

# Correlation between wildfire statistical data, weather and climate

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**Abstract**—The object of this paper is to show the intercorrelations existing between statistics of wildfires (occurrences:  $N$ ; areas burned:  $A$ ), climatic parameters (precipitation:  $P$ ; temperature:  $T$ ) and net primary productivity:  $NPP$ . To this purpose, statistics of wildfires have been studied in several regions of the world, focusing on temperature and precipitation. The present analysis has been performed on French Mediterranean Departments (Bouches-du-Rhône, Hérault, and Var), Northern Ontario (Canada), Alicante Region (Spain), Yellowstone National Park –YNP-(USA), San Diego (California, USA). Concerning the temperature, the monthly analysis of fire occurrence shows two distinct periods with different fire production laws, both being of the Arrhenius type: the first one corresponding to the vegetation during the rest period, the second one during the vegetative production period. Concerning the precipitation, the monthly analysis of fire occurrence led to two distinct laws depending on the region climatic type (or eventually the seasonal characteristics). Thus, the monthly variation of fire occurrence (in log scale) is a linear increasing or decreasing function according to precipitation. In French Mediterranean Regions we have shown that these expressions are bound to the rate of soil water extraction by the plant roots (a limiting step of plant production?). Out of the intrinsic importance of the presented results, in the field of primary productivity (dependence on Kelvin temperature) it brings a confirmation of the reality of our hypothesis on the role of the limiting steps of plant production in the rate of wildfire production.

## Introduction

Wildland fire studies on a statistical point of view are more fructuous in information than the individual determinist studies. They are the only ones allowing correlating wildland fires with intrinsic factors (nature and composition of vegetation, water content...) or extrinsic factors (precipitation, air temperature, wind, lightning...) given an area and period of time. In the first part of this document, we will discuss our studies of the dependence of fires occurrence and burnt area on meteorological data (precipitation and temperature). That will finally lead us to show you show how correlations obtained can be representative of climate of some regions

# Wildfire and Climatic Parameters

Statistics of wildfires have been studied in several regions of the world, focusing on temperature and precipitation. The present analysis has been performed on French Mediterranean Departments (Bouches-du-Rhône, Hérault, and Var), Northern Ontario (Canada), Alicante Region (Spain), Yellowstone National Park –YNP-(USA), San Diego (California, USA).

## ***Wildfires and Precipitation***

**Daily correlations: lightning fires in North-western Ontario**—Wildland fires may have different possible causes, most of them being human causes. To avoid any influences coming from various causes we have taken account in a preliminary study only a natural cause: lightning ignited fires.

A number of Canadian fires are lightning ignited fires: according to Boulard (1993) they represent a proportion of 30 to 50 percent of fires.

Flannigan and Wotton (1990) have investigated the relationship between lightning activity and the occurrence of lightning-ignited forest fires in the North-western region of Ontario. They found that Duff Moisture Code and the multiplicity of the negative lightning discharges were the most important variables for estimating the number of lightning ignited fires. Fires have been counted with corresponding values of local precipitation and temperature. From data files provided by the authors and completed by the Ontario Ministry of Natural Resources (Ward 1994), we have analyzed the data relating to UTM:15 zone, to be 1,152 fires accounted in 1988.

In this region, in a log scale (fig. 1), the variation of fire occurrence is a linear increasing or decreasing function of precipitation. The distinction between the two regimes has been done comparing temperature periods:

$$\begin{aligned} \text{Log } N &= 1.019 + 0.0622P && \textit{For dry and cold period} \\ \rightarrow N &= 10.44 e^{+0.143P} \end{aligned}$$

$$\begin{aligned} \text{Log } N &= 2.739 + 0.2517P && \textit{For humid and warm period} \\ \rightarrow N &= 548 e^{-0.579P} \end{aligned}$$

