Land Surface Temperature Retrieval from the uncooled Microbolometer array of FOREST-2.

Authors

Christian Mollière, Lukas Kondmann,
Diogo Rio Fernandes, Patrick Schnierle,
Julia Gottfriedsen, Marc Seifert, Martin Langer

Affiliations

OroraTech GmbH, St.-Martin-Str. 112-114, 81669 Munich, Germany

The FOREST-2 mission marks a notable advancement towards our objective to achieve a sub-daily land surface temperature (LST) product with a spatial resolution of 200m GSD or better. The integration of uncooled microbolometer technology is not only more cost-effective, but it is also highly scalable when compared to other cooled sensor systems. By implementing this technology on a larger scale, we are on track to provide a sub-daily, global LST product by the end of 2024. Further extensions to the sensor network will enhance the revisit cadence to 30 minutes in the coming years.

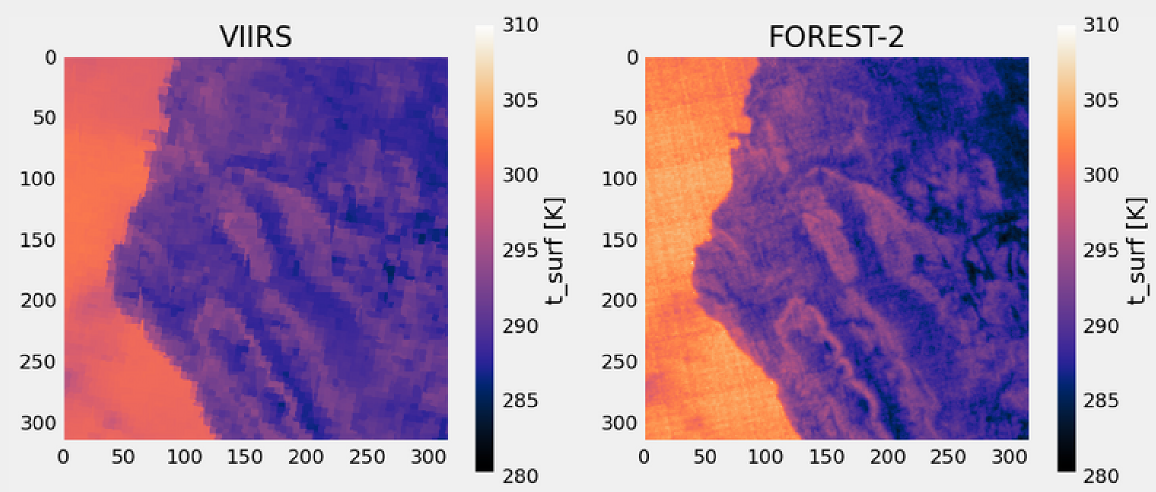

Figure 1: Quasi-simultaneous overpass of VIIRS and FOREST-2 in Burundi, East Africa.

Retrieval Algorithms

Our sensor features two long-wave infrared and a mid-wave infrared band. Given the wide bandwidth of these channels we opt for a single channel retrieval algorithm. This is implemented by directly solving the radiative transfer equation for the surface temperature and applying a subsequent linear calibration layer. In later hardware iterations we will consider to implement a split-window algorithm as well.

Emissivity Modeling

Accurate estimation of the underlying surface emissivity is detrimental to a precise LST data product. We rely on an ensemble of emissivity models that are based on Sentinel-2 NDVI measurements as well as a variety of land classfication datasets [1]. We obtain specific emissivity values by convoluting our sensors band response with spectra from the ECOSTRESS spectral library.

Atmospheric Modeling

We model the atmospheric upwelling and downwelling radiances as well as its transmittance explicitly using the LibRadTran framework. Using a variety of atmospheric forecasts we are able to model sub-daily variations of the stratified molecular species as well as temperature and pressure gradients. The model computations are performed for a number of input samples before interpolating the results on a raster for further LST processing.

