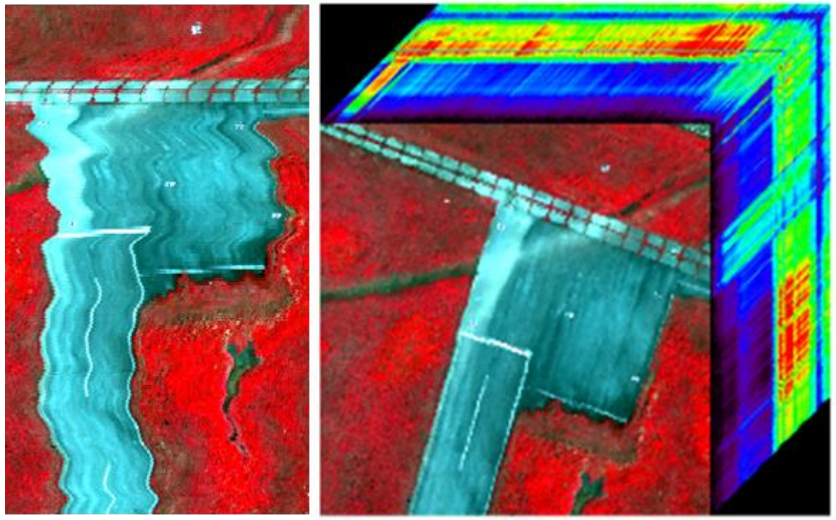
INTERNATIONAL REMOTE SENSING SUMMER SCHOOL , IV EDITION

Experiencing Remote Sensing on Sardinia inland site: Advanced summer school on instruments and methodology for a CAL/VAL site for Optical data

SAN VERO MILIS | SARDINIA, ITALY | 21. - 25. JULY 2025

Introducing the UAV hyperspectral scanning

Michal Gallay, Katarína Onačillová, Ján Šašak



INSTITUTE OF GEOGRAPHY, FACULTY OF SCIENCE,
PAVOL JOZEF ŠAFÁRIK UNIVERSITY IN KOŠICE, SLOVAKIA

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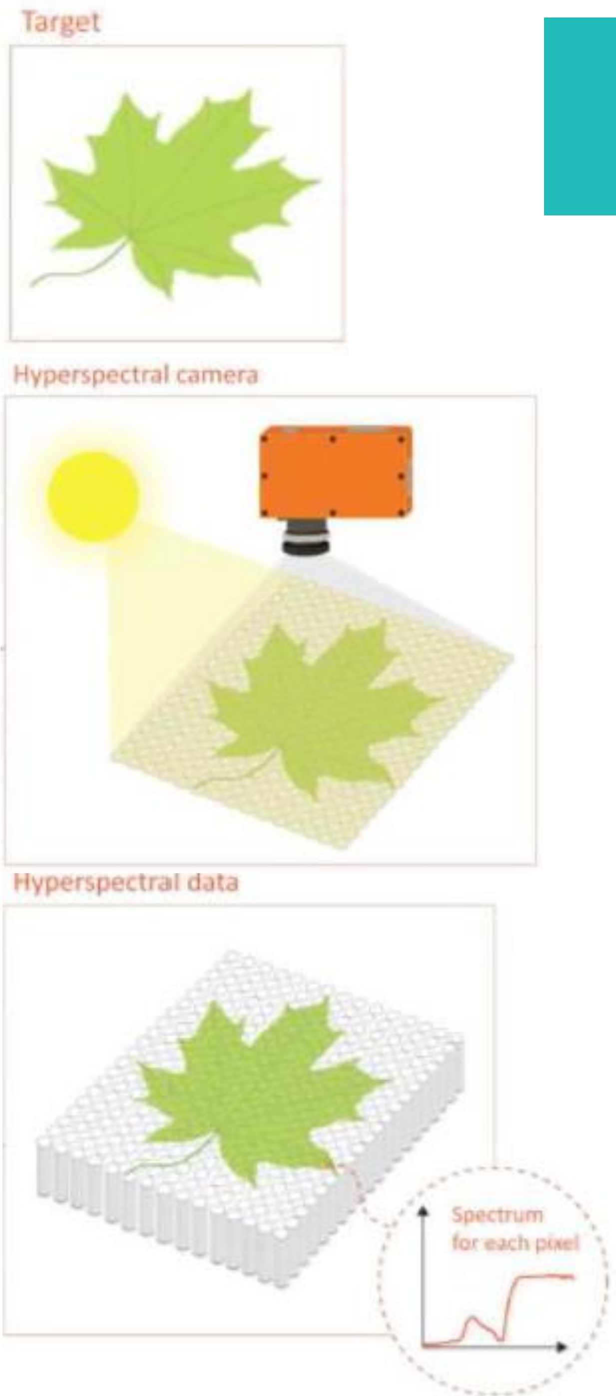
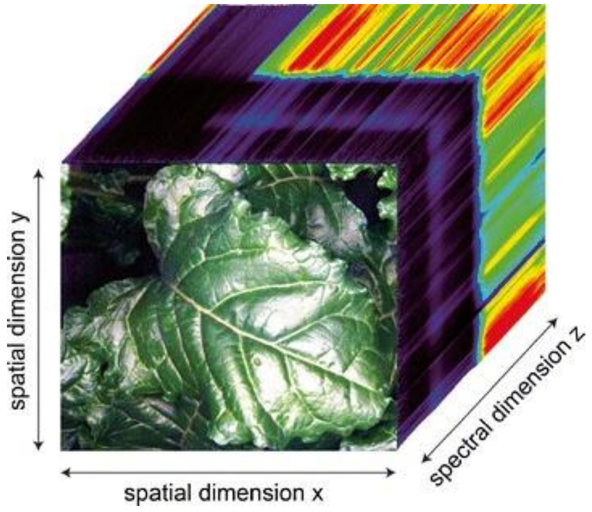
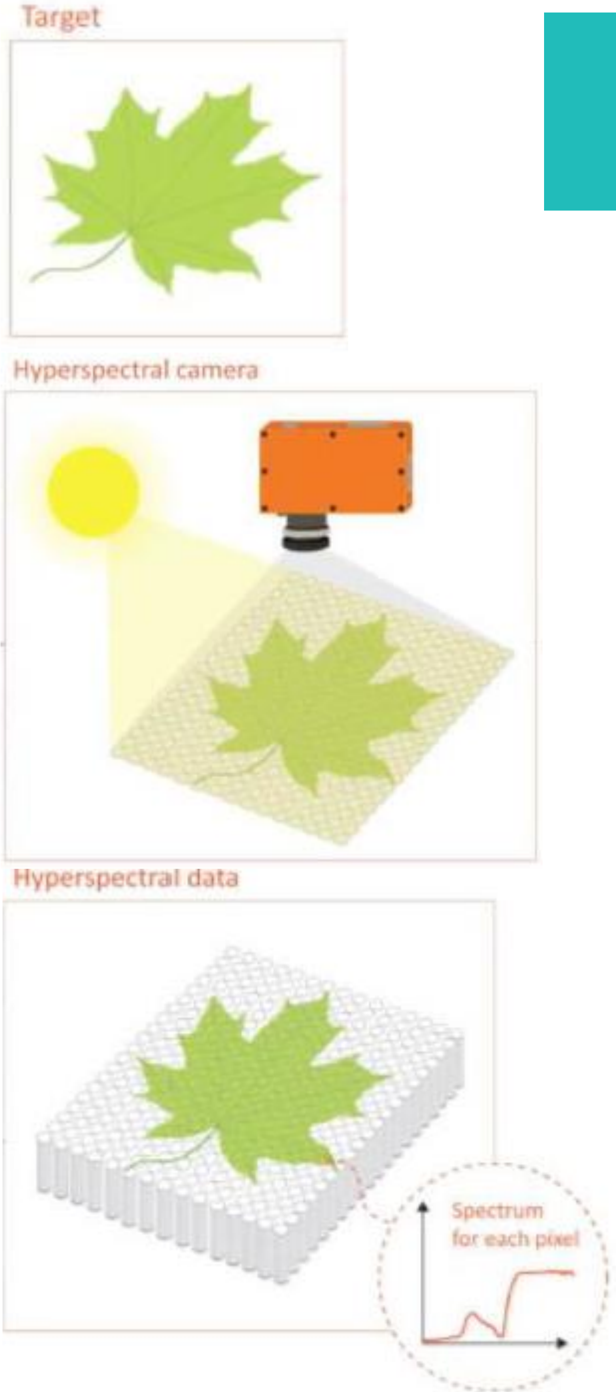
HYPERSPECTRAL CAMERA



- Imaging spectrometer used for hyperspectral imaging
- Can measure thousands or hundreds of thousands of spectra
- The collected spectra are used to form an image of the target, thus we get spectrum and location
- Data that hyperspectral imaging provides is called a data cube

  → This is huge amount of accurate information

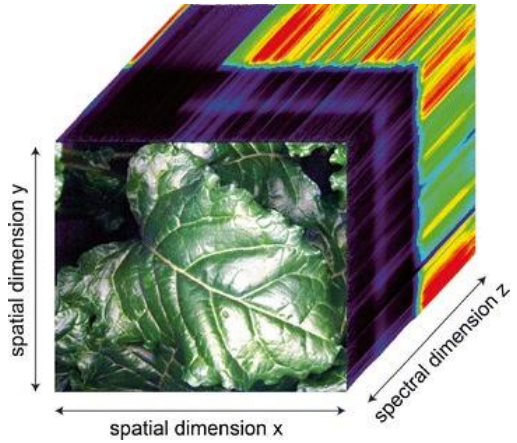


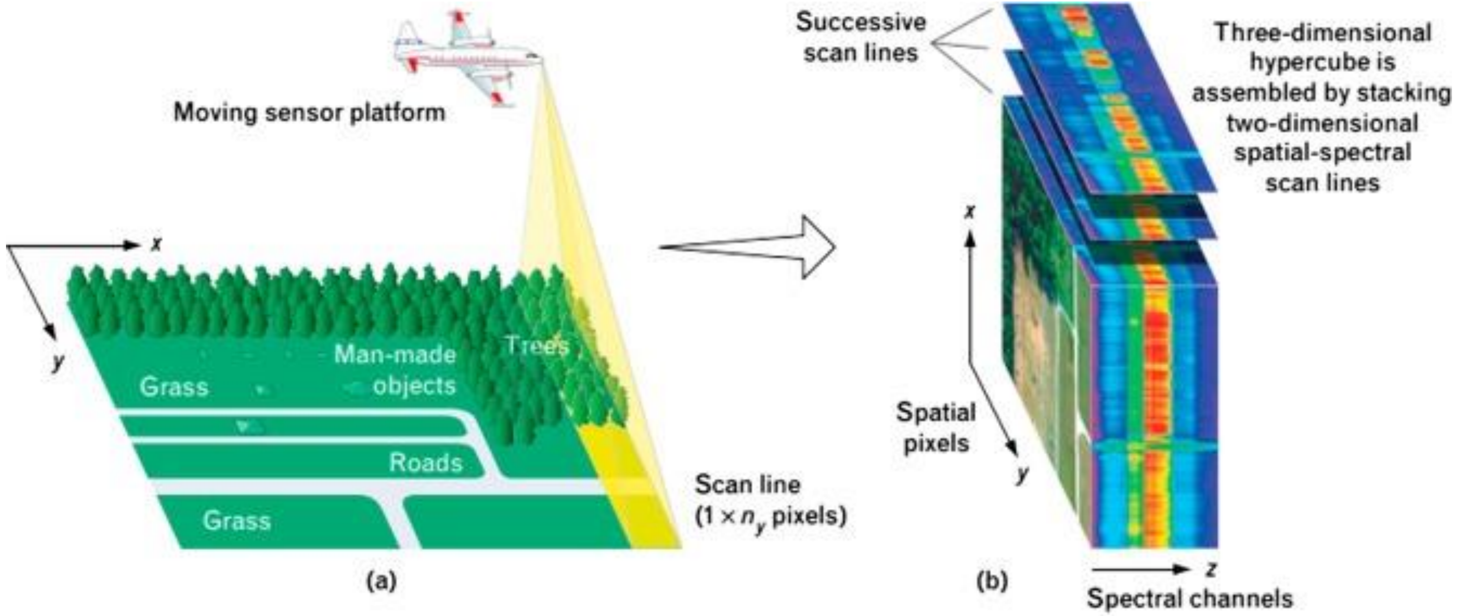


HYPERSPECTRAL CAMERA

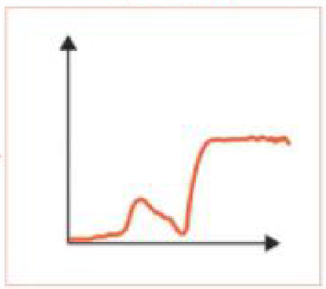
WHY data cube?

When HS camera moves relative to target we get our 3rd dimension, which is also location, but in perpendicular direction. This is why it’s called a cube.

