Measurement and Analysis of Bidirectional Reflectances

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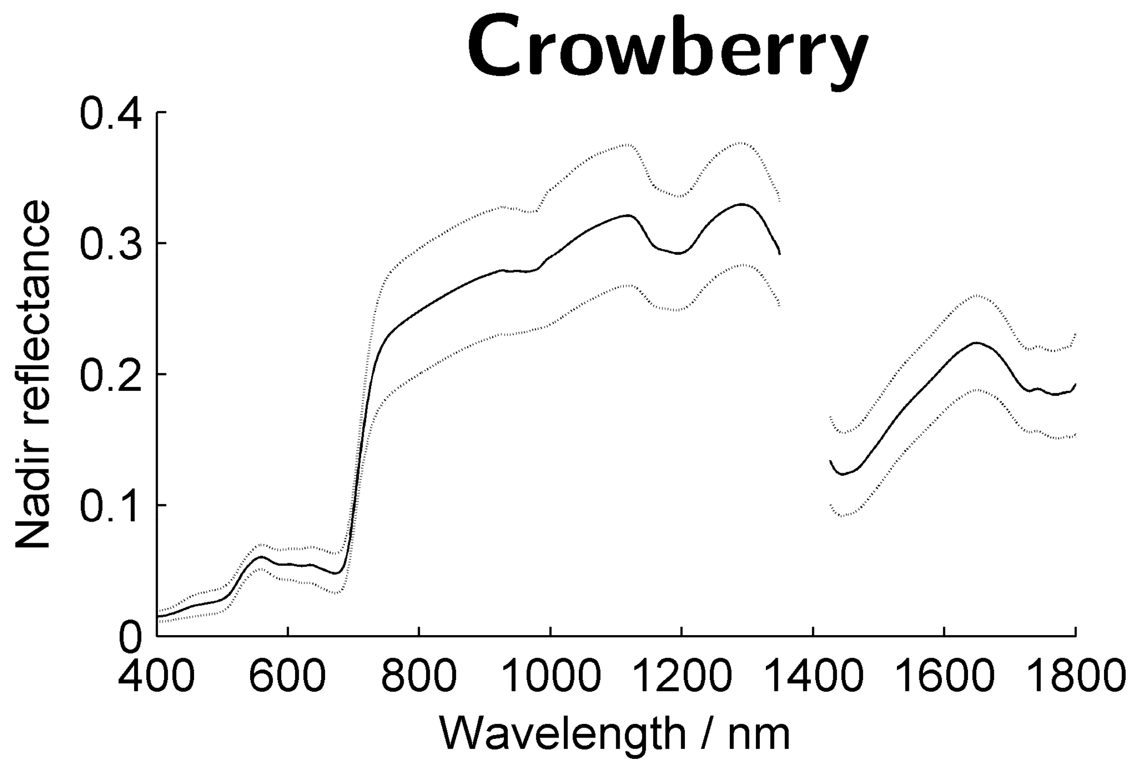
- Concepts
- Examples of anisotropic reflectance
- Measuring multiple view angle reflectances at field
- Airborne measurements

CONCEPTS

Reflectance factor

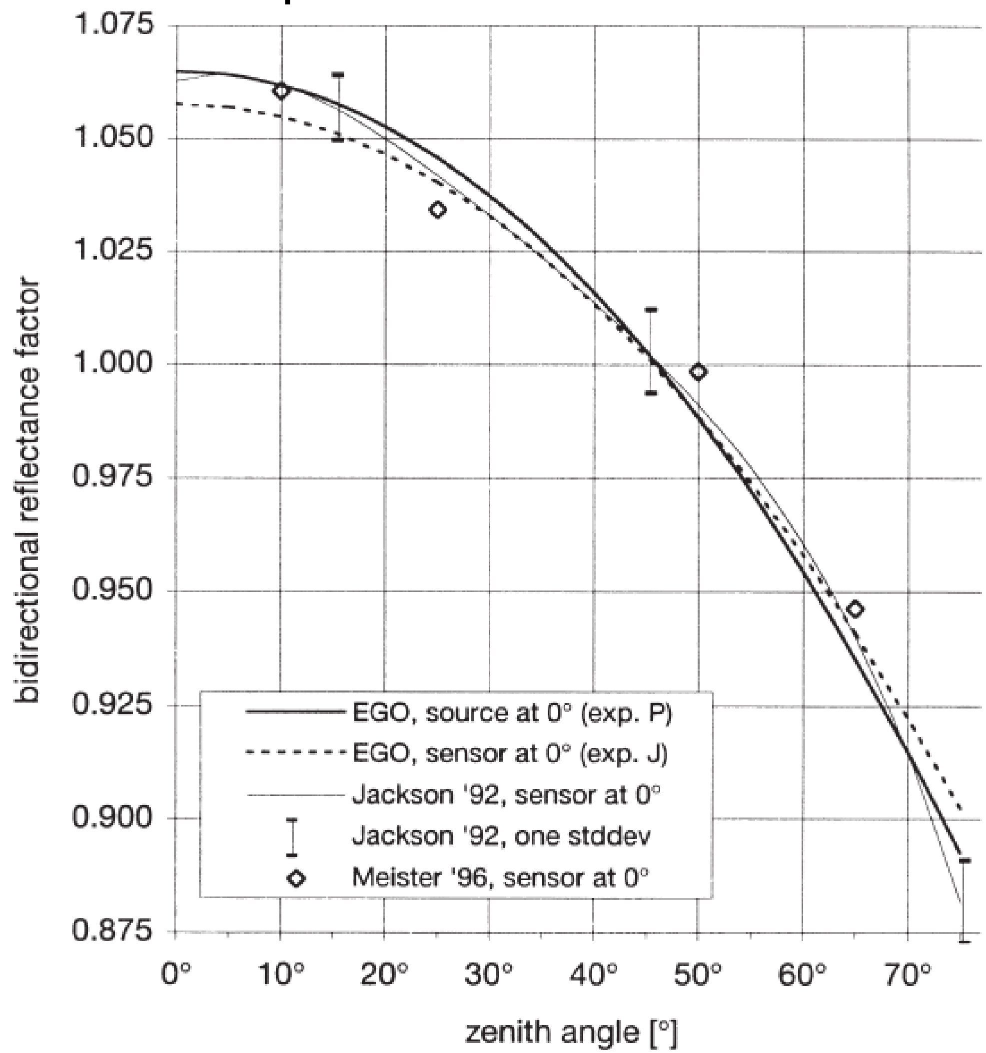
- Radiance from target divided by radiance from white matte (Lambertian) surface
  - 0 for black surface
  - 1 for white diffuse surface (Lambertian)
- The most typical reference material is Spectralon



Lambertian surfaces

- An ideal surface that
  - …is perfectly matte
  - …scatters same amount of light to all view directions
  - …is not affected by illumination direction
- Do not exist in real life!
  - All surfaces are more or less anisotropic scatterers
  - Not even Spectralon is Lambertian!

