Polarisation of vegetation: what we know, what we don't know

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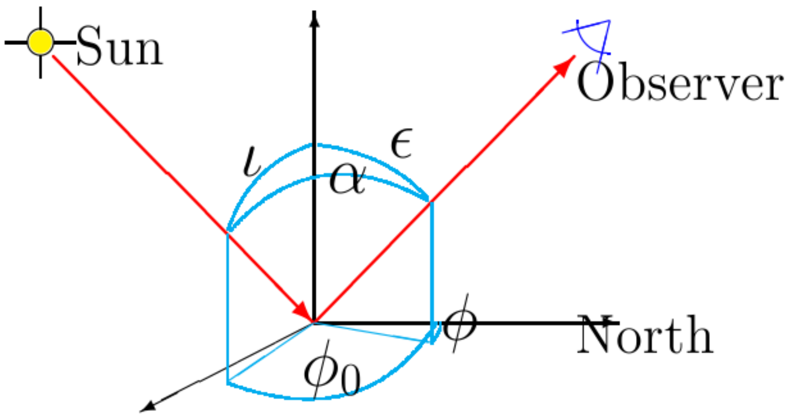
Background

- Polarisation interesting for astronomy and remote sensing
- More used for atmospheric and space applications, less for land surfaces (difficult, enough other sources)
- Large part of land surface remote sensing community totally unaware of polarisation, even physics in general
- Systematic reflectance and scattering measurements with polarisation all too rare
- Only part of observed polarisation features understood and modelled

Bidirectional reflectance factor (BRF)



- Observed reflectance depends on four angles
- R=I/I_Lambert (unidirectional collimated incidence)
- $I(\varepsilon,\Phi)=\cos\iota/\pi\ R(\varepsilon,\Phi,\iota,\Phi_0)\ F_0(\iota,\Phi_0)$
- To model polarisation, **I**=[I,Q,U,V] and **R**= 4*4 matrix
- Degree of linear polarisation I=-Q/I

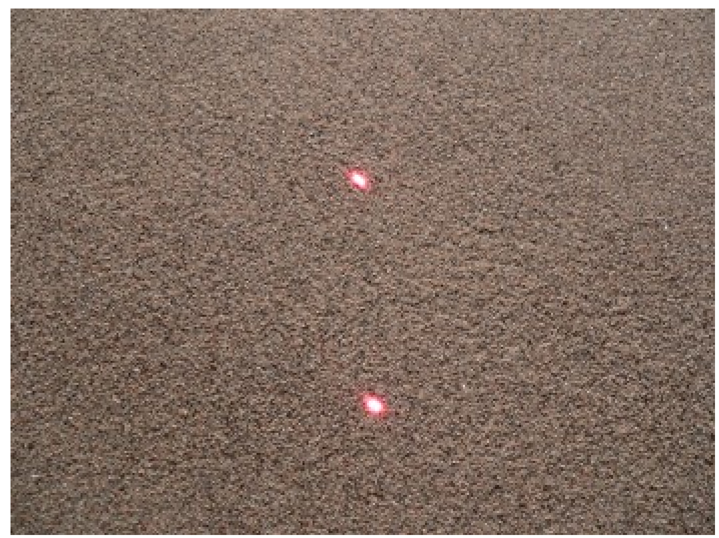
Theory

- Generally requires solving the single scattering with full polarisation, and 3 D RT with full polarisation.
  - But this is slow, and
  - We don't know enough to model even single scattering with full polarisation
- Often assumed, that
  - multiple scattering scrambles the polarisation directions, and is thus mostly unpolarised
  - most of polarisation comes from the single Fresnel reflection from leaf surface
- This explains the main features, but not perfectly
  - Quite often polarisation predictions completely wrong
  - Too few parameters
- Better models require hard electromagnetics,
  - Work in progress, e.g. SAEMPL project and many other model efforts

Measurements,
FIGIFIGO = Finnish Geodetic Institute Field Gonio-spectro-polari-radiometer

