Long-term Dynamics of Land Surface Temperature over Europe: Towards a Daytime normalized AVHRR Land Surface Temperature Product

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ABSTRACT - *In this study a statistical orbit drift correction method was applied to TIMELINE AVHRR LST from NOAA 7, 9, 11, 14, 16, 18 and 19 afternoon overpasses at 12 sites across Europe. The corrected LST anomalies were validated against Ta anomalies from nearby meteorological stations. The results showed an improvement of the correlation (R) between the LST and Ta anomalies at most sites. A few sites showed a decrease of R, which can be explained by complex land cover (urban) or missing daytime effects of LST (at forest sites). After the orbit drift correction, the long-term trends of the LST anomalies were much closer to the Ta trends. Furthermore, climatological features visible in the Ta time series (like e.g. a warm period in the late 1980s) are more distinct in the LST time series after the correction. However, similar studies reached higher correlations between LST and Ta anomalies. This can be explained by a more uniform generation of the LST and Ta anomalies. Further improvements and validation are necessary to obtain a reliable and continent-wide orbit drift correction for AVHRR. It is also planned to extend the analysis to further orbit drift correction methods and also to other validation data, e.g. Landsat LST.*

1 INTRODUCTION

LST is an important quantity for tracing the impact of changing climatic conditions on our environment from local to global scale. Changes in LST represent on the one side climate change processes like global warming and on the other side land surfaces processes like urbanization and deforestation. LST is recognized as one of the Essential Climate Variables (ECVs) by the World Meteorological Organization and has a strong link to near surface air temperature.

For monitoring conditions repeatedly over large areas, satellite derived LST has become an indispensable tool. However, to make climate relevant statements and quantify the impact of land surface variables over long time, we need sensors that are, unlike e.g. the Moderate Resolution Imaging Spectroradiometer (MODIS), available for more than 30 years. The Advanced Very High Resolution Radiometer (AVHRR) is the only sensor providing spatially and temporally continuous, daily measurements for 40 years. The TIMELINE project ("Time Series Processing of Medium Resolution Earth Observation Data Assessing Long-Term Dynamics in our Natural Environment", www.timeline.dlr.de) of the Earth Observation Center (EOC) of the German Aerospace Center (DLR) aims at the generation of a homogeneous multi-decadal time series from AVHRR data over Europe and North Africa (Dech et al. 2021). The resulting collection of remote sensing products contains land and sea surface parameters, a.o. LST (Reiners et al. 2021). It is planned to offer these products online to a wider community using a free and open data policy.

However, the different overpass times and the orbital drift effect hide actual trends and anomalies in LST. Several methods exist to account for this effect of varying acquisition times on LST time series, which can be classified into physical and statistical methods. While physical models, as e.g. proposed by Liu et al. 2019 try to reconstruct the diurnal LST cycle, statistical models try to delineate the orbit drift signal from the time series itself.

In this study, the statistical daytime correction model by Julien and Sobrino 2021 is applied to the TIMELINE LST data and its performance is analyzed at different sites with different land cover across Europe. The model uses the regression between the LST anomalies and the corresponding SZA anomalies for each day of the year throughout the time series. This allows to remove the orbit drift effect for each sensor. An additional offset is used to adjust the observation times of the sensors.

An important requirement for these methods is that they preserve the actual trends in LST. However, especially for the period before the year 2000 no independent LST datasets exist to validate these methods. As an approximation, historical measurements of near surface air temperature (Ta) at various stations across Europe can be used. Despite the known differences between LST and Ta at short time scales, it is expected, that long term trends correspond in these two variables. In this study the performance of the model is validated through the correlation of the monthly anomalies of LST and Ta and through the comparison of their long-term trends.

2 DATA AND METHODS

2.1 Study sites

For the evaluation of the orbit drift correction 12 sites across Europe have been selected from the BEnchmark Land Multisite ANalysis and Intercomparison of Products (BELMANIP) network (Baret et al. 2006). These sites are characterized by a homogenous and stable land cover on the AVHRR sensor scale. This is important to reduce the influence of land cover change on the LST climatology at the respective site.

