Geophysical Research Abstracts
Vol. 21, EGU2019-10399, 2019
EGU General Assembly 2019

A multi-resolution daily air temperature model for France from MODIS and Landsat thermal data

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Climate change and urbanization expose a growing number of people to health risks due to increased ambient temperature (T_a). Chronic and acute T_a exposure are associated with increased mortality and morbidity, especially among vulnerable populations such as the elderly and infants. Understanding and monitoring these risks requires spatially- and temporally-resolved T_a at high resolutions. This is challenging both in rural areas, which have large spatial extents and often few weather stations, and urban areas, where the complex built environment can produce temperature variation at scales of a few hundred meters. We present a model of daily minimum, maximum, and mean T_a from 2000 through 2016 at a base resolution of 1 km^2 across continental France and at an increased resolution of 200 x 200 m^2 over large urban areas. We start by extending a technique that was previously used to predict 1 km daily mean T_a in France (Kloog et al., 2017): we use linear mixed models to calibrate T_a observations from weather stations with remotely sensed daily 1 km land surface temperature (LST) from the MODIS instrument on the Terra and Aqua satellites. We also include MODIS monthly composite 1 km NDVI, elevation, population density, and land cover. We use these mixed models to predict daily 1 km T_a, then fill gaps where LST is missing (e.g. due to cloud cover) with a second set of linear mixed models that calibrate our 1 km T_a predictions at each location with T_a observations from nearby stations. This base resolution model performs very well, with ten-fold cross-validated R^2 of 0.921 (T_{min}), 0.968 (T_{mean}), and 0.954 (T_{max}), MAE of 1.4 ˚C (T_{min}), 0.9 ˚C (T_{mean}), and 1.4 ˚C (T_{max}), and RMSE of 1.9 ˚C (T_{min}), 1.3 ˚C (T_{mean}), and 1.8 ˚C (T_{max}) for the initial calibration stage. To increase the spatial resolution over urban areas, we train random forest and gradient boosting regression models to predict the daily residuals of the 1 km T_a models on a 200 x 200 m^2 grid. These models are based on latitude, longitude, day of year, 1 km predicted T_a, elevation, population density, land cover, and top-of-atmosphere brightness temperature and NDVI from the Landsat 5, 7, and 8 satellites composited by month across all years in the study period. Finally, we use a generalized additive model to ensemble the random forest and gradient boosting models with spatially varying weights. We add the resulting daily 200 m predicted residuals to the daily 1 km predicted T_a to obtain daily 200 m predicted T_a. This model also performs well, with the ensemble stage achieving ten-fold cross-validated R^2 of 0.792 ($Resid_{min}$), 0.892 ($Resid_{mean}$), and 0.845 ($Resid_{max}$), MAE of 0.4 ($Resid_{min}$), 0.3 ($Resid_{mean}$), and 0.3 ($Resid_{max}$), and RMSE of 0.6 ($Resid_{min}$), 0.4 ($Resid_{mean}$), and 0.5 ($Resid_{max}$).

Kloog, I., Nordio, F., Lepeule, J., Padoan, A., Lee, M., Auffray, A., Schwartz, J., 2017. Modelling spatio-temporally resolved air temperature across the complex geo-climate area of France using satellite-derived land surface temperature data. Int. J. Climatol. 37, 296–304. https://doi.org/10.1002/joc.4705