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Letter to the Editor

Retrieval of land surface temperature from combined AVHRR data

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Abstract. Accurate retrievals of land surface temperature (LST) from space are of high interest for studies of land surface processes. Here, an operationally applicable method to retrieve LST from NOAA/AVHRR data is proposed, which combines a split-window technique (SWT) for atmospheric correction with a Normalised Difference Vegetation Index threshold method for the retrieval of land surface emissivity. Preliminary results of LST retrievals with this "combined method" are in good agreement with ground truth measurements for bare soil and wheat crops. The results are also compared with results from the same SWT but using emissivities from laboratory measurements.

Key words. Meteorology and atmospheric dynamics (radiation processes; instruments and techniques) – Radio science (remote sensing)

1 Introduction

Among the main driving forces behind investigations of land surface temperature (LST) in remote sensing is the importance of LST for environmental studies, numerical weather prediction, and climatological studies. However, accurate LST retrievals require the precise determination of atmospheric corrections and land surface emissivity (LSE). Explicit radiative transfer calculations to derive atmospheric corrections are possible but computationally very expensive; the costs can be reduced by performing approximate calculations, e.g. using artificial neural networks (Göttsche and Olesen, 2002). However, due to its simplicity, the split-window technique (SWT) with different refinements is widely used. The SWT takes advantage of the close correlation between the differences in absorption in the IR window region from 10–13 μm (i.e. NOAA/AVHRR channels 4 and 5) and atmospheric correction, which is mainly determined by the water vapour and air temperature profiles. The land surface is generally very heterogeneous and the LSE in a satellite pixel is usually unknown. Therefore, LSE errors are the most important source of error for LST retrievals (Schädlich et al., 2001). Precise LST retrievals require a method which accurately estimates LSE at the spatial resolution of the satellite sensor; a review of current methods for passive sensor data is given by Dash et al. (2002). Different components of the surface, for example, bare soil and vegetation, can have (and usually have) different temperatures and emissivities. Consequently, LST retrieved from radiances is representative for the mixture of components in the sensors field of view and does not have to match the temperature of an individual component. However, for a sensor with a spatial resolution that matches the target size, this intrinsic averaging is advantageous. Here, the strong correlation between the time series of LSE, the Normalised Difference Vegetation Index (NDVI), and the plant cover fraction (P_v) found by Wittich (1997) is exploited for LSE estimation.

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2 Methods

Based on the SWT for seasurface temperature, Coll et al. (1994) proposed the following equation for retrieving LST from NOAA/AVHRR channels 4 and 5:

$$T = T_4 + [1.34 + 0.39(T_4 - T_5)] \cdot (T_4 - T_5) + 0.56 + B(\epsilon)\,, \tag{1}$$

where

$B(\epsilon) = 0$ for SST retrieval,
$B(\epsilon) = \alpha(1-\epsilon) - \beta\Delta\epsilon$ for LST retrieval,
$\epsilon = (\epsilon_4 + \epsilon_5)/2$ is the mean emissivity, and
$\Delta\epsilon = \epsilon_4 - \epsilon_5$ is the spectral emissivity difference.

α and β can be estimated for a particular area as functions of the brightness temperature if the atmospheric water vapour content is known. Otherwise, climatological values for α and β can be used (Coll and Caselles, 1997). Equation (1)

Table 1. Validation results for the Walpeup bare soil data set (Prata, 1994b). Rms LST error, standard deviation, and error range are given

Coll and Caselles (1997) Lab. emissivity measurements	Combined method NDVI-derived emissivity
Error: -3.0 ± 2.0 [°C]	Error: -2.0 ± 1.6 [°C]
Range: $-6.2/0.4$ [°C]	Range: $-4.6/0.4$ [°C]

can be used for LST retrieval if emissivity values are available. Instead of using a priori knowledge about emissivity, for example, from laboratory measurements, here LSE is determined using a simplified version of the NDVI threshold method (Sobrino and Raissouni, 2000; Sobrino et al., 2001). The NDVI method first estimates the fractions of vegetation (P_v) and bare soil ($1 - P_v$) in the field of view of the sensor (Carlson and Ripley, 1997). P_v has a square root relation with scaled NDVI, which is nearly independent of atmospheric correction (Eq. 2). For $NDVI_{\min} = 0.2$ (bare soil) and $NDVI_{\max} = 0.5$ (full vegetation), P_v is given by:

$$P_v = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right)^2 = \frac{(NDVI - 0.2)^2}{0.09} \,. \quad (2)$$

