DUE GLOBTEMPERATURE PROJECT

Definition of a Common Nomenclature for LST

[Technical Note]

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0. Executive Summary

A variety of definitions exists for terms associated with the retrieval, validation and exploitation of land, lake and ice surface temperatures. No single resource exists which attempts to draw together all the applicable terms with community agreed definitions. Indeed, it is frequently the case that many terms are used interchangeably, in some cases inconsistently. The purpose of this Technical Note is to provide a unifying resource of definitions for the broad range of terminology associated with surface temperatures of the land, inland waters, and sea-ice of the Earth. The objective is for developers and users alike to utilise this nomenclature as a reference independent of satellite / airborne / ground instrumentation and retrieval methodology.

In order to achieve community acceptance of the nomenclature presented here, the definitions have been iterated with the International Land Surface Temperature and Emissivity Working Group (ILSTE-WG); this being a representative sample of the view of the wider data provider, LST expert, and user communities. The overall objective can be summarised thus: to provide a nomenclature that both LST experts and LST users can identify and adopt to facilitate improved communication.

1. Introduction

The purpose of this Technical Note on a common nomenclature for Land Surface Temperature (LST), Land Surface Emissivity (LSE) and related physical quantities is to provide a single reference source for terminology for the LST community including science community, space agencies, producers and global user community.

This report includes an introduction to the physical principles behind the retrieval of LST and LSE from both thermal infrared and microwave (Section 2.1) and a comprehensive list of key terms applicable to the retrieval, validation and exploitation of surface temperature and surface emissivity (Section 2.2). A basis for this common nomenclature was first documented in [AD-1], and has since been modified and appended following and iterative loop with experts and data providers from the International Land Surface Temperature and Emissivity Working Group (ILSTE-WG).

1.1. Applicable documents

Table 1: List of applicable documents

Reference Number	Document	Reference
[AD-1]	GlobTemperature Technical Specification	GlobTemp-WP1-DEL-06

1.2. Reference documents

Table 2: List of reference documents

Reference Number	Reference
[RD-1]	Li, Z.-L., et al., Satellite-derived land surface temperature: Current status and perspectives. Remote Sensing of Environment, 2013. 131: p. 14-37.
[RD-2]	Becker, F. and Z.L. Li, Surface temperature and emissivity at various scales: Definition, measurement and related problems. Remote Sensing Reviews, 1995. 12(3-4): p. 225-253.
[RD-3]	Kerr, Y.H., J.P. Lagouarde, and J. Imbernon, Accurate land surface temperature retrieval from AVHRR data with use of an improved split window algorithm. Remote Sensing of Environment, 1992. 41(2): p. 197-209.

Reference Number	Reference
[RD-4]	Dash, P., et al., Retrieval of land surface temperature and emissivity from satellite data: Physics, theoretical limitations and current methods. Journal of the Indian Society of Remote Sensing, 2001. 29(1-2): p. 23-30.
[RD-5]	Remedios, J., Sentinel-3 Optical Products and Algorithm Definition: Land Surface Temperature. Report to ESA (S3-L2-SD-03-T03-ULNILU-ATBD). 2012.
[RD-6]	Dash, P., et al., Land surface temperature and emissivity estimation from passive sensor data: theory and practice-current trends. International Journal of remote sensing, 2002. 23(13): p. 2563-2594.
[RD-7]	Hunt, G.R., Electromagnetic radiation: the communication link in remote sensing. Remote sensing in geology, 1980. 2: p. 5-45.
[RD-8]	Franc, G. and A. Cracknell, Retrieval of land and sea surface temperature using NOAA-11 AVHRR· data in north-eastern Brazil. International Journal of Remote Sensing, 1994. 15(8): p. 1695-1712.
[RD-9]	Bignell, K., The water-vapour infra-red continuum. Quarterly Journal of the Royal Meteorological Society, 1970. 96(409): p. 390-403.
[RD-10]	Roberts, R.E., J.E. Selby, and L.M. Biberman, Infrared continuum absorption by atmospheric water vapor in the 8–12-µm window. Applied Optics, 1976. 15(9): p. 2085-2090.
[RD-11]	Sobrino, J., J. El Kharraz, and Z.-L. Li, Surface temperature and water vapour retrieval from MODIS data. International Journal of Remote Sensing, 2003. 24(24): p. 5161-5182.
[RD-12]	Pinheiro, A.C.T., J.L. Privette, and P. Guillevic, Modeling the observed angular anisotropy of land surface temperature in a savanna. IEEE Transactions on Geoscience and Remote Sensing, 2006. 44: p. 1036-1047.
[RD-13]	Sobrino, J.A. and J. Cuenca, Angular variation of thermal infrared emissivity for some natural surfaces from experimental measurements. Applied Optics, 1999. 38(18): p. 3931-3936.
[RD-14]	Qin, Z. and A. Karnieli, Progress in the remote sensing of land surface temperature and ground emissivity using NOAA-AVHRR data. International Journal of Remote Sensing, 1999. 20(12): p. 2367-2393.
[RD-15]	Hulley, G.C., S.J. Hook, and T. Hughes, MODIS MOD21 Land Surface Temperature and Emissivity Algorithm Theoretical Basis Document. Report to NASA, 2012.
[RD-16]	Holmes, T., et al., Land surface temperature from Ka band (37 GHz) passive microwave observations. Journal of Geophysical Research: Atmospheres (1984–2012), 2009. 114(D4).

