Field goniometer measurements for biophysical parameter retrieval in support of Chris data evaluations

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- Motivation
- Strategic research goals
- *The general concept*
- The ground segment
- Measurement systems developed
- ProSailh parameter retrieval
- Conclusions/Outlook

Research environment:

- Close to application
- “local” and “precison” as headlines
- in the Life Science domains:
  - Agriculture
  - Forestry
  - Limnology
  - Environmental

- ***“all out of the data set”*** **idea** ***failed!***

- Concept:
  - implementation of existing information and knowledge
  - ***Fit into existing assessment and evaluation schemes!***

- Requirements from the application:
  - ***Decision support for management issues***
  - ***Up to decision making (➔ real time systems in precision farming)***

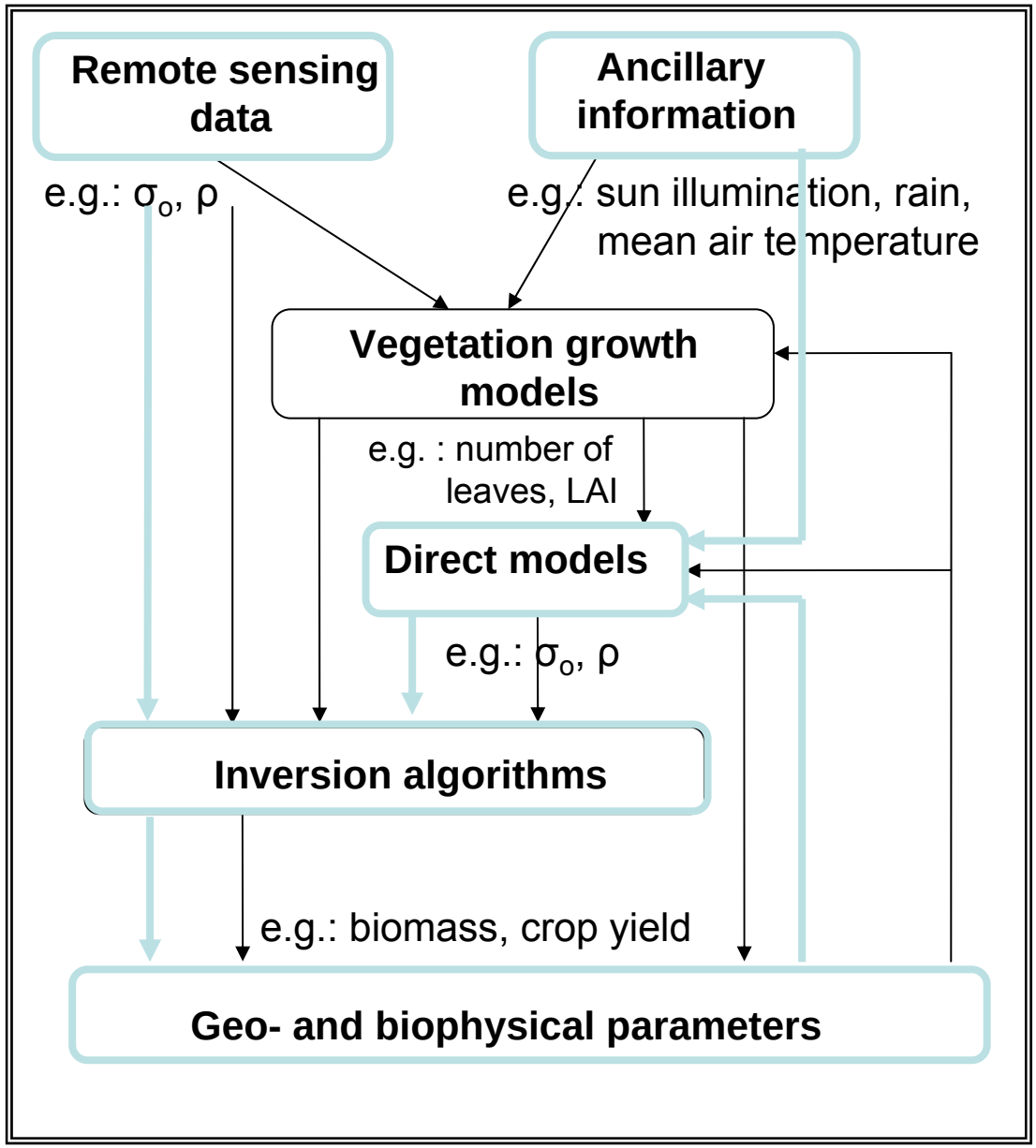
Strategic research goals

Derivation of ***Geo- and biophysical parameters*** from RS data

-

ESA´s strategic goal for the next decade (stated 1998)

AO /1-3381



under investigation

General investigation concept:

operational application chain

application map

expected reflection

laboratory loop

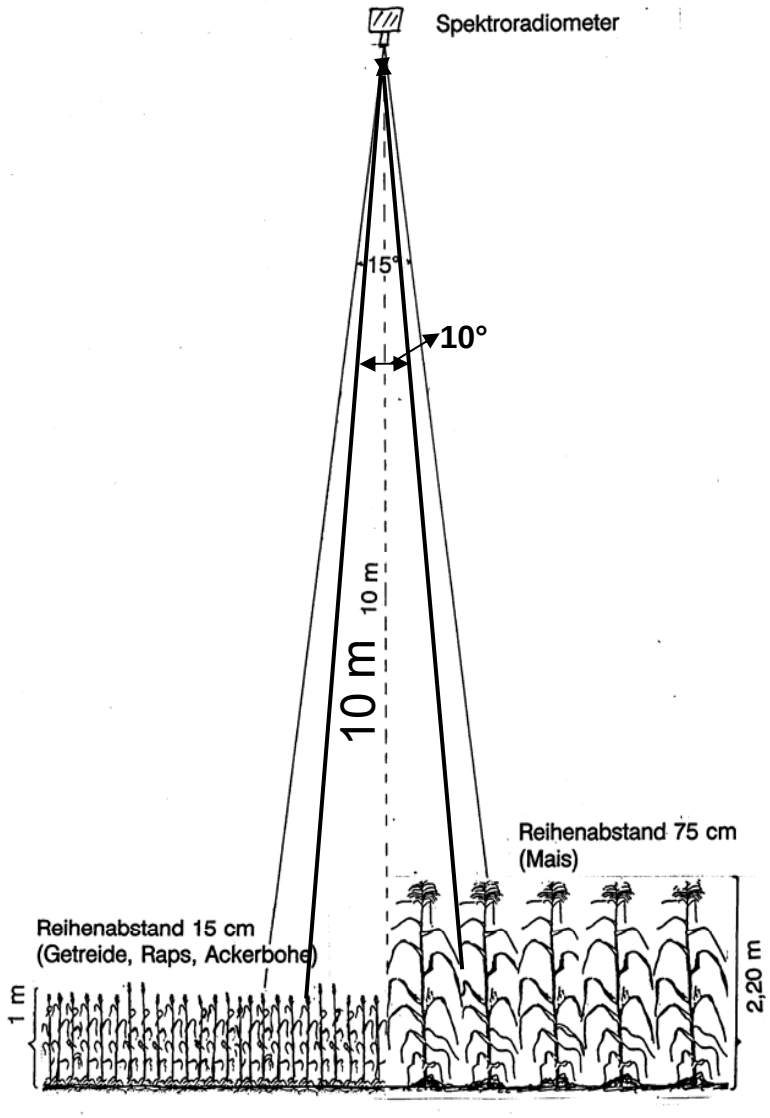
reflection
models
growth / yield

stand
parameter

structure data

meteorological-,
biomass, bio-geo-
chemical data
management data

Basic requirements on the measurement device:



"high, mobile and fast enough to achieve an acceptable amount of representative measurements for more than one surface during comparable illumination conditions"

➔representative plot section
➔high: 10m above target
➔max 10° aperture angle (IFOV)
➔mobile: movable within the plot
➔fast: one series within 20 min
➔comparable illumination conditions about 1 h timeframe

Step by step optimization:

Solutions for directional measurements:

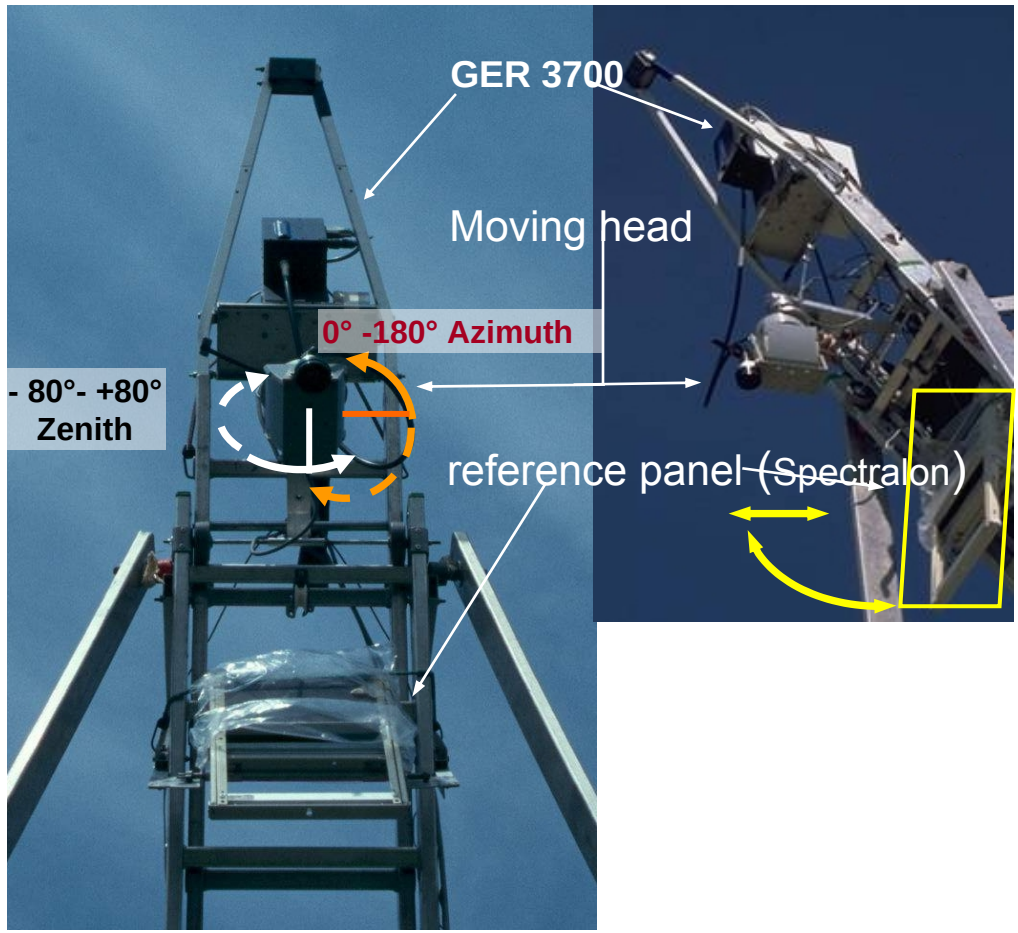
1. MUFSPEM development (IKB Dürnast “precision farming” project)
2. MGS development (HTO Bayern project water framework directive, application within a co-operation with BOKU, Austria)

Performance test and complementarities assessment:

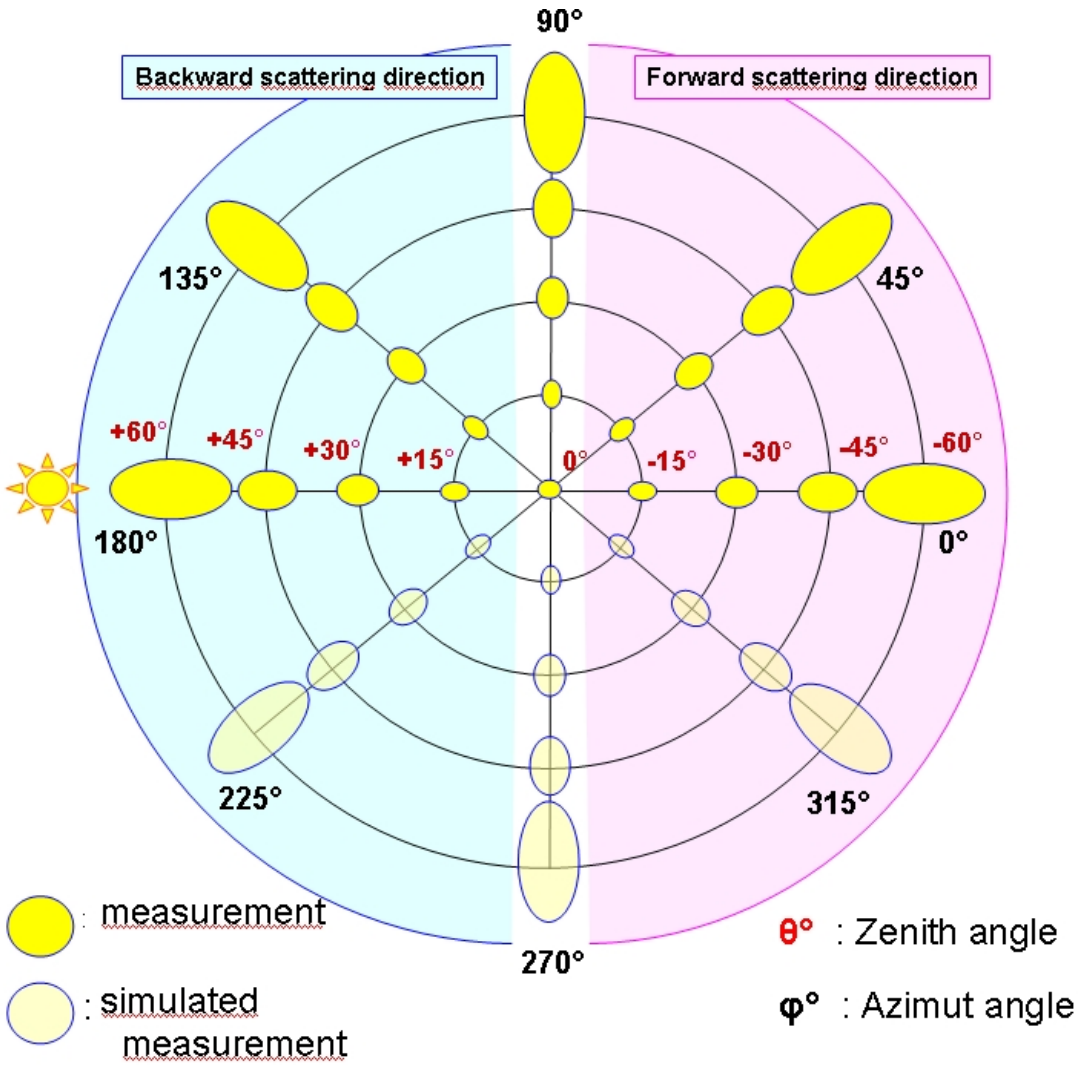
- GonioExp06 goniometric systems intercomparison campaign at the CHRIS super test site “Gilching”

Mobile Unit for Field Spectroradiometric Measurements ***(MUFSPEM)***

Developed in the frame of IKB Dürnast project
Funded by DFG



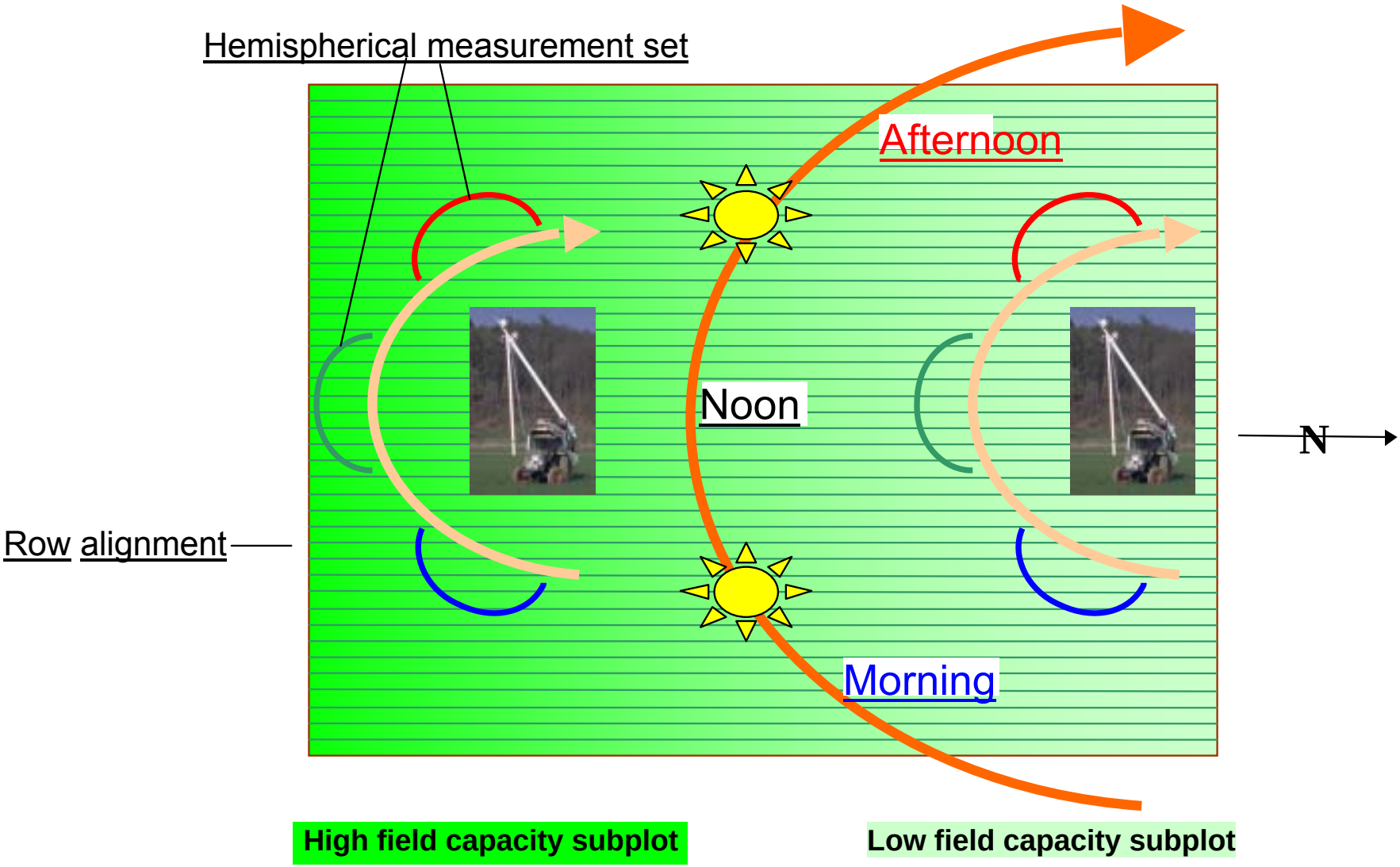
MUFSPEM „half“ hemisphere measurement scheme:



- Plot section homogeneous
- Different footprint (size and area) for each BRf measurement
- Reference measurements „spectralon plate“ at the beginning and at the end of the series.
- time period for one series: 15-20 min, interpolation according to registration time of the measurement for reflectance calculation

And: Differing positions across the day

Change of position in accordance with the principal plane



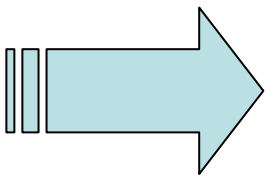
Aim: range of backscatter values within one plot over the day

Evaluation of results:

➔ ***High and low field capacity subplots show different angular backscatter behaviour !***

TOC BRf measurements/ fields differ with:

- view zenith angle ➔ expected
- across the vegetation period ➔ expected
- sun zenith angle ➔ expected, but the magnitude was surprising!

