Australian Government
Department of Agriculture, Fisheries and Forestry

Australian Plague Locust Commission

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An evaluation of MODIS NDVI imagery for monitoring locust habitat.

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An evaluation of MODIS imagery.

Background

The Australian Plague Locust Commission (APLC) uses NOAA AVHRR NDVI imagery routinely as a tool to assess vegetation conditions in known locust habitat areas. In 2004 there was some uncertainty about the continuity of NOAA satellite series launches and also some temporary instrument failures that potentially compromised the availability of NDVI imagery. Therefore, an investigation of the suitability of using MODIS as an alternative source of vegetation monitoring information was undertaken. With the launch of the NOAA 'N' satellite in March 2005, the NOAA AVHRR program now appears assured till 2015, barring satellite failure. However, the potential advantages of higher resolution MODIS data in terms of discrimination of vegetation variation in smaller areas, such a creek lines, floodouts, crops or irrigation remain worthy of investigation.

This report outlines the method of converting single band MODIS NDVI binary files to a format suitable for incorporation in the APLC's current Decision Support System and a comparison of these NDVI values with those of AVHRR data currently sourced from ERIN (Department of the Environment and Heritage -DEH) and the West Australian Department of Land Information (DOLI) to enable MODIS NDVI data to be automatically processed and used in the same way as AVHRR NDVI imagery.

MODIS data

The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments offer a means of regular global monitoring of vegetation growth and changes at a higher spatial resolution (250 m pixel size) than the current NOAA AVHRR (1000 m pixel). MODIS is onboard NASA's Terra (EOS AM) and Aqua (EOS PM) satellites. Terra orbits the Earth with passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS view the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. Technical specifications on the satellites is available from the NASA website at: http://modis.gsfc.nasa.gov/about/

There are a range of data products produced from MODIS data for studying land, ocean and atmospheric processes. There are several Vegetation Index (MODIS VI) products produced as part of the Land Science program, including a Normalised Difference Vegetation Index (NDVI), similar to the NDVI produced from NOAA Advanced Very High Resolution Radiometer (AVHRR) data. NOAA NDVI has been used for monitoring regional and global vegetation growth for over 20 years (Tucker 1986, Justice *et. al.* 1985, Price 1987) and vegetation in other arid environments (Prince & Justice 1991, Tucker 1996). The individual spectral bands in the visible and near infrared used to produce the MODIS NDVI are similar, but not identical, to those used to generate the AVHRR NDVI.

MODIS has very similar electromagnetic frequency detection ranges in bands 1 and 2 (used to calculate the NDVI) to the NOAA-AVHRR sensor so there is a high degree of correspondence in the NDVI from the 2 sensors, most notably at the lower end of the NDVI range, slightly less so at the top end. The MODIS sensor has onboard calibration for the visible channels so will be much more stable over time than the NOAA AVHRR. MODIS bandwidths for channels 1 and 2 are:

1 – EOS MODIS 620 to 670 nm (NOAA AVHRR/3 Band 1 is 580 to 680 nm)
2 – EOS MODIS 841 to 876 nm (NOAA AVHRR/3 Band 2 is 725 to 1000 nm)

These are processed using the common NDVI formula ((Band 2-Band 1)/(Band 2+Band1)). DOLI has provided MODIS NDVI since 2004, along with AVHRR NDVI images, as part of the arrangement for the delivery of satellite vegetation index data to the Bureau of Rural Science and the APLC via the Department of Environment and Heritage (DEH). The current direct FTP (File Transfer Protocol) arrangement with DOLI has ensured current NDVI imagery is generally available within a week of the end of the 14 day compositing period.

Methods
NDVI image data from the different sensors and, for AVHRR, different sources (DEH and DOLI) were compared using the frequency distributions of pixel values for entire images and selected regions. Visual inspection indicated that the same spatial features of vegetation are highlighted in all images, so pixel frequencies should be comparing reflectance of the same general features. MODIS NDVI has 4 times the spatial resolution of AVHRR, so MODIS frequencies were divided by 16 to give equivalent values. Pixel values from two 1.5 X 1.5 degree (150X150 1km AVHRR pixels, 500X500 250m MODIS pixels) regional sub-areas around Broken Hill and Moree (NSW) were extracted to compare data for specific low-cover and mixed crop/forest landscapes.

MODIS file characteristics
Binary composite image files are routinely collected by FTP from the DOLI server, after email information of their availability. AVHRR image files are 14 MB, while those for MODIS are 16 times as large (226 MB), so there is some overhead in download, processing, storage and display time compared with AVHRR data. MODIS data files are rescaled to 8 bit data range (i.e. 0-255) by DOLI from the original 10-bit data output of the sensor. The files are at 0.0025 decimal degrees spatial resolution, i.e. 4 times the NOAA resolution. The samples and lines are 16596 by 13600 representing a top left origin file with geographic co-ordinates from -10.00 to -44.00 and 112.51 to 154.00. Unlike current NOAA files with geographics measured from the centre of the pixel, the MODIS data is produced through ER-Mapper with the geographics measured from the top-left of the pixel, so the dimensions are not an exact multiple of the AVHRR image dimensions. In effect the geographic extent of MODIS files is -10.00 to -43.9999999 (latitudinal range) and 112.51 to 153.999999 (longitudinal range).

