Generation of an improved land surface temperature time series to support permafrost modelling in the northern high latitudes

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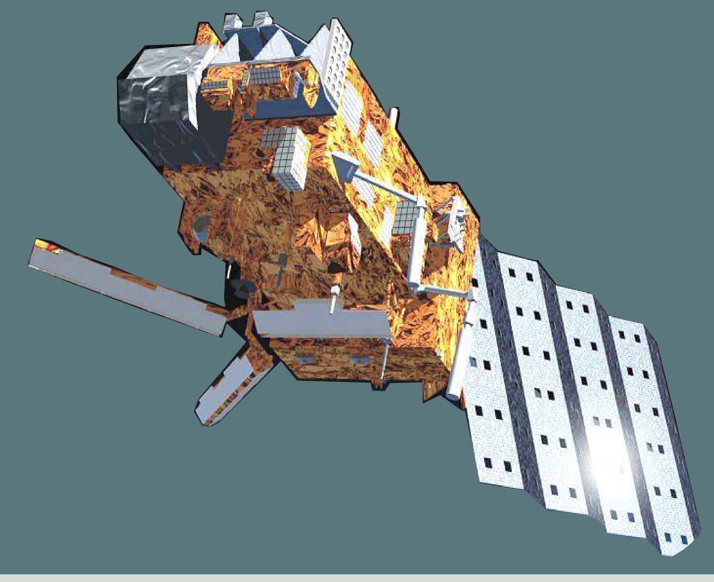
OESCHGER CENTRE CLIMATE CHANGE RESEARCH



OVERVIEW

- Due to arctic amplification, the Arctic region is warming thrice as fast as anywhere else. The warming affects the sensible ecosystem, vegetation dynamics and the cryosphere (sea ice, snow and permafrost). Permafrost is particularly sensitive to the warming climate because thawing affects the stability of the bedrock, damages infrastructures and releases organic carbon.
- At a global scale, it is still difficult to map the presence of permafrost at medium to high-spatial resolution. However, land surface temperature (LST) obtained from remote sensing data is available daily and globally. Permafrost models can relate physical surface variables such as LST to the ground thermal regime.
- To compute LST on a hemispheric scale, we use the advanced very high resolution radiometer (AVHRR) global area coverage (GAC) dataset starting in 1981. The GAC dataset has a spatial resolution of 4 km². Due to the considerable spatial variability of the thermal ground regime the LST time series should have a spatial resolution of at least 1km² (Westermann 2015, Obu 2019). The present LST product will be spatially enhanced by spatio-temporal fusion algorithms with the help of auxiliary data (emissivity and NDVI datasets) and generative adversarial networks (GANs).
- Before downscaling the LST product, the 40 years LST time series needs to be consistent and in line with the validation requirements. Here we show the processing steps involved in the production of such a dataset.

Obu et. al., (2019) Northern Hemisphere permafrost map based on TTOP modelling for 2000–2016 at 1 km2 scale, Earth-Science reviews

Westermann et. al., (2015a) A ground temperature map of the North Atlantic permafrost region based on remote sensing and reanalysis data. Cryosphere 9,1303–1319.