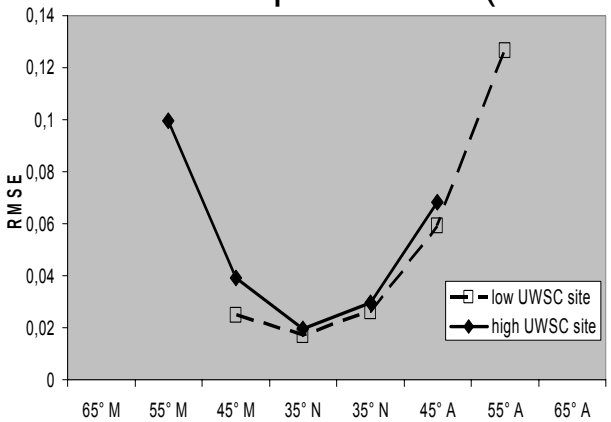


Arising question:

Do physical models consider these diurnal differences ??

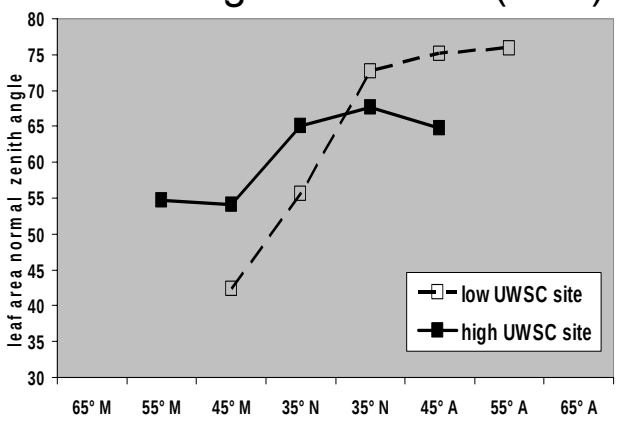
Parameter retrieved by ProSail inversion, **maize EC 67**

Root mean square error (RMSE)



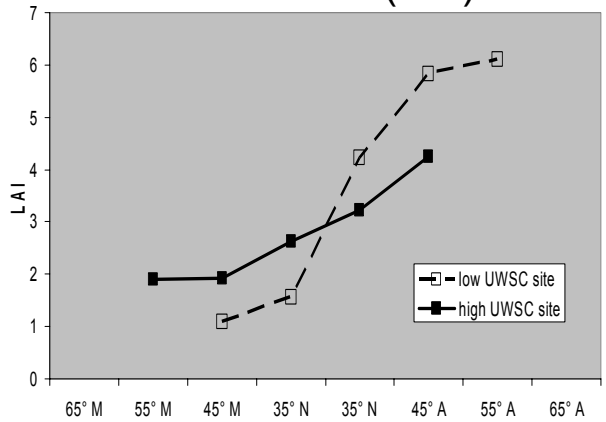
morning (M), noon (N), afternoon (A)

Leaf angle inclination (LAD)



morning (M), noon (N), afternoon (A)

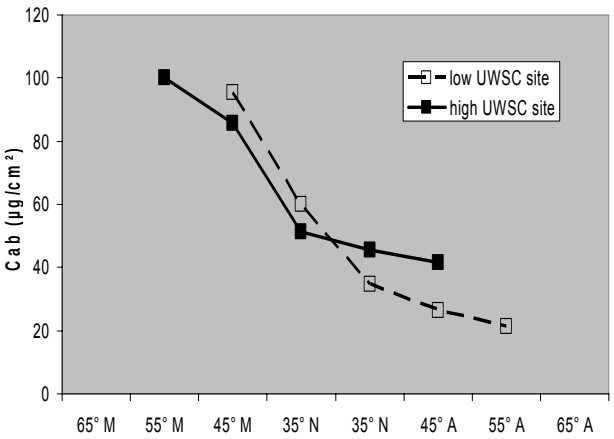
Leaf area index (LAI)



morning (M), noon (N), afternoon (A)

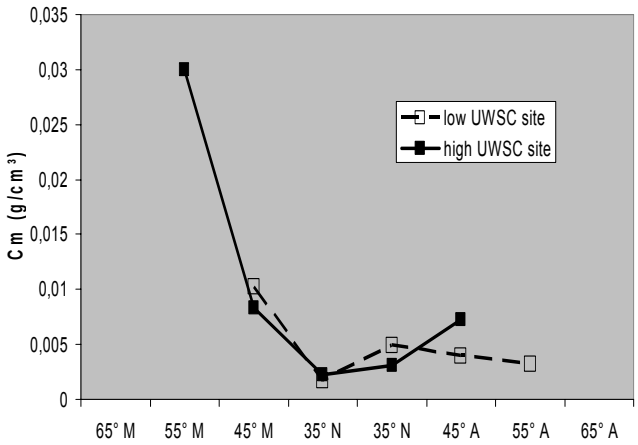
sun zenith angle

Chlorophyll a+b content (Cab)



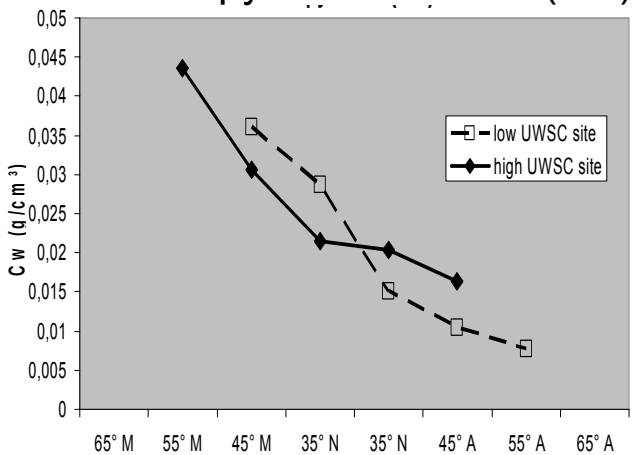
morning (M), noon (N), afternoon (A)

Canopy dry matter (Cm)



morning (M), noon (N), afternoon (A)

Canopy water content (Cw)



morning (M), noon (N), afternoon (A)

sun zenith angle

Source: Manakos et al. 2002

Which may be the reasons ???

➔ measured area is not really homogeneous !!

- management lanes,
- aligned ears, leaves due to wind, etc.
- field capacity differences
- growth differences
- Etc.

➔ Changing atmospheric conditions during one series

- (affecting the measurement esp. via the white ref. meas.)

➔➔ ProSail not adapted sufficiently ???

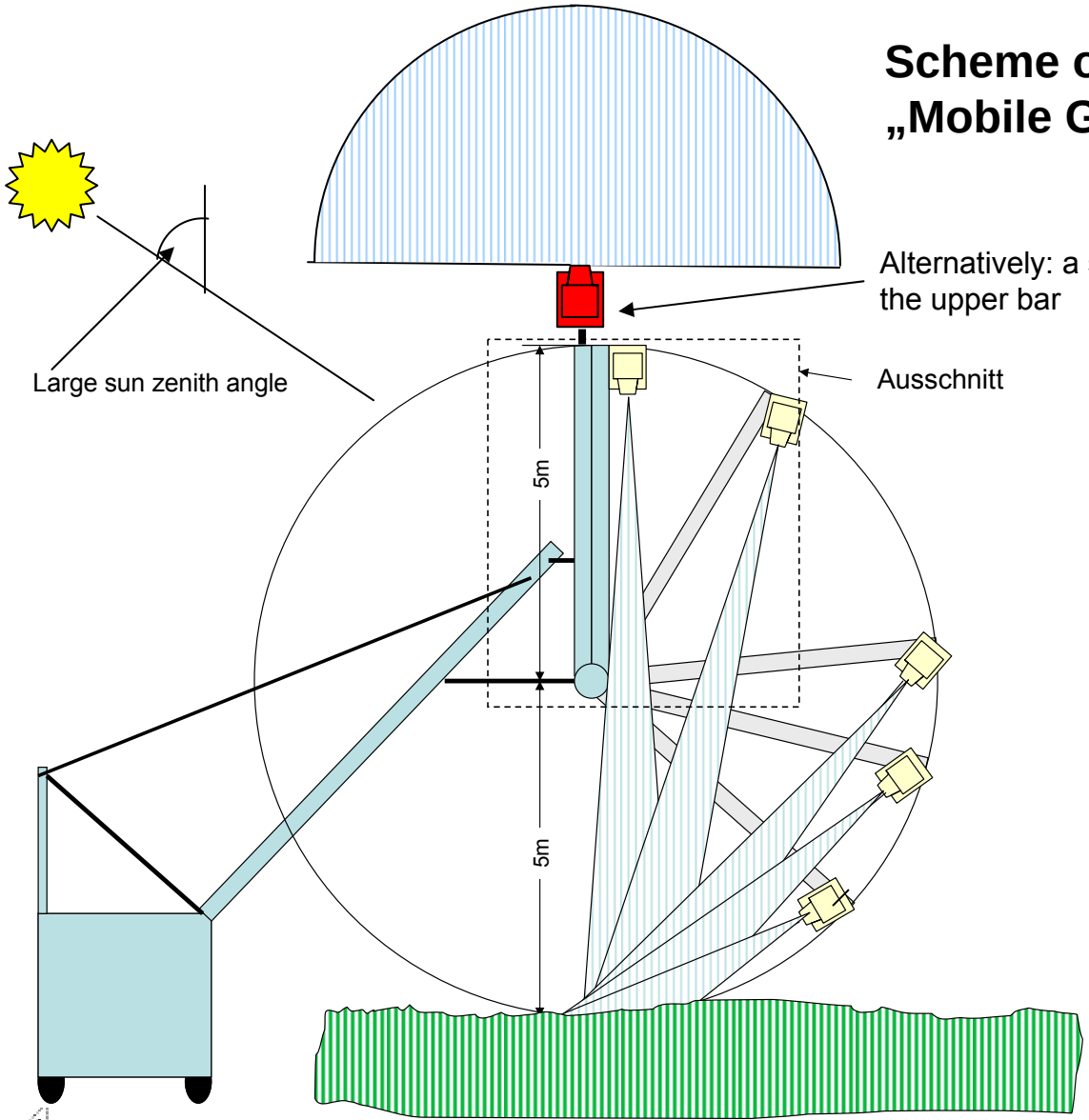
➔ **too many error sources to check**

➔ **need to reduce variables for back tracing**

Line 1: Improved measurement system !

Line 2: further adaptation of physical models !

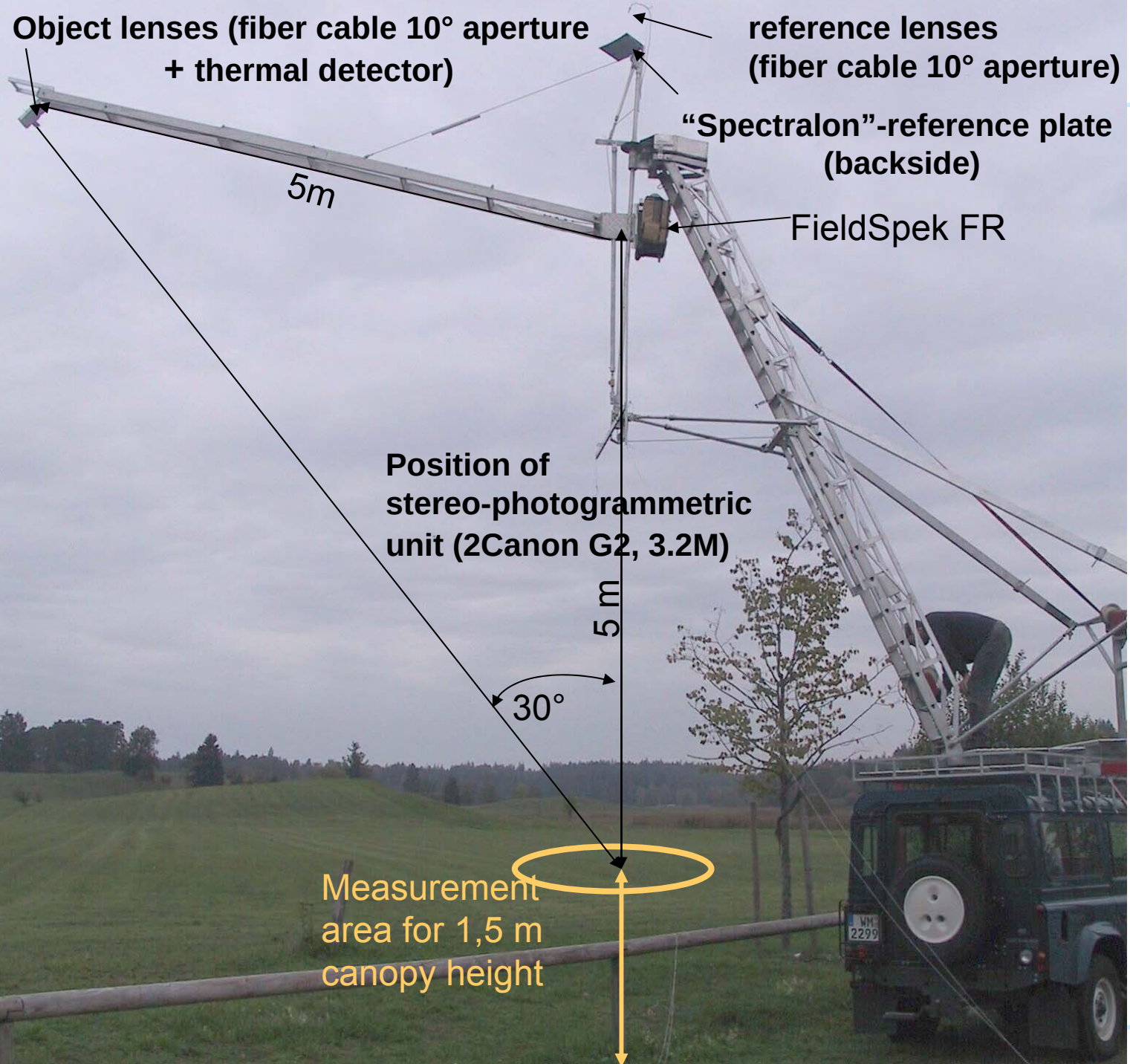
Development line 1: Improved measurement system !



Scheme of a new „Mobile Goniometric System“ (MGS)

Main design feature: “*inscribed –”*or “*contact angle*” principle!

Always the same subplot measured, view angle controlled changes of the footprint less than 10%!



