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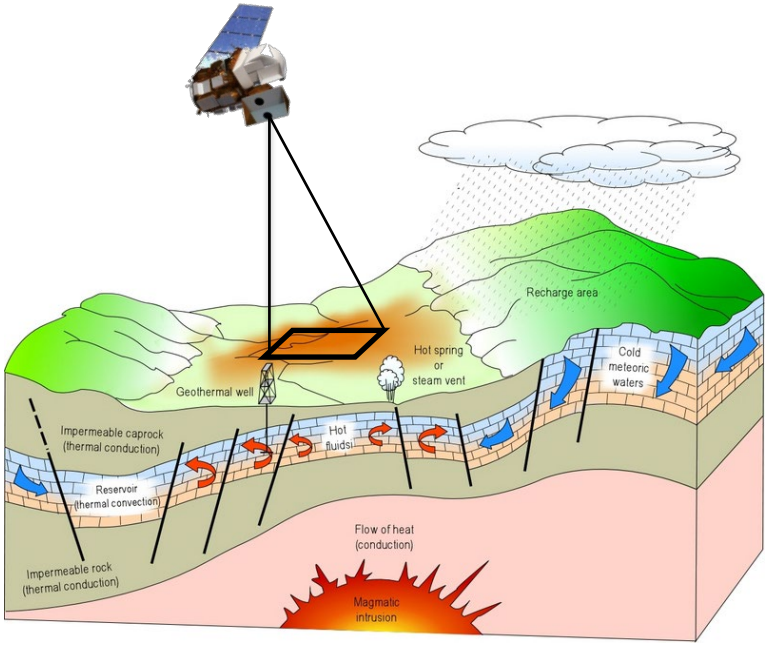
DETECTING GEOTHERMAL ANOMALIES FROM SPACE – WHAT IS THE CURRENT STATE-OF-THE-ART?

CHRIS HECKER, AGNIESZKA SOSZYNSKA, THOMAS GROEN

(… AND MANY CONTRIBUTORS)

ITC FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

WHAT ARE GEOTHERMAL SYSTEMS AND SURFACE MANIFESTATIONS?



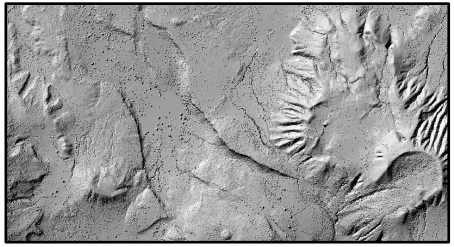
source: Geothermal-energy.org

Review Paper RS for geothermal: https://doi.org/10.1016/j.jag.2014.05.007
Day/Night thermal RS for geothermal: https://doi.org/10.1016/j.jag.2019.101991
Olkaria geothermal FieldLab: https://doi.org/10.1029/2021EO153904

GT surface manifestations:

Clay alteration (reflective RS)

Structures (LiDAR / RADAR)



Surface hotspots (Thermal RS)

=> Starting point for detailed exploration

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ISSUES IN THE PAST (CASE OF THERMAL ANOMALIES)

- Anomaly thresholds manually determined (per case area)

- Other anomalies are “bigger”
  - Size of anomalies small compared to pixel
  - Wrong overpass time
  - Effect of thermal inertia not captured

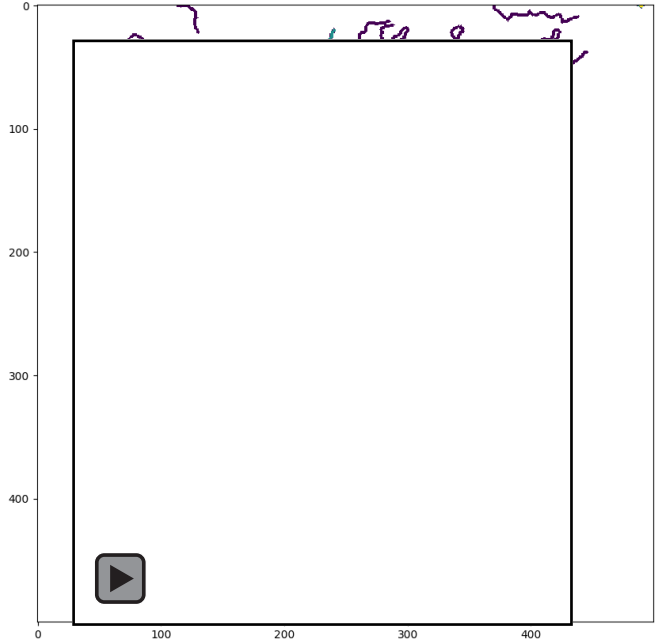
⇒ Anomalies due to insolation bigger than due to extra heat flux

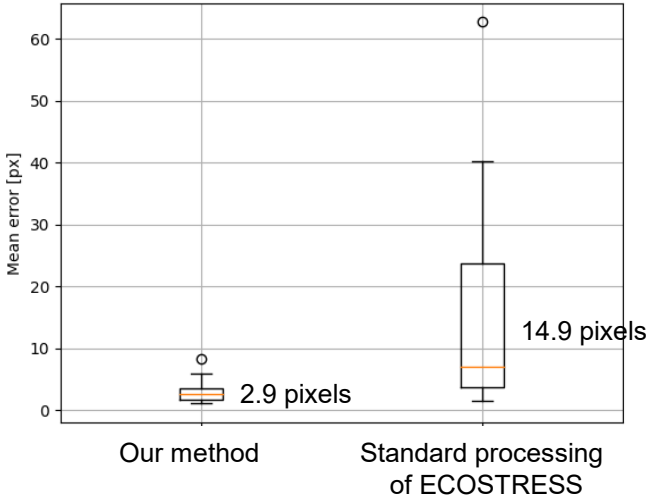
⇒ Even at sunrise effect still measurable (Coolbaugh et al., 2007)

ECOSTRESS TO THE RESCUE

- Experimental thermal sensor on ISS (since 2018)
- Designed for plant stress
- Ideal to test new approaches:
  - Precessing orbit (different acquisition times)
  - Diurnal time series
  - Suitable pixel size (~70m)

CHALLENGE – ABSOLUTE GEOLOCATION ACCURACY





Source: **Soszynska et al (2022)**
https://doi.org/10.3390/s23115079

Our solution:

- Matching of water body edges
- Using up-to-date Sentinel-2 reference for each ECOSTRESS image

