# EFFECT OF DEM RESOLUTION ON ASTRONOMIC RADIATION

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**KEY WORDS**: DEM, Astronomic Radiation, Resolution, Sensitive Analysis

**ABSTRACT:**

The development of digital terrain analysis based on DEM is helpful for the simulation of astronomic radiation in rugged area. However the effect of DEM scale causes great uncertainty to the simulation. Taking loess hilly region and mountain of Qinling as test area, this paper conducts the relationship between simulated astronomic radiation and DEM resolution through simulating daily, monthly and yearly astronomic radiation based on a serial of DEMs with different resolutions. The experiment result shows that simulated astronomic radiation increases gradually with decrease of DEM resolution. When DEM grid cell size is greater than relative heights of test area, radiation simulation is stable and the terrain factors such as slope gradient and aspect do not impact the redistribution of solar radiation any more. In loess hilly region, when DEM grid cell size is near 1 000- meter, the relative error on yearly astronomic radiation is about 22% that is above to a winter's radiation in this area. In Qinling mountain area, errors are relative small and the maximum of relative error is 17.8%. In a word, the impact of DEM resolution of simulating solar radiation is greater in hill than that of mountains.

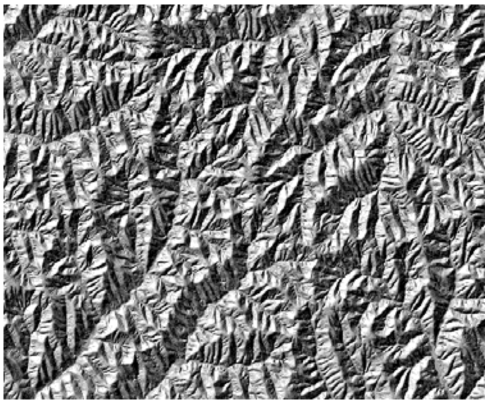
## 1. INTRODUCTION

The astronomic radiation in mountain and hill area is strongly affected by the relief. Chinese scholars, such as Zuo Dakang (1991), Weng Duming (1988), Fu Baopu (1989) propose a model for calculating global and local astronomic radiation in China, which is the base of simulating astronomic radiation. Dozer(1990) put forward a way for calculating astronomic radiation based on DEM at the first time. Chinese scholars Li Xin (1996), Zeng Yan (2003) and Yang Xin (2004) research the simulation of astronomic radiation in different areas based on the DEMs with different scales and get abundant results. But all of those researches do not take the effect from the scale of DEM into account. The raster resolution is an important spatial parameter which can decide the precision of the terrain from DEM. The slope, aspect and terrain shade from DEM will show the great discrepancy, when the resolution changes. The astronomic radiation is the base of direct radiation and is an important part for global radiation. In the paper, we take the loess hill area in North Shaanxi and the QinLing mountain area as test area, use DEM in different resolutions as basic data, and research the basic characteristics of astronomic radiation simulation based on DEM at different scales.[1]

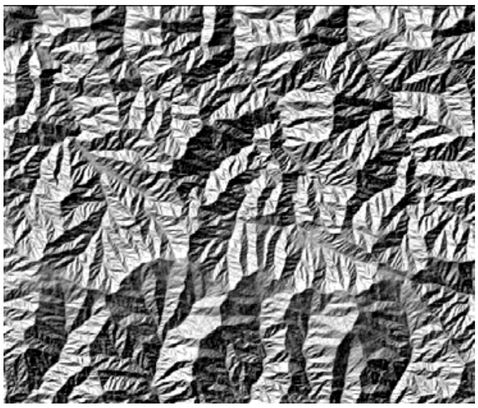
## 2. EXPERIMENT BASIS

### 2.1 Test area

The hilly area of the Loess Plateau and Qinling is taken as study site, shown as Figure 1. The loess hill area located in middle of YanHe river, southwest of YanChuan County, north in Shaanxin Province. The geo-corrdinate is between 109°52′30″—110°00′00″E and 36°42′30″—36°47′30″N, with a total area of 21 $Km^2$. The altitude difference is 328M. The surface is broken and terrain is rugged. The mean slope is 27°, and the climate of the area is warm temperature continental monsoon semi-arid climate.



a. hilly area of the Loess Plateau



b.Qinling

Figure.1 The hillshade map of test area

The Qinling mountain area lies in the edge of ZhouZhi County and FoPing County of South ShaanXin Province, the highest peak of Qinling mountain. The geo-corrdinate is between 107°59′37″—108°15′21″E and 33°39′38″—33°50′23″N, with the total area of 92 $Km^2$,.Its altitude difference is 1734M and the

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average slope is 31°. The climate of the district is subtropical continental monsoon humid climate.

