A Hyperspectral Thermal Infrared Imaging Instrument for Natural Resources Applications

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Centre de Recherche Public Gabriel Lippmann

TELOPS

Universität Trier

Outline

- Motivation for setting up a HS-TIR platform
- The instrument setup (Telops Hypercam-LW)
- First experiment
  - Introduction
  - Objective
  - Methods
  - Some initial results
- Planned activities in HS-TIR research
- Conclusions

Motivation

- TIR data can be used for many important natural resources applications, e.g.
  - landscape characterization
  - estimation of evapotranspiration and soil moisture
  - drought monitoring
  - urban heat islands
  - air quality studies
- Fits well into departmental research line
- Complements regional multi-sensor airborne platform

Centre de Recherche Public (CRP-GL)

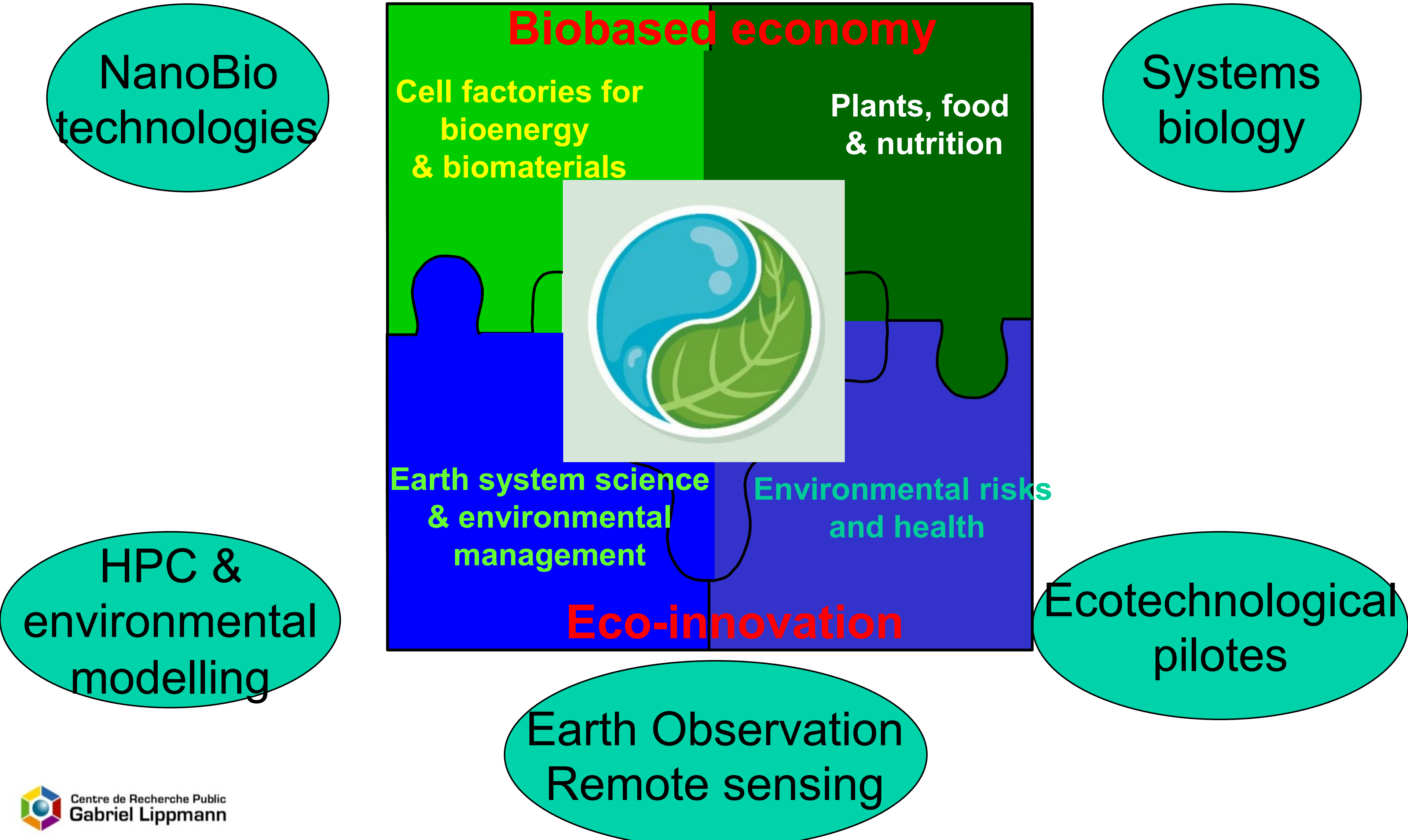
Department 'Environment and agro-biotechnologies' (EVA)

EVA

= 120 staff (researchers, PhD students, technicians), 20 PI

= interdisciplinary competences (agronomists, biologists, geographers, toxicologists, nutritionists, hydrologists, climatologists, engineers,….)

EVA: Four research lines using cutting-edge technologies



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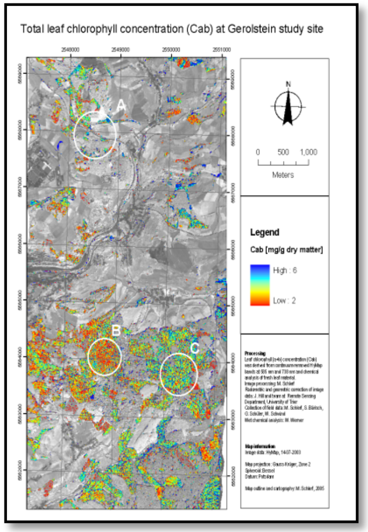
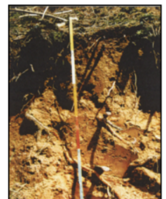
Hyperspectral RS activities

Leaf nitrogen concentration



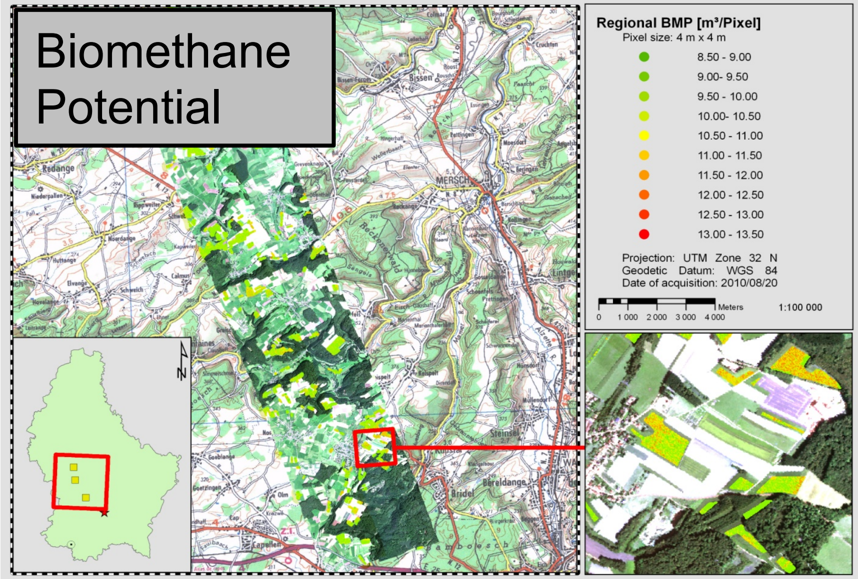
Loam over limestone
- BS: 75-97-98 %
- N: 3480-1300-650 mg kg^{-1}



