Source: Maaten-Theunissen M, Spiecker H, Gärtner H, Helle G, Heinrich I (Eds.) (2011): TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 9. GFZ Potsdam, Scientific Technical Report STR 11/07, Potsdam, p. 158 - 165.

Toward multi-parameter records (ring width, $\delta^{13}C$, $\delta^{18}O$) from tropical tree-rings - A case study on *Tectona grandis* from Java, Indonesia

K. Hennig [1], G. Helle [1], I. Heinrich [1], B. Neuwirth [2], O. Karyanto [3] & M. Winiger [2]

[1] Potsdam Dendro Lab, GFZ - German Research Centre for Geosciences, Section 5.2 Climate Dynamics and Landscape Evolution,Telegrafenberg, 14473 Potsdam, Germany
[2] Department of Geography, University of Bonn, Meckenheimer Allee 166, D - 53115 Bonn, Germany
[3] Faculty of Forestry, Gadjah Mada University, Yogyakarta, Indonesia
E-mail: khennig@gfz-potsdam.de

Introduction

Climate in Indonesia is mainly dominated by the equatorial monsoon system and tends to be linked to ENSO warm events which result in extensive droughts over the Indonesian archipelago (Hackert and Hastenrath 1986). Hence, dendroclimatological studies from this region carry a great potential to improve land-based rainfall proxy records. The potential of tropical tree species as recorders of climate variability has not been fully exploited due to the frequent lack of visible, annual growth rings. However, as one of a few tropical tree species Teak (*Tectona grandis*) shows distinct annual growths boundaries. In earlier studies ring-width chronologies from Indonesian teak have been established and used for climatic reconstructions (e.g., Berlage 1931; D´Arrigo et al. 1994; D´Arrigo et al. 2006). Multi-parameter studies, comprising wood anatomy or tree-ring stable isotopes, are still scarce in the tropics and the influence of climate and other environmental factors on tree-ring stable isotope ratios of Indonesian teak has not been studied in detail, yet. Here we present the first stable isotope ($\delta^{13}C$ and $\delta^{18}O$) records back to AD 1900 developed from Indonesian teak. These parameters as well as tree-ring width chronologies from the same material were compared with climate data in order to test their potential for climate reconstructions.

Materials and Methods

Study site and climate conditions

The samples were collected in a lowland rain forest at an elevation of around 380 m a.s.l.. The study site, named Donoloyo, is located 90 km east of the city of Yogyakarta in the eastern part of Central Java, Indonesia (07°52’S, 111°11’E), as shown in figure 1.