### 2.2 Test dataset

The original DEM is generated from topographic map by the standard of DEM production of SBSM (State Bureau of Surveying and Mapping). The DEM of loess hilly area is generated from 1:10000 scale topographic map with the 5m resolution. The DEM of Qinling area is established based 1:50000 scale topographic map with the 25m resolution. The projection of the basic DEM is Gauss Krige and the coordinate system is Xi'an 1980. The DEMs with different resolution for test from the basic DEMs are achieved by resample method.

## 3. EXPERIMENT

There is great variability in the terrain parameter derived from the DEM with different scales, and it will affect the precision of the simulation. The astronomic radiation is the base of direct radiation and is an important part the global radiation, so the accuracy of the astronomic radiation simulation will directly affect the precision of direct radiation and global radiation. The paper discusses the effect of the DEM resolution on the astronomic radiation.

### 3.1 Astronomic radiation model

$$S_0 = \frac{I_0 T E_0}{2\pi} \sum_{i=1}^{n} \left[ u \sin\delta\left(\omega_{s,i} - \omega_{r,i}\right) + v\cos\delta\left(\sin\omega_{s,i} - \sin\omega_{r,i}\right) - w\cos\delta\left(\cos\omega_{s,i} - \cos\omega_{r,i}\right) g_i \right] \quad (1)$$

$$\begin{aligned} U &= \sin\varphi\cos\alpha - \cos\varphi\sin\alpha\cos\beta \\ V &= \sin\varphi\sin\alpha\cos\beta + \cos\varphi\cos\alpha \\ W &= \sin\alpha\sin\beta \end{aligned} \quad (2)$$

In the equation, $S_0$ is the astronomic radiation of one cell in relief area, $I_0$ is the constant for solar, T is the length of a day, $E_0$ is the revised factor of earth orbit[1-3], $\varphi$ is the latitude, $\alpha$ is slope , the $\beta$ is aspect and the n is dispersed number of the insolation-duration. The $\omega_{r,i}$ and $\omega_{s,i}$ are sunrise hour angle and sunset hour angle on the slope in *i*th differential time unit t, and $g_i$ is the terrain shading. The extraction of the terrain parameters are based on DEM, including slope, aspect and relief shading. Moreover, we calculate the astronomic radiation of cell by cell in different period after the composite analysis of multi-layers.

### 3.2 Implementation of the test

From the model, we find out the terrain parameters (slope, aspect and terrain shading) can affect astronomic radiation. The test analyzes the difference between the terrain parameters and the DEMs in different scales and discusses the effect to the result of astronomic radiation simulation. The procedure is showing as following steps:

Step 1: Generation of DEM in different scales. The DEM of 1:10000 scales reflects the actual terrain and can be used as the basic DEM. We resample the DEM with neighbourhood window of 3*3, 5*5 and 7*7(in 10m interval) till 105m. The terrain parameters are not so sensitive to the DEM resolution when the DEM resolution is coarser than 105m. Hence the resample interval is enlarged to 50m and the final resample resolution is 1005m. To keep the similarity of the terrain and avoid interpolation, we take the centre point of the grid of DEM in 1:10000 scales for resample. The Qinling area is relatively large, so the resample process in this area is based on the DEM in 1:50000 scale.

Step 2: Simulation of astronomic radiation based on the DEM in different DEM resolutions. The key point of the process is to get the insolation-duration of each cell of the DEM. So the sunshine time is dispersed to 36 intervals. The racy tracing algorithm is applied to judge whether the cell is shaded in each differential unit. At last, we summed the result to get the daily astronomic radiation. The monthly mean radiation is represented by that of typical day of each month. The details of algorithm are proposed by Yang (2004)

Step 3: model construction
The model that used to describe the astronomic radiation changes with DEM resolution is established. It could be used to calculate the error of different scales, which provides dataset for analysis.

Step 4: analyzes the relationship between the astronomic radiation simulation and the resolution of the DEM in different slopes and aspects.

