# Comparison of different radiation estimation models and their influence on APSIM model simulation results

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# Outline

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2. Technical route
3. Materials and methods
4. Research results
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# 1 Purpose and significance of research

- Daily solar radiation is a very important parameter in earth science, agriculture science, and other fields. However, compared with the conventional meteorological observatory, there were few observatories of the global radiation. Therefore, the estimation of solar radiation had become a focus. A variety of models for estimating solar radiation using conventional meteorological factors such as sunshine hours, temperature, cloud cover, humidity, precipitation, etc. In many radiation models in which the smallest error, there is no consensus.
- Crop model has become one of the most powerful tools for agricultural research, radiation as a necessary parameter for the crop model, currently in the absence of radiation observation area using crop models, radiation parameter is based on the radiation model to obtain. Different radiation

estimation model has different error, it is unknow that radiation estimation model influence on the effect of the APSIM model.

- In this paper, we provide the basis for selecting the appropriate solar radiation model for North China application. On the other hand, according to whether there is error amplification effect, it will provide a scientific basis for the reasonable selection of radiation model in crop model.

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# 2 Technical route

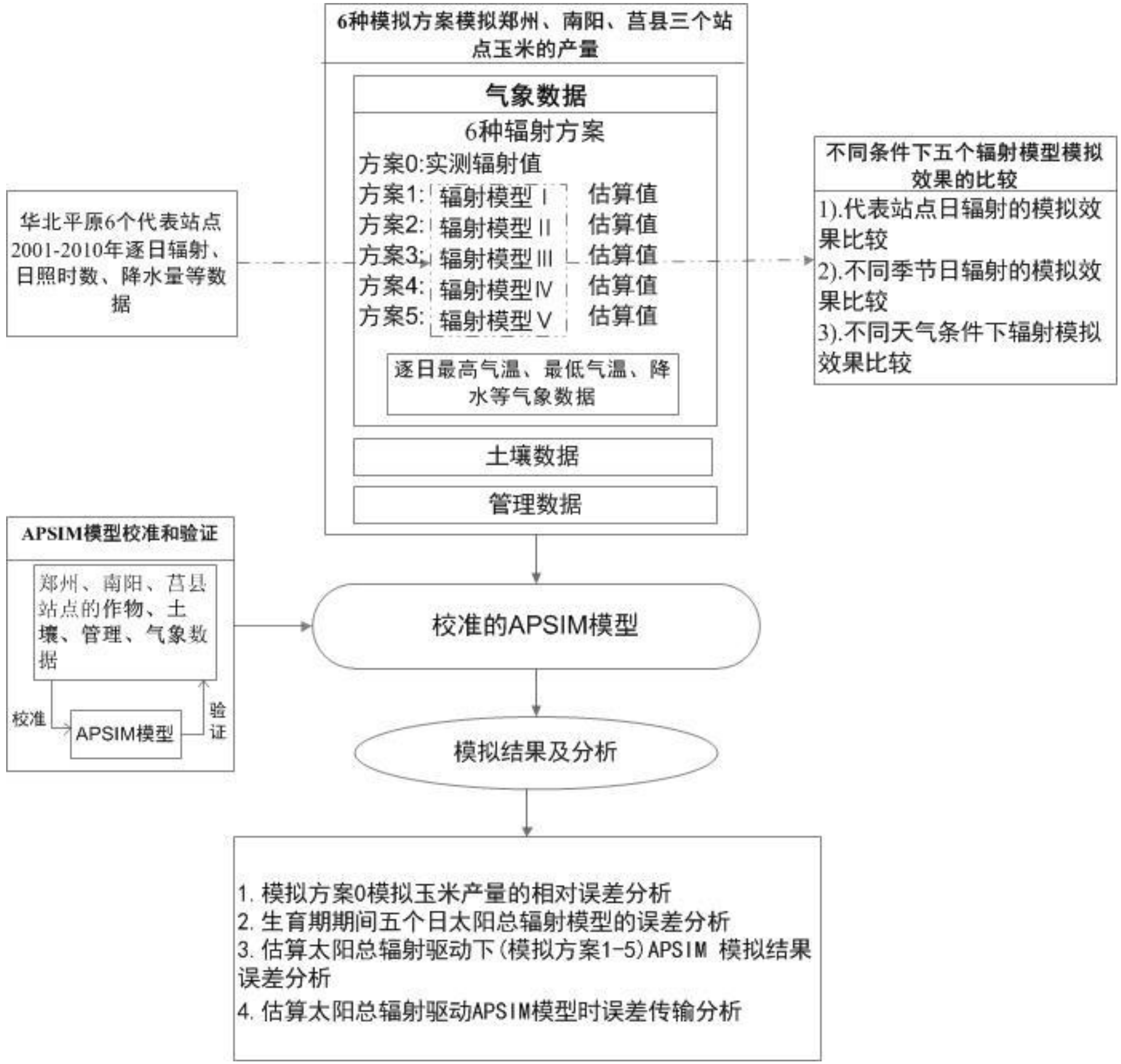



Fig.1 Technical route

# 3 Materials and methods

## □ Materials

- **Five radiation models required the data**

Daily observation solar radiation and meteorological data (from 2001 to 2010) of six representative stations in Northern China Plain.

