FEATURED ARTICLE
Thermal infrared work at ITC – a personal, historic perspective of transitions

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Figure 1: Ground truthing radiant temperatures of coal fire -related thermal anomalies detected from space over an area in Inner Mongolia, China in 2003.

Over the past 20 years, my work in thermal infrared remote sensing (TIR-RS) has gone through a number of changes and transitions that have fundamentally impacted my daily work.

This is my personal perspective of these changes, but I am confident that many of you will have followed similar paths and will recognize part of my journey.

The early days

When I started working at ITC in 2001 thermal infrared remote sensing was exactly how it was described in the (geologic) remote sensing books of Sabins, Drury and Lillesand and Kiefer [1-3]: it was heavily based on a single, broadband channel 6 of the Landsat-series satellite suit, striping and "salt and pepper" in the images were common and relative radiant temperature comparisons were often used, as emissivity information of the targets were not known or had to be guessed from a land cover classification.

In that context, ITC executed a number of large coal fire detection and intervention projects in northern provinces of China and in India. TIR-RS with Landsat and later MODIS [e.g., 4] data was used to detect areas with unusual radiant temperatures, so called "thermal anomalies" as early warning indicators and for monitoring extinction efforts for coal fires in the shallow subsurface.

The regional monitoring was followed up by field visits with thermal hand-held cameras and radiant thermometers (Figure 1), and occasionally with an airborne thermal campaign of questionable quality.

Enter ASTER

Shortly after I had made my first baby-steps in TIR-RS, ASTER showed up on the scene. It was a game-changing sensor with multi-spectral capabilities in the TIR in addition to the typical SWIR bands that we had already become familiar with from the landsat suit sensors.

The multi-spectral TIR bands enabled the spaceborne thermal community for the first time to extract emissivity directly from the data, providing not only better kinetic temperature estimates, but also spectral LWIR information for regional geologic mapping.

ITC already had a strong research group on SWIR spectroscopy, so we decided that expanding into the TIR/LWIR domain would help to capture those minerals that are elusive in the SWIR, such as non-hydroxylated silicates (feldspars, quartz, garnets etc).

I reached out to those already working in the thermal domain and found a small, but very welcoming community. I visited Simon Hook at JPL and Lake Tahoe (Figure 2), Wendy Calvin at UNR, Lyle Mars and x`Jim Crowley at USGS, and Mike Ramsey at UPittsburgh for advice, and I received overwhelming support.

This fact finding mission resulted in two custom-made LWIR spectrometers, one for our ITC lab facilities [5] and one for the field.

Since then, we have fine-tuned the design and I have hosted and shared my knowledge with a number of visitors from England, Luxembourg, Germany, Sweden and Australia to pay it forward to the thermal community.

Apart from the typical spectral geology applications, I had the opportunity to measure plastics, solar panels and arctic avian eggshells [e.g., 6] with visiting colleagues, to name a few.

Organizing the community

As TIR-RS became a bit more mainstream, we realized that many of us were working on similar issues. To bundle efforts and increase efficiency,

I founded and chaired a new Special Interest Group on Thermal Remote Sensing (SIG-TRS) of the European Association of Remote Sensing Laboratories (EARSeL), together with Claudia Kuenzer from DLR in 2008.

Claudia and I chairing the group together was an expression of the special duality of TIR-RS, where some of the applications are focused on land surface temperatures while other researchers are interested in the emissivity and material properties.

Figure 2: Maintenance visit to JPL's Lake Tahoe validation buoy for spaceborne TIR sensors with Simon Hook (not in the picture) and research staff from UC Davis in 2006.

None of these groups could ignore the other field entirely, as the measured radiance data were an expression of both. Keeping the two communities under one organizations also created a bit more clout in what was still a niche application in remote sensing.

Under this SIG-TRS umbrella we organized various activities, particularly dedicated TIR sessions and side events at conferences to bring the thermal community (particularly of Europe) together and avoid thermal infrared topics being dispersed over less suitable conference sessions.

Figure 3: demonstration of our then new the prototype field LWIR spectrometer at the GRSG AGM of 2009 in London

Most memorable for myself was the 2009 GRSG AGM in London, where we added an entire TIR day to the programme, illustrating the thermal infrared interest within the GRSG community, as well as the support from the GRSG Committee for TIR topics.

At the end of the day we demonstrated the use of our (then brand new) ITC LWIR field spectrometer to the audience in the respectable halls of the Linnean Society Of London (Figure 3). As of 2020, Claudia and I have stepped down as chairpeople of the SIG-TRS to pass the baton to the next generation TIR enthusiasts.