## 4. EXPRIMENT RESULT AND ANAYSIS

### 4.1 Daily astronomic radiation

$$S_{loess} = 3\times10^{-7} X^3 - 2\times10^{-4} X^2 + 0.052X + 23.984$$
$(X \le 350)$ $R^2 = 0.99$ (3)

$$S_{mountain} = 1\times10^{-8} X^3 - 2\times10^{-5} X^2 + 0.0169X + 24.641$$
$(X \le 1000)$ $R^2 = 0.99$ (4)

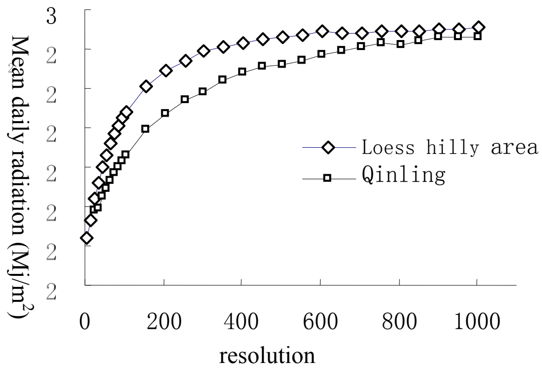


Figure2 mean radiation change with DEM resolution

The mean daily astronomic radiations in two test areas increase with the decrease of DEM resolution, which is shown as Figure 2. The reason is that the terrain becomes gentler when grid size of DEM increases. The insolation-duration is greater in less shaded area. However, the ratio is different in study site. The daily radiation in loess hilly area increases rapidly when the resolution is coarser than 200m and become gentler when the resolution is coarser than 350m, which is expressed as Formula (3) .In the formula, X is the grid size of DEM (m), and S is the daily astronomic radiation (MJ/m$^2$). The 350m is a critical value for the X and which is near the average altitude difference in the loess hill area, and the radiation will not change when X is higher than 350m. It shows the terrain will not be a notable influential factor for radiation when the grid size of DEM is larger than the relative height of test area. In the Qinling Mountain area, the relative altitude difference is higher than that of loess

### 4.2 Annual astronomic radiation

In the test, the DEM of 5m resolution is the most accurate DEM, correspondingly factors derived from it is the most accurate. Hence, we take the result of simulation from the 5m resolution DEM as criterion to statistic the error of simulation in different resolution (See Appendix A).In the loess hilly area, the error of annual astronomic radiation is equal to that of 12$^{th}$ month when the DEM resolution is 25m. However, the error will be greater than the total radiation in the winter of this area (1333.7 MJ/m$^2$) when then DEM resolution is coarser than 105m. The maximum relative error in this area is 22%. For the Qinling Mountain area, the error increases gently. In this area, the error equals to the radiation of the 12$^{th}$ month (428.8MJ/m$^2$) when the DEM resolution is 95m. But the error approaches the average monthly radiation (753.68 MJ/m$^2$), when the DEM resolution is 155m.

The error is greater than the total radiation in the winter of this area (1424.6 MJ/m$^2$) when the DEM resolution is coarser than 605m. Its maximum relative error of this area is 17.82%.
The relative altitude difference in Qinling Mountain area is high. Hence, the increase of radiation is gentler with the decrease of DEM resolution. So the simulation value in the mountainous area with great relative altitude difference is not so sensitive to the resolution of DEM.

### 4.3 Terrain Analysis of astronomic radiation

The terrain parameters (Slope, Aspect, Terrain shade) which are used in the astronomic radiation simulation are derived from DEM. Hence, these parameters will change when the DEM resolution changes. The accuracy of simulation will be influenced with the change of DEM resolution.

1 .Slope

The Figure 3 shows the slope decreases notably with the decrease of DEM resolution. The slope of a same area will vary when the resolution of DEM changes. The slope of loess hilly area decreases from 32° to 1° in different resolution and affects the accuracy of the astronomic radiation simulation.

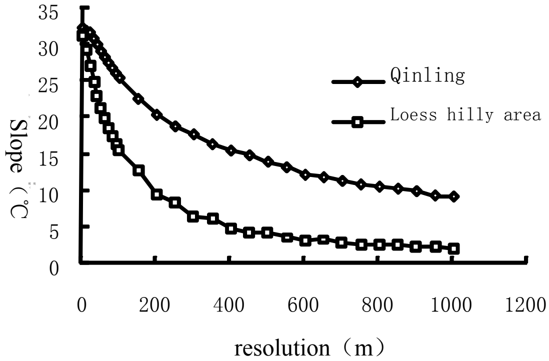


Figure.3 relationship between mean slope and with DEM grid cell size

The Figure 4 is the trend of average daily radiation with the slope changes. And the figure shows the same trend in both Qinling Mountain area and loess hill area. The astronomic radiation increases with the slope decrease. So, when the grid size of DEM increases, the terrain become more flat, and the slope from DEM based on window analysis decreases notably. The astronomic simulation value increases, whose value is near to the radiation on the flat.

