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Tree-rings and the climate of New Caledonia (SW Pacific).

Preliminary results from Araucariaceae.

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Abstract

The dendroclimatologic potential of some Araucariaceae of New Caledonia (including *Agathis*, or kauris, and *Araucaria*) is assessed using ring thickness and $\delta^{18}\text{O}$ measurements. New Caledonia is a group of islands in the SW Pacific that are currently under influence of ENSO events. Endemic to New Caledonia, the long-living species of *Agathis lanceolata* and *A. ovata*, growing on poor ultramafic-derived soils may provide valuable proxies for the local climate and for ENSO. These trees present visible growth bands of changing thickness along their circumference. However, several bands are locally absent, and the growth axis is generally offset with respect to the geometrical axis of the tree. This led us to compute so-called composite ring thickness profiles, accounting for the geometry of growth bands on the whole surface of a tree disk. Our computational method involves 10 optical

density profiles measured along 10 equally spaced radii drawn from the bark toward the growth axis, and 10 to 20 master rings, that can be easily identified on the whole disk. Growth bands visible on less than 5 radii were discarded. Our method is similar to the cross-dating method used by dendrochronologists, except that it is applied here to a single tree disk. Our samples consist of three disks of *Agathis lanceolata*, one disk of *A. ovata*, and one disk of *Araucaria columnaris*. Multiple regressions have been computed between composite profiles and climatic variables i.e. monthly and yearly temperatures and rainfall amounts. The best correlation is found between the width of the ring growing between July (n-1) and June (n) with the rainfalls of June (n), June (n-1) and June (n-2). Monthly rainfalls allow to explain between 20% to 50% of the ring thickness variance, a result similar to that obtained with other studies on *Agathis* of New Zealand. No temperature parameter appears in the most stable regressions. 30 measurements of tree ring cellulose $\delta^{18}\text{O}$ have been conducted on one single disk selected for the strong climate-ring width correlation. While earlier studies have used $\delta^{18}\text{O}$ measurements to identify seasonal cycles in tropical woods and date the rings, our data suggest that the direct use of $\delta^{18}\text{O}$ is misleading due to false rings that do not correspond to a complete growth year. When these false rings are identified from the disk analysis and discarded, a fair visual correlation with the total rainfall during the growth season is obtained. This requires information that cannot be found in single growth band thickness profiles, for example as obtained by coring. Thus, Araucariaceae of New Caledonia may present a valuable potential for dendroclimatology. However, reconstructing a chronology of this region will require more extensive sampling and possibly an account of additional species.

Keywords : dendrochronology; kauri; ENSO; $\delta^{18}\text{O}$; rainfall; New Caledonia

48 **1. Introduction**

49

50 New Caledonia is an island group in the SW Pacific (figure 1) that experience currently El
51 Niño-Southern Oscillation (ENSO) climatic events. During standard conditions, the surface
52 waters of the tropical Pacific ocean are warm (28°C-29°C) in the West and cold (22°-23°C) in
53 the East. The so-called warm water pool is related to increased evaporation and precipitation.
54 During El Niño events, this warm pool is displaced toward the East on the whole equatorial
55 band and the Western Pacific experiences dryer than usual conditions. During the opposite La
56 Niña situation, the warm pool and the associated heavy precipitation zone migrate farther to
57 the West (Philander, 1990). Since ENSO phenomena are dominated by time periods spanning
58 from 3 to 9 yrs, high resolution proxies are required for their study (Rodbell et al., 1999).
59 Continental sedimentary records in New Caledonia provided a 10-100 yrs time resolution
60 (Stevenson et al., 2001; Wirmann et al., 2006). High resolution paleoclimatic studies around
61 New Caledonia mainly rely on coral sampled near the Phare Amedee islet, located 20 km
62 seaward of Noumea, slightly landward of the barrier reef. Quinn et al. (1998) provided $\delta^{18}\text{O}$
63 records in *Porites lutea* since 1657 A.D. which they use to reconstruct past ocean water
64 temperatures. They show also that ocean temperatures measured during the 20th century are
65 fairly well correlated to ENSO. Watanabe et al. (2003)) and Ourbak et al. (2006), working on
66 shorter time series, showed that $\delta^{18}\text{O}$ in *Diploastrea* corals and that Sr/Ca and Mg/Ca in
67 *Porites* corals were temperature-dependent and thus could potentially provide pluricentennial
68 high resolution ocean temperature reconstructions. However, the main island of New
69 Caledonia is a large landmass of nearly 170.000 km² including a continuous central mountain
70 range of an average 1000 m altitude. Its climate should therefore not only be controlled by the
71 ocean.

In the temperate climatic zone, and where one climate parameter is a limiting factor for growth, tree rings are widely used to build annually resolved climate reconstructions (e.g. Schweingruber, 1996). In addition, there is growing evidence that tropical trees may also present growth bands related to climatic parameters (Ogden, 1978; Dtienne, 1989; Jacoby and D'Arrigo, 1990; Worbes, 1995; Bullock, 1997). It has been demonstrated that during a long dry season the growth of tropical trees stops and that this induces the formation of annual rings in Indonesia (Berlage, 1931), Thailand (Buckley et al., 1995) and in Costa Rica (Enquist and Leffler, 2001). An extensive bibliography of tree ring research in the tropics can be found in Worbes (2002). When annual rings cannot be visually identified, high resolution stable isotopic measurements of wood cellulose may provide a new dating method using the seasonal cycles of cellulose $\delta^{18}\text{O}$ produced in response to the seasonal cycles of tropical precipitation $\delta^{18}\text{O}$ (Evans and Schrag, 2004; Poussard et al., 2004; Poussard and Schrag, 2005). In the North Island of New Zealand, 1000 km south of New Caledonia, chronologies of *Agathis australis*, a long-lived rainforest tree, have been established by Buckley et al. (2000).

