THE DAIS LA PEYNE EXPERIMENT: USING THE OPTICAL AND THERMAL DAIS BANDS TO SURVEY AND MODEL THE SURFACE TEMPERATURE

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ABSTRACT

In the summer of 1998, an experimental flight was carried out with the Digital Airborne Imaging Spectrometer (DAIS7915) over the Peyne test site in southern France. DAIS is a hyperspectral system with 72 bands from visible to shortwave infrared wavelengths and 7 bands in the thermal infrared. This study investigates the integrated use of thermal- and optical bands for extracting information from DAIS to simulate the thermal behaviour of the soil surface and the vegetation. Field survey during the days around the over flight time yielded information on the daily thermal cycle of various surfaces. Next a geostatistical sampling approach and interpolation algorithms were used to produce maps of soil properties controlling the thermal behaviour of the soil surface. Conditional simulation provided insight in the spatial distribution of the uncertainty of the soil properties. The field data showed that significant differences exist between the surface temperature of the various soil types and land cover. The optical DAIS images were converted from radiance into reflectance using the empirical line method. The uncalibrated digital numbers of the thermal DAIS bands were converted into absolute temperature values by using field measurements collected during the overflight. Next, the DAIS optical spectral bands were used to assess the vegetative cover and the land cover type on a pixel-by-pixel basis. A dynamic, spatial model was built simulating the surface temperature over 48 hours. Input for the model was extracted from the DAIS imagery and collected in the field. This model was calibrated by field temperature measurements.

1 INTRODUCTION

Soil temperature and soil moisture control to a large extent biological and chemical processes such as decomposition, nitrification, seed germination and root growth. Information on the spatial and temporal variability of surface temperature is important for various disciplines such as soil science and agricultural science. In the summer of 1998, an experimental flight was carried out with the Digital Airborne Imaging Spectrometer (DAIS7915) over the Peyne test site in southern France (Lucieer, 1999). During this flight, images of five flightstrips were acquired. The sensor collects images from the visible, near infrared and thermal infrared parts of the spectrum (table 1). The simultaneous combination of optical and thermal bands is unique for remote sensing observations at this scale. The high spatial resolution of approximately 6 by 6 m together with the high spectral resolution of 24 nm for the optical parts and 1.0 µm for the thermal part of the spectrum allows us to investigate the usefulness of the diagnostic absorption features and of the entire spectral shape for environmental applications.

Spectrometer	Bands	Detector	Coupling	Wavelength Range	Bandwidth
1 VIS/NIR	32	Si	DC	0.4 – 1.0 µm	12 – 35 nm
2 SWIR I	8	InSb	AC	1.5 – 1.8 µm	36 – 56 nm
3 SWIR II	32	InSb	AC	2.0 – 2.5 µm	20 – 40 nm
MIR	1	MCT	AC	3.0 – 5.0 µm	2.0 µm
4 THERMAL	6	MCT	AC	8.7 – 12.3 µm	0.6 – 1.0 µm

Table 1: System characteristics of the DAIS 7915 spectrometer (Strobl, 1996a).

The optical and infrared parts of these images give information on vegetation, land use and soil type. The thermal images provide information on the spatial variation of surface temperature and hence, on the heat- and water balance in the catchment. With the information of the thermal images, insight on the thermal behaviour of surfaces (soils and vegetation) can be obtained. With the aid of a thermal model, the thermal behaviour of soils and vegetation can be predicted, and our knowledge on thermal images and the information in these images can be enlarged (Strobl, et al., 1996a, 1997; Muller, 1997; Hausold, 2000). The Peyne catchment is chosen as the research area for this study, for its large variance on a small scale. This variance presents itself in the vegetation and land use, the rocks and soils, and the morphology of the landscape.