2nd assembly test in Iffeldorf, 01.10.2003

Movements of
the goniometer-arm for
zenith-angles
from nadir to 60°

The device platform is
oriented 45° toward the
main axis of the car

2nd goniometer assembly test, 1.10.03, Iffeldorf

Trailer with goniometer device ready for transport,
Special construction, Landtechnik Müller company,
Engeneered by Ludwig Hunsrucker
Electronic device for rotation control: ANDRICH Industrieelektronik

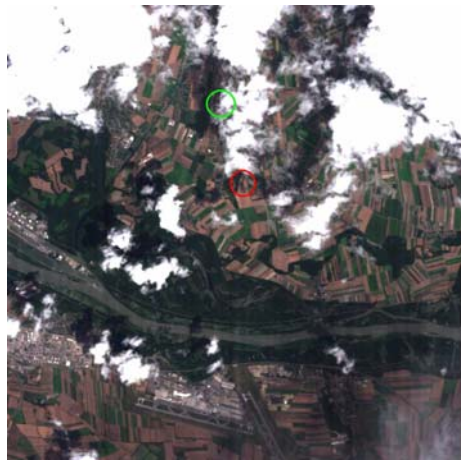
First test under “operational conditions:

*The whole evaluation chain was intended to be tested within a co-operation with the **University of Natural Resources and Applied Life Sciences (BOKU)**, Vienna, Austria, in support of a FP6 project.*

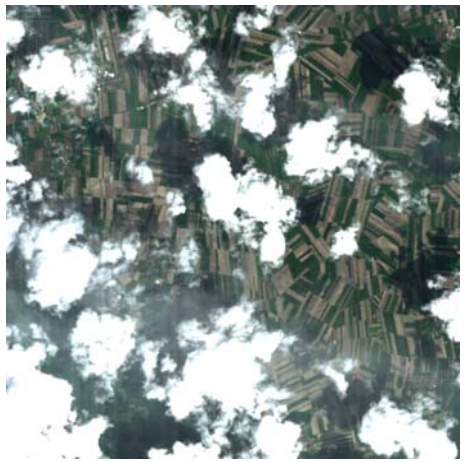
Unfortunately bad luck with Chris data acquisitions!

13.07.2005

21.07.2005



25.05.2006



10.08.2006

Solely the “laboratory loop” could be tested

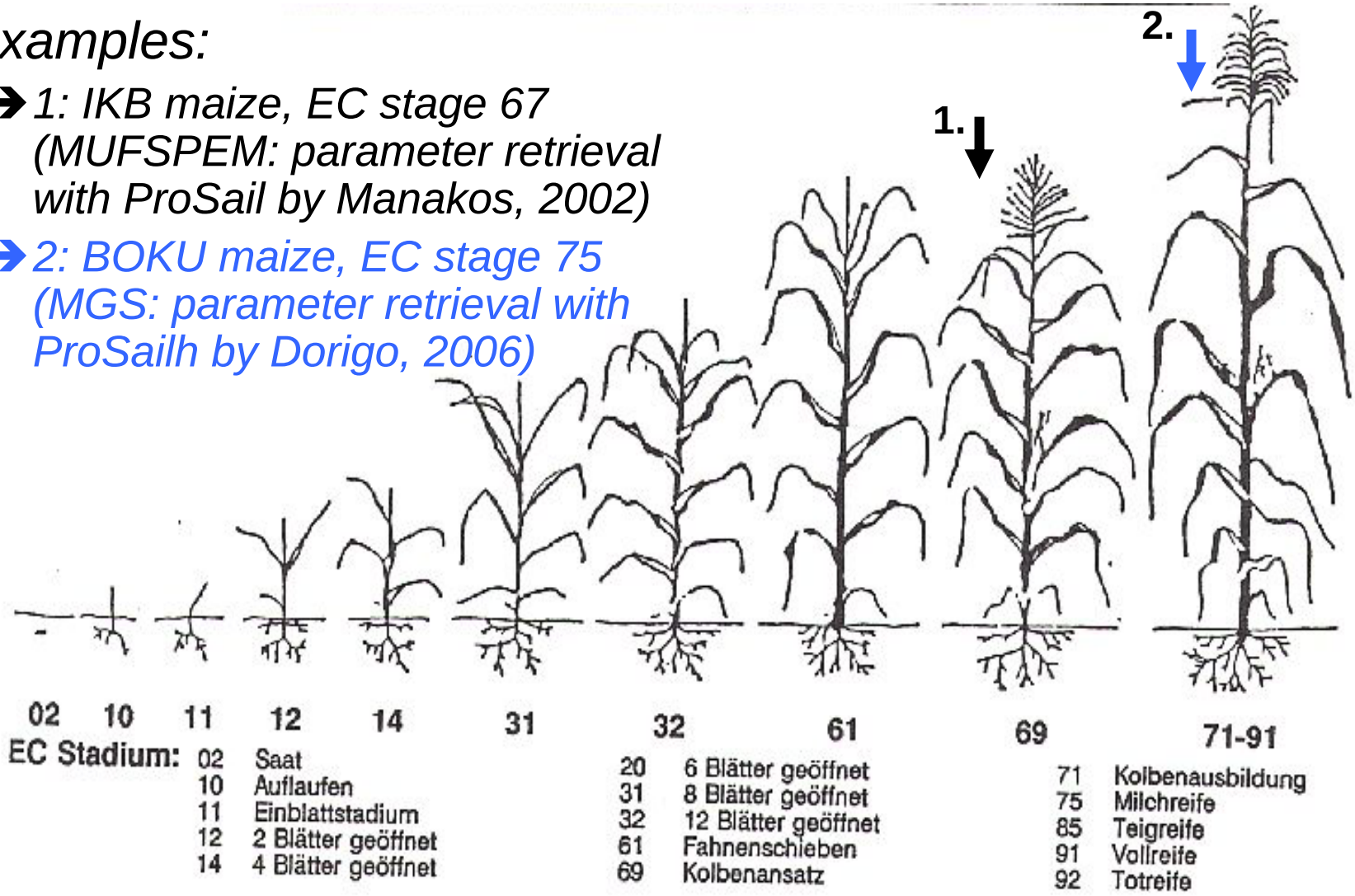
BOKU field campaign 2005

First operational field campaign within a co-operation with the BOKU, summer saison 2005

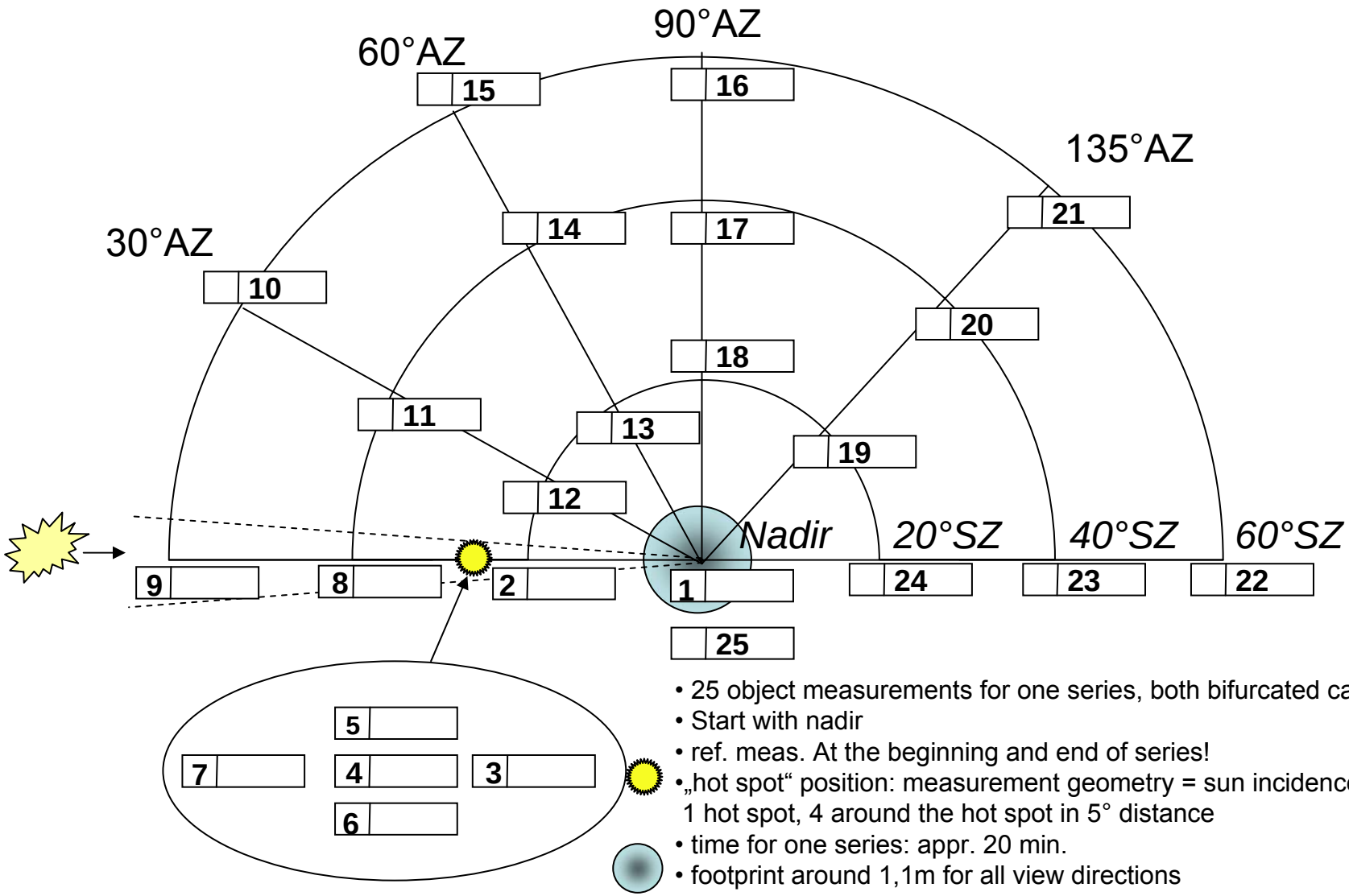
Measurements at the Augärten drought stress and control testplots in Vienna, Austria, 31.08.05

Development stages of maize (Eucarpia Scale, EC)

- *Examples:*
  - *1: IKB maize, EC stage 67 (MUFSPEM: parameter retrieval with ProSail by Manakos, 2002)*
  - *2: BOKU maize, EC stage 75 (MGS: parameter retrieval with ProSailh by Dorigo, 2006)*

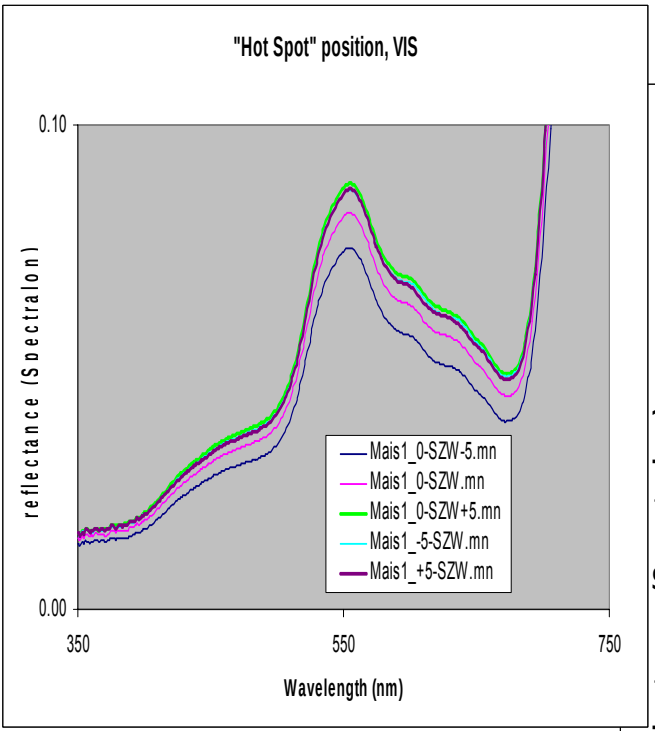


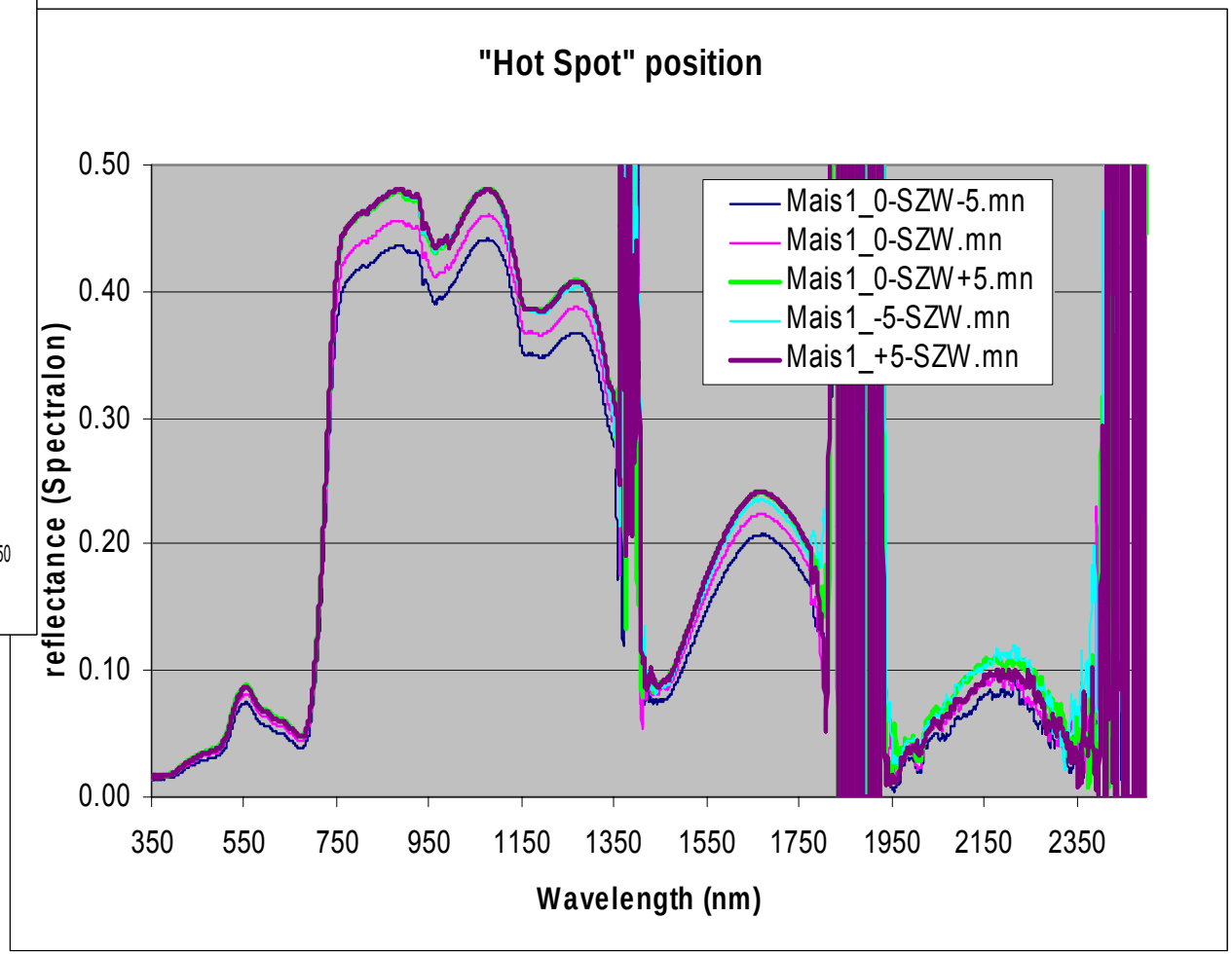
Data take sequence adaptation BOKU



- 25 object measurements for one series, both bifurcated cables
- Start with nadir
- ref. meas. At the beginning and end of series!
- „hot spot“ position: measurement geometry = sun incidence
  1 hot spot, 4 around the hot spot in 5° distance
- time for one series: appr. 20 min.
- footprint around 1,1m for all view directions

Step 1: **Maize, Raasdorf (BOKU) „hot spot“ surrounding**

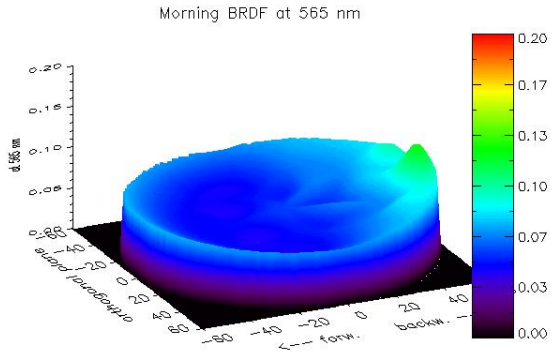


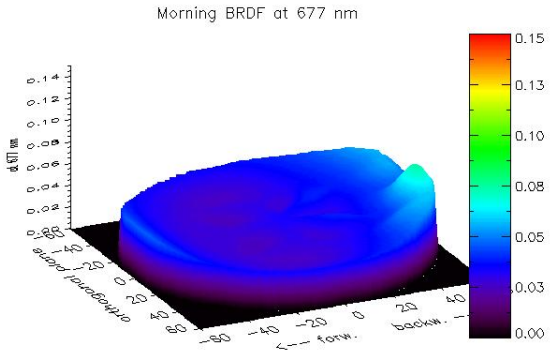


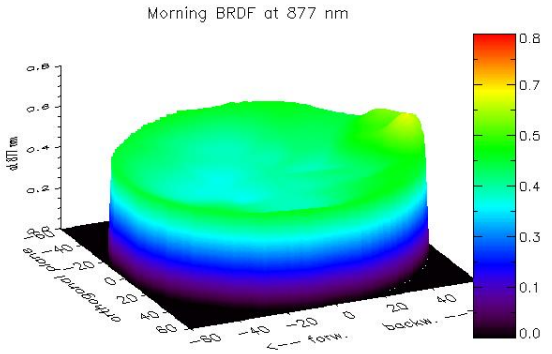
MGS system seems to measure quit accurate!