Araucariaceae of New Caledonia include 5 species of *Agathis* and 8 species of *Araucaria*, all endemic, representing 45 % of the species of the family globally (Manaut et al., 2003). Some of these species are growing on poor ultramafic-derived soils, in particular, *Agathis lanceolata*, which is present as an emergent tree in the rainforest of the south of the main island. Owing to its use as construction material during the 19th century *A. lanceolata* almost disappeared from New Caledonian forests and as a result, it presently benefits from an integral protection. *A. ovata*, another long-living tree endemic to New Caledonia, grows also on ultramafic-derived soils, generally just below mountain passes. Individuals having a trunk circumference of more than 2 m are common. Cherrier and Nasi (1992) have repeated circumference measurements on 146 individuals of *A. ovata* and *A. lanceolata* over a 10 years

interval. They deduced a circumference growth of 0.2 to 0.5 cm/yr for *A. lanceolata* and 0.1 to 0.5 cm/yr for *A. ovata*. The maximum growth was obtained for samples having a diameter between 60 and 150 cm while some small diameter individuals had almost zero growth. Moreover, it is known that *Agathis* growing in ornamental plantations have larger growth rates than in natural forests, since they are generally planted at a comfortable distance from each other, and they benefit from a soil worked down to near 1 m depth and generally enriched with fertilizer (Whitmore, 1980). The demography of *A. ovata* has also been studied by Enright et al. (2003), who concluded that individuals having a 30 cm diameter at breast height (dbh) could be as old as 700 yrs, and that a dbh of 100 cm could correspond to an age of 1500 yrs. However, their samples consisted mainly of individuals of less than 5 cm dbh. This could explain why the growth rate reported by Enright et al. is less than half the minimum growth rate found by Cherrier and Nasi.

During the seventies, the New Caledonian Center of Tropical Trees Studies collected several samples of *A. lanceolata*, which had been marked yearly for 7 years. Nasi and his team (Nasi, 1982) have shown that these trees were producing generally one growth band per year. Some samples, having a dbh of 50 cm, were estimated to be as old as 350 yrs. As some *Agathis* living in New Caledonia are more than 5 m in diameter, this implies that the potential of availability of climatic records is more than a millennium. However, seasons are less marked in New Caledonia than in New Zealand and no relationship between climatic variables and the thickness of growth bands of trees has been proved there. Moreover, Nasi (1982) has shown that *Agathis* produced anomalous growth bands, that were only present on part of the tree circumference. Such anomalous bands are common on tropical trees (Stahle, 1999). They have been attributed by Priya and Bhat (1998) to the occurrence of dry periods during rainy seasons, inducing the formation of latewood, or to rainy events during the dry seasons, that promote transient growth. According to the current practice of

dendrochronology, growth bands will be termed either as rings, when they are assumed to correspond to a full growth year, or as false rings, if otherwise. In addition, kauris commonly present off-centered growth axes, especially when they grow in windy areas or on steep slopes. This could hinder correct interpretation of cores, which are usually drilled toward the geometrical axis of the tree.

The present paper aims to assess the potential for climatic studies of *Agathis lanceolata* including comparison with the related species of *A. ovata*, both of which are endemic to New Caledonia and growing on ultramafic soils. These species are compared with *Araucaria columnaris*, using a sample growing on soil derived from continental rocks. In order to gather bidimensional information on growth bands structure, we use whole disks sawn perpendicularly to the trunk at about 1 m height. We will first describe our samples, then the method used to obtain the mean geometric characteristics of rings from a disk. Following this, we discuss the statistical relationship between these geometric characteristics and the climate of New Caledonia. Finally we present 30 $\delta^{18}\text{O}$ measurements made on one of our samples to provide some further clues on their relationship to climatic variables.

2. Material

2.1. Field Sampling

The results presented here arise mainly from 3 disks of *A. lanceolata* collected in December, 1981 from three individuals growing inside the Rivière Bleue Provincial Park, 30 km north-east of Noumea at 220 m altitude (figure 1). These trees were growing on ultramafic parent soils, that are low in nitrogen, phosphorus, potassium and calcium, but high in iron, magnesium, nickel, chromium, cobalt and manganese (Jaffré, 1980). However, the ultramafic

rocks (peridotites) in this area contain several diorite inclusions. During alteration, diorite may provide locally additional nutrients to soils. The sampling area is located only a few meters above a swampy zone, connected to the Yaté artificial lake. Since its construction in 1950, the lake flooded the area upstream from the Yaté dam. Five *A. lanceolata* of this area have been marked yearly between 1974 and 1981, at the beginning of each cold season, by opening a 5 cm × 1 cm window across the bark to the cambium. The growth was locally affected by the wounding because of the development of cicatricial tissues but as the wounding is very small compared to the diameter of the trees, this did not impact the overall tree growth rate. Following this, these 5 trees were sawn to provide disks for analysis. As each individual presented generally one growth band between two marks, Nasi (1982) has interpreted these growth bands as annual tree rings. Of these five disks, only three (L1, L2, and L3) are now available. The samples L1, L2, and L3, have circumferences of 155 cm, 153 cm, and 165 cm, respectively. From detailed ring counting, Nasi (1982) estimated the ages of L1, L2 and L3 to be 29, 215, and 350 yr, respectively. L1 was an isolated tree, while L2 and L3 were located inside the forest. This and a possible difference in soil composition could explain the higher growth rate of L1. It should be noted that in the upper Rivière Bleue zone, several *A. lanceolata* escaped commercial exploitation during the 19th and 20th centuries and are now more than 5 m in diameter.

In order to compare the growth of different species, our study includes a sample of *A. ovata* (O1) of dbh 100 cm, growing at 440 m altitude on peridotites, just below the Col du Cintre (figure 1). Since this tree, in contrast to the *Agathis lanceolata* individuals, was growing in a well drained area, perhaps it is more sensitive to drought. Unfortunately, it was partly rotten so that only the external 15 cm could be interpreted. Based on extrapolation of the 150 rings counted within these 15 cm, the whole individual was assumed to contain 400 to 500 rings.

We included in our study an individual of *Araucaria columnaris* (C1) growing at Noumea (figure 1) on soils derived from a parent rock consisting of alternating silt and clay layers and thus richer in nutrients than ultramafic-derived soils. Our disk was 45 cm in diameter and included about 50 rings.

Our limited sampling was insufficient to allow the reconstruction of a chronology from New Caledonian Araucariaceae. Nevertheless, this preliminary study aims to assess the sensitivity to climate of ring thicknesses and the variability of this sensitivity.

