

## Global monitoring of interannual changes in vegetation activities using NDVI and its relationships to temperature and precipitation

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(Received 26 June 2000; in final form 22 November 2000)

**Abstract.** Interannual trends in annual and seasonal vegetation activities from 1982 to 1990 on a global scale were analysed using the Pathfinder AVHRR Land NDVI data set corrected by utilising desert and high NDVI areas. Climate effects on interannual variations in NDVI were also investigated using temperature and precipitation data compiled from stational observations. In the northern middle-high latitudes, vegetation activities increased over broad regions because of a gradual rise in temperature. NDVI increases were also detected in the tropical regions, such as western Africa and south-eastern Asia. Plant photosynthetic activities on the other hand, decreased remarkably in some arid and semi-arid areas in the Southern Hemisphere, because annual rainfall decreased during this period.

### 1. Introduction

Global warming resulting from an increase in atmospheric CO<sub>2</sub> concentration is one of the most significant problems on the Earth. Photosynthetic activity by vegetation, which fixes carbon as biomass in the biosphere, plays a key role in the global carbon cycle (Schimel *et al.* 1995), and can be inferred using a satellite-derived vegetation index (Goward *et al.* 1985) such as Normalized Difference Vegetation Index (NDVI).

For example, interannual increase in NDVI associated with lengthened plant growing season in the northern high latitudes has been pointed out (Myneni *et al.* 1998). However, global geographical distribution of decadal trends in NDVI has not yet been obtained.

Climate effects are expected as one of the factors of interannual variations in vegetation activities, and relationships between NDVI and climate data have been investigated on regional (e.g. Li and Kafatos 2000) and global (Schultz *et al.* 1995) scales. Although Schultz *et al.* (1995) reported that interannual NDVI data were not highly correlated with climate data, it might be inappropriate to utilise

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satellite-sensed land surface temperature data and NDVI data without proper corrections when comparing NDVI and climate variables.

In this study, interannual trends in NDVI were investigated seasonally and annually on a global scale using the Pathfinder AVHRR (Advanced Very High Resolution Radiometer) Land NDVI data set from 1982 to 1990, which was corrected utilising desert and high NDVI areas (James and Kalluri 1994, Ichii *et al.* in press). In addition, climate effects on NDVI variations over this period were examined using land air temperature and precipitation data obtained at ground meteorological stations.

## 2. Methods and data sets

The Pathfinder AVHRR Land NDVI data set was produced from data observed by the National Oceanic and Atmospheric Administration (NOAA) meteorological satellites; NOAA-7, -9, and -11, and covers the periods from July 1981 to September 1994 at 8 km spatial and ten days or one month temporal resolutions. The monthly data from December 1981 to December 1990 were used in the present study, because the eruption of Mt Pinatubo in June 1991 might affect the data obtained since then (Myneni *et al.* 1998). This data set was originally corrected for various factors such as intra-sensor degradation; however, some residual errors have still been found to exist due to incomplete atmospheric correction resulting from lack of appropriate water vapour and aerosol data, and so on (Myneni *et al.* 1998). To eliminate these errors, the authors applied further correction to the data set by utilising two targets that were expected to be time-invariant in NDVI, namely, desert (no photosynthetic activity) and dense forest (saturated NDVI; Carlson and Ripley 1997) areas. In addition, geometric resampling was performed in order to reduce original spatial resolution by 8 km, to 1° latitude by longitude gridding, so as to suppress noise. These monthly NDVI data for consecutive three and twelve months were averaged to generate seasonal and annual NDVIs for each year at each grid.

The seasonal and annual NDVIs for nine years at each cell were regressed linearly as a function of time to estimate their change rates except for areas of insufficient data ( $n < 5$ ) or low mean NDVI ( $< 0.05$ ), and areas with statistical significant tendencies ( $> 10\%$ ) were extracted. In the regions where distinct NDVI trends existed, correlations between NDVI and land air temperature or precipitation were examined to investigate climate effects on interannual variations in vegetation activities. The climate data sets were constructed from station observations at 5° spatial resolution and one month time intervals, and the temperature data were expressed as anomalies from 1961 to 1990 (Jones 1994, Hulme *et al.* 1998).