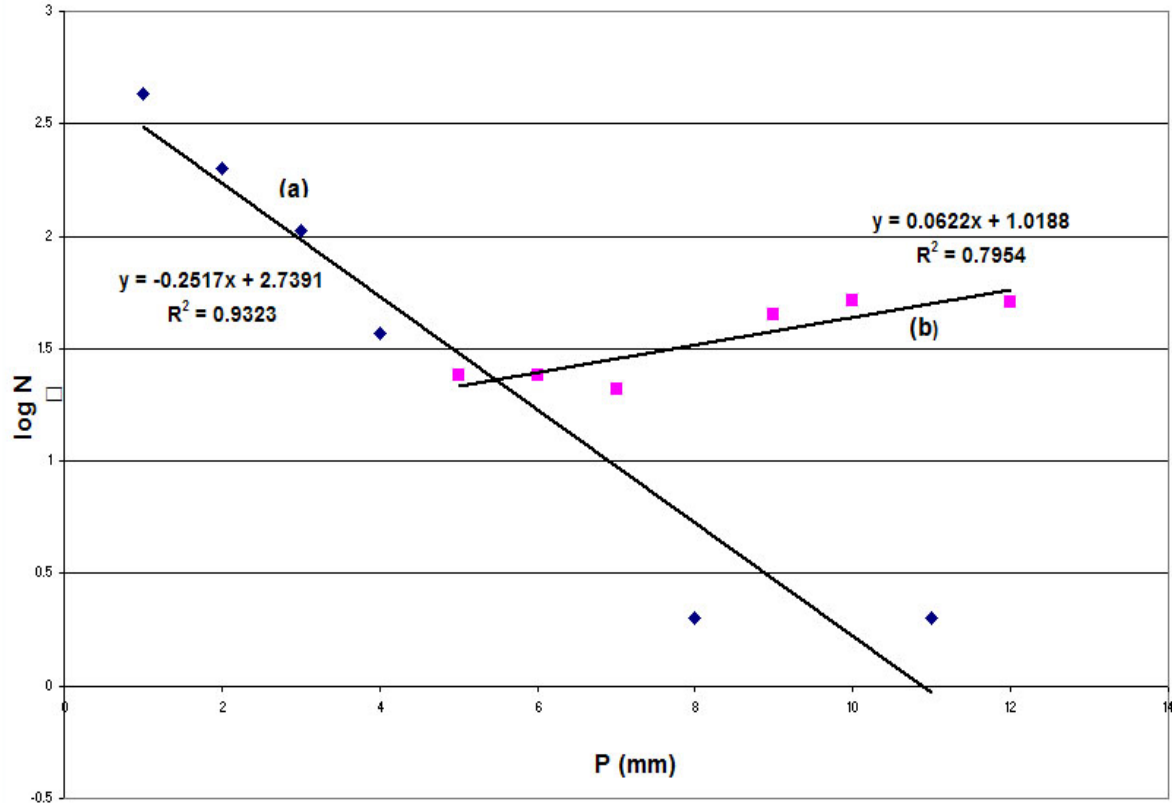


Figure 1—Log N = g(P). Ontario, UTM15, 1988.

Humid period for precipitation must be associated to warm period for temperature. So precipitation highly contributes the evapo-transpiration during this period (positive exponent). Dry period for precipitation must be associated to cold period for temperature. So precipitation contributes to evapo-transpiration at a low rate.

The humid and warm periods approximately correspond to the periods of vegetation production in this region (sub arctic region).

**Daily correlations: wildfires in West Var (1973)**—Olivier (1975) has studied the role of vegetation and ecological factors on the “Basse Provence” region wildfires. Individual wildfires were registered from area as low as 0.01 ha over the whole year 1973.

Occurrence of fires and precipitations were summarized by half a month values (fig. 2). Again we observe the same type of behavior:

- (1)  $\text{Log } N = 0.6306 + 0.0107P$       *For humid and cold period*
- (2)  $\text{Log } N = 1.1716 + 0.0125P$       *For dry and warm period*

The warm and dry period approximately corresponds to the period of vegetation production in this region (Mediterranean region).

Such typical relations have been found in other Mediterranean regions such as:

- Languedoc-Roussillon region (data from Rambal 1984):

(3)  $\text{Log } N = 2.8961 - 0.0047P$

- Alicante region (data from Terol 1987):

(4)  $\text{Log } N = 1.537 - 0.029P$

So the monthly occurrence of fires in Mediterranean regions in the warm period is a function of the exponential form:

$$N = \text{Constant} * e^{-\alpha P}$$

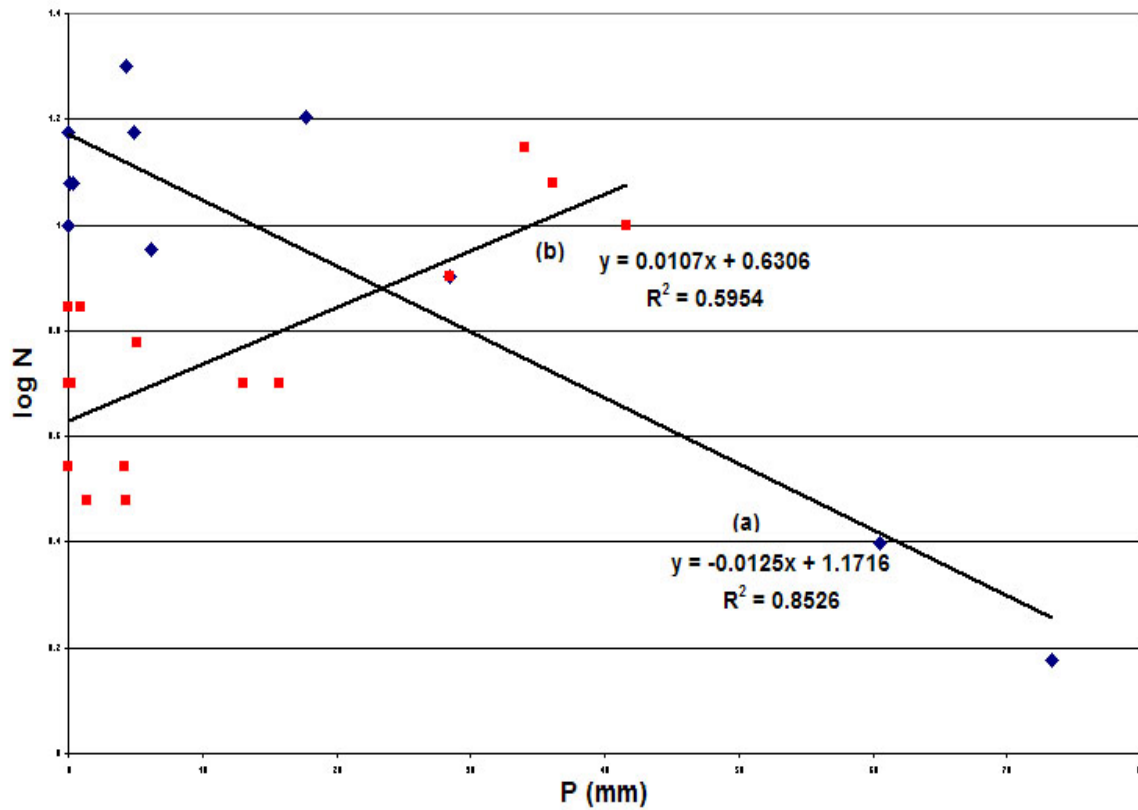


Figure 2—Log N = g(P). West Var, 1973.

In order to interpret these equations, it is necessary to examine the dynamics of water in the ecosystem, that is to say, soil water balance and the relative importance of its different terms with season (particularly during the summer season, in the Mediterranean regions; Humbert and Najjar 1992).