2.2. Climatic data

New Caledonia is situated at the southern limit of the tropical zone and thus benefits from a semi-tropical climate (figure 2). It is exposed to trade winds blowing from the southeast 300 d/yr. Thus, southern New Caledonia, including Noumea, receives a lot of rain. The climate is characterized by a dry season from September to November, followed by rainy and hot season extending from December to March. The climate then cools progressively until June, when the cold season sets in. The optimal growth period of New Caledonian trees spans therefore from December to June. During the hot season, tropical depressions form north of New Caledonia and induce rainy events during their southeastward trajectory. Winter depressions originate from the Coral Sea, situated between New Caledonia and Australia. They consist of cold fronts propagating westward to New Caledonia and are known as "coups d'ouest". Temperature and rainfall data have been recorded in Noumea since 1862. However, several data are missing up to 1899. The mean total annual rainfall is 1100 mm, but large variability results from droughts during El Niño events, and from rainy periods during La Niña events (Morliere and Rebert, 1986) so that extreme rainfall amounts are 500 mm and

2000 mm. Nicet and Delcroix (2000) and Manton et al. (2001) have shown in addition that climatic data averaged over the whole New Caledonia were fairly well correlated with SOI, but that this correlation was poor for some individual stations and some time periods. For example, a severe drought was recorded in 1969 in the absence of a El Niño phase, and 1967 was very wet during a weak La Niña phase. The mean maximum monthly temperature is 32°C in Noumea during the month of January, while the minimum one is 17°C during July, with a low mean daily amplitude of 6°C. The climatic records obtained from Noumea were used in our study, as they are the oldest and the most complete records. However, shorter records spanning a few years to a few decades are also available from various places of south New Caledonia. They show that rainfall increases with altitude and from North to South of the landmass with a monthly distribution similar to that of Noumea (Jaffré, 1980). For example, the station of Montagne des Sources located a few km from our sampling site of *Agathis lanceolata* (L1 to L3) and at a 780 m altitude recorded mean monthly maximal and minimal temperatures of 25°C and 12°C, respectively, and a mean rainfall of 3000 mm.

The Southern Oscillation Index (SOI) is widely used to measure the strength of ENSO events (Philander, 1990). This index is calculated from the pressure difference between Tahiti in French Polynesia and Darwin in Australia. It is available for download at <http://ccsm.ucar.edu/cas/catalog/climind/soi.html>. As the SOI is considered as a climatic index in the south Pacific, it will be included in our climatic dataset.

2. Analysis of growth band distribution

2.1. Determination of mean ring thickness

Our 3 disks of *Agathis lanceolata* present off-centered structures with extreme radii of 22 and 26 cm, 21 and 24 cm, and 16 cm and 31 cm, for L1, L2, and L3, respectively. The growth bands consist of pale-colored thin walled tracheid (i.e. cells of the xylem) that are limited by dark-colored thick-walled tracheids (figure 3a). But, in contrast to temperate climate conifers, the limits of growth bands is only a few tracheids wide and eventually is discontinuous (figure 3a). Moreover, several growth bands are difficult to detect on the whole circumference due to the fading of their dark limit (figure 3b), or due to wedging of rings (figure 3c). Thus, the band thickness distribution depends on the radius under consideration. This is demonstrated, for example, on the long radius (figure 4b) and the short radius (figure 4d) of our sample L3. Starting from the bark and stopping at the same ring boundary at about 5 cm from the growth center, we have counted 256 and 356 growth bands along these two radii.

In order to use the information present on the whole disk, we have computed the total integrated ring thickness, starting from a digitized image of the disk. First attempts to detect automatically the band limits were unsuccessful due to the following reasons: (i) the optical density and thickness of a given band change along its circumference, (ii) the non constant number of bands along different radii, (iii) the presence of radial structures having an optical density similar to that of band limits (see figure3). However, for our L1 and C1 samples, growth bands were wide enough to be traced directly on a paper on which automatic detection of their limits was worked out. Due to a mean band thickness below 1 mm, and due to the large number of bands, this method could not be applied for our other samples. Our composite method relies on information from 10 equally spaced radii of a disk and from 15-20 master rings visible along the whole circumference. Master rings are commonly used in dendrochronology for cross-dating several tree samples. Usually, they represent years of growth that can be easily identified from several trees from a given area (Schweingruber,

1996). In this study, master rings have been used for cross-dating the 10 radii of a single disk. Master rings were first drawn manually on the digitized disk image using the magnetic pen tool of Adobe Photoshop software and were assigned a thickness that makes them easier to detect. The band limits were then numerically detected within 50 pixels wide strips around the 10 radii, using the following iterative method: the sum of the optical densities along a series of directions within less than ten degrees from the previous band limit is computed over the 50 pixel wide strip. The next band boundary is defined by the direction of maximum cumulated optical density. This direction is then used as the central direction for computing the next band boundary. The first band boundary is assumed to be perpendicular to the radius. This produces a mean optical density profile where band boundaries appear as maxima and the master rings are absolutely black. The detection of band boundaries involves manual adjustment of some parameters for each radius (e.g. mean optical density, width and optical density range for detection of a band limit). Finally, it yields a band limit detection equivalent to manual measurements.

The last step consists of integrating the information of the 10 individual radii to compute a mean ring thickness profile. A simple average of the 10 individual profiles will result in a poor signal-to-noise ratio on the mean profile since growth bands from the same time period do not correspond on the different profiles, due to the presence of false rings. Things are not significantly improved if the time scale of each profile is deformed to allow correspondence of the master rings: the different profiles can be averaged only on a narrow zone around each master ring, as long as no incomplete ring is observed. This led us to identify incomplete rings and to introduce a zero thickness band when they are not present on a given profile. Starting from the longest radius, such a zero thickness growth band is inserted in the next profiles at each place where a band disappears. It is assumed that the thinnest bands are the most likely to disappear. Then growth bands present on less than 5 radii are

considered as false rings, and the thicknesses of true rings are averaged to produce the mean profile. This arbitrary limit of 5 radii produces a composite profile with the same number of rings as that of the longest radius. This implies that the number of false rings on this radius is equal to the number of rings which cannot be detected on it, although they are considered as true annual rings, since they are present on more than 5 other radii. The threshold of 5 radii complies with the result obtained by Nasi (1982) from annual marking of 12 different trees during seven successive years. Moreover, this value maximizes the correlation with climatic data (see below). However, since it is established on a statistical basis, our composite profile may include some false rings, while some true rings are lacking. Figure 4 represents the ring thicknesses obtained for L3 along the long radius, the short radius, and the composite profile. They are compared with climatic data recorded in Noumea and with the SOI. In the next sections, we apply signal analysis methods to assess the climatic information included in these composite profiles.