Spectralon @ 600 nm

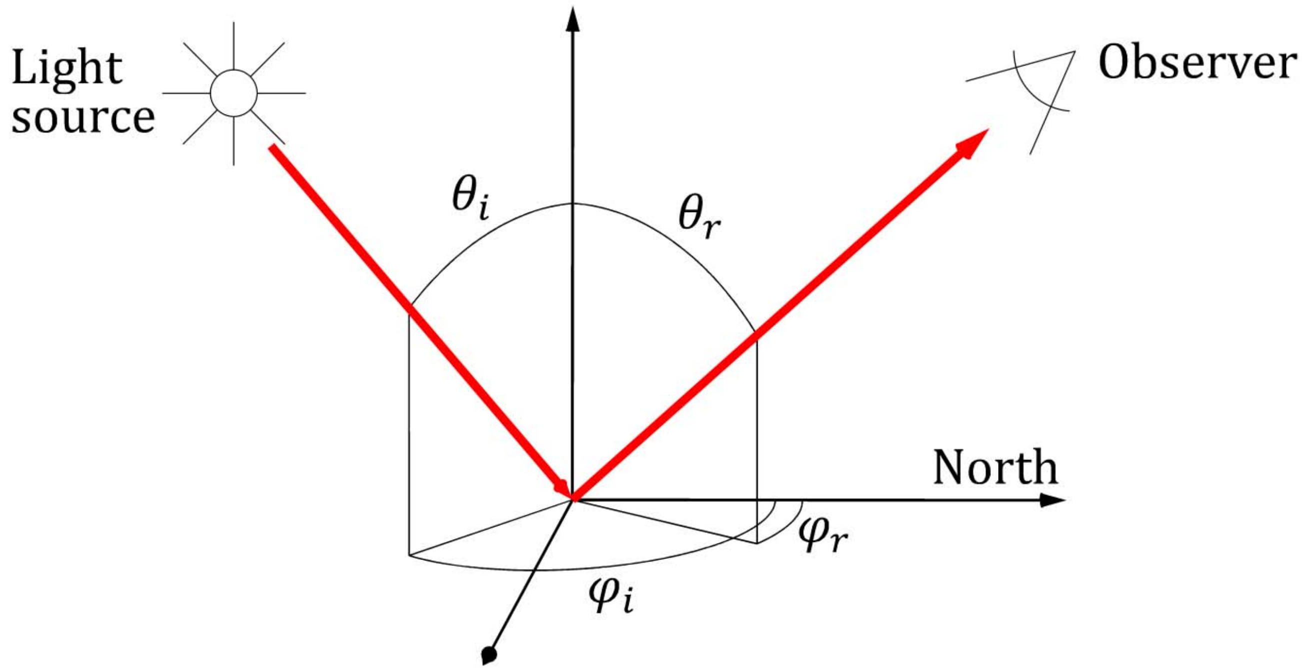


Sandmeier et al., RSE, 64,176-191 (1998)

Bidirectional Reflectance Factor

- Anisotropy of reflectance is described with concept Bidirectional Reflectance Factor (BRF)
- Bidirectional geometry is defined by illumination and view directions

θ zenith angle
φ azimuth angle



A bit more theoretical concept

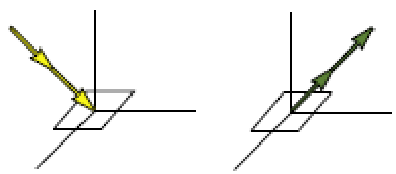
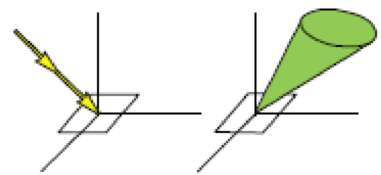
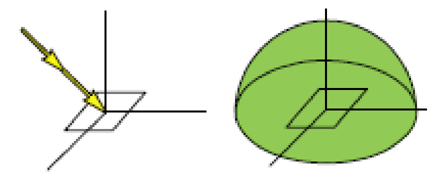
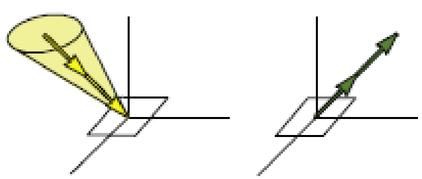
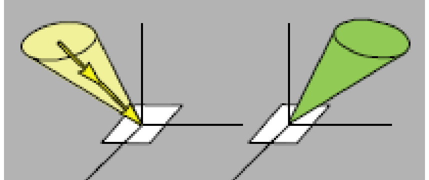
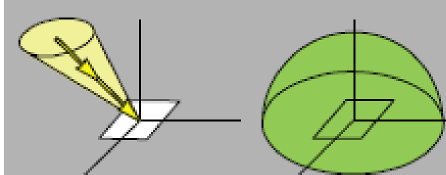
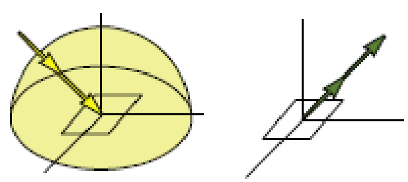
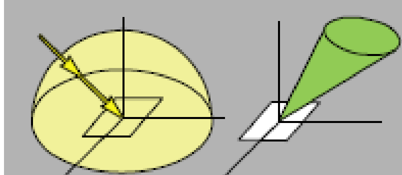
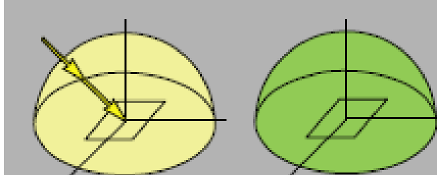
- BRDF == Bidirectional Reflectance Distribution function

$$BRF = \pi \cdot BRDF$$

- BRDF equals albedo if integrated over (hemi-)sphere
- Good for integrals in models, but usually not relevant for practical applications

Geometry is not always bidirectional

Relation of incoming and reflected radiance terminology used to describe reflectance quantities

Incoming/Reflected	Directional	Conical	Hemispherical
Directional	Bidirectional CASE 1 	Directional–conical CASE 2 	Directional–hemispherical CASE 3 
Conical	Conical–directional CASE 4 	Biconical CASE 5 	Conical–hemispherical CASE 6 
Hemispherical	Hemispherical–directional CASE 7 	Hemispherical–conical CASE 8 	Bihemispherical CASE 9 

G. Schaepman-Strub et al. / Remote Sensing of Environment 103 (2006) 27–42

Sunlight?

