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Estimation and analysis of net primary Productivity of Ruoergai wetland in China for the recent 10 years based on remote sensing

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Abstract

Ruoergai wetland is the biggest plateau peat wetland in the world. It plays an important role in the ecological construction and environmental protection for the upper reaches of Yangtze and yellow river. Using remote sensing technology to monitor annual and inter-annual NPP change is the key to evaluate the health condition of ecosystem of the wetland. In this study, an accuracy evaluation and model optimization function were designed to optimize the Light Utilization Efficiency (LUE) parameter of Carnegie-Ames-Stanford Approach (CASA) model, and optimized model was used to estimate and analysis spatial distribution and seasonal and annual variation of the Net Primary Productivity (NPP) for the recent 10 years of Ruoergai wetland. Results showed that, (1) Maximum light utilization efficiency used in the original model cannot reflect spatial heterogeneity of vegetation distribution. Parameter of CASA model need to be further optimized when applied in the regional scale. (2) Spatial distribution pattern of NPP in Ruoergai wetland is highly correlated with topography factor. (3) NPP of Ruoergai wetland shows a slight decline trend on the time series for the recent 10 years and area of the slight decline trend is about 67%, and there are 22% grassland who's NPP is severe decrease.

Keywords: Ruoergai Wetland; NPP; Light Utilization Efficiency; Parameter Optimization; CASA;

1. Introduction

Net primary productivity (NPP) is the organic matter which is accumulated by green plant in unit time and unit area. Not only seemed as an important variable of the vegetation activity, it is also the judgment of carbon balance of ecosystem and regulation of ecological process [1]. With high economic value and a variety of ecological functions, wetland is a special ecosystem which is transition from land to fresh water. It is thought to be the source of material and has a function of converter. It also seemed as the sink of CO2 and the stabilizer of climate on the global scale. It has important means for the study of the change of environment [2]. However, for the increasing of

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population and rapid growth of economics, ecosystem of wetland faces strong impact and damage. As an essential part of the wetland ecosystem, NPP is one of the factors which can reflect health of wetland ecosystems. However, for the difference of wetland, inconvenient of traffic and other reasons, traditional survey methods of NPP face much inconvenient for the man power and material reasons. Remote Sensing technology has provided supporting of large area wetland survey and can provide information such as vegetation type and distribution, land use type and area, biomass distribution, water characteristic, community evapotranspiration, LAI and chlorophyll content from different spatial resolution satellite images. Using remote sensing technology to monitor annual and inter-annual of NPP change is beneficial to evaluate the health condition of ecosystem of wetland.

Ruoergai wetland locates on the east edge of Qinghai-Tibet plateau. It is a typical inland wetland in China and is the world's largest concentrated area of peat swamp [3-4]. It plays an important role for ecological construction and environmental protection for the upper reaches of Yangtze and yellow river and also has important impact for the sustainable development of regional economy. Currently, large attentions have been attracted by the grassland degradation and shrinkage of wetlands problems in this place [5-8]. However, researches mainly focused on exploration and qualitative description of environmental change while quantitative assessment of vegetation health on the region level for the Ruoergai wetland are still lack of sufficient. Study of quantitative NPP of Ruoergai wetland from long term change and whole area view hasn't been reported.

Using quantitative remote sensing and data assimilation method, this paper is to study the changing condition of NPP for Ruoergai wetland for the recent 10 years and quantitative analysis change trend in order to provide scientific data for the protection of Ruoergai wetland. CASA (Carnegie-Ames-Stanford Approach) model which is a light utilization efficiency model and fully considered the environmental condition and vegetation characteristics was used in this study. It has been used widely [9-11]. In CASA model, light utilization efficiency (LUE) is characterized as an indicator of plants ability for fix solar energy. It is an important concept of photosynthesis and a key parameter of vegetation productivity when using remote sensing method to monitor NPP on regional scale. However, it leads results often difficult to reflect the spatial heterogeneity of distribution of mountain vegetation, and it is because that CASA model is a large scale model and it considers a lot of the spatial heterogeneity on the global scale where these spatial heterogeneity generally affected by latitude, climate zone, land and ocean rather than regional scale factor such as shady slope and sunny slope or the water condition. In this study, after building geo-database whose datasets such as NDVI of MODIS, Meteorological data, vegetation cover, and field data under series methods such as NDVI reconstruction and Meteorological spatiality, we designed an parameter optimization and accuracy assessment function to optimize the LUE of different vegetation cover and in order to estimate 227 single scenes NPP and 10 scenes NPP of Ruoergai wetland from 2000 to 2009.