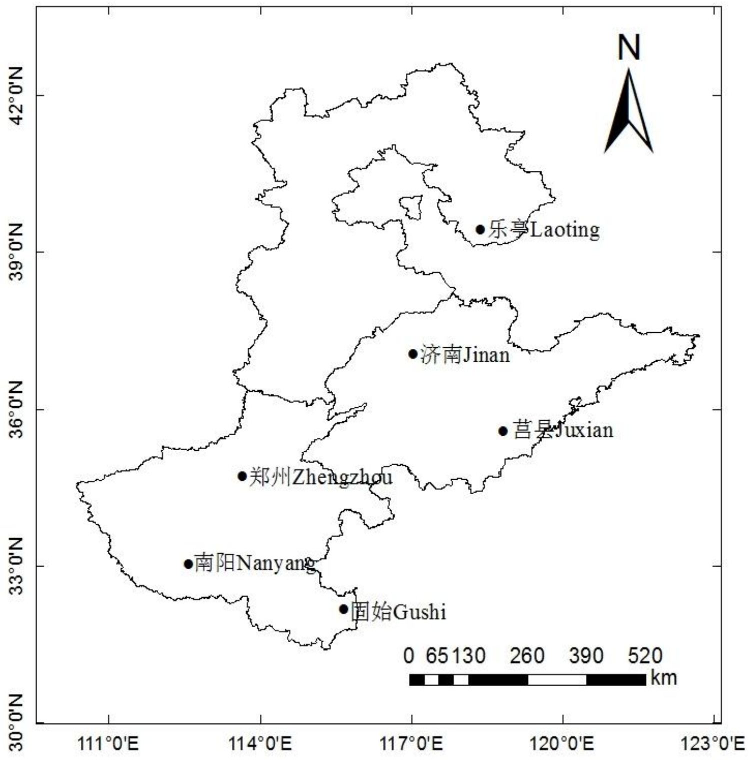



Fig.2 The geographical distribution of the selected meteorological stations

- **APSIM maize model to adjust the data required**

✓ There are solar radiation data and weather data and maize data at the same time Juxian, Zhengzhou, Nanyang (2001-2012) three stations in North China Plain.

(1) Crop data: Maize varieties, sowing date, seeding density, sowing depth, spacing, fertilization and irrigation measures, growth period (emergence, flowering and maturity) and yield.

(2)Meteorological data： Daily maximum temperature, minimum temperature, precipitation, total solar radiation.

(3) Soil data： Stratified soil bulk density, saturated water content, field water holding capacity, wilting coefficient and so on.

# Methods

- Five representative models were used to estimate solar radiation in this paper, under the analysis and comparison previous solar radiation estimation models.
- APSIM maize model parameter adjustment using trial and error method.
- The establishment of six simulation schemes

✓ Five radiation models: the Angstrom-Prescott model, Ogelman model, the Bahel model, the comprehensive model of sunshine duration and diurnal temperature range model (referred to as the comprehensive model) and Liu's model (followed by simulation scheme 1-5) were used to simulate the total solar radiation and validated against measurement (simulation scheme 0).

- Evaluation of the radiation model mainly using the following indicators: Correlation coefficient(R), Mean absolute error(MAE,%),Root mean square error（RMSE,MJ ·m$^{-2}$ ·d$^{-1}$）,Normalized root mean square error (NRMSE,%).
- Evaluation of the APSIM model mainly using the following indicators: The consistency index between simulated value and measured value (D index), MAE,RMSE, NRMSE.
- **Estimation error of radiation value during growth period（$\varepsilon_i$）：**

$$\varepsilon_i = \frac{\overline{R_i} - \overline{M}}{\overline{M}} \times 100\%$$

Where, $\overline{R_i}$ is the average value of the daily radiation values simulated by the radiation model used in the maize growth period simulation scheme $i$（$i$=1、2、3、4 、5）,$\overline{M}$ is the average value of measured daily radiation values during the growth period.

- Radiation errors transmitted to yield errors($\Delta C_i$)

Scheme 1-5 radiation errors transmitted to yield errors （$\Delta C_i$）: Scheme 0 is the standard, the yield error of Scheme 1-5 （$C_i$） minus the yield error of Scheme 0 （$C_0$）.

$$\Delta C_i = C_i - C_0$$

$$C_i = \frac{Y_i - Y}{Y} \times 100\% \qquad C_0 = \frac{Y_0 - Y}{Y} \times 100\%$$

Where, Y is the measured yield value,$Y_i$ is the simulated yield value of Scheme $i$（$i$ =1、2、3、4 、5）,$Y_0$ the simulated yield value of Scheme 0.

# 4 Research results

- **Validation and analysis of radiation models used in Northern China**
- **APSIM model in the study of regional applicability evaluation**
- **Different radiation estimation models influence on APSIM model simulation results**

# 4-1 Validation and analysis of radiation models used in Northern China

## □ 4-1.1 Five radiation models

Model I: A-P model

$$\frac{Q}{Q_0} = a + b\frac{n}{N}$$

Model II: Ogelman model

$$\frac{Q}{Q_0} = a + b\frac{n}{N} + c(\frac{n}{N})^2$$

Model III: Bahel model

$$\frac{Q}{Q_0} = a + b\frac{n}{N} + c(\frac{n}{N})^2 + d(\frac{n}{N})^3$$

Model IV: Comprehensive model

$$\frac{Q}{Q_0} = a\ln(T_M - T_m) + b(\frac{n}{N})^c + d$$

Model V: Liu's model

with sunshine duration:

$$\frac{Q}{Q_0} = \mathrm{a}_0 + \mathrm{a}_1(\frac{\mathrm{n}}{N}) + \mathrm{a}_2 \lg(W + P)$$

without sunshine duration:

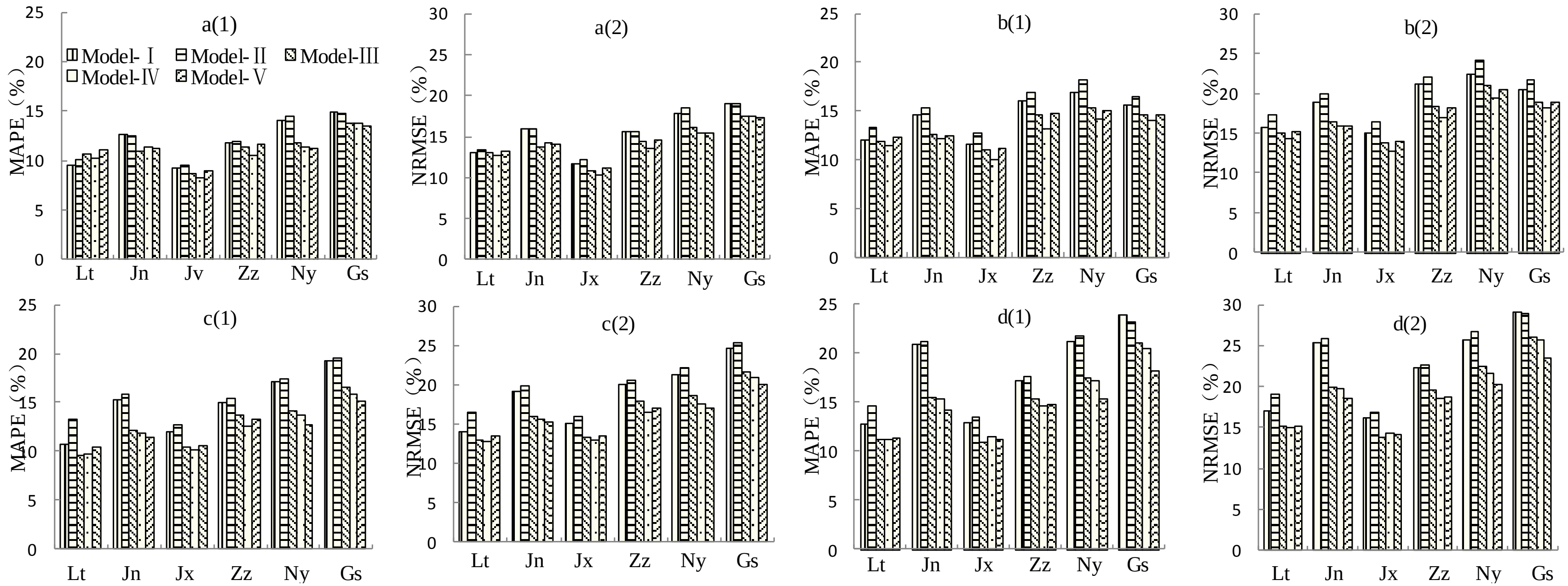
$$\frac{Q}{Q_0} = \mathrm{b}_0 + \mathrm{b}_1(T_M - T_\mathrm{m}) \times (1\text{-}Abs)$$

# 4-1.2 Daily observation solar radiation data (from 2001 to 2010) of six representative stations were used to compare the effect of five models

Table 1 Statistical characteristics values of the daily solar radiation calculated by five models in each station

| Station | Model | Correlative coefficient(R) | Mean absolute error(MAE,%) | Root mean square error （RMSE,MJ m$^{-2}$ d$^{-1}$） | Normalized root mean square error (NRMSE,%) |
|---|---|---|---|---|---|
| Laoting | I | 0.95 | 11.01 | 2.10 | 15.17 |
| | II | 0.95 | 12.37 | 2.29 | 16.55 |
| | III | 0.96 | 10.86 | 2.01 | 14.52 |
| | IV | 0.96 | 10.60 | 1.94 | 14.06 |
| | V | 0.96 | 11.34 | 2.04 | 14.84 |
| Jinan | I | 0.94 | 14.99 | 2.46 | 19.19 |
| | II | 0.94 | 15.39 | 2.55 | 19.82 |
| | III | 0.94 | 12.33 | 2.10 | `16.35 |
| | IV | 0.94 | 12.22 | 2.09 | 16.21 |
| | V | 0.95 | 14.44 | 2.42 | 18.79 |
| Juxian | I | 0.96 | 11.09 | 1.94 | 14.36 |
| | II | 0.95 | 11.79 | 2.08 | 15.43 |
| | III | 0.96 | 10.12 | 1.77 | 13.10 |
| | IV | 0.96 | 9.68 | 1.68 | 12.47 |
| | V | 0.97 | 10.35 | 1.79 | 13.29 |
| Zhengzhou | I | 0.94 | 14.59 | 2.55 | 19.80 |
| | II | 0.94 | 15.06 | 2.62 | 20.33 |
| | III | 0.95 | 13.41 | 2.27 | 17.58 |
| | IV | 0.95 | 12.32 | 2.11 | 16.34 |
| | V | 0.96 | 13.47 | 2.25 | 17.45 |
| Nanyang | I | 0.93 | 16.67 | 2.62 | 21.81 |
| | II | 0.93 | 17.38 | 2.78 | 23.12 |
| | III | 0.93 | 14.28 | 2.39 | 19.89 |
| | IV | 0.94 | 13.61 | 2.24 | 18.65 |
| | V | 0.95 | 13.54 | 2.32 | 19.26 |
| Gushi | I | 0.93 | 17.35 | 2.74 | 22.43 |
| | II | 0.93 | 17.56 | 2.81 | 23.00 |
| | III | 0.93 | 15.68 | 2.49 | 20.34 |
| | IV | 0.93 | 15.20 | 2.44 | 19.91 |
| | V | 0.94 | 14.91 | 2.42 | 19.80 |

## 4-1.3 Daily observation solar radiation data (from 2001 to 2010) of six representative stations were used to compare the effect of five models, according to different seasons.