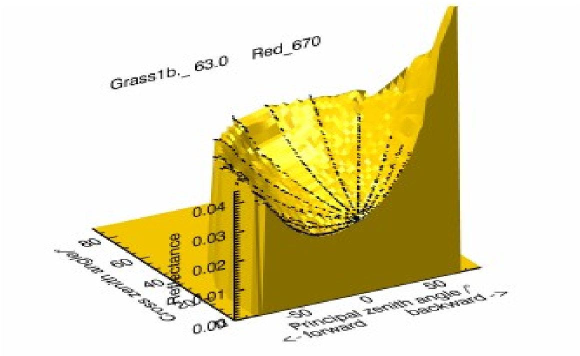
- 400-2400 nm
- Glan-Thomson polariser, full spectral range
- 3 Stokes parameters: I, Q, U
  - V under construction
- Full hemisphere
- Unpolarised illumination

How vegetation differs from non-vegetation,
Some examples, four cases: grass, lichen, snow, sand

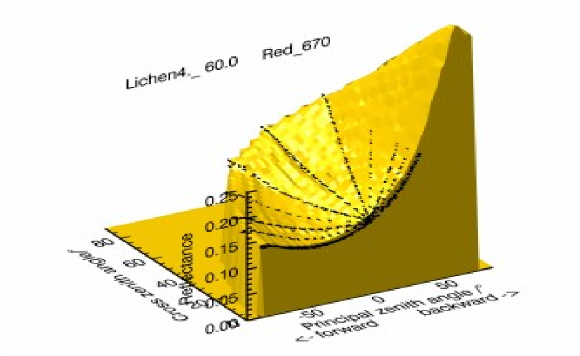


Reflectance (BRF) in 640 nm

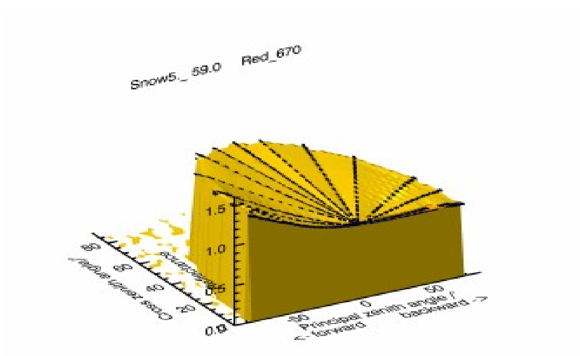
Grass



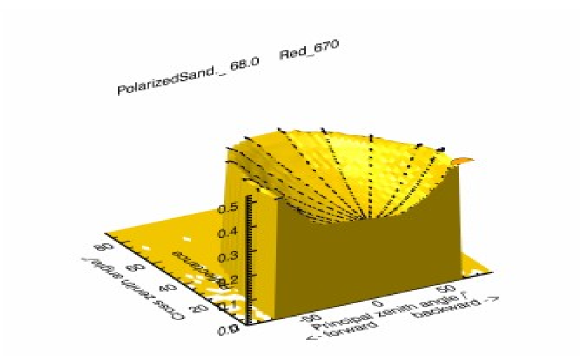
Lichen



Snow



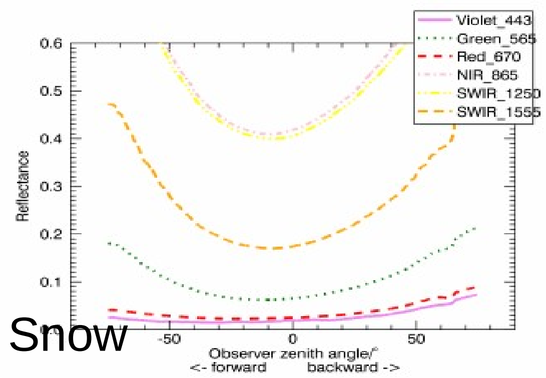
Sand



- Bowl shape, forward and backward scattering
-

Reflectance in the principal plane, six wavelengths

Grass



