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Wheat Leaf Area Index Dataset of Luancheng Station, Hebei, China (2019) — China Leaf Area Index Observation Cal-Val Network's Serial Dataset

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Abstract: The leaf area index (LAI) observation calibration-validation network site at Luancheng Station, Hebei province (central coordinates: 114°41′34.80″E, 37°53′22.51″N), was completed on March 22, 2019. This site is part of China's LAI observation calibration-validation network (China LAI Cal-Val) initiated in 2018 and utilizes the LAI wireless sensor network observation system (LAI-NOS) to automatically collect continuous LAI data. Luancheng Station is a typical northern station within the China LAI Cal-Val network and operates in a winter wheat-summer maize rotation system in the warm temperate zone of China. At this site, LAI data were collected throughout the wheat growing season of 2019, from March 25 to June 10, from three adjacent LAI-NOS nodes (0901, 0902, and 0904). A dataset was assembled based on the steady window algorithm by extracting data of early morning and evening. The dataset includes (1) the geographic locations of the three LAI-NOS nodes at Luancheng Station in 2019; (2) daily LAI data of the three LAI-NOS nodes at Luancheng Station from March 25 to June 10, 2019. The dataset is archived in .xlsx, .shp, and .kmz formats and consists of nine files with a size of 25.6 KB (compressed into two files with a total size of 21.9 KB).

Keywords: Luancheng, Hebei; wheat; China LAI Cal-Val; LAI-NOS; steady window algorithm

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[2] Sun, Y., Yang, J., Gao, H. L., *et al*. Wheat leaf area index dataset of Luancheng Station Hebei China (2019)—China Leaf Area Index Observation Cal-Val Network's serial dataset [J/DB/OL]. *Digital Journal of Global Change Data Repository*, 2023. https://doi.org/10.3974/geodb.2023.09.08.V1. https://cstr.escience.org.cn/CSTR:20146.11.2023.09.08.V1.

1 Introduction

The leaf area index (LAI), a dimensionless value, is widely recognized as half of the total green leaf area per unit ground area[1]. LAI is critical for the study of vegetation canopies. As a core structural parameter of the vegetation canopy, it is closely related to biological and physical vegetation processes, such as photosynthesis, respiration, and transpiration. LAI can provide quantitative information on energy exchanges at the surface of the vegetation canopy[2]. It is an important input parameter for global ecological research, such as for reflecting vegetation growth, evaluating vegetation productivity, and analyzing carbon cycling and climate. Hence, quick and accurate acquisitions of LAI data are essential to evaluate plant growth and the structure and function of ecosystems.

In recent years, benefiting from the rapid progress in remote sensing technology, several satellites with different temporal/spatial resolutions and imaging modes have been launched, providing users with rich remote sensing data. On this basis, various LAI remote sensing data products have been derived, such as MODIS LAI, GLASS LAI, and GEOV1 LAI[3] (Table 1). The inversion process of LAI remote sensing data products is affected by surface heterogeneity, remote sensing data, computational models, and other factors. The application of LAI products depends on their accuracy and reliability and on whether they can capture the actual conditions of surface parameters. Accordingly, the research on the validation of LAI remote sensing products with ground truth values is of great significance. The ground truth values of LAI remote sensing products generally come from ground observation values that represent ground targets. LAI measurements can be direct and indirect. Direct measurements have the highest accuracy among all LAI measurement methods and are often taken as a calibration standard for other methods, but they are destructive and require considerable time, labor, and material resources. Additionally, the representativeness of the sample is sometimes debatable. Regarding the collection method of leaves, direct measurements can be subdivided into destructive and non-destructive approaches[4]. The former include methods based on representative trees, regional sampling, grid points, and grid networks, while the latter refer mostly to deciduous leaf collection[5, 6].

