Some Research and Applications in the CSIRO (Australia) Earth Observation Centre on Scene Brightness due to BRDF.[1]

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ABSTRACT

Scientists at CSIRO (Australia) engage in a coordinated group of related projects involving land surface reflectance anisotropy. One of the underlying themes of the work is to test/establish the existence of a stable underlying “typology” of BRDF directly attributable to land surface spectral and structural parameters that will allow sensible selections of the “shape functions” used in correction and inversion algorithms. This requires the existence and use of well established field sites and a range of measurements other than radiometer data. There exist established sites now and there are serious canopy and land cover missions planned in the future which may provide more of this type of data. BRDF research in CSIRO EOC Research involves Data Normalisation (AVHRR, Scanners, Videos, Air Photos, calibrations Sites, Panels) Atmospheric Correction (AVHRR, Scanners) Determining Landcover Structure (Photography, Scanners) and BRDF characterisation. At many current Calibration and Validation sites modelled so far around the world, semi-empirical functions seem sufficient. However, for more complex land surfaces, atmospheric & BRDF effects will need to be separated and it is not clear whether and how consistent the results obtained will be. In all cases of the application of scene brightness correction from AVHRR NDVI to video data mosaicking, we have a fundamental issue of whether there is a consistent and simple typology of BRDF? Photography and scanner data, as well as video & AVHRR are all being collated and documented at established sites in Australia in mapped ecological regions to help test the feasibility of the proposed Landcover BRDF Typology and to assess the Australian Structural Typology using simple and detailed models.

INTRODUCTION

A range of earth observation research activities in CSIRO (Australia) are promoted and coordinated through a unit called the CSIRO Earth Observation Centre (EOC, see http://www.eoc.csiro.au). The EOC has been formed to coordinate CSIRO Earth Observation activities in generic science. It is developing and supporting activities aimed at establishing coordinated validation missions and calibration and validation sites in Australia to develop long term high quality data and well characterised land surface parameters. The sites provide potential validation for a range of products of satellite global measurements programs.

CSIRO earth observation scientists engage in a number of related research and applications oriented projects involving land surface reflectance anisotropy. These particularly involve the issue of scene brightness, or BRDF (Bidirectional Reflectance Distribution Function or variation in scene radiance with sun and look position) effects. An underlying themes of the work is to test/establish the existence of a stable underlying "typology" of BRDF directly attributable to land surface spectral and structural parameters that will allow sensible selections of the "shape functions" used in correction and inversion algorithms. This requires the existence and use of well established field sites and a range of measurements other than radiometer data. There now exist established sites and there are important canopy and land cover missions planned in the future which may provide more of this type of data.

BRDF related activity in CSIRO EOC Research involves:

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- Data Normalisation (AVHRR, Scanners, Videos, Air Photos, calibrations Sites, Panels)
- Atmospheric Correction (AVHRR, Scanners)
- Determining Landcover Structure (Photography, Scanners) and
- BRDF characterisation.

Landcover Structure is known to be a major factor in the BRDF shape and the magnitude of its variation with sun and look angle. The opportunity to use BRDF to establish and/or monitor landcover structure is a major Research and Development task. However, there are a number of areas where scene brightness R&D already operational and this paper is primarily concerned with them.

DATA NORMALISATION & ATMOSPHERIC CORRECTION

Data Normalisation & Atmospheric Correction activities are aimed at achieving “seamless” mosaicking of video & scanner data as well as normalisation and standardisation of satellite data - especially AVHRR and future environmental satellite data. In the case of satellite applications, calibration sites must have their BRDF characterised and in a lesser scale activity it is clear that field panels used for reflectance measurements must also be carefully characterised (EOC Discussion Paper, 1996). One pragmatic objective is to produce base series of data that users now happy to use image processing (such as filtering and classification) and are familiar with Spot and Landsat can use with impunity. This has not been true of airborne data nor AVHRR data in the past.

In current work of this kind around the world, there is an acceptance of the key role of the ‘Kernel Function’ approach for which many applications are near operational. In the kernel function approach, the land surface brightness variation is modelled statistically by a class of simple functions. Advanced examples of this is the AMBRALS model (which is really a set of kernels of choice) being applied for the MODIS BRDF product (Strahler *et al*., 1995; Wanner *et al*., 1995) and the RPV model being applied to the MISR BRDF product (Rahman *et al*., 1993).

One outcome of the rising understanding of and capacity to model BRDF in the last 10 to 15 years has been the wider acceptance and recognition of its crucial role in atmospheric correction. The kernels approach has provided a tool for BRDF to be introduced into standard atmospheric models which leaves us to consider what kernels are needed to deal with the land surfaces we are interested in?

VIDEO DATA

Video data are used for low cost environmental monitoring. Such monitoring requires consistent & standardised information. However, a great deal of cost has been added to video data to try and achieve this consistency in the face of the BRDF and atmospheric effects which compound calibration and instrument problems. The extensive hotspot & BRDF effects are a *major* problem for central perspective sensors like videos and cameras (even digital ones). Reducing this added cost is an important *commercial* objective.

