Regionalization of evapotranspiration modelling using multitemporal spectral unmixing of NOAA/AVHRR data

ULRICH STRASSER, STEPHAN SCHÄDLICH, STEFAN TASCHNER & WOLFRAM MAUSER
Institute for Geography, Department of Geography and Geographical Remote Sensing, University of Munich, Luisenstrasse 37, D-80333 Munich, Germany
e-mail: u.strasser@iggf.geo.uni-muenchen.de

Abstract A regionalization concept is presented which compares results from actual evapotranspiration (*aET*) rates modelled hourly, using the physically based SVAT-model PROMET for a test site with both microscale and mesoscale input data sets. In our approach the model structure does not change but different data sets and methods are used to gain the input parameters for the two scales. Land use information is derived by classification of LANDSAT-TM data for the microscale (resolution 30 m) and unmixing of a time series of NOAA/AVHRR data for the mesoscale (resolution 500 m). The difference in the modelled *aET* rates is 6%. The concept developed in southern Bavaria is then applied to the mesoscale target area of the Weser drainage (resolution 1000 m) to prove its transferability.

INTRODUCTION

PROMET (Mauser & Schädlich, 1998) is a process-oriented multiscale evapotranspiration model consisting of a physical soil-vegetation-atmosphere transfer (SVAT-) kernel model and a spatial raster-GIS modeller. The kernel model is based on the Penman-Monteith equation (Monteith, 1965), a plant physiological submodel considering the influence of environmental parameters on canopy resistance (modified after Baldocchi *et al.*, 1987) and a soil water submodel (Eagleson, 1978). During the winter period the snow water equivalent is modelled by a snow submodel (modified after Todini, 1996). With this model a regionalization concept to calculate hourly *aET* rates is developed for the test site (100 km^2) and then applied to the target area of the Weser drainage basin (37 500 km^2).

CONCEPT OF REGIONALIZATION

The Penman-Monteith equation is a scale independent physical description of the evapotranspiration process for a large variety of environmental conditions. Assuming that lateral fluxes can be neglected, PROMET can be used for all scales. A unique set of input parameters describing the land surface can be given for each homogeneous vegetation-soil combination. This leads to a spatial representation of homogeneous pixels for the microscale (resolution 30 m, coverage ~100 km^2). For the mesoscale (resolution 500 and 1000 m, coverage ~10 000 km^2 and ~37 500 km^2) this is not valid because pixels in Central Europe consist of a mixture of vegetation-soil entities. Usually upscaling and regionalization are achieved by the derivation of representative elementary areas, introduction of effective parameters, similarity analysis or aggregation (Kalma & Sivapalan, 1995). In PROMET, regionalization is performed by a scale dependent pre-processing of the input data sets (Table 1). For the microscale, pixels are assumed to be homogeneous. This means that there is only one combination of land use, soil type and topo-class (elevation/slope/aspect) per pixel. For the mesoscale, pixels can be heterogeneous concerning their land use. The *aET* for a pixel is calculated by summing up the weighted *aET*s of the different combinations of land use with the soil and topo-class of the pixel.

Table 1 Scale dependent derivation of input parameters in PROMET.

Input parameter	Microscale ($100\ km^2$)	Mesoscale: Southern Bavaria ($10\ 000\ km^2$)	Weser catchment ($37\ 344\ km^2$)
Digital Elevation Model	Resolution 30 m	Resolution 500 m	Resolution 1000 m
Soil texture distribution	Digitized map 1:5000	Digitized map 1:500 000	Digitized map 1:1 million
Land use (seasonal)	LANDSAT-TM classification	NOAA/AVHRR unmixing	NOAA/AVHRR unmixing
Meteorology (hourly)	One meteorological station	One meteorological station	Interpolated meteorological fields (64 stations)

