of dust has implications for radiative forcing of the atmosphere, nutrient enrichment of the ocean, depletion of valuable topsoil and also human health. Longer periods of drought following flooding in all likelihood will result in larger, more intense dust storm events that will affect greater numbers of people. Understanding the origins and the destination of airborne dust will lead to better management of the adverse effects. Detecting dust storms through the use of remotely sensed imagery is the only effective way of observing on a country or global scale the transport of dust. This paper looks at how combining know algorithms, an extensive and continual archive of satellite-based data, a workflow engine and a HPC environment can deliver a powerful tool to researchers.

2. THE MODIS INSTRUMENT AND DUST ALGORITHMS

2.1 The MODIS Instrument

The work described herein is based solely on MODIS data. It may be extended at some stage to include data from other satellites and instruments.

The MODIS instrument contains 36 spectral bands ranging from approximately 0.4 μm – 14.5 μm. This combination of bands was chosen to facilitate many algorithms that produce bio-physical parameters. Development is ongoing with new algorithms and improvement of current algorithms addressing ever more complex environmental issues. The spatial resolution of the MODIS bands varies from 250 m at nadir (bands 1 and 2), 500 m (bands 3 – 7) and 1000 m for all other bands. The Terra and Aqua satellites have a revisit period of 14 days but the wide swath of approximately 2500 km means that every part of Australia is imaged by both the Terra and Aqua instrument at least twice per day. The spatial coverage, spectral coverage and temporal frequency make MODIS ideal for environmental monitoring and change detection.

2.2 Dust Algorithms

This case study will focus on four dust detection algorithms; the first 3 are taken directly from Baddock et al. (2009) where algorithms from Sokolik (2002) (Equation 1), Roskovensky and Liou (2005) (Equation 2), and Miller (2003) (Equation 3) are evaluated. Equation 4 is not an algorithm per se but a product that shows great potential for detection of atmospherically borne particulates. This paper is not an evaluation of dust algorithms; this is covered in Baddock et al. (2009). It aims to evaluate how such algorithms can be implemented within a workflow system mated to a HPC, an extensive archive and a powerful search tool. The first 3 algorithms [described here by equations (1) – (3),] are currently implemented within the workflow system. Here *D* is the dust factor per pixel generated by the algorithms. Equation (4) describes the production of the reflectance change (RC) product for an individual MODIS band.

$$D = \left(BT_{32} - BT_{31}\right) \quad (1)$$

where BT_{31} = brightness temperature of MODIS band 31
BT_{32} = brightness temperature of MODIS band 32

$$D = \left\{ -\left[\frac{R_4}{R_{16}} * a + \left(\left(BT_{31} - BT_{32}\right) - b\right) \right] \right\} \quad (2)$$

where a = scaling factor (0.8)
b = btd offset (2.0)
R_4 = MODIS band 4 reflectance
R_{16} = MODIS band 16 reflectance
BT_{31}, BT_{32} = same as in equation (1)

$$D = \left[\left(BT_{31} - BT_{32}\right) + \left(2R_1 - R_3 - R_4 - BT_{31}\right) - \left(R_{26}\right) + \left(1 - BT_{31}\right)\right] \quad (3)$$

where R_1, R_3, R_4, R_{26} = MODIS band reflectances indicated by the subscript number
BT_{31}, BT_{32} = same as equation (1)

$$RC = R_{AC} - DR \quad (4)$$

where R_{AC} = Atmospherically corrected reflectance
DR = Forward-modelled directional reflectance from the BRDF model

Each of the algorithms from Baddock et al. (2009) makes use of the brightness temperature difference (BTD) between the

* Corresponding author.
** This work form part of the National eArchitecture Taskforce (NeAT) and the Terrestrial Ecosystem Research Network (TERN).

primary thermal infrared channels on MODIS (bands 31 and 32). These bands are centred around 11.03 µm and 12.03 µm respectively. According to Miller (2003), imaging the surface through elevated dust has a lower BT than the land skin temperature and the difference of these 2 bands has the opposite sign to cirrus cloud. The other factors in equations (2) and (3) are primarily concerned with discrimination of dust from cloud in the images or the further highlighting of mineral dust using the colouration properties of MODIS reflectance bands (Baddock et al., 2009; Hansell et al., 2007; Miller, 2003; Roskovensky and Liou, 2005).