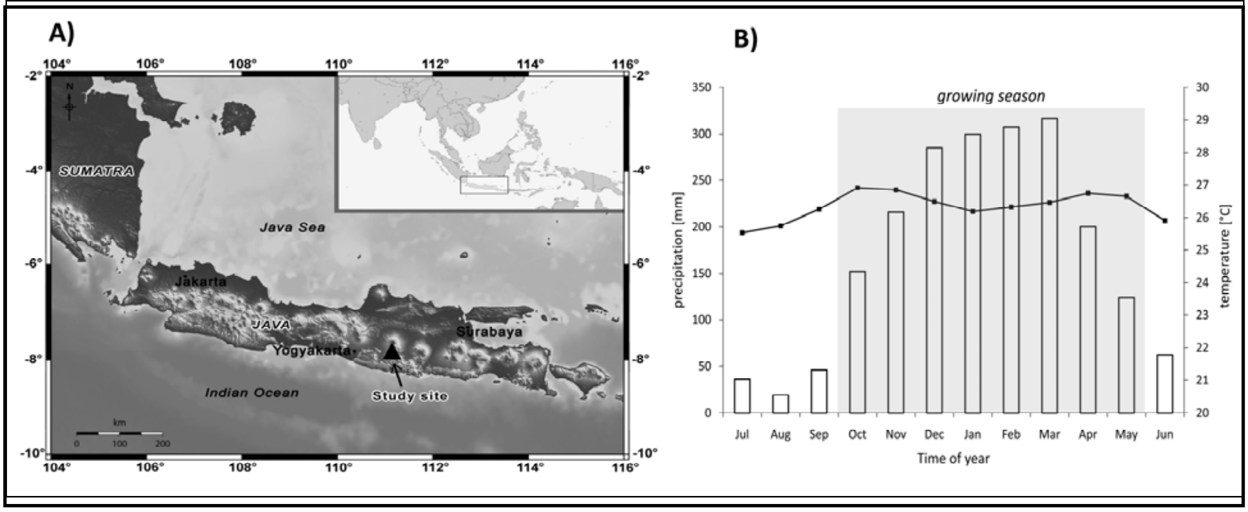

Figure 1: A) Map showing the location of the study site (Donoloyo) in a lowland rain forest (380 m a.s.l.) in the eastern part of Central Java (07°52’S, 111°11’E). B) Mean monthly precipitation (bars) and temperature (line) at the study site derived from gridded climate data (CRU TS 3.0, 1901-2006). The growing season is highlighted in grey.

The study site, among several others, was part of earlier investigations on ring width by D`Arrigo and co-workers. It revealed significant but comparatively low correlation between SST and growth (e.g., D'Arrigo et al. 2006). We re-sampled the site in November 2008 and initiated a stable isotope study in order to test whether or not the additional parameters provide better or different relationships to climate data than ring width have revealed in previous studies (Berlage 1931; Jacoby & D'Arrigo 1990; D'Arrigo et al. 2006; D'Arrigo et al. 2008).

In this study, gridded (0.5°x0.5°) climate data, provided by the Climatic Research Unit of East Anglia University, Norwich, UK covering the time period 1901-2005 (CRU TS 3.0, Mitchell and Jones 2005), were used for correlation analyses. The long-term mean annual values for precipitation and temperature are 2062 mm and 26.3°C, respectively. Precipitation is assumed to be the limiting factor for tree growth in the study area, because of a distinct seasonality, as well as well drained soil. Central and Eastern Java are influenced by the equatorial monsoon climate which is characterized by a rainy season (north-west monsoon), persisting from November to April and a dry season (south-east monsoon) from May to October (Fig. 1B). The vegetation period (growing season) for *Tectona grandis* in Central and Eastern Java generally lasts approximately from the beginning of October to the end of May. Leaf flushing starts with the onset of the monsoon rains and flowering occurs toward the end of the rainy season. Approximately from June/July to September, that is, during the dry season, the species is leafless and consequentially in a state of cambial dormancy (Coster 1927; Coster 1928).

Sample material

For this study two cores each from 16 dominant *Tectona grandis* trees were collected. Ring widths were measured subsequently and cross-dated using the programs TSAPWin (Rinn 2005) and COFECHA (Holmes 1983). The final tree-ring width chronology (TRW) is based on cores from 11 trees, 5 individuals were not included due to cross-dating problems. For dating purposes, we followed Schulman's (1956) convention for the southern hemisphere, which assigns to each tree-ring the starting date of radial growth. All trees of our site chronology were, in average, older than 240 years, however, only the 19th and 20th centuries were investigated in this calibration study. This was done for allowing a direct comparison of raw values of ring-width and stable isotope records over a period in which any age-related growth trends can be neglected as being minor of higher order.