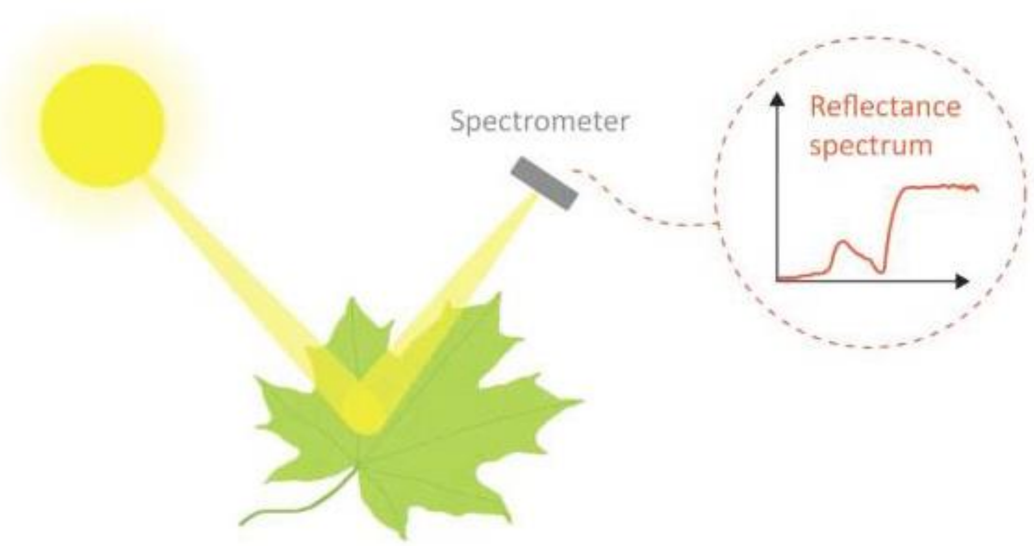




SPECTRAL SIGNATURES



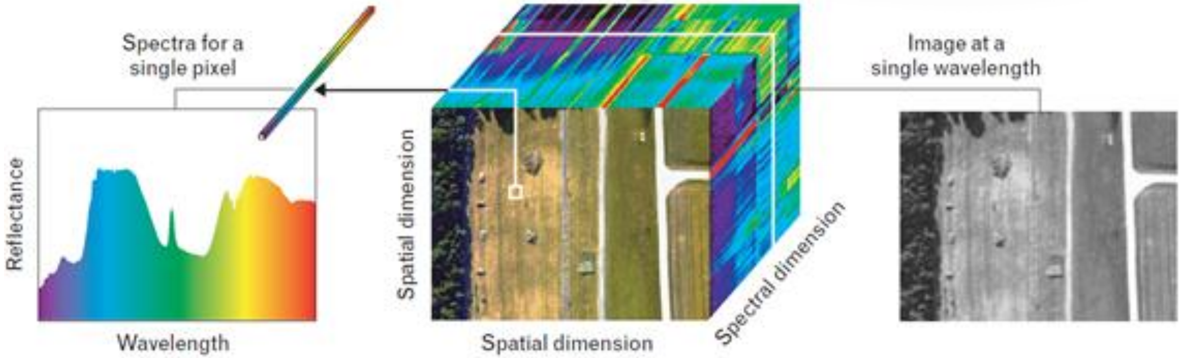
- Spectral signatures can be compared to fingerprints
- Since every material and compound reacts to light uniquely, their spectral signatures are unique too
- Just like fingerprints can be used to identify a person, spectral signatures can be used to identify material



- Spectrometer is an instrument that splits incoming light into a spectrum
- In the example on the left light going through the spectrometer is reflected, and the result is called a reflectance spectrum

UAV HYPERSPECTRAL REMOTE SENSING

- Hyperspectral imaging combined with UAS:
  - fast, flexible and non-destructive detection of subtle spectral features
- Chance to develop R&D infrastructure via the EU structural funds

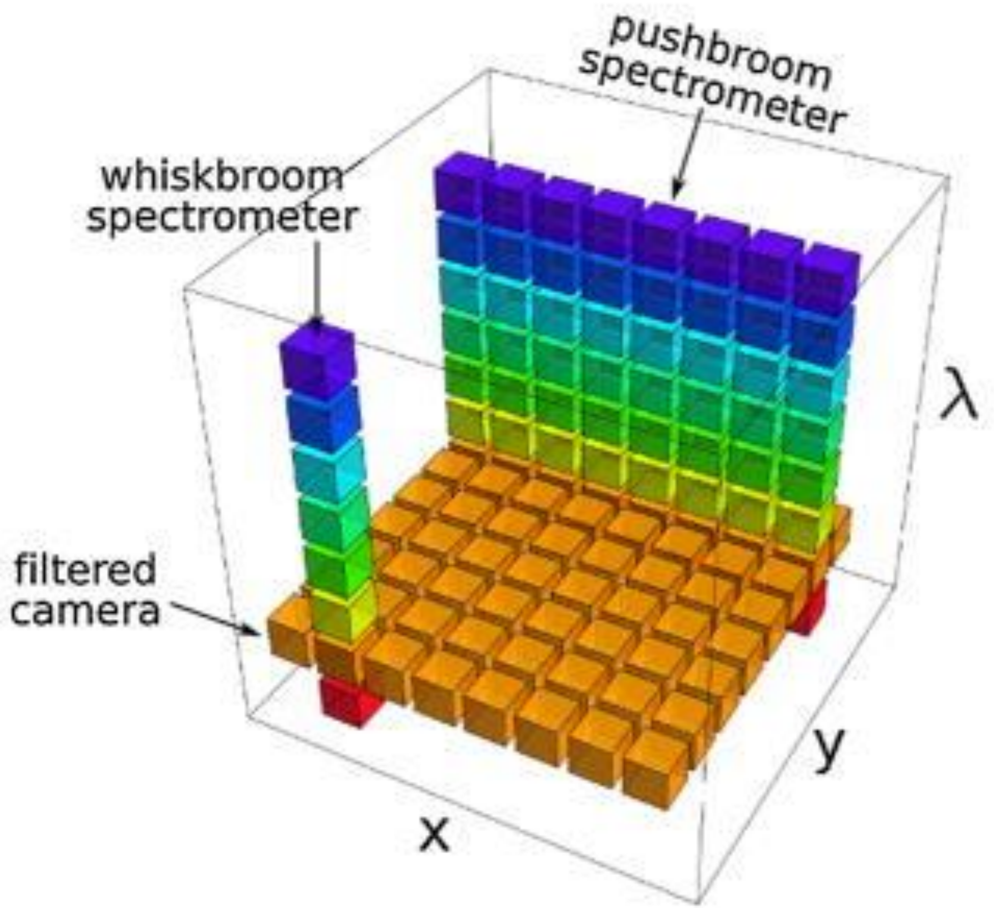


European Union
European Regional Development Fund

UVP TECHNICOM

OUR UAV HS SYSTEM

Push-broom (line) imaging scanner



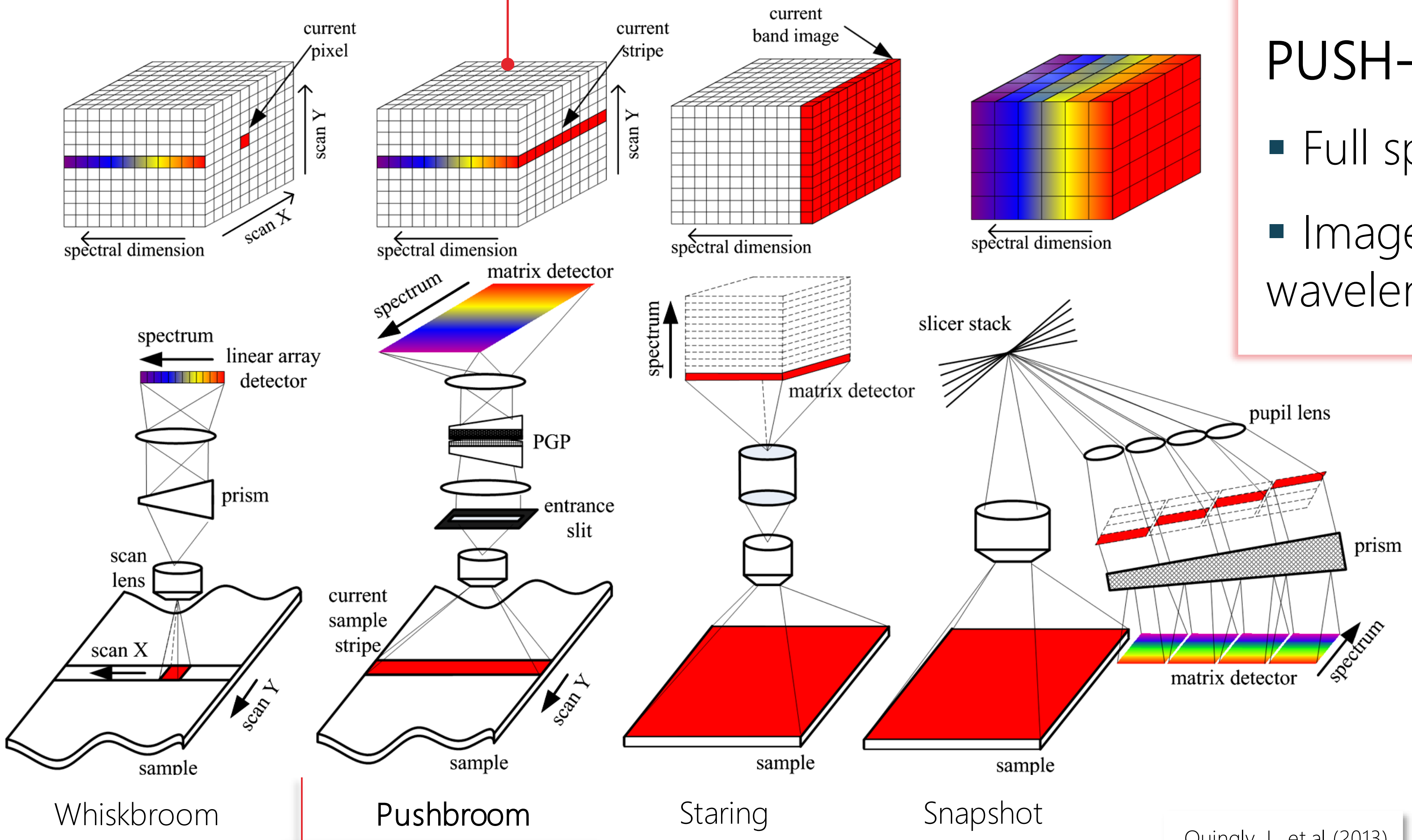
PUSH-BROOM

- Full spectral data simultaneously
- Image is recorded per line, for all wavelenghts at the same time

SPECTRAL IMAGING

OUR UAV HS SYSTEM

Push-broom vs other typical spectral imaging approaches



PUSH-BROOM

- Full spectral data simultaneously
- Image is recorded per line, for all wavelenghts at the same time

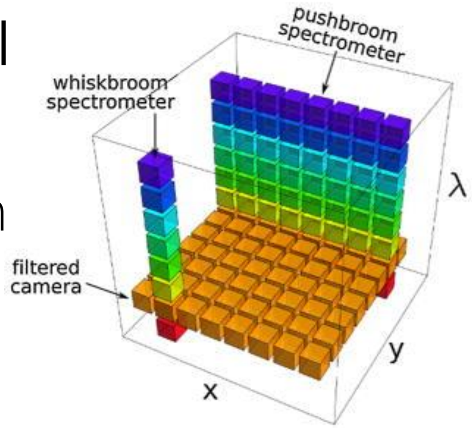
Quingly, L. et al (2013)

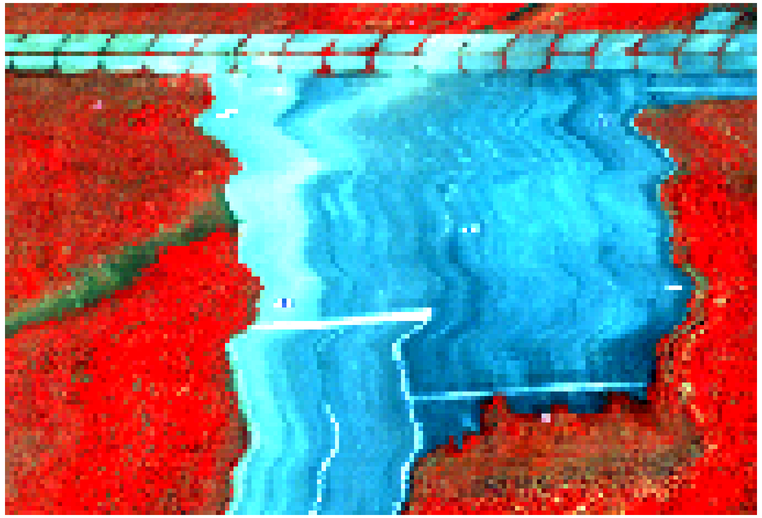
OUR UAV HS SYSTEM

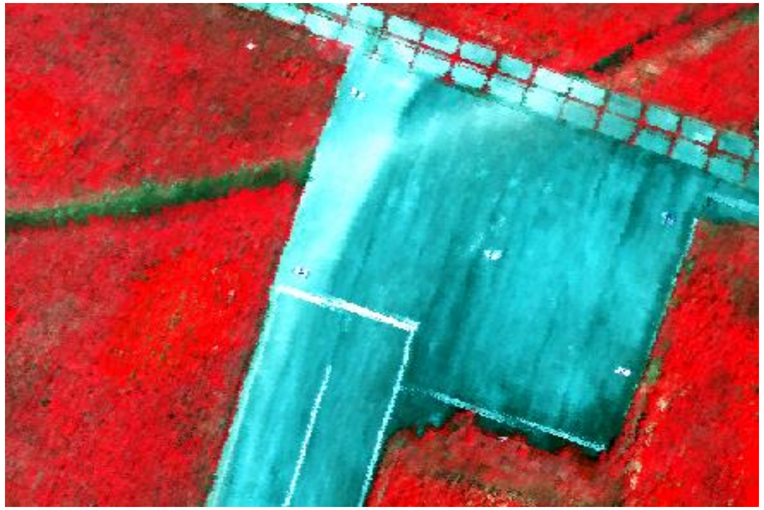
Rectification process

- With a push-broom spectrometer, **full spectral image is recorded per line**
- However, each line of airborne pushbroom images is **collected at different time instants**
  - ➢ perspective geometry varies with each line
  - ➢ different line displacement

➢ Rectification process is needed







OUR UAV HS SYSTEM

Boresight calibration of push-broom sensor

- Rectification of the raw image data:
  - ➢ requires measuring **position and attitude** of the sensor enabled by **IMU/GNSS unit on-board the UAV**
- Accurate alignment of overlapping data strips requires **compensating for geometric distortions caused by boresight misalignment** → BORESIGHT CALIBRATION

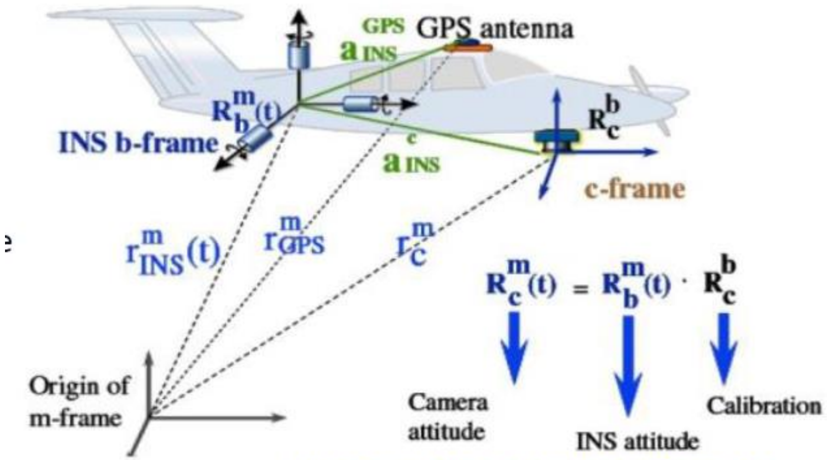
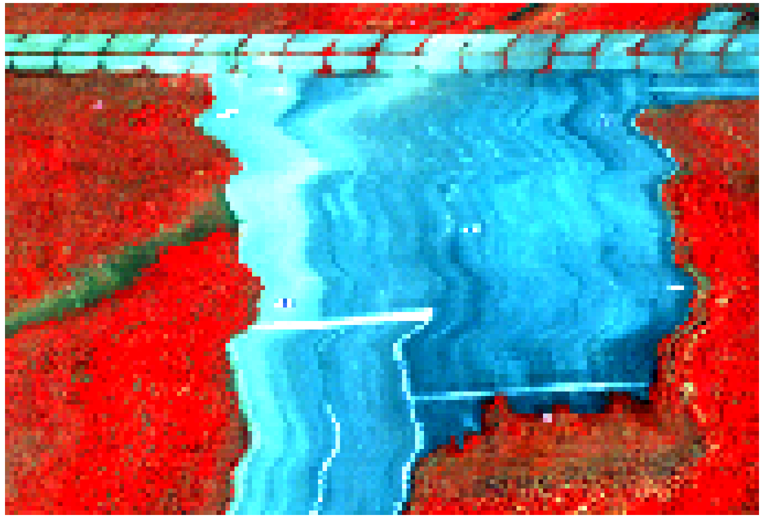
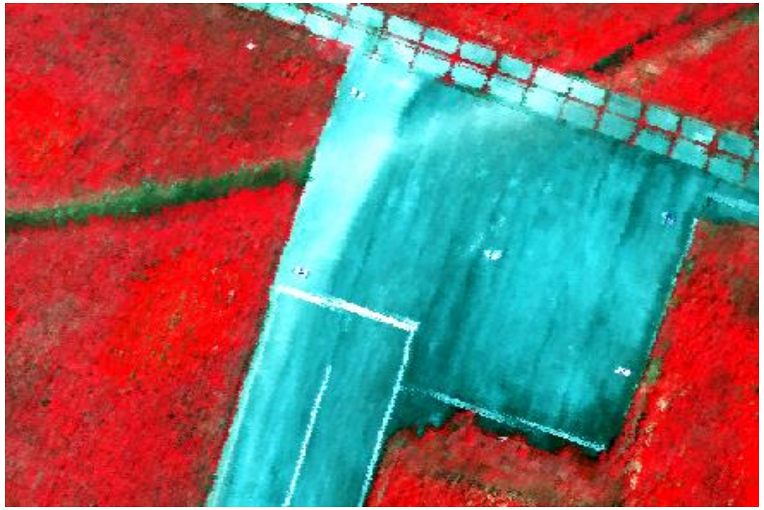