- Bidirectional (BRF) or biconical (BCRF) reflectance factor is a good approximation for laboratory measurements
- Sunlight is a combination of directional (or conical) and hemispherical illumination
- Sunlight reflectances are called usually HDRF, although they do not follow the definition exactly.

An easy diffuse correction

- Sunlit reflectances are HDRF by nature.
  If you need BRF you need to make a diffuse correction

$$HDRF = \frac{L^{\text{Target}}}{L^{\text{WR}}} \rho^{\text{WR}}$$

$$BRF = \frac{L^{\text{Target}} - L^{\text{Target}}_{\text{Diffuse}}}{L^{\text{WR}} - L^{\text{WR}}_{\text{Diffuse}}} \rho^{\text{WR}}$$

- Assumption: Reflected diffuse light is isotropic

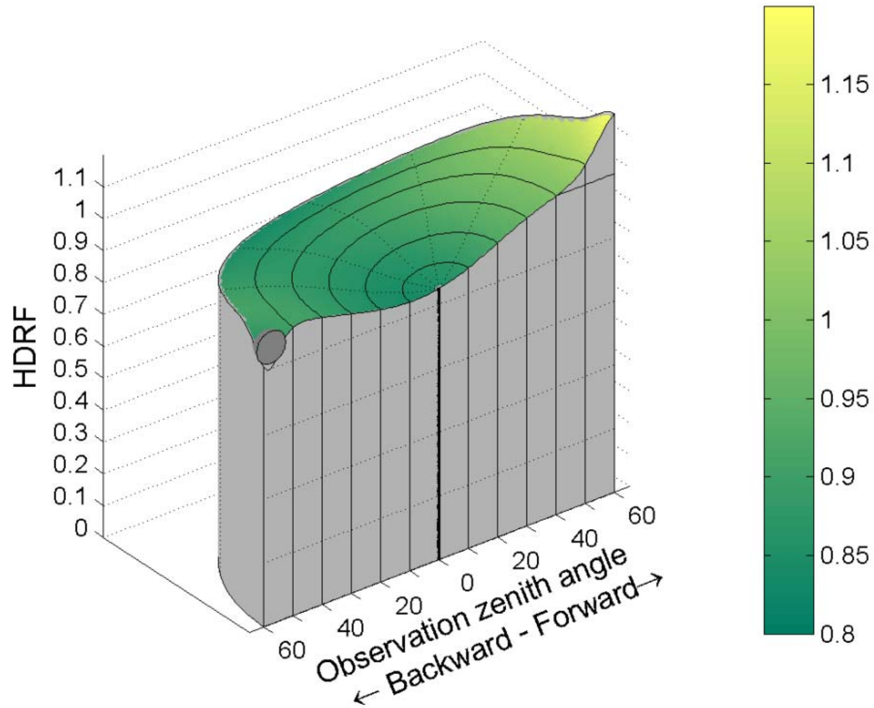
Concepts to remember

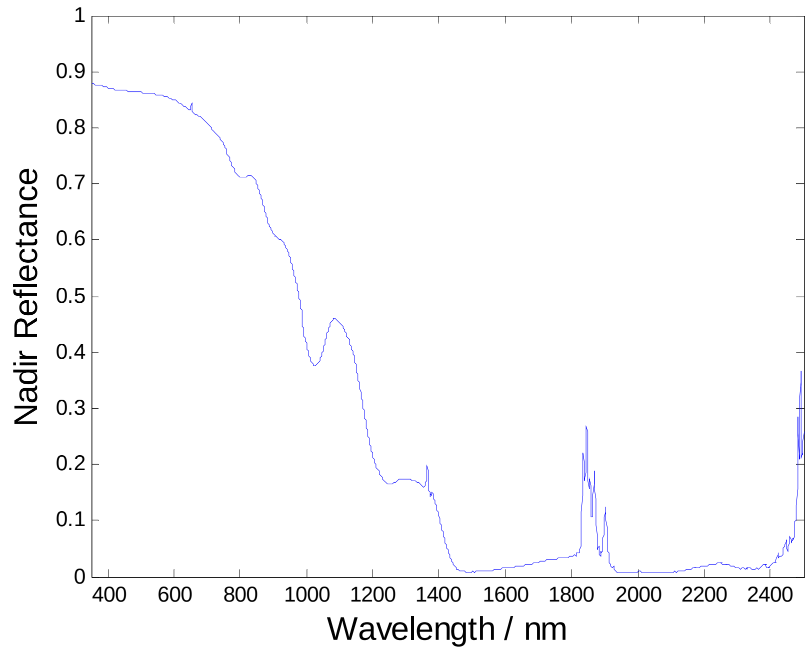
- BRF = Bidirectional Reflectance Factor
  - BRDF = BRF / π
- HDRF = Hemispherical Directional RF
  ≈ Sunlight reflectance factor
- Conical can usually be assumed to be same as directional
  - HCRFs of natural surfaces are rather linear in <10° resolution

EXAMPLES OF BRF / HDRF

Snow (Sodankylä)

