ACTA UNIVERSITATIS SZEGEDIENSIS

PARS CLIMATOLOGICA SCIENCIARUM NATURALIUM

CURAT: G. KOPPÁNY

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TOMUS XXVIII–XXIX.

SZEGED (HUNGARIA)

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Editor

DR. GYÖRGY KOPPÁNY

Technical editor

DR. JÁNOS UNGER

Publisher

József Attila University, Faculty of Sciences
(H-6720 Szeged, Aradi vértanúk tere 1.)

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ACTA CLIMATOLOGICA
Universitatis Szegediensis, Tom. 28–29., 1995.

SOLVENT LIQUIDS ON PLANETS

by
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Folyadék oldószerek a bolygókon

A szerzők megvizsgálják a legnagyobb mennyiségben előforduló folyékony állapotok feltételeit, általában és a Naprendszeren belül. Két lehetséges folyadék érdemel különleges figyelmet: a víz és az ammonia, mindkettő bőséges és jó oldószere mind a molekuláris, mind az apoláros anyagoknak. Mindkét vegyületnek jelen kellett lennie a jelenlegi földi élet születésénél, és legalább az egyiküknek folyékony állapotban.

We investigate the condition for abundant liquid states on planets, in general and in the Solar System. Two possible liquids, both abundant for molecules and both apolar good solvents get particular attention: water and ammonia. Both compounds must have been present at the parental location of present terrestrial life, at least one of them as a liquid.

Key-words: liquids, solvents, ammonia, water, p–T field of materials, ice meteorites, ammonia-silicates, double-liquid regions in the Solar System

1. INTRODUCTION

Terrestrial life is based on amino acids, and amino acids are somewhat exotic in aquatic environment. They would be simple and natural amphoteric compounds in a chemistry in ammonia solvent (having an organic acid radical on one end and an amino radical, i.e. basic radical of ammonia solvent on the other). So proto-life is more probable in ammonia solvent or in water heavily contaminated by ammonia. This focuses attention on the sufficient and necessary conditions to have liquid water or/and ammonia somewhere on a planet.

2. STELLAR CHEMISTRY

The five most abundant elements of the Solar System are, in decreasing order, hydrogen, helium, oxygen, carbon and nitrogen (*Novotny,* 1973). This fact gets its origin from cosmology, astrophysics and nuclear physics, so it seems to be rather general. The explanation goes in 3 steps.

1) The hot early Universe produced a gas of cca. 95 % hydrogen and 5 % helium (in number %) with no more than 0.01 % of any other nuclei (*Wagoner, Fowler and Hoyle,* 1967). All other elements were produced later in the stars in fusion processes.

2) The stellar fusion is governed by nuclear structure and binding energy. Then H produces only He. H and He cannot produce Li, since ^{5}Li is unstable; He+He cannot produce Be, since ^{8}Be is unstable; H+He+He cannot produce boron, since ^{9}B is unstable (*Novotny,* 1973). The first possible product beyond helium is the deeply bound ^{12}C from 3 He and then H can be consecutively incorporated into C, producing N and O. The primary product is C, but the binding is deepest in O, hence the abundances.

3) In fusion a Coulomb barrier appears. Therefore H fusion needs cca. 10 million K, the He fusion cca. 100 million K, and later steps even higher. Higher and higher masses are needed to continue the fusion. In addition, with decreasing mass the lifetime in the main branch (core H fusion) is substantially longer. Therefore the next fusion step, resulting in aluminium, magnesium &c., is exponentially rarer in stellar evolution. Iron is the deepest bound nucleus, therefore it is the final stage of any fusion, so iron is slowly accumulating in the Universe.

Therefore, although abundances change with time and central star, the general pattern is that H dominates, He is abundant but chemically inert and cannot condensate therefore ignorable henceforth. Then O, C and N is the next abundance step about

0.001 each, Mg, Al and Si the next one (maybe with Na), Fe (+Ni) is still important and other atoms are rare enough.

Consequenly, around *any* star the solid bodies (planets) can consist of: i) iron and refractory oxides near the star; ii) ices far outside; and 3) carbon and silicates at middle distances. This third point deserves some discussion. The schematic temperature map of the Solar System is shown by *Fig. 1.*

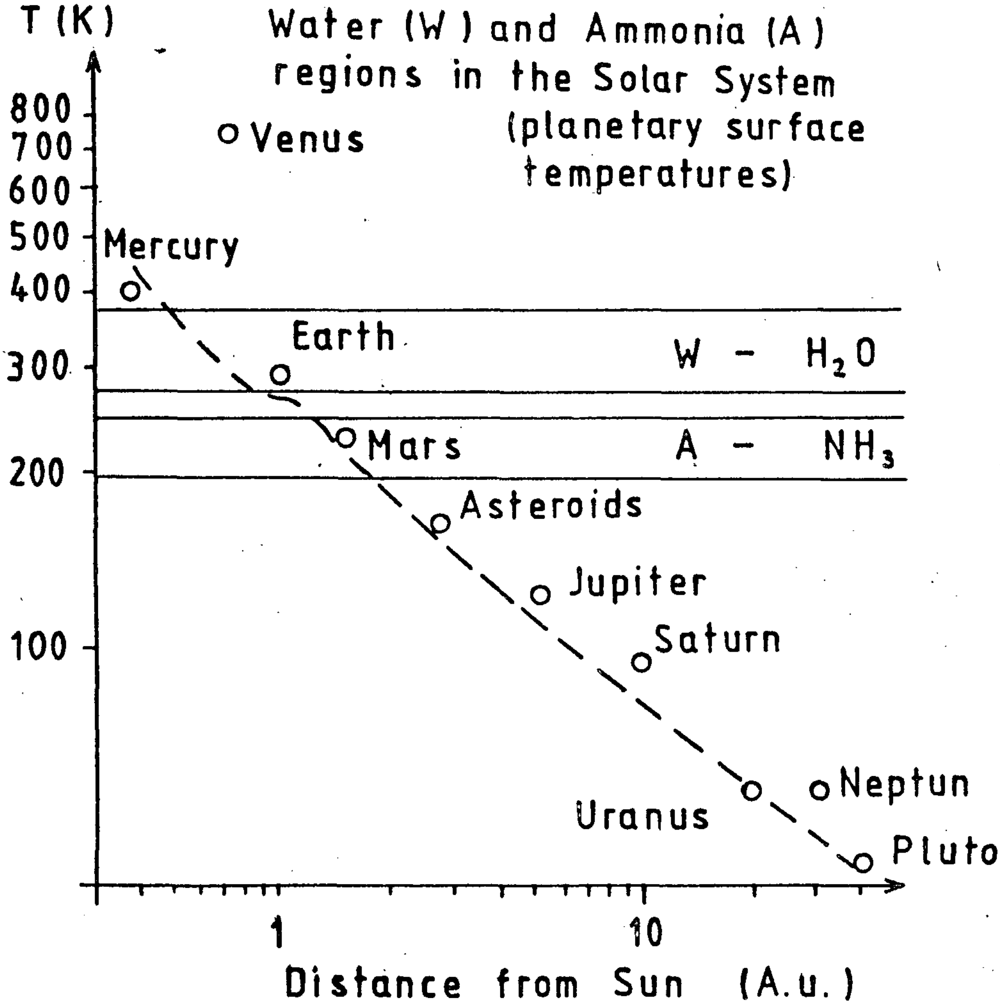

Fig. 1 Temperature regions in the present Solar System

Sun's planetary system represents some 0.15 % of the total mass, but the majority of this is Jupiter and Saturnus, mainly H and He. A stone planet retaining substantial atmosphere seems to have to have, say, third of terrestrial mass, so 10^{-6} part of solar mass. So the only elements, solid in middle temperatures, which can build up substantial planets, are C, Mg, Al, Si, S, Ca, Fe (and Ni). Others cannot dominate the mass.

These solids can take up gaseous elements into compounds, as the abundant H, N and O. Now let us see the possibilities.

C is very abundant, but its simple compounds with H, N or O are gaseous in the temperature range considered. So during condensation, or afterwards in radioactive heating, much C is lost from the solid body. (The same is true for S.) Therefore one guesses that in most stellar system the bodies os substantial stony planets are dominated from the compounds of Si, Al and Mg, called generally as *silicates;* maybe together with those of Ca (a characteristic *earth metal*). Si's oxigen compounds are *not* gaseous at middle temperatures. The atmospheres may contain the abundant gases H, He, N and O, together with their gaseous compounds with each other, with C and S. There are more than 1000 H atoms for each C one in stars and interstellar gases (*Novotny,* 1973). Therefore the most abundant form of carbon compounds may be methane, CH_4, or derivatives.

Now let us see, which can be the dominant liquid on the surface or in the atmosphere, if liquid can exist on the planet at all. The most abundant liquid will be the general solvent of the planetary chemistry. According to the above arguments, 3 molecules are possible in large quantities: water OH_2, ammonia NH_3 and methane CH_4. Other possible combinations as e.g. dicyan C_2N_2, oxygen O_2 etc. are expected in smaller amount according to cosmic abundances. Now, methane is not liquid at middle temperatures, and it is not too good a solvent either, being apolar. But ammonia and water are roughly similar to each other; the differences are quantitative not qualitative. (See Chap. 3) Therefore the most probable alternative of terrestrial chemistry under planetary circumstances is a chemistry with liquid NH_3 as solvent. We guess that this would be rarer than the aquaeous chemistry, and in Sects. 5 and 6 we shall give arguments and rough estimates for this; however liquid ammonia oceans do not seem very exceptional in the Galaxy.

The ammonia-based chemistry (A-chemistry henceforth as compared to the familiar terrestrial W-chemistry) is not a very exotic topic and some experiments have been performed. Anyway, it needs -40 C° at normal atmospheric pressure or 8 atm at room temperature, not impossible in laboratories. Ammonia-based biochemistry is a more difficult matter. However, the starting blocks of ammonia-based organic chemistry are familiar molecules of terrestrial chemistry too.

Non-aqueous solutions can produce reactions unfamiliar to water-based common sense (*Audrieth and Kleinberg,* 1953). A general definition of acids, bases and salts can be made with respect to the solvent, following e.g. *Lewis.* Then the solvent dissociates to a pair of positive and negative ions; acid is the molecule which dissociates to the positive ion of the solvent, and a foreign negative ion; basis is the molecule dissociating to the negative ion of the solvent and a foreign positive ion; salt is a molecule which does not give any ion of the solvent in dissociation. A neutralisation reaction is in which a basis reacts with an acid, giving a salt and more solvent. So the relations (ignoring such details as hydratation &c.) go as

Table 1
Fundamental comparative chemistry

Solvent	Water	Ammonia
Dissoc.	H - OH	H - NH_2
Acid	P-H	P-H
Basis	Q-OH	Q-NH_2
Salt	P-Q	P-Q
Neut. r.	P-H+Q-OH=	P-H+Q-NH_2=
	=P-Q+H_2O	=P-Q + NH_3

Therefore every aqueous acid is acid in ammonia, and H_2O is in addition an acid there: but no aqueous basis is basis in ammonia.

The simplest neutralisation reaction in water goes as

$$NaOH + HCl = NaCl + H_2O$$

Mutatis mutandis, we can keep the structure and get the „mirror" ammonia-based neutralisation reaction as e.g.

$$NaNH_2 + HOH = NaOH + NH_3$$

or, by words, in ammonia sodium amide and ice is expected to produce sodium hydroxyde and ammonia; indeed, this reaction goes even under terrestrial circumstances, without being solved in ammonia, if water vapour of cca. 200 C° is ejected on sodium amide crystalls.

In environments where NH_3 is liquid, H_2O is expected to be still abundant, and either a liquid or a solid (cf. Chap. 7). So water or water ice is an important matter there; similarly as ammonia was on the pre- and protobiotic Earth.

3. THE COMPARISON OF WATER AND AMMONIA AS SOLVENTS

Let us compare the properties of water and ammonia *as solvents*. Methane qualitatively differs from both, being apolar. Therefore methane is a poor solvent of some salts. On the other hand, water and ammonia differ only qualitatively. For more details see *Bailar et al.* (1973).

Table 2

Main physical properties of the two solvents

Property	Water	Ammonia
Freezing p. K	273	195
Boiling p., K	373	240
Crit. temperature, K	647	405
Crit. pressure, atm	218	112
Density (liq.), g/cm^3	1	0.65
Dipole moment	1.85	1.47
Dielectric constant	81	22
Spec. heat (l)	1	1.1
Melting heat, cal/g	80	84
Evapor. heat, cal/g	541	327

For solubilities of salts, we mention that NaCl definitely dissolves worse than in water (as most chlorides too); the numbers are 2.1 g vs 36 in 100 g solvent. However for bromides the solubility is more comparable. Ammonia practically cannot solve chlorides of earths; but can solve some metals in relevant quantities, while water cannot.

Therefore in general ammonia is not worse a solvent than water on Earth. The high specific and melting heats are advantageous to stabilize the environment and to make the meteorologic phase transitions gradual. Ammonia is nearly as polar as water, so in general solves salts almost as well as water, although differences may be large for individual salts; and ammonia in general is the better solvent of organic compounds. The dielectric constants are comparable and high, although the difference is substantial. Ammonia is much inferior in self-dissociation; however by solving electrolites (e.g. any salt or water ice) the ionic concentration will be enhanced.

For ammonia-water mixtures we note that they mix without limits. The phase diagram is very complicated; the lowest freezing eutectic is $2H_2O*NH_3$, with cca. 176 K melting point at 1 atm. With methylalcohol ammonia can also mix without limit.

We will not deal here with the details of biochemistry, with the properties of amino acids and their formation; for that see *Bérczi and Lukács* (1994a). Here we note only that amino acids are solvable both in water and in ammonia.

4. ON THE ABUNDANCES OF LIQUIDS IN THE SOLAR SYSTEM

Apart from theory we know something about *present* abundances, and on Earth something about prehistory too.

Present astronomy does not show any liquid on Mercury, Venus, Mars and on the asteroids. On Mars subsurface water or H_2O-CO_2 mixtures or chlatrates are not totally ruled out. On some Galilean moons of Jupiter liquid water is probable below the frozen ice crust, and on Io volcanoes throw up liquid sulphur. Its liquid space is impossible on the low pressure surface but not below. For the moons of Saturn, Uranus and Neptune data are scarce. Atmospheric pressure is substantial on Titan and Triton, and sometimes criovulcanism is assumed. See e.g. *Kargel* (1992). As for Earth, liquid water is very abundant; other liquids are not too frequent but liquid hydrocarbons are not rare. For the freezing and boiling points af paraffines and some of their derivatives are shown by *Fig. 2.*

The atmosphere of present Earth is product of billion years of biologic activity. E.g. free oxygen is impossible without continuous oxygen source. The palaeoatmosphere is a matter of speculation. *Miller* (1953) was able to produce amino acids in an artificial reducing atmosphere with H_2O, CO_2, NH_3 and H_2. While H_2 and H_2O do not need explanation, and CO_2 is present at Venus and Mars, NH_3 seems to belong to the outer

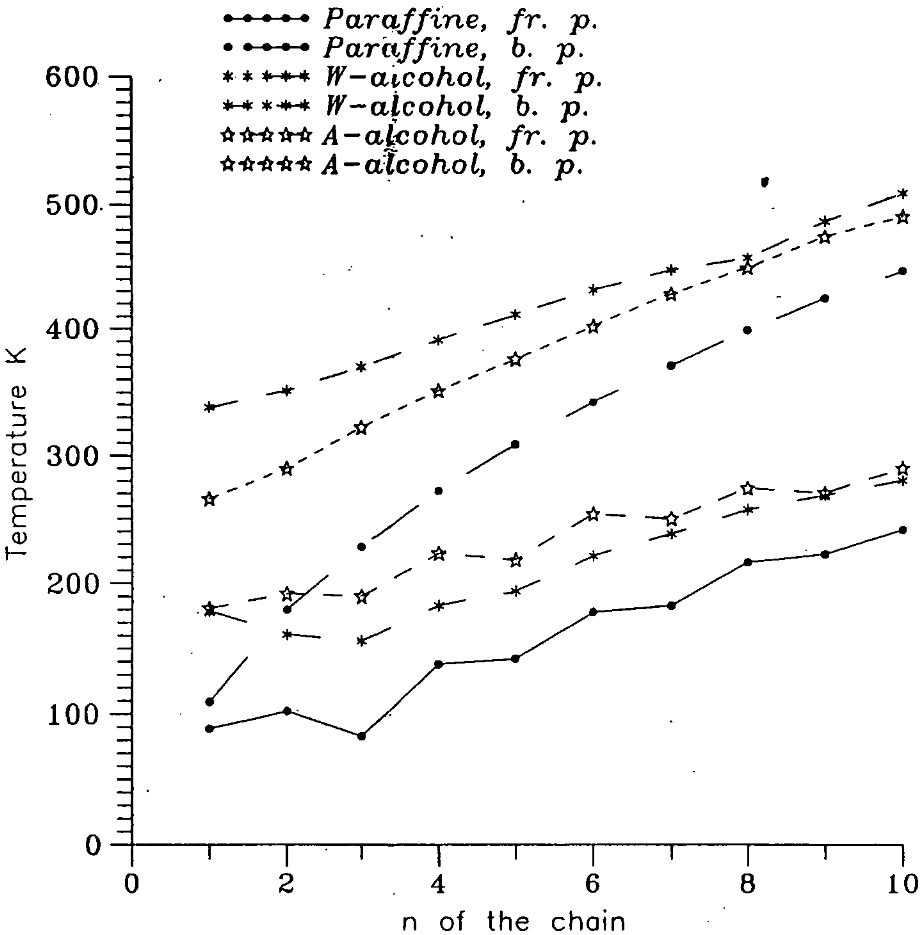

Fig. 2 Freezing and boiling points of paraffine chains and alcohols of different chemistries

Solar System, and so its original presence is often questioned. Two important definite observations indeed do not confirm the simple schemes.

Szalay (1975) found H_2, H_2O, N_2, CO_2 and CH_4 in precambrian sediments, but not NH_3. No geologic traces of the often assumed „primordial bouillon" of sugars, amino acids, nuclear acid building stones &c have been found. The earliest layers seem poor in nitrogen; e.g. the amino acid concentration of such sediments seem to be not higher than 10^{-9} (*Schöpf, Kwenvolden and Barghoorn,* 1968). This low concentration comes from the Fig Tree layer where the oldest fossil microorganisms were identified (3.7 – 3.0 Gy old). So ammonia on proto-Earth (liquid or gas) is indicated by life byt not confirmed by geology. Water must have been liquid at least at some parts of the terrestrial surface from the time of oldest preserved microorganisms. Other liquids seem to have been always of minor abundance.

A possibility is extraterrestrial origin of terrestrial life from an ammonia-rich planet: a microorganism survived space travel on meteorite, found an ammonia-free atmosphere and their descendants converted the reducing atmosphere into oxidative. This is possible if there was life somewhere else in the Solar System. Up to now there has not been found any evidence for such extraterrestrial life, but it may have existed on proto-Mars with substantial atmosphere. It is interesting to see what were the possibilities for ammonia to have appeared in the terrestrial and Martian palaeoatmospheres. For any case, some 2 Gy ago Mars was geologically active, gases and vapours continuously emerged and the atmosphere must have been dense enough to keep *something* (water or ammonia) in liquid state because huge riverbeds have been preserved up to now.