Binary image files are converted to ESRI GRID format (a single-channel cell-based or raster format with associated value attributes) by attaching a header file which defines the data range, position and line/column size of the files, prior to passing them through the IMAGEGRID command. GRIDS allow for interrogation of pixel values, individually of for defined areas, and allows for a variety of display parameters, including simple image processing. The header file ‘modis.hdr’ is given in Appendix A.
The data processing and storage steps are automated for image to output grid conversion by an ArcInfo AML, similar to those used for AVHRR NDVI images

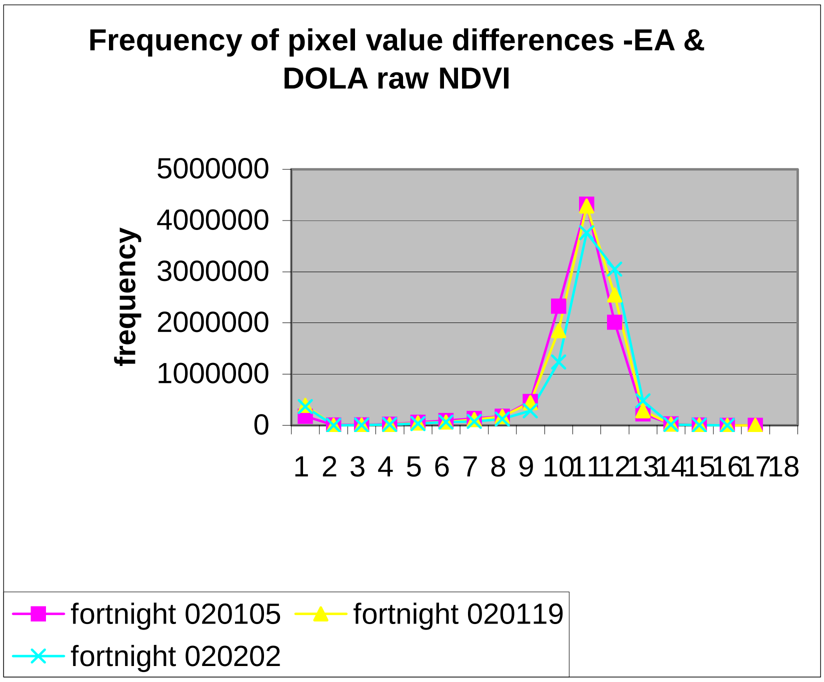
(procmodis.aml - Appendix A) and any rescaling for image matching is included at this stage.

AVHRR NDVI calibration differences between sources.

When DOLI began directly supplying AVHRR NDVI files at the start of 2003, a comparison of data values was made with the ERIN (DEH) images supplied since 1999. ERIN had routinely recalibrated AVHRR NDVI from individual Band 1 and Band 2 data, to ensure conformity with their 1991-1999 time series data, and also applied a stringent masking of potential cloud affected or anomalous pixel values. Therefore, the NDVI products from the two sources were not identical.

A previous comparison of a sequence of AVHRR images for early 2003 showed DOLI images have consistently higher NDVI data values (Figure 1) than DEH (ERIN) images, with differences for a single image normally distributed around a mean difference of 10 (of 255) data values. This process was repeated for recent NDVI from both sources to determine their current correspondence.

Figure 1: Data from 2002 comparison of AVHRR NDVI between DEH (ERIN) and DOLI images. Pixel frequency of difference between image pairs for the same dates.



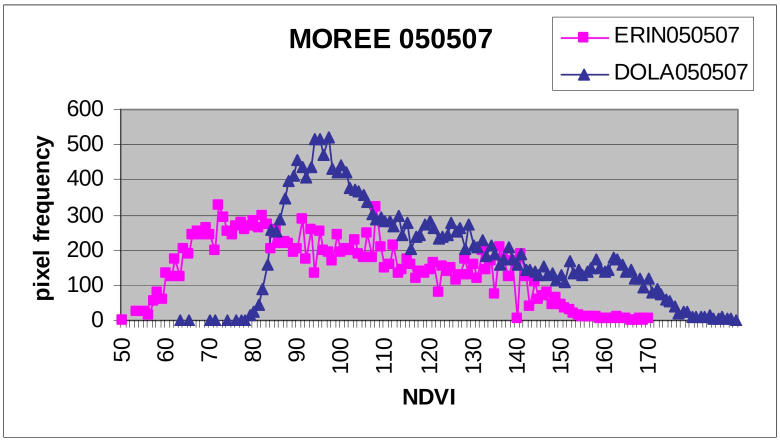
Several recent ERIN raw NDVI images (050423, 050507) were obtained from ERIN to check for differences in current imagery between sources. Comparison of pixel values showed that DOLI AVHRR imagery NDVI values are consistently higher than the recalibrated ERIN images. (Figure 2 & 3, Appendix B). Over the entire continent this difference has a peak value of 15 for the pair of images examined, but there is regional variation in this value, with mean differences ranging from 12 at Broken Hill to 22 at Moree. For the whole Australia image difference values in (Appendix B, Sheet2-A) the pixels in the range 50-100 largely comprise pixels in the ocean, where they have been set to value 0 in the ERIN data, but are not removed from DOLI data.