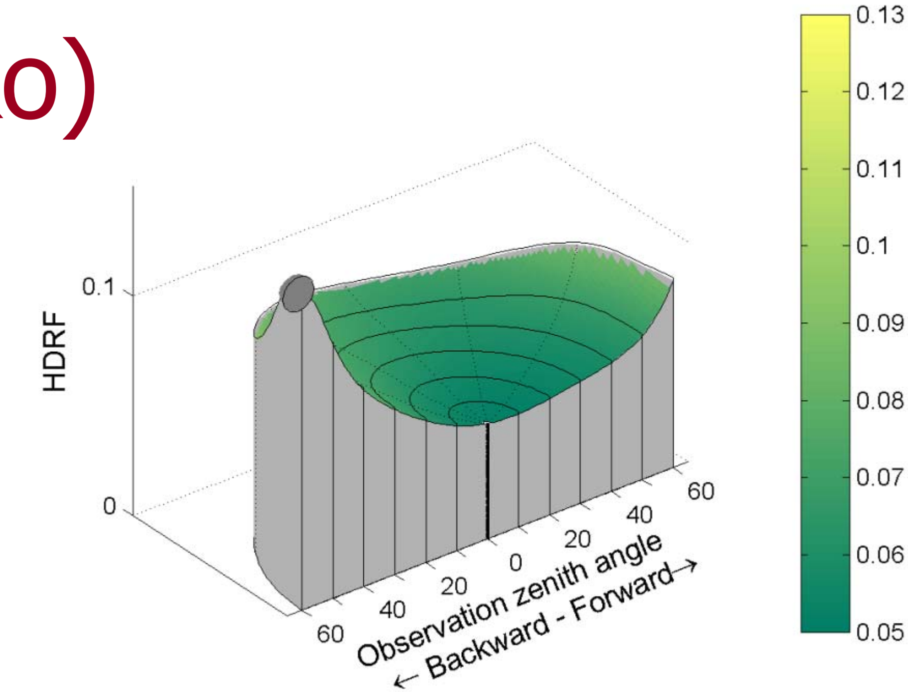
- Melting snow with wet surface layer
- Forward scatterer

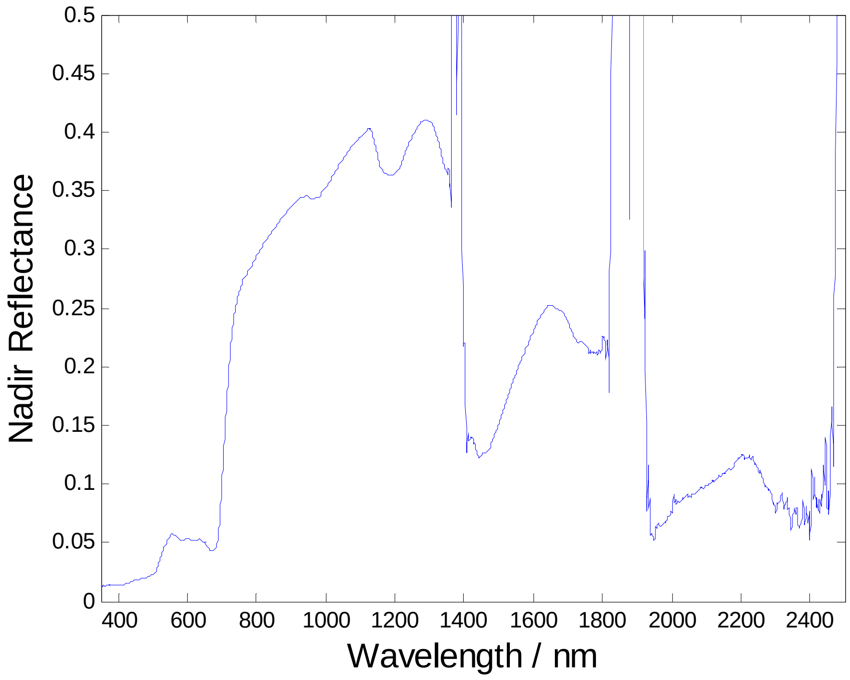




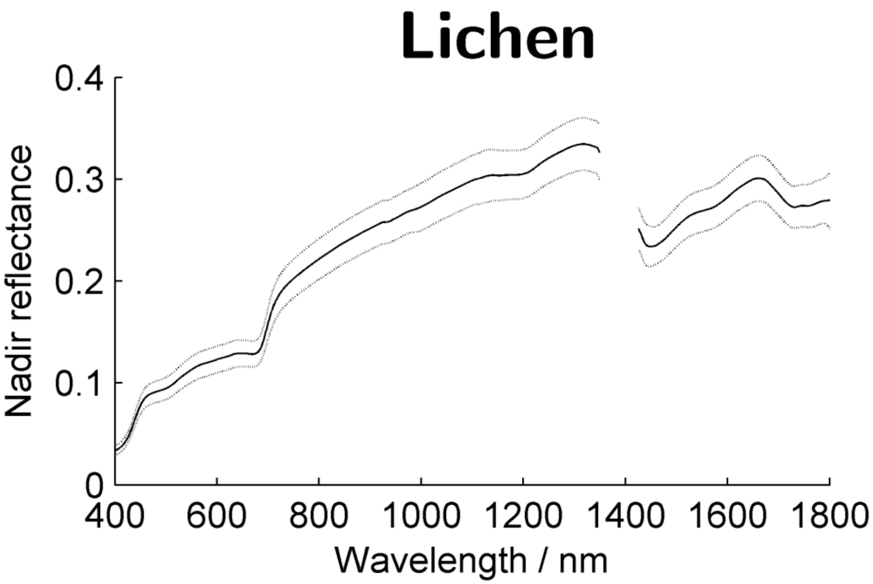
Dwarf birch (Abisko)