2. Study Areas and Method

2.1. Study Area

Ruoergai is a completely hilly plateau. It locates on a relatively stable block which had been planted in the tertiary period and had become a peneplain which continuously distributes on the western of Sichuan Plateau. There are alpine and gorge around it and altitude is about 4000 meters while internal of Ruoergai plateau is mainly hill and strathand and the altitude is about 3400 to 3700 meters. It is a relatively sedimentation section in the strong uplift in quaternary Period. Thickness of quaternary sediments is about 100 meters and the thickest can reach 300 meters. Branch of valley in the upstream deposited generally and it evolved into strath with none riverbed. This had provided geomorphic foundation for the formation of swamp and accumulation of peat. Vegetation of Ruoergai is mainly meadow and swamp meadow, and there is no forest in it. There are Festuca nivina, Kobresia setchuanensis, Elymus nutans in Ruoergai plateau and the main species of Swamp meadow are Carex muliensis and Kobresia tibetica. According to the community of plant, phenology can be classified into 3 periods which are the green stage from 25 April to 11 June, the growth stage from 12 June to 11 august and the turn yellow period from 12 august to 24 April the next year [12]. The average population density of this area is about 3.4 persons per kilometer and land use is mainly nomadism, half-free migration as its major characteristic.

Climate of this area is cold and wet and annual mean temperature is about 0.7～3.3℃. For the great transparency of atmospheric of plateau, radiation of this area is extremely strong and temperature differ from day to night is about

15～16℃. There is a long frost period. Herbaceous peat swamp distributes widely and the direction is mainly north-to-south. Area of terrace Swamp is larger than others [4].

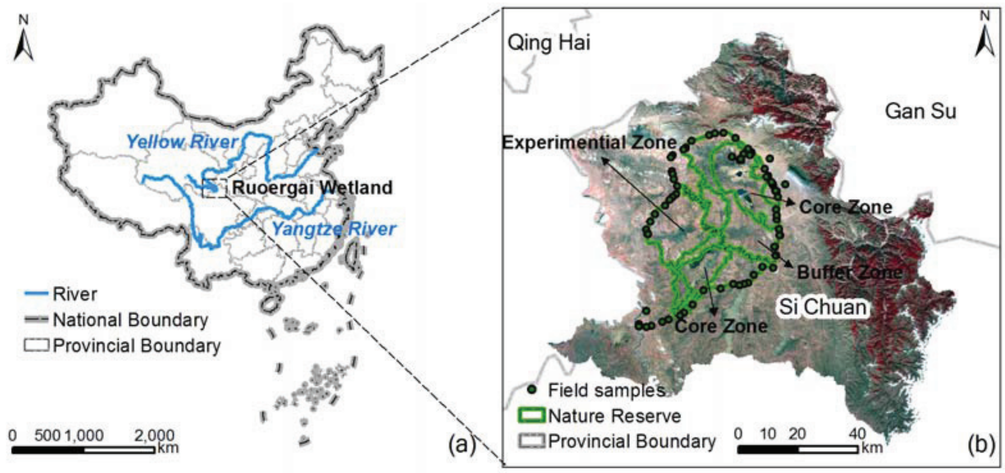


Fig.1. Location of Study area (Ruoergai Wetland)

2.2. Data Collection and Analysis

2.2.1. Remote Sensing Data

MODIS Time Series MOD13Q1 product with spatial resolution 250 meter and composed by 16 Days MVC Method was used in this study. This dataset was provided by USGS and can be accessed at https://lpdaac.usgs.gov/lpdaac/products/modis_products_table [13]. 227 tiles of MOD13 Q1 products from 2000 to 2009 were collected. As these products may be affected by cloud, atmosphere, or ice-snow cover, we first used the S-G filter to reconstruct the NDVI time series dataset in order to reduce noise and improve data quality in the data pre-process procedure [14].

2.2.2. Meteorological Data

Due to the sparse distribution of radiation site in China, there will be a large bias when interpolating scattered data into grid data using traditional interpolation method. It is series especially in the mountain area for difference of solar radiation between shady slope and sunny slope cannot be reflected by interpolation method. Precision of simulated NPP will be directly affected by the spatial solar radiation when using the light utility efficiency model. Therefore, a DEM solar radiation simulation method was used in this study to estimate the spatial solar radiation and the precision of estimation results is better [15-16].

2.2.3. Field Data

Field data was collected in September, 2009. According to the regional randomly sampling theory [17-18], the number of field sampling points can be calculated as follow:

$$n = \frac{n_0}{1 + n_0 / N} \qquad (1)$$

$$n_0 = (\frac{u_a \times S}{\sigma})^2 \qquad (2)$$

$$S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{X})^2} \tag{3}$$

Where n is number of sampling point, u_a is double-sided quantile of a in the standard normal distribution. u_a is 1.96 when degree of confidence is 95%,. σ is the absolute error limit. S is mean standard deviation of annual NPP gross in study area.

Table2. NPP of the field data

Vegetation cover	Number	Mean ($gCm^{-2}a^{-1}$)	Std	max ($gCm^{-2}a^{-1}$)	Min ($gCm^{-2}a^{-1}$)
High cover dry grass	12	497.80	30.14	532.00	416.10
Middle cover dry grass	8	314.16	48.76	378.10	220.00
Low cover dry grass	12	87.95	41.15	134.90	23.75
Wet grass	16	140.36	70.78	233.22	33.25
Marsh grass	8	86.62	43.17	152.00	28.50

Stratified sampling and harvest method were used in the biomass measure of sampling point. As shown in fig1b, there are 57 sampling points and distance of each point is about 1000 meters. An empirical factor of 0.475 was used when transfer biomass into NPP [19-20].

