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ORIGINAL ARTICLE

Regional differences in the carbon isotopic compositions of teak from two monsoonal regimes of India

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ABSTRACT

Inter and intra-annual carbon isotope compositions ($\delta^{13}C$) of several annual growth rings of teak trees from two monsoonal regimes from India were studied and compared with the corresponding oxygen isotopic ($\delta^{18}O$) variations. In teak from both the regimes, amplitudes of intra-annual $\delta^{13}C$ were ~2-3 times lower than that observed in $\delta^{18}O$. Seasonal cycle with lower $\delta^{13}C$ values at the middle and higher at ring boundaries was observed for teak from central India, dominated by the southwest monsoon. Positive correlations of intra-annual $\delta^{13}C$ values with the corresponding $\delta^{18}O$ values of the same rings and with relative humidity (RH) of the concurrent period suggest a dominant role of RH in controlling $\delta^{13}C$ values of teak from central India. Intra-annual $\delta^{13}C$ variations of teak from southern India, receiving both the southwest and northeast monsoons, revealed an initial decreasing trend followed by an increasing trend before culminating in depleted ^{13}C values at the end of the growing season. No correlation was observed between intra-annual $\delta^{13}C$ and $\delta^{18}O$ variations of teak trees from southern India. Regional differences in the climatology of $\delta^{13}C$ of atmospheric CO_2 or the lengths of growing season could be likely reasons for differing intra-annual $\delta^{13}C$ variations of teak from the two climatic regimes.

1. Introduction

In addition to reconstruction of past rainfall and temperature, the isotopic investigations of tree-rings are useful in many ways. These include assessing changes in the water use efficiency of plants (Duquesnay et al., 1998; Saurer et al., 2004); identifying past insect outbreaks (Simard et al., 2008), assessing the relative importance of relative humidity (RH) and light availability on the tree growth (Saurer et al., 1997), climate investigations at sub-annual time scales (e.g., Poussart et al., 2004; Anchukaitis et al., 2008; Berkelhammer and Stott, 2009; Managave et al., 2010), identifying past cyclonic activity (Miller et al., 2006), establishing chronology in trees lacking visible growth rings (Evans and Schrag, 2004) and isotope finger-printing for establishing the provenance of wood (Kagawa and Leavitt, 2010).

Plant physiological models developed for estimating carbon ($\delta^{13}C$) (Farquhar et al., 1982) and oxygen ($\delta^{18}O$) (Farquhar and Lloyd, 1993; Roden et al., 2000; Barbour et al., 2004) isotopic compositions of photosynthates have provided quantitative insights into how the ambient climate influences $\delta^{13}C$ and $\delta^{18}O$ of newly formed photosynthates. Detailed plant physiological studies have demonstrated the validity of these models (e.g., Cernusak et al., 2005, 2008). Studies have also indicated the processes that could modify the isotopic composition of photosynthates during transport from the leaf to the bark (Roden et al., 2000; Helle and Schleser, 2004; Brandes et al., 2006; Gessler et al., 2009; Ogee et al., 2009).

Carbon isotopic composition of tree-rings is useful for quantifying the past climate variability (e.g., Ramesh et al., 1985; Barber et al., 2000; Leavitt 2002, 2007; Vaganov et al., 2009; Treydte et al., 2009; Schubert and Jahren 2011; Managave and Ramesh, 2012). Combination of carbon and oxygen isotope studies of tree-rings can be used effectively for interpreting environmental conditions during photosynthesis (Saurer et al., 1997; Scheidegger et al., 2000). Utilizing the plant physiological models, several studies have demonstrated usefulness of a combined study of $\delta^{13}C$ and $\delta^{18}O$ of tree-rings in climate reconstruction (Anderson et al., 1998; Barbour et al., 2002; Battipaglia et al., 2007; Danis et al., 2006; Gessler et al., 2009; Li et al., 2011; Loader et al., 2010; Ogee et al., 2009; Poussart et al., 2004; Poussart and Schrag, 2005; Roden et al., 2005; Roden 2008; Simard et al., 2008; Sidorova

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et al., 2008).

Compared to the numerous isotopic studies on temperate tree rings, the isotopic investigations on tropical trees are quite limited (Evans and Schrag, 2004; Poussart et al., 2004; Verheyden et al., 2004; Poussart and Schrag, 2005; Cernusak et al., 2005, 2008; Anchukaitis et al., 2008; Ohashi et al., 2009; Managave et al., 2010, 2011; Sano et al., 2012; Kumar et al., 2014). Intra-annual $\delta^{18}O$ variations of teak form India have been characterized by Managave et al. (2010, 2011). Except for the Himalayan region, no study in India has been carried out to characterize intra-annual $\delta^{13}C$ variations of trees. Here we present the results of intra-annual $\delta^{13}C$ investigations of teak trees from two different monsoonal regimes from India.

2. Material and methods

2.1. Monsoonal regimes

The movement of the Intertropical Convergence Zone (ITCZ) sets two monsoonal regimes in India (Gadgil 2003). Northward movement of the ITCZ brings southwesterly oceanic winds, which leads to rainfall, the southwest monsoon (SWM), over most of Indian plains during June to September. Southward movement of the ITCZ results in rainfall, the northeast monsoon (NEM), over southern India during October to December. The relative humidity during the SWM and NEM is higher relative to the non-monsoon months and generally follows the monthly rainfall trend. Pre-monsoon showers are observed during April and May at both the regions.