Australian Groups who have used empirical methods with video data are the Perth Minesite Rehabilitation group (Ong *et al*., 1995) and the Alice Springs rangelands group (Pickup et al., 1995). The Alice Springs work involves a variant on the kernel function approach applied to images averaged along a run. The model is then used to balance the brightness variations in the individual frames. The Perth Minesite Rehabilitation group have been working to overcome spatial and angular variation by an innovative use of a base image with little or no brightness variation - in their case a Landsat image.

At CSIRO Mathematical & Information Science (CMIS), work is in progress to statistically analyse video images against known kernels using robust statistical methods. The objective for the video data producer is (low cost) seamless mosaics approximating reflectance. However, there are a number of research questions. For example, “Are there a few universally representative functions? Do they change with land cover”? Since the archive of video data may supply their own answer to these questions, it has been decided to explore them with the range of existing kernels.

CAL_VAL SITES

Calibration Sites [& Reflectance Panels!] need BRDF Models if they are to be successfully used with satellite (or even airborne) data. An Australian high reflectance calibration and aerosols site at Tinga Tingana in northern South Australia has been modelled by Denis O'Brien and Ross Mitchell at CSIRO Division of Atmospheric Research (DAR) using a kernel model due to Staylor and Suttles (1986) as discussed in Cosnefroy *et al*. (1996).

At Tinga Tingana, the high reflectance and temporal consistency of the target meant BRDF dominated the AVHRR variation as the sun and view angles changed over a one-year period. Validation Sites also need good BRDF Models. Fred Prata (also from DAR) is characterising sites at Uardry near Hay in NSW and Amburla near Alice Springs this year using innovative ground and tower based measurements. These efforts are part of a network of validation sites characterisation and a new site in the north of Australia is planned to be established this year.

At many Validation sites modelled so far around the world, simple kernel functions seem sufficient. However, for more complex land surfaces, atmospheric & BRDF effects will need to be separated and it is not clear whether and how consistent results will be obtained. Questions which arise in this activity are:

- Can all corrections be done with simple functions?
- If not, are there a few simple "forms" for specific Landcover types (i.e. is there a "Typology" of Landcover BRDF and associated kernels)?
- How do you separate Atmospheric & BRDF effects?

These questions are crucial since it is one thing to characterise the relatively simple land surface of a calibration sites, a bit harder for a validation site and possibly very difficult for a general land surface. They are also very pertinent at a time when people are keen to establish a consistent and standardised set of environmental data series. Such series of AVHRR, Landsat and other data that are coming on-line (even airborne data) can be dominated by BRDF effects.

NDVI COMPOSITING AND CONSISTENT AVHRR DATA TIME SERIES

In particular, there has been a very useful discussion recently concerning AVHRR NDVI data. These data are a primary long term data series that many people wish to use for environmental monitoring or environmental reporting. However, producers and users in Australia (Richard Smith, WASTAC, DOLA, WA) are understandably worried by the greening of deserts in winter. Li *et al*. (1996) have shown that the scene brightness can account for up to 30% of the variation *of NDVI* for some land covers. They have since established the effectiveness of simple kernel models for reducing this effect - but the problem is land cover dependent.

Following on from this work, Qi *et al*. (1996) and Qi and Kerr (1997) have discussed how scene brightness corrections using kernels should interact with Maximum Value NDVI compositing and atmospheric correction. Basically, they concluded the best choice of method is to correct for "BRDF" first, then composit and finally atmospheric correct. The reason for this is that the BRDF effect increases the NDVI which leads to problems with the compositing. Essentially, the compositing (selecting pixel with maximum NDVI over a period) was introduced to select against cloud and edge pixels since these tend to have reduced NDVI. The resulting selected pixel from the compositing period supplies the Maximum Value NDVI. However, since atmospheric correction alone *increases* the BRDF effect, it makes the compositing result worse and results in pixels from the edges or with greater sun/look variations become the selected pixels.

It seems that any attempt to provide consistent and standardised AVHRR data - especially for environmental monitoring - *must* account for BRDF and should *not* be atmospherically corrected without account of BRDF.

There is little doubt of the value or need for scene brightness correction in areas as diverse as AVHRR NDVI and video data mosaicking. In each case, however, we still have a fundamental issue of whether there is a consistent and simple typology of BRDF? In particular:

- Is there a consistent Typology of BRDF which relates to land cover structure?
- Is it representable by simple BRDF (eg Kernel) functions that can provide consistency & standards?
- can remote sensing consistently monitor changes in the coefficients of the functions or/or changes in functional form?
- Do the changes recorded key in to significant structural changes in the surface cover?

The last point raises the land cover structure question.

LANDCOVER & STRUCTURE

Landcover Structure concerns vertical & horizontal spatial variation of components of the vegetation - or the ‘gappiness’ of canopies. It is a key element in the ecology of a landscape and a key element in fluxes of water, heat & carbon. Both in models of the ecology and the remote sensing, biomass is not enough! Landcover derived from spectral data is dominated by cover. However, it is the spatial distribution, gappiness & variance of canopies that is needed for monitoring major system changes.