Sands of Buntsandst.
- BS: 8-3-8-27 %
- N: 2320-1230-200-100 mg kg^{-1}

Schlerf et al. 2010

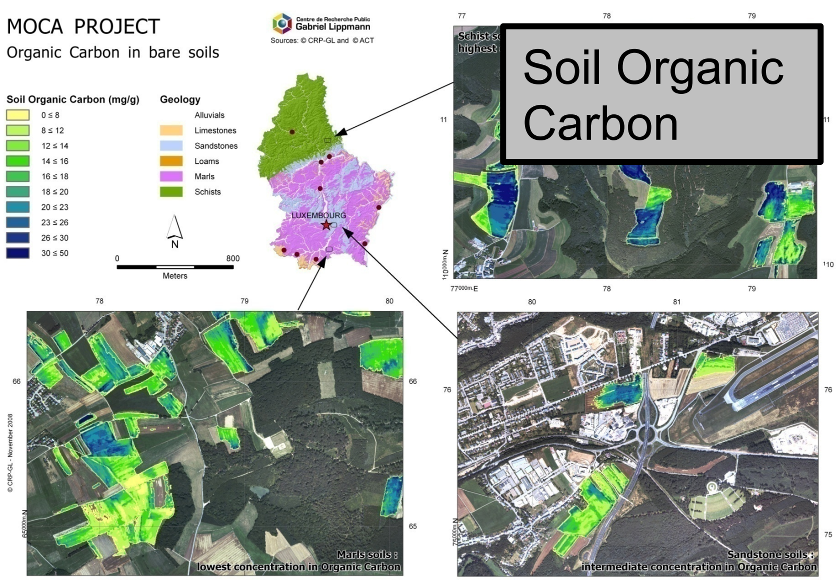
Biomethane Potential



Project: Hyperspec

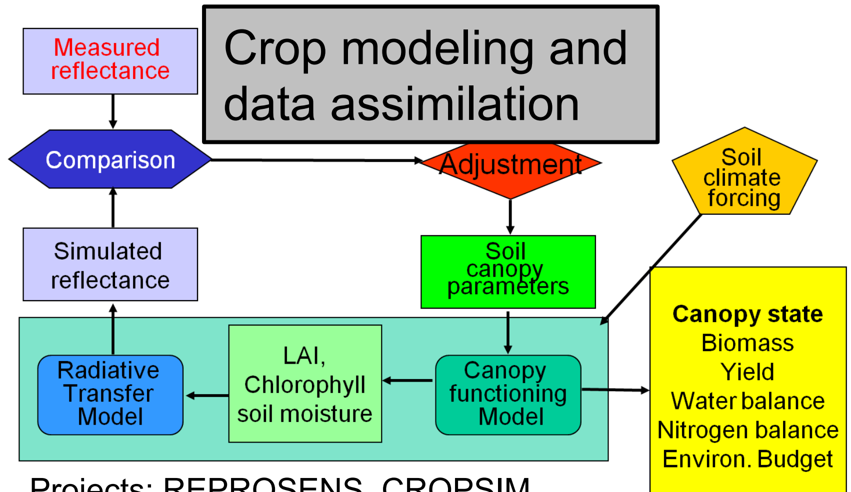
Udelhoven et al. 2011

Soil Organic Carbon



Stevens, Udelhoven, Hoffmann et al. 2011

Crop modeling and data assimilation



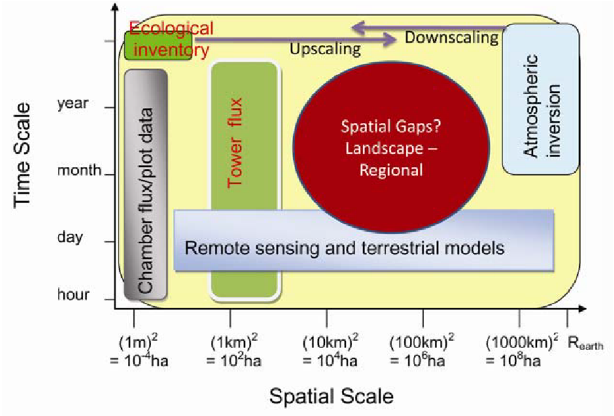
Projects: REPROSENS, CROPSIM

R&I programme EPOS: Ecosystem Processes at varying Scales

1. Remote sensing and *in situ* measurements

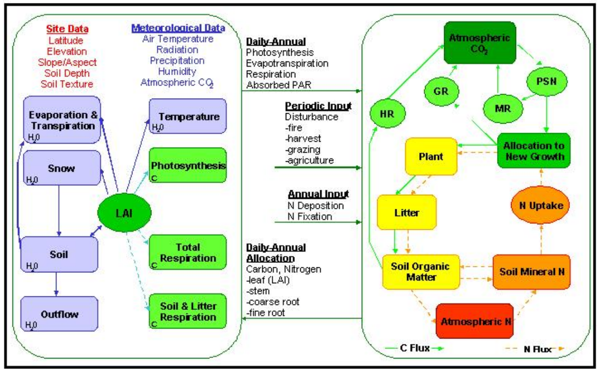
Multiple platform-sensor combinations to measure land surface attributes and fluxes

3. Concepts at various scales



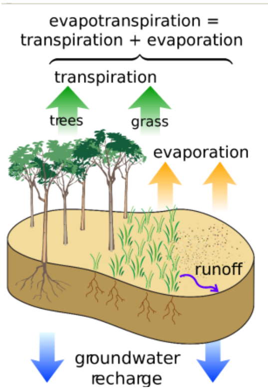
Spatial and temporal scales of different approaches (from Chen and Coops, 2009)

2. Ecohydrological models and regional climate models



Carbon, nitrogen, and water cycling in an eco-system process model

4. Applications



- •Improved estimates of ET and NPP
- •Plant stress mapping
- •Crop condition monitoring

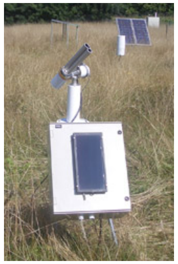
Earth observation equipment

SPAD

ASD FieldSpec II & III+
Spectrometers (CRP)

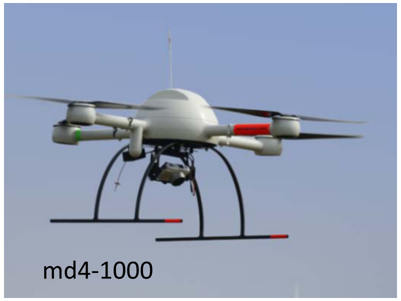
Leaf clip

LiCor LAI 2000
Plant Canopy
Analyzer

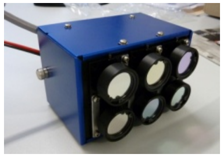


Sunphotometer

Terrestrial laser scanner
(UT)

