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Improved Algorithm of SCS-CN Model Parameters in Typical Inland River Basin in Central Asia

Jin J Wang [1, 2, 3,4],Jian L Ding [1,3,4*], Zhe Zhang [1,3,4], Wen Q Chen [1,3,4]

[1] Ecological postdoctoral research station, Xinjiang University, 831401 Urumqi, China

[2] Xinjiang Vocational and Technical College of Communications , 831401 Urumqi, China

[3] College of Resources and Environment Science , Xinjiang University , 830046 Urumqi , China

[4] Key Laboratory of Oasis Ecology of Ministry of Education , Xinjiang University , 830046 Urumqi , China

Corresponding author: Ding Jian Li. E-mail: watarid@xju.edu.cn.

ABSTRACT. Rainfall-runoff relationship is the most important factor for hydrological structures, social and economic development on the background of global warmer, especially in arid regions. The aim of this paper is find the suitable method to simulate the runoff in arid area. The Soil Conservation Service Curve Number (SCS-CN) is the most popular and widely applied model for direct runoff estimation. In this paper, we will focus on Wen-quan Basin in source regions of Boertala River. It is a typical valley of inland in Central Asia. First time to use the 16m resolution remote sensing image about high-definition earth observation satellite "Gaofen-1" to provide a high degree accuracy data for land use classification determine the curve number. Use surface temperature/vegetation index (T_S/VI) construct 2D scatter plot combine with the soil moisture absorption balance principle calculate the moisture-holding capacity of soil. Using original and parameter algorithm improved SCS-CN model respectively to simulation the runoff. The simulation results show that the improved model is better than original model. Both of them in calibration and validation periods Nash-Sutcliffe efficiency were 0.79, 0.71 and 0.66,038. And relative error were3%, 12% and 17%, 27%. It shows that the simulation accuracy should be further improved and using remote sensing information technology to improve the basic geographic data for the hydrological model has the following advantages: 1) Remote sensing data having a planar characteristic, comprehensive and representative. 2) To get around the bottleneck about lack of data, provide reference to simulation the runoff in similar basin conditions and data-lacking regions.

1. Introduction

The direct runoff simulation provides total water resource for hydraulic structure design and the calculation of peak flow discharges. The Soil Conservation Service (SCS) which is known as curve number (CN) model developed by the U.S. Department of National Resources Conversion Service (NRCS) is an extensively used method for estimating and predicting runoff. Because of simplicity and stability, the model has fruitful application case all over the world.

The original Curve Number method can be traced back to infiltrometer tests carried out by the SCS. The purpose was to establish basic data to evaluate the effects of watershed treatments and soil conservation measures on the rainfall-runoff process. The curve number (CN) is derived from the tables given in the National Engineering Handbook for catchment characteristics, such as soil texture, land use, hydrologic condition, and initial soil moisture condition.

Another important parameter of SCS model is initial abstraction coefficient (λ), it plays an important role in calculating the direct runoff, the hydrograph of peak flow, and the runoff distribution time(Baltas et al., 2007a).The original SCS-CN model calculated the initial abstraction (Ia) as a constant 20% of the maximum potential retention (S), based on observed rainfall and runoff data in North America valleys in 1954.Since then, the initial abstraction ratio, defined as Ia /S, has been applied to estimate direct runoff in many different countries. Although λ is set to 0.2 in the original SCS-CN model adjusted from experimental data in North America, the validity and applicability of this result is ambiguous in other regions of the world (Ponce and Hawkins, 1996a; Shi et al., 2009a). For example, for 50% of rainfall events used in 0.2.(Tedela et al. 2012a), λ ranged is 0.095~0.38, whereas for all rainfall events λ ranged is set 0.013 to 2.20. λ is described as a regional parameter (Mishra and Singh, 2003a), because its selection requires refinement for regional watersheds.

The SCS-CN model supplies sufficient room for variation due to the rainfall difference on spatial and temporal. For example, the measured rainfall-runoff data, and the different grades of antecedent soil moisture content (AMC) (Ponce and Hawkins, 1996a; Mishra et al., 2006a). The AMC is a function of the total rainfall of 5 days ago and the infiltration capacity of watershed soil. it is divided into three classes, AMC-I(dry), AMC-II (normal), and AMC-III (wet), The ARC-II grade is considered as the reference condition for CN values choose from National Engineering Handbook tables (SCS, 1971a).But the evaporation is variably in different catchments caused the soil water retention quality is difference in the same rainfall situation.