Now comes the theory. According to the *Barshay-Lewis model* (1975) ammonia could have condensated somewhere outwards from Saturn. Gas evaporation from the bulk of Earth may have seriously contributed to the palaeoatmosphere, but the present Earth litosphere seems very poor in ammonia.

Ammoniates and aminated silicates may help, if they contributed to primordial Earth, and then lost the ammonia when the bulk of the planet was being heated up. Unfortunately the present knowledge about silicates with structural ammonia is next to nothing so they are not included into condensation calculations for the early Solar System. Therefore no serious theoretical predictions exist for the ammonia content in the inner Solar System. Anyway, hydrated, ammoniated and aminated silicates must have been more abundant in the Martian condensation than in the terrestrial process. In addition, a collision with an ammonia-rich planetesimal during the formation of Earth or Mars is not impossible. A planetesimal of $R \sim 1000$ km from beyond Uranus could have filled up the terrestrial palaeoatmosphere to 1 atm partial pressure. Of course, then remains the problem that no geologic remnant of this ammonia is found on Earth. From Mars data are very scarce.

5. ON CONDENSATION MODELS OF SOLAR SYSTEM

For the details of planetary composition one must see in which sequence the abundant elements form their compounds. Condensation models of the Solar Nebula have deduced the type and sequence of mineral belts which has been formed around the early Sun. (*Barshay and Lewis,* 1975; *Grossman and Larimer,* 1974; *Grossman,* 1972). In these models the temperature was the main factor which differentiated the belts according to the principal mineral constituents.

From a gas with solar elementary abundance water, ammonia, and methane ices were the most important (by mass, volume, modal weight) condensates in the outer Solar System. *Lewis* (1974) worked out in details the sequence of condensation for outer solar system mineral constituents, mainly ices. We refer here this work and show the steps of the equilibrium condensation sequence, as follows:

Table 3

The Lewis-Barshay sequence of condensation

Temperature	Chemical process, mineral transformation or condensation
ca. 500 K	Formation of **TREMOLITE** (from Ca, Al, Mg, Silicates with H_2O)
ca. 400 K	Formation of **SERPENTINE** (from Mg(Fe), Silicates with H_2O)
ca. 170 K	Condensation of **WATER-ICE** (which exhaust all H_2O gas)
ca. 110 K	Formation of **$NH_3.H_2O$ AMMONIA-CLATHRATE** (exhausts all NH_3)
ca. 60 K	Formation of **$CH_4.8H_2O$ METHANE-CLATHRATE** (exhausts all solid H_2O)
ca. 25 K	Condensation of CH_4 and Ar gases to **METHANE-** and **ARGON-ICE**
ca. 8 K	Condensation of Ne gas to **NEON-ICE**
ca. 7 K	Condensation of H_2 gas to **HYDROGENE-ICE**

The last two condensations are strongly hypothetical, and observe that crystals with structural water are included but those with structural ammonia are not; such crystals are known, e.g. $CaCl_2$ can take up 8 molecule ammonia into its lattice.

This table shows that the most abundant volatile phase, the H_2O first appears as a component added to the higher temperature condensates to transform (metamorphose) them: such forming hydrous silicates of tremolite and serpentine.

There is a wide gap in temperature between these hydrous silicates condensation and ice-condensation. In this region carbonaceous compounds condensate according to the *Ryoichy-Anders model* (1981), but these results were yet unknown in 1974, when Lewis calculated his sequence referred here.

Ammonia probably enters too into stones and form ammoniated silicates. However for it there is another possibility. The ammonium ion can substitute potassium and rubidium in silicate *lattice points*. Potassium is rare and rubidium is negligible; the ammonium ion can form from NH_3 and H at moderate temperatures where NH_3 is abundant. In the Solar System this region is definitely outside the terrestrial orbit; some ammonium compound is reported from Ceres (*King et al.*, 1993). The best known terrestrial ammonium silicate is buddingtonite (*Erd et al.*, 1964). Such silicates may have formed in condensation and may have entered the proto-planets. At higher temperature the ammonium ion disintegrates, ammonia leaves the silicate, and H is left behind. (The substantial size difference disrupts the lattice.)

Water, ammonia and their mixtures condensate somewhere between 200 K and 100 K. In this region first the water-ice, then a compound ice of $NH_3.H_2O$ ammonia clathrate precipitates. Considering the Cameron adiabat from the *Lewis-Barshay model* (1975) which intersects the phase boundary of water-ice at ca. 170 K between Jupiter and Saturn we may estimate the planetary provinces of the W–A mixtures.

Then one can see that water of the inner planets does *not* come from water-ice condensation. The proto-temperature there was just low enough for silicate condensation, much above ice freezing point. So the stony planets formed their water from hydrated silicates; and ammonia can be formed analogously from ammonia or ammonium-bearing silicates. Under appropriate climatic conditions, large bodies of aquaeous (W) or ammonia (A) solvent can form on the surface.

There are two types of planetary provinces, where W–A hybride chemistry could have developed. One type of province is on the satellites of these two giant planets. Mainly subsurface inner zones may be considered as suitable places for liquid conditions to any of the two solvents. The other type of province is on the Jovian Planets themselves. Their atmospheres contain such zones, where the necessary p–T conditions are suitable for W–A organic chemistry.

In the early protosolar nebula the temperatures differed from the present. Reasons can be manifold, and one of them is the different protosolar luminosity. In our system we can deduce the condensation temperatures from the compositions of the planets (*Barshay and Lewis,* 1975). The proto-temperatures seem to have been roughly the doubles of the present equilibrium blackbody temperatures. Then Earth was just at the inner boundary of the hydrated silicate belt, with a small amount of primordial bulk water. Mars was well inside of the hydrated silicate belt, the bodies of the asteroid belt must have originated with mixtures of H_2O ice and hydrated stones (a fact suggesting internal fragility), and H_2O ice is a main component in the Galilean moons of Jupiter. Outwards from Jupiter ammonia gradually takes over. Unfortunately the papers contributing to *Table 3* did not include stony components with structural ammonia, which may exist, but of course cannot be expected in natural terrestrial environment, where ammonia does not have a chance to replace the dominant water. In addition, silicates do exist in which some alkalies are substituted by ammonium ion, e.g.

buddingtonite (*Erd et al.,* 1964). So behind the orbit of Mars *Table 3* cannot be complete in the present state of knowledge. Obviously rough guesses should be done until the ammoniate analogons of hydrated silicates will be known better.

6. ON THE ASTRONOMIC POSSIBILITY OF AMMONIA SOLVENT AND A-CHEMISTRY

Now we can look around for extraterrestrial environments with at least some physicochemical possibility for liquid water or/and ammonia. We follow the complex map of *Figs. 3–5*. It is a p–T phase diagram.

The curvilinear triangles indicate regions where liquid OH_2 (dashed) and NH_3 (solid) are possible. The corresponding localities are obviously planetary surfaces, depths or atmospheres. The almost horizontal T–p curves are the condensation lines of some important molecules (*Barshay and Lewis*, 1975). By intersecting them with the Cameron adiabats (on the extreme left) one gets the actual condensation conditions in the Solar System; for other planetary systems only the actual adiabat differs, for which see *Bérczi and Lukács* (1994b). The present average values for Venus, Earth, Mars and Titan are indicated by fans, whose apices are the planetary surfaces, and otherwise they are depths or atmospheric localities; model atmospheric layers of Jupiter and Saturn are shown by the steep curves.

Present Venus is too hot for both solvents, although the upper atmosphere may be conform with liquid H_2O. There no large contiguous body of the solvent can exist; one may at most contemplate about an earlier W-life of the original not too hot surface to emigrate to the upper atmosphere.

Present Earth is conform with liquid H_2O, and according to geology this was so at least in the last 3.7 billion years. Present Earth is not conform with liquid NH_3, except for some underwater situations, where however liquid ammonia would be in hopeless minority; on proto-Earth atmospheric pressure may have been quite high and then ammonia might have been in liquid phase.

Present Mars in average is not suitable for any of the solvents. A very moderate simultaneous increase of temperature *and* pressure would put it within the liquid H_2O region, and such situations may or may not exist in subsurface chambers of the giant extinct (?) volcanoes. On the other hand the present temperature with a substantial paleoatmosphere (from 1 atm upwards) might create a possibility for A-chemistry. Observations show ancient riverbeds of running liquid, but do not tell if it was water or ammonia. If liquid ammonia existed in the Martian past, it contained substantial amount of solved H_2O, from the ice.

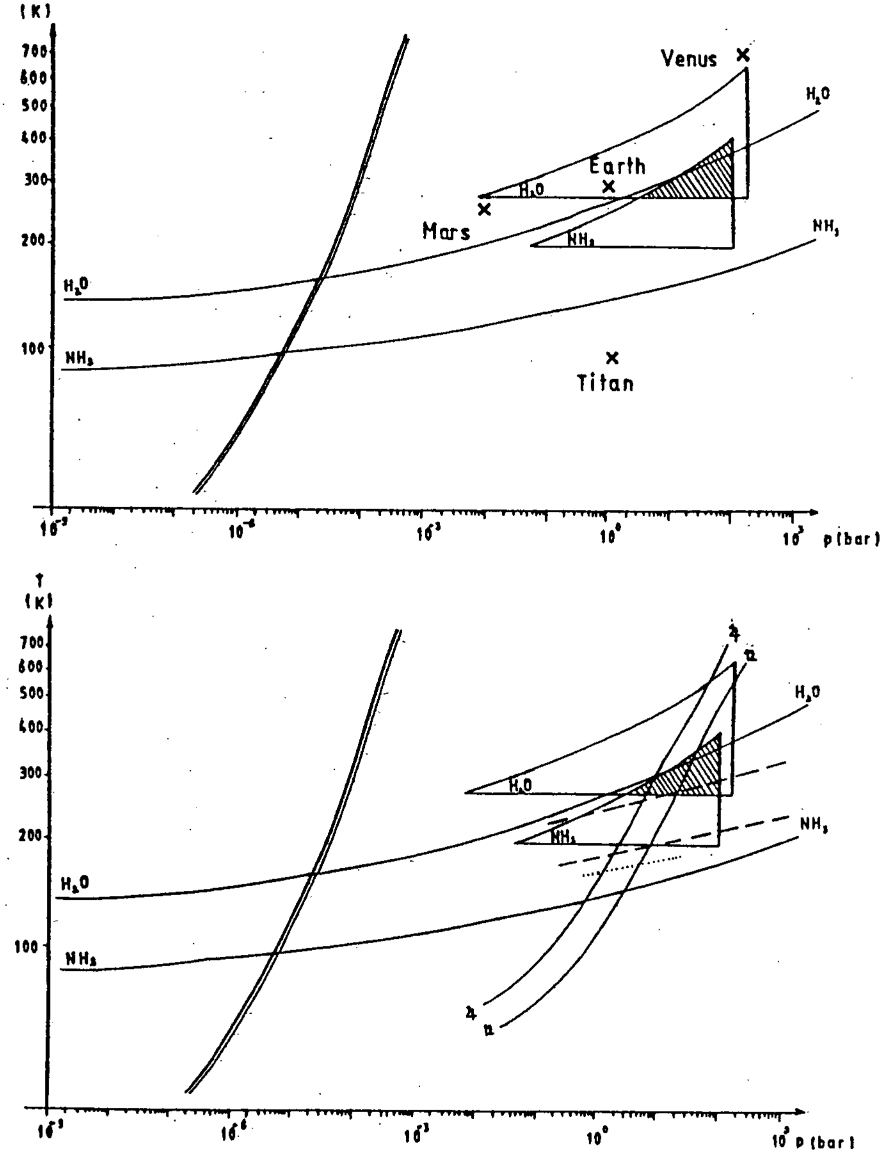

Fig. 3 The combined T−p diagram of the Solar System and the two main solvents (details in the text)

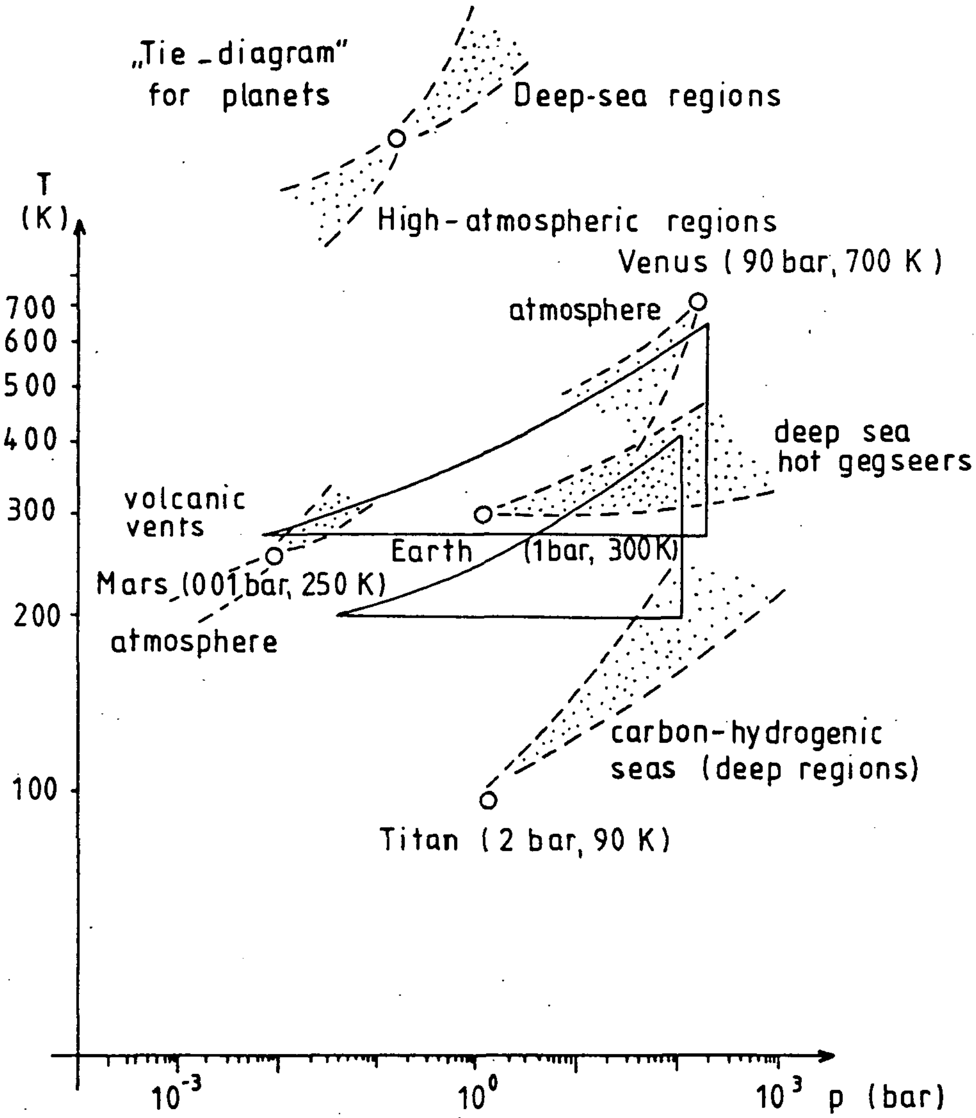

Fig. 4 Planetary surface p−T conditions extended up to the atmosphere, and down below surface or sea level

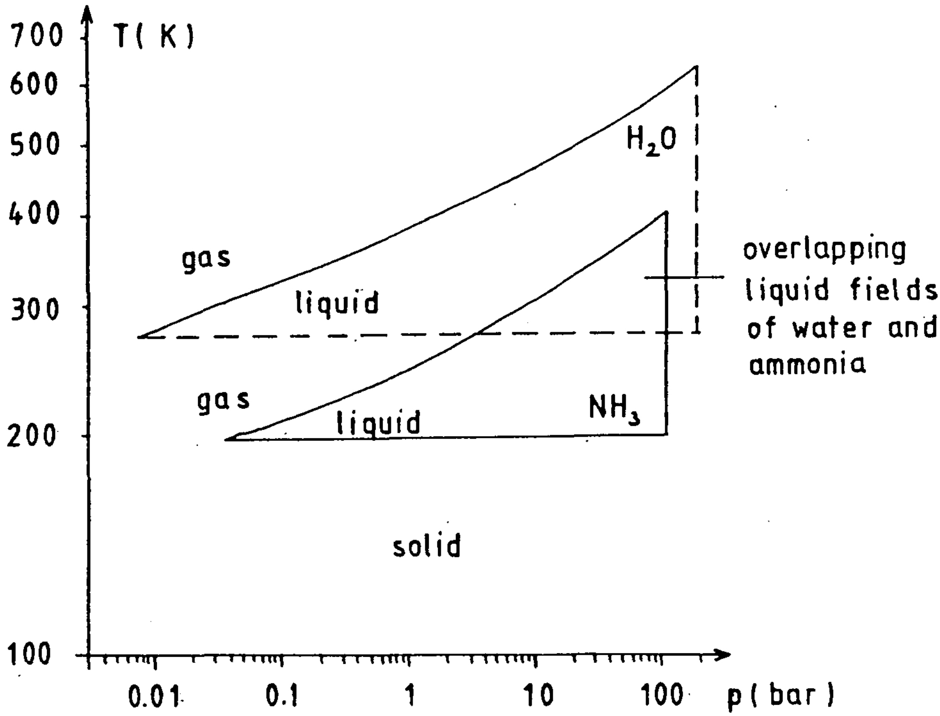

Fig. 5 Melting and boiling conditions for water and ammonia

Titan seems too cold for any of the solvents, although ammonia may be a major constituent of it.

Somewhere in the atmospheres of the two gas giants ammonia may be a liquid; it is not clear if life could have started in an atmosphere.

Because of the very low pressures no asteroid surface can have had any of the two solvents in liquid phase in the last 4 billion years.

In the overlap region (hatched) both possible solvents are in liquid phase. In this case the more abundant one will determine the fundaments of local chemistry. Our guess is that according to cosmic abundances water will generally dominate.

Around stars the belt for liquid ammonia partly overlaps with that for water, and lies on its outer side. For stars not too different from Sun the planets condensated there will inevitably contain structural water in the litosphere, so on a planet with ammonia oceans water still will be available in ice phase and therefore hydroxyle ions will appear in the solvent. For much different stars the thermal history of the protostar should be investigated to decide if hydrated silicates condensated in the belt of cca. 250 K equilibrium blackbody temperature in the later fusion era of the star. In addition, as told above, we do not know too much in the present state of art about the condensation of silicates with structural ammonia, a major source of surface ammonia (*Bérczi and Lukács*, 1994b).