- A thick layer at the top of a mountain
- Concave shaped HDRF

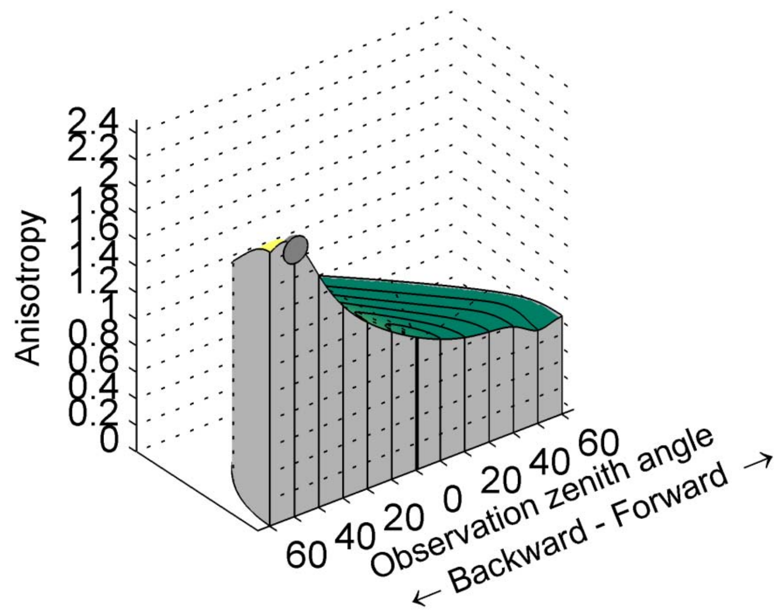




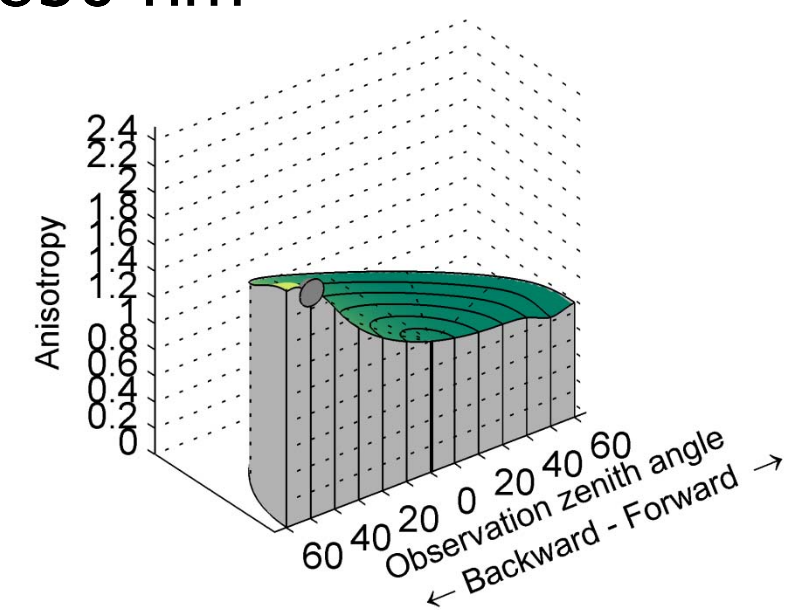
Lichen

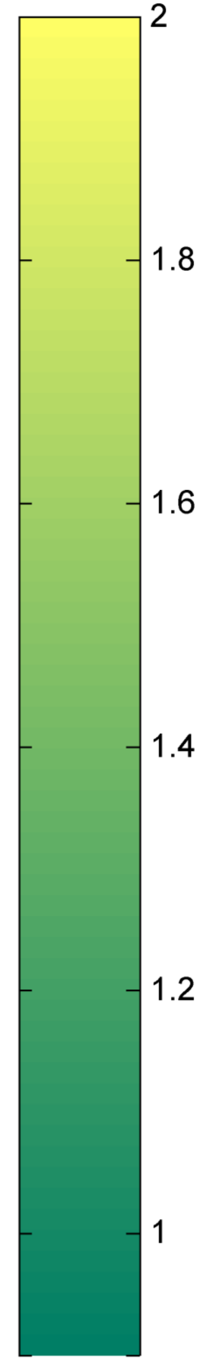


550 nm



850 nm



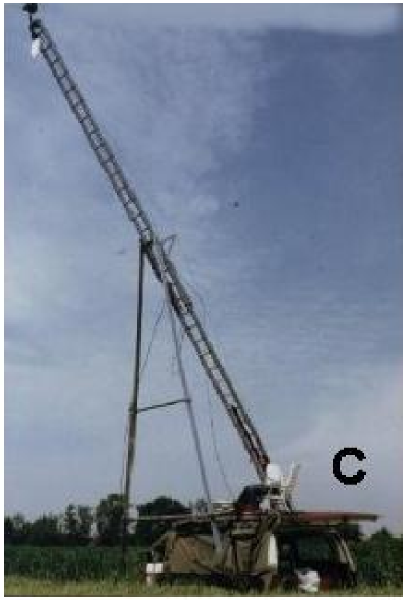


MEASURING BIDIRECTIONAL REFLECTANCE FACTOR

How to measure BRF?

- All reflectance factors have some illumination and view geometry
- The question is really: How to measure reflectance from multiple directions while registering of illumination and view geometry?
- Goniometer devices have been built to do the job

Some large scale goniometers



A. EGO
B. FIGOS
C. MUFSPEM
D. Sandmeier Field Goniometer
E. PARABOLA III

FGI goniometer model III

Model III goniometer

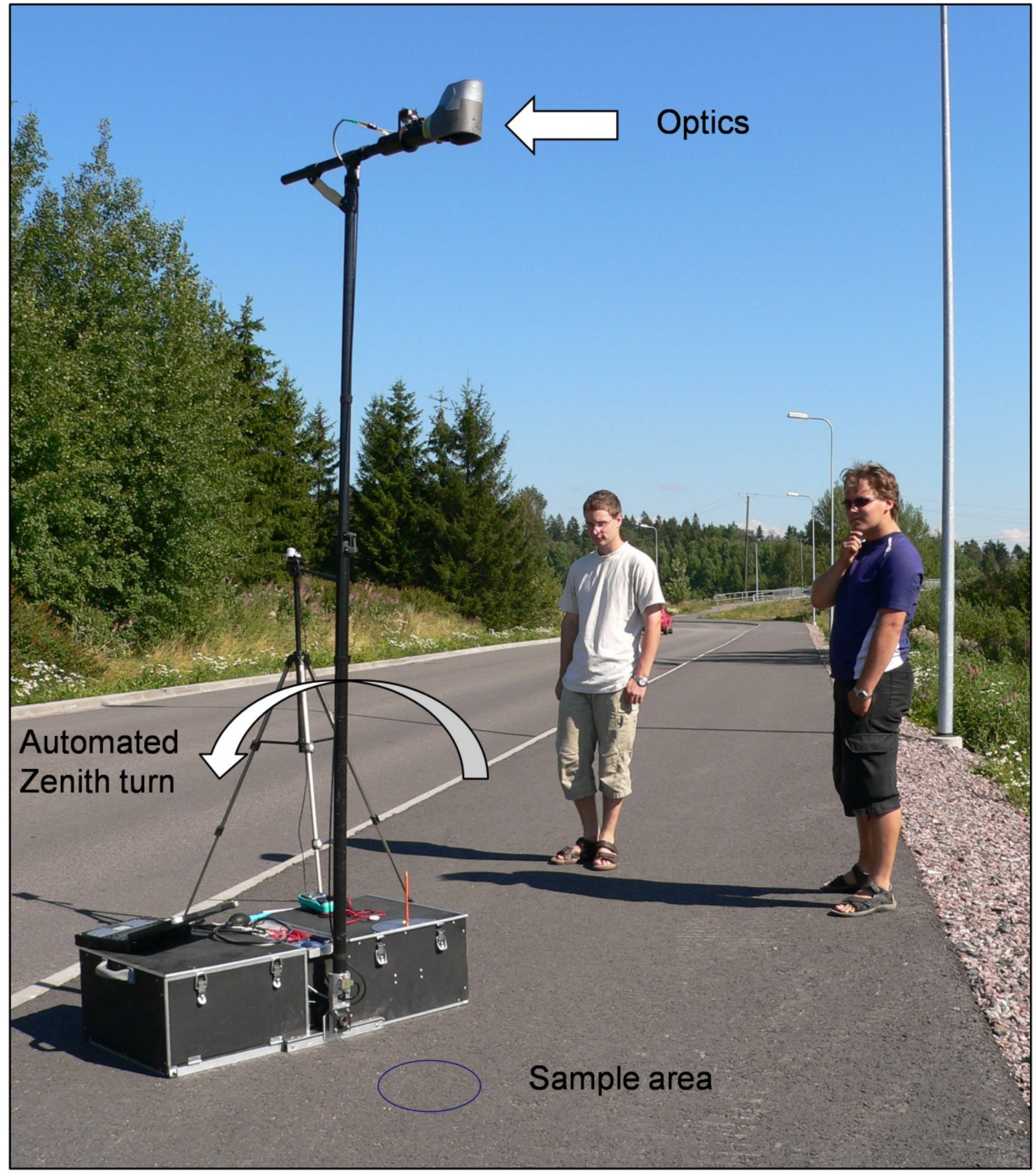
- A fine instrument, but…
  - Heavy
    - limited only to road access sites
  - Large
    - needed a trailer,
    - not suitable for rough ground
  - Manual use
    - slow
    - prone for human errors
  - Laboursome
    - 3 busy operators