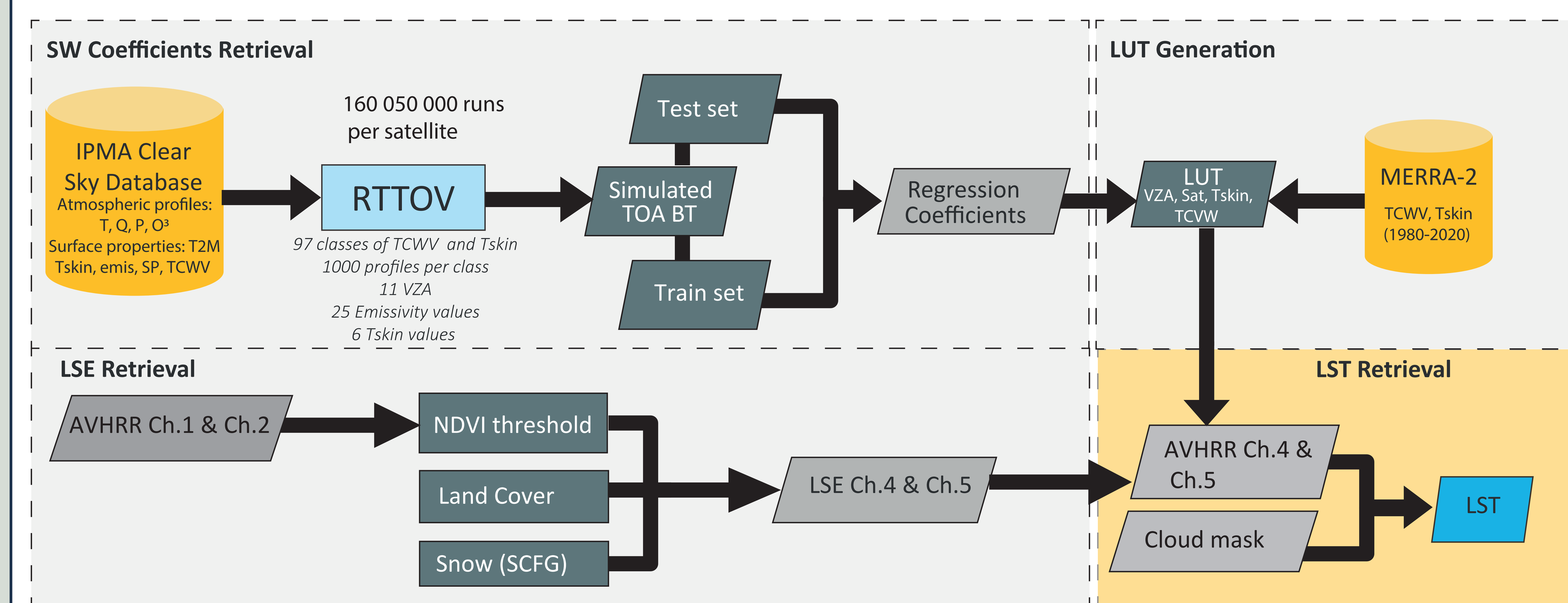
METHODS

In this study, a split-window (SW) algorithm is used to compute LST. This involves radiative transfer modelling with the Radiative Transfer for the Television Infrared Observation Satellite Operational Vertical Sounder code (RTTOV). Atmospheric profiles from the IPMA clear-sky database are utilized to run RTTOV and simulate top-of-atmosphere (TOA) brightness temperatures (BT). The final look-up-table (LUT) is generated with MERRA-2 data.

SW Coefficients

$$LST = \left(A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_4 + T_5}{2} + \left(B_1 + B_2\frac{1-\varepsilon}{\varepsilon} + B_3\frac{\Delta\varepsilon}{\varepsilon^2}\right)\frac{T_4 - T_5}{2} + C$$

ε : mean LSE of Ch.4 and Ch.5



SW Algorithm: Wan, Z.; Dozier, J. A generalized split-window algorithm for retrieving land-surface temperature from space. Geosci. Remote Sens.IEEE Trans.1996,34, 892–905

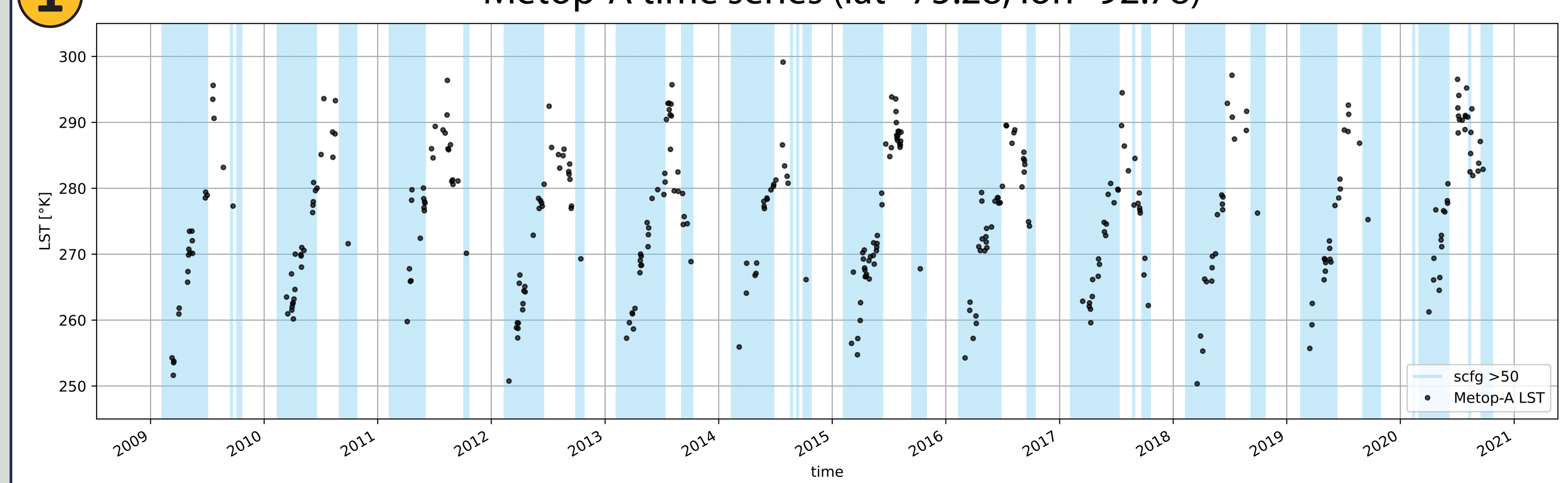
RTTOV (NWC SAF): Saunders, R.,Hocking, J., Turner, E., Rayer, P., Rundle, D., Brunel, P., Vidot, J., Roquet, P., Matricardi, M., Geer, A., Bormann, N., and Lupu, C., 2018: An update on the RTTOV fast radiative transfer model (currently at version 12), Geosci. Model Dev., 11, 2717-2737

