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Estimation of Air Temperature at Sites in Maritime Antarctica Using MODIS LST Collection 6 Data †

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Abstract: It is known that changes in temperature could cause changes in the Antarctic Ice Sheet, which would have an immediate and long-term impact on the global mean sea level [1]. For this reason, the monitoring of air temperature (T_a) is of great interest to the scientific community. On the other hand, Antarctica constitutes an area of difficult access, which makes it difficult to obtain in-situ data. Because of this, land surface temperature (LST) remote sensing data have become an important alternative for estimating T_a. In this work we estimate T_a from daytime and nighttime LST data at maritime Antarctic sites in the South Shetland Archipelago using empirical models, based on the addition of spatiotemporal variables [2]. We have used T_a data from the Spanish Antarctic stations and from the PERMASNOW project stations [3]. MOD11A1 and MYD11A1 (Collection 6) MODIS LST products were downloaded from the Google Earth Engine platform [4] and only the highest quality data were selected. Outliers associated with clouds were removed with filters. Two different multilinear regression models were tested: models for each individual station and global models based on the data from all the stations. The simple regression analysis LST against T_a showed that a better fit is always achieved with daytime LST data (R^2 average = 0.73) than with nighttime LST data (R^2 average = 0.56). The performance of the models was improved with the addition of spatiotemporal variables as predictive variables, with which we obtained an average R^2 = 0.75 for daytime data and an average R^2 = 0.60 for nighttime data. The global models allowed to improve the correlation and reduce the errors with respect to the models obtained using individual stations. Global models provide a precise description of the behavior of the temperature in maritime Antarctica, where it is not possible to install and maintain a dense network of weather stations.

Keywords: MODIS; land surface temperature; air temperature

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1. Introduction

Air temperature (T_a) monitoring is of great interest to the scientific community. This is particularly important in polar areas, since it is known that T_a can influence the behavior of the active layer of permafrost [5], and that important changes in temperature could lead to changes in the accumulation of snow on the Antarctic ice sheet, which would have both an immediate impact and a long-term impact on the global mean sea level [1].

In polar areas, in addition, it is essential to use remote sensing data to monitor meteorological variables, given the scarcity of in situ data and the impossibility of maintaining a wide network of meteorological stations, therefore the land surface temperature (LST) is used as a proxy for T_a. Specifically on Livingston Island, Recondo et al. [2] obtained models for estimating T_a using MODIS LST collection 5 (C5). On the other hand, it is known that in collection 6 (C6) numerous improvements were made in the Generalized Split-Window (GSW) algorithm [6]. This makes it necessary to update the studies with MODIS LST (C6) data. For that reason, in this work we estimate T_a from daytime and nighttime LST data at maritime Antarctic sites in the South Shetland Archipelago using empirical models, based on LST with the addition of spatiotemporal variables [2].

2. Materials and Methods

2.1. Study Area

This work focuses on the Livingston Island, in the South Shetland Islands (SSI) archipelago (Figure 1), which occupies an area of 3687 km² and is located in the Maritime Antarctic. The Juan Carlos I (JCI) Spanish Antarctic base is located on this island.

