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Yale-NUIST Center on Atmospheric Environment

# Effects of Aerosol Optical Depth on the Solar Radiation in the Yangtze Delta Region

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# OUTLINE

- Background and Objectives
- Materials and Methods
- Results and Discussions
- Conclusion

# Background

- Global solar radiation in most parts of the world is decreasing since the 1950s.
- The trend of cloud is not significant。

The changes of aerosol may play an important role in the variation of the global solar radiation.

- It must rely on reanalysis to get more continuous spatial and temporal radiation data.
- The radiation data of MERRA have positive biases with observations, the main causes of biases may be light cloud and aerosol.

Correction of reanalysis data is helpful to improve the accuracy of the research of climate change.

# Objectives

- In this study, impacts of AOD changes on solar radiation received by ground surface were analyzed in Yangtze Delta region. The relationship between AOD and direct solar radiation and diffuse radiation, was established. And, the solar radiation and diffuse radiation of MERRA was modified. The results of the study can be used for driving and verifying climate model and analyzing water cycle and energy balance.

# Materials and Methods

## （I） variation characteristics of global solar radiation, diffuse radiation and AOD in Yangtze Delta region

**global solar radiation and diffuse radiation data:**

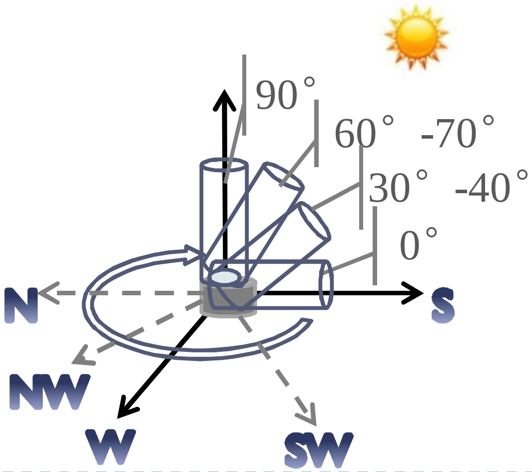
| Site | Latitude and Longitude | Period of $S$ | Period of $S_{df}$ |
|---|---|---|---|
| Nanjing | 32° N、118° 48′E | 1961/01/01-2012/12/31 | 1961/01/01-1989/12/31 |
| Hangzhou | 30° 14′N、120° 10′E | 1961/01/01-2012/12/31 | 1961/01/01-1989/12/31 |
| Cixi | 30° 16′N、121° 13′E | 1961/07/01-1990/12/31 | 1961/07/01-1990/12/31 |
| Shanghai | 31° 1′N、121° 26′E | 1961/01/01-1990/12/31 | 1961/01/01-1990/12/31 |
| | 31° 24′N、121° 29′E | 1991/07/01-2012/09/30 | 1991/07/01-2012/09/30 |

**AOD data:**

Terra and Aqua level2: 10km×10km

# Materials and Methods

- **（2）Analysis of relationship between global solar radiation and AOD**
- a: AOD with direct solar radiation and diffuse radiation were fitted by geometric regression method.
- b: Experiment on the effect of AOD on global solar radiation




# Materials and Methods

## （3） Correction of global solar radiation and diffuse radiation data for MERRA

$k_t$：

$$b_{Sm} = \frac{S_m - S}{S_m}$$

$$b_{Sm} = a \cdot k_t + b$$

$$k_t = \frac{S}{S_e}$$

$$S_e = S_{sc}[1 + 0.033\cos(360 t_d / 365)]\sin\beta$$

$$S = \frac{(1-b) S_m S_e}{a S_m + S_e}$$

AOD：

$$b_{Dm} = \frac{D_m - D}{D_m}$$

$$b_{Dm} = a \cdot AOD + b$$

$$D = (1 - a \cdot AOD - b) \cdot D_m$$



[*Gu et al.*,1999] [*Zhao et al.*,2013]

# Results and Discussions

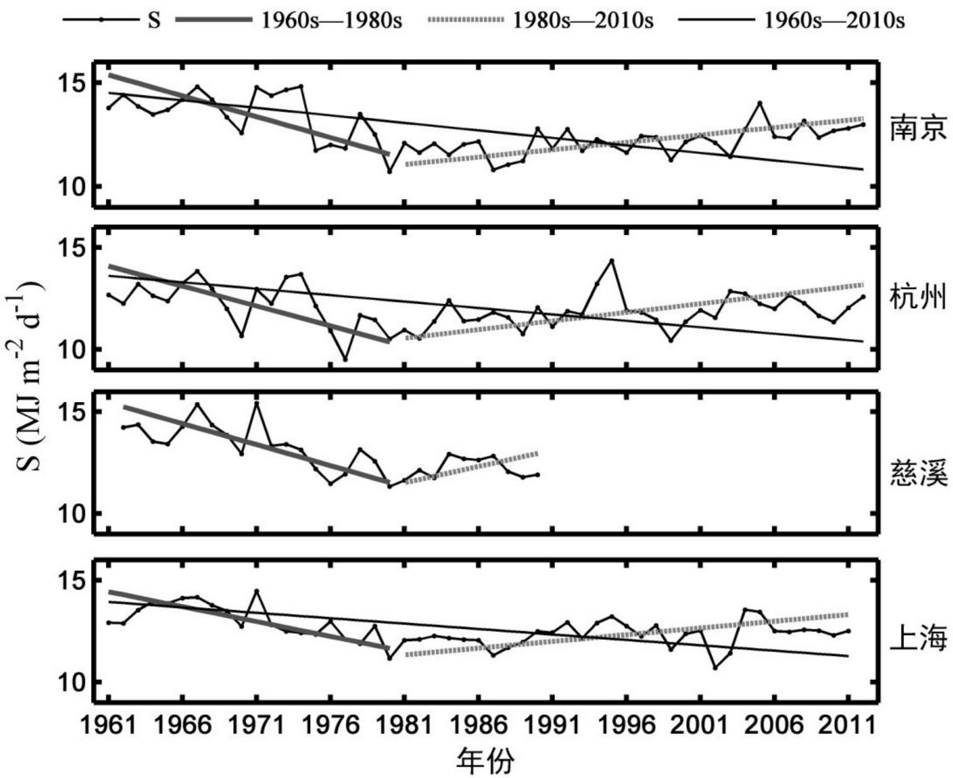



Figure 1 Annual variation characteristics of global solar radiation (S) in Nanjing, Hangzhou, Cixi and Shanghai

Table 1 the Mann-Kendal test results of annual variation characteristics of global solar radiation in Nanjing, Hangzhou, Cixi and Shanghai

| | 1960s-1980s | 1980s-2010s | 1960s-2010s |
|---|---|---|---|
| Nanjing | -0.98 * | 0.36*** | -0.26** |
| Hangzhou | -0.98** | 0.3** | No significant change trend |
| Cixi | -1.4*** | ð | ð |
| Shanghai | -1.01*** | 0.17** | -0.21** |

Units are MJ/m$^2$ every ten years

The*、**、*** Representatives passed the test of reliability 90%, 95% and 99% respectively.