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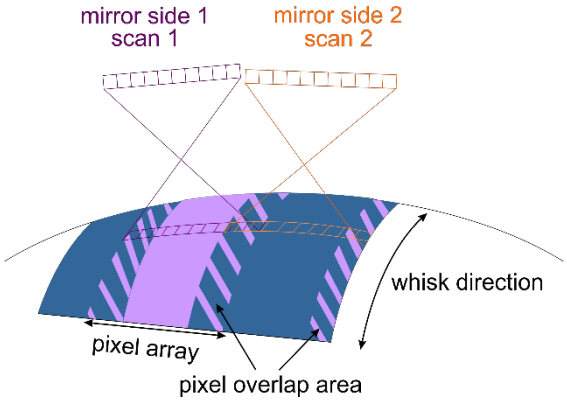
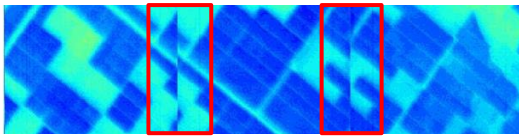
CHALLENGE – RADIOMETRIC ARTIFACTS (REL. GEOLOC)

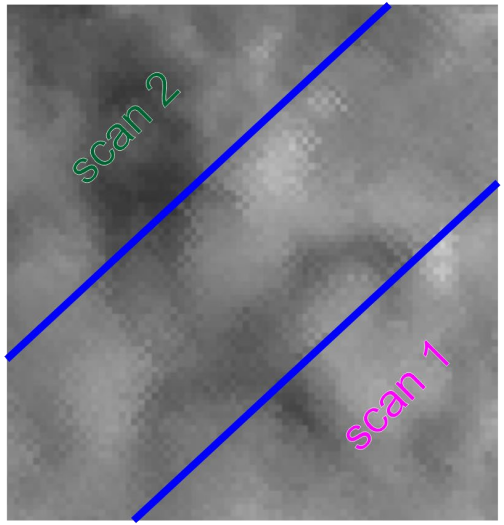




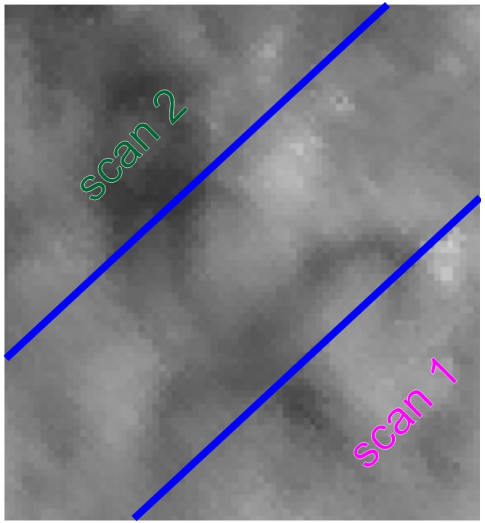
Source: ECOSTRESS L1 User Guide

ECOSTRESS image from 04.02.2021

APPEEARS processing



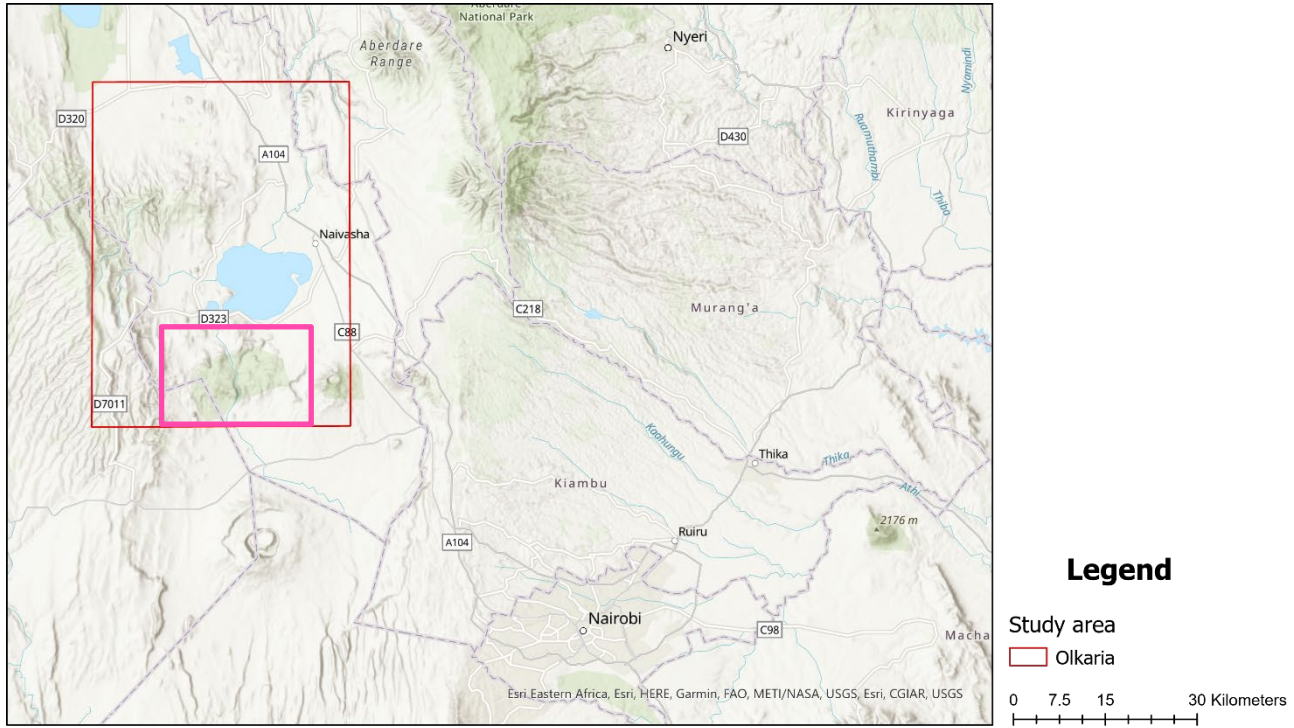
Single scan processing



Our implementation

Geolocation bias characterization work continued by **Soszynska and Ghent (U of Leicester)**