FIGIFIGO

Finnish Geodetic Institute Field Goniospectrometer

FIGIFIGO Key features

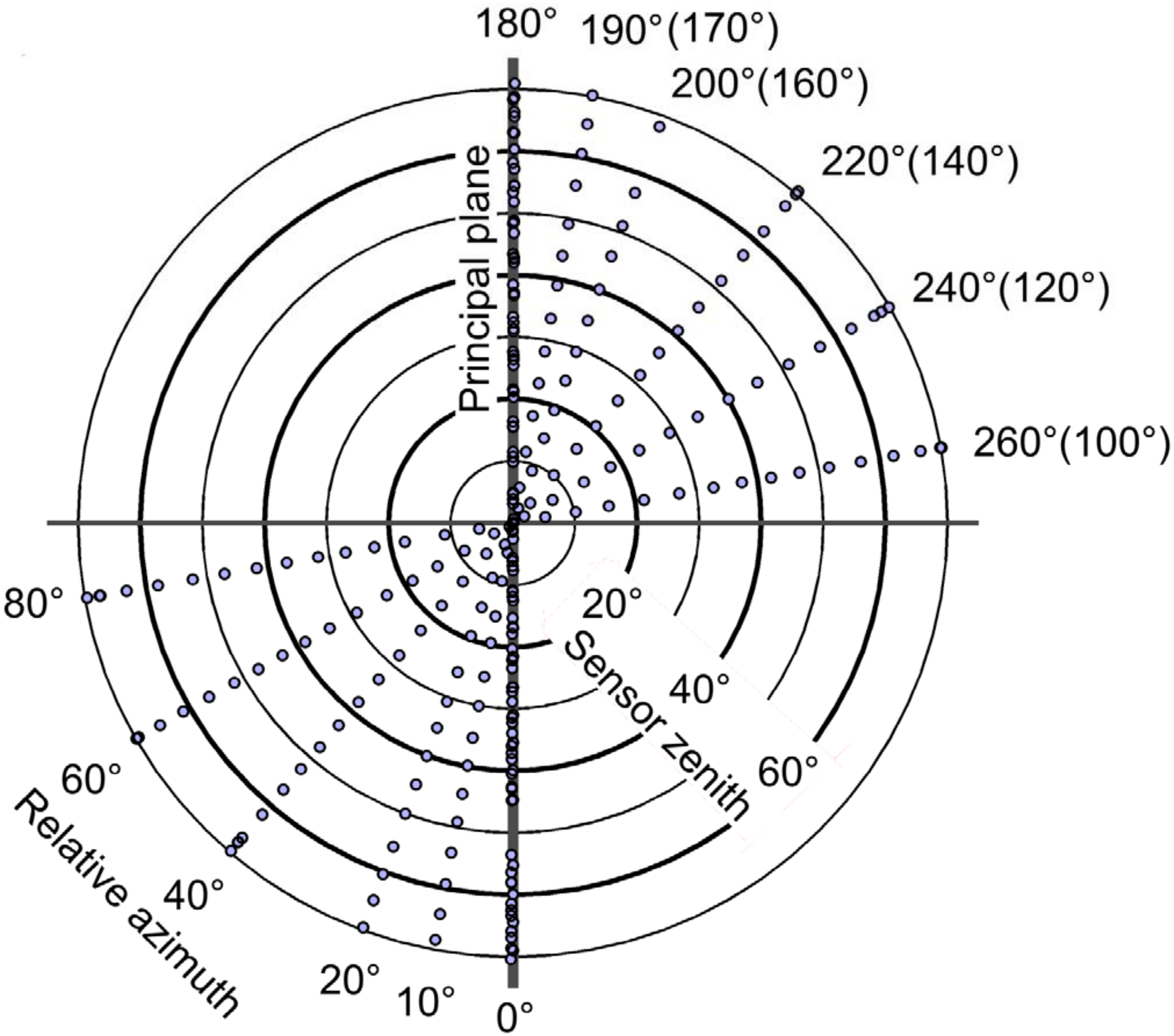
- Automated zenith turn
- Manual azimuth turn
- ASD FieldSpec Pro FR
  - 350-2500 nm
  - Changeable optics
  - Field of view 5-25 cm
- Option: Computer turned linearly polarizing optics



Portability

- Battery powered
- Quick to assemble
- 30 kg
- Fits inside an estate car
- A rugged control computer

Measurement plan



- A half hemisphere takes 10 minutes

Problem: How to determine view direction?

