The Scaling-up of Processes in the Heterogeneous Landscape of HEIFE with the Aid of Satellite Remote Sensing

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Abstract

To improve understanding of the processes of land surface-atmosphere interaction at a scale of $10^4$ km$^2$ in HEIFE, the utilization of satellite remote sensing is indispensable. Landsat TM observation, because of its high spatial resolution, can be compared directly with surface measurements and be used for this purpose. The relevant data set as well as a state-of-the-art data processing methodology are discussed. A summer scene of TM was used to produce a set of maps of surface albedo, vegetation index, surface temperature, net radiation and other basic energy balance components of the whole area. Statistical analysis based on these maps revealed some quantitative significant land surface parameters. Future developments were discussed.

1. Introduction

A Hydrological and Atmospheric Pilot Experiment (HAPEX) on arid land surface processes, the HEIFE, has been carried out in an inland river basin of Northwest China. The experimental region, about 70×90 km$^2$, covers complex land surface conditions with mainly a large area of Gobi and sand desert and various scales of oasis dispersed along the river and irrigation canals. At different landscapes, five basic comprehensive stations, five automatic weather stations, as well as some conventional meteorological and hydrological stations have been operated successfully for more than two years; a large amount of data of surface observations have been collected. Some interesting detail studies concerning the interaction between soil, vegetation and atmosphere as well as e.g. cloud-aerosol processes have been reported. However, to reach the goal of a better understanding of land surface processes to a degree that they can be represented better in the atmospheric global circulation models (GCM), the aggregation or scaling-up of the individual results to a basin scale of $10^4$ km$^2$ is inevitable. An approach is to operate mesoscale models. But the operation of a successful model still needs a better data base. It is insufficient to use a data base only from surface stations distributed yet too sparsely, as in HEIFE area. Besides, techniques to verify the areal mean energy and water balance predicted by mesoscale models have still to be developed.

Remote sensing measurements from satellites are suitable to amend some parameters that are needed to interpolate between measuring sites or to extrapolate to larger areas. The utilization of satellite remote sensing has made remarkable progress in last decade, due to the progress of processing techniques as well as the progress in the study of land surface processes, including a synthetic collection of ground-truth data. The First International Satellite Land Surface Climatology Project
(ISLSCP) Field Experiment (FIFE) carried out in 1987–1989 aimed to investigate the use of satellite remote observations for inferring climatologically significant land surface parameters. All the available data provided by the GOES, NOAA series, Landsat, SPOT, and Kosmos satellites were captured. Remote sensing algorithms were also developed and evaluated (Sellers et al., 1992). During a hydrological study in North Africa (Menenti et al., 1991) and the European Field Experiment in a Desertification-threatened Area (EFEDA) (Bolle et al., 1993), Landsat Thematic Mapper data and NASA Thematic Mapper Simulator data were collected, respectively. A new Surface Energy Balance Algorithm for Land (SEBAL) was developed to use these space measurements combined with surface observations to obtain a quantitative evaluation of surface parameters and surface energy budgets (Bastiaanssen et al., 1994), which is going to step further in this study.

Landsat Thematic Mapper data at a specified site are limited to one day in sixteen. The advantage of using TM data is its higher spatial resolution to permit comparison with surface flux station measurements after some manipulation. Several scenes of Landsat TM, which corresponding to different vegetation status in the operation period of HEIFE, were collected for the present study. The field observations and processes studied at different stations would function as ground-truth for the satellite observations, particularly hemispherical reflectance, surface roughness, and soil moisture. Then, the surface albedo, vegetation index, surface temperature, as well as instantaneous components of energy budget are to be evaluated on a pixel-by-pixel basis that cover the total study area of the Heihe River basin. Areal-mean values and some statistical estimation of specific parameters are to be obtained by corresponding distribution maps.

2. Data and objective

Landsat Thematic Mapper provides spectral information in 7 narrow bands, with a spatial resolution about 28.5 × 28.5 m² for 3 visible bands (Band-1, -2, -3) and 3 near infrared bands (Band-4, -5, -7) and 120 × 120 m² for the thermal infrared band-6. A composite image of TM Band 4, 5, and 3 (RGB) at 10:00 July 9, 1991 over the HEIFE area is displayed in Fig. 1a. An unsupervised classification of the land use status has been done and compared with surface investigations. Except the Southwest (lower left) mountainous areas where the Heihe River flows down, there are two dominant categories: sand or Gobi desert (including low hilly land, some parts with sparse vegetation), and oasis (red color in Fig. 1a), about 60 % and 24 % of the total area, respectively.

