Landscape seasons and air mass dynamics in Latvia

Ādolfs Krauklis and Anita Draveniece

Abstract. Latvia is located in the middle of an area where the boreal and nemoral zones and the regions of oceanic and continental climate meet, and it was studied as a model territory of the most typical variation of boreo-nemoral ecotone. The subject of this study was seasonal dynamics of the state of landscapes and diachronous links between seasons.

It was found that landscapes undergo 12 seasonal states or seasons during the annual cycle of insolation and air mass occurrence. Each season may be distinguished by a definite amount of solar radiation, distinctive state of heat and water balance, phenological state of vegetation, and a distinctive occurrence of different air mass types and their particular "association". During each season these variables show a particular combination of numerical values and a distinctive landscape pattern.

Although Latvia is a country of humid climate, on average 4 months/year evaporation exceeds the amount of precipitation, an equally long time evaporation is less than precipitation and for the remaining 4 months evaporation is close to zero, but precipitated water is accumulated in the form of snow. During 8 months, net radiation is positive in Latvia, while for 9 months/year subpolar (subarctic) air is the most frequent air mass type, and only three summer months show a slight prevalence of warmed subpolar air. However, for spring and summer seasons a typical air mass is mid-latitude air, too. In summer subtropical air arrives which is yet less frequent than arctic air which is brought to Latvia in autumn, winter and spring seasons. The geographical position of Latvia is one with a prevalence of transformed maritime air masses in spring and summer (mean yearly frequency, too), and occurrence of typical maritime air in autumn and winter. Continental air affects Latvia infrequently.

Key words: landscape season, air mass types, net radiation, precipitation, evaporation, boreo-nemoral ecotone.

1. Introduction

Geographical landscapes of Latvia, similarly to these elsewhere on the edge of mid-latitudes between 56°N un 58°N, receive abundant sunlight in summer, when the sun lies above the horizon more than 17 hours a day and therefore insolation is almost as high as near the equator. On the other hand, in mid-winter, when the day-length is less than 7 hours, the rate of incoming solar radiation in Latvia is the nearly the same as the rate received by the subarctic zone. As a result, air masses experience relevant seasonal variations, too, and these affect solar radiation and the heat and water cycles in landscapes. Moreover, the latitudinal gradients of solar radiation vary during the year, and consequently the movement of air masses over different latitudes, from oceans to continent, and the nature of westerly air flow (westerlies) undergo corresponding changes.

From a geographical point of view Latvia is the most representative area of the boreo-nemoral ecotone, holding a middle position in relation to its northern, southern, eastern and western boundaries, and is located in the widest part of this ecotone (from the south of Finland to north-east of Poland). The widest part coincides with the submeridional boundary between the European "peninsula" and continental part both with specific patterns of nature zonality [Krauklis 2000; Krauklis, Zariņa 2003], but with respect to annual temperature range (commonly used for assessing the degree of climate continentality) is close to the 22°C isotherm (Figure 1).

The subject of research was the seasonality of the state of Latvia's landscapes induced by zonal patterns of insolation and air mass circulation. The present study was aimed at developing a vision of landscape as a diachronous cycle of its seasonal variations and to contribute to understanding of the boreo-nemoral ecotone (ecotone of boreal coniferous and nemoral deciduous forest zone) from such standpoint.

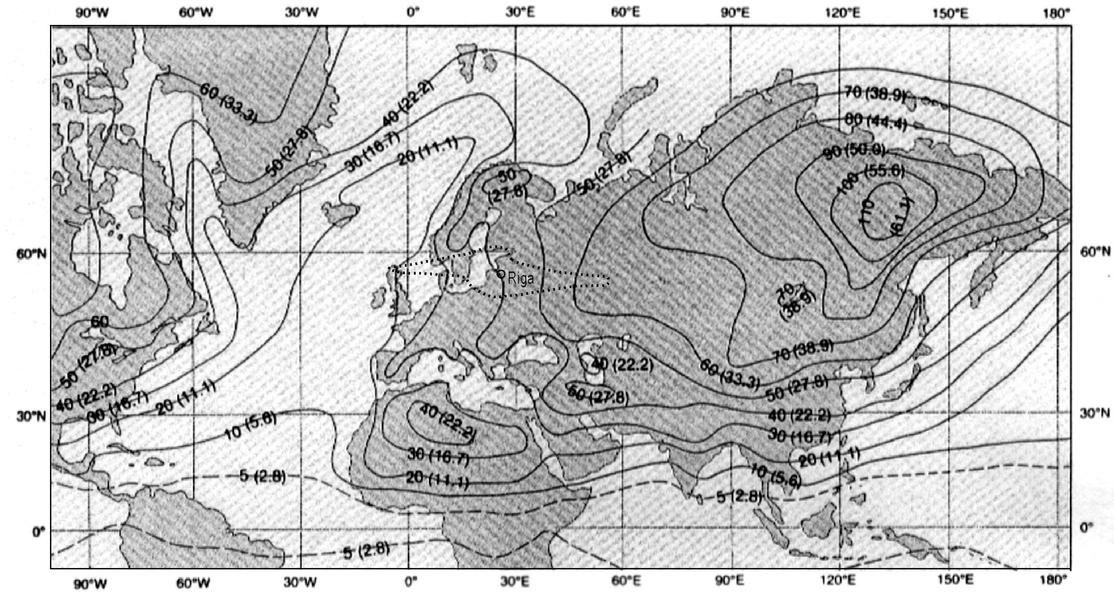


Figure 1. The approximate boundary of the ecotone between the European boreal and nemoral zones (dashed line). Isopleths of annual temperature ranges in Fahrenheit degrees, with Celsius equivalents in parenthesis after R. C. Scott [1992].

2. Data and methods

To describe the division of the year into seasons and to trace the diachronous nature of and links between the seasons, a comparative study of net radiation, air temperature, atmospheric precipitation, air mass types and the state of vegetation was carried out, taking into consideration the diurnal rhythms and interannual variations. While the annual course of different air mass types is usually left beyond the scope in such kind of studies here it is followed up. For this purpose, the observation data for a 11-year period (1990-2000) were extracted at the Latvian Hydrometeorological Agency, and long-term means were considered, too (Table 1).

Net radiation is defined as the difference between the gain through incoming short-wave solar radiation and loss through reflected short-wave and emitted long-wave or terrestrial radiation. In Latvia, actinometric observations, including net radiation measurements, are carried out only in one station, yet the observation station site has been relocated three times. For a long time (1948-1972) the station was located in Riga (56º58´N, 24º02´) and the long-term means of net radiation used in this study have been calculated after the measurements made in this site. Since 1991, after relocation from Zoseni (57º09´N, 25º54E´, Vidzeme upland), the station is located in Zilani (56º31´N, 25º´55 E, on the Daugava). Unfortunately, a considerable number of data gathered during the 11-year period of the study were rejected due to low-quality and even missing measurements. As result, the authors used for this study the data for 6 years (1986-1988, Zoseni, 1994-1996 Zilani).

Air masses were determined for the 11-year period using twice-a-day (00 UTC and 12 UTC) upper air observation data for Riga and also Liepaja (till 1992). M.Geb's [1971] method, which is based on climatological identification of air masses at the same time checking them with respect to their typical heat content (pseudopotential temperature θ_{850}) at 850 hPa level, was applied. The method implies the analysis of frontal zones and weather systems at that level. A distinction is made between maritime (m), transformed maritime (x) and continental (c) air masses, considering that transformation of maritime air into x air requires at least 24 hours. Transformation of an air mass is caused by several factors, such as surface temperature, moisture and topography. The type of air mass trajectory, whether cyclonic or anticyclonic, also has a bearing on its transformation.

The 850 hPa level is roughly at the height of 1.5 km, usually above the atmospheric boundary layer with almost no diurnal temperature variation. Consequently, the underlying surface, such as a cool sea, does not affect the air temperature.

Table 1

Basic source data*

Monthly sum of net radiation (Zosēni – 1986-88; Zilāni –1994-96), MJ/m²													
Years	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1986	-0.9	3.8	72	166	278	351	260	192	62	2.7	-9.6	-3.9	1373
1987	-0.24	-14.0	18	156	183	213	342	224	107	60	14	3.6	1306
1988	0.28	9.2	46	232	420	295	336	193	115	44	-0.3	-1	1689
1994	7.3	53.0	115	145	319	271	429	235	94	37	-28	-32	1645
1995	-50.8	12.0	94	222	327	399	363	292	116	12	-44	-60	1682
1996	-41.0	-52.0	-32	166	260	352	300	295	122	28	-8.4	-23	1367
AVG	-14.2	1.9	52	181	298	314	338	239	103	31	-12.6	-19	1512
Normal	-25.8	-8.4	50.3	209	327	365	327	226	130	25	-13	-29	1583
Air temperatures at 2m (Riga), °C													
Years	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
1990	0.9	4.4	4.7	8.2	10.9	15.2	16.3	17.0	10.7	7.6	3.7	-0.5	8.3
1991	-0.1	-3.3	1.9	5.9	9.1	14.2	17.8	18.1	12.7	7.9	4.2	0.5	7.4
1992	1.3	0.3	2.9	4.7	12.1	16.4	18.4	17.9	13.3	3.8	1.5	0.9	7.8
1993	-0.5	-0.3	0	6.3	15.2	13.6	16.7	15.1	9.0	6.1	-3.8	-0.6	6.4
1994	-0.7	-9.1	-0.1	8.2	9.9	13.4	19.3	17.2	13.5	6.0	2.0	-0.6	6.6
1995	-2.7	1.6	1.9	6.0	11.2	17.6	17.4	17.4	12.3	9.3	0	-5.6	7.2
1996	-6.4	-9.0	-3.0	6.1	11.9	14.4	15.8	19.2	10.3	8.5	4.6	-4.9	5.6
1997	-2.1	0.3	0.5	3.6	9.6	16.8	19.6	20.4	12.4	5.4	2.2	-3.4	7.1
1998	0.5	0.2	-0.5	7.7	12.6	16.7	16.7	15	12.7	6.8	-4.3	-2.9	6.8
1999	-2.3	-4	2.0	9	10	19.4	19.9	17.1	14.9	7.3	2.2	-0.3	7.9
2000	-1.4	0.8	1.7	10.7	12.2	15.1	17.0	16.3	10.9	10.0	5.2	1.5	8.3
AVG	-1.2	-1.6	1.1	6.9	11.3	15.7	17.7	17.3	12.1	7.2	1.6	-1.5	7.2
STDEV	2.2	4.3	2.0	2.0	1.7	1.9	1.4	1.6	1.7	1.8	3.2	2.4	2.2
Normal	-5.0	-4.8	-2.0	4.6	10.7	14.3	17.1	15.7	11.7	6.2	1.5	-2.6	5.6
Precipitation (Riga), mm													
Years	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
1990	67.3	44.6	35.2	4.1	37.6	73.2	108	102.6	110	69.2	72.9	27	752
1991	34.5	44.6	41.9	20.2	82.9	108.3	19.9	62.7	151.7	57	56.2	35.3	715
1992	52.5	42.3	38.7	52.1	34.5	51.6	52.6	49	117	82.4	84.2	39.2	696
1993	62.5	53.0	26.2	18.4	7.9	35.4	149.4	100.6	74.2	59.5	8.2	59.5	654
1994	51.8	14.5	41	62.6	44.9	79.1	15.5	78.7	69.2	69.3	61.2	53.6	641
1995	53.6	48.6	51.6	34.3	73	104.9	43.1	81.7	59.6	76.9	46.3	26.5	700
1996	32.0	46.5	16	16.3	80.4	41.8	88.6	14.7	20.8	97.5	58.1	46.9	560
1997	32.2	33.3	22.9	52.9	72.1	81.6	38.7	25.3	87.6	176.1	67.5	46.4	737
1998	42.2	59.5	20.9	21.2	54.4	52.5	105.1	101.1	31.5	84.4	20.8	51	665
1999	80.5	88.4	28.9	32.8	40.5	31.8	55.9	116.4	66.6	121.6	27	91.9	782
2000	39.7	27	66.3	18.3	29.9	48.4	150.3	69.4	21.2	43.3	65.9	29.9	610
AVG	49.9	45.7	35.4	30.3	50.7	64.4	75.2	72.9	73.6	85.2	51.7	46.1	681
STDEV	15.7	18.9	14.7	18.4	23.9	26.7	48.1	32.8	41.3	36.8	23.6	18.8	
Normal	35	31	27	37	46	64	83	75	65	58	54	42	617

* Monthly data from the Archives of Latvian Hydrometeorological Agency; normals (long-term means) for the net radiation after *Reference book on the Climate of the USSR*, issue 5, part 1 [1966], for temperature and precipitation after *Latvijas daba*,Vol.2 [1995].