2.2. Spectral density analysis

Some of our profiles seem to present periodicities, which led us to a preliminary frequency analysis. Since spectral analysis is not the main topic of the paper, a simple and robust method is adopted here. As the Fourier transform of the signal is known to produce noisy spectra, the Fourier transform of the autocorrelation function is used here instead (Press et al., 1992). Taking the autocorrelation enhances periodic components of the signal. Moreover, the larger lag components of the autocorrelation function, which are those who introduce noise in the spectrum, are discarded with windowing techniques. This method is easy to implement, robust (Oppenheim and Shafer, 1974) and may be applied for various length data such as our three ring thickness profiles. The composite profile of L3 presents

only one noticeable period at 22 yrs, while the short radius does not present any clear periodicity and the long one exhibits only one peak at 6.6 yrs. Our sample L2 did not produce any marked periodicity, while O1 presents marked periods at 28, 17 and 8 yrs. For the climatic variables, rainfall data present a smooth peak at 20 yr and a large spectral content for periods longer than 4 yrs without any clear additional peak, while temperature presents two marked peaks at 21 and 2.3 yrs. These results confirm the visual impression that our samples present marked periodicities. The 20-22 yrs period is present in L3, in the temperature and in rainfall data. This could indicate that a common process having a near 20 yr period is present in our observations and that it has been undersampled in O1, probably because several annual rings are absent on this profile. This period is also present in the Interdecadal Pacific Oscillation which has been shown to modulate ENSO (Folland et al., 1999; Salinger et al., 2001). As a whole, the tree growth spectra present little power near the frequencies commonly associated to ENSO, while temperature and rain present power near 2.3 yr and 4 yr, i.e. close to 3.2 yr, which Quinn et al. 1998 found the most reliable period in SOI. This could result from the large noise introduced up to a few years period by the imperfect false ring identification. Besides, data sampled at near a one year time interval such as tree rings are not perfect for the definition a signal at a few years period. The spectral approach deserves further exploration using more sophisticated methods when a larger sample set becomes available. It could help to select the individuals presenting the best correlation with climate.

2.3. Correlation analysis

Figure 5 represents the ring thicknesses recorded in the profiles of all our samples and the climatic variables of figure 4. The relationship between tree ring thickness and climatic variables is not obvious. This leads us to a statistical analysis of the correlation between tree

rings and climate. We used monthly temperatures and rainfalls as well as cumulated rainfall on various time periods, i.e. during the wet season, the dry season and the growth season, that is assumed to extend from July until June of the following year. Annual temperatures and rainfall as well as the SOI have also been considered.

The method used is multiple regression of the Statistical Analysis Software (SAS Institute, 2004). At each step, this method extracts the variable corresponding to the largest explained variance, using partial least squares. This variable is added to the regression if it corresponds to a Pvalue of the Fisher test of less than 5%. When a variable is added to the regression, all the previous variables are considered again, and those corresponding to a Pvalue less than 5% are ruled out. This method is well suited for highly correlated variables, such as our climatic data (Radhakrishna and Rao, 1967; Wang and Chow, 1994). In order to include non linear combinations of climatic variables, tests were also performed with their logarithms, since adding logarithms results in the logarithm of the product of the variables, but these tests did not allow the extraction of any significant variable.

The correlation results are summarized in table 1. Monthly rainfalls are denoted by P, followed by the name of the month and the number of the year. so that PJune(n) is the rainfall of the month of June of the growth season. Correlations have also been computed for different radii numbers on which a growth band should be present to be considered as a true ring. This resulted in a broad maximum for 5 radii. Therefore this value has been adopted to build the composite profiles. The first observation is that temperature does not appear in this table. This does not mean that temperature does not influence growth, since rainfall and temperature are correlated. In fact, generally negative yet significant correlations appear with monthly temperatures if rainfalls are discarded from our analysis. Such correlations have also been found by Buckley et al. (2000) for kauris of Northern New Zealand. However, these correlations vary largely between our individuals, even if they belong to the same species.

The second observation is that only low total or partial explained variance can be obtained. Thus, our data have also been run with the DENDROCLIM software, which is devoted to cross correlation analysis of tree rings and has been benchmarked by Biondi and Waikul (2004). When using our sample L3, for which the best correlations with climate have been found by SAS (see table 1), the only significant correlations given by DENDROCLIM are those with the rainfall of June of the year preceding growth, and with the rainfall of June of the year before, with correlations of 0.37 and 0.24. Since the correlation coefficients are the square root of the explained variances, the corresponding explained variances are 0.14 and 0.06, respectively, which are exactly those found by SAS. The reduced number of significant climatic variables found by DENDROCLIM may result from the computation of the error in the correlation, based on the bootstrap method, while SAS uses the results of least squares. Our correlation coefficients are similar to those found by Buckley et al. (2000) with the kauris of New Zealand. We prefer however, to further use the explained variances (R^2) of table 1 since they are additive and provide the total explained variance. Table 1 also shows that the R^2 coefficients vary according to the individual sampled, even for the 3 *A. lanceolata* individuals, that were located within an area of 100 m radius. Our samples L2 and L3, although presenting similar growth rates, do not exhibit the same correlations with climate. Based on our correlation analysis, the sample L3, only, will be suitable for building future chronologies of New Caledonia.

