Tree stems and tides – A new approach and elements of reflexion *(reviewed paper)*

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Abstract: In the context of chronobiological research on trees, a high-sensitivity device was developed to measure low-potential electric currents along the bole of two trees growing under open conditions. Rhythmic variations of the (bio-)electric potentials are found, linked on the one hand to daily photoperiods and on the other to lunar periodicities, depending on the physiological phase of the trees.

Abstract: Im Rahmen der chronobiologischen Forschung an Bäumen wurde ein hoch empfindliches Verfahren entwickelt zur Messung von schwachen elektrischen Spannungen entlang des Stammes von zwei frei wachsenden Bäumen. Es wurden rhythmische Variationen im (bio-)elektrischen Potenzial gefunden, einerseits gekoppelt an die täglichen Photoperioden, andererseits an lunare Periodizitäten, in Abhängigkeit von der physiologischen Phase der Bäume.

Introduction

Recent chronobiological research, based on extensometric stem-diameter measurements of trees held in greenhouses or growing under open conditions, shows divergent results concerning the rhythmicities in the respective systematic, fluctuating dimensions. This leads to the question of a possible complementarity of the observed phenomena and if other aspects of the tree physiology could perhaps show independently similar rhythmic variations.

Context

It is a well known phenomenon that trees (as all other plants) have a diurnal water uptake driven by the water vapour deficit (evapotranspiration) due to solar radiation (as review about photoperiodism: see THOMAS & VINCE-PRUE 1997). This cyclic water flux is noticeable in high-precision stem-diameter measurements, superimposed on the effect of secondary growth during the vegetation period. In order to explore the periodicity of stem diameter fluctuations in relation to another factor, the gravitational influence of the moon, VESALA *et al*. (2000) applied Fourier analysis to data taken from Scots pine trees (*Pinus sylvestris* Mill.) growing in open conditions. This work was linked to a previous one, where the authors (Zürcher, Cantiani, Sorbetti-Guerri and Michel (ZÜRCHER *et al*. 1998), based on data from CANTIANI *et al.* 1994) reported a daily synodic (tidal) variation of the stem diameters of two young Norway spruce (*Picea abies* (L.) Karst.) trees grown in containers at a controlled temperature in continuous darkness, and where the diameter variations fitted closely to the gravimetric curves. Unlike the results of ZÜRCHER *et al*. (1998), VESALA *et al*. (2000) found no indication of tidal influence on stem diameters of trees growing under natural photo-thermo-periodism. The authors emphasized the extreme weakness of the changes exerted by tides, and the improbable role of gravimetry on the physical, or on the biological level.

In face of this apparent divergence, this contribution proposes new findings and some points for reflexion, as possible steps to gain a better understanding of the processes involved.

Sap flow of trees under controlled conditions

Concerning the importance of the growing conditions and the capability of plants to adapt their physiological rhythms to their environment, we refer to the more recent publication of MILLET & MOALLEM (2001), who studied the growth rhythms and sap flow in Mandarin Orange tree (*Citrus deliciosa* Tenore). These authors observed (by a similar Fourier analysis of the data as used in VESALA *et al*. (2000)) that the sap flow changes its period of 24 h under regular LD-conditions (14 h light / 10 h darkness) to a 25 hour-period when maintained under LL-conditions (constant light / constant temperature). For our understanding, this reveals the same basic synodic lunar rhythm as for *Picea*, appearing under constant light as well as under constant darkness.

A precision about tidal rhythms

For a correct data interpretation, it is important to specify that the considered daily lunar period is 24 h 49 min, (instead of 25 h 49 min considered in VESALA *et al*. 2000). From the geodetical point of view, the effective tidal forces result from the addition of different periodical components: the partial tides. These are, in decreasing order of importance: the semi-diurnal main lunar tide (M2, period 12.4 h), the diurnal main declination tide (K1, 23.9 h), the semi-diurnal main solar tide (S2, 12.0 h) and the diurnal main lunar tide (O1, 25.8 h). M2 is the principal reason why tides occur generally twice during a lunar day (24.8 h).

A complementary approach: Electro-physiology with recent methodological developments

Using another approach (HOLZKNECHT 2002), the electrical potential in the sapwood of Norway Spruce in an open site (Radein, South Tyrol) was recorded, as well as of Stone Pine (*Pinus cembra* L.) in a container, but under uncontrolled atmosphere and with a high-frequency, long-term data acquisition system. This technical device represents the most recent development of the methodology initially developed by BURR (1947), who discovered lunar-correlated variations in tree potentials.