7. DISCUSSION

The goal of this paper was to clarify the necessary planetary and stellar conditions for liquid water or ammonia, good solvents in planetary chemistries. This condition selects 2 belts around any star, partly overlapping; plus a high enough atmospheric pressure to avoid sublimation, i.e. a substantial planetary radius. For water solvent the belt starts just outside of Venus's orbit and marginally reaches Mars. The ammonia belt overlaps at the outer edge of the water belt and extends to greater distances roughly by 40 %. However substantial atmospheric pressures are needed too, present on Earth but not on today's Mars.

It seems that even in aquaeous environment the emergence of life would need or would be speeded up by substantial amount of ammonia. Ammonia seems to be not abundant in the internal part of the aquaeous belt because of the high temperature of the nebula.

Applying all these to the Solar System, Venus is almost in the water belt, but in her present status the high greenhouse effect evaporated water. Venus must always have been poor in ammonia.

For Earth there is a problem. Earth is and seems always have been in the water belt. However in 1 AU not too much ammonia must have been in the solar nebula, while terrestrial life suggests substantial ammonia stores on the early Earth. To be sure, ammonium silicates have been suggested for ammonia source (*Eugster and Munoz*, 1966), and they could have taken part in the formation process of proto-Earth (albeit in this temperature zone even ammonium silicates seems to have been rare), or Earth may have got an impact of an ammoniated planetesimal from the outer system. The problem is that the earliest known deposits are N-poor, even in the neighbourhood of the first known fossil procariotes. This controversy needs an explanation, not available now.

Neither water nor ammonia is liquid on present Mars. Some 2 Gys ago Mars had some liquid because riverbeds are seen. Then Mars may have had either liquid ammonia with abundant water ice, partly solved, or liquid water, with abundand gaseous ammonia, partly solved; Mars may have got substantial amounts of both hydrated and ammoniated and ammonium silicates. We only note that *King et al.* (1993) found ammonium saponite on Ceres by spectroscopy. Therefore there is a chance that ancient Mars generated life, either W or A.

Outwards from Mars liquid water is impossible; for liquid ammonia we got that it is improbable in the outer system.

Finally we note that there is a narrow temperature range where neither water nor ammonia is liquid but an ammonia-water mixture is. At 1 atm pressure this range is between 176 and 195 K, which is cca. at 2.2 AU. There is no substantial body here in the Solar System, but by pure chance a planet may appear at analogous position in another system. In such a solvent chemistry will be rather complicated and we cannot guess if the sharply tuned processes of any biochemistry are compatible with such an ambivalent system, although our biomolecules seem to be WA hybrides.

Acknowledgements

Partly supported by the OTKA Funds N° T/007410 and T/014958 and by MEC-94-1613.

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ACTA CLIMATOLOGICA
Universitatis Szegediensis, Tom. 28–29., 1995.

SOME CONSIDERATIONS CONCERNING MORPHOCLIMATIC CONDITIONS OF THE ROMANIAN CARPATHIANS

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Néhány meggondolás Román Kárpátok morfoklimatikus viszonyairól

A cikk a figyelem középpontjába helyezi azt a módot, ahogyan a Román Kárpátok sajátos éghajlati viszonyai – amelyekre időszakos (évszakos, hónapos), ill. térbeli (magassági, szélességi) változékonyság jellemző – befolyásolják a domborzatalakító folyamatok lefolyását. A megismerő és megmagyarázó eljárás a Peltier diagrammok használatát veszi igénybe a domborzatalakító folyamatok típusának és intenzitásának megállapításához (felaprózódás, szétmállás, periglaciális jelenségek, folyóvízi folyamatok), még karakterisztikus hónapok esetében is (január, július, április, október). A morfoklimatikus viszonyok összképét a karakterisztikus hőmérsékleti intervallumok és a jellemző napok (nyári, téli, csapadékos, havazásos, hóréteges, fagyos, derűs, alacsony hőmérsékletű napok) egészítik ki minden egyes állomás esetében. A figyelembe vett 13 meteorológiai állomás a következő geoökológiai övekben található: félniválís (2250–2300 m felett), alpesi (2000 és 2250–2300 m között), szubalpin (1750–1800 és 2000 m között) és erdő (1750–1800 m alatt).

The article brings in attention the way on which the specific climatic conditions of the Romanian Carpatians – characterized by temporal variability (seasonal and monthly) and spatial variability (according to the altitude and the latitude) – influence the unfurling of geomorphological processes. The cognitive and explanatory approach benefits by the utilisation of the Peltier diagrams which emphasize the type and intensity of geomorphological processes (mechanical and chemical weathering, periglacial processes, fluvial action), including those for the characteristic months (January, July, April, October). The board of the morphoclimatic conditions is completed by the thermic characteristic intervals and by the characteristic days (summer, winter, serene, frost, freezing, precipitation days, days with snow, days with snow layer) for each meteorological stations. The 13 stations taken into consideration correspond to the next geoecological domains: seminival belt (above 2250–2300 m), alpine belt (between 2000 and 2250–2300 m), subalpine belt (between 1750–1800 and 2000 m) and forest belt (below 1750–1800 m).

Key-words: morphological conditions, goecological belts, Carpathians

The climatic conditioning of morphogenesis is primordial: it is realized in different ways and it controls directly the distribution and the intensity of certain processes. The theorists of climatic geomorphology (e.g. *Tricart and Cailleux*, 1965) consider that, among the elements that define the climate, temperature and precipitation are the most important.

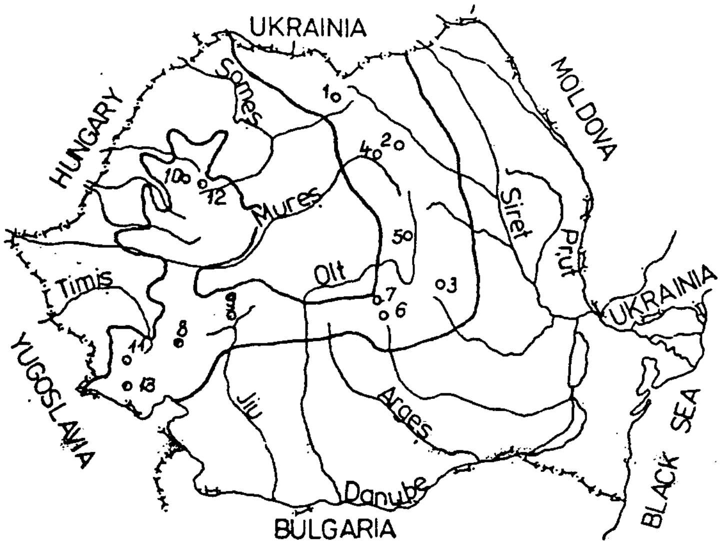


Fig. 1 Location map of meteorological stations

It is generally known how these two climatic elements vary in the Romanian Carpathians depending on latitude, longitude, circulation of air masses, exposure, altitude, etc.

Therefore, in order to outline the morphoclimatic conditions specific to this mountaineous area, we considered necessary to have in view data from meteorological stations having different positions in the mountain range (*Fig. 1, Table 1*).

We have used the geoecological belts established by Kotarba for the Tatra Mountains (*Kotarba*, 1987). The Romanian Carpathians have similar conditions. Therefore we have adapted the sane vertical division into zones of geoecoligical features, based not only on altitude, but also on temperature:

- seminival belt, above 2250 – 2300 m;
- alpine belt, between 2000 m and 2250 – 3000 m;
- subalpine belt, between 1750 – 1800 m and 2000 m;
- forest belt, below 1750 – 1800 m.

The climatic geomorphology is not interested only in the independent evolution of temperature or of precipitation, but also in the correlation which determines direcly the type and the rapidity of morphogenetic processes.

Table 1
Selected Romanian Carpathians meteorological stations

Station	Location	Altitude	Geoecological belt
		m.a.s.l.	
1. Iezer	Eastern Carpathians	1785	subalpine
2. Ceahlau	Eastern Carpathians	1897	subalpine
3. Lacaut	Eastern Carpathians	1777	subalpine
4. Toplita	Eastern Carpathians	687	forest (corridor)
5. Miecurea Ciuc	E.Carpathians	720	forest (depression)
6. Omu	Southern Carpathians	2505	seminival
7. Predeal	Southern Carpathians	1093	forest
8. Tarcu	Southern Carpathians	2180	alpine
9. Petrosani	S. Carpathians	581	forest (depression)
10. Vladeasa	Apuseni Mountains	1836	subalpine
11. Semenic	Banat Mountains	1440	forest
12. Baisoara	Apuseni Mountains	1385	forest
13. Bozovici	Banat Mountains	260	forest (depression)

In order to discover some mathematical relations of this correlation geomorphologists succeeded into establishing some morphoclimatic systems and even into defining them in terms of temperature and precipitations. Thea also named the predominant processes for each system (*Peltier*, 1950; *Pégui*, 1961).

Peltier diagrams illustrate:

- the affiliation to the morphoclimatic regions;
- the intensity of mechanical weathering and of chemical alteration;
- the intensity of fluvial action.

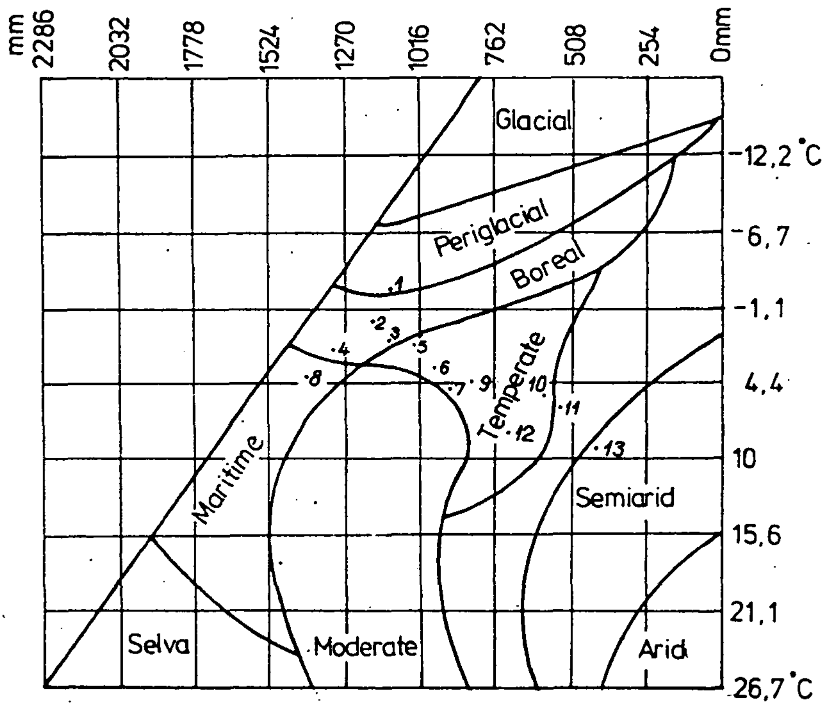


Fig. 2 The affiliation of the stations to the morphoclimatic systems in a Peltier diagram

Applied to the meteorological data from the Romanian Carpathians, these diagrams point out:

(i) the morphoclimatic systems to which are affiliated the selected stations are (*Fig. 2*): periglacial system (with physical dominate) – Omu; boreal system (here appears the biological dominate, too) – Iezer, Tarcu, Vladeasa; temperate system (the rivers are the main agents of the „normal erosion" (sense *Macar*, 1946); thanks to the submediteranian influences, the Semenic stations is situated at the limit ot the temperate system and maritime system.

(ii) the fluvial action is (*Fig. 3*): maximum in the subalpine and forest belts and medium (moderate) in the seminival and alpine belts.

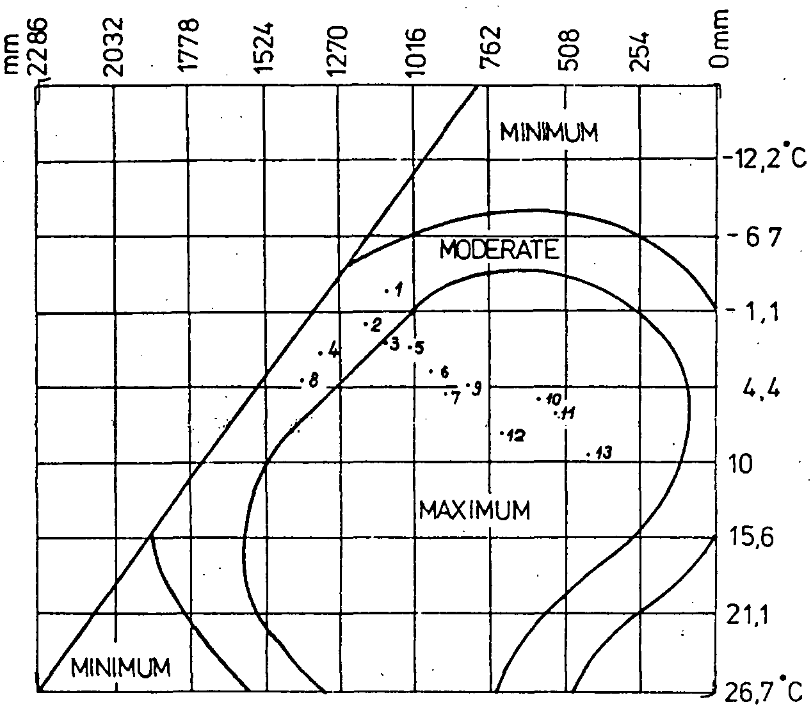


Fig. 3 The intensity of fluvial action after a Peltier diagram

(iii) the main morphogenetic processes in the studied area (*Fig. 4*): a slight mechanical weathering in seminival belt – Omu, situated upper than the maximum level of the precipitations, the low values of precipitations and temperatures make the chemical alteratio to be minimum; a moderate chemical alteration and freezing for rest of the stations.

Applied to the characteristic months, January and July, but also to the „trasitional" months, April and October, the Peltier diagrams emphasize the annual evolution of the intensity processes, depending on the morphoclimatic conditions. Thus, in January:

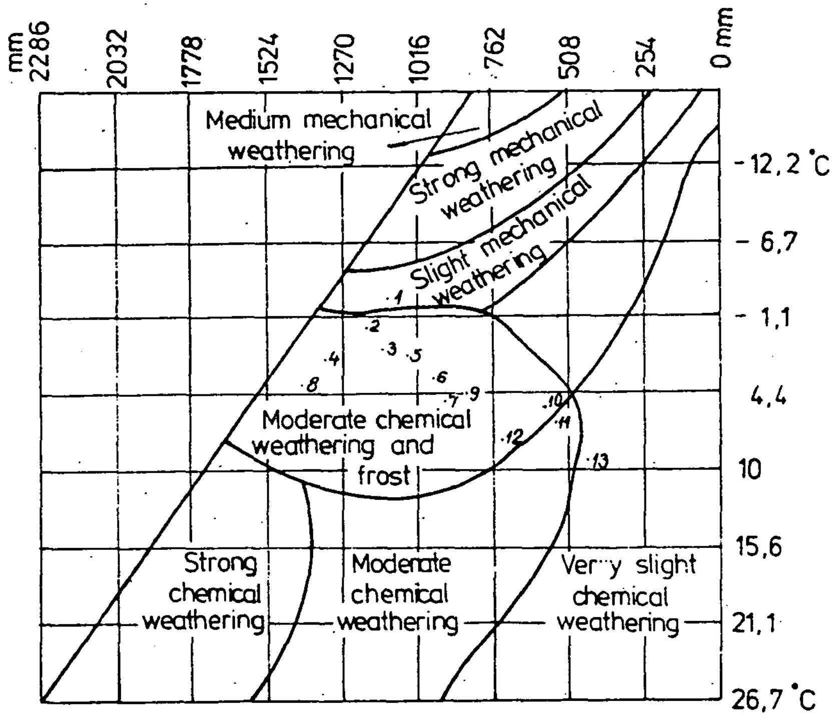


Fig. 4 The type and the intensity of the predominant processes after a Peltier diagram

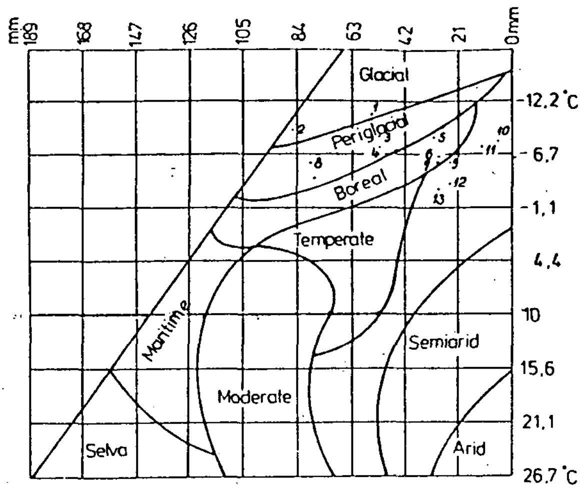
(i) the morphoclimatic conditions define the glacial system at Omu and Tarcu, the periglacial system at Vladeasa, Iezer and Semenic, and the boreal system in the rest (*Fig. 5a*):

(ii) the fluvial action is minimun in the seminival and alpine belt, and moderate and maximum in the other belts (*Fig. 6a*);

(iii) the main morphogenetic processes is the mechanical desintegrations is minimum and, „transitional" in seminival, alpine and subalpine belts (*Fig. 7a*).

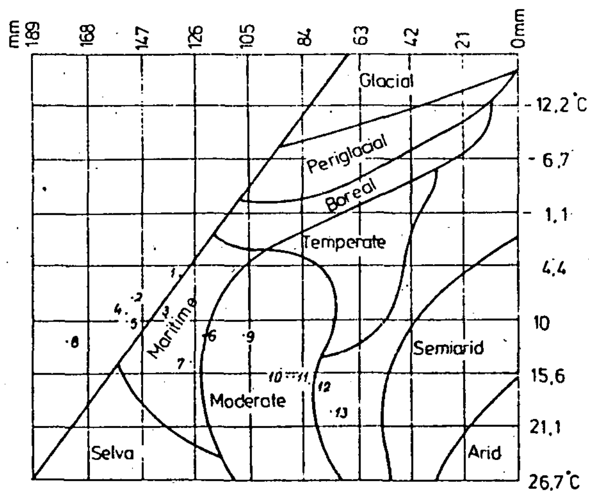
In July, with higher temperatures and precipitations:

(i) the morphoclimatic conditions define the temperate, moderate and maritime systems (*Fig. 5b*);



(a)

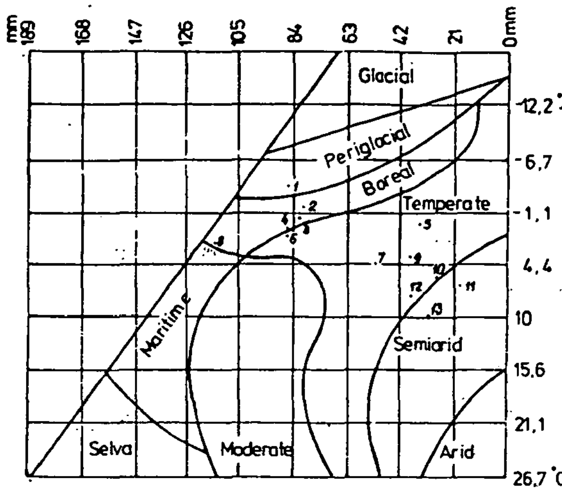
1 - Vf. Omu ; 2 - Tarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuti ,
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băişoara ;
10 - Toplita ; 11 - Miercurea - Ciuc ; 12 - Petroşani ; 13 - Bozovici .



