A short analysis of the temperature dependence of French Provence cicada chirps frequency and ambient air temperature.

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This paper is dedicated to my son in law Ronny Heinz, recovering from major surgery.

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Summary:

Nearly 90 recordings of the French Provence cicada chirps were made under different ambient air temperatures, mostly above 30°C. It could be verified that the chirp repetition frequency rises with temperature, analogue to the findings given in A. Dolbears paper on crickets from 1897. An empirical "cicada thermometer" law has been established using 32 different recordings. It also was found that the individual chirp frequencies are close to 5 kHz and seem to be more or less constant, and not influenced by air temperature.

1. A historic recall

Since many, possibly century-long times it has been observed that the chirp frequency of crickets varies with temperature: crickets chirp faster when the temperature is higher. The best-known author observing this, and formulating a law having his name is the American physicist Amos Emerson DOLBEAR who published in 1897 a paper titled "The Cricket as a Thermometer" **[ref.1]**.
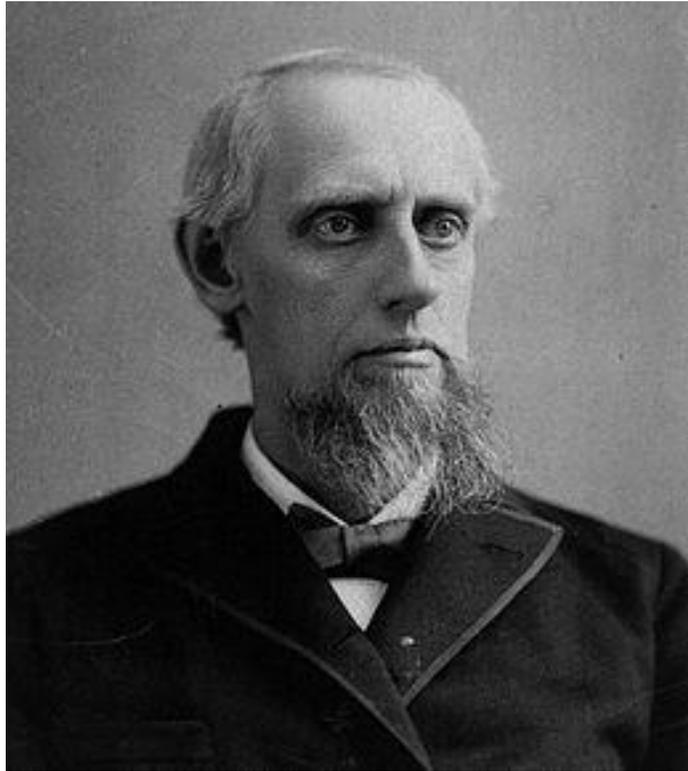

Fig. 1. Amos Dolbear (link)

The cricket Dolbear was observing (the Oecanthus fultoni, also called Snowy Tree Cricket) chirps mostly at night, and he finds about 120 chirps per minute at a temperature of 70°F (21.1°C), i.e. a frequency of 2 Hz. In his paper he gives his law as:

Let T. stand for temperature and N, the rate per minute.

$$T. = 50 + \frac{N-40}{4}$$

Fig.2. Dolbear's law as given in his paper from 1897

T is the temperature in degrees Fahrenheit; if the Celsius scale is used, and instead of N the frequency f in Hertz (f = N/60), this law becomes:

$$T[C] = 10 + (f*60-40)/7.2 \qquad [eq.1]$$

Dolbear's law became quite famous, and was often used in educational matters, to show how to transform a biological observation into a mathematical law. The French-Swiss **meteosuisse** website **[ref.2]** for instance talks about his law (and gives a sketch of a graph with temperature in Fahrenheit!), but in a short sentence observes that his parameters might not be valid for other (for instance European) crickets.

Crickets are not the only insects that show a similar stridulating behavior. Hubert and Mable Frings (Pennsylvania State University) published in 1957 a paper "The Effects of Temperature on Chirp-Rate of Male Cone-Headed Grasshoppers Neoconocephalus Ensiger" **[ref.3]**, which chirp mostly at night. They conclude that the chirp repetition rate is too high to record by the ear, so they use a high speed tape recorder played back at lower speed, and find about 780 chirps/minute (i.e. 13 Hz) at 26°C.