Reference Number	Reference
[RD-17]	Weng, F. and N.C. Grody, Physical retrieval of land surface temperature using the special sensor microwave imager. Journal of Geophysical Research: Atmospheres, 1998. 103(D8): p. 8839-8848.
[RD-18]	Njoku, E.G. and L. Li, Retrieval of land surface parameters using passive microwave measurements at 6-18 GHz. Geoscience and Remote Sensing, IEEE Transactions on, 1999. 37(1): p. 79-93.
[RD-19]	Joint Commitee for Guides in Metrology, Evaluation of Measurement Data - Guide to the Expression of Uncertainty in Measurement. 2008.
[RD-20]	Norman, J.M. and F. Becker, Terminology in thermal infrared remote sensing of natural surfaces. Agricultural and Forest Meteorology, 1995. 77: p. 153-166.
[RD-21]	Vinnikov, K.Y., et al., Angular anisotropy of satellite observations of land surface temperature. Geophysical Research Letters, 2012. 39(23): p. L23802.
[RD-22]	Schneider, P., et al., Land Surface Temperature Validation Protocol (Report to European Space Agency). 2012(UL-NILU-ESA-LST-LVP).
[RD-23]	GES DISC, Goddard Earth Sciences Data and Information Sevrices Center http://disc.sci.gsfc.nasa.gov/).
[RD-24]	Merchant, C.J., et al., The surface temperatures of Earth: steps towards integrated understanding of variability and change. Geosci. Instrum. Method. Data Syst., 2013. 2(2): p. 305-321.
[RD-25]	Schaepman-Strub, G., et al., Reflectance quantities in optical remote sensing—definitions and case studies. Remote Sensing of Environment, 2006. 103(1): p. 27-42.
[RD-26]	AMS, American Meteorological Society Glossary of Meteorology [Available online at http://glossary.ametsoc.org/wiki/"term"].
[RD-27]	Wan, Z. and J. Dozier, A generalized split-window algorithm for retrieving land surface temperature from space. IEEE Transactions on Geoscience and Remote Sensing, 1996. 34: p. 892–905.
[RD-28]	CEOS, Committee on Earth Observation Satellites (http://www.ceos.org/).

1.3. Glossary

BT---------------- Brightness Temperature
CEOS-------------- Committee on Earth Observation Satellites
ESA --------------- European Space Agency
EUMETSAT------ European Organisation for the Exploitation of Meteorological Satellites

FV/FVC----------- Fractional Vegetation Cover
ILSTE-WG------- International Land Surface Temperature & Emissivity Working Group
IST ---------------- Ice Surface Temperature
LPV --------------- Land Product Validation
LSAT -------------- Land Surface Air Temperature
LSE---------------- Land Surface Emissivity
LST ---------------- Land Surface Temperature
LSWT------------- Lake Surface Water Temperature
MW--------------- Microwave
NASA------------- National Aeronautics and Space Administration
PW---------------- Precipitable Water
RTE --------------- Radiative Transfer Equation
SW---------------- Split Window
TCWV------------ Total Column Water Vapour
TIR ---------------- Thermal Infrared
TOA-------------- Top-Of-Atmosphere
VAA--------------- Viewing Azimuth Angle
VZA--------------- Viewing Zenith Angle
WGCV------------ Working Group on Calibration and Validation

2. Definitions

A variety of definitions exist for terms associated with the retrieval, validation and exploitation of land, lake and ice surface temperatures. No single resource exists which attempts to draw together all the applicable terms with community agreed definitions. Indeed, it is frequently the case that many of the terms defined here in Table 3 are used interchangeably, in some cases inconsistently. The purpose of this Technical Note is to provide a unifying resource of definitions for the broad range of terminology associated with surface temperatures of the land, inland waters, and sea-ice of the Earth. The objective is for developers and users alike to utilise this nomenclature as a reference independent of satellite / airborne / ground instrumentation and retrieval methodology.

2.1. Physical Principles

Measurements of LST play a key role in describing the physics of land-surface processes on regional and global scales as they combine information on both the surface-atmosphere interactions and energy fluxes within the Earth Climate System (ECS). An increased recognition of the importance of LST for hydrological, ecological, agricultural and climatic studies has driven the development of LST data products and measurements from space. However there are still significant challenges to retrieving LST due to the ill-posed nature of the problem [RD-1].