However, it is noteworthy to notice that all our samples present a statistically significant correlation with the rainfall of the month of June of the growing season, of the previous season, or with that of the year before. We have verified that this correlation relied only on external rings. This is an indication that no systematic over-or-undersampling is introduced in our ring counting process. The correlation with PJune (n-1) and PJune(n-2) may be due to the accumulation of nutrients in the root of the tree, which are used during the

372 coming growing seasons extending from July to June of the following years. Accumulation in
373 the root system of carbohydrates which are further used during a growth season is common
374 for trees (see for example Jacoby and D'Arrigo, 1990). The correlation with PJune(n-1) and
375 PJune(n-2) observed for our sample L3 may be an indication either that for a poor soil and a
376 very thin organic cover, accumulation of nutriment inside the root system may be needed for
377 more than one year before growth, or that one true ring has been misinterpreted as a false ring
378 in the external part of this sample so that all inner rings are shifted one year in the past. On the
379 other hand, higher rainfall during June(n) may extend the duration of the growth season,
380 which could explain the positive correlation with PJune(n). The presence of Pjuly in two of
381 the regressions could reinforce these hypotheses.

382 For our sample L3, presenting the best correlations with climate, it appears that these
383 correlations are only obtained with the composite profile while the individual profiles present
384 much lower correlations. As a consequence, our results can not be applied to data obtained by
385 coring. As the individual radii of L3, however, present correlation with climate similar to
386 those obtained with the single profile of O1, we suspect that a whole disk of *A. ovata* could
387 provide a valuable climatic proxy.

389 3. $\delta^{18}\text{O}$ profiling

391 Isotopic composition of the tree cellulose is known to provide information on the
392 annual rainfall of temperate climates (Raffali-Delercq et al., 2004). Poussard et al. (2004)
393 have recently shown that $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ measured in cellulose of some tropical species were
394 also linked to climate. Recall that $\delta^{18}\text{O}$ measurements are defined as the relative difference
395 between the $^{18}\text{O}/^{16}\text{O}$ ratio of the sample and that of the SMOW standard. We have measured
396 $\delta^{18}\text{O}$ of the α -cellulose of the 30 external growth bands of the longest radius of L3. One of the

widest of these 30 bands has been divided into four parts to check the variability of the oxygen isotopic composition inside a single band. A strip 2 cm wide and 0.5 cm thick has been sawn along this long radius and each ring cut out, then grinded and mixed. The α -cellulose from two samples of 0.25 mg of each of these bands has been extracted following the method discussed in Green (1963) and Leavitt and Danzer (1993) and analyzed for $\delta^{18}\text{O}$. The precision of the measurements has been estimated to 0.25‰, which is the standard deviation of repeated measurements of Raffali-Delerce et al. (2004). Thus, values from the two samples were averaged if these values differed by less than 0.25‰, and if not, they were discarded. Given the insufficient length of our sampling, the SAS regression procedure could not be used, since it involves monthly and annual rainfall and temperature of the growth year and of the two precedent years, i.e. 78 climatic data. Thus, its is likely that a reasonable fit of our 30 $\delta^{18}\text{O}$ measurements could have been found, even if they were perfectly random.

Our measurements have been, therefore, directly compared with the total rainfall of the growing season (figure 6), which has been shown to be proportional to $\delta^{18}\text{O}$ in both temperate (Raffali et al., 2004) and tropical climates (Poussard et al., 2004; Poussard and Schrag 2005). The scale $\delta^{18}\text{O}$ scale in figure 6 has been reversed to emphasize the anticorrelation with rainfall. If each ring of our radius is assumed to correspond to a growth year, the correlation between $\delta^{18}\text{O}$ and the annual rainfall is weak (figure 6), except for the last 7 growth bands, for which the annual marks of Nasi (1982) demonstrate that one growth band was produced per year. This led us to use the composite profile of L3 obtained in the previous section to identify the false rings and possible missing rings within our sampled strip of L3. Several false rings, including 2 sets of successive 3 false rings were identified within these 30 sampled bands. They are marked in bold on figure 6. It is also notable that the two samples presenting larger than 0.25‰ discrepancy between their two $\delta^{18}\text{O}$ measurements also corresponded to false rings (dotted bold segments in figure 6). When measurements

corresponding to false rings are discarded, the $\delta^{18}\text{O}$ profile is visually similar to that of the annual rainfall. We have verified that this profile was only slightly changed if measurements from the false rings were averaged with that of the following or of the previous true ring. However, the visual relationship between $\delta^{18}\text{O}$ and rainfall only produces of a low correlation of -0.18. Careful examination of both curves show that, although similar in shape, they usually present an offset of 1 yr, and that the correlation seems to be inversed between 1965 and 1968. This suggests that either small random time offsets persist in our composite profile or that the $\delta^{18}\text{O}$ signature of a ring does not depend only on the rainfall during its growth year, a result also indicated by the correlation of ring thickness with the years preceding the growth year. Thus, our results could be improved by a better identification of the rings and a better knowledge of the conditions capable of inducing the formation of multiple growth bands during a single growth year.

Moreover, $\delta^{18}\text{O}$ may be not only correlated with annual rainfall but also with the geographical origin of rainy events. Further discussion on the origin of $\delta^{18}\text{O}$ signature of tree rings would require $\delta^{18}\text{O}$ data for rain, surface waters and groundwaters of New Caledonia, which are for the moment not available. On the other hand, the multi-sampling of the widest growth band of our strip did not indicate any relation with climatic details inside its growth year, in contrast with the results of Poussard and Schrag (2005). It is concluded from our results that more extensive $\delta^{18}\text{O}$ sampling is needed in New Caledonia.

4. Summary and conclusion

Growth bands can easily be observed in New Caledonia *Araucariaceae*. However it is known that kauris may produce several bands during a single year (Boswijk et al., 2006). These bands are generally present only on a part of the trunk circumference and should not be

447 considered for reconstructing a chronology. Similarly, a true annual ring may also be present
448 only on a part of the circumference. Moreover, as the growth axis of these trees is generally
449 off-centered, ring profiles obtained by coring without a previous knowledge of the growth
450 axis may be difficult to interpret as opposed to full disks sawn perpendicularly to the trunk.