Transition to hyperspectral airborne data

My personal research interests in LWIR spectroscopy took a sudden turn in 2009 when I was offered the opportunity to work with airborne SEBASS data (Figure 4). Dean Riley (formerly Aerospace Corporation) and Conrad Wright (formerly SpecTIR) had acquired a combined VNIR-SWIR-LWIR dataset over a mineral exploration study area in Yerington, Nevada that I was given the opportunity to work on. I completed my PhD on the dataset and we have had numerous masters students working with me in the area since.

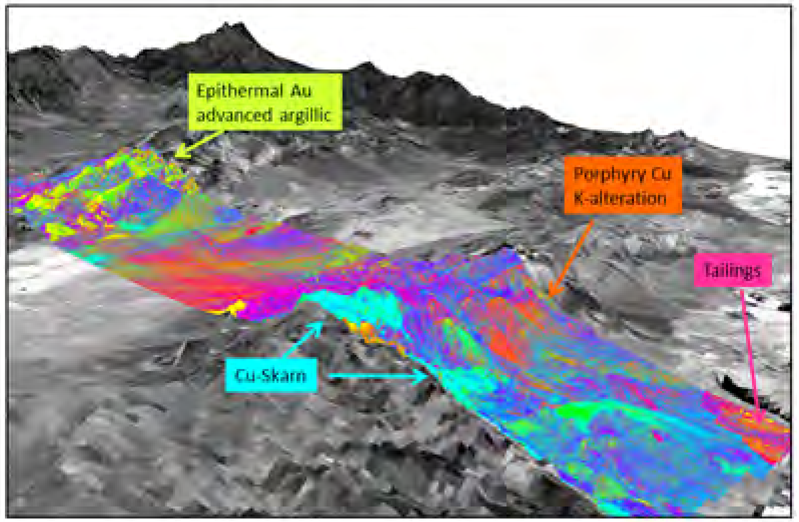

Figure 4: mosaiced and decorrelation-stretched LWIR color composite of airborne SEBASS data (4m pixels) over the Yerington Batholith in Nevada, USA highlighting different alteration styles in the areas. Draped over a grayscale ASTER band & DEM.

SEBASS was (and is) a truly exceptional sensor. With 128 bands in the LWIR as well as MWIR, it was the first hyperspectral airborne LWIR sensor I had worked with. On the downside, its 128-pixel swath was extremely narrow and together with the liquid Helium cooling, it made deployability a challenge. Additionally, data sharing was restricted due to the "dual use" (military/civil) nature of the sensor, which is particularly difficult in an truly international classroom, as we have at ITC.

However, SEBASS was in my perspective a trail-blazer for the “explosion” of sensors that followed. Aerospace itself created follow-on instruments (e.g. MAKO and MAGI) that overcame some of the earlier SEBASS limitations.

But also commercial suppliers entered the market, like ITRES offered the spectral TASI sensor, Telops its airborne version of the Hypercam and SPECIM the OWL camera, to name a few.

With this technological development commercial operations of airborne spectral TIR sensors (outside of the defence and R&D realm) suddenly became a reality.

In the past few years, much effort has been put into atmospheric correction and emissivity separation algorithms by data providers to further lower the threshold for commercial users and deliver reliable Level2 (or higher) data products to the end users.
While there are still minor issues to be solved, we are now at the point where commercially available airborne hyperspectral TIR data is becoming a reality.

Transition to geothermal applications

Under the global need to transition away from our hydrocarbon-based economy, new applications of thermal remote sensing became increasingly opportune to add to the more traditional mineral exploration applications.

In 2013 ITC started working on geothermal exploration topics, and by 2014 lead an international multi-year geothermal capacity building programme (GEOCAP, [7]) which partially investigated remote sensing for geothermal exploration and monitoring in Indonesia.

Earlier work (particularly by teams from UNR and linked to Wendy Calvin and the late Jim Taranik) had shown that spaceborne TIR remote sensing could be used to map surface temperature anomalies related to fumarole activities [e.g., 8].

Our own results demonstrated that potential as well [9] but it worked best in desert-like environments and with night time data of high temperature contrast. In any non-ideal situation the delicate balance could easily shift towards inconclusive or no results.

The main reasons are a) vegetation cover, b) the pixel size of the spaceborne thermal data are often coarse compared to the actual surface expressions (often fumarole vents), and c) the overpass time of sun-synchronous satellites is not ideal for thermal anomaly detection (too early in the night to subdue effect of differential solar heating and different heat capacity of the materials) [10].

Because of the first reason (vegetation cover) we decided that, particularly for the Indonesian context, focusing on proximal sensing of drilling data would be the more promising avenue.

For the latter two reasons, we decided to launch an airborne campaign over a test area in Flores to see what unknown thermal anomalies could be detected from high-spatial resolution airborne thermal data instead.