Validation

In order to calibrate and validate our LST data product we chose a multi-step approach to get the best possible product. This entails cross-sensor validation with other missions, such as Landsat, VIIRS and ECOSTRESS. Additionally, we compare against the global network of in-situ measurement ground stations such as SURFRAD and the GBOV network. An initial validation result can be seen in Figure 3.

Validation of Atmospheric Modeling

The atmospheric model's performance was evaluated using hemispheric downwelling irradiance data from seven NOAA SURFRAD stations over a year, resulting in an 8% MAPE. The validation provides insight, but the bands of FOREST-2 represent only a fraction of the ground stations' radiometric measurements, so the validation is not entirely representative of the model's specific performance for our instrument. Figure 2 displays the preliminary outcomes of the validation.

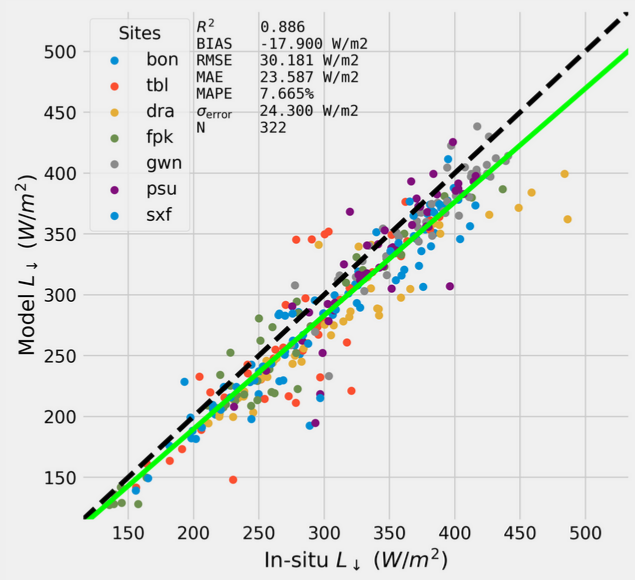

Figure 2: Proxy validation of atmospheric model component.

First look on processor performance

The calibration of FOREST-2's TOA radiance products is ongoing, so only an estimate of the anticipated LST product performance is available. The team cross-calibrated on a quasi-simultaneous L1 product of VIIRS and found an RMSE below 2K, meeting the target requirements. However, water bodies showed a slight overestimation of LST, which may be due to additional water vapor above the surface. A comprehensive evaluation on a larger scale is necessary to determine the final performance.

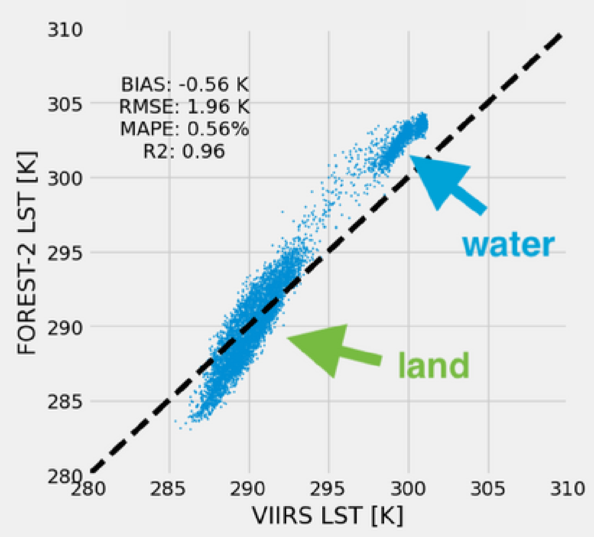

Figure 3: Validation of retrieved LST against quasi-simultaneous VIIRS acquisition, after cross-calibration.

Enabling downstream users using Super-Resolution

The team researched methods to increase the spatial resolution of data products by using multi-spectral super-resolution (MSSR) to fuse additional high-resolution datasets. The model conducts uncertainty quantification for every pixel in the output product, which will be calibrated in the future. The team achieved a significant increase in spatial detail, as shown in Figure 4, that may provide better insight into local irrigation management. The results will be compared with higher resolution thermal sensors to validate the model. Although not able to fully reconstruct the smallest scale detail, the model still adds significant value to the resulting data product.