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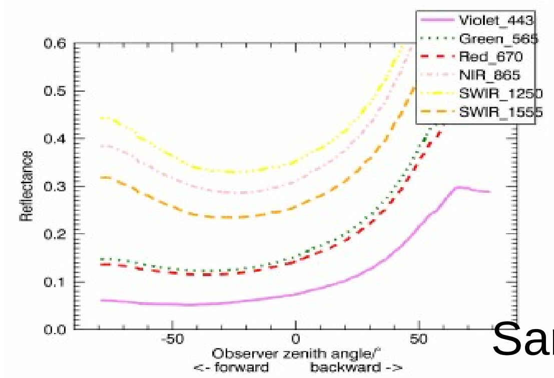
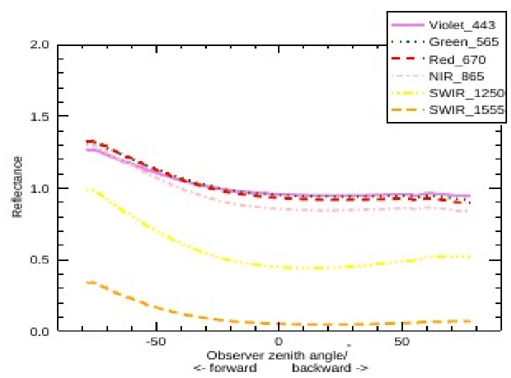


Snow



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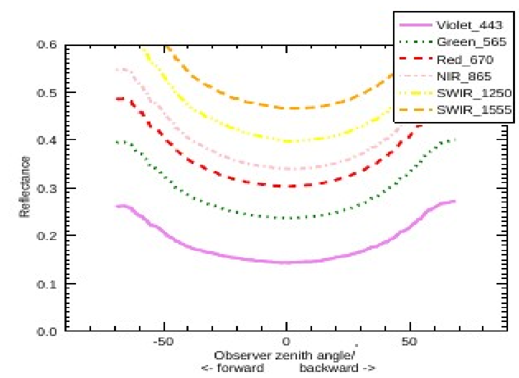
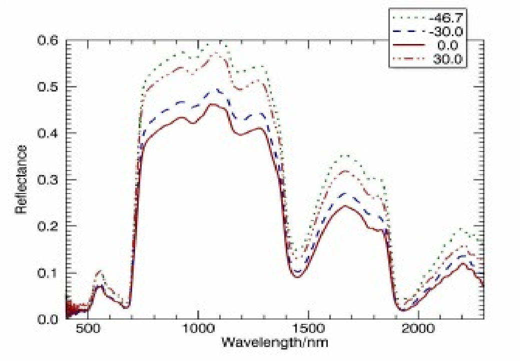


- More details visible
- Wavelengths differ, but most features remain
- Large differences between species, but hard to get invertible signals

Reflectance spectra, four direction in the principal plane, vegetation certainly differs from non-vegetation

Grass



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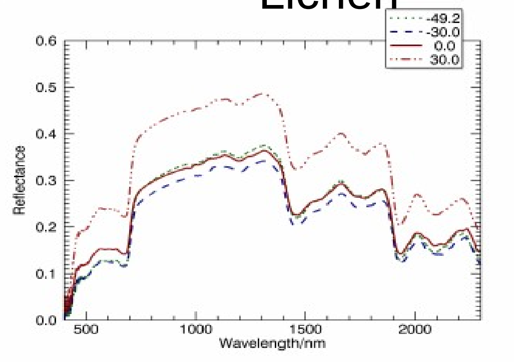

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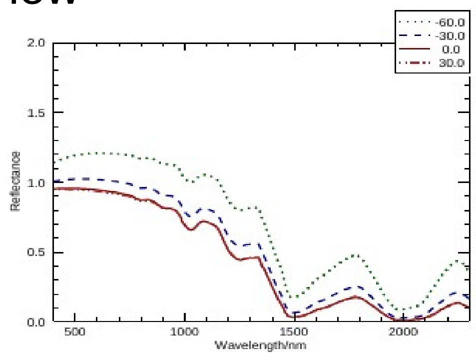