We integrated our ITC-owned FLIR x6570sc cooled thermal camera into an existing airborne Leica mapping and LiDAR setup of a local commercial data supplier (Figure 5).

Figure 5: Part of the team from UT-ITC, U. Gadjah Mada, and airborne operator APG at the open hatch of the Pilatus Porter PC-6 at the Komodo International Airport, Indonesia (2018). The down-looking thermal broadband FLIR camera is visible between the Leica LiDAR head (big black box in center of image) and the water supply of the pilot (towards the right)

In an area where previously only a single ASTER pixel had been identified as thermally anomalous, we could now identify numerous new fumaroles and warm ground in the 50cm airborne early morning thermal data [11]. The alignment of the thermal anomalies also showed clear underlying surface structures which could be compared to deeper structures seen in previously acquired geophysical datasets.

From remote to proximal sensing

Another transition that I have gone through in the past 10 years, and with me many other spectral geologists, is from air- and spaceborne remote sensing to the proximal sensing domain in the laboratory.

At first sight it appears mainly an engineering challenge to get a hyperspectral imaging sensors equipped with the right fore-optics and lighting to use them on conveyor belts or drill tray scanners.

The processing chain is largely similar to the airborne imagery, but with the added benefit of less atmospheric disturbance and typically quite high signal-to-noise ratio. As usual, the devil is in the details and the closer you look, the more challenges you find.

One of these challenges is the co-registration of VNIR-SWIR-LWIR images from separate instruments that don't share a fore-optic.

Two specific ones for the thermal infrared are the effect of sample surface roughness on the results [12] and the compensation of the self-emission of the sample as they are being heated by the illumination sources.

And of course the geologic crux is how to combine information from different wavelength ranges into the most sensible (I leave it to each of you to judge what you think this should be) geologic/mineralogic information possible. As a community, we have made great strides but there are some major challenges still left to be tackled.

In the proximal sensing realm, we are currently progressing with SWIR and LWIR imaging for geothermal drill cutting characterization. These cuttings are coarse sand-sized particles that result from the drilling of the reservoir rocks in a geothermal prospect.

In geothermal exploration cuttings are much more common than drill cores, due to the much lower drilling costs, and the challenge is to identify important, yet elusive hydrothermal alteration minerals in the small cuttings that tell us about the current situation as well as the history of the reservoir in terms of environmental conditions.

The circle closes

In a recent development, I have somewhat returned to my thermal roots: the detection of surface temperature anomalies with spaceborne TIR data, in this case from the thermal infrared ECOSTRESS sensor on the International Space Station.

Due to its specific orbit, ECOSTRESS has an advantage over instruments on the more traditional sun-synchronous and geostationary orbits; it allows for different acquisition times but still at a near-global coverage and at a fairly high (70m) spatial resolution.

Opposite to my early days we are now detecting geothermal rather than coal fire-related temperature anomalies. With the precessing ECOSTRESS orbit, we also have the opportunity to choose ideal times of the day for the anomaly detection, and to quantify the influence of overpass time on the detection success rates.

A post-doc researcher has recently started working at ITC on the project with study areas in Kenya, Indonesia and New Zealand. For the Kenya study area we have installed ground-based thermal cameras for long-term monitoring of fumarole activity in Olkaria geothermal field (Figure 6; [13]).

Figure 6: Installation of ground-based thermal cameras for the long-term monitoring of geothermal fumaroles.
Team picture of project staff from partners KenGen and UT-ITC (2019)

Through my own thermal infrared path over the past 20 years, I have observed a transition in the TIR platforms from spaceborne over airborne towards proximal sensing.

If miniaturization of hardware continues, LWIR spectrometers may move to larger UAV platforms in the coming years just like the SWIR sensors are currently doing.

In the instrument domain we have seen a change from relative instrument scarcity to a situation where now several commercial options for airborne hyperspectral LWIR acquisitions are available.

And in the application direction, we have seen moves towards alternative energy resources, such as geothermal energy.

But with critical raw materials being essential for the upcoming energy transition as well, a renewed interest in spectral geology and remote sensing for mineral exploration can certainly be expected.

And what wavelength range could we possible look at when we require additional information on REE-bearing silicates and Li-rich pegmatites … ?

Exactly!

Acknowledgments

Chris Hecker is an Associate Professor in Thermal Infrared Sensing at ITC-University of Twente, The Netherlands.

Next to his research, he teaches classes in Spectral Geology and Thermal Infrared Remote Sensing in the Graduate Specialization Applied Remote Sensing.

Chris expresses his sincere gratitude to the thermal infrared community and all its members with which he has had a very constructive exchange of the collective thermal wisdom, or of ideas on how to gather that wisdom in the future.

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