Remote Sensing Parameterization of Regional Net Radiation over the Heterogeneous Land Surface of GAME-Tibet, HEIFE and AECMP'95

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1. Introduction

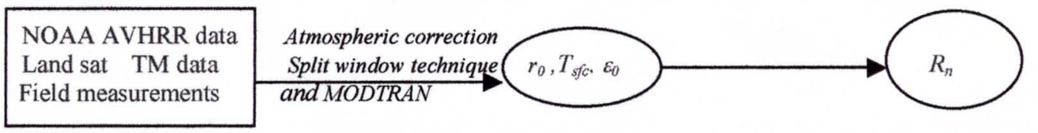
The regional distribution of net radiation plays a very important role in the exchange processes of water and heat on the land surface. So the observational study on net radiation is an important component in many land surface processes experiments, such as GEWEX Asian Monsoon Experiment on Tibetan Plateau (GAME/Tibet), the HEIhe basin Field Experiment (HEIFE) and Arid Environment Comprehensive Monitor Plan, 95 (AECMP'95). There have already been some initial studies in some stations reported based on these data sets. However, the investigation of the regional distribution of surface net radiation is not enough for the heterogeneous landscape of GAME/Tibet, HEIFE and AECMP'95 areas. The objectives of this study are estimating the regional distribution of surface albedo and surface temperature, appraising the regional distribution of net radiation over the areas of GAME/Tibet, HEIFE and AECMP'95 using the satellite remote sensing and field observations.

2. Satellite data and field observational data

Three NOAA-14 AVHRR scenes (15:43 BT, June 12, 1998; 14:21BT 16 July, 1998 and 14:25h BT, August 21, 1998) of the GAME/Tibet area, one Landsat TM scene of the HEIFE area (11:00BT, July 9 1991) and one Landsat TM scene of the AECMP'95 area (11:00BT, August 21 1995) were used in this study. All of the scenes were with clear day. The most relevant data, collected at the stations of GAME/Tibet, HEIFE and AECMP'95 to support the analysis of satellite images, consist of land surface albedo, surface temperature, surface radiation budget components, Tether-sonde data, radio-sonde data and the vegetation state, etc.

3. Theory and scheme

Using remote sensing data (*eg*. NOAA AVHRR data and Landsat TM data) and field observations can derive the surface net radiation flux densities over the heterogeneous landscape. The procedure is as



In other words, the regional net radiation can be derived from

$$R_n(x,y) = (1 - r_0(x,y)) \bullet K_\downarrow(x,y) + L_\downarrow(x,y) - \varepsilon_0(x,y)\sigma T_{sfc}{}^4(x,y) \ , \tag{1}$$

Where $r_0(x,y)$ is surface albedo, $\varepsilon_0(x,y)$ is surface emissivity, $T_{sfc}(x,y)$ is surface temperature, $K_\downarrow(x,y)$ is incoming short-wave radiation flux density and $L_\downarrow(x,y)$ is incoming long-wave radiation flux density. The surface emissivity of $\varepsilon_0(x,y)$ is a function of the vegetation coverage, it can be derived from the model of Valor and Caselles (1996). The incoming long-wave radiation flux density $L_\downarrow(x,y)$ can be derived from radiative transfer models such as MODTRAN directly. The incoming short-wave radiation flux density $K_\downarrow(x,y)$ in Eq. (1) can be derived from MODTRAN. It means that atmospheric short-wave transmittance τ_{sw} can be derived from MODTRAN directly. Hence $K_\downarrow(x,y)$ can be obtained as

$$K_\downarrow(x,y) = \tau_{sw} K^\downarrow{}_{TOA}(x,y) , \tag{2}$$

Where the regional variation of radiation flux density perpendicular to the top of atmosphere $K^{\downarrow}_{TOA}(x,y)$ is a spectrally integrated form of in-band radiation flux density perpendicular to the top of atmosphere $K^{\downarrow}_{TOA}(B)$. And

$$K^{\downarrow}{}_{TOA}(x,y)=\frac{K^{\downarrow}exo(b)\cos\theta_{sun}(x,y)}{d_s^{\ 2}} \quad , \tag{3}$$

Where $K^{\downarrow}_{exo}(b)$ is the mean in-band solar exo-atmospheric irradiance undisturbed by the atmosphere $\theta_{sun}=0^0$, d_s is the earth-sun distance, θ_{sun} sun zenith angle.