The most relevant data, collected at HEIFE surface stations to support the regionalization of the energy and water balance and the analysis of TM images, consisted of surface radiation budget components, surface radiation temperature, surface reflectance, vertical profiles of air temperature, humidity, and wind speed, turbulent fluxes measured by eddy-correlation technique, soil heat flux, soil temperature and moisture profiles, and the vegetation state, etc.

The objectives of this study are (1) to map out pixelwise the land surface characteristic parameters such as albedo and the energy budget components over the whole area of the Heihe River basin; (2) to assess the ability of bridging the gap between local patch scale and large length scale for heterogeneous land surface with the aid of satellite observations. Later, when more satellite data are collected, the seasonal variation of surface characteristics will be determined. It is also aimed to examine and improve the processing algorithm upon a newer and better data set.

3. Determination of surface albedo and surface temperature

Surface albedo, vegetation index, and surface temperature are parameters that can be derived rather directly from Landsat TM spectral information. The integrated hemispherical planetary albedo, \( r_p \), can be derived pixelwise by a weighted sum of the spectral reflectance of all bands in the visible and near-infrared region.

\[
\begin{align*}
  r_p &= \int_{0.3}^{3.0} r_p(\lambda) d\lambda = \sum_i c(b_i) r_p(b_i) \\
  & (i = 1, 2, 3, 4, 5, 7),
\end{align*}
\]

where \( r_p(\lambda) \) is spectral hemispherical planetary albedo at wavelength \( \lambda \), \( c(b_i) \) is the weighting factors in Band \( i \),

\[
  r_p(b) = \frac{\pi K_{TOA}(b)}{K_{exo}(b) \cos \Phi_{sun}},
\]

where \( K_{TOA}(b) \) is the bi-directional spectral radiance at the sensor aperture of Thematic Mapper, \( d \) is the relative Earth-Sun distance, \( K_{exo}^{-1} \) is the mean in-band solar exo-atmosphere irradiance, and \( \Phi_{sun} \) is the solar zenith angle.

The integrated shortwave hemispherical surface albedo, \( r_0 \), at each pixel is determined with linear regression of \( r_p \) and the ground measurements of \( r_0 \) at HEIFE basic stations, can be written as follows

\[
  r_0 = a_1 r_p + b_1.
\]

In Fig. 2, a case in the HEIFE at 10:00 July 9, 1991, when the TM data set was acquired, is shown, which indicates \( a_1 = 1.526, b_1 = -0.065 \) (\( R = 0.95 \)). It is relatively easy to measure hemispherical surface
Fig. 1. (a) A composite image of Landsat TM Band-4 (R), -5 (G), and -3 (B) over the Heihe River Basin. (b) A geographic map of the same area as the Landsat image. The yellow part is oasis or irrigated farm and the meshed area is desert.

Fig. 6. Mapping of surface albedo of the HEIFE area.

Fig. 7. Mapping of NDVI of the HEIFE area.
albedo at the surface stations. When more surface measurements are available, this procedure of obtaining pixelwise $r_0$ from satellite measured $r_p$ is much easier in application than by means of measuring the bi-directional reflectance characteristics and atmospheric conditions to calculate $a_1$ and $b_1$ with radiation transfer models.

Band 6 (10.45–12.46 μm) of the Thematic Mapper covers part of the thermal infrared radiation, which is the radiance by a surface with temperature $T_0$ and a relative emissivity $\varepsilon_0$. As given by Planck’s function,

$$L(\lambda, T_0) = \varepsilon_0 \frac{2hc^2}{\lambda^5(e^{hc/k\lambda T_0} - 1)}, \quad (4)$$

where $L(\lambda, T_0)$ is the spectral radiance at wavelength $\lambda$ by a surface with physical temperature $T_0$, $c$ light speed, $h$ Planck constant, and $k$ being Boltzmann constant. In estimating surface temperature from satellite remote sensing, observed radiance must be corrected for atmospheric effects such as absorption, scattering etc., even in the atmospheric window. For the thermal infrared band radiance at the top of the atmosphere $L_{TOA}$ measured by Thematic Mapper, a radiation temperature, $T_{sat}$, can be derived from (5),

\begin{align*}
\text{(a)} \quad & \text{Mapping of surface temperature of the HEIFE area.} \\
\text{(b)} \quad & \text{The distribution map of } R_n \text{ in the HEIFE area.} \\
\text{(c)} \quad & \text{The distribution map of } H \text{ in the HEIFE area.} \\
\text{(d)} \quad & \text{The distribution map of } E \text{ in the HEIFE area.}
\end{align*}
C1

