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Analysis and prognosis of low temperatures adverse to plants using Markov chains

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सार — मार्कोव चेन और पौधों के लिए खतरनाक चुने हुए आरम्भिक तापमानों का प्रयोग करते हुए, यूनान के कड़ाके का पाला-संवेदनशील क्षेत्र के लिए न्यूनतम तापमानों का विश्लेषण और सांख्कीय पूर्वानुमान का पता लगाने का प्रयास किया गया है। दो देहलीजों, भौतिक और शारीरिक (शीत अनाजों के लिए) "शून्यों" पर, दो स्थितियों (निचले और ऊपरी के लिए) और तीन स्थितियों (दो के मध्य तीसरे को मिलाकर) के लिए अलग से विचार-विमर्श किया गया।

कड़ाके का पाला, सिरहन की ठंड (शून्यों के मध्य) और गरम तापमानों की संभावित पूर्वानुमान मार्कोव के सिद्धान्त के अनुप्रयोग के साथ संभव है जो मध्यावधि पूर्वानुमान के मामले में विशेषकर उपयोगी है।

ABSTRACT. Using Markov's chains and selected threshold temperatures critical to plants, analysis and statistical forecasting of minimum temperatures for a frost-sensitive area of Greece are attempted. Two thresholds, the physical and the physiological (for winter cereals) "zeros", are considered separately for two states (a lower and an upper one), and three (*plus* a third between the two) states.

Probabilistic forecasting of frost, chilly (between "Zeros") and warm temperatures is possible, with the application of Markov's theory, and useful, particularly in the case of a medium-range forecast.

1. Introduction

The protoplasm in living plants can function properly only within a restricted temperature range. Marginal temperatures may drastically retard and even stop growth and out-range temperatures may cause injury to plants. No growth of agricultural importance takes place when the temperature approximates the freezing point. Many tropical and subtropical plants may be killed by chilly (low but not freezing) temperatures, whereas cold-climate plant may be frozen without injury.

Though low-temperatures effect varies with the developmental phase and the physiological state of the crop, critical growth impeding or harmful to plants temperatures can be distinguished (Ventskevich 1961) among the most pronounced are the physical and the physiological "zeros". Below the physical zero frost occurs, while below the physiological "zero"—different for each plant category and about 4° C for winter cereals—chilly temperatures do not allow practically any growth.

The occurrence of frost has been investigated in a rather good detail mainly because of its economic effect on high-value crops and because some crops can be protected. Schnelled (1963, 1965) has published a a comprehensive work on all aspects of frost and frost protection. The agrometeorological advice against frost deals mainly with crop-site selection (Baier 1965; Schnelle 1965; Hogg 1970) and the protection against damage (*e.g.*, Desjardins and Siminovitch 1968; Valli 1970 and Tabard 1971). To meet these goals climatological analysis, in the former case, and synoptic forecasting, in the latter case, of minimum temperatures are mainly used.

However, since biological clocks are set up to work only when temperature exceeds the physiological zero, analysis and forecasting of chilly and above, physiological zero temperatures are essential for estimating growth and development rate and useful when measures to alter the thermal regime experienced by plants can be taken.

Markov chains were shown (Gringorten 1971; Hansen and Driscoll 1977; Lestienne 1978; Alexandersson 1985; Charantonis and Liakatas 1989; Charantonis 1989) to be a powerful tool in the forecaster's hands and they will be used here for analysis and forecasting of adverse (frost and chilly) temperatures.

2. Methodology and data

To achieve this purpose, the range of minimum temperatures is sub-divided to between-limits and/or below and above limit states by two threshold temperatures, namely, 0° C and 4° C. Thus, two and three states cases are considered. In the first, there are a lower and an upper state, defined by either of the thresholds, and in the second, apart from a lower (below 0° C) and an upper (above 4° C) states, a middle state, defined by both thresholds, is also included. Markov chains theory, used for analysis and prognosis of these temperature states, is described in detail in the paper (Charantonis and Liakatas 1989).