The cause of this temperature dependency is that crickets are cold blood insects, and higher ambient air allows them more vigorous physical activity, as scratching with their legs over the wings (stridulation) or oscillating special plates of their body (cymbalising) to make the characteristic noise. Usually there are as well a lower and a higher temperature limit outside which the crickets do not chirp anymore. This has been studied for instance in the 1975 paper by Thomas J. Walker "Effects of Temperature on Rates in Poikilotherm Nervous Systems" **[ref.4]**, where not the chirp repetition rate but the wing-stroke rate is analyzed.

2. **The cicada of the French Provence (cigale de Provence)**

This paper studies the chirp repetition rate of the French "cigale" (cicada orni, "cigale grise"), which lives mostly in the trees and is known as the noisiest of the 16 different cicadas of the Provence (with a noise level up to 90 dB):

Fig.3. Cicada orni (https://Luberon.fr)

This cicada stops chirping (in French: "s'arrêtent de cymbaliser") when temperature is lower than 22°C or higher than 36-38°C (approx. values); the noise is made not by the legs striking the wings (i.e.

stridulating), but by two abdominal vibrating chitin plates (here in grey on the picture), an activity which correctly is called "cymbalising":

Fig.4.The grey cymbal plates of the Cicada orni ([link](#))

3. The observations and measurements of chirp repetition frequency.

The observations have been made in the French Provence, in the vicinity of the Southern region of the Mont Ventoux, at an altitude of approx.. 400m asl. The cicadas sang in the trees (mostly needle and oak trees), were invisible and stopped when hearing approaching footsteps. It is assumed that all were of the most frequent and noisy **cicada orni** type.

During the measurement period used here (30 July to 17 August 2024) the weather was typically sunny, dry and hot.