Image courtesy of https://openi.nlm.nih.gov/faq.php#copyright

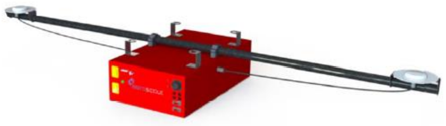




OUR UAV HS SYSTEM

Hyperspectral payload

AISA Kestrel 10



- Push-broom camera, 4.75 kg
- F/2.4, FOV: 40°
- Spatial resolution: 1024 or **2048 pix**.
- **Spectral range: 400 – 1000 nm**
- Spectral sampling: 1.75/3.5/7 nm
- **Max. number of spectral bands: 342**
- Radiometric res: 16bit unsigned integer
- Frame rate: <100 Hz
- SNR : 400-800
- Total system power: <41 W

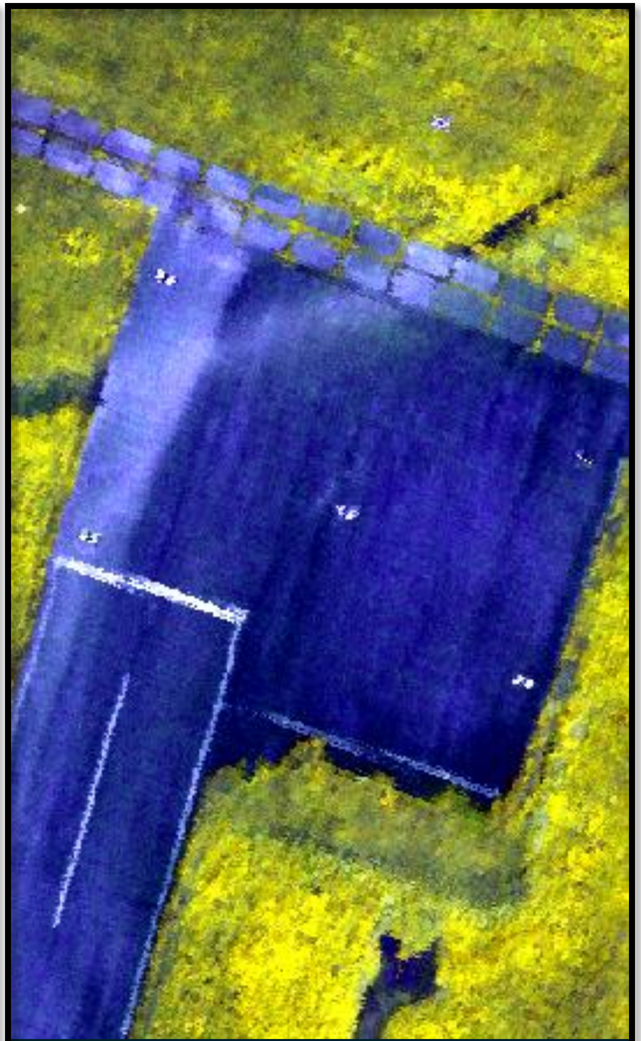
SPECIM
SPECTRAL IMAGING

UAV HYPERSPECTRAL MISSION

PLANNING

DATA ACQUISITION

DATA PROCESSING



RESULTS

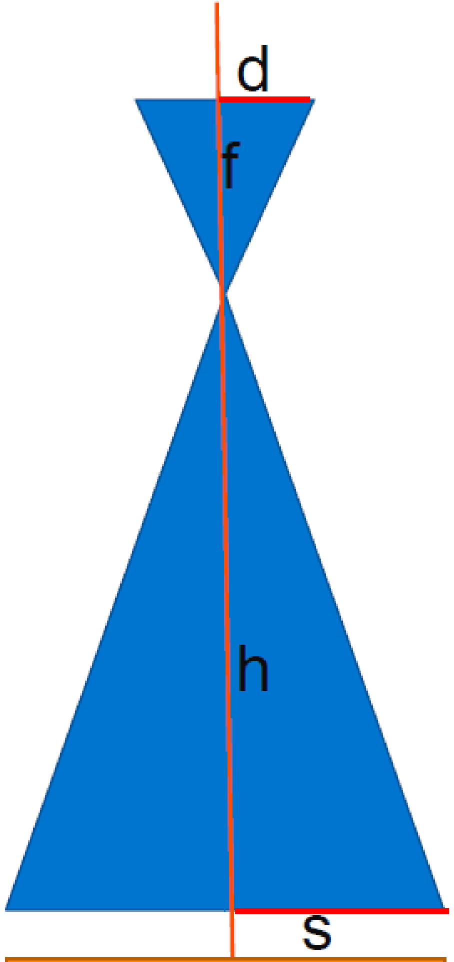
UAV flight mission: area of interest (AOI)

Stagno di Salede Porcus
Northern part, 500 x 1000 m

2000 m

500 m

Flight mission parameters: FOV, swath width, spatial resolution



- Detector width 2d, Focal length f
- Height h, Swath width 2s
- For AISA Kestrel 10
  - 2d = 1024 x 24 um = 24.576 mm
  - f = 35.445 mm
  - FOV = 2* atan (d/f) =~ 38.2 vs. 40.2 measured
  - Swath = h*2d/f = ~ h * 0.69
  - Ground pixel = h * 0.024 / f = h * 0.00068

Height [m] / [ft]	Swath [m] / [ft]	Ground pixel
500 / 1640	346 / 1137	0.34 / 1.1
1000 / 3280	693 / 2274	0.68 / 2.2
1500 / 4920	1040 / 3411	1.0 / 3.3

SPECIM SPECTRAL IMAGING

Flight mission parameters: FOV, swath width, spatial resolution

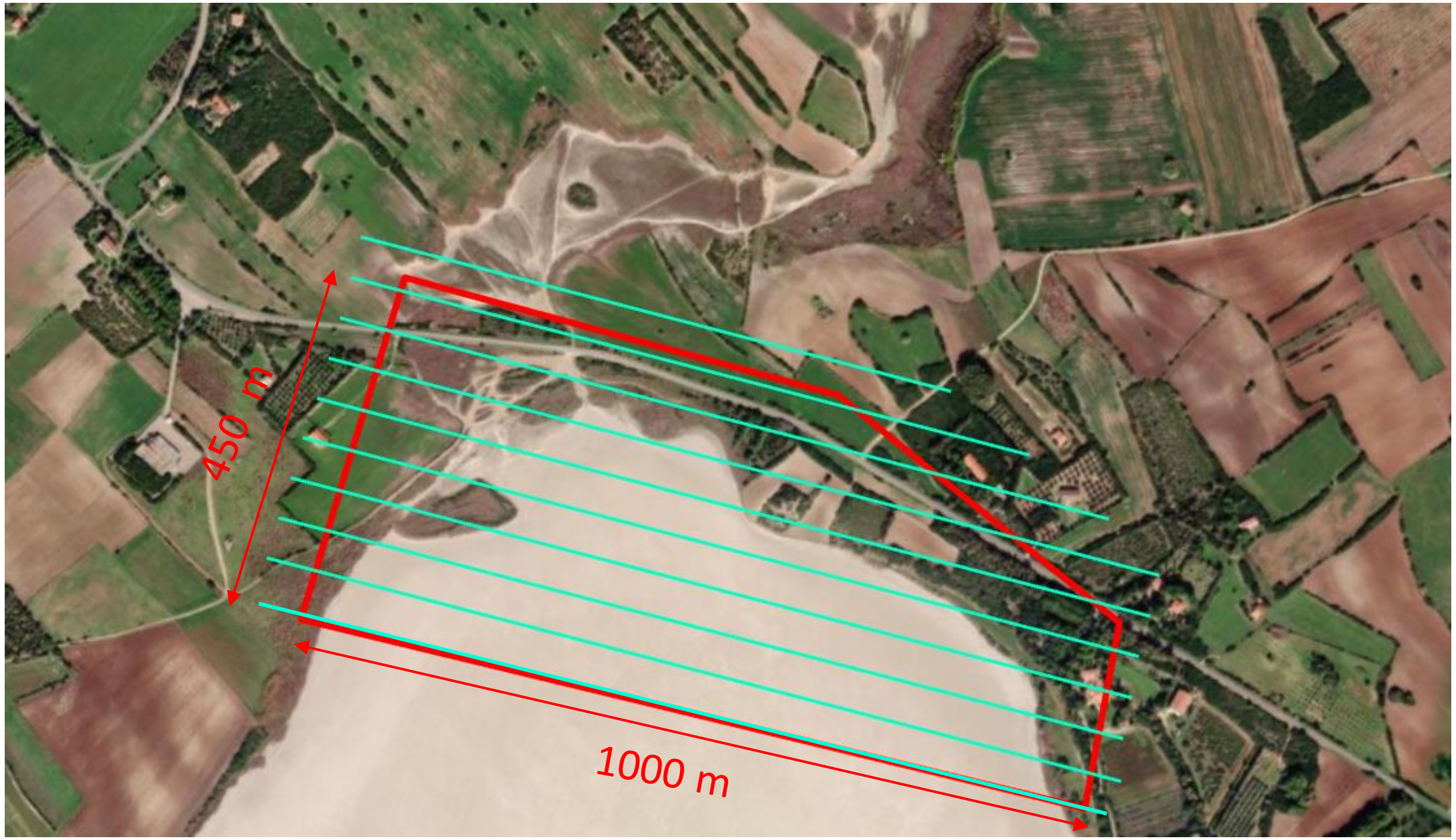
Stagno di Salede Porcus
Northern part, 500 x 1000 m

HS camera FOV = 40°
Tan(40°/2) x 90 m flying height = 29,1 m, approx. **58 m swath width**

If 1024 pixels per line: 58 : 1024 = 5,6 cm

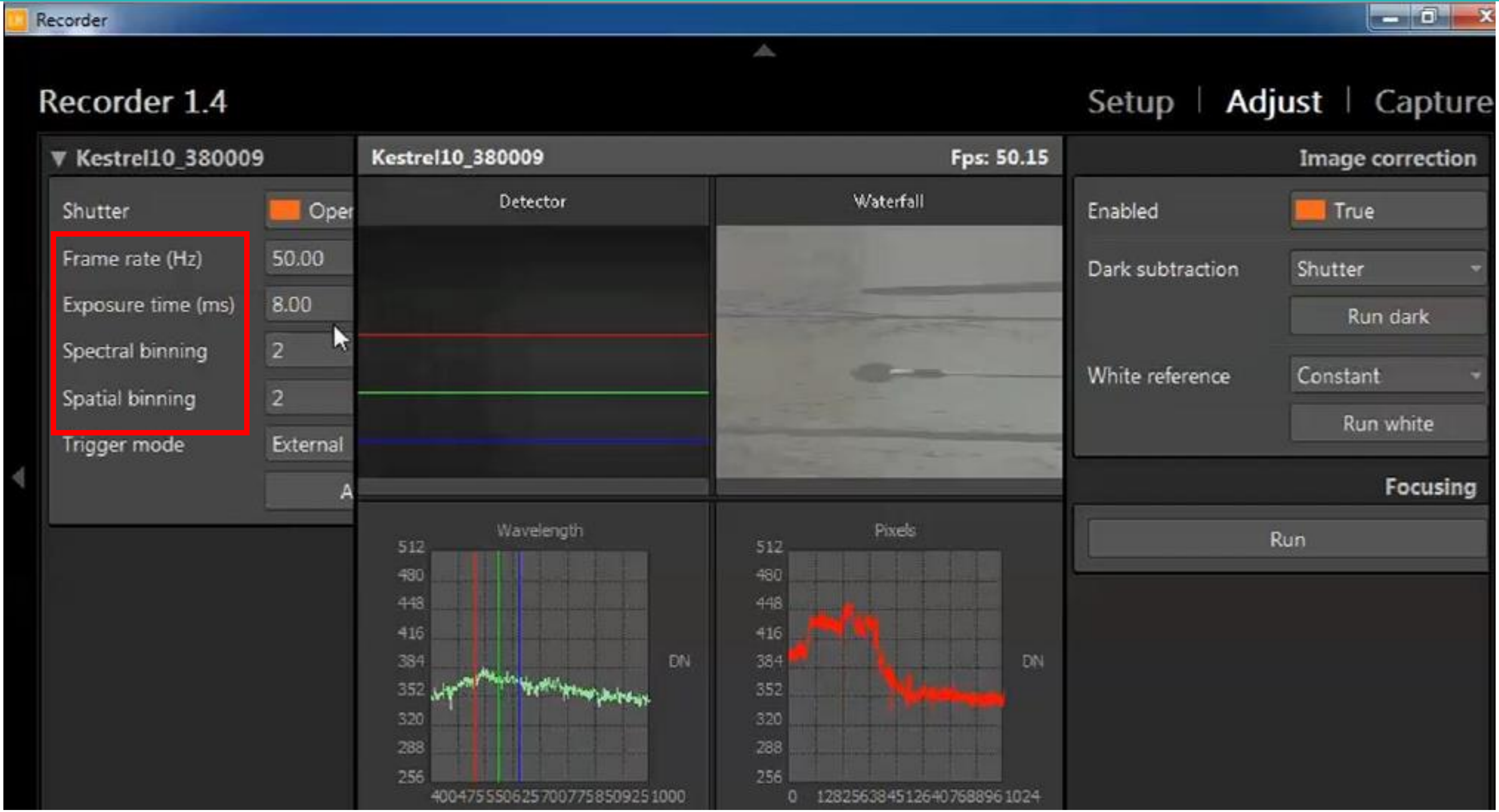
Number of flight lines given a 450 m width of AOI, **E-W direction**:
450 m/58 m = 7.75 lines