Data related with time was processed into the same time resolution and spatial resolution with MODIS NDVI dataset and geodatabase of meteorological and remote sensing dataset was built up finally.

2.3. Carnegie-Ames-Stanford Approach Model

CASA (Carnegie-Ames-Stanford Approach) model is a light use efficiency model which fully considered environment factor and vegetation self-characteristics [11].It needs less parameter than other models and this may avoid errors caused by human experiments when lack of sufficient data. For satellite data was used in CASA model, it can dynamically monitor NPP across a large area and with high time resolution. CASA model considers two major driving variables of NPP which is the intercepted photosynthetically active radiation (IPAR) and light utilization efficiency (ε). The two variables are correlated with some indicators such as NDVI, soil moisture, rainfall, mean temperature and others. CASA model can provide powerful technology method for research of NPP such as the spatial distribution, seasonal variation and inter-annual variation of wetland vegetation. NPP of CASA can be expressed by IPAR and ε as follow:

$$NPP(x,t) = IPAR(x,t) \times \varepsilon\ (x,t) \tag{4}$$

Where *IPAR(x,t)* is the intercepted photosynthetically active radiation of pixel x in t time while $\varepsilon(x,t)$ is light utilization efficiency of pixel x in t time.

Vegetation has maximum light utilization efficiency under ideal conditions, but it may affected by temperature and moisture content in a real condition.

$$\varepsilon(x,t) = T_{\varepsilon 1}(x,t) \times T_{\varepsilon 2}(x,t) \times W_{\varepsilon}(x,t) \times \varepsilon_{\max} \tag{5}$$

where $T_{\varepsilon 1}(x,t)$ and $T_{\varepsilon 2}(x,t)$ is stress factor of light utilization efficiency in low temperature and high temperature; is factor of water stress and it reflects the effect of water condition; $\varepsilon_{\max}$ is maximum light utilization efficiency under ideal condition which is 0.389 in the original model. Computing method of parameters in CASA model can consult relevant reference [9, 21-22].

2.4. Accuracy evaluation and model optimization function

For CASA is a global scale model and there may be some unreasonable parameter setting when applied in regional scale, in this study, we designed an accuracy evaluation and model optimization function to optimize parameter of CASA model and function shown as follow:

$$E_k = \sum_{j=1}^{n_k} (NP\,\mathrm{Pr}_j - NPP_j(\varepsilon))^2 \quad (6)$$

$$\varepsilon_k = \varepsilon(\mathrm{E_k} \to \min(\mathrm{E_k})) \quad (7)$$

Where E_k is the error between field and simulated NPP of the kth vegetation; n_k is number of sampling points of kth vegetation; NPPr is measured value of field point; $NPP_j(\varepsilon)$ is estimated value for kth vegetation by modal; ε_k is maximum light utilization efficiency of kth vegetation.

Equation (6) is an opening up quadratic equation, and it has a minimum value. When the E_k reaches it's the least value it means that ε_k achieves it's the best result.

2.5. Trend Analysis Model

Simple difference model and simple linear regression analysis model was used to analyze trend of NPP from 2000 to 2009. Simple difference method subtracts images which cover same area but are acquired at different time phases and it uses the different value between images to reflect the variation [23]:

$$D_{ij} = NPP_{ij}^{t1} - NPP_{ij}^{t2} \quad (8)$$

Where D_{ij} is the different value of pixel in row i column j; NPP_{ij}^{t1} is NPP of time phase $t1$ in row i column j.

Simple linear regression analysis simulates the tendency of each grid as follow [24]:

$$\Theta_{slope} = \frac{n \times \sum_{j=1}^{n} j \times NPP_j - \sum_{j=1}^{n} j \sum_{j=1}^{n} NPP_j}{n \times \sum_{j=1}^{n} j^2 - (\sum_{j=1}^{n} j)^2} \quad (9)$$

where n is number of monitored years; NPP_j is average value of the jth year; Θ_{slope} is slope of the trend line, it should explain that trend line is not simple line connecting start year and end year, $\Theta_{slope} > 0$ means change tendency of NPP among n years is increasing, on the contrary, it may decrease.