451 Our 5 tree samples were gathered in the South New Caledonia, a region subjected to
452 ENSO events and characterized by poor ultramafic-derived soils. Three of them are older than
453 200 yrs. We have computed composite ring thickness profiles, integrating information from a
454 full disk, starting from automatic identification of growth band limits along 10 equally spaced
455 radii and manual drawing of 10 to 20 master rings on the whole circumference of the disk. We
456 assumed that bands present on less than half a complete circumference should be discarded.
457 This criterion complies with observations of bands produced between annual marks during the
458 seven year experiment of Nasi (1982) and also produces the best correlation between
459 composite ring profiles and climate. However, as this criterion is only valid on a statistical
460 basis, it may lead to some wrong identifications of true rings and false rings. Moreover,
461 information regarding the maximum optical density of latewood is not retained in the
462 composite profile.

463 Our study includes 10 individual profiles from 4 disks plus one radius from the fifth
464 disk, giving a total of 41 profiles, which is much lower than those used by Buckley et al.
465 (2000) to build their chronology of Northern New Zealand on kauris. Consequently, the
466 present study should only be considered as an assessment of the potential of New Caledonian
467 Araucariaceae for future dendrochronology studies.

468 Climatic data of New Caledonia only explain a low part of the variance of our ring
469 profiles. Significant (i.e. Pvalue <5% in Fisher test) correlation is found with monthly
470 temperatures but the annual rainfall only appears after the multiple regression process. This
471 does not mean that the growth of our species does not depend on temperature, but that the

regression with the annual rainfall is more stable. This implies that information related to rainfall rather than to temperature is likely to be obtained from tree ring studies in New Caledonia. For our samples, interannual variability of monthly rainfall amounts allows explanation of between 20% and 50% of the ring thickness variability, and less than 37% if the sample is older than 100 yrs. It should be emphasized that the correlation coefficients (square root of explained variance) with monthly rainfalls are similar to those obtained by Buckley et al. (2000) for kauris of New Zealand.

A correlation with the rainfall of June (n) (i.e. following growth) or June (n-1) (preceding growth) arises in almost all our samples, whatever the species, the location, altitude or the soil of the sampling site. This month marks the onset of the cool season lasting until September, followed by the dry season until December. Therefore, it may be considered that the month of June marks the beginning of the slow growth season and that a high rainfall during June may increase the duration of this growth or allow accumulation of nutrients for later use.

30 measurements of tree ring cellulose $\delta^{18}\text{O}$ have been conducted on one single disk selected for its better climate-ring width correlation. While earlier studies have used $\delta^{18}\text{O}$ measurements to identify seasonal cycles in tropical woods and date the rings, our data suggest that the direct use of $\delta^{18}\text{O}$ is misleading due to false rings that do not correspond to a complete growth year. When these false rings are identified from the disk analysis and discarded, data from the external part of our sample L3 present a general pattern anticorrelated with that of annual rainfall during the growth season (July(n-1) to June(n)). However, a slight random offset of 1 yr between $\delta^{18}\text{O}$ and annual rainfall and a 4 yr period where the correlation is reversed yielded a correlation of only -0.18. We note that false rings could not have been discarded without our composite profile, relying on the information of the whole disk. Additional $\delta^{18}\text{O}$ data on Araucariaceae of New Caledonia are needed to assess

more precisely their relationship with the climate. Poussard et al. (2004) and Poussard and Schrag (2005) have shown that dense sampling inside rings allows detection of the variation of the climate inside a single year. This deserves a systematic study in New Caledonia to assess the ability of this method to detect false rings.

Our results rely on a reduced sampling. They have to be confirmed by more data on tree rings in New Caledonia. Moreover due to the low correlation found with climate, a large number of samples and/or careful sample selection will be required to build a chronology. As individuals of *A. lanceolata* larger than a few meters in diameter are known in New Caledonia, accumulating tree ring data may lead to a chronology on a time period of 500-1000 yr.

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References

Atlas climatique de la Nouvelle Calédonie, 1995, Météo-France, Noumea, 103p.

522 Berlage, H.P., 1931. Over het verband tusschen de dikte der jaarringen van djatiboomen
 523 (Tectona grandis L. f.) en den regenval op Java. Tectona, 24, 939-953.

524 Biondi, F., Waikul, K., 2004. DENDROCLIM2002: A C++ program for statistical calibration
 525 of climate signal in tree-ring chronologies. Comp. and Geosci., 30, 303-311.

526 Boswijk, G., Fowler, A., Lorrey, A., Palmer, J., Ogden, J., 2006. Extension of the New
 527 Zealand kauri (*Agathis australis*) chronology to 1724 AC. The Holocene, 16, 188-189.

528 Buckley, B.M., Barbetti, M., Watanasak, M., D'Arrigo, R., Boonchirdchoo, S., Sarutanon, S.,
 529 1995. Dendrochronological investigation in Thailand. Int. Assoc. Wood Anatomists J., 16,
 530 393-409.

531 Buckley, B., Ogden, J., Palmer, J., Fowler, A., Salinger, J., 2000. Dendroclimatic
 532 interpretation of tree-rings in *Agathis australis* (kauri). 1. Climate correlation functions
 533 and master chronology. J. R. Soc. New Zealand, 20, 263-275.

534 Bullock, S.H., 1997. Effects of seasonal rainfall on radial growth in two tropical tree species.
 535 Int. J. of Biometeorology, 41, 13-16.

536 Cherrier, J.F., and Nasi, R. 1992. Placettes de suivi de croissance en forêt naturelle de
 537 Nouvelle Calédonie. Report CIRAD-CTFR, Noumea.

538 Détienne, P., 1989. Appearance and periodicity of growth rings in some tropical woods. Int.
 539 Assoc. Wood Anatomists Bull., 10, 123-132.

540 Enquist, J.B., Leffler, A.J., 2001. Long-term tree ring chronologies from sympatric tropical
 541 dry-forest trees: individual response to climatic variations. J. Tropic. Ecol., 17, 41-60.

542 Enright, N.J., Miller, B.P., Perry, G.L.W., 2003. Demography of the long-lived conifer
 543 *Agathis ovata* in maquis and rainforest, New Caledonia. J. Veg. Sci., 14, 625-636.

544 Evans, M.N., Schrag, D., 2004. A stable isotope-based approach to tropical
 545 dendroclimatology. Geochim. Cosmochim. Acta, 68, 3295-3305.