# Results and Discussions

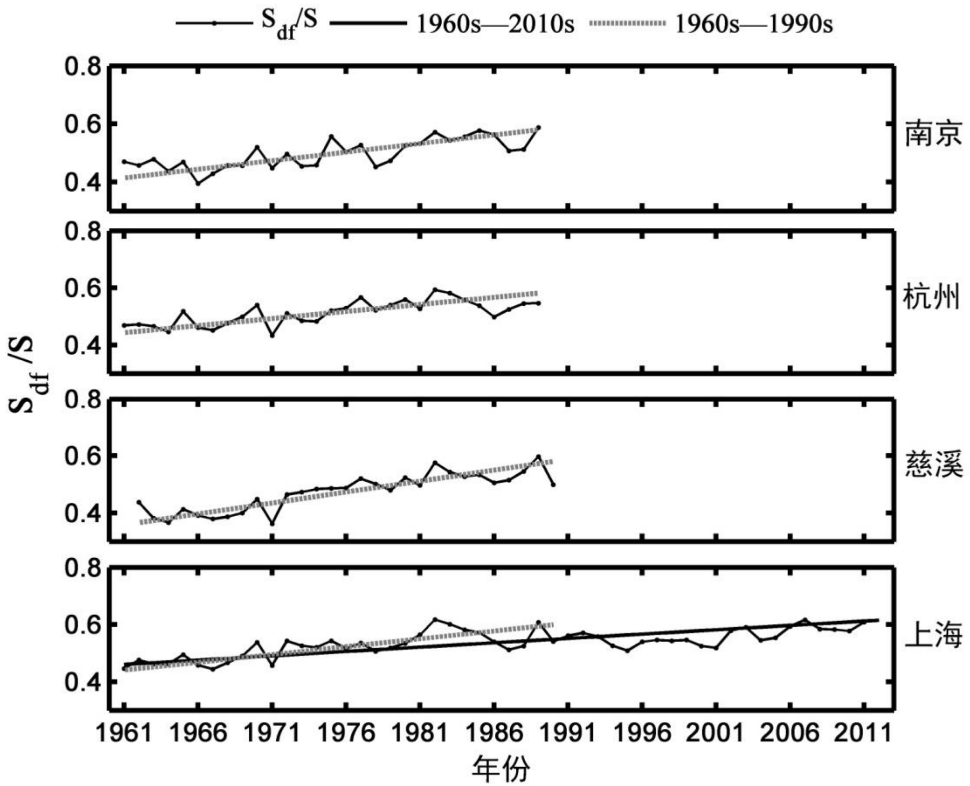



Figure 2 Annual variation characteristics of diffuse radiation proportion in Nanjing, Hangzhou, Cixi and Shanghai

Table 2 the Mann-Kendal test results of annual variation characteristics of diffuse radiation proportion in Nanjing, Hangzhou, Cixi and Shanghai

| | 1960s-1990s | 1960s-1990s |
|---|---|---|
| Nanjing | 4.25%*** | ð |
| Hangzhou | 3.75%*** | ð |
| Cixi | 6.75%*** | ð |
| Shanghai | 4.23%*** | 2.25%*** |

Units are every ten years

The*、**、*** Representatives passed the test of reliability 90%, 95% and 99% respectively.

# Results and Discussions

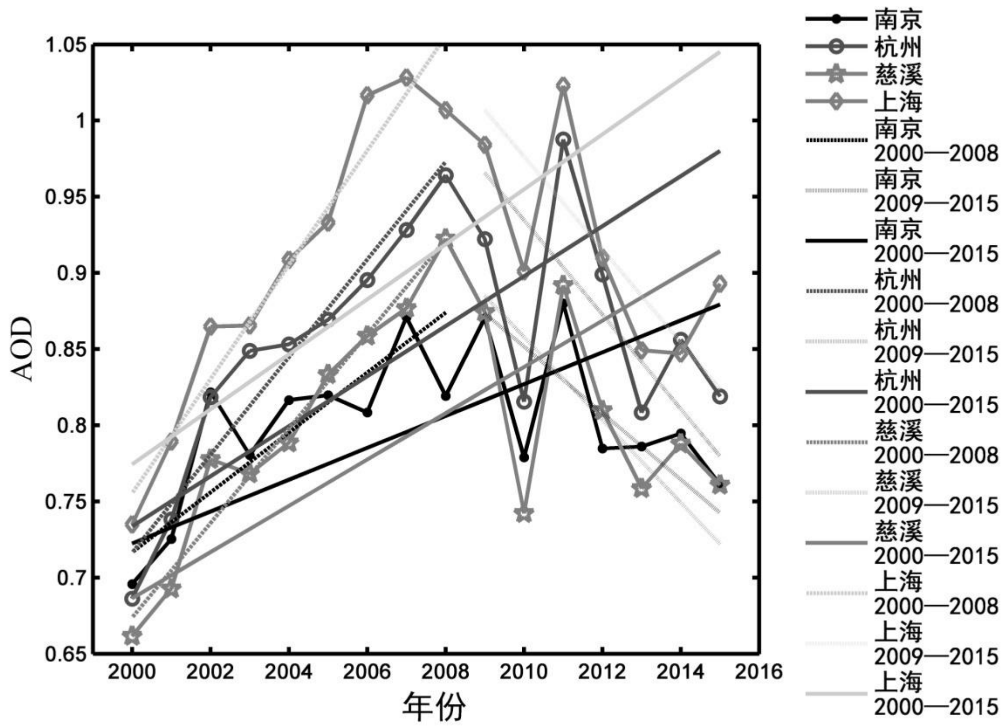



Figure 3 Annual mean value of AOD in Nanjing, Hangzhou, Cixi and Shanghai

Table 3 the Mann-Kendal test results of annual variation characteristics of AOD in Nanjing, Hangzhou, Cixi and Shanghai

| | 2000-2008 | 2009-2015 | 2000-2015 |
|---|---|---|---|
| Nanjing | 0.017 * | No significant change trend | No significant change trend |
| Hangzhou | 0.031*** | No significant change trend | No significant change trend |
| Cixi | 0.031*** | No significant change trend | No significant change trend |
| Shanghai | 0.039*** | No significant change trend | No significant change trend |

Units are every years

The*、**、*** Representatives passed the test of reliability 90%, 95% and 99% respectively.