TOC BRf field of maize, Raasdorf, 29/30th of August 2006

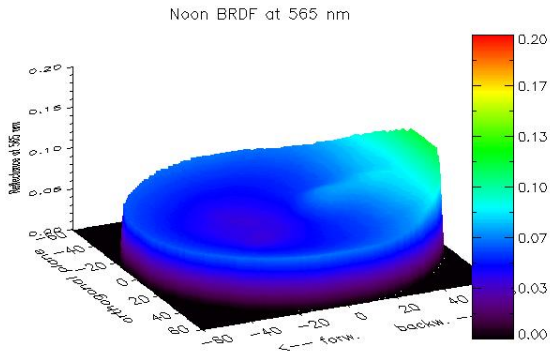
Morning

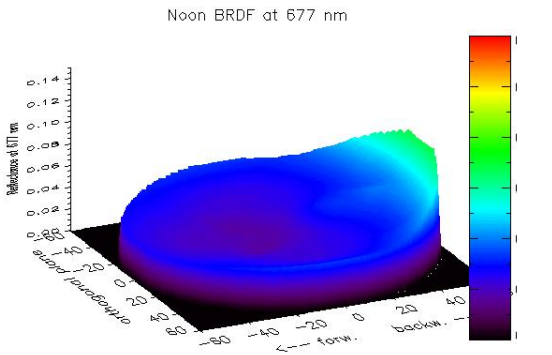


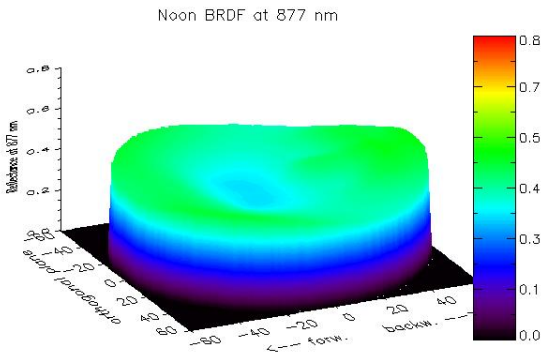




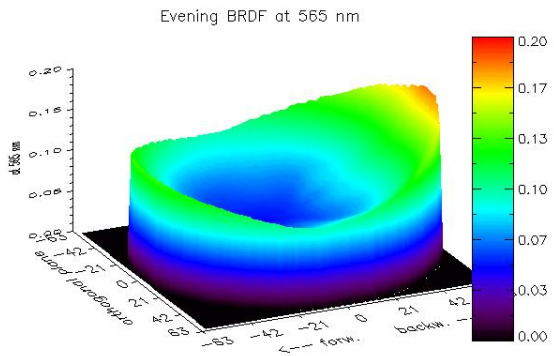
Noon

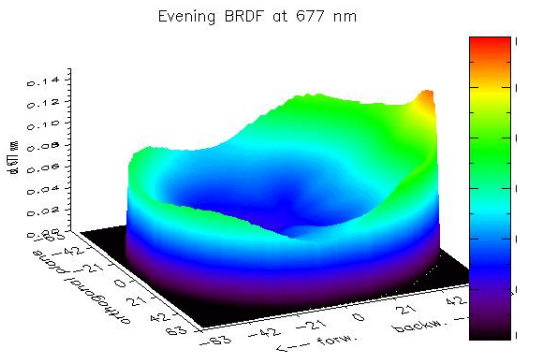


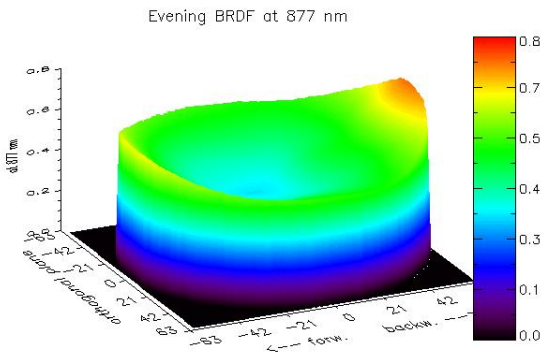




Evening







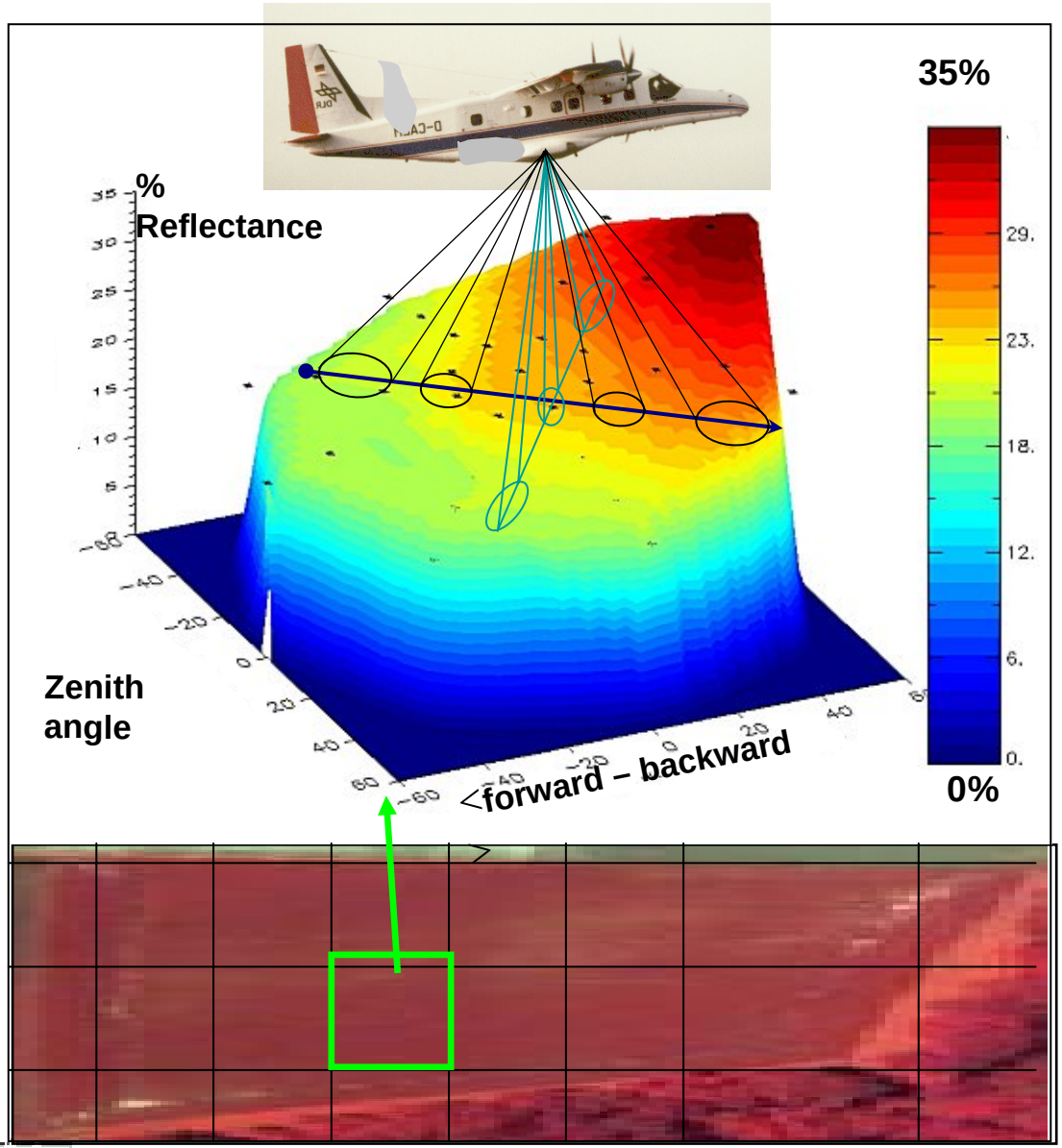
Development line 2: Adaptation of physical models !

- PROSPECT + SAILh:
- Covariance between different view constellations and spectral bands
- Result contains flag for spectral similarity
- Based on LUT: 100000 random selections for every variable
- Input LUT based on prior knowledge (e.g. Koetz et al., 2005)
- Prior estimate (μ + σ) of canopy variables

	LUT entries (min-max)	A priori estimates
Leaf chlorophyll a+b ($\mu g/cm^2$)	10 – 80	40 ± 16
Leaf water content (g/cm^2)	0.01 – 0.03	0.025 ± 0.005
Dry matter content / SLW (g/cm^2)	0.003 – 0.01 ($\cong$ 0.25 * Cw)	0.007 ± 0.0003
Leaf structure parameter	1.2 – 1.8	1.63 ± 0.26
LAI	1 – 7	4 ± 1.5
ALA (°)	55 – 65	60 ± 14
Hotspot	0.01 – 0.2	0.1 ± 0.023
Soil brightness	0.7 – 1.3	1.0 ± 0.2

ProSailh model adaptation by Wouter Dorigo, 2006

BOKU experiment results:



Questions (some off..):

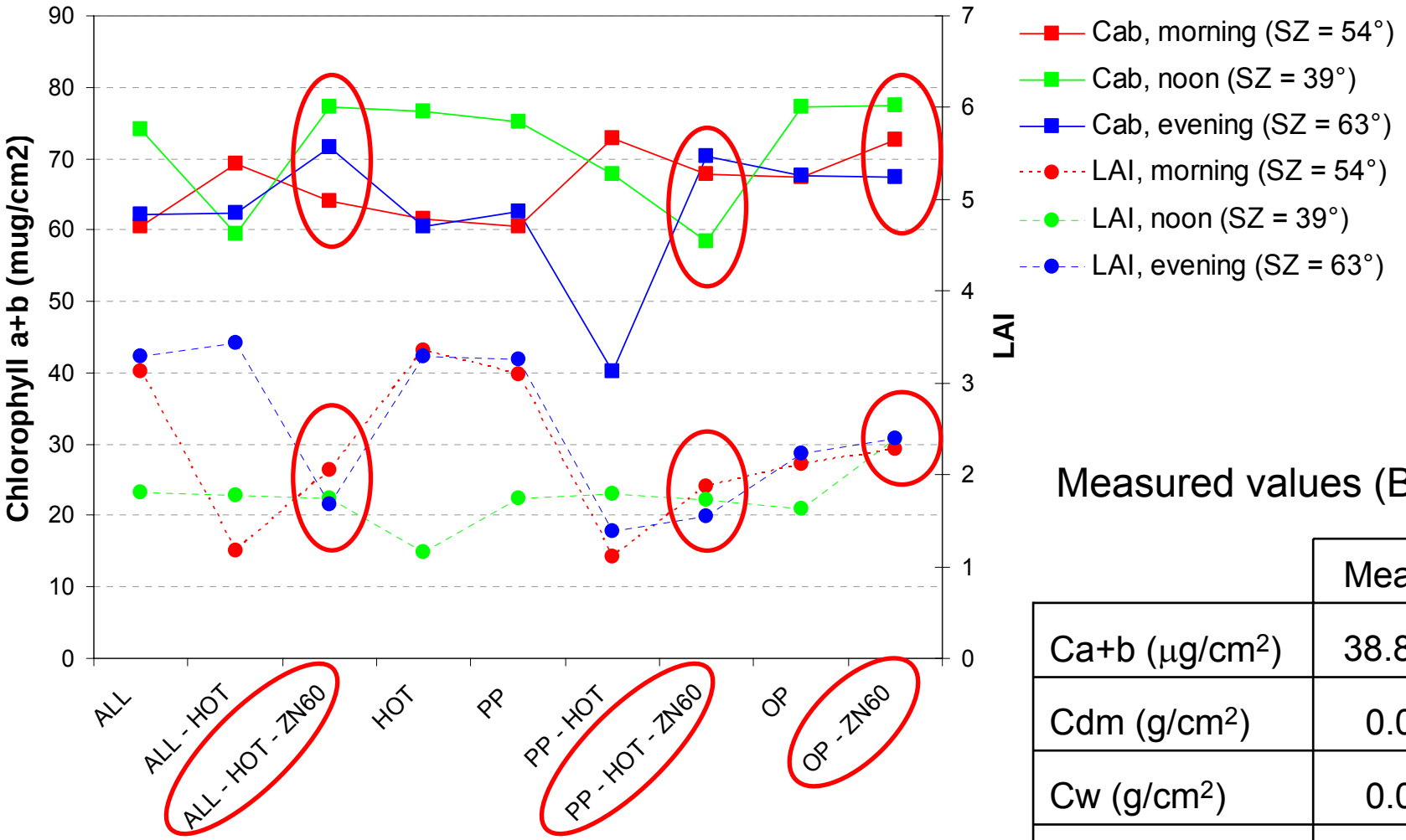
➔ **Are there improvements in physical model inversion ?**

➔ Does parameter retrieval work for all view geometries?

➔Does parameter retrieval work with a reduced set of view angles?

➔ *atmospheric, topography, unsystematic error sources (row, wind direction, mangament lines, etc.) not addressed within the present study!*

Results – Diurnal variation



Measured values (BOKU):

	Mean (SD)
Ca+b (μg/cm²)	38.8 (7.51)
Cdm (g/cm²)	0.00745
Cw (g/cm²)	0.01289
LAI (LAI-2000)	2.68 (0.25)

ProSailh model adaptation and parameter retrieval by Wouter Dorigo, 2006

Analysis of results BOKU experiment:

- ***Retrieval of parameter in the diurnal cycle became more stable !***
- ***But: large discrepancies between direct measured and retrieved parameter!!***

Arising questions (some off…!)?

Does the goniometer concept of MGS resample the BRf field with a sufficient accuracy?
➔*System intercomparison!*

How to optimize the accompanying measurements ?
➔ *Extended set of accompanying measurements*
➔*Two independent measurement methods for each bio-geo-chemo-physical parameter! (if applicable)*

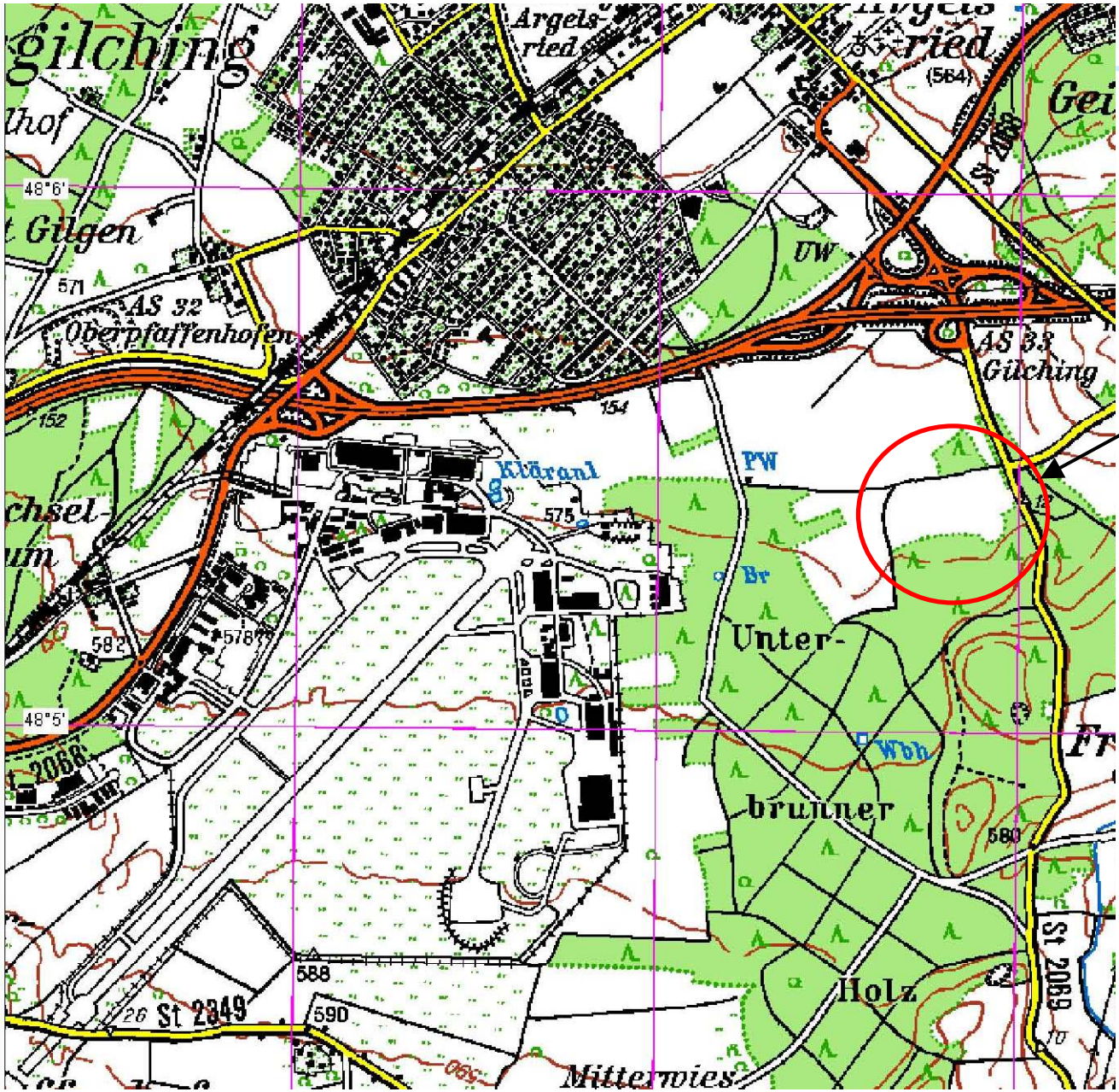
Need for further adaptation of physical models!