To study scene brightness and structure in forests, CSIRO has also spent effort on obtaining airborne and field data in the past. For example, low and medium wide angle aerial photography was collected at a well measured site at Goonoo near Dubbo in NSW. The experiments used 120 degree aerial photography with an anti-vignetting filter which allowed assessment of models rather than instrument characteristics. The Li-Strahler model with two spectral components fitted well. At high resolution, variance dominated the BRDF ‘Mean’ signal. This scene variance is important and often dominates a single frame requiring frame stacking to average.

To overcome the high spatial variance in the photography, Daedalus Data were also flown for Goonoo. By flying into or at 90° to the sun it was possible to sense in or across the principal plane. By taking along scan averages of up to 1000 lines, a common sun-sensor geometry was achieved for each scan line and each average. The SWIR and Thermal provided good reference BRDF channels for modelling as they were not affected by atmosphere.

Since then, photography and scanner data of this type, as well as video & AVHRR are all being collated and documented to help test the feasibility of the proposed Landcover BRDF Typology and to assess the Australian Structural Typology using simple and detailed models. The capacity and potential for these studies to help with validation and interpretation of the global products that will come on-line in the near future is a prime opportunity and one of particular interest to the CSIRO EOC.

SEARCH FOR A STRUCTURAL TYPOLOGY

The search for consistency among photography, video data, scanner data and even AVHRR data is being pursued in a project being undertaken by CSIRO Information & Mathematical Sciences. The pilot for this work used data from the Daedalus Goonoo flights with the following results:

The data for Goonoo State Forest were collected by a Daedalus or DATM scanner (DATM stands for Daedalus Advanced Thematic Mapper scanner) for CSIRO DWR as a test for the Li-Strahler model. Unfortunately, there was a problem with the blue, green and red bands so the models were originally tested using the SWIR (Short wave Infra Red, DATM bands 9 and 10) (see Figure 1) and Thermal band (DATM band 11). However, this was no major problem as the model being tested assumed no atmospheric effects and no multiple scattering. The objective was to see if the geo-optical model was correct in the unadorned cases. The atmospheric effects in the SWIR and thermal are very small and do not contribute significantly to the directional signature. Also, in the SWIR and thermal the simple model with no multiple scattering was quite good. This is particularly so as both vegetation and shadows are respectively very dark and cool in these bands and have high contrast (at least at Goonoo in summer) with the sunlit background.

All of the models listed in Jupp and Strahler (1996) from Strahler *et al*. (1995) have been fitted for the current pilot study. In addition, the model due to Staylor and Suttles (1986) as discussed in Cosnefroy *et al*. (1996) has been fitted. This has had some favour with POLDER people and atmospheric people. It was the kernel used by CSIRO scientists (Denis O'Brien and Ross Mitchell) to correct the Tinga Tingana data and should obviously therefore be included as a candidate in the testing.

The kernels are the "AMBRALS" set consisting of singly or combined models developed as described in Roujean *et al*. (1992) and Wanner *et al*. (1995) called:

- Ross Thin
- Ross Thick
- Roujean
- Li Sparse
- Li Dense
- Walthall

The NIR band(s) (see Figure 2) can also be used for kernel fitting and have been so. They were not originally used as the model being tested at Goonoo did not compute multiple scattering in the canopy. The SWIR and Thermal provided ideal tests for the simple models and the multiple scattering present in the NIR is such that the Ross and Li-dense models should be much more useful than the simple Li-sparse which fits the SWIR Goonoo data very well. The main point is that these data are for the same landscape for which field work had established that it was relatively low cover of trees with established structural properties.

The results of the testing in the SWIR and NIR are summarised as follows (they are ordered by increasing NSR which is explained below):

Short Wave Infra Red Data for Goonoo							
Page	**Model**	**k0**	**k1**	**k2**	**SE**	**R^2**	**NSR**
E	Li_Sp	177.2658	47.35126	0	4.936181	0.96135	0.53023
F	R_Thin+Li_Sp	182.3403	-24.989	49.96207	4.021908	0.97436	0.606878
E	R_thick+Li_Sp	185.8543	-114.387	56.59068	4.092269	0.973455	0.617782
I	Staylor & Suttles	-352.131	-94.546	2225.06	10.25693	0.833239	1.18344
C	Roujean	173.1894	138.8606	0	10.43852	0.827161	1.208809
D	R_Thn+Rouj	168.2913	54.29317	136.8691	7.854958	0.902198	1.231747
C	R_thick+Rouj	163.9187	181.4008	103.9104	8.051075	0.897253	1.265975
H	R_thin+Li_Dens	221.0022	-96.1096	93.78764	8.39515	0.888284	1.326726

G	Li_Dens	188.122	68.27081	0	12.33672	0.758586	1.491802
B	Walthall	135.3267	-83.1465	56.03012	11.84039	0.777776	1.999712
C	R_Thick	129.2309	412.113	0	15.22707	0.632213	2.016965
G	R_thick+Li_Dens	181.0995	63.55604	59.79771	12.25507	0.761937	2.091149
D	R_Thin	114.9428	62.73437	0	23.81444	0.100411	7.915239

The statistics should be obvious except for the “NSR”. The NSR or Noise to Signal Ratio is defined as:

$$NSR = \frac{100}{\sqrt{F}}$$

$$F = \frac{R^2}{1-R^2}\frac{M-p}{p}$$

where F is the usual F-Ratio with M as the number of data values, p as the number of parameters and this is used to apply the NSR criterion. The NSR criterion is an heuristic in which the model with minimum NSR is the best and/or most parsimonious model.