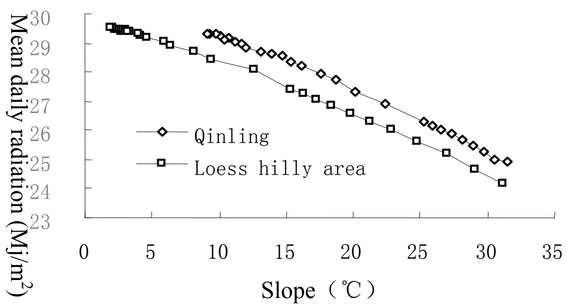


Figure.4 relationship between mean daily astronomic radiation and slope

2. Aspect

Figure 5 shows the trend of average radiation in 8 aspects with resolution change. The radiation in each aspect changes in different degrees. When the DEM resolution coarsens, the final result is near to the same value. When the DEM resolution becomes coarser, the astronomic radiation in the N, NE, NW aspect increases largely. The increase of radiation on the east and west is slow at first, and then become gentler. The radiation in the S, SE, SW increases. When the resolution is coarser than 200m, the radiation increases slightly and decreases later, finally it becomes smooth. So, the radiation in the shaded terrain, the radiation increases rapidly. With the coarsening of DEM resolution, the terrain is smoothed and flat. Moreover, due to the limitation of aspect algorithm based on window scanning, the proportion of aspect changes and the radiation on the northern slope increase. So the radiation on the northern slope increased most fast when the DEM resolution coarsens. In the loess hilly area, the average radiations in different aspects concentrate rapidly when the DEM resolution coarsens. The terrain effect of the aspect to the radiation distribution is not obvious when the DEM resolution is coarser than 400m. On the contrary, the radiation in Qinling Mountain area is more concentrated. The aspects in this area still work when then resolution is coarser than 1000m. So, when the grid size of DEM is coarser than maximum altitude difference of the area, the aspect will not influence the redistribution of local radiation is not notable.

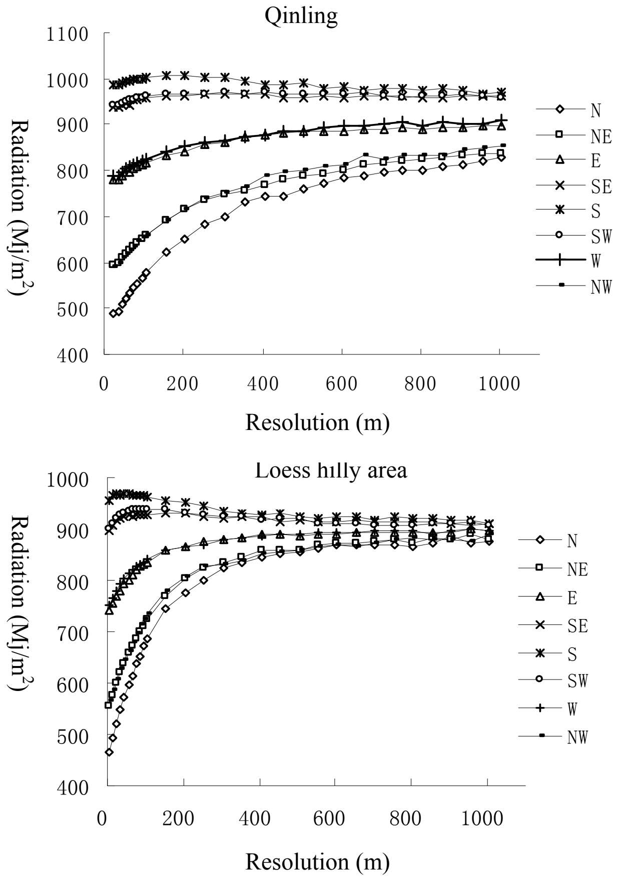


Figure.5 radiation change with grid resolution at different aspect

## 5. CONCLUSION AND DISCUSSION

1. The radiation of different DEM scale varies greatly .The radiation increases rapidly at first and then become smooth. The astronomic radiation in the loess hilly area increases rapidly when the DEM resolution is coarser than 350m. After that, it becomes smooth. Differently, the astronomic radiation of Qinling Mountain area keeps a steady increase.

2. Taking the simulated astronomic radiation based 5m DEM as criteria, the error of annual astronomic radiation changes with different DEM resolution and different types of terrain. In the loess hilly area, the error equals to the monthly radiation of the winter when the resolution is 25m. But the error will be greater than the winter radiation when the DEM resolution is coarser than 105m. In the Qinling Mountain area, the terrain is rugged and the error increases slowly. The error will be greater than the winter radiation of the area when the resolution is coarser than 605m. So the resolution of the DEM is more influential to the radiation simulation when the terrain is gentler.