The measurements were made with the "Voicememo" app of an iPhone 13 mini. The format of the audio files (of at least 16 seconds length) is .m4a. Installing the FFmpeg codec allowed to read these files with Audacity (version 3.6.1) on a Win10 based laptop. Normally the volume had to be amplified, and the chirps were counted manually for a period showing a clean signal:
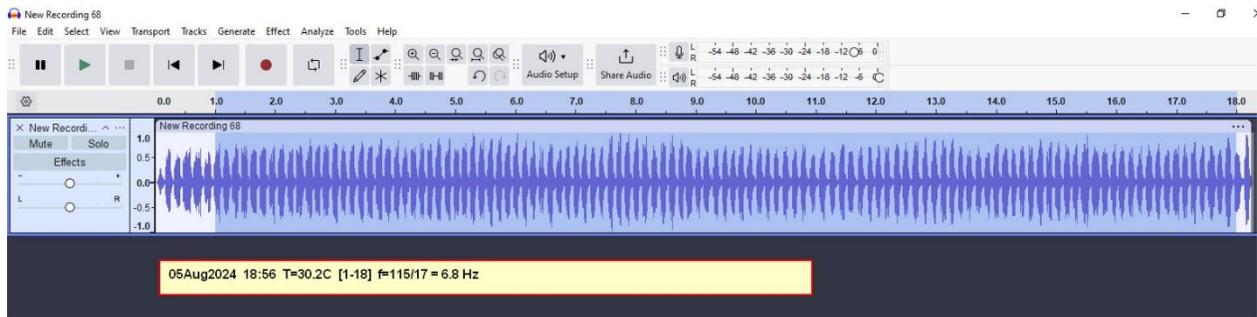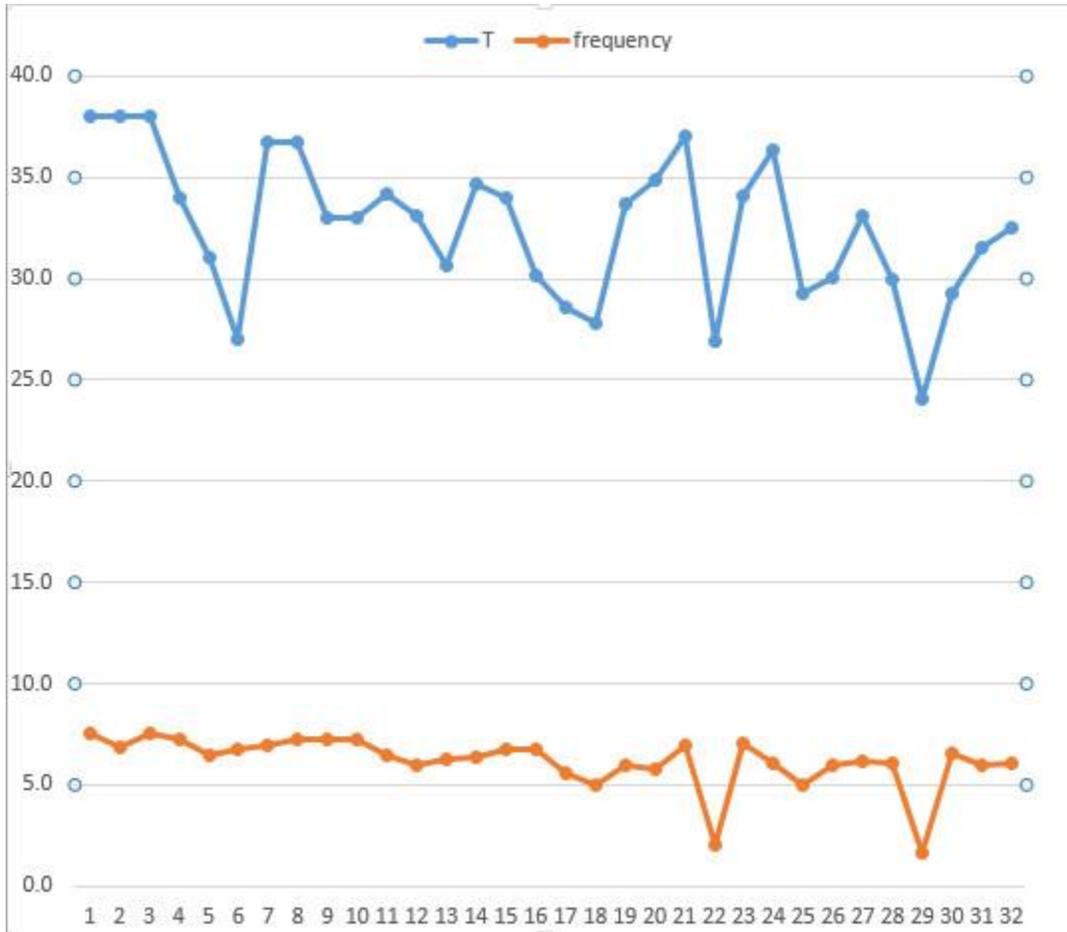

Fig.5. Screenshot of record 68 in Audacity, with region 1-18s used for counting.

Usually the songs start and end with a slower chirping rate, so these transition periods were never included in the time-span relevant to the count. The two following graphs represent the results of 29 measurement series from 30 July to 17 August 2024.

Fig.6. Air temperature in [°C] and chirp repetition frequency in [Hz]

The chirp repetition frequencies are very close, around 6 Hz, but two much lower frequencies at lower temperatures are clearly visible.