a：Spring；b：Summer；c：Autumn；d：Winter

a1、b1、c1、d1 ：MAE　a2、b2、c2、d2：NRMSE

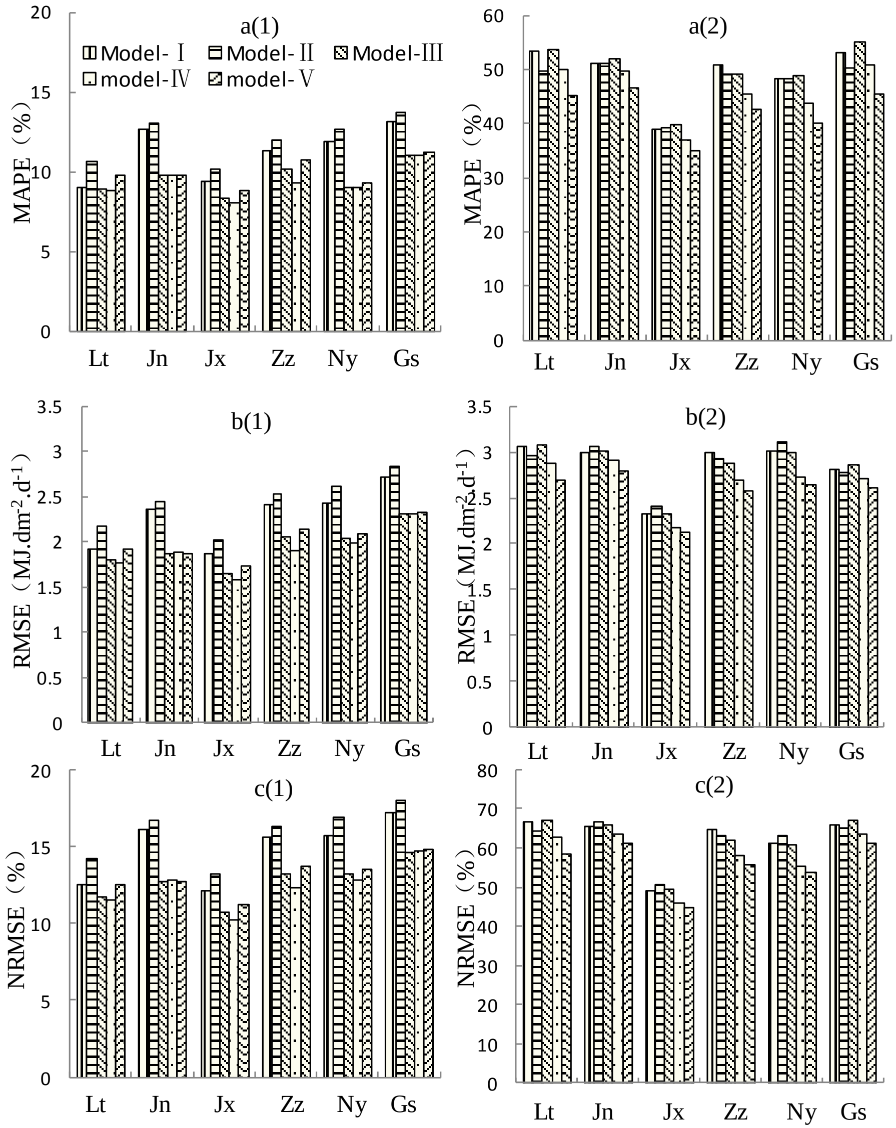
Note：Lt、Jn、Jx、Zz、Ny、Gs is Laoting, Jinan, Juxian, Zhengzhou, Nanyang, Gushi, respectively. The same as below.

**Fig. 3 Simulated error of five models during different seasons in each station**

Table2 The average value of simulated error during each season

| Season | Model | Average MAE(%) | Average NRMSE (%) |
|---|---|---|---|
| Spring(Mar.,Apr., May) | I | 11.97 | 15.46 |
| | II | 12.19 | 15.75 |
| | III | 11.17 | 14.27 |
| | IV | 10.86 | 13.95 |
| | V | 11.24 | 14.27 |
| Summer(Jun.,Jul., Aug.) | I | 14.46 | 18.89 |
| | II | 15.47 | 20.21 |
| | III | 13.32 | 17.21 |
| | IV | 12.45 | 16.22 |
| | V | 13.36 | 17.05 |
| Autumn(Sep.,Oct.,Nov.) | I | 14.81 | 18.94 |
| | II | 15.65 | 20.00 |
| | III | 12.67 | 16.66 |
| | IV | 12.19 | 15.94 |
| | V | 12.20 | 15.95 |
| Winter (Dec., Jan.,Feb.) | I | 18.08 | 22.52 |
| | II | 18.56 | 23.28 |
| | III | 15.19 | 19.42 |
| | IV | 14.99 | 19.06 |
| | V | 14.11 | 18.31 |

## 4-1.4 Daily observation solar radiation were used to compare the effect of five models, according to weather conditions.




a：MAE；b：RMSE；c：NRMSE
a1、b1、c1：sunshine duration
a2、b2、c2、d2：without sunshine duration

Fig. 4 Simulated error of five models under sunshine duration and without conditions

# 4-2 APSIM model in the study of regional applicability evaluation

## 4-2.1 The final identification of the maize parameters.

Table3 The main parameters of maize in APSIM at each station

| Parameter | Code | Juxian | Zhengzhou | Nanyang |
|---|---|---|---|---|
| Maximum grain number per head | head_grain_no_max | 620 | 600 | 600 |
| Grain-filling rate（mg·grain$^{-1}$·d$^{-1}$） | grain_gth_rale | 10 | 10 | 12 |
| Thermal time required from emergence to end of juvenile（℃·d） | tt_emerg_to endjuv | 150 | 125 | 150 |
| Photoperiod slope | photoperiod_slope | 20 | 18 | 18 |
| Thermal time required from flowering to maturity(℃·d) | tt_flower_to_maturity | 730 | 670 | 720 |