Rambal (1984) has studied soil water balance and water uptake characteristics by *Quercus Coccifera L*, which cover in the garrigue more than 100,000 ha in the French Mediterranean region.

Water balance equation:  $\Delta S = P * R * AET * D$

Where  $\Delta S$  is the daily change in stored water, P is the precipitation, R is the surface runoff, AET is the actual evapo-transpiration and D is the flow of water at the bottom of the root zone measured in mm/day.

The study of water balance during every year shows that when yearly precipitations are less than 578 mm, deep drainage loss is negligible and almost all the precipitations infiltrating the soil are lost by evapo-transpiration. Studying the water uptake at different deepness in the summer, Rambal proposed a relation between the relative deep uptake and the precipitation. According to Rambal, precipitation modifies relative water uptake Y (%) according to an exponential law:

$$Y = 25.7 * e^{-0.006 * X} \quad r^2 = 0.963$$

X being precipitation in June and July.

This relative water uptake is also the expression of relative actual evapotranspiration, which is the equivalent of photosynthetic fixation of carbon within the same period (Frontier and Viale 1991; Ramade 1994). Photosynthetic activity on plants leads to formation of new twigs and chemical modifications of old ones, then to production of fire sensible biomass.

**Interannual occurrence of fires in Var area**—Yearly occurrences of fires have been correlated to precipitation with the data of Var area, for the period 1974 to 1986 (Promethee Databank). Several 1-year periods have been tested, and the best result was found taking a period starting in July. The correlation equation is:

$$\text{Log } N_{\text{annual}} = 2.90 - 0.000365P_{\text{annual}} \quad \text{with } r^2 = 0.98$$

Thus, we can conclude that in Mediterranean regions, during the vegetation production period, occurrences of wildfires (monthly or yearly) are regulated by the deep water uptake rate of plant roots.

## ***Wildfires and Temperatures***

Quantitative effects of temperature on wildfire statistics have not been developed as for precipitation. In order to approach the problem we appealed to chemical kinetics laws.

Considering the parameters of fire occurrence N or area burnt A, during a defined time interval and in a given region as reaction rates in chemical kinetics, we studied their possible dependences to Arrhenius factor  $E/RT$ , E being the activation energy of the reaction, R the gas constant, and T Kelvin temperature (compare: lightning fires dependence on precipitation and temperature, Bernard 2004).

**Lightning fires in North-western Ontario**—Coming again to North-western fire data (fig. 3), we observe two Arrhenius plots, the first being the warmest period and the second the coldest one. During the vegetation production period

(warmest period) the activation energy corresponds to photosynthesis. During the vegetation rest period (coldest) the activation energy corresponds to U.V.B. energy.

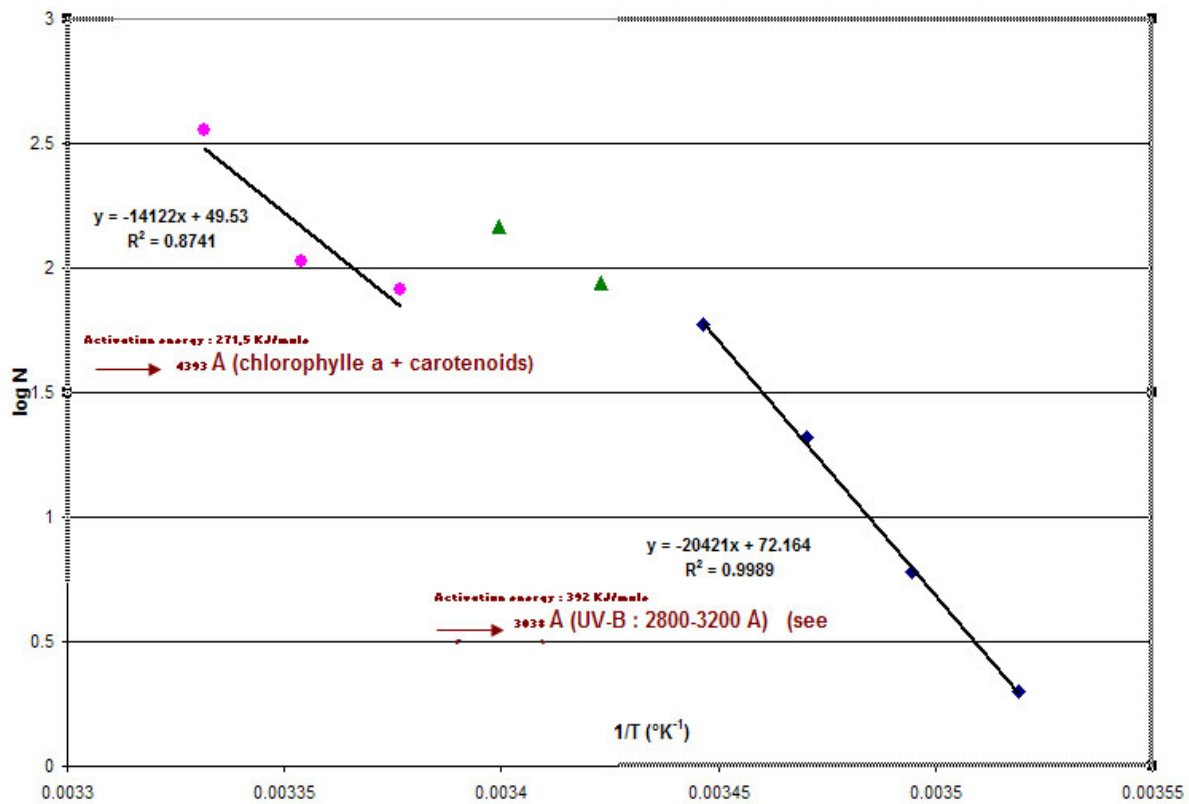


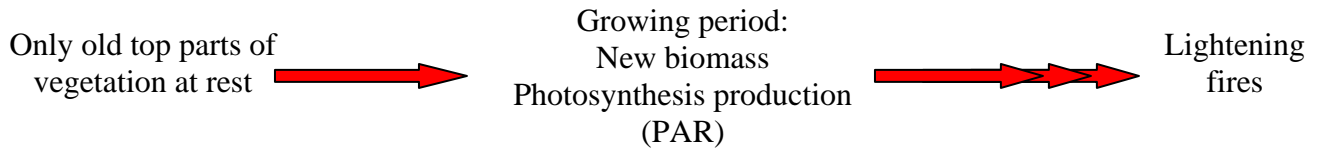
Figure 3—Log N = f(T). Ontario, UMT 15, 1988.