DETECTION OF GEOTHERMAL ANOMALIES USING ECOSTRESS DATA: STUDY AREA IN KENYA



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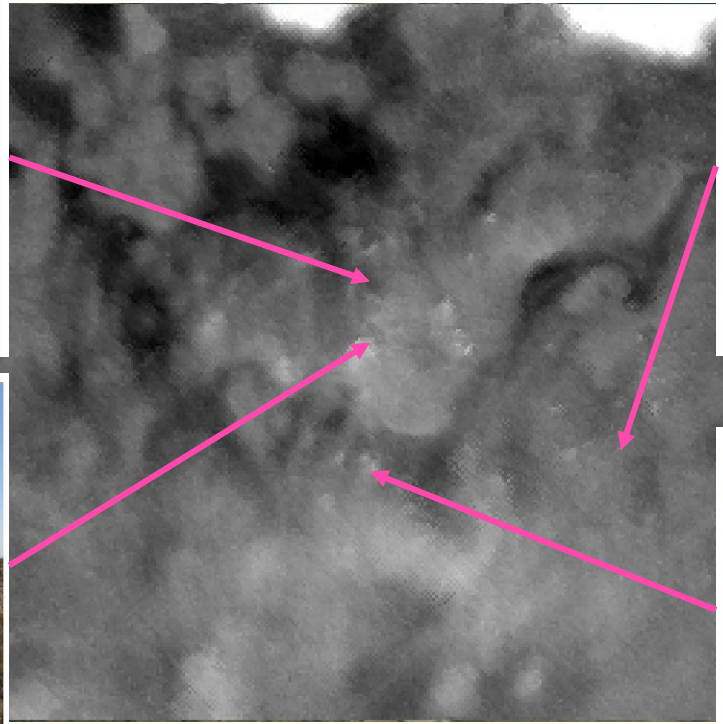
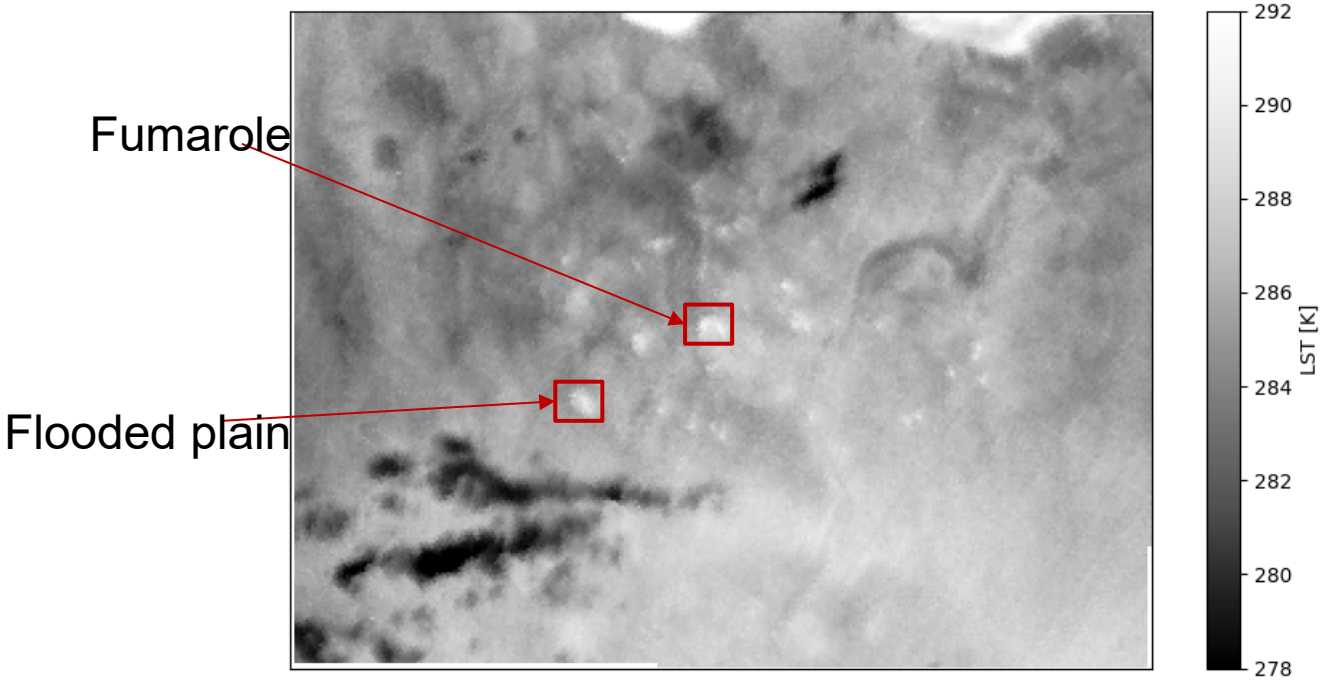
DETECTION OF GEOTHERMAL ANOMALIES USING ECOSTRESS DATA: STUDY AREA FUMAROLES



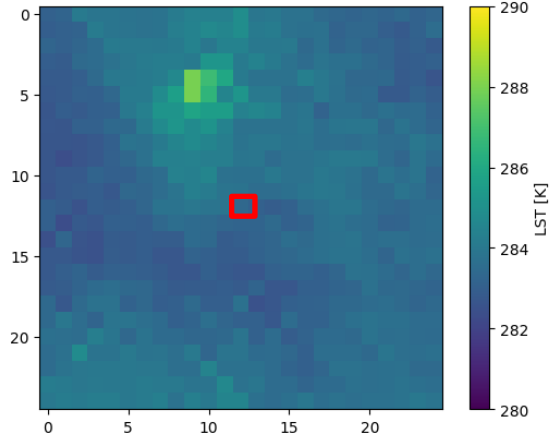
DETECTION OF GEOTHERMAL ANOMALIES USING ECOSTRESS DATA: STUDY AREA FUMAROLES (2)

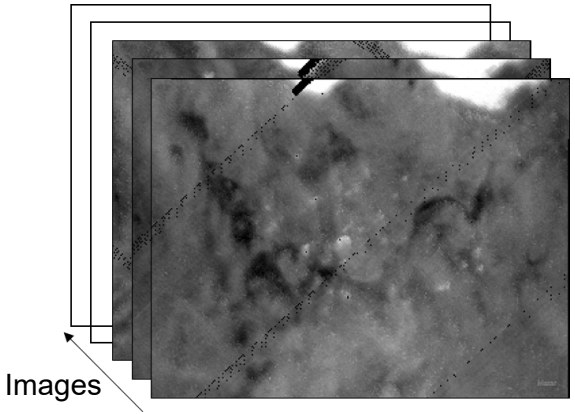


ANOMALY DETECTIONS (1) - KENYA

Approach

- Pixel is analysed in **comparison to its surroundings** (kernel-based)
- **Detection threshold** is calculated for each kernel position
- LST of the pixel is compared to the threshold (and possibly marked as **anomalous**)
- **Kernel** size is **adapted**, if a larger anomaly is detected
- Detected areas are **summed and normalized** throughout the study period
- Pixels which are detected in **at least 3 images**, are treated as valid detections