PRELIMINARY RESULTS

LST Time series at two points-of-interest (POI) in Siberia

1

Metop-A time series (lat=75.28, lon=92.78)



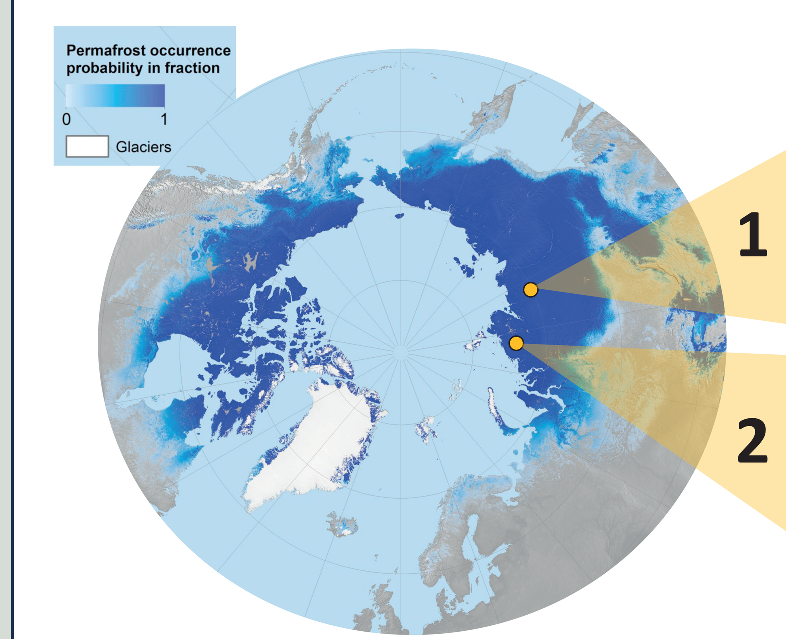
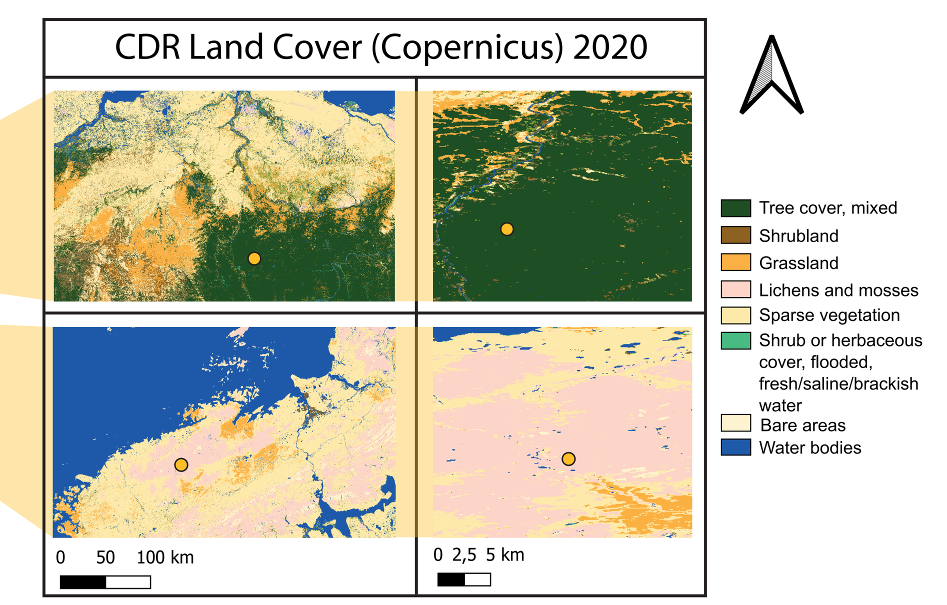