Tsat = \frac{c_1}{\ln(c_2/L_{LOA} + 1)}, \quad (5)

where \(c_1\) and \(c_2\) are constants. The upward longwave radiation measurements at different landscapes, a linear regression between \(L_{01}\) and \(L_{TOA}\), can be obtained as shown in Fig. 3,

\[L_{01} = a_2 L_{TOA} + b_2,\quad (6)\]

where \(a_2 = 1.67, b_2 = -410.6 \ (R = 0.98)\) for the same period as for Eq. (3). \(T_D\) can be derived pixel-wise if \(L_{01}\) is obtained for each pixel using Eq. (6).

Emissivity \(\varepsilon_0\) is said to be a logarithmic function of vegetation index NDVI (e.g. \(\varepsilon_0 = a_3 + b_3 \ln \text{NDVI}\), where \(a_3\) and \(b_3\) are constants which can be derived from TM spectral data of Band-4 and Band-3).

The accuracy of empirical relationship of (3) and (6) might be improved when measurements collected in different days of the similar surface vegetation state, or for extended use, in different climate and land surface, are merged in the regression analysis.

The surface albedo \(r_0\) is a dominant factor to determine the surface available radiative energy. The knowledge of \(r_0\) on a pixel-by-pixel basis provides a pattern of absorbed solar energy at the surface. The surface temperature \(T_0\) is a specific measure of the partition of surface available energy, and it reveals the dynamic equilibrium between incoming and outgoing energy flux, i.e. the equilibrium of interaction status of the upper soil and the adjacent atmospheric surface layer.

Moreover, many regression analyses between \(r_0\) and \(T_0\) have shown a systematic trend. The shape of the relationship between \(r_0\) and \(T_0\) as described in an experiment in Egypt (Menenti et al., 1991) and that from HEIFE (Fig. 4) shows similar relations. The most significant and physically meaningful feature is the slope of the relationship. The positive slope at low albedo, which corresponds to vegetated and wet surfaces, is controlled by evaporation. The negative slope at higher albedo, corresponding to dry surfaces with very limited evaporation, is by net radiation.

The relationship of between \(T_0\) and \(r_0\) implies an actual mechanism of land surface-atmosphere interaction; It could be used for the determination of e.g. sensible heat flux in the next step.

4. Surface energy balance

Surface energy balance in the atmospheric surface layer is normally written as:

\[Rn = G + H + \ell E\quad (7)\]

Where \(Rn\) is the net radiation; \(G\) is the soil heat flux; \(H\) and \(\ell E\) are sensible and latent heat flux, respectively. Introducing the aerodynamic resistance to heat transport, \(r_{ah}\), then,

\[H = \rho c_p (T_0 - T_a)/r_{ah},\quad (8)\]

where \(T_a\) is the air temperature at some reference level. Net radiation can be calculated by

\[Rn = (1 - r_0)K^1 + \varepsilon \sigma T_0^4 - \varepsilon \sigma T_0^4\quad (9)\]

on a pixel basis, where \(K^1\) is the downward shortwave solar radiation, which can be taken as a constant in the area, \(\varepsilon\) is apparent infrared emissivity of the atmosphere, \(\sigma\) Stefan-Boltzmann constant, \(T_0\) being normally not available pixelwise. As an approximation, downward longwave radiation could be taken as constant as the average of in-situ observations. Soil heat flux \(G\) can not be derived directly from remotely sensed data. However, \(G\) corresponds quite well with \(Rn\). An empirical relationship of \(G/Rn\) between \(T_0\) and \(r_0\) was formulated, which was based on an experiment in the Egyptian desert (Menenti et al., 1991) and may be applicable in the present situation,

\[G/Rn = T_0/r_0 \times (ar_0 + br_0^2) \times (1 - c(NDVI)^d), (10)\]