Pseudopotential θ_{850} or equivalent potential temperature (Theta-e) serves as a good indicator of an air mass. It can be used to compare both moisture content and temperature of the air. θ_{850} is the temperature an air parcel would have if raised vertically from some pressure and temperature until it became saturated and all water vapor were condensed out by a pseudo-adiabatic process (it is assumed that water vapor that condenses out immediately falls out of the parcel as rain) and then the parcel were brought dry adiabatically down to the 1000 hPa level.

In the upper air, the observation data of 850 hPa relative humidity, temperature, and dewpoint were extracted, and the two latter were used for calculation of pseudopotential temperatures.

Air mass frequency was calculated taking into consideration the days with frontal passage, i.e. 100% included also the days when fronts moved over Latvia, but, for the description of a particular air mass, the fronts were excluded. It is common for Latvia to be affected by sequences of fronts, yet it is also important to note that between two similar air masses or at a gradual transformation of an air mass a boundary cannot be drawn. Frontal passage is connected with a sharp discontinuity in temperature and humidity values at the surface and the 850 hPa level, but within one air mass the same weather remains for several days or at least one day. Distinctive air masses show different types of weather and it strongly depends on the season. There are various hydrometeors or visible water manifestations following vapour condensation in the atmosphere, e.g. fog, clouds, rain, snow, mist, which are observed both in a frontal zone and within an air mass.

The labor-consuming nature of air mass identification and the lack of any preliminary study of that kind in Latvia were the main reasons for the relatively short duration of the period subjected to investigation. Besides, the most complete 850 hPa charts were available only from the last decade of the 20th century, because the DWD began to deliver European Meteorological Bulletins to the Latvian Hydrometeorological Agency only after restoration of Latvia's independence. The Bulletins contain, along with Europe's surface weather charts at 00 UTC and surface weather charts of the Northern Hemisphere at 12.00 UTC, also the 850 hPa 12.00 UTC chart. However, the period 1990-2000 turned out to be the warmest on record and, in order to encompass the whole set of air masses that may affect Latvia, the study sometimes had to be extended back to 1987 [Draveniece 2003].

Each air mass is a widespread body of air and it covers an area which is commonly larger than the territory of Latvia. It is true that the same air mass over landforms of different relief (uplands, lowlands) and under the influence of other geographical factors may produce different amounts of precipitation or exert distinctive effects on the surface temperature. Yet this aspect and transitional conditions during passage of atmospheric fronts (transition zones between different air masses) are not treated in this work. Besides, the differences in the annual cycle and seasonal variations in different parts of Latvia are only slightly touched upon. The study is for the greatest part grounded on the observations and measurements performed in the central part of Latvia (Riga), and consequently the findings should be mainly attributed to the central region. However, discussing the results of this study, an emphasis is put on the facts and conclusions which might be significant for the whole of Latvia and even for the entire boreo-nemoral ecotone.

3. The cycle of the seasons induced by the zonal pattern of insolation

3.1. The periods of negative and positive net radiation

The net radiation (*Rnt*) is the solar energy absorbed by the earth (land and water surface). The annual course of **net radiation** (*Rnt*) clearly shows two periods: on average for four months – from the end of October through the second half of February – the mean diurnal *Rnt* is negative in Latvia, and during the remaining eight months it is positive (Figure 2).

The term *negative Rnt* means that the influx of solar radiation to the earth's surface (incoming short-wave radiation or insolation) doesn't exceed the total amount of reflected short-wave and the emitted outgoing long-wave radiation (difference between the net long-wave radiation at the surface and atmospheric counter-radiation, primarily by clouds). As result, the heat and water turnover in the landscape is very limited, the majority of living beings experience biological dormancy, and a great part of migratory birds have left Latvia. The mean diurnal sum of *Rnt* is positive, when the incoming short-wave radiation exceeds the energy lost to space. Therefore heat may be gained and accumulated in atmosphere through vigorous turbulent updrafts from the land and water along with intensive evaporation and active life processes are possible.

The seasonal changes of insolation and net radiation stem from the annual course of day-length and the height of the Sun, which depend on geographical latitude. However, the influence of this factor is strongly modified by atmosphere circulation, which brings to the territory of Latvia both maritime and continental air masses that have originated in different latitudes and therefore differ greatly by their heat content, moisture, wind speed and particularly by cloud cover. Therefore the annual course of net radiation is much like the curve of sunshine duration, which briefly reflects the dynamics of the day-length relative to the height of mid-day Sun and the number of days with cloudy or clear skies (Figure 2, Table 2).

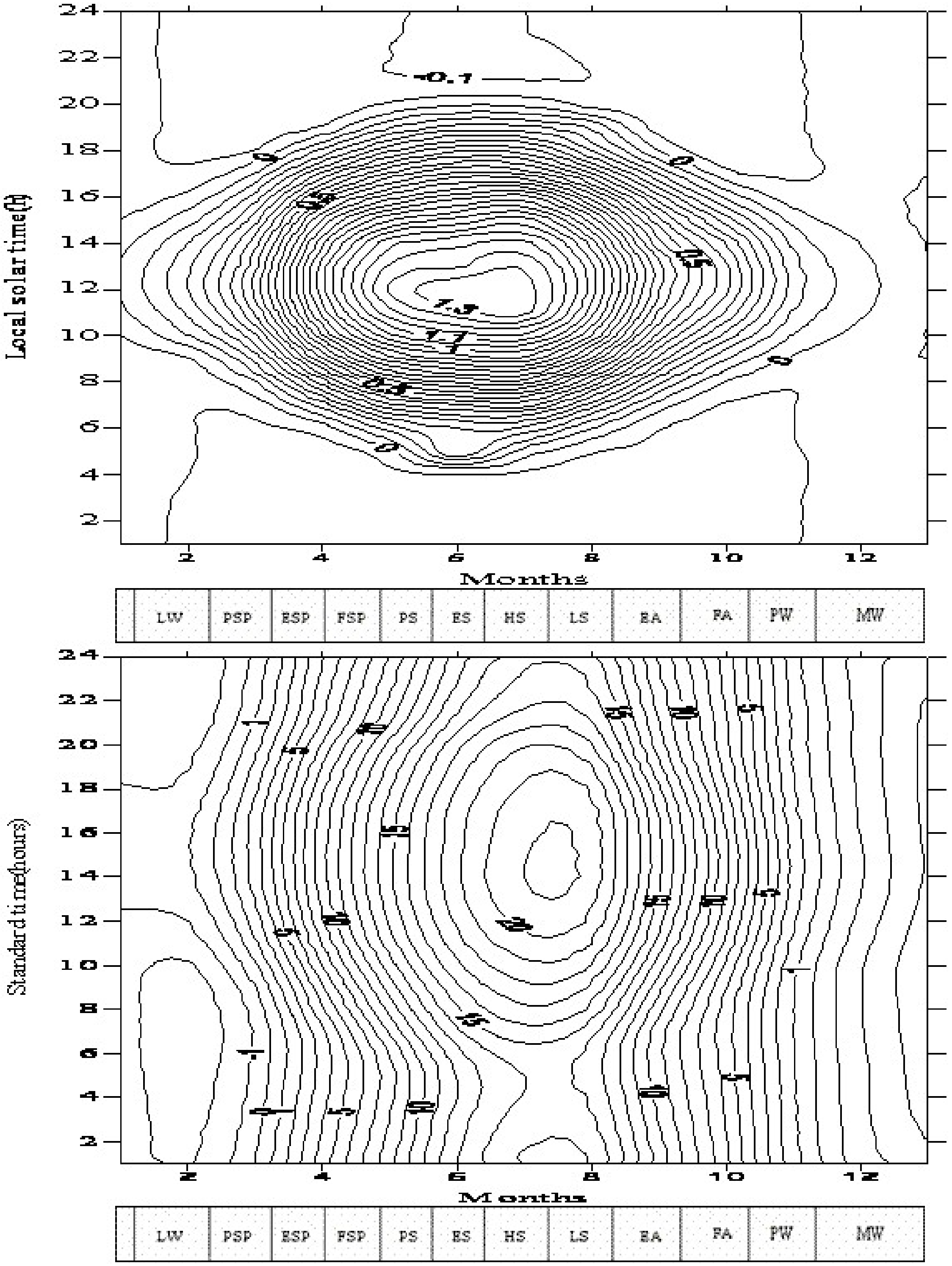


Figure 2. *Above*: the mean hourly net radiation in MJ/m² averaged over six years within 1986-1996 period. The isopleth interval is 0.05 MJ/m². *Below*: the mean hourly air temperature (thermograph data) in ºC (Riga) averaged over 11-year period 1990-2000. In Riga (57ºN, 24ºE), the difference between the standard time and local solar time is –24 minutes.
The cycle of the seasons: MW – mid-winter, LV – late winter, PSP– pre-spring, ESP – early spring, FSP – full spring, PS – pre-summer, ES – early summer, HS – high summer, LS – late summer, EA – early autumn, FA – full autumn, PW – pre-winter.

Table 2

General information (Riga)

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Day-length (hours, minutes)	7:21	9:24	11:43	14:13	16:31	17:47	16:40	14:40	12:38	10:00	7:28	6:45	
Height of midday Sun (degrees)	11.8	19.9	30.8	42.7	51.8	56.3	54.6	47.2	36.1	24.6	14.6	9.7	
Clear skies (days) *	1	1.4	3.2	2.0	3.3	1.8	2.7	1.7	1.8	0.7	0.6	0.6	21
Cloudy days*	20.6	17.0	12.5	12.9	10.2	11.0	12.0	10.8	10.9	16.9	22.2	21.5	178
Sunshine duration (hours)	36	61	140	197	268	282	276	235	166	91	35	25	1812
Relative sunshine duration (%)	18	25	42	49	56	57	56	54	48	32	17	14	44
Incoming solar radiation at surface (MJ/m²)	41.4	98.4	246.7	379.1	568.9	549.7	564.5	460.3	262.8	129.2	48.8	28.8	3379

* After *Reference book on the Climate of the USSR*, issue 5, part 4 [1969]; clear skies are reported as 0-2 units of total cloudiness and cloudy days as 8-10 units of total cloudiness.
The rest data after *Reference book on the Climate of the USSR*, issue 5, part 1 [1966]. The relative sunshine duration is the recoded duration expressed as percentage of the longest possible duration of that specific time.

In the beginning and the end of *the period of negative net radiation* (in other words – winter) the day-length in the central part of Latvia is ca 9 hours and the height of midday Sun is around 20º (at winter solstice – December 21 – these parameters are only 6.5 hours and 9.5º). Winter is also remarkable for the highest number of cloudy days and the least number of clear days, so that the actual duration of sunshine shortens to 15-20% of the maximum sunshine. Consequently, the intensity of solar energy influx is quite small; moreover the cloud cover reduces the long-wave radiation emitted to the space and the reflected radiation. As a result, during four months the mean diurnal sum of *Rnt* is only slightly below zero, and for some hours in the midday usually is above zero.

The described state of landscape is typical of mid-winter, which lasts from around a month before to a month after the winter solstice. The previous phase or pre-winter still shows a small decrease of *Rnt*, but during late winter an increase of *Rnt* is clearly seen (Figure 2).Yet, the division of Latvia's winter into phases by decrease, minimum and growth of *Rnt* is of secondary importance, because the influence of atmosphere circulation commonly makes the average differences within one phase larger than interphase differences, and, besides, the lowest diurnal radiation *Rnt* has been observed in mid-, pre- and late winter (Table 1).

Of much greater heterogenity is the two times longer *period of positive net radiation*, which encompasses the customary *spring,* su*mmer and autumn* seasons. This period consists of a phase of stable *Rnt* growth (second half of February to first half of May, with a steeper growth from the middle of March till the middle of April) and stable decrease (end of July to end of October, with a steeper fall from the beginning of August till the end of September), and the culminant phase (yearly maximum) between the two mentioned phases.

Although generally viewed, the annual course of *Rnt* follows the curves of day-length and the height of mid-day sun, during the culminant phase, from the first half of May through the end of July, such relationship is not observed. In the beginning and at the end of the phase, the height of midday Sun is 51.5º and the day-length 16.5 hours, but in the middle of period (summer solstice) these increase to 56.5º and almost 18 hours. However, during the entire phase the sunshine duration and also *Rnt* stay invariably at a high level. The latter surpasses 1.2 MJ/m²·hour 3-5 hours per day on average (Figure 1). An explanation behind this is that also in summer the radiation pattern strongly depends on the changing cloud cover determined by atmosphere circulation. However, the *Rnt* culminant phase (as distinct from the period with negative *Rnt*) coincides with the yearly minimum of cloudiness and thus with the phase of maximum potential sunshine (Table 2).