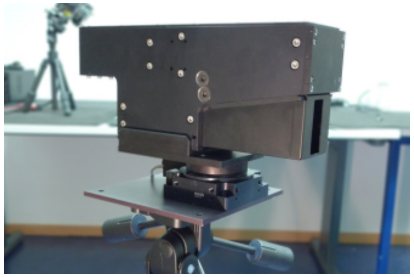


Quadrocopter (UT)



Multispectral
camera

Hyperspectral LWIR imager
Telops Hyper-Cam (CRP)



VIS/NIR/SWIR
hyperspectral camera
HySpex (UT)

GPS

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Common multi-sensor airborne platform with complementary sensors

VITO (B)

APEX (400-2500 nm)
Data pre-processing capabilities
Storage capacities

Research Center Jülich (D)

HyPlant:
Fluorescence sensor (650 – 800 nm)
AISA Dual (400-2500 nm)

CAE- Aviation (L)

CRP-GL (L)

Telops Hypercam (8000-12000 nm)
HPC-System
Storage capacities

University of Trier (D)

HySpex:
(400-2500 nm)
UAV (Md-1000) with
MCA-Multispectral camera
(400-1000 nm)

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Cooperation at lab/field level

ITC

UNIVERSITY OF TWENTE.

Bruker Vertex 70 FTIR

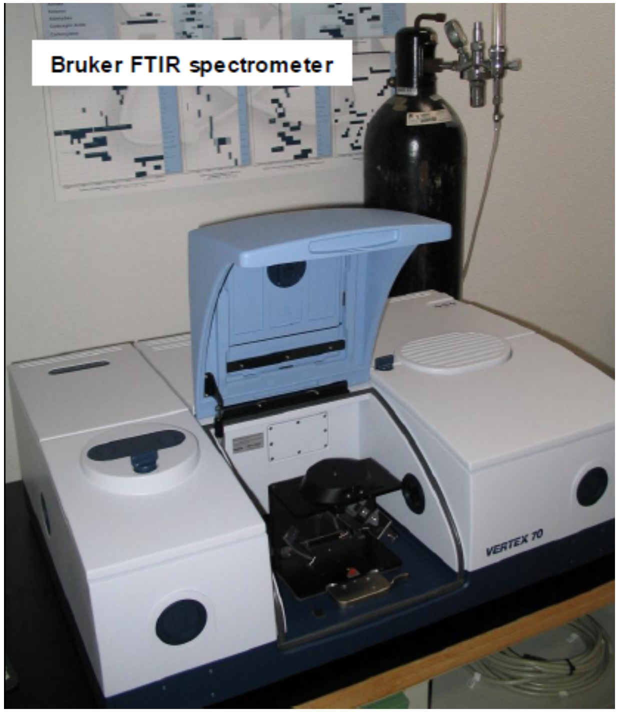

Image by Chris Hecker, ITC

Midac Illuminator 4401 FTIR

3-16 µm

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Telops Hypercam-LW base instrument

- Fourier transform infrared (FTIR) spectrometer
  → higher achievable SNR
- Michelson interferometer
- MCT focal plane array detector
  → adjustable acquisition area
- 2 internal calibration blackbodies
  → fast calibration
- Operability from -10°C to + 45°C
- Acceptable weight (30 kg)

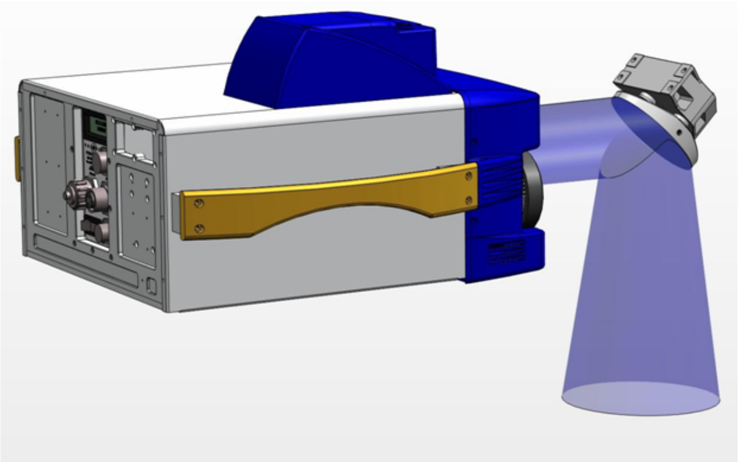
Telops Hypercam-LW base instrument

Hyper-Cam-LW specifications

Parameter	Unit	Hyper-Cam-LW
Spectral Range	µm	7.7 – 12
Spectral Resolution	cm^{-1}	0.25 to 150 (user adjustable)
Image Format	-	320 x 256 pixels
Field of View	Degrees	6.4 x 5.1 (nominal)
	Degrees	25.6 x 20.4 (0.25X telescope)
Typical NESR	nW/cm^2srcm^{-1}	< 20
Radiometric Accuracy	K	<1