There is a consistent small difference (2.5%) in NDVI pixel value between ERIN and DOLI supplied AVHRR imagery. As images are displayed on a relative scale by the

APLC and it is not known if there is any specific threshold in terms of current greenness as a proportion of potential which has direct relevance to locusts, this difference could be compensated for by adjusting display colours. However, the 'relative' NDVI (developed by Shane Cridland at ERIN) used by the APLC (Deveson *et. al* 1999, 2005) uses historically recorded ranges of individual pixel NDVI and previous season minima to recalculate current NDVI as a proportion of its potential range. These values come from the ERIN calibrated data, so the differences between sources are also propagated in all modified NDVI values from DOLI raw NDVI data, particularly at the low end of the NDVI scale which is of particular interest to the APLC. Consequently a uniform downward adjustment of DOLI NDVI has been applied to maintain consistency with the historical range data.

Figure2. Comparison of AVHRR NDVI values from ERIN (pink) and DOLI (blue) for the 14 days beginning 7/5/2005, in the Moree (a) and Broken Hill (b) regions.

(a)



(b)

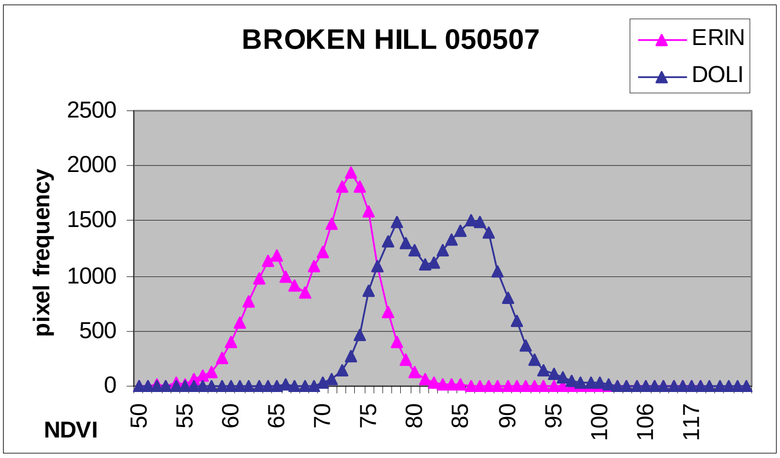
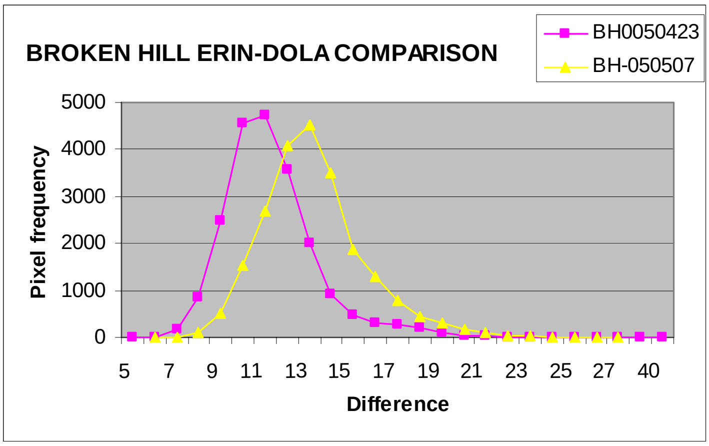
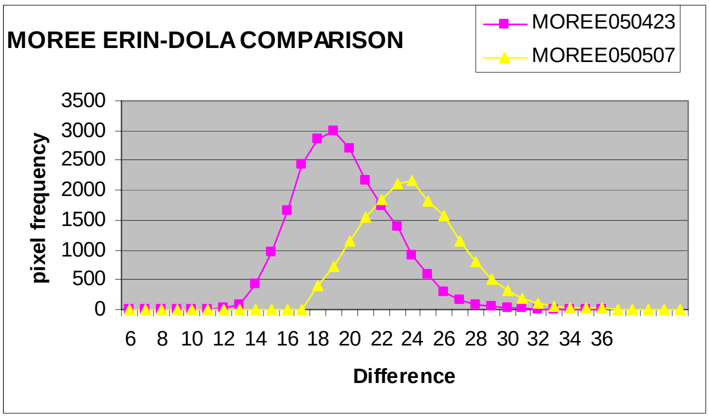


Figure 3. Frequency distribution of difference between NDVI pixel values from ERIN and DOLI near Broken Hill (a) and Moree (b) regions for two 14-day periods beginning 23/4/2005 (pink) and 7/5/05 (yellow).