(b)

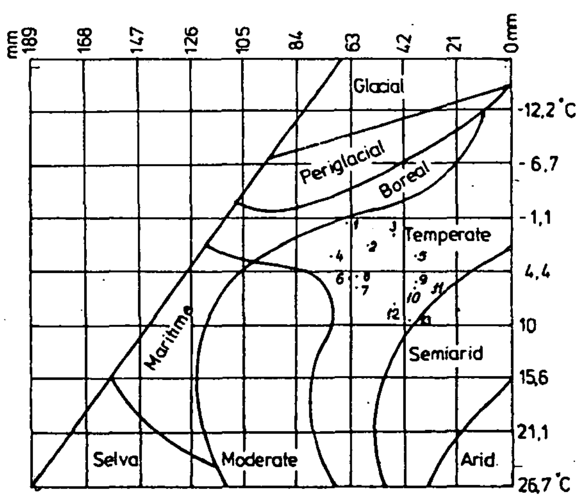
1 - Vf. Omu ; 2 - Tarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuti ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic , 9 - Băişoara ;
10 - Toplita ; 11 - Miercurea - Ciuc ; 12 - Petroşani ; 13 - Bozovici

Fig. 5 The affiliation of the stations to the morphoclimatic systems in a Peltier diagram, for the months January (a), July (b), April (c) and October (d)



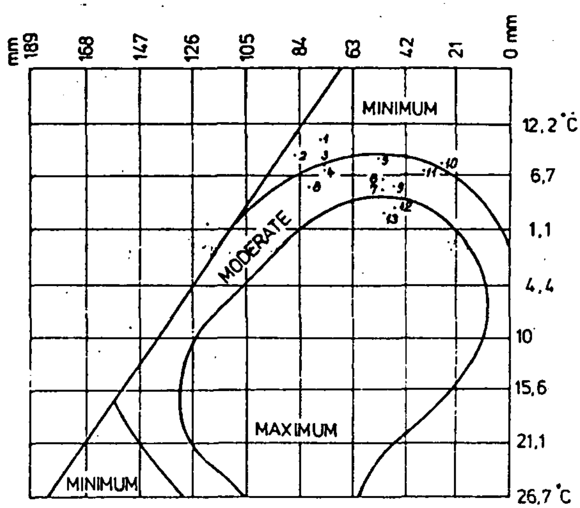
1 - Vf. Omu ; 2 - Ţarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuţi ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băişoara ;
10 - Topliţa ; 11 - Miercurea - Ciuc ; 12 - Petroşani ; 13 - Bozovici .

(c)



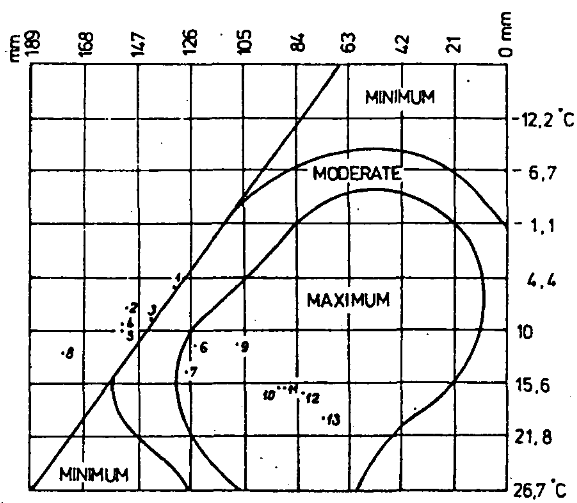
1 - Vf. Omu ; 2 - Ţarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuţi ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băişoara ;
10 - Topliţa ; 11 - Miercurea - Ciuc ; 12 - Petroşani ; 13 - Bozovici .

(d)



(a)

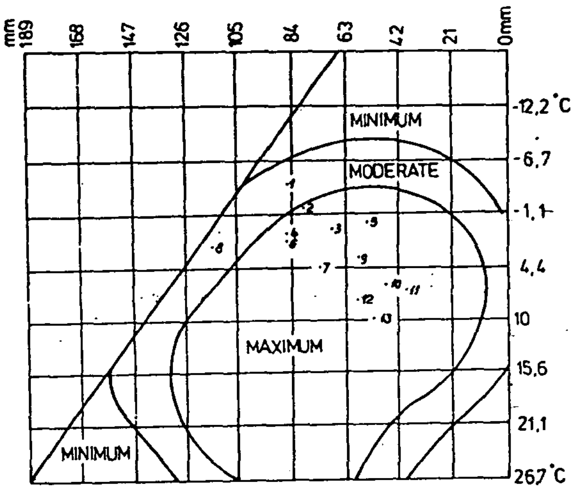
1 - Vf. Omu ; 2 - Tarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuți ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băișoara ;
10 - Toplița ; 11 - Miercurea - Ciuc ; 12 - Petroșani ; 13 - Bozovici.



(b)

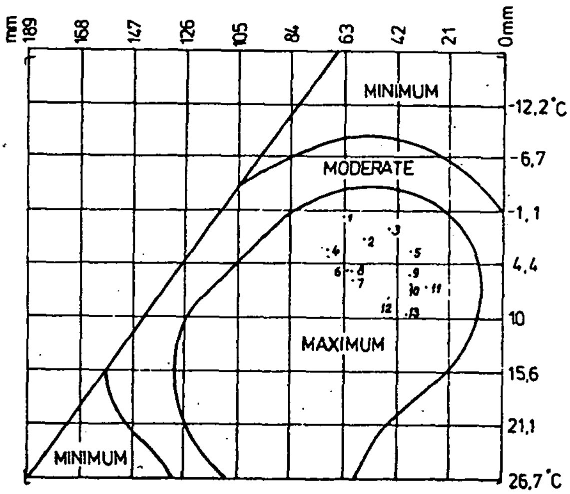
1 - Vf. Omu ; 2 - Tarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuți;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băișoara ;
10 - Toplita ; 11 - Miercurea - Ciuc ; 12 - Petrosani ; 13 - Bozovici .

Fig. 6 The intensity of fluvial action after a Peltier diagram, for the months January (a), July (b), April (c) and October (d)



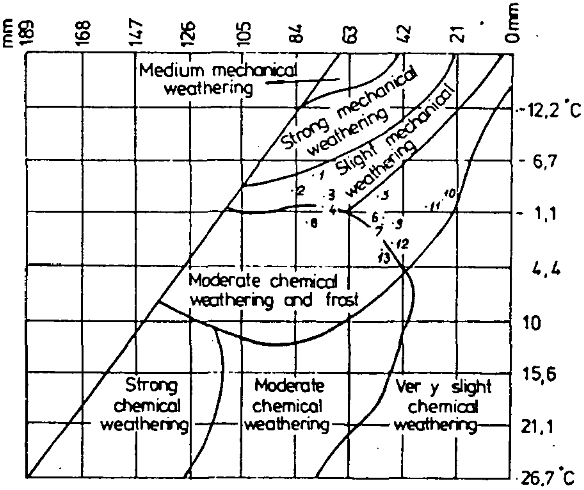
1 - Vf. Omu ; 2 - Ţarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuţi ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băişoara ;
10 - Topliţa ; 11 - Miercurea - Ciuc ; 12 - Petroşani ; 13 - Bozovici .

(c)



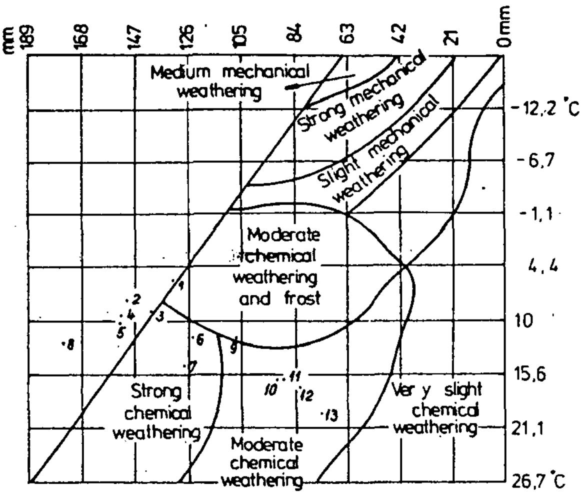
1 - Vf. Omu ; 2 - Ţarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuţi ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băişoara ;
10 - Topliţa ; 11 - Miercurea - Ciuc ; 12 - Petroşani ; 13 - Bozovici .

(d)



1 - Vf. Omu ; 2 - Ţarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuţi ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băişoara ;
10 - Topliţa ; 11 - Miercurea-Ciuc ; 12 - Petroşani ; 13 - Bozovici .

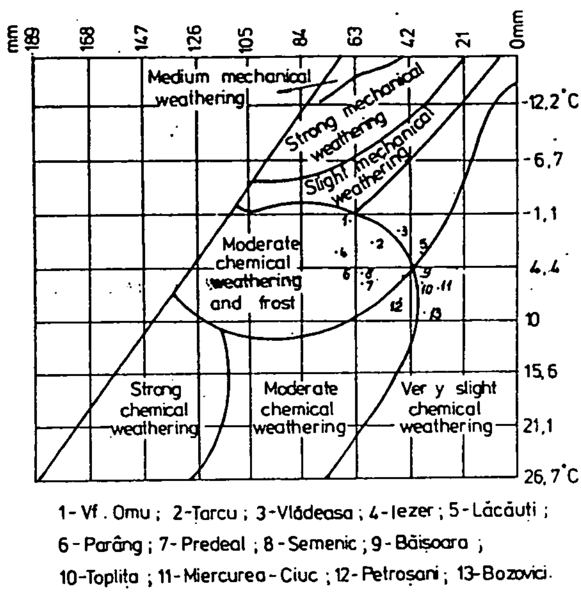
(a)



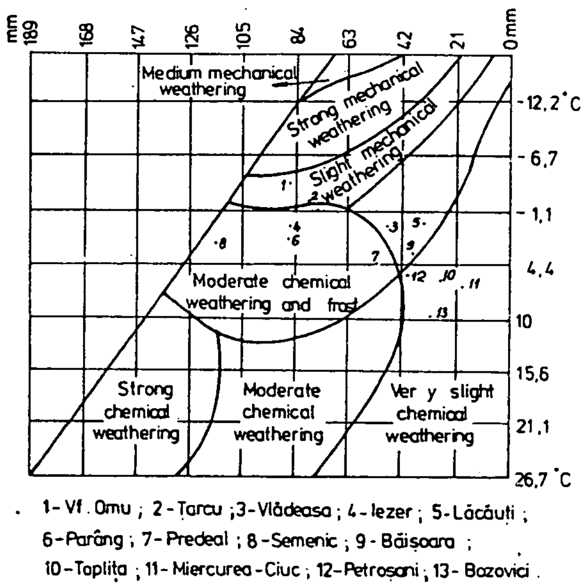
(b)

1 - Vf. Omu ; 2 - Ţarcu ; 3 - Vlădeasa ; 4 - Iezer ; 5 - Lăcăuţi ;
6 - Parâng ; 7 - Predeal ; 8 - Semenic ; 9 - Băişoara ;
10 - Topliţa ; 11 - Miercurea - Ciuc ; 12 - Petroşani ; 13 - Bozovici .

Fig. 7 The type and the intensity of the predominant processes, after a Peltier diagram, for the months January (a), July (b), April (c) and October (d)


mm
189
168
147
126
105
84
63
42
21
0mm
Medium mechanical weathering
Strong mechanical weathering
Slight mechanical weathering
Moderate chemical weathering and frost
Strong chemical weathering
Moderate chemical weathering
Very slight chemical weathering
-12,2°C
-6,7
-1,1
4,4
10
15,6
21,1
26,7°C
1- Vf. Omu ; 2-Tarcu ; 3-Vlădeasa ; 4-Iezer ; 5-Lăcăuti ;
6-Parâng ; 7-Predeal ; 8-Semenic ; 9-Băişoara ;
10-Toplita ; 11-Miercurea-Ciuc ; 12-Petroşani ; 13-Bozovici.

(c)


mm
189
168
147
126
105
84
63
42
21
0mm
Medium mechanical weathering
Strong mechanical weathering
Slight mechanical weathering
Moderate chemical weathering and frost
Strong chemical weathering
Moderate chemical weathering
Very slight chemical weathering
-12,2°C
-6,7
-1,1
4,4
10
15,6
21,1
26,7°C
1- Vf. Omu ; 2-Tarcu ; 3-Vlădeasa ; 4-Iezer ; 5-Lăcăuti ;
6-Parâng ; 7-Predeal ; 8-Semenic ; 9-Băişoara ;
10-Toplita ; 11-Miercurea-Ciuc ; 12-Petroşani ; 13-Bozovici.

(d)

(ii) the fluvial action is maximum in the forest belt and moderate in the other belts (*Fig. 6b*);

(iii) the predominant processes is the chemical alteration which is strong (Parang, Predeal) and moderate for the rest (*Fig. 7b*).

In April, the increase of the temperatures and the precipitations in liquid state create conditions specific to:

(i) the morphoclimatic conditions define the periglacial system at Omu, the boreal system at Tarcu and Iezer, the semiarid system in depression (Bozovici, Miercurea Ciuc) and the temperate system in the rest (*Fig. 5c*);

(ii) the fluvial action is moderate at Omu, situated upper than the level of maximum precipitations and snow layer is still present, and Semenic, with losses through evaporation, and maximum at the rest of stations, because of the liquid precipitations added to the melt of the snow (*Fig. 6c*);

(iii) the morphogenetic processes are: the chemical alteration which is moderate in the alpine, subalpine and forest belts, minimum in depression and corridor and the minimum mechanical weathering in the seminival belt (*Fig. 7c*).

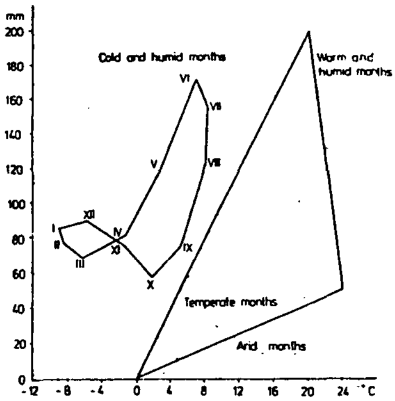
In October temperatures and precipitations define the temperate system (*Fig. 5d*), the fluival action is maximum (*Fig. 6d*), and the chemical alteration is the predominant process and it is minimum in the depressiom (Bozovici, Miercurea Ciuc) and moderate in the upper belts (*Fig. 7d*).

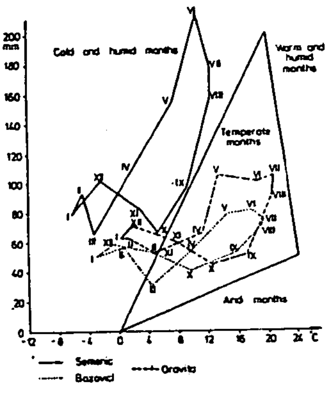
Based on the mathematical correlation of temperature and precipitations, the Pégui diagrams classify the months in cold and humid, temperate and arid, warm and humid (*Pégui*, 1961).

Thus, at Omu and Tarcu stations, all the months are „cold and humid" and this justifies their affiliation to the periglacial morphoclimatic system. At other stations (e.g. Predeal, Parang, Petrosani, Baisoara) more months are „temperate" and the higher values of temperature make the chemical alterations more intensive (*Fig. 8*).

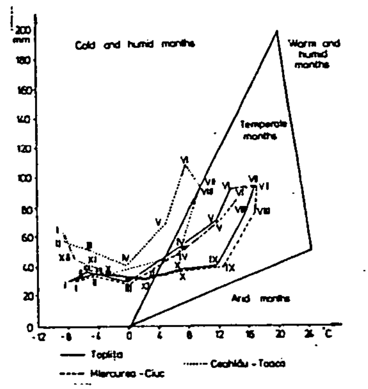
Fig. 8 Pégui climatograms for meteorological stations from Romanian Carpathians

(a)

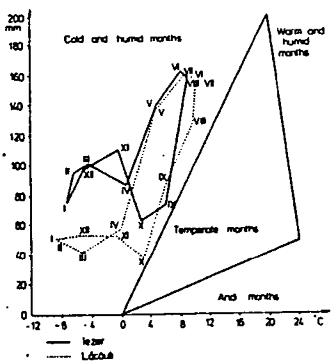



Cold and humid months
Warm and humid months
Temperate months
Arid months
mm
°C
Semenic
Oravita
Bozovici

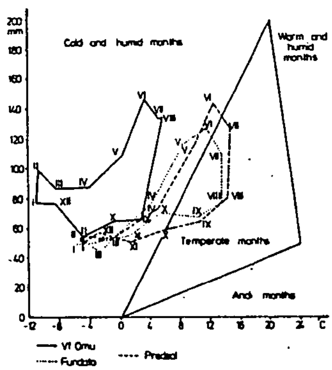
(b)


Cold and humid months
Warm and humid months
Temperate months
Arid months
mm
°C
Toplita
Ceahlău - Toaca
Miercurea - Ciuc

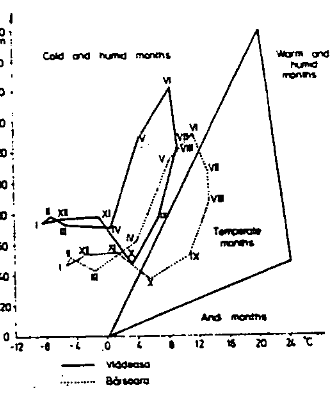
(c)


Cold and humid months
Warm and humid months
Temperate months
Arid months
mm
°C
Iezer
Lăcăuţ

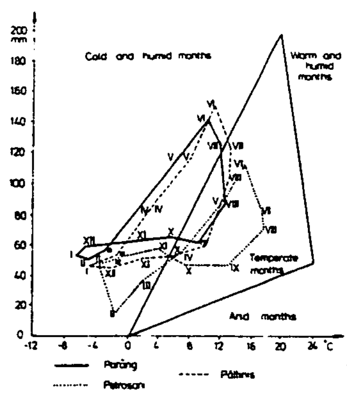
(d)


Cold and humid months
Warm and humid months
Temperate months
Arid months
mm
°C
Vf Omu
Predeal
Fundata

(e)


Cold and humid months
Warm and humid months
Temperate months
Arid months
mm
°C
Vlădeasa
Bărsoara

(f)


Cold and humid months
Warm and humid months
Temperate months
Arid months
mm
°C
Parâng
Păltiniş
Petroşani

(g)

The graphic representation of the minimum and maximum temperatures outlines the intervals with freezing-thawing cycles and the interval with negative temperatures (*Fig. 9*). We can note that higher is the altitude of the stations, the longer and latter is the interval with freezing-thawing cycles. The intervals with negative temperatures, which indicate very favourable conditions for the maintenance of permafrost (*Urdea*, 1993), have durations directly proprortional to altitude.

