Retrieval of Key Hydrological Parameters in the Yellow River Basin Using Remote Sensing Technique

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Abstract:

Precipitation、evapotranspiration and runoff are three key parameters of regional water balance. Problems exist in the traditional methods for calculating such factors，such as explaining of the geographic rationality of spatial interpolating methods and lacking of enough observation stations in many important area for bad natural conditions.

With the development of modern spatial info-techniques, new efficient shifts arose for traditional studies. Guided by theories on energy flow and materials exchange within Soil-Atmosphere-Plant Continuant (SPAC), retrieval models of key hydrological parameters were established in the Yellow River basin using GMS-5 and FengYun-2 meteorological satellite data. Precipitation and evapotranspiration were then estimated: (1) Estimating the amount of solar energy that is absorbed by the ground with surface reflectivity, which is measured in the visible wavelength band (VIS); (2) Assessing the partitioning of the absorbed energy between sensible and latent heat with the surface temperature, which was measured in the thermal infrared band (TIR), the latent heat representing the evapotranspiration of water; (3) Clouds are identified and cloud top levels are classified using both VIS and TIR data. Hereafter precipitation will be calculated pixel by pixel with retrieval model.

Daily results are first obtained, which are then processed to decade, monthly and yearly products. Precipitation model has been calibrated and tested with ground truth data; meanwhile, the evapotranspiration result has been verified with Large Aperture Scintillometry (LAS) presented by Wageningen University of the Netherlands. Further studies may concentrate on the application of models, i.e., establish a hydrological model of the Yellow river basin to make

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the accurate estimation of river flow volume and even monitor the whole hydrological progress.

Key words: Yellow River Basin, hydrological parameter, remote sensing, retrieval

1. Introduction

Precipitation、evapotranspiration and runoff are three key parameters of regional water balance. Problems exist in the traditional methods for calculating such factors，such as explaining of the geographic rationality of spatial interpolating methods and lacking of enough observation stations in many important area for bad natural conditions. With the development of modern spatial info-techniques, new efficient shifts arose for traditional studies.

Since the 1980's, applications of meteorological satellites, related to the energy and water balance of the earth surface, have emerged (Price 1982, Moses, J.F. and E.C. Barrett. 1984, Rosema, A. 1986, Marks, D., and J. Dozier. 1992). Surface reflectivity, measured in the visible wavelength band (VIS) enables the estimation of the amount of solar energy that is absorbed by the ground. The surface temperature, measured in the thermal infrared band (TIR), enables the assessment of the partitioning of the absorbed energy between sensible and latent heat, the latter representing the evapotranspiration of water.In the early 1980's the European Space Agency funded the Group Agromet Monitoring Project (GAMP). In this project use was made of METEOSAT TIR and VIS data. The actual evapotranspiration and thermal inertia of the Niger delta in Mali were monitored and analyzed during a complete growing season (Rosema 1986). In 1990 a first experiment took place in real time monitoring of evapotranspiration and vegetation growth conditions in the Western Sahel region, for the purpose of locust and food early warning under order of FAO (Rosema 1993).

Sino-Dutch cooperation project " Establishment of a Chinese Energy and Water Balance Monitoring System for Desertification and Food Security Applications " was launched in 1999. A Chinese Energy and Water Balance Monitoring System (CEWBMS) had been established. The data resources of the system are GMS-5 and FengYun-2 meteorological satellite. Multiple kinds of energy and water balance parameters could be revised and processed into standard products with CEWBMS. Guided by theories on energy flow and materials exchange within Soil-Plant-Atmosphere Continuant (SPAC), retrieval models of key hydrological parameters were established in the Yellow River basin using the CEWBMS system. Decade precipitation and evapotransporation data of the year 2000 were achieved. All results had been justified and tested with ground truth data. The object of the paper is to introduce methodology, results and main conclusions of this work.

2. Data acquisition

2.1 Meteorological satellite data

A GMS/Feng Yun-2 receiving station was installed in the Institute of Geographic Science and Natural Resources Research (IGSNRR), CAS, Bei Jing, in the early 2000. Since then GMS-5 data have been received hour-by-hour and archived on a daily basis. Both Japanese GMS-5 and the new Chinese geostationary meteorological satellite Feng Yun-2 could provide the following data that will be used for precipitation and evapotranspiration retrieval:

(1) Visible data at 1.25 km spatial resolution (sub satellite)

(2) Thermal infrared data at 5 km spatial resolution (sub satellite)

On this system the pre-processing and processing software developed by EARS will be installed. In the framework of this project, all of these data were calibrated and geo-referenced for further processes.