# 4-2.2 Validation results

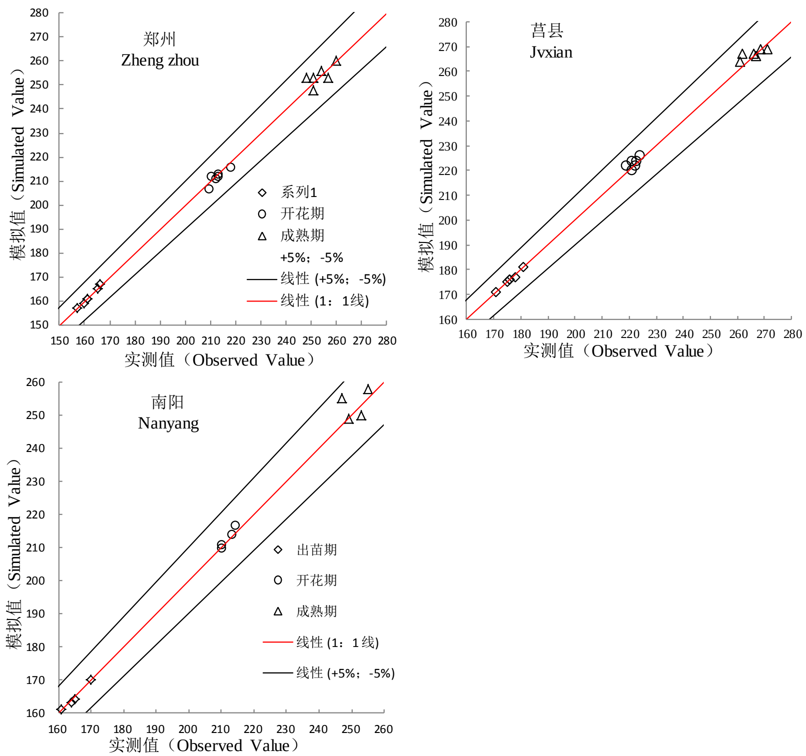



Fig.5 Validation results between simulated and measured days

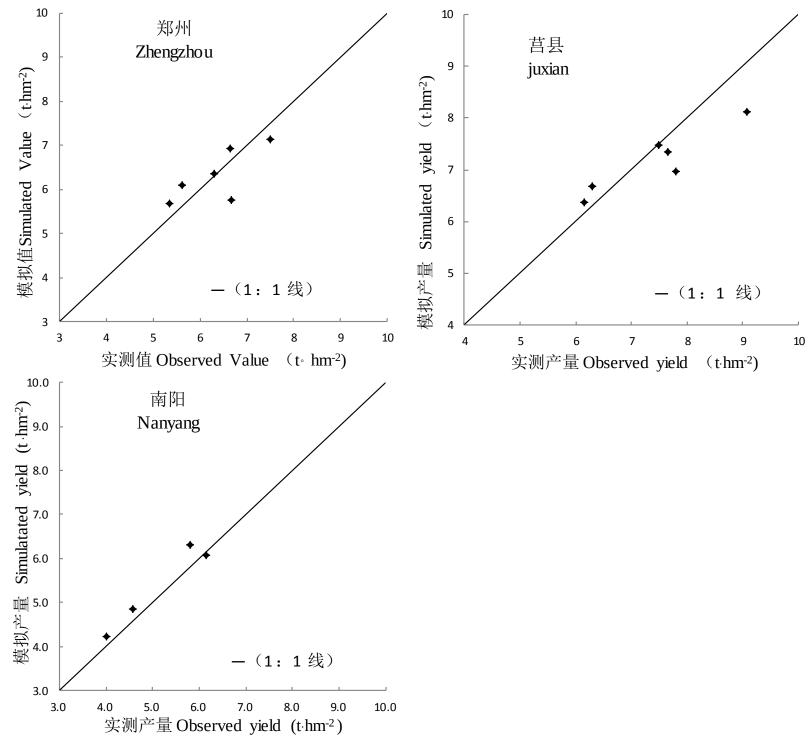



Fig.6 Validation results between simulated and measured yields

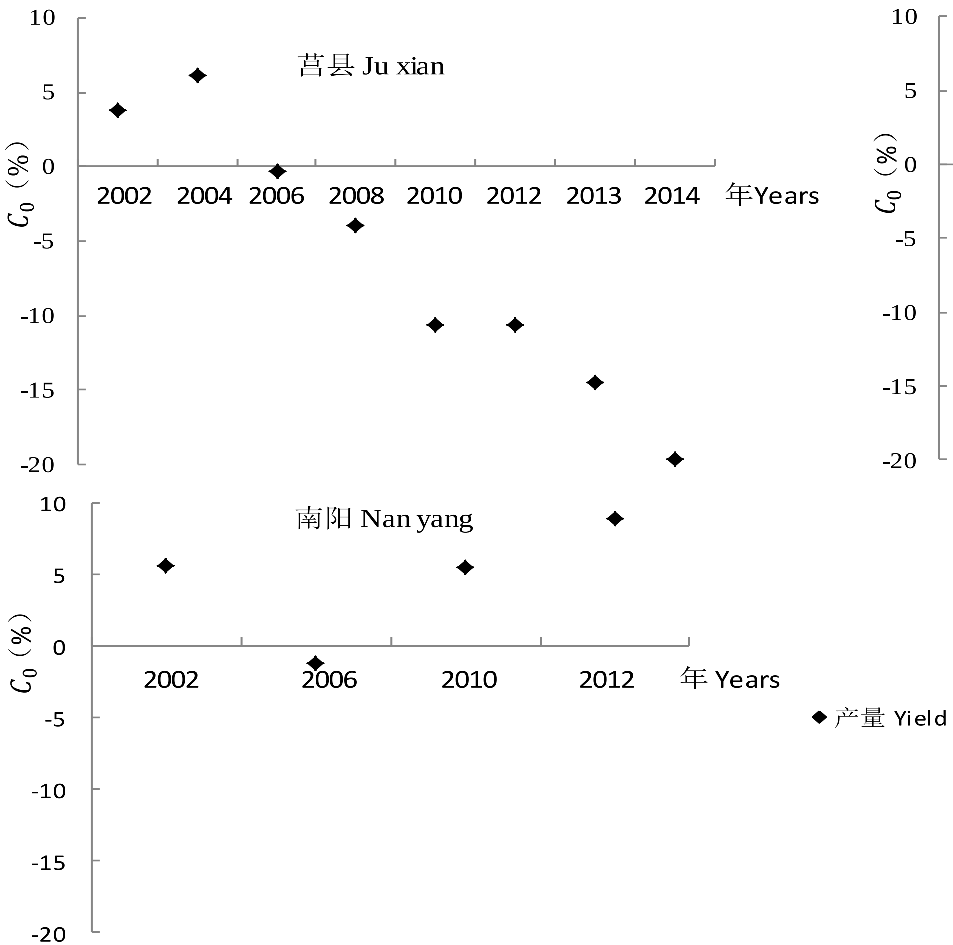
Table 4 Statistical indicators for validated APSIM model

| Station | Item | D | MAE | RMSE | NRMSE(%) |
|---|---|---|---|---|---|
| Zheng zhou | Emergence days（d） | 0.99 | 0.33 | 0.76 | 0.33 |
| | Flowering days（d） | 0.92 | 1.33 | 1.90 | 0.89 |
| | Maturity days（d） | 0.81 | 2.67 | 3.82 | 1.51 |
| | Yield （$t{\cdot}hm^{-2}$） | 0.85 | 0.40 | 0.62 | 11 |
| Juxian | Emergence days（d） | 1.00 | 0.17 | 0.41 | 0.23 |
| | Flowering days（d） | 0.69 | 1.75 | 2.05 | 0.93 |
| | Maturity days（d） | 0.77 | 2.08 | 2.59 | 0.97 |
| | Yield （$t{\cdot}hm^{-2}$） | 0.87 | 0.46 | 0.56 | 7.61 |
| Nan yang | Emergence days（d） | 0.99 | 0.50 | 0.71 | 0.43 |
| | Flowering days（d） | 0.87 | 1.25 | 1.66 | 0.78 |
| | Maturity days（d） | 0.61 | 3.50 | 4.53 | 1.80 |
| | Yield （$t{\cdot}hm^{-2}$） | 0.97 | 0.27 | 0.31 | 6.01 |