- In sunlight measurements it is necessary to determine goniometer orientation
- An electronic compass is a plausible solution, but accuracy is at best 2° and it is vulnerable to magnetic disturbances
- Dual-antenna GPS would be an ideal solution, but currently they are large and expensive

Answer: A hemi-spherical sky camera

- All the measurements are taken in direct sunlight
- Sun position can be calculated using GPS data
- A hemispherical sky camera is mounted on the goniometer body
- Sun is detected from the image and with assistance from an inclinometer the orientation is calculated.

\+ we get automated cloud/sky images

Problem: Non-constant illumination

- The intensity and the spectrum of the incident irradiance varies over time

- A hemisphere of BRF measurements may take up to 20 minutes.
- In that time sun has moved ~5 degrees

- Even thin, practically invisible, clouds affect the irradiance

Answer: Record the changes in your data

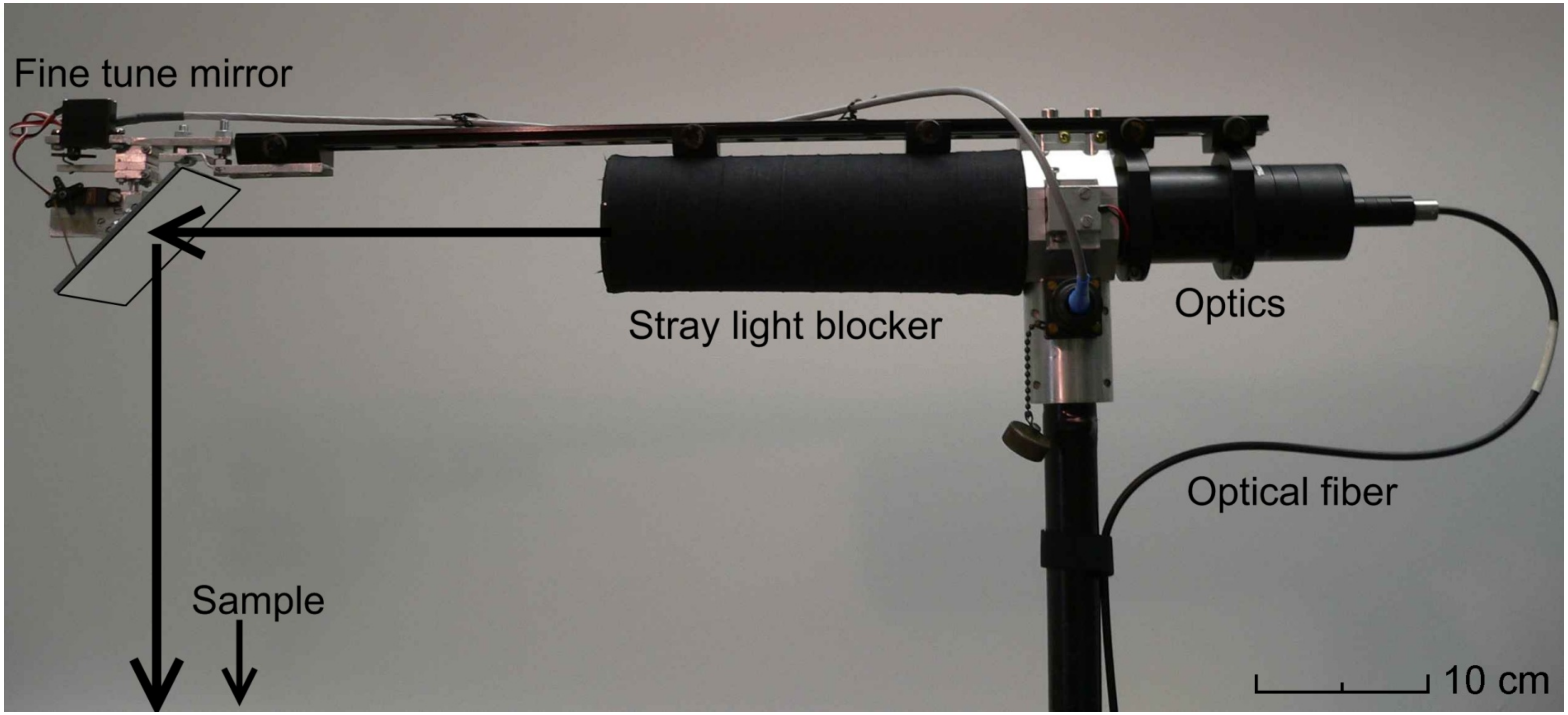
- Work only on clear sky days
- Measure white reference often
- Measure white reference before and after the target and interpolate

- Use a sun photometer to record illumination and scale each spectrum with that
  - Use a second spectrometer if possible

Problem: spectrometer footprint position

- On heterogenous surfaces, the spectrometer footprint should be held constant in order to produce consistent BRF.
- Two major error sources
  - Rotation of a goniometer
  - Elevation of the sample

Answer: laser pointer & active optics



- Spectrometer optics have laser pointers to show the footprint position
- Sample elevation is entered and a servo controlled mirror adjusts the footprint according to tilt.

Problem: Representativeness of the sampling

- The BRF measurement is usually taken from a small area, ~15cm in diameter
- It is too slow to repeat measurements in tens of spots

Answer: Use traditional field spectroscopy for support

- Take a spectrometer and measure tens of reflectances around the area
  - Scale the BRF with mean reflectance spectrum
- Repeat principal plane BRF measurement in a few places
  - Most distinct BRF effect are seen on principal plane

Tips for succesfull measurements

- Always take tea/coffee/candy/sandwiches with you
  - Hungry/cold/bored operators produce low quality results
- Wear sunglasses
  - You need to watch for clouds and stare at the Sun
- Take your time to observe the target
  - Natural samples always have more details and properties than you might imagine

BRF retrieval accuracy

- The general accuracy of FIGIFIGO BRF measurement is between 1-5% for a well defined sample
- Accuracy depends especially on wavelength, sample reflectance factor, and solar zenith angle
  - Spectrometer noise causes error that is proportional to reflected radiance
  - Levelling of Spectralon panel

Level your Spectralon!

- If a Spectralon panel is tilted even slightly towards the Sun, the panel will receive and reflect significantly more light and spoil the reference.

$$\frac{E_{\Delta\theta}}{E_{ideal}} = \frac{\cos(\theta_i - \Delta\theta)}{\cos(\theta_i)} \approx 1 - \Delta\theta \tan(\theta_i)$$

- E.g. at 60° solar zenith angle the panel is tilted only 1°, the reflectance factor will have an error of 3%.
- A panel held on hand can easily be tilted 5 degrees! Use a bubble level, not eye!