THE STUDY AREAS

The test site for the comparison of the model calculations for the micro and mesoscale is located in the Bavarian Alpine Forelands. The land use of this area is grassland (46%), forest (18%), settlements (11%), agriculture (12%) and other (13%). Field sizes vary between 1 and 2 ha and the soils mainly consist of loam (58%) and loamy sand (27%). The annual rainfall is ~1000 mm. The target area for the application of the developed regionalization concept for the mesoscale is the Weser drainage basin with the German uplands in the south and the North German lowlands in the north. Its climate is characterized by moderate temperatures and a mean annual precipitation of ~750 mm. The land use is forest (35%), agriculture (35%), grassland (18%) and settlements (12%). Fields are of a medium size (up to 50 ha). The soils consist of loamy sand (36%), loam (24%) and sand (22%).

MULTITEMPORAL SPECTRAL UNMIXING

The images of NOAA/AVHRR satellites with their daily coverage of large areas are used for the derivation of land use information for the mesoscale. NOAA/AVHRR produces time series of 4 to 6 images per day in 4 to 5 reflective bands. The resulting data set consists of a multitemporal reflection profile of each pixel of the land surface. This expresses the different temporal developments of the land use during the vegetation period.

A multitemporal spectral unmixing procedure is applied to determine the fraction of each land use category in each pixel. Linear unmixing is based on the assumption that the spectrum of the reflected solar radiation from a surface is linearly composed of the weighted spectra of its components ("endmembers"):

$$R_{mix,b} = \sum_{em=1}^{n} \left(F_{em} \cdot R_{em,b}\right) + \varepsilon_b \tag{1}$$

where $R_{mix,b}$ is the spectral pixel reflectance in band b, $R_{em,b}$ is the spectral reflectance of the endmember in band b, F_{em} its fraction, n the number of endmembers and ε_b the error term for band b. Thereby the weight of each endmember spectrum is its fractional surface area. The boundary condition is:

$$\sum_{em=1}^{n} F_{em} = 1 \tag{2}$$

The resulting linear equation system is solved by fitting the modelled to the measured spectrum through altering the area weights until the minimum *r.m.s. error* is found. The *r.m.s. error* is:

$$r.m.s.\,error = \sqrt{\frac{\sum_{j=1}^{n} \left(R_j - R_{j*}\right)^2}{n}} \tag{3}$$

where R_j is the calculated and R_{j*} is the measured spectral pixel reflectance in band j. The linear equation system can be solved unambiguously if the number of endmembers does not surpass the number of bands plus one. If the endmember spectra are known, the unmixing procedure calculates the percentage of each land use category in a pixel.

Before unmixing the NOAA/AVHRR data set was calibrated, geometrically corrected and appropriate endmembers chosen from homogeneous areas identified from ground truth campaigns. To achieve an even weighting of all bands they were standardized before the unmixing calculation.

Under mid-European meteorological conditions AVHRR images are almost never cloudfree for large areas. Therefore a cloud mask based on thresholds was implemented in the procedure.

The unmixing was carried out in the test area (with 4 endmembers) as well as in the target area (with 5 endmembers). Fractions with negative percentages or such greater than 100% occurred in the unmixing results. They were standardized to a sum of 100%, ensuring that the correction is distributed to all endmembers and the boundary condition (equation (2)) is not violated.

The validation of the unmixing results was carried out by comparison with LANDSAT-TM classifications (Mauser & Schädlich, 1998; Strasser & Mauser, 1997). The average derivation of the areal fractions in the two images is 5.8%. This shows that the method presented to derive land use data for mesoscale areas works adequately in different geographical regions.