Log N = 49.52 – 14,122 / T → **Warmest period**  
 $E_{act} = 271.5 \text{ KJ/mol.}$  → 439.3 nm (Chlorophyll A)

Log N = 72.164 – 20421 / T → **Coldest period**  
 $E_{act} = 392 \text{ KJ/mol.}$  → 303.8 nm (U.V.B)

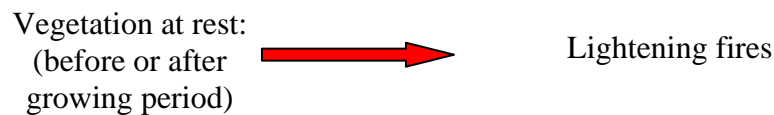
In analogy with the chemical kinetics laws, to interpret those results, we need to use the law of the bottleneck (the rate of the global reaction is determined by the slowest rate among the different successive reactions that compose it).

### Warmest period



**Rate of global processes (N) controlled by rate of the biomass production**

### Coldest period



**Rate of global processes (N) controlled by U.V. flux**

(cf climatologic theory of wildland fires, Bernard, 1998, 1999, 2000, 2004, 2005)

**Wildfires in Bouches-du-Rhône area 1986**—Two Arrhenius linear plots are observed for monthly wildfire in Bouches-du-Rhône area (fig. 4) with a good square correlation coefficient ( $R_2 = 0.93$ ), one for the summer period and another for the winter period. These results must be interpreted using the same argument as for the wildfires in North-western Ontario.

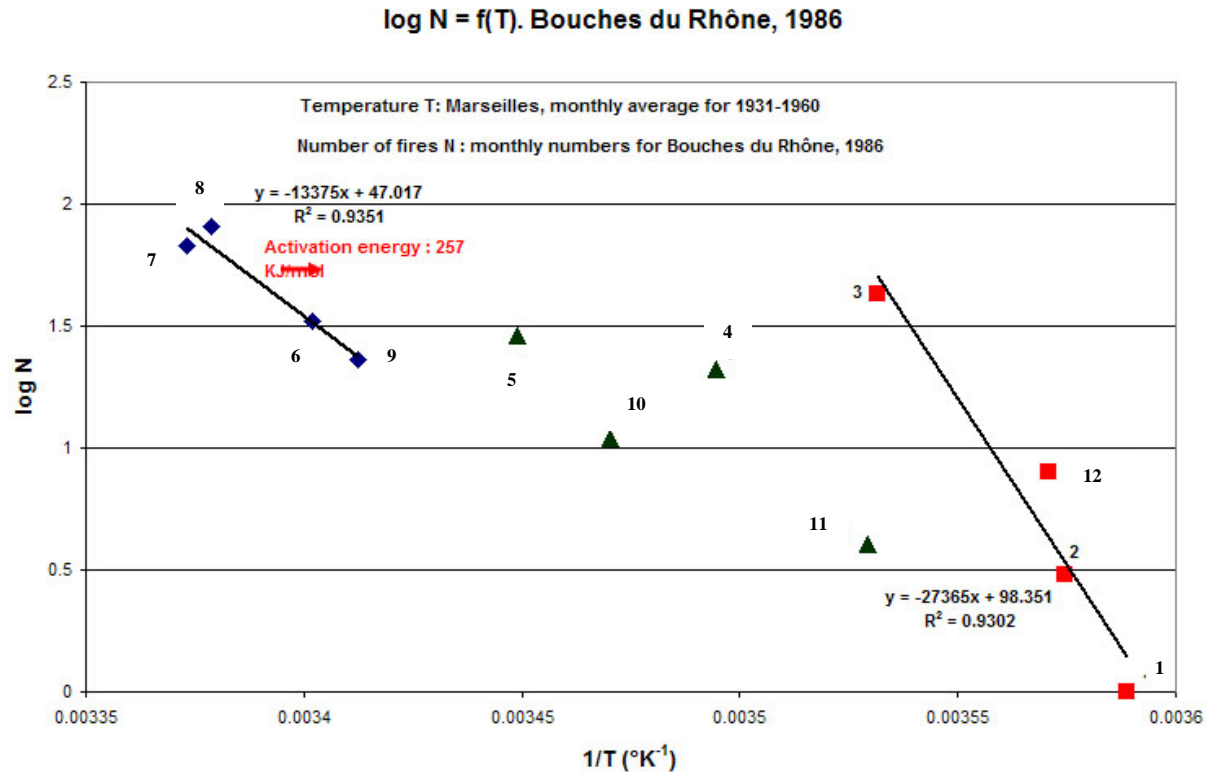
Other equations of Arrhenius type have been observed for Mediterranean type regions:

- Languedoc-Roussillon area (temperature in Montpellier)

$$\text{Log } N = -5797 * 1 / T + 22.034 \quad (R_2 = 0.461)$$

- Southern California, USA, 2005 (temperature in San Diego)

$$\text{Log } N = -28674 * 1 / T + 99.04 \quad (R_2 = 0.497)$$

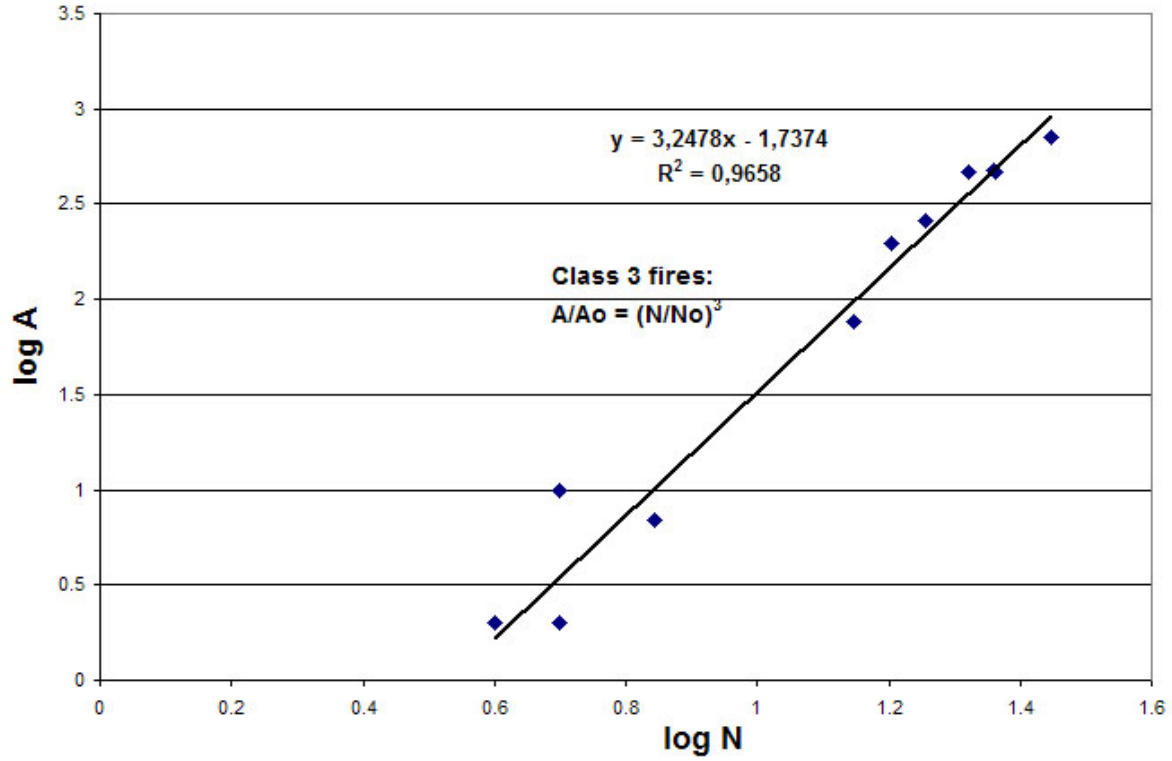


**Figure 4**—Log N = f(T). Bouches-du-Rhône, 1986.

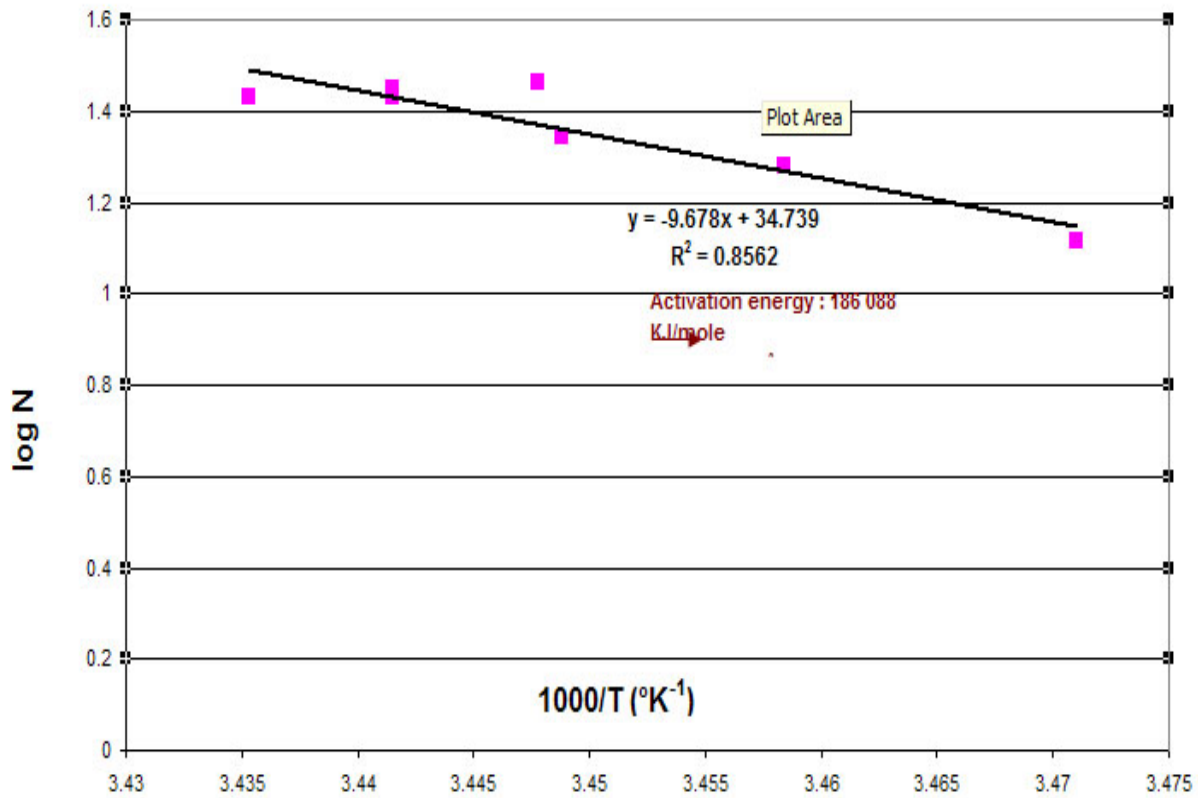
**Annual Wildfires in Yellowstone National Park**—They have been extensively analysed as much on area burnt as on wildfire occurrences, and as much on lightning caused fire as on human ones (Douglas 1975; Romme 1989; Despain 1998). See Bernard (1998): interpretation of fire intensity in Yellowstone National Park for the 1700-1990 period, 1998.