Flow chart of this study show as follows:

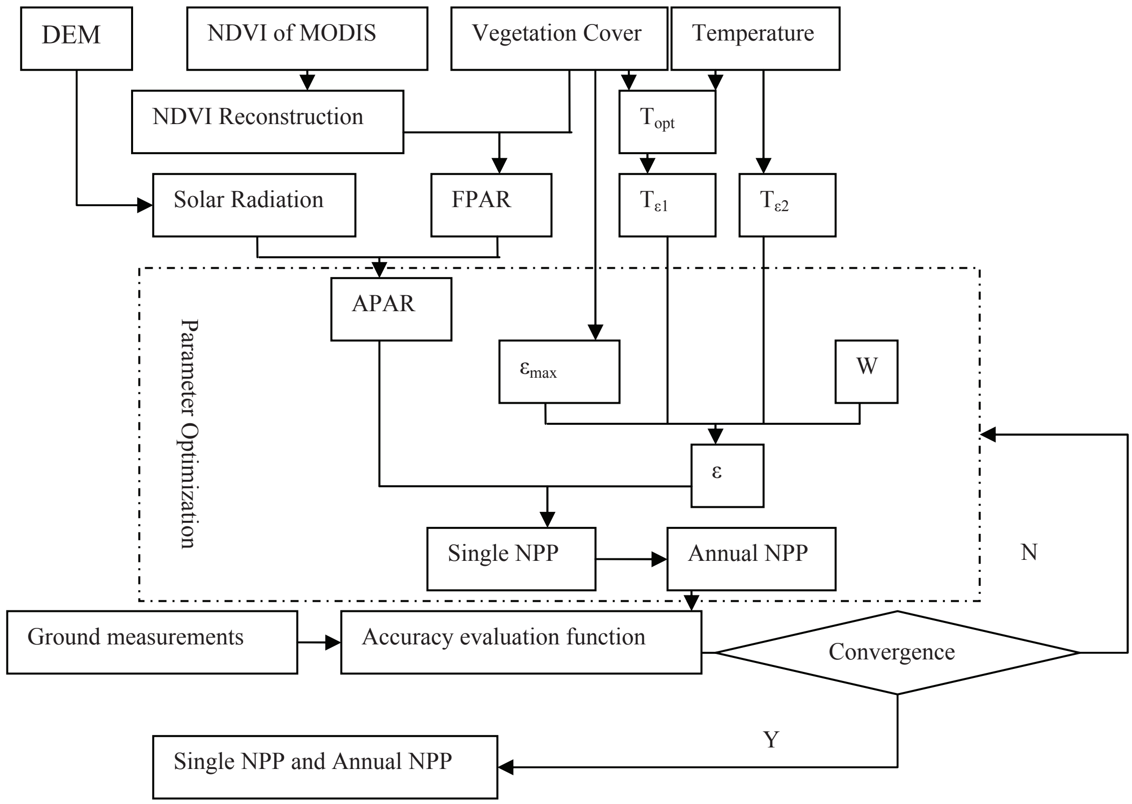


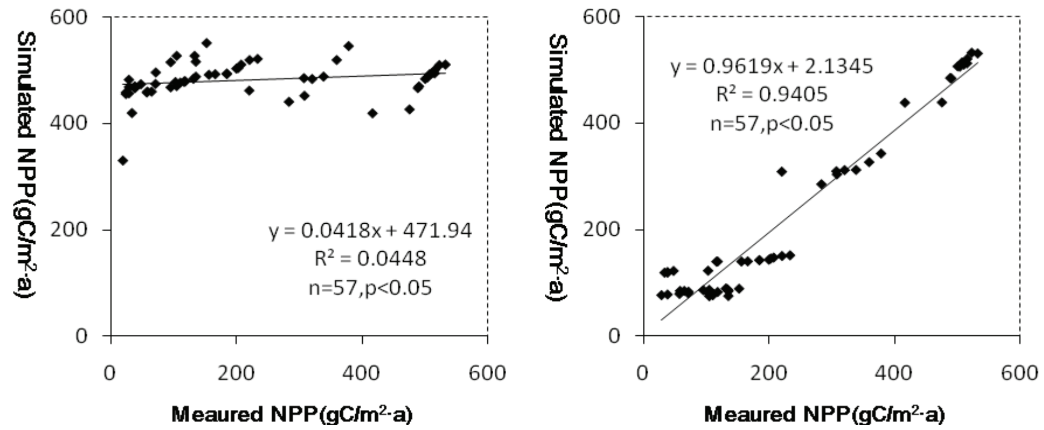
Fig.2. Flow chart of this study

3. Result and Analysis

3.1. Parameter Optimization Result

According to the parameter optimization and accuracy assessment function, combining with the field NPP data, this paper optimized LUE of CASA model of Ruoergai wetland. For the filed NPP data isn't too much, points were divided into 5 parts and cross-validation method was used to avoid over fitting. Simulated data of the field points before and after the optimize process were show in fig3.