**It can be seen from Fig. 5 and Table 4 that the APSIM model can accurately simulate the growth and yield of maize**

## ➢ 4-3 Different radiation estimation models influence on APSIM model simulation results

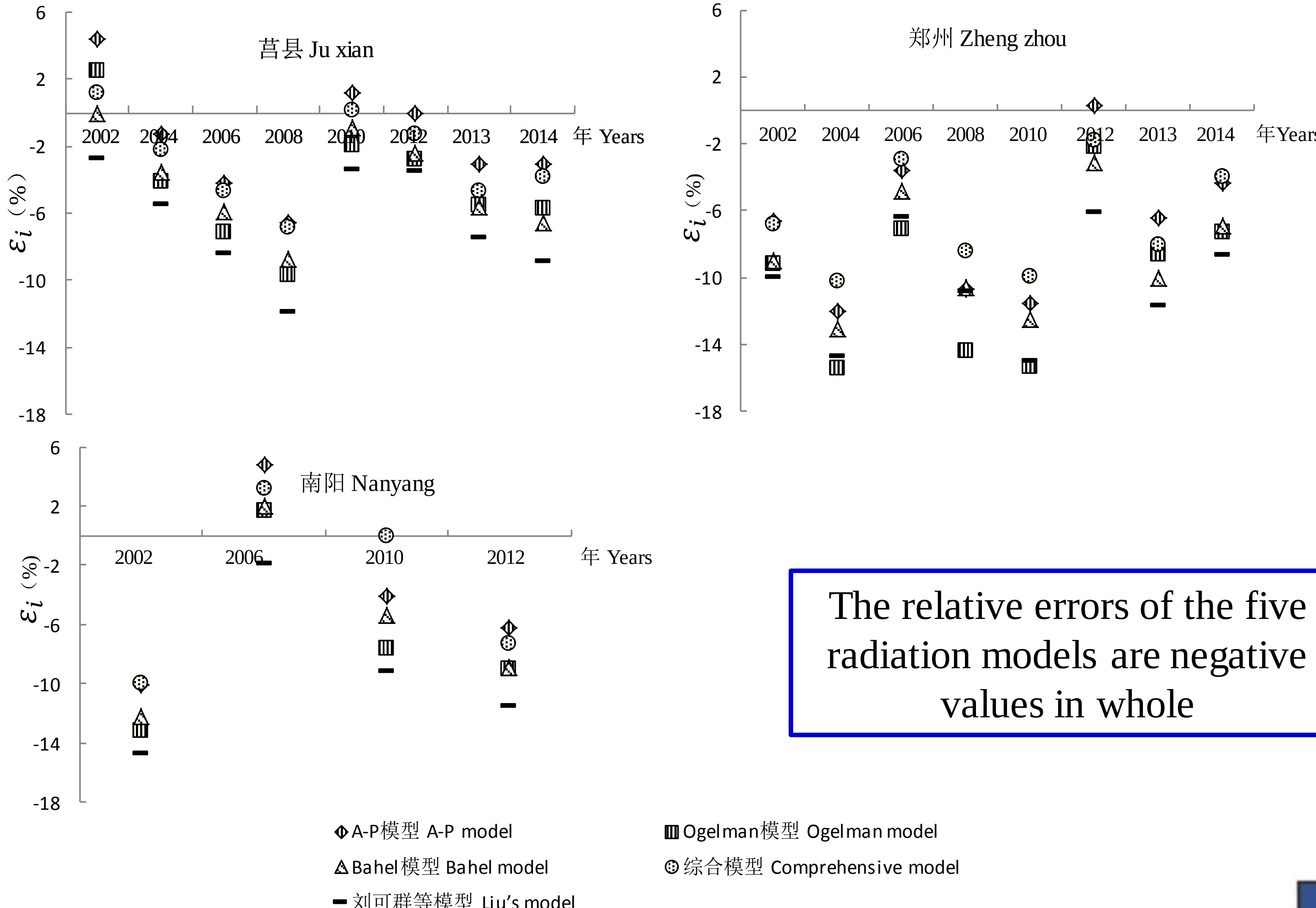
### ☐ 4-3.1 Simulated scheme 0 (radiation value is the measured value) simulation of maize yield error analysis




**It is better to use the measured radiation to drive the APSIM maize model to simulate the yield.**

Fig.7 Relative errors of simulated yield of APSIM Maize model driven by observed daily solar radiation

# 4-3.2 Error analysis of five radiation models during growth period




The relative errors of the five radiation models are negative values in whole

Fig.8 The five radiation model estimation errors during growth period

## 4-3.3 Simulated scheme 1-5 simulation of maize yield errors analysis

Table 5 The yield errors of the different simulation schemes（$C_i$） and radiation errors transmitted to the yield errors（$\Delta C_i$）（Juxian station）