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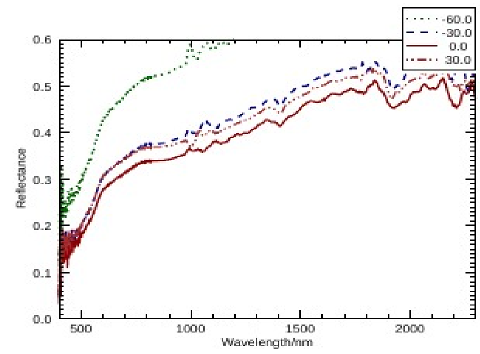
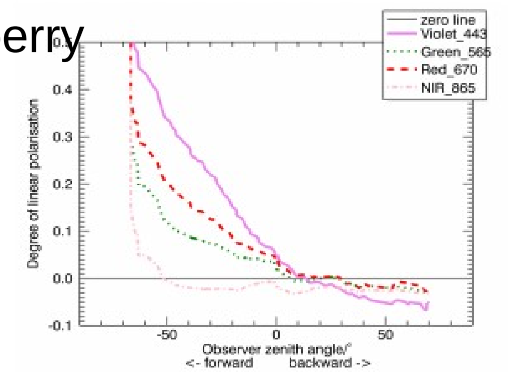


- Spectrum gives very strong signals
- Easy to identify vegetation, and even do basic classification
- Further subclassing and quantitative interpretation still challenging,

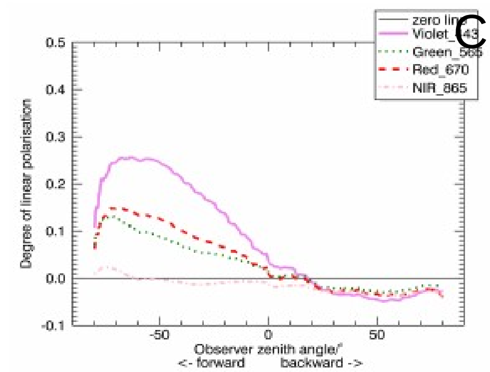
  (all vegetation quite similarily green, but lichen and some specialities)

The degree of linear polarisation (P=-Q/I=-R_21/R_11) in the principal plane,

Lingonberry

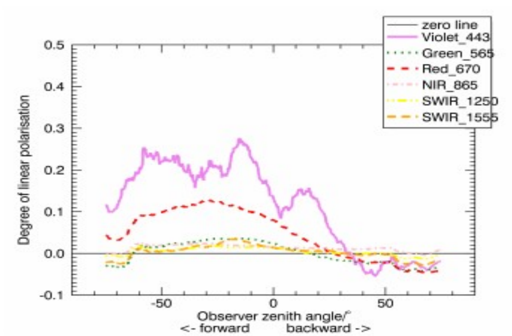


Crowberry

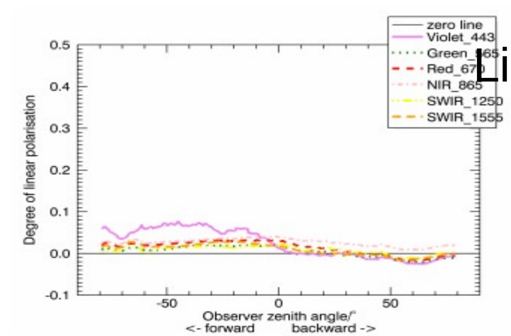


- Can be quite similar for many targets
- Some differences in polarisation maximum and minimum
- Wax covered leaves cause large forward polarisation
- Negative branch near backscattering
- Fluctuations large inside each type
- Not very good signal alone, but can in some cases give additional informaation
- (violet channel very noisy here)