(a)



(b)

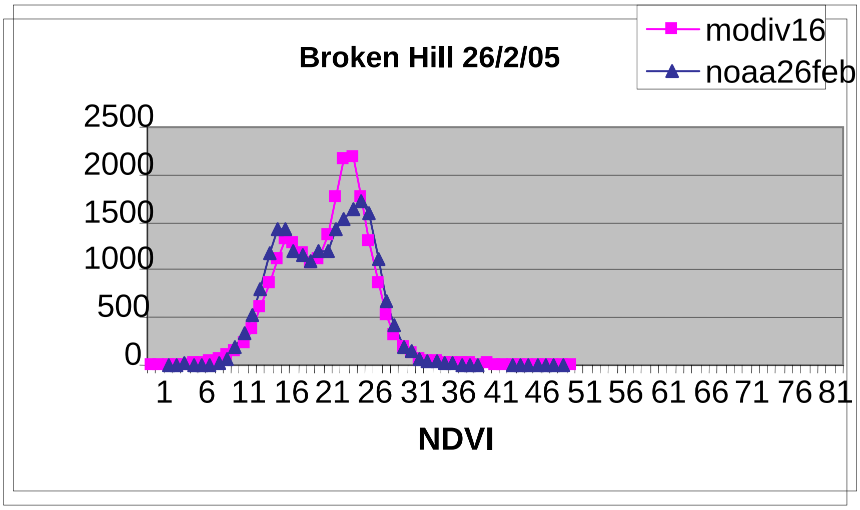


Comparison of NDVI from AVHRR and MODIS

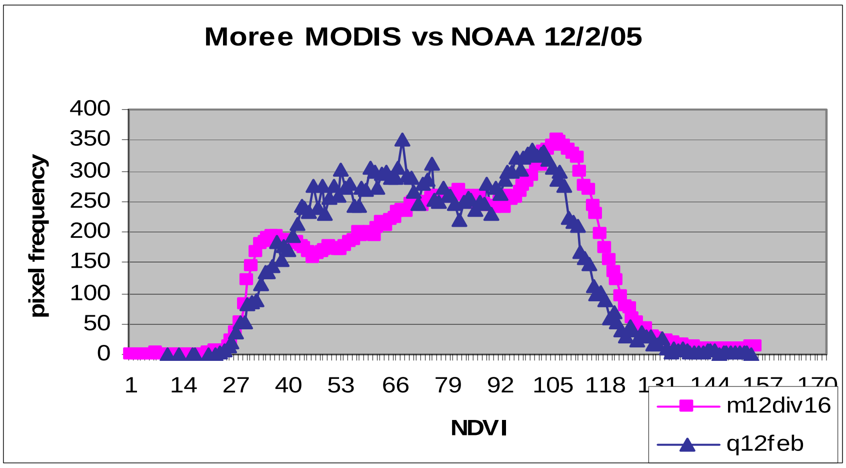
A sequential pair of MODIS NDVI images, for the time periods 12/2/2005-25/2/2005 and 26/2/2005-10/3/2005, were converted to GRID format and compared to AVHRR NDVI from DOLI for the same time periods. The results are shown graphically in Appendix C, and one example is shown in Figure 4). The correspondence between these data, particularly within the Moree and Broken Hill test regions, suggest that sensor band range differences are minor and that MODIS NDVI could be used as a direct replacement for NOAA AVHRR NDVI data. The very high peak of value around 50 in the continental MODIS data (Appendix C-SHEET 1) again represents ocean pixels which were not removed for this exercise. Visual examination of the feature discrimination potential of MODIS shows the potential advantage of MODIS data in the identification of forest scrub, irrigation areas as contextual information, and of identifying restricted green areas, such as along creeklines (Appendix D). The test images are from a generally dry period (February 2005). This is reflected in the contrast between pastures in NSW, and forest/scrub, which is actively growing at this time. The area around Conargo (NSW) where greener vegetation is clearly detectable in both AVHRR and MODIS images following rain in early February 2005 was supporting a substantial locust population at this time (Appendix D – C,D).

Figure 4. Frequency distribution of NDVI pixel values for AVHRR (DOLI) (blue) and for MODIS (pink) for fortnight 12/2/2005 for Broken Hill (a) and Moree (b) test areas

(a)



(b)



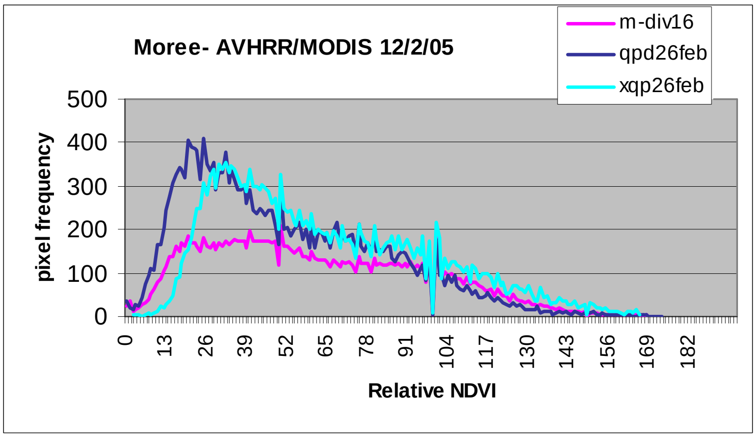
Relative NDVI from MODIS data

Recalculation of MODIS NDVI to the relative scaling used by the APLC for AVHRR data presented a number of problems. MODIS data have only been produced in the last few years, so the historical variation that has been recorded over 20 years for AVHRR is not available to calculate a MODIS equivalent. DOLI initially provided a MODIS maximum and minimum for 2003-04 and these data were included in the initial calculations of relative index images. The calculation of a relative NDVI uses the formula ((current NDVI - minus minimum value for previous season) divided by maximum difference]) * 100), where maximum difference is the highest recorded value minus the lowest recorded value). The result is presented as a percentage of that range. However, the outputs included large negative and large positive values over substantial parts of each image, because of zero values in the long-term minimum and long-term maximum values lower than maxima in current images.

