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Review

Satellite-derived land surface temperature: Current status and perspectives

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ABSTRACT

Land surface temperature (LST) is one of the key parameters in the physics of land surface processes from local through global scales. The importance of LST is being increasingly recognized and there is a strong interest in developing methodologies to measure LST from space. However, retrieving LST is still a challenging task since the LST retrieval problem is ill-posed. This paper reviews the current status of selected remote sensing algorithms for estimating LST from thermal infrared (TIR) data. A brief theoretical background of the subject is presented along with a survey of the algorithms employed for obtaining LST from space-based TIR measurements. The discussion focuses on TIR data acquired from polar-orbiting satellites because of their widespread use, global applicability and higher spatial resolution compared to geostationary satellites. The theoretical framework and methodologies used to derive the LST from the data are reviewed followed by the methodologies for validating satellite-derived LST. Directions for future research to improve the accuracy of satellite-derived LST are then suggested.

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1. Introduction

As the direct driving force in the exchange of long-wave radiation and turbulent heat fluxes at the surface–atmosphere interface, land surface temperature (LST) is one of the most important parameters in the physical processes of surface energy and water balance at local through global scales (Anderson et al., 2008; Brunsell & Gillies, 2003; Karnieli et al., 2010; Kustas & Anderson, 2009; Zhang et al., 2008). Knowledge of the LST provides information on the temporal and spatial variations of the surface equilibrium state and is of fundamental importance in many applications (Kerr et al., 2000). As such, the LST is widely used in a variety of fields including evapotranspiration, climate change, hydrological cycle, vegetation monitoring, urban climate and environmental studies, among others (Arnfield, 2003; Bastiaanssen et al., 1998; Hansen et al., 2010; Kalma et al., 2008; Kogan, 2001; Su, 2002; Voogt & Oke, 2003; Weng, 2009; Weng et al., 2004) and has been recognized as one of the high-priority parameters of the International Geosphere and Biosphere Program (IGBP) (Townshend et al., 1994). Due to the strong heterogeneity of land surface characteristics such as vegetation, topography, and soil (Liu et al., 2006; Neteler, 2010), LST changes rapidly in space as well as in time (Prata et al., 1995; Vauclin et al., 1982) and an adequate characterization of LST distribution and its temporal evolution, therefore, requires measurements with detailed spatial and temporal sampling. Given the complexity of surface temperature over land, ground measurements cannot practically provide values over wide areas. With the development of remote sensing from space, satellite data offer the only possibility for measuring LST over the entire globe with sufficiently high temporal resolution and with complete spatially averaged rather than point values.

Satellite-based thermal infrared (TIR) data is directly linked to the LST through the radiative transfer equation. The retrieval of the LST from remotely sensed TIR data has attracted much attention, and its history dates back to the 1970s (McMillin, 1975). To better understand the Earth system at the regional scale and to get the evapotranspiration with an accuracy better than 10%, LST must be retrieved at an accuracy of 1 K or better (Kustas & Norman, 1996; Moran & Jackson, 1991; Wan & Dozier, 1996). However, direct estimation of LST from the radiation emitted in the TIR spectral region is difficult to perform with that accuracy, since the radiances measured by the radiometers onboard satellites depend not only on surface parameters (temperature and emissivity) but also on atmospheric effects (Li & Becker, 1993; Ottlé & Stoll, 1993; Prata et al., 1995). Therefore, besides radiometric calibration and cloud screening, the determination of LSTs from space-based TIR measurements requires both emissivity and atmospheric corrections (Li & Becker, 1993; Vidal, 1991). Many studies have been carried out, and different approaches have been proposed to derive LSTs from satellite TIR data, using a variety of methods to deal with the emissivity and atmospheric effects (Becker & Li, 1990b; Gillespie et al., 1998; Hook et al., 1992; Jiménez-Muñoz & Sobrino, 2003; Kealy & Hook, 1993; Kerr et al., 1992; Pozo Vazquez et al., 1997; Price, 1983, 1984; Qin et al., 2001; Susskind et al., 1984; Tonooka, 2001; Wan & Dozier, 1996; Wan & Li, 1997). Consequently, there have been quite a large number of publications on LST retrieval algorithms and methods. It is important to present an overview of the state of the art in LST retrieval algorithms and to direct future research into improving the accuracy of satellite-derived LST. Although there have been earlier reviews on LST retrieval from space, presented by Prata et al. (1995) and Dash et al. (2002), since then there have been several new developments in LST retrieval algorithms and this review is intended to supplement those reviews with latest approaches. The objective of this paper is to review the progress in estimation of LST from TIR data primarily taken using sensors onboard polar-orbit satellites which have been acquiring data since the mid-eighties and to suggest directions for future research on the subject. Section 2 provides the theoretical basis for retrieving the LST from satellite TIR data and briefly discusses some major difficulties in LST retrieval from space measurements, including: (i) the coupling of the LST, the land surface emissivity (LSE) and the atmosphere; (ii) the physical meaning of satellite-derived LST; and (iii) validation problems related to satellite-derived LST. Section 3 presents an overview of a variety of methods and algorithms for estimating the LST. For each method or algorithm, the main theoretical basis and assumptions involved in the development of the model will be outlined, and the method's advantages, drawbacks and potential will be highlighted. Section 4 reviews methods of validating satellite-derived LST. Finally, Section 5 suggests future developments and provides perspectives on retrieving LST from remotely sensed data.

2. Basic theoretical background

All objects with temperatures greater than absolute zero emit radiation, and the amount of radiation from a black body in thermal equilibrium at wavelength λ and temperature T is described by Planck's law:

$$\mathrm{B}_\lambda(\mathrm{T}) = \frac{C_1}{\lambda^5\left[\exp\left(\frac{C_2}{\lambda \mathrm{T}}\right) - 1\right]}, \tag{1}$$

where $\mathrm{B}_\lambda(\mathrm{T})$ is the spectral radiance (W m^{-2} $\mu\mathrm{m}^{-1}$ sr^{-1}) of a black body at temperature T (K) and wavelength λ (μm); C_1 and C_2 are physical constants ($C_1 = 1.191 \times 10^8 \mathrm{W}\mu\mathrm{m}^4 sr^{-1}\ m^{-2}$, $C_2 = 1.439 \times 10^4\ \mu\mathrm{m} \cdot \mathrm{K}$). Because most natural objects are non-black bodies, the emissivity ε, which is defined as the ratio between the radiance of an object and that of a black body at the same temperature, must be taken into account. The spectral radiance of a non-black body is given by the spectral emissivity multiplied by Planck's law as shown in Eq. (1). Obviously, if the atmosphere exerts no influence on the measured radiance, LST (i.e. T) can be retrieved by making temperature as the subject of Eq. (1) once the emitted radiance and emissivity are known. The wavelength λ_{max}