It seems that for the SWIR data, Li Sparse wins hands down possibly with the Ross Thin added (Figure 3). This is good as it is the one which fits this case from the physical point of view! There are some surprises (such as the changes in sign if the Ross Thin or Ross thick kernels are added to the Li Sparse) but it is early days in this testing yet. The next set of tests used the NIR DATM and in the future some models with and without atmospheres as well as video data will be tested in this way.

Near Infra-red Data for Goonoo							
Page	**Model**	**k0**	**k1**	**k2**	**SE**	**R^2**	**NSR**
H	R_thin+Li_Dens	147.079	47.78977	29.26081	3.502321	0.94246	0.924381
G	Li_Dens	163.4284	41.94886	0	5.698611	0.84756	1.12149
F	R_Thin+Li_Sp	131.0527	75.13833	12.64905	5.030711	0.881283	1.373089
I	Staylor & Suttles	-198.333	-2.83037	1028.496	6.778957	0.784433	1.386745
G	R_thick+Li_Dens	159.7873	32.95353	37.55559	5.650526	0.850227	1.570175
D	R_Thin	113.9895	97.34751	0	7.784933	0.715508	1.667475
C	R_Thick	127.2115	251.8626	0	8.01025	0.698802	1.736124
D	R_Thn+Rouj	124.4304	95.69547	26.78684	6.42441	0.806392	1.833102
C	R_thick+Rouj	116.577	322.5939	-31.8567	6.963711	0.772523	2.030073
B	Walthall	117.6883	19.75226	38.71823	7.818818	0.713227	2.372214
E	R_thick+Li_Sp	127.8383	246.0352	0.626357	8.011406	0.698926	2.455387
E	Li_Sp	146.3111	20.49936	0	9.972013	0.533206	2.47427
C	Roujean	133.0636	30.29701	0	13.71882	0.116527	7.281399

This time, there has been a big change. The Li Dense and Li-x plus Ross Thin (Figure 4) are the best choices. Note that these fits are for the same landcover. So it appears that we have an issue here. What do the different models mean? If it is the same land surface, why is there not one model?

We must face the fact that the two bands we have chosen resulted in such different kernels. To get a Li Dense in one case and a Li Sparse in the other when we know the forest is relatively sparse and structurally identical is somewhat confusing. How can we make sense of such a result when the objective is not just to fit data but to interpret the results in terms of the land cover? To try and overcome this, We also fitted the models with Li Sparse (which with its shape parameters at 2.0 matches the structure we know from associated field data, models and both DATM and photographic data) and the Walthall model. The reason for this was that the Walthall model could be seen as the tool to model the (symmetric) multiple scattering leaving the Li Sparse to fit the hotspot. The results are summarised as follows (noting that there is now an extra parameter making it a four parameter model):

Li Sparse + Walthall Fits for Goonoo								
Data	Model	k0	k1	k2	k3	SE	R^2	NSR
NIR	Li_Sparse + Walthall	149.066	69.573	-4.8834	33.5135	2.51117	0.97044	0.799953
SWIR	Li_Sparse + Walthall	182.4694	-8.2947	-9.4779	50.3514	4.05396	0.973968	0.749344

The model provides a good fit in the NIR and the model is also competitive with the previous Li dense fit. The differences between the cases are simply noise fitting I suspect. There are some effects in these data such as the fact that the Principal Plane and 90 to PP data were not flown exactly together nor perfectly in those directions. The result, however, is very satisfying in that the structure component is identical and the differences are due to the multiple scattering.

The resulting plots are shown as Figures 5 and 6. In addition, Figures 7 and 8 show what happens if you separate the fitted components due to the Walthall and Li Sparse kernels. It is clear that the Walthall model takes out a symmetric bowl shaped variation very like what is expected from the multiple scattering in the canopy. In the SWIR case it is effectively flat and not present. This final result shows that it *is* possible to use the 'same' structural model in more than one band - at least at Goonoo for this one case. Much more needs to be done to get a generally consistent result.

From this simple pilot study, it has been decided to develop a much more extensive study involving a wide range of data (including data sets from video systems, airborne scanners, Polder, ATSR and AVHRR) and analytic tools which is now underway at CSIRO. For example, the testing methodology now also involves using Ridge and eigenvalue Analysis to examine correlations between the kernels and the effects this introduces. This study will be reported and its findings may help in the development of a "global" BRDF Typology in the future.

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Norm Campbell's group in Perth, especially Harri Kiiveri, Fiona Evans and Suzanne Furby have developed a systematic testing process of from which the results quoted here form a small part. Fred Prata, Denis O'Brien and Ross Mitchell have supplied data, knowledge and activity for this EOC Thread activity as have Vanessa Chewings, Peter Hick and Cindy Ong from their extensive holdings of video data of many land covers and many sun and view angles.