GonioExp06 at the Gilching CHRIS supertestsite

The "GonioExp06" field goniometric measurement system intercomparison campaign at the Chris supertestsite Gilching

A pilot study without external funding performed by the partner:

- Remote Sensing Laboratories (RSL) of the University of Zürich (FIGOS)
- Institute for Geography and (IGGF) of the University of Munich (super test site Gilching, field measurements)
- Remote Sensing Technology Institute (IMF) and German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) (AISA and Rosis, ProSailh inversion)
- Limnological Station of the Technische Universität München (MGS)
- (University of Natural Resources and Applied Life Sciences (BOKU), Vienna, Austria, invited)


Test area
Date: 24.06.06
Time: ~11:15

GonioExp06

Systems for directional measurements during the GonioExp06 intercalibration campaign in Gilching at the CHRIS supertestsite Gilching, 19th to 28th of June 2006

FIGOS and AISA systems

Crop: Triticale

MGS

Goals *GonioExp06*

- To compare different concepts for field goniometer systems and establish the minimum data set for:
  - BRDF approximation
  - Repetitions (each single measurement, TOC BRF field, diurnal cycle, etc.)
  - Accompanying measurements
- To compare the bio-geo-physical parameter retrieval success using data from the differing systems
- To test and develop up- and downscaling algorithms by ground and air-/spaceborne data set comparison
- To derive recommendations for a systematic campaign for BRDF approximation
- To develop a data set for teaching purposes
- Etc.

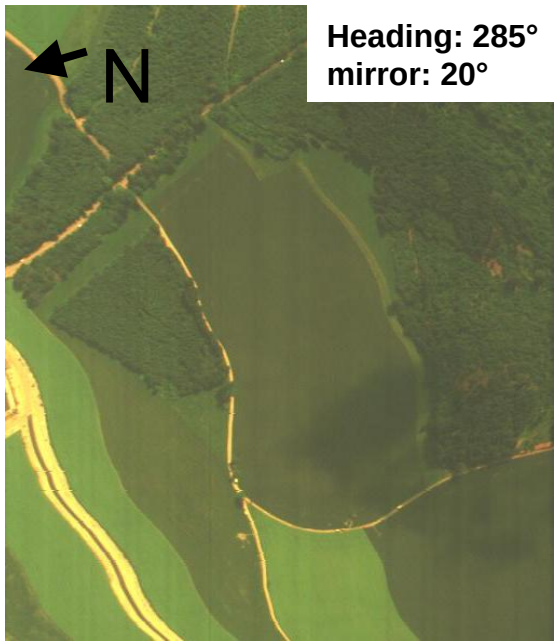
Chris Data set Gilching, 21.06.06

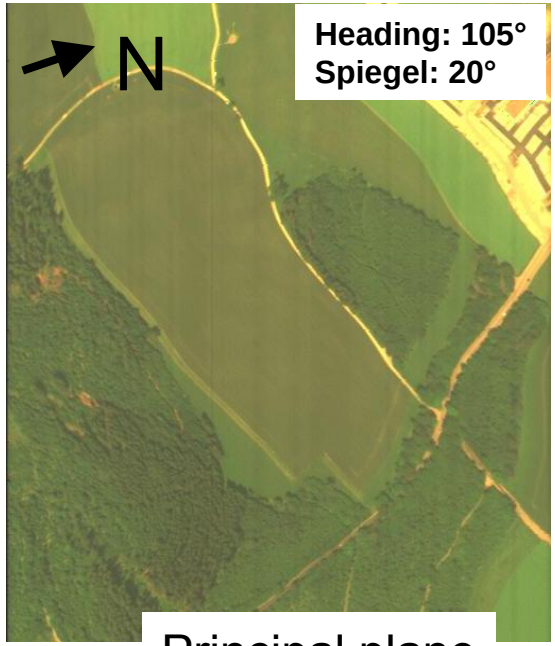
GonioExp06 test area “Gilching”

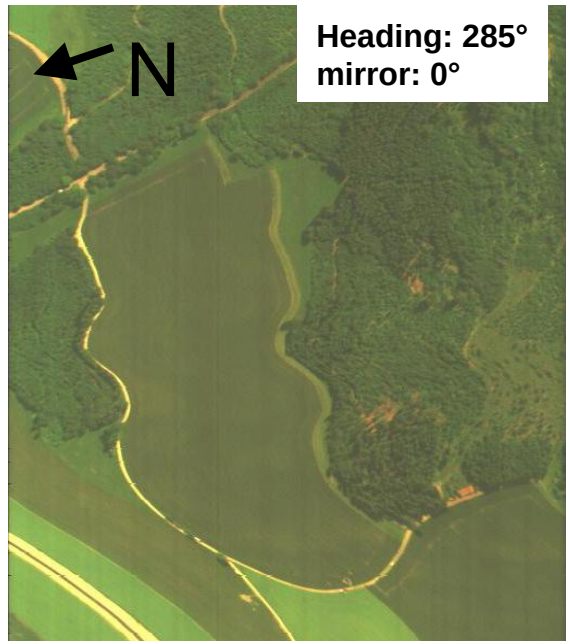
Bad luck again!
Solely the nadir view
Imaged the test site!

Promising quick looks from the ROSIS data sets which have been flown with three view angles parallel to the principal plane and nadir view in the 90° plane!

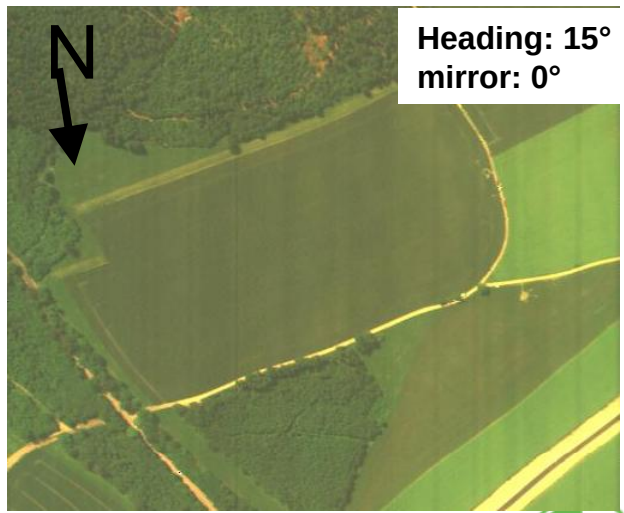
ROSIS data quicklooks, 24.06.06, appr. 11.15h







Principal plane



Orthogonal plane

- Results from the GonioExp06 will be presented at he next CHRIS/Proba workshop, April 2007!

- We wish to thanks ESA and the CHRIS/Proba management for data provision and offering a podium for presenting our research, the Deutsche Forschungsgemeinschaft (DFG) for funding the research in the frame of the IKB Dürnast project and the Bavarian State government for funding the new constructed goniometer device in the frame of the High Tech Offensive Bayern program (HTO), the DLR for manpower and discussion, the EU for co-funding the BOKU experiment

Thanks for attention!!

1th solution (MUFSPEM):

Stable instrument position, changing view direction
(PARABOLA; WAAC concept)

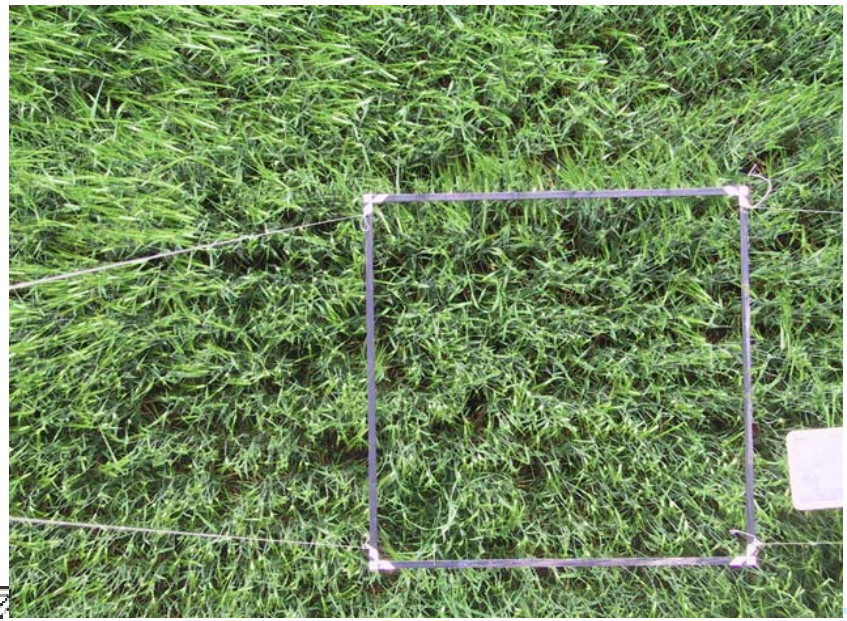
Assumptions:	**Consequences**
(i) Helmholtz reciprocity theorem is supposed to be valid	• arrangement is delivering measurements which are acceptable from the physical point of view
(ii) the backscatter characteristic right and left of the principal plane is symmetrical,	• measurements can be restricted on one part of the hemisphere (time saving assumption)
(iii) the plot as a whole is the object of interest:	• contradictory to the goniometer principle, not the observation position is changed but the measured section of the plot (simplify the measurement arrangement)

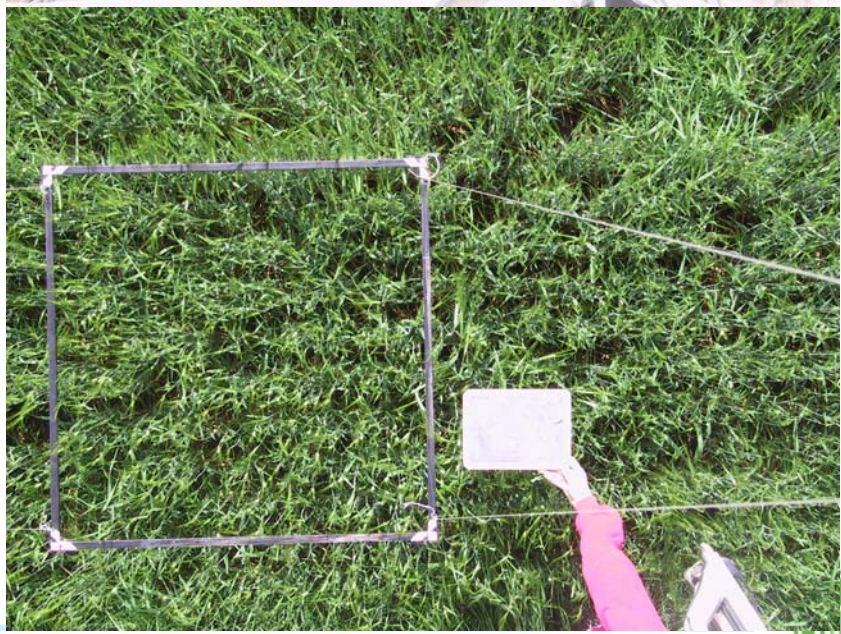
2nd solution: MGS

- ***Goniometer like view direction changes*** ***(FIGOS, EGO concept),***
- ***additional: quasi identical surface area, 10m above surface***

Assumptions:	**Consequences**
(i) Helmholtz reciprocity theorem is supposed to be valid	**• arrangement is delivering measurements which are acceptable from the physical point of view**
(ii) the backscatter characteristic right and left of the principal plane is symmetrical,	**measurements can be restricted on one part of the hemisphere (time saving assumption)**
(iii) the plot as a whole is the object of interest:	• contradictory to the goniometer principle, not the observation position is changed but the measured section of the plot (simplify the measurement arrangement)

Solved with the MGS!



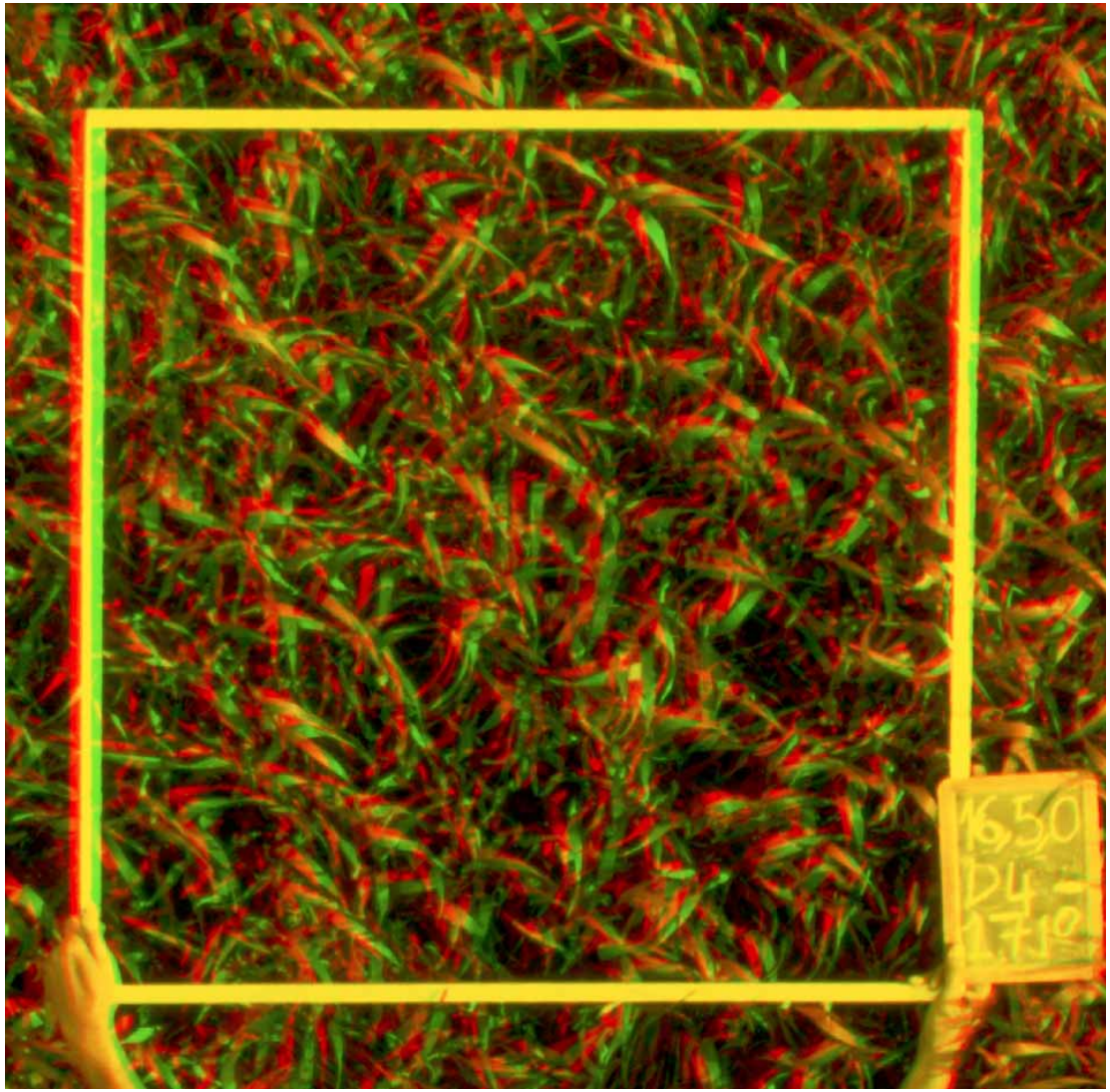


Other imponderabilities:

- Diurnal cycle:
  - Changing conditions across the day (cloud, aerosol, wind)
  - row direction related illumination effects
  - Etc.
- Vegetation period:
  - Soil wetness
  - Atmospheric conditions
  - Diseases
  - Fertiliser effects (agriculture)
  - Canopy structure changes (e.g. storm thrown forests, down trampled reed, mowed grasslands, wind aligned ears, etc.)
  - Etc.
- „Human factor“ in data evaluation !!

A lot of additional disturbing sources to be accounted !!

Parameter extraction:



Parameter to be measured:
- fraction of vegetation / non vegetation (soil)
- fraction of leave, stalk, bloom, ears, etc.
- shaded, sunlit, specular reflection
- LAI
- LAD
- etc.