Fig. 5: Permafrost probability calculated as the fraction of model runs with MAGT below 0 °C. Adapted from Obu et al. 2019



Location of GAC pixel

Fig. 6: Land Cover of POIs

2

Metop-A time series (lat=70.72, lon=113.8)

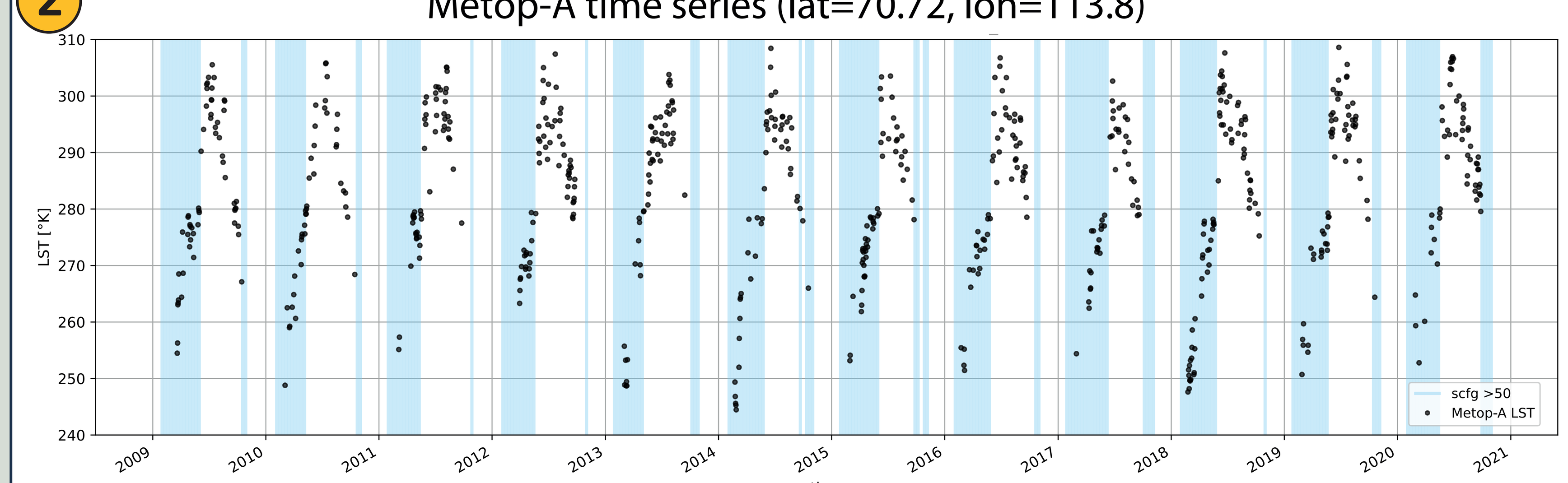


Fig. 7 and 8: LST time series and snow cover from Metop-A at POI 1 (top) and POI 2 (bottom)

DATA

EUMETSAT AVHRR GAC fundamental data record (FDR)

The FDR, based on historic GAC data (1978-2020) from the AVHRR, will be used for this project. This data record is produced by the EUMETSAT Climate Monitoring Satellite Application Facility (CM SAF), which is a consortium with contributions of several European meteorological services (DWD, SMHI, KNMI, RMIB and FMI). In addition, newly processed cloud masks from the CLARA-A3 dataset are utilized. Both data records are kindly provided by Martin Stengel (DWD).

ESA Snow CCI+ phase 2

Daily snow cover fraction on ground (SCFG) dataset

Auxiliary Data

- Land surface emissivity (LSE): JPL spectral library
- CDR Land Cover Data (Copernicus)
- Atmospheric profiles from IPMA Clear-Sky Database
- Long-term global reanalysis dataset (MERRA-2)

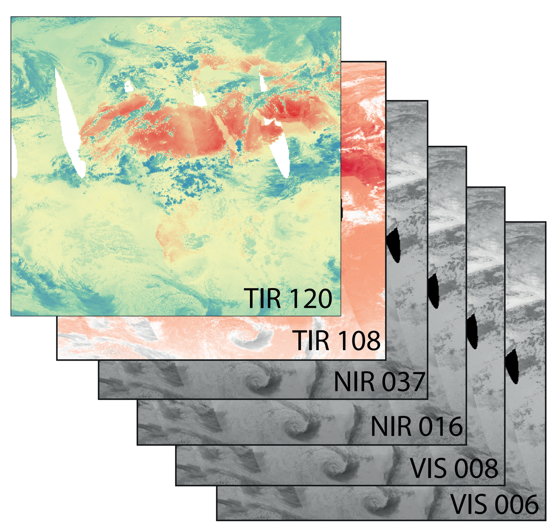


Fig. 1: AVHRR channels

Clear-Sky Database: Ermida, S.L.; Trigo, I.F. (2022) A Comprehensive Clear-Sky Database for the Development of Land Surface Temperature Algorithms. Remote Sens., 14, 2329.