Account for 20% flight line overlap:
7.75/0.80 = 9.68 so that **10 flight lines**



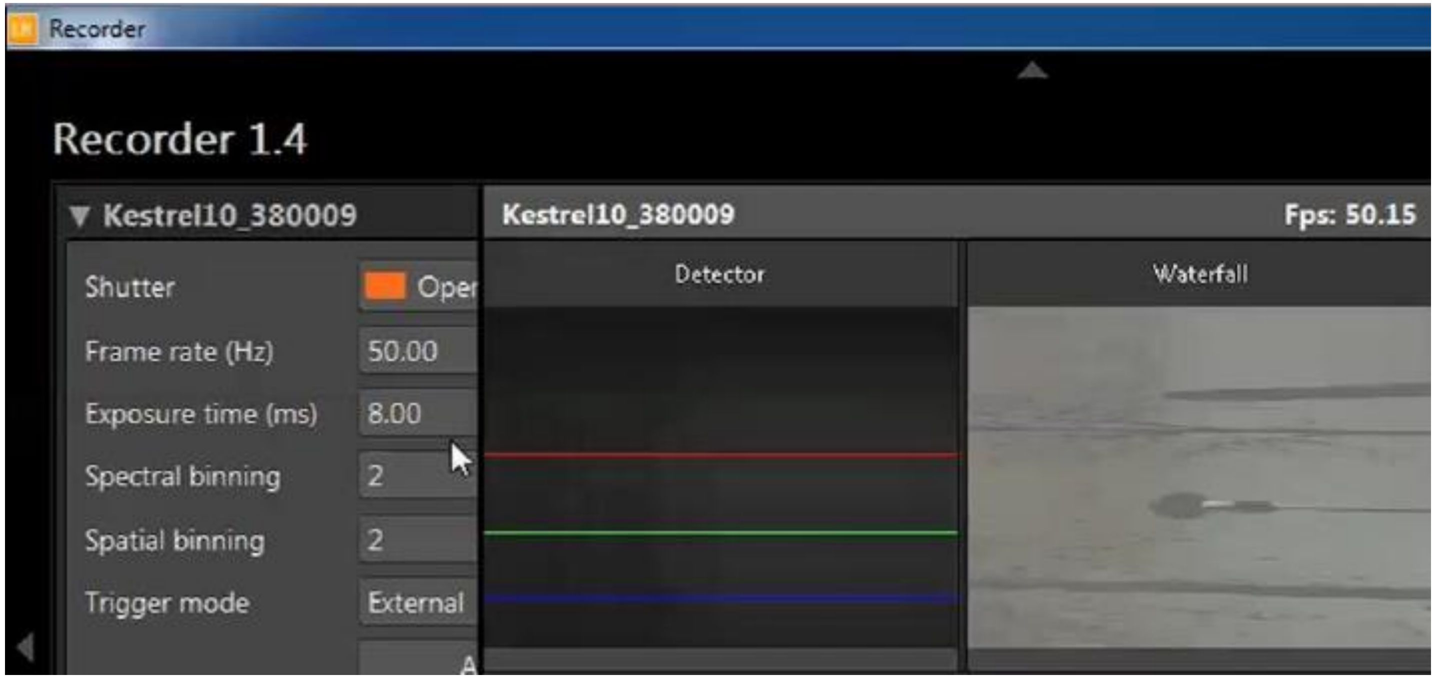
Frames Per Second : Flight speed/pixel size =
5 m/s / 0.056 m = 89.2 thus 90 FPS
Exposure time 1/FPS: 1/90 = 0.011 s = 11 ms

Settings of the HS camera before the mission



Frame rate and frame time

- rame rate, iven in frame er se on f s or , efines the a e for our tar et sam lin
- In air orne s stems this is relate to airs ee , or roun s ee to e more e a t
- If our roun s ee is 60 m/s ou et 1 m sam lin on the roun usin 60 f s
- ur ma . frame rate is 100 , an ma fli ht s ee 10 m/s
- hus, with this s ee we an sam le at 10 m



Frame rate and frame time

- rame time is also alle frame interval
- It is iven in millise on s ms
- rame time is inverse of frame rate 1/f s
- It hel s ou to un erstan the relationshi etween frame rate an e osure time

- or e am le:

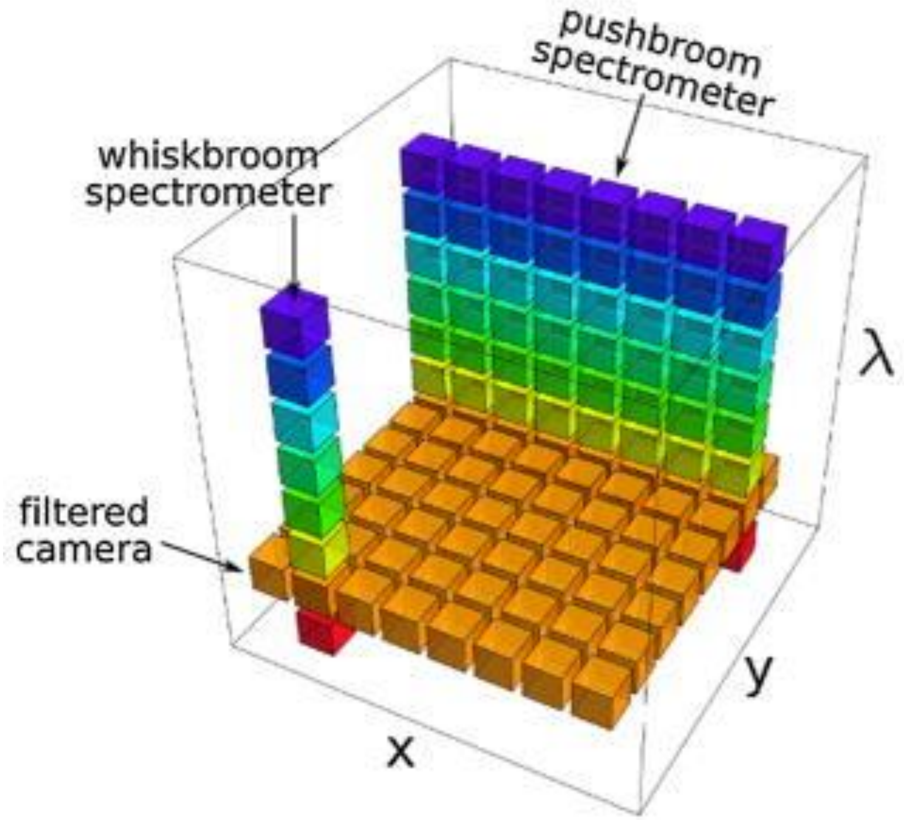
Frame rate [Hz]	Frame time [ms]
50	20
60	16.67
100	10

Motion blur

- otion lur o urs when ou have relative motion etweenthe sensor an tar et
- **he lon er the e osure time, more lur there is**
- It makes the ima e to look softer an less shar
- o ma imise si nal ou woul like to use as lon e osure time as ossi le, ut **from lur ers e tive the shorter e osure time woul e etter. ou nee to om romise**
- **Be areful of overe osure more si nal than an e re or e un ere osure low si nal an low N**
- ule of thum : o set the suita le frame time, the re or e si nal of a white tar et is at a out 5 of a a it there is some reserve a a it

Spectral and spatial binning of the recorded signal

- Binnin is the ro e ure of om inin the si nal from a num er of a a ent i els into an out ut for a sin le i el
- Binnin an e on- hi summin or off- hi summin or avera in
- In all AI A instruments non-s mmetri al 2 1, 2 4, 2 8 innin is referre
- erti al innin settin efines s e tral an wi th
- ori ontal innin ontrols s atial resolution
- rame rate is in e en ent of innin
- N im roves u to square root of the innin fa tor



Spectral and spatial binning of the recorded signal

- here are two rimar enefits from innin
- Im rove N , ue to less rea noise, u to a fa tor of innin
- In rease frame rate, when verti al s e tral innin is a lie
- ori ontal innin re u es s atial resolution

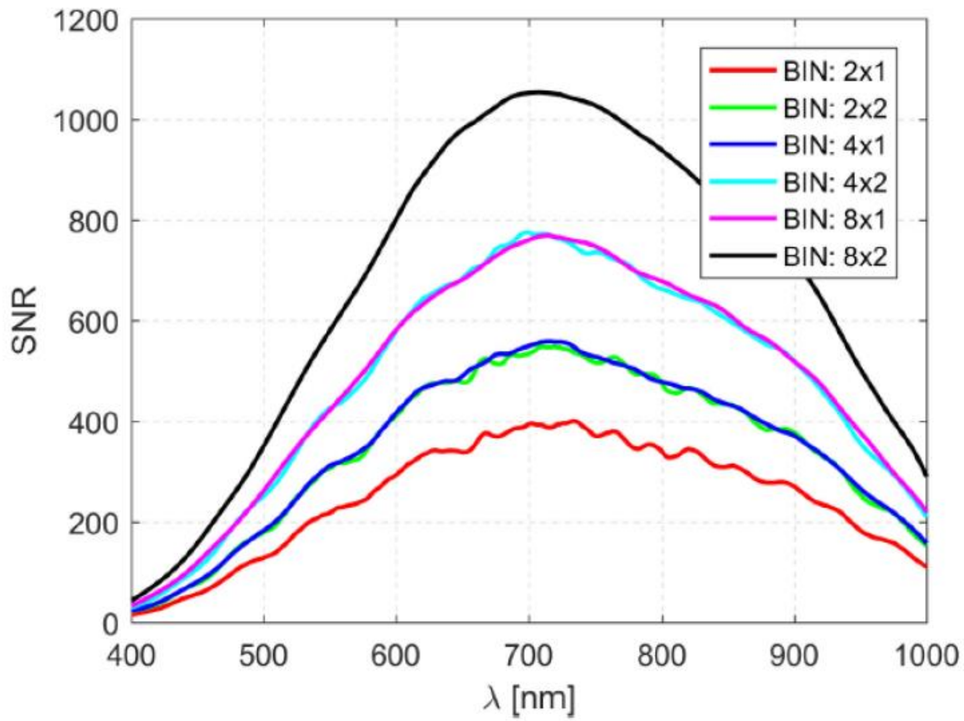
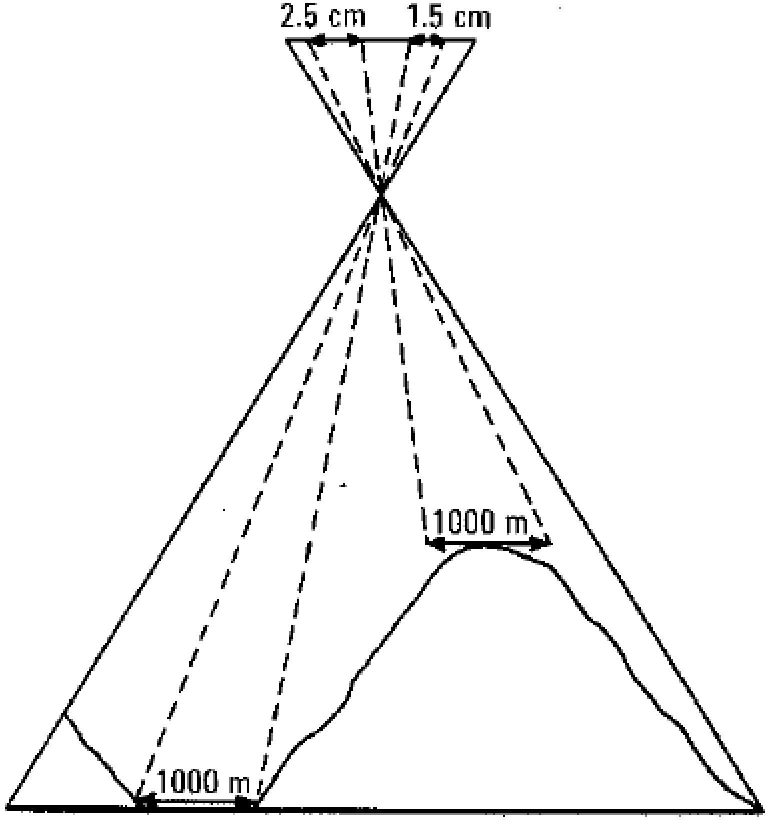


Figure 1.
Spectral SNR with halogen illumination.