In this recent thesis, the influence of climate and lunar periodicity on the continuous, technically undisturbed electrical ac-potential ($P_{ac-a \text{ for authentic, } c \text{ for current}}$) in the sapwood of trees was studied. P_{ac} was measured with gilded copper-electrodes horizontally inserted in the sapwood at the stem base (refer-

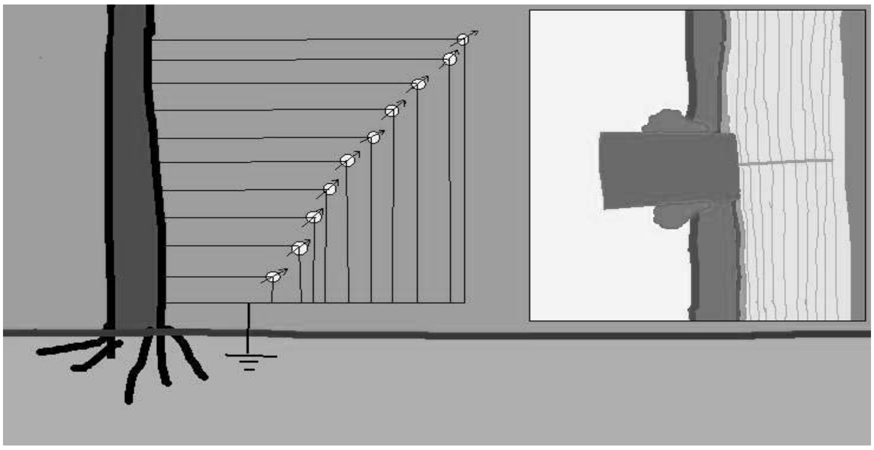

Figure 1: **Schematic structure of an electrode (right) and disposition of an equidistant series along the tree stem (left), inclusively grounding.**

Abbildung 1: Schematischer Aufbau einer Elektrode (rechts) und Platzierung einer Serie mit gleichem Abstand entlang des Baumstammes (links), inklusive Erdung.

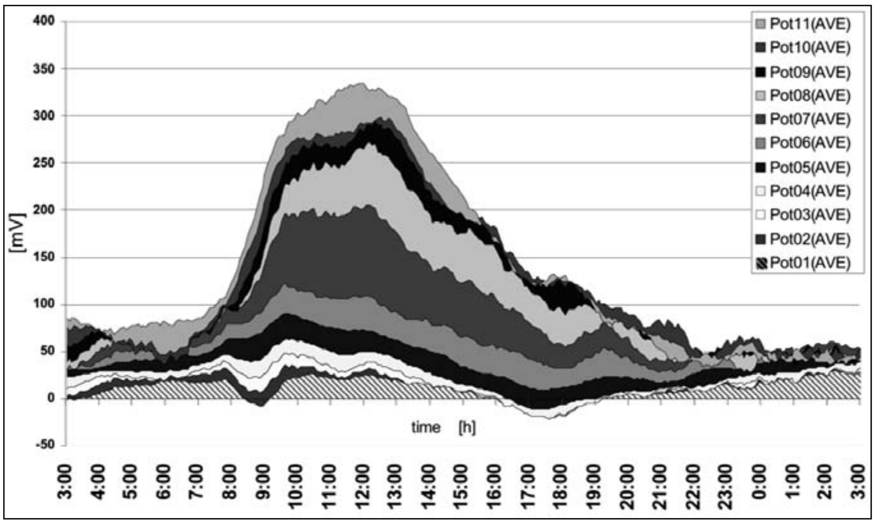

Figure 2: **Summarized P_{KRG} for the whole set of measurements. The partial curves are compensated and relative to the respective mean value from 3:00 to 5:00 a.m.**

Abbildung 2: Kompensiertes, relatives Gesamtpotenzial P_{KRG} für die Mess-Serien während 24 Stunden. Die einzelnen Kurven sind kompensiert und im Verhältnis zum Mittelwert von 3.00 bis 5.00 Uhr umgerechnet.

ence potential E_0) and at 1, 2, 3…11 meters (E_{1-11}) above the reference electrode. The potential course along the stem was measured every minute and the average value stored every five minutes with a data logger. The 80-year old Spruce was followed from summer 2000 until spring 2001 and the 12-year old potted Stone Pine during winter 2001/2002. From the measured P_{ac} a compensated, relative, summarized potential (P_{KRG}) and $\cap P_{KRG}$ (as the mean value per electrode and meter) were calculated. *Figure 1* illustrates the fixation mode and the disposition of the electrodes on the main tree. The method of calculation for P_{KRG} is explained with a practical example (*figure 2*).

