Simplified Methods for Potential Evapotranspiration Estimation and Their Applications: Postprint

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Abstract

Potential evapotranspiration plays a crucial role in research on regional water balance, drought assessment, crop water requirements, and other related areas. However, the spatialization of potential evapotranspiration has long been a challenge in such studies. Based on observational data from 66 meteorological stations in the Xinjiang region from 1960 to 2017, the spatialization of potential evapotranspiration (ET0) was implemented using a simple parametric equation. The research results indicate: The spatial distribution of the two important parameters a and c in the simplified parametric equation demonstrates certain regularities; parameter a exhibits a pattern of high values in the southeast and low values in the northwest; parameter c increases with increasing elevation. Compared with the Penman-Monteith method, the R^2 values of the fitting results from the simplified parametric equation exceed 0.90 at daily, monthly, and seasonal scales, and increase as the temporal scale becomes coarser. A comparison of the fitting results from the simplified parametric equation with CRU data and MOD16A2 data reveals that: the simplified parametric equation yields higher R^2 values when validated against the Penman-Monteith method, demonstrating superior performance in terms of fitting accuracy and bias metrics, whereas the R^2 values obtained from CRU and MOD16A2 data are lower. The potential evapotranspiration obtained by the simplified parametric equation features high accuracy and higher spatial resolution (500 m × 500 m), and represents a simple yet effective method suitable for potential evapotranspiration estimation in the Xinjiang region.

Full Text

A Simplified Method and Its Application for Estimating Potential Evapotranspiration

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Abstract: Potential evapotranspiration (ET) plays an important role in estimating regional water balance and crop water demand and assessing drought. However, spatial interpolation of potential evapotranspiration remains a challenge for relevant research. In this study, a simple parametric model was used to achieve the spatialization of ET in Xinjiang based on observed data from 66 meteorological stations from 1960 to 2017. The results indicated that: (1) The two important parameters *a* and *c* of the simplified parametric model showed certain regularity in their spatial distribution. Parameter *a* was spatially high in the southeast but low in the northwest of Xinjiang, while parameter *c* increased with altitude; (2) Compared with the Penman-Monteith method, the R^2 values of the simplified parametric model at daily, monthly, and seasonal scales were all higher than 0.90, and they increased with increasing time scale; (3) Comparison between the fitting results of the simplified parametric model and the CRU and MOD16A2 data revealed that the R^2 values fitted with the simplified parametric model and the Penman-Monteith method were high, with better fitting results and smaller errors, but the R^2 values fitted with CRU and MOD16A2 were low. Moreover, the accuracy of potential evapotranspiration and the spatial resolution (500 m × 500 m) obtained by the simplified parametric model were high. Therefore, the simplified parametric model is a convenient and effective model for calculating ET at regional scale and can be applied to estimate potential evapotranspiration in Xinjiang.

Keywords: potential evapotranspiration (ET); parametric equation; Penman-Monteith method; spatial interpolation

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1 Data and Methods

1.1 Data Sources

This study utilized meteorological data from 66 national standard meteorological stations in Xinjiang [Figure 1: see original paper], including daily observations of average temperature, maximum temperature, minimum temperature, sunshine duration, wind speed, and relative humidity from 1961 to 2014, obtained from the China Meteorological Administration (http://data.cma.cn). For validation purposes, we used CRU TS 3.2 ET data (http://data.ceda.ac.uk/badc/cru/data/cru_ts/cru_ts_3.23/data/) covering 1961-2014 and MOD16A2 ET data (http://files.ntsg.umt.edu/data/NTSG_Products/MOD16/GEOTIFF_0.5 covering 2000–2014, both interpolated to a 0.5° × 0.5° grid.

1.2 Methods

1.2.1 Parametric Model Development We developed a simplified parametric model based on the Penman-Monteith equation [**?**]. The model form is expressed as:

$$f(x_1, x_2) = \frac{1 - cx_2}{\langle MATH_0 005 \rangle}$$

where x_1 represents extraterrestrial radiation (R_a) in MJ • m^{2} • d^{1}, x_2 represents average temperature (T) in ℃, and $f(x_1, x_2)$ yields the ET estimate. The denominator structure follows the Penman-Monteith framework, with parameters a and c requiring calibration. The term $(1 - cT)$ represents the temperature-dependent component of the Penman-Monteith equation [**?**].