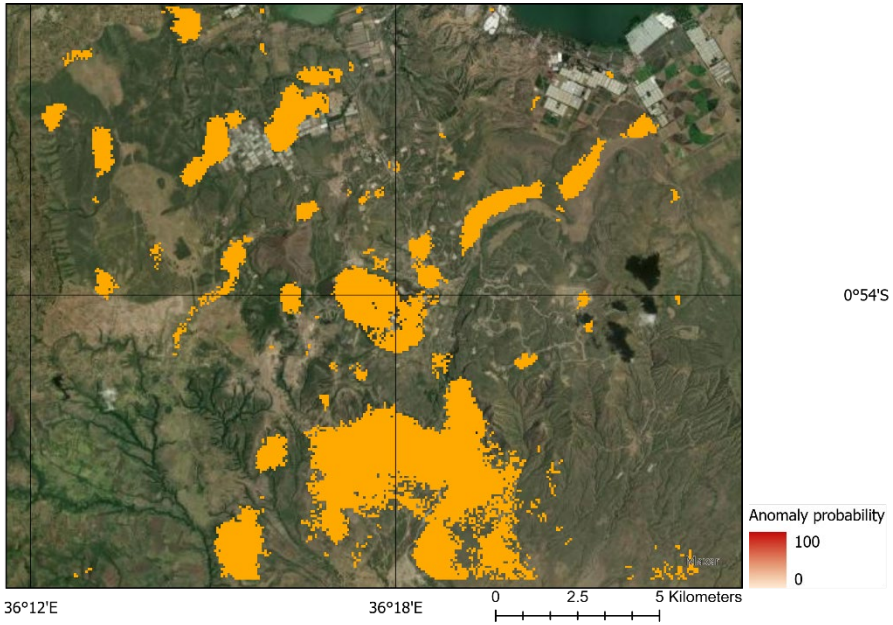




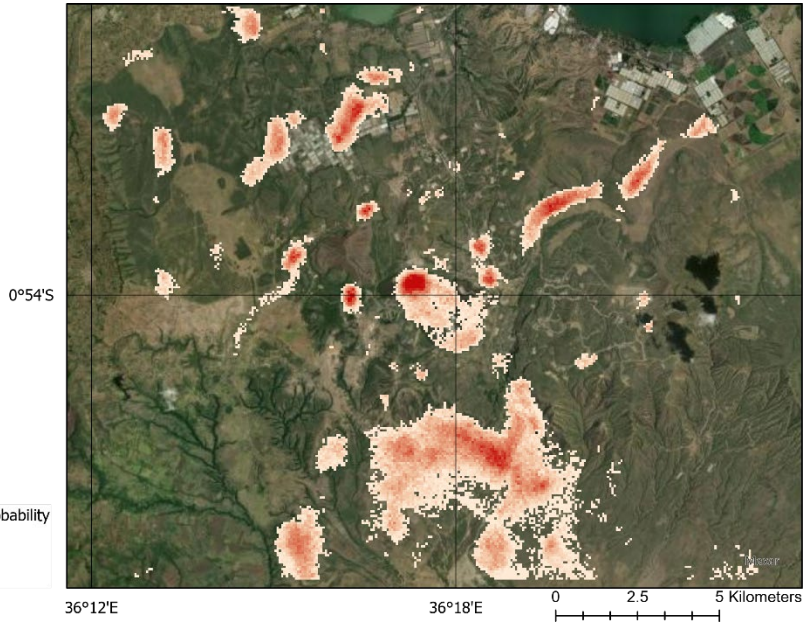
Source: **Soszynska et al (2024)**
https://doi.org/10.1016/j.rse.2024.114103

ANOMALY DETECTIONS (2)