For the isotope analyses, five cores of different trees were chosen according to the following criteria: i) correct dating and high synchronicity of ring-width sequences as indicated by statistical parameters such as Gleichläufigkeit (GLK), Cross-Dating-Index and t-value, ii) good wood quality and iii) as few as possible problematic zones (such as false or narrow rings). For the period of AD 1900-2007 the entire annual rings from all cores were separated with a scalpel and finely ground to assure homogeneity. Resin extracted wood material was used instead of cellulose due to some very narrow rings which would have not provided sufficient amounts of cellulose for the conventional online IRMS determination of $\delta^{13}C$ and $\delta^{18}O$. However, recent research has shown that the cellulose extraction is not as crucial as had been suggested previously (Borella et al. 1998; McCarroll & Loader 2004; Verheyden et al. 2005; Taylor et al. 2008). Consequently, only extractives, such as wood resins and oils, but also glue, pencil and chalk remains were removed from the wood with boiling de-ionized water and ethanol in a new multiple sample isolation system for solids (Wieloch et al. 2010). The $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios were measured by combustion and low-temperature pyrolysis (at 1080°C), respectively, using an elemental analyzer (Model NA 1500; Carlo Erba, Milan, Italy) coupled to an IRMS (Isotope Ratio Mass Spectrometer; Micromass, Ltd. Manchester, UK). The results are given in the conventional δ notation relative to the international standards VPDB and VSMOW. Sample replication resulted in a precision of better than ±0.1‰ for $\delta^{13}C$ values and ±0.25‰ for $\delta^{18}O$ values. Carbon isotope records are displayed as discrimination Δ, which is the shift between the carbon isotope ratios of the air relative to the isotope ratios of the tree-rings. Similarly, to the conventional δ notation in ‰, the discrimination Δ in ‰ follows as: Δ [‰] = ($\delta^{13}C_{atm}$ – $\delta^{13}C_{TR}$)/(1 + $\delta^{13}C_{TR}$ x 10^{-3}). Hence, the records of Δ are free from the well-known trend of declining $\delta^{13}C_{atm}$-values due to fossil fuel burning and deforestation since AD 1850 (e.g. Helle & Schleser 2004).

The resulting series were compared with the CRU 3.0 (precipitation, air temperature) and HadSST2 gridded data sets (sea surface temperature, SST) (Rayner et al. 2006). Data from meteorological stations were acquired, but not used in this study due to short lengths and a lot of missing values.

In order to investigate the climate-proxy relationships, precipitation, air temperature and SST covering the periods 1901-2005 and 1901-2007, respectively, were compared with tree-ring data (TRW, Δ, $\delta^{18}O$) by calculating Pearson's correlation coefficient.

Results

Site chronologies

The three chronologies of tree-ring width (TRW), ^{13}C discrimination (Δ) and oxygen isotope ratio ($\delta^{18}O$) are shown in figure 2.

The top graph of figure 2 shows the dated ring width series along with the mean chronology. The series from 11 trees agree reasonably well (mean inter-series correlation of 0.54, GLK=69%, cf. Table 1), and the EPS of 83% (slightly below the commonly adopted value of 85%) indicates that the chronology is replicated sufficiently back to AD 1800. However, the variability of the raw dataset is not stable over time with obvious periods of high scatter (1860-1880/1900-1920/1940-1970). Furthermore, a trend toward greater variability is visible over the second half of the 20th century. Although human influence cannot be excluded, a strong direct impact is very unlikely since the site is a protected area, used for seed collection since many years.

In the middle plot of figure 2, the carbon isotope chronology, presented as ^{13}C discrimination (Δ), derived from five individuals and selected according to the criteria described above, is displayed. The mean inter-series correlation is rather low (r=0.41) as well as the EPS value (EPS=0.64) (cf. Tab. 1). Even without the outlier tree r and EPS increase only slightly to r=0.44 and EPS=0.67. For comparison, the EPS value for ring width of those five trees is of the same order, namely 0.68. The mean year-to-year variability of Δ is rather low (< 1‰, with few exceptions) as compared to the differences among the trees in mean Δ (2-4‰) and to tree-ring $\delta^{18}O$. This indicates that ecological long-term changes seem to have a much stronger impact on Δ than short-term variations. Apart from this, one tree shows much higher ^{13}C discrimination than the others (see dashed line in Fig. 2). According to the model concept of carbon isotope fractionation during photosynthesis of C3-plants (Farquhar et al. 1982) high ^{13}C discrimination stands for a high ratio of c_i over c_a (c_i = leaf internal CO_2 concentration; c_a = atmospheric CO_2 concentration) due to a high stomatal conductance and/or a low assimilation rate. Interestingly, the tree with the higher ^{13}C discrimination is characterized by rather slow growth in general. A fact, that points to a strong impact of the assimilation rates on Δ. The averages of Δ of all the trees are relatively close for the first half of the 20th century. However, since the end of the 1950s two trees display a distinct increase in Δ, whereas two other trees show no changes and one a slight decline in Δ. This suggests that the individual tree responses are changing in time, probably due to differences in genetics or micro site conditions (e.g., nutrient supply).