While no reflectance change algorithm for dust detection has been developed, it is included here as it shows great potential both for detection of dust but also for discrimination from cirrus cloud. The RC product is generated by subtracting the expected surface reflectance derived from a BRDF model from observed atmospherically corrected surface reflectance (Broomhall et al., 2009). The BRDF is essentially a running average of the surface reflectance where the reflectance for any set of solar and sensor geometries can be derived. This evolves slowly with each successive observation. Any observation where there is some rapid change in reflection due to such things as dust plumes is easily observable.

3. YABI WORKFLOW ENGINE AND HIGH PERFORMANCE COMPUTING ENVIRONMENTS

The YABI workflow engine is a web-based graphical interface that allows a selection of tools to be used to construct complex processing streams. These tools may take any form and are only limited to what will run on the HPC system mated to the workflow engine. Currently much of the remote sensing processing implemented in YABI uses the seaWiFS Data Analysis System (SeaDAS). This will be extended to use the International MODIS/AIRS Processing Package (IMAPP), the International Polar Orbiter Processing Package (IPOPP) and many other tools. YABI is used at the Centre for Comparative Genomics (CCG) at Murdoch University to run genetic simulations and has been adapted to run remote sensing workflows, named RS-YABI (Fearns et al., 2010). Figure 1 shows a workflow stream for generating dust products and imagery.

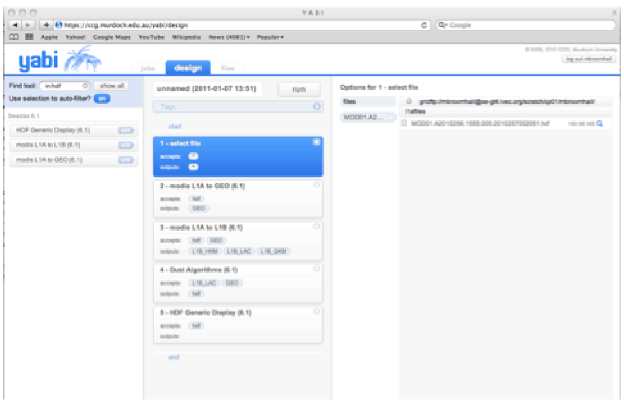

Figure 1. The web-based interface to the RS-YABI workflow engine showing the workflow stream for generating dust products.

The interface from Figure 1 displays tools or modules in the left panel. These are dragged and dropped into the central panel to create the workflow. Each of the modules understand how they are required to be linked to each other and will indicate if they are incorrectly used. The panel on the right shows the output from each stage of the processing. Products from any of the stages are accessible directly from the interface. The dust products workflow stream is part of a suite of algorithms and streams that will constitute a remote sensing workflow. The proposed remote sensing workflow is shown in the flowchart in Figure 2. The red checked box highlights the dust products workflow stream. The proposed RC dust product stream is highlighted in blue.

This system is mated to iVEC's HPC system located at Murdoch University. This system is based on a SGI Altix 1300 comprising 512 cores each with 2 GB of memory and a combined 10 TB file system. Flow control is taken care of by the RS-YABI workflow engine. Multiple instances of this workflow stream can be run concurrently and limited multiple processing within the same stream is also possible. Full multiple processing within a single stream is under development. This work is part of the National eResearch Architecture Taskforce (NeAT).

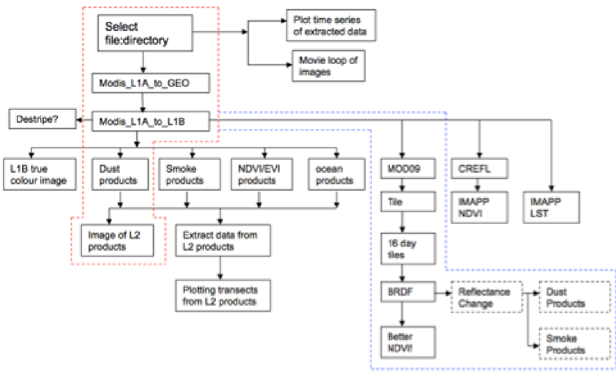

Figure 2. The remote sensing workflow structure. The dust products stream is indicated in red, the proposed RC dust product stream is indicated in blue.

4. RESULTS OF THE CASE STUDY

The following figures show the performance of the dust detection algorithm output from the remote sensing workflow system. Figures 3 – 6 show an Aqua swath from the 27/09/2008. Figure 3 shows the MODIS true colour image produced by the SeaDAS MODIS processing system. There are a number of dust plumes present in this image but they are extremely difficult to see without prior knowledge of their location. The 3 dust algorithms outputs are shown in Figures 4 – 6. Here there is distinct evidence of dust. Figure 4 shows the Equation 1 image where the dust is evident as white streaks going north-west to south-east. All of the outputs from these algorithms have been scaled to make the evidence of dust more visually distinctive.