The extraterrestrial radiation R_a is calculated using the FAO-56 formulation:

$$R_a = \frac{24 \times 60}{\pi} G_{sc} d_r [\omega_s \sin(\phi) \sin(\delta) + \cos(\phi) \cos(\delta) \sin(\omega_s)]$$

where G_{sc} is the solar constant (82 kJ • m^{2} • min^{1}), d_r is the inverse relative Earth-Sun distance, ω_s is the sunset hour angle, ϕ is latitude, and δ is solar declination. All calculations were implemented in MATLAB.

Model calibration was performed using a stepwise iteration method, with parameter a varying at 0.0001 increments and parameter c at 0.01 increments within physically reasonable ranges. The calibrated model, denoted ET , was validated against Penman-Monteith estimates (ET d) using three metrics: coefficient of determination (R^2), mean absolute error (MAE), and relative bias (BIAS) [**?**]. R^2 measures the goodness of fit, with values closer to 1 indicating better performance, while MAE (mm) and BIAS (%) quantify the magnitude and direction of errors between ET and ET d.

1.2.2 Spatial Interpolation To generate spatially continuous ET estimates, we interpolated the model parameters using climate variables as covariates. Temperature surfaces were generated using the Anuspline software package, which employs a thin-plate smoothing spline interpolation method that effectively incorporates elevation effects [**?**]. Radiation surfaces were produced in ArcGIS using the spatially explicit radiation equation described above. The interpolation procedure involved: (1) calibrating parameters a and c at station locations using observed temperature and radiation data; (2) interpolating these parameters across the study area using temperature and elevation as predictors to generate spatial fields a and c ; and (3) applying the parametric model with these interpolated parameters to compute gridded ET estimates (ET d). Finally, we compared these modeled values with station-based ET calculations to assess spatial accuracy.

2 Results

2.1 Model Validation

Comparisons between ET d and ET at multiple time scales revealed strong agreement [Figure 2: see original paper]. At the daily scale, ET d showed slight underestimation during early growth stages (1-86 days) and late stages (300-365 days), with mean absolute errors of 0.28 mm and 0.25 mm, respectively. During mid-season (167-230 days), the model performed better, with MAE reduced to 0.08 mm [Figure 2a: see original paper].

At the monthly scale, ET d and ET showed close correspondence, though some divergence occurred in April, May, August, September, and October, where MAE reached 7.47 mm and maximum error was 10.19 mm. Seasonal patterns indicated that summer months exhibited the largest discrepancies, with MAE of 7.74 mm and maximum error of 12.19 mm [Figure 2b: see original paper].

Overall, the mean absolute error across all stations was 5.31 mm [Figure 2c: see original paper]. The MAE distribution showed distinct seasonal patterns: values were higher in January, April, July, September, and December, and lower in March, June, August, and October. The spatial distribution of MAE indicated that approximately 60% of stations had MAE values below 0.40, demonstrating good model performance across most of the region [Figure 3: see original paper].

The R^2 values between ET d and ET exceeded 0.99 at all aggregated time scales (daily, monthly, and seasonal), specifically reaching 0.991, 0.991, and 0.993, respectively. At the monthly scale, R^2 values at 66 stations averaged 0.94, with 33.33% of stations showing $R^2 > 0.95$, 57.09% between 0.92–0.95, and only 3.03% below 0.90. These results indicate that the simplified parametric model captures ET variability with high fidelity, approaching the accuracy of the full Penman-Monteith method while requiring fewer input variables.

2.2 Spatial Distribution of Parameters and ET

The spatial patterns of parameters a and c revealed clear climatic controls [Figure 4: see original paper]. Parameter a showed a southeast-to-northwest gradient, with higher values in the southeastern arid regions and lower values in the northwestern mountainous areas. Parameter c demonstrated a strong positive relationship with elevation, increasing at higher altitudes. The calibrated values ranged from 0.0001 to 0.000047 for a and from 0.04 to 0.015 for c, reflecting the diverse hydroclimatic conditions across Xinjiang.

The spatial distribution of annual ET (1960–2017) averaged 1028 mm, with significant regional variation [Figure 4c: see original paper]. July ET reached 1130 mm in southern areas but only 864 mm in northern regions, showing a clear latitudinal gradient. The relative bias (BIAS) of the model was 0.0160, well within the acceptable range of ±0.04, indicating minimal systematic error.

Validation against independent datasets showed that while the parametric model performed well when compared with Penman-Monteith calculations ($R^2 > 0.90$), correlations with CRU and MOD16A2 products were weaker. This discrepancy likely stems from differences in input data quality and spatial resolution. Nevertheless, the simplified parametric model, with its 500 m × 500 m spatial resolution, provides a robust and computationally efficient alternative for regional ET estimation in Xinjiang, particularly in data-scarce regions where full meteorological observations are unavailable.

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

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