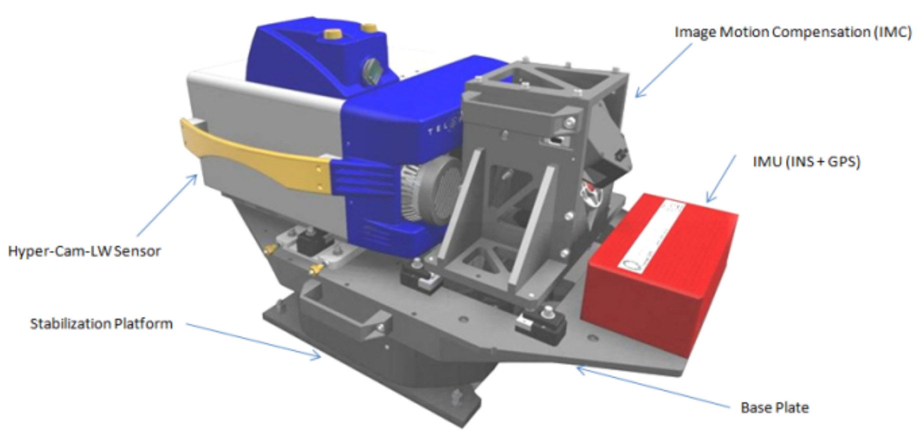
Modification for vertical measurements

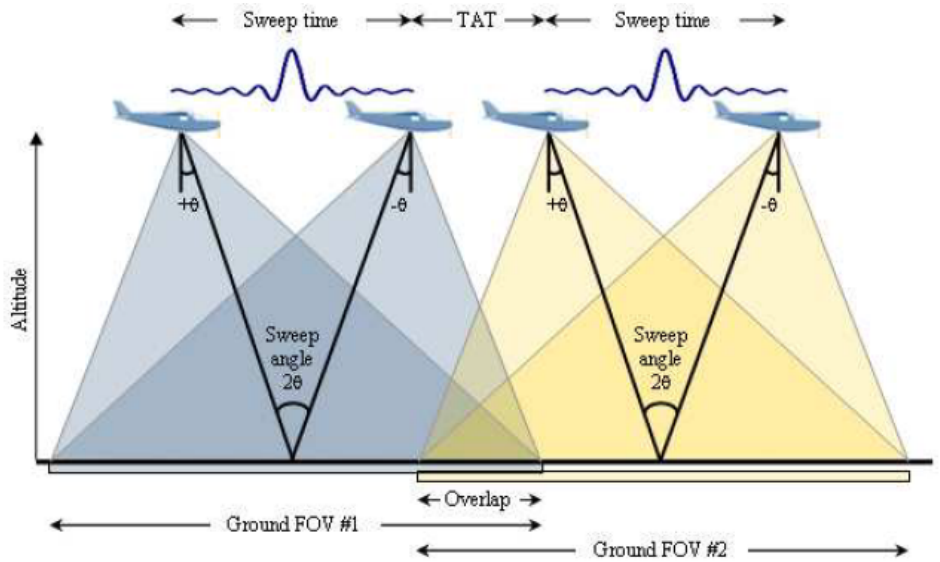
- Facilitates vertical measurements at ground level
- 45° tilted gold coated mirror that is located in the instrument's field of view
- 0.25x telescope
  - FOV at a sensor-target distance of 1.5 m is 672 x 538 mm
  - Resulting pixel size is 2.1 mm
- Airborne mode at 1500 m
  - FOV: 672 / 168 m
  - Pixel size: 2.1 / 0.53 m



Airborne platform

- Stabilization platform: dampens the airplane vibrations and compensates the airplane yaw
- Image Motion Compensator (IMC) mirror: compensates the airplane pitch, roll and forward motion
- GPS/INS unit: enables ortho-rectification and geo-referencing



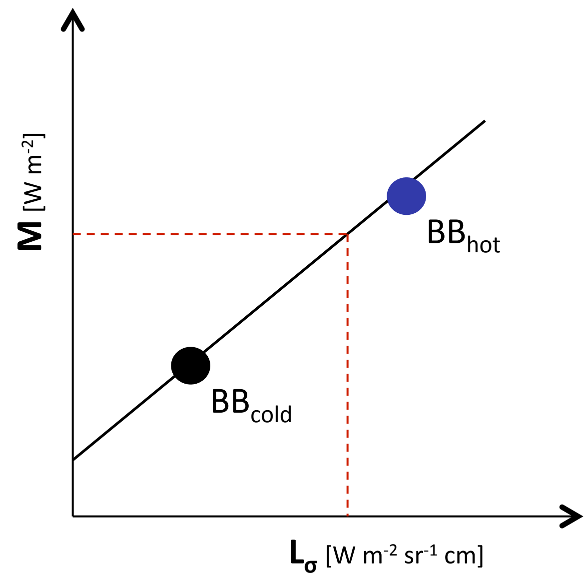


Sample preparation

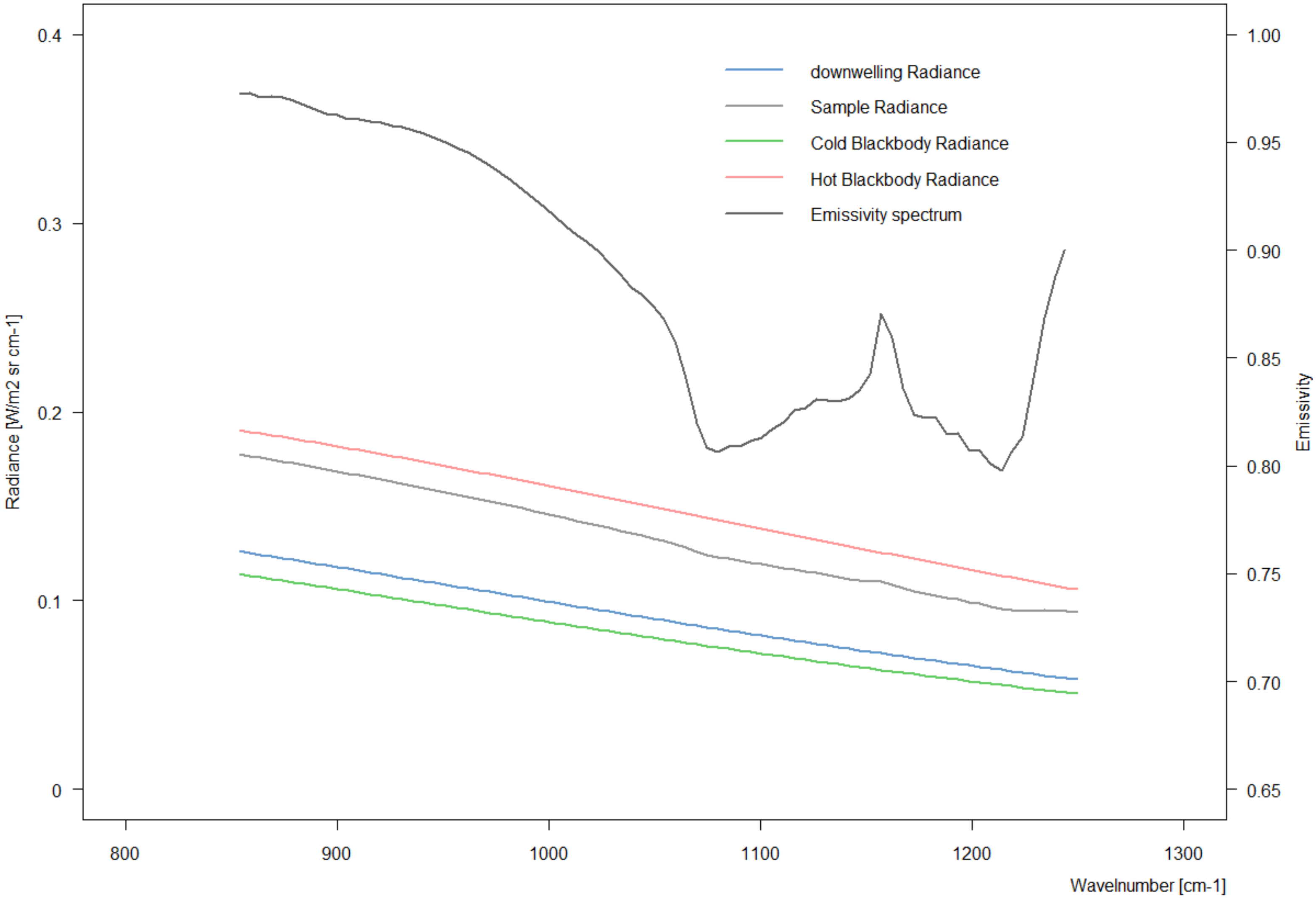
- Rock and mineral samples
  - Sandstone from the Lower Trias (Bunter Sandstone)
  - Calcite
  - Quartz
- The rock sample was heated up (~30 K above ambient temperature)
- Measure sample T with contact thermometer.
- The sample was placed at 3 m distance to the sensor perpendicular to the optical axis of the camera.
- 64 x 20 Pixel, 109 Bands

Instrument calibration

- 2-point calibration
- cold and hot BB temperatures were set to 15°C and 65°C, respectively
- ambient temperature was 22°C
- Knowing the BB T and ε, BB spectral radiance was determined using the Planck function
- Calculation of gain and offset for every pixel
- Conversion of scene's raw spectra into calibrated radiance spectra



Instrument calibration



Background radiation

- Reflected or emitted radiance from background objects (walls and ceiling in the lab) significantly contribute to the target measurement
- Background radiation (downwelling radiance) was measured by collecting the radiance of a diffuse reflective aluminium plate
- The aluminium plate's exact temperature (ambient) was measured using a contact thermometer.
- The (unknown) emissivity of the aluminium plate was determined relative to an infragold target with known emissivity (measured with a Bruker Vertex 70 FTIR spectrometer)
- The resulting overall emissivity value was 20% which is in good agreement with values found in literature.