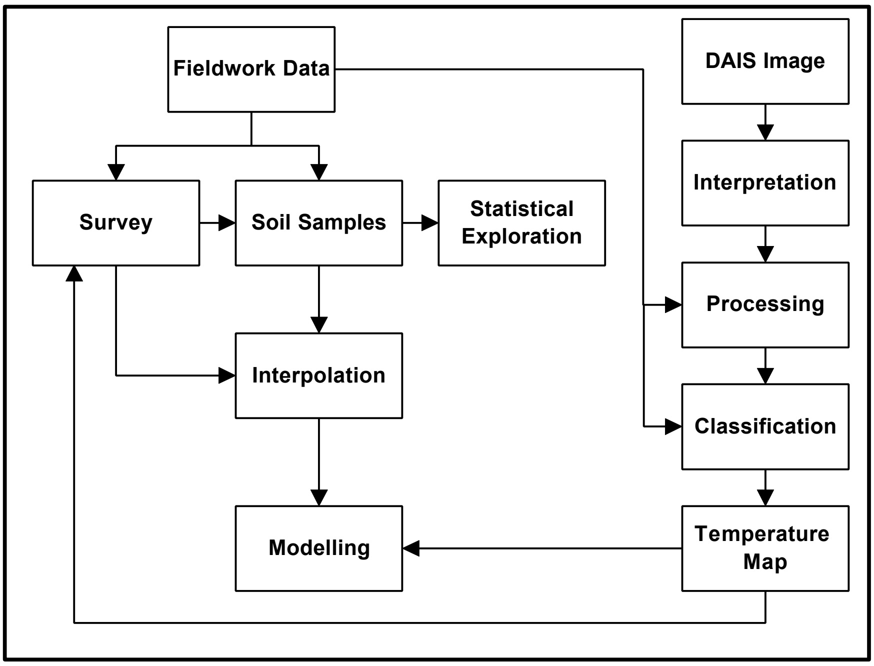

Figure 1: Flow diagram of the research approach

The objectives of this study are to 1) investigate the integrated use of optical and thermal remote sensing information acquired simultaneously, 2) to map differences in surface temperature in the Peyne catchment and to explain these variations and 3) to develop a regional model simulating the spatial and temporal variation of surface temperature using information extracted from DAIS and collected in the field. This paper describes the approach and methods used and the preliminary results. A flow diagram of the research approach is given in figure 1.

2 STUDY AREA AND DATA COLLECTION

The study area is situated in the south of France and forms a part of the catchment of the river ‘Peyne’. This sub-catchment of the Hérault is located about 60 km west of Montpellier (N: 43°35’ and E: 3°15’). The size of the study area is about 12 km^2, and is chosen in such a way that it is completely covered by the DAIS imagery. It is situated in the central part of the Peyne catchment. This part of the catchment covers most of the natural variation present in the area. Three parts can be distinguished in the area. A northern part that is moderately undulating and that is vegetated with maquis. The present soils are shallow, and the underlying rock is predominantly calcareous and flysch. The central part is a transition zone, which is covered by garrigue vegetation. In the southern part, the plains are mostly used for vine culture. In the south-east, the area is bordered by a basalt-ridge. The climate in the study area is characterised by short, high intensity rainfall events in spring and autumn and by persistent dry periods in summer. Most precipitation falls in the early spring and the autumn. The average winter- and summer temperatures are 3 ^{o}C and 25 ^{o}C respectively. The altitude of the area varies from 90 to 350 m. above see level (Andrieux, 1993).

A two-month field-campaign was carried out, during which the DAIS-flight took place. During this field-campaign, a survey was carried out, and several field measurements were taken. During the survey, information on landcover type and the percentage of vegetation cover was collected. Vineyards show significant variation in management and coverage. Therefore, additional information was collected on vineyards such as the orientation of the rows, whether the soils were ploughed or not, the percentage of litter and whether the plants were tied up or not. As input for the surface temperature model, measurements were taken on soil moisture, soil density and soil porosity. The soil moisture measurements are corrected for their variability in time. Temperature measurements were taken with a handheld radiant thermometer. Two sets of temperature data are distinguished; the first set is a temperature timeseries of 12 hours. Temperature measurements for this timeseries were taken every 30 minutes of bare soil surfaces and vegetation surfaces. The other temperature data set, comprise the temperature values and variations of the different landcover types. These temperature measurements are used for the surface temperature model. Furthermore, optical reflectance spectra of the landcover types were measured with a portable field spectrometer (ASD FieldSpec), and of a number of characteristic points. The exact geographical location for each of the points was determined by a Differential Global Positioning System. Both the spectral- and DGPS data are used to correct the DAIS images.