In the thermal infrared (TIR) atmospheric window, the radiance is dependent both on the true surface temperature and the surface emissivity according to Planck's law, modified by atmospheric processes. Even if atmospheric attenuation is well characterised the problem of retrieving surface temperature and emissivity from multi-channel measurements from a single acquisition is still ill-posed since the number of available measurements (channels) is always one less than the number of variables (emissivity in each channel and the surface temperature).

Satellite derived LST can be regarded as the surface skin temperature in the instrument field of view. However, due to the varying topographic and highly heterogeneous nature of the earth's surface make the estimation from space non-trivial [RD-2]. This effect is further exacerbated when scaled to satellite spatial resolution, for example in dense woodland the LST is the effective emitting temperature of the canopy whereas in open woodland the measured LST is the average of canopy, vegetation body and ground temperatures. Therefore satellite LST measurements are defined as the average temperature of surface types within a pixel weighted by the relative fractional cover of each surface type within the pixel [RD-3]. There are also additional practical limitations to be considered within this discussion [RD-4]:

- Limit of instrumental spectral spread of channels
- Function of viewing angle
- Atmospheric attenuation
- Reflected down-welling irradiance – depends on forward model used

- Consistent use of LST definition
- LST is measured with different accuracies depending on instrument characteristics including spectral range
- Land Surface Emissivity (LSE) depends on spectral range

2.1.1. Physical Basis for the estimation of LST and Emissivity in the TIR

Planck's law describes the radiation emitted by a black body in thermal equilibrium at a given temperature (T). Through the inversion of Planck's law estimates of LST could be made in principle from satellite observations of top-of-atmosphere (TOA) radiances (L) as the radiative energy emitted by the surface is directly related to the temperature. However, in reality atmospheric effects have to be considered.

The starting point for any LST algorithm is consideration of the thermal radiative transfer equation for monochromatic radiation emitted and reflected from a surface that is assumed homogenous, and received by a spaceborne radiometer. The homogeneous area is defined by the angular field-of-view of the radiometer. The monochromatic radiance received at the satellite-borne radiometer for a given wavenumber may be written [RD-5]:

$$I_\nu(s) = \int_\nu \mathbf{F}_\nu\left\{\tau_\nu(\mathbf{s})\mathbf{I}_\nu^{\mathrm{surface}}(\mathbf{s}) + \mathbf{I}_\nu^{\mathrm{atmos}}(\mathbf{s})\right\}\mathrm{d}\nu \tag{1}$$

$$I_\nu^{surface} = \epsilon_\nu B_\nu[T_s] + \frac{1}{\pi}\int_{\Omega-} \mathrm{n}\cdot\mathrm{s}\,\varrho_\nu(\mathrm{s},\mathrm{s}')\mathbf{I}_\nu^{\mathrm{sky}}\,\mathrm{d}\boldsymbol{\Omega} \tag{2}$$

$$I_\nu^{atmos} = \int_0^\infty B_\nu[T(p)]\frac{\partial\tau}{\partial z}(z,\infty)\mathrm{d}z \tag{3}$$

where I_ν is the radiance at the radiometer, $I_\nu^{surface}$ is the surface leaving radiance, I_ν^{atmos} is the radiance from the atmosphere, τ is the atmospheric transmittance, ν is wavenumber, z is height and *p* is pressure, F_ν is the filter response function of the radiometer, s is a unit vector defining the view direction, s$'$ is a unit vector defining the sun's direction, T_s is the surface temperature, ϵ_ν is the surface emissivity, B_ν is the Planck function, ϱ_ν is the surface reflectance, and I_ν^{sky} is the downwelling sky radiance.

If the surface is in thermodynamic equilibrium with the atmosphere, then according to Kirchhoff's law:

$$\int_{\Omega-} \mathrm{n}\cdot\mathrm{s}\epsilon_\nu(\mathrm{s})\,\mathrm{d}\Omega = \int_{\Omega+} \mathrm{n}\cdot\mathrm{s}\left\{1-\frac{1}{\pi}\int_{\Omega-}\mathrm{n}\cdot\mathrm{s}'\,\varrho_\nu(\mathrm{s},\mathrm{s}')\mathrm{d}\Omega'\right\}\mathrm{d}\Omega \tag{4}$$

where n is the unit vector normal to the surface, with Ω^- and Ω^+ being the downward and upward hemispheres respectively. We assume that the surface is Lambertian. Then ϵ_ν and ϱ_ν are independent of direction,

$$\epsilon_\nu = 1 - \varrho_\nu \qquad (5)$$

The flux density of sky radiation is:

$$F_\nu^{sky} = \int_0^{2\pi} \int_0^{\pi/2} I_\nu^{sky} \cos\theta \sin\theta \, \mathrm{d}\theta \mathrm{d}\phi \qquad (6)$$

where θ is the satellite zenith view angle, and ϕ is the satellite azimuth view angle.