For the comparison with Ta, the nearest measuring station to the respective BELMANIP site with the same land cover was selected from the EU Surface Temperature for All Corners of Earth (EUSTACE) network (Rayner et al. 2020). The map on Figure 1 shows the location of the BELMANIP sites and the corresponding EUSTACE stations. The

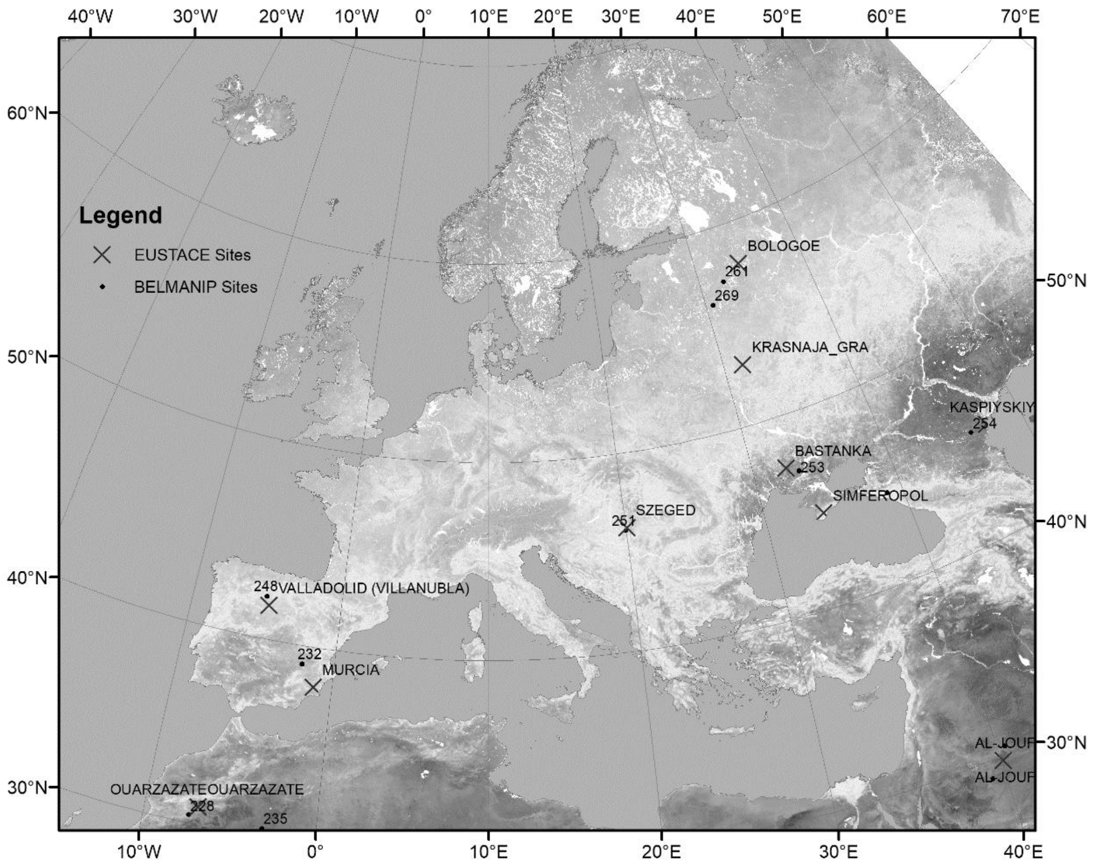

Figure 1: Map of the Study Sites from BELMANIP and EUSTACE network

smallest distance is between the cropland site 251 and the station Szeget (19 km), the hugest distance is between the Urban site 269 and the station Krasnaja Gra (369 km).

2.2 TIMELINE LST

The TIMELINE LST product was derived from the brightness temperatures of AVHRR channels 4 and 5. Atmospheric correction was performed with an extension of the Split Window Algorithm by Becker and Li 2007 for AVHRR 2 and 3 and an extension of the Mono Window Algorithm by Qin, Karnieli and Berliner 2001 for AVHRR 1. Frey, Kuenzer and Dech 2017 extended these algorithms with a different set of coefficients for daytime and nighttime, each AVHRR sensor, sensor view angle class, Total Columnar Water Vapor (TCWV) class and LST class. The Level 3 products consist of daily, 10-days and monthly composites of LST. While the daily composites contain the best LST observation of the day (lowest sensor zenith angle), the 10-daily and monthly composites contain maximum, minimum, median and mean LST for the respective period.

Daily LST and monthly maximum LST was extracted at the nearest pixel to the respective BELMANIP site. Only data from afternoon overpasses (12.00-16.00h true solar time) from NOAA-7, 9, 11, 14, 16, 18, and 19 was taken.

2.3 Air Temperature Data

Ta data were taken from the (EUSTACE) project (Rayner et al. 2020), which offers daily homogenized measurements from meteorological stations. From the dataset the daily maximum Ta was selected (Tmax) and aggregated to monthly maximum Ta.