As it shown in fig3a, simulated results differ a lot from filed measured NPP data according to the original CASA model, and the correlation is only 0.2 which means there is little correlation between simulated NPP and field measure NPP. While optimized the maximum LUE of different vegetation cover in CASA model, accuracy of simulated NPP have been greatly improved and the correlation coefficient is 0.96 which means that simulated NPP and filed measured NPP are highly correlated.



a b

Fig.3. Comparison of estimated NPP before and after Maximum LUE simulation
(a) NPP of field point of the original CASA model; (b) NPP of field point after the Maximum LUE simulation

The Maximum LUE of different vegetation cover in Ruoergai wetland was shown in table 3:

Table 3. Maximum LUE of vegetation of Ruoergai wetland

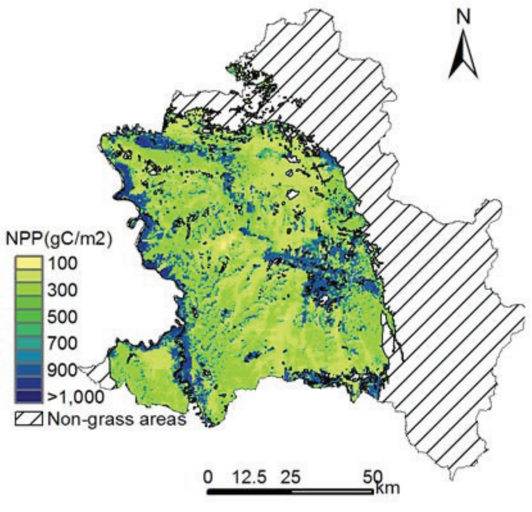
Vegetation Cover	Number of sampling points	Maximum LUE/gCMJ^{-1}		
		Minimum	Maximum	Result
High cover dry grass	12	0.690	0.776	0.723
Middle cover dry grass	8	0.331	0.484	0.450
Low cover dry grass	12	0.036	0.192	0.128
Wet grass	16	0.055	0.31	0.196
Marsh grass	8	0.043	0.191	0.117

As it shown in table3, the maximum LUE of high cover dry grass is 0.723gCMJ-1 and the range is from 0.69 gCMJ-1to 0.776 gCMJ-1; Maximum of LUE of middle cover dry grass is 0.450 gCMJ-1 and the range is from 0.331 gCMJ-1 to 0.484 gCMJ-1. Maximum LUE of high and middle cover dry grass is higher than the original set of maximum LUE in the model which is 0.389 gCMJ-1 while lower cover dry grass and wet grass and marsh grass is lower than the original set. It also can be seen from table2 that Maximum LUE of high cover grass is higher than other vegetation covers, and maximum LUE is similar between lower cover dry grass and marsh grass.

Compared with relevant studies, Maximum LUE simulated in this study is between CASA model's 0.389 gCMJ-1 and Running's [25] simulated results which is 0.608 gCMJ-1. Some studies have point that maximum LUE in original CASA model is a little high or low when using in some areas in China [26-27]. However, these studies mainly focused on the compared of Maximum LUE, while studies of grass land are mainly on the plain where the spatial heterogeneity of plant isn't obviously rather than in the mountain and wetland areas. As simulated in this study, high and middle cover dry grass is close to Running's results, while for the special of wet grass and marsh grass, researches are little and in our study it can been seen that maximum LUE of them aren't high.

3.2. Spatial Distribution pattern and the amount variation of NPP for recent 10 years

Mean NPP from 2000 to 2009 was calculated and showed in fig4a.



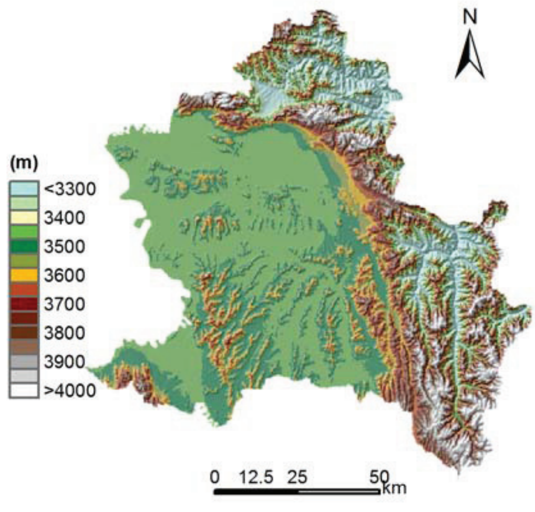
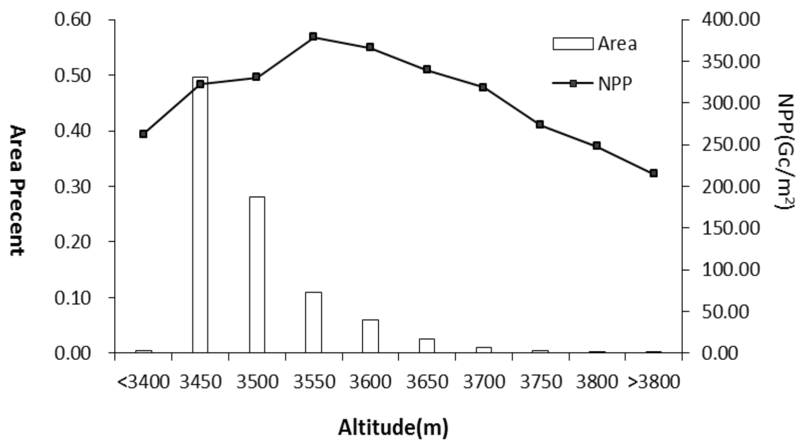