$$I_\nu^{surface} = \epsilon_\nu B_\nu[T_s] + \{1 - \epsilon_\nu\} L_\nu^{sky} \qquad (7)$$

$$L_\nu^{sky} = \frac{F_\nu^{sky}}{\pi} \qquad (8)$$

This leads to the definition of surface temperature as sensed by a space-borne infrared radiometer:

$$T_s = B_\nu^{-1} \left\{ \frac{I_\nu^{surface} - (1 - \epsilon_\nu) L_\nu^{sky}}{\epsilon_\nu} \right\} \qquad (9)$$

This definition has the attribute that T_s is directly measurable from space, is valid at any scale, and for a homogeneous surface it is equivalent to the thermodynamic temperature. The definition is only strictly true for monochromatic radiation. For sufficiently narrow channels (≈ 1 µm width) with relatively smooth filter response functions, the variation of the Planck function with wavenumber is small. Thus an integration of the various quantities (I_ν, ϵ_ν, L_ν^{sky}, etc.) over the filter function is appropriate.

However propagation of the emitted spectral through the atmosphere is affected by a number of factors which must be accounted for in order to estimate LST. The spectral distribution of the energy emitted by a ground object also varies with temperature, Wien's displacement law states that the peak of a black body curve peaks at wavelength (λ_{max}) inversely proportional to the target temperature. Any shift in that peak is a direct consequence of Planck's law. The product of the target temperature and its respective λ_{max} is known as Wien's displacement constant:

$$\lambda_{max} \times T = 2.897\,7721 \times 10^{-3} \, m\,K \qquad (10)$$

For the Earth with an assumed ambient temperature of 300 K, λ_{max} is approximately 9.7µm [RD-6], therefore theoretically longwave radiation in relation to physical ground surface temperature can be remotely observed around 10 µm (Figure 1). The atmospheric window in the TIR between 8-14 µm where atmospheric attenuation of signal is minimal also contains the 'Reststrahlen' bands which are associated with resonance vibrations due to silicon-oxygen bonds that cause a decrease and shift in emissivity as silica content increases [RD-7]. The second atmospheric window in the MIR between 3-4 µm contains reflected solar and emitted thermal radiances during the day time and only emission at night.

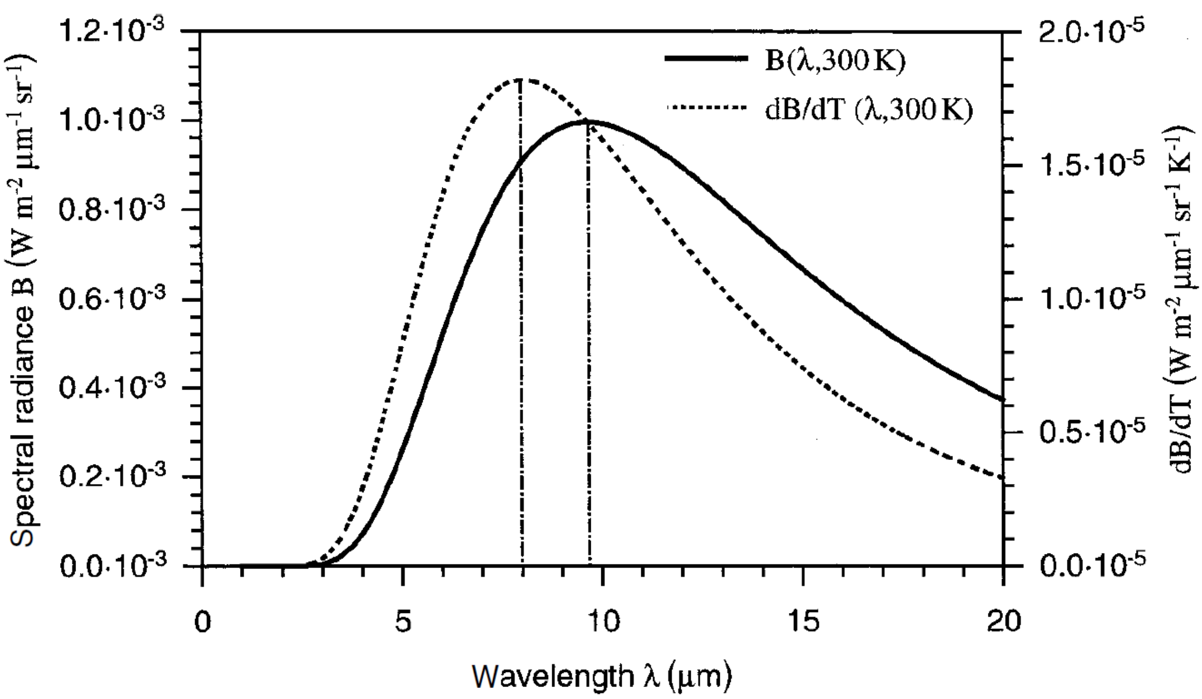

Figure 1: Dependence of spectral radiance and its first derivative with respect to temperature as a function of wavelength for a blackbody at 300 K. Peaks of both curves (B and dB/dT) lie between 8 and 9.7 µm respectfully. Image taken from [RD-6].