VALIDATION

For the validation a combination of in situ data and existing satellite LST products (MODIS, EDLST from EUMETSAT) is used. In-situ data from the following networks are used:

- KIT network
- SURFRAD stations

Fig. 3: Tower in Evora. Isolated groups of evergreen oak trees and grassland. Image courtesy of Frank Göttsche

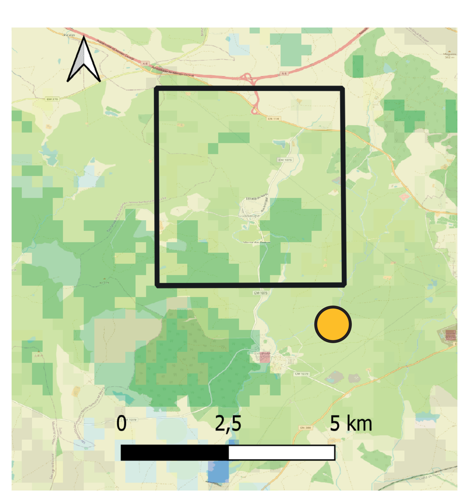


Fig. 2: Location of the Evora site and GAC pixel for validation

Example of validation at the Evora site (Portugal)

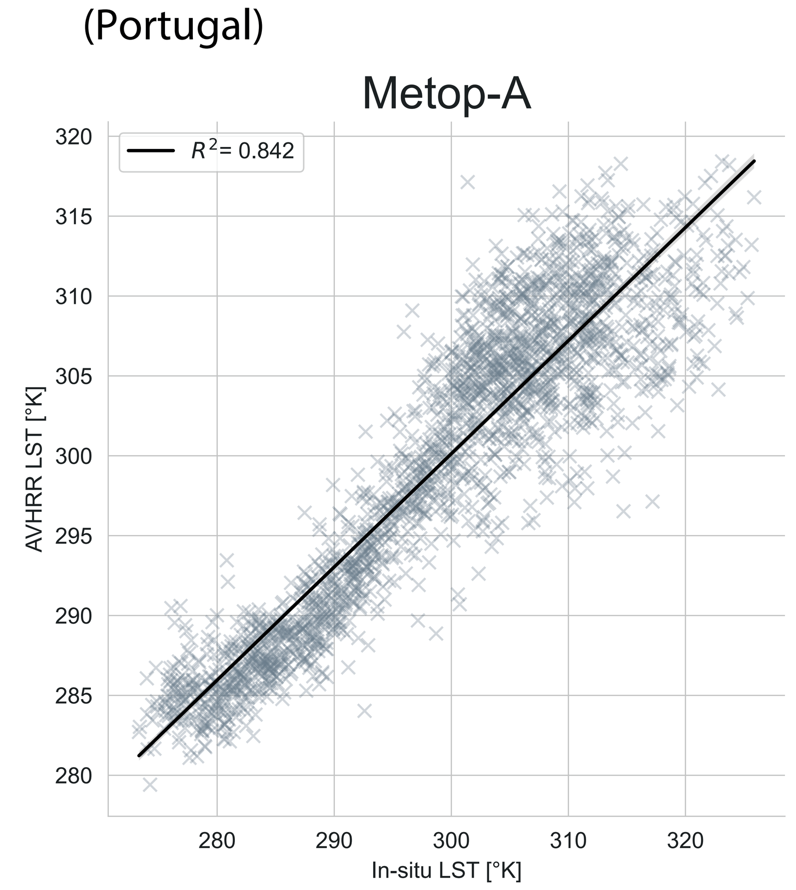


Fig. 4: Computed LST at the Evora site

CONCLUSION & OUTLOOK

- Brightness temperature simulations resulting from RTTOV runs with atmospheric data from IPMA show promising performance.
- Emissivity plays an important role in the computation of LST: land cover composed of lichens and mosses has a very low NDVI leading to errors when determining LSE only based on NDVI threshold. Hence the LSE determination is a combination of NDVI information and values from spectral libraries.
- Snow has an important insulating effect, especially in late spring/early summer.
- This dataset will be downscaled to a target resolution of 1 km² with GANs and spatio-temporal fusion algorithm with the help of fine-grained auxiliary data.

Sharing is encouraged

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