3 DAIS IMAGERY AND PROCESSING

3.1 The DAIS 7915 instrument

The Digital Airborne Imaging Spectrometer (DAIS7915) is a 79 channel, high-resolution spectrometer. The DAIS is an experimental scanner, financed by the European Union and DLR, and built by the Geophysical Environmental Research Corporation (GER). The 79 spectral bands cover the range from the visible- to the thermal wavelengths. The scanner can be mounted on the Dornier DO 228 aircraft. Table 1 gives the specifications for the different spectrometers. Six spectral bands between 8 en 12 µm are used for the measurement of the radiant temperature of land surfaces. Besides the high spectral resolution, the DAIS 7915 also has a very high spatial resolution. At a flight altitude of approximately 3000 m. the spatial resolution of the recorded image is 6 by 6 meter.

Before processing, the 79 bands were used for a visual inspection of image quality. Image quality is generally good in the visible and near infrared bands. Striping occurred in most of the SWIR bands. The striping in some SWIR bands is probably caused by vibration of the Dornier DO228 prop-engines (Strobl, 1996b).

3.2 Georeferencing of the DAIS imagery

The Peyne flight strip was flown from the north-west to the south-east. The first step in the georeferencing of the image is a rotation of the flight strip to the geographical north. The flight strip is rotated over 137 degrees with the cubic convolution resampling method. A spatial subset of the flight strip is taken to reduce the size of the image. This spatial subset corresponds with the size of the study area. Fifty DGPS measurements were taken in order to correct for the distortions in the image. The RMS-error of the image, caused by the distortions, comes to 7.856 pixels. Transformation with a second-degree polynomial with the cubic convolution resampling technique gave the best results for the Peyne flight strip. Most of the large-scale distortions are corrected, but some of the small-scale distortions cannot be corrected because of the rough transformation algorithm.

3.3 Processing of the optical DAIS bands

In order to perform noise reduction, the Minimum Noise Fraction transformation (MNF) can be used. This transformation algorithm can be described as a cascaded Principal Component transformation (PCA). The MNF transformation decorrelates and rescales the noise in the data. The output of the MNF transformation is a given eigenvalue for each MNF band. When the eigenvalue of an MNF band is small (less than one), the image is noise dominated (Green, 1998). The MNF images with the largest eigenvalues can be transformed back to the original data space. The original data space is restored, however without the determined noise.

To correct for atmospheric effects, the empirical line method is applied. This method uses field measurements to correct the atmospheric effects. Reflectance spectra of homogeneous targets measured in the field are compared to the corresponding areas in the image. A linear regression function is computed for each spectral channel in the image. The regression has been calculated by fitting the regression line through the spectra. The advantage of this calibration technique is the removal of the solar irradiance curve and the atmospheric path radiance, because of the difference in path length through the atmosphere. The distance between the DAIS sensor and the ground is approximately 3000m, while the path length of the field spectrometer is only less than one meter (de Jong, 1998b). In order to obtain a good empirical line conversion function, reflectance spectra of dark and bright targets are used, like water, asphalt and soil.

To classify the DAIS image into land cover classes, the Spectral Angle Mapper (SAM) Classification algorithm is used. This classification method is a supervised classification technique, which uses field derived spectral endmembers (Kruse et al., 1993). The SAM classification algorithm results in a continuous land cover map.

3.4 Processing the thermal DAIS bands

The TIR spectrometer on the DAIS scanner measures the radiant temperature, radiated from objects on the earth surface. The unit of the thermal DAIS bands is given in radiance in [mW/(cm*ster*µm)^2]. In order to study the thermal properties and behaviour of surfaces in the study area, the radiance was converted to absolute temperature in degrees Celsius of the various land cover types in two steps: the radiant temperature is converted to blackbody temperatures and next, the blackbody temperature is converted to absolute temperatures.