2.4 Methodology

The statistical orbit drift correction method by Julien and Sobrino 2021 is referred to as ‘C0’ in their publication. It uses a linear regression between the LST anomalies and a second degree fit of the sun zenith anomalies for each sensor. For the calculation the daily LSTs were aggregated for each day of the year through the complete time series of the respective sensor. The anomaly is the deviation of each observation to the mean of the respective day. The same procedure was carried out to calculate the sun zenith anomalies. A second-degree fit was applied to the sun zenith anomaly time series to reduce noise.

The orbit drift contribution (ODC) to LST can then be described with the formula:

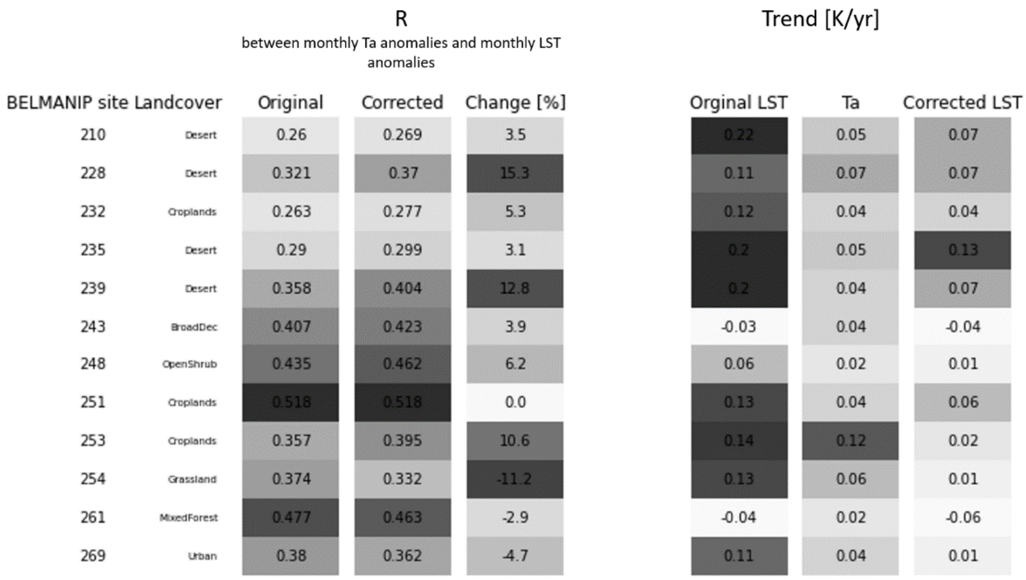

Figure 2: Results of the Orbit Drift Correction for all sites: Correlation coefficients (R) between LST and Ta anomalies (left) and long-term trends of uncorrected LST, Ta and corrected LST (right)

$$ODC = a_i * SZA\_anom\_fit_i \quad (1)$$

where $SZA\_anom\_fit_i$ is the second degree fit of the sun zenith angle anomalies and ai is the regression coefficient. The regression coefficients were fitted to the LST anomaly time series via least square fitting. To correct the LST time series the ODC was subtracted from the LST values.

For the validation the monthly maximum LST anomalies and the monthly maximum Ta anomalies were correlated before and after the correction. Also, the long-term trends of both variables were compared before and after the correction.

3 RESULTS

3.1 Correlation between LST and Ta anomalies

Figure 2 shows an overview for all sites of the correlation coefficient (R) between monthly LST anomalies and Ta anomalies, as well as the trends before and after the correction. Looking at the left side of the Figure it becomes visible that R increases for 8 of 13 sites. For three sites (228-Desert, 239-Desert, 253-Croplands) the increase is over 10 %. Two sites show a small decrease of R (261-Mixed Forest, 269-Urban), one site shows a decrease over 10% (254-Grassland). For 251-Cropland the R stays the same before and after the correction.

3.1 Comparison of the long-term trends

Looking at the right side of Figure 2 it becomes visible, that before the correction the long term LST trends are one magnitude higher than the Ta trends at almost all sites. After the correction the LST trends are in a similar range as the Ta trends except for the site 253-Croplands. Similar trends of corrected LST and Ta can be observed at 228-Desert and 232-Croplands. Nearly similar trends are observed at 210-Desert, 251-Croplands and 248-Open Shrub. For the sites 243-Broadleafed/Deciduous Forest, 254-Grassland, 261-Mixed Forest and 269-Urban the LST trend almost vanished or even was turned into negative through the correction.