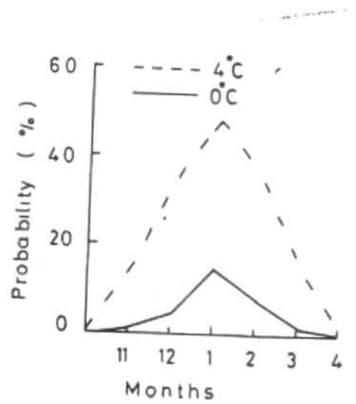

Fig. 1. Cold-season variations of minimum temperature absolute probabilities below 0° C and 4° C

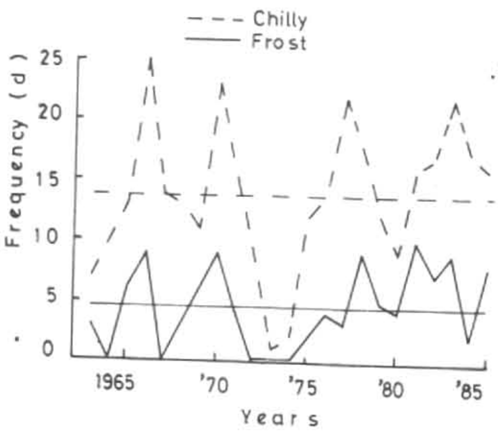

Fig. 2. Interannual variations of January frequencies of frost and chilly days, along with corresponding mean values

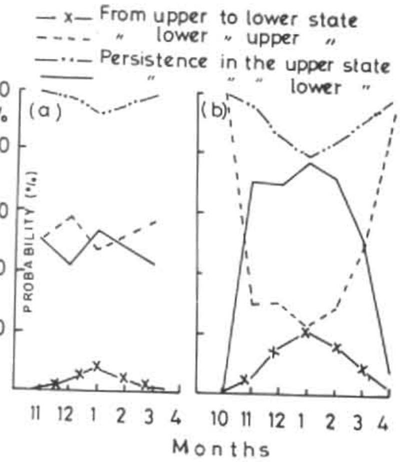

Fig. 3. Cold-season variations of minimum temperature transition (from the upper to the lower state, or from the lower to the upper state, and persistence (in the upper state, or in the lower state, probabilities for the day following the initial, with reference to: (a) 0° C and (b) 4° C

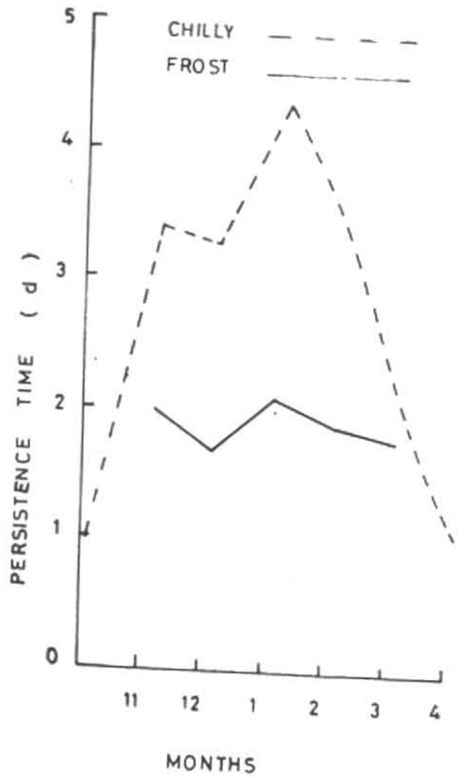

Fig. 4. Cold-season variations of mean persistence times (days) of frost and chilly temperatures