Indirect measurements usually obtain LAI data through optical instruments and therefore are also known as optical instrument methods. Common optical instruments include the LAI-2000 plant canopy analyzer, the TRAC analyzer, and hemispherical imaging-based LAI meters. Compared with direct measurements, indirect measurements are widely used for ground data acquisition of vegetation canopy parameters due to high portability, speed, efficiency, and measurement accuracy, as well as strong versatility. Amid the development of wireless network technologies, the combination of wireless sensor networks and LAI measurements based on optical instruments has been widely applied in practice. Developed with this technology, the LAI wireless sensor network observation system (LAI-NOS) has all the advantages of single-point measurements based on the optical instrument method, permitting long-term and large-scale monitoring with remote sensing. The measurement results are accurate and reliable, convenient for maintenance, and provide long-term, stable, and reliable ground observation data for LAI remote sensing products[7].

LAI is the ratio of vegetation leaf area to land area, which tends to not change significantly in a short period of time. However, changes in the data collection environment (such as variations in illumination, winds, clouds, and other environmental conditions) can cause large fluctuations in the measured value. While manual measurements can be conducted in the morning and evening or in windless or cloudy weather, automatic instruments have difficulty in determining the suitability of environmental conditions. At the same time, the

LAI-NOS generally samples every 5 min, resulting in a large number of redundant LAI values. To address this issue, this paper analyzed the production and validation results of the Wheat LAI Dataset of Luancheng Station, Hebei, China (2019)—China LAI Observation Cal-Val Network's serial dataset. The steady window algorithm was used to screen and preprocess the raw measurements, remove outliers, and obtain valid ground measurements per day[8].

Table 1 Major LAI remote sensing data products

Product	Source	Spatial resolution	Temporal resolution	Main features
MODIS LAI	National Aeronautics and Space Administration	0.5 km	8 d	Global coverage, suitable for large-scale regional LAI monitoring
SPOT/VEGETATION LAI	Institute Géographique National	0.5 km	10 d	Provides high-precision LAI monitoring data, suitable for as agricultural and forest studies
GLOBMAP LAI	Institute of Geographic Sciences and Natural Resources Research, CAS	1 km	10 d	Provides high-quality LAI monitoring data that can be applied in conjunction with other remote sensing products
CYCLOPES LAI	European Geosciences Union	0.5 km	10 d	Provides high-quality LAI monitoring data by combining multiple remote sensing and ground observation data
GLASS LAI	Beijing Normal University	0.5 km	8 d	Uses a generalized neural network

2 Metadata of the Dataset

The metadata of the Wheat leaf area index dataset of Luancheng Station Hebei China (2019)—China Leaf Area Index Observation Cal-Val Network's serial dataset is summarized in Table 2.

Table 2 Metadata summary of the Wheat leaf area index dataset of Luancheng Station Hebei China (2019)—China Leaf Area Index Observation Cal-Val Network's serial dataset

Items	Description
Dataset full name	Wheat leaf area index dataset of Luancheng Station Hebei China (2019)—China Leaf Area Index Observation Cal-Val Network's serial dataset
Dataset short name	LuanchengLAI_2019
Authors	Sun, Y., Aerospace Information Research Institute, Chinese Academy of Sciences, sunyuan@aircas.ac.cn Yang, J., Aerospace Information Research Institute, Chinese Academy of Sciences, yangjian@aircas.ac.cn Gao, H. L., Aerospace Information Research Institute, Chinese Academy of Sciences, gaohailiang@aircas.ac.cn Tao, Z., Aerospace Information Research Institute, Chinese Academy of Sciences, taozui@aircas.ac.cn Wang, C. M., Aerospace Information Research Institute, Chinese Academy of Sciences, wangchunmei@aircas.ac.cn Gu, X. F., Aerospace Information Research Institute, Chinese Academy of Sciences, guxf@aircas.ac.cn Zhou, X., Aerospace Information Research Institute, Chinese Academy of Sciences, zhouxiang@aircas.ac.cn
Geographical region	LAI observation calibration-validation network at Hebei Luancheng Station of the China LAI observation Cal-Val network
Year	March 25–June 10, 2019
Temporal resolution	One day
Spatial resolution	10 m×10 m

(*To be continued on the next page*)

(*Continued*)