Consequently, by average indices, the first half of May and the end of July are significant "turning" points clearly seen from the annual curves of *Rnt*, cloudiness and sunshine duration, but within this period, the three indices do not show substantial seasonal variations. In reality, the situation of each particular year is more complicated. A more or less continuous culminant phase of *Rnt* which would last for 2.5 months may occur rarely, as it happened in the summer of 1995, when Rnt in MJ/m²·month was 327 in May, 399 in June and 363 in July. In most cases, one of the three months stands out against the other two: the data at our disposal showed that, in the six years studied, the highest accumulated monthly *Rnt* was three times in June, twice in July and once in May; besides once it reached the maximum even in August (1997), which perhaps could be considered untypical. On average these years showed higher *Rnt* in July than in June (Figure 2), but according to long-term average values (climatic norms), which were calculated some time ago, it has been slightly higher in June (Table 1).

3.2. Annual course of air temperature against the background of net radiation: lag effects

The annual course of **air temperature** *(T)* is similar to that of *Rnt*, yet it shows some specific features. The most important (in the context of this article) is the temperature inertia or time lag, which manifests itself as a one-month delay in relation to the seasonal cycle of *Rnt*. The *T* lag or delay exerts an essential effect upon the physical and biological state of landscape, and forms the basis for four seasonal phases with typical "transitional" nature. These are pre-winter – a time from the outset of the negative *Rnt* period until setting in of a period when mean diurnal temperature (T_d) steadily falls below zero; pre-spring – from the end of the negative *Rnt* period until stable rise of T_d above 0ºC; pre-summer – from setting in of *Rnt* culminant phase until the rise of T_d to the mean value of *T* of the warmest month; late summer – from setting in of steady *Rnt* fall until the beginning of steady T_d fall (Figure 2).

The lag effect becomes strikingly apparent, when comparing the numerical values of *Rnt* and T_d in the seasons of their growth and decrease. During the vernal and autumnal equinoxes (21 March and 23 September) *Rnt* is roughly the same (around 3 MJ/m²·day), while T_d has not yet persistently passed 0ºC in the second half of March, rises up to 10ºC in the first half of May (beginning of *Rnt* culminant phase), falls persistently below 10ºC in the second half of September and falls below 0ºC only at the end of November (around a month after the negative *Rnt* period has started).

T reaches the yearly maximum in the second half of *Rnt* culminant phase or even later; within the years 1990-2000, July has been the warmest month in five years, August in four years, but June only in two years. On average, the mean *T* is highest in July (*T* unlike *Rnt* is much higher in July than in June) and only slightly higher than in August (Figure 2, Table 1). Thus, after the summer solstice, the rate of *Rnt* and *T* becomes relatively stable at a level close to the yearly maximum, and the most appropriate designation of this phase, which lasts from the end of June until the end of July, could be high summer. The former and comparatively shorter time from the beginning of June until summer solstice is a phase with less consistent *Rnt* and noticeably lower *T*, and could be defined as early summer.

The *T* time lag is more pronounced in winter. According to long-term data, the lowest monthly mean *Rnt* (-29.3 MJ/m²) is in December, but the lowest monthly mean *T* (-5ºC) in January; in February the mean *T* is almost as low (-4.8ºC), but *Rnt* has already risen to – 9.8 MJ/m²· month (Table 1). Although within the period 1990-2000, winters were much warmer, the effect of time lag remained valid. The clearest evidence of this is that on average the coldest month was February, when *Rnt* had already steadily risen above zero (Figure 2; Table 2). Although in winters the monthly *Rnt* was the lowest in December or January, February was the coldest month four of the 11 years, January twice, December three times and November once. Moreover, the lowest monthly mean *T* of February fell to -9.2º (1994 and -9.0º (1996), but in January only to -6.4º, in December to -5.6ºC and in November to -4.3ºC. Yet, all these months also showed positive monthly mean *T*, with the highest in November (+5.2º) and February (+4.4º) and the lowest in December (+1.5º) and January (0.9º). Thereby, in terms of the rate of net radiation and air temperature the three winter phases demonstrate high interannual variations, and from year to year these phases may manifest themselves in very different versions, particularly with reference to the beginning of winter (November) and the end of winter (February).

3.3. Precipitation: seasonality and interannual fluctuations

The annual course of **atmospheric precipitation** *(P)* differs greatly from that of *Rnt* and *T*. The data of an 11-year period (1990-2000) show that each month can produce a very low amount of *P*, but a high amount may occur within only a short half-year (Figure 3). Consequently, the year may be divided into two periods which differ essentially by maximum and mean amounts of precipitation, but are similar in relation to minimum monthly amounts of *P*. December – April is a low precipitation period, when monthly means do not exceed 30-50 mm, but the highest monthly amounts are 60-90 mm. June-October on the other hand is a period of high precipitation with monthly means around 65-85 mm and the highest monthly amounts around 110-180 mm. The transition phases between these two, in terms of precipitation, distinctive 5-month phases are May (a month, when culminant phase of *Rnt* sets in) and November (the starting phase of negative *Rnt* and the final phase of positive *T*).

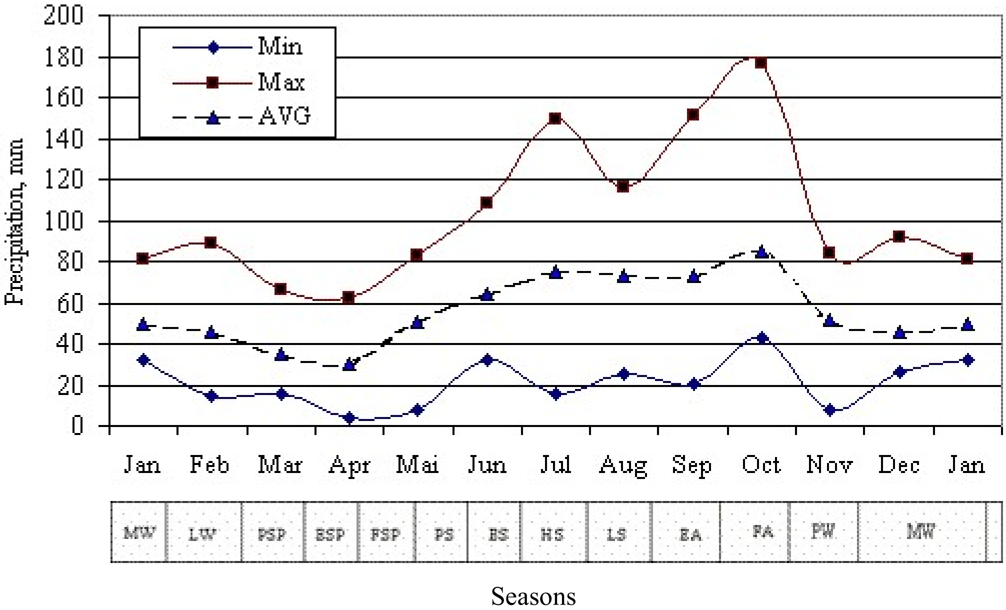


Figure 3. The highest, lowest and average amount of monthly mean precipitation (Riga) in the 11-year period (1990-2000). The seasons see in Figure 2 and the text

In Latvia, the lowest amount of *P* is commonly observed in the phase when *Rnt* and *T* gradients are the highest – around vernal equinox (March/April), and the highest amount varies spatially and in time. In coastal areas (Liepaja and Riga) the highest monthly amounts have been registered during the phase of *Rnt* and *T* decline, primarily after autumnal equinox (October), but in inland regions generally around summer solstice (June/July). However, the yearly minima and maxima of *P* are very uncertain in time, and in different locations these manifest themselves in different ways.

In Riga, which is located on the coast of Riga Bay, but from three sides (east, south and west) is encircled by land, the lowest amount of precipitation for the year during the 11-year study period was observed in 8 months (twice in April, May and November, once in, February, March, July, August and December). Yet April and May are the driest months (minimum monthly amounts ca 5-15 mm, monthly means 30-35 mm and the highest amount 65 mm). According to long-term data, these months also show the least number of days with measurable precipitation (12-13 days per month), the greatest number of days with clear skies and the lowest relative humidity at the surface (Table 2). The described pattern partly lasts until May, but the first low-precipitation months December and January are radically different – the number of days with measurable precipitation (18-19 days per month), the cloudiness and the relative humidity at the surface show the highest values of the year.

October turned out to be the wettest month either by mean monthly precipitation (85.2 mm), the maximum monthly precipitation (176.1 mm) or the mean monthly amount (43.3 mm) within the 11-year period in Riga. Moreover, it is one of the few months which has never produced the yearly minimum precipitation. Yet the maximum monthly precipitation in October has been the yearly maximum in only 3 years, of the same frequency as in September and July. Twice the yearly maximum occurred even in June. Consequently, the yearly maximum precipitation in Latvia may occur in very different seasons (in summer and in autumn) in terms of solar radiation, air temperature and the state of vegetation However, more detailed study would be necessary, because, according to the long-term data that do not include the 11-year period studied, the yearly amount of precipitation is smaller and only one maximum in summer has been recorded, with the following months showing a gradual decrease until March (Table 2).

It should be noted that a distinction should be made between frontal and non-frontal or air mass precipitation. Non-frontal precipitation normally falls within an unstable air mass and can be distinguished by its high intensity. However, sometimes a stable air mass can also produce drizzle from the low stratus clouds. A study of precipitation in the Baltic Sea area based on radar data (2000-2001) showed that the maximum fraction of non-frontal precipitation was in the summer months (May-September), comprising 60-80%, and occurring especially in the afternoon, while in the cold half-year only 30-45% of precipitation was non-frontal [Walther *et.al* 2003]. Therefore, the attribution of precipitation to a particular air mass type should be to a certain extent considered arbitrary.

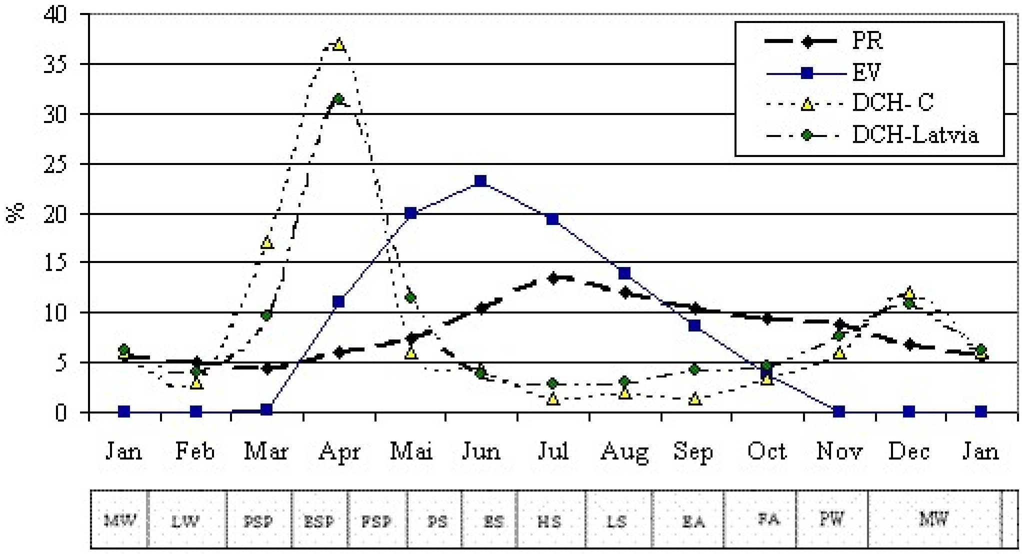
3.4. Seasonal changes in the water balance

Over the territory of Latvia the water balance is generally as follows: on average 35% of the total annual precipitation contributes to runoff and 65% to total evaporation [Latvijas daba, 1998]. Yet, the curves of annual course of these parameters may be to a great extent attributed to the lag effects in water balance. In terms of climate and landscape ecology, the most important effects are as follows (Figure 4).

The period of low precipitation overlaps the period of the highest runoff: on the whole around one third of annual runoff (according to observation data, 34% in Kurzeme, which is the most oceanic part of Latvia, and 37% in Latgale, which is more continental) [Sarma 1990] flows into the sea during the two months (March, April) with the lowest precipitation, when the ground receives only 10% of the annual amount of precipitation (Table 1). Similarly, the increase of soil moisture is very rapid during the period of minimum precipitation. It is more than clear that in these months almost all runoff and stocking up of soil moisture comes from precipitation that fell in the previous winter months and accumulated in the landscapes as snow and ice, but with setting in of spring, along with rapidly growing solar radiation, the air temperature rises and these two also join the hydrologic cycle.