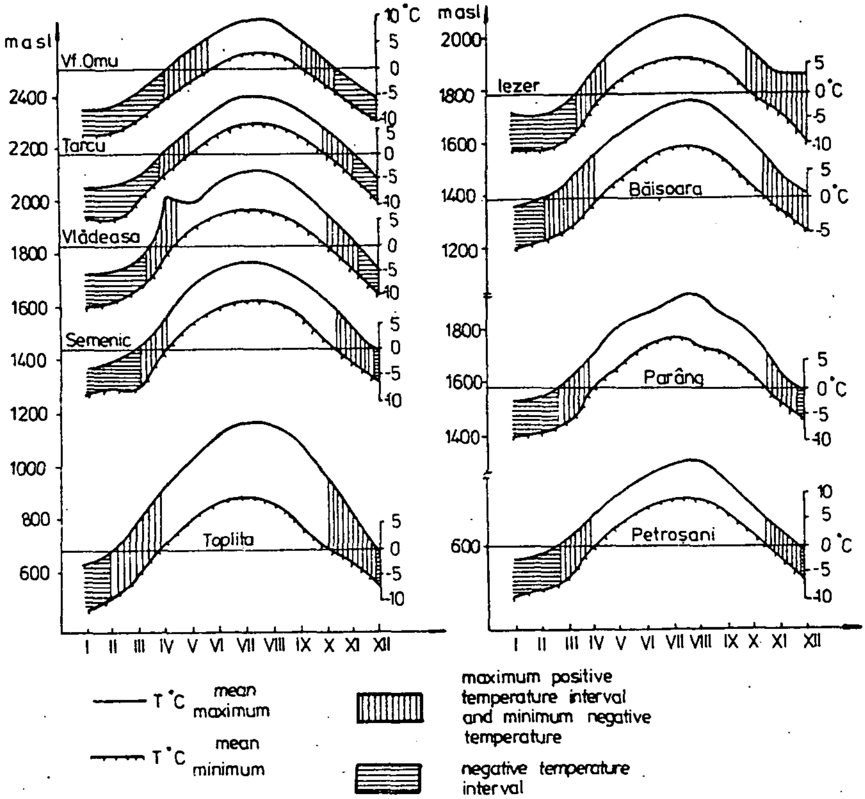


Fig. 9 Mean maximum and minimum air temperatures and characteristic intervals for some meteorological stations from Romanian Carpathians

The box-plot of monthly temperatures at selected meteorological stations from the Romanian Carpathians gives the range in monthly air temperatures during the year, conditions characteristic for most stations from this area (*Fig. 10*).

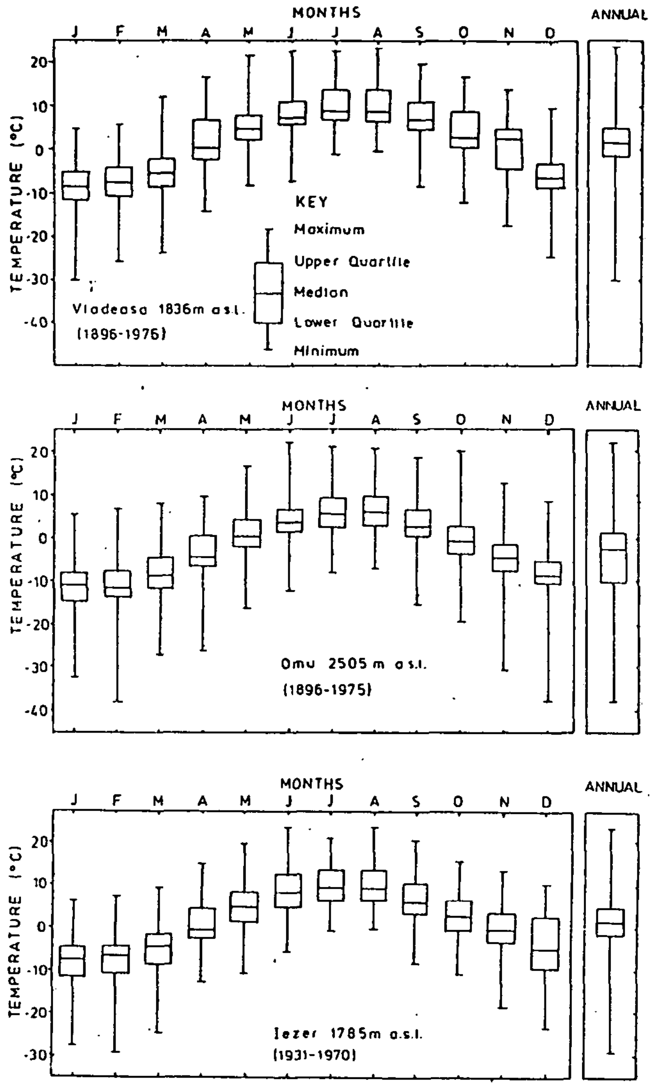


Fig. 10 Box-plots of the distribution in monthly temperatures, at some selected meteorological stations from the Romanian Carpathians

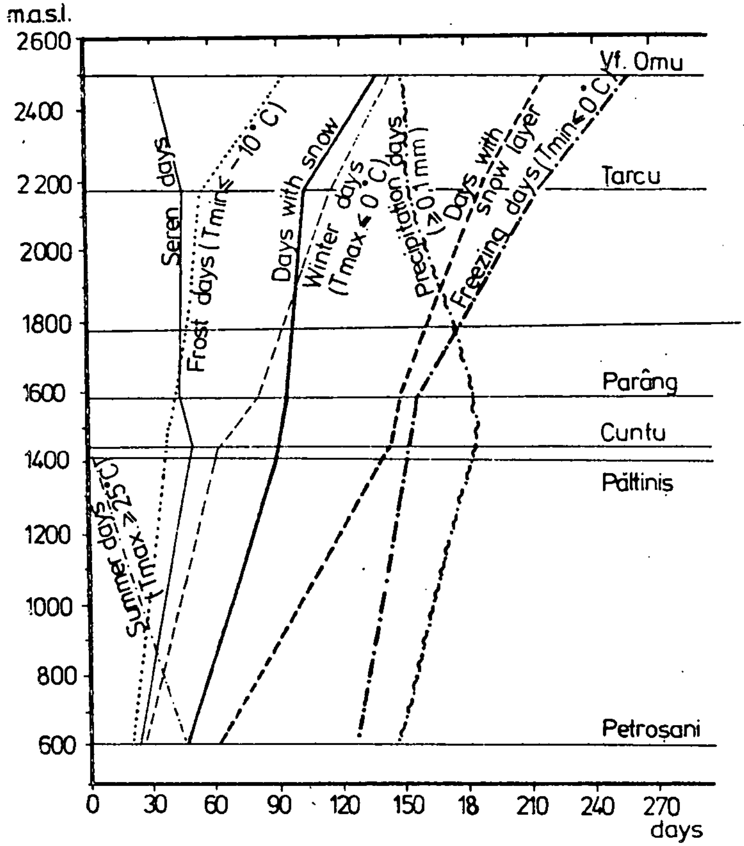


Fig. 11 „Daily characteristics" for some selected stations from Romanian Carpathians

Very useful in the geomorphological research is the study of the „characteristic days" (*Urdea*, 1992) whose names give informations about temperatures – „summer days", „winter days" – precipitations – „days with snow", „precipitation days" – or processes – „freezing days", days with snow layer". Generally, the number of the characteristic days increases with altitude, the exceptions are: the summer days, which disappear upper than 1500 m, and the precipitations days, which decrease upper than the maximum level of precipitations situated at 1500 m (*Fig. 11*).

The morphoclimatical conditions influence, as we have already said, the intensity of processes: but the resultant forms depend, to a great extent, an different local faxtors (rock, degree of wethering, biological component, etc.).

However, we considered that the graphic representations of climatological data lead to relevant conclusions and can be an useful instrument both at the beginning and at the end of a geomorphological research.

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ACTA CLIMATOLOGICA
Universitatis Szegediensis, Tom. 28-29., 1995.

TEMPERATURE INVERSION IN THE CSÍK BASIN

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Hőmérsékleti inverzió a Csíki-medencében

A Csíki-medence a Keleti-Kárpátok központi részében, Hargita megye délkeleti részén fekszik. Nyugaton a Hargita-hegység, keleten a Csíki-havasok és a Nagyhagymás déli része határolják. Átlagos tengerszint feletti magassága 650-700m. A Csíki-medence azon medencék egyike, amelyekben az év különböző időszakaiban a hideg légtömegek sokáig stagnálhatnak. A melegebb légtömegek a medencében lévő hideg levegőréteg felett helyezkednek el és így kialakul a hőmérsékleti inverzió. A legnagyobb időtartamú és intenzitású inverziók télen, januárban fordulnak elő, amikor átlagosan 10-16 napot tesznek ki. A leghosszabb feljegyzett inverzió 22 napos volt és 1956 február 5-27. között észlelték. Az intenzitást, ami elérheti a 10 °C-t, elősegíti az éjszakai hőkisugárzás is. A legvastagabb inverziós réteg (100-200m) ugyancsak a januárra jellemző. Az inverzió kísérője a köd, amelyből a medence lakói következtetni tudnak az inverzió jelenlétére. A medence klímájának másik jellemzője a szélcsend, ami elősegíti a levegő stagnálását. A Csíki-medence éghajlatának ismerete nemcsak tudományos, hanem gyakorlati jelentőséggel is bír, lévén, hogy nagyban befolyásolja az alacsony hőmérsékletek megjelenését, ami a maga során meghatározó az élővilág, a gazdaság és a lakosság egészségi állapotára.

The Csík Basin is situated in the middle section of the Oriental Carpathians as well as in the south-east of Hargita County, between the Hargita Mountain in the west and the southern part of the Nagyhagymás Mountain and the Csiki Mountain, at average height of 650-700m above sea level. The Csík Depresson is one of those intramountaneous basins where during particular periods of the year the cold masses of air can stagnate for long. The warmer air from the surrounding higher parts takes place above the colder and denser air of the basin and as a result a temperature inversion appears. The longest and most stable inversion can be observed during the winter months, especially in January, in average 10-16 days. In this time of the year the synoptic conditions are characterised by high pressure and cold continental air which stagnates in the basin. In winter the intensity, which can reach 10 °C, as well as the frequency are increased by the heat radiation during clear nights. The thickest layer of air (100-200m) with temperatures of inversion can also be observed in January. A characteristic phenomenon from which the inhabitants of the depression can deduct the presence of inversion is the fog that develops as a result of the condensation of the humidity of the air as it reaches the cold surface. The knowledge of this climatic peculiarity in the Csík Basin is important not only from the scientific point of view but also from the practical one as during the inversion the lowest temperatures appear which influence the living world, different branches of the economy as well as the health of the population through promoting the accumulation and stagnation of the noxes in the basin.

Key-words: Csík Basin, near-surface inversion, air pollution, air stagnation (calm), foggy days, air humidity, influence on the living world, economy and health

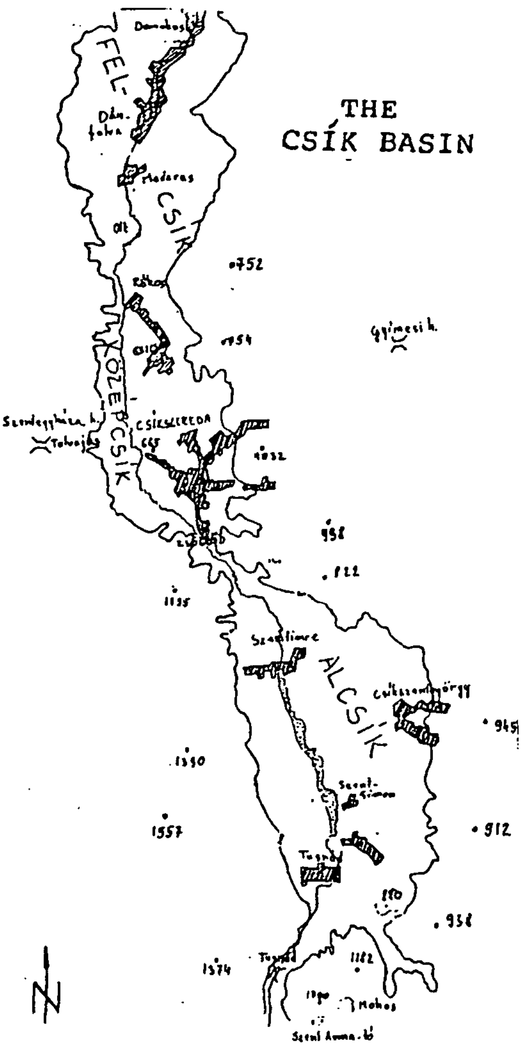

Fig. 1 The geographical situation of the Csík Basin (Romania)

The Csík Basin is situated in the middle section of the Oriental Carpathians as well as in the south-east of Hargita County, between the Hargita Mountain in the west and the southern part of Nagyhagymás Mountain and the Csíki mountains at 650–700 m average height above sea level. Its coordinates are the 25° 50' eastern longitude and the 46° 20' northern latitude. Its geology is made up of volcanic and fluvial sediments which formed a 300–800 m thick layer. Its most important river is the Olt along which, in the lowest parts of the basin large eutrophic swamps and turbaries formed.

The climate of the basin is made special by the mountains situated perpendicularly to the direction of the general atmospheric circulation. The mean annual temperature is 5.8 °C, the average annual precipitation is 540 mm, which is 3 °C and 100 mm less than is Székelyudvarhely, situated in the same conditions except for it is not surrounded by mountains from west. Because of the tectonic thresholds from Csíkrákos and Csíkzsögöd, from north to south the three definite parts of the basin : Felcsík, Középcsík and Alcsík (Upper-, Middle- and Lower Csík) are clearly individualized.

The only meteorological center of the basin is functioning since 1955 in Csíkszereda. Placed in the northern part of the town on 661 m height above sea level it has the 46° 22' and 25° 44' coordinates.

The Csík Depression is one of those intramountainous basins where during particular periods of the year the cold masses of air can stagnate for long. The warmer air from the sorrounding higher parts takes place above the colder and denser air of the basin and as a result the temperature inversion appears.

In the Csík Basin the temperature inversion is characteristic not only through its duration and intensity but also through its frequency, as the local conditions make possible its development in any season of the year. The inversion can be pointed out especially on the basis of air temperature. However it is very difficult to analyse such a complex natural phenomenon without stepped meteorological centers and aerological measurements. Because there is a lack of such data we can analyse the temperature inversion taking into account the practical observations, number of sunny hours and foggy days as well as the frequency of winds of different directions and the lull.

The longest and most stable inversion can be observed during the winter mounths, especially in January, 10–16 days on average. In this time of the year the synoptic conditions are characterized by high pressure and cold continental air from north-north-west which enter the depression and stagnate. In this season the intensity, which can reach 10 °C, as well as the frequency are increased by the heat radiation during clear nights helped by the blanket of snow which cools even more the cold and dense air which flows from the surrounding mountains. The thickest (100–200 m) layers of air with temperatures of inversion can also be observed during January.

During the summer because of the shortness of the nights, the high specific heat of soil and the high frequency of breezes the night radiations have much less effect, thus the summer layers of inversion are very thin.

In spring and autumn the rarity inversion is caused by the great instability of the masses of air. In autumn the inversion can be observed in 5–6 days on average, while in spring only in 2–3 days.

Except for the winter, when the inversion is longer, the phenomenon begins to develop in the first hours after midnight, it has the highest frequency in the morning hours and are quite rare during the midday hours when the sun warms the soil and air.

Depending on the synoptic conditions the duration of the temperature inversion can go from hours to days. When the invasion of the cold continental mass of air lasts long the inversion can last for weeks. The longest registered inversion was 22 days long between 5–27 February 1956 but inversions of such duration are fairly rare.

A characteristic phenomenon that follows and of which the inhabilitants of the depression deduct the presence of inversion is the fog that develops as a result of condensation of the humidity of the air as it reaches the cold surface. The thickness of the foggy layer depends on how intense the inversion is.

The most frequent inversions can be observed in Alcsík and Középcsík because Felcsík is situated above the fog which shows the inversion.

The diffence between the temperatures from above and below the inversion layer can also influence the physical condition of the precipitation. As a consequence it happens quite often that while in the depression it is snowing on the surrounding hights it is raining.

An important characteristic of the climate of the depression is the calm which has the highest extent during winter: 62.5% on average, while in January 64.2%. This is the reason why the foggy layer does not dissipate until another mass of air moves it out of the depression. This stillness is explained by the fact that the warmer layer of the inversion situated above the cold one prevents the convection.

The unfiltered smoke coming out of the chimneys of factories and plants ascend only to this limit and then it spreads horizontally as the vertical dispersion is impossible. This polluted stratum can be well observed from the adequate heights of the surrounding mountains. Just like the smoke the fog also ascends only to the lower part of the warm stratum. This is shown by the adaptation of the natural vegetation : at the height of the warm air there can be found the broad-leaved forests (beech trees), while the pine trees live in the lower, colder parts of the depression.

The knowledge of this climatic peculiarity of the Csík Basin is important not only from scientific point of view but also from the practical one as during the inversion appear the lowest temperatures which influence the living world, different branches of the economy as well as the health state of the population through promoting the accumulation and stagnation of the noxes.

Because of the inversion the sunny hours in the depression decrease very much (on average 1778 hours/year, minimum 50 in December; maximum 230 in July) but the number of foggy days is greatly increased (on average 82 days, but in 1980 there were registered 152 foggy days) as well as the relative humidity content of the air (there are many days in which it is over 74%, the maximums being registered in winter: 86–89%).

Measurements of the quality of the air are made in Csíkszereda. The SO, NO, and NH content are measured in the western industrial part of the town and at the Environmental Agency. The content of ammonia in the air in the industrial district is only 1% over the allowable value. It is to be noted that the polluting enterprises do not have aerological laboratories and that their filters do not work.

Another negative phenomenon in the town is the lack of green belts which should be planted between the industrial and the housing zones because the western industrial zone is situated in the way of the movement of the air so the polluted air is directed over the town. In spite of this there cannot be noticed differences in the demographic factors between the polluted and clean zones. The required calculations at the Health Center of Csíkszereda however, show that especially the respiratory and circulatory diseases and cancerous cases are increasing: in 1985 one of 65 people, while in 1989 one of 37 people was ill. The increase of cancerous diseases is the following: in 1985 one of 632 people, while in 1988 one of 439 people had the disease.

These facts show that preserving our relatively pure environment in its actual state and also its improvement must be considered of major importance no matter how confusing and hard our present day economical problems are.

ACTA CLIMATOLOGICA
Universitatis Szegediensis, Tom. 28-29., 1995.