# Results and Discussions

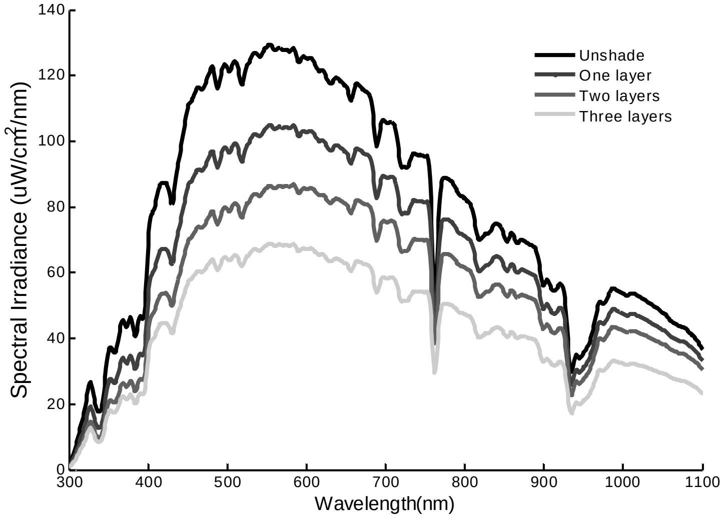



Figure 4 Solar radiation spectrum under different layers of plastic films

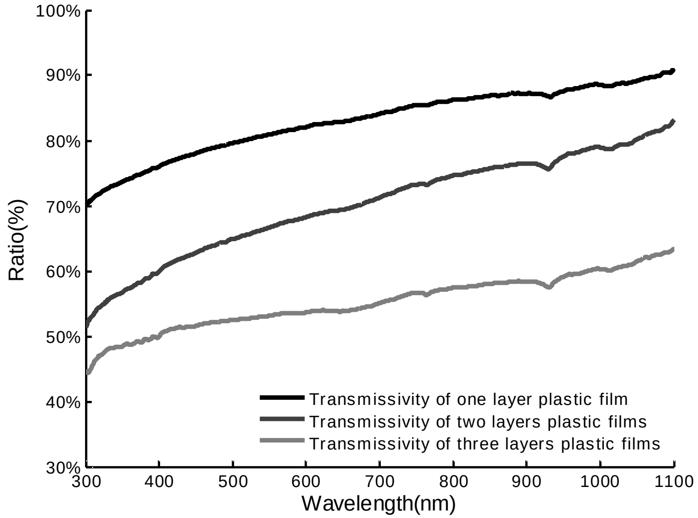
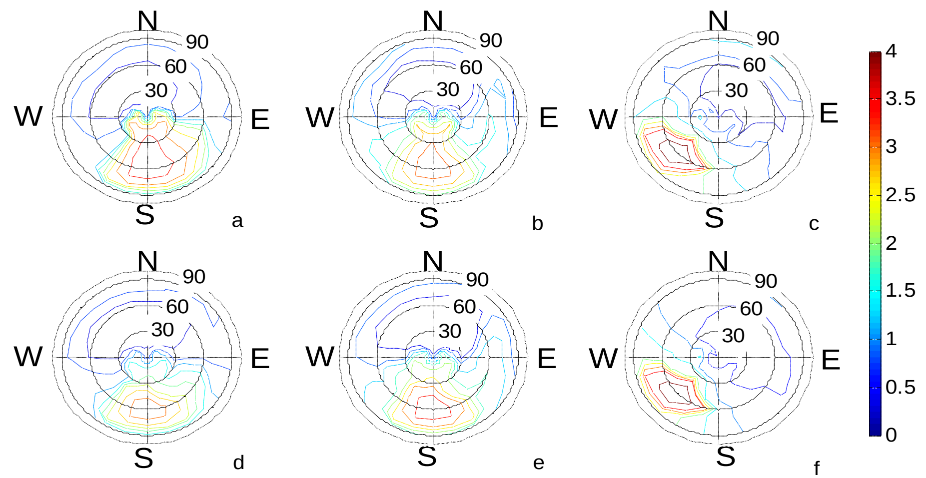



Figure 5 Transmittance of different wavelength under different layers of plastic films

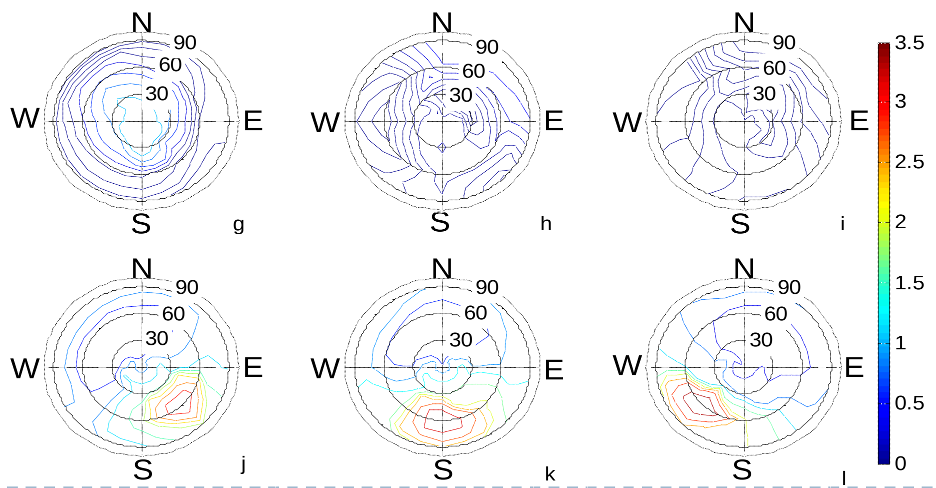
Table 4 The ratio of the visible light intensity to global solar radiation intensity under different shading conditions

| | 未遮膜条件下 | 遮12丝1层 | 遮12丝2层 | 遮12丝3层 |
|---|---|---|---|---|
| 可见光波段辐射总量（uW/cm²） | 34528.47 | 27896.53 | 22970.16 | 18309.27 |
| 太阳总辐射波段辐射总量（uW/cm²） | 63123.42 | 52350.03 | 44116.41 | 34677.09 |
| 可见光波段占太阳总辐射波段辐射比例（%） | 54% | 53% | 52% | 53% |