Emissivity retrieval (summary)

- Assume constant emissivity in a certain region
  - Emissivity was assumed to have a certain fixed value over a defined wavelength region
  - ε was set to a value of 0.97 at the wavelength of the maximum brightness temperature following the approach by Kealy & Hook (1993).
- Fit Planck curve
  - This allowed to iteratively fitting a Planck radiance curve to the measured sample radiance spectrum.
  - The fitting was performed over wavebands from 850 to 905 wavenumbers.

Emissivity retrieval (details)

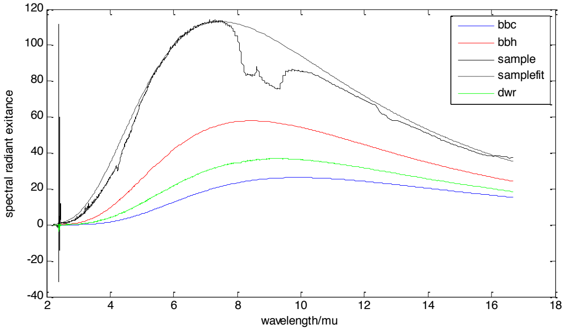
- Blackbody radiance was simulated in unit wavenumber σ, commonly used in spectroscopy as (http://www.spectralcalc.com)

$$L\_bb_\sigma(T) = 2 \times 10^8 hc^2\sigma^3 \frac{1}{e^{\frac{100\,hc\sigma}{kT}}-1} Wm^{-2}sr^{-1}(cm^{-1})^{-1}$$

where, L_bb_σ is the spectral radiance emitted by a BB at the absolute temperature T for wavenumber σ, h is the Planck constant, k is the Boltzmann constant, and c is the speed of light.

- The blackbody radiance was then fitted to the measured sample radiance L_sa_σ over the defined waveband region by adjusting T assuming the predefined emissivity ε_σ:

$$L\_sa_\sigma = \varepsilon_\sigma \, L\_bb_\sigma(T)$$



- Finally, spectral emissivity ε_σ was calculated as:

$$\varepsilon_\sigma = \frac{L\_sa_\sigma - L\_dw_\sigma}{L\_bb_\sigma(T) - L\_dw_\sigma}$$

where L_dw_σ is the downwelling (background) radiance.

Testing reproducibility

- Replicate measurements of the same sample material
- Acquisition of multiple data cubes in a short time interval (image subsets 64 x 20 pixels, spectral res. of 6.2 cm^{-1})
- BS sample heated up to 60°C
- 20 frames were captured within 30 s (cooling of sample <0.5 K)
- 3 runs, thus 58 frames were measured (two frames were removed)
- From 58 emissivity spectra computation of mean and standard deviation

Reference spectra

Bruker Vertex 70 FTIR

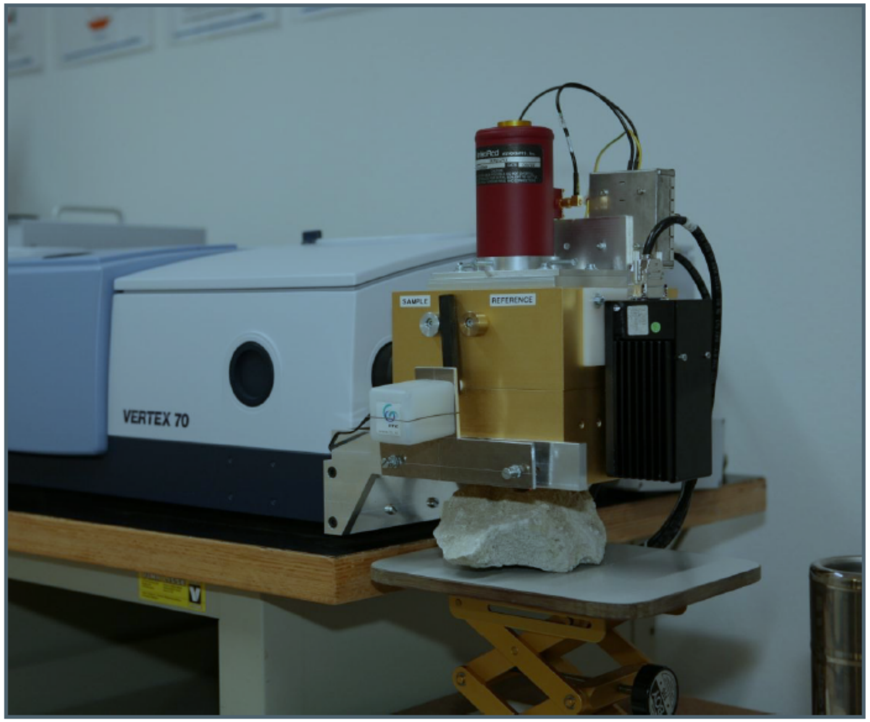
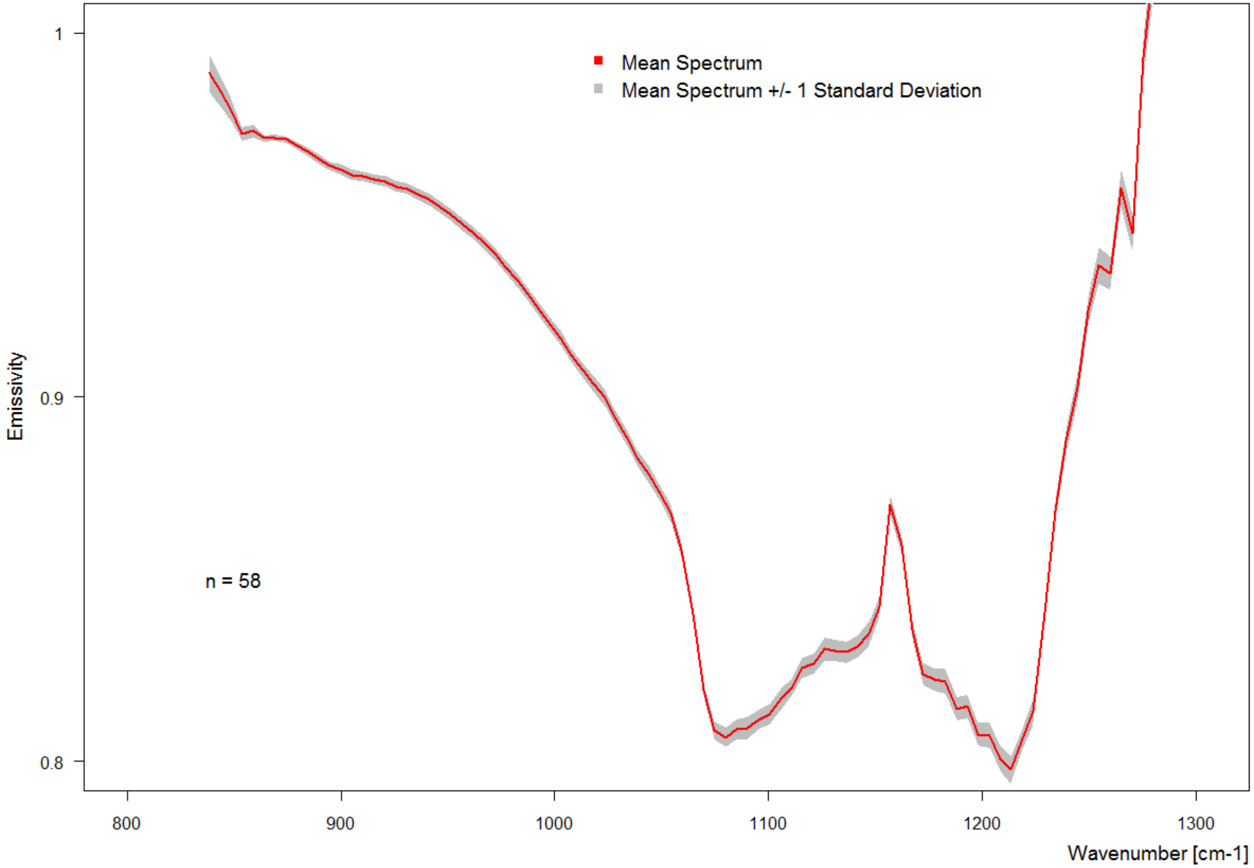