The results for oxygen isotopes ($\delta^{18}O$) from the same five individuals are shown in the bottom plot of figure 2. In contrast to ^{13}C discrimination, the individual series are quite well correlated (r=0.53, GLK=74%, EPS=0.85, cf. Table 1) and the variability is rather stable throughout the entire 20th century.

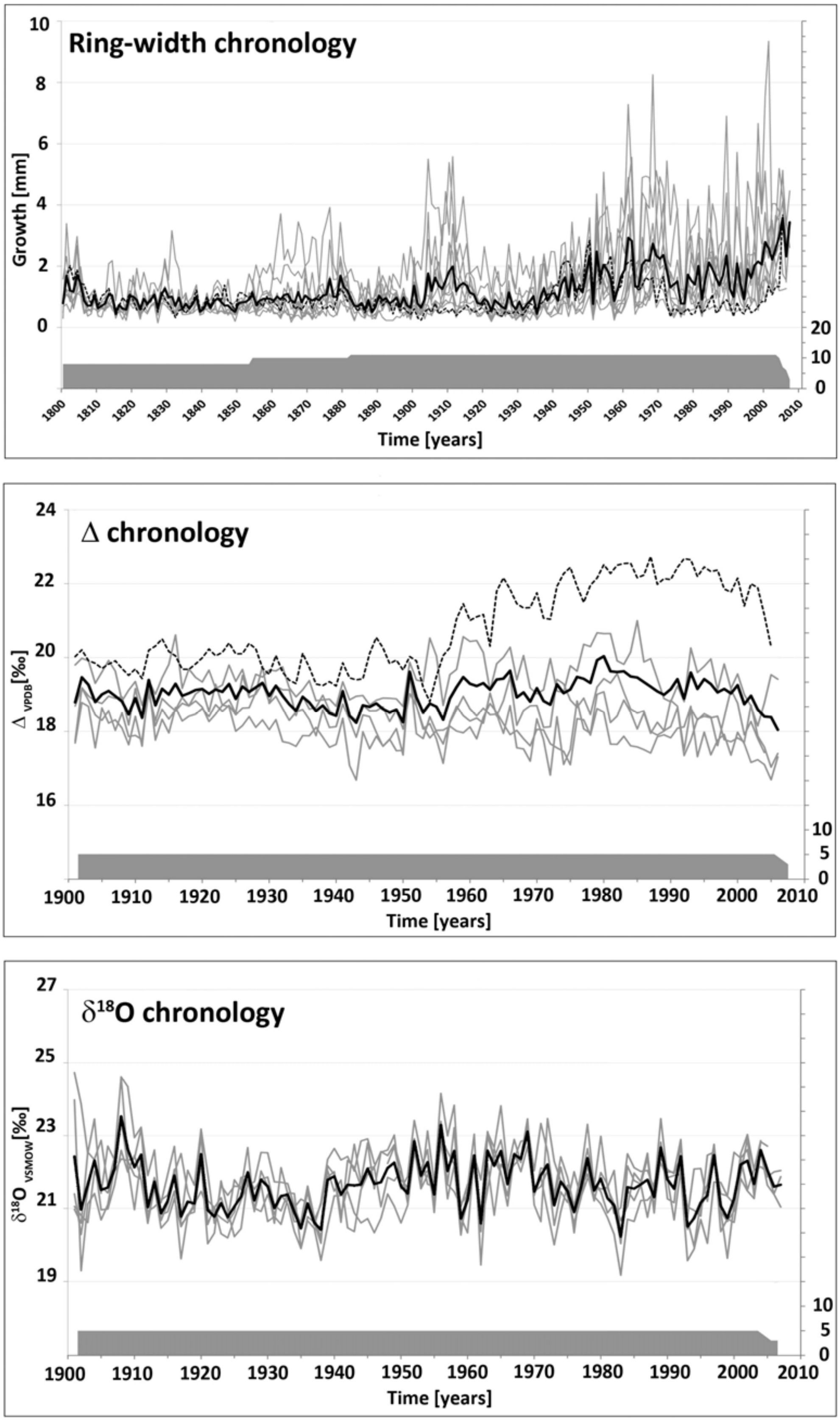

Figure 2: Raw tree-ring width and isotope chronologies and sample depth (thick black lines represent the mean chronology of each parameter). Note that the tree with rather high ^{13}C discrimination (Δ) is characterized by slow growth (dashed graphs in top and mid panel).