Items	Description
Data format	.xlsx, .shp, .kmz
Data size	25.9 KB
Data files	(1) Geographic location data and photos of three LAI-NOS nodes at Luancheng Station in 2019; (2) daily LAI data of the three LAI-NOS nodes at Luancheng Station from March 25 to June 10, 2019
Foundations	Ministry of Finance of P. R. China (Y930280A2F, Y930070A2F)
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	(1) ***Data*** are openly available and can be freely downloaded via the Internet; (2) end users are encouraged to use ***Data*** subject to citation; (3) users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) if ***Data*** are used to compile new datasets, the "ten percent principal" should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[9]
Communication and searchable system	DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS

3 Methods

3.1 LAI-NOS Algorithm

The LAI-NOS hardware includes sensor terminals, collection nodes, sink nodes, and auxiliary equipment, with servers and clients mainly for storing and managing data. Figure 1 shows the overall framework of the LAI-NOS[10]. The LAI sensor terminal is simple in structure, small in size, and convenient for deployment, featuring high measurement accuracy. It is mainly used for acquiring and analyzing vegetation canopy images and measuring parameters, and is suitable for measuring scrubby gramineous plants and shrubs, as well as tall trees.

The LAI-NOS follows three steps to acquire vegetation canopy parameters: canopy image acquisition, image analysis and processing, and parametric statistics and calculation. For this study, the acquisition of vegetation canopy images was completed through hemispherical photography, which involves shooting from a bottom-up or top-down perspective. The OV2640 fisheye lens produced by OmniVision was used to collect vegetation canopy images, featuring a short focal length (<16 mm) and a large field of view (typically close to 180°). The imaging principle of the fisheye lens[11] is illustrated in Figure 2.

The Beer-Lambert law states that the absorption of sunlight by a homogeneous solution relates to its path through the solution and the solution concentration, but not to the incident light. Assuming that the leaves of the vegetation canopy are randomly distributed and have random inclination angles, the area of a single leaf is much smaller than the total area of the canopy, and the overall vegetation canopy can be regarded as a homogeneous solution with leaves as solutes. According to the Beer-Lambert law, the intensity of solar radiation after it is attenuated by passing through the canopy is given by the following Equation:

$$I_1 = I_0 \times e^{-K \times LAI} \tag{1}$$

$$T(\theta) = e^{-K \times LAI} \tag{2}$$

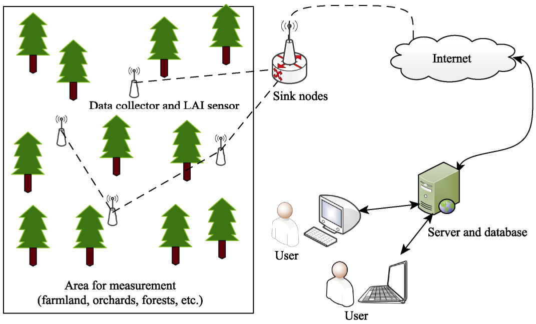

Figure 1 Overall framework of the LAI-NOS[10]

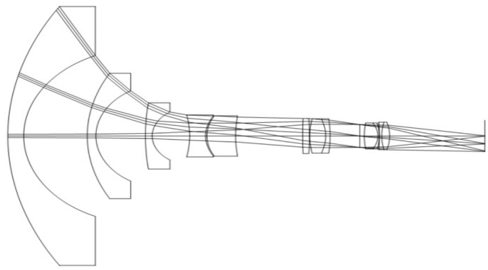

Figure 2 Imaging principle of fisheye lens

where I_0 is solar radiation above the canopy; I_1 is the solar radiation below the canopy after being blocked out by the canopy; K is extinction coefficient; $T(\theta)$ is the transmissivity at an incident angle of θ. Considering the direct incidence of light, $T(\theta)$ can express the porosity of the canopy; K relates to the incident angle of light θ and the leaf inclination angle β. Then, the calculation Equation for LAI is derived according to the intensity of solar radiation:

$$K(\theta)=\frac{G(\theta,\beta)}{\cos\theta} \tag{3}$$

$$LAI_e=-\frac{\ln(T(\theta))\cos\theta}{G(\theta,\beta)} \tag{4}$$

where $G(\theta,\beta)$ is the projection function, which represents the projection area per unit leaf area on a plane perpendicular to the direction of θ when the viewing angle is θ and the leaf inclination angle is β; LAI_e is the LAI value without considering the clumping effect[12]. From the imaging principle of hemispherical images, θ in the above equation is the camera's angle of view.