In summary, we need to explore new ways to improved model parameter calculation method. The purpose is to reduce the model parameters, simplified model structure, decreasing model error due to different geographical environment of the river basin.

2. Material

2.1. The Study Area

The study area of this paper is located in Xinjiang of China in central Asia. It lies in the plain of upstream Boertala River in Xinjiang（44°50′～45°58′N，80°07′～81°05′E）, named as Wen-quan basin. The total area of Wen-quan basin is 999 km2, the annual average precipitation is 228 mm, the average DEM is 3500 m. This watershed surrounded by mountains and January to February more than half of the total mountain area is covered by snow, a depth of more than 20 cm, as depicted in Fig.1. (Dou Yan et al., 2010a). The basin accumulated snow from November to march every year. Snow melting flood started to happen with the temperature rising from April, and the snowmelt became the major supply for the basin in spring. Precipitation is increasing from June to September, and the rainfall became the major supply for the basin in summer. The direct runoff of Wen-quan basin is consists of two parts: rainfall and snowmelt, and with more flood disaster in April to September in the year, especially in Tuha farm, Zhalemute, chagange, angelige, and kundelun farm. The snowmelt flooding affects the continuous development of husbandry and peoples life-property safety in these regions. There have a hydrologic station and a weather station in Wen-quan basin.

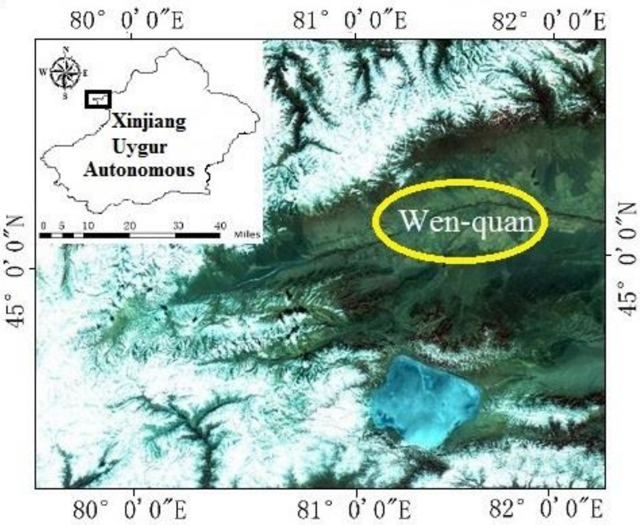


Figure 1. Watershed location in the study area of China.

This paper used many different sources of data which mainly include the meteorological, the hydrologic, the soil type, the land use types, the high-definition earth observation satellite "Gaofen-1" image, and the landsat8 OLI image. Depicted the details is shown in Table1.

Table 1. Geographical data for study area.

Data type	Data description
Meteorological data	Daily precipitation and temperature observations data from 3-4th in 2013 in study area
Hydrologic data	Daily runoff observation data of Boertala River hydrological Station from 3-4th in2013
Soil type and soil moisture	Filed observations data include land use and 36 points soil moisture
Soil texture	Extract from harmonized world soil database ;the resolution is 1km，It uses FAO90 soil classification system.
Remote-sensing image	① "GF-1"satellite image serial number：229827; DATE ACQUIRED：2014-05-19；② Landsat8 OLI image WRS_PATH:147; WRS_ROW：29; DATE ACQUIRED：2013-06-05；③SRTM90 m resolution DEM data.

3. Method

3.1. Original SCS-CN Model

The wildly used and popular method for direct runoff simulation is the SCS-CN model, it is based on water balance equation and two assumptions. The water balance equation is:

$$P = Q + F + I_a \tag{1}$$

Where, P is the total rainfall depth (mm), Q is the direct surface runoff (mm), F is actual retention after runoff begins, and Ia is the initial abstraction (mm).