Table 1: Descriptive statistics for the tree-ring width (TRW), ^{13}C discrimination (Δ) and oxygen isotope (δ^{18}O) chronologies. CL: length of chronology; SD: standard deviation; GLK: Gleichläufigkeit; NET: see Esper et al. (2001); Cor: Series intercorrelation; AC 1: first order serial autocorrelation

	Time-span	CL	# of trees	mean	SD	GLK [%]	NET	corr	EPS	AC 1
TRW	1800-2007	208	11	1.69	1.22	69	0.64	0.54	0.83	0.64
Δ	1900-2007	108	5	19.02	0.37	64	0.41	0.41	0.64	0.54
δ^{18}O	1900-2007	108	5	21.65	0.66	74	0.28	0.53	0.85	0.22

Climate response

The climate response plots present Pearson's correlations between the stable isotope records and the climate data, respectively (Fig. 3). Correlations between TRW and climate are not shown here because they do not differ from previous analyses (D´Arrigo et al. 1994, 2006, 2008).

We grouped and arranged the data according to the growing period of the trees, that is, October of the current year (date of the tree ring) to September of the following year.

The Δ chronology (Fig. 3, 2nd row) shows no highly significant correlation with any climate parameter. However, the response to monthly and seasonal mean temperatures is mainly positive in sign, whereas precipitation of previous year`s October and November has a negative influence on ^{13}C discrimination.