The relationship between temperature and chirp repetition rate becomes clearer in the scatterplot of temperature versus chirp repetition frequency.
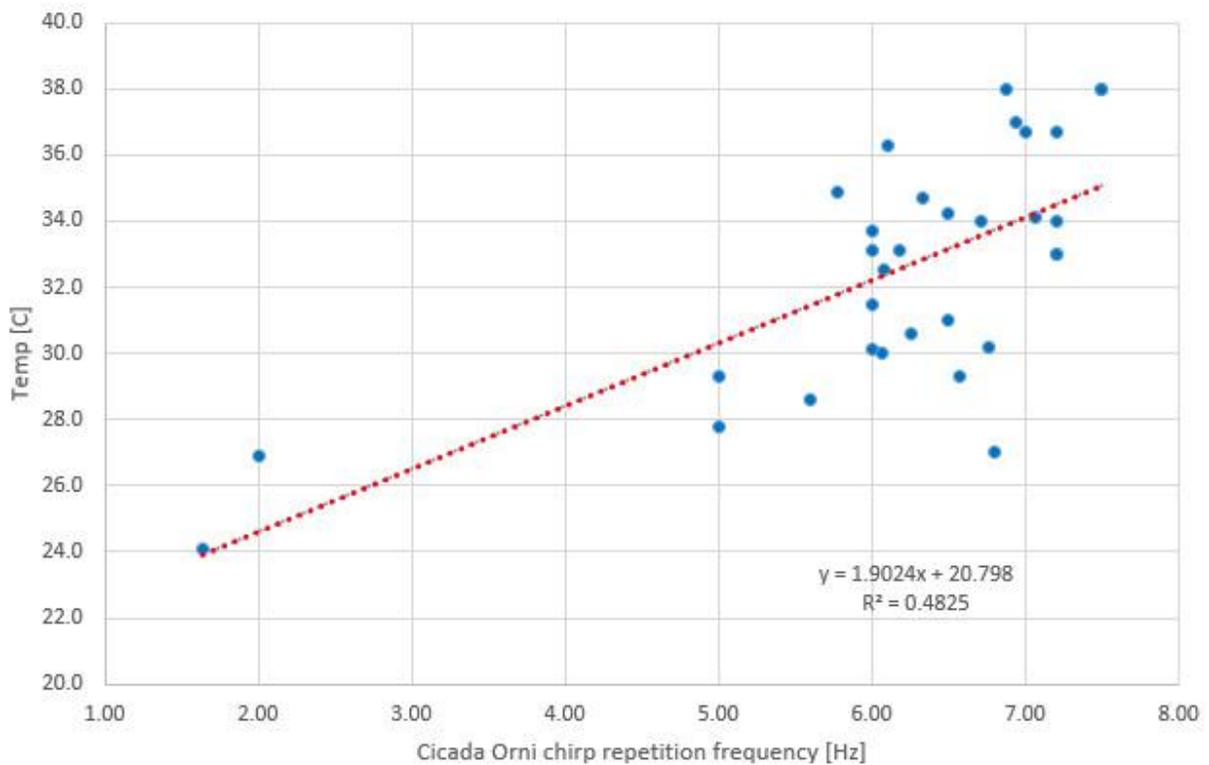
Fig. 7. Air temperature versus chirp repetition frequency (29 series).

There is quite a lot of scattering in the results, but the linear regression line is clearly positive with an acceptable (but not spectacular!) goodness of fit R^2 = 0.48. The cricket thermometer based on the Provence **cicada orni** is based on the following formula:

$$T = 1.93*f + 20.8 \quad [eq.2]$$

with air temperature T in Celsius and chirp repetition frequency f in Hz.

This formula suggests a zero frequency at about 20.8°C, which is close to the temperature given in the literature where the cicadas stop chirping (22°C).

The chirp repetition frequencies found in this research are completely different and much higher than the Dolbear measurements of the Snowy Creek crickets, which are of a 2 Hz magnitude. This shows that the parameters (slope and zero bias) of a "cricket (or cicada) thermometer" are valid only for a certain insect type and possibly a certain region.