MICROCLIMATE INVESTIGATIONS IN AND NEAR THE FOREST OF ÁSOTTHALOM

by

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Mikroklíma vizsgálatok az Ásotthalom környéki erdőben és közelében

1994. szeptember 5-10. között óránkénti mérések történtek az Ásotthalom környékén fekvő erdőben és ennek közelében, három különböző mérőpontban: 1. nyílt terepen, 2. tűlevelű és 3. lombhullató erdőben. Jelen dolgozatban a léghőmérséklet, relatív nedvesség és talajközeli szélsebesség adatait hasonlítottuk össze a három különböző helyen végzett mérések alapján. Az adatokban jól tükröződik az erdő mérséklő hatása, továbbá a szélsebesség növekedésekor az esti, illetve éjszakai időszakban bekövetkező hirtelen változás a relatív nedvességben és a léghőmérsékletben.

A series of hourly observations were made in and near the forest of Ásotthalom between 5-10-th September 1994 at three different sites, namely: 1. open space, 2. pine forest and 3. deciduous forest. In present paper the air temperature, the relative humidity and near surface wind speed observations were compared taken into account differences among the data obtained from three different sites. The moderating effect of forest was clearly mirrored in data as well as rapid changes in ralative humidity and air temperature as consequence of increasing wind speed durind twilight or night hours.

Key-words: microclimate, pine and deciduous forest, rapid changes in relative humidity and air temperature

INTRODUCTION

A field expedition was carried out by students of József Attila University of Szeged in period of 5–10-th September 1994, in and near the forest of Ásotthalom. Hourly measurements were made in 120 hour period including air temperature, relative humidity, wind speed (in km/h) and soil temperatures at 2, 5, 10 and 20 cm depths. The purpose of this paper is to point out microclimatic characteristics of different sites, namely: 1. open space, about 100 m distance from the forest, 2. pine forest, without clearing in its closest vicinity, 3. deciduous forest about 10 m distance from a small clearing. The soil temperature measurements are excluded from present investigation. The woodlands of Ásotthalom is about 30 km west of Szeged. It was planted first in early 20-th century and its present extension might estimated several square km. The forest consists of numerous types of trees, like locusts, birches, oaks, pines etc. The forest area is interrupted by clearings of very different sizes, thus it is an ideal field for investigation microclimatic characteristics.

The weather during the expedition was mostly calm, cloudless and sunny with few cumulus or cirrus, except the last day, when it turned cloudy or overcast with rain. Thus this weather was rather favourable for observation of microclimatic differences forming in undisturbed radiation. The measurements were continuous day and night at each of the mentioned three spots. The expedition was organized and supervised by Department of Climatology of the University.

COMPARISON OF MICROCLIMATIC CHARACTERISTICS

As it has been expected, the extreme values of wind speed, daily variations in air temperature as well as in relative humidity were observed at spot located in open space area. The temperature variations based on hourly measurements are presented in *Fig. 1.* Apperent extreme daily maxima and minima occured in open space area mainly 6-th, 7-th and 8-th September due to undisturbed radiation conditions. In 9-th September in late afternoon increasing cloudiness indicated the weather front having passed over the area and accompanied by rain of medium intensity in night and early hours of 10-th September. Hence the differences in meteorological elements among the open space and forest became insignificant.

Noticeable changes occured in afternoon of 6-th and at midnight of 8–9-th September in air temperature as well as in relative humidity. Namely the wind speed forced up to 7.6 km/h in open space area, 2.3 km/h and 3 km/h in forest observation

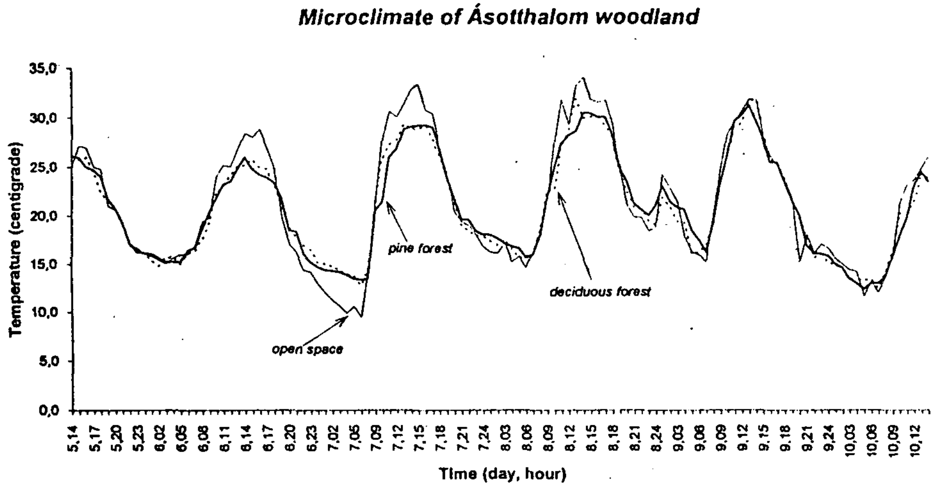

Fig. 1 Hourly air temperature observations in Ásotthalom woodland, about 30 km west of Szeged from 5 to 10 September, at three different sites

spots, respectively at 3 p.m. in 6–th September. At the same time the temperature increased and relative humidity decreased. Much more significant and similar phenomenon occured at midnight of 8–9-th September: the wind forced rapidly from 0 to 2.5 km/h in open space area, meanwhile the relative humidity dropped from 94 to 34 per cent in open space spot, and from 84 or 82 to 57 or 56 per cent in the forest. At the same time the air temperature increased suddenly from 18.4 to 24.2 C degrees in open space and from 19 or 20 to 21.8 or 23.0 degrees in the forest into contrast with normal daily variation of these elements (see *Fig. 2* and *3*).

At the first glances the wind speeds seemed very low even in cases of their strengthening. The reason was that the cup anemometers were fixed close to the ground, about at 1.2 m height. Hence the roughness of the ground (small dunes, sand hills) has had especially braking deffect on the air motions. Evidently the wind speed must have increased rapidly in higher air-layers, and has grown by several times stronger at 15–20 m, i.e. on the top of woodlands.

The temperature maxima measured by maximum thermometers were as follow:

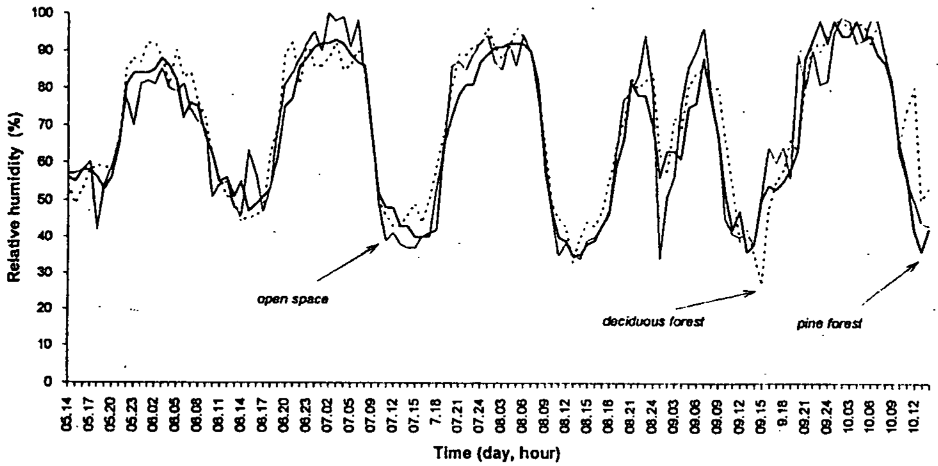

Fig. 2 Hourly relative humidity observations; the time and locations are the same as in *Fig. 1*

	5.	6.	7.	8.	9.	10.	September, 1994
open space	29.5	31.0	35.0	34.5	34.5	26.5	C degrees
pine forest	27.6	28.0	32.2	30.2	30.2	23.9	"
deciduous forest	27.6	28.0	32.6	30.5	30.9	24.3	"

The maxima were higher by 2–4 C degrees in open space, than in the forest, and up to 0.7 C degrees higher in deciduous forest, than in pine forest. The latter slight surplus might be explained by small clearing close to the spot in deciduous forest.

The daily variations in relative humidity were normal with maxima at nights, and minima in the afternoons except the midnight of 8–9-th September, when it dropped rapidly due to awakening wind, which swept up the inversion in lower layers. The differences between open space forest in relative humidities are not quite consequent. Nevertheless in some cases (e.g. in 6–7, 8–9 September) the greatest daily variations occured in open space, in other cases (e.g. at night 5–6, 7–8, in the afternoon of 9-th September) extreme values were observed in deciduous forest (see *Fig. 2*).

The awakening winds were always strongest in the open space spot and reached its maximum (about 10 km/h) at 9 o'clock p.m. in 9-th September, when a weather front passed through the area. The difference of wind speed between open space and forest is completely convincing. It was pointed out that the maxima of wind-speed usually occured around noon between 10 a.m. and 3 p.m., except the case of passing through front in 9-th September (*Fig. 3*). So it was proved that in undisturbed background situation the wind speed exhibits a clear daily variation with moderate strengthening around noon and almost completely calm weather at night.

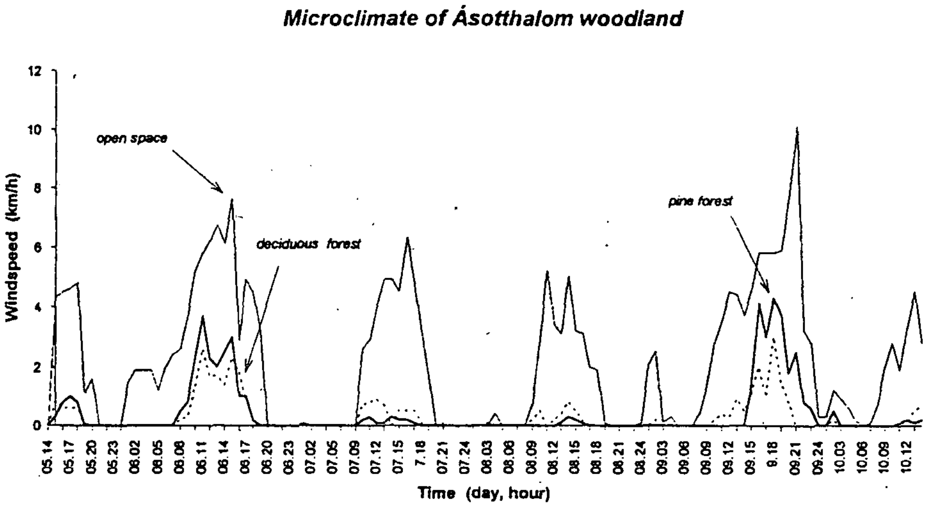

Fig. 3 Hourly windspeed observations about 1.2 m above the ground: the time and location are the same as in *Fig. 1*

It is noteworthy to mention that the observations took place nearly one km far from the nearest village, Ásotthalom, and surrounded by woodlands. So the influence of the village was absolutely out of question. This expedition has been the first one in this area and its repeat is expected in coming years. Similar investigations of microclimate had been completed in 1950-s and 1960-s by professor R. Wagner, previous head of Department of Climatology at József Attila University of Szeged, but in quite different areas, like Mountain Bükk in northern part Hungary and partly in Great Hungarian Plain (*Wagner*, 1959, 1963, 1969, 1970; *Kiss*, 1959; *Oberska-Starkel*, 1970; *Boros and Suhai*, 1970). It is hoped that the continuation of such investigations will yield more and more new knowledge on the microclimate making enable the analysis of different heat and air moisture balance under different microclimatic conditions.

Acknowledgements

The author expresses his gratitude to *dr. János Unger*, senior lecturer and *Miss Judit Ondok* graduated student for their precious help in elaboration of data and design of figures in this paper.

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ACTA CLIMATOLOGICA
Universitatis Szegediensis, Tom. 28–29., 1995.

PERSISTENCE PROBABILITY OF THE DROUGHT INDEX MADE BY PÁLFAI FOR FIVE REGIONS OF THE HUNGARIAN GREAT PLAIN

by

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A Pálfai-féle aszály-index megmaradási hajlama a magyar Nagyalföld öt körzetében

E dolgozatban szerzők egy speciális aszály-index (*PAI*) statisztikai jellemzőit vizsgálták az 1901–1992 közötti időszakra. Kiszámították a 92 éves átlagokat a Magyar Alföld 5 régiójára. Ezt követően megmaradási valószínűségeket definiáltak külön-külön, azon esetekre, amikor a kiindulási év száraz, illetve nedves volt – három különböző módon: 1. elméleti valószínűségeket határoztak meg (*E*), függetlenséget feltételezve az egymást követő évek között, 2. kiszámították az anomália előjelének megmaradását (*A*), 3. s az anomália előjelének megmaradását abban az esetben, ha a kiindulási év nagyon nedves volt (alsó kvartilis, Q_1), vagy nagyon száraz volt (felső kvartilis, Q_4). Az eredményeknek prognosztikai értékük lehet néhány esetben a Magyar Alföld egyes régióiban.

With making use of a special drought index (*PAI*), the authors investigated its statistical characteristics for a period of 1901–1992. For five regions of the Hungarian Great Plain the 92 year averages were calculated. Then the persistence probabilities were determined if an initial year was wet or dry, respectively, in three different ways: 1. theoretical probabilities, assuming independence between successive years (*E*), 2. the persistence of sign of anomaly (*A*), 3. the persistence of sign of anomaly if the initial year was very wet (lower quartile, Q_1) or very dry (higher quartile, Q_4). The results may yield prognostic value in some cases and some regions of the Hungarian Great Plain.

Key-words: drought index, prediction of drought, persistence probability

INTRODUCTION

Pálfai (1988) developed an index (PAI) for characterizing drought which takes into consideration on the one hand mean temperature of the vegetation period (April-August), on the other hand total precipitation during the vegetation period and the previous months. Its definition is as follows.

$$PAI = 100 * t_{IV-VIII}/P_{X-VIII}$$

where *PAI* – drought index (centigrade per 100 mm)
$t_{IV-VIII}$ – mean temperature of the period between April–August
P_{X-VIII} – weighted precipitation amount of the period between October–August.

The weighted coefficients are as follows. October: 0.1, November: 0.4, December–April: 0.5, May: 0.8, June: 1.2, July: 1.6, August: 0.9.

As it has been established (*Pálfai and Boga*, 1992; *Koppány and Csikász*, 1994), both the drought index and the aridity index of Budyko show that the Hungarian Great Plain, mainly the middle part of this region, is the most arid region of Hungary. This is why the examination of the PAI – drought indices was limited for the Hungarian Great Plain and a little eastern part of Transdanubia (*Pálfai, Boga and Lábdi*, 1993, 1994). The Hungarian Great Plain was divided into 5 regions and mean *PAI* – drought indices were determined for these regions, respectively.

In order to predict dry and wet years the first step is considered to investigate persistence probability. The time series of *PAI* – drought indices for the period of 1901–92 are used as data base in this paper.

METHOD

Means of *PAI* – drought indices for the period of 1901–1992 are determined separately for 5 regions of the Hungarian Great Plain (Nyírség–Szabolcs, North Transtiszania, Northern part between Danube and Tisza, Southern part between Danube and Tisza, South Transtiszania, *Fig. 1*). After this, probabilities (frequencies) were counted for the *PAI* – drought indices to be lower than mean (wet year) or higher than mean (dry year). On the basis of substituting extreme precipitation and temperature data into the *PAI*-formula, it can be stated that drought index is dependent mainly on

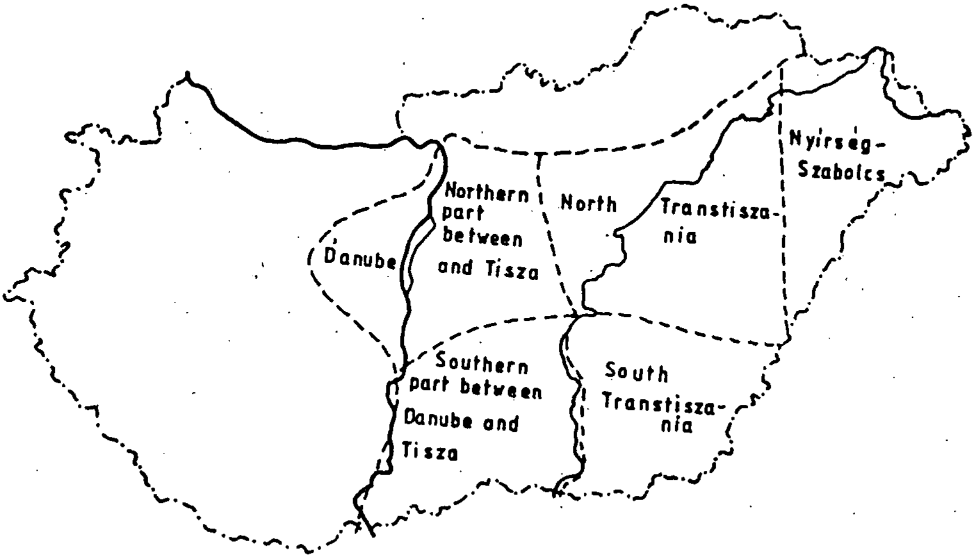

Fig. 1 The examined regions in the Hungarian Great Plain

precipitation. Consequently monthly sums of precipitation fluctuate within much wider limits than mean monthly temperatures. After this, rank-analysis of PAI – drought indices was performed. In this way it was possible to determine lower and higher quartiles for each of these 5 regions.

Taking into consideration basic probabilities of wet years ($PAI < PAI_{mean}$) as well as dry years ($PAI > PAI_{mean}$) theoretical persistence probabilities were counted for one, two, three, four, five successive years following wet or dry years, assuming independence. The used formula was as follows:

$$q_i = q^{i+1}$$

where q_i is probability of the event with q basic probability in the i-th year following the initial year.

Question is as follows. After a wet or dry year – in comparison with theoretical possibility – what is the probability of continuing the series of wet or dry years: 1. if the PAI – drought index is lower (wet year) or higher (dry year) than the 92-yearly mean, 2. if the *PAI* – drought index is in the interval of the lower quartile (Q_1 : very wet year) or in the interval of the higher quartile (Q_4 : very dry year) in the initial year.

RESULTS

Table 1 shows *PAI* – drought indices for the 5 regions of the Hungarian Great Plain, as well as lower and higher quartiles (Q_1 and Q_4) furthermore basic probabilities of wet and dry years.

Table 1
Basic statistics for the examined 5 regions of the Hungarian Great Plain (1901–1992)

	Nyírség–Szabolcs	North Transtiszania	Northern part between Danube and Tisza	Southern part between Danube and Tisza	South Trans-tiszania
PAI_{mean}	4.49	5.1	4.97	5.02	5.09
Q_1	3.46	4.07	4.05	4.0	4.02
Q_4	5.42	6.08	5.7	5.79	5.9
wet year, basic probability	0.56	0.55	0.55	0.54	0.51
dry year, basic probability	0.44	0.45	0.45	0.46	0.49

It can be established that for the examined 92-year period the least arid region was Nyírség–Szabolcs but the most arid one was Transtiszania. It is apparent that frequency of wet years is higher than that of dry years in each region. The asymmetry is lowest in the region of South Transtiszania but highest in Nyírség–Szabolcs.