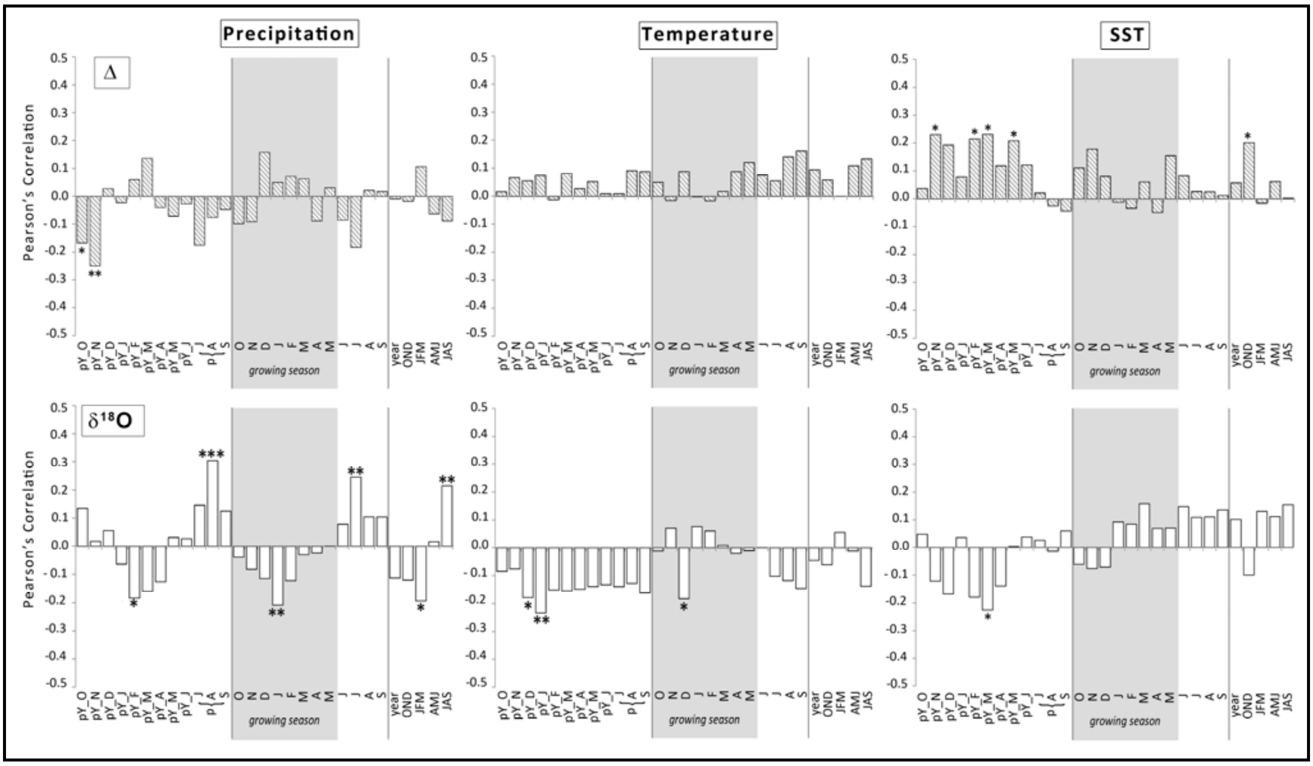

*Figure 3: Correlations between Δ- and δ^{18}O- records and climate data for the period 1901-2005. The diagrams for each climate parameter are separated into three parts by vertical lines. The left part displays the months (previous year October to current year September) prior to the actual growing period (grey shaded area), the middle parts shows the months of the actual growing period (October to September) and the right part depict seasonal means. Stars denote the significance levels: * 90% / ** 95% / *** 99%.*

A climate response analysis of δ^{18}O (Fig. 3, 3rd row), generally shows significant positive correlations with precipitation of the dry season and negative relationships with the wet season. Pre-season August, the driest month of the year directly before growth begins, displays the highest significance (r=0.30, for p<0.01). As for the growing period, precipitation in January has the strongest negative effect on tree-ring δ^{18}O at our site. The relationships between δ^{18}O and temperature as well as SST show notable significance in some periods. The air temperature has some weak negative relationship with tree-ring δ^{18}O, whereas SST shows no clear pattern of tree response.

Discussion and Conclusions

We developed a 208-year long tree-ring width chronology (AD 1800-2007) and 108-year long carbon and oxygen isotope chronologies (AD 1900-2007) of *Tectona grandis* from a site of eastern Central Java.

Climate correlation tests show that tree growth is influenced by seasonal precipitation amounts and that it has a strong positive response to SST data which is a moisture indicator, similar to the results of previous studies from D´Arrigo et al. (1990, 1994, 2006).

The correlations between the carbon isotope record (Δ) and any of the three climate parameters were not highly significant. This may be due to the poor representativeness (low EPS and GLK) of the selected five sample trees. It may also be due to a very minor influence of climatic quantities on the processes underlying carbon isotope variability, i.e., ^{13}C discrimination and carbon assimilation. More samples need to be analyzed and other environmental factors than climatic factors need to be studied to understand the carbon isotope variability at the Indonesian site.

Drought influenced sites very often showed good correlation between tree-ring δ^{13}C and precipitation in semi-arid or arid regions. However, during the vegetation period humid conditions persist at our site, and some kind of drought stress at the beginning or the end of the growing period may not have a significant impact.

Indeed, the δ^{18}O record shows notable significant correlation coefficients with precipitation of pre-season August (driest month) and current year January (wettest month). Interestingly, the correlations found are opposite in sign. Pre-season August has a positive relationship with tree-ring δ^{18}O, while the correlation with January is negative. This is very likely because the rainfall of pre-season August reflects the highest δ^{18}O while precipitation in January is characterized by the lowest δ^{18}O signature of the year (Fig. 4). Hence, tree-ring δ^{18}O probably reflects the relative portion of August to January precipitation with subsequently changing isotope signatures derived from the so-called “amount effect” and/or changing origin of air moisture (e.g., Araguas-Araguas et al. 2000).