The results (Fig. 1) for the Weser drainage basin show the predominant agricultural (cereals and root crop) land use in the northern centre of the drainage

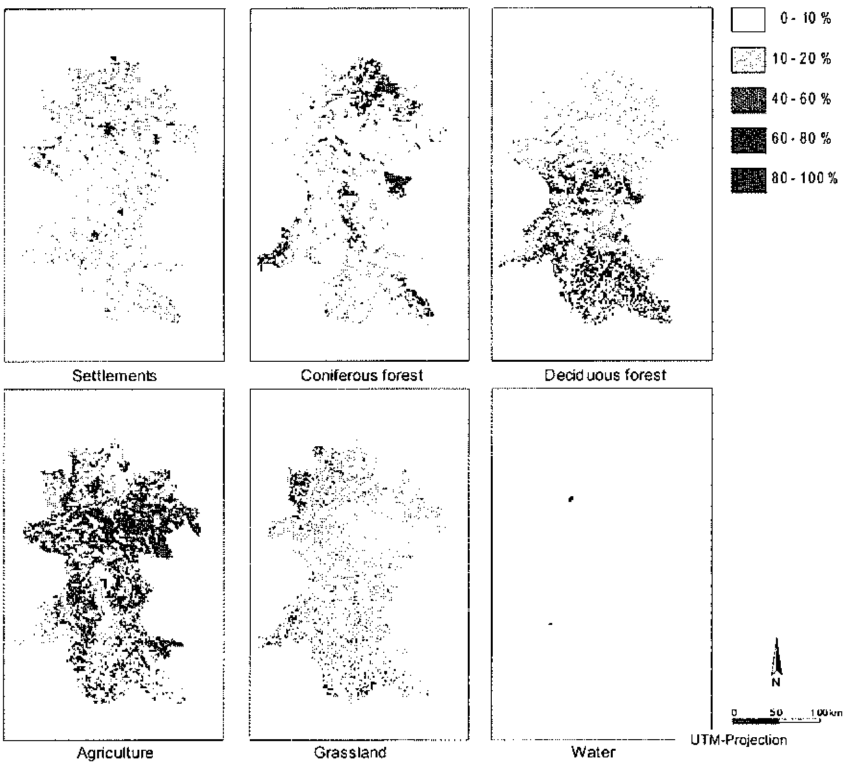

Fig. 1 Result of the multitemporal spectral unmixing of NOAA/AVHRR data for the target area (Weser drainage basin). Resolution is 1000 m.

basin. Grassland, however, is concentrated in the northwestern corner (marshes). In the southern part extensive deciduous forests can be found, whereas the coniferous forests are mostly located in the eastern uplands (Harz mountains) and the Lüneburger Heide in the north. Large settlements (Hannover, Braunschweig, Kassel) appear as dark pixel agglomerations in the settlement layer.

RESULTS AND VALIDATION

The verification of the results modelled with PROMET was carried out by regression analysis between the model results and Bowen-Ratio-measurements for different land use types and showed good correlation coefficients (Schädlich & Mauser, 1996). For the comparison of the model results at the microscale test site with spatial input data sets at micro and mesoscale resolution, cumulative spatial *aET* rates were calculated for April–October 1993 (Fig. 2). In both cases meteorological data were taken from the German Weather Service station Raisting. On the left side of Fig. 2, the land use information from a LANDSAT-TM classification (9 landcover categories) and special soil survey were used, on the right side the unmixed NOAA/AVHRR data (5 landcover categories) and the Bavarian soil map were used. The spatial pattern of the *aET* distributions, mainly caused by the different land use types, is similar. The small *aET*