Jagdalpur (19.09°N, 81.96°E and Palakkad (10.77°N, 76.65°E) (shown in Fig. 1) are Indian Meteorological Department (IMD) stations near Jagdalpur and Parambikulam, respectively. Fig. 2 shows the monthly variations in precipitation, temperature, relatively humidity and cloud cover at the two locations. Precipitation, temperature and relative humidity are from station observations from 1951 to 1980 CE (IMD, 1999). Cloud cover data for Jagdalpur (at grid points of 19.25°N, 82.25°E) and for Palakkad (grid points of 10.25°N, 76.25°E) are from a monthly data set of Climate Research Unit TS2p1 (Mitchell and Jones, 2005). As compared to Jagdalpur, Palakkad receives a higher proportion of the NEM rainfall; the ratios of rainfall received during the NEM and SWM at these stations are ~0.11 (for Jagdalpur) and ~0.27 (for Palakkad). Because of the NEM rainfall, October, November and December are more humid and cloudy at Palakkad than at Jagdalpur (Fig. 2).

2.2. CO_2 climatology

In India, data regarding monthly variations of concentration of atmospheric CO_2 and its $\delta^{13}C$ ($\delta^{13}C_{air}$) are available for only a few locations and cover a limited interval of time. These include Cabo de

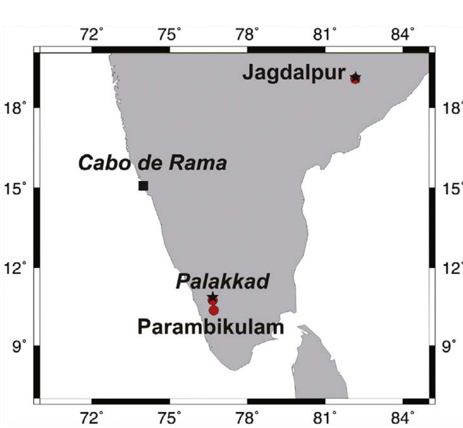

Fig. 1. Locations of tree-ring samples (circles), IMD stations (stars) and Cabo de Rama (square).

Rama (also known as Cape Rama) (15.1°N, 73.8°E, 60 m asl) (Fig. 1), Goa, a costal station on the west coast of India. Monthly data for Cabo de Rama are for a period from 1993 to 2001 (WMO World Data Centre for Greenhouse Gases at http://ds.data.jma.go.jp/gmd/wdcgg/). While explaining CO_2 climatology at Cabo de Rama, Bhattacharya et al. (2009) showed that (1) during the SWM season, the prevailing southwesterly winds bring an air mass whose concentration and $\delta^{13}C$ of CO_2 are similar to that of the southern hemispheric air mass, (2) a seasonal minimum in CO_2 concentration that is expected in July and August, likely due to a higher photosynthetic activity ensuing with the onset of SWM, is not observed at Cabo de Rama as a result of the presence of a strong southwesterly oceanic air mass during that period, (3) a seasonal minimum in CO_2 concentration occurs post SWM season (in October) when local vegetation activity is still dominantly photosynthetic, and (4) a seasonal maximum in CO_2 concentration is observed during February-March due to a higher contribution from plant and soil heterotrophic respiration and anthropogenic emission. Lin et al. (2015) have also shown that the air masses up to ~ 1 km height at Pondicherry, a southern Indian station, are from southern hemisphere during the southwest monsoon season. Top panels of Fig. 2 depict mean monthly variations in CO_2 concentration and its $\delta^{13}C$ at Cabo de Rama. The error bars associated with the mean monthly values are obtained after correcting for the trend in the monthly values (for the period from 1993 to 2001), an effect of addition of CO_2 liberated from fossil fuel burning. For this, lines (least square regressions) were fitted to the yearly variations of the monthly values. The error bars are 1-sigma standard deviations of deviations of actual monthly values of these parameters from their respective fitted values. The rates of changes in CO_2 concentration and its $\delta^{13}C$ at Cabo de Rama were 1.9 ppm/yr and −0.03‰/yr, respectively.

2.3. Growth pattern of teak

Teak in the study area is a deciduous species and its growth is mainly confined to the rainy season (Sudheendrakumar et al., 1993; Palanisamy et al., 2009). Depending upon the location, new leaves appear from April to June and trees shed their leaves from November to January; they remain leafless for about 3–4 months (Palanisamy et al., 2009). Studies of teak growth (Sudheendrakumar et al., 1993) and cambial activity (Priya and Bhat, 1999) have clearly established a positive relationship between rainfall and teak growth in India. Priya and Bhat (1999) have showed that (1) pre-monsoonal rains lead to cambial reactivation and (2) co-occurance of the highest cambial activity and the highest rainfall. This suggests a non-uniform growth pattern of teak with a higher growth during July to September relative to that during pre-monsoon and post-monsoon periods.

2.4. Samples

Table 1 shows details regarding samples and sampling locations. Standard dendroclimatological procedures were followed for dating the samples. Details regarding climatic conditions at these sites and dating of the disc samples are given by Managave et al. (2011). Sampling details of the sample from Parambikulam (disc sample) are also given by Bhattacharyya et al. (2007). All the intra-annual data are from the disc samples as it facilitated higher resolution sampling. Two cores from different radial directions were taken from three teak trees from Parambikulam area and one from each tree was used only for inter-annual isotopic analysis. Regional master chronologies (Borgaonkar et al., 2010) were referred to while dating core samples from Parambikulam. Details such as widths and the cambial ages of the selected rings are given by Managave et al., 2010 Table 1 Auxiliary material) and Managave et al. (2011, Table 1).