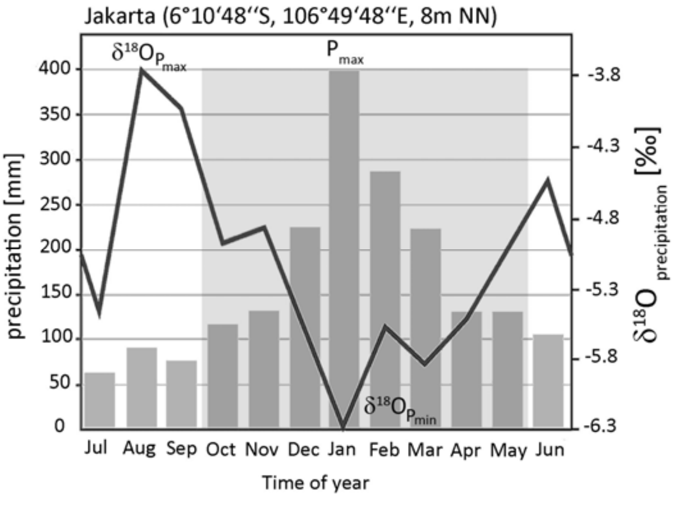

Figure 4: Average monthly precipitation sums (grey) and $\delta^{18}O_{Precip}$ in precipitation (black) for Jakarta/Indonesia. The grey shadow marks the growing season. (GNIP: http://www-naweb.iaea.org)

An influence of evapotranspiration on ^{18}O-enrichment of leaf water could not be detected, probably because the effects on tree-ring δ^{18}O act in the same direction as changes in δ^{18}O of precipitation under dry and wet conditions. Dry conditions result in high ^{18}O-enrichment in precipitation as well as in leaf water and wet conditions evoke the same effects in opposite direction. An influence of ground-water due to water uptake from deeper soil during the vegetation period seems to be unlikely since the soil at the site is well-drained and teak has a shallow root system.
In conclusion, the results of this calibration study point out that the isotope ratios of carbon and oxygen show weaker climate signals than tree-ring width, at least when only 5 trees are considered and the chronologies show relatively weak values of EPS and GLK etc. and thus more trees need to be analyzed. Furthermore, future efforts will focus on highly resolved intra-annual δ^{18}O studies which may provide more detailed insights into the influence of seasonally changing precipitation amounts and $\delta^{18}O_{Precip}$ on tree growth and tree-ring δ^{18}O records. This may improve land-based rainfall reconstructions based in multiple tree-ring parameters.

Acknowledgments

Many thanks to Rosanne D‘Arrigo for providing some of the samples for this study and to Tomy Listyanto and Navis Rofii for their assistance in the field work. We are grateful to Carmen Bürger for support in the laboratory and Isabel Dorado, Thomas Wieloch and Katja Fregien for fruitful discussions. This study is funded by German Science Foundation (DFG) (HE3084-2).

References

Araguas-Araguas, L., Froehlich, K., Rozanski, K. (2000): Deuterium and oxygen-18 isotope composition of precipitation and atmospheric moisture. *Hydrological Processes* 14: 1341-1355.

Berlage, H. P. (1931): On the relationship between thickness of tree rings of Djati (teak) trees and rainfall on Java. *Tectona* 24*:* 939-953.

Borella, S., Leuenberger, M., Saurer, M., Siegwolf, R. (1998): Reducing uncertainties in δ^{13}C analysis of tree rings: pooling, milling and cellulose extraction. *Journal of Geophysical Research* 103 (D16): 519-526.

Braak, C. (1931): Klimakunde von Hinterindien und Insulinde. Handbuch der Klimatologie, Bd. IV, Teil R. Berlin.

Coster, C. (1927): Zur Anatomie und Physiologie der Zuwachszonen- und Jahresringbildung in den Tropen. *Ann. Jard. Bot. Buitenzong* 37: 49-160.

Coster, C. (1928): Zur Anatomie und Physiologie der Zuwachszonen- und Jahresringbildung in den Tropen. *Ann. Jard. Bot. Buitenzong* 38: 1-114.

D'Arrigo, R. et al. (2006): The reconstructed Indonesian warm pool sea surface temperatures from tree rings and corals: Linkages to Asian monsoon drought and El Niño–Southern Oscillation. *Paleoceanography* 21. PA2005.