546 Folland, C.K., Parker, D.E., Colman, A.W., Washington, R., 1999. Large scale modes of
 547 ocean surface temperature since the late nineteenth century. In: Beyond El Niño: decadal
 548 and interdecadal variability, Navarra, A. (Ed.), Springer, Berlin, pp. 73-102.
 549 Green, J.W., 1963. Wood cellulose. In: Method of Carbohydrate Chemistry, III, R.L. Whistler
 550 (Eds), Academic Press, New York, pp. 9-20.
 551 Jacoby, G.C., 1989. Overview of tree-ring analysis in tropical regions. Int. Assoc. Wood
 552 Anatomists Bull., 10, 99-108.
 553 Jacoby, G.C., D'Arrigo, R., 1990. Teak (*Tectona Gandis* L.F.), a tropical species of large-
 554 scale dendroclimatic potential. *Dendrochronologia*, 8, 83-98.
 555 Jaffré, T., 1980. Etude écologique du peuplement végétal des sols dérivés des roches
 556 ultrabasiques en Nouvelle Calédonie, Travaux et documents de l'ORSTOM No 124,
 557 ORSTOM, Paris.
 558 Leavitt, S.W., Danzer, S.R., 1993. Method for batch processing small wood samples to
 559 holocellulose for stable carbon isotope analysis. *Ann. Chem.*, 65, 87-89.
 560 Manauté, J., Jaffré, T., Veillon, J.M., Kranitz, M.L., 2003. Revue des araucariaceae de
 561 Nouvelle Calédonie. IRD/Province Sud of New Caledonia, Noumea, New Caledonia.
 562 Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennesy, K.J., Nicholls, N., Chambers,
 563 L.E., Collins, D.A., Daw, G., Finet, A., Gunawan, K., Inape, H., Isobe, T.S., Kestin, T.S.,
 564 Lefale, P., Leyu, C.H. Lwin, T., Maitrepierre, N., Ouprasitwong, N., Page, C.M., Pahalad,
 565 J., Plummer, N., Salinger, M.J., Suppiah, R., Tran, V.L., Trewin, B., Tibig, I., Yee, D.,
 566 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and the South
 567 Pacific: 1961-1998. *Int. J. Climatol.*, 21, 269-284.
 568 Morliere, A., Rebert, J. P., 1986. Rainfall shortage and El Niño-Southern Oscillation in New
 569 Caledonia, Southwestern Pacific. *Mon. Wea. Rev.*, 114, 1131-1137.

570 Nasi R., 1982. Essai pour une meilleure connaissance et une meilleure compréhension des
 571 araucariacées dans la végétation calédonienne. Mémoire d'Ingénieur, GERDAT-CTFT,
 572 Nogent sur Marne, France.

573 Nicet, B., Delcroix, T., 2000. ENSO-related precipitation changes in New Caledonia,
 574 Southwestern tropical Pacific: 1969-98. Mon. Wea. Rev., 128, 3001-3006.

575 Ogden, J., 1978. On the dendrochronological potential of Australian trees. Aust. J. Ecol., 3,
 576 339-356.

577 Oppenheim, A.V., Schafer, R.W., 1974. Digital signal processing. Prentice Hall, Englewood
 578 Cliffs, N.J., USA.

579 Ourbak, T., Correge, T., Malaize, B., Le Cornec F., Charlier K., Peypoupet, J. P., 2006. A
 580 high-resolution investigation of temperature, salinity, and upwelling activity proxies in
 581 corals. Geochem. Geophys. Geosyst., 7, Q03013, doi:10.1029/2005GC001064.

582 Philander, S.G.H., 1990. El Niño, La Niña and the Southern Oscillation. Academic Press, San
 583 Diego, CA.

584 Poussard, P.F., Evans, M.N., Schrag, D.P., 2004. Resolving seasonality in tropical trees:
 585 multi-decade high resolution oxygen and carbon isotope record from Indonesia and
 586 Thailand. Earth Planet. Sci. Lett. 218, 301-316.

587 Poussard P.F., Schrag, D.P., 2005. Seasonally stable isotope chronologies from northern
 588 Thailand deciduous trees. Earth. Planet. Sci. Lett., 235, 752-765.

589 Press, W.H., Teukolsky, S.A., Vetterling, W.T., Flannery, B.P., 1992. Numerical recipes in
 590 Fortran. The Art of Scientific Computing, 2nd ed. Cambridge University Press, New
 591 York, NY, USA.

592 Priya, P.B., Bhat, K.M., 1998. False ring formation in teak (*Tectona grandis* L.f.) and the
 593 influence of environmental factors. Forest Ecol. Manag., 108, 215-222.

594 Quinn, W.H., Crowley, T.J., Taylor F.W., Hénin, C., Joannot P., Join, Y., 1998. A multi-
 595 century stable isotope record from a New Caledonia Coral : Interannual and decadal sea
 596 surface temperature variability in the souhtwest Pacific since 1657 AD.
 597 *Paleoceanography*, 13, 412-426.

598 Radhakrishna, C., Rao, J., 1967. Linear statistical inference and its application. John Wiley
 599 and Sons, New York.

600 Raffalli-Delerce G., Masson-Delmotte V., Dupouey J.L., Stievenard M., Breda N., Moisselin
 601 J.M. 2004. Reconstruction of summer droughts using tree-ring cellulose isotopes: a
 602 calibration study with living oaks from Brittany (western France). *Tellus*, 56-2, 160-174.

603 Rodbell, D. T., Seltzer G. O., Anderson, D. M., Abbott, M. B., Enfield, D. B., Newmann, J.
 604 H., 1999. An~15,000-year record of El Niño-driven alluviation in southwestern Ecuador.
 605 *Science*, 4401, 516-520.

606 Salinger, M.J., Renwik, J.A., Mullan, A.B., 2001. Interdecadal Pacific Oscillation and South
 607 Pacific climate. *Int. J. Climatol.*, 21, 1705-1721.