There are three major atmospheric effects that need to be considered when measuring LST [RD-8]:

1. Absorption by atmospheric constituents.

2. Upward atmospheric emission: the contribution of emission from atmospheric layers due to atmospheric temperature.

3. Downward atmospheric irradiance reflected at the surface and attenuated along the upward path. This is a combination of 1) and 2) and ϱ_{ν}

In the TIR window regions water vapour is the principal feature in atmospheric absorption [RD-9, RD-10]. This effect is demonstrated in Figure 2 where MODTRAN calculations of atmospheric transition for a set of MODIS channels from radiosonde soundings are plotted as a function of total column water vapour (TCWV). Therefore frequent information on the distribution of temperature and humidity is needed for accurate calculations.

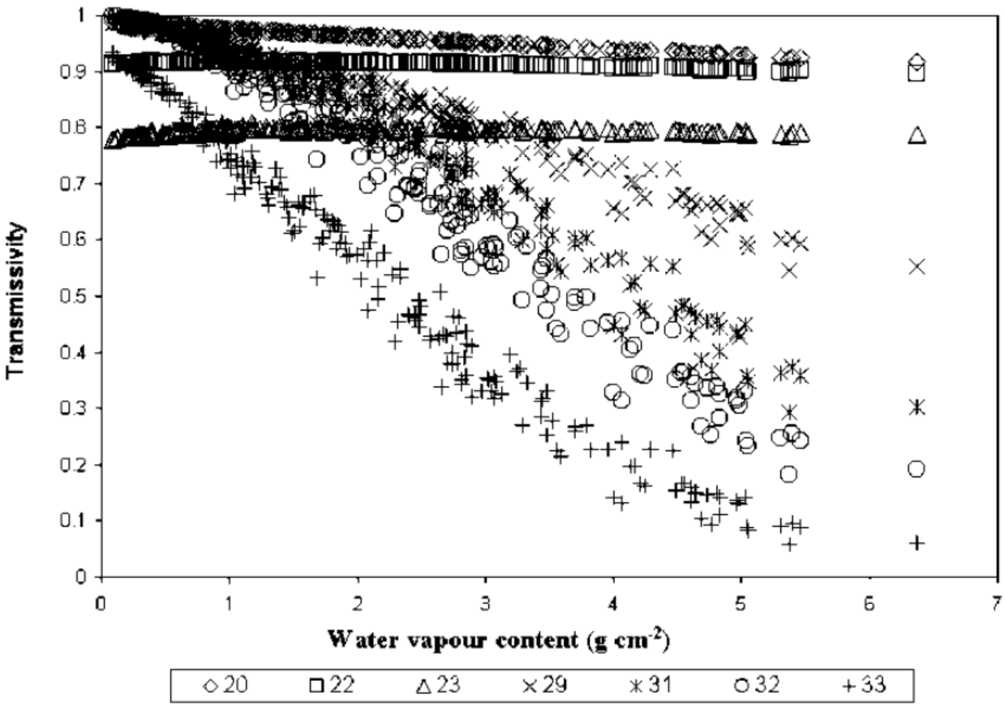

Figure 2: Effect of total column water vapour on atmospheric transmittances in MODIS channels 20, 22, 23, 29, 32 and 33 for a nadir viewing geometry. Image taken from [RD-11]

Observed TOA radiances are also dependent on the satellite zenith angle. Spectral emissivities over land are highly variable compared to sea surfaces and vary greatly with moisture content, vegetation and texture [RD-4]. The sensitivity of LST measurements to satellite zenith angle arises from the combined effects of angularly anisotropic surface emissivity at the microscopic scale (both during the day and night), and the different proportions of scene components observed by a sensor under different sun-view geometries [RD-12]. The zenith angle dependence for various surface types is illustrated in Figure 3.