Main Results

The measurements on Spruce and their processing (Fourier analysis and graphically) show a general parallelism of the P_{ac} data from single electrodes to the successive moon phases of November 2000 to January 2001, and possibly its tropic/sideral rhythm (*figure 3*). Furthermore, they reveal a correlation between the P_{KRG} and the curve of the calculated gravimetric tides for the last week of the decreasing lunar phases in November and December 2000, and around the December 2001 new moon for Stone Pine, respectively. *Figure 4a* illustrates the synchronicity of the bio-electrical P_{KRG} values and the systematic variations of the gravimetric tides for Stone Pine during the 5 days before and 2 days after the new moon of December 2001. The analysis of the period before and around new moon, when compared with the period after new moon reveals a progressive «alignment» of the electro-physiological rhythms to the gravimetric tides (*figure 4b, 4c*). Interestingly, one secondary period of 4.17–4.34 d (corresponding in *figure 4c* to F max2 = 0.23–0.24 d^{-1}) was also found in human physiology by Strestik *et al.* (2001), with 4.23 d.

On the other hand, and similarly to Vesala *et al.* (2000), no correlation of this type was found during the vegetative period, which is attributed to the fact that the diurnal photoperiodism and the physiological activity are stronger than lunar influences in this phase and thus conceals them. An interesting exception: during a brief period around full moon, from August 14th to August 18th, 2000, possibly linked with a short phase of reduced physiological activity (known to occur for Norway Spruce at that period of summer), the correlation with the gravimetric tides had already appeared (*figure 5a, 5b, 5c*). As visible in *figure 5b*, it is noteworthy that the first frequency maximum F max1 = 0.13–014 d^{-1} corresponds to a longer period of ca. 7.7–7.1 d (mean 7.4 d); Brown & Chow (1973) had found the basic period of 7.4 d in their experiment of water absorption by bean seeds, Milton (1974) observed this rhythm on maize held under constant conditions. The second frequency maximum F max2 = ca. 0.34 d^{-1} corresponds to a period of ca. 2.94 d (= 1/10 of the lunar month), as was additionally found by Strestik *et al.* (2001).

Possible causes and further aspects

We agree that it is difficult to imagine how a direct gravitational effect could be responsible for the observed «stem tides». Rather than direct causality, one can consider that even very