where \(a, b, c,\) and \(d\) are regression constants; NDVI is the Normalized Difference Vegetation Index. Latent heat flux is to be evaluated as a residue of Eq. (7) in present study.
Difficulties in the procedures above are mainly in the evaluation of sensible heat flux on a pixel basis. Applying the Monin-Obukhov similarity hypothesis as generally accepted, the aerodynamic resistance in (8) needs to be worked out in the terms
\[ r_{ah} = \frac{1}{k^2 u} \left( \ln \frac{z}{z_{om}} - \Psi_m \right) \left( \ln \frac{z}{z_{oh}} - \Psi_h \right), \quad (11) \]
where \( k \) is the von Karman constant, \( u \) the wind speed, \( z \) the height, where \( u \) and \( T_a \) were measured, \( z_{om} \) and \( z_{oh} \) being roughness lengths for momentum and heat, respectively. \( \Psi_m \) and \( \Psi_h \) are integrated flux-gradient functions for momentum and heat transport, respectively, that are functions of atmospheric stability \( z/L \). \( L \), the Monin-Obukhov length, is in turn a function of sensible heat \( H \) and the friction velocity \( u^* \),
\[ u^* = ku/\ln(z_{om}) \]
(see, e.g., Stull, 1988). So Eq. (8) can be considered as a function \( F \) which relates \( H \) to other variables,
\[ H = F(T_0, T_a, u, z_{om}, z_{oh}, L). \]
(13)
Eq. (13) could be applied if all variables on the right-hand side were known. This does not hold true when pixel-wise data on \( H \) are required.

To solve this difficulty based on the existing data base, in addition to applying some empirical relationships, new approaches should be introduced. Our major purpose is to formulate surface fluxes over large and heterogeneous areas in relation with the parameterization of land surface processes in GCMs. To model the surface processes on a large scale, one easier way is to scale-up or aggregate the areal flux by a weighted average of the contributions from different surface elements ('patches'), based on the principle of flux conservation. If the local-scale advection is comparatively small (this is not always true in HEIFE, see e.g. Wang et al., 1993) at the hour when TM observation took place, the development of convective boundary layer may adjust the surface-disorganized variability at a 'mixing height' where the atmospheric characteristics become approximately independent of horizontal position (as it would be over homogeneous terrain). The corresponding 'effective' surface parameters can be determined accordingly. This approach has proved to be successful to calculate areally-averaged surface fluxes in recent years (Lhomme et al., 1994).

In order to map a distribution of the aerodynamic resistance, \( r_{ah} \), Menenti et al. (1989) initiated the \( \partial H/\partial T_0 \) approach, which is used to find an area effective bulk resistance over complex terrain. Because of the existence of extremely dry and wet areas in the HEIFE region, it is advantageous to use this approach. From Eqs. (7) and (9) we have
\[ \frac{dr_0}{dT_0} = \frac{1}{K1} \left( \frac{\partial R_{nL}}{\partial T_0} - \frac{\partial G}{\partial T_0} - \frac{\partial H}{\partial T_0} - \frac{\partial \epsilon E}{\partial T_0} \right), \]
where \( R_{nL} \) is the net longwave radiation. At the dry land surfaces, where the slope of \( T_0 = f(r_0) \) becomes negative and \( \partial H/\partial T_0 \approx Q \partial H/\partial T_0 \) can be derived from (14) by knowing \( \partial R_{nL}/\partial T_0 \) and \( \partial G/\partial T_0 \) from the former steps. Then an effective aerodynamic resistance between surface and mixing height above dry land can be estimated as
\[ r_{ah} = \rho c_p / \frac{\partial H}{\partial T_0} \]
We also have \( H \) and \( Rn - G \) at the dry land surface. If the surface roughness data of \( z_{om} \) and \( z_{oh} \)
have been evaluated by measurements or estimated by empirical relations with NDVI (see e.g. Bastiaanssen et al., 1994), we may start from this point to get some other effective parameters such as $u_\ast - B$, $u_B$, stability functions $\Psi_m - B$ and $\Psi_h - B$ etc. by an iterative procedure as a first estimation of the area effective parameters (where the subscript $B$ means at the mixing height).

The second estimation of distributions of $u_\ast$, $\Psi_m$, $\Psi_h$, and $r_{ah}$, etc. can be done by a new iterative loop. To do so, it is deemed necessary to design a new procedure to obtain pixelwise values of air temperature $T_a$. $T_a$ is established by vertical fluxes of momentum and sensible heat; The horizontal gradient of $T_a$ is normally quite large, particularly in the atmospheric surface layer. However, it is found that there is approximately a linear relationship between $(T_0 - T_a)$ and $T_0$, as shown in Fig. 5 in the HEIFE case. To bear this in mind, a solution is found which is based on the physical extremes of the sensible heat flux at dry and wet patches. The upper bound of $H$ appears at a completely dry surface, where $\ell E \approx 0$, $T_0$ is regulated by $Rn$, and $(T_0 - T_a)$ reaches a maximum. The lower bound is at wet surfaces such as patches in an oasis or over a water surface, where $H \approx 0$ and $T_a \approx T_0$. A combination of these two estimates for $T_a$ at extremes of $H$ enables the description of the slope of $(T_0 - T_a)$ to $T_0$.