When the incident angle is 57.5°, the projection function value is independent of the leaf inclination angle, and the projection function G value is close to 0.5[13, 14]. Equation (5) can be simplified as:

$$LAI_e=-\frac{\ln(T(57.5°))\cos 57.5°}{0.5} \tag{5}$$

In practice, the assumption of a random distribution of leaves is difficult to satisfy, especially in forest areas, where the measurement results are affected by the clumping effect, resulting in significant errors in the final LAI value. Wilson *et al*. introduced the clumping index Ω_θ to correct the accuracy and reliability of LAI measurements. Common approaches for calculating Ω_θ include the finite-length averaging method, the gap-size distribution method, and the path-length distribution method[15]. The finite length averaging method can be used to calibrate the LAI and eliminate the clumping effect by measuring and calculating the sub-line transect of finite length. The calculation Equation of Ω_θ is as follows:

$$\Omega_\theta=\frac{\ln\overline{\left(T(\theta,\varphi)\right)}}{\overline{\ln(T(\theta,\varphi))}} \tag{6}$$

where, Ω_θ is the clumping index of the field of view ring corresponding to the viewing angle θ; $T(\theta,\varphi)$ is the canopy porosity at the viewing angle θ and azimuth angle φ.

When the canopy porosity is 0 within a certain range of viewing angles, the clumping index cannot be calculated. At this time, it is considered that there is only one background pixel within the sub-viewing angle, and the calculation is shown in Equation (7):

$$T(\theta,\varphi)=\frac{1}{N} \tag{7}$$

where N is the total number of pixels in the effective area of the hemispherical image. The true LAI can be obtained after correction with the Ω_θ:

$$LAI=\frac{LAI_e}{\Omega_\theta} \tag{8}$$

3.2 Raw Data Acquisition

The area for raw data acquisition of the LAI-NOS is located at the Luancheng Station in the LAI ground observation network of the Chinese Academy of Sciences. This area locates in Shijiazhuang city, Hebei province. Luancheng Station is in a semi-humid region with a climate of warm-temperate monsoon, in the center of the arid climate zone of the North China Plain. It has an annual precipitation of 530 mm and an altitude of 160–820 m, with a mild climate, sufficient sunshine, moderate precipitation, and four distinct seasons. Luancheng Station is dominated by meadow cinnamon soils. The farmland ecosystem is a winter wheat-summer maize double cropping system representing the typical high-yield agricultural ecological type of meadow cinnamon soil in the north of the North China Plain. It is also located in the Taihang Mountain piedmont plain, with an area of 49,800 km^2 and 38 million mu (≈2,533,333.33 ha) of arable land, characterized by intensive high-yield, resource-constrained, well-irrigated agricultural, and suburban agricultural ecology.

The measuring frequency of each node in the LAI-NOS is 5 min, and each node automatically measures 288 points of raw LAI data every day and sends them back to the server. This dataset comprises all the valid raw data from the LAI-NOS from March 25 to June 10, 2019, with a total of more than 24,000 points of data, including time of data acquisition, air temperature, and LAI. The valid raw data totaled more than 10,000 points after some missing or invalid data caused by weather effects were removed.

(a) Site photo of the experimental area of Luancheng Station

(b) Layout of instruments at Luancheng Station

Figure 3 Experimental area and nodes at Luancheng Station

3.3 Data Processing

The LAI accuracy correction algorithm of the LAI-NOS follows three steps: (1) extract data of early morning and evening, and then filter out predefined outliers, such as those caused by environmental factors, i.e., too bright or too dark light, cloud interference, and equipment failures in data collection; (2) use the box plot to filter out data outliers; (3) use the steady window algorithm to accurately tune the original data. The core idea of the steady window algorithm is to find the steadiest interval with the smallest standard deviation of LAI in the time window, and then take the average value of LAI in that interval as the representative value of LAI for that day. Finally, the daily wheat LAI dataset (2019) was obtained from the LAI-NOS at Luancheng Station.