For $0.5 > NDVI > 0.2$, Sobrino et al. (2001) utilise an empirical relationship between P_v and the mean LSE, and P_v and the spectral difference of LSE for AVHRR channels 4 and 5:

$$\epsilon = (\epsilon_4 + \epsilon_5)/2 = 0.971 + 0.018 P_v$$
$$\Delta\epsilon = \epsilon_4 - \epsilon_5 = -0.006(1 - P_v) \,. \quad (3)$$

For $NDVI \geq 0.5$, Sobrino et al. (2001) consider the pixel to be fully vegetated ($P_v = 1$) and the channel emissivities are set to $\epsilon_4 = \epsilon_5 = 0.990$. For $NDVI \leq 0.2$, the pixel is considered as soil with sparse vegetation or bare soil ($P_v = 0$) and an empirical relationship between the mean LSE in AVHRR channels 4 and 5 and reflectance ρ_1 in channel 1 is used:

$$\epsilon = 0.980 - 0.042\rho_1$$
$$\Delta\epsilon = -0.003 - 0.029\rho_1 \,. \quad (4)$$

The effective ground leaving thermal radiance can be obtained by averaging the radiative contributions of the cover fractions. The "combined method" is tested with validation data from NOAA/AVHRR for the Walpeup site in Australia (Prata, 1994a, b); unfortunately, numerical values for the visible and near-infrared channel are not included in his papers. Therefore, not only are the measurements in Prata (1994b) utilized for the validation, but also used is a plot of the variation of the reflectance in the VIS (channel 1) with the ratio of reflectance in the NIR (channel 2) to reflectance in the VIS, which is related to NDVI (Prata, 1994a); Fig. 4. Prata only listed critical data and the number of plotted points equal 12 for bare soil, 12 for growing crops, and 14 for mature crops. However, for bare soil all but one measurements are plotted and the corresponding reflectance can be obtained, if one assumes that (a) the missing data point overlaps with another one and (b) the reflectance decreases with an increasing date. Assumption (b) is plausible because the plotted vegetation index for the bare soil area increases from April until the 30 May 1990, which is probably due to an increase in weeds. For the growing wheat crop and the mature wheat crop, only 2 data points can be used, since Prata (1994a) only gives NDVI values at the critical date.

Table 2. Validation results for the Walpeup wheat crop data set (Prata, 1994b). T_g, T_a, and T_s are the ground, air, and retrieved surface temperature, respectively. T_s was obtained using the combined method

Wheat crop		T_g [°C]	T_a [°C]	T_s [°C]	$T_g - T_s$ [°C]
Growing	22/08	12.57	10.33	11.57	1.00
	02/10	28.64	26.64	32.01	−3.37
Mature	22/10	37.11	26.85	39.11	−2.00
	25/11	44.61	35.18	45.34	−0.73

3 Results

The combined method, which is proposed in this paper, uses the same coefficients α and β for calculating the correction $B(\epsilon)$ due to LSE, as in Coll and Caselles (1997), but the LSE is obtained differently: whereas Coll and Caselles utilise emissivity values based on laboratory measurements of soil samples (Prata, 1994b), the combined method obtains LSE from NDVI data calculated from NOAA/AVHRR data. Table 1 shows validation results for both approaches for the Walpeup bare soil data set.

From Table 1 it can be seen that the combined method performs better than the original method of Coll et al. (1994), which utilises emissivity from laboratory measurements. The reason is that the land surface is composed of many different materials and is far from being homogeneous. Therefore, the laboratory emissivity measurements of the soil samples are not representative for areas at satellite pixel scale. In contrast, emissivity obtained from satellite-derived NDVI data represents an effective value at satellite pixel scale: particularly for inhomogeneous agricultural areas this value is more representative of the real situation of natural surfaces.

On 22 August, the LST for the growing wheat crop, which was obtained using the combined method, deviates from the average of the measured ground and air temperature by only 1.0°C (Table 2). On a photograph of the growing wheat crop

Table 3. Comparison of results obtained with the method of Coll et al. (1994) and using the combined method. Rms LST error, standard deviation, and error range are given

Coll and Caselles (1997) Representative emissivity	Combined method NDVI-derived emissivity
Error: -0.1 ± 2.1 [°C]	Error: -1.6 ± 1.4 [°C]
Range: $-4.3/3.7$ [°C]	Range: $-3.4/-0.1$ [°C]

from 4 August 1990 taken at Walpeup (Prata, 1994b), it can be seen that parts of the surface were bare; Prata (1994a) suggests using a 0.7 fraction of bare ground ($P_v = 0.3$) for the effective temperature calculation. On 22 August, the satellite viewing angle was 13.6° from nadir; therefore, its influence on the observed P_v can be neglected (Carlson and Ripley, 1997). However, since the wheat crop grew between 4 and 22 August, P_v is set to 0.5. On 2 October, the viewing angle was 46.3° from nadir and the growing wheat crop was yellow and nearly mature; a wheat crop is at full cover when it is yellow. Therefore, probably no bare ground was observed on that date. From the above, the ground temperature is assumed to be suitable for validation purposes. The surface temperature data obtained with the combined method (Table 2) are now compared to those obtained by Coll and Caselles (1997). If measurements are made in the shadow of vegetation, the ground temperature can be expected to be lower than LST retrieved from satellite data. This may explain why T_s is higher than T_g in Table 2.