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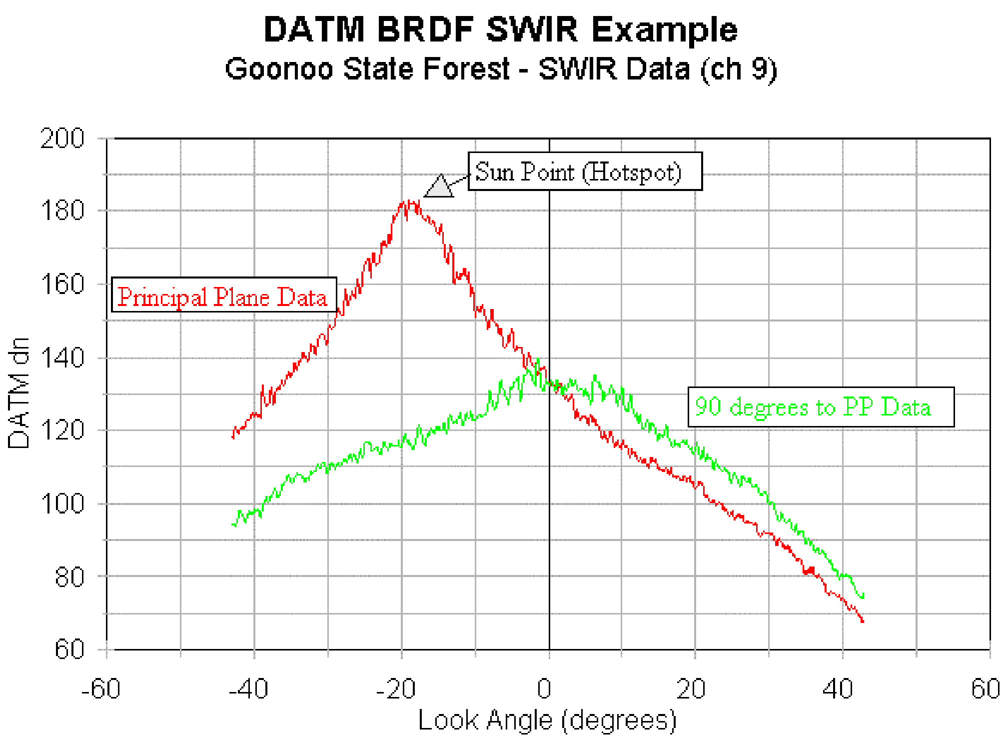
DATM BRDF SWIR Example
Goonoo State Forest - SWIR Data (ch 9)
Sun Point (Hotspot)
Principal Plane Data
90 degrees to PP Data
DATM dn
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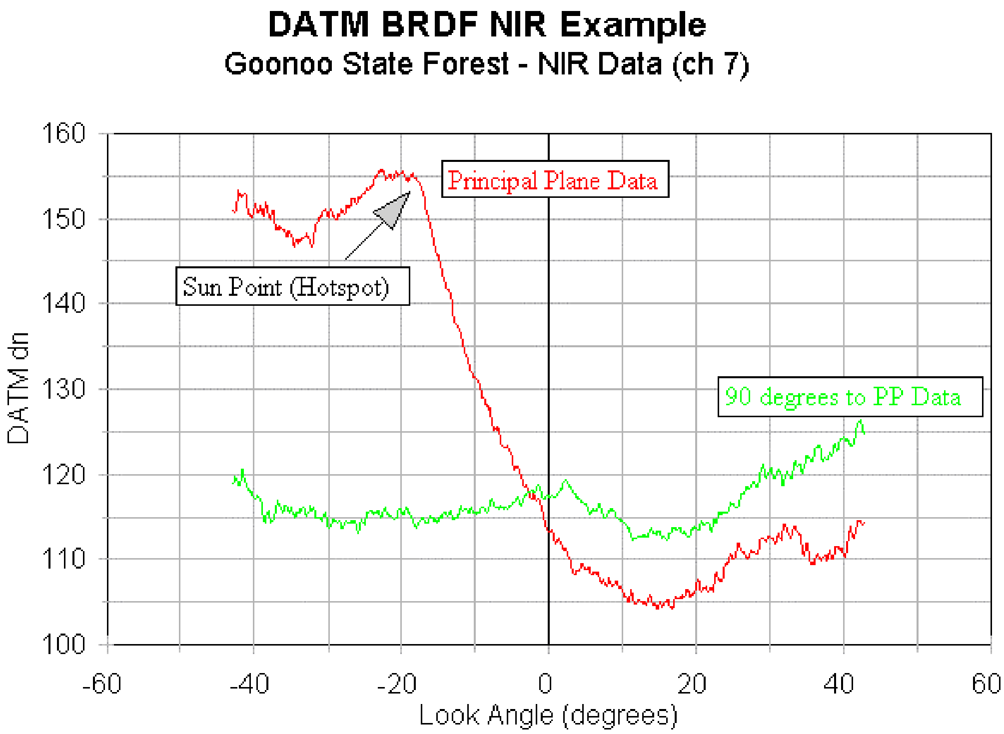