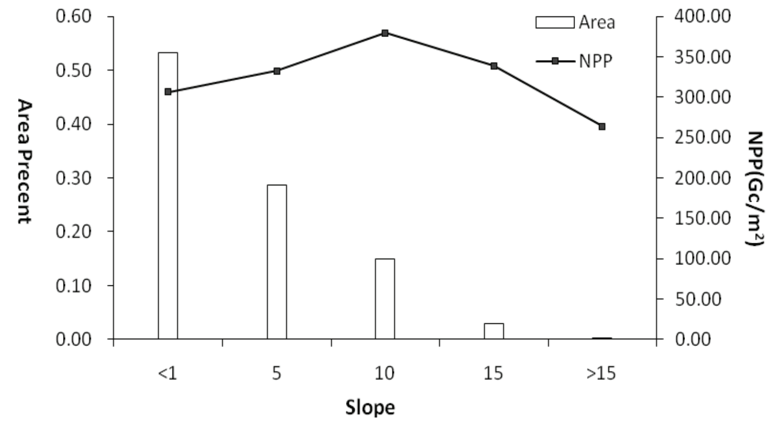
Fig.4. Compare between mean NPP distribution for recent 10 years and the topography
(a) mean NPP distribution for recent 10 years; (b) 90m SRTM of Ruoergai)

As it shown in fig4, spatial distribution pattern of NPP in Ruoergai wetland is highly correlated with the topography factor. Wetland in Ruoergai distributes widely and concentrates into pieces. Herbaceous peat swamp highly developed and mainly distribute on the first terrace of the main stream of black river. Swamp was mostly distributed in the north-south or southwest-northeast direction. View from the region, the hydrology and the permutations and combinations of vegetation communities differ a lot among the swamps which developed on different topography positions.

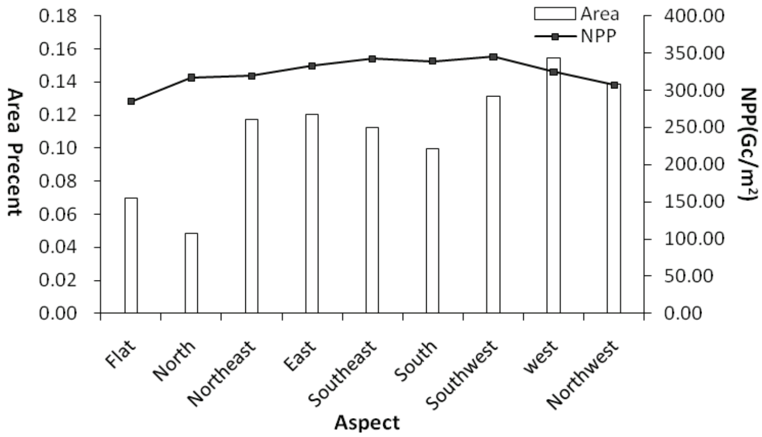
Compared with fig4a and 4b, the distribution trend of NPP is a little high in the east where NPP in the north and south is a little low. NPP zonal statistics of altitude slope and aspect are shown in fig5.



(a)



(b)



(c)

Fig.5. Zonal statistics of mean NPP for recent 10 years and the topography
(a) zonal statistics between NPP and altitude;(b) zonal statistics between NPP and slope; (c) zonal statistics between NPP and aspect)

As it shown in fig5a, area of grassland whose altitude of 3450~3500m accounted for 78% of the whole grassland. Mean NPP in this altitude is about 318.11gC/m^2; area of grassland whose altitude of 3550~3650m accounted for 17% of the whole grassland. Mean NPP in this altitude is about 346.4gC/ m^2.

As it shown in fig5b, area of grassland whose slope is less than 1degree is the largest. Terrain in this slope gradient is flat and area account for 53% of the whole grassland. Mean NPP of the grassland is about 306.3gC/ m^2. Slope gradient whose slope from 1 to 5 degree account for 29% of the whole grassland. This slope gradient is gentle slope and the mean NPP is about 332.55gC/ m^2. Slope gradient whose slope from 5 to 10 degree account for 29% of the whole grassland. This slope gradient is gentle slope and the mean NPP is about 332.55gC/ m^2.

As it shown in fig5c, correlation isn't significant between NPP and aspect, and NPP of southern and southwest aspect is higher than others aspect.