# Results and Discussions




- Figure 6 Global solar radiation intensity in different direction under clear sky and shading condition in clear sky （a: clear sky 11:00 b: clear sky 12:00 c: clear sky 14:00 d: shading condition in clear sky 11:00 e: shading condition in clear sky 12:00 f: shading condition in clear sky 14:00 ）




- Figure 7 Global solar radiation intensity in different direction under cloudy sky and haze （g: cloudy sky 10:00 h: cloudy sky 12:00 i: cloudy sky 14:00 j: haze 10:00 k: haze 12:00 l: haze 14:00 ）

# Results and Discussions

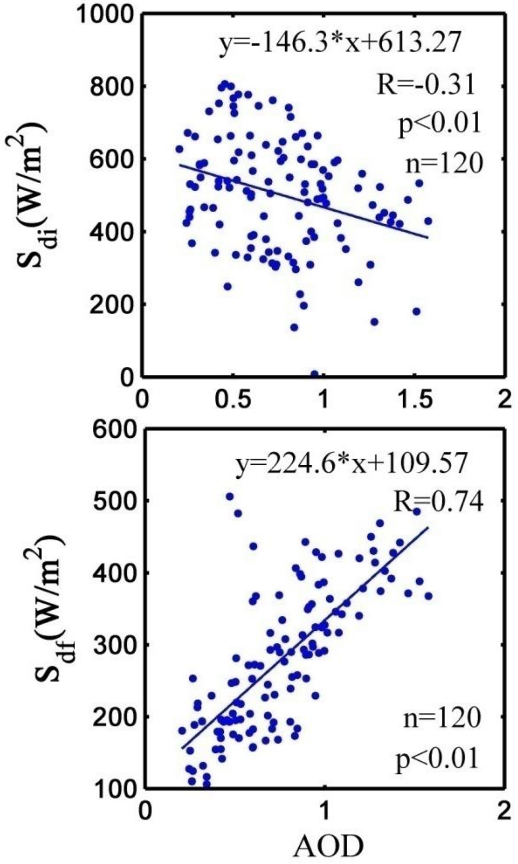



Figure 8 The relationship between AOD and direct radiation and diffuse radiation

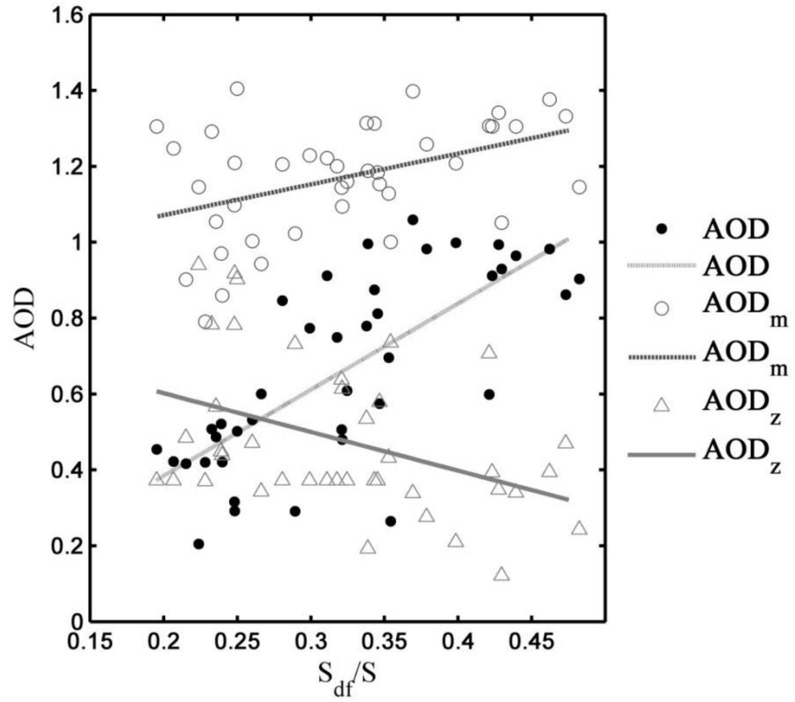



Figure 9 AOD represented by plastic film under different diffuse radiation ratios