Most of the wildfires in Y.N.P. are class 3 fires (fig. 5). We observe the same Arrhenius law with the lightning fires (fig. 6) on the annual occurrence criterion.





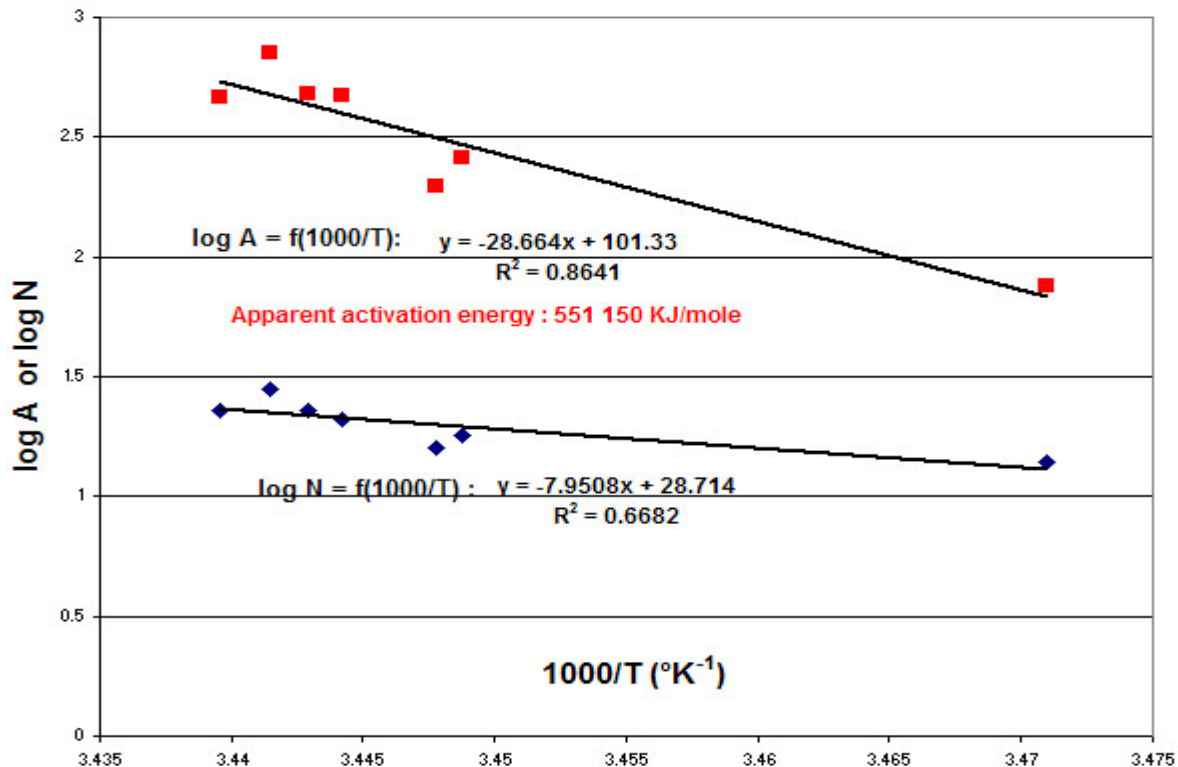
**Figure 5**—Yellowstone National Park:  $\log A = f(\log N)$ . Human caused fires. Years: 1933, 1934, 1940, 1947, 1948, 1949, 1953, 1954, 1955, 1960, 1967, 1968.



**Figure 6**—Yellowstone National Park:  $\log N = f(T)$  Lightning fires. Years: 1933, 1948, 1949, 1952, 1960, 1961, 1963.

For the human caused fires, the Arrhenius law is verified for both annual occurrences and area burnt criterion (fig. 7).

Thus, we can conclude that the rate of photosynthetic radiations regulates the monthly occurrence of fires during the vegetation production period and yearly occurrences of fires and area burnt at the interannual scale.



**Figure 7**—Yellowstone National Park:  $\log A = f(T)$  and  $\log N = f(T)$ . Human caused fires. Years: 1933, 1934, 1940, 1948, 1949, 1953, 1960.

## Wildfire and Climate

During the vegetation period we define the occurrence of fires as function of variable P and T.

$$(1) \text{Log } N = a + b * P$$

$$(2) \text{Log } N = c - d / T$$

We observe the following conditions on the constants:

- $c : c > 0$ ,

- $d : d > 0$ ,
- $a : a > 0$ ,
- $b : b > 0$  (NW Ontario Climate)  
 $b < 0$  (Mediterranean type Climate)

In the equation 1, N is univocal of P, in the number 2, N is univocal of T. P and T are measured data or data taken from meteorological stations and are interdependent in the vegetation production period.

Identifying the two equations, we get:

$$(3) P = (c-a) / b + d / (b * T)$$

We now need to compare this relation (3) to real temperature and precipitation data of different regions.