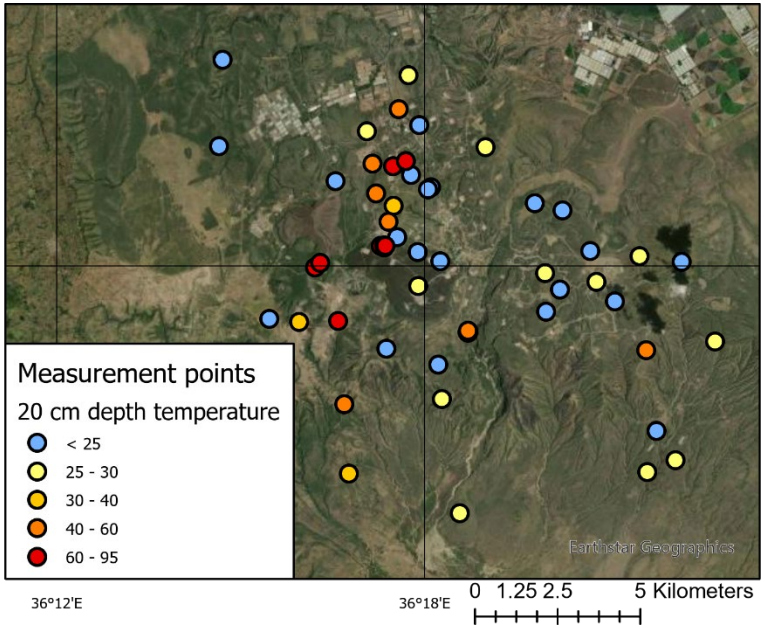
Binary detection map



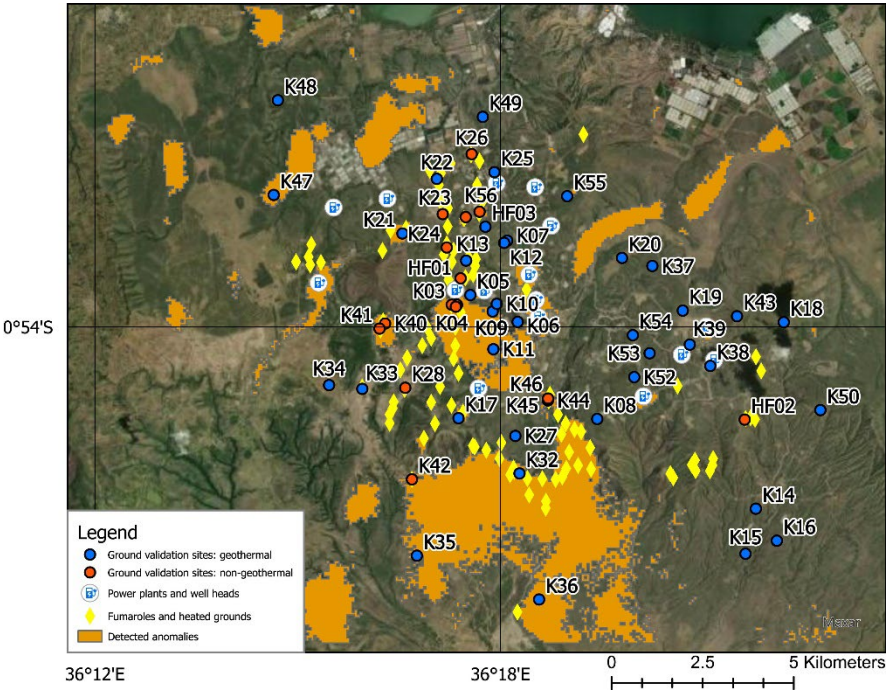
Anomaly Index



ANOMALY DETECTIONS (3) – GROUND TRUTH



ANOMALY DETECTIONS (4)

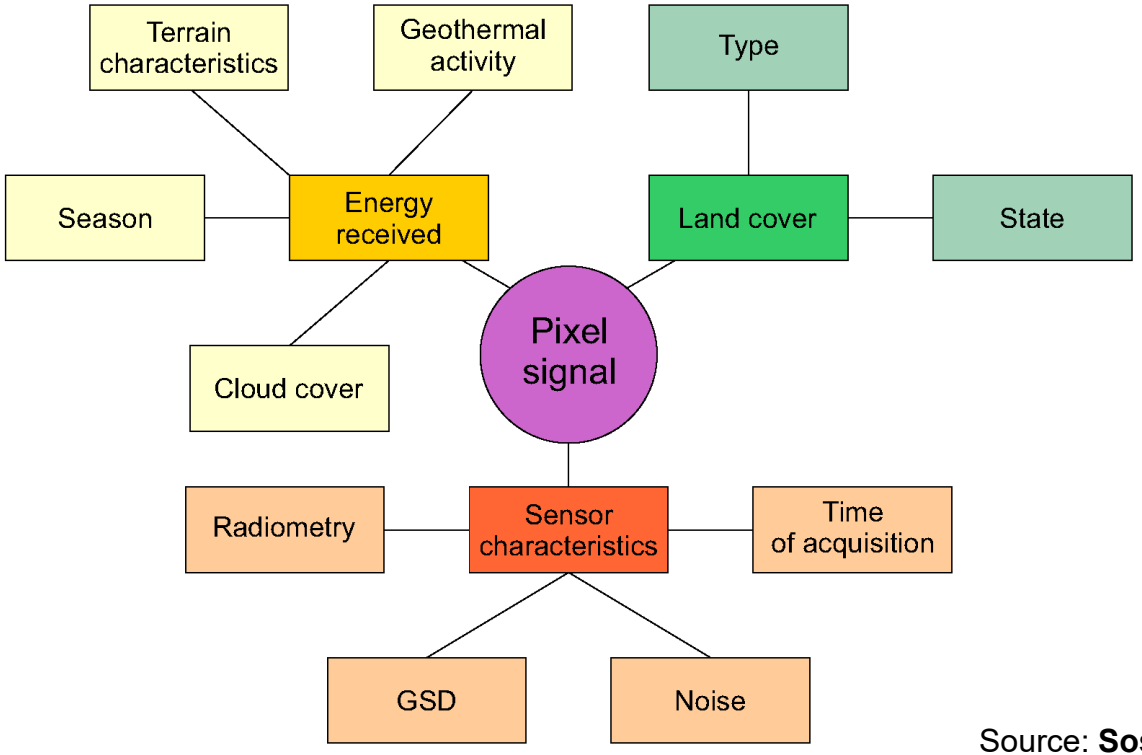


	Detection	Randomised contiguous areas	Randomised pixels
Overall accuracy (geothermal and non-geothermal)	68%	57% ± 7.1%	60% ± 4.9%
Producers accuracy (geothermal)	82%	34% ± 22.0%	19% ± 9.5%
Producers accuracy (non-geothermal)	62%	68% ± 9.9%	78% ± 6.2%
Users accuracy (geothermal)	48%	29% ± 13.2%	28% ± 11.5%
Users accuracy (non-geothermal)	89%	71% ± 6.8%	69% ± 2.9%
Omission error (geothermal)	18%	66% ± 22.0%	81% ± 9.5%
Omission error (non-geothermal)	38%	32% ± 9.9%	22% ± 6.2%
Commission error (geothermal)	52%	71% ± 13.2%	72% ± 11.5%
Commission error (non-geothermal)	11%	29% ± 6.8%	31% ± 2.9%
Fumarole accuracy	55%	33% ± 13.0%	21% ± 4.4%

Results clearly better than random but what effect creates the errors?

