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To cite this article: Jiaxin Jin et al 2014 IOP Conf. Ser.: Earth Environ. Sci. 17 012018

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Monitoring responses of Mason Pine to acid rain in China based on remote sensing vegetation index

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Abstract. Since the 1970s, acid rain has remained in the public spotlight in both Europe and the United States and recently has emerged as an important problem in other regions such as Southeast Asia. To reveal responses of Masson Pine to acid rain during a long time series in central China, we used the interpolation dataset of acid rain and the Global Inventory Modeling and Mapping Studies (GIMMS) normalized difference vegetation index (NDVI) data to derive the monthly pH and NDVI trajectories based on acidity gradients from 1992 to 2006. Then we analyzed inter-annual and seasonal variation of vegetation growth by improved sinusoidal fitting and regression analysis. In the environment of strong acidity and moderate acidity, the growth of Masson Pine was inhibited during the study period, while the slight acidity promoted growth of Masson Pine to some extent. For the multi-year monthly changing trend of NDVI, late spring to mid autumn, the NDVI showed a decreasing trend, especially in June, while from late autumn to the following spring, the NDVI showed a rising tendency, specifically in December and March.

1. Introduction

Since the 1970s, acid rain has remained in the public spotlight in both Europe, the United States and Southeast Asia, especially in China [1]. Possible effects of acidic deposition on plants have been the topic of intensive research efforts all over the world. Previous studies pointed that acid stress could affect plant physiology such as leaf surface wax layer, Chlorophyll and so on [2]. Although these researches on the impact of acid rain on vegetation have had achieved a lot, there were still some limitations due to the drawbacks of controlled experiments and test sites, which could not reveal the response of plants to acid rain in natural conditions for a wild study field or long time series.

Stress induction affects the physiological behaviour of plants, resulting in differences in reflectance patterns and thus providing potential for remote sensing vegetation index diagnosis of vegetation stress. The most widely used vegetation index is known as NDVI (normalized difference vegetation index), which is the difference between the near-infrared and red bands divided by the sum of these two bands. It is significant correlated with LAI (leaf area index), chlorophyll content and other biochemical index [3]. NDVI has been extensively applied as a characterization of environmental

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stress on vegetation, and Jacob Garty [4] pointed out that NDVI is a sensitive and efficacious parameter to assess the impact of acid rain on vegetation.

Masson pine (Pinus massoniana) is a widely distributed, acid stress-sensitive and high economic and ecological valuable plant in China. Since the beginning of the 1980s, large areas of masson pine have exhibited decline, even injured to death resulting from air pollution and acid rain [5]. Unfortunately, the damage of acid deposition on masson pine forest is still not well understood. In this paper, we aimed to detect inter-annual responses of masson pine to acid rain from 1992 to 2006 in China based on precipitation acidity and remotes sensing.

2. Materials

2.1 GIMMS/NDVI
The Global Inventory Modeling and Mapping Studies (GIMMS) normalized difference vegetation index (NDVI) data sets were generated to provide a 25-year satellite record of monthly changes in terrestrial vegetation, at a spatial resolution of 0.083°. New features of this dataset include reduced NDVI variations arising from calibration, view geometry, volcanic aerosols, and other effects not related to actual vegetation change [6].

2.2 Precipitation acidity
The precipitation acidity (pH) is observed at selected meteorological stations of China Meteorological Administration (CMA). On-site quality control measures are performed routinely following the guideline of Standard Operation Manuals of CMA-ARMN. Through Data verification and data validation, data from 74 stations out of 89 are chosen for the following analysis [7].

2.3 Vegetation
The distribution of masson pine was obtained from a digitized vegetation map of China with a scale of 1:1,000,000 (Editorial Board of Vegetation Map of China 2001), and resampled to a spatial resolution of 0.083° to be consistent with the NDVI dataset.

3. Methods

3.1 Precipitation acidity interpolation
The monthly spatial precipitation acidity in China was interpolated at a spatial resolution of 0.083° using the 74 sites data from 1992 to 2006 by the ordinary Kriging [8]. According to multi-year average pH, the interpolated acidity was divided into 3 levels, including pH<4.8 (L1), 4.8<pH<5.0 (L2) and 5.0<pH<5.6 (L3). Based on the distribution of masson pine and acidity gradients in China, we derived the monthly average pH and NDVI from the acidity interpolation data and GIMMS/NDVI data from 1992 to 2006 respectively for the following analysis.

3.2 Inter-annual variations
In order to describe the inter-annual trend of NDVI of masson pine during the study period, we used the improved sinusoidal model based on research of Zhang (2008) [9] to fit NDVI curve in each masson pine pixel. In additional, linear regression analysis was used to detect inter-annual variation of NDVI in each month.

4. Results and discussion
The yearly average pH values at three acidity levels were respectively 4.74, 4.87 and 5.23, and showed significant differences (p<0.05) among them. Through the curve fitting for the NDVI of masson pine, the result (Figure 1) showed that at L1 and L2, the monthly average NDVI appeared a declining trend from 1992 to 2006, indicating the growth of masson pine was inhibited, and the severe the acidity was, the more serious the inhibition was. On the contrary, at L3, an increasing NDVI was observed during
the study period, suggesting acid rain promoted the growth of masson pine to some extent which may be associated with the fertilization effect of nitrogen deposition in acid rain.

![Figure 1. Average inter-annual trend of NDVI of masson pine and pH status at different acidity levels](image)

Through linear regression analysis, overall, the linear trend of NDVI of masson pine at each acidity level appeared declining from early spring to mid autumn and rising during the other season (Figure 2). The rate of increasing trend of NDVI of masson pine at L3 was maximum in spring, and the rate of decreasing was minimum in summer and autumn, while that at L1 was just opposite with the former. In winter, there was no obvious pattern about the impact of different acidities on the NDVI trend. Through analysis of variance, we found that for the multi-year monthly average NDVI of masson pine among different levels of acid rain, the significant differences ($p<0.05$) mainly lasted from late autumn to next early spring when the temperature were relatively low, while that was roughly consistent in summer, indicating that the acid rain may impact on the cold resistance of pine to some extent. However, there were many uncertainties in detection responses of masson pine to acid rain due to anomalous values of NDVI, of soil feedback and other disturbs.
Figure 2. Average inter-annual variation of NDVI in each month at different acidity levels and the significant of differences among them

Acknowledgement
Funding support partially from NSF of China (41101315 & 41171324), and The State Key Fundamental Science Funds of China (2011CB302705, 2010CB950702 and 2010CB428503), Zhejiang Province Environmental Protection Science and technology project (2010B01), The Funds for Ph.D. Education (2011091110028), The State High Technology Funds of China (2009AA122001 and 2009AA122005), The State Key Basic Research Funds of China (2007FY110300-04 and 08), The Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions, Zhejiang province key science and technology innovation team (2010R50030).

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