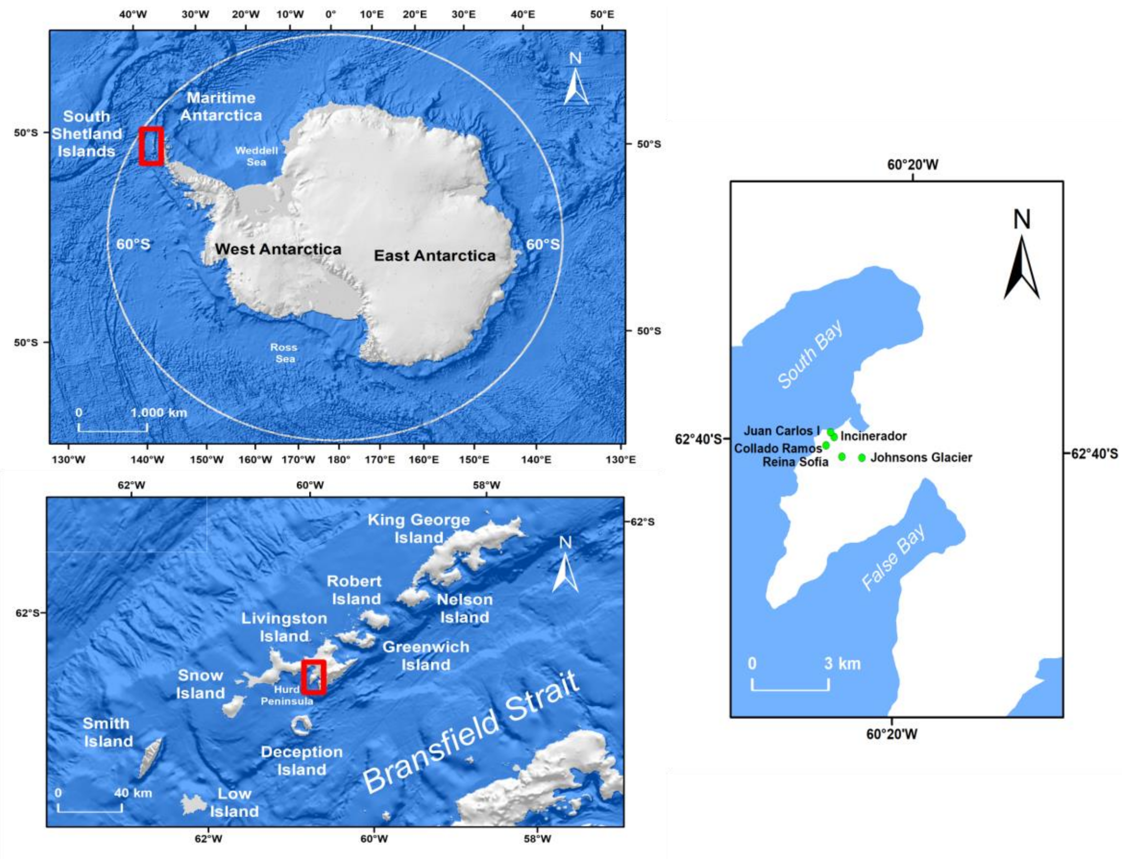

Figure 1. Study area. Left top image: map of Antarctica and, in red rectangle, SSI archipelago. Left bottom image: Livingston Island and, in red rectangle, Hurd Peninsula, where are located the stations used in this work. Right image: Location of the stations.

2.2. In Situ Data

T_a data have been taken from the stations of the State Meteorological Agency (AEMET) and from the PERMASNOW project [3,7], the locations of which are shown in Figure 1. Temporal range includes the years between 2000 and 2020. Mean daily air temperature was calculated and data from all stations were calibrated as indicated in Recondo et al. [2].

2.3. MODIS LST Data

MOD11A1 and MYD11A1 (C6) data were downloaded from the Google Earth Engine platform [4] and only the highest quality data were selected. On the other hand, considering that sometimes the MODIS cloud mask fails [8,9], LST data were filtered using

MOD10A1 and MYD10A1 products, respectively, and those corresponding to "clouds" were eliminated.

3. Results and Discussion

Previous studies have shown that MODIS LST products can be used to estimate T_a in Antarctica [10]. Firstly, we tried simple linear regression models for each station separately. The best fits were achieved with daytime data (average R^2 = 0.73) than with nighttime data (average R^2 = 0.56). As an example, in Figure 2 we show the best results obtained with daytime and nighttime data, both of them using T_a from JCI station (see Figure 1).

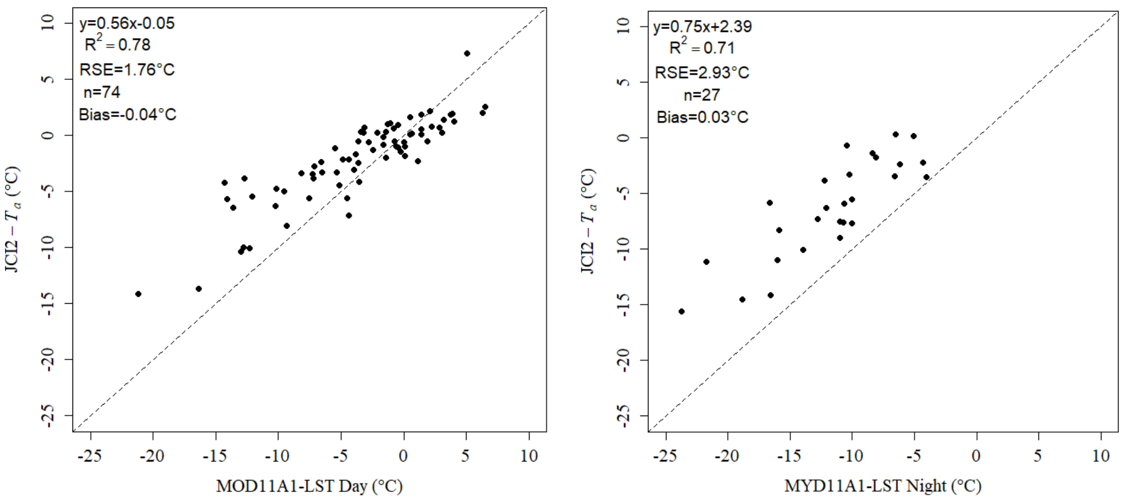

Figure 2. Linear correlation between JCI mean daily air temperature and MOD11A1 daytime LST (on the left) and MYD11A1 nighttime LST (on the right).

These values of R^2 are in the range of the results obtained in the analysis of the correlation between T_a and LST, in other study areas [11,12]. Likewise, although the average R^2 values of the diurnal data from Terra and Aqua are similar (0.73 and 0.72, respectively), the data from Terra show lower RSE values than those from Aqua. On the other hand, these results are much better than those obtained with the C5 data ($R^2 \leq 0.4$).

The performance of the model is improved with the use of a Fourier harmonic decomposition model [2]. For all the stations, R^2 values are higher compared to the simple linear regression model and better results were obtained with daytime data (R^2 in the range 0.65 to 0.81) than with nighttime data (R^2 in the range 0.53 to 0.75), confirming previous results obtained using C5 [2].

Finally, we built a unique model by adding spatio-temporal variables and using the T_a from all the stations (see Table 1). In general, this model improved the correlation and reduced the errors. However, although the application of the unique model has not achieved the same level of accuracy for the estimation of T_a in all cases, it is a useful tool for extending the analysis to areas where it is not possible to obtain in situ data.

Table 1. Unique model to estimate T_a from LST and spaciotemporal variables. The structure of the models is[1] $T_a = c_1 + c_2 LST + c_3\, t + c_4\, sen\, 2\,\pi t + c_5 \cos 2\,\pi t + c_6 c + c_7 s + c_8 h + c_9 r + c_{10} a + c_{11} H$

MODIS	*n*	R^2	RSE
Terra-Day	368	0.76	1.56
Terra-Night	258	0.60	2.30
Aqua-Day	539	0.73	2.34
Aqua-Night	191	0.68	2.98

[1] Where c_i are constants, LST and T_a are given in °C; *t* is the time in units of decimal year; *c* is the curvature (m^{-1}); *s* is the slope (°); *h* is the height (m); *r* is the roughness (dimensionless); *a* is the aspect (rad) and H is the time of observation of the LST.

All results, both from each station and the unique model, were validated using leave-one-station-out cross validation method using R^2_{CV} and $RMSE_{CV}$ statistics. Generally, as expected, in validation the regression values are lower and the errors are higher. As in the model, the best results are obtained with the Terra-Day data (R^2=0.75, RMSE=2.19)

4. Conclusions

In this work, we estimate T_a from daytime and nighttime LST data at sites in the SSI archipelago, in Maritime Antarctica, using empirical models. The results of simple linear regression models of LST vs in-situ T_a are consistent with those obtained in other study areas and also with other satellites and/or sensors, and constitute evidence of the good agreement between T_a and LST.

A unique model including spatio-temporal variables allows the estimation of T_a from LST over areas where in-situ T_a is not available.

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Data Availability Statement: MODIS data are available in the Google Earth Engine platform (http: //earthengine.google.org accessed on 15 August 2023).

Conflicts of Interest: The authors declare no conflict of interest.

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