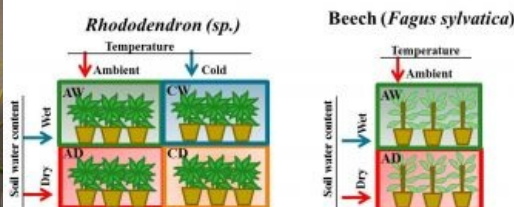


MONITORING RESPONSES OF VEGETATION TO CLIMATE CHANGE

Thermal Infrared Reveals Vegetation Stress



Climate change or other environmental changes may affect the health of plants. Conventional methods for determining how vegetation responds to changes in temperature and humidity measure the reflectance of the visible and near-infrared part of the electromagnetic (EM) spectrum on the leaves. A study using a non-destructive thermal infrared spectrometer has now demonstrated that persistent stress also affects the thermal infrared emissivity of plants. This finding paves the way for using thermal spectroscopy to monitor responses of vegetation to climate change.

(By Thomas Groen, Christoph Hecker and Maria Buitrago, ITC, University Twente, The Netherlands)

Detection of vegetation stress has been mainly done through visible (VIS) and near infrared (NIR) spectroscopy, partly because most (satellite) sensors and spectrometers cover these wavelengths and also because it was assumed that stress would not affect the wavelengths above $2.5\mu\text{m}$. Advances in spectrometers for capturing thermal infrared (TIR) ($3\mu\text{m}$ and upwards) makes it possible to accurately capture the emissivity of vegetation in the TIR spectrum and so to challenge the above-mentioned assumption. Emissivity is the relative emission of electromagnetic radiation compared to the emission of a perfect black body as defined by Boltzmann.

Equipment

The instrument used to capture the emissivity in the TIR domain of the EM spectrum was a customised Bruker Vertex 70 Fourier Transformed Infrared (FTIR) spectrometer, which is an industry standard (Figure 1). A gold-coated integrating sphere was mounted to an external port of the spectrometer for collecting the energy emitted by leaves in the spectral range from $1\mu\text{m}$ to $16\mu\text{m}$ in a non-destructive manner. The common method requires pulverisation of the leaves, which destroys the structure of the leaves. In the authors' set-up, the emissivity of individual leaves can be measured without picking the leaf from the plant by placing a leaf in front of the measurement port of the sphere. This keeps the leaf surface, with all its intricate developmental information, intact and enables repeat measurements to be conducted on the same leaf. Furthermore, the measurements can be compared with the output of TIR sensors mounted on airborne and satellite platforms much more effectively.

Species

Two types of plants – beech and rhododendron – were selected for conducting the study. Both species can grow in mountains but also at low altitudes. They can cope with high and low rainfall and high and low temperatures. Their stress responses to unfavourable conditions are therefore a good model for testing how stress is reflected in the emissivity of the TIR domain. Both species, planted in pots, were cultivated in a controlled environment for one growing season. The rhododendron plants were exposed to both water stress and temperature stress for a period of six months, from July to December, and underwent four treatments (Figure 2). The beech plants were only exposed to temperature stress (two treatments: ambient and dry) and the experiment lasted three months, from July to September. For the rhododendron plants drought was simulated by reducing the water supply to 20% of the field capacity and covering the pots with plastic to avoid effects of rainfall while being placed outdoors. The control group was watered weekly up to field capacity. The amount of water was controlled by weighing the pots. For both the rhododendron plants and beech plants, temperature stress was simulated by

placing the plants for three months in a cooled greenhouse in the summer and for three months outdoors in the autumn. The control group was placed for three months outdoors in the summer and for three months in a greenhouse in the autumn at a mean temperature of 19.1°C (Figure 3). In each treatment 15 plants of each of the species were used, requiring 60 rhododendron plants and 30 beech plants. Five healthy and representative leaves of the 90 plants were marked (Figure 4) and measured at the start and again at the end of the growing season.

Results

Some parts in the TIR domain show changes when plants grow under stressful conditions compared to plants which grow under ambient conditions and changes in emissivity can be seen especially in the longer wavelengths (7 to 14µm). However, the two species respond differently. In the beech plants the emissivity drops, while in the rhododendron plants the emissivity increases under stressful conditions. These different responses may possibly be caused by differences in the species' survival strategies.

Outlook

Operational TIR sensors, including the SEBASS and Hyper-Cam sensors, are mainly used for geological exploration and assessing the chemical composition of gaseous and solid substances. This study shows that these sensors also have potential for vegetation monitoring and can complement the conventional VIS and NIR methods. The results have been achieved under controlled laboratory conditions. In practice, TIR sensors will be mounted on an aircraft or satellite platforms, and water vapour in the atmosphere strongly interferes with TIR energy emitted from the ground. Nevertheless, TIR sensors enable monitoring of how plants respond to climate change. In view of global warming, plants that are temperature-limited, such as at higher altitudes in mountainous regions, will be released from temperature stress and this will be reflected in their emissivity values. This could be a precursor for more dramatic changes in land cover as a result of climate change, such as trees colonising at higher altitudes where they have previously been unable to grow. Therefore, capturing their TIR emissivity will make it possible to detect responses of vegetation to climate change at an earlier stage.

Concluding Remarks

The mechanism underlying the emissivity in the TIR domain and the responses to changing environmental conditions require further analysis. This proof of concept is a first step in unravelling how capturing TIR emissivity can contribute to monitoring vegetative responses to climate change.

Further Reading

Buitrago, M.F., Groen, Th. A., Hecker, C., Skidmore, A.K. (2016) Changes in thermal infrared spectra of plants caused by temperature and water stress, *ISPRS Journal of Photogrammetry and Remote Sensing* 111, pp. 22–31

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Authors

Dr Ir Thomas A. Groen has been an assistant professor in remote sensing of vegetation at ITC, The Netherlands, since 2007. Detecting vegetative responses to external factors is at the core of his research.

Email: t.a.groen@utwente.nl

Dr Christoph Hecker is an assistant professor in geologic remote sensing at ITC focusing on thermal spectroscopy of Earth materials and their alterations to environmental conditions.

Email: c.a.hecker@utwente.nl

Ir Maria F. Buitrago is a PhD candidate at ITC. The main subject of her research is remote sensing and the responses of plants in thermal infrared.

Email: m.f.buitragoacevedo@utwente.nl

Figures

Figure 1, Thermal infrared spectrometer.

Figure 2, Stress conditions for rhododendron (left) and beech. AW: ambient and wet; AD: ambient and dry, CD: cold and dry, CW: cold and wet.

Figure 3, Temperature-controlled conditions in a greenhouse.

Figure 4, Marked leaves.