We can write the two hypothesis as follows,

$$\frac{Q}{P - I_a} = \frac{F}{S} \tag{2}$$

$$I_a = \lambda S \tag{3}$$

Where, S is the potential maximum retention (mm) after runoff begins; λ is the initial abstraction coefficient. Depending on above equations, we can express the direct surface runoff simulation equation as follows:

$$Q = \frac{(P - \lambda S)^2}{P + (1 - \lambda)S} \tag{4}$$

S can be transformed to a dimensionless CN, varying in a logical range (0, 100) and can be expressed as in Eq. (5).

$$S = \frac{25400 - 254CN}{CN} \tag{5}$$

The CN values can be calculated from the valley characteristics, for example: the land use/cover, hydrologic condition, hydrologic soil group, and antecedent moisture condition) (SCS, 1971).

3.2. New Proposed Model

This paper through the following methods to improve the SCS model parameter algorithm:

3.2.1. Rainfall modified. Primary model of SCS is a pure study on rainfall and runoff. In order to satisfy the character of mix supplied runoff, the precipitation revised to the sum of rainfall and snowmelt. The snowmelt calculated by degree-day model. The equation written as follow:

$$P = P_r + P_s \tag{6}$$

Where, P is the daily total precipitation (mm), Pr is observed daily rainfall (mm), Ps is the daily snow-melting (mm). because of the simple structure and less parameters involved, the degree-day model used in calculate the Ps in Eq.(7).

$$P_s = DDF \cdot PDD \tag{7}$$

Where, DDF is degree-day factors (mm/（d·℃）), PDD is called the positive degree-day factor. Based on result of Zhang Yong(Zhang Yong, 2006), we used the method of Kriging spatial interpolation calculate PDD of Wen-quan basin is 2.7 mm/（d·℃）. we can express the PDD as follow:

$$PDD = \sum_{t=1}^{n} H_t * T_t \tag{8}$$

Where, Tt is the average temperature for a period. Ht is logical variable. Tt≥0℃, Ht=1.0. Tt≤0℃, Ht=0.0.

3.2.2. Potential maximum retention (S) modified. Potential maximum retention (S) of original SCS-CN model is calculated by curve number. This paper use remote sensing estimation the S, in order to reduce the parameters of SCS model. The remote sensing data has polygon characteristics, through remote sensing obtain the value of S also has polygon characteristics. It has global and representative in large basin. We use the relationship of surface temperature and vegetation index (TS/VI) combined with technology of remote sensing information extract inversion the soil moisture of study area. And then combined with water absorption balance of soil to calculate the value of S. improve methods introduced described as below.

Potential maximum retention is determined by the soil texture, the soil infiltration, the surface vegetation coverage, the land use/cover, hydrologic condition, hydrologic soil group, and antecedent moisture condition in original SCS-CN model. The process of estimate to S is very complicated. Based on water absorption balance of soil to calculate the potential maximum retention, we can explain as follow:

$$S=C（W_{max} - W_{soil}） \quad (9)$$

Where, C is adjustment coefficient, W_{max} is saturated soil moisture content, obtained by field measuring the soil porosity and soil bulk density. In this paper, we take the 100% to calculate due to lack of data. W_{soil} is antecedent soil moisture, use the method of remote sensing and TS/VI to calculate. Model parameters unit unified mm. Moran results show that the changes relationship between the surface temperature and soil moisture is very close. Take the vegetation index (VI) as the x-axis, the surface temperature (TS) as y-axis can be constructed corresponding temperature - vegetation drought index (TVDI) and fitting equation to calculate the soil moisture content effectively. Where, the normalized difference vegetation index (NDVI) is calculated by the satellite of landsat8 OLI image combining Equation 5 as follow:

$$NDVI = (NIR-R) / (NIR+R) \quad (10)$$

Where, R is red band belong to band 4 of OLI; NIR is near infrared band belong to band 5 of OLI. The surface temperature is calculated by the Landsat8 TIRS based on atmospheric correction method.

4. RESULTS

Use improved method of SCS model and original SCS model respectively to simulate the 18 rainfall events runoff of Wen-quan basin, in 2013.