## 3. Results and discussion

Global distribution of statistically significant trends in annual NDVI from 1982 to 1990 is shown in figure 1. In the Northern Hemisphere, NDVI increasing trends were found broadly from the high latitudes to the equatorial regions, including north-western America, Europe, northern China, western Africa, and south-eastern Asia. On the other hand, NDVI decreased in some parts of the Southern Hemisphere, especially in arid and semi-arid regions such as northern Australia and Argentina. Most of extracted pixels with significant NDVI trends were satisfied with  $n = 9$ . Figure 2 also indicates statistically significant changes in NDVI on a global scale for each season. In the northern middle-high latitudes, NDVI increased in several regions, especially between March and November, and the rates of increase were

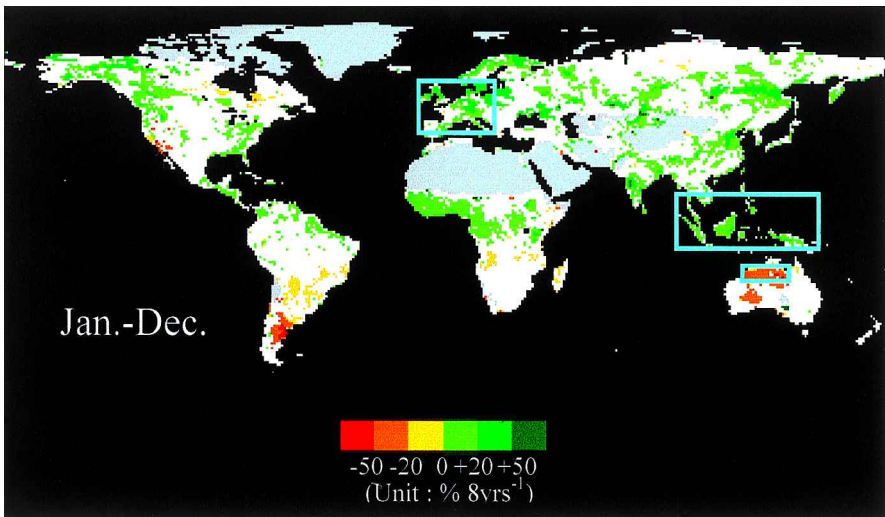


Figure 1. Global distribution of interannual changes in annual NDVI from 1982 to 1990. Areas showing statistically significant ( $>10\%$ ) NDVI trends are indicated in colour from green to red. Grey regions indicate areas of insufficient data ( $n < 5$ ) or low mean NDVI ( $< 0.05$ ). White regions indicate areas in which statistically significant NDVI trends were not found. Blue rectangles indicate representative areas examined for correlation between NDVI and climate data.

particularly high in spring and autumn, which probably corresponds to lengthened growing season of vegetation (Myneni *et al.* 1998). Although NDVI increased mainly from June to November over the tropical regions, NDVI decreased almost throughout the entire year in some arid and semi-arid areas in the Southern Hemisphere.

The areas that showed significant trends can be divided into three categories: northern middle-high latitudes, tropical regions, and arid and semi-arid areas in the Southern Hemisphere. Then, relationships between NDVI and climate variables were examined for NDVI increase/decrease areas, as shown in figure 1, of these three categories.