DATM BRDF NIR Example
Goonoo State Forest - NIR Data (ch 7)
Principal Plane Data
Sun Point (Hotspot)
90 degrees to PP Data
DATM dn
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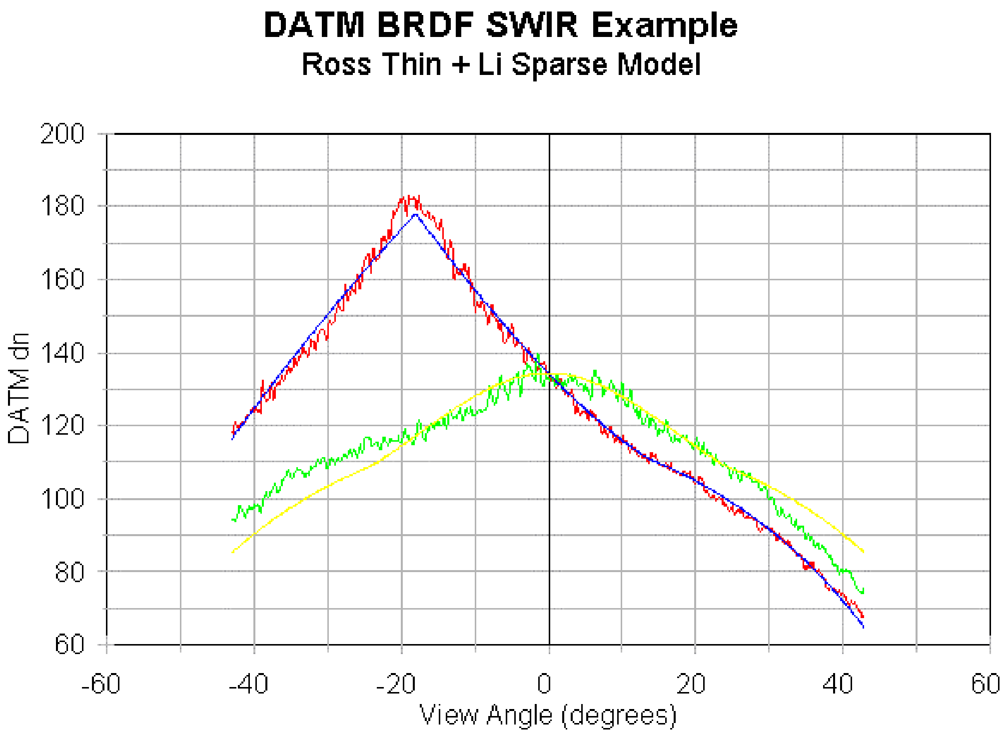
DATM BRDF SWIR Example
Ross Thin + Li Sparse Model