Ultimate error source: Definition of the sample

- With natural surfaces a great error source is already built in to the samples. How can you describe the sample
- A special care must be taken in collecting metadata for the samples

Fi

BRF/HDRF DATA LIBRARY AND ANALYSIS

Storing FIGIFIGO data

- Raw data is converted to a standardized format
- A processed FIGIFIGO dataset consists of a number of datapoints each with fields:
  - Reflectance factor spectrum
  - Light and view directions (LightZen, LightAz, SensorZen, SensorAz)
- These datapoints and metadata are stored to a hdf5 library file
- The library file is stored to *FGI Reflectance Library*

FGI reflectance library

- Currently the library contains BRF/HDRF measurements of over 150 samples
- A pdf datasheet is produced from each library file
  - Shows contents of the file
  - Describes the reflectance properties of the sample
- The library files can be opened using e.g. Matlab or IDL tools
  - A toolbox is available: *FGI Reflectance toolbox for Matlab*

AIRBORNE HDRF RETRIEVAL: UNMANNED AERIAL VEHICLES

UAV

- Autonomous Unmanned Aerial Vehicle (UAV)
- Microdrone MD4-200
- Battery powered
  - 14-20 min per battery
- Flight computer
  - GPS, barometer, inertia, gyro
- Control
  - Automated route flight
  - Manual radio control

Properties

- Easy to use
- Price 25 k€
- Payload 200–300 g
- Wind limits
  - Flyable: 8 m/s
  - Imaging: 4 m/s
- No other weather limits
- Position accuracy ± 1 m

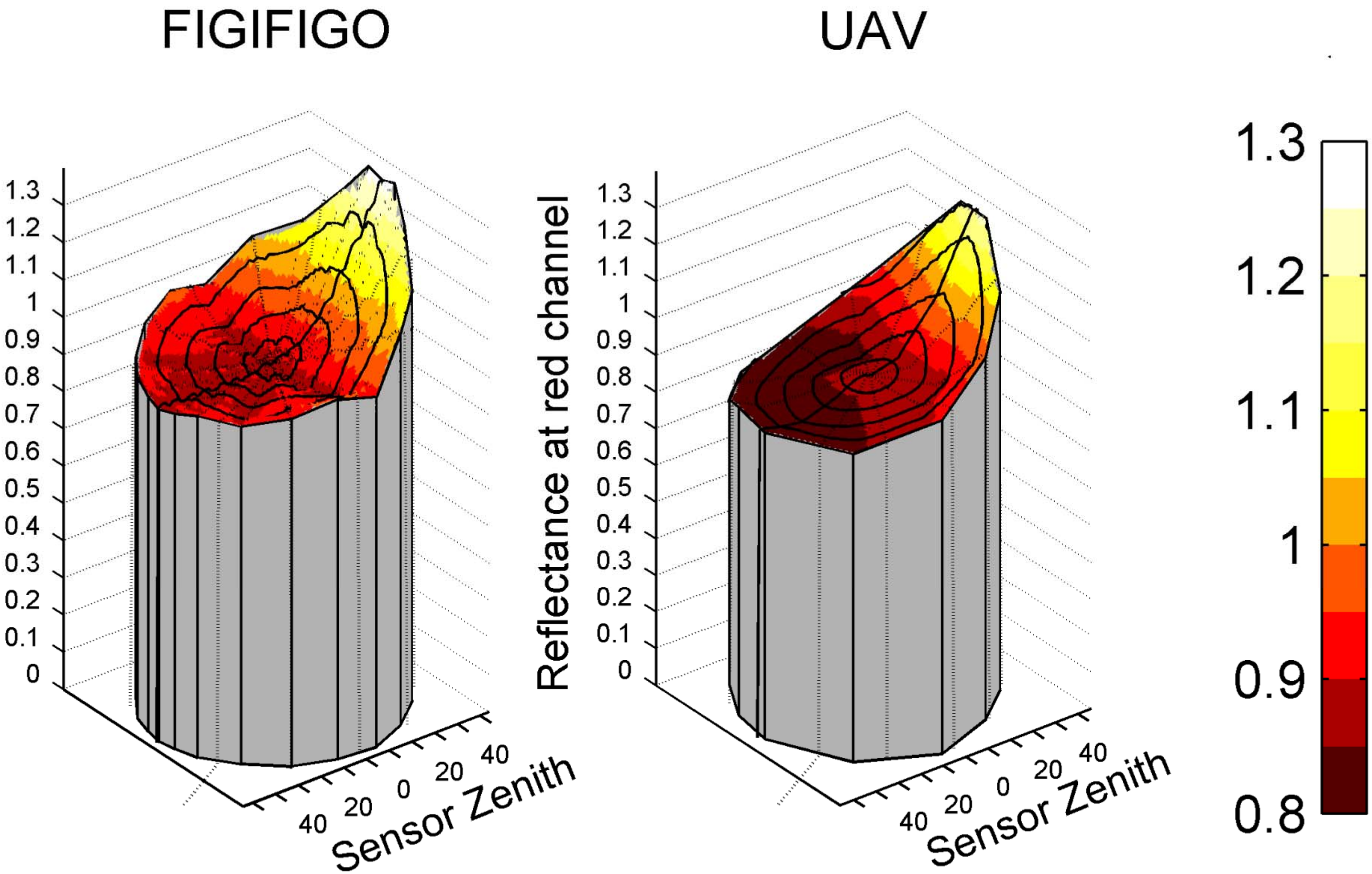
Current Sensors

- Ricoh GR II
  - 10 megapix
  - f = 9.8 mm
    (28 mm)
- 2 versions
  - Normal RGB
  - NIR modified
- A servo tilted mount

HDRF retrieval using UAV

- 31 images of a snow field were taken from various directions
- Images were calibrated to reflectances using empirical line method
- The images were georefenced
- Product: A HDRF map of the area

Comparison of UAV and goniometer HDRFs



Hakala et al. 2010

CONCLUSIONS

Conclusions / Take home messages

- Reflectance factor is a function of both view and illumination angle
- BRF/HDRF effects are error source if ignored, but also a possible source of information.
- If you want to have accurate reflectance factors
  - Take Spectralon reflectance in to account
  - Always level your Spectralon panel with a bubble level!