In the northern middle-high latitudes, annual and seasonal NDVIs and temperature were positively correlated ( $R^2 = 0.3\text{--}0.7$ ) in most of extracted areas (e.g. figure 3), whereas correlation between NDVI and precipitation was not significant. Therefore, interannual rise in temperature is expected to have brought about an NDVI increase in these regions. In the tropical zone, the correlation between NDVI and climate variables was not strong ( $R^2 < 0.2$ ), and therefore effects of temperature and precipitation on the interannual NDVI increase are small. Although possible reasons for increased NDVI might include accelerated vegetation activities due to  $\text{CO}_2$  fertilisation, further analysis is necessary because a significant change in NDVI did not appear in the Amazon area, where anthropogenic deforestation and its regrowth are expected to be complicatedly affecting NDVI variations. Figure 4 indicates interannual variations in annual NDVI and precipitation in northern Australia and shows a linear correlation between them ( $R^2 = 0.75$ ). A similar correlation was also found in Argentina ( $R^2 = 0.54$ ). This relationship between annual NDVI and rainfall agrees with result of a previous study performed for the Sahel region (Malo and Nicholson 1990). Therefore, the interannual decrease in plant activities was due to a decrease in precipitation in these arid and semi-arid areas.

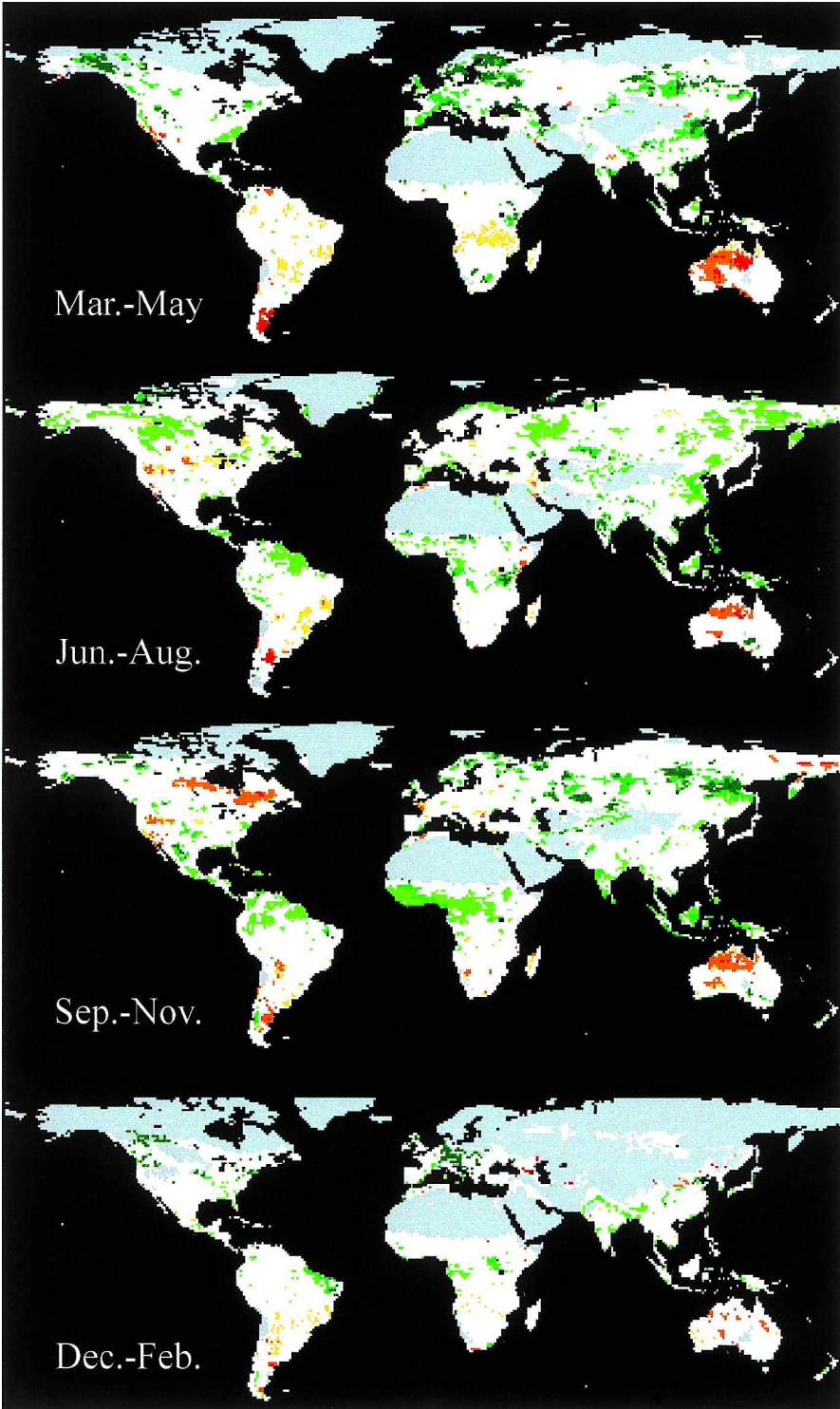


Figure 2. Global distribution of interannual changes in seasonal NDVI from 1982 to 1990. Details are as same as in figure 1.

(a)

(b)

Figure 3. (a) Interannual variations in annual NDVI (solid line) and temperature anomaly (dotted line) in Europe (40°N–60°N, 10°W–20°E) from 1982 to 1990. (b) Correlation between NDVI and temperature anomaly.

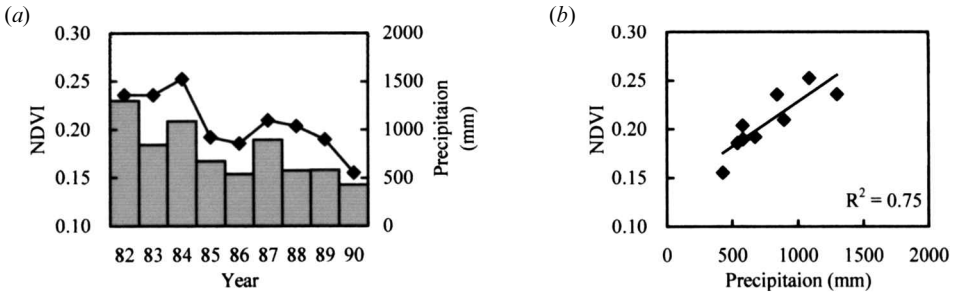


Figure 4. (a) Interannual variations in annual NDVI (solid line) and precipitation (grey bar) in northern Australia (15°S–20°S, 120°E–140°E) from 1982 to 1990. (b) Correlation between NDVI and precipitation.