Graded NPP statistics from 2000 to 2009 in 200gC/ m^2 intervals and the component proportion ratio was calculated through SPSS and shown in fig6:

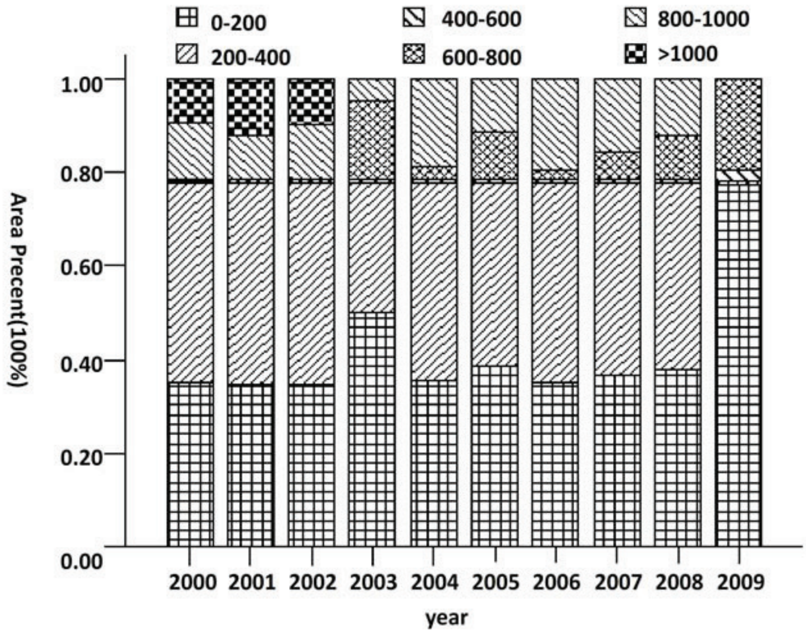
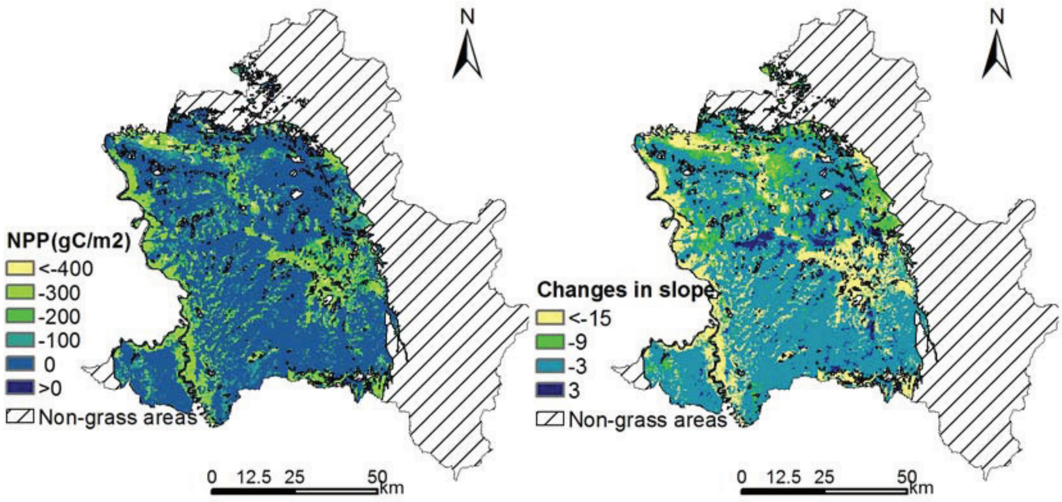


Fig.6. Component character of NPP from 2000 to 2009 of Ruoergai wetland

As it shown in fig6, accumulation amount of NPP mainly concentrates in 0~400gC/ m^2, and area in this NPP range account for 78% of Ruoergai wetland. Area of 0~200gC/ m^2 account for 40% and area of 200 gC/ m^2~400gC/ m^2 account 38%. Higher than 400gC/ m^2 is small and accounts for about 20% of the area of Ruoergai wetland. There was about 10% of area whose NPP is higher than 1000gC/ m^2 before 2002 while didn't exit after 2002. Area of 800gC/ m^2-1000gC/ m^2 reduced gradually while 600gC/ m^2-800gC/ m^2 increased.

3.3. Spatial variability of NPP from 2000 to 2009

Difference between 2000 and 2009 was calculated using simple difference method and the spatial variation map was shown in fig7a. We also use the simple linear regression method to analysis NPP change trend and the changes in slope were shown in fig7b.



(a) (b)

Fig.7. Change trend of NPP of Ruoergai wetland
(a) change trend between 2000 and 2009; (b) changes in slope from 2000 to 2009

Simple difference method result reflects the change trend between 2000 and 2009. As it shown in fig7a, NPP of Ruoergai wetland shows a decline trend between the two years and area of change amplitude between 0 to 200gC/ m^2 accounts for the largest.

For the simple difference method just calculated difference between two ending times, simple linear regression method can eliminated some extent impact of extreme weather of a given year and can response to the evolution of vegetation NPP more realistic [28]. Define the Θ_{slope} into 4 range which are almost invariant, slight decrease, moderate decrease, severe decrease, area of each range was calculated and shown in table3:

Table3. Statistics of the NPP change trend

Changes in slope	Range name	Area(km^2)	Area Percent
<-15	severe decrease	1236.25	0.22
-15~-9	moderate decrease	437.63	0.08
-9~-3	slight decrease	3678.69	0.67
-3~3	almost invariant	162.94	0.03

As it can be seen from fig7b and table3, it showed a decline trend from 2000 to 2009. Areas of 3678.69 km^2 which distribute in most place showed a slight decrease trend and it account for 67% of the whole wetland. Areas about 1236.25km^2 shown a severe decrease trend and it account for 22% of the whole wetland and these areas mainly distribute in the HaQiu lake core protect zone. Ruoergai wetland showed a slight degradation in overall performance trends.