4.1. Calculation the Parameters of Original SCS-CN Model

Original SCS model simulation requires different parameters, for example: the curve number, the potential maximum retention (S), and the initial abstraction coefficient (λ). The cn value is the first parameter to calculate that synthesize the surface vegetation coverage, the land use/cover and classification, hydrologic condition, hydrologic soil group (HSG), and antecedent moisture condition (AMC) to determine. Depending on the soil infiltration rate and minimum soil texture, the hydrologic soil group is divided into A, B, C, D 4 categories, the soil infiltration rate reduce in turn from A to D. the HSG criteria can be find in Table 2. And then extract the soil texture of Wen-quan basin with GIS from the harmonized world soil database. The result show that the soil texture in the study area composed with sandy loam and loamy sandy. The soil hydrology group classified of Wen-quan basin is A. The curve number is affected by soil moisture, so the SCS model divided the soil moisture into three levels, AMCI is dry, AMCII is average, AMCIII is moist. Statistics the precipitation events of study area in 2013, we can identify the antecedent soil moisture condition of study area is AMCII. Use the 16m resolution remote sensing image about high-definition earth observation satellite "Gaofen-1" to provide a high degree accuracy data of the land use classification for SCS-CN to determine the curve number. The classification accuracy is 86.43% and kappa coefficient is 0.837, detail is shown in Figure 2. The classification area of land use and its AMCII curve number in study area shown in Table 3. The Wen-quan basin curve number is 73.33.

Table 2. Hydrologic soil group classification of SCS-CN model.

Soil classification	Minimum of infiltration rate/($mm \cdot h^{-1}$)	Soil texture
A	>7.26	sand; loamy sand; sandy loam;
B	＞3.81～7.26	Loam; silt loam
C	＞1.27～3.81	sandy clay loam
D	0～1.27	clay loam; silt clay; clay; sand clay

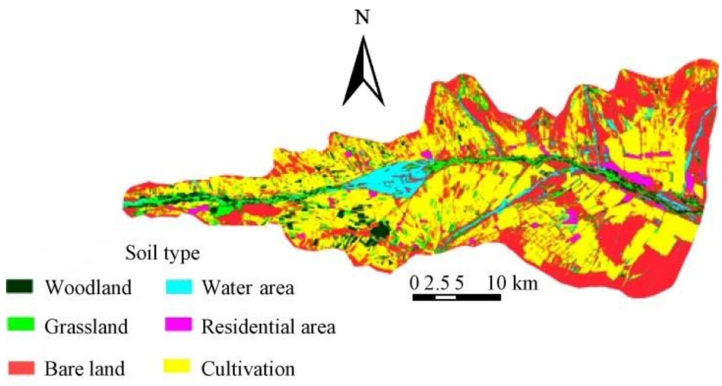


Figure 2. Land use classified of Wen-quan watershed based on GF-1 image.

Table 3. Curve number value and areas of different land use under medium soil moisture.

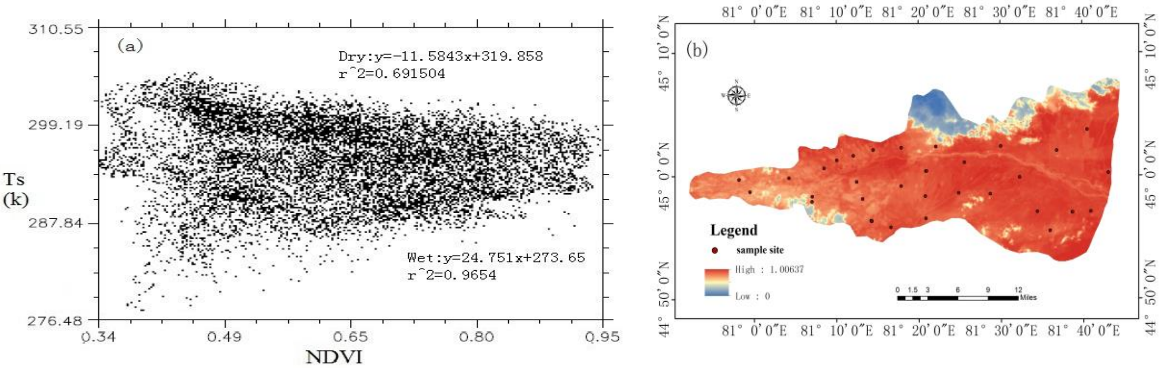
Soil type	Land use area/km^2	Total area percent/%	Curve number of hydrologic soil group A and AMCII
Residential area	21.1	2.1	1.06
Cultivation	449	44.9	31.91
Woodland	40	4.0	1.80
Bare land	375.8	37.6	28.97
Grassland	53.9	5.4	3.67
Water area	59.2	5.9	5.92
Total area	999	CN	73.33

Take the curve number to Eq. (5) and estimate the potential maximum retention in study area is 92.37. Statistics 101 rainfall events of Wen-quan basin in 2013, modified the precipitation to the sum of rainfall and snowmelt and use the degree-day model calculate the snowmelt.