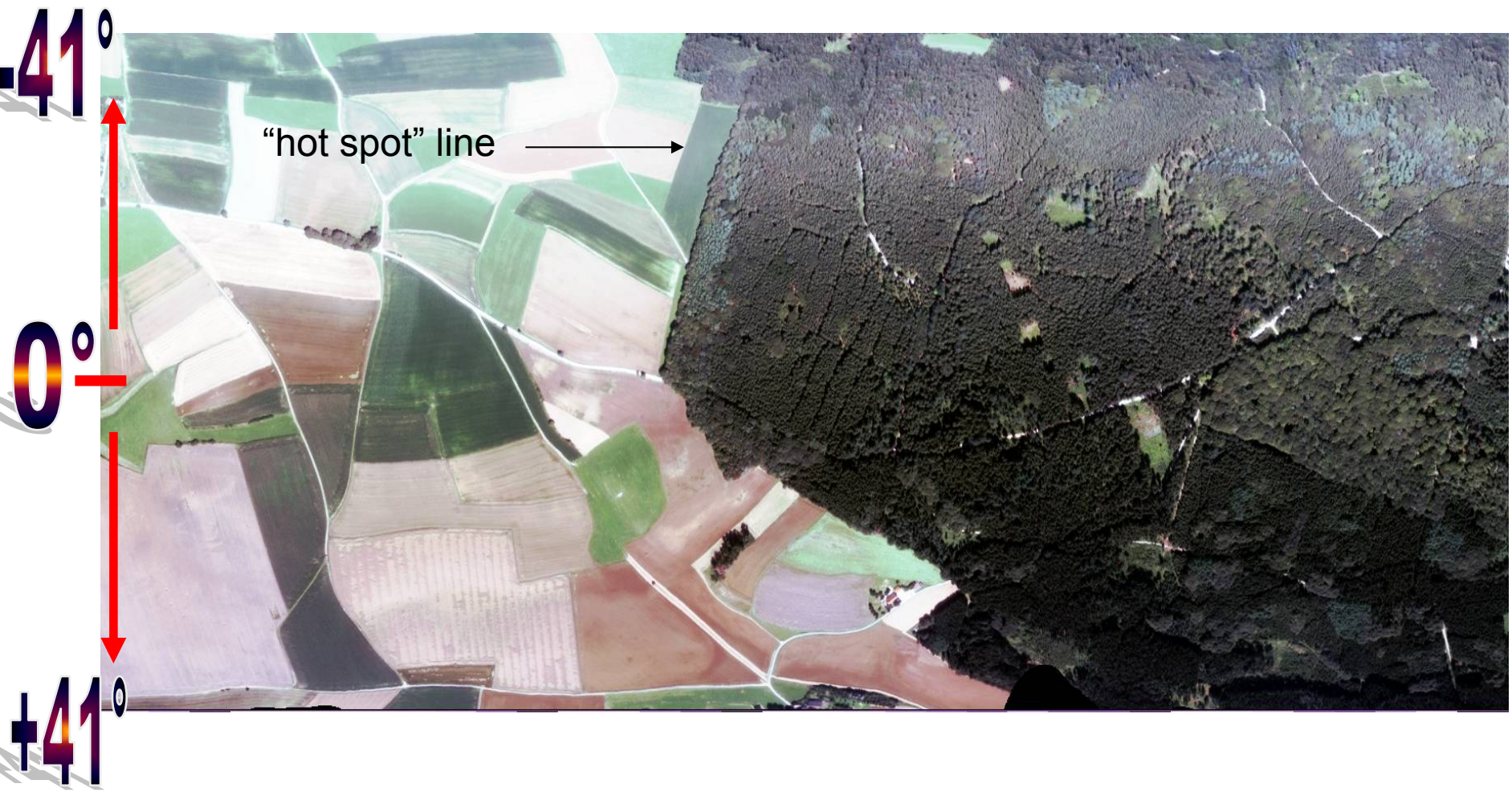
Software solution:
Wilfried Linder, IPI Hannover on base of BLUH and LISA
in progress

- **Problems to be solved or bypassed:**
  - ***illumination to observation geometries !***
  - ***changing illumination conditions***

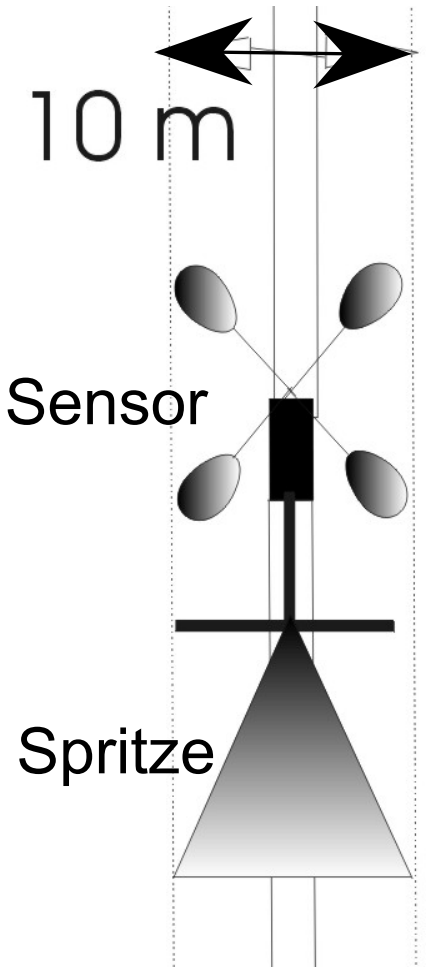
- Prospect:
  - Access to an additional, mostly uncorrelated signature: the ***angular signature***

Air borne sensor

Daedalus ATM data set



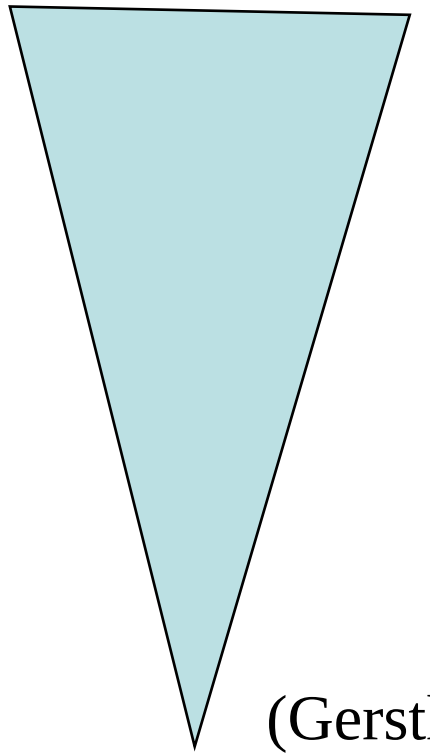
„Real-time“ Sensor



Hydro Agri sensor

5 Signature types are known in RS:

- spectral:
  pigment- and water status, cell structure
- angular:
  plant architecture, canopy structure
- textural:
  pattern of similar frequency inside a structure
- polarisation
  not sufficient explored, to low experience
- temporal
  change of signatures between two or more observations



(Gerstl, 1990)

Information content with respect to the status of objects

- The evaluation of spectral signatures is well known!
- But, how to assess the information from angular signatures???

Interim results:

"on-track" multiangular data are imaging the anisotropic behaviour of surfaces !!

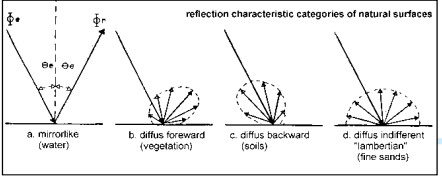
expectations:

- derivation of angular signatures
- information on the structure of surface elements
- To complement information from spectral signatures

experience:

- anisotropy-signal is controlled by diverse external factors!!
- ***very promising results on agricultural sites!!!***

Potential for surface type status assessment ???



Principle of anisotropy signature evaluation from stereo band data

nadir band 3/ 4

band 7

band 6

sun

ϕ_V sensor azimuth band 6 : 105.9°

ϕ_S solar azimuth : 89.5°

ω phase angle sun- band 7 : 16.4°

θ_S solar zenith : 51.2°

θ_V sensor zenith band 6/ 7 : 21.4°

for / back < 1

for / back > 1

θ_V

S

θ_S

ω

principal plane

ϕ_V

ϕ_S

E

W

N

MOMS-02 ground track

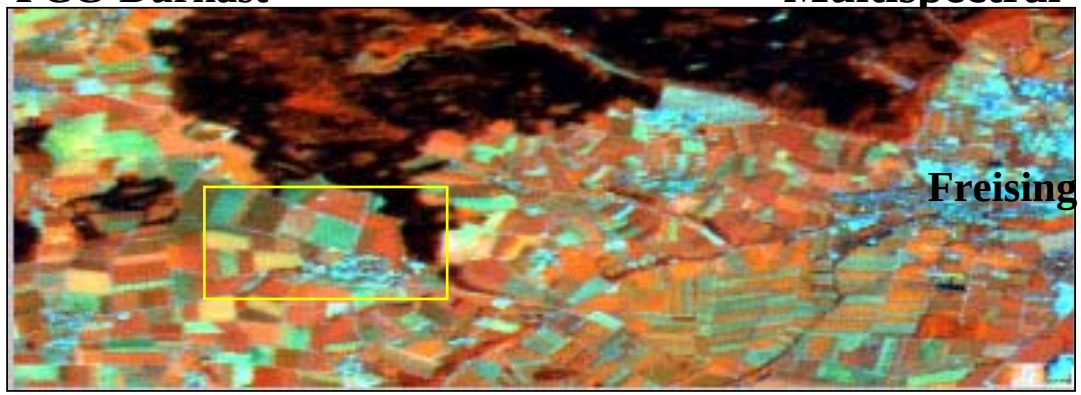
"hot spot" effect

“Multispectral” versus “anisotropy” representation

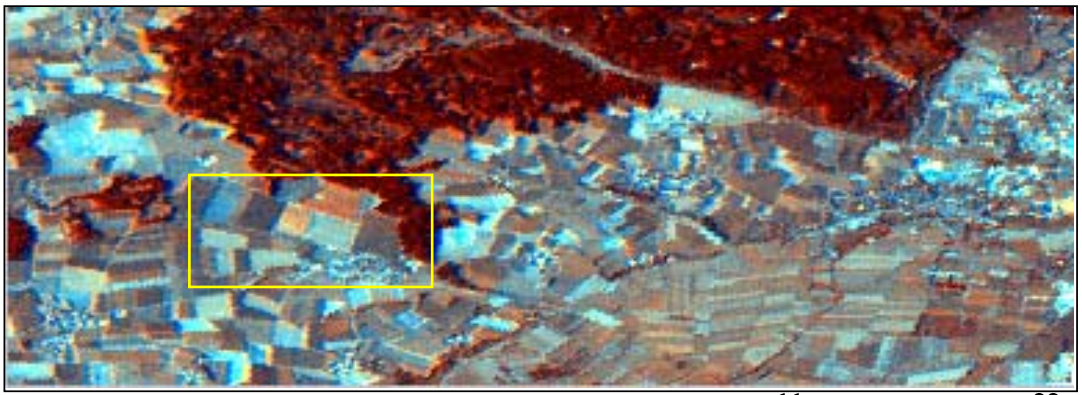
MOMS-2P data set from the Kranzberger Forst area near Freising

FCC Dürnast

“Multispectral”

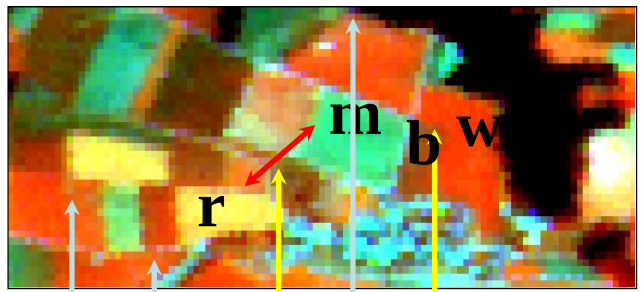


RGB =
ms 4
(st6+st7)/2
ms 1

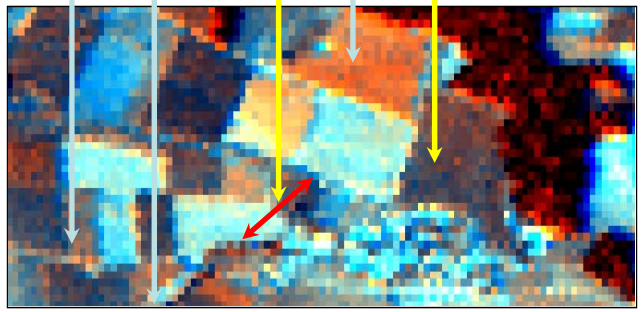


RGB =
st 6 / st 7
st 6
st 7

“Anisotropy”

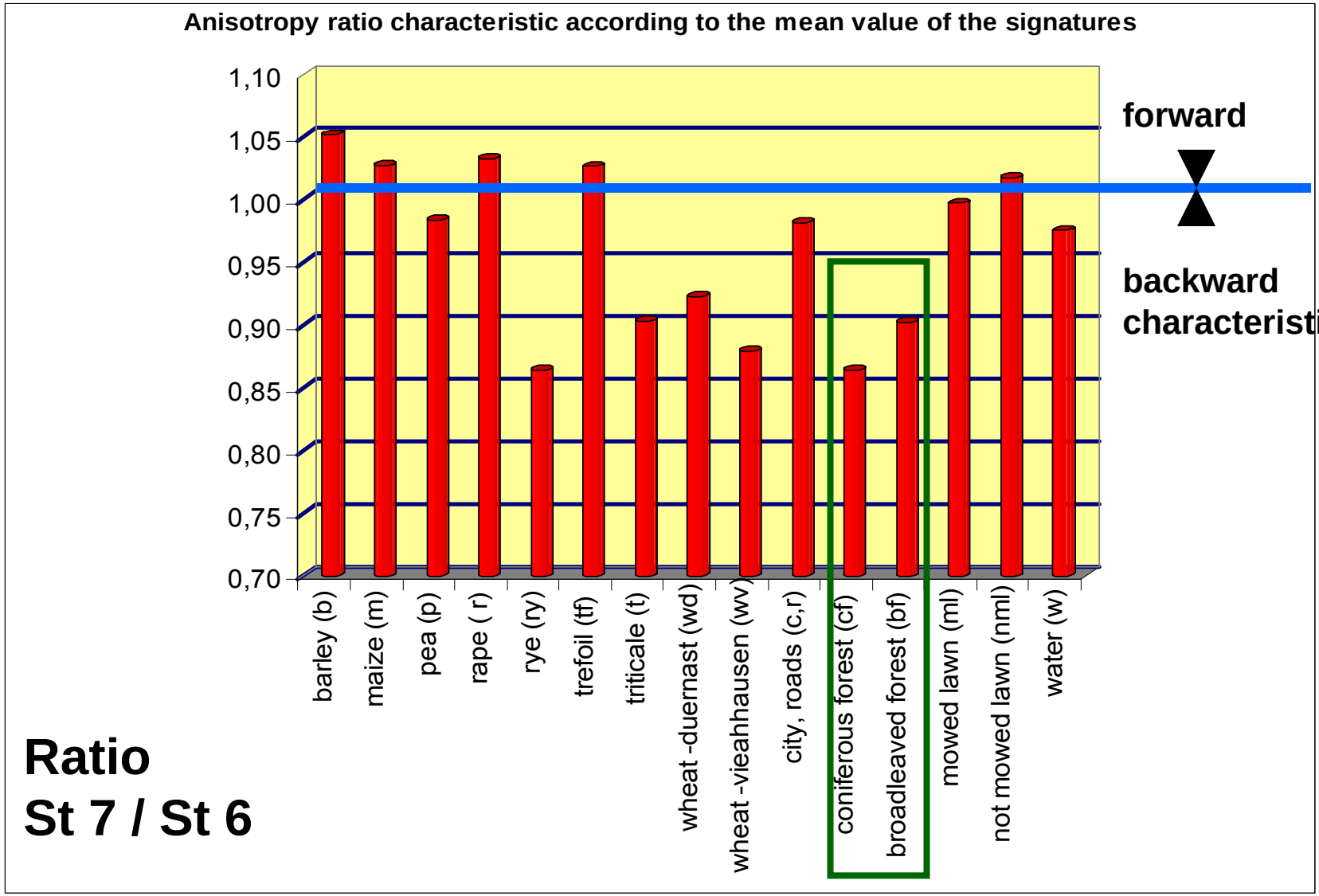


r = rape, m = maize, b = barley, w = wheat



Spectral and angular signatures are related to differing physical properties. The combination of both give us the most information about the surfaces, leading to a significant improvement in identification and status assessment

Anisotropy behaviour of different surface categories



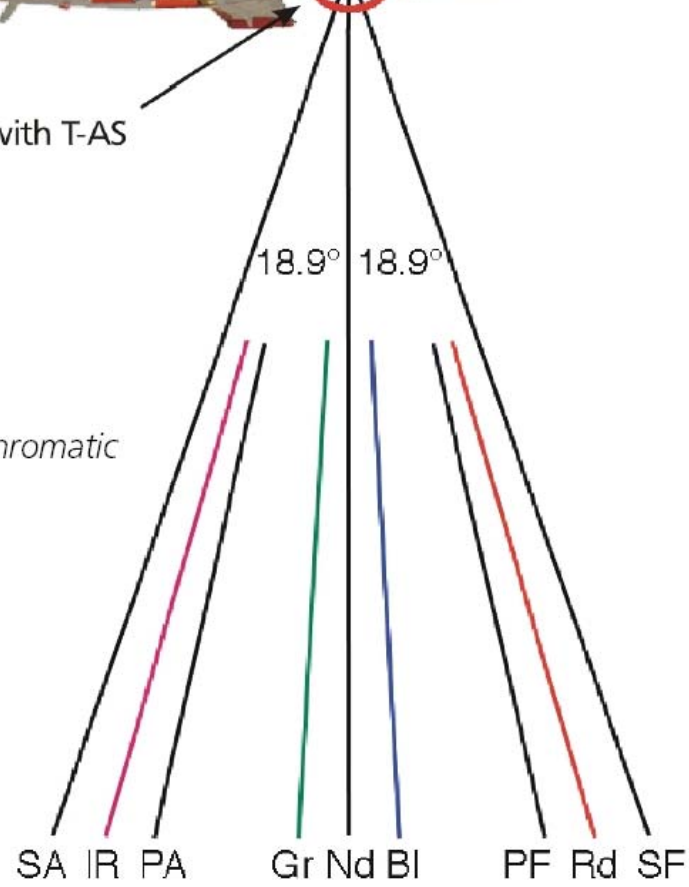
Ratio
St 7 / St 6

Yes, but difficult to be interpreted!!