At first, the abundance of spring water mainly contributes to the amount of runoff, but afterward enables the growth of evaporation, at the same time slowing down drying out of soil under the conditions of fast growing potential evapotranspiration. This effect is the strongest in early and full spring. It still continues in pre-summer, and comes to an end in early summer. Although the period of high precipitation sets in, the amount of runoff in May-June falls sharply from 14.5-16% to 3-8% of annual normal [Sarma 1990], because this is the time of the most intense evaporation. The total evaporation in May –June is on average from 18 to 21% of the annual amount (in March and April, the averages are 2 and 10%, respectively [Zubenok 1976].

During both summer months of high precipitation (July, August) the proportion of evaporation in the water balance is very high and the amount of runoff is low: July (full summer) and August (late summer) together produce 26% of the annual amount of precipitation and 31% of the annual amount of evaporation, and only 8-9% of the annual runoff. During the subsequent months, until November (pre-winter), the evaporation radically decreases. The course of runoff is totally different. In accordance with the findings of Sarma (1990), the more oceanic part of Latvia shows on average the amount of runoff has dropped to the minimum values in June and July (Early and High summer), and then starts gradually growing until mid-winter, when the second yearly maximum (December and January together produce 22% of yearly runoff) is observed, in spite of the small amount of precipitation at that time of the year. In more continental regions runoff falls to the annual minimum only in Early autumn (September has on average 2% of the annual normal runoff), and its winter maximum, which occurs already in December, is comparatively modest (8.5% of annual runoff). Both parts of Latvia also show the second minimum of runoff, which occurs in February and is more pronounced in regions with less maritime influence.



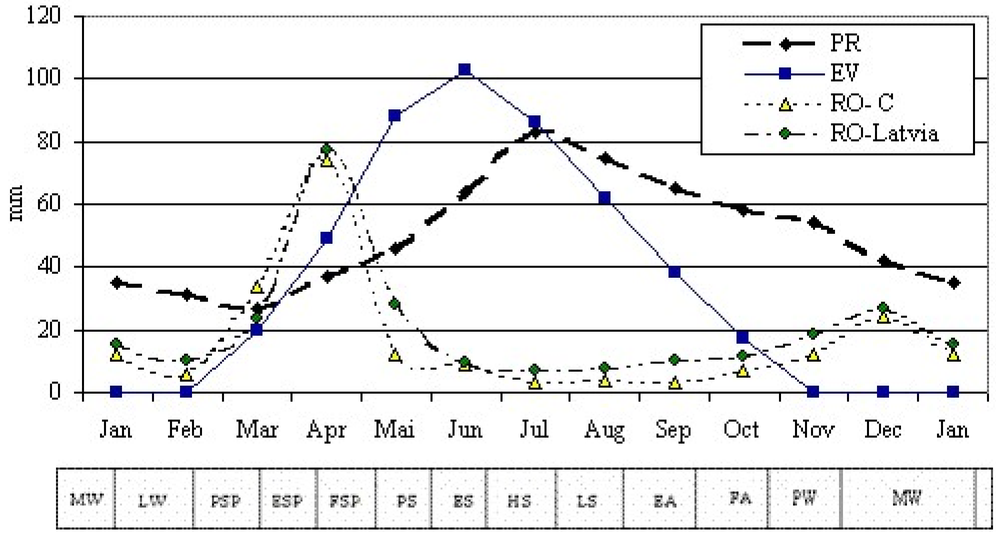


Figure 4. Annual course of precipitation (PR), evaporation (EV), river discharge (DCH) and total runoff (RO). *Above* – each item as a percentage of the yearly sum; *below* – absolute numerical values (mm). The data of precipitation [Latvijas daba 1995] and evaporation [Zubenok 1976] were referred to Riga, the data on river discharge [Sarma 1990] and runoff – to the whole territory of Latvia (Latvia) and its central part (C). Approximate annual course of runoff (mm) was calculated by distributing the annual runoff (425 mm – Latvia, 200 mm – central part of Latvia) proportionally to monthly average discharge (%).

Thus, the relation between the processes forming water balance differs completely with season. In terms of landscape ecology, the greatest importance should be attached to the seasonality of the ratio between precipitation and evaporation. Although Latvia, in the same way as the entire boreonemoral ecotone, belongs to an area of humid climate, a comparison of the widely accepted data on annual precipitation [Latvijas daba 1998] with the values of total evaporation calculated after a “complex method for determining evaporation” at the respectable Main Geophysical Observatory in Russia [Zubenok 1976] showed that on average annually during four months (April-July) evaporation exceeds precipitation, during four months (August-October, March) it is less than the amount of precipitation and during the remaining four months (November-February) evaporation is so small that it may be considered as zero (Figure 4). If the compared data is correct, the water balance in Latvia’s landscapes, viewed from time dimension, is a diachronous cycle of three equal periods: “overconsumption”, “restoration” and “conservation” of water supply.

The reduced runoff in summer is how the “overconsumption” manifests itself. Another well-known fact is the decrease of soil moisture, which is a common problem in cultivated areas, but often becomes critical for natural vegetation, too. According to this data, the highest “overconsumption” or evaporation in excess of precipitation, occurs in May (Pre-Summer) at 42 mm and June (Early summer) at 39 mm. In July (High summer) both processes get balanced, and already in August (Late summer) the precipitation exceeds evaporation by 13 mm or, in other words, a gradual “compensation” of the former “excess consumption” of water starts. In September (Early autumn) excess precipitation rises to 27 mm, but in October (Full autumn) reaches the maximum at 51 mm. This water in most cases remains in soils and groundwater. The runoff grows gradually or doesn’t essentially exceed the minimum level, and apparently only after the high precipitation period in autumn the saturation of soil with water and the groundwater level is enough high to ensure a noticeable increase of runoff at the beginning of winter. Freezing of soil might be that even a more important factor of the runoff increase. In any event, in autumn water accumulation in soils occurs and its greatest portion remains in the landscape until spring and summer when the accumulated water compensates to a greater or smaller extent the excess of runoff and/or evaporation over the precipitation.

Stocking up or “conservation” of water, caused by winter frost, manifests itself more clearly. In this respect a particular attention should be paid to snow cover (Table 3). Before ensuring fast growth of runoff and evaporation with the start of positive temperature period, it has essentially affected the state of landscapes in winter [Temnikova 1958; Draveniece 1997]. Firstly, it exerts influence on the variables of solar radiation and heat balance and secondly, the dynamics of wildlife. Yet, seasonal dynamics of the snow cover itself is extremely variable and strongly varies over the territory of Latvia, therefore the characteristics of snow cover still would need to be studied more in detail.

Table 3

Characteristics of snow cover (Riga)

Years	First snow	Continuous snow cover		Last snow	Duration (days)	Days with measurable snow cover						
						Oct	Nov	Dec	Jan	Feb	Mar	Apr
89/90	22.XI	*	*	20.II	39	0	9	14	10	6	0	0
90/91	30.XI	*	*	22.IV	57	0	2	12	13	26	3	1
91/92	31.X	*	*	25.IV	41	0	1	11	10	15	2	2
92/93	13.X	*	*	12.IV	68	7	11	4	13	15	17	1
93/94	23.X	24.I	10.III	28.III	106	1	12	23	25	28	17	0
94/95	19.X	14.XII	7.II	5.IV	69	1	1	16	22	15	13	1
95/96	2.XI	18.XII	10.IV	12.IV	134	0	4	27	31	29	31	12
96/97	27.XI	13.XII	18.II	24.IV	83	0	2	19	31	16	13	2
97/98	24.X	23.XI	5.I	21.III	101	8	11	31	12	21	18	0
98/99	8.XI	8.XI	26.III	27.III	95	0	23	31	18	28	26	0
99/00	15.XI	15.XII	11.II	21.III	91	0	13	20	31	14	13	0
2000*	28.XI	-	-	-	13*	0	0	4	-	-	-	-
Norm	14.XI	24.XII	13.III	6.IV								

* In 2000, the data for October-December

[Draveniece [1997]; the Archives of Latvian Hydrometeorological Agency]

3.5. Vegetation period

Characteristic of Latvia's climate is a half-year long vegetation period, when, unlike the other half-year (dormant period), the plants are growing, blooming, producing fruits and ripening them. In terms of phenology it might be the time from the unfolding of leaves to their falling [Schaefer, Tischler 1983; Leser 1997], yet more often this stage is restricted to climatic or agro-climatic interpretation – in the mid-latitudes it is associated with the period when the mean daily temperature exceeds 5ºC [Schultz 1995] or with the number of days when the mean daily temperature exceeds 10ºC [Ozenda 1994; Hendl und Liedtke (Hrsg.) 1997].

In accordance with the phenological observations [Latvijas dabas un vēstures kalendārs 1967-2004], in most of Latvia the first signs of vegetation renewal (bud burst of several tree and shrub species, blooming of the willow, and the occasional decoration of bare spots by the first spring ephemeroids) are already seen in early spring, when the daily temperature rises above 0ºC, and even earlier. The remnants of summer greenness and some blooms may be even seen until the first winter frost in November. Yet, in general, the vegetation matches the features referred to in the definition of the vegetation period, when the daily temperature exceeds 5ºC. In most cases it sets in about 2-3 weeks after vernal equinox (mid-April) and comes to an end a month after autumn equinox (end of October).

In the beginning of the described period the landscape outside coniferous forests is still dominated by gray color. Yet, the vegetation processes are already getting more intensive. Commonly the circulation of birch sap has started, and the shrub species widespread in Latvia, such as alder and hazel-trees, are blooming and the grass germinates. Soon after that leaves start to unfold, first the shrubs, then the trees. In the herb layer, the spring ephemeriods of nemoral zone (mainly *Hepatica nobilis*, *Corydalis Halleri*, *Anemone nemorosa* and *A.ranuncoloides)* far and wide form blue, white and sometimes yellow flower carpets, which appear as bright colourful clusters in the generally gray landscape. In a short time the mean daily temperature rises by up to 10ºC (it usually occurs by the end of the first decade of May), all trees and shrubs have burst into leaf, the grasslands have become green.

Thus, the beginning of vegetation period, a season less than one month in duration, which is typical of the change from a gray (except coniferous forests) early spring landscape with melt waters in the bare spots and isolated snow patches to a green and blooming landscape, might most appropriately be named Full spring. Afterwards, when daily air temperature rises above 10ºC, the main phase of vegetation period sets in and lasts until the end of the culminant phase of net radiation (end of July), encompassing the three following stages of summer (Figure 5).

The first stage of the main phase of the vegetation period is pre-summer, a season of the renewal of highly active life processes, which, despite the still possible "return of cold", distinguishes itself with a rapid increase of the number of blooming species and high biomass production. It follows from the phenological studies carried out in Estonia that during the next stage – early summer, the number of blooming species in the forest biogeocenosis of boreo-nemoral type (the dominant tree species is spruce, but in ground cover and shrub layer and tree stand, too, the species of deciduous broad-leaved forest hold a significant position) reach the maximum (shortly before/after summer solstice). Apparently, early summer and the following high summer are the main seasons of the annual course of biomass production, decomposition of dead biomass and biosphere-atmosphere gas exchange [Schultz 1981].

In high summer the state of vegetation is much the same. Yet, as regards zonal forests in July, the phenospectra of the herb layer generated at the Vooremaa Forest Ecology Station in the growing season of 1973 showed hardly any not-yet blooming species, while the number of blooming species was gradually decreasing. Some time later, almost half of herb-layer species will have already come to the phenophase of developing and ripening of fruits or even seed dispersal, and a quarter will have reached pre-dormancy quiescence [Kannukene 1979]. In other words, during high summer the processes which ensure reproduction and dissemination of species and prepare the plants for survival during the period of winter dormancy and for resuming activity during the next vegetation period, gradually come to the forefront. Moreover, the biomass production decreases essentially and green mass dies off more intensively. Later on, in the second half of vegetation period, these processes are the main ones.

In late summer (August) deciduous trees and shrubs, as well as coniferous trees, are still green, but the leaves have already lost the initial lush and in places have started yellowing, while uncut and non-depastured grasslands have turned into gloomy grey and brown plains of standing dead and withered grass. By the end of month the above ground parts of summer green species are almost entirely dead. At the end of August, coloring of shrubs and trees is accelerated by the frequent dropping of air temperature at night close to 0°C, and with this Early autumn sets in. A month later, at the end of this stage, only coniferous trees and winter crop fields are green.