Image by Chris Hecker, ITC

- Same rock samples were measured at ITC lab
- Bruker Vertex 70 FTIR spectrometer
- Measurement protocol as described in Hecker et al. 2012
  - DHR measurements
  - Emissivity=1-DHR

Results: Reproducability

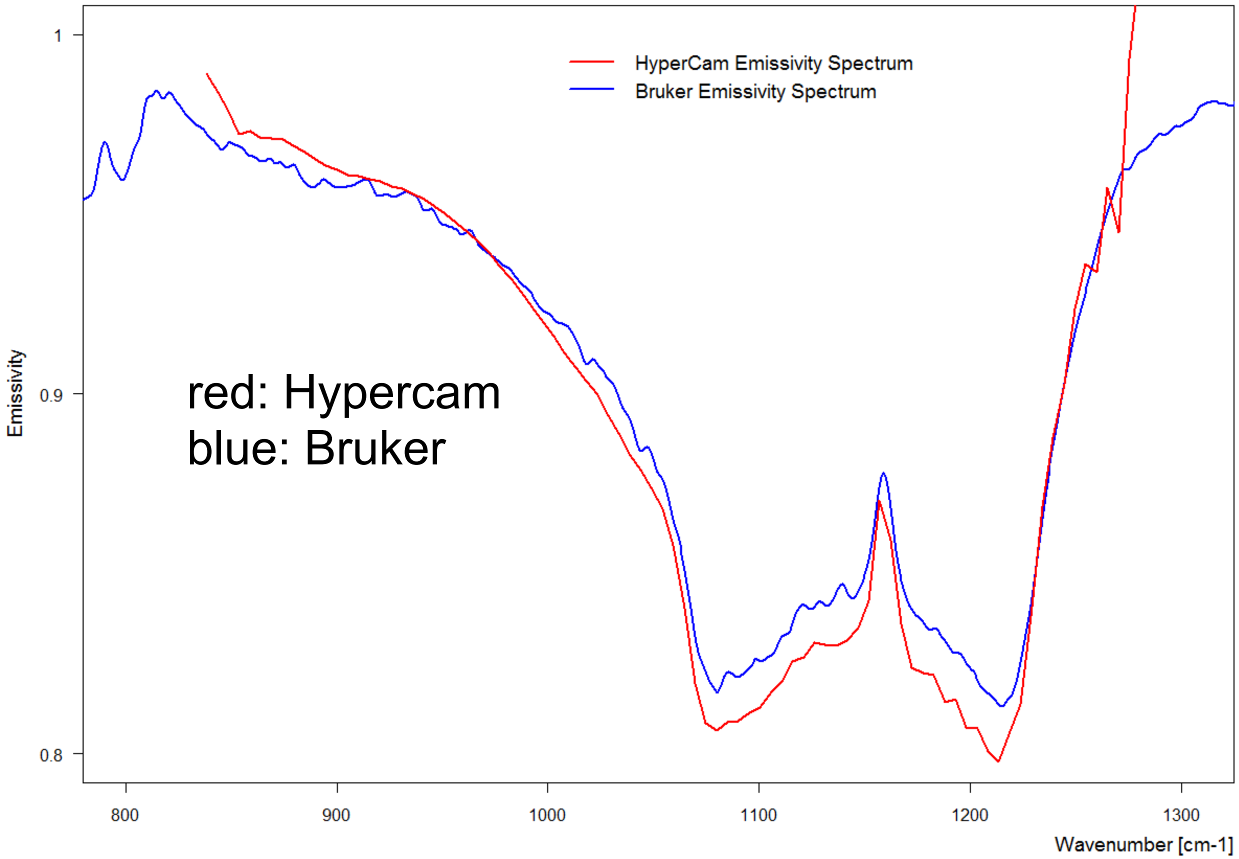
Bunter Sandstone



- standard deviations <0.01
- variation coefficients of up to 1.25%
- → good reproducibility
- Hecker et al. (2011) with lab instrument: variation coefficients of 0.25%-1.75%