Surface albedo and surface temperature in Eq.(1) can be derived in different ways depend on the different remote sensing data. Using the NOAA AVHRR data, the surface albedo can be derived from the models of Paltridge and Mithchell(1990) and Valiebte et al (1995). Surface temperature $T_{sfc}(x,y)$ can be derived from split window technique (SWT) (Becker and Li,1990; Becker and Li, 1995;Sobrino *et al.* ,2000). The split window technique gives the surface temperature as a simple linear combination of the brightness temperatures T_i and T_j measured in two adjacent thermal infrared channels i and j, namely

$$T_{sfc}=A_0+A_1T_i+A_2T_j \, , \tag{4}$$

Where A_0, A_1 and A_2 are local coefficients which depend mainly on spectral emissivities of surface. The accuracy of surface temperature T_{sfc} retrieval is dependent on the correct choice of the coefficients A_0, A_1 and A_2 (Becker and Li, 1995). It means that the surface temperature derived from NOAA AVHRR can be determined as

$$T_{sfc}=F(T_4,T_5,\varepsilon_4,\varepsilon_5,W,\theta)\, , \tag{5}$$

Where T_4 and T_5 are the brightness temperatures of channel 4 and 5 of AVHRR, ε_4 and ε_5 the spectral emissivities of channel 4 and 5 respectively, W water vapor content, θ the view angle of satellite. Eq.(5) can be expressed by different algorithms(Becker and Li ,1995). Based on many case studies in Tibetan Plateau area, the surface temperature over this area can be determined as

$$T_{sfc}(x,y)=T_4(x,y)+1.56[T_4(x,y)-T_5(x,y)]\ +0.28[T_4(x,y)-T_5(x,y)]^2+(48-5W)(1-\varepsilon)\ . \tag{6}$$

Using the Landsat TM data, a four-stream radiative transfer assumption for atmospheric correction in solar spectral bands (Verhoef, 1997) is introduced to derived the surface albedo. Surface temperature $T_{sfc}(x,y)$ in Eq.(1) can be derived from Landsat TM thermal infrared band-6 (10.2-12.5 μm) spectral radiance. Because the 10.2-12.5 μm TM band is relatively transparent to radiation transfer in atmospheric layer under the cloud-free sky, the absorption in this band is smaller except under the turbid weather condition, the main substance of continuous absorption are water vapor and aerosol. The upward thermal radiance at wavelength λ passing through the local atmosphere layer is described by

$$\chi\frac{dL_\lambda}{d\delta}=L_\lambda-B_\lambda \quad , \tag{7}$$

Where δ is atmosphere optical thickness, $\chi=\cos\Theta$, Θ is the angle between normal of the horizon and radiative stream, and B_λ is black emitted radiance as given by Planck function

$$B_\lambda(T)=\frac{c_1}{\pi\lambda^5\left[\exp(\frac{c_2}{\lambda T})-1\right]}\, , \tag{8}$$

Where T is temperature, c_1 and c_2 are constants. There are following boundary condition for radiative transfer

$$\begin{cases} L_\lambda(\delta_0,\chi)=B_\lambda(T_{sfc}) & \delta=\delta_0 \\ L_\lambda(0,\chi)=0 & \delta=0 \end{cases} \, . \tag{9}$$

Then the upward radiance can be derived after integrating equation (6) as

$$L_\lambda(\delta,\chi)=L_\lambda(T_{sfc})e^{\frac{\delta-\delta_0}{\chi}}+\int_\delta^{\delta_0}B_\lambda[T(\delta')]e^{\frac{\delta'-\delta}{\chi}}\,d\delta\ , \tag{10}$$

Where $L_\lambda\ (T_{sfc})$ is upward radiance emitted from land surface, δ' atmospheric optical thickness at an arbitrary altitude, the satellite sensor detected radiance $L_S(x,y)$ for each pixel will be considered as two parts: contribution from land surface and from atmosphere layer

$$L_S(x,y)=\tau\ L_0(x,y)+S(x,y)\, , \tag{11}$$

Where $L_0(x,y)$ is emitted band radiance from the land surface, $S(x,y)$ band upward radiance at the top of atmosphere emitted from the atmospheric layer, and τ band average transmittance. $S(x,y)$ and τ can be derived from the simulation of MODTRAN model . Equation.(11) can be rewritten as