In order to obtain a blackbody image from the six thermal DAIS bands of the 1998 DAIS flight, an empirical approach is applied. The following steps are taken:

1. Minimum Noise Fraction transformation: In order to remove image noise from the six thermal bands, the MNF transformation was used. Four MNF bands are of good quality, these bands are used for the inverse MNF transformation.
2. Field reference data into blackbody temperature: In order to recalculate the thermal DAIS bands to a temperature map in degrees Celsius, field measurements are used. During the 1998 DAIS over flight, temperature measurements were taken of all land cover types. The measurements were taken with a radiant thermometer. This radiant thermometer measures the radiant temperature in degrees Celsius in the atmospheric window between 8 and 14 µm. During the measurements, an emissivity of 1 was applied. The resulting blackbody temperatures are shown in table 2.

Field measurements	Blackbody Temperature °C
Water (Lac Vailhan)	24.2
Bare soil (parcel 15)	43.2
Maquis	30.5
Grassland (parcel 45)	34.7
Grassland (parcel 111)	42.1
Garrigue	32.6
Asphalt (crossing Dam)	51.6
Pine forest	27.4

Table 2: Field measurements of the average blackbody temperature in the 8-14 µm atmospheric window

3. Calculation of mean radiance temperature in the 8 - 14 µm region: In order to compare the field measurements with the radiant temperature in the DAIS image, the mean radiant temperature of the six thermal bands has to be calculated. In this way, the information content of the six thermal bands is being reduced to one radiant temperature band.
4. Empirical Line correction: With the previous data it is now possible to calculate a linear regression function. The empirical line function calculates a mathematical function between the field temperature measurements and the thermal DAIS data at the same location with a satisfying correlation (R^2=0.92). The resulting map is an image containing for each pixel the blackbody temperature in degrees Celsius.

To convert the blackbody temperatures into absolute temperatures, emissivity data are required. In the Peyne area, there is a large variation in land cover types and hence, a large variance of emissivity values. Therefore, it is not correct to apply a method such as the reference channel method, as this method assumes a constant emissivity in the reference channel. This emissivity value is an average value for silicate rocks and not applicable for the Peyne situation.

An alternative approach for emissivity correction is applied in this study. The unique combination of optical- and thermal bands with the same resolution in the DAIS scanner allows us to use the information content of the optical bands for correction of the thermal bands. The optical DAIS bands are used to classify land cover (paragraph 3.3). Next, the resulting land cover map is used for converting the blackbody temperature map to an absolute temperature map by assigning to each land cover type the corresponding emissivity value. These emissivity values are derived from laboratory and field emissivity measurements by Rubio et al., (1997). Table 3 shows the emissivity value for each land cover type:

Land cover type	Emissivity	Comment
Water (Lac Vailhan)	0.990	
Maquis	0.986	Mean of several deciduous trees
Garrigue	0.984	Mean of dry grassland, rosemary and juniper
Pine forest	0.982	
Vineyard	0.995	
Grassland	0.990	
Bare soil	0.954	Calcareous soil
Buildings (Neffies)	0.950	Mean of clay and limestone

Table 3: emissivity values of the different land cover types, derived from Rubio et al.(1997).

Next, the absolute temperature is calculated by multiplying the blackbody temperature with the emissivity. This map is used for further study of temperature differences and processes within the study area.

4 STATISTIC AND GEOSTASTIC ANALYSIS

4.1 Statistical analysis of the survey data

One of the objectives of this study is to gain insight in the spatial distribution of surface temperature in the area and whether significant differences exist between the surface temperatures of the land cover types. This question can be answered with the temperature data derived from the DAIS image. For each land cover type, the surface temperature is derived by digitizing polygons on the DAIS thermal image and sampling the temperature values. These temperature values and their statistical properties are then analysed. Figure 2 displays the difference in mean temperature per land cover type.