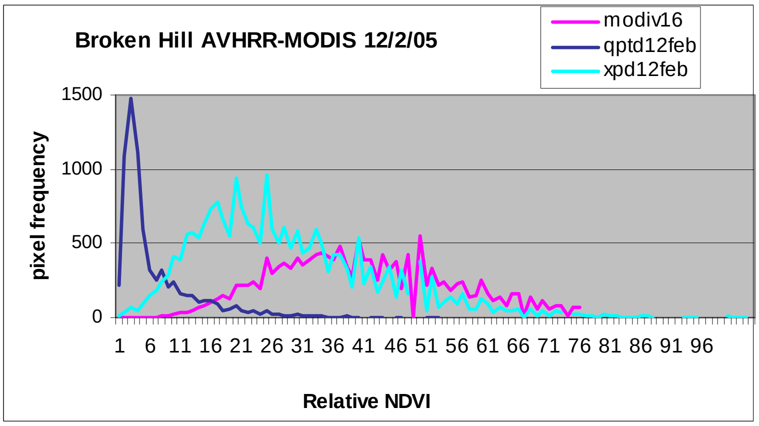
Given the close correspondence in initial NDVI values between MODIS and AVHRR data, a recalculation using the historical maxima and seasonal minima grids for AVHRR NDVI, provided by ERIN, by resampling these to a 0.003 grid cell size was undertaken. The results produced outputs much closer to the current AVHRR relative index from DOLI.

Figure 5 Examples of Relative NDVI (APLC index), calculated for areas around Moree and Broken Hill, using current DOLI AVHRR (qpt – black) uncorrected DOLI AVHRR (xpt – blue) and MODIS (mod16-pink) image data. Data for 14-day period beginning 26/2/05 (a) Moree and (b) Broken Hill.

(a)



(b)



However, plotting of the adjusted DOLI relative NDVI (i.e. 4% reduction in NDVI prior to calculation of proportion of range value) against MODIS relative NDVI showed that the subtraction adjustment created a shifted distribution and, in particular, the DOLI relative NDVI at the low value end of individual range relegated a significant number of pixels to value 1 (see Appendix D, Sheet 3 A) C), and therefore the potential loss of lower end information.

Conclusion

NDVI imagery from both AVHRR and MODIS provided by DOLI are closely calibrated, and could be used interchangeably by the APLC for interpreting vegetation condition. Relative NDVI, that is – the NDVI recalculated as a proportion of the potential greenness for any location - can be calculated for MODIS imagery by using smoothed historical maxima and minima from AVHRR data. The consistently higher

NDVI values in the DOLI AVHRR data compared to ERIN AVHRR, however, mean that the calculated relative NDVI will also be slightly higher with values > 100 occurring more frequently. This is probably preferable to rescaling all DOLI data downward before generating relative products, except if direct comparison is to be made with earlier ERIN data. The sequence of DOLI AVHRR NDVI will all be reprocessed to remove the previous subtraction adjustment to match ERIN data. MODIS data have been supplied to us as part of an experimental evaluation, and have been included in the annual payment to DOLI via DEH. The arrangement between BRS and DEH is currently being renegotiated and it appears that the APLC contribution, which for direct data supply without any reprocessing by ERIN, would be about the same as previously.

MODIS NDVI image data could be readily integrated into the APLC's current Decision Support System (DSS) in the same way as current AVHRR imagery. The increase in resolution afforded by MODIS NDVI imagery provides a much clearer picture of the ground cover in heterogeneous environments. It is possible that MODIS may provide a small advantage over AVHRR NDVI imagery in detecting small localised areas of green vegetation suitable for locust breeding. The relevance of this increased resolution and increased contextual information to monitoring or managing locust populations has not been tested in an operational situation and it is unclear if potential additional cost in acquiring MODIS would be warranted.

References

Deveson E., Cridland S. & Odjnanovic L (unpubl.). NOAA AVHRR image sequences detect ground vegetation response to rainfall in potential locust habitats.
APLC Internal research Report (1999)

Deveson E., Jenkins T., Graham R., Murray D. & Wardle J (unpubl). Field Evaluation of NDVI relative greenness imagery – Broken Hill 2002-03. APLC Internal Research Reports – 2005.

Justice C.O., Townshend J.R, Holben B.N & Tucker C.J. (1985) Analysis of the phenology of global vegetation using meteorological satellite data. *Int. J. Rem. Sens.* **6**, 1271-1318.

Price, J.C. (1987) Calibration of satellite radiometers and comparison of vegetation indices. *Rem. Sens. Environ*. **21**, 419-422.

Prince, S.D & Justice, C.O (1991) (Editorial) Special issue on remote sensing of the Sahelian environment. *Int .J. Rem. Sens*. **12**, 1137-46.

Tucker,C.J. (1986) Maximum Normalized Difference Vegetation Index Images for sub-Sahara Africa for 1983- 1985, *Int.J. Rem. Sens*., 1986, **11**, 1383-1384.