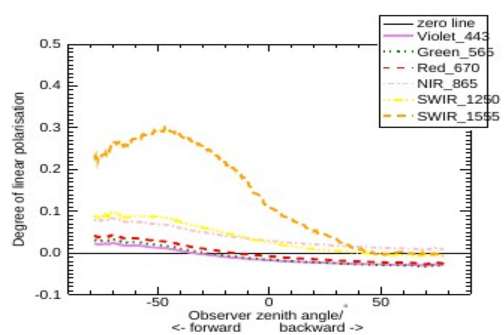
Grass



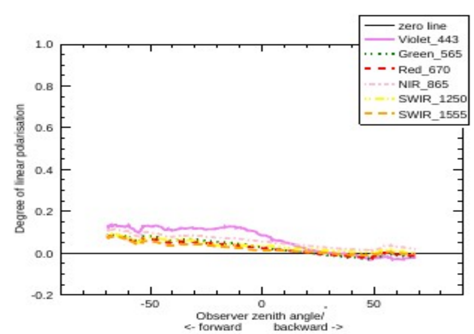
Lichen



Snow

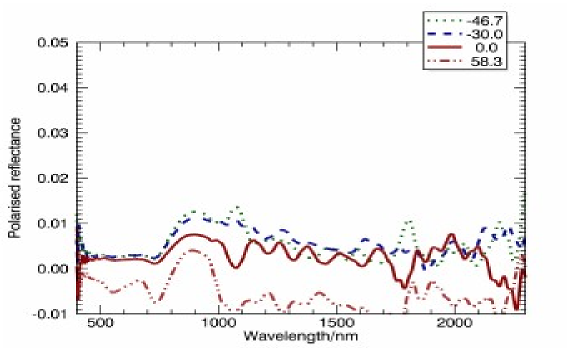


Sand



Polarised reflectance spectrum (R_21).
Spectrally R_21 is smoother than R_11, and follows similar patterns, but some new colour features are possible.
Forward Fresnel (flat part)+ something, backward non-Fresnel

Grass



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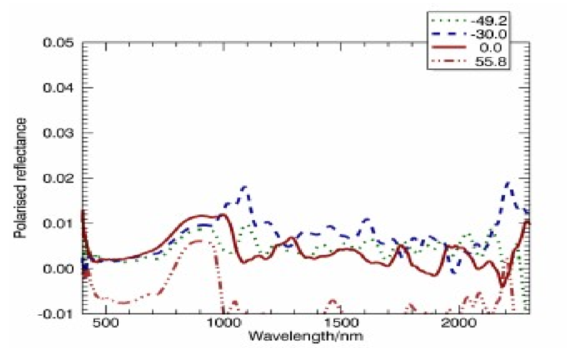

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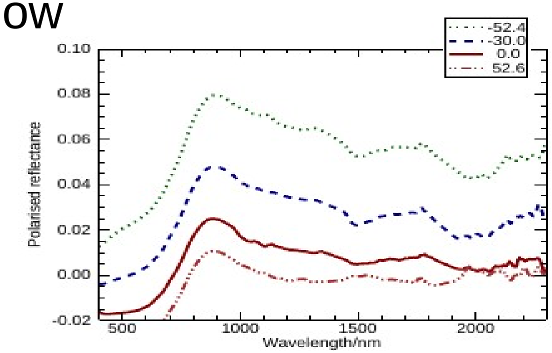
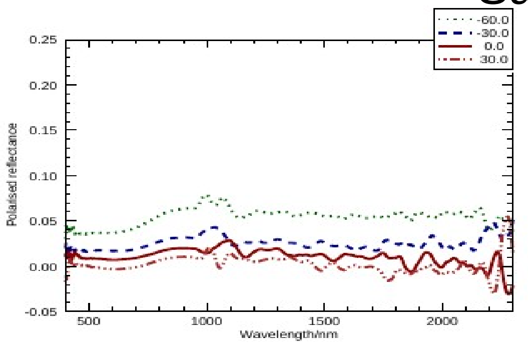


Sand



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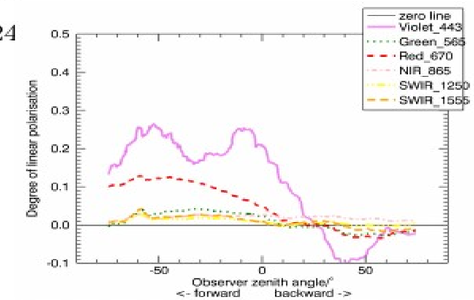
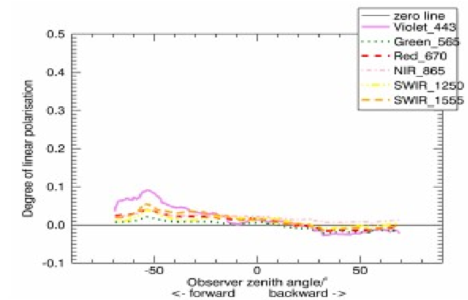
Polarisation signal is stronger when the Sun is lower.
Grass and lichen at two solar zenith angles:

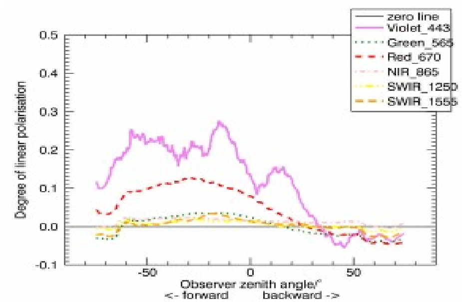
45°

24

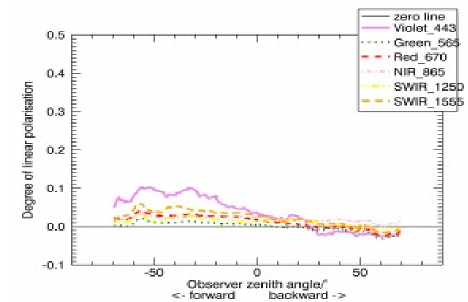




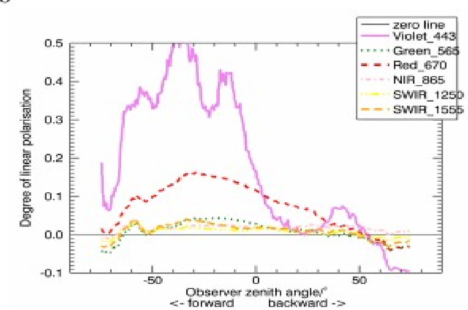
63°



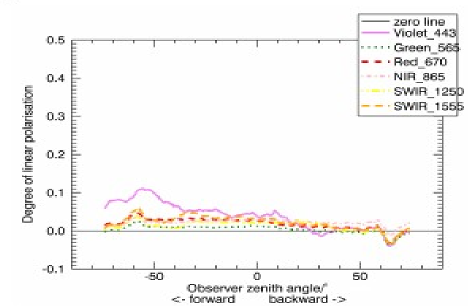
59°



70°



71°



What did we learn?

- Generally, spectrum is the best way to separate vegetation from non-vegetation, and identify some classes, but limited in further identification
- BRF shape, forward spike, backscattering, give some more signals, not as much as wanted
- Forward polarisation can further aid differentation
  - But alone less useful
- Backward polarisation needs more studies
- We don't understand the spectral behaviour enough

From other research

- Polarisation is sensitive to leaf orientation, useful in monitoring growing phase of e.g. wheat
- Tassels and flowers reduce forward polarisation
- Chlorophyll yields also some amount of circular polarisation
- But otherwise not too many promising ideas

Still don't know

- Some colour effects in forward polarisation
  - Maybe related to surface microstructure
- Polarisation maximum shifted from Brewster angle
  - Just measurement inaccuracy?
  - Multiple scattering?
- Negative backward polarisation
  - What could it tell?
- Actually, only very few samples measured, in uncomparable conditions, we don't really know very much to say anything strong

Some conclusions for polarisation remote sensing

- Observe forward scattering, 80-130 degrees phase angles
- High image rate to catch directional pattern and locate the maximum
- Low spectral resolution enough, 2-10 channels
- Measure, when Sun quite low, zenith angles > 60 degree
- Need clear and stable sky
- Don't rely on polarisation alone, but combine intelligently with spectrometry, goniometry, photogrammetry, lidars

Final conclusions

- Polarisation interesting topic, and can add something to vegetation remote sensing
- Much more modelling needed
  - 3D polarised RT
  - Electromagnetic scattering
  - Leaf structures
- More measurements
  - New samples
  - Systematic variations
  - More complete, all Stokes parameters, full Muller matrices
- Polarisation a good test bench for models