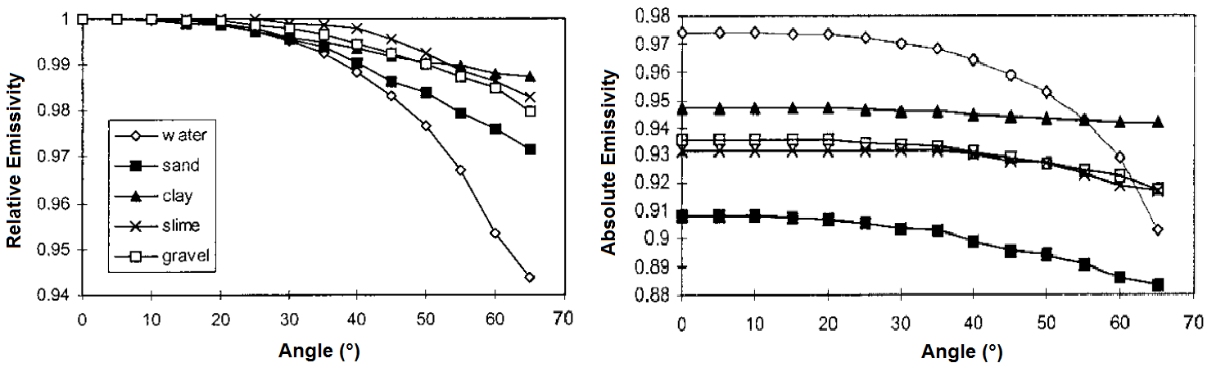

Figure 3: Emissivity dependence on satellite viewing angle for five surface types in both relative and absolute terms. Image adapted from [RD-13].

There are two main approaches to deal with the atmospheric effects when retrieving LST:

1. In single channel retrieval schemes a radiative transfer model can be used to correct for atmospheric effects. In its simplified form the radiative transfer equation (RTE) can be expressed as:

$$L^{sat} = \varepsilon\tau(\theta)B(T_s) + L^{\uparrow}(\theta) + (1-\varepsilon)\tau(\theta)L^{\downarrow} \qquad (11)$$

   Where L^{sat} is the TOA radiance measured by the instrument, $\tau(\theta)$ is the atmospheric transmission for the zenith angle θ, $B(T_s)$ is the black body emission for surface temperature T_s, $L^{\uparrow}$ is the upwelling radiance and $L^{\downarrow}$ is the down welling irradiance divided by π. The first and the second terms account for the atmospheric correction.

2. Split window (SW) algorithms which look to simplify the atmospheric effects of on radiation transmission to the sensor [RD-14].

The so-called split-window method, utilises the radiances reaching the sensor in two channels whose band centres are close in wavelength. This method provides an estimate of the surface temperature from two brightness temperature (BT) measurements and assumes that the linearity of the relationship results from linearisation of the Planck function, and linearity of the variation of atmospheric transmittance with column water vapour amount.

Over land, emissivity can vary significantly with surface cover and type, and the surface and atmosphere must be treated as a coupled system. There are two approaches to solving the problem of LST determination using the split-window channels. The first assumes that the effects due to the land and atmosphere can be decoupled and the method is then to separate out the surface effects (emissivity) from the atmospheric effects (water vapour). The second approach is to accept that the surface and atmosphere are coupled, solve the problem without taking explicit account of either emissivity or water vapour, but to allow for their effects simultaneously [RD-5].

The difficulty of the first approach is that an estimate of the emissivity must be provided or retrieved and validated for the ill-posed retrieval problem to be solved, with thus the surface temperature being the only unknown variable. For surfaces that can be approximated as Lambertian (isotropic) - such as ocean, ice, or densely vegetated scenes - where the emissivity is relatively spectrally flat the emissivity can be assigned *a priori* from a land-cover classification [RD-15].

The SW approach is usual for sensors that have two or more bands in the TIR region; while multispectral sensors with three or more bands in the TIR allow non-deterministic approaches so that spectral variations in the retrieved emissivity can be related to surface composition and cover, in addition to retrieving the surface temperature [RD-15].

2.1.2. Physical Basis for the estimation of LST and Emissivity in the microwave

Observations from passive microwave (MW) sensors can also be used to provide additional or alternative observations TIR measurements of LST. The key advantage of MW observations is that there is increased sampling in cloudy conditions although IFOV are significantly larger than their TIR sounder counterparts. Instruments use detectors centred on the Ku (18 GHz) and Ka (37 GHz) bands with vertical and horizontal polarization filters. Vertically polarised Ka channels are more frequently used for LST estimation as there is reduced sensitivity to soil moisture with relatively high atmospheric transitivity [RD-16]; however other studies have utilised 19.35/22.23 GHz [RD-17] and 6-18 GHz [RD-18] frequencies. Brightness temperatures (BTs) measured by MW sensors over land increase linearly due to changes in emissivity and temperature with minimal effect due to variability in atmospheric transmittance [RD-17]. An example of atmospheric transmittance and soil moisture dependencies of global LST retrievals is illustrated in Figure 4.