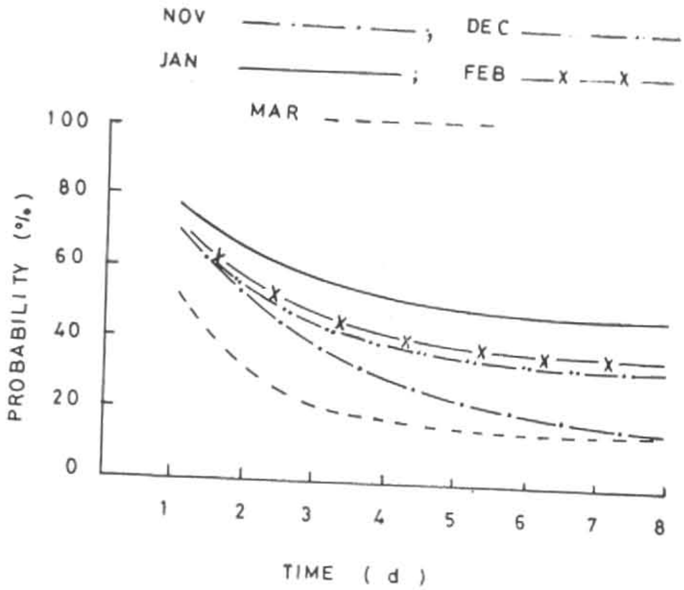

Fig. 5. ν-step, up to 8 day, transition probabilities for the lower than 4° C state and all cold-season months, Nov, Dec, Jan, Feb and Mar

Minimum temperature data from a rather long series (1961-1983) for a frost-sensitive area (Arta) in northwest Greece are used to estimate persistence and transition probabilities, for the two and three states cases, separately.

3. Two states probabilities

In Fig. 1 the monthly variations of absolute probabilities of occurrence of minimum temperature below or above the thresholds are shown for the cold season. Frost temperatures can be observed only between November and March, with a rather low minimum frequency in January (14.4%), whereas chilly temperatures are much more common throughout the same period (maximum frequency 45.8%) and can be observed also in October and April.

In a 23-year series of minimum temperatures (Fig. 2) it may be noticed that yearly variations of below 4°C and

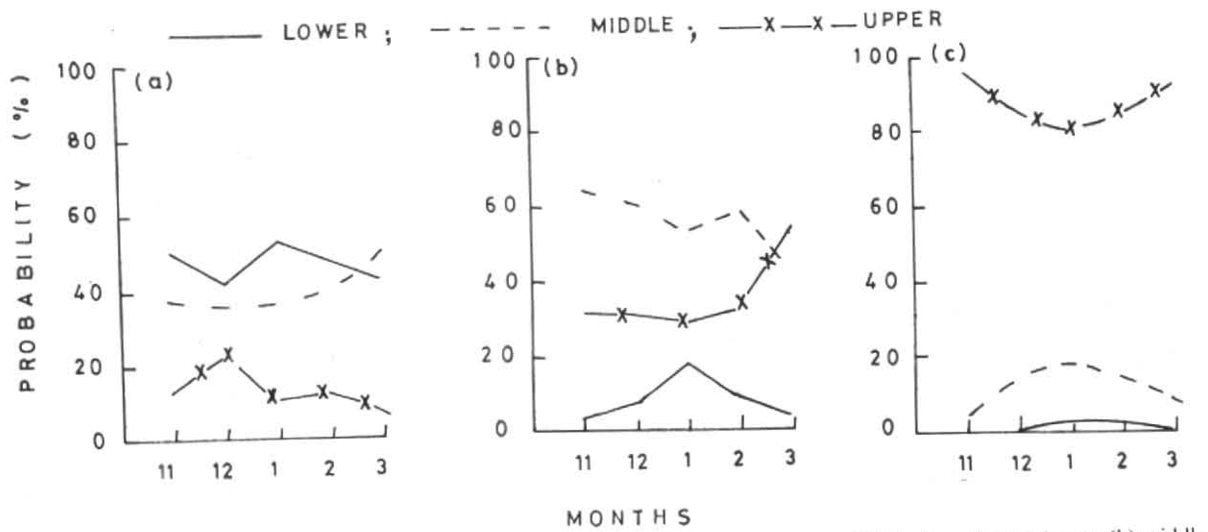

Fig. 6. Cold-season variations of minimum temperature persistence and transition probabilities from the (a) lower, (b) middle and (c) upper state, to the lower, middle and the upper state