Source: **Soszynska et al (2024)**
https://doi.org/10.1016/j.rse.2024.114103v

DETECTION OF GEOTHERMAL ANOMALIES USING ECOSTRESS DATA: VARIABLES INFLUENCING DETECTION



Source: **Soszynska et al (in prep.)**

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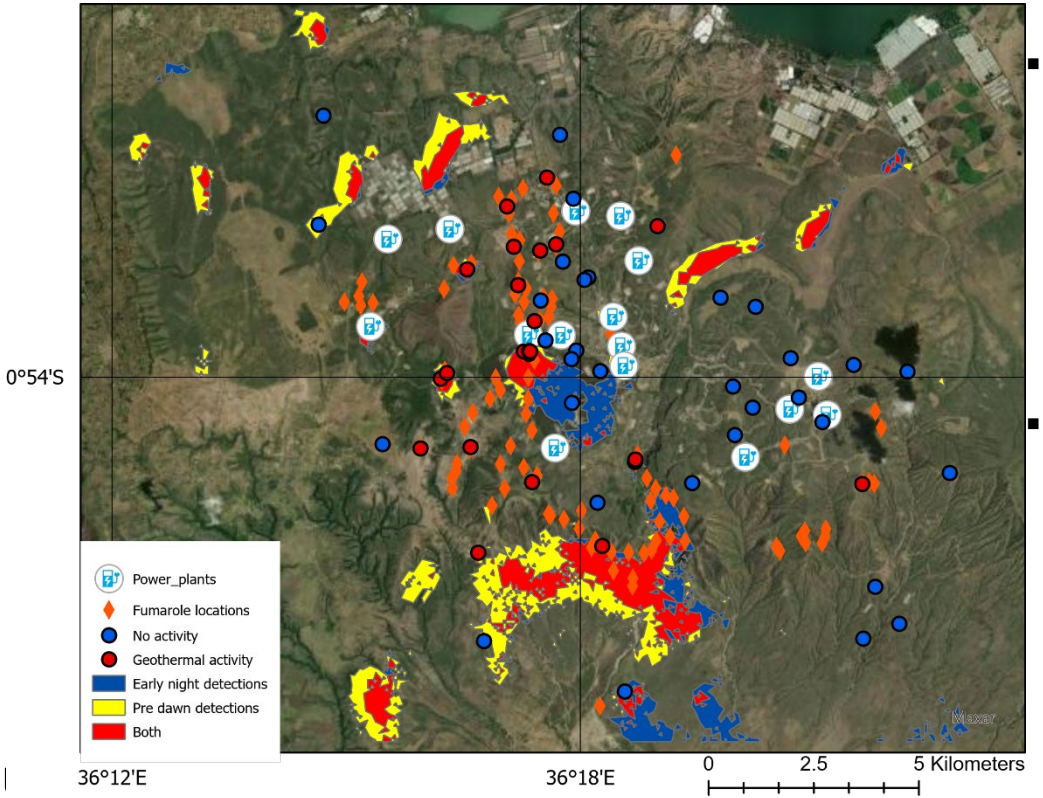
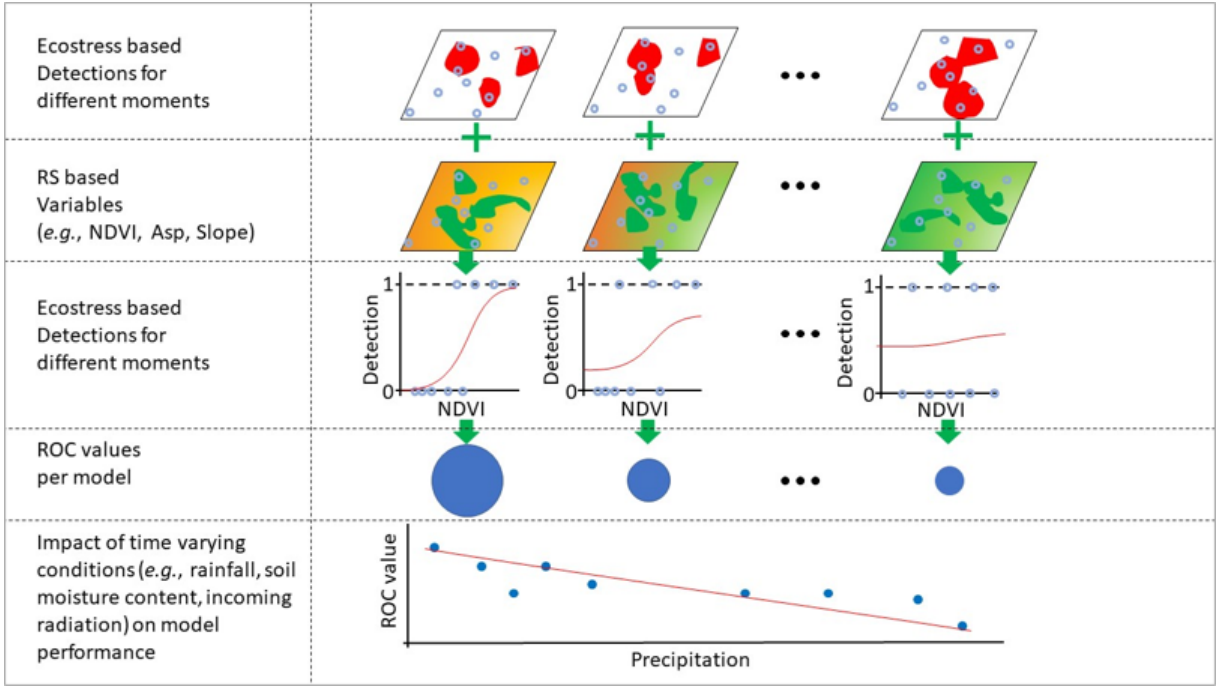


- Pre-dawn detections are generally larger and usually extend the early-night detected hotspots
- Some areas are detected in early-night only, likely due to heat capacity causing false anomalies