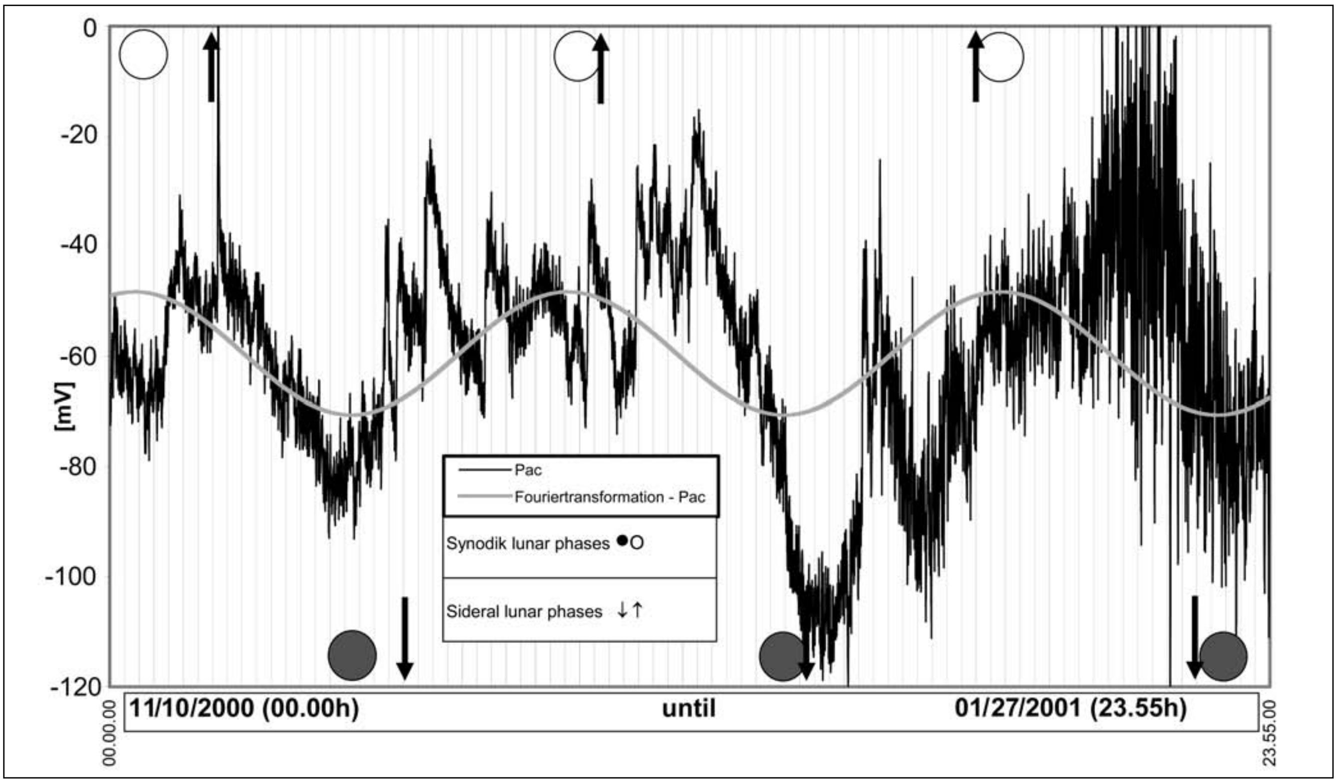

Figure 3: **Rhythmic variations of the electrical potential P_{ac} in a single electrode of Norway Spruce (*Picea abies* (L.) Karst.), in apparent synchrony with the synodic and sidereal / tropic lunar phases from November 2000 to January 2001.**

Abbildung 3: Rhythmische Variationen des elektrischen Potenzials P_{ac} in einer einzelnen Elektrode bei der Fichte (Picea abies (L.) Karst.), in sichtbarer Synchronie mit den synodischen und siderisch / tropischen lunaren Phasen von November 2000 bis Januar 2001.

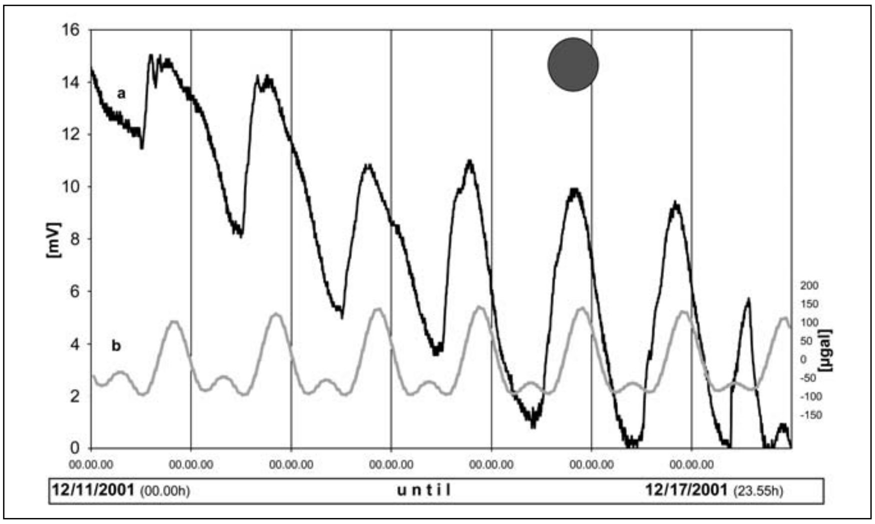

Figure 4a: **Rhythmic variations of the electrical potential P_{KRG} (a) of Stone Pine (*Pinus cembra* L.), in apparent synchrony with the calculated gravimetric tides (b), around new moon of December 2001 (shown period: from Dec. 11 to Dec. 17, 2001; New moon: Dec. 15, 2001).**

Abbildung 4a: Rhythmische Variationen des elektrischen Potenzials P_{KRG} (a) bei der Zirbe / Arve (Pinus cembra L.), in sichtbarer Synchronie mit den berechneten gravimetrischen Gezeiten (b), um Neumond im Dezember 2001 (dargestellte Periode: vom 11. bis 17. Dezember 2001; Neumond: 15. Dezember 2001).

