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A Spatio-Temporal Model for Forest Fire Detection Using MODIS Data

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Contextual algorithm and Muti-temporal analysis are currently the most widely used in fire detection based on remote sensing technology. However, muti-temporal analysis ignores the correlation between the inspected pixel and its neighboring pixels (spatial heterogeneity) (Equation (1)). Contextual algorithm only focuses on a single scene, and ignores the internal differences of the background pixels, which increases the commission error. Due to the muti-temporal analysis and contextual algorithm are used for different processes of fire detection, the combination between them will increase the accuracy for fire detection.

$$\frac{BT^i_{t_1}}{BT^o_{t_1}} = \alpha\frac{BT^i_{t_2}}{BT^o_{t_2}}=\beta\frac{BT^i_{t_3}}{BT^o_{t_3}}=\dots \tag{1}$$

Where $BT^i_{t_n}$ is the bright temperature (BT) of the valid neighboring pixel i of the inspected pixel o at time t_n,(i=1,2,…,N), N is the number of the valid neighboring pixels(Which depends on the condition of context), $BT^o_{t_n}$ is the BT of o at time t_n.

In this paper, We coupled the muti-temporal analysis with contextual algorithm and proposed a region-adaptive spatio-temporal model for forest fire detection: (1) Pre-processing: Cloud, water, potential background fires and bright fire-free targets masking (refer to the context method); (2) Adjust the threshold for identifying potential fire-points for different study areas (Equation 2); (3) The spatial relationship of BT between the inspected pixels and its neighboring pixels in current time is build based on the spatial relationship of BT between them in the multiple previous images, and the BT of the inspected pixels is estimated based on the present spatial relationship and the BT of its neighboring pixels and using inverse distance weighted method (Equation 3). (4) The predicted BT value of the inspected pixel at a certain time is the weighted sum of the value obtained by (3) and the real BT value of the inspected pixel at the previous time (Equation 4); (5) Relative fire pixels judgment(refer to the context method).

$$\mathrm{BT}_4 > \mathrm{BT}_{4S}, D_{\mathrm{BT}} > 10\mathrm{k}, \rho_{0.86} < 0.3 \tag{2}$$

Where BT_j,ρ_j are the BT and the reflectance in channel j respectively, $D_{\mathrm{BT}} = \mathrm{BT}_4 - \mathrm{BT}_{11}$,BT_{4S} is the background BT in whole study area.

$$\widehat{BT}^o_{t_n} = \sum_{i=1}^{N}[F^i_{t_n} \times W^i_{t_n} \times BT^i_{t_n}] \tag{3}$$

Where $F^i_{t_n} = a \times \frac{BT^o_{t_n}}{BT^i_{t_n}} + (1-a) \times F^i_{t_{n-1}}, a \in [0,1], F^i_{t_1} = 1, W^i_{t_n}$ is the inverse distance weighted coefficient of the valid neighboring pixel i at time t_n, $\widehat{BT}^o_{t_n}$ is the predicted BT value of the inspected pixel o at time t_n, this equation applies to 4-band and 11-band.

$$\overline{BT}^{o}_{t_n} = b \times \widehat{BT}^{o}_{t_n} + (1 - b) \times BT^{o}_{t_{n-1}}, b \in [0, 1] \tag{4}$$

Where $BT^{o}_{t_{n-1}}$ is the real BT of the inspected pixel o at time t_{n}, $\overline{BT}^{o}_{t_1} = \widehat{BT}^{o}_{t_1}$.

The proposed model was applied to forest fires in Victoria(Australia) in 2009, southern California(America) in 2016 and Fort McMurray(Alberta, Canada) in 2016, using MODIS time-series images. The proposed algorithm described in this paper can significantly reduce the commission error and detect more fire pixels than MOD14 using Landsat-8 images as a reference dataset. The spatio-temporal model make full use of spatial information and temporal information and is proved to be more effective than the optimized contextual algorithm.

Keywords: Fire detection; Spatio-temporal model; MODIS