608 SAS Institute, 2004. SAS/STAT 9.1 user's guide, SAS Institute Inc., Cary, NC.

609 Schweingruber, F.H., 1996. Tree rings and Environment Dendroecology. Haupt, Vienna.

610 Stahle, D., 1999. Useful strategies for the development of tropical tree-ring chronologies. *Int.*
 611 *Assoc. Wood Anatomists J.*, 20, 249-253.

612 Stevenson, J., Dodson, J.R., Prosser, L.P., 2001. A late Quaternary record of environmental
 613 change and human impact from New Caledonia. *Paleogeog. Paleoclimatol. Paleoecol.*,
 614 168, 97-123.

615 Wang, S.G., Chow, S.C., 1994. Advanced linear models : theory and applications. Marcel
 616 Dekker, New York, pp. 146-223.

617 Watanabe, T., Gagan, M.K., Corregge, T., Scott-Gagan, H., Cowley, J., Hantoro, W.S., 2003.
618 Oxygen isotope systematic in *Diploastrea-heliopora* : new coral archive of tropical
619 paleoclimate. *Geochim. Cosmochim. Acta*, 67, 1349-1358.

620 Whitmore T.C., 1980. A monograph on *Agathis*. *Plants Systematics and Evolution*, 135, 41-
621 69.

622 Wirrmann, D., Semah, A.M., Chacornac-Rault, M. 2006. Late Holocene paleoenvironment in
623 northern New Caledonia, Southwestern Pacific, from a multiproxy analysis of lake
624 sediments. *Quat. Res.*, 66, 213-232.

625 Worbes, M., 1995. How to measure growth dynamics in tropical trees: a review. *Int. Assoc.*
626 *Wood Anatomists J.*, 16, 337-351.

627 Worbes, M., 2002. One hundred years of tree-ring research in the tropics - a brief history and
628 an outlook to future challenges. *Dendrochronologia* 20, 217-231.

629

Figure captions

Figure 1. Location of the sampling area, and of New Caledonia in the southwest Pacific (inlet). Each sampling area is labeled by its sample reference. L1-L3 correspond to the three *A. lanceolata*, O1 to the *A. ovata*, and C1 to the *Araucaria columnaris*. The greyed area figures the extent of the southern ultramafic massif.

Figure 2. Mean climate of Noumea (1888-2004). The bar chart shows the annual rainfall and the curve shows the mean monthly temperature.

Figure 3. Ring structure of *A. lanceolata*. a) The limits of growth bands (vertical arrows) consists of a thin and discontinuous series of thick-walled dark-colored tracheids. b) Fading of a ring limit (horizontal arrow) from right to left. This ring limit cannot be detected at the left end of the picture. c) a series of wedging rings (horizontal arrow), where decreasing width rings merge together (from right to left). Radial structures perpendicular to rings with the same optical density as ring limits may be observed on these three pictures.

Figure 4. Comparison of the climatic data with the different ring thickness profiles from L3. a): Climatic data: annual rainfall during the growth season, i.e. July to June (solid bars), and mean annual temperature (solid line), both recorded in Noumea. The SOI index, averaged on a 1 yr moving window, is represented with a dashed line (arbitrary unit). Growth band thicknesses (arbitrary units) of our L3 sample along the longest radius (b), the composite profile, averaged on the whole disk (c) and the short radius (d).

Figure 5. Comparison of thickness profiles recorded with our different samples (arbitrary vertical units, vertical scale at the right). The annual temperature and rainfall of figure 1 are also indicated at the top of the figure. Note that O1 corresponds to a single profile while the other samples correspond to synthetic profiles averaged over the whole disk. For L3 and L2, the 100 last years, only are displayed, since for older rings no correlation with climatic data is possible.

Figure 6. Comparison between $\delta^{18}\text{O}$ measured in L3 with the annual rainfall during a growth year (July of a given year until June of the following year). Top: rainfall; bottom: $\delta^{18}\text{O}$ data. In order to emphasize the anticorrelation with annual rainfall, the $\delta^{18}\text{O}$ axis has been reversed. The black curve, including dotted and thick parts represents raw data. Data from false rings are indicated in bold. False rings where two measurements resulted in a $\delta^{18}\text{O}$ discrepancy of more than 0.25‰ (see text) correspond to the dotted segments. In the red curve, false ring data have been discarded. Both $\delta^{18}\text{O}$ curves are identical in the external part of L3, where the annual marks indicate that there are no false rings.

Correlation between tree ring thickness and monthly rainfalls			
Variable	Explained variance (R ²)	Cumulated explained variance	Pvalue
ARAUCARIA COLUMNARIS (C1)			
Pjune (n)	0.18	0.18	0.0125
Pjune (n-1)	0.14	0.32	0.0161
Pmay (n)	0.08	0.41	0.036
Papril (n-1)	0.09	0.5	0.0425
AGATHIS LANCEOLATA (L1)			
Pdecember (n-1)	0.216	0.216	0.0192
AGATHIS LANCEOLATA (L2)			
Pjune (n)	0.05	0.05	0.0133
Papril (n-2)	0.05	0.10	0.0147
Pjuly (n-2)	0.06	0.16	0.0167
Pmay (n-2)	0.04	0.20	0.0328
Pjune (n-1)	0.04	0.24	0.0471
Pjuly (n-1)	0.04	0.28	0.0471
AGATHIS LANCEOLATA (L3)			
Pjune (n-1)	0.14	0.14	0.0001
Pjune (n-2)	0.06	0.20	0.0109
Pdecember (n-1)	0.05	0.25	0.0147
N. dry months (n)	0.05	0.30	0.0196
Pjanuary (n-1)	0.04	0.34	0.0337
Pdecember (n-2)	0.03	0.37	0.0347
AGATHIS OVATA (O1)			
Pdecember (n-2)	0.06	0.06	0.0110
Pjuly (n)	0.05	0.11	0.0264
Pjune (n-1)	0.05	0.16	0.0366
Pjune (n)	0.05	0.21	0.0379

Table 1

Figure 1

Figure 1 Liebeau et al.

Figure 2

Figure 2 Lieubeau et al.

Figure 3

Figure 3 Lieubeau et al.

Figure 4

Figure 4 Lieubeau et al.

Figure 5

Figure 5 Lieubeau et al.

Figure 6

Figure 6 Lieubeau et al.