Figure 5 shows an RGB enhancement utilising Equation 3. The red contribution to the image is the D factor from Equation 3, the green and blue contributions are from MODIS bands 4 and 3 reflectances respectively. The presence of dust here is indicated by the pale red colour, cloud is indicated by turquoise, green and bright red indicate underlying surface features. This image shows the main dust features but misses the less dense plumes.

Figure 6 shows the Equation 2 image. Here the cloud and water appears black and are in essence masked out of the image. The white streaks, as in Figure 4 indicate the presence of dust.

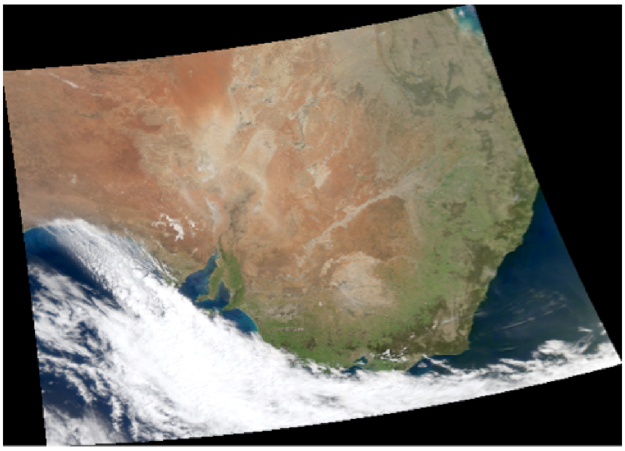

Figure 3. Aqua MODIS true-colour image for the 27/09/2008 at 04:30 UTC.

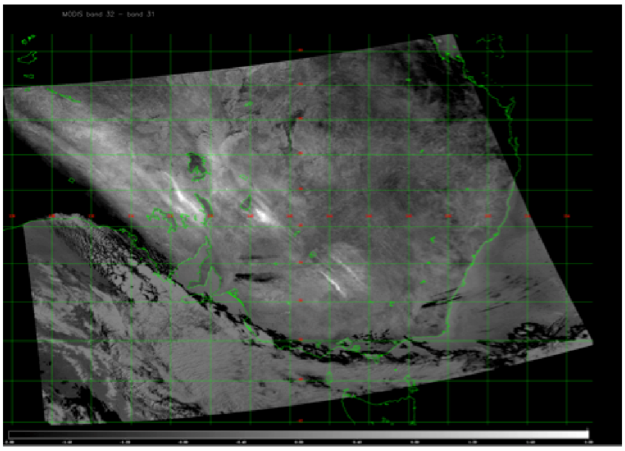

Figure 4. Aqua MODIS Equation 1 image for the 27/09/2008 at 04:30 UTC.

Figures 7 show a Terra image from the 24/09/2006 at 01:30 UTC. Figure 7 is included here for comparison with Figure 8. Figure 8 shows an RGB image where the red, green and blue contributions to the image are provided by the reflectance change image from MODIS bands 1, 4 and 3 respectively. As mentioned previously, RC derived from BRDF responds to rapid changes so anything transient within the atmosphere is shown up very well.

Figure 8 shows a subset of the MODIS swath centred on the large dust plume. The plume stands out from the background just as effectively as the plume in the Equation 1 image in Figure 7, but has the advantage of containing a great deal of spectral information evident in the colouration of the image. This imagery can also be produced at the native resolution of 500 m or use reprojected 250 m data, giving up to 16 times as many pixels as the imagery produced from Equations 1 – 3.

Figure 9 shows a single pixel width transect through this large dust plume (almost 650 km wide) as indicated by the green line in Figure 8. This shows the change in reflectance for MODIS bands 1 – 5 and 7.

As this transitions from left to right in the image and left to right in the graph, features within the image are easily identified in the graph.