Fig. 2a–e show probabilities counted for each region. In those years which were considered only by the sign of anomaly of their *PAI*-drought index, but not by the value of anomaly, persistence probabilities are shown by diagrams marked with *A*. Diagrams marked with Q_1 or Q_4 show persistence probabilities of years, *PAI* – drought indices of which can be found in the intervals of lower or higher quartiles (very wet or very dry years).

According to the examinations actual persistence probabilities are well higher than values to be expected theoretically (*E*), for almost each region. Actual persistence probabilities are extremely high in the first and second year, in comparison with theoretical persistence probabilities. In the third year actual persistence probabilities generally decrease significantly and hardly differ from values to be expected theoretically, except South Transtiszania and following wet years Southern part between Danube and Tisza, North Transtiszania as well as Northern part between Danube and Tisza. In the fourth and fifth years actual persistence probabilities decrease below 0.1 , except the region of South Transtiszania (see *Table 2*).

Table 2

Persistence probabilities following the years of lower quartile (Q_1) as well as higher quartile (Q_4) (1901–1992)

Nyírség–Szabolcs	North Trans-tiszania	Northern part between Danube and Tisza	Southern part between Danube and Tisza	Souht Trans-tiszania
		Q_1		
1. 0.565	0.61	0.56	0.52	0.56
2. 0.348	0.35	0.39	0.26	0.26
3. 0.174	0.26	0.26	0.13	0.17
4. 0.087	0.087	0.13	0.13	0.086
5. 0.043	0.043	0.04	0.04	0.0
		Q_4		
1. 0.52	0.44	0.44	0.39	0.39
2. 0.26	0.17	0.17	0.17	0.26
3. 0.087	0.0	0.0	0.04	0.17
4. 0.087	0.0	0.0	0.0	0.13
5. 0.0	0.0	0.0	0.0	0.087

By the help of *Fig. 2* and *Table 2* statistical predictions can be performed in some cases considering drought. In the first year following a wet one *PAI* – drought index lower than mean can be expected with a probability of 57–60% in the regions of Nyírség–Szabolcs, North Transtiszania and Northern part between Danube and Tisza.

Values of persistence probabilities do not differ significantly following years which belong to A and Q_i categories. Persistence probabilities for wet years decrease remarkably in the third year, even much more for further years. In the regions of South Transtiszania and Southern part between Danube and Tisza values of persistence probability for wet years are generally well higher in the first, second and third year than values to be expected theoretically. Probability of four successive wet years is practically 0, or very low (but in the region of Northern part between Danube and Tisza this value is 26%).

In years following dry years probability of arid (dryer than mean) weather is well over the value to be expected theoretically, but persistence probability of it is much lower than in case of wet years. Practically it cannot be expected for the series of dry years to continue for four successive years – only the region of South Transtiszania has a remarkable probability (13–20%) for persistence of arid (dryer than mean) years for four successive years.

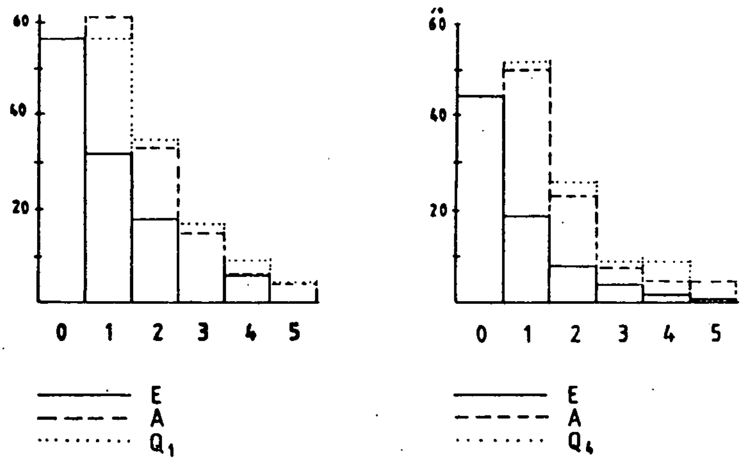

Fig. 2a Persistence probability of the PAI-drought indices in the region of Nyírség–Szabolcs (1901–1992)

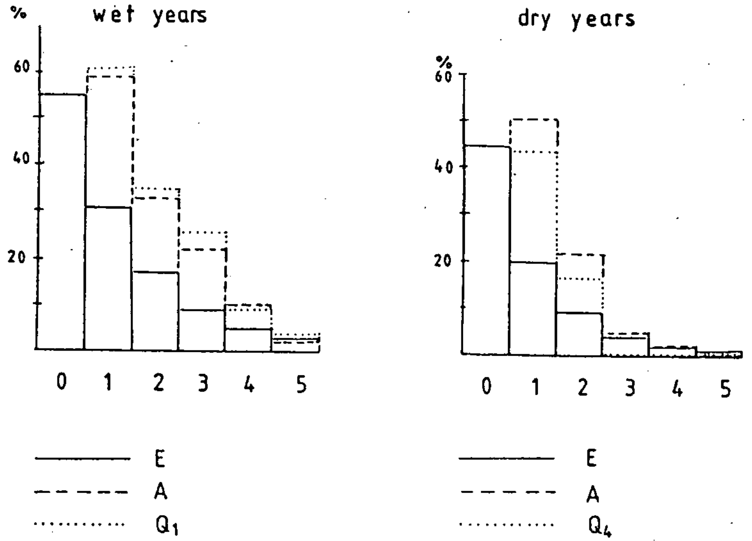

Fig. 2b Persistence probability of the PAI-drought indices in the region of North Transtiszania (1901–1992)

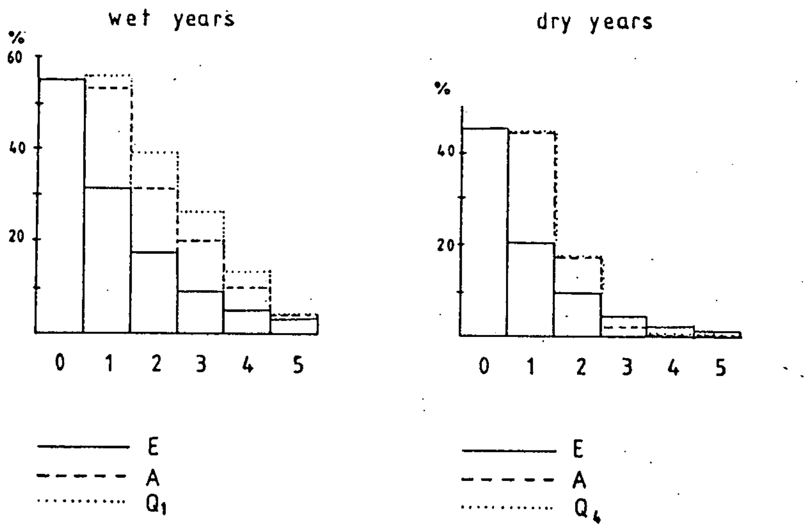

Fig. 2c Persistence probability of the PAI-drought indices in the region of Northern part between Danube and Tisza (1901–1992)

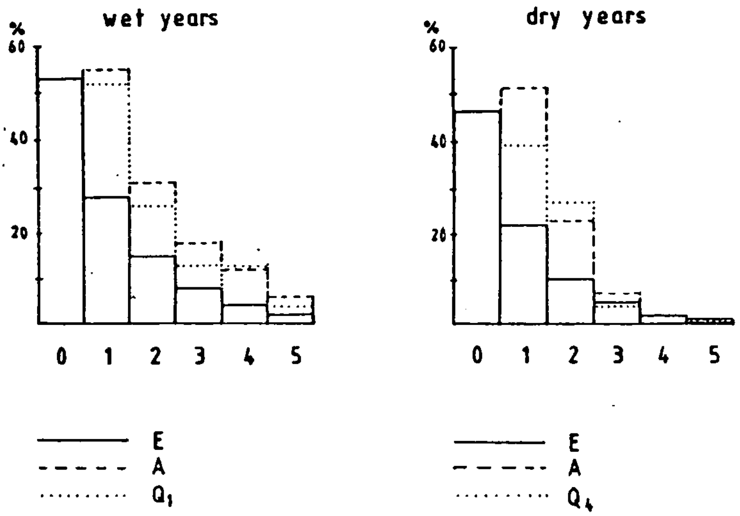

Fig. 2d Persistence probability of the PAI-drought indices in the region of Southern part between Danube and Tisza (1901–1992)

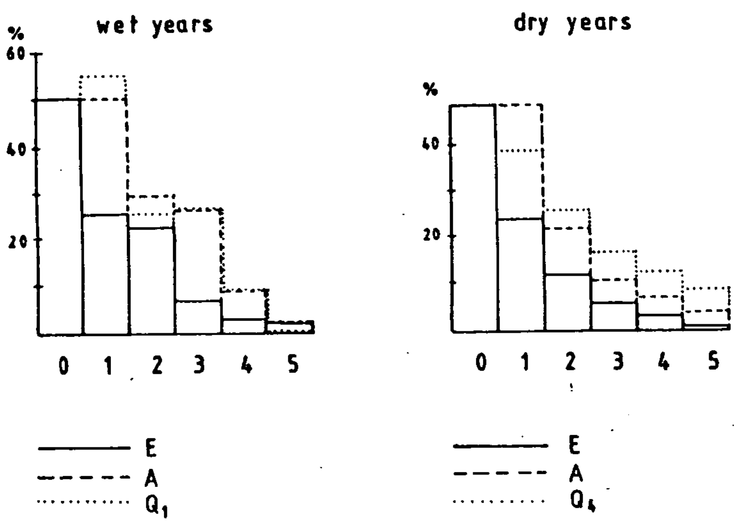

Fig. 2e Persistence probability of the PAI-drought indices in the region of South Transtiszania (1901–1992)

CONCLUSION

According to the experience persistence of wet or dry years is well higher for at least 2–3 successive years following the initial year than values to be expected. High persistence probability for the first year following the initial year, as well as low or 0 probabilities counted for three, four, five successive years can be used for prognostic aims. Namely the latter shows break of the series of anomalies with the same sign, that is to say it shows increased probability of *PAI* – anomaly with opposite sign.

Acknowledgements

This paper was supported by the OTKA Foundation, as the research subject No. T 4115.

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ACTA CLIMATOLOGICA
Universitatis Szegediensis, Tom. 28-29., 1995.

SOME FEATURES OF URBAN INFLUENCE ON TEMPERATURE EXTREMITIES

by
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A város hatása a hőmérsékleti szélsőségekre

A dolgozat a különböző beépítettségű területek hatását elemzi a nyári, téli és fagyos napok számának területi eloszlására, valamint az első és utolsó fagyos nap bekövetkezésének dátumára és a fagymentes időszak hosszára. A vizsgálat a Szegeden működött városi állomáshálózat adatsorain alapul. Az eredmények szerint a területi eloszlások nagymértékben függenek a beépített területek sűrűségétől és építési anyagaitól, továbbá a nagyobb vízfelületek hatása is meglehetősen jelentős.

This paper examines the influence of different built-up areas on the spatial distribution of numbers of summer, winter and frost days, as well as of dates of the last and first frost days and the lengths of the frost-free period. The investigation is based on the data series of an urban station network set up in Szeged, Hungary. The results revealed that the distribution patterns largely depend on the density and the building materials of the built-up areas, furthermore that the influence of large water bodies is rather significant.

Key-words: Urban station network, temperature extremities, spatial distribution, Szeged, Hungary

INTRODUCTION

The investigation of effects modifying climate in human settlements is a very important topic of climatology. During the recent decades the urban areas and the ratio of urban population have grown continuously so the analysis of the modifying effects and their physical explanation are required. There have been several papers, some valuable overviews and books about the results (e.g. *Probáld*, 1974; *Oke*, 1974, 1979; *Landsberg*, 1981) and there are a lot of ways of examination procedures. One way, for example, is the investigation of the date of the last frost day in different parts of the city (*Woollum*, 1964) or of the frequency of days which are interesting in some kind of meteorological aspect. This paper aims to reveal the areal distribution of such climatological indicators.

STUDY AREA AND URBAN STATION NETWORK

Szeged is situated in the south-east of Hungary at 79 m above sea level (46°15'N, 20°09'E). The town and its surroundings are free from orographical effects (altitude differences inside the town are only a few metres) and it is a long way from large water bodies except the River Tisza intersecting the town (*Fig. 1*). So its geographical situation is favourable to have relatively undisturbed urban climate. Szeged had 175 000 inhabitants in the investigated years (1978–1980) and its built-up area was approximately 46 km^2. The study area has continental climate with a long warm season by Trewartha's classification (*Péczely*, 1979). The main average meteorological parameters of Szeged region are as follows:

- mean annual temperature is 11.2 °C,
- mean January and July temperatures are −1.2 °C and 22.4 °C respectively,
- mean annual precipitation is 573 mm,
- mean annual sunshine duration is 2102 hours (*Péczely*, 1979).

In 1977 a network was established in the town where meteorological observations had been taken between July 1977 and May 1981. Air temperature, humidity (3 or 4 times a day), maximum and minimum temperature and precipitation were measured. The stations more or less represented the different built-up areas of the town (*Fig. 1*).

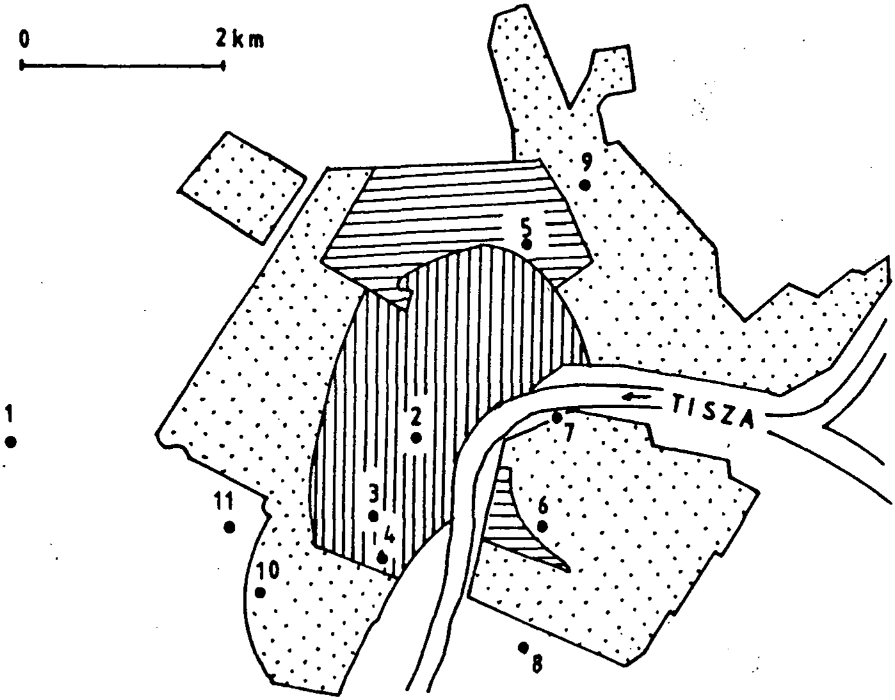

Fig. 1 The urban climatological station network and the main types of built-up areas in Szeged

- Downtown (2–4 storey old buildings)
- Housing estates with pre-fabricated concrete slabs (5–10 storey buildings)
- Suburbs (detached houses with gardens)

The 11 different observation sites and their features are as follows:

– The station, which is free from urban climate modifying effects (Station 1 = Aerological Observatory of Hungarian Meteorological Service), is situated at a distance of 4.4 km to the west of the town centre. The surrounding area is a cultivated land and it is considered to be a good example of the rural area.

- Station 2 was located in the town centre in a paved square bounded by multi-storey buildings.
- Station 3 was beside the 3-storey University building and in this way it represented the climate of streets with more storey buildings built from traditional materials.
- Station 4 was between the town centre and the suburb with detached houses and gardens.
- Station 5 was set up at a new housing estate with 5–10 storey buildings built from pre-fabricated concrete slabs.
- Station 6 was located at the grovy garden of the Children's Hospital bounded by busy streets.
- Station 7 on the river bank represented the modification effects of Tisza.
- Station 8 was set up at the southern edge of the town in the University Botanical Garden.
- Station 9 was at the suburb to the north-east of the town centre.
- Station 10 was at the suburb to the south-west of the town centre.
- Station 11 was situated in a site with small lakes and natural vegetation.

PROCEDURES AND DATA SELECTION

The results of some earlier investigations using daily and monthly temperature means verify the existence of the urban heat island in Szeged (e.g. *Károssy and Gyarmati*, 1980; *Unger*, 1992a, 1992b; *Unger and Csáki*, 1994). The aim of this study is to investigate the influence of different built-up areas on temperature using extreme days. The meteorologically extreme days are created with the help of daily minimum and maximum temperatures.

The extreme days and their criteria are as follows:

summer day – daily maximum temperature > 25 °C,
winter day – daily maximum temperature < 0 °C,
frost day – daily minimum temperature < 0 °C.

Data are avaliable for three entire years, from 1978 to 1980. It means 1096 days altogether for each station. *Table 1* shows the absolute numbers of the different extreme days experienced at each stations in this period.

For further examination the average date of the last and the first frost and the average length of the period without frost were determined for each stations and as a consequence for the different parts of the town (*Table 2*).

In *Table 1* the counted values of Station 4 and 9 are missing since big gaps were found in data series. The absence of data also caused a further lack (Station 3) among the stations in *Table 2*. So the data series which can be used for a fair examination are the ones of the remaining stations.

Table 1

The absolute numbers of the extreme days by stations over a 3-year period (1978–1980)

Station	Summer day	Winter day	Frost day
1.	208	63	265
2.	243	37	222
3.	258	–	–
5.	231	61	187
6.	216	48	251
7.	184	54	184
8.	214	62	290
10.	211	68	237
11.	198	61	193

Table 2

The average dates of the latest and the first frost and the average lengths of the frost-free period by stations
(1978 - 1980)

Station	Last frost	First frost	Length of the frost-free period in a year (day)
1.	24 April	26 October	185
2.	21 March	28 October	221
5.	21 March	31 October	224
6.	5 April	28 October	206
7.	21 March	28 October	221
8.	23 April	19 October	179
10.	6 April	26 October	205
11.	5 April	26 October	204

In order to exhibit the areal distribution of the different parameters in the town isolines can be drawn using the values of *Table 1* and *2*. In the next part of the paper the different areal features of these parameters and their behaviours will be analysed and explanation is going to be made.

We must add, however, that the threshold values of the extreme days are a bit arbitraries. For example an area within the town with maximum temperature -1 °C and an another one with -10 °C on the same day have also winter days, but as we can imagine they mean rather different situations from human bioclimatological aspects (clothing, demand of fuel consumption, etc.). But the simplicity of this method to approach the question of urban climate modifying effects supports this way of the examination as one of the possible ways which can show these effects expressively.