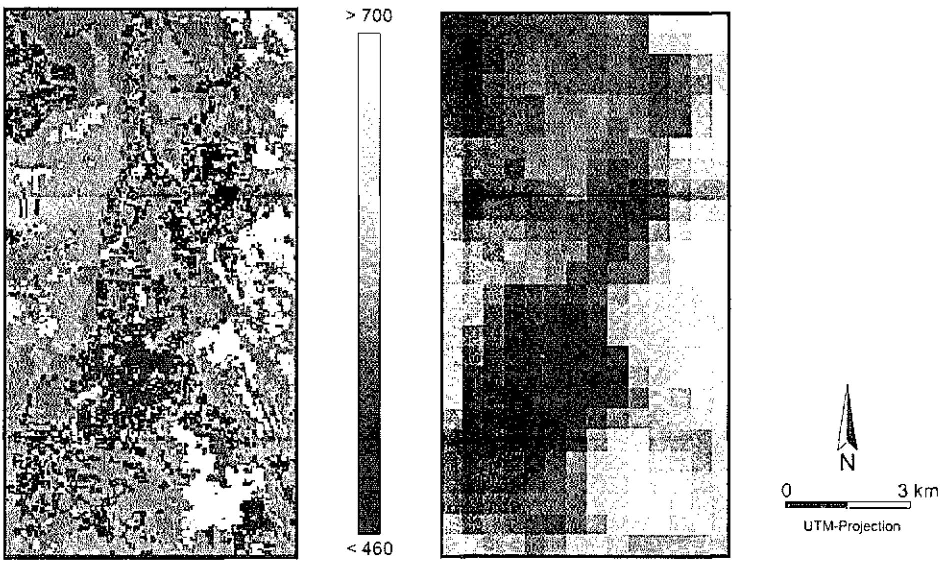

Fig. 2 Modelled *aET* for the test site April–October 1993 with microscale (left, resolution 30 m) and mesoscale (right, resolution 500 m) input data (mm/season).

rates around the city of Weilheim and the high *aET* rates of the forests can be seen in both images. The mean areal sum of *aET* rates calculated with the microscale input data is 622 mm, the one calculated with the mesoscale input data, 584 mm. This leads to a difference of 38 mm or 6%.

For the target area of the Weser drainage basin the spatial distribution of hourly *aET* rates was calculated for the year 1994. The accumulated spatial *aET* distribution (Fig. 3) shows a pattern mainly influenced by topography and vegetation: the lowest accumulated *aET* (<200 mm) can be found in the cities and lower regions of the area, the highest (>650 mm), in the upper regions where the forests are situated and the precipitation reaches its relative maximum.

The modelled water balance for the target area is compared with measured discharges at the drainage basin's gauge. The spatial mean of the accumulated *aET* for the considered year and the entire Weser drainage basin (Fig. 3) is 560 mm, the interpolated rainfall 869 mm. This results in a runoff of 309 mm. The mean annual runoff measured at the Intschede gauge for the period 1951–1970 is 294 mm (Keller, 1979). The difference is 15 mm or 5%. This leads to the conclusion that the methods developed can be transferred to different regions and still prove their validity. In the future a year-per-year validation between modelled and measured discharges will be performed for a 34 year meteorological time series to further quantify the validation results.

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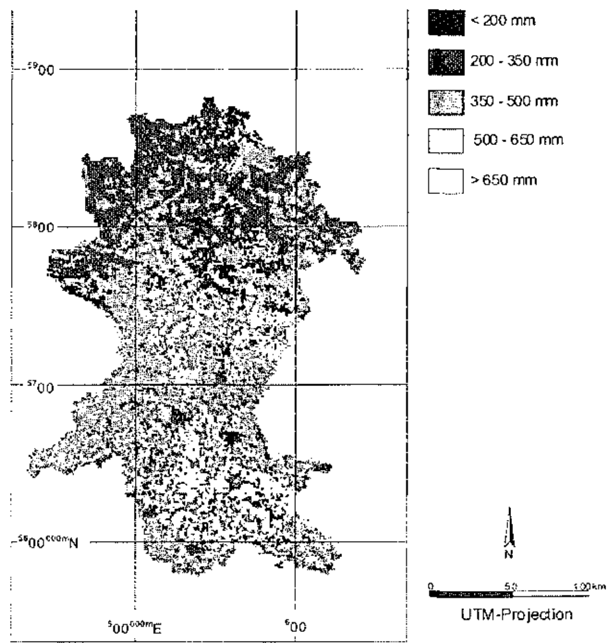

Fig. 3 Aggregated modelled hourly *aET* 1994 for the target area (Weser drainage basin). Resolution is 1000 m.

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