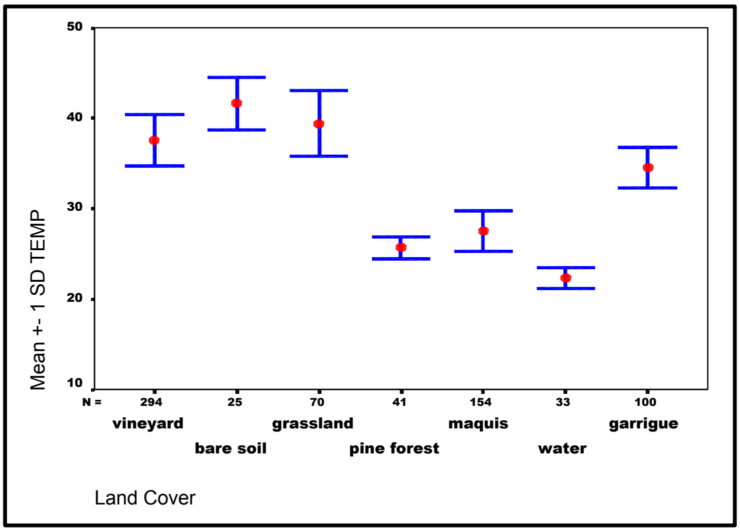

Figure 2: Average temperatures and standard deviations for each land cover type (derived from DAIS).

4.2 Geostatistical analysis of the field data

The three measured soil parameters: soil moisture content, porosity and bulk density are input parameters for the surface temperature model. The purpose of this model is to gain information on the spatial distribution of the surface temperature in time. In order to calculate the spatial distribution, continues maps of the soil parameters are required. These continues maps are derived by interpolation of the point samples with the conditional simulation interpolation technique. The main advantages of this technique are that insight in the prediction variance for each pixel (spatial) is obtained, as well as insight in the model's response to the input range.

For each of the variables, two variograms have been computed: one variogram for the cultivated (southern) area and the other for the uncultivated (northern) area. Exactly 500 realisations have been computed with the conditional simulation technique. Resulting maps of the mean value and the standard deviation for soil moisture content are given in figure 3. The mean gives a good impression of the spatial distribution of the variable under consideration. The standard deviation gives an impression of the range of possible results.

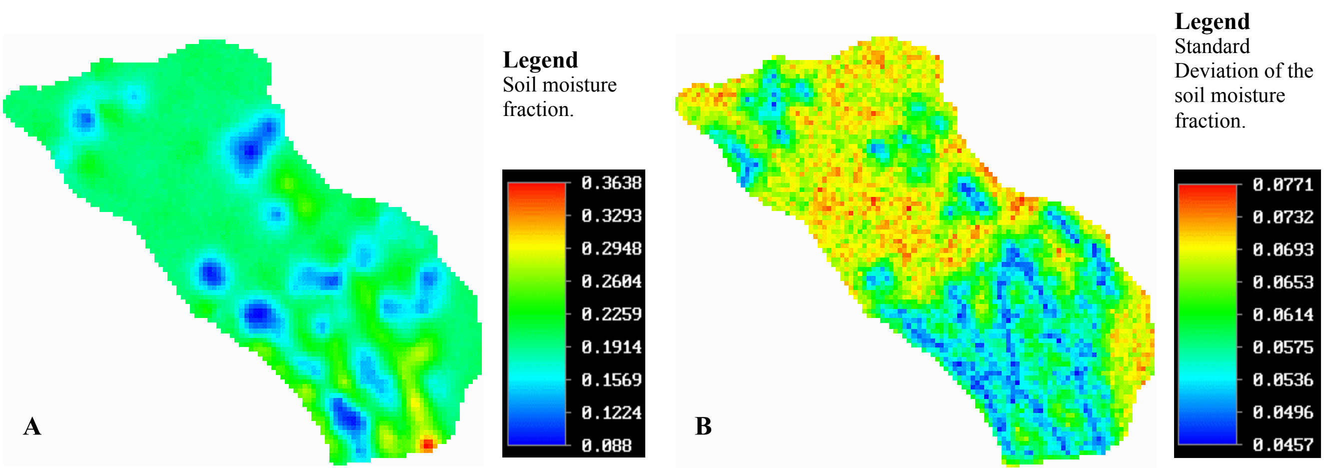

Figure 3: Regional distribution of **A** soil moisture content and **B** standard deviation of the soil moisture content