# Results and Discussions

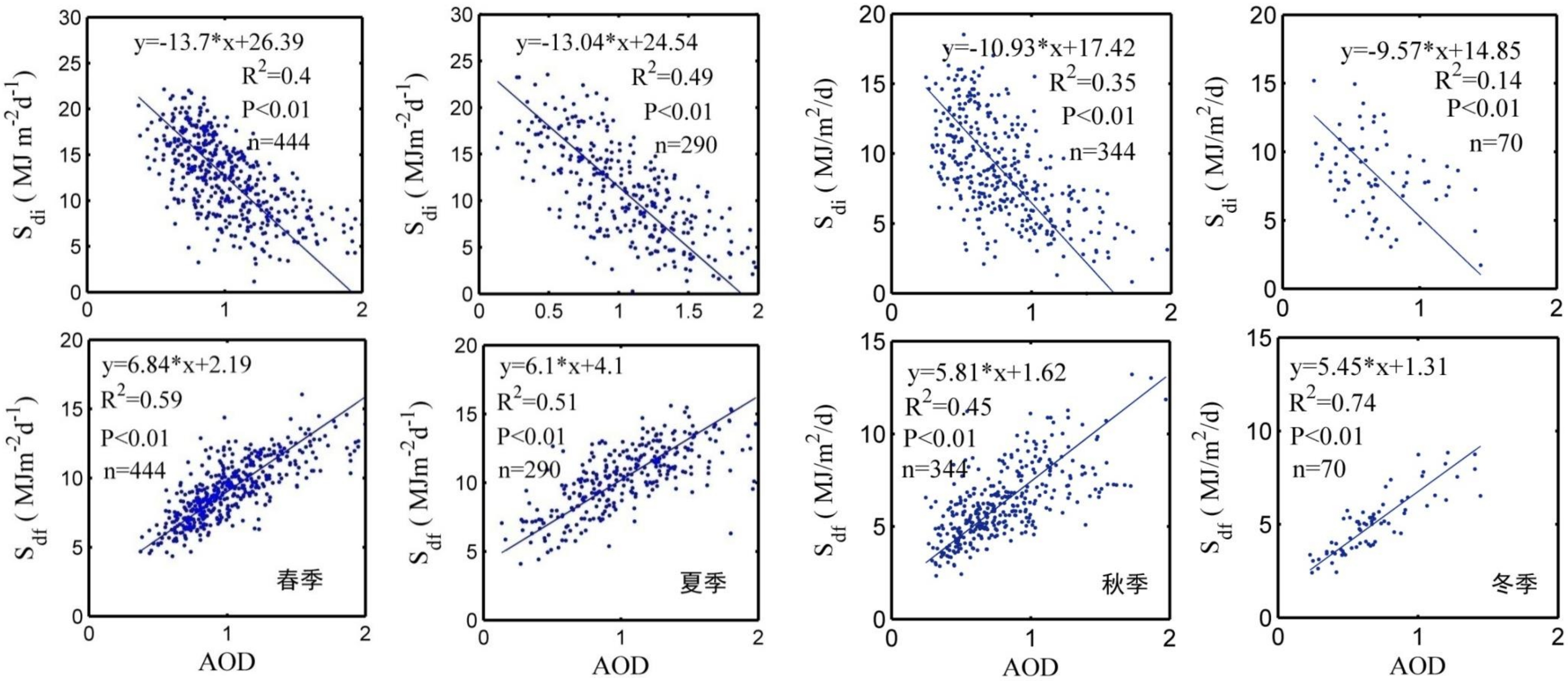



Figure 10 The relationship between AOD and direct radiation and diffuse radiation at all seasons

# Results and Discussions

$k_t$>0.65

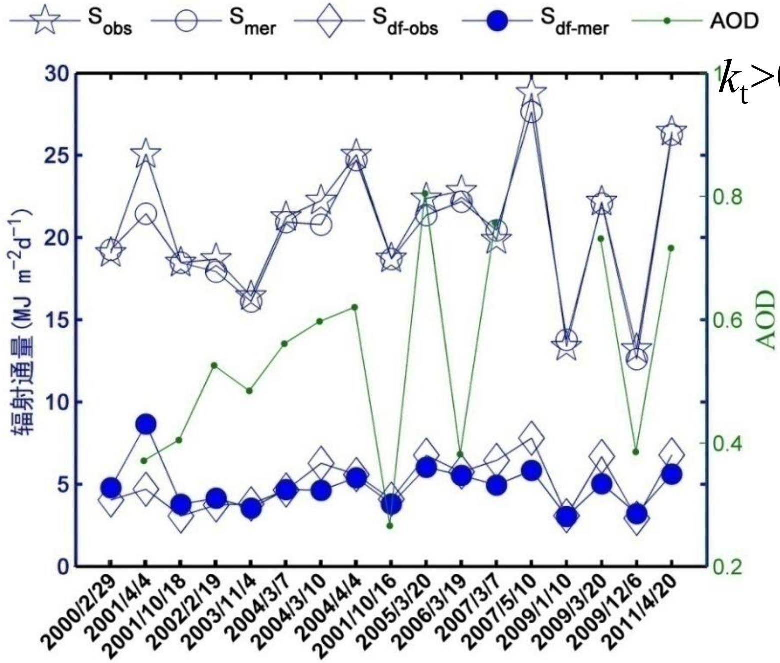
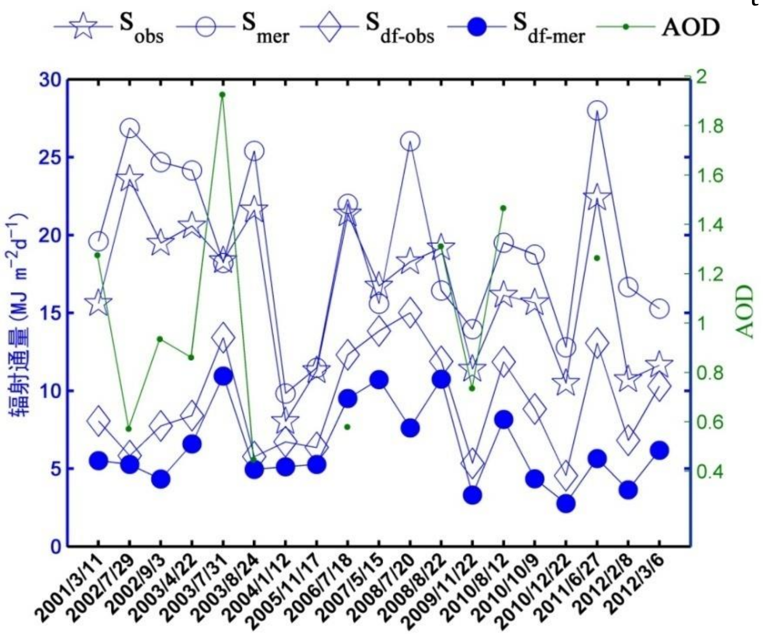
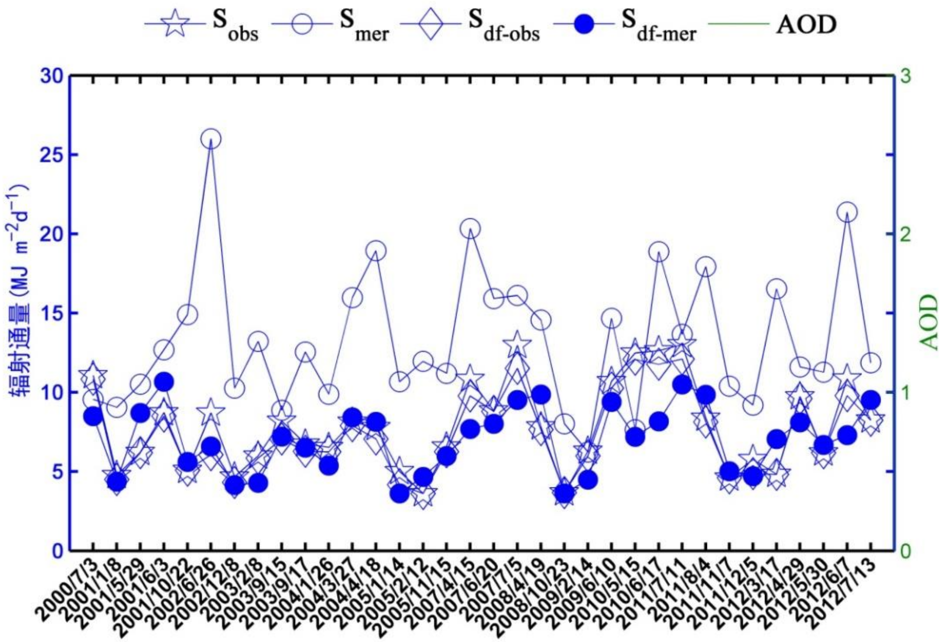