DSM and ortorectification

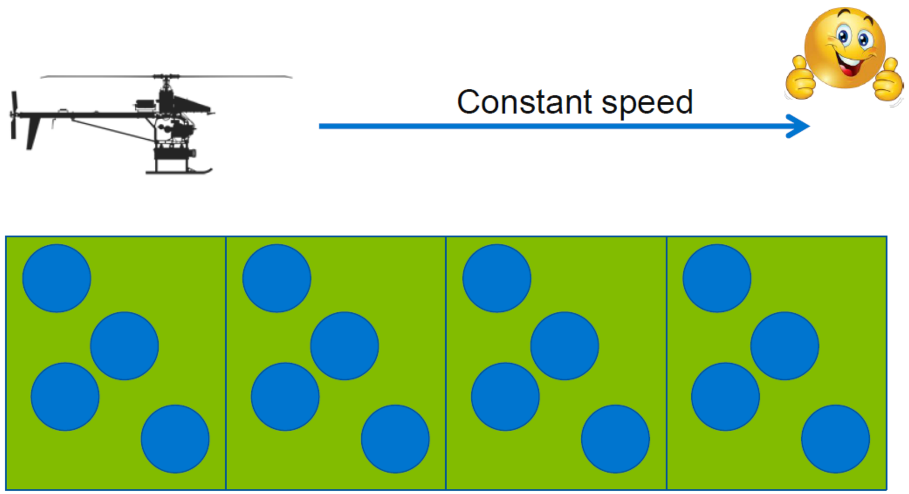
- ften the roun elevation an hei ht of o e ts on the roun varies relativel lar e amounts om are to hei ht
- In su h a ase it s im ortant to use Di ital surfa e mo el D when ro essin the ata, e ause tar et o e t si e han es
- or flat surfa es onstant elevation an e use an is suffi ient no D



Issues to consider for mission planning/flight

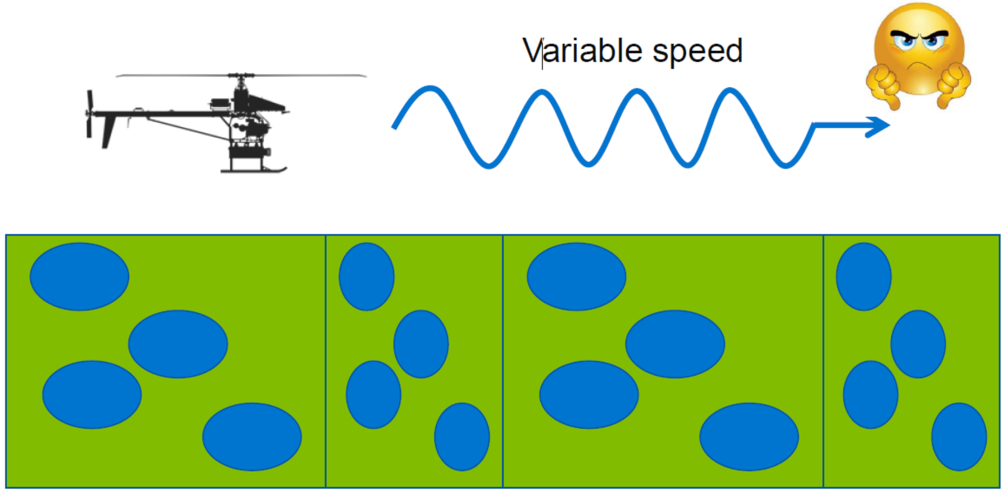
- Flying with pushbroom sensor is different from 2D image cameras
- Try to maintain as well as possible
- Constant speed
- Constant altitude
- Constant heading vs. course ..., not so easy due to wind/UAV tilt
- When acquiring data
- Do not hover above target/area
- Do not turn in-place

FLYING WITH CONSTANT SPEED



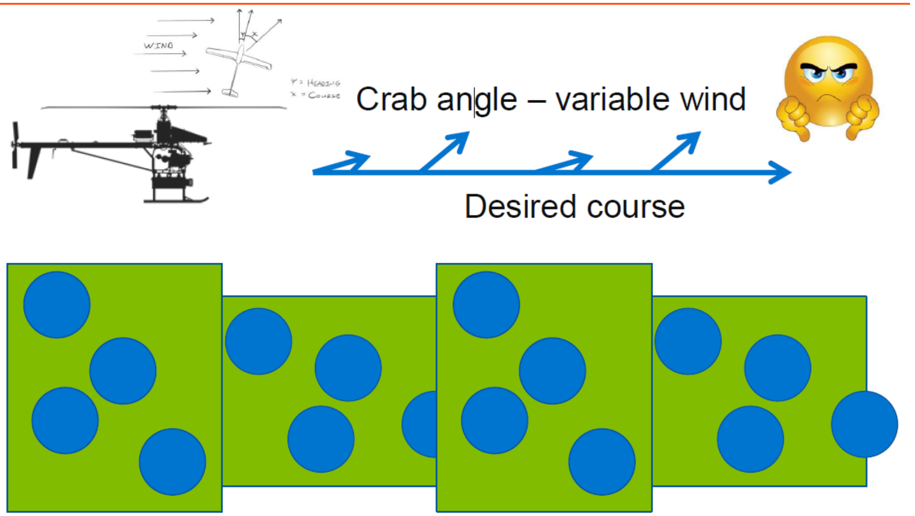
← No speed distortion →

FLYING WITH VARIABLE SPEED



← Speed distortion →

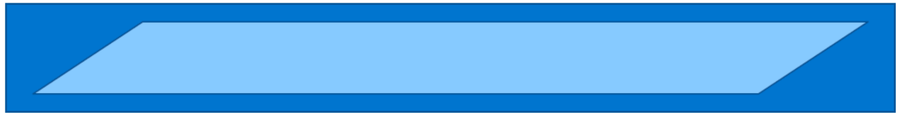
FLYING WITH VARIABLE CRAB ANGLE



← Variable crab angle →

FLYING WITH CONSTANT CRAB ANGLE

- - Pushbroom sensor slit direction changes causing
  - Sampling not prependicular to flight direction
  - Narrower swath width, possibly leaving gaps between flight lines



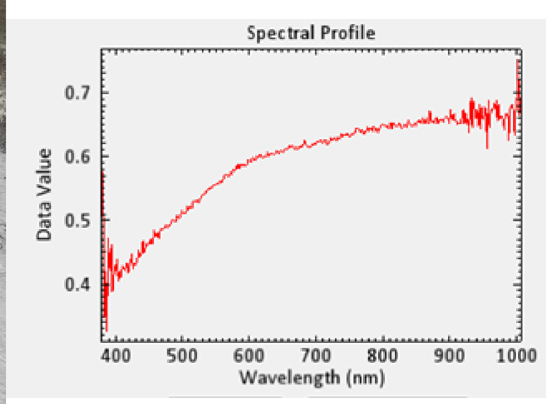
Hyperspectral data acquisition and processing

Stagno di Sal'e Porcus

18-20 July 2023

Michal Gallay, Ján Kaňuk, Ján Šašak, Katarína Onačillová

PAVOL JOZEF ŠAFÁRIK UNIVERSITY IN KOŠICE



Description of UAV HS mission in the northern part of Salle Porcus, Sardegna, IRSS 2023

There were 2 UAV HS missions:

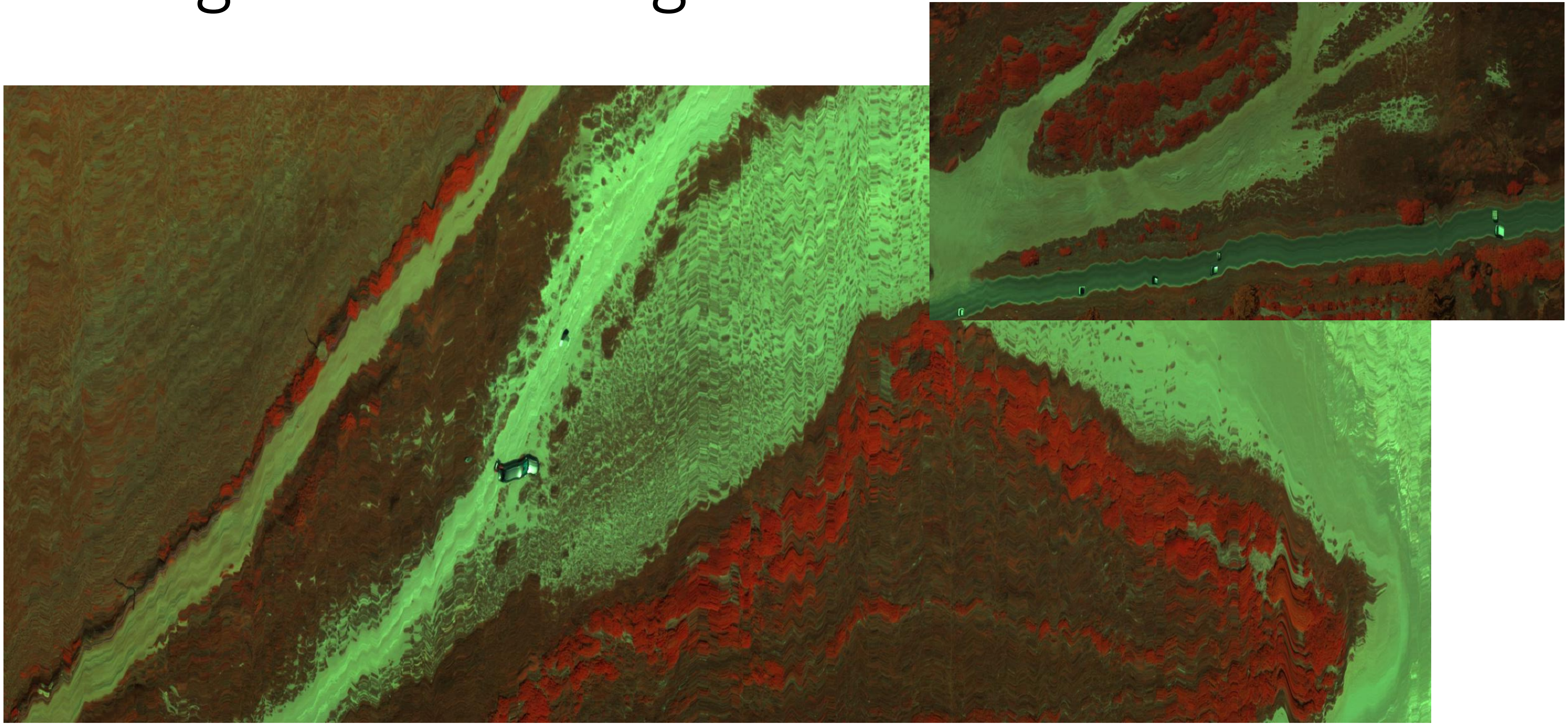
- 18.7.2023, sunny, grey sky with haze? of high cirrus, over 40°C, between 11-13:00
- 20.7.2023, sunny, blue sky, no visible cirrus, about 36°C, between 11-14:00

- 19.7.2023, radiometric targets were spectraly measured in the field, they were put on the surface of the salt lake, ASD FieldSpec, by Massimo from INGV Rome

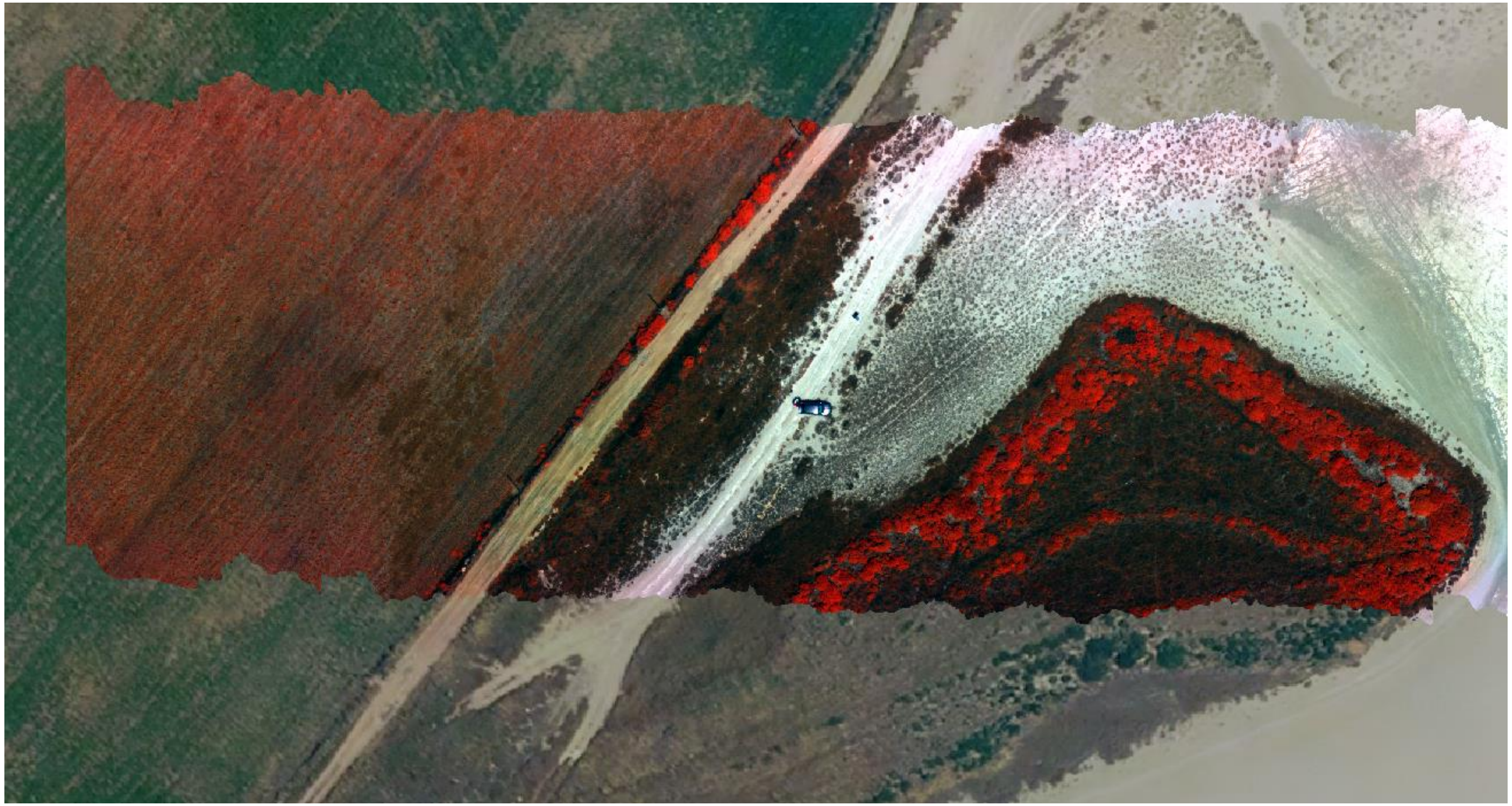
- Sensor: AISA Kestrel 10 by Specim
- Above ground flying height: 80 m
- Geospatial reference WGS 84 during acquisition,
  - after post-processing WSG 84 UTM 32 N

- DSM for orthorectification: cell size 50 cm, derived from lidar VUX1 UAV scanning performed on 18/07/2023