RESULTS AND DISCUSSION

In the case of summer days the spatial distribution shows the highest numbers (above 240 days) at Station 2 and 3 (*Fig. 2*). This was expected because they are situated in the town centre where the effect of increasing temperature is the strongest. At the warmest site of the town the annual average number of days, when the temperature exceeds 25 °C is 86, this means almost 3 months. The housing estate called „Tarján" (Station 5) appears as the second warmest area of the town. This area is a housing estate with 5 – 10 storey buildings, which were built from concrete slabs and its bulding-density is relatively high.

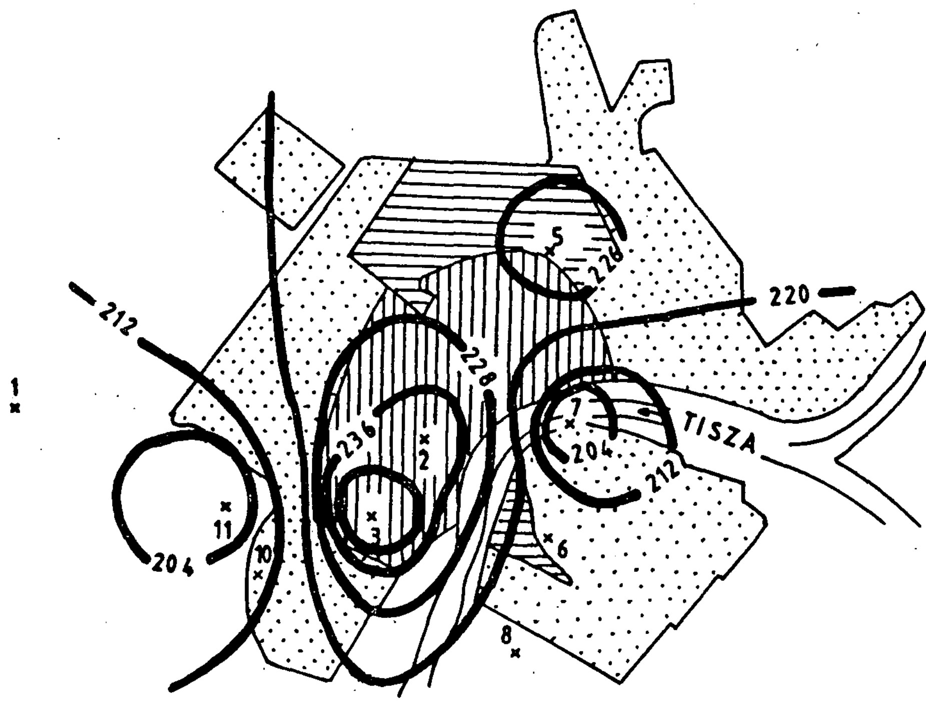

Fig. 2 Spatial distribution of the absolute number of summer days over a 3-year period (1978 – 1980)

The isoline of 220 separates the warm and the cool parts of the town. The cooler parts consist of the suburbs with detached houses and gardens as well as the open spaces, for instance areas around Station 1, 8 and 11. There are two places where the number of summer days is under 200 (Station 7 and 11). The large mass of water moderates the temperature extremities, thus in summer it decreases the temperature. Both observation sites were set up near water bodies, viz. near the River Tisza and near small lakes and the numbers are only 184 and 198 respectively. In the former case the mass of water is larger and it streams so the moderate effect of the river is stronger than the one of shallow lakes. At the coolest site of the town the annual average number of summer days is only 61, this means 2 months, thus in the town centre the period of summer days lasts almost 1 month longer than at the river bank (it is important to mention that the periods are not necessarily continuous).

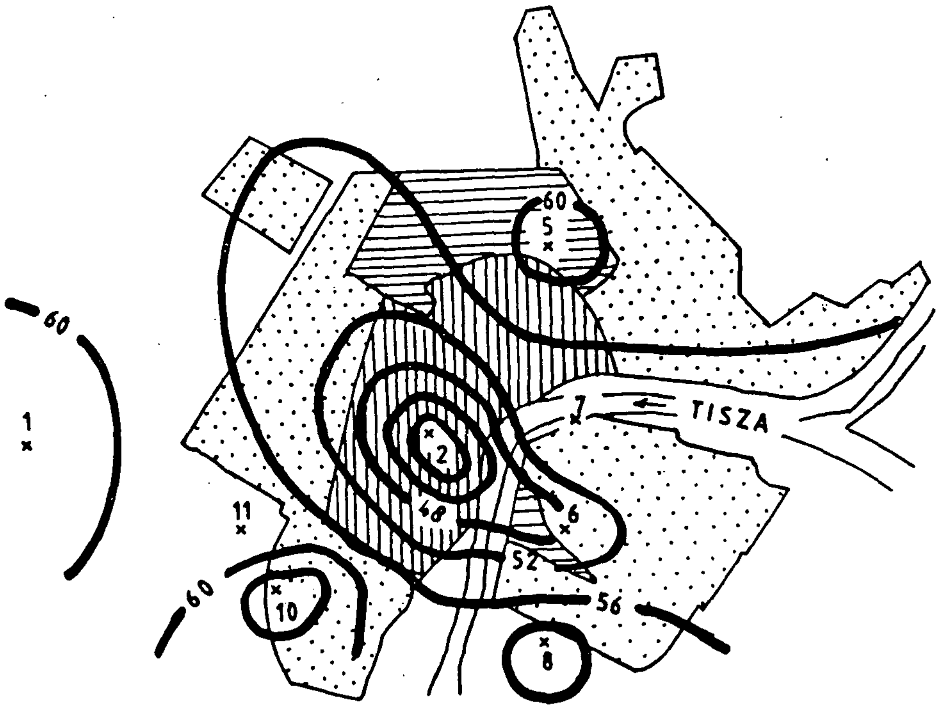

Fig. 3 Spatial distribution of the absolute number of winter days over a 3-year period (1978–1980)

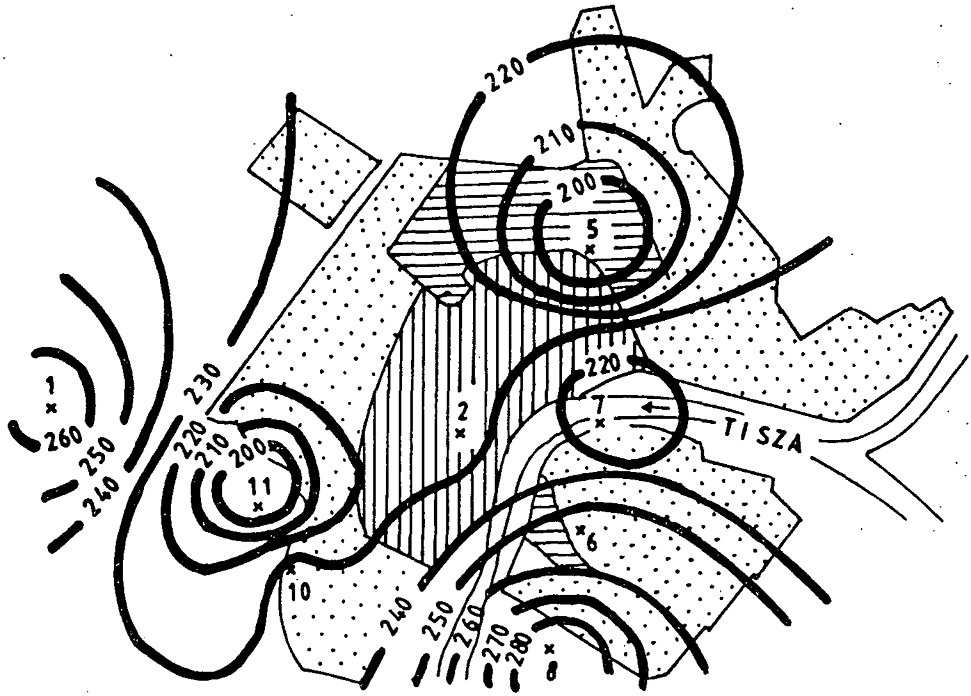

Fig. 4 Spatial distribution of the absolute number of frost days over a 3-year period (1978–1980)

In the case of winter days the isoline of 56 can be emphasized as a border between the cold and the less cold parts of the town (*Fig. 3*). The less cold areas are around Station 2 in the town centre. At this site there are only 37 days (or 12 on annual average) when the temperature does not exceed 0 °C.

The isolines are not concentric around the centre but stretch along the river and towards the housing estate with concrete slabs called „Odessa" which is located at the opposite bank. The large mass of water and concrete building materials moderate the temperature extremities, thus in winter they increase the temperature. It is interesting to observe that the area of „Tarján" housing estate (Station 5) which has the same thermal behaviour as the centre in summer, in winter it is similar to the suburbs and open spaces. The explanation requires further investigations.

Cold areas appear around Station 1, 8 and 10, at the edges of the town, where there are mainly vegetated open spaces. The last observation site has the most winter days, this means 23 days on annual average. So there are half as many winter days in the centre as in the suburbs because of the temperature increasing effect of the town.

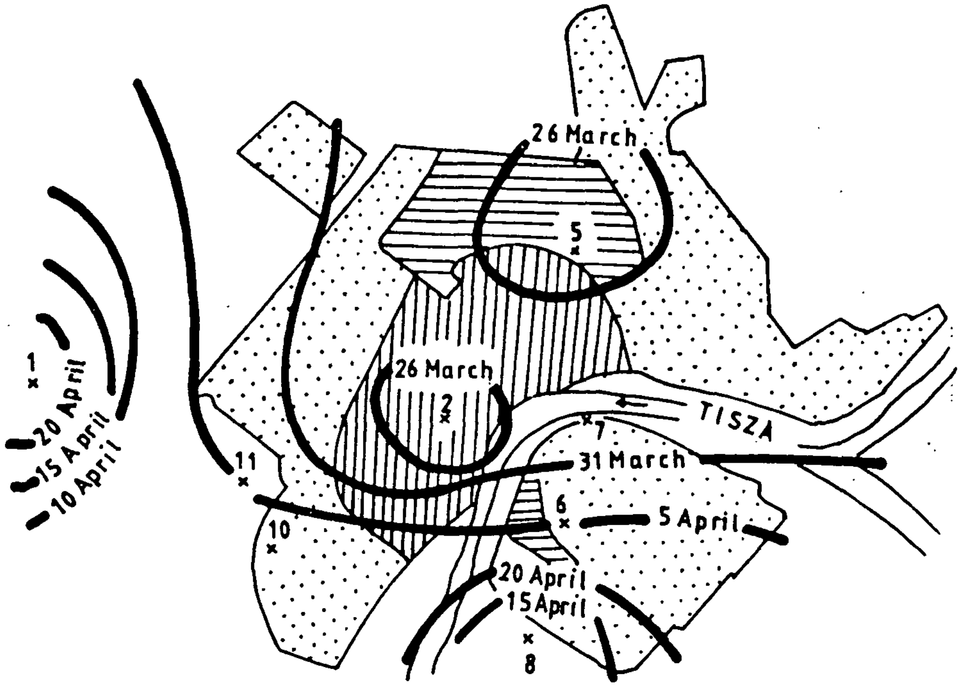

Fig. 5 Spatial distribution of the average date of the last frost (1978 - 1980)

This almost 2 week difference is very significant from the aspects of human bioclimate and of heating demand.

As regards the areal distribution of frost days over the three year period, its behaviour is regulated in the same way as mentioned above in the former two cases (*Fig. 4*). The warm areas are near large water bodies (Station 7 and 11), in the „Tarján" housing estate (Station 5) and in the town centre (Station 2). The cold areas are at the edges of the town in a vegetated area and in an open space (Station 8 and 1). The difference between the coldest and warmest areas is 106 days, which means more than one month on annual average (35 days).

The spatial distribution of the average date of the last frost (*Fig. 5*) reveals that it occurs in the city core, in the housing estate and at the river bank the earliest (21 March). Towards the suburbs this time appears later and later. The Botanical Garden (Station 8) and the rural station have the latest times, namely 23 and 24 April. This is more than one month time difference and the features of the areal distribution of the time may provide a very important piece of information for the keeping of urban parks, tree lines and small gardens.

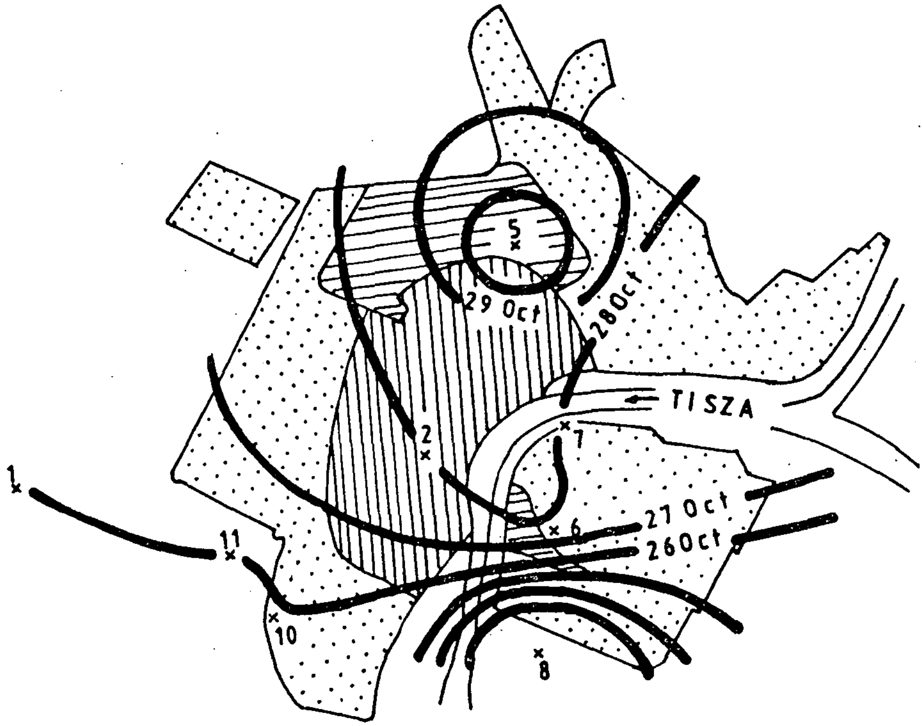

Fig. 6 Spatial distribution of the average date of the first frost (1978–1980)

In the case of the first frost the areal differences are smaller than at the last frost (*Fig. 6*). The first frost sets in 19 October in the southern suburbs (Station 8). Towards the centre and the housing estate in the north the first frost appears later and at around the Station 5 sets in 31 October. The difference is less than two weeks (12 days). It means that the thermal delaying effect of the town in autumn is less stronger than in spring.

The period between the last and the first frost is the frost-free period which has a great influence on the vegetation growth and the demand of fuel consumption (*Fig. 7*). Because this period depends on the dates of the last and the first frost, as we can expect, the length of the period is the longest in the inner part of the town (over 210 days) and the shortest at the southern and western outskirts (under 190 days). The warmest area (around Station 5) has a frost-free period of 224 days in a year (about 7.5 months) while the coldest area (around Station 8) has a period of 179 days (about 6 months). Thus the difference is rather significant, it is 1.5 months.

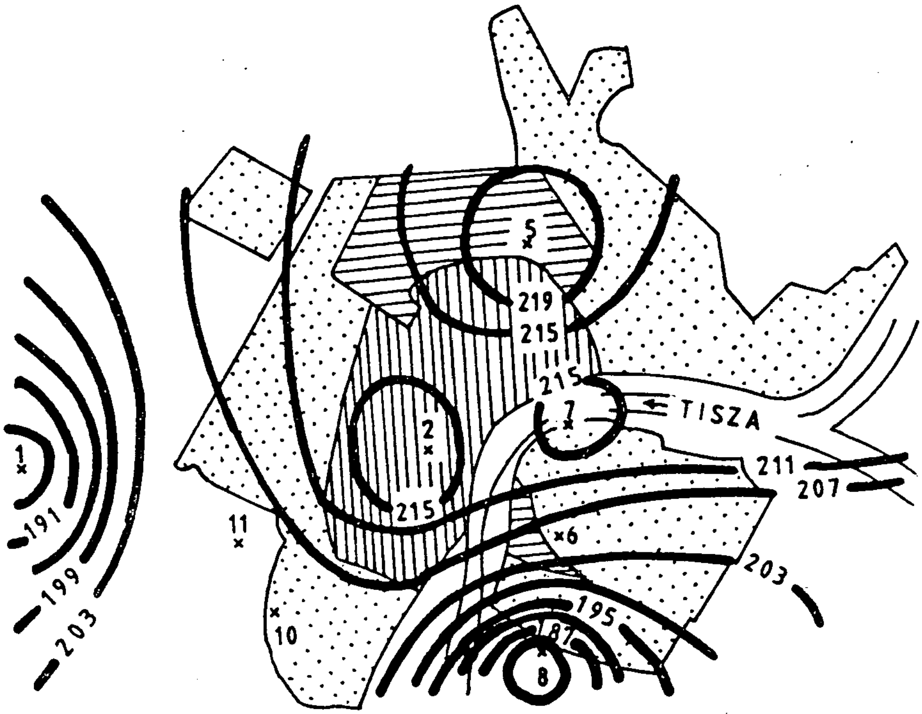

Fig. 7 Spatial distribution of the average length of the frost-free period (1978–1980)

CONCLUSIONS

The first part of the investigation revealed the spatial distributions of extreme days. The city core and the „Tarján" housing estate have the most summer days, the city core has the less winter days and the „Tarján" housing estate and the city core have the less frost days.

The above statements derive from the facts that these areas have large impermeable and small vegetated surfaces, the drainage system conducts the most part of the precipitation and their building materials have different physical properties from the elements of the natural surface, as well as the artificial heat release originated from industrial, traffic and household sources can be very significant. The urban morphological srtucture with streets, squares, tall and low buildings is also very different from the natural one, which also alters the energy balance. As the figures show already in a medium sized town like Szeged these alterations result in a rather noticeable heat exceed which is reflected in the frequency of the extreme days.

The modifying effect of large water bodies, mainly of the river, appears clearly. The large heat capacity of the water moderates the warm in summer and the cold in winter, thus near the river the frequencies of summer and frost days are the lowest, the frequency of winter days is rather low.

In aspect of human bioclimate the high number of summer days in the town centre is a bit disadvantageous because of its large heat stress effect. On the other hand the decreasing number of winter and frost days towards the centre from the suburbs is advantageous because of its decreasing cold stress effect.

In the next part the investigation revealed the spatial distribution of the dates of last and first frost days, as well as of the length of frost-free period. The areas where the last frost day occurs early and the first frost day late, viz. the frost-free period is rather long, are the same ones which are warm according to the results of the first part mentioned above.

The use of the maps with isolines can be a useful mean for keeping of urban parks, tree lines, other green areas and small gardens, as well as for the assessment of heating demand of buildings.

To sum it up, the temperature increasing effect of the town from the outskirts towards the centre is revealed by the study and it also verifies the existence of the heat island in Szeged.

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