Spatiotemporal Variation Characteristics of Surface Evapotranspiration and Drought in Oasis Areas of Southern Xinjiang over the Past 14 Years (Postprint)

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Abstract

Utilizing MOD16 evapotranspiration product data from 2001–2014, MOD13 vegetation [WTBX]NDVI[WTBZ] data, and conventional meteorological data, a hybrid linear two-source remote sensing evapotranspiration model was optimized and improved based on vegetation index, surface net radiation, and air temperature to fit surface evapotranspiration and analyze spatiotemporal dynamic variation characteristics of actual evapotranspiration (ET) and potential evapotranspiration (PET). The applicability of MOD16 data in oasis areas was validated by combining with measured evaporation pan data from meteorological stations. Furthermore, the Evapotranspiration Drought Index (EDI) was defined and ΔEDI was calculated to analyze drought characteristics in the study area, providing a certain basis for research on evapotranspiration estimation in large-area special terrain and drought monitoring. The results indicate: (1) MOD16 product data demonstrated good correlation with measured evaporation pan data in the study area, passed the 0.01 significance test, and it is feasible to validate evapotranspiration estimation in the southern Xinjiang oasis region based on MOD16 data. (2) From 2001 to 2014, the annual average evapotranspiration showed little overall change, with significant seasonal variations; ET and PET exhibited opposite spatial variation trends; the annual average difference between ET and PET was large, indicating severe surface water shortage in oasis areas. (3) The annual average value of the EDI index in oasis areas was generally large, and ΔEDI provided relatively reliable reflection of drought conditions and assessment of drought severity.

Full Text

Preamble

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Abstract:
Evapotranspiration was estimated based on NDVI, surface net radiation, and air temperature using China monthly meteorological data and MODIS remote sensing data, including evapotranspiration data (MOD16) and normalized difference vegetation index data (MOD13). The parameters of the mixed linear dual-source remote sensing evapotranspiration model were simplified and improved to estimate surface evapotranspiration in the oasis region of southern Xinjiang. Spatial and temporal variation characteristics of actual evapotranspiration (ET) and potential evapotranspiration (PET) from 2001 to 2014 were analyzed. Based on correlation analysis of measured evaporation data from meteorological stations in southern Xinjiang, the applicability of MOD16 products in oasis regions was verified as credible through statistical testing. According to the evapotranspiration drought index (EDI), the distribution characteristics of drought in the oasis of southern Xinjiang were analyzed, and the degree of drought was determined by EDI anomaly. Results reflect that the annual mean evapotranspiration from 2001 to 2014 shows little change, with significant differences among the four seasons. The highest evapotranspiration occurs in summer and the lowest in winter. The spatial trend of ET and PET is in opposite situations. In addition, there is a huge disparity between the annual values of ET and PET, indicating that surface water shortage is serious in the oasis. Furthermore, the average annual value of the EDI index in the oasis area is fairly large, and the response of EDI anomaly to drought and the judgment of drought degree are reliable. From the perspective of energy and water balance, this research simplifies model parameters and enhances model applicability, providing guiding significance for large-scale evapotranspiration estimation and drought monitoring.

Keywords: southern Xinjiang; oasis; surface evapotranspiration; evapotranspiration drought index (EDI); spatial and temporal variation characteristics

2. Data and Methods

2.1 Data Sources

MOD16 evapotranspiration data and MOD13 NDVI data from 2001–2014 were used in this study. The meteorological data included monthly precipitation, temperature, humidity, sunshine hours, and wind speed from national meteorological stations in southern Xinjiang. The MOD16 product provides 8-day, monthly, and annual ET/PET data at 1 km resolution, while MOD13 provides 16-day NDVI data at the same resolution. All remote sensing data were processed using ArcGIS software for format conversion, projection transformation, and resampling to ensure spatial consistency.

2.2 Model Description

The NISHIDA dual-source remote sensing evapotranspiration model was simplified and improved for application in the study area. The model calculates evapotranspiration by separating vegetation transpiration and soil evaporation components.

(1) Simplified Dual-Source Model
Based on NISHIDA et al. [12], the model calculates ET as a linear function of NDVI and temperature. The key equations are:

$$ET = (1 - f_V) \cdot ET_S + f_V \cdot ET_V$$

where f_V is the vegetation fraction cover, ET_S is soil evaporation, and ET_V is vegetation transpiration.

The component fluxes are calculated as:

$$ET_S = a_0 \cdot R_n$$
$$ET_V = a_2 \cdot R_n \cdot \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \cdot \frac{T}{T_{max} - T_{min}}$$

where R_n is net radiation, T is surface temperature, $NDVI_{max}$ and $NDVI_{min}$ are the maximum and minimum NDVI values, and T_{max} and T_{min} are the maximum and minimum temperatures.

(2) Evapotranspiration Fraction (EF)
The evapotranspiration fraction is defined as the ratio of actual to potential evapotranspiration:

$$EF = \frac{ET}{PET}$$

(3) Evapotranspiration Drought Index (EDI)
The EDI is calculated based on the difference between PET and ET:

$$EDI = \frac{PET - ET}{PET} = 1 - \frac{ET}{PET}$$

EDI values range from 0 to 1, where higher values indicate more severe drought conditions.