Figure 11 Comparison of the observed data of the global solar radiation and diffuse radiation in clear sky, partially cloudy sky and cloudy sky with MERRA's data

*0.35<$k_t$<0.65*




$k_t$<0.35




[*Kudish et al.*,1996]

# Results and Discussions

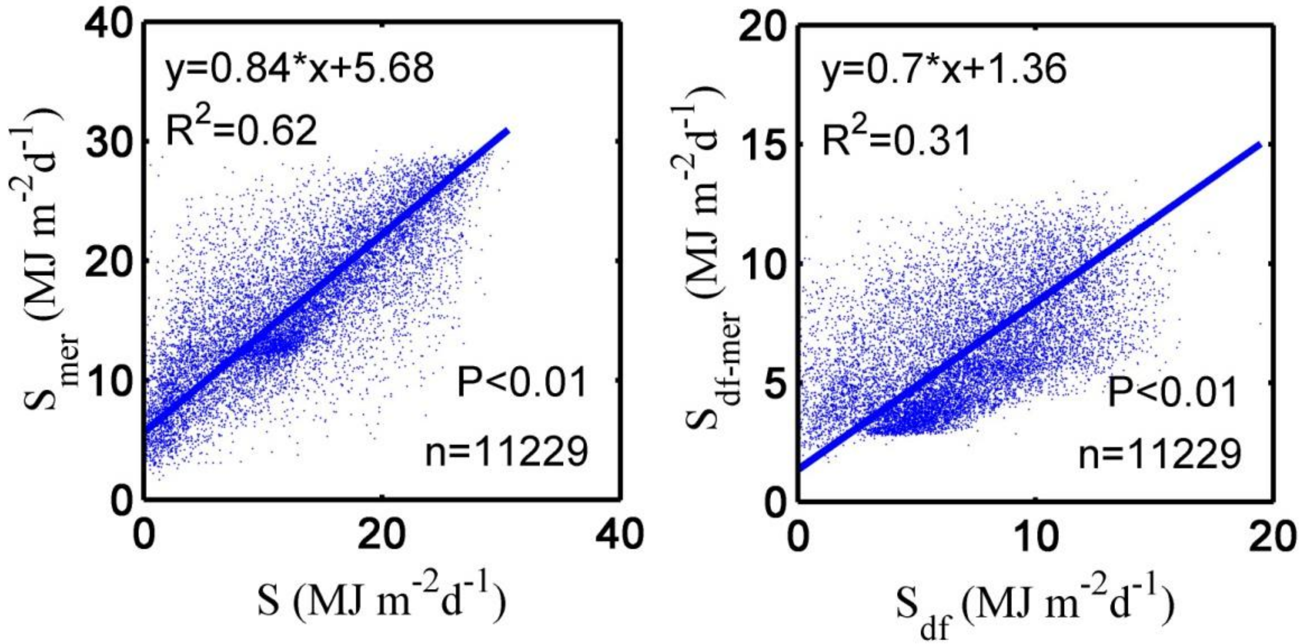



Figure 12 Comparison of the observed data of the global solar radiation and diffuse radiation with MERRAô s data

# Results and Discussions

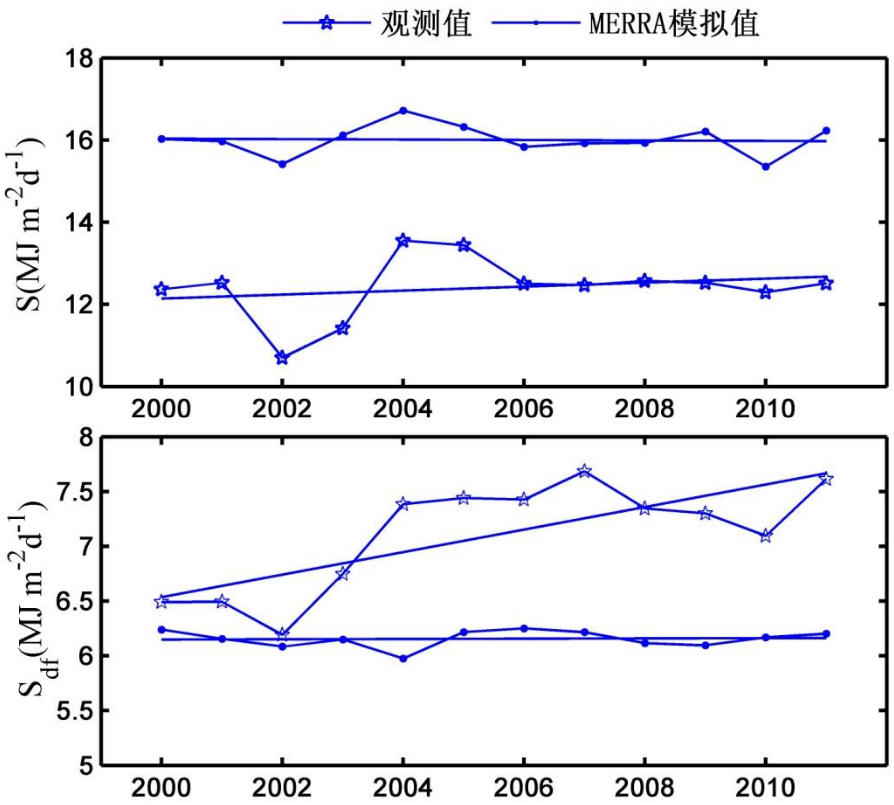



Figure 13 Comparison of the annual mean observed data of the global solar radiation and diffuse radiation with MERRAôs data

Table 5 Correlation test of the annual mean observed data of the global solar radiation and diffuse radiation with MERRAôs data

| | Mann-Kendal test | empirical relationship | $R^2$ |
|---|---|---|---|
| $S_{obs}$ | No significant change trend | y=0.048*x+12.09 | 0.05 |
| $S_{mer}$ | No significant change trend | y=-0.006*x+16.04 | 0.003 |
| $S_{df\text{-}obs}$ | 0.1MJ/m$^2$ /y * | y=0.1*x+6.43 | 0.56 |
| $S_{df\text{-}mer}$ | No significant change trend | y=0.001*x+6.15 | 0.004 |

The*Representatives passed the test of reliability 90% respectively.