Results: Emissivity spectra

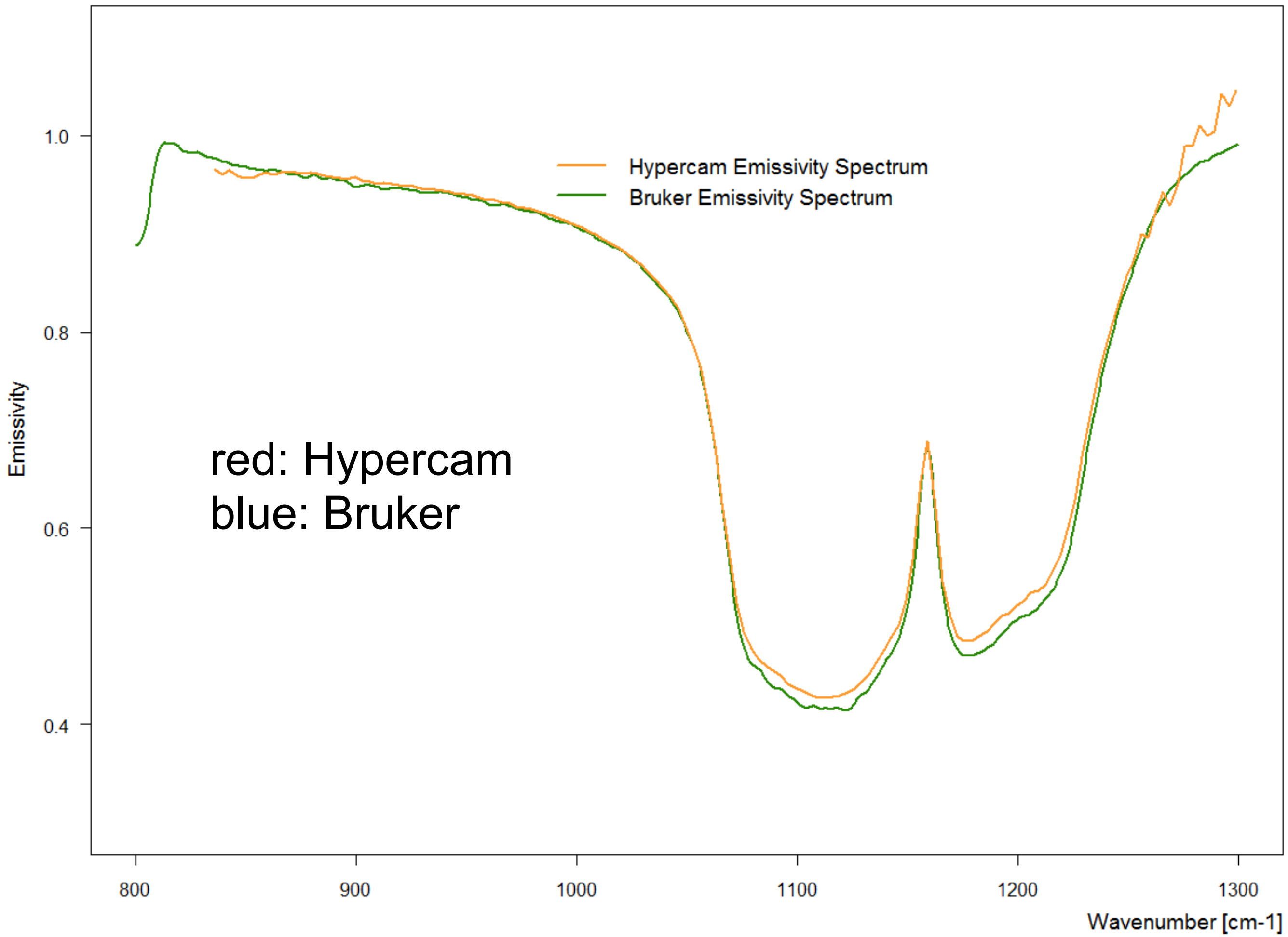
Bunter Sandstone



- relatively good agreement of emissivity values
  - best left/right of the quartz doublet
  - less at the doublet
- Good agreement of the positions of the minima at 10,800 cm^{-1} and 12,200 cm^{-1}