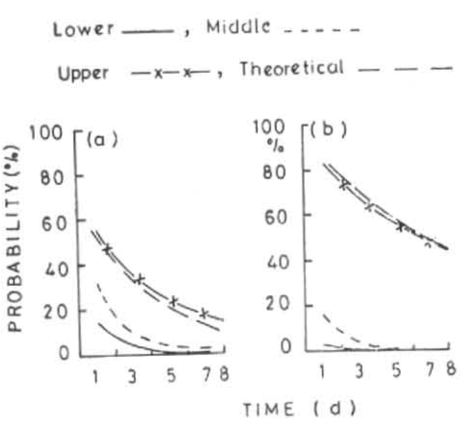

Fig. 7. Actual for the lower, middle and upper state and also a theoretical for the last state persistence probabilities up to 8 consecutive days in (a) January and (b) March

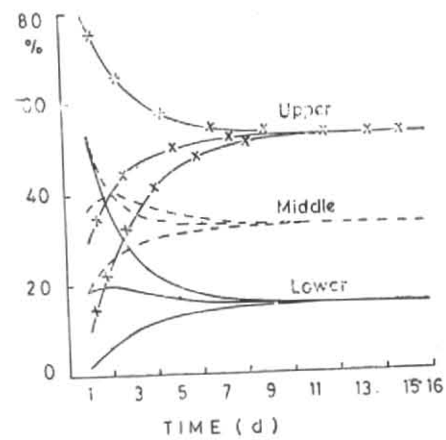

Fig. 8. ν-step, up to 16 days, transition probabilities for the lower, middle and upper state and various starting temperature states (1 lower, 2 middle and 3 upper)

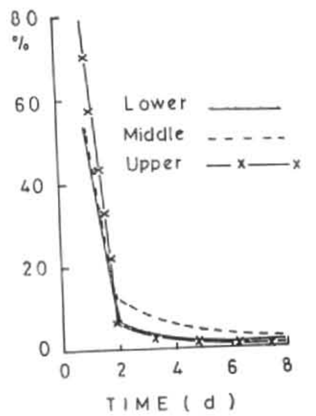

Fig. 9. First-return probabilities of minimum temperature to the lower, middle and upper state, after a number (up to 8) of days

below 0° C January — temperature frequencies are quite pronounced but similar for both threshold cases; chilly years are frosty years too. However, though frost-free years are not rare (about 22% probabilities, chilly temperatures are experienced by living organisms each year, with a peak frequency 25 (not necessarily consecutive) days, three times higher than that for frost.

Transition probabilities above or below the chosen critical temperatures are shown for each cold-season month in Fig. 3 (a). Once minimum temperature is higher than 0° C it tends to remain higher the next day, the probability of falling below being smaller than 10% even in January. However, if frost is observed, there is a 45-55% probability throughout the period for frost also in the following day. Transition probabilites with reference to the 4° C threshold show a similar, though greater, monthly variability (Fig. 3b).

Mean persistence time of frost and chilly temperatures varies in the cold period of the year, little in the first case around two days and much in the second case from one day at the beginning and the end of the period to more than four days in January (Fig. 4).

The ν-step transition probabilites for the lower than 4° C state are given in Fig. 5 for all cold months. These probabilities vary with time (ν) when this is rather small, but become independent of time, approaching the values of absolute probabilities, when $\nu \geqslant 5$ (apart from November when the corresponding value of ν is greater than eight). The variation patterns of ν-step transition probabilities are similar for each month. However, between month variability is considerable; when they become steady (*i.e.*, absolute probabilities) they are three times higher in January than in March.