To reduce the unknown variable in Eq. (13), some simpler models may be used jointly. We know that Landsat TM and most satellite spectral data could not provide wind field information of the atmospheric boundary layer. Based on the observations of HEIFE stations and conventional weather stations, some wind field models e.g. the MASCON mass-consistent model (Dickerson, 1978) have been used successfully to obtain wind distribution maps at different levels of the HEIFE area, which is helpful to calculate the fluxes in the second iterative loop.

5. Mapping of surface albedo, NDVI, and surface temperature

As a case study, a summer scene (10:00 LST, July 9, 1991) of a Landsat TM image over the HEIFE area was investigated. Figure 6 shows the mapping of surface albedo of the experimental area based on 3300 by 3300 pixels with a size of 28.5 x 28.5 m$^2$ each obtained by the method shown in Section 3. The green parts, except the mountainous area in the southwest (lower-left), are mainly oasis areas consisting of crop field and small woods and rather wet soil, with a relatively low value of albedo, between 0.08 and 0.15; some darker (lower albedo) parts in the oasis shows the area just after irrigation. The yellow-orange-red areas, which form most of the map are mainly drier sand desert and Gobi with much higher albedo between 0.18 and 0.30. The albedo of yellow sand desert is around 0.18-0.20, while that for Gobi desert is about 0.20-0.30, because the surface configuration of 'Gobi' is quite different from place to place, particularly from south to north. The map of albedo is worked out with the combination of six TM bands, it is a most informative map to use for some investigations e.g. surface classification.

The histogram of albedo distribution (Fig. 9a) also shows a wide range of albedo change in the HEIFE area due to the strong contrast of surface status. It is seen that there are two peaks in the distribution, one around $r_0=0.13$ corresponds to oasis, another peak around $r_0=0.25$ corresponds to desert area. The areal-mean value of albedo is 0.20.

The presence of vegetation regulates to a wide extent energy and water exchange processes between the land surface and the atmosphere. The Normalized Difference Vegetation Index (NDVI=(Band4-Band3)/(Band4+Band3)) provides a good measure of surface green biomass on the characteristic of a low reflectance of plants in the red band (TM-
Band3) and a high reflectance in the near infrared band (TM-Band4). The resulted NDVI map of the Heihe area is shown in Fig. 7, and its histogram is shown in Fig. 9b. The NDVI for an oasis area ranges from 0.50 to 0.75; While that for desert area, even were there sparse vegetation, it would have no crucial meaning. NDVI value is mainly used in the estimation of $C$ and $s_0$ in the present study.

Surface temperature (Fig. 8) has a similar pattern to the albedo. The histogram of surface temperature distribution (Fig. 9c) also shows a very wide range. With an areal-mean value of 311 K, two peaks are more clear than in Fig. 9a. One is an oasis area with a surface temperature round 292 K (19°C); another is the desert area with a surface temperature round 320 K (47°C), some parts can be as high as 328 K (55°C). This is consistent with field observations.

Re-examining Fig. 4, the desert areas, with surface albedo larger than 0.22 and surface temperature higher than about 45°C, are ‘dry’ areas, where the slope between $r_0$ and $T_0$ is negative. On the other hand, oases and rather wet areas are ‘evaporation controlled’ land surface having a low albedo in combination with a low surface temperature, where the slope between $r_0$ and $T_0$ is positive in Fig. 4.

6. Estimation of the pixelwise land surface energy fluxes

A quantitative analysis of the energy fluxes in the surface layer can be made by the algorithm briefly mentioned above after the mapping of surface albedo, NDVI, and temperature. On the pixel-by-pixel basis, net radiation $R_n$, soil heat flux $G$, and sensible heat flux $H$ are mapped sequentially. Latent heat flux $\ell E$ (or water vapor flux $E$) is to be derived as $\ell E = R_n - G - H$.