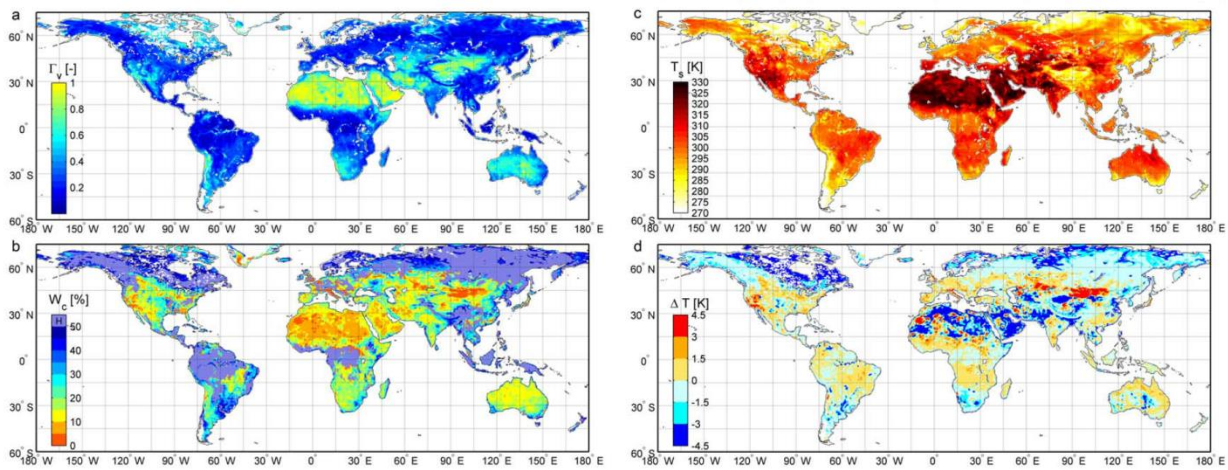

Figure 4: Dependence of vegetation (a) and soil moisture (b) on LST retrievals at 37 GHz (c). Bias of retrieval compared to radiative transfer calculations shown in (d). Images taken from [RD-16]

2.2. Common Nomenclature

As a baseline, the definitions are first collated from the growing source of literature on LST. For LST validation, for instance, several definitions are adopted from [RD-19], which is the standard for Metrology nomenclature. In order to achieve community acceptance of the nomenclature presented here, the definitions have been iterated with the International LST & E Working Group (ILSTE-WG); this being a representative sample of the view of the wider data provider, LST expert, and user communities. Furthermore, liaison with the Land Product Validation (LPV) sub-group of the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV), both directly and through contacts within the ILSTE-WG aim to promote this nomenclature for inclusion in an LPV "Best Practices Guide for LST".

While some of these terms may be more qualitative than the more precise mathematical terminology as presented in [RD-19], their use is now so embedded in the psyche of the LST data provider and user communities it is pertinent to provide a unified definition of these terms so as to ensure consistency within this field. For a more precise mathematical definition of thermal remote sensing properties, such as directional and hemispherical radiometric temperatures, or directional and hemispherical emissivities, one is referred to [RD-20]. Rather the objective here is to provide a nomenclature that both LST experts and LST users can identify and adopt to facilitate improved communication.

Table 3: Physical Nomenclature. Starred entries indicate terms that are defined only in the context in which they are used, i.e. in terms of a particular sensor wavelength and a given approximation to the radiative transfer equation.

Terminology	Definition	Comments
Absolute bias	A systematic error between a measurement and the true value [RD-19]	This is of theoretical importance only here, as the exact true value of LST cannot be known due to measurement error
Accuracy	Accuracy can be thought of as the degree of conformity of the measurement of a quantity to the accepted value or the "true" value [RD-19]	
Angular anisotropy	It is defined as a difference in a material's physical or mechanical properties when viewed along different directions or axes [RD-12, RD-21]	For LST this refers to the surface emissivity at the macroscopic scale; and that at each specific location, and at each specific time, the dependence of LST on Sun position and viewing geometry is absolutely unique
Biome	The term biome in LST science is a generic type of vegetation, a biome set being used to constitute a land cover classification for all land points	For some LST retrieval schemes coefficients may be categorised by biome

Terminology	Definition	Comments
Brightness temperature (BT)	Brightness temperature is the signal observed at the satellite instrument, calibrated to radiance and converted to the equivalent temperature of a perfectly emitting surface. Effectively it is the directional temperature obtained by equating the measured radiance with the integral over wavelength of the Planck's Black Body function times the sensor response. It is the temperature of a black body that would have the same radiance as the radiance actually observed with the radiometer [RD-20]	
Calibration	Calibration is the process of quantitatively defining the system response to known, controlled system inputs [RD-22]	It may involve the subsequent implementation of correction factors from ground or in-flight calibration to transform the measured signals in a satellite instrument to calibrated radiances
Discrepancy	Discrepancy describes the lack of similarity between two measurements, where this is outside some expected error bound. [RD-22]	
Error	Result of a measurement minus a true value of the measurand [RD-19]	Note that in practice, at least for LST, a true value cannot be determined and therefore a conventional true value is used instead
Fractional Vegetation Cover (FV / FVC)	The ratio of the vertically projected area of vegetation on the ground to the total vegetation area	For satellite data In simplified terms this is the fraction of a specified area that is covered by green vegetation. For LST retrieval this parameter has often been used to infer emissivity given emissivities for the fully vegetated or low vegetation states
Ground Truth	In situ measurements of a measurand	However, this term is generally not used because in situ measurements are not actually 'truth'