2.2 Validation data

The validation dataset consists of two types of data:

(1) Site data. Precipitation data were derived from the WMO Global Tele-communications System (GTS) and evapotranspiration data were collected by site observation.

(2) Regional data. Precipitation and evapotransporation data of each sub-division of Huang He River Basin were provided by Commission for Administration of Huang He River.

3. Methodology

3.1 Rainfall monitoring

The most widely used approach to automatic satellite rainfall mapping is based on statistical regression between cold cloud duration (CCD) and rainfall measurements. Here cold clouds are defined as clouds with IR cloud top temperatures below a certain threshold. A statistical technique has been developed to use the GMS5 cloud information to interpolate rainfall between the rainfall stations reporting on the WMO Global Tele-communications System (GTS).

The first step is cloud statistics. Clouds were divided into five classes using cloud top temperature threshold technique. Cloud classes and according thresholds were shown as table 1 :

Table 1. Cold cloud classification

The second step is to estimate rainfall for each pixel on the basis of a multiple regression with the GTS rain gauge data in the region:

$$P=\sum_{i=1}^{5}(a_i \times CD_i)+b \qquad (1)$$

Where CDi is the cloud duration at cloud level i, ai and b are regression coefficients. In order to account for geographic variations in the cloudiness-rainfall relation, a geographic scaling factor is introduced, which is calculated as the ratio of the actual and the estimated rainfall at each rainfall station:

$$S_j = R_j / R_{est,j} \qquad (2)$$

This scaling factor is then interpolated pixel by pixel between the GTS rainfall stations on the basis of a weighted inverse distance technique. The rainfall field is finally obtained by multiplication of the estimated rainfall (Rest) with the geographic scaling factor (S) in each pixel.

3.2 *Actual evapotranspiration*

The determination of actual evapotranspiration on the basis of GMS-5 or Feng Yun-2 data was carried out in several steps: calculation of net radiation, calculation of the sensible heat flux, determination of the actual evapotranspiration.

(1) Calculation of net radiation.

Net radiation is calculated as the net result of the short wave (solar) and long wave (terrestrial) radiative fluxes and is expressed as a daily average:

$$I_n=(1-a)I_g+L_n \qquad (3)$$

Where a is surface albedo, which could be derived from visible band data of GMS-5; I_g is the daily average solar irradiation at the earth surface and L_n is the net long wave (thermal) radiation loss. I_g is the function of location (longitude and latitude) and time (solar declination and the day of a year). L_n could be calculated with formula as follow:

$$L_n=\varepsilon_0(1-\varepsilon_a)\sigma T_a^4+(4\varepsilon_0\sigma T^3)(T_0-T_a) \qquad (4)$$

Where ε_0 is surface emission ratio; ε_a is atmosphere emission ratio; σ is Stefan-Bolzman constant; T_0 、 T_a and T stand for surface temperature, atmosphere temperature and (T_0+T_a)/2 respectively.

(2) Calculation of sensible heat flux

The sensible heat flux into the atmosphere is proportional to the temperature difference across the atmospheric boundary layer (T_0-T_a). The simple formulation is:

$$H=(\alpha_c+\alpha_r)(T_0-T_a) \qquad (5)$$

Where α_c stands for surface resistance, meanwhile α_r stands for resistance of atmosphere.

(3) Having determined the net radiation (In) and the sensible heat flux (H) the latent heat flux (i.e. the actual evapotranspiration in energy units) can obtained on the basis of regional energy and water balance:

$$LE = I_n - H - G \qquad (6)$$

The item G is the heat flux into the soil, which at the daily time scale is very small, may be considered as a constant.

4. Results and verification

A boundary file of sub-division of Huang He River Basin at 1:100,000 scale had been produced in ArcInfo^{TM} coverage format. With help of ArcInfo^{TM} GIS software, precipitation and evapotranspiration of each sub-basin could be achieved.

4.1 Precipitation

Estimated precipitation data, compared with site data, were shown as follows.

Table 2 Comparision of estimated precipitation and rainfall station data

Table 2 shows that the retreival model of precipitation worked fairly well, especialy in arid and semi-arid areas(eg. Lanzhou—Hekou).