Table 3 compares the results obtained with the two methods: it can be seen that the average error for the combined method is larger than the one obtained by Coll and Caselles (1997): the likely reason is the limited available data for the validation of the combined method. However, the scatter of errors of the combined method is smaller than for Coll and Caselles's algorithm; furthermore, the combined method is simple and does not require further assumptions or an adjustment of emissivity in order to minimise the error. The good performance of the method is based on its use of NDVI, which is highly correlated with LSE at satellite pixel scale. The combined method directly relates LST to NDVI and improves the accuracy of retrieved LST by reducing the emissivity error. Strictly speaking, the combined method cannot be applied at nighttime because at that time NDVI is not available; however, the fractional vegetation cover determined at daytime can also be used at nighttime, if the weather and surface conditions are not changing too rapidly and the viewing geometry for the daytime NDVI data is close to the one for the night-time IR data. For polar orbiters, e.g. NOAA/AVHRR, the last condition is usually not fulfilled; in contrast, data from geostationary satellites, e.g. Meteosat Second Generation, are acquired under constant viewing geometry and, therefore, also allow for the use of temporal composites of NDVI.

4 Conclusions

We combined the SWT for atmospheric correction of Coll et al. (1994) with a NDVI threshold method to retrieve LSE (Sobrino et al., 2001), which accounts for the contributions from bare soil and vegetation separately. The method was verified using ground truth data from literature (Prata, 1994b), for which the retrieved LST error is estimated to be about 2°C. There is a dependence of LSE on the viewing angle, which for very large angles can result in a difference of up to 4°C compared to near nadir views. However, measurements performed by the authors suggest that this dependence can be neglected for angles <40°. A major advantage of LSEs derived from NDVI over LSEs determined from ground truth measurements is that they are representative for the land surface at satellite pixel scale. Since the combined method makes no further assumptions and is easily implemented, it is well suited for practical applications.

References

Carlson, T. N. and Ripley, D. A.: On the relation between NDVI, fractional vegetation cover, and leaf area index, Remote Sens. Environ., 62, 241–252, 1997.

Coll, C., Caselles, V., Sobrino, J. A., and Valor, E.: On the atmospheric dependence of the split-window equation for land surface temperature, Int. J. Remote Sens., 15, 105–122, 1994.

Coll, C., Caselles, V.: A split-window algorithm for land surface temperature from advanced very high resolution radiometer data: Validation and algorithm comparison, J. Geophys. Res., 102 (D14), 16 697–16 713, 1997.

Dash, P., Göttsche, F.-M., Olesen, F.-S., and Fischer, H.: Land surface temperature and emissivity estimation from passive sensor data: theory and practice; current trends, Int. J. Remote Sens., in press, 2002.

Göttsche, F.-M. and Olesen, F.-S.: Evolution of neural networks for radiative transfer calculations in the terrestrial infrared, Remote Sens. Environ., 80, 157–164, 2002.

Prata, A. J.: Land surface temperatures derived from the advanced very high resolution radiometer and the along track scanning radiometer, 2, Experimental results and validation of AVHRR algorithms, J. Geophys. Res., 99 (D6), 13 025–13 058, 1994a.

Prata, A. J.: Validation data for land surface temperature determination from satellites, Div. of Atmos. Res., Commonw. Sci. and Ind. Res. Org., Melbourne, Victoria, Australia, Pap. 33, pp. 36, 1994b.

Schädlich, S., Göttsche, F.-M., and Olesen, F.-S.: Influence of land surface parameters and atmosphere on Meteosat brightness temperatures and generation of land surface temperature maps by temporally and spatially interpolating atmospheric correction, Remote Sens. Environ., 75, 39–46, 2001.

Sobrino, J. A. and Raissouni, N.: Toward remote sensing methods for land cover dynamic monitoring, Application to Morocco, Int. J. Remote Sens., 21, 353–366, 2000.

Sobrino, J. A., Raissouni, N., and Li, Z.-L.: A comparative study of land surface emissivity retrieval from NOAA data, Remote Sens. Environ., 75, 256–266, 2001.

Wittich, K.-P.: Some simple relationships between land-surface emissivity, greenness and the plant cover fraction for use in satellite remote sensing, Int. J. Biometeorol., 41, 58–64, 1997.