# Results and Discussions

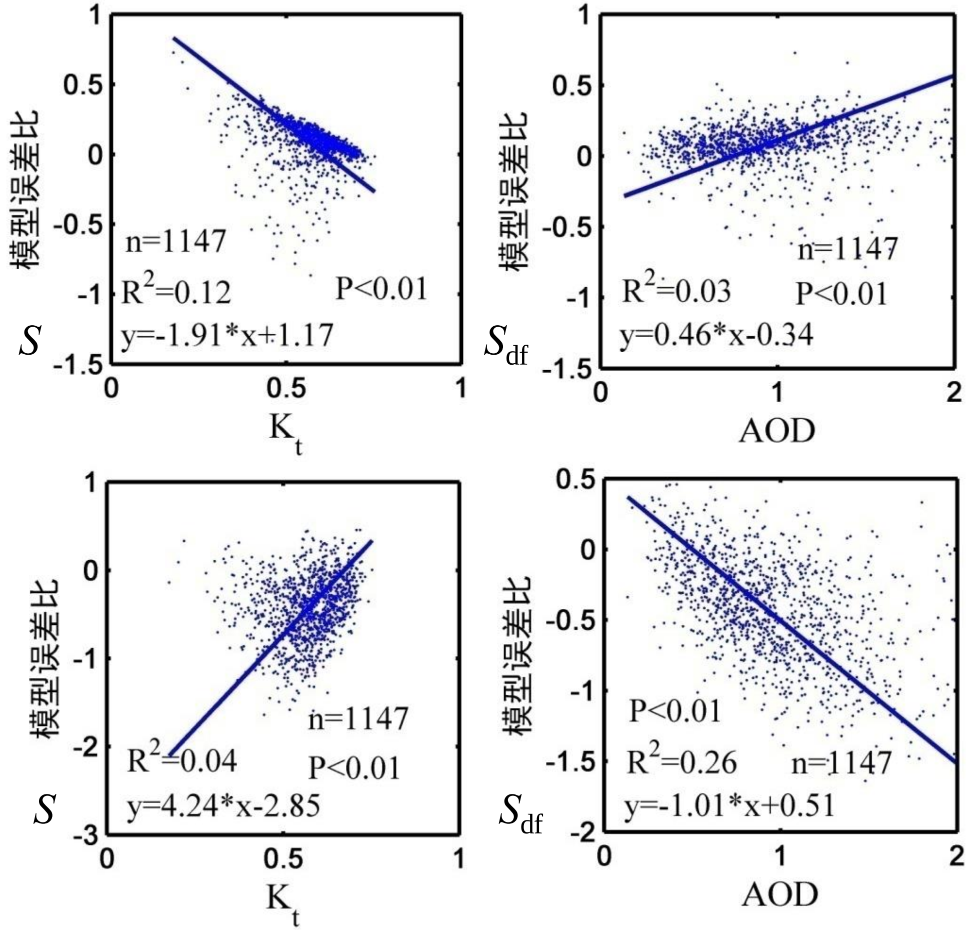



Figure 14 Relationship between daily clearness index(AOD) and daily global solar radiationôs model bias ratio( diffuse radiationôs model bias ratio)

# Results and Discussions

Table 6 Statistics of the daily, monthly mean and annual mean global solar radiation and diffuse radiation in MERRA before and after correction

| | | MERRA | | | Corrected MERRA | | |
|---|---|---|---|---|---|---|---|
| | | ME | RMSE | $R^2$ | ME | RMSE | $R^2$ |
| $k_t$ | Daily $S$ | 183.48 | 347.73 | 0.66 | -18.17 | 281.81 | 0.75 |
| | Monthly $S$ | 356.94 | 380.12 | 0.87 | -7.41 | 114.77 | 0.90 |
| | Annual $S$ | 354.74 | 358.52 | 0.51 | 0.15 | 24.06 | 0.90 |
| | Daily $S_{df}$ | -234.85 | 316.04 | 0.43 | 50.14 | 342.79 | 0.42 |
| | Monthly $S_{df}$ | -107.72 | 136.38 | 0.85 | 1.96 | 80.22 | 0.87 |
| | Annual $S_{df}$ | -100.79 | 110.08 | 0.20 | -0.26 | 35.23 | 0.52 |
| AOD | Daily $S$ | 183.48 | 347.73 | 0.66 | -17.3 | 363.33 | 0.54 |
| | Monthly $S$ | 356.94 | 380.12 | 0.87 | 3.66 | 198.89 | 0.73 |
| | Annual $S$ | 354.74 | 358.52 | 0.51 | -0.18 | 68.12 | 0.32 |
| | Daily $S_{df}$ | -234.85 | 316.04 | 0.43 | 54.29 | 278.96 | 0.63 |
| | Monthly $S_{df}$ | -107.72 | 136.38 | 0.85 | 20.34 | 113.01 | 0.86 |
| | Annual $S_{df}$ | -100.79 | 110.08 | 0.20 | 0.09 | 24.42 | 0.77 |

