Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Determination of annual and seasonal daytime and nighttime trends of MODIS LST over Greece - climate change implications

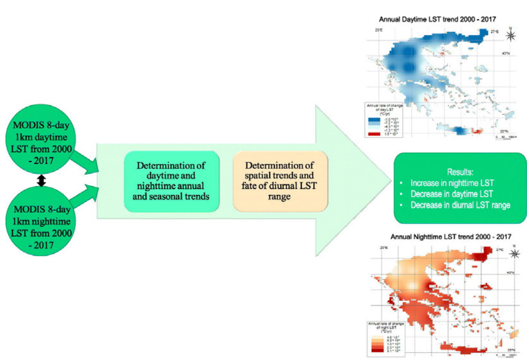
Dimitrios Eleftheriou, Kyriakos Kiachidis, Georgios Kalmintzis, Argiro Kalea, Christos Bantasis, Paraskevi Koumadoraki, Maria Eleni Spathara, Angeliki Tsolaki, Maria Irini Tzampazidou, Alexandra Gemitzi *

Department of Environmental Engineering, Faculty of Engineering, Democritus University of Thrace, 67100 Xanthi, Greece

HIGHLIGHTS

- Daytime and nighttime MODIS LST data all over Greece were obtained for 2000–2017.
- Annual and seasonal trends of daytime and nighttime LST were computed.
- Spatial trends were also highlighted.
- Diurnal LST range trends were also evaluated on an annual and seasonal basis.
- Climate change is expressed as increase in LST_{min} and decrease in diurnal range.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 August 2017
Received in revised form 21 October 2017
Accepted 21 October 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Land surface temperature (LST)
Terra/aqua MODIS
Diurnal temperature range
Climate change
Greece

ABSTRACT

Climate change is one of the most challenging research topics during the last few decades, as temperature rise has already posed a significant impact on the earth's functions thus affecting all life of the planet. Land Surface Temperature (LST) is identified as a key variable in environmental and climate studies. The present study investigates the distribution of daytime and nighttime LST trends over Greece, a country in the Mediterranean area which is identified as one of the main “hot-spots” of climate change projections. Remotely sensed LST data were obtained from MODerate Resolution Imaging Spectroradiometer (MODIS) sensor in the form of 8-day composites of day and night values at a resolution of 1 km for a 17-year period, i.e. from 2000 to 2017. Spatial aggregates of 10 km × 10 km were computed and the annual and seasonal temporal trends were determined for each one of those sub-areas. Results showed that annual trends of daily LST in the majority of areas demonstrated decrease ranging from $-1 * 10^{-2}$ °C to $-1.3 * 10^{-3}$ °C, with some sporadic parts showing a slight increase. A totally different outcome is observed in the fate of night LST, with all areas over Greece demonstrating increasing annual trends ranging from $4.6 * 10^{-5}$ °C to $3.1 * 10^{-3}$ °C, with highest values in the South-East parts of the country. Seasonal trends in day and night LST showed the same pattern, i.e., a general decrease in the day LST and a definite increase in night. An interesting finding is the increase in winter LST trends observed both for day and night LST, indicating that the absolute minimum annual LST observed during winter in Greece increases. Our results also indicate that the annual diurnal LST range is decreasing.

* Corresponding author.
E-mail addresses: dimielev2@env.duth.gr (D. Eleftheriou), kyrikiac@env.duth.gr (K. Kiachidis), georkalm@env.duth.gr (G. Kalmintzis), argykale@env.duth.gr (A. Kalea), chribant2@env.duth.gr (C. Bantasis), parakoum@env.duth.gr (P. Koumadoraki), marispat1@env.duth.gr (M.E. Spathara), angetsol3@env.duth.gr (A. Tsolaki), maritzab@env.duth.gr (M.I. Tzampazidou), agkemitz@env.duth.gr (A. Gemitzi).

https://doi.org/10.1016/j.scitotenv.2017.10.226
0048-9697/© 2017 Elsevier B.V. All rights reserved.

1. Introduction

According to the most recent Intergovernmental Panel on Climate Change (IPCC) report (IPCC, 2014) greenhouse gases (GHG) are the highest in history and climate changes are already evident in a wide variety of natural systems. These impacts are clearly attributed to human activities, while the most prominent and indisputable change is global warming with the consequent diminishing of snow and ice and sea level rise.

Besides the increased concentration of atmospheric CO_2 and the consequent temperature rise of 0.7–0.8 °C in comparison to the pre-industrial period (European Environmental Agency, 2010), there are several environmental factors that are affected by climate change. Some indicative factors are the changes in the duration, aerial extent and frequency of droughts (Di Matteo et al., 2017) and the various shifts in precipitation magnitude and its seasonal distribution (Easterling et al., 2000). Climate change prediction models give clear indications of more frequent and higher intensity phenomena such as heat waves, storm surges, warmer days with a corresponding reduction in cold days during the year, as a result of increased GHG emissions in the atmosphere (IPCC, 2014). Climate projections have suggested that global temperature may rise up to 1.8–4.0 °C until the end of the century, if measures to limit global GHG fail to control their emissions (European Environmental Agency, 2010).