Take the 101 rainfall events observed runoff, the modified precipitation, and the potential maximum retention into Eq. (4) calculate the initial abstraction coefficient (λ). Screen 18 rainfall events to simulate the runoff in study area by boundary condition of precipitation greater than infiltration, and use 12 events for parameter calibration, 6 events for validation. Selected median, mean, and mode of 12 events initial abstraction coefficient to simulation the runoff respectively and find that accuracy is the highest when the initial abstraction coefficient (λ) is 0.45 in study area.

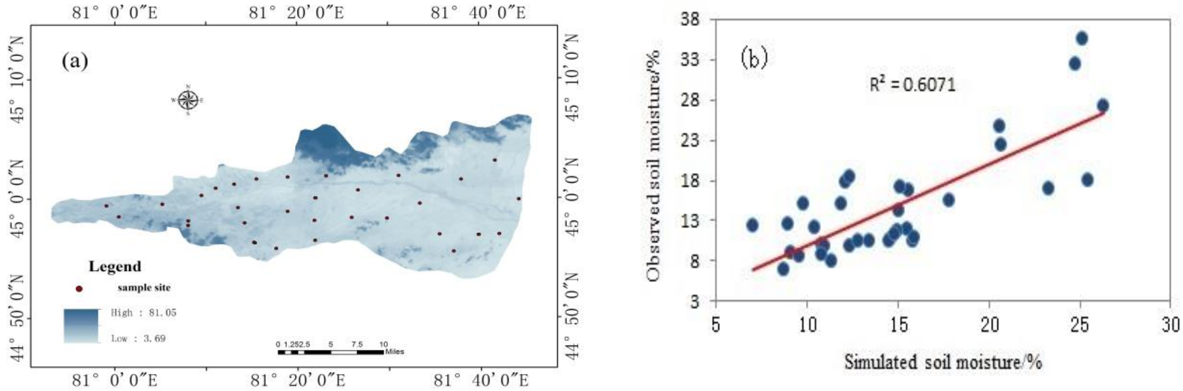
4.2. Calculation the Parameters of Improved Method

After the improved method of SCS model to simulate the runoff need two parameters, potential maximum retention (S) and initial abstraction coefficient (λ). S is determined by saturated soil moisture content and soil moisture content. Saturated soil moisture content equals 1. The soil moisture content calculate as follow:(1) use of landsat8 remote sensing image extract the information of NDVI and LST to build the 2D scatter plots and TS / VI fitting equation to calculate the TVDI in Wen-quan basin, shown as Figure 3.



a. Ts/VI characteristic spaces Dimensional scatter plot of Wen-quan watershed.
b. Distribution of TVDI in Wen-quan watershed.
Figure 3. Characteristic spaces and TVDI distribution in Wen-quan watershed.

Use of space distribution of TVDI to calculate the surface soil moisture content space distribution of study area in June 5, 2013, described the map as Figure 4a. Spatial distribution of soil moisture consist by a number of pixels, each pixel corresponds to a soil moisture digital number representatively. Combined with formula (9) calculated potential maximum retention (S) is 85.61 mm, the initial abstraction coefficient (λ) is 0.499 in study area. Take the flied data verification the accuracy of soil moisture which inversion by remote sensing and TS/VI method. The result show that both calculated and measured soil moisture correlation coefficient is 0.6071 and relative error coefficient is -0.2%, shown as Fig.7b. It proved that accuracy of inversed soil moisture is reliability.