#### 4. Conclusion and remarks

The present study consists of two components. (1) Global maps of interannual trends in NDVI from 1982 to 1990 were produced in order to identify areas in which significant trends were present. (2) Correlations between NDVI and temperature or precipitation were analysed, as a result, climate effects on interannual NDVI variations according to regions were divided into three groups that reflect climate classifications. These results suggest possible interannual changes in vegetation activities and some of the reasons, however, it is necessary to keep in mind that this study is not conclusive due to limitation of remotely sensed data quality.

In future studies, correlation for each fine grid scale should be examined, and anthropogenic effects such as deforestation ought to be considered so as to enable more concise investigation of relationship between NDVI and climate variables. The present study, as well as future studies, will be helpful in estimations of response of the terrestrial biosphere to global change.

#### Acknowledgments

The authors would like to thank the Distributed Active Archive Center (Code 902.2) at the Goddard Space Flight Center, Greenbelt, MD, USA, for producing and distributing the Pathfinder AVHRR Land data set in its present form. The original data products were produced under the NOAA/NASA Pathfinder Program by a processing team headed by M. James of the Goddard Global Change Data Center; and the science algorithms were established by the AVHRR Land Science

Working Group, chaired by J. Townshend of the University of Maryland. The temperature data set 'ltgrid19511990.dat.gz' and the precipitation data set 'g55wld0098.dat' (Version 1.0) were constructed and supplied by P. D. Jones and M. Hulme, respectively, at the Climate Research Unit, University of East Anglia, Norwich, UK. We are indebted to them for their helpful work.

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