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4. The frequency of the individual chirps

One would expect that the cicadas make faster cymbalising movements when the temperature is higher, but our measurements do not confirm this: analyzing how the chirp frequencies (which are all in the kHz range) change with temperature gives results which might be surprising: the next 4 figures (found by zooming into the audio files, with the time in seconds on the top scale) show the results of records 89, 72 ,87 and 78 corresponding to temperatures of 24.1, 27.8, 30.0 and 37.0°C:
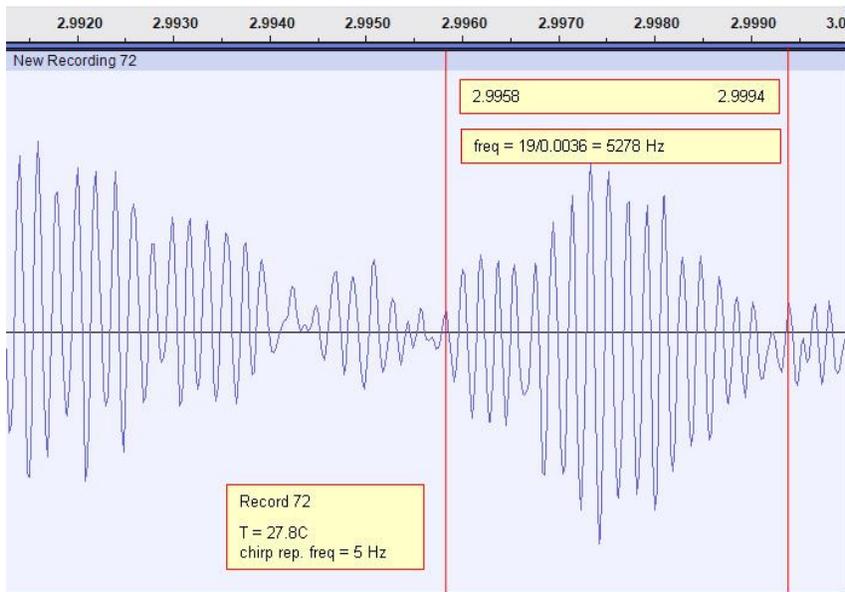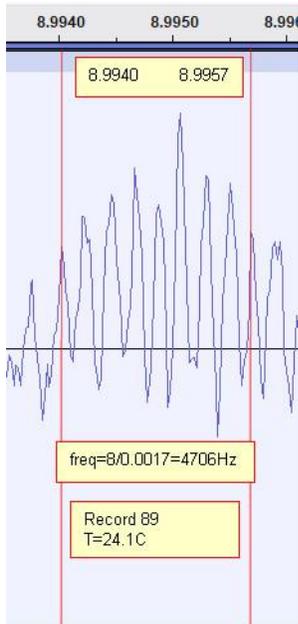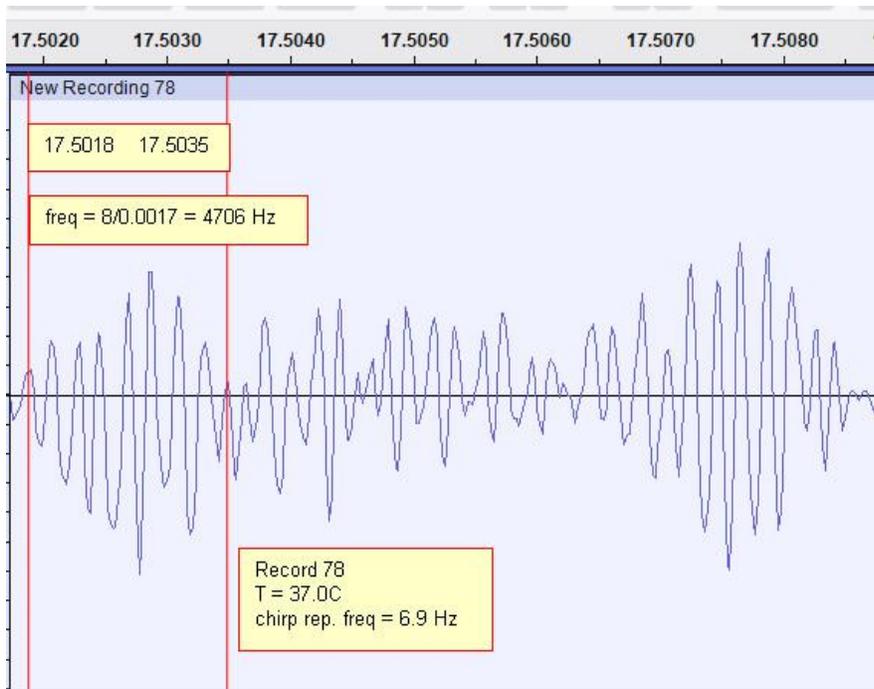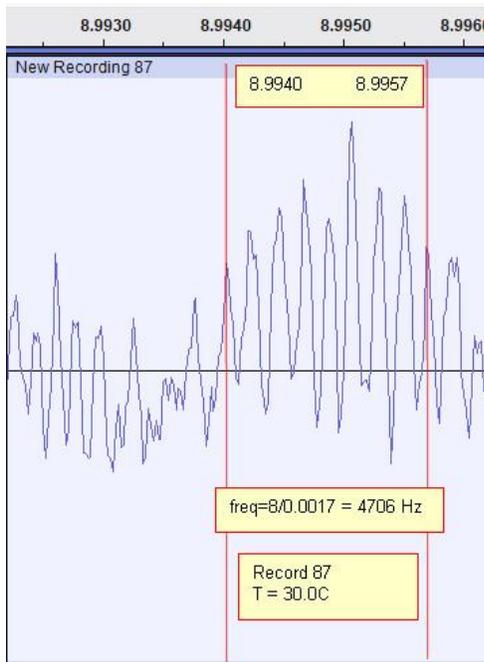
Fig. 8 – 11. Individual chirp frequencies are more or less independent of the air temperature