| Year | Simulation scheme | $C_i$ (%) | $\Delta C_i$ (%) | Year | Simulation scheme | $C_i$ (%) | $\Delta C_i$ (%) |
|---|---|---|---|---|---|---|---|
| 2002 | 1 | 8.62 | 4.88 | 2010 | 1 | -7.69 | 2.95 |
| | 2 | 5.20 | 1.46 | | 2 | -12.56 | -1.92 |
| | 3 | 5.37 | 1.63 | | 3 | -9.10 | 1.54 |
| | 4 | 6.67 | 2.93 | | 4 | -8.46 | 2.18 |
| | 5 | -0.16 | -3.90 | | 5 | -13.08 | -2.44 |
| 2004 | 1 | 3.81 | -2.38 | 2012 | 1 | -9.81 | 0.77 |
| | 2 | -0.63 | -6.82 | | 2 | -17.42 | -6.84 |
| | 3 | 2.06 | -4.13 | | 3 | -8.16 | 2.42 |
| | 4 | 4.60 | -1.59 | | 4 | -9.26 | 1.32 |
| | 5 | -0.16 | -6.35 | | 5 | -12.24 | -1.66 |
| 2006 | 1 | -11.20 | -10.93 | 2013 | 1 | -17.39 | -2.96 |
| | 2 | -19.33 | -19.06 | | 2 | -22.76 | -8.33 |
| | 3 | -9.74 | -9.47 | | 3 | -18.23 | -3.80 |
| | 4 | -8.67 | -8.4 | | 4 | -17.28 | -2.85 |
| | 5 | -14.67 | -14.4 | | 5 | -21.39 | -6.96 |
| 2008 | 1 | -13.46 | -9.54 | 2014 | 1 | -21.96 | -2.32 |
| | 2 | -21.96 | -18.04 | | 2 | -25.33 | -5.69 |
| | 3 | -13.99 | -10.07 | | 3 | -25.16 | -5.52 |
| | 4 | -12.42 | -8.50 | | 4 | -22.31 | -2.67 |
| | 5 | -26.01 | -22.09 | | 5 | -27.91 | -8.27 |

Table 6 The yield errors of the different simulation schemes（$C_i$） and radiation errors transmitted to the yield errors（$\Delta C_i$） (Zhengzhou station)

| Year | Simulation scheme | $C_i$ (%) | $\Delta C_i$ (%) | Year | Simulation scheme | $C_i$ (%) | $\Delta C_i$ (%) |
|---|---|---|---|---|---|---|---|
| 2002 | 1 | -10.16 | -11.27 | 2010 | 1 | -35.83 | -22.34 |
| | 2 | -13.65 | -14.76 | | 2 | -43.63 | -30.14 |
| | 3 | -10.95 | -12.06 | | 3 | -34.18 | -20.69 |
| | 4 | -9.21 | -10.32 | | 4 | -30.58 | -17.09 |
| | 5 | -12.22 | -13.33 | | 5 | -39.58 | -26.09 |
| 2004 | 1 | -37.50 | -46.25 | 2012 | 1 | -15.47 | -10.67 |
| | 2 | -47.86 | -56.61 | | 2 | -24.67 | -19.87 |
| | 3 | -27.86 | -36.61 | | 3 | -14.53 | -9.73 |
| | 4 | -25.36 | -34.11 | | 4 | -13.07 | -8.27 |
| | 5 | -34.11 | -42.86 | | 5 | -24.93 | -20.13 |
| 2006 | 1 | -20.34 | -23.88 | 2013 | 1 | -10.00 | -14.44 |
| | 2 | -31.72 | -35.26 | | 2 | -17.33 | -21.77 |
| | 3 | -13.43 | -16.97 | | 3 | -11.33 | -15.77 |
| | 4 | -11.75 | -15.29 | | 4 | -7.78 | -12.22 |
| | 5 | -18.47 | -22.01 | | 5 | -15.33 | -19.77 |
| 2008 | 1 | -21.80 | -24.36 | 2014 | 1 | -6.13 | -1.46 |
| | 2 | -32.78 | -35.34 | | 2 | -7.73 | -3.06 |
| | 3 | -15.04 | -17.60 | | 3 | -4.93 | -0.26 |
| | 4 | -12.18 | -14.74 | | 4 | -3.60 | 1.07 |
| | 5 | -16.39 | -18.95 | | 5 | -6.93 | -2.26 |

Table7 The yield errors of the different simulation schemes（$C_i$） and radiation errors transmitted to the yield errors（$\Delta C_i$） （Nanyang station）

| Year | Simulation scheme | $C_i$（%） | $\Delta C_i$（%） | Year | Simulation scheme | $C_i$（%） | $\Delta C_i$（%） |
|---|---|---|---|---|---|---|---|
| 2002 | 1 | -12.88 | -18.56 | 2010 | 1 | -1.00 | -6.47 |
| | 2 | -18.34 | -24.02 | | 2 | -13.18 | -18.65 |
| | 3 | -10.26 | -15.94 | | 3 | -0.75 | -6.22 |
| | 4 | -9.83 | -15.50 | | 4 | 1.00 | -4.47 |
| | 5 | -17.90 | -23.58 | | 5 | -14.68 | -20.15 |
| 2006 | 1 | 7.79 | 9.09 | 2012 | 1 | -25.17 | -33.96 |
| | 2 | 0.65 | 1.95 | | 2 | -35.86 | -44.65 |
| | 3 | 4.87 | 6.17 | | 3 | -22.93 | -31.72 |
| | 4 | 5.03 | 6.33 | | 4 | -18.79 | -27.58 |
| | 5 | -3.25 | -1.95 | | 5 | -31.55 | -40.34 |

$\varepsilon_i$: Yield errors    $\Delta C_i$: Radiation errors transmitted to the yield errors

Scheme 4 has the smallest error compared with other schemes.