5 THE SURFACE TEMPERATURE MODEL

5.1 Model description

In this study, a regional model for surface temperature prediction on a sub-catchment scale is built. Most surface temperature models however, can only be applied on a point- or small plot scale (Berge, 1986). To apply a surface temperature model at a regional scale, the spatial distribution of the input variables must be known i.e. the input variables used are maps. The input data used here are field measurements and data derived from the DAIS imagery. For additional information and data such as constants and resistance values, the following sources are used: Campbell (1985), Feddes et al. (1978), Météo France (1998) and Ward & Robinson (1990). The physical basis of the model used here is the 'coupled soil moisture and surface temperature prediction model described by Ács et al. (1991). The model describes the energy balance of the surface as:

$$\frac{\delta T_g}{\delta t} = \frac{F(T_g)}{C_1} \tag{1}$$

T_g = surface temperature [^oK]
t = time [600 sec. = 10 min.]
$F(T_g)$ = function of surface energy balance components [W m^{-2}]
C_1 = bulk heat capacity per unit area [J m^{-2} K^{-1}]

Where $F(T_g)$ is the function of the surface energy balance components:

$$F(T_g) = S - R(T_g) - LE(T_g) - H(T_g) - G(T_g) \tag{2}$$

S = shortwave radiation balance [W m^{-2}]
$R(T_g)$ = longwave radiation balance [W m^{-2}]
$LE(T_g)$ = latent heat flux [W m^{-2}]
$H(T_g)$ = sensible heat flux [W m^{-2}]
$G(T_g)$ = heat flux into the soil [W m^{-2}]

In both equations 1 and 2, several components depend on the surface temperature. Consequently, to initialise the model, a regional surface temperature map must be available. In this study, the temperature map derived from the DAIS images is used as input map. As a result, the model starts at the time and date of DAIS image acquisition.

5.2 Model results

A sensitivity analysis of the model revealed that the vegetation type is the most important variable in determining the surface temperature. This is confirmed by the high correlation between surface temperature and NDVI. The Root-mean-square factor of this correlation is 0.76. An other important factor controlling the modelled surface temperatures is the variation of the stomatal- and surface resistance values. These values are necessary for the calculation of the latent heat fluxes. The resistance values were taken from literature (Ward & Robinson, 1990) but the original values seemed to underestimate the resistance. Therefore, the stomatal- and surface resistance values for these mediterranean sclerophyllous vegetation types were slightly enlarged.

The model is calibrated with the two sets of radiant temperature measurements. The first set consists of radiant temperature measurements of all landcover units, collected in the field. These measurements were taken at the moment the DAIS flight took place. This set is used to calibrate the average of the surface temperature curve, computed by the model. A second model calibration is performed with a temperature timeseries of 12 hours. When comparing the two surface temperature curves, it appears that the temperature extremes computed by the model are larger than the maxima measured in the field. There are some possible causes for this difference. The first one is the time gap between the model and measurement data. An other possible cause for differences, is that the measurements represent only one spot of bare soil, while the model results are the average of all the bare soil temperatures in the study area. After calibration, the model gives a fairly good average estimate of a 48 hour surface temperature cycle of the study area. The resulting temperature curves for the different landcover types are shown in figure 4.

