

基于 Landsat-MODIS 图像填充与时空融合的 红树林物候优化提取*

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摘要:【目的】植被物候是指植物生命周期中与季节变化相关的现象。红树林是一种生长在海水和淡水交接处沼泽的森林,准确提取物候信息对于获得红树林生长变化以及维护海岸带生态系统至关重要。然而,受限于滨海地区多云环境和卫星过境时间,大部分研究使用低时间分辨率、无云原始图像序列提取物候特征。结合图像空值填充和时空融合算法是一个能够优化红树林物候提取的思路,但数据量、计算量较大,红树林的遥感物候提取仍然面临挑战。【方法】以中国福建漳江口、广东淇澳岛、广西北仑、海南东寨港的红树林为对象,基于2020年的30m Landsat、250m MODIS数据和500m MODIS数据,在Google Earth Engine上结合图像填充算法和时空融合算法进行红树林物候优化提取。首先,基于500m MODIS数据,采用Gap Filling and Savitzky-Golay filtering (GF-SG)算法合成局部无空值的Landsat NDVI数据序列。其次,采用线性插值填充250m MODIS NDVI逐日数据的空缺值,并用S-G滤波平滑时间序列。进一步使用ESTARFM-like算法从Landsat和MODIS时间序列中拟合计算出高分辨率时间序列。最后,通过基于中心日期前后超过动态阈值的观测值比率差异提取时间节点的最大分离方法估计物候参数。【结果】(1)基于GF-SG算法在Landsat和MODIS影像中都表现出比较好的空值填补和图像重建效果。与原始图像相比,重建Landsat NDVI图像的RMSE分别为0.088、0.131、0.100和0.083,重建MODIS NDVI图像的RMSE分别为0.088、0.131、0.100和0.083。(2)ESTARFM-like算法能够拟合30m逐日NDVI数据,其结果与GF-SG拟合NDVI图像在不同红树林场景都表现出较强的一致性, R^2 分别为0.991、0.710、0.997和0.999。(3)4个地区的红树林NDVI都展现出明显地季节性特征。1月至4月,NDVI序列具有下降趋势或处于低值;4月后NDVI序列先升高后降低。(4)不同地区红树林的生长开始期(SoS)、生长期长度(LoS)具有明显差异,呈现纬度越南、SoS越早的特点。但东寨港的SoS晚于漳江口,可能是气候因素导致的物候异常。生长结束期(EoS)、最大绿度(MaxGreen)无规律性差异。【结论】研究证实了图像空值填充和时空融合算法在红树林物候提取中的应用潜力,提出的方法对于更广泛、便捷地监测红树林物候提供参考依据。

关键词: 时空融合; 物候; 红树林; NDVI; Google Earth Engine

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Optimized Extraction of Mangrove Phenology based on Landsat-MODIS Image Filling and Spatio-temporal Fusion

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Abstract: 【Objective】Vegetation phenology pertains to the study of seasonal life cycle events in plants. Mangroves, a type of forest grows in intertidal zones where seawater and freshwater converge, require precise phenological monitoring to understand their growth dynamics and sustain coastal ecosystems. However, the cloudy conditions in coastal regions and the timing of satellite passes often necessitate the use of low temporal resolution, cloud-free image sequences for extracting phenological features. The Combination of image gap filling and spatio-temporal fusion algorithms can enhance the accuracy of mangrove phenology extraction, but this approach requires extensive data and computational resources. Consequently, remote sensing phenology extraction of mangroves remains challenging. 【Method】Mangroves in Zhangjiangkou (Fujian), Qi'ao Island (Guangdong), Beilun (Guangxi), and Dongzhaigang (Hainan), China, were selected as research subjects using 30m Landsat, 250m MODIS, and 500m MODIS data from 2020. The image filling algorithm and spatio-temporal fusion algorithm were combined on Google Earth Engine to optimize mangrove

phenology extraction. Firstly, 500m MODIS data was processed using the Gap Filling and Savitzky-Golay filtering (GF-SG) algorithm to synthesize the Landsat NDVI data series, eliminating local null values. Secondly, linear interpolation addressed missing values in the 250m MODIS NDVI daily data, followed by Savitzky-Golay (S-G) filtering to smooth the time series. An ESTARFM-like algorithm was then applied to fit and compute high-resolution time series from the combined Landsat and MODIS data. Finally, phenological parameters were ultimately estimated using the maximum separation method, which relies on the differential ratio of observations exceeding the dynamic threshold before and after the central date. **【Result】** (1) The GF-SG algorithm showed effective gap filling and image reconstruction for both Landsat and MODIS images. Compared with the original images, the RMSE of the reconstructed Landsat NDVI images were 0.088, 0.131, 0.100 and 0.083, and the RMSE of the reconstructed MODIS NDVI images were 0.088, 0.131, 0.100 and 0.083, respectively. (2) The ESTARFM-like algorithm effectively fits 30m daily NDVI data, demonstrating high consistency with GF-SG fitted NDVI imagery across various mangrove scenes, with R^2 values of 0.991, 0.710, 0.997, and 0.999, respectively. (3) The NDVI of mangroves in the four regions exhibited distinct seasonal variations. From January to April, the NDVI series displayed a downward trend or remained at a low value; after April, the NDVI series initially increased and then decreased. (4) Significant differences exist in the start of growth (SoS) and length of the growth period (LoS) of mangroves across different regions, with an earlier SoS observed at lower latitudes. However, Dongzhaigang's SoS is later than that of Zhangjiangkou, likely due to climate-induced phenological anomalies. No consistent differences are observed in the end of growth (EoS) and maximum greenness (MaxGreen). **【Conclusion】** The study confirmed the potential of image gap filling and spatio-temporal fusion algorithms for extracting mangrove phenology. The proposed method offers a valuable reference for more comprehensive and convenient monitoring of mangrove phenology.

Key words: spatio-temporal fusion; phenology; mangrove; NDVI; Google Earth Engine.