We find that the frequencies are about 4700 to 5200 Hz, with no clear temperature dependence. As the cymbalising noise is amplified by the insects body cavity (playing the role of a Helmholtz resonator), the

resonant frequency depends mostly on the geometric characteristics of the male insect, and not on external factors like air temperature.

The cicada orni is known to be very noisy, but this estimation should be taken with a grain of salt. The next figure shows a measurement done approximatively at the foot of a tree of ca. 10m height where somewhere it its crown a cicada was chirping:


Fig.12. Noise-level and spectrogram (Decibel X app for IOS)

52 dBA is not a deafening noise level, more that of a normal conversation. Note the spectrogram on the upper part of the screenshot which shows a frequency peak at 4706 Hz, exactly the same as the frequency found in 3 of the 4 plots given above (fig. 8,10,11).

5. Irregularities in chirp duration

Listening in a rather superficial manner to the cymbalising song of the cicada gives the impression of a very regular beat; but if one listens for a longer period (one or several minutes), one gets the impression of certain irregularities showing up here and there (ignoring the fade in and fade out at the start and end of the chirping period). The audible impression is that of a rather short speeding up or slowing down at irregular times. The next figure shows several plots of recording no.92 made the 17th August at 13:00 local time, air temperature being 32.5C and overall (i.e. average) chirp repetition frequency of about 6.1 Hz.
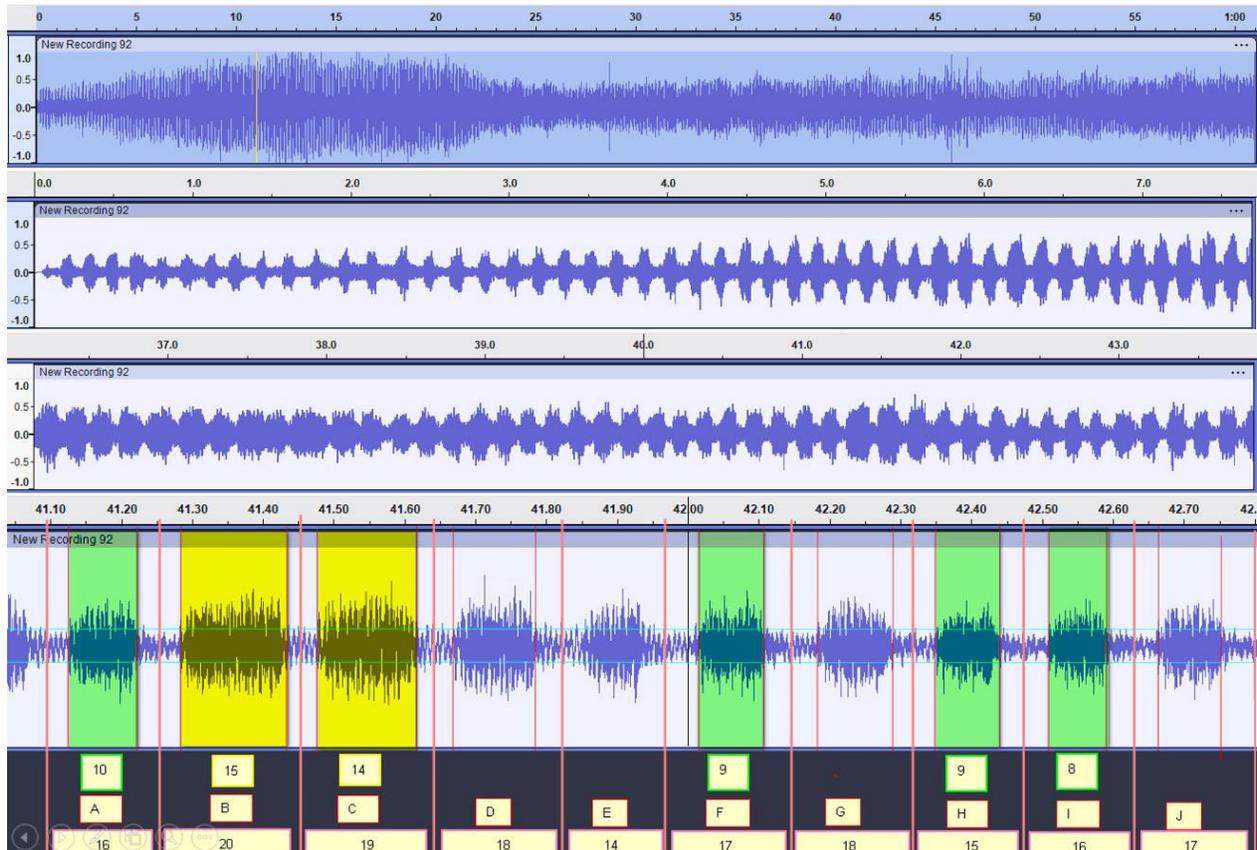
Fig. 13. Irregularities in chirp duration