4.2 Evapotranspiration

A LAS(Large Aperture Scintillometry) station had been installed in a meteorological station in Zhen Zhu city, North China since December, 1999. Actual evapotranspiration had been observed on daily basis. Estimated evapotranspiration varied constantly with that of site observed data.

Figure 1 Comparision of estimated evapotranspiration and site observed data at Zhen Zhou city, 2000

Analysys was also carried out on regional scale. Good results were achieved except for one sub-basin:Hua yuankou—Sea. This is mainly caused by the very narrow shape of the sub-basin, and the width is even smaller than that of one pixel of GMS-5 image (5km).

Table 3 Comparision of estimated evapotranspiration and government reported data

5. Discussion

The paper presented efficient and operational methods for precise estimates of precipitation and evapotranspiration with meteorological satellite data. Validation work demonstrated that the results were reliable both at site and regional scales. For small areas according to pixel size of GMS-5 image, the precision might decline dramatically.

Further studies may concentrate on the application of models, i.e., establish a hydrological model of the Yellow river basin to make the accurate estimation of river flow volume and even monitor the whole hydrological progress.

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Table 1. Cold cloud classification

Name of classes	Count range of GMS infrared band	Temperature range (K)	Height range (km)
Cold	< 45	< 226	> 10.8
high	45~60	226~240	8.5~10.8
Middle high	60~90	240~260	5.2~8.5
Middle low	90~120	260~280	2.2~5.2
low	>120	>280	<2.2

Table 2 Comparision of estimated precipitation and rainfall station data

Name of sub-basins	estimated precipitation(eP)		site precipitation(sP)		eP/sP (%)
	mm	$10^9 \times m^3$	mm	$10^9 \times m^3$	
Heyuan-Long Yangxia	388.6	511.7	413.2	544.0	94.1
Long Yangxia—Lanzhou	382.4	356.6	412.6	384.8	92.7
Lanzhou—Hekou	176.0	283.3	182.9	294.5	96.2
Hekou—Longmen	312.1	349.8	338.9	379.8	92.1
Longmen—San Menxia	405.2	770.8	478.6	910.5	84.7
San Menxia—Hua yuankou	592.1	245.9	657.1	272.9	90.1
Hua yuankou—Sea	580.1	131.1	681.5	154.0	85.1
Erdos special division	152.7	69.8	165.6	75.7	92.2
Total	**340.8**	**2719.0**	**381.8**	**3016.2**	**90.2**

Figure 1 Comparision of estimated evapotranspiration and site observed data at Zhen Zhou city, 2000

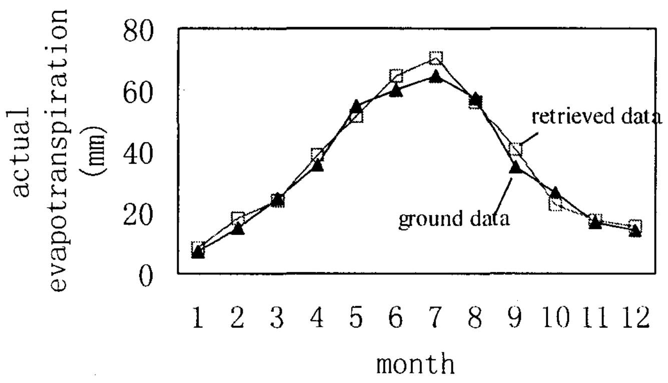

Table 3 Comparision of estimated evapotranspiration and government reported data

Name of sub-basins	Estimated evapotranspiration(eE)		Reported evapotranspiration(rE)		eE/rE (%)
	mm	$10^9 \times m^3$	mm	$10^9 \times m^3$	
Heyuan-Long Yangxia	368.5	485.3	321.6	423.5	114.6
Long Yangxia—Lanzhou	337.8	315.0	297.0	277.0	113.7
Lanzhou—Hekou	227.3	365.9	257.7	414.8	88.2
Hekou—Longmen	286.1	320.7	323.6	362.7	88.4
Longmen—San Menxia	384.3	731.1	479.1	911.5	80.2
San Menxia—Hua yuankou	438.1	182.0	565.2	234.8	77.5
Hua yuankou—Sea	441.0	99.7	880.2	199.0	50.1
Erdos special division	198.9	90.9	165.6	75.7	120.1
Total	**324.7**	**2590.4**	**363.3**	**2898.3**	**89.4**