# 4-3.4 Errors transmission analysis when estimated radiations driven APSIM model

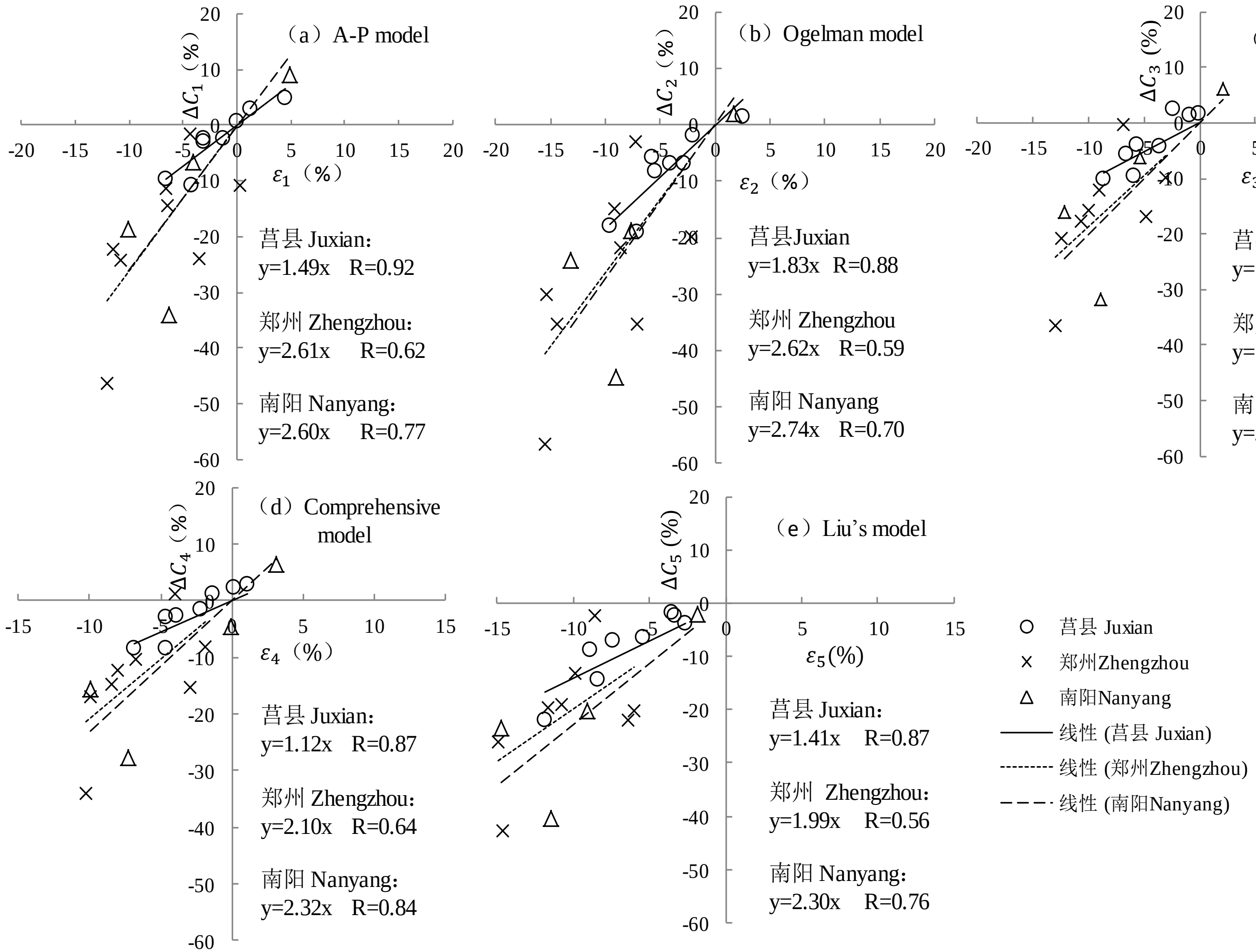



Fig.9 The relationship between different radiation model estimation errors($\varepsilon_i$)and transmitted to yiel errors($\Delta C_i$)

The statistical results show that the radiation errors brought by the five radiation models had enlarged the final results of maize yield simulated by APSIM model. In Juxian,Zhengzhou,Nanyang station, A-P model drives the APSIM model, the radiation error ($\varepsilon_i$) was amplified by 1.49, 2.61 and 2.60 times, respectively, average 2.23 times; Ogelman model was amplified 1.83,2.62, 2.74 times, average 2.28 times; Bahel model was 1.02, 1.86,2.00 times respectively, average 1.63 times；Comprehensive model was 1.12, 2.10, 2.32 times, average 1.85 times ;Liu’s model was 1.41,1.99,2.30 times，average 1.90 times. In a whole, amplified times **Ogelman model＞A-P model＞ Liu’s model ＞ Comprehensive model ＞Bahel model.**

# 5 Conclusions

- Validation and analysis of radiation models used in Northern China

- Angstrom-Prescott model（I）、Ogelman model（II）、Bahel model（III）、 Comprehensive model（IV）and Liu’s model （V）Five models and the corresponding coefficient showed high accuracy in estimating the solar radiation in Northern China. Juxian and Laoting station simulation effect were relatively good, Jinan and Zhengzhou station followed, Gushi and Nanyang station were relatively poor.
- In the four seasons. Model IV showed best in spring, summer, and autumn, while model V showed best in winter, following by model IV.
- Under the condition that sunshine duration existed, model IV showed best. In contrast, without sunshine duration, all of

the simulation results were "bad“, model IV showed best.

- In summary, five models could be used to estimate the daily solar radiation in Northern China Plain, and model IV (Comprehensive model) showed the highest accuracy.

## ➢ APSIM model in the study of regional applicability evaluation

The APSIM model can accurately simulate the growth and yield of maize.

## ➢ Different radiation estimation models influence on APSIM model simulation results

- Different radiation estimation models had significantly different effect on the APSIM model yield simulation results, **scheme 4 rendered the best result.**

- The radiation errors brought by the five radiation models had enlarged the final results of maize yield simulated by APSIM model. The propagation error transferred to APSIM maize model simulation yield was 2.23, 2.28, 1.63, 1.85, 1.90 for the Angstrom-Prescott model, the Ogelman model, the Bahel model, the comprehensive model and the Liu's model respectively. It is obvious that the selection of the radiation model and the empirical coefficient of the radiation model should be given full consideration; with regard to the errors of crop yield simulation caused by radiation models two factors should be taken into account: the errors of the five radiation models and these errors transmitted to the crop model with augmentation. Generally speaking, Scheme 4 has the smallest error compared with other schemes. Therefore it is recommended to be used to drive APSIM model in the absence of field measurement of radiation.

# 6 Innovation

- This paper compares the applicability of five common solar radiation in North China, which provides reference for the selection of radiation model in North China.

- In this paper, the effect of radiation model error on crop simulation was analyzed for the first time. The effects of different radiation models on APSIM model simulation of maize yield error were discussed(whether there is error amplification effect). On the one hand, the APSIM model is used to select the appropriate radiation model in North China. On the other hand, it provides scientific basis for the reasonable selection of the radiation model in the crop model concerned with the error amplification effect.

# Thanks !