3. The slope and radiation is inverse relation. The aspect decreases obviously with the coarsening of DEM resolution and the radiation increases. When resolution of the DEM coarsens, the average radiations on the aspects concentrate to the same value. In the loess hilly area, the statistical value of each aspect is almost the same when the resolution of the DEM is coarser than 400m. The aspect will not impact the redistribution of local radiation.

4. Astronomic radiation is the base of simulating solar direct radiation, global radiation, and so on. More efforts are needed to study the relationship of DEM resolution and solar radiation.

## ACKNOWLEDGMENTS

Thanks for financially support from the National Natural Science Foundation of China (No.40571120, No.40671148), Specialized Research Fund for the Doctoral Program of Higher Education (No.20050319006) and the National High Technology Research and Development Program of China (2006AA12Z212), Research Foundation of Nanjing Normal University (2008105XGQ0048).

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**APPENDIX A.**

| Resolution (m) | Loess hilly area | | | Qinling | | |
|---|---|---|---|---|---|---|
| | Annual radiation ($MJ/m^2$) | Error ($MJ/m^2$) | Relative error (%) | Annual radiation ($MJ/m^2$) | Error ($MJ/m^2$) | Relative error (%) |
| 5 | 8824.24 | 0.00 | 0.00 | - | - | - |
| 15 | 9003.66 | 179.42 | 2.03 | - | - | - |
| 25 | 9190.87 | 366.63 | 4.15 | 9083.95 | 0 | 0 |
| 35 | 9350.64 | 526.40 | 5.97 | 9114.34 | 30.39 | 0.33 |
| 45 | 9487.30 | 663.06 | 7.51 | 9213.38 | 129.43 | 1.42 |
| 55 | 9605.71 | 781.46 | 8.86 | 9292.42 | 208.47 | 2.29 |
| 65 | 9702.18 | 877.94 | 9.95 | 9361.96 | 278.00 | 3.06 |
| 75 | 9798.02 | 973.78 | 11.04 | 9438.24 | 354.29 | 3.90 |
| 85 | 9872.32 | 1048.08 | 11.88 | 9494.50 | 410.55 | 4.52 |
| 95 | 9944.87 | 1120.62 | 12.70 | 9551.22 | 467.27 | 5.14 |
| 105 | 10001.80 | 1177.56 | 13.34 | 9602.31 | 518.35 | 5.71 |
| 155 | 10242.70 | 1418.46 | 16.07 | 9830.16 | 746.21 | 8.21 |
| 205 | 10385.34 | 1561.10 | 17.69 | 9975.26 | 891.31 | 9.81 |
| 255 | 10477.44 | 1653.20 | 18.73 | 10116.33 | 1032.38 | 11.36 |
| 305 | 10558.43 | 1734.19 | 19.65 | 10190.43 | 1106.48 | 12.18 |
| 355 | 10602.63 | 1778.38 | 20.15 | 10286.25 | 1202.30 | 13.24 |
| 405 | 10643.80 | 1819.55 | 20.62 | 10359.14 | 1275.19 | 14.04 |
| 455 | 10678.21 | 1853.97 | 21.01 | 10414.92 | 1330.96 | 14.65 |
| 505 | 10698.44 | 1874.20 | 21.24 | 10446.14 | 1362.19 | 15.00 |
| 555 | 10719.30 | 1895.06 | 21.48 | 10482.66 | 1398.71 | 15.40 |
| 605 | 10742.12 | 1917.88 | 21.73 | 10527.13 | 1443.17 | 15.89 |
| 655 | 10733.22 | 1908.98 | 21.63 | 10564.53 | 1480.58 | 16.30 |
| 705 | 10725.44 | 1901.20 | 21.55 | 10600.24 | 1516.29 | 16.69 |
| 755 | 10754.87 | 1930.62 | 21.88 | 10637.27 | 1553.32 | 17.10 |
| 805 | 10758.33 | 1934.09 | 21.92 | 10624.68 | 1540.73 | 16.96 |
| 855 | 10754.44 | 1930.20 | 21.87 | 10665.15 | 1581.20 | 17.41 |
| 905 | 10761.81 | 1937.56 | 21.96 | 10694.69 | 1610.74 | 17.73 |
| 955 | 10766.60 | 1942.35 | 22.01 | 10701.71 | 1617.76 | 17.81 |
| 1005 | 10783.56 | 1959.32 | 22.20 | 10702.28 | 1618.33 | 17.82 |