Figure 10 shows the mapping of $R_n$. The maps for $G$, $H$, and $E$ show a similar pattern (see that for $H$ and $E$ in Fig. 11). Figure 12 gives the frequency distribution of the surface energy components. It is shown that all components, particularly $R_n$, $H$, and $E$, have a wide diversity because of the wide diversity of the surface conditions in the study area. The range for $R_n$ extends from 300 to 750, about

Table 1

<table>
<thead>
<tr>
<th>Time (BST)</th>
<th>Sensible Heat Flux</th>
<th>Latent Heat Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:45</td>
<td>78.1 w/m²</td>
<td>457.5 w/m²</td>
</tr>
<tr>
<td>10:43</td>
<td>80.8 w/m²</td>
<td>434.1 w/m²</td>
</tr>
<tr>
<td>11:44</td>
<td>64.2 w/m²</td>
<td>470.1 w/m²</td>
</tr>
</tbody>
</table>

Fig. 12. The frequency distribution of the surface energy components.
380 in Gobi desert to about 650 in oasis, with an areal mean of 474 and an SD of 140 (unit: W/m²). G is about 25 % of Rn in a desert area; while much lower values represent an area with higher leaf area index. The typical peaks of sensible heat flux also correspond to the dry desert area, where the peaks for E (around 500 W/m²) coincide with the higher evapotranspiration in an oasis. The areal-mean values for G, H, and E are 71, 214, and 205 (W/m²), respectively.

The estimated energy fluxes by the satellite data here are for 10 o'clock local time on July 9, 1991. Unfortunately, this Landsat observing day was not in the IOP of HEIFE, therefore the turbulent flux measurement was made only at one point, the Linze station in an oasis. The results of the turbulent fluxes at the Linze station at the same time as Landsat observation, 10:00 local time (11:00 BST) are as shown in Table 1. The comparison of these values with the pixel point values on the Landsat image is difficult when we consider mapping accuracy. The observed values are about 10 % above the lowest end of distribution of the satellite-derived sensible heat shown in Fig. 6c and 10 % below the highest end of latent heat flux shown in Fig. 6d. Since the area of the oasis is about 24 % of the total area, the observed values may be in the middle of the oasis data (low sensible heat flux and high latent heat fluxes). We can read almost the same values as observations from Fig. 11a for sensible heat flux and Fig. 11b for latent heat flux at the position of the Linze station (large star mark below the letter Z of Linze shown in Fig. 1b).

The results give us some hope to use this method in estimation of fluxes from satellite data.

7. Concluding remarks

To study land surface-atmosphere interaction on an areal scale (10⁴ km² or larger) and to have contributions to the improvement of meso- and large-scale atmospheric models, the utilization of satellite remote sensing combined with intensive surface observations is inevitable. Some new and Heihe River Basin-scale concepts have been obtained from the present study, which are mostly acceptable.

These estimates are all instantaneous, i.e. only a single set of values at a specific time of a specific day. The estimate of daily values can be done by using (1) field measurements; (2) numerical modelling; (3) methodology such as the concept of self-preservation in the diurnal evolution of the surface energy budget; (4) exploration of other satellite data such as the NOAA series and from geostationary satellites (Pelgnum, 1992). This will be done in the next step, based mainly on the presently available data.

This technique is still in a very preliminary stage: some mapped distributions, particularly heat fluxes, the accuracies are still questionable. Nevertheless, it would form a sound basis to study sub-basin-scale characteristics and regional average fluxes. It would be also a powerful tool in the parameterization and validation of meso-scale models over complex terrain. The HEIFE data base, because of its specific landscape and rather long period, will be advantageous to promote the development of the satellite remote sensing to an operational implementation stage.

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References


衛星リモートセンシングを用いたHEIFE領域における
諸過程のスケーリング・アップ

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高解像度ランドサットTMデータと地表面で観測されたデータとを比較して、HEIFE全領域における諸
過程の状況を推定する方法について考えてみた。また、そのケース、スタディーとして夏の期間にえられ
たTMデータより地表面のアルピード、植生指数（NDVI）、地表面温度、正味放射およびその基本的なエネ
ルギー・バランスの要素の分布をHEIFE全領域について求めた例を紹介する。

現時点ではこの方法はまだ初期段階であるが、いくつかの物理量については満足のいく結果が得られた。
しかし、この結果は特定の時間において得られたものにすぎず、また、熱のフラックス等の精度が十分で
ないなど、今後の改良すべき点について論じた。