(4) Parameter Optimization
Model parameters (a_0, a_2) were optimized using measured data from meteorological stations. The Hargreaves equation was used to calculate PET for validation purposes:

$$PET = 0.0023 \cdot R_a \cdot (T_{mean} + 17.8) \cdot \sqrt{T_{max} - T_{min}}$$

where R_a is extraterrestrial radiation.

2.3 Validation of MOD16 Products

The accuracy of MOD16 ET products was evaluated using observed evaporation data from 23 meteorological stations in southern Xinjiang during 2006–2010. Statistical analysis showed significant correlation ($p < 0.01$) between MOD16 estimates and ground measurements, with correlation coefficients ranging from 0.72 to 0.85 across different stations. The root mean square error (RMSE) was 12.3 mm/month, indicating acceptable accuracy for regional-scale studies. However, MOD16 PET products showed systematic overestimation compared to Hargreaves-calculated PET, particularly in arid regions, suggesting the need for local calibration.

2.4 Calculation of EDI and Drought Classification

Monthly EDI values were calculated for each pixel based on the ratio of MOD16 ET to PET. Drought severity was classified into five levels according to EDI anomalies: no drought (EDI $<$ 0.3), mild drought (0.3 EDI $<$ 0.5), moderate drought (0.5 EDI $<$ 0.7), severe drought (0.7 EDI $<$ 0.9), and extreme drought (EDI 0.9). The EDI anomaly was computed as the deviation from the 14-year mean value, allowing identification of drought events and their spatial extent.

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3. Results and Analysis

3.1 Temporal Variation Characteristics

The annual average ET from 2001–2014 was 248.59 mm, while PET averaged 882.20 mm, showing a significant water deficit. Interannual variation was notable: ET ranged from 201.92 mm to 288.75 mm, with the highest value in 2012 and relatively low values during 2007–2009. PET ranged from 850.29 mm to 971.64 mm, peaking in 2004 and showing lower values in 2003 and 2010.

Seasonal analysis revealed distinct patterns: summer ET accounted for 47.1% of the annual total (116.23 mm), while winter ET was only 7.8% (31.12 mm). Spring and autumn contributed 25.3% and 19.8%, respectively. The seasonal distribution of PET followed a similar pattern but with much higher magnitudes, reaching 356.40 mm in summer.

3.2 Spatial Distribution Patterns

[Figure 2: see original paper] shows the spatial variation of annual mean evapotranspiration. High ET values (>300 mm) were concentrated in the oasis areas with dense vegetation cover, particularly in the Kashgar and Aksu regions. Low ET values (<150 mm) were observed in the surrounding desert areas. The spatial pattern of PET [Figure 4: see original paper] showed an inverse relationship, with higher PET values in desert areas due to higher temperatures and lower humidity.

[Figure 3: see original paper] illustrates seasonal ET distribution: summer ET exhibited the strongest spatial heterogeneity, with oasis areas showing 3–4 times higher values than desert areas. Winter ET showed minimal spatial variation across the entire region.

3.3 Drought Analysis Using EDI

The average annual EDI for the oasis region was 0.72, indicating prevalent moderate to severe drought conditions. Areas with EDI > 0.9 (extreme drought) covered approximately 15% of the oasis region, primarily in marginal areas with poor water supply. The EDI anomaly analysis identified 2004, 2008, and 2011 as major drought years, with spatial extents exceeding 60% of the oasis area. The correlation between EDI anomaly and standardized precipitation index (SPI) was 0.68 ($p < 0.01$), confirming the reliability of EDI for drought monitoring in this region.

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4. Discussion and Conclusions

(1) MOD16 ET products demonstrate credible accuracy in oasis regions of southern Xinjiang, with statistical validation showing significant correlation with ground measurements. However, PET products require local calibration due to systematic overestimation in arid environments. The simplified dual-source model effectively reduces computational complexity while maintaining physical basis, enhancing applicability for large-scale studies.

(2) From 2001–2014, the oasis region experienced severe water shortage, with ET averaging only 28% of PET. The significant seasonal variation, with summer ET exceeding winter ET by nearly fourfold, reflects strong vegetation controls on water consumption. The opposite spatial trends of

ET and PET highlight the critical role of irrigation in sustaining oasis ecosystems.

(3) The EDI index effectively captures drought severity and spatial extent in southern Xinjiang oasis areas. The high average EDI value (0.72) indicates persistent water stress, with extreme drought conditions affecting 15% of the region. The reliable response of EDI anomaly to drought events demonstrates its utility for operational drought monitoring.

(4) This study simplifies model parameters from an energy-water balance perspective and enhances model applicability for regional evapotranspiration estimation. The integration of remote sensing data with ground observations provides a robust framework for large-scale water resource management and drought early warning systems in arid regions.

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Note: Figure translations are in progress. See original paper for figures.