a. SRWC of the Wen-quan watershed

b. Correlation analysis of the soil moisture between measured and simulated

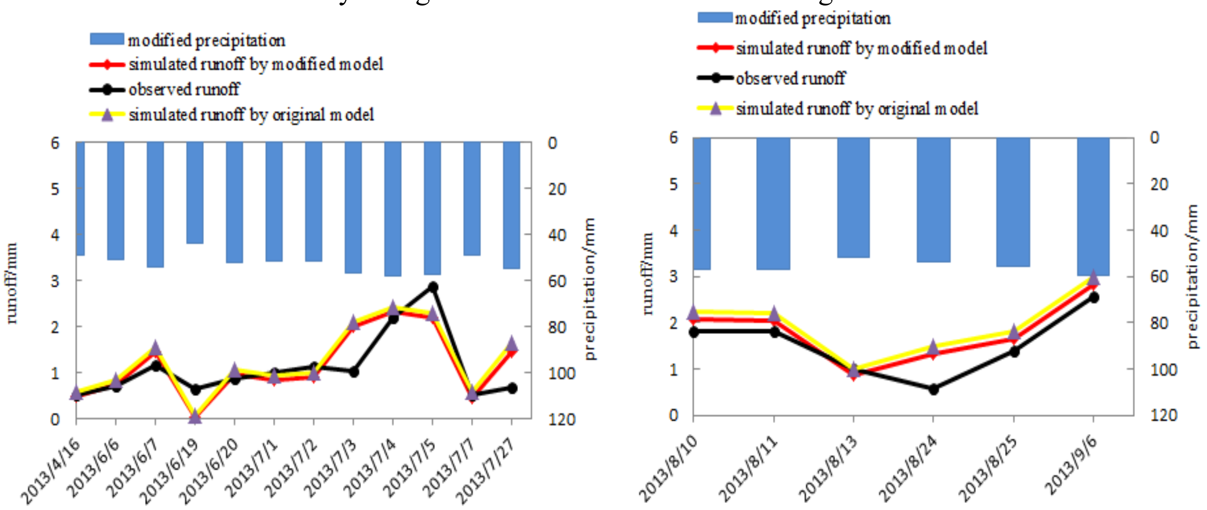
Figure 4. Soil moisture distribution and verification in Wen-quan watershed.

4.3. Comparing Estimated Runoff Results

The original and improved SCS model runoff simulation results of 18 rainfall events shown in Figure 5.Two models results compared to observed runoff had a relatively consistent trend. The simulation and observed runoff has a positive correlation with modified precipitation. Both original and improved SCS model Nash-Sutcliffe efficiency and relative error coefficients shown as Table 4.

5. DISSCUSSION

Compared with previous studies, this paper based on structure of original model improved the parameters calculation method. Use data observed by landsat8 and GF-1 satellite to calculate the potential maximum retention of study area. It has following advantages: 1) The calculated potential maximum retention(S) just like remote sensing data has planar characteristics. It has a good representation at large scale. 2) Because of the updated remote sensing data, the potential maximum retention(S) with better timeliness. 3) This method need fewer parameters and the data easy to obtain, it can addresses the lack of hydrological data on arid and semi-arid region.



a. Compared of observed and simulated runoff by calibration periods. b. Compared of observed and simulated runoff by validation periods.

Figure 5. Compared of simulated and observed runoff between original and modified model in Wen-quan watershed.

Table 4. NSE (Nash-Sutcliffe efficiency) and RE (relative error) for simulation performance assessments.

Assessment indexes	Calibration periods		Validation periods	
	Original SCS model	Modified SCS model	Original SCS model	Modified SCS model
NSE Nash-Sutcliffe efficiency	0.71	0.79	0.38	0.66
Relative error/%	12	3	27	17

6. CONCLUSIONS

• This paper use landsat8 OLI remote sensing image and combine with TS/VI inversion the soil moisture of Wen-quan basin, compared with the measured results,soil moisture correlation coefficient is 0.6071 and relative error coefficient is -0.2%. The results indicated that the accuracy of inversed soil moisture is available to apply in the SCS model.

• Soil moisture which inversed by remote sensing composed of many pixels has a planar characteristic. It represents an average soil moisture value of study area. By using inversed data to calculate the potential maximum retention have already realized indirect the point data change to the planner. Results showed that the improved model simulation value is better than original model. Both of them in the validation periods correlation coefficient were 0.66,038. And relative error were17%, 27%. It is further explained that we can use remote sensing to inversion the land surface parameters for SCS-CN model and modified algorithm of SCS-CN model parameters can improve the accuracy of the simulation results. This method has the advantage of requiring less computation with few parameters and a simple structure. It can avoid being influenced by lack of data and have feasibility and practicability. The method can be used for similar conditions of study area, especially helpful the lack of data basin to simulate the runoff. With the large-scales and complex underlying surface conditions, the simulation precision should be further improved. Radar image is an effective way to improve the accuracy.

7. Acknowledgements (optional)

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8. References

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