DETECTION OF GEOTHERMAL ANOMALIES USING ECOSTRESS DATA: VARIABLES INFLUENCING DETECTION



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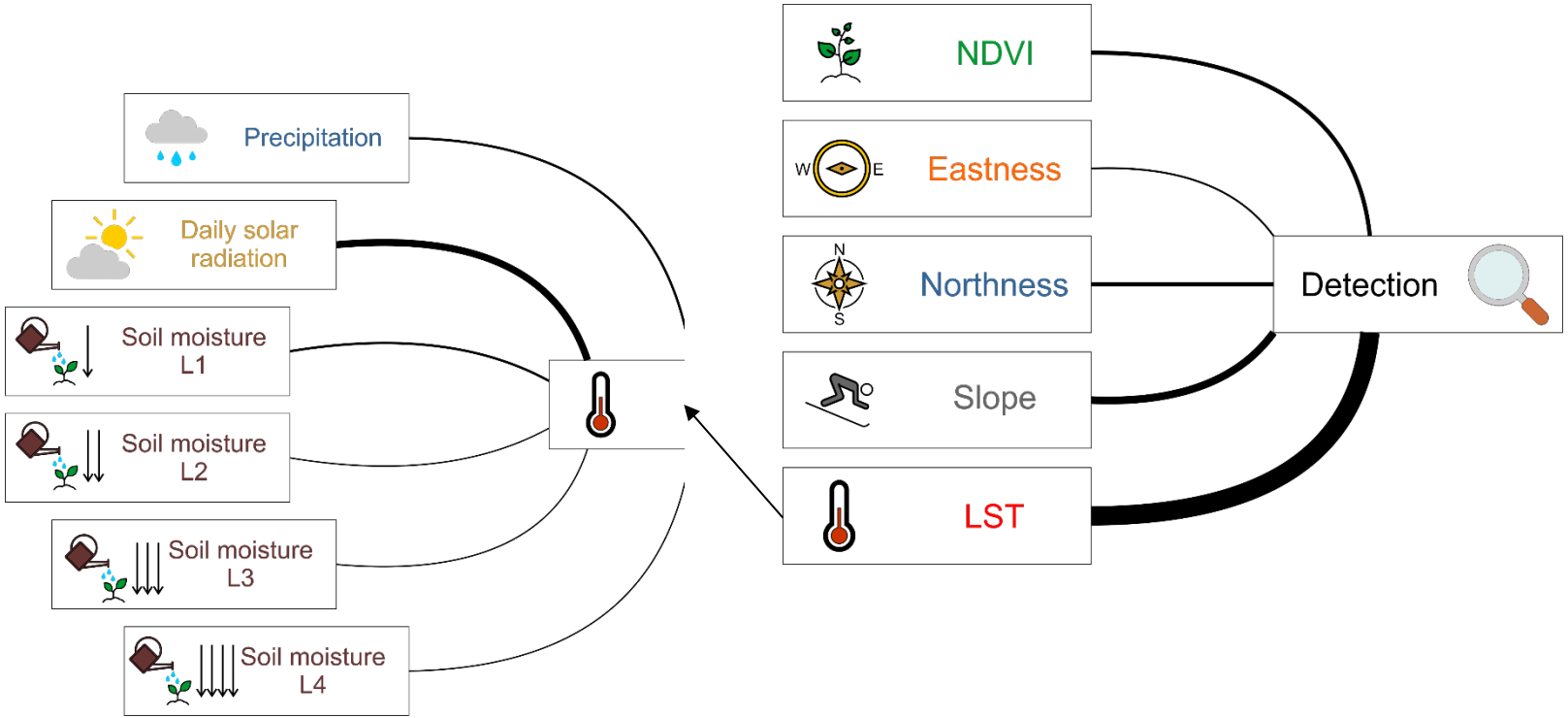
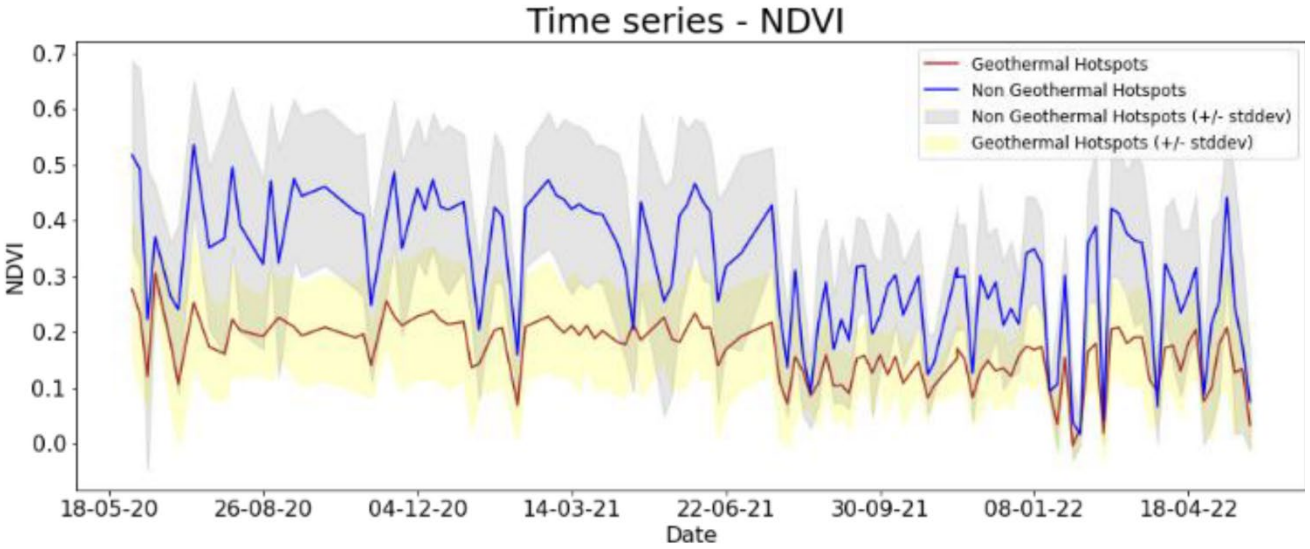


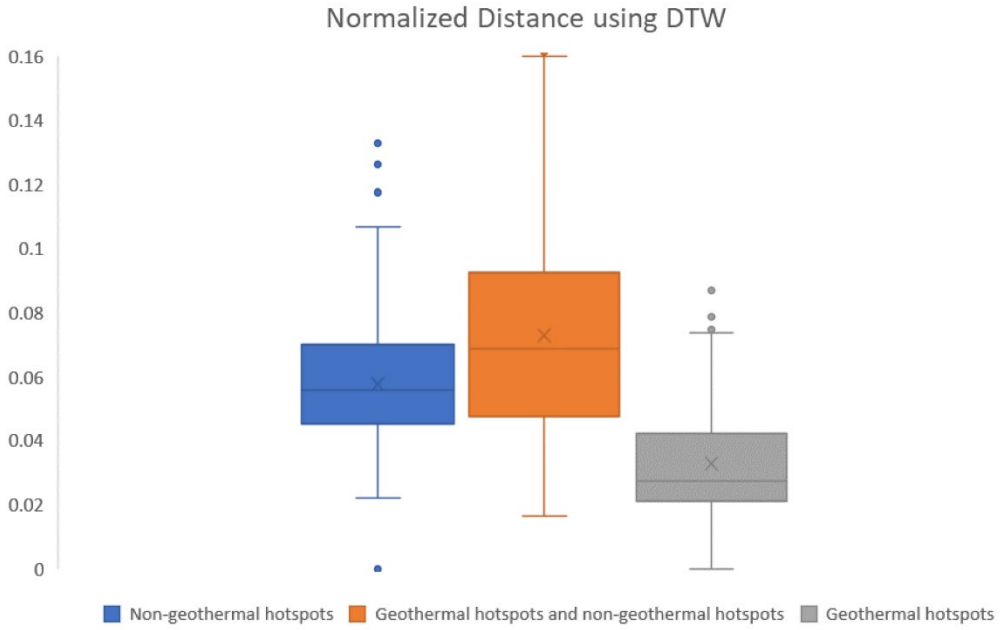
HOW DOES VEGETATION BEHAVE?



- Vegetation very dynamic over 2 years for both true and false detections
- NDVI does respond to individual rain events (not visible at this scale)
- How does the response shape (to rainfall event) look like?