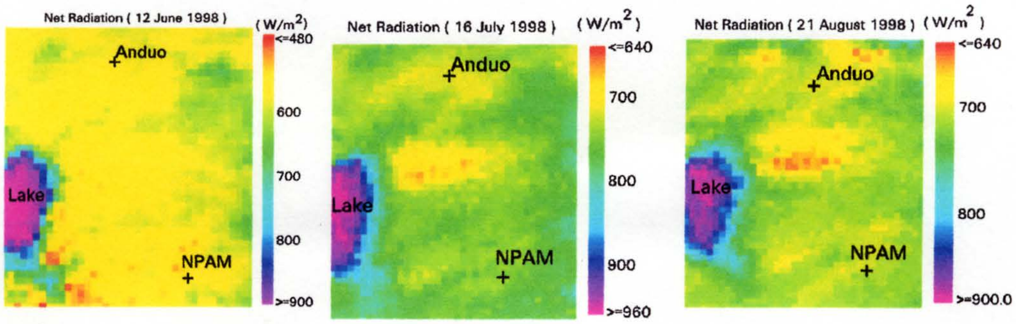
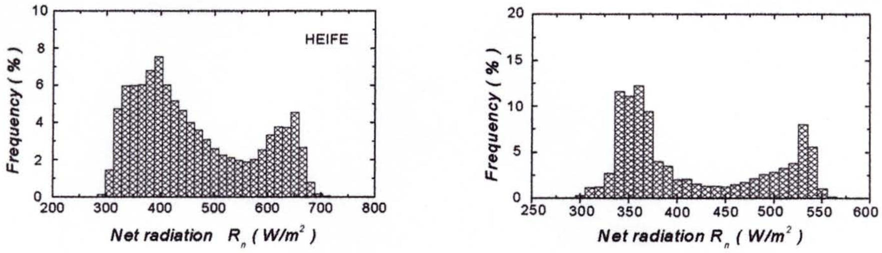


Fig.2 The distribution maps of net radiation flux densities in the GAME/Tibet area.



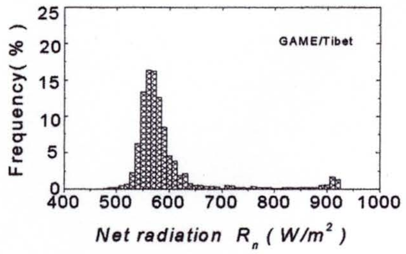


Fig.3 The frequency distributions of net radiation flux density in the areas of GAME/Tibet, HEIFE and AECMP'95

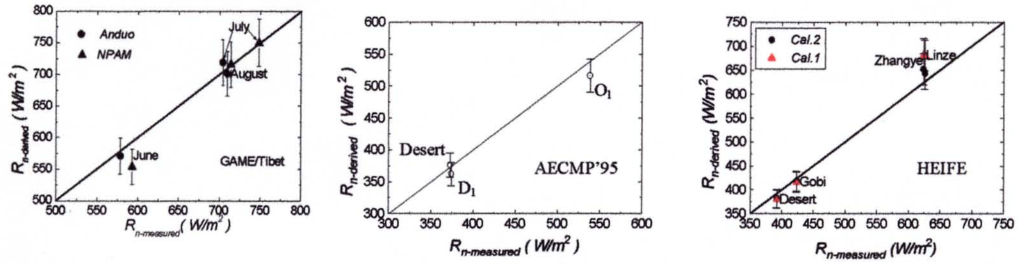


Fig.4 Validation of the derived results against the field measurements net radiation flux densities in the areas of GAME/Tibet, HEIFE and AECMP'95, together with 1:1 line.

corresponds to the Gobi desert area; For AECMP'95 area, one around R_n =540 W/m^2 corresponds to oasis, another peak R_n=360 W/m^2 corresponds to the Gobi desert. The net radiation in HEIFE area over the oasis (wheat) is higher than it in AECMP'95 (corn), the reason is that the surface albedo and surface temperature in AECMP'95 area is large than it in HEIFE area. (3) The distributions of net radiation in GAME/Tibet area have different values in different month. (4)The derived net radiation flux densities over three cases study area are very closed to the field measurements with *MAPD* being less than 5%.

5. Concluding remarks

The regional net radiation flux densities over the areas of GAME/Tibet, HEIFE and AECMP'95 have been obtained with the aid of remote sensing and field observation, which are mostly acceptable. It forms a sound basis to study the exchange processes of water and heat on the heterogeneous land surface.

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References (Omitted)