Terminology	Definition	Comments
Ice surface temperature (IST)*	The surface temperature of ice bodies including land ice, and sea-ice, measured in situ or estimated from satellites	
Intercomparison	The process of comparing two or more (LST) data sets to allow evaluation of their relative consistency [RD-22]	
Land surface air temperature (LSAT)	A measurement of the average kinetic energy of the air near the surface of the Earth. This is usually measured at 2m height at meteorological stations [RD-23, RD-24]	
Land Surface emissivity (LSE)	Emissivity describes a material's ability to emit the thermal energy as a fraction of that which would be emitted from a perfectly emitting surface (a blackbody) [RD-22]	Emissivity is a function of wavelength
Land surface temperature (LST)*	Land Surface Temperature (LST) is the mean radiative skin temperature derived from thermal radiation of all objects comprising the surface, as measured by remote sensing ground-viewing or satellite instruments [RD-20, RD-22]	It is a basic determinant of the terrestrial thermal behaviour, as it controls the effective radiating temperature of the Earth's surface
Lake surface water temperature (LSWT)*	The skin temperature of lake bodies including inland seas, reservoirs measured in situ and estimated from satellites [RD-24]	
Measurand	A measurand is the particular quantity subject to measurement [RD-19]	
Precision	Precision is the closeness of agreement between independent measurements of a quantity under the same conditions [RD-19]	

Terminology	Definition	Comments
Radiance	Measure of the quantity of radiation emitted from the surface. The spectral radiance is the radiant flux in a beam per unit wavelength and per unit area and solid angle of that beam [RD-25]	Radiance is the spectral radiance integrated over wavelength
Radiometric temperature	Derived from a radiative energy balance of a surface and is the best approximation to the thermodynamic temperature based on a measure of radiance [RD-20]	
Random error	Result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions [RD-19]	
Reference standard	Measurement standard designated for the calibration “in situ” of other (similar) measurement systems. Usually applied to instruments of a given kind or at a given location for which the reference standard has been agreed to be relevant [RD-22]	
Relative bias	A systematic error between measurements obtained from different data sources [RD-22]	
Relative error	The relative error is the error of measurement divided by a true value of the measurand [RD-22]	
Satellite azimuth angle	The length of the arc of the horizon (in degrees) intercepted between North and the direction of the satellite from the observation point measured clockwise from the reference direction [RD-26]	This is frequently referred to as the Viewing Azimuth Angle (VAA)

Terminology	Definition	Comments
Satellite zenith angle	The angle between a straight line from a point on the earth's surface to the satellite and a line from the same point on the earth's surface that is perpendicular to the earth's surface at that point [RD-26]	This is frequently referred to as the Viewing Zenith Angle (VZA)
Skin temperature	The temperature of a layer of a medium of depth equal to the penetration depth of the electromagnetic radiation at the given wavelengths [RD-20]	Surface brightness and radiometric temperatures are the effective temperature that a radiometer would measure near the surface, including emissivity effects and reflected downwelling radiance
Soil temperature	The sub-surface temperature measured at a given depth in soil [RD-26]	
Solar azimuth angle	The length of the arc of the horizon (in degrees) intercepted between North and the direction of the sun from the observation point measured clockwise from the reference direction [RD-26]	
Solar zenith angle	The angle between a straight line from a point on the earth's surface to the sun and a line from the same point on the earth's surface that is perpendicular to the earth's surface at that point [RD-26]	
Split-Window (SW)	Refers to the use of adjacent infrared filtered bands (channels in an instrument) to correct for atmospheric effects based on differential absorption [RD-27]	
Systematic error	Mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions minus a true value of the measurand [RD-19]	

Terminology	Definition	Comments
Thermodynamic temperature	Thermodynamic temperature is a macroscopic quantity that is an absolute measure of temperature. A statistical interpretation of the thermodynamic temperature is referred to as the kinetic temperature, and it is a macroscopic quantity defined on a microscopic scale in terms of the mean kinetic energy of solid particles [RD-20]	
Total column water vapour (TCWV)	Amount of water (depth of vertical column of unit-crossectional area) which would be obtained if all the water vapour in a specified column of the atmosphere were condensed to liquid [RD-23]	
True value	A true value is the value consistent with the definition of a given particular quantity [RD-22]	
Uncertainty	A parameter associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand, that is the value of the particular quantity to be measured [RD-19]	
Validation	The process of assessing, by independent means, the quality of a given set of data products [RD-28]	Primarily this is an assessment of the accuracy using equivalent in situ observations
Validation loop	The validation loop describes the iterative process between algorithm development and validation, where validation findings are investigated and reflected in algorithm changes with the final goal of improving the output product [RD-22]	

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