4. Discussion

In this study, to decrease the uncertainty in data source and improve the accuracy of the input parameter, we used a Savitzky-Golay filter to reconstruct the MODIS NDVI time-series datasets and a DEM based method to estimate solar radiation under the complex terrain conditions. Considered that MODIS time-series NDVI datasets might be affected by ice/snow or cloud, Savitzky-Golay filter was firstly used to reconstruct this datasets in the preprocess stage in order to decrease noise and get high quality NDVI time-series. Drop points which were caused by noise were amend and the reconstruction curve of NDVI time-series reached the up-envelope. For the sparse of radiation station, it is hard to estimated solar radiation using the geostatistic method especially for the complex terrain area. As an key input parameter of the CASA model, solar radiation was estimated through a DEM based method in this paper. According to the validation of the radiation station, this method can get highly accuracy result and is suit for complex terrain areas.

In the flow chart of this paper, a parameter optimization function was designed in order to evaluate and optimize parameter of CASA model. It is reasonable to optimize parameter of CASA model when it is applied on the regional scale. General speaking, large scale model consider a lot of the spatial heterogeneity on the global scale where these spatial heterogeneity generally affected by latitude, climate zone, land and ocean etc., and when it applied on the regional scale condition, it surely exists some unreasonable. Heterogeneity of vegetation of regional scale is mainly caused by the topography factor, such as shady slope and sunny slope or the water condition. CASA model was first used to estimate the NPP on the global scale and sooner applied to NPP research on the middle scale. In this study spatial heterogeneity of grassland are mainly caused by the topography factor and water factor, so we need to optimize parameter in this model in order to improve accuracy of the simulated result.

Generally speaking, model optimization problem was consisted by parameter which affected the value of objective function, the objective function and the limiting condition of these parameters. In this study, light utility efficiency was chose as the preparative optimization parameter. It is a major factor which can respect the efficiency of plant to fix the solar energy and it is an important concept for plant photosynthesis. It is also a key parameter for monitoring the NPP on regional scale. In the leaf scale, light utility efficiency is a constant for it reflect the plant photosynthesis. However, it differs with the vegetation type when observed in the canopy scale through the remote sensing technology. As discussed above, CASA model is a global model and the light utility efficiency was set as a constant in order to reflect the global trend. When applied on the middle or small scale, it should be optimized to improve the estimation accuracy, and it is reasonable for long time monitoring of ecosystem for the regional scale.

Spatial distribution pattern of NPP of Ruoergai wetland has a great relationship with the slope factor and NPP of Ruoergai wetland showed a slight decrease trend from the general trend for the recent 10 years. Slope factor affected water condition and also affected the mean NPP spatial distribution which can be seen from figure 5b. Degradation of Ruoergai wetland is mainly caused by human impacts. Although government has realized importance and necessity of Ruoergai wetland protect and make some preserve area, it still has a decline trend for recent years. In 1970s, to improve the stock rage of grassland and Pasture utilization, Ruoergai County diged thousands of ditches to drain the water into the Yellow river, and this has lead area of wetland shrink a lot. In 1990s, government has realized the importance of protecting of Ruoergai wetland, and built up a nature reserve, however, it still need a scientific and probable protection method and a long term protection.

5. Summary

In this study, combined with remote sensing data, meteorological data, topographic data, soil data, survey data etc., we designed an accuracy evaluation and model optimization function to optimize the light utilization efficiency parameter (LUE) of CASA model, and use the optimized model to estimate and analysis spatial distribution and seasonal and annual variation of the NPP for the recent 10 years of Ruoergai wetland. And the results show that:

1. Maximum light utilization efficiency of the original model can't reflect spatial heterogeneity of vegetation distribution. Parameter of CASA model need to be further optimized when applied in the regional scale. According to compare results before and after the maximum LUE optimize process, it can be seen that estimated accuracy of NPP has improved a lot and the estimated data can reflect difference between different vegetation cover after the optimize process.

2. Spatial distribution pattern of NPP in Ruoergai wetland is highly correlated with topography factor. Spatial distribution pattern of NPP shows that area of grassland whose altitude of 3400~3500m accounted for 78% of the whole grassland and grassland whose slope is less than 1degree accounted for 58% of the whole grassland. Correlation isn't significant between NPP and aspect.

3. NPP of Ruoergai wetland shows a slight decline trend on the time series for the recent 10 years and area of the slight decline trend is about 67%, and there are 22% grassland whose NPP is severe decrease.

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