- Examples where we failed

HRSC (High Resolution Stereo Camera)

HRSC-A with T-AS



SA - Stereo backward, panchromatic
IR - Infrared
PA - Photometric backward, panchromatic
Gr - Green
Nd - Nadir, panchromatic
Bl - Blue
PF - Photometric forward, panchromatic
Rd - Red
SF - Stereo forward, panchromatic

Technical Data

HRSC	-A	-AX	-AXW
focal length	175 mm	151mm	47 mm
field of view	38° x 12°	41° x 29°	30° x 79°
number of CCD lines	9 (4 colors)	9 (4 colors)	5 (2 colors)
pixels per line	5272	12172	12172
pixel size	7 µm	6.5 µm	6.5 µm
radiometric resolution	8 bit	12 bit	12 bit
max. scan frequency	450 lines/sec	1640 lines/sec	1640 lines/sec
stabilization	Zeiss T-AS platform		
data recording	Sony high speed data recorder		
geo referencing	ApplAnix POS/DG Navigation system with GPS and INS		

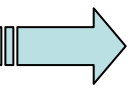
http://solarsystem.dlr.de/FE/abteilung/pdfs/HRSC-AXW-handout.pdf

HRSC “Anisotropy”-image

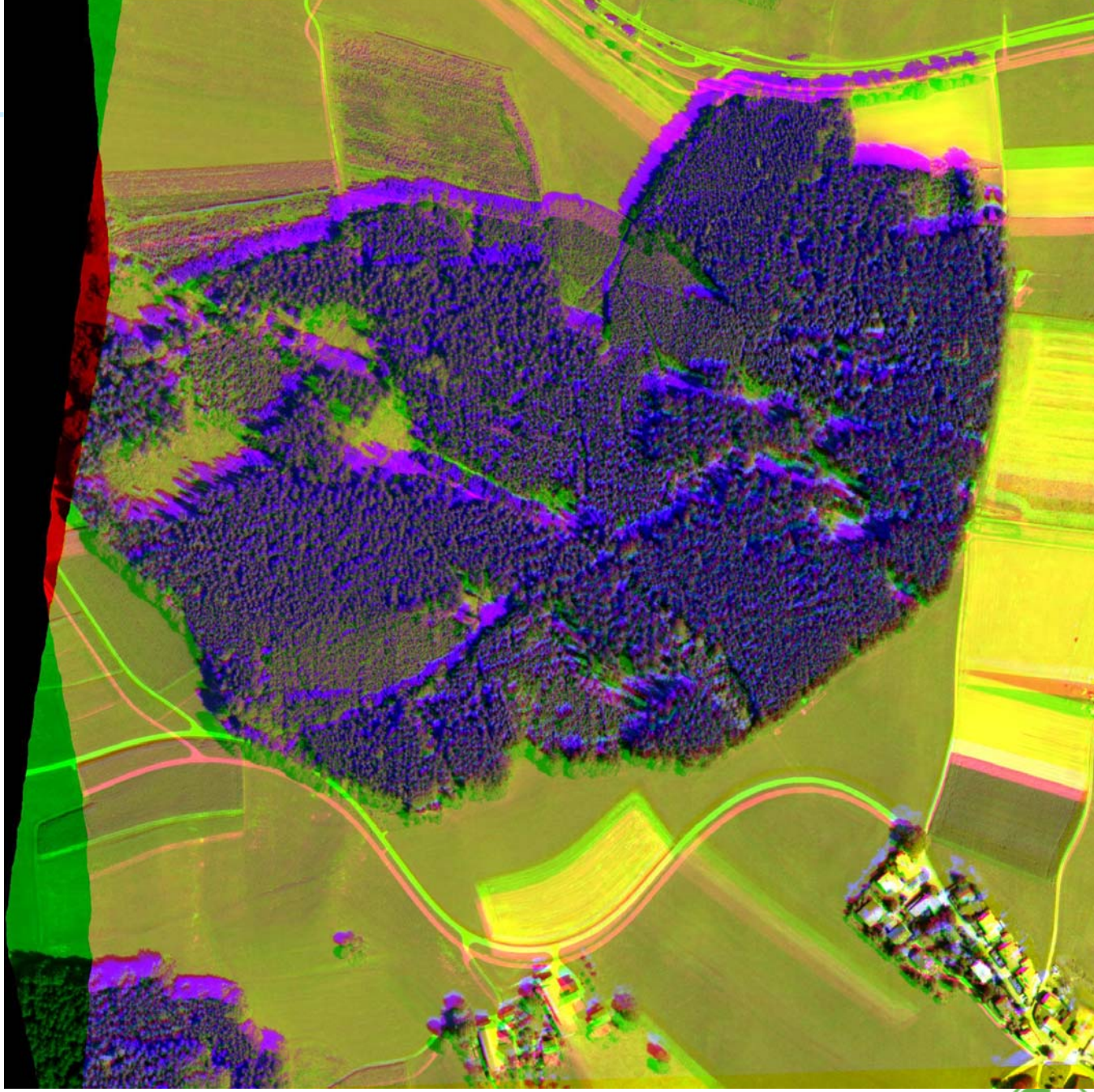
RGB =
s1 (18,5° forward)
s2 (18,5° backward)
s1/s2

Testsite
Waging-Tachinger Lake

“HighTech Offensive Bayern” project
“Applied fresh water remote sensing”

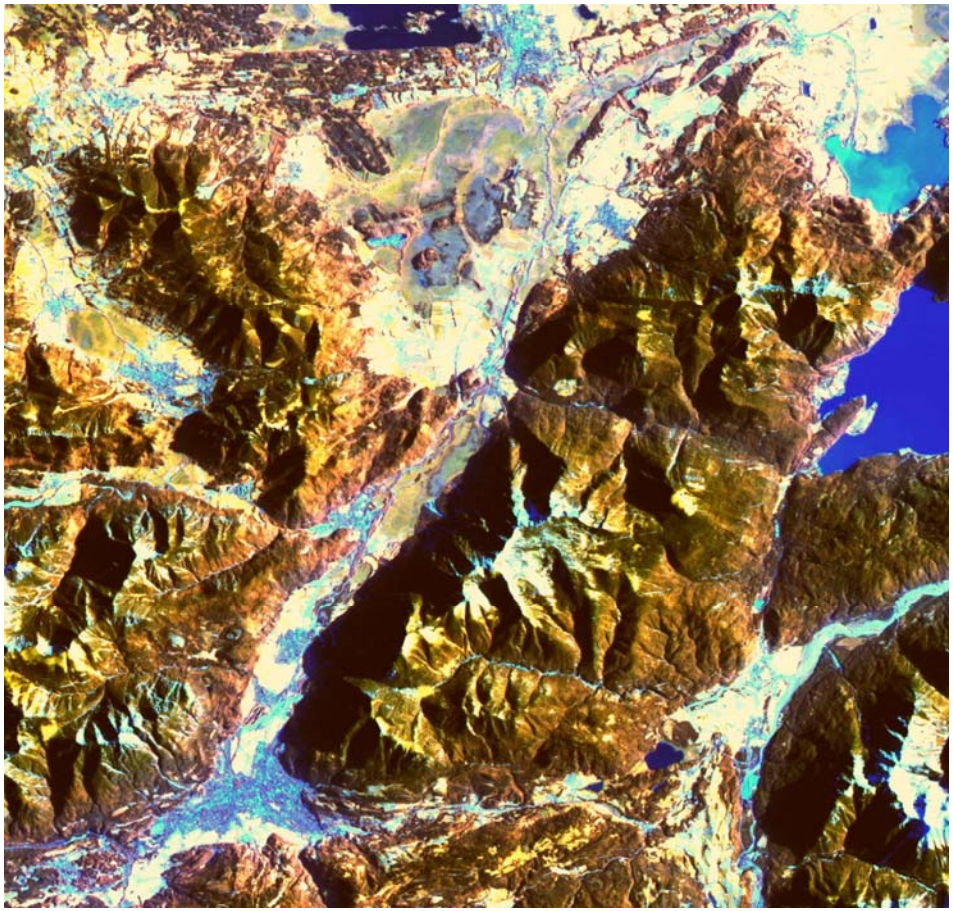


Very complex geometry!

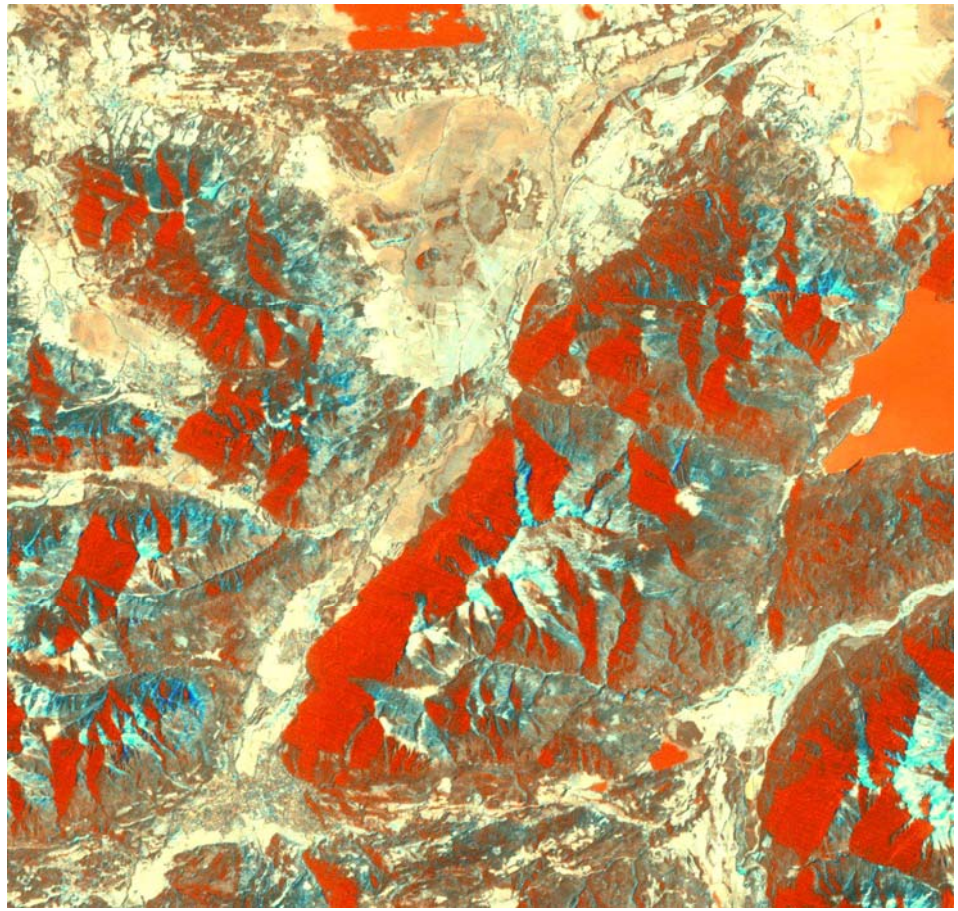


Topography

- MOMS-2P mode D data, Oberammergau Testsite, Bavarian Alps



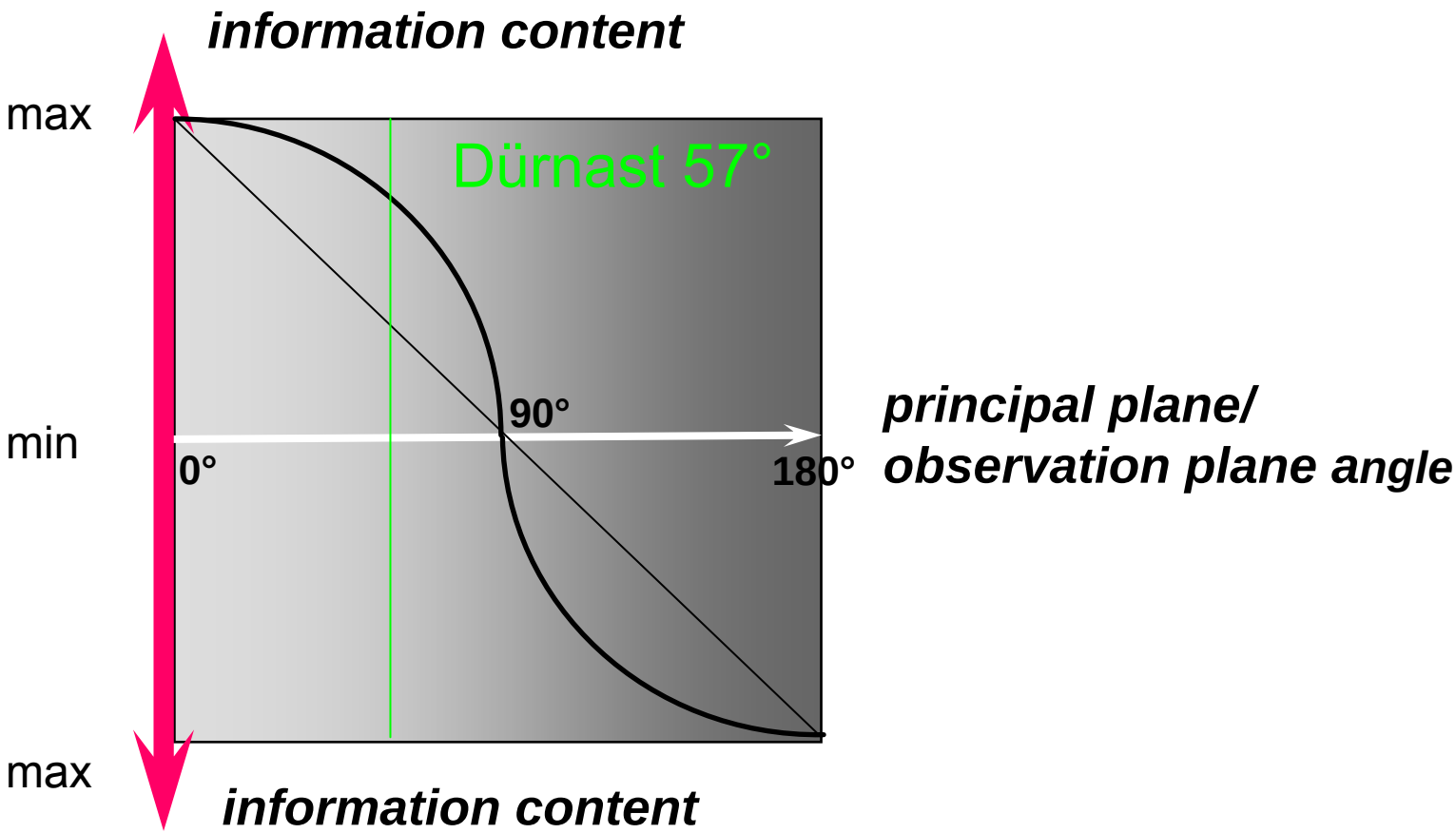
RGB: NIR, (st6 + st7)/2, blue



RGB: (st6 / st7), 6, 7

Hypothesis:

„The information content of the „anisotropy ratio“ is controlled by the angle between the principal plane and the observation plane“ and may be described by a function!“ **But which one??**



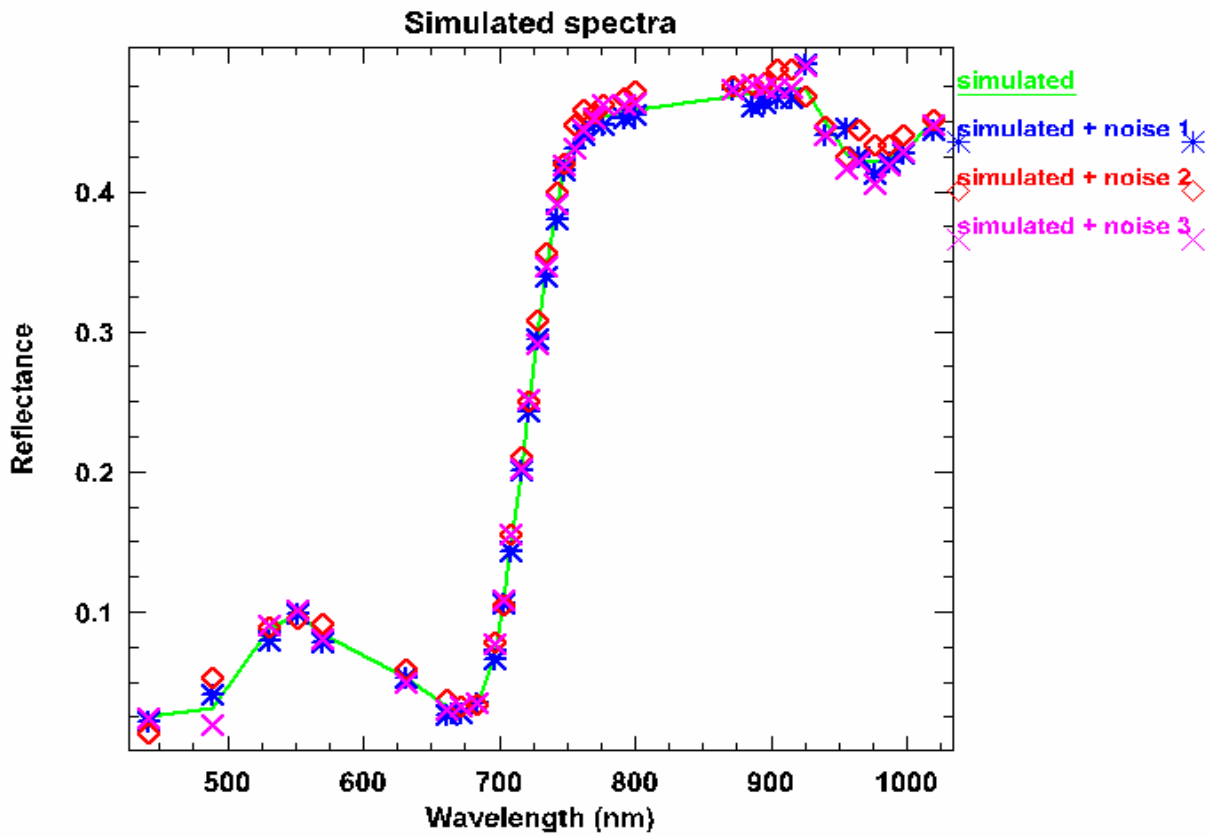
1. Goniometer principle (EGO, FIGOS)

Vogt, P., M. M. Verstraete, B. Pinty, M. Menenti, A. Caramagno, and M. Rast (1999):

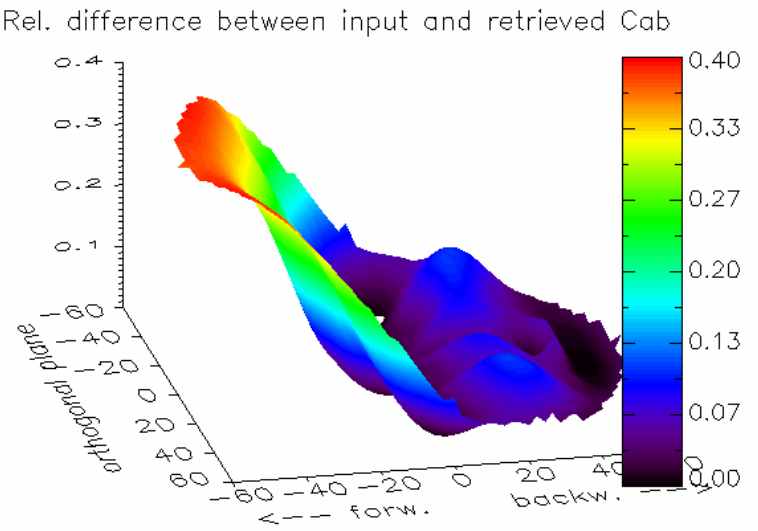
'On the retrieval accuracy of the albedo and BRF fields: Potential of the LSPIM/PRISM sensor', Joint Research Centre Publication **EUR 19016 EN**.