# Results and Discussions

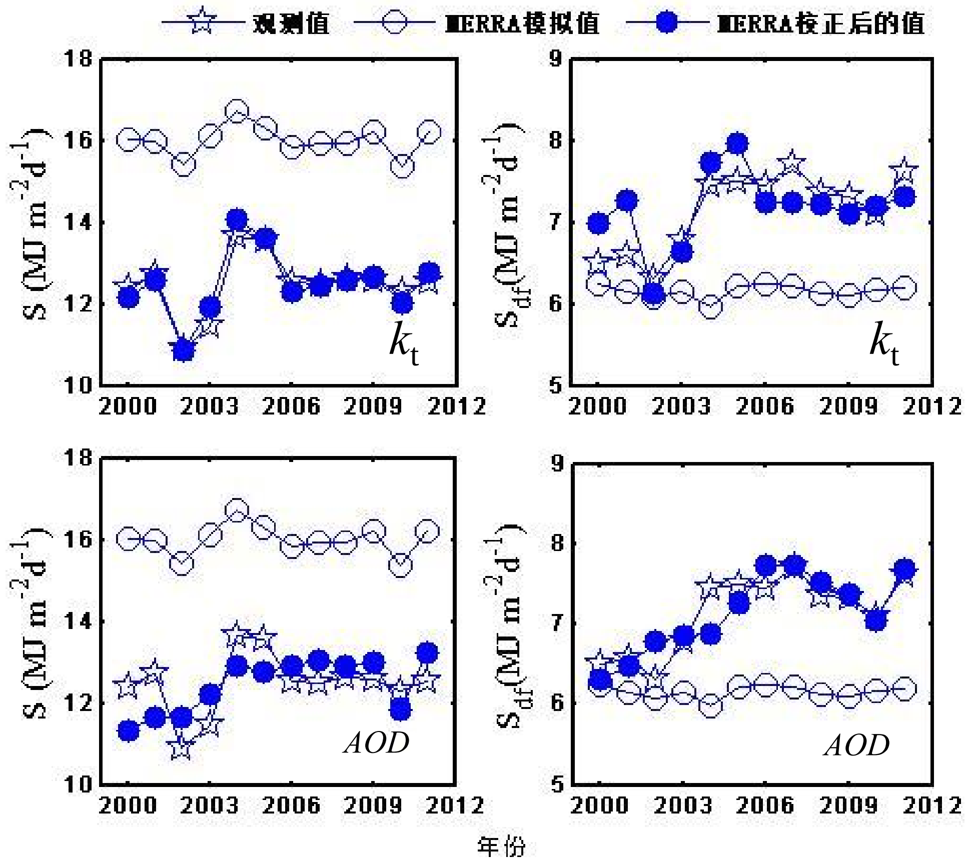



Figure 15 Comparison of the annual mean global solar radiation and diffuse radiation in MERRA before and after correction

# Results and Discussions

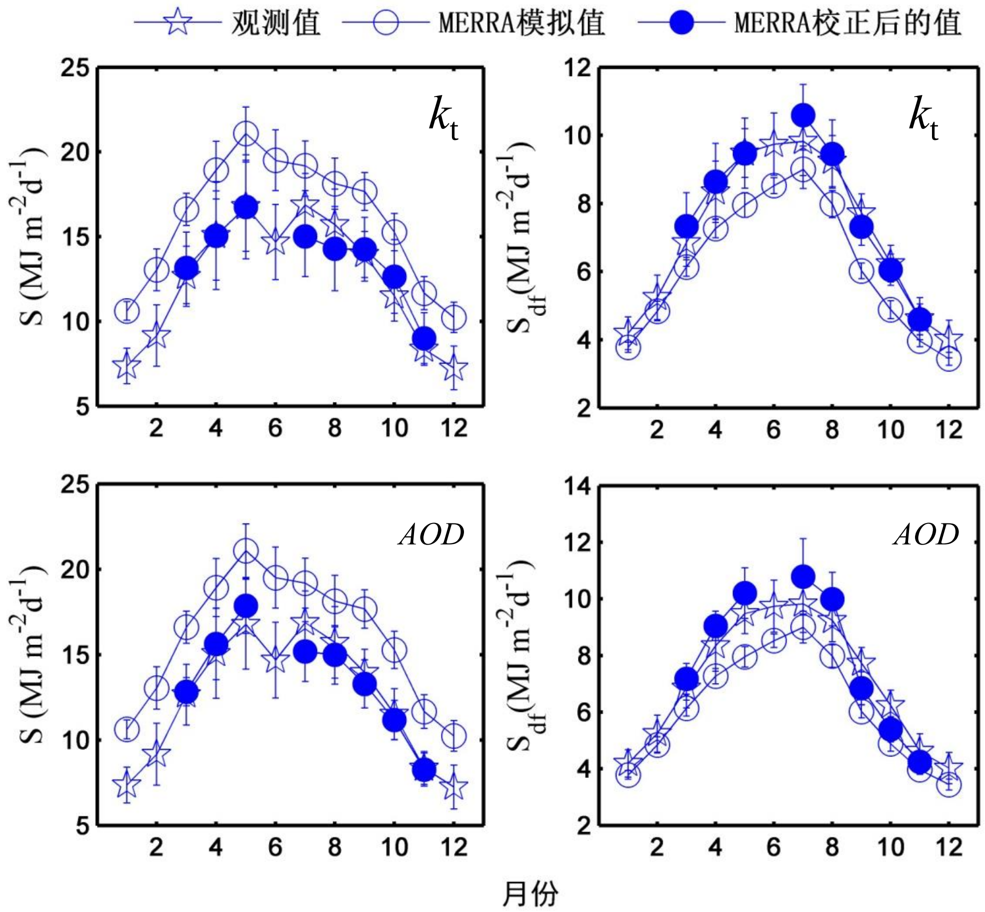



Figure 16 Comparison of the monthly composite global solar radiation and diffuse radiation in MERRA before and after correction

# Conclusion

- (1) Analyzing the changes of global solar radiation, diffuse radiation, and AOD in Nanjing, Hangzhou, Cixi and Shanghai station, we found global solar radiation decrease before 1980 and increase after 1980 in the Yangtze River Region. However, the diffuse radiation showed slow growth trend. Compared with it in 1961, the diffuse radiation proportion to global solar radiation increased nearly 20% in 2012. AOD had increased before 2008, and had declined slowly after 2008.
- (2) The field experiment simulating the effects of AOD on solar radiation was performed. The results showed that the proportion of the visible light intensity in global solar radiation intensity was not changed under shading condition which simulates AOD increase. The solar radiation under shading was still anisotropy, which was the same to the solar radiation property in haze.

# Conclusion

- (3) The relationships between direct solar radiation and diffuse radiation and AOD were analyzed in Shanghai station. We found the linear relationships between global solar radiation and diffuse radiation and AOD were obvious. And linear regression coefficient between diffuse radiation and AOD can reach 0.53. The results indicated that the diffuse radiation is affected by the AOD, obviously.
- (4) The relationship between AOD and the solar radiation and diffuse radiation can be used to correct the global solar radiation and diffuse radiation of MERRA. Comparing with the observed data, we found the global solar radiation of MERRA was higher than observed global solar radiation. However, the inter-annual changes of the two values are consistent. The diffuse radiation of MERRA was lower than the observed values. The observed annual average diffuse radiation obviously increased from 2000 to 2015, however, the inter-annual changes in diffuse radiation of was not obvious in the same period.
- (5) We used the clearness index and AOD to correct global solar radiation and diffuse radiation of MERRA. The results showed that clearness index corrected solar radiation better. However, the diffuse radiation corrected by AOD was better than that corrected by clearness index.

## Conclusion

- （1） Innovation: Analysis of the effect of AOD on diffuse radiation, and the diffuse radiation data of MERRA are corrected by AOD to make the MERRA radiation data more accurate.
- （2） Deficiencies: AOD data have more default, which will affect the correction.

THANK YOU!