APPENDIX A.
Characteristics of MODIS instrument and satellite platforms, header file for processing binary MODIS image data and the ESRI AML file for generating GRID format files.

Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	228.7 kg
Power:	162.5 W (single orbit average)
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Design Life:	6 years

```
Modis.hdr
#start file
Header file for MODIS NDVI raw binary image data (DOLI)

nrows      13600     # no of lines
ncols      16596     # no of pixels/line
nbands     1       # no of channels of data
nbits      8       # 8 bit data
byteorder  I       # INtel byte order
layout     bil     # band interleaved by line
skipbytes  0     # no bytes in  header
ulxmap 112.510
ulymap -10.000
xdim .0025
ydim .0025
#
```

```
/* ---------------------------------------------------------------------------
/*
/*   procmodis.aml - allows manual processing of named files from
/*                DOLA salad server
/*                prompts for image name we will just get date
/*                file to process to a georeferenced grid.
/*   it then calls routine image to process the output
/* history: 02/05 - TD
/* generated NEWMIN and NEWMAX from NOAA NDVIs and then resampled
/* to .003 using bilinear sampling
/* this overcomes problems with a short MODIS history and is only used
/* for relative scaling (compared with nearest, but not cubic)
/*  fixed to run in grid module the whole way from imagegrid
/* puts the output 'mod<yymmdd>' grids in /image/modis
/* writes a .clr file for each so they can be added to Arcview
/* projects with colour scheme set up
/* assumes that the input files are not compressed
```

```
/* and has form "newaplcmodisndvi"<yymmdd>
/* looks for them in /image/modis
/* DOES NOT USE THE 'DIRTY FUNCTION' DOLANDVI - 10, the processes
/* 03/03 - modified to ensure no values > 255 in final output

/* -----------------------------------------------------------------------
&echo &on
&messages &on
/*
&fullscreen &popup

&menu procmodis.menu &pos 150 50 ~
 &stripe 'MODIS NDVIimages'
/*check we have a value to work with
&if [null %file%] &then
  &return &warning  No start date was given or it was bad?!


/* set directory variables to locate files
/* &sv year := [substr [DATE -USA] 7]
&sv pathway := /image/modis
&sv datapath := /image/modis
&lv file

/* first we go through for the PTD, then PDF
&sv a := newaplcmodisndvi
&sv p := modr
&sv f := qmod
&workspace %pathway%

&call images      /* gets and processes image file

&call makeptd

&label bailout

&return
/*********************************************************************
/*        routine - image
/*        gets image file, formats it and processes it to a grid
/**********************************************************************
&routine images

/* ----------------------------------------------------------

/* copy file to work area in usable format
&workspace %pathway%
&severity &error &ignore
&system cp %datapath%/%a%%file% %pathway%/%a%%file%.bil
&system cp %pathway%/modis.hdr %pathway%/%a%%file%.hdr
&system cp %pathway%/ptd.clr %pathway%/%f%%file%.clr
&severity &error &fail

/* now compress up the orig file again
&system compress %datapath%/%a%%file%

/* before executing imagegrid check if imagex etc are there
/* and delete them if they are


&if [exists %pathway%/%a%%file% -grid] &then
```