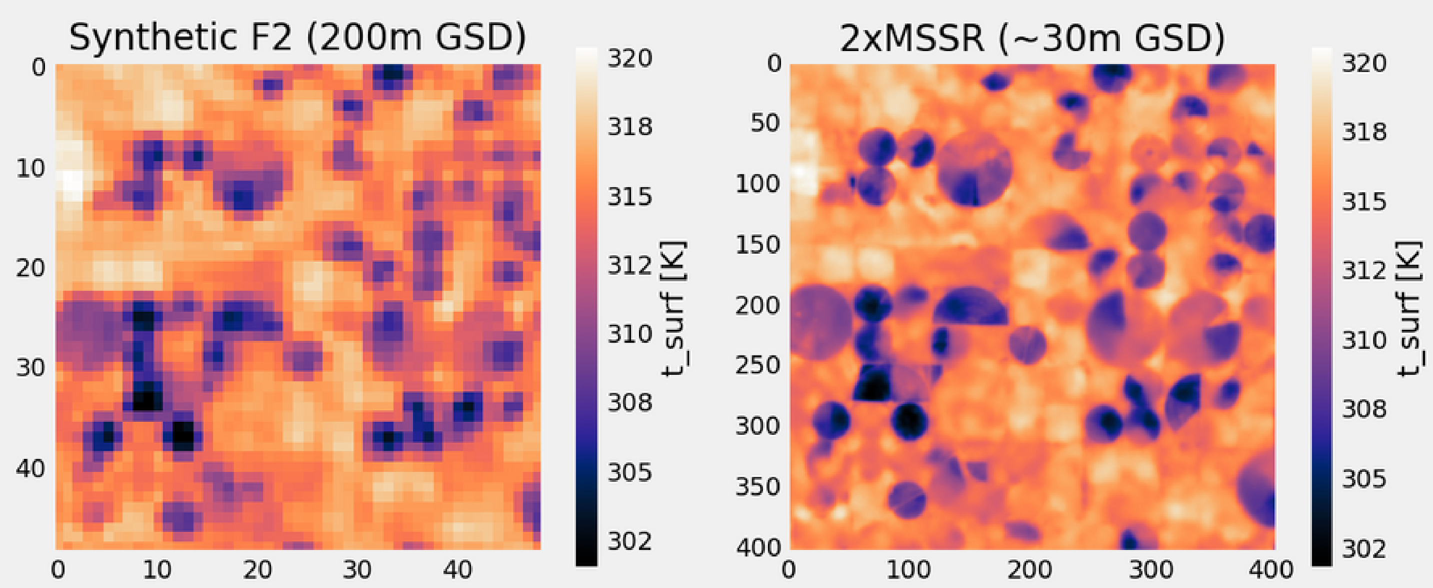

Figure 4: Application of MSSR model on synthetic FOREST-2 data derived from Landsat-8 LST. The scene shows agricultural land use in Kansas, USA.

Conclusion

- By the end of 2024, we are targeting to provide sub-daily high resolution LST data products on a global scale using our network of thermal sensors with a radiometric accuracy of around 2K with 200m native GSD.
- Super-resolution aggregates will power use cases that require higher spatial resolutions down to 30m GSD.

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Related Literature

[1] E Valor. "Mapping land surface emissivity from NDVI: Application to European, African, and South American areas," in Remote Sensing of Environment, vol. 57, no. 3, pp. 167–184, 1996.

[2] C. Mollière, J. Gottfriedsen, M. Langer, P. Massaro, C. Soraruf and M. Schubert, "Multi-Spectral Super-Resolution of Thermal Infrared Data Products for Urban Heat Applications," IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, Pasadena, CA, USA, 2023, pp. 4919-4922, doi: 10.1109/IGARSS52108.2023.10283339.

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