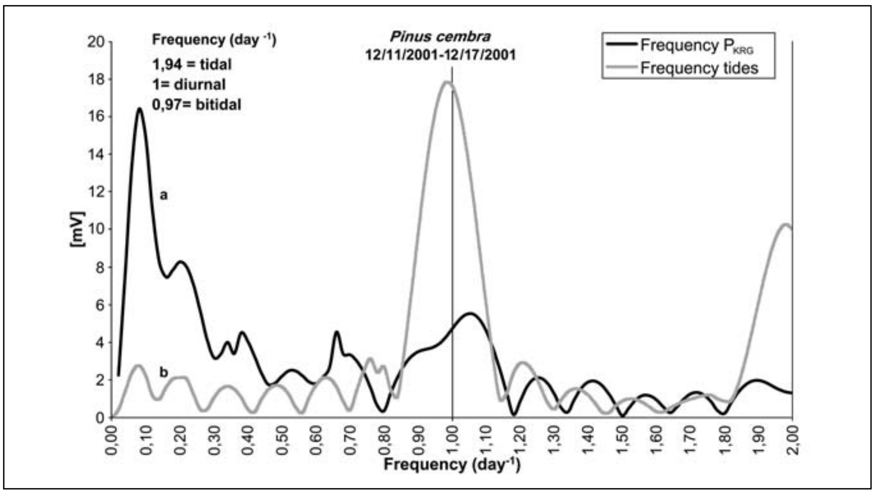

Figure 4b: **Amplitudes of various frequencies (a) in the electrical potential P_{KRG} (Fourier analysis) before and around new moon of December 2001 (Dec. 11 to Dec.17, 2001), compared to the frequencies (b) in gravimetric tides.**

This analysis makes visible that the tree is actually not yet «in tune» with the gravimetric tides.

Abbildung 4b: Amplituden von verschiedenen Frequenzen (a) im elektrischen Potenzial P_{KRG} (Fourier- Analyse), vor und um Neumond im Dezember 2001 (11. bis 17. Dezember 2001), verglichen mit den Frequenzen (b) in den gravimetrischen Gezeiten. Diese Analyse zeigt, dass der Baum noch nicht «im Einklang» mit den Gezeiten steht.

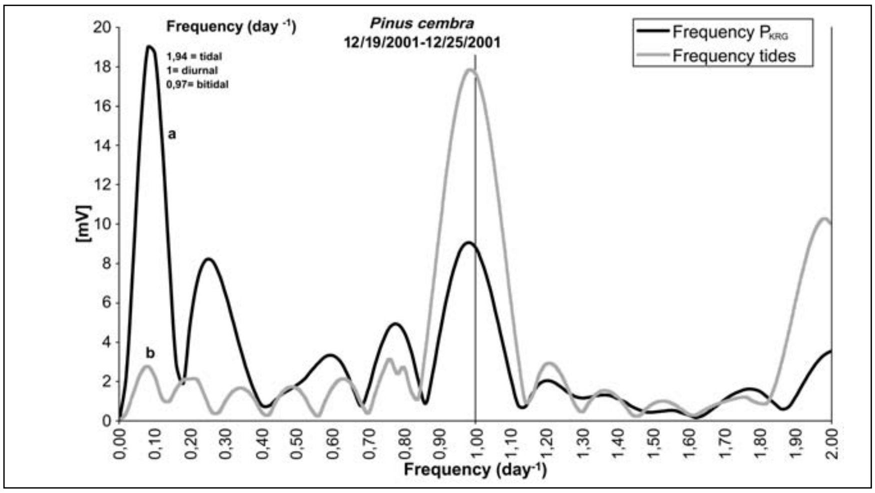

Figure 4c: **Amplitudes of various frequencies (a) in the electrical potential P_{KRG} (Fourier analysis) after new moon of December 2001 (from Dec. 19 to Dec. 25, 2001), compared to the frequencies (b) in gravimetric tides.**

Here, the synchrony with gravimetric tides becomes evident (F max5 = 0.97 d^{-1} indicating a period of 24.7 h).