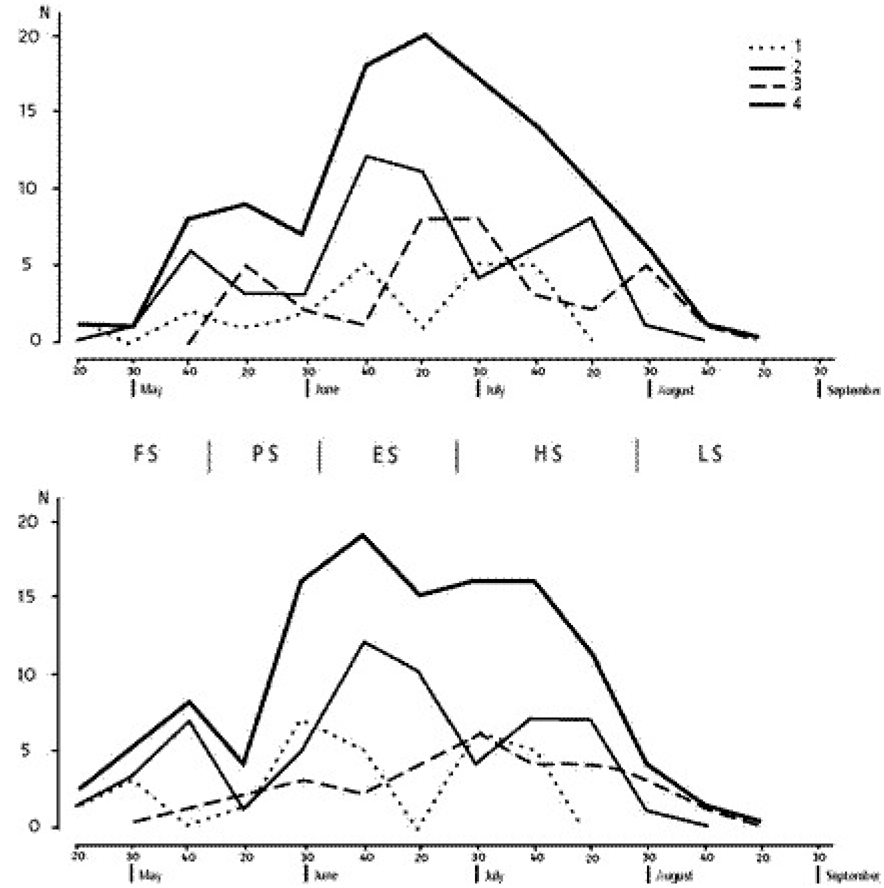


Figure 5. Flowering graphs of herb-layer species for 1972 (above) and 1973 (below). N-number of species in the phase of: 1 – start of flowering; 2 – full flowering; 3 – end of flowering; 4 – total of species in flowering stage, after Kannukene (1979). FS, PS, ES, HS, LS – landscape seasons see Figure 2 and text.

Vegetation period ends in full autumn – the most colorful season with yellow and red tree crowns and wonderful leaf carpets on the ground. This season is opened by three almost concurrent events of equal importance for climate and ecology – autumnal equinox, falling of daily mean temperature below 10ºC and often and severe autumn frost occurrence in the air. The end of the season coincides on average with the time, when daily mean temperature drops below 5ºC (normally in the end of October), yet sometime dead leaves still remain attached to the tree for a considerably long time.

3.6. Landscape seasons

Considering the described interrelations of landscape states the annual cycle may be divided into 12 seasons:

Midwinter (MW): end of November to second half of January;

Late winter (LW): second half of January to second half of February;

Pre-spring (PSP): second half of February to end of March;
Early spring (ESP): end of March to middle of April;
Full spring (FSP): middle of April to first half of May;
Pre-summer (PS): first half of May to beginning of June;
Early summer (ES): beginning of June to end of June;
High summer (HS): end of June to end of July;
Late summer (LS): end of July to end of August;
Early autumn (EA): end of August to second half of September;
Full autumn (FA): second half of September to end of October;
Pre-winter (PW): end of October to end of November.

The criteria of such division were pointed at and justified in the preceding discussion and figures. However, to complete this part of work, it might be appropriate to emphasize some conclusions which yet need to be studied in greater detail. They are as follows: (1) each season may be distinguished by a definite pattern of solar radiation, distinctive state of heat and water balance, biological turnover, phenological state of vegetation; (2) during each season these variables show a particular combination on numerical values and a distinctive landscape image; (3) every season has an effect on the state of landscape in the following seasons (theoretically – throughout the year); (4) transitions between the seasons are both gradual and sharp, but in all cases these may be clearly identified by several quantitative and qualitative features.

From this chapter it also follows that differences between seasons may be related to air mass occurrence (Figure 6). Since air mass types and their frequency is a factor which has been left beyond the scope in landscaper research, two following chapters are devoted to this item.

4. Air mass occurrence

4.1. Air mass types

Latvia's atmosphere in the context of air masses is related to other parts of Europe and the northern hemisphere in general, and experiences day-to-day, as well as seasonal, changes. Following M.Geb's (1981) classification, air masses were ranked according to their heat content. In addition to the determined backward trajectory, the typical 850 hPa temperature and pseudopotential temperature were considered (Figures 7, 8). At the same time the air masses arriving in Latvia were described in relation to their source region and some typical weather conditions [Draveniece 2003].

4.2. Seasonal changes of air masses

Based on the 850 hPa temperature and pseudopotential temperature, the monthly mean values for a 11-year (1990-2000) period were found. These might describe the average or theoretical air mass in Latvia.

From October to March, the average air mass was transformed maritime subpolar air xP. However, the average October air mass could hardly be distinguished from mP air. Regarding the heat content, the corresponding temperatures take up an intermediate position between the xP and mP air, so the decisive role was attached to moisture content. This finding fits in with the mapping of European air mass source regions in winter drawn by M.Geb (1981). The xP is a relatively temperate air in winter months and usually produces a sheet-like or layered (stratus) cloud cover the entire sky. It commonly occurs when warm, moist mP air moves over cold ground surface during winter. Stratus clouds produce little precipitation, usually in the form of drizzle. Occasionally, xP may produce partly cloudy or fair weather, depending on the degree of transformation.

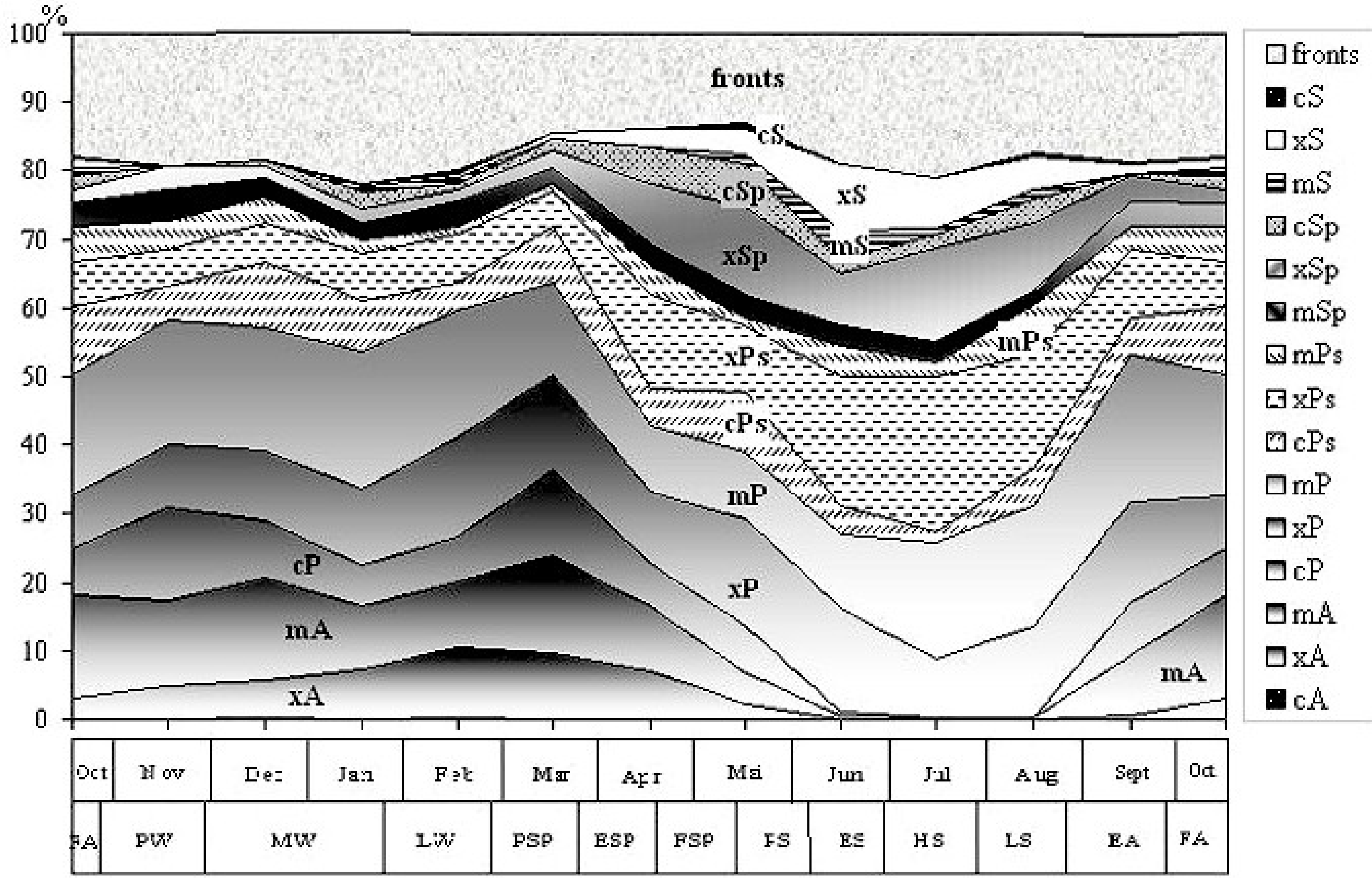


Figure 6. Monthly mean frequency of air masses at 850 level over Latvia (1990 –2000). Landscape seasons see in Figure 2 and the text

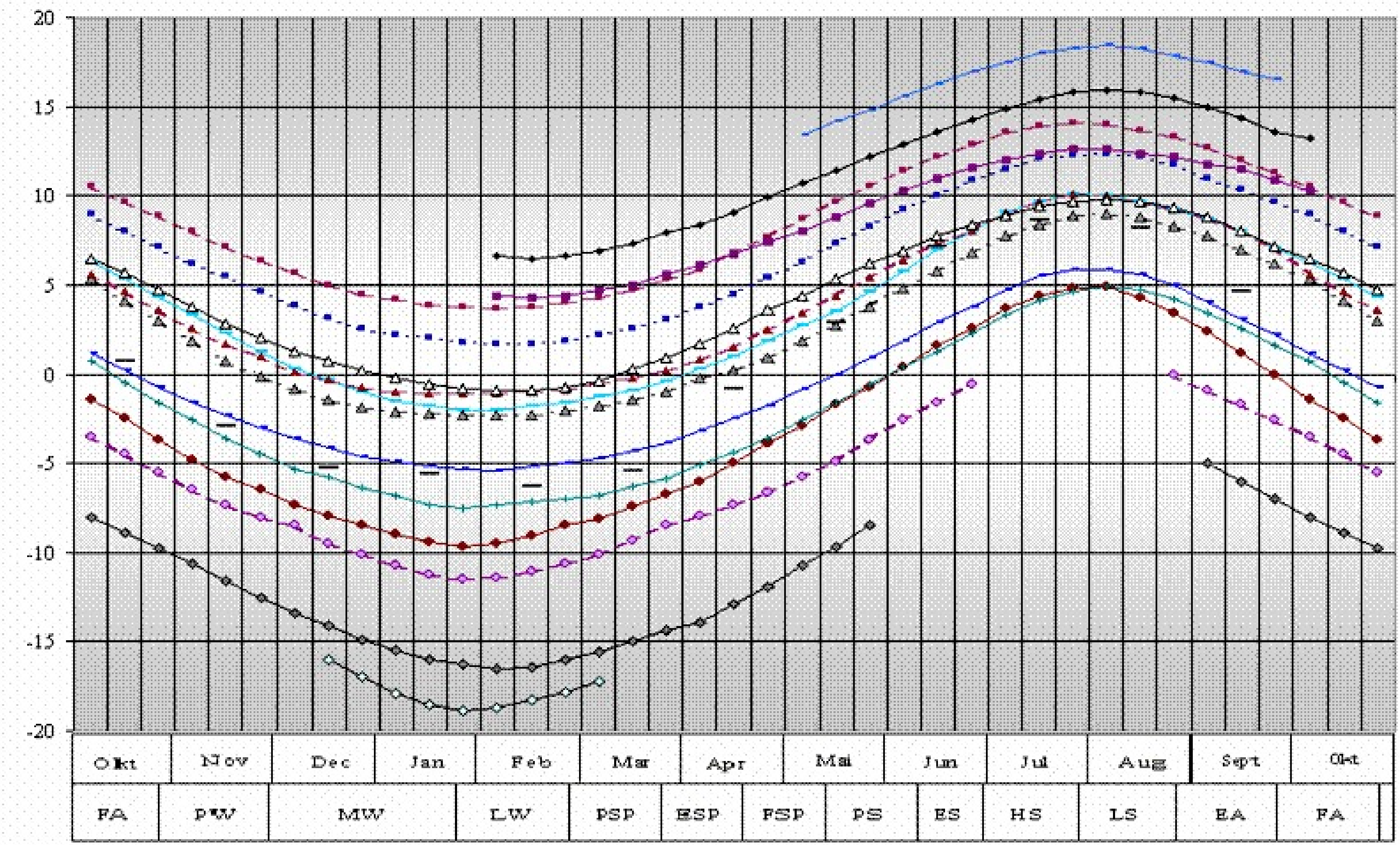


Figure 7. *Main*: Decadal mean temperatures (°C) of European air masses at 850 hPa level after Geb (1981). *Supplemental*: monthly mean temperatures in °C at 850 hPa level (Riga).