3.2 The results at the site 239-Desert as an example

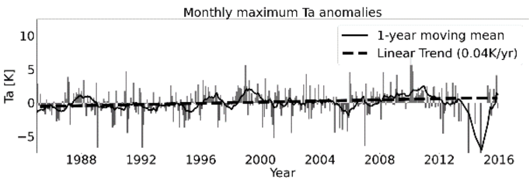

Figure 3: Monthly anomalies of maximum Ta at 239-Desert

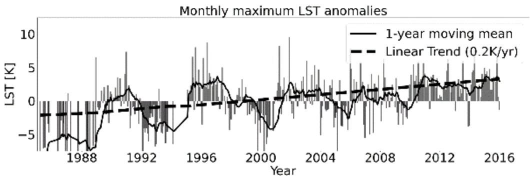

Figure 4: Monthly anomalies of maximum uncorrected LST at 239-Desert

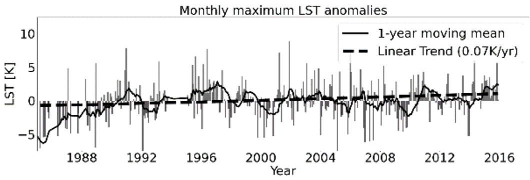

Figure 5: Monthly anomalies of maximum corrected LST at 239-Desert

An alternative interpretation of the LST or Ta climatology is the observation of climatological features in the time series. For example, the Ta time series at site 239 at Figure 3 shows warm periods in the late 1980s and 1990s. These warm periods can be related to climate modes like El Nino/Nina and can represent heatwaves and droughts. Looking at the time series of uncorrected LST anomalies at Figure 4 these warm periods are hidden by the orbit drift effect. However, after the correction the one year moving mean of the LST anomalies shows a similar progress as the moving mean of the Ta anomalies, as visible in Figure 5.

4 DISCUSSION

The purpose of this study was to apply the statistical orbit drift correction method by Julien and Sobrino 2021 on the TIMELINE LST data and to validate the results against historical Ta measurements. Julien and Sobrino 2021 validated their method against geostationary SEVIRI measurements form 2009-2015 with bias absolute values under 1 K. However, their validation method provides no information, if the orbit drift correction is preserving the actual changes of LST over time.

Our validation showed that the orbit drift correction improved the R between the monthly LST anomalies and Ta anomalies at most sites. At four sites the correction did not increase or even decrease the R, which could be explained by several reasons: One site (261) is a forest site, where the influence of the daytime on LST is not strong. Site 251 already has a comparatively high R, which was not improved through the correction. Site 269 has urban land cover, where the complex structure of the surface at the AVHRR scale could influence the performance of the model. The strong decrease of R at the grassland site (254) has still to be investigated.

Already Gutman 2010 applied a similar orbit drift correction method AVHRR data from NOAA-9, 11 and 14 over the Sahel area. A visual comparison of the corrected LST anomalies with Ta anomalies at Niamey Niger showed a good accordance. Ta anomalies were also used in a recent study by Good et al. 2022 to assess the stability of the LST_cci datasets derived from MODIS and AATSR. The correlation between LST anomalies and Ta anomalies in their study reached correlation coefficients between 0.77 and 0.94. However, the generation of their monthly Ta anomalies were based on the same coordinates and day as the LST anomalies, opposed to our study.

Further improvements are possible to enhance the significance for subsequent studies: First, the generation of the Ta anomalies and the LST anomalies should follow the strategy by Good et al. 2022 to get higher correlations between the Ta and LST anomalies. Second, it is possible to enhance the model describing the relationship between the LST anomalies and the sun zenith angle anomalies. For example, Julien and Sobrino 2022 introduced a seasonal component to the model, which could improve the results. Third, also physical models using the diurnal cycle of LST should be tested within this framework. And at last, there is Landsat remote sensing LST dating back to the 1980s, which also could be an independent source to validate orbit drift correction methods for AVHRR.

5 CONCLUSIONS

A statistical orbit drift correction method was applied to TIMELINE LST at 12 sites across Europe. The corrected LST anomalies were validated against Ta anomalies from nearby meteorological stations. Following results were obtained:

The orbit drift correction method…

- …improved R between the monthly anomalies of LST and Ta at most of the study sites.
- …leads to more realistic long-term trends of LST at most study sites.
- …mostly preserves climatological events in the LST time series at most study sites.

Further improvements and validation are necessary to obtain a reliable and continent-wide orbit drift correction for AVHRR.

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