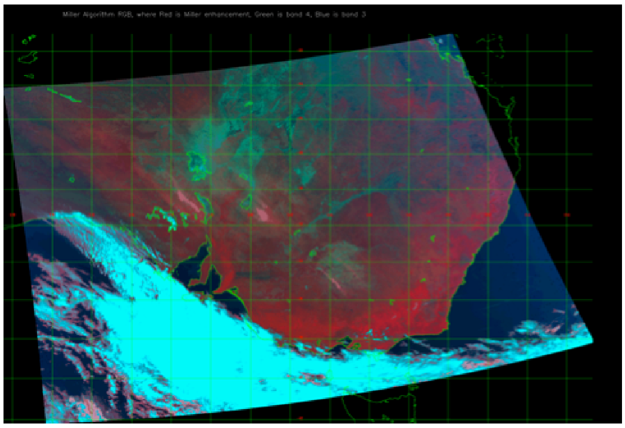

Figure 5. Aqua MODIS Equation 3 algorithm image with RGB enhancement for the 27/09/2008 at 04:30 UTC.

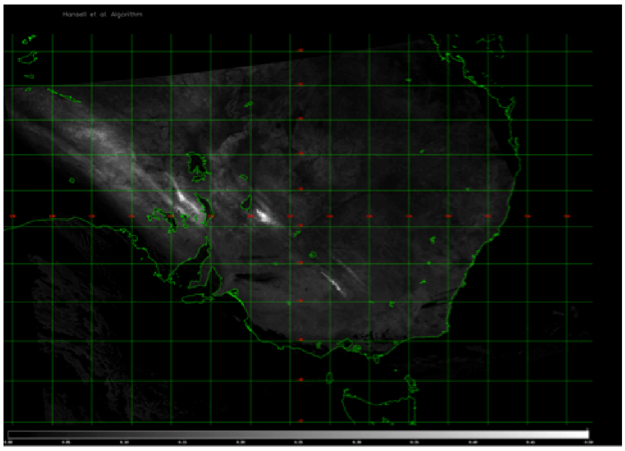

Figure 6. Aqua MODIS Equation 2 image for the 27/09/2008 at 04:30 UTC.

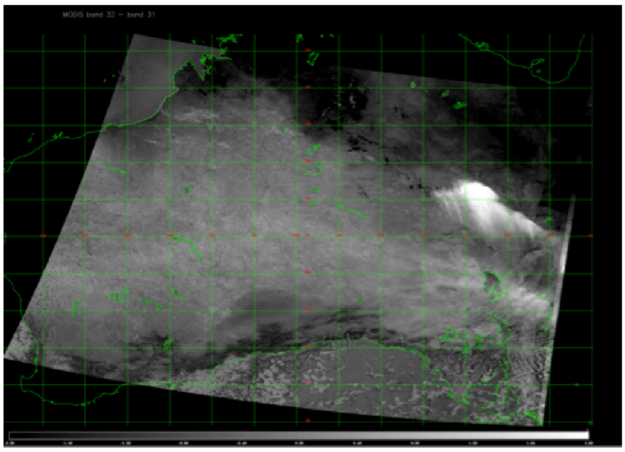

Figure 7. Terra MODIS Equation 1 image for the 24/09/2006 at 01:30 UTC.

Clouds and cloud shadows in the image show a consistent change across the spectral range but have opposite responses.

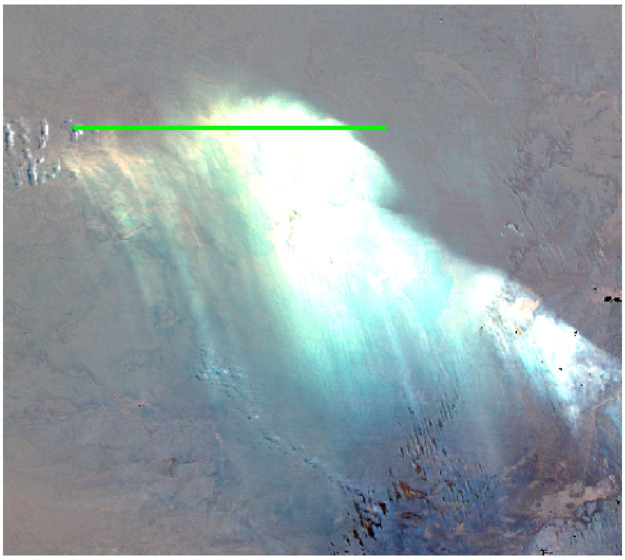

Figure 8. Terra MODIS Equation 4 1.25 km reprojected RGB image for the 24/09/2006 at 01:30 UTC.