4. Three states probabilities

Reference to both threshold temperatures, simultaneously, leads to the definition of three temperature states. Transition probabilities from each state to one of the other two, as well as probabilities of persistence in the same state also the following day are shown for all cold months in Fig. 6. Minimum temperatures tend to persist with a higher probability the higher the temperature state is. Transition probabilities are generally lower than persistence probabilities and still lower if temperature is to jub to the other extreme state. When transition is from the middle state, temperature is more likely to change to the upper than to the lower state.

The persistence probabilities up to eight consecutive days are presented for a winter month (January) and a spring month (March) in Fig. 7. Probabilities diminish with increasing number of days (v) and are maximum for the upper and minimum for the lower state. In January (Fig. 7 a) there is practically no frost risk after the fifth day, whereas in March (Fig. 7 b) frost can happen only one day. Winter cereals may experience chilly temperatures for up to eight days in January and up to four days in March. Also shown in Fig. 7 are the theoretical persistence probabilities estimated with the form:

$$P(i, j) = {}^{*}[1-p(i, j)], \; i = 1, 2, 3$$

only for the upper state, because for the rest, the theoreticals are indistinguishable from the actual curves, as almost is the case for the upper state.

The v-step transition probabilities for the three states in January are given in Fig. 8, which is similar with Fig. 5. These probabilities are associated with the initial temperature and it takes them twice as long (10 days) as in the two states case to become independent of time and reach absolute probabilities.

First return probability of minimum temperatures to a certain state on the day v, passing from any other state on the previous v—1 days, is smaller than 10% already from the second day (Fig. 9). On the first day the chance in about 80% is that minimum temperature is higher than 4°C and in about 55%, it is between 4° C and 0° C or lower than 0° C.

5. Results

Analysis of minimum temperatures has defined the periods free of frost (15 March - 10 November) and chilly (for winter cereals) temperatures (1 May-19 October). Frost may be observed at maximum (in January) one out of four days, but maximum frequencies of chilly temperatures are three times higher.

The sensitivity of the investigated area to low temperatures, thus determined, must be a matched with crop requirements so that, by choosing the right especially perennial crop and variety, to avoid frequent significant yield losses. Once established in the field, a crop may require application of costly, but possibly justifiable for high value (*e.g.*, citrus) crops, practices to minimize adverse weather effects, as those of very low minimum temperatures. Agricultural weather forecasting then may help farmers to take proper and timely protective measures. Besides synoptic forecasting, prognosis of adverse to plants low temperatures using Markov's chains may be quite useful, particularly when medium-range probabilistic forecasts have to be issued.

Persistence and transition probabilities have been shown to depend on season, temperature state and forecast period. They are maximum in the middle and diminish towards the edges of the cold season. Minimum temperatures tend to persist with a higher probability the higher the temperature state is. Also, persistence probabilities decrease with lengthening the period of forecasting. Thus, there is practically no frost risk after a five-days frost spell in January and just one day in March. However, winter cereals may experience chilly temperatures for an uninterrupted period almost twice longer than for frost. Compared with persistence transition probabilities are generally lower and still lower if temperature is to transit (through the middle) to the other extreme state. Transition from a low temperature state is easier to the next upper state.

Therefore, forecasting minimum temperature on day $v+i$ is associated with the state of temperature on day v. This effect of the "initial" temperature is strong on the first day ($i=1$), diminishes with $i>1$ and is erased after a period twice longer for three than for two states (five days), meaning that v-step transition probabilities. become then constant and equal with the corresponding absolute probabilities. However, imposing the restriction that temperature between v and $v+i$ days may have passed from any other but a certain temperature state, the return probability of this state on day $v+i$ is very small, even for the second day of forecast.

The same procedure of analysis could used for thresholds critical to other crops, like the base temperature of 10° C for maize (Liakatas 1978) and cotton (Roussopoulos 1981). On the other hand, since temperatures adverse to plants are not only very low but also extremely high temperatures, study of temperature states determined by thresholds chosen on the other side of the temperature range would also pay.

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