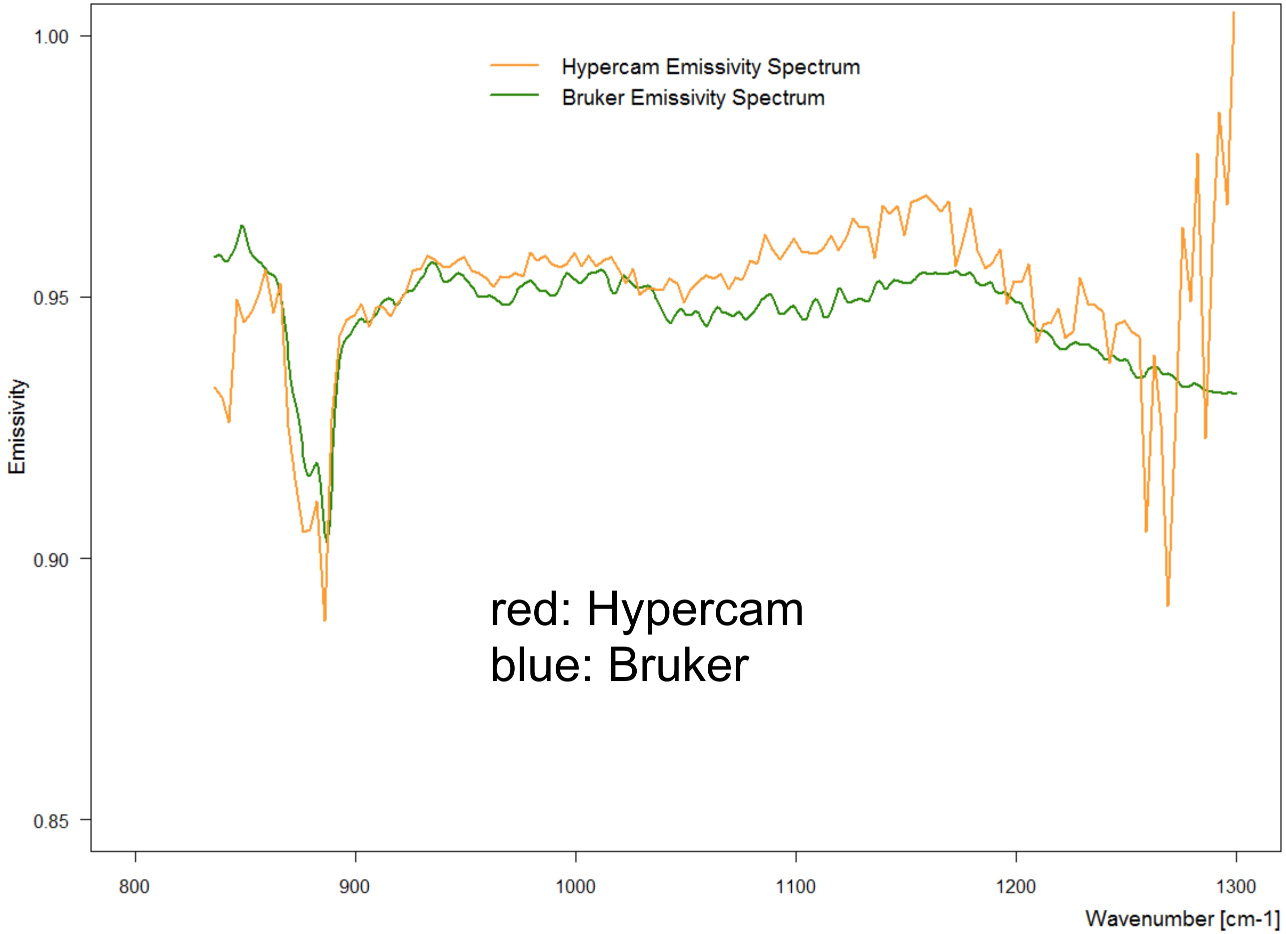
Results: Emissivity spectra

Quartz

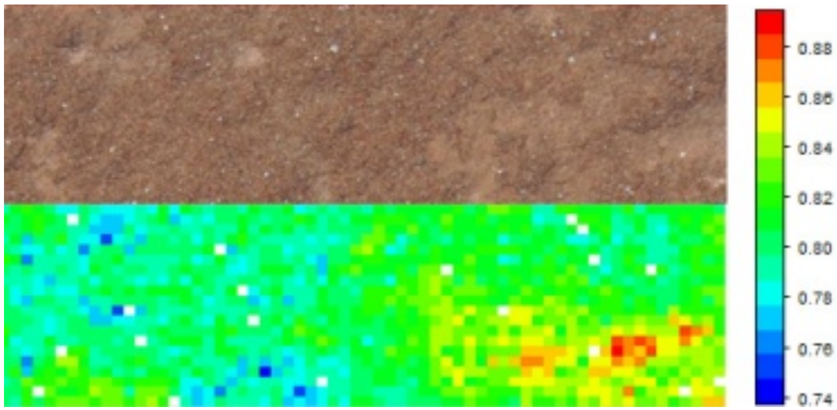


Results: Emissivity spectra

Calcite

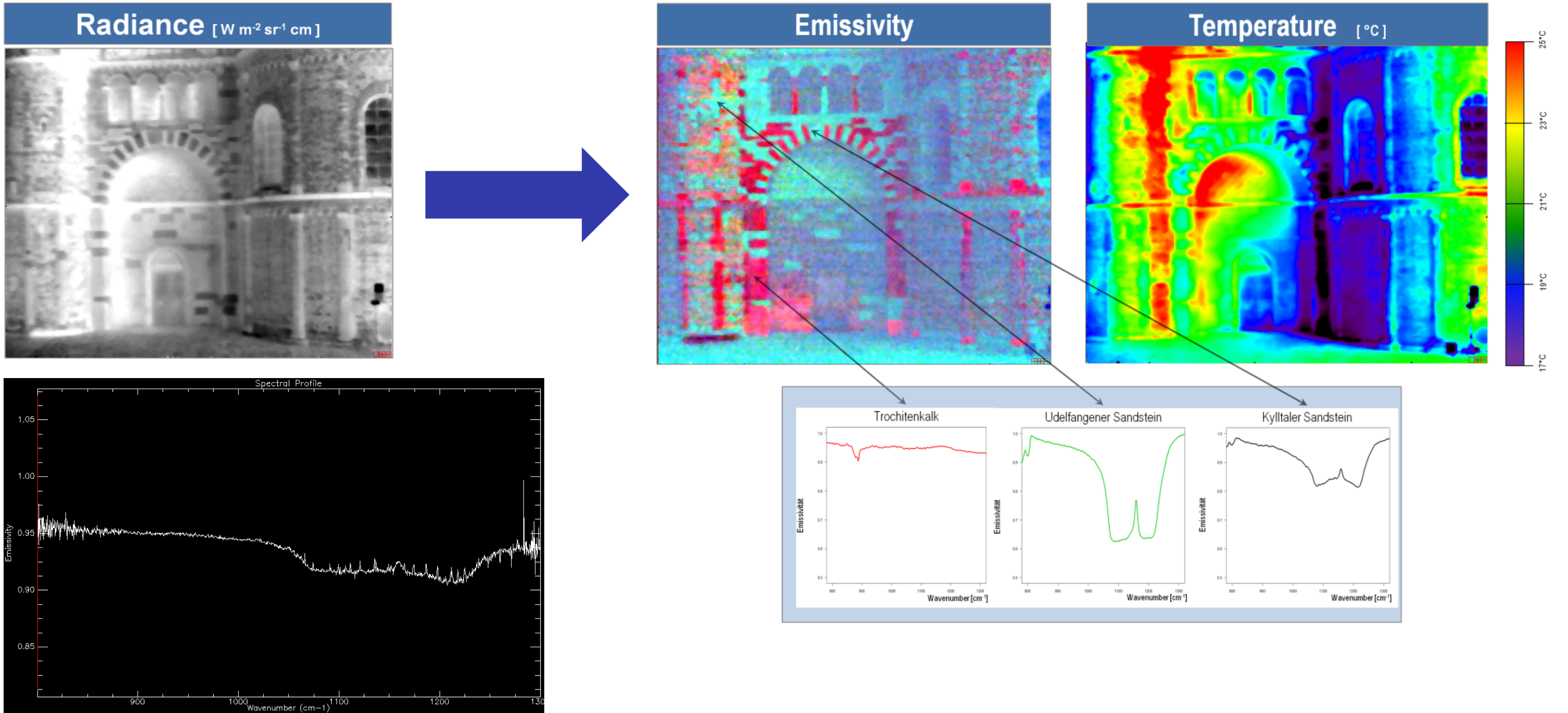


Results: Spatial variability of emissivity



- clear variation of emissivity over the sandstone surface (not obvious from the image in the visible)
- dominant matrix of emissivity values of 0.81-0.83 (green)
- marked areas
  - with much smaller values of 0.76-0.78 (blue)
  - larger values of around 0.86-0.88 (red).
- Influential factors: material, surface structure, viewing angle, geometry, temperature, etc.

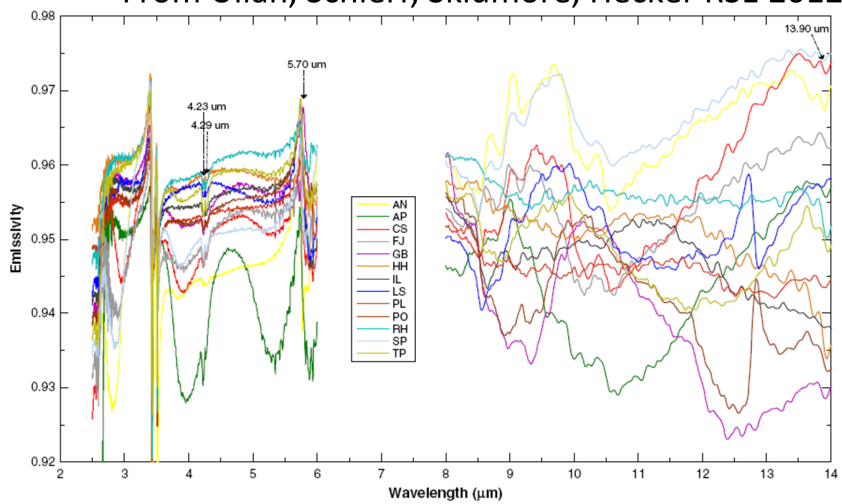
Mapping rocks



Next steps

- Use a better TES algorithm
- Correct for atmosphere effects
- Extent to other surface materials
- Extent previous lab study on plant species discrimination to canopies

From Ullah, Schlerf, Skidmore, Hecker RSE 2012



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Planned research activities / ideas

- Mapping of water-deficit stress in agricultural crops for improved water management (1 PhD started 2012 + 1 PhD student start 2013)
- Photosynthetic activity of plants (HyPlant +Hypercam) (within FLEX)
- Urban heat island effect in the City of Luxembourg (Hypercam+HySpex+Lidar)
- Air quality studies
- CRP is interested in cooperation and in providing services to third parties

Time line

- April 2012: Delivery of Hypercam
- May/June 2012: First experiments
- July 2012: Summerschool
- August/September 2012: More experiments
- October 2012: Shipping to Telops
- Januar 2013: Delivery of airborne module
- March 2013: Processing scheme operation (VITO)
- April 2013: Installation to aircraft (CAE)
- May 2013: First test flight in Luxembourg

Conclusions

- Initial results look promising:
  - Successful retrieval of mineral and rock emissivities at lab scale
- A lot of work still needs to be done
- First airborne test campaign foreseen in summer 2013

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