## ***Wildfires in North-western Ontario***

Referring to the figure 1 for precipitation and figure 3 for the temperature, here are the equations expressed with the real data from North-western Ontario:

$$(1') \text{Log } N = 1.019 + 0.0622P$$

$$(2') \text{Log } N = 49.5 - 14,122 / T$$

By identification, we get:

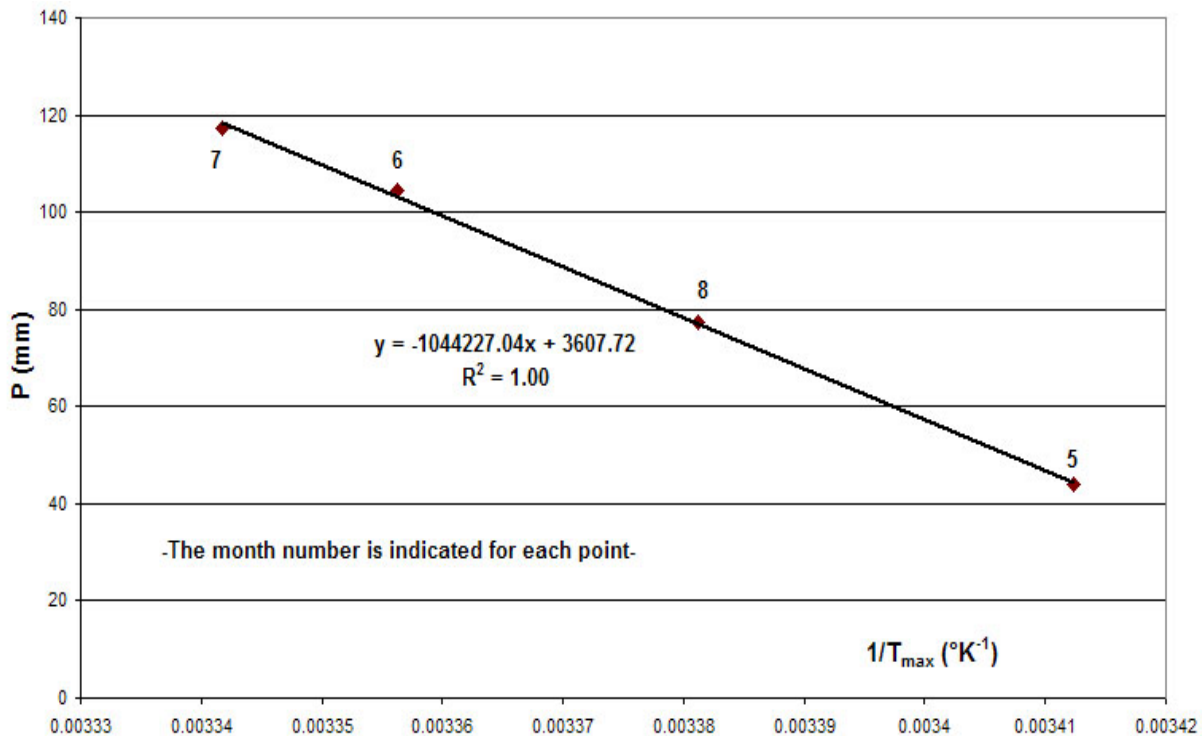
$$(3') P = 780 + 0.227 * 10^6 / T$$

To compare those data, we choose the 1988 meteorological data from Sioux Lookout station in Ontario, and try to demonstrate this relation monthly from May to August 1988. Figure 8 shows what we found for each studied month. We found an equation that even has a **correlation coefficient equal to 1**:

$$P = 3,607 - 1.044 * 10^6 / T \quad (R_2 = 1)$$

We observe:

- Climate data from Sioux Lookout verify the linear correlation  $P, 1/T$
- Precipitation from Sioux Lookout is found 4.6 times larger than from the N.W. Ontario region.



**Figure 8**—Climatologic chart of Ontario, UTM 15, Canada at Sioux Lookout meteorological station.  $P = f(T_{max})$ . May-August 1988.

## ***Wildfires in the Languedoc-Roussillon Area***

From statistics data of fires over 10 years. The next equation (1'') and (2'') are explained in a deeper way in a former publication (compare "Application of the concept of climatologic chart to Mediterranean climate variability," Bernard and Nimour 2005).

Here are the equations expressed with the real data from Promethee database and from Rambal (1984). For Montpellier, we found:

$$(1'') \text{Log } N = 2.896 - 0.0047 P$$

$$(2'') \text{Log } N = 22.034 + 5,797 / T$$

By identification, we get:

$$(3') P = -4,071.91 + 1.234 * 10^6 / T$$

To compare those data, we choose the average values of meteorological data from Montpellier station in Languedoc-Roussillon (the average values of each month are calculated over the 1964 to 1982 period for precipitation, and the 1980 to 1982 period for temperatures). We try to demonstrate this relation monthly from July to October. Figure 9 shows what we found for each studied month. We found an equation that even has a **correlation coefficient equal to 0.9995**:

$$P = -3,932.7 + 1.00 \cdot 10^6 / T \quad (R^2 = 0.9995)$$

The agreement is very satisfactory: Climate data from Montpellier verify the linear correlation  $P, 1/T$