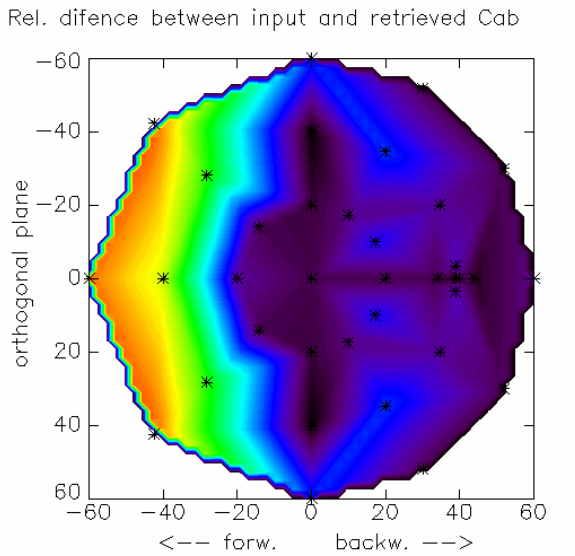
Simulated data (pure and with simulated atmospheric and sensor noise):

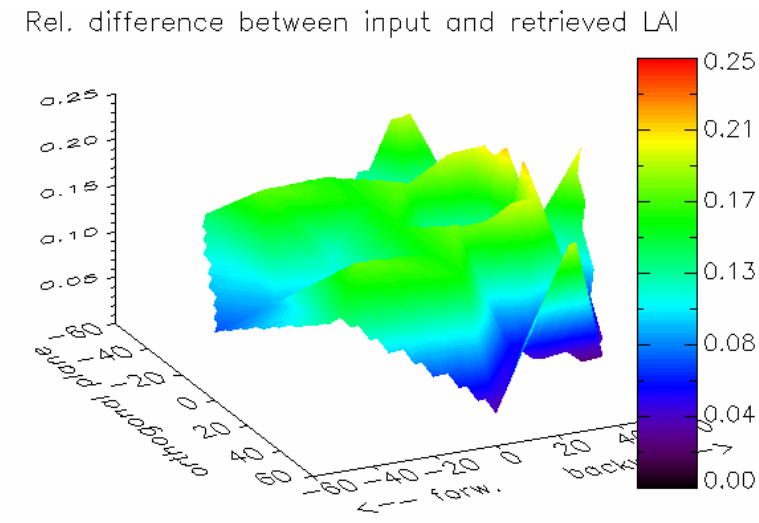
Leaf chlorophyll a+b (μg/cm²) : 40
Leaf water content (g/cm²) : 0.025
Dry matter content / SLW (g/cm²) : 0.0065 (≅ 0.25 * Cw)
Leaf structure parameter : 1.7
LAI : 4.0
ALA (°) : 60
Hotspot : 0.1
Soil brightness : 1.0

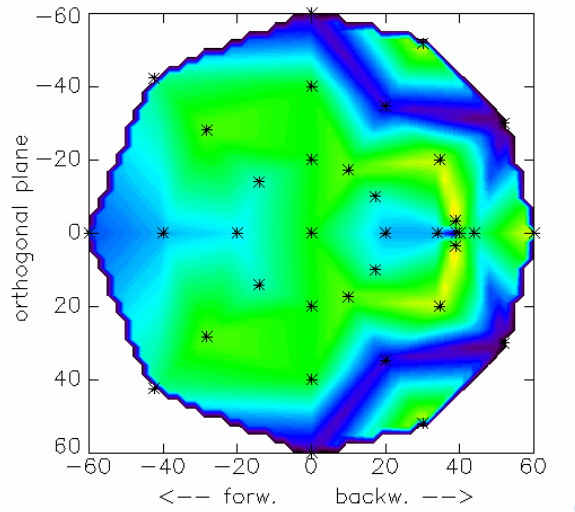


Example for nadir view
SZ = 39°

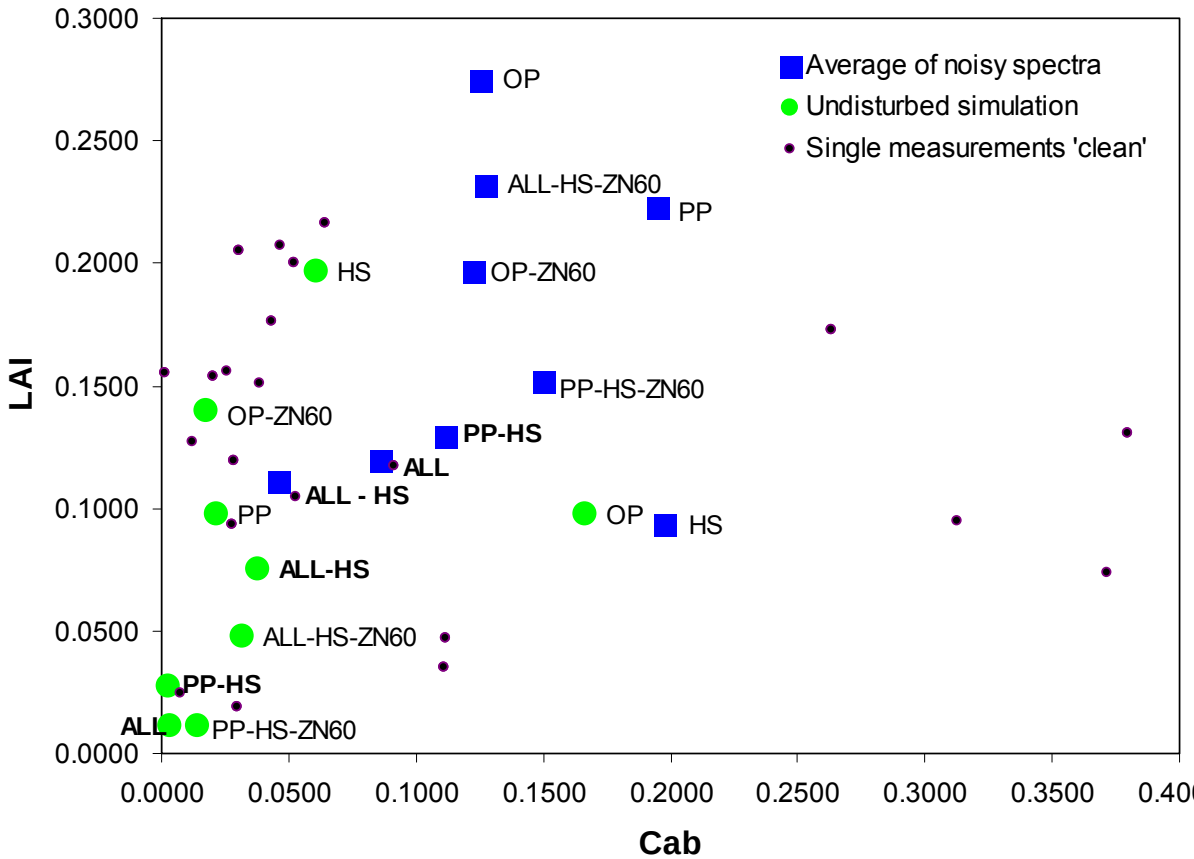

Rel. difference between input and retrieved Cab
orthogonal plane
<-- forw.
backw. -->
0.40
0.33
0.27
0.20
0.13
0.07
0.00


Rel. difence between input and retrieved Cab
orthogonal plane
<-- forw.
backw. -->
−60
−40
−20
0
20
40
60


Rel. difference between input and retrieved LAI
orthogonal plane
<-- forw.
0.25
0.21
0.17
0.13
0.08
0.04
0.00


Rel. difference between input and retrieved LAI
orthogonal plane
<-- forw.
backw. -->
−60
−40
−20
0
20
40
60

- Compare different view constellations for simulated data
- Every single measurement
- All measurements together (+/- Hot spot)
- All measurements in principal plane (+/- Hot spot, +/- 60° zenith)
- All measurements in orthogonal plane (+/- 60° zenith)
- Only hotspot



In brief:

- Laboratory loop should describe the geophysical system as accurate as possible
- The operational loop should apply this knowledge for normalizing and interpreting RS data sets according to the needs of an operational application

Specific goals “laboratory loop” :

The ***creation*** of **calibration data bases** for the ***adaptation*** and the ***inversion*** of **physical models**

➔ measurements appropriate for BRDF approximation (TOC BRf field)
➔ measurements covering the whole vegetation period
➔ measurements covering most of the variations (growth differences) within a surface (e.g. subplots with differing field water storage capacities)

Surface types under investigation:
forests, crops, grassland, reed

Our requirements on a measurement device ?

MUFSPEM success stories :

• The Mobile Unit for Field Spectroscopy Measurements (**MUFSPEM**), has been used over the period 1999 – 2001

• The concept for the measurement arrangement to be **high**, **mobile** and **fast** ➔ ***was reached***

• A data base for BRDF approximation throughout the vegetation period of ***winter wheat***, ***winter barley*** and ***maize*** (74, 51 & 67 available BRDF-hemispheres respectively) has been created. **Rape** (about 15) not evaluated until now.

MGS technical data:

MGS „goniometer“ device:

- height above ground: 10-12,5m, above canopy: 10m
- positioning accurracy: azimuth +/- 3° zenith +/- 2° (worst case)
- azimuth angle range: 270°
- zenith angle range: 0° to 70°
- rotating assembly on the roof rack: 360°
- mounting time 2 persons: appr. 1h

Photogrammetric stereo device:

- 2 Canon G2 digital cameras, remote control
- base distance: 1m
- height above canopy: 5m
- software by Wilfried Linder based on BLUH and LISA

Detectors:

- Field Spec FR (350 – 2500nm) ASD company
- bifurcated fiber cable for alternate object/ reference measurement
- Heitronics KT 15D 8-14µm

Conclusions BOKU experiment:

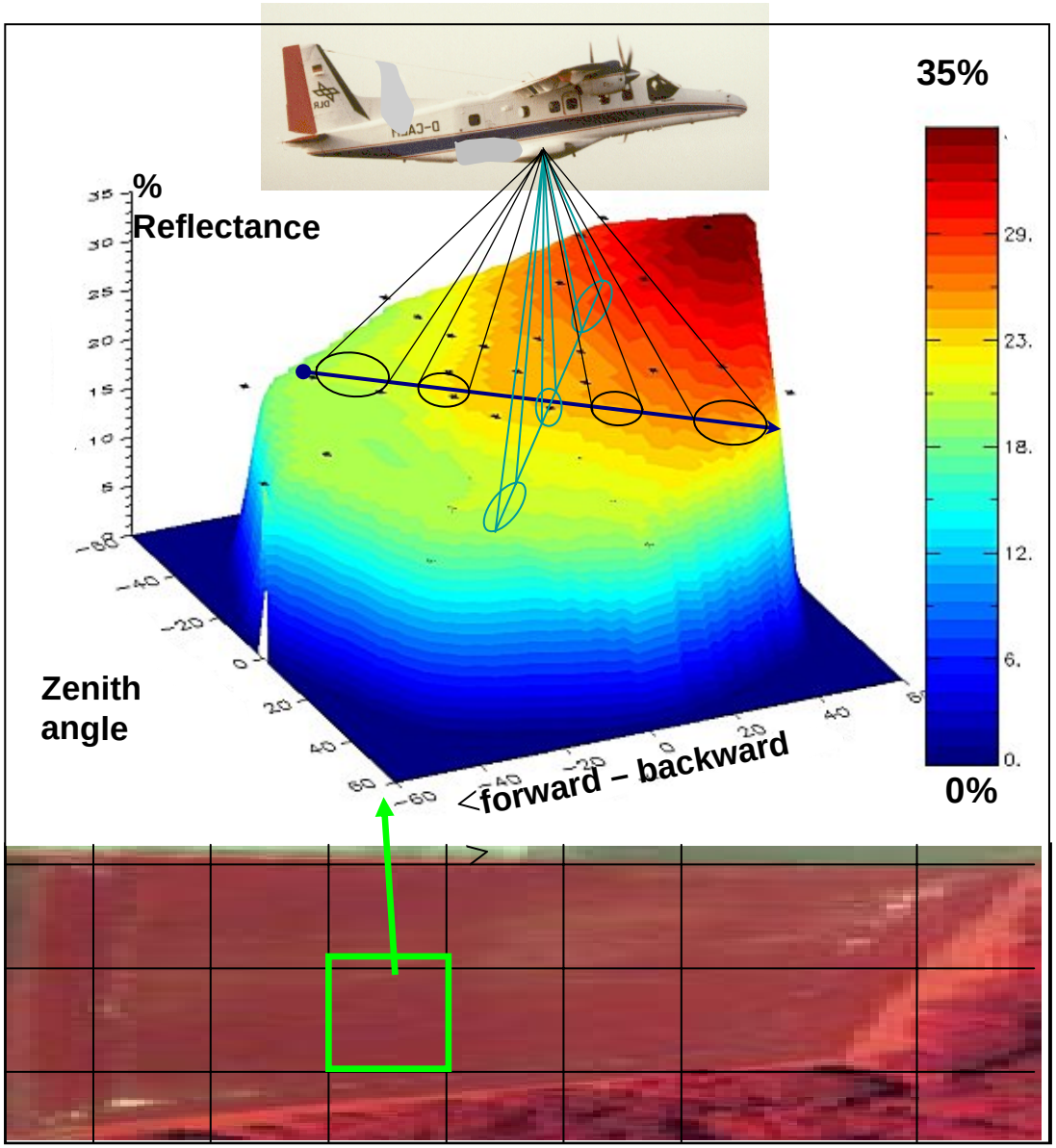
- **Theory:**
  - Inversion most stable for all view angles together without hot spot
    ➔ in hot spot model uncertainties too large
  - Practical configuration (CHRIS): PP without hotspot and SZA60°
    ➔ large SZA: higher measurement and modeling errors, low SNR

- **Practice:**
  - LAI and Cab retrieval is stable for daily course for :
    - All - HOT - SZA60°
    - PP - HOT - SZA60°
    - OP – SZA60° (large spectral deviations => strongly dependent on LUT inputs)
  - LAI overestimated, chlorophyll a+b underestimated

MGS status BOKU Campaign:

- **Solved problems (subset):**
  - ✓ Same surface section measured for all view angles (goniometer principle) ➔ measured backscatter signal is directly comparable
  - ✓ Reference and object measurements within seconds ➔ same illumination conditions
- **Weak points (major):**
  - Fiber cable transmission decrease from 1700nm to 2200nm from around 60% to 25% and is blocked above 2200nm
  - Azimuth angle may be affected by wind induced displacements of the arm
  - Ground reference measurements (“ground truth”) restricted on LAI 2000 and SPAD measurements, LAD from Photographs
  - Etc.
- **Open points (subset):**
  - o Integration of the thermal device (Heitronics KT 15D, 8 – 14 µm)
  - o Shutter solution for alternate object and reference measurements not used during BOKU campaign!
  - o Software solution for the photogrammetric evaluation of stereo pairs still not finished
  - o Do more accurate accompanying measurements improve modelling?
  - o Functionality, results compared to other goniometer systems?
  - o ***Up/downscaling complex to/from CHRIS, other RS data sets!***

BRDF data base required for:



➔directional effects removal from RS data (normalization/calibration issues)

➔Estimation of bio-geo-physikal parameter by model inversion from RS data sets („operational loop“)

➔ *mandatory for thematic information analysis from multidirectional data sets*