Example of raw data before rectification and georeferencing



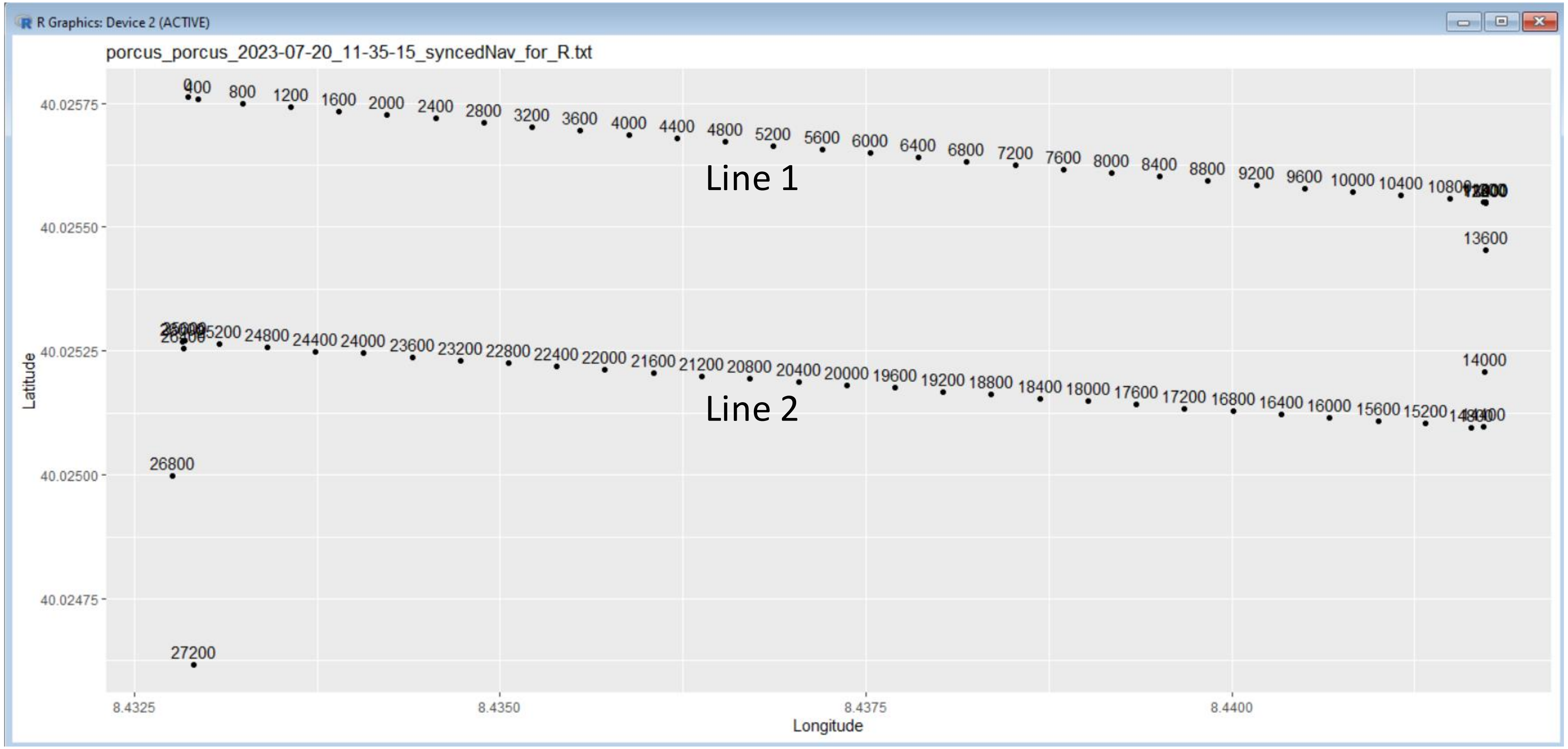
Example of spatial accuracy with respect to orthophoto 2019 *SardegnaSentier*i.it



WSG 84 UTM 32 N

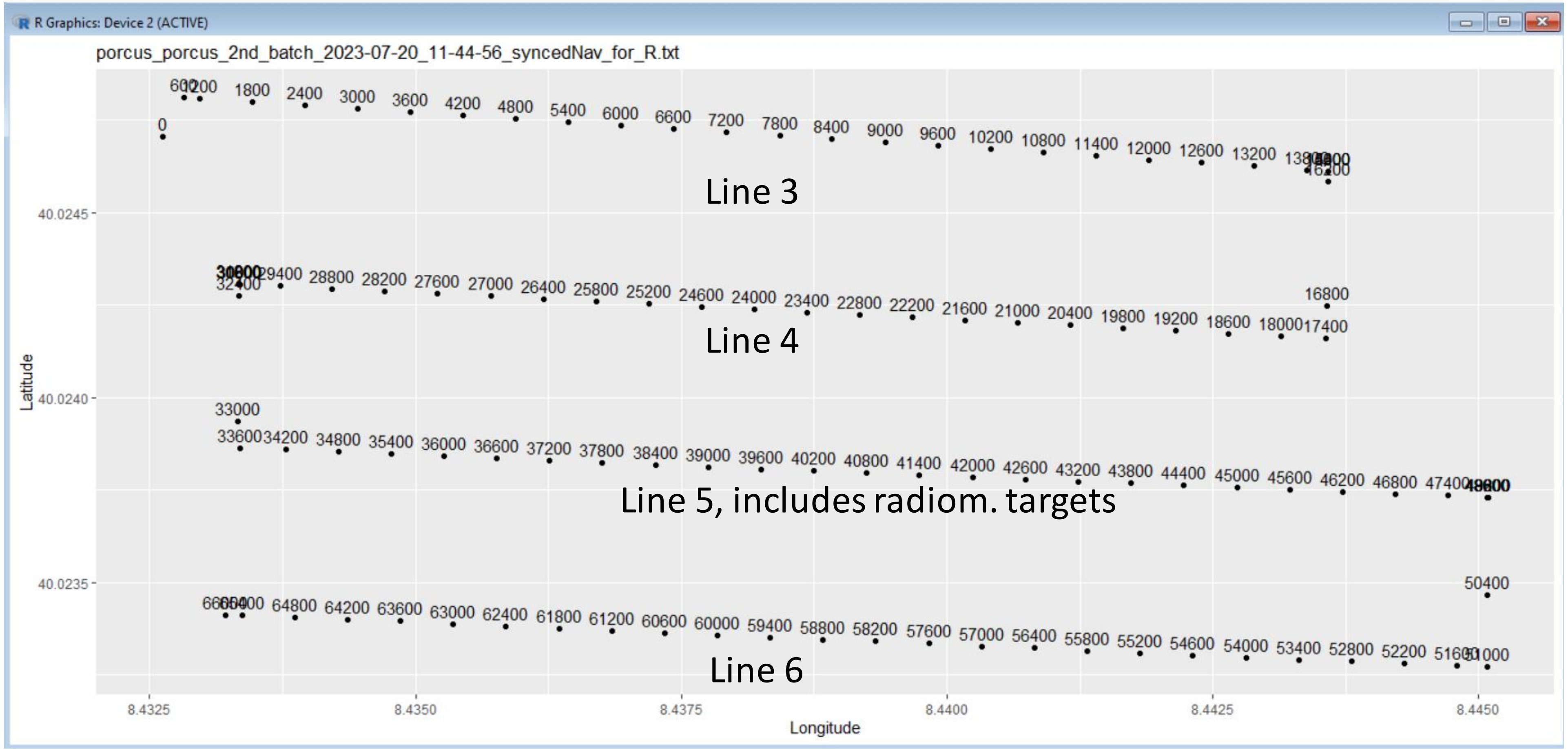
Flight trajectory and image line numbers

20 July 2023, spectral x spatial binning for data acquisition 2 x 2



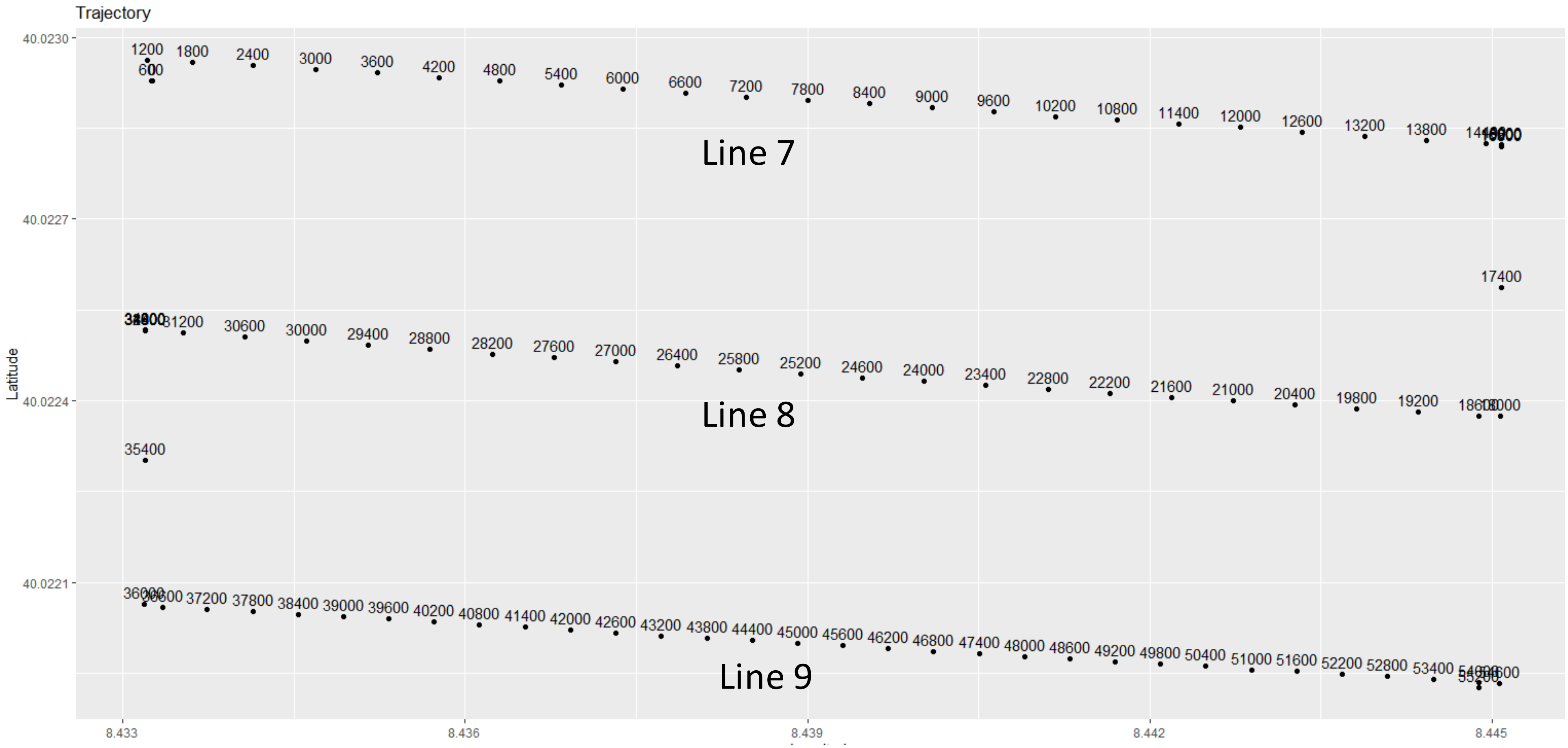
Flight trajectory and image line numbers

20 July 2023, spectral x spatial binning for data acquisition 2 x 2



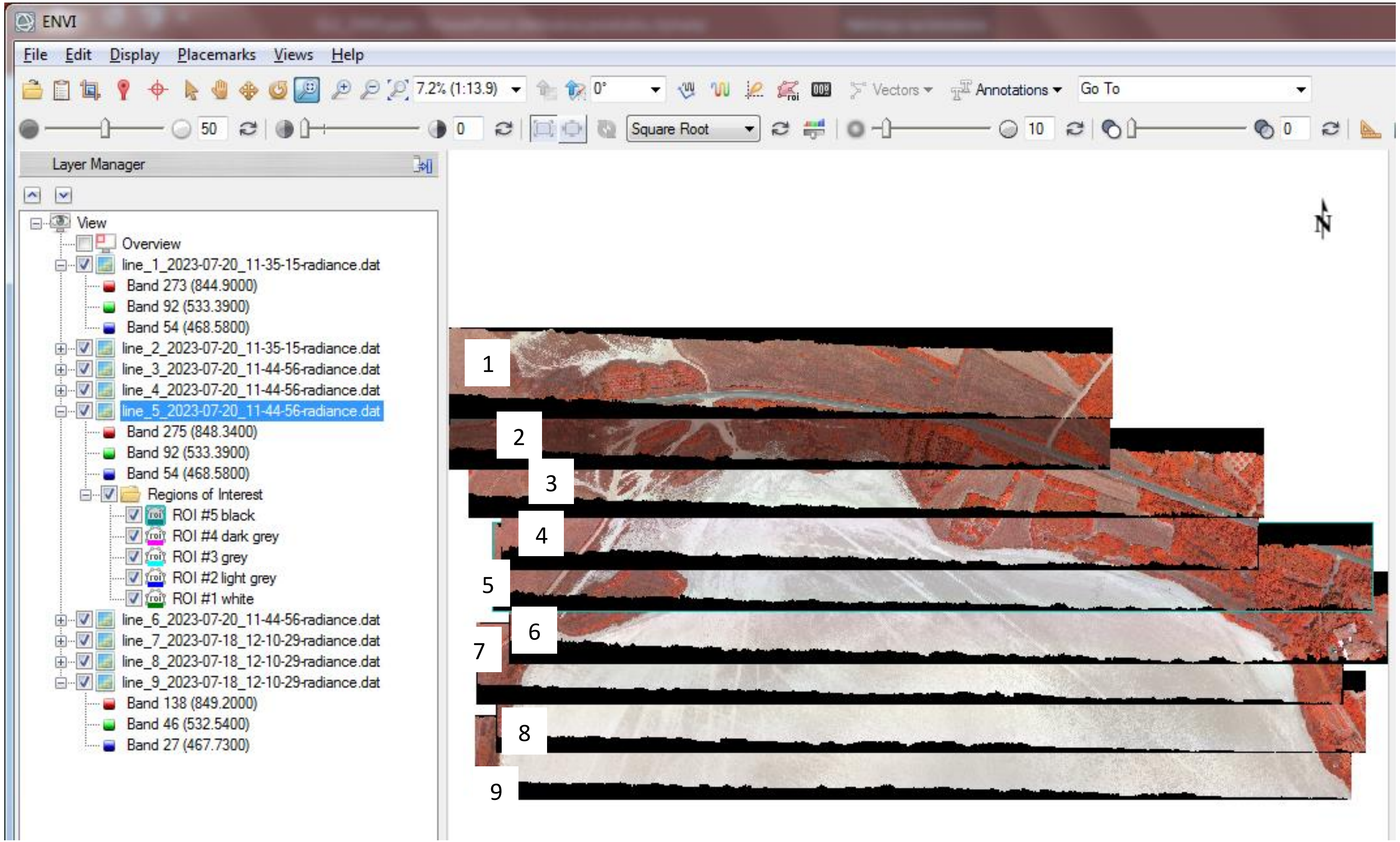
Flight trajectory and image line numbers

18 July 2023, spectral x spatial binning for data acquisition 4 x 2



Line 1-6 acquired 20 July and lines 7,8,9 on 18 July 2023 raw data processed in CaligeoPro, a software by Specim

- DN processed as **raw data – dark current, then into radiance**
- Georeferenced AISA data file radiometrically corrected to radiance (mW/cm^2*str*um)*1000.00