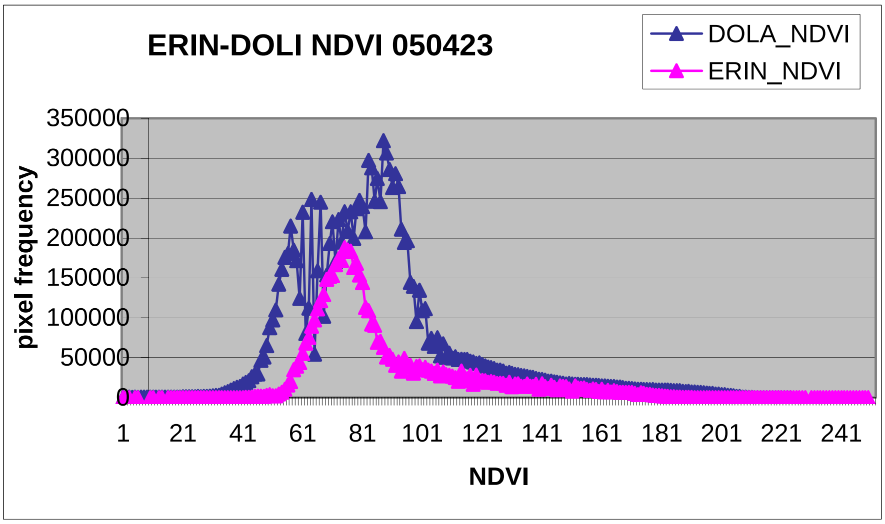
```
  &do
    &return &warning 'that grid already exists \
         I'm gunna kill and recreate it?'
    kill %pathway%/%a%%file%
    /*&severity &error &ignore
  &end

/* check module, go into GRID, then do the imagegrid command

&if [show program] = ARC &then
GRID

arc imagegrid %pathway%/%a%%file%.bil %p%%file%

/* delete intermediate 'bil' file from input directory
&system rm %pathway%/%a%%file%.bil
&system rm %pathway%/%a%%file%.hdr

&return
/****************************************************8
/* routine makeptd  - just subtract 10 from aplc<yymmdd> and go
&routine makeptd

&if [show program] = ARC &then
GRID

verify off
/* NOW some intermediate steps from the RAW ndvi to the PTD
/* make the surrogate PTD
&if [exists z -grid] &then
 kill z
&if [exists zz -grid] &then
 kill zz
&if [exists zzz -grid] &then
 kill zzz
&if [exists %pathway%/%f%%file% -grid] &then
  &do
    &type 'that grid already exists \
   Im gunna kill and recreate it?'
    kill %pathway%/%f%%file%
    /*&severity &error &ignore
  &end


/* we will not bother with the subtract 10 line
/* but we will make all the ocean 255

/*z = (%p%%file% - 10 - min0203)
/*this is long way but a bit cleaner
setcell 0.003
/*setmask masktest
/*tempo = con(%p%%file% < 75, 255, %p%%file%)
/*setmask off
/*z = merge(tempo, %p%%file%)
/*kill tempo

/* this is quick way
/*setcell 0.002
setmask masksea
/* we will drop the subtraction to test
z = (%p%%file% - newmin)
```

```
zz = con(z == 0, 1, con( z < 0, 1, z))
/*zz = con(%p%%file% == 0, 1, con( %p%%file% < 0, 0, %p%%file%))
setmask off
zzz = float(zz)
zzzz  = int (( zzz  DIV newmaxdif) * 100)
/*%f%%file%  = int (( zzz  DIV newmaxdif) * 100)
%f%%file% = con(zzzz >= 255, 255, zzzz)

&sys cp ptd.clr %f%%file%.clr

/*&if [exists z -grid] &then kill z
/*&if [exists zz -grid] &then kill zz
/*&if [exists zzz -grid] &then kill zzz
/*arc kill z
/*arc kill zz
/*arc kill zzz

&if [exists zzzz -grid] &then
arc kill zzzz


/* now we will display the sucker
/* WE dont need a shadeset because we use a colormap file
ap mapextent %p%%file%
gridpaint %f%%file% # # # %f%%file%.clr

/* exit the grid environment
quit
/*&thread &delete report
&return
/**************************************************************************
```

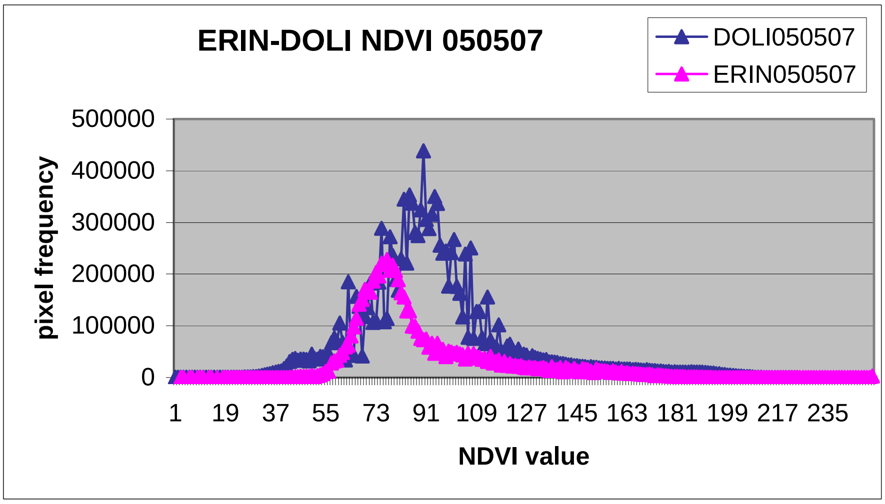
APPENDIX B-SHEET 1

Frequency distribution of pixel NDVI values for Australia for ERIN & DOLI NDVI- April and May 2005