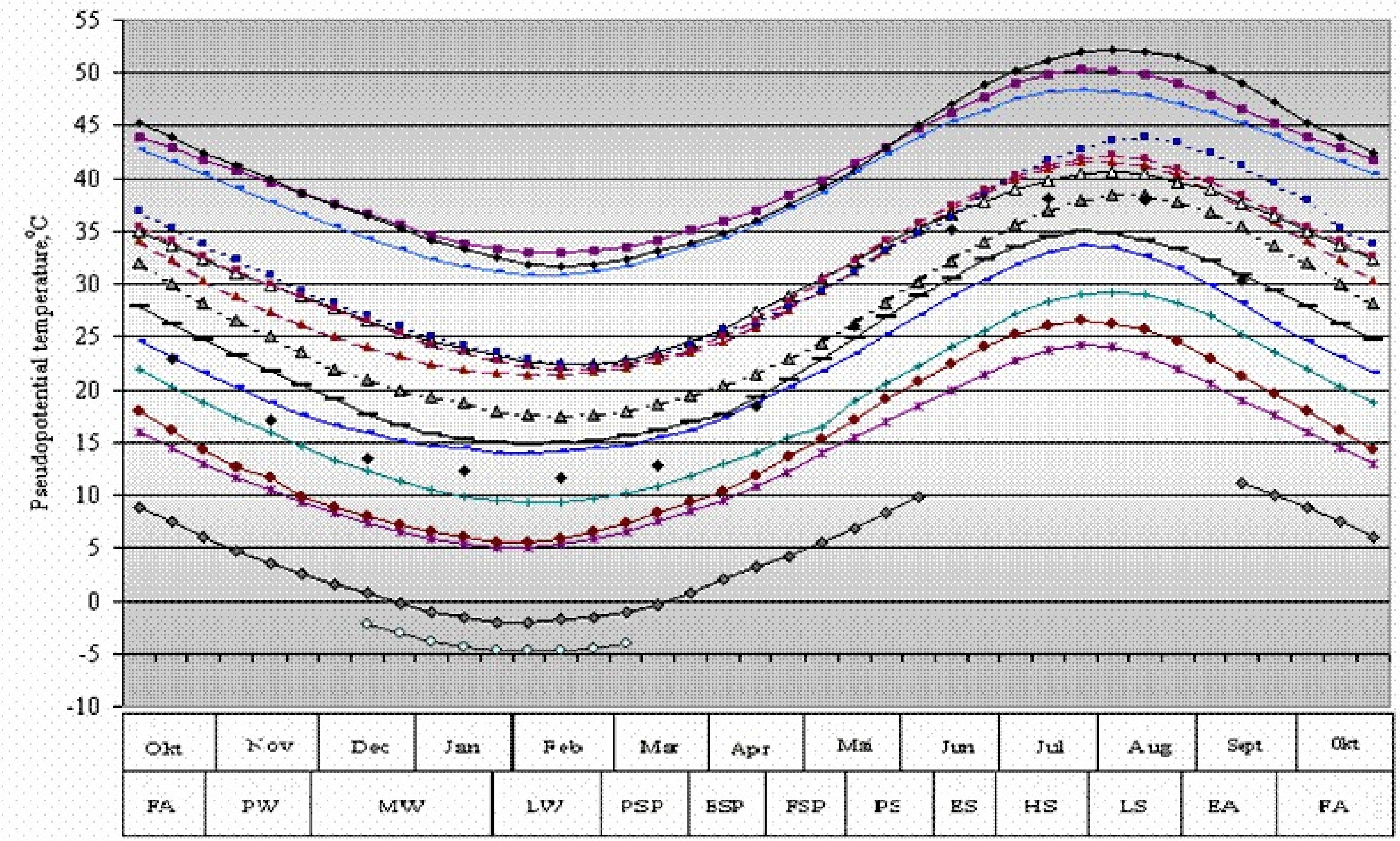


Figure 8. *Main*: Decadal mean pseudopotential temperatures (ºC) of European air masses at 850 hPa level after Geb (1981). *Supplemental*: monthly mean temperatures in ºC at 850 hPa level (Riga)

After vernal equinox, the 850 hPa temperature and pseudopotential temperature curves get much steeper and begin to level out only in June. It was found that in April to August the average air mass was warmed subpolar air xP_s. Furthermore, the May air mass exhibited a greater similarity to continental air or higher degree of transformation, but the September average air mass, still within the limits of one standard deviation of xP_s air, showed more similarity to mP air. The xP_s air mass is on average 3° to 4° warmer than mP air at 850 hPa level, but the pseudopotential temperatures differ even more (Figure 8). During Latvian spring-summer seasons, xP_s air produces warm to temperate weather and local convection is rather good. When a high-pressure ridge develops, sunny weather sets in with fair weather clouds and mid-day temperature may rise to 24 or 25°C. Under cyclonal circulation, the weather is slightly cooler, partly cloudy and rain alternates with sunny weather.

The mapping of European air mass source regions generated by Geb (1979) shows a shift of mid-latitude (S_p) air mass source region to the north, which starts in spring. While in April and May Latvia still lies on the edge of the xP air region, in summer months the northern boundary of mid-latitude xS_p air (limited by +15ºC isotherm over land) expands to the Finnish Gulf and to the north of the 60°N parallel over the Scandinavian peninsula. Thus, in summer under favourable conditions, an air mass over Latvia would potentially show the typical characteristics of mid-latitude xS_p air. Apparently, the closeness of Latvia to the northern edge of mid-latitudes entails the damping of radiative heating in the warm part of the year by relatively high occurrence of cool air (mP, xP).

To summarize, all year round the average monthly air mass in Latvia is transformed maritime air, because Latvia lies in a transitional position, where maritime air moving from west to east gradually is transformed into continental air, i.e. the continentality increases. This general tendency is cancelled or counteracted by the influence of the Baltic Sea. Bukantis [1995] found that the most obvious influence of the Baltic Sea on climate, depending on land relief, was in the coastal belt about 30-100 km wide.

The annual cycle of **air mass frequency** may be divided into two periods with transition periods between them. The pattern of air mass occurrence forms against a background of variation of the properties of each air mass from month to month as the temperature of an air mass changes and, consequently, its moisture content and stability, both at the surface and at 850 hPa level. By the annual occurrence of different air mass types and their influence on weather, three kinds of air masses may be distinguished: all-season, seasonal and irregular.

All-season air masses, for instance, xP, mP, cP_s, xP_s, arrive in Latvia each year and each month, showing smaller or greater annual variation. Others, such as xA, mA, cP, xS_p, xS, are strongly seasonal air masses. These arrive each year and while showing annual variations, pertain to certain months with little or no influence the rest of the year. Irregular air masses, such as cA, cS, are strongly seasonal, do not arrive in Latvia each year, and bring extreme (the coldest and the hottest) weather. The all-season air masses play a double role, making a background for seasonal air masses to stand out against, and at the same time may show themselves as a prevailing air mass type. The maritime subpolar air mP may be considered the core air mass. While the role of seasonal and irregular air masses is unequivocal – these bring either warm or cold weather (the surface daily mean temperatures are clearly above or below the monthly mean temperatures), the all-season air masses exert an almost contradictory influence on weather. In October-March these masses manifest themselves as warm or temperate air, in transitional seasons as temperate, and in June-July as cool air.

October to mid-April shows a particular combination of air masses. Within the 11-year period (1990-2000), the frequency of mP air together with xP air (its first modification) was above 30% or more specifically from 30% (October) to 38% (January), excluding the days with frontal passages. At that time of the year, these air masses manifest themselves as warm or temperate ones, and interchange with cold air masses xA, mA, cP (the surface daily mean temperatures are clearly below the monthly mean temperatures). The latter bring about and maintain winter weather (snowfalls/clear skies and negative air temperatures). The occurrence of each separate cold air mass varies from month to month while their frequency is within 6 to 18%, but altogether cold or winter air masses dominate during 30 to 40% of days (fronts excluded), excepting January, which had a slightly lower frequency (27%). The frequency of warm air masses, namely, warmed subpolar, mid-latitude and subtropical air, varies from 24% in February to 37% in October (fronts excluded). Thus, October to mid-April may be designated a period of subpolar and arctic air (P+A period) (Figure 6).

Table 4

Description of characteristic air masses over Latvia

Abb-rev.	Description
cA	**Continental arctic air** The coldest air mass; it comes to Latvia with north-easterly or easterly airstreams; occurs only in winter (December – early March). It originates over the Arctic basin and Siberia, where snow and ice cover chills the lower layers and forms a marked temperature inversion up to 850 hPa. In winter, the source region is limited by the -15°C isotherm. The air is bitterly cold (≤-40°C). The lack of moisture causes cloudless weather without precipitation. An infrequent air mass in Latvia.
xA	**Arctic air –** transformed maritime type It brings slightly milder weather than cA air and usually comes with northerly and north-easterly airstreams. Identified from September till the first half of May. After a series of cyclones, a concluding ridge of high pressure may develop in the maritime arctic air over Scandinavia and this air is transformed into xA air, a drier and colder air. Less frequently xA air develops from cA air. In winter the daily temperature may decrease to -25°C and even below -30°C at night; the skies are clear or partly cloudy. It is a cold air mass in all seasons. In spring and early autumn this air causes frost.
mA	**Maritime arctic air** Identified from September till the first decade of June. It usually comes with north-westerly and westerly airstreams from north-western Atlantic as a cold air stream out of cP or cA sources. While it moves over the relatively warm water surface, it is warmed and becomes unstable: cumulus and cumulonimbus clouds and often showers of snow, sleet, hail or rain occur. In late autumn it brings the first snowfall. In early December under negative net radiation, the inflow of mA air leads to snowfall and forming of a continuous snow cover. During transition seasons, this air is unstable and multiple episodes of rain with great drops and hail and gusty wind occur during daytime. At night the clouds tend to disperse. Radiative fogs in autumn. In spring and early autumn this air causes frost. In summer, this air is shallow and moving southward it modifies to the point where it can no longer be identified and is then indicated as mP air.
cP	**Continental subpolar air** It is brought with easterly, south-easterly or north-easterly airstreams. Does not reach Latvia from June through August. It is a cold air mass in all seasons and has the same characteristics as cA air, i.e. low dewpoints, low temperatures and a high degree of stability, but it is warmer. Precipitation, if any, is usually light due to the low moisture content. The source region of cP air extends from the East European Plain southward to the territories north of the Black Sea and westward to the rivers Dniester and Visla. In midwinter, the near surface temperature may fall to -15°C with clear skies, but fog or haze may form. Sometimes St and Sc clouds are observed. Light snowfall can occur. In spring and early autumn this air causes frost.
xP	**Subpolar air –** transformed maritime type An all-season air mass in Latvia brought with northerly and north-westerly airstreams. In winter its' source region extends from the western coasts of Scandinavian and Jutland peninsulas to the 25°E meridian; the northern boundary lies along the northern coast of Bothnian Bay and the southern boundary lies to the south of Latvia and the southern coast of the Baltic Sea. When spring sets in, the xP source region shrinks poleward and in summer its southern boundary lies along the Finnish Gulf. In winter it is often generated from mP air through transformation as uniform grayish (stratus) clouds often cover the entire sky. There is little or no precipitation At other times partly cloudy skies may be observed. In summer, when after a series of cyclones a concluding ridge of high pressure develops over Scandinavia and Finland in mA air, it is quickly transformed into xP air. Spring frosts may occur.
mP	**Maritime subpolar air** The most common air mass in Latvia brought with north-westerly, westerly airstreams. In winter, the source region for mP air extends over the northern part of the Atlantic Ocean to the northern and western coasts of the Scandinavian peninsula, including the North Sea. While the air travels over the relatively warm Atlantic Ocean, it warms from below and becomes unstable. As a result, mP air is notorious for producing cloudy weather, fog, drizzle and long-lasting light to moderate rain. In winter months it is a temperate air mass which causes the rise of temperature as a result of which very often thaw sets in. When mP air moves over non-ice covered Baltic Sea in winter, the relatively warm seawater makes the air rise, increasing the chance of showers. In the summer half-year it is the most frequently occurring cool air mass bringing generally good weather conditions (+16º to +20ºC at midday, +9 to +11ºC at night in July). Occasionally, because of surface heating, a shower or thunderstorm may be observed in the daytime.
cP_s	**Warmed continental subpolar air** Identified in all seasons. Cannot be related to a particular birthing region because this air initially originates from subpolar air. In winter it develops from mP air through transitional from xP_s air moving over snow-free land of Western and Central Europe; the process takes around 1 week. In summer months, it arrives with southern and south-eastern airstreams from Ukraine, southern part of European Russia and Central Europe. It may also develop from continental mid-latitude or subtropical air, when it flows into a neighbouring cooler region. Associated with clear skies or partly cloudy weather, no precipitation.