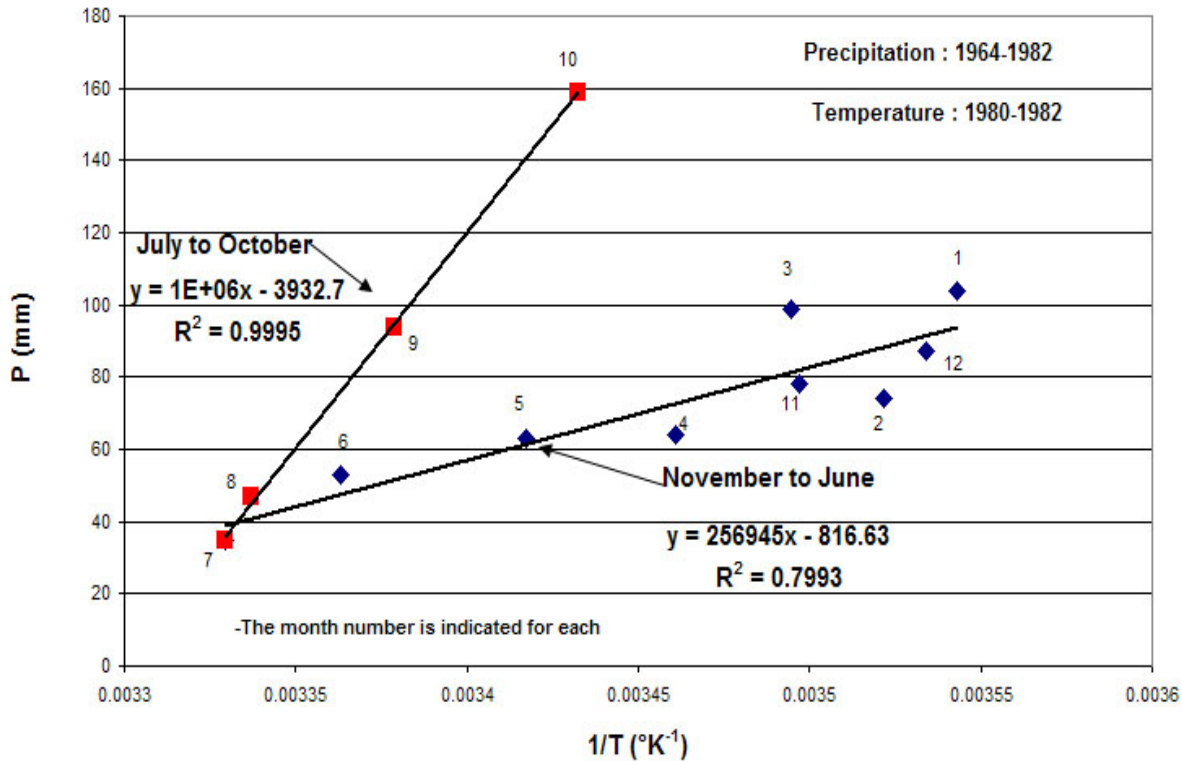


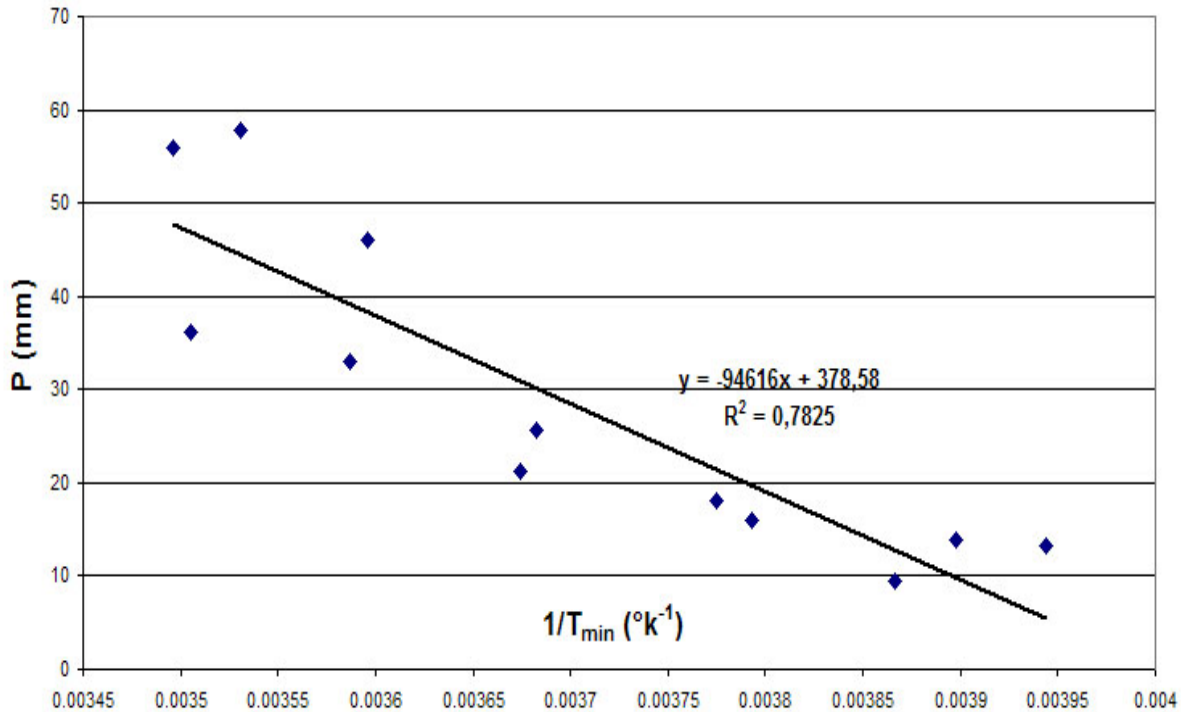
Figure 9—Climatologic chart of Montpellier.

## A Concept of Climatologic Chart

Other reconstructions of climate from wildfire occurrence have been stated. That confirms the generality of the method. So we introduced the concept of climatologic chart (“A concept of climatologic chart,” Bernard and Nimour 2004), which is based on the law of interaction between the vegetation, the soil, the water, the atmosphere, and the solar radiations.

Climatologic charts could be more useful than historic representations of climate characteristics (climatogram, Emberger or Gaussen ombrothermal diagrams) to build a new classification of climate in order to perceive any possible climate changes (compare “Application of the concept of climatologic chart to Mediterranean climate variability,” Bernard and Nimour 2005).

To illustrate the prior statement, we can refer to figure 10 as an example of semiarid climate.



**Figure 10**—Climatologic chart of Willistone (North Dakota) January-December 1971 to 2000.

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