Spectral x spatial

binning during acquisition flight

Line 1 : 2x2 – processed as 8x2

Line 2 : 2x2 – processed as 8x2

Line 3 : 2x2 – processed as 8x2

Line 4 : 2x2 – processed as 8x2

Line 5 : 2x2 – processed as 8x2

Line 6 : 2x2 – processed as 8x2

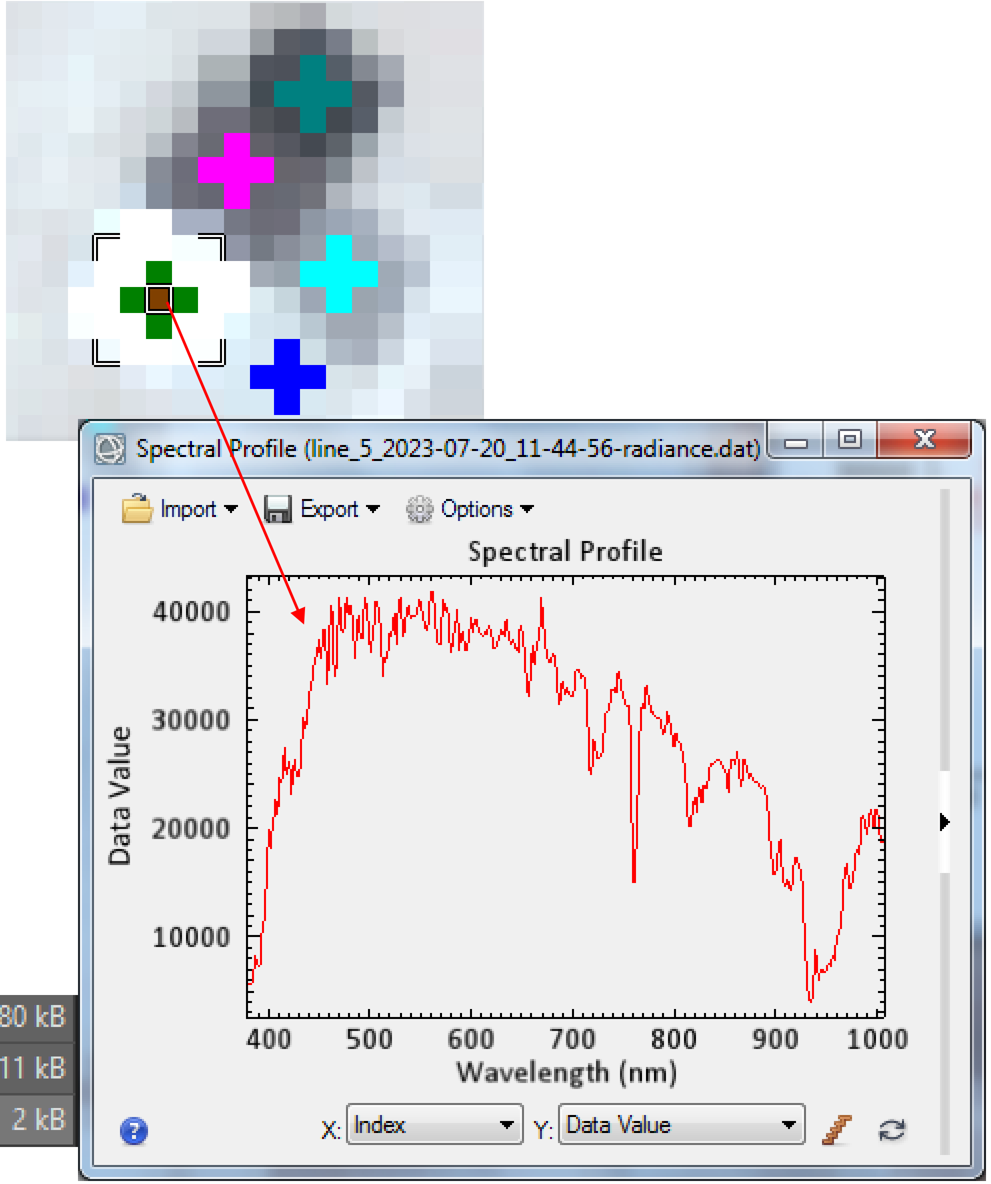
Line 7 : **4x2** – processed as 8x2

Line 8 : **4x2** – processed as 8x2

Line 9 : **4x2** – processed as 8x2

Spectral radiance

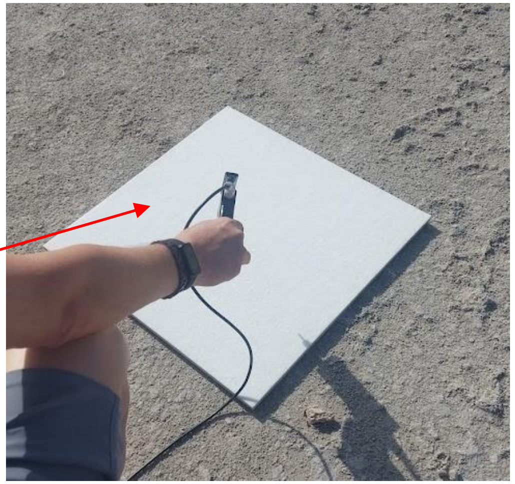
- (mW/cm^2*str*um)*1000.00
- The radiance was produced by:
- Subtracting dark current values/signal from raw data
- Calibrating the resulting DN to calculate radiance by 8 spectral x 2 spatial binning
- Radiance values should be divided by 1000 to get mW/cm^2*str*um
- resulting spatial resolution /pixel is 0.1 m
- 368 spectral bands from 380-1000 nm
- Orthorectification was based on a lidar DSM of 0.5 m spatial resolution
- This is the output from CALIGEO PRO software and should be used in ENVI for reflectance calculation
- Resulting files DAT (image data), HDR (header info), for the image file, OPT (metadata about processing the raw data)



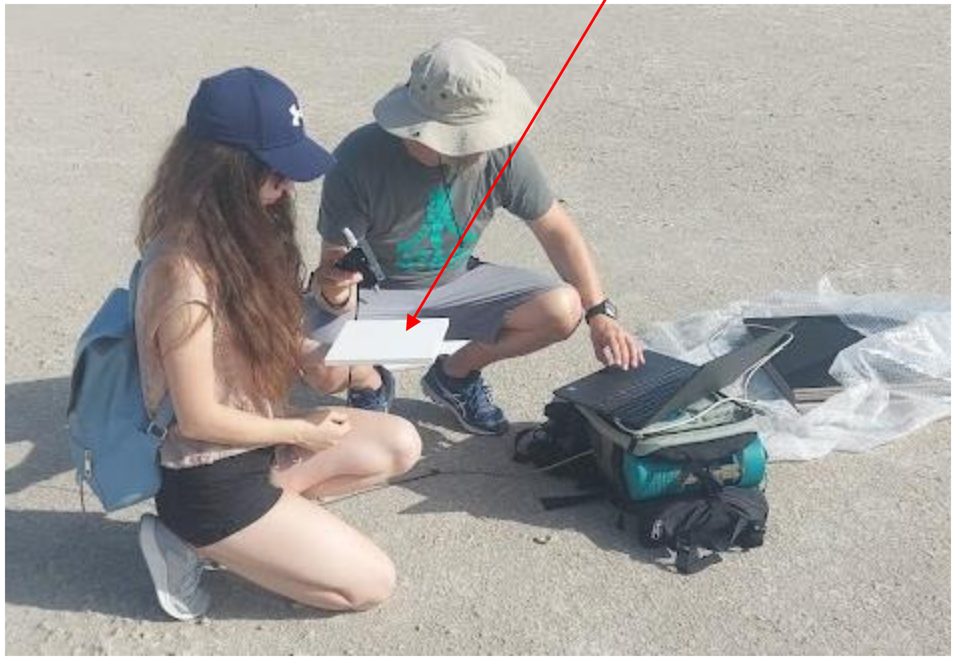
line_1_2023-07-20_11-35-15-radiance.dat	10. 2. 2024 9:24	Súbor DAT	4 947 680 kB
line_1_2023-07-20_11-35-15-radiance	11. 2. 2024 11:53	Súbor HDR	11 kB
line_1_2023-07-20_11-35-15-radiance.opt	10. 2. 2024 8:22	Súbor OPT	2 kB

Empirical line correction to calculate reflectance

- Spectral radiance data was used
- Based on 5 radiometric targets made of felt
- Reflectance of the targets measured in the field 19 July by ASD field spectrometer
- This reflectance was used in ELC to calculate reflectance of lines 1-6 from radiance data
- Alternatively just the white target could be used for simpler atmos. correction.
- Reflectance = (DN/DN white ref) x Reflectance white ref
- E.g. Reflectance for DN = 50 = (50/217) x 0.85 = 0.19

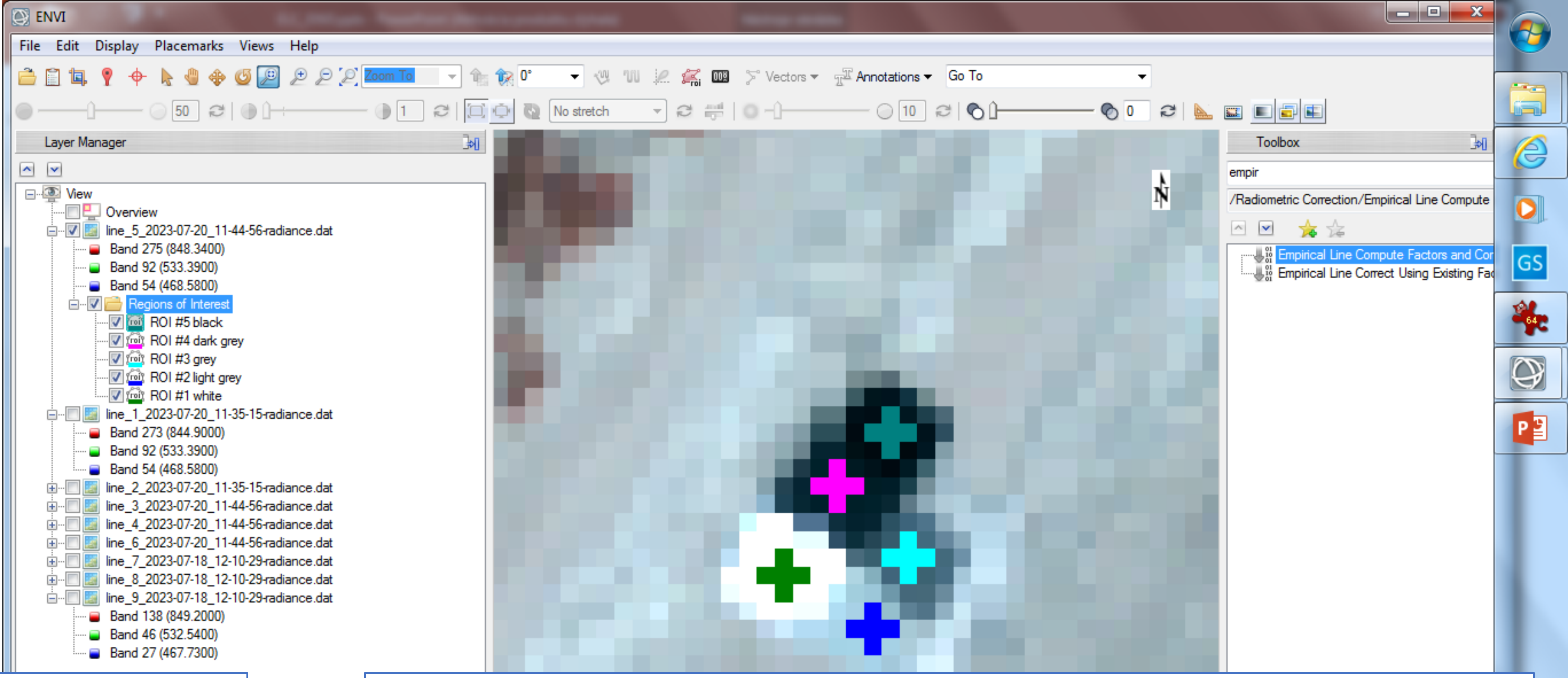


Spectralon reference panel

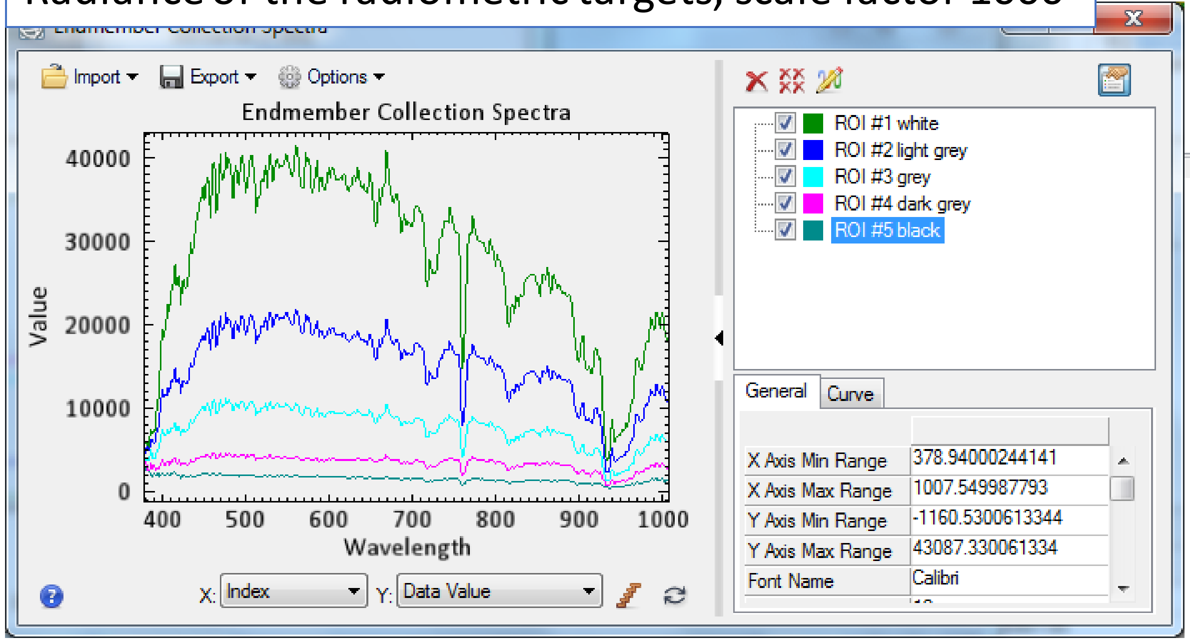


Radiometric targets in Line 5 with ASD field measured spectral reflectance

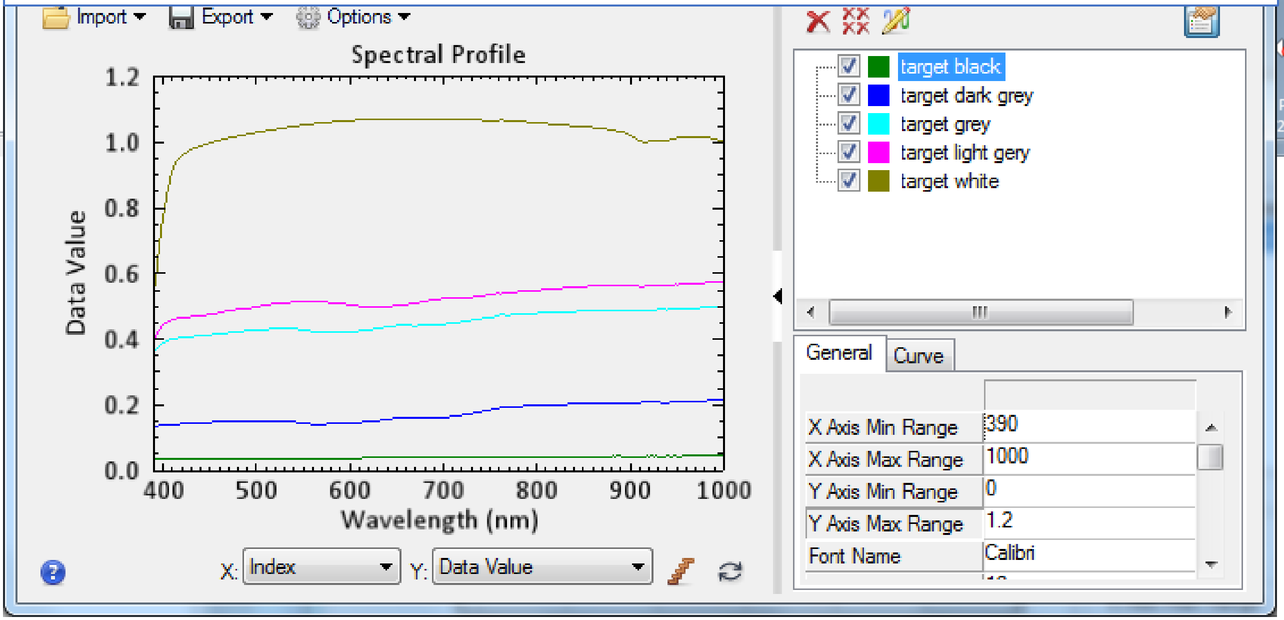
NB: ASD field measured reflectance of white target is higher than 1