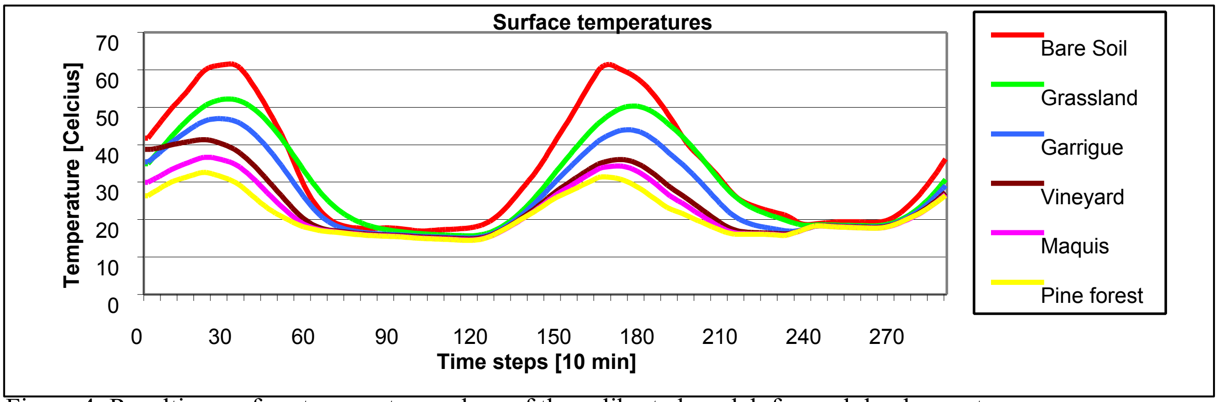

Figure 4: Resulting surface temperature values of the calibrated model, for each landcover type

The regional distribution of the surface temperatures is mainly the result of differences in landcover. Bare soils have higher surface temperatures then vegetated areas. An other factor controlling the regional temperature distribution, is the slope aspect. Slopes facing the north, receive less sunlight, and are consequently colder (figure 5).

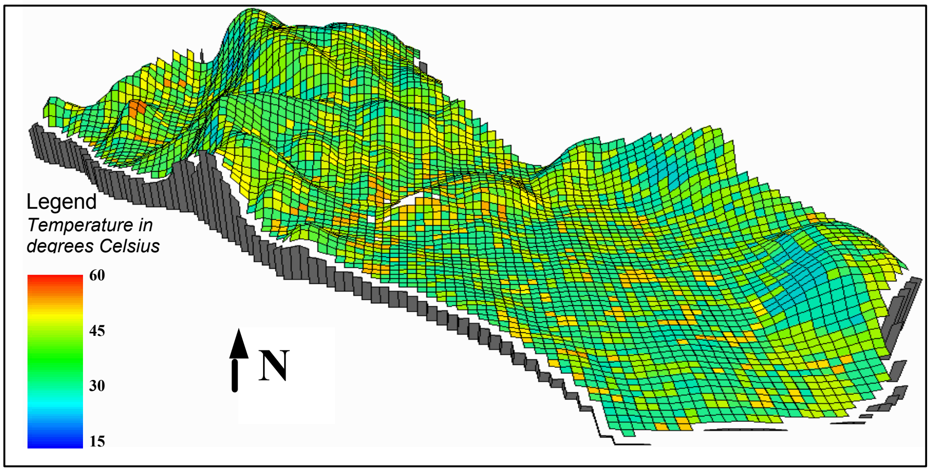

Figure 5: calibrated model surface temperature result of the study area at 29-06-1998 at 12:00

6 DISCUSSION AND CONCLUSIONS

In this study optical and thermal images acquired by DAIS during the Peyne experiment are integrated and used to run, validate and calibrate a regional simulation model of surface temperature. Additional model input and validation information is derived from field surveys and from literature. DAIS image analysis shows that image quality was acceptable in visible and near infrared wavelengths but that striping in the shortwave infrared bands hampers the use of this spectral part. Empirical line methods were successfully applied to convert radiance data of the optical and thermal bands into reflectance and surface temperature respectively.

All surveyed landcover types differ significantly of each other regarding their surface temperatures. From the model and survey results, it is concluded that vegetation cover is the major factor controlling surface temperature. Interpolation of the soil properties (soil moisture content, porosity and bulk density) is achieved by applying geostatistical interpolation techniques. The computed variograms of field data are of satisfactory quality. The interpolation technique used is conditional simulation and the resulting maps give insight in the spatial distribution of data uncertainty. The uncertainty of the interpolated maps are within an acceptable range for running the spatial version of the model. The three resulting maps are used as input in the surface temperature model.

The model used for predicting surface temperature is a physically based model using the surface energy balance for calculating surface temperatures at a regional scale. The model collects input variables from the DAIS imagery, meteorological data, field measurements and literature. The model is most sensitive to land use and the resistance values, used in calculation of the latent heat flux. Preliminary model results show that the model gives a fairly good average estimate of a 48 hour surface temperature cycle of the study area.

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