Abb-rev.	Description
xP_s	**Warmed subpolar air –** transformed maritime type Identified in all seasons. Cannot be related to a particular birthing region because this air initially originates from mP air in winter half-year or warmer maritime air mass types in summer half-year. In winter months develops as a transitional form of mP air, when it moves over a snow-free land of Western and Central Europe and under weak advection. Under these conditions, mP air is transformed into xP_s air within a day. It is warmer than mP air and more stable. It may also develop from mP_s air. In winter, an overall cloud cover forms, but in summer, normal convection develops with fair-weather clouds, and usually sunny weather sets in.
mP_s	**Warmed maritime subpolar air** All-season air mass. Cannot be related to a particular birthing region. Develops from mP air, when it is brought to subtropical latitudes of the Atlantic Ocean and returns with a north-eastern airstream across Europe. In winter, this air causes intensive and durable thaw; low-level clouds, rain and sleet; drizzle and fog. Average daily temperatures in mid-winter may reach +4º to +6ºC. In summer, the cloud cover is less than in mP air and consists primarily of fair-weather clouds. In summer, average daily temperatures are +17º to +19ºC, with mid-day maximum temperatures up to +24ºC and no precipitation.
mS_p	**Maritime mid-latitude air** All-season air mass. With the exception of origin, this air's typical heat-moisture content differs little from mP_s air. Usually originates over North Atlantic to the west of the British Isles. Its birthing region's northern and southern boundaries shift with seasons (40º northern latitude (winter) to around 60ºN). In winter, it is a stable air mass, bringing fast rise of temperature, intensive thaw, drizzle, fog and low-level stratus clouds. Much less stable in the summer half-year; a marked convection develops, expressing itself through cumulus and cumulonimbus clouds, rain showers and thunderstorms.
xS_p	**Mid-latitude air –** transformed maritime type Mainly spring-autumn air mass; plays insignificant role from October till March. A very warm air mass. Originates over the continent from temperate or warm maritime air (mP_s or mS_p), which gradually loses its moisture content, and in summer months also warms up. More often is brought with southern and south-eastern airstreams. Clear or partly cloudy skies, daytime temperatures may rise to +29ºC; showers and thunderstorms occur in the afternoon hours. Unlike subtropical air, which produces daytime temperatures above +30ºC, mid-latitude air would normally reach +25º to +30ºC.
cS_p	**Continental mid-latitude air** A warm air mass arriving in Latvia mainly in summer months. From spring to summer this air's source region shifts to the northeast and in summer it occupies the East European Plain and Central Europe, coming rather close to Latvia. Usually brings sunny and very warm weather with great diurnal temperature amplitude. Sometimes slight cloudiness. July midday temperatures reach +29º to +30ºC and it is warm also at night (around +15ºC). Fog formation in evening hours; morning dew.
mS	**Maritime subtropical air** A warm air mass, which reaches Latvia primarily from May till August, but occasionally may arrive in cold half-year, too. Relatively high temperatures accompany the inflow of mS air and the moisture content is greater than in any other air mass. The air that arrives over Latvia usually originates over the southern part of the North Atlantic. During winter a very stable air mass, bringing thaw, moist weather with fog, drizzle and low-level clouds. Average daily temperatures may reach +4ºC in January. In summer half-year it has the same properties as its counterpart in winter, yet it is less stable, with cumulus and cumulonimbus clouds, rain showers and thunderstorms; in summer this air brings very warm weather, the daily temperatures reaching +30ºC.
xS	**Subtropical air –** transformed maritime type A very warm air mass in all seasons. Normally arrives from April to October with southern airstreams from the regions of Mediterranean and Black Sea, but may reach Latvia in cold half-year, too. In mid-winter the daily maximum may reach +5ºC. The warmest Latvian summer weather with sultry days is mainly brought by this air mass. In July, the daytime temperatures may exceed +30ºC. Very great diurnal temperature range with high temperatures at night, too.
cS	**Continental subtropical air** A very warm air mass bringing the highest air temperatures. Observed only in May through August and not every year. It is brought from the southern part of European Russia or the Balkan peninsula. The northern boundary of this air lies along the +20ºC isotherm. This air brings very hot, sunny and dry weather with fog forming in evening hours and morning dew. A great diurnal temperature range with high day-time and night temperatures: +17º÷ +22ºC at night and +34º÷+35ºC in midday. Clear skies. No precipitation.

This period is followed by a transition interval (mid-April to May) or a period of no dominant air mass, when almost all types of air masses, except those bringing extreme winter or summer weather, arrive in Latvia. It coincides with a period of transition in the northern hemisphere (end of March to early June) from winter to summer atmospheric circulation, which is more dependent on solar radiation. The westerly circulation gradually weakens, and therefore meridional circulation often develops, whereby either arctic air masses or warm mid-latitude and even subtropical air arrives in Latvia.

June to August may be distinguished by prevalence of warmed subpolar xPs air, which manifests itself as temperate air, and the highest yearly frequency of mid-latitude xSp air and subtropical air mS and xS. Within the 11-year period, the frequency of xPs air was 22 to 24% days while its source air mass mP air showed lower frequency and manifested itself as a cool air mass. Together with the other cool air mass xP air, the coolest air masses occurred in 31 to 36% days (fronts excluded). From June till August the cold/winter air masses do not reach Latvia. Maritime and transformed maritime subpolar air is an indispensable part of the June-August air mass pattern, and exerts a tempering influence on weather during that time. When these air masses arrive more frequently, they cause rather untypical weather to set in, as it happened in summer of 1962, when enhanced cyclonic activity brought cool air and much rain throughout the entire summer. Generally, from June till August, warmed subpolar and mid-latitude air arrived in Latvia on 48 to 54% of days (fronts excluded). Thus, this time could be named Ps+Sp period, and it is followed by a short transition period.

In early autumn (end of August to end of September) cold air masses (mA, cP) start arriving in Latvia, yet their frequency in the 11-year period was merely 20%, while the occurrence of warmed subpolar and mid-latitude air (Ps+Sp) decreased almost by a factor of two, comprising only 26% (fronts excluded). While warm southerly air masses leave the stage and cold arctic and subpolar air enter, the temperate mP air expands its influence. Within the 11-year period its average frequency was 25% (fronts excluded).

5. Relationship of air mass occurrence to landscape seasons

The description of relations between the air mass occurrence and landscape seasons is started with full autumn, which begins the period of subpolar and arctic air (P+A period).

Full autumn, FA *(the third decade of September till the end of October)*

Full autumn may also be named "golden autumn" – the trees have coloured after the first killing frosts (brought by arctic or continental subpolar air), and the growing season has come to an end. By the end of FA, a massive leaf fall usually occurs and the last migratory birds leave. Birch, aspen and ash are perhaps the last whose leaves fall to the ground. The wildlife comes to winter dormancy. The incoming short-wave radiation decreases noticeably, and was 129 MJ/m^2 in October comprising on average merely a half of that received in September. The net radiation is still positive and the average monthly temperature is normally above +5°C.

Full autumn is the first season of subpolar-arctic period (P+A), with the average frequency of regular mP and xP air during the 11-year period at 30% and that of cold air masses (xA, mA, cP) also at 30%, mA air prevailing. October was notable for high occurrence (41%) of maritime air masses (mainly mA and mP air) and considerably lower occurrence of transformed and continental air, each comprising ca 30% (Figure 6, Table 5). Full autumn showed two combinations. In 6 years of 11 a cold, windy and damp weather set in, because strong cyclonic circulation pattern brought cold (xA, mA, cP) and temperate (xP, mP) air masses, but in other years fair weather was observed, as in 1990, 1991, 1995 and 1996. In cold months, when active depressions move eastward, once the associated weather fronts have passed through, Latvia is left in a stream of mA or mP air. Consequently, showers of rain, snow or sleet often occur. In October, arctic air masses arrived on average 6 days per month (18%), but in cold months these prevailed 9 to11 days. For instance, in 1992, 1993, 1994, 1997, the first snow cover formed in the second half-month with the inflow of mA air, and in 1997 its thickness in Riga was even 32 cm. October's snow cover is always short-term. Within the 11-year period there were two Octobers (1992, 1998), when snow cover in Riga existed for 7-8 days. However, arrival of mA air in October doesn't necessarily mean prolonged negative temperatures; these may fall at night-time below 0°C, but in midday the temperatures are +4° to +5°C (Riga). Lasting of snow cover for 7-8 days occurred because anticyclonal weather set in (mA transformed into xA air), and the air temperatures fell below 0°C. In cold Octobers with frequent arrivals of maritime, primarily mP and mA, air and high frontal activity, higher amounts of precipitation were recorded.

Thus, setting in of P+A period may occur rather rapidly, unless delayed by Old Wives' summer, a weather singularity, which then makes the transition period more gradual. Full autumn may also bring summer-in-autumn or "Old Wives' summer', which may occur several times or none at all as seen above. Such weather occurred in the first half of October in 1991, 1995, 2000. For instance, in the period from 6th to 13th October 1991, warmed continental subpolar air cP_s was brought into Latvia, when an anticyclone dominated over the European part of Russia. Warm, sunny weather set in with great diurnal temperature variations. During daytime, the air temperature increased to +18° to +22°C, but at night, because of strong radiation cooling, the temperature was around +4° to +9°C. Another episode was in the first half of October 1995, when an anticyclone formed in very warm air masses, south-western winds brought continental and transformed maritime mid-latitude air (cS_p, xS_p), and warm weather prevailed. On 10th October the temperature increased to +20° to +23°C, which was close to absolute maximum of October, and for several days around that date a period of Old Wives' summer occurred.

In general, during the 11-year period, October was the wettest month. Full autumn showed high annual variation of arctic and warm mid-latitude air mass frequency, yet interannual variation of October's average temperature was moderate. The standard deviation of near-surface monthly air temperatures and 850hPa pseudopotential temperatures were also moderate (Figures 7, 8, Table 5).

Pre-winter, PW *(end of October to end of November)*

Pre-winter marks the beginning of solar winter. The incoming short-wave radiation continues decreasing and during the 11-year period (1990-2000) the November average was 49 MJ/m², which was half of that in October. Although occasionally Rnt may be close to zero or slightly above zero, in most cases it is negative. Regardless of that the diurnal air temperature commonly still remains positive. During PW the landscape comes to winter dormancy.

In PW, maritime subpolar air mP and its first modification xP air dominated in one third of days, comprising together 32% (fronts excluded). Both manifested themselves as temperate air. The mP air commonly arrives behind the cold front of a cyclone and brings mild (> 0°C) air temperatures. It is an unstable air mass and brings greatly changeable weather: clouds (mainly cumulus forms), sleet, snowfalls and then briefly clear skies. The xP air is more stable.