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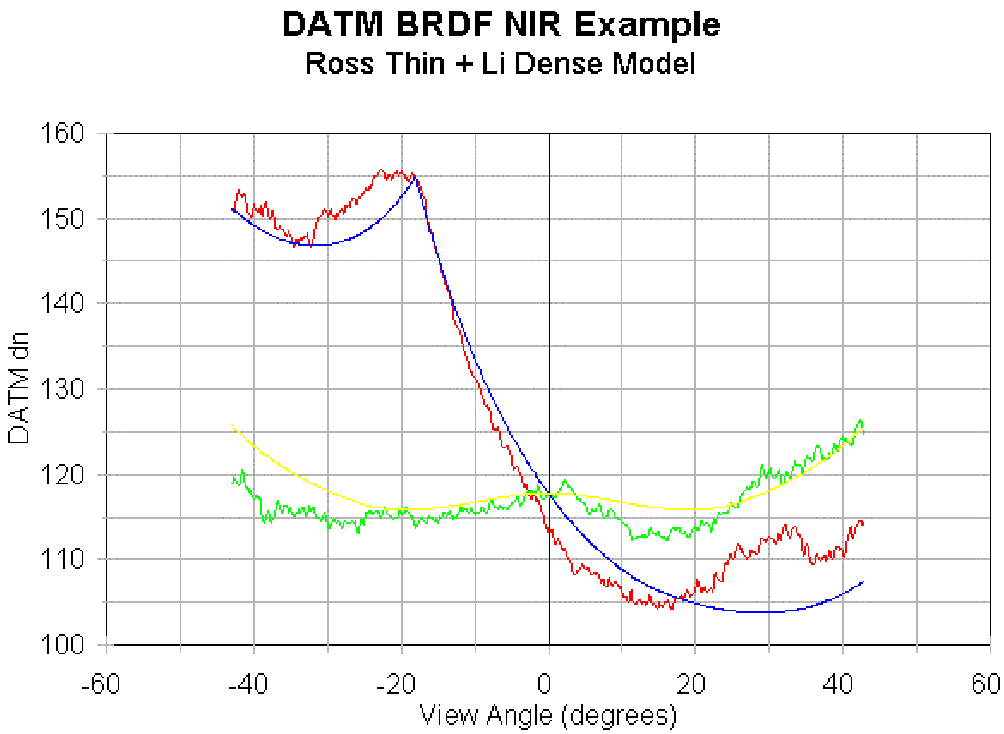
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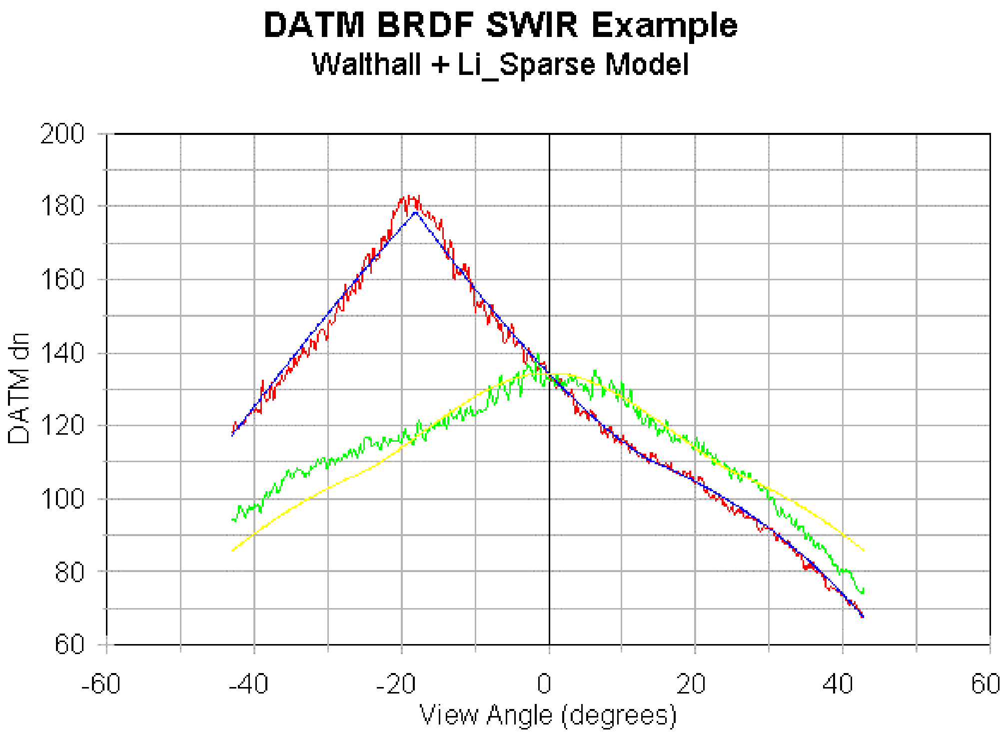
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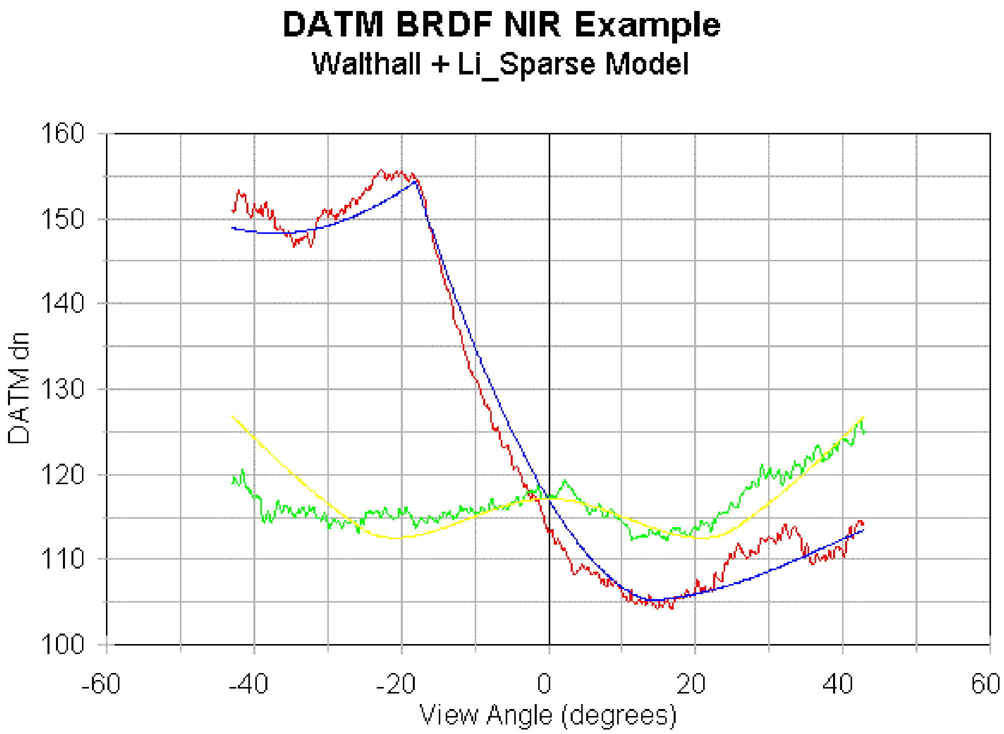