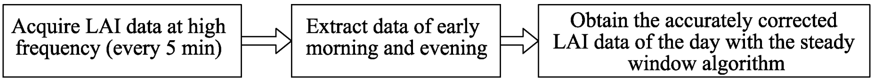

Figure 4 Accurate correction strategy for LAI data of the LAI-NOS

With the steady window algorithm, the accurate correction of raw data proceeds as follows:

(1) Preprocess each piece of data to determine whether there are any outliers that need to be removed, such as those resulting from communication anomalies, image darkness, failed conversion of data formats, improper allocation of image memory, and image overexposure.

(2) Set the window size as m, and calculate the mean and variance corresponding to each window through window sliding, as shown in Equation (9) and (10):

$$\bar{x}_j = \frac{1}{n-1}\sum_{i=1}^{m} x_{ij} \tag{9}$$

$$\sigma_j^2 = \frac{1}{n-2}\sum_{i=1}^{m}\left(x_{ij} - \bar{x}_j\right)^2 \tag{10}$$

where, $\bar{x}_j$ is the average of the j-th window; x_{ij} is the i-th data of the j-th window; σ_j^2 is the variance of the j-th window.

(3) Equation (10) finds the minimum variance in Equation (9) and is evaluated with the following conditions:

$$min\left(\sigma_j^2\right) < \delta \tag{11}$$

where, δ is the set threshold, with an empirical value of 0.5. The empirical value greater than 0.5 indicates that the variance is too large and the data is unstable.

(4) If there is a variance satisfying Equation (11), the average value of the window corresponding to this variance is taken as the representative value of LAI. If not, the system concludes that no valid data are available for that day.

4 Data Results and Validation

4.1 Data Composition

The dataset contains LAI data collected in the wheat growing season from March 25 to June 10, 2019 (from wheat turning green period to maturation), from three adjacent LAI-NOS nodes (0901, 0902, and 0904) at Luancheng Station. It includes (1) the geographic location of three nodes at Luancheng Station in 2019; (2) daily LAI data of the three LAI-NOS nodes at Luancheng Station from March 25 to June 10, 2019. The dataset is archived in .xlsx, .shp, and .kmz formats, and consists of nine files with a size of 25.6 KB (compressed into two files, 21.9 KB).

4.2 Data Products

The daily wheat LAI dataset (2019) from March 25 to June 10, 2019 was obtained from the three LAI-NOS nodes at Luancheng Station of the China LAI observation Cal-Val network.

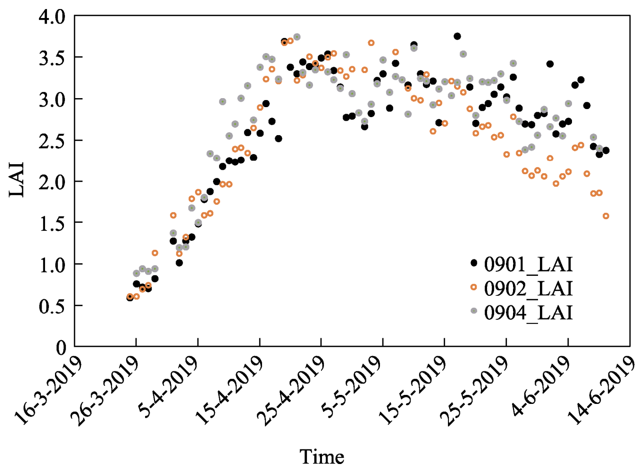

Figure 5 Daily LAI data at three LAI-NOS nodes of Luancheng Station in Hebei (Mar. 25–June 10, 2019)

4.3 Data Validation

To verify the accuracy of the LAI measurements of the LAI-NOS system, an experiment was carried out on August 15, 2023, at Luancheng Station in the LAI ground observation network of the Chinese Academy of Sciences, and the LAI-2200C of LI-COR Company, USA, was used for reference. The specific process of data acquisition was as follows: Through back-to-back measurements, one group of researchers collected the LAI value with LAI-2200C at the same position of the LAI-NOS node; another group downloaded the LAI value of the day from the system; then Passing-Bablok (PB) regression was carried out on the measurements of the two groups. PB regression is a method of statistical analysis that widely used in the comparative study of methods and instruments. It uses non-parametric regression to fit parameters a and b of the linear equation $y = \mathrm{a} + \mathrm{b}x$.