D’Arrigo, R. et al. (2008): Pacific and Indian Ocean climate signals in a tree-ring record of Java monsoon drought. *International Journal of Climatology* 28: 1889-1901.

Eckstein, D., Bauch, J. (1969): Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. *Forstwissenschaftliches Centralblatt* 88: 230-250.

Esper, J., Neuwirth, B., Treydte, K. (2001): A new parameter to evaluate temporal signal strength of tree-ring chronologies*. Dendrochronologia* 19: 93-102.

Farquhar, G.D., O’Leary, M.H., Berry, J.A. (1982): On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Australian Journal of Plant Physiology* 9: 121-137.

Geiger, F. (1915): Anatomische Untersuchungen über die Jahresringbildung von Tectona grandis. In: Pfeffer, W. (ed.): Jahrbücher für wissenschaftliche Botanik. 521-607.

Hackert, E. C., Hastenrath, S. (1986): Mechanisms of Java rainfall anomalies. *Monthly Weather Review* 114: 747-757.

Helle, G & Schleser, G.H. (2004): Interpreting climate proxies from tree-rings. In: Fischer, H., Floese, G., Kumke, T., Lohmann, G., Miller, H., Negendank, J.F.W., Von Storch, H. (ed.): The KIHZ project: Towards a synthesis of Holocene proxy data and climate models.129-148.

Holmes, R.L. (1983): Computer-assisted quality control in tree-ring dating and measurements. *Tree-Ring Bulletin* 43: 69-78.

Jacoby, G.C., D'Arrigo, R.D. (1990): Teak (Tectona grandis L.F.) a tropical species of large-scale dendroclimatic potential. *Dendrochronologia* 8: 83-98.

Leavitt, S.W., Long, A. (1984): Sampling strategy for stable isotope analysis of tree rings in pine. *Nature* 311: 145-147.

McCarroll, D., Pawellek, F. (1998): Stable carbon isotope ratios of latewood cellulose in Pinus sylvestris from northern Finland: variability and signal-strength. *The Holocene* 8: 675-684.

Mitchell, T.D., Jones, P.D. (2005): An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology* 25: 693-712.

Rayner, N.A., Brohan, P. , Parker, D.E., Folland, C.K., Kennedy, J.J., Vanicek, M., Ansell, T., Tett, S.F.B. (2006): Improved analyses of changes and uncertainties in sea surface temperature measured in situ since the mid-nineteenth century: the HadSST2 data set. *Journal of Climate*: 19, 446-469*.*

Rinn, F. (2005): TSAP - WinTM. Time Series Analysis and Presentation for Dendrochronology and Related Applications. Version 4.6. Heidelberg.

Schulman, E. (1956): Dendroclimatic Change in Semiarid America. University of Arizona Press, Tuscon.

Stokes, M.A., Smiley, T.L. (1968). An Introduction to Tree-ring Dating. University of Chicago, Chicago, Reprinted 1996. University of Arizona Press, Tucson, US, 73pp.

Schweingruber, F.H. (1983): Der Jahrring. Standort, Methodik, Zeit und Klima in der Dendrochronologie. Verlag Paul Haupt. 234p.

Taylor, A.M., Brooks J., Lachenbruch, B., Morrell J.J., Voelker S. (2008): Correlation of carbon isotope ratios in the cellulose and wood extractives of Douglas-fir. *Dendrochronologia* 26: 125-131.

Verheyden, A., Roggeman, M., Bouillon, S., Elskens, M., Beeckman, H., Koedam, N. (2005): Comparison between $\delta^{13}C$ of α-cellulose and bulk wood in the mangrove tree Rhizophora mucronata: implications for dendrochemistry. *Chemistry and Geology* 219: 275–282.

Weischet, W., Endlicher, W. (2000): Südostasien. Regionale Klimatologie. Teil 2. Die alte Welt. Teubner Verlag. 625p.

Wieloch, T., Helle, G., Heinrich, I., Voigt, M., Schyma, P. (2010): A novel device for the batch-wise isolation of α-cellulose from small-amount wholewood samples. *Dendrochronologia:* in press.