Abbildung 4c: Amplituden von verschiedenen Frequenzen (a) im elektrischen Potenzial P_{KRG} (Fourier- Analyse), nach Neumond im Dezember 2001 (vom 19. Dez. 2001 bis 25. Dez. 2001), verglichen mit den Frequenzen (b) in den gravimetrischen Gezeiten. Hier wird die Synchronie mit den gravimetrischen Gezeiten evident (F max5 = 0,97 d^{-1} entspricht einer Periode von 24,7 h).

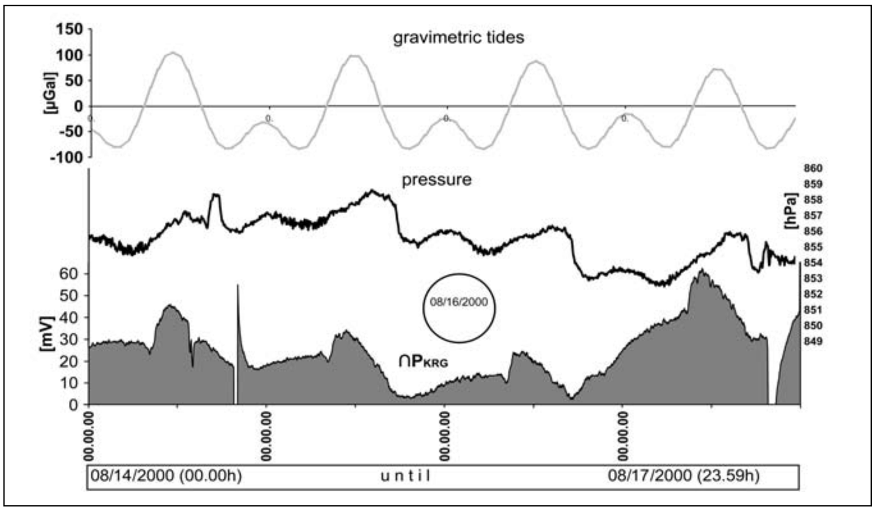

Figure 5a: **Rhythmic variations of the mean compensated, relative and summarized electrical potential $\cap P_{KRG}$ of Norway Spruce (*Picea abies* (L.) Karst.), in apparent synchrony with the calculated gravimetric tides, around the full moon of August 2000, possibly during a short physiological period of rest.**

Notice the simultaneous variations of the atmospheric pressure, with a slight shift compared to tides (and potentials).

Abbildung 5a: Rhythmische Variationen des mittleren kompensierten, relativen Gesamtpotenzials $\cap P_{KRG}$ bei der Fichte (Picea abies (L.) Karst.), in sichtbarer Synchronie mit den berechneten gravimetrischen Gezeiten, um Vollmond im August 2000, möglicherweise während einer kurzen physiologischen Ruheperiode. Zu beachten sind die simultanen Variationen des atmosphärischen Druckes, mit einer leichten Verschiebung im Vergleich zu den Gezeiten (und Potenzialen).

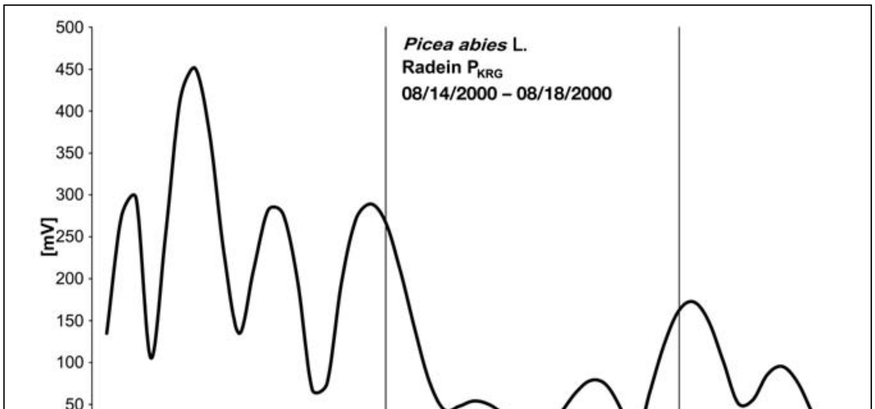

Figure 5b: **Amplitudes of various frequencies in the electrical potential $\cap P_{KRG}$ (Fourier analysis) around full moon of August 2000 (from Aug. 14, 2000 to Aug. 18, 2000).**

The 4th Frequency maximum F max4 = ca. 0.96 d^{-1} corresponds to a period of 25 h and indicates synchrony with the gravimetric tides.