Intercept a is a measure of the systematic difference between the two methods. The 95% confidence interval of intercept a can be used to test the hypothesis that a = 0. If the confidence interval of a contains the value of 0, the assumption is accepted, and there is no significant difference between the value of a and 0; otherwise, the hypothesis is rejected, and the value of a is significantly different from 0. Slope b is a measure of the proportional difference between the two methods. The 95% confidence interval of slope b can be used to test the hypothesis that b = 1. If the confidence interval of b contains a value of 1, the assumption is accepted, indicating that there is no significant difference between the value of b and 1; otherwise, the hypothesis is rejected, which means that the value of b is significantly different from 1.

The intercept of the PB regression was 2.411,5, and the 95% confidence interval is −0.653,4–3.697,1, including 0 (Table 3). The slope of the PB regression was 1.081,6, and the 95% confidence interval was 0.526,0–2.443,0, including 1. Because the 95% confidence interval of the slope contained ±1 and the 95% confidence interval of intercept included 0, the LAI-NOS data at Luancheng Station was deemed valid, with a significant correlation with the actual LAI-2200C data.

Table 3 PB regression analysis of LAI-NOS and LAI-2200C data at Luancheng Station, Hebei province

Parameter	Intercept a	95% CI	Slope b	95% CI
Result	2.412	−0.653–3.697	1.082	0.526–2.443

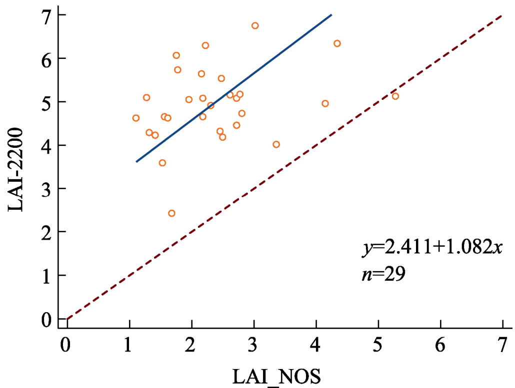

Figure 6 Sample distribution and regression equation of LAI-NOS and LAI-2200C data at Luancheng Station, Hebei province

5 Discussion and Conclusion

This paper illustrated the wheat LAI dataset of Luancheng Station, Hebei, China (2019) — China LAI Observation Cal-Val Network's serial dataset. In this dataset, more than 10,000 pieces of effective raw data of the LAI-NOS were obtained at a frequency of 5 min from March 25 to June 10, 2019. The steady window algorithm was used to screen and preprocess the raw data and filter out the outliers. A portion of effective ground measurement data was obtained every day and represented the relative true value of LAI remote sensing products, thus providing data support for the validation of LAI remote sensing products. This dataset has evident advantages for validating long-time series of LAI remote sensing products, especially in application scenarios including different phenological growth periods and different scales. The research of this dataset only focused on the images near the research site, in a limited geographical scope. How to validate LAI remote sensing products for long time series on a national and even global scale remains an important issue. In the future, a validation test can be extended to the measured sample areas of different vegetation types all over the country to evaluate the uncertainty of LAI remote sensing products in these areas. A longer time series for data verification will be constructed to further evaluate the changes in LAI remote sensing products.

Author Contributions

Gu, X. F. , Zhou, X. ,Yang, J. , Yu, T. designed the algorithms of the dataset. Chen, Y. P. contributed to the data processing and analysis. Sun, Y. completed data validation and wrote the paper.

Conflicts of Interest

The authors declare no conflicts of interest.

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