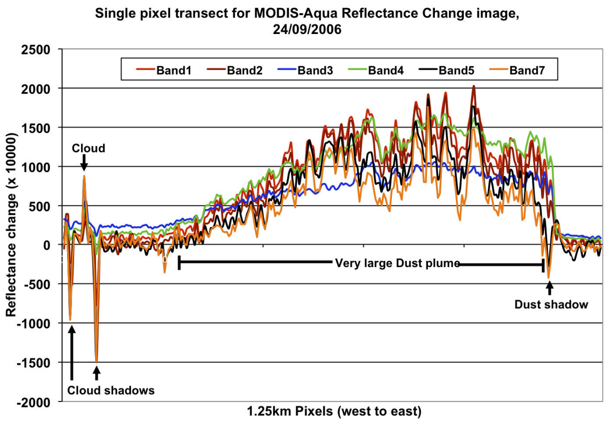

Figure 9. Single pixel transect indicated by the green line in Figure 8.

The dust plume itself shows where the plume becomes extremely thick when first band 4 then band 3 and finally band 7 RC values exceeds the RC values in band 3. Mie scattering theory for single scattering predicts that the magnitude of scattering should decrease with increasing wavelength and hence reflectance. The increase in reflectance at longer wavelengths shows either extreme amounts of multiple scattering or the existence in the dust plume of particles that are several orders of magnitude larger than the wavelength of the light, resulting in geometrical scattering.

5. DISCUSSION

This case study has shown that it is possible to rapidly implement a number of dust detection algorithms within RS-YABI. It shows that utilising a web-based interface coupled to a HPC system makes it possible for a researcher with little to no knowledge of remote sensing techniques can easily generate useful products.
Baddock et al. (2009) has stated, and this has been reinforced by this case study, that not one single algorithm presented here performs the best on all occasions for all conditions. It has also been stated (Baddock et al., 2009, Miller, 2003) and shown by this case study that the best representation of each algorithm can involve manipulating thresholds and scaling for different conditions. Running an ensemble of dust detection algorithms provides the best chance of successful detection of dust events.
Reflectance change dust detection has been introduced here even though it has not yet been implemented in RS-YABI. It has great potential to provide extra information to the current dust detection algorithms. Using spectral reflectance change in conjunction with the BTD method from Equation 1 may provide a new algorithm to the ensemble presented here.

6. CONCLUSION AND FUTURE WORK

The RS-YABI system will allow the implementation of a variety of algorithms and aid a wide range of researchers who might not have advanced skills in remote sensing data processing.
The dust algorithms presented in this case study were included within RS-YABI quite rapidly and have delivered good results with a minimum of complexity.
Inclusion of new techniques and smart, automated methods to manipulate thresholds and scaling of the existing algorithms will allow researchers access to a number of methods for dust detection with a few simple clicks of a mouse.
The dust detection algorithms will need to be validated using ground truth data from a number of stakeholders. The dust detection system will be evaluated with feedback from end users in conjunction with field instruments to give a valuable research tool for research.

REFERENCES

M. Baddock, J. Bullard, R. Bryant, “Dust source identification using MODIS: A comparison of techniques applied to the Lake Eyre Basin, Australia”, Remote Sensing of Environment, vol. 113, p.p. 1511 – 1528, 2009

M. Broomhall, B. McAtee, S. Maier, “An Investigation of the Remote Sensing of Aerosols Based on MODIS data for Western Australian Conditions”, Innovations in Remote Sensing and Photogrammetry, Lecture notes in Geoinformation and Cartography, Springer, p.p. 133 – 148, Oct 2009

P. Fearns, M. Bellgard, M. Broomhall, H. Chedzey, R. Garcia, A. Hunter, E. King, M. Lynch, D. Schibeci, G. Smith, “Web Based Processing of Remote Sensing Data in a Workflow Environment”, (These proceedings)

R. Hansell, S. Ou, K. Liou, K. Roskovensky, S. Tsay, C. Hsu, “Simultaneous detection/separation of mineral dust and cirrus clouds using MODIS thermal infrared window data”, Geophysical Research Letters, vol. 34, Jun 2007

S. Miller, “A consolidated technique for enhancing desert dust storms with MODIS”, Geophysical Research Letters, vol. 30, No. 20, Oct 2003

J. Roskovensky, K. Liou, “Differentiating airborne dust from cirrus clouds using MODIS data”, Geophysical Research Letters, vol. 32, Jun 2005

I. Sokolik, “The spectral radiative signature of wind-blown mineral dust: Implications for remote sensing in the thermal IR region”, Geophysical Research Letters, vol. 29, No. 24, Dec 2002