Radiance of the radiometric targets, scale factor 1000

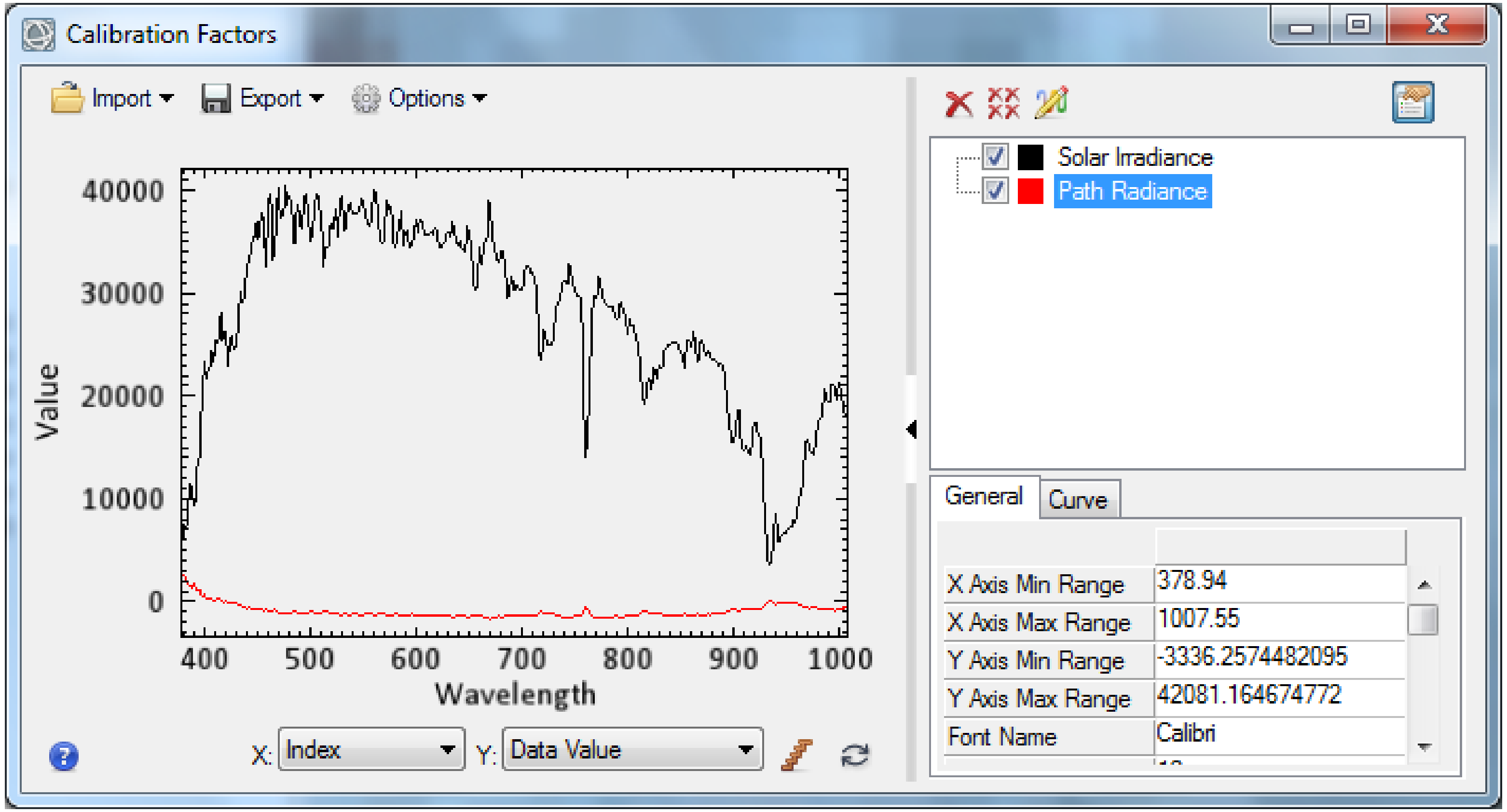


ASD field measured reflectance of the radiometric targets

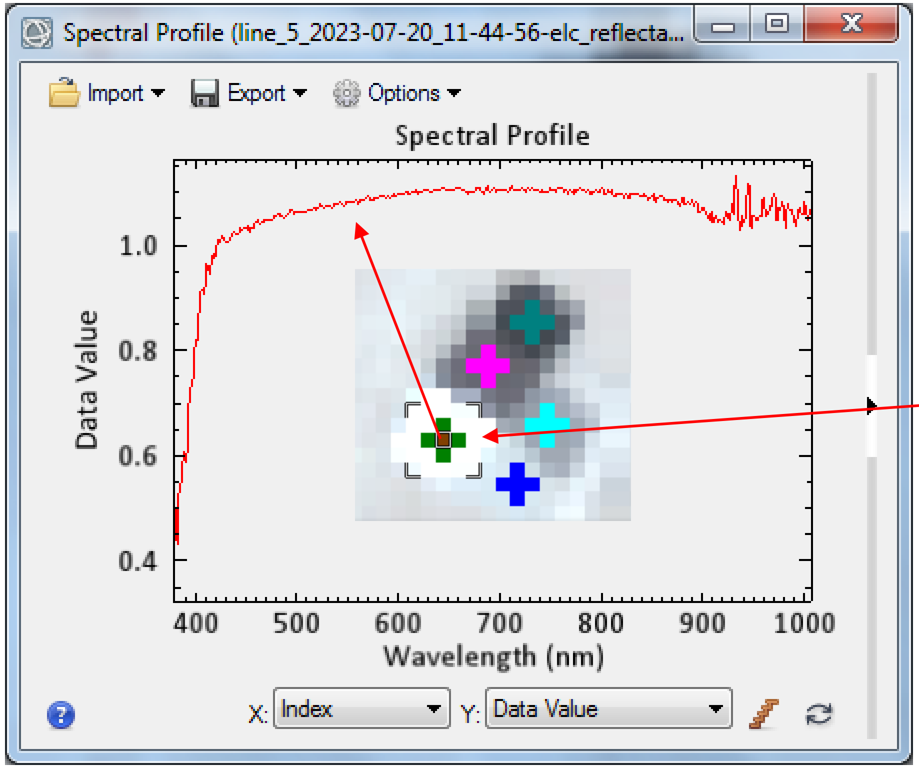


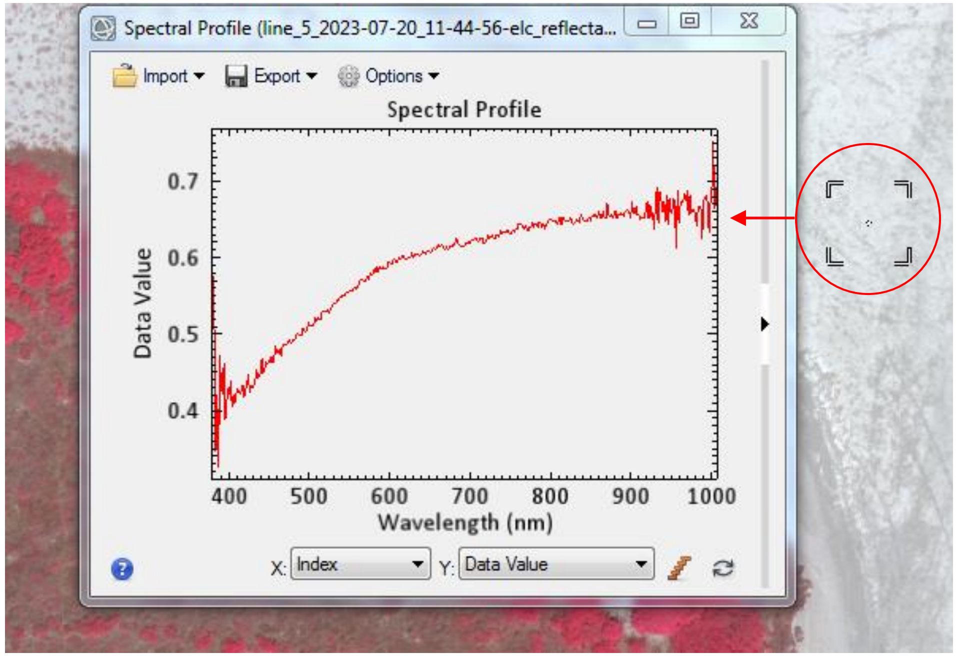
Calibration factors – solar and path radiance calculated based on line 5 radiometric targets

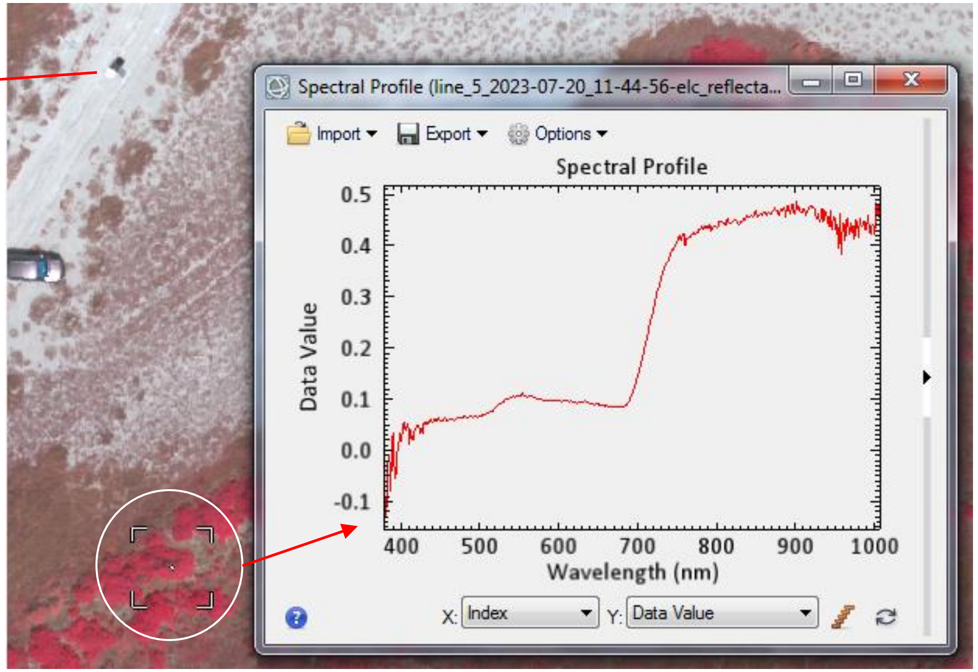
- Calibration factors file used to calculate reflectance of line 1,2,3,4,6
- Lines 7,8,9 have different spectral and spatial binning during acquisition, therefore, could not be corrected with this ELC methods



ELC reflectance







Empirical line correction (ELC)

- Lines 7-9 were flown earlier on Tuesday with different spectral binning (4x2) which causes problem in applying ELC based on radiometric targets flow on Thursday at 2x2 binning
- FLAASH could be used to derive reflectance
- ELC reflectance in the image of line 5 is higher than 1 for the white target, as the field measurement was above 1 for this target.
- The supplier of the radiometric targets (a Finish company) measured reflectance of the felt, and it is about 0.2 value lower than measured in the field by ASD spectrometer (compare it for the white target)
- these laboratory measurements were not used to date, reflectance is calculated for lines 1-6 based on the ASD reflectance measurements of the targets in the field.
- This issue should be tested.

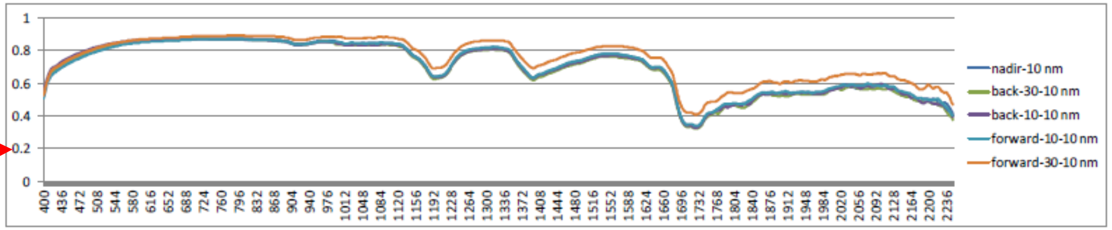
Reflectance Measurement
Metsälinkki White

WhiteFelt

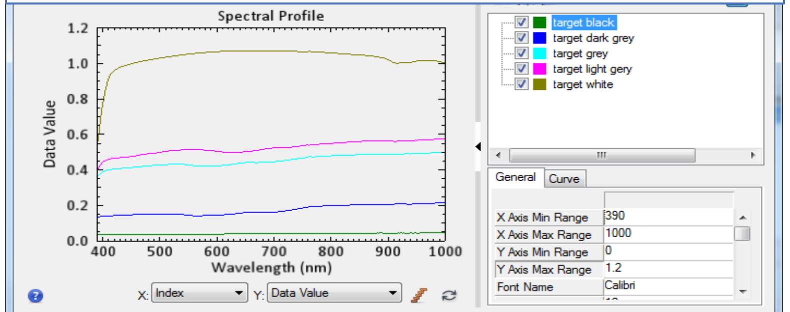
Metadata

Authors:	Teemu Hakala / MML
Target name:	Level 5 - White
Measurement instrument:	Reflectometer
Measurement light source:	Laboratory light source
White reference target:	Spectralon 99%
Measurement campaign:	2020 MosaicMillFelt
Measurement time	2020 January
Measurement location	FGI lab

Reflectance curve 400 – 2250 nm



ASD field measured reflectance of the radiometric targets



GRAZIE PER ATTENZIONE!