The upper plot shows the complete record of about 60 seconds length, than a zoom at the first 8 seconds with a more or less visible regular beat, a zoom into the 36s-44s time segment which suggest a short-lived change after the 41th second, and finally a zoom into the 41.1s – 42.8s time span. Clearly several chirps (marked with yellow) are distinctly longer than others (marked in green): the upper green or yellow boxes show the duration in 100th of seconds, the lower pink boxes show the length of an individual chirp from the center of the low noise preceding interval to the next one. The two horizontal turquoise lines aid to find at least approximately the start and end of each complete chirp sequence.

The difference between the longest and shortest chirp here is 15-8 = 7 100th second (0.07s), nearly a 88% increase from the shortest to the longest; by consequence the duration of the total chirp (from minimum

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to minimum, given by the pink lines) also changes. For the two examples this change is 20 to 16 100th seconds, i.e. 25% relative to the shortest duration.

This example documents that finding the chirp repetition frequency by counting for a relatively short period gives only an average.

6. Conclusion

This short research done with minimal instrumental hardware documents that the chirp frequency of the French Provence cicada raises with the ambient air temperature (as first mentioned in the Dolbear law for a different cricket population), but being mostly in the 5 to 7 Hz region for usual warm summer temperatures. The empirical thermometer scale is T = 1.93*f + 20.8 in metric units (temperature T in Celsius, chirp repetition frequency f in Hz).

The frequency of the individual chirps (which are caused by the cymbalising movement of chitin plates, amplified by body cavity resonance), seem to be more or less constant in the 5kHz region, and independent of air temperature.

References

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4. Thomas J. Walker "Effects of Temperature on Rates in Poikilotherm Nervous Systems: Evidence from the Calling Songs of Meadow Katydids". J. comp. Physiol. 101, 57-69 (1975), Springer Verlag.