Table 5

Average annual frequency of air masses over Latvia (1990-2000)

Air mass types	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	AVG	STDEV
cA					1		1					0.2	
xA	3	9	13	10	13	10	17	35	26	17	15	15.5	8.8
mA	23	33	38	36	33	35	26	33	22	24	26	30	5.6
cP	15	25	15	29	27	18	40	16	33	22	13	23	8.6
xP	36	40	37	53	37	30	48	38	42	63	54	43.5	9.8
mP	72	50	59	54	56	66	51	50	70	51	73	60	8.7
cPs	31	32	34	25	20	19	30	18	14	19	24	24	6.4
xPs	43	46	43	35	41	37	34	42	36	36	43	40	3.9
mPs	11	15	11	13	16	8	12	13	8	14	16	13	2.7
mSp	14	15	12	13	14	18	8	13	13	11	5	12	3.7
xSp	15	24	19	14	23	29	18	28	14	20	20	20	5.1
cSp	10	5	7	19	12	13	7	7	9	5	3	9	4.6
mS	3	4	2	1	2	9	4	4	3	2	2	3	2.1
xS	5	5	8	3	7	13	11	5	9	20	12	9	5
cS	3		1		4		2					1	1.5
fronts	72	62	67	60	60	60	57	63	66	61	59	62	

In the context of air masses, PW can be called a winter season, because the winter air masses gain the upper hand over warmer air masses, and during the 11-year period these (xA, mA, cP) comprised altogether on average 40%. Sleet and slush occurred almost each year. Pre-winter is known for establishing of first snow cover, which lasts for at least one, but commonly several days. Forming of permanent snow cover is not typical for pre-winter because the near surface air temperature normally falls below 0°C at the end of the month and therefore, regardless of negative net radiation, the ground usually has not cooled yet to ≤ +2°C (prerequisite for forming of permanent snow cover). Yet, in November 1998 the snow cover lasted for 23 days, and actually was a continuous snow cover.

Falling of snow often occurs in arctic air (mA), arriving behind the cold front. Arctic air masses (xA, mA) arrived each year with an exception of the year 2000, when arctic air was not identified at all. The xA air is the coldest air mass in PW. It may produce only light snow, if any, and the air temperature at nighttime may fall below -10°C. For instance, in the middle of November 1994, while the city (Riga) heat-island effect prevented the minimum here from falling below -7°C, minima near -13°C were recorded in the eastern part of Latvia.

PW showed a high frequency (yearly maximum) of continental subpolar cP air. In 1993, 1998 and 1999 it was brought into Latvia for 9-10 days. The spells of cold weather in these years were due to anticyclones persisting over the European part of Russia when the Siberian high extended westwards. Consequently, the mean diurnal temperatures fell below zero at the end of first decade (1993, 1998), which was 2-3 weeks earlier than normal. Although severe cold is unusual at this time of year, in 1993 and 1998, November's average temperatures turned out to be the yearly minimum temperatures.

Warm spells (≤ 4 days) may occur during PW when the warm mid-latitude (mS_p, xS_p, cS_p) air flows into Latvia. Such warm spells were noted in eight years of the eleven studied.. For instance, in the 2nd decade of the PW of 2000, when exceptionally mild south-western winds brought transformed maritime mid-latitude air xS_p, the near surface daily air temperatures varied from +1.5°C to +5° C over the territory of Latvia.

As a whole, November is drier than the previous months because the prevailing air mass temperatures are already quite low and therefore hold less moisture. Moreover, the frequency of continental air masses increases. Pre-winter showed a high annual variation of the prevailing air mass. On the one hand, in 2000 the mP air prevailed, while arctic air was not identified at all, and, on the other hand, in 1998 the cold air masses, primarily cP and xA air dominated for 18 days, and mP air was identified only 3 days. As a result, November's average temperatures showed almost the highest interannual variation. The standard deviation of surface air monthly mean temperatures and 850hPa pseudopotential temperatures was very high, too (Figures 7, 8).

Midwinter, MW (beginning of December through third decade of January)

In December-January the incoming short-wave radiation reaches the minimum and stays low in January, too. *Rnt* is negative. A persistent cloud cover resulting from both frequent frontal passages and establishing of air mass cloudiness (caused by cooling above a colder land surface) cuts off direct solar radiation. Thus, a favourable situation for the snow cover to last for an extended period of time sets in. In general, coming of December generally heralds the coming establishment of a continuous snow cover over Latvia (on average, December 8-29) except the coastal territories adjacent to the Baltic Sea, where it is established in the first decade of January. Yet, the seasons 1989/90 and 1992/93 didn't see establishing of a continuous snow cover at all (Table 3).

During northern hemisphere winters, because of larger radiation contrasts and a stronger equator-pole temperature gradient, westerly circulation is more vigorous and moves fronts and air masses through the mid-latitudes. Therefore air masses moving relatively rapidly to Latvia from either source region either retain their initial properties or lose their humidity and cool down if their motion is less intensive. However, when the trajectory of mP air lies over western and central European land surface which is not covered with snow, it may transform into warmer and more stable air mass xP_s.

In MW, subpolar and arctic air masses prevail. In the 11-year period during December-January the occurrence of temperate/warm mP and xP air was on average 34-38% and of winter air masses 34-27 %. Similarly to pre-winter, the frequency of the core air mass (mP air, which usually brings warming of weather and even thaws) was high at 21-24% (fronts excluded). With regard to snow cover, a distinction should be made among the subtypes of arctic air. The cA and xA air and continental subpolar air cP would enable the existence of snow cover but would not increase its thickness, although cP air may produce light snowfall. In the 1990s the coldest cA air was identified only in the last week of December 1996. The temperature minimum over snow covered territories dropped to -30º to -36ºC. The xA air affected Latvia each January, yet it was not identified each December. The xA air brings the customary severe winter weather, when the daily average temperatures may fall to -25° or -26°C. The first half of MW (December) showed as high a frequency of continental air as the previous season (PW), but the second half was very much dominated by mP air.

In mid-winter, a day or two may occur, when midlatitude (mS_p, xS_p) air arrives, and in January 1998 even subtropical xS air reached Latvia. These very warm air masses together with warmed subpolar air comprised together ca 30% (fronts excluded).

As a whole, MW produced precipitation < 60 mm/month. In the 11-year period, MW was characterised by the lowest annual variation of the prevailing air mass frequency compared to other seasons. The standard deviation of monthly near surface air and 850 hPa pseudopotential temperatures were lower than in other winter months (Table 1, Figure 8). However, it should be noted that the present study did not include any winter with an extended inflow of cA air because 1987/1988 was the start of a period of relative mild winters. January 1987 is known to be the coldest on 100-year record. An unusually cold outbreak of cA air from the north-east brought near record low January temperatures (-37°C) and a record long period of very low (-25° to -30°C) temperatures.

Late winter, LW *(third decade of January to end of February)*

In early February the incoming short-wave radiation starts gradually increasing and doubles by the end of the month (98 MJ/m²). Regardless of the slight increase of solar radiation, February was the coldest month in five of the 11 years. Late winter is dominated by subpolar and arctic air masses. In the 11-year period the frequency of temperate/warm mP and xP air was 39% and that of winter air (xA, mA, cP) 32% (fronts excluded). With an exception of the extremely warm February 1990 with only a couple of days of mA air, in late winter the frequency of arctic air masses slightly increased. Frosts are common and, although rarely, the cA air may affect Latvia. February 1994 was such a really cold month, with a minimum of –29.4°C on the coldest day in Riga and even lower (-33°C) elsewhere in Latvia as a result of cA air. Late winter shows an increased occurrence of transformed maritime air masses. The reason for this is xA air, which is more frequent at this time than in any other month because a short period of anticyclonic weather often occurs in early February. The anticyclones often form over Northern Europe in maritime air of arctic origin, which gradually is transformed into xA air and brings severe frosts in cold Februaries. The air mass t_{850} and θ_{850} are almost the same as in January (Figures 7, 8).

LW showed the lowest frequency of warmed subpolar air P_s, and also mid-latitude and subtropical air.

In February of 1990, which was the warmest February on a 100-year record, when precipitation was only in the form of rainfall, the unusual warmth "woke up" the dormant plants and birch sap started rising in the last week of February. It was an extremely warm month due to several spells of mid-latitude and even subtropical air. Average diurnal temperatures stayed above zero almost the whole month except 16-19 February.

LW is a dry season. In the 11-year period, the mean monthly precipitation for February was 35 to 55 mm over the territory of Latvia and 45.7 mm in Riga, comprising here 7% of yearly precipitation. Unless anomalous warm weather occurs, a continuous snow cover is common for February, which is maintained and renewed by winter air masses. On the whole, February's average temperatures showed more variation than any other month (10.5°C), and the standard deviation of near surface air temperature and 850 hPa pseudopotential temperatures θ_{850} was higher than in any other month (Table 1, Figure 8).

Pre-spring, PSP *(end of February to end of March)*

Pre-spring is the season of transition from winter to spring. The decline of winter starts at the end of February, when *Rnt* on average becomes positive, and lasts until vernal equinox. From February to March the incoming short-wave radiation increases 2.5 times, reaching 247 MJ/m², *Rnt* grows significantly and the solar heat increase is truly noticeable. However, the increase of air temperature is rather slow, and monthly mean temperatures from February to March increased by 2.7ºC (Riga).

At the first glance, the landscape continues its winter dormancy, but flowering of alder (*Alnus*) and hazel (*Corylus*) starts, occasionally as early as the end of February. The first spring thaws occur, and pre-spring is known for the disappearance of a continuous snow cover, which occurs on average before March 31 over the whole territory of Latvia. The first migratory birds return.

PSP is dominated by subpolar and arctic air masses. In the 11-year period, the frequency of temperate/warm mP and xP air was 31% and that of winter air (xA, mA, cP) was 42%, reaching the peak in their annual course. The cold cA air was no longer identified, because the region of its influence retreated northwards. The coldest March weather, with minimum temperatures of -20ºC and mid-day temperatures of up to -5ºC, is brought by transformed maritime arctic air xA. Of the three cold air masses the most frequent was mA air and slightly less frequent was cP air. High occurrence of winter air masses favours longer duration of snow cover or enables the development of snow cover after a warm February. In March 1996 the above air masses dominated for 22 days, prolonging the duration of snow cover, which started melting only in the beginning of April. On the other hand, March 1992 showed a low proportion of winter air masses (25%), which was the reason why snow cover melted already in the beginning of the month.

Warm air masses may arrive either within the warm sector of a cyclone or along the ridge of high pressure. Periods of the presence of mid-latitude air masses occurred 8 years within 11-year period. In 1990, even a brief period when subtropical air masses (mS, xS) were present occurred. Along with great diurnal temperature range, the warmest days (1-3 days/month) produced mid-day temperatures above +15ºC. On 19 March 1990 the mid-day temperature was +16.9ºC in Riga and +16.3ºC in Rezekne. Moreover, the daily temperature range was very high (12.4ºC in Rezekne). On average, the proportion of warm air masses in March was 23% (fronts excluded). PSP is notable for the highest average frequency of continental air (primarily cP and cP_s) masses, which were more frequent in the first and second decade of March. Consequently, a characteristic feature of this season is great diurnal temperature range, particularly on days with clear skies or slight cloudiness, when continental or transformed maritime air prevails. This season is also characterised by a low amount of precipitation. During the 11-year period, the average monthly precipitation in March was less than 50 mm (Riga).

In the 11-year period, the average heat content of March air masses expressed by θ_{850} was +12.8ºC, and the standard deviation of near surface air temperature and 850 hPa pseudopotential temperature was still high (Table 1, Figure 8).

Early spring, ESP *(end of March to middle of April)*

From March to April, the incoming short-wave radiation grows 1.5 times and *Rnt* triples (Tables 1, 2 and Figure 2). Landscapes have more than twelve hours of daylight. The growing net radiation is spent for melting snow and heating of soil. In early spring, snow melts completely. The snow cover disappears on average from March 29 (coastal territories adjacent to the Baltic Sea) till April 16 (the eastern part of Latvia). In the first half of April, the arctic air masses behind the cold front bring snow, and very often snow cover (even up to 10 cm) establishes itself for several days all over Latvia. This process may occur several times. Therefore the landscape of early spring is notable for the abundance of water on the ground and in the soil. More migratory birds return and the circulation of birch sap comes to an end. Unless some early coltsfoot decorates the landscape, it is meanwhile quite pale.

Along with the increase of air mass temperature and heat content, the character of air mass transformation starts changing substantially. Moving eastward from the Atlantic Ocean, maritime air masses experience modification because of gradual heating from the underlying land and loss of moisture, for instance mP→ xP_s→ cS_p or mA→ xP [Geb 1981]. Continental air is also transformed under growing solar radiation (cP→cP_s).

In ES the weather of Latvia is greatly influenced by anticyclonal atmospheric circulation. An area of high pressure may be located either over the European part of Russia, a ridge of high pressure may spread from the Azores High, but often a ridge of high pressure develops over Scandinavia behind a cold front. The latter passes quickly onwards and decays. Depending on the position taken up by the area of high pressure, transformed maritime air (xP, xP_s or xS_p) or the corresponding subtype of continental air is identified.

Reviewing of every-day air mass occurrence from vernal equinox to mid-April unambiguously showed that on average it was still the P+A pattern. The mP air together with xP air, its first modification, arrived on 36% and cold winter air masses (xA, mA, cP) prevailed on 34% of days. However, a small increase of xP_s air was observed, its frequency increasing to 10% (fronts excluded). On the whole, warm (P_s, S_p) air masses arrived on average as often as in other P+A seasons (30%). Occasionally, ES may bring very warm weather