Abbildung 5b: Amplituden von verschiedenen Frequenzen im elektrischen Potenzial $\cap P_{KRG}$ (Fourier-Analyse), um Vollmond 2000 (vom 14. bis 18. August 2000). Das 4. Frequenz-Maximum F max4 = ca. 0,96 d^{-1} entspricht einer Periode von 25 h und belegt eine Synchronie mit den gravimetrischen Gezeiten.

small forces applied rhythmically (in our case with the daily synodic lunar period of 24.8 h) can have the effect of amplifying some recurrent processes. One argument that supports this view is the fact that other organisms, even moving freely in all directions, can also demonstrate such a «tidal rhythm»: behavioural scientists have established in their famous speleological and «bunker» experiments that the basic physiological rhythm in people allowed full freedom of movement whilst isolated from daily influences follows not a 24-hour cycle but rather a 24.6–24.8-hour cycle (ASCHOFF & WEVER 1962, Siffre in POIREL 1975, corresponding to 62 and 205 days in underground isolation). WINFREE (1987) also notes such an approximately 24-hour-50-minute clock for humans and higher mammals, which could have a lunar-synodic origin.

In a recent publication (DORDA 2004) developed a quantized gravitational model that describes the effect of the moon's movement on organic systems, in the form of rhythmically varying coherent H_2O clusters, acting as «Zeitgeber» (time generators); such physico-chemical changes allow Dorda to confirm the measured extensometric tides (ZÜRCHER *et al.*

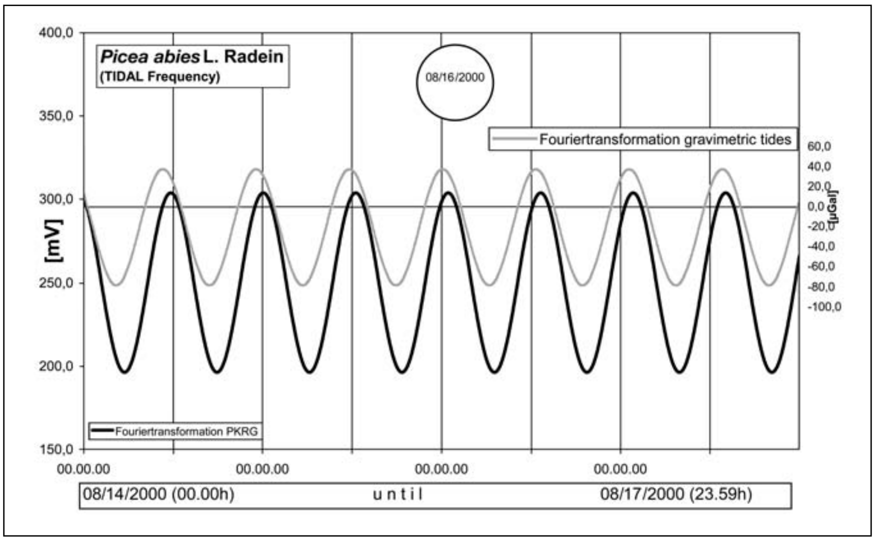

Figure 5c: **Comparison of the Fourier-transformed tidal component of the variations in electrical potentials with the Fourier-transformed gravimetric tides of the same period.**

Abbildung 5c: Vergleich der Fourier-transformierten tidalen Komponente der Variationen des elektrischen Potenzials mit den Fourier-transformierten gravimetrschen Gezeiten der selben Periode.

1998) and could play the same role in the electrophysiology of plants. Another hypothetical factor could be the geomagnetic field, which is known to vary in phase with the position of the moon (BIGG 1963) that also has an effect on water properties. DUBROV (1978), member of the Soviet Academy of Sciences, demonstrated with many experimental examples the importance of this essential factor. As suggested by BURR (1947), atmospheric electric fields could potentially cause fluctuations in trees – a hypothesis that remains to be examined. In a later work BURR (1972) reported an effective correlation between fluctuations of tree potentials and the eleven-year cycle of sunspot activity, which is known to have an influence on the atmospheric electric field.