A) fortnight beginning 23/04/2005

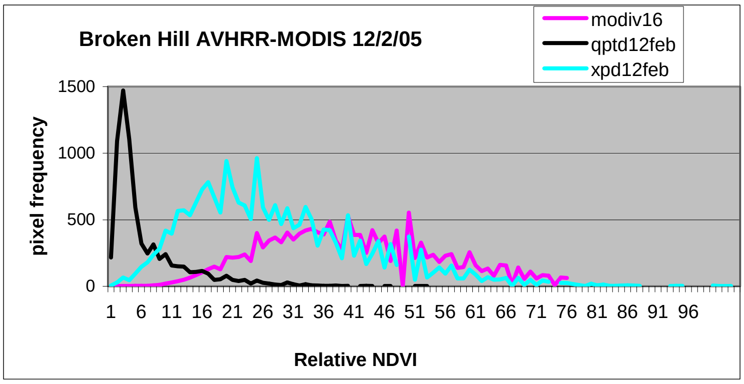


B) fortnight beginning 5/7/2005

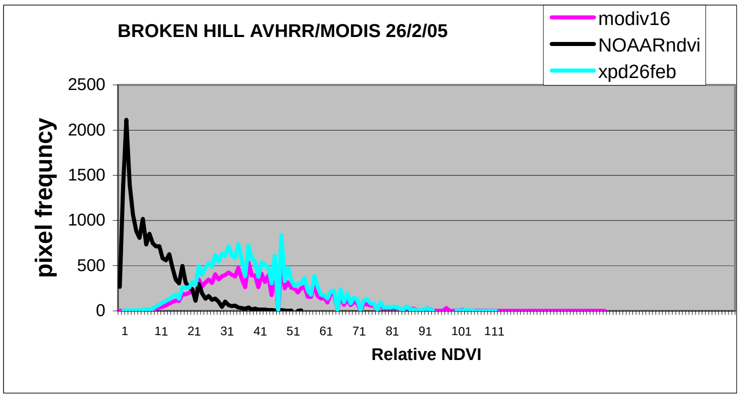


APPENDIX C-SHEET: (part2)
Comparison of calculated Relative NDVI values from DOLI AVHRR (xpd- blue), adjusted to ERIN range (qpt black) and MODIS (mod16-pink) for the Moree (a,c) and Broken Hill (b,d) regions.

b)



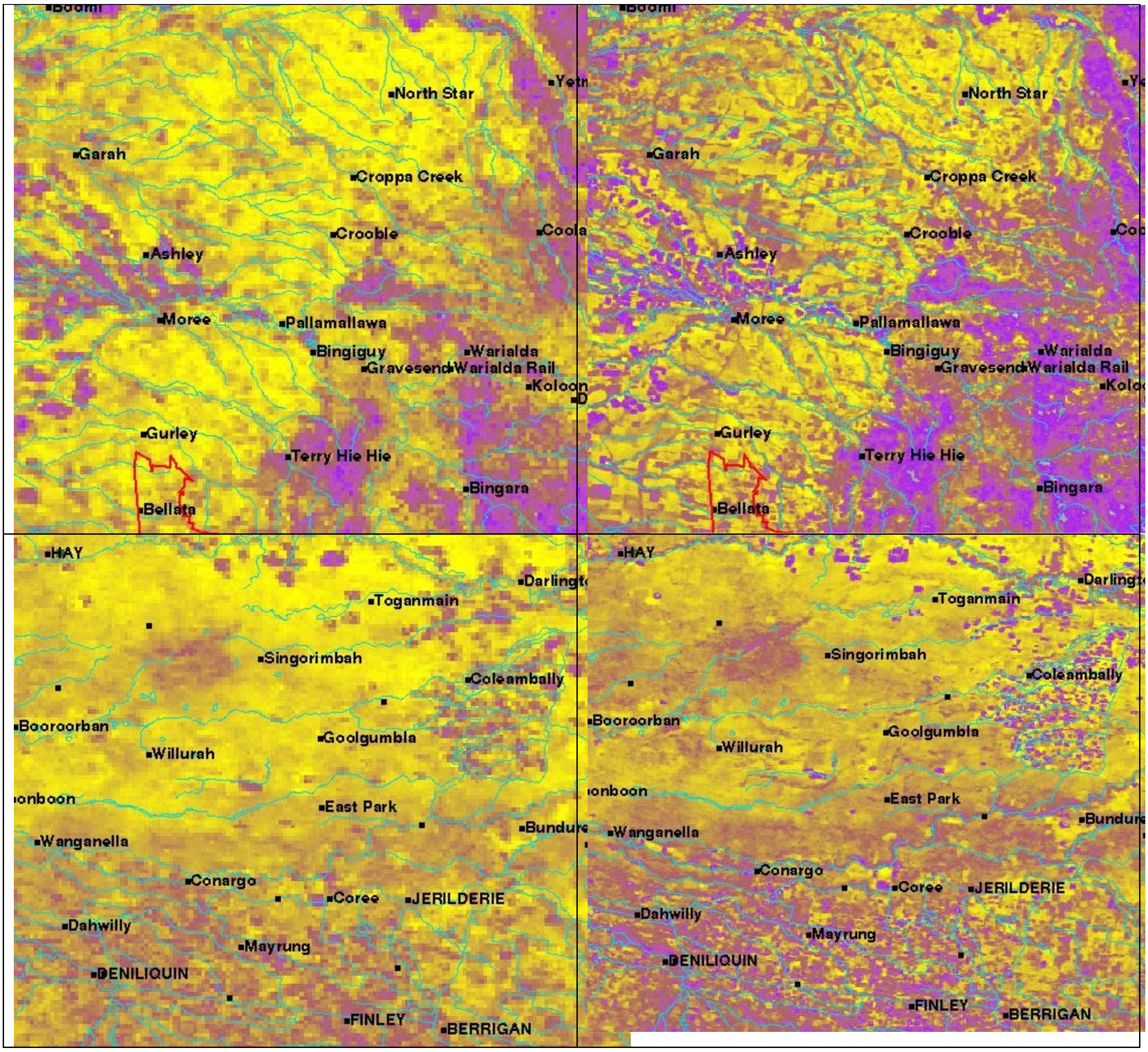
d)



APPENDIX D:

Example areas from both AVHRR and MODIS relative NDVI images from February 2005. Scale 1:1000000

a) NOAA AVHRR Moree b) TERRA MODIS Moree



c) NOAA AVHRR –Jerilderie d) TERRA MODIS - Jerilderie