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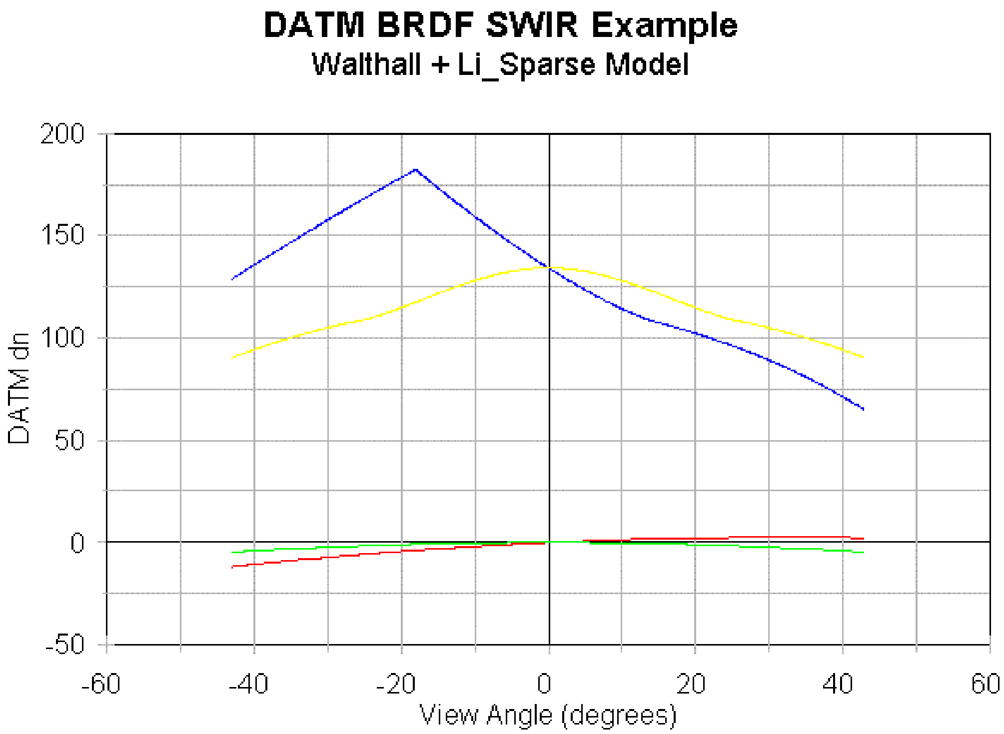
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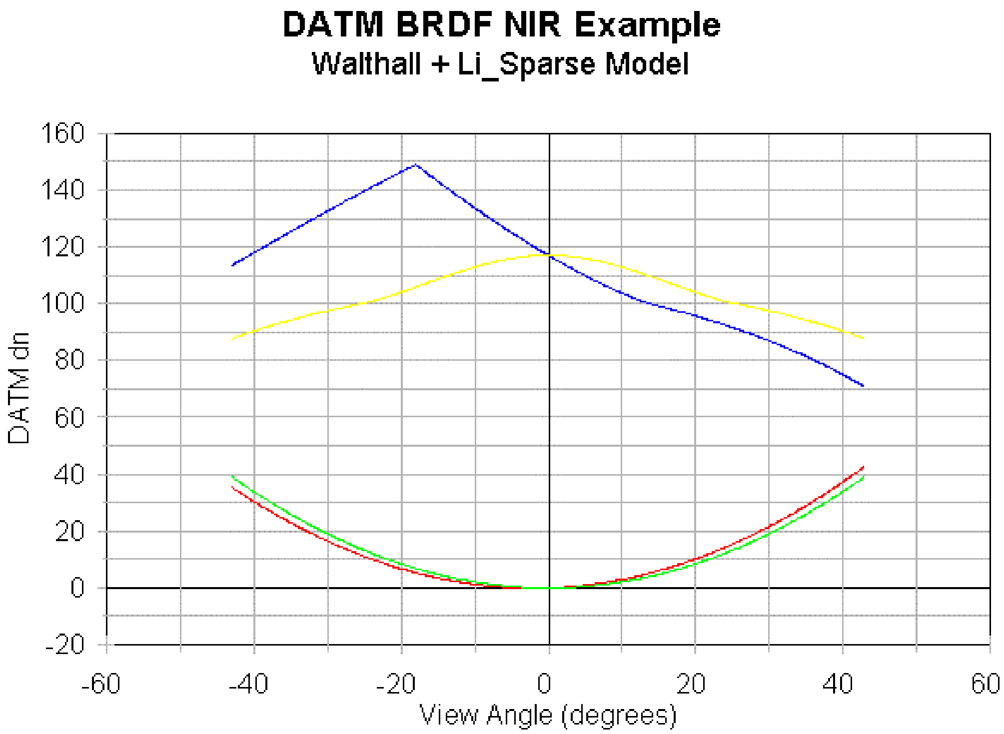
60
View Angle (degrees)


DATM BRDF NIR Example
Walthall + Li_Sparse Model
160
140
120
100
80
60
40
20
0
-20
DATM dn
-60
-40
-20
0
20
40
60
View Angle (degrees)