Source: MSc thesis Anna Arora (2023)

HOW DOES VEGETATION BEHAVE? (2)



Dynamic Time Warping:

- Comparing the time series shapes around rainfall events
- Low values represent similar shapes (similar to SAM)

=> True geothermal hostpots have most similar shape within their group (grey) since veg density is low

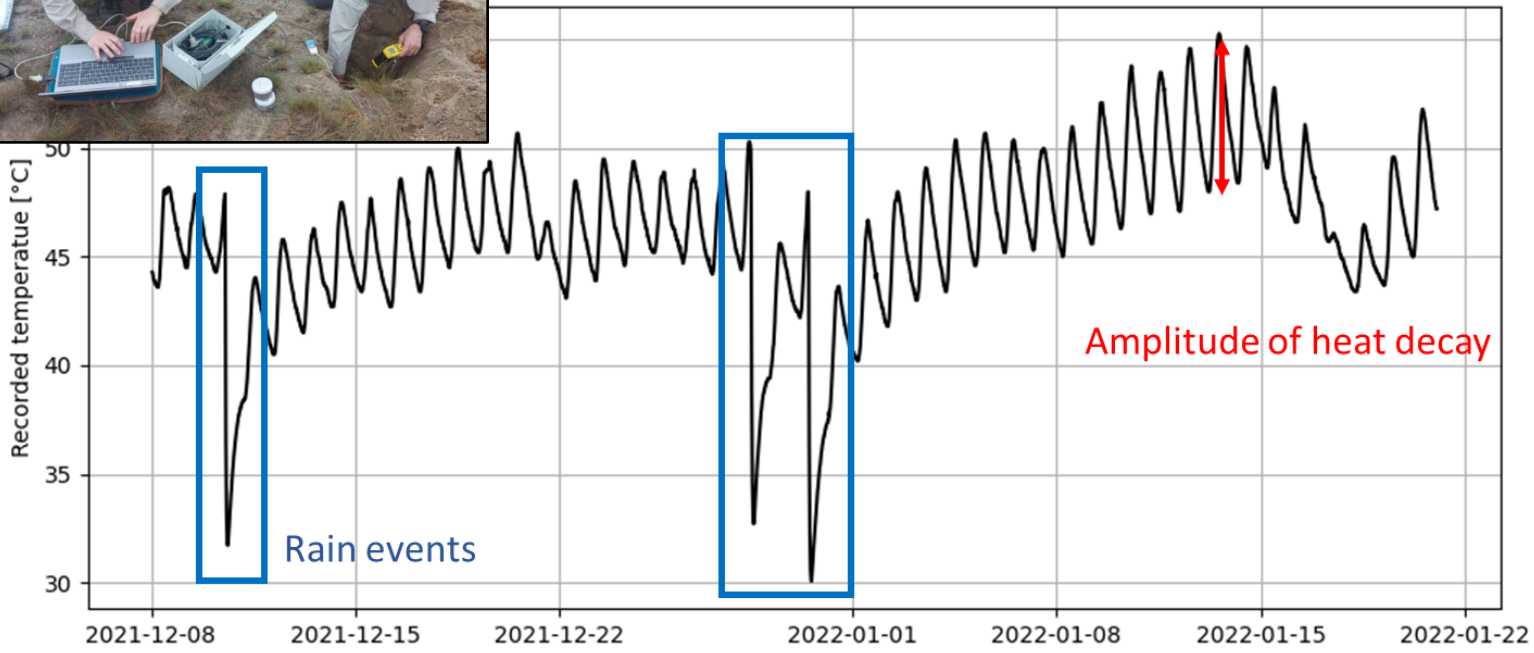
=> Veg density seems better characteristic than time series behaviour (in this area!)

Source: MSc thesis Anna Arora (2023)

REMAINING ISSUES

- Heat capacity: What if we dont look at absolute temperature but decay of temperature? => soil loggers => Agnieszka
- Only a few scenes of ECOSTRESS; others sensors are coarse
- Can we go truly global? => Alexey
- Processing: in cloud rather than local machine

PRELIMINARY RESULTS – SOIL TEMPERATURE DECAY



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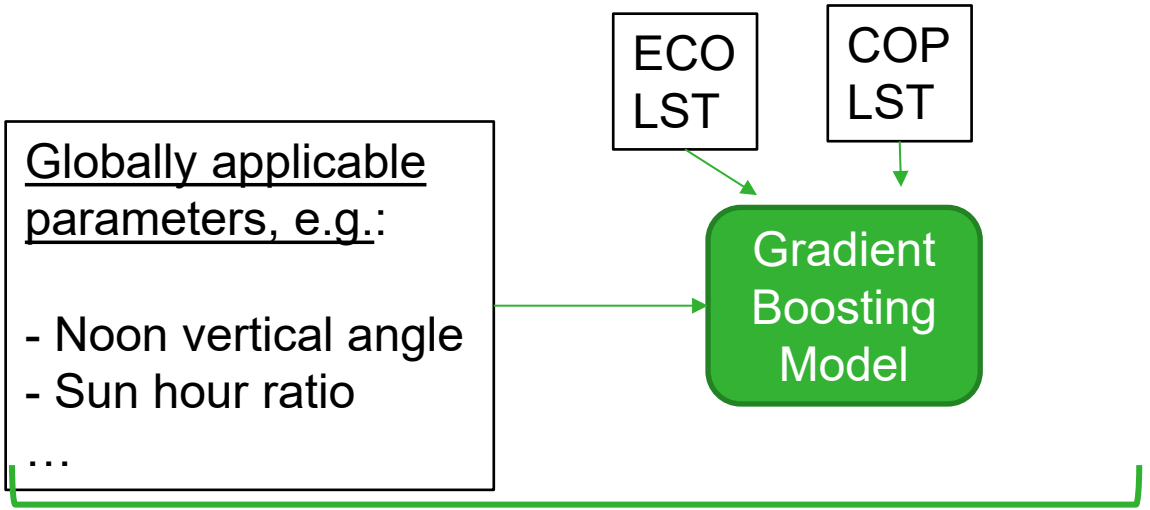
Source: Soszynska et al (in prep)

UNIVERSAL DOWNSCALING WITH ML

- Super-resolution image (high temporal, high spatial)
- Reconstruct hourly time series under changing weather conditions



Source: Noskov et al (in prep)

TAKE-HOME MESSAGE

- Geolocation is problematic => solved
- Radiometry is problematic => work around and correction in progress
- Use ECOSTRESS if precessing orbit is important. Alternative: ASTER

- For GT anomalies:
  - use multiple images (reduce “noise”)
  - use multiple times (early / late night) to give additional info and confidence
  - Temperature decay is observable could help decide normal vs anomalous
  - Near-global automatic anomalies are being worked on

ACKNOWLEDGEMENTS

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- Partner organizations:

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