As already mentioned, interesting experimental work in our view deals with synodic variations of the water uptake by bean seeds under constant conditions (BROWN & CHOW 1973). Important test series showed strong systematic variations (up to 20 %) of absorbed water, with distinct peaks near full moon, new moon, first quarter and last quarter. This implies that gravimetry is not the only influence involved, being at its lowest (minima of daily variations) at the first and the third quarter. MILTON (1974) also found such a «weekly» lunar rhythm in maize germination and initial growth under controlled conditions.

Conclusion and perspectives

These new electrophysiological data make evident that trees can show a certain flexibility between inner lunar-correlated rhythms and the solar-based photoperiodism, depending on the environmental conditions and their actual physiological activity/inactivity. It is interesting that this phenomenon is apparently not limited to plants. The circadian rhythmicity is therefore submitted to a permanent readjustment between an «inner» component of about 25 hours and an external component of 24 hours (WEVER 1979). These short rhythms appear generally linked with fluctuations of longer periods. Moreover, in an international, long-term processing of general and cardiovascular mortality, phase shifts of the lunar waves have been observed in relation to solar activity (STRESTIK *et al.* 2001). We adopt the conclusion of these authors: «Although the proper mechanism of the supposed influence of tides on the biosphere is not known, our results lead to the conclusion that the lunar factor should be taken into account in any investigation of external influences on biological processes».

Summary

In the context of previous research on rhythmic tree stem diameter variations depending on the environmental factors (controlled greenhouse vs. outdoor), a high-sensitivity device was developed to measure low-potential electric currents along the bole of two trees (adult *Picea abies*/young *Pinus cembra*) growing under open conditions (in Radein, South Tyrol). Rhythmic variations of the (bio-)electric potentials are found, with mainly the usual photoperiod during the vegetation time, and with clearly lunar periods during the winter rest. These results constitute a synthesis of the formerly apparently diverging results on diameter measurements, and confirm specific conditions under which lunar rhythms effectively occur.

Zusammenfassung

Baumstämme und Gezeiten – Eine neue Betrachtungsweise und Diskussionsbeitrag

Im Kontext früherer Forschungen über rhythmische Variationen des Stammdurchmessers von Bäumen in Abhängigkeit von den Umweltfaktoren (in kontrolliertem Gewächshaus oder Freiland) wurde ein hoch empfindliches Verfahren entwickelt mit dem Ziel, schwache elektrische Spannungen entlang des Stammes von zwei frei wachsenden Bäumen zu messen (eine adulte Fichte, *Picea abies* (L.) Karst. und eine junge Zirbe oder Arve, *Pinus cembra* L., in Radein, Südtirol). Es wurden rhythmische Variationen des (bio-)elektrischen Potenzials gefunden, mit vorwiegend der bekannten Photoperiode während der Vegetationszeit, und mit eindeutigen lunaren Perioden während der Winterruhe. Diese Ergebnisse stellen eine Synthese zwischen den bisher scheinbar divergierenden Resultaten bei Durchmessermessungen dar, und bestätigen die spezifischen Bedingungen, unter welchen die lunaren Rhythmen effektiv vorkommen.

Résumé

Le fût des arbres et les marées – Nouvelle approche et éléments de réflexion

Dans le contexte de précédentes recherches sur les variations du diamètre du tronc d'arbres en fonction des facteurs environnementaux (en serre contrôlée ou à l'extérieur), un appareillage à haute sensibilité fut développé dans le but de mesurer les courants électriques faibles le long de la tige de deux arbres croissant en conditions ouvertes (un épicéa adulte, *Picea abies* (L.) Karst. et un jeune arolle / pin cembro, *Pinus cembra* L., à Radein, Tyrol du Sud). Des variations rythmiques des potentiels bio-électriques sont décelées, présentant principalement la photopériode usuelle durant la phase de végétation et des périodes clairement lunaires durant la phase du repos hivernal. Ces résultats constituent une synthèse des conclusions jusqu'ici apparemment divergentes tirées des mesures de diamètres et confirment les conditions spécifiques sous lesquelles les rythmes lunaires se présentent effectivement.

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