The Mediterranean is characterized as one of the main "hot-spots" as indicated by climate change projections (Giorgi, 2006). Based on the most advanced sets of climate model simulations a substantial drying and warming of the Mediterranean region, especially in the warm season up to the end of the present century is predicted (Giorgi and Lionello, 2008). Such decrease in rainfall, combined with the increased temperature, is likely to affect crops as the rainy season is expected to shorten (Pnevmatikos and Katsoulis, 2006) with a consequent reduction in soil moisture available for plant growth and an increase of evapotranspiration. A reduction in the productivity of cereal crops in the Mediterranean region has already been detected (Olesen and Bindi, 2002), which also contributed to the emergence of economic difficulties that need to be confronted, since a large part of the revenues of those countries is based on the primary sector of economy (Balint et al., 2017). Concerning forests, it has been observed that they demonstrate a natural adaptability to changing climate conditions. Nevertheless, their growth and sustainability may be affected by continual fluctuations in the frequency and duration of rainfall as well as shifts in temperature. In the Mediterranean particularly, temperature rise is expected to result in a decrease in forest growth, which in combination to the projected increased frequency and intensity of fires may potentially affect wood production and the related ecosystem functions (European Environment Agency, 2010). As a result scientists have recognized the need for acquiring time series data for the identification of climate change in the Mediterranean region (Abboud-Abi Saab et al., 2004).

Modern science has introduced new ways of acquisition, evaluation and analysis of environmental data. Nowadays, monitoring can be conducted by using satellite observations, that offer a wide range of parameters for each environmental indicator (Neteler, 2010). Remote sensing has become an increasingly important source of information for climate change research. Monitoring networks have been providing in situ observations at high resolution in many parts of the world. There are still however sparsely monitored areas, where remotely sensed data constitute the only source of information (Alsdorf et al., 2007; Sun, 2013). Sun (2013) indicates the decline of water resources monitoring networks and the increased dependency on remotely sensed information for water resources assessment. Recent works using remotely sensed land surface temperature observations have demonstrated the wide range of environmental applications of those data sets, e.g. for the determination of soil moisture (Fang and Lakshmi, 2014), evapotranspiration computations (Mu et al., 2011), land use and climate change assessments (Hereher, 2017; Zhang et al., 2017), among others. Zhang et al. (2017) showed that urbanization results in LST increase which affects the environmental equilibrium. Rising temperatures have been observed both in land and ocean. Gleckler et al. (2016) found that in recent decades oceans continued warming and that the warming signal is reaching deeper in the ocean. Pal and Ziaul (2016) indicated that deforestation for extending the urban and industrial areas causes LST rise during all seasons. Other anthropogenic activities, like the creation of new agricultural territories by drying existing lakes, substantially affect the regional LST in Mediterranean countries like Egypt (Hereher, 2017). The anthropogenic warming signature is thus evident and it is safe to assume that future human activities may cause various environmental hazards, especially when future GHG emissions and global temperature exceeds the desirable limits (IPCC, 2014). It is therefore of primary importance to detect any changes related to temporal and aerial distribution of surface temperature.

Surface temperature is a vague term and may refer to skin temperature (or radiometric surface temperature), surface air temperature (or air temperature at shelter height) and aerodynamic temperature (or the temperature at the height of roughness length for heat) (Jin and Dickinson, 2010). Aerodynamic temperature cannot be measured directly and it is commonly linked to LST (Chehbouni et al., 1996). Therefore, climate assessments are based on either air temperature or LST. The term Land Surface Temperature refers to the radiative skin temperature at land surface and can be perceived as the heat feeling to the touch in a particular location on Earth's surface. Although LST differs from air temperature in its physical meaning and means of measurement, it is correlated to air temperature but can be different based on land cover or sky conditions. LST is most times 2–6 K higher than the aerodynamic temperature at daytime and lower than the aerodynamic temperature at nighttime (Jin and Dickinson, 2010). Air temperature is typically measured 1.5 m above the ground level with sensors protected from radiation and adequately ventilated (Mildrexler et al., 2011). LST can be measured either using earth based methods, i.e. hand-held radiation thermometer or by satellite or aircraft-based sensor technologies measuring thermal radiance from land surface (Jin and Dickinson, 2010). LST is derived from satellite observations over large areas using the thermal infrared (TIR) spectral channels, after removing atmospheric attenuation effects.

The present study aims at investigating the annual and seasonal trends of nighttime and daytime LST over Greece during the last 17 years. Data were acquired from the MODIS sensors on board Aqua and Terra satellites. Data were analyzed in both annual and seasonal trends, as well as in spatial context and were evaluated taking into account various land uses in Greece. Results showed that remotely sensed LST data may well reveal trends in surface temperature and highlight areas where land uses have altered the LST regime. Climate change implications were expressed as increases in minimum LST and changes in diurnal LST ranges.

2. Data and methods

2.1. Aqua/terra MODIS sensor and LST data

MODIS is a key instrument onboard Terra and Aqua satellites which are part of the NASA's Earth Observing System. Both satellites are at sun-synchronous, near-polar circular orbit. Terra passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon (https://modis.gsfc.nasa.gov/about/, accessed 10/08/2017). Terra MODIS and Aqua MODIS scan the entire Earth every 1 to 2 days, obtaining data in 36 visible/infrared bands. MODIS products have been widely used as they cover a wide spectrum of land variables, including land cover classification, vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI), hydrological variables such as evapotranspiration and climate variables such as LST and emissivity. Their quality is comprehensively validated and the algorithms to derive MODIS products are

Please cite this article as: Eleftheriou, D., et al., Determination of annual and seasonal daytime and nighttime trends of MODIS LST over Greece - climate change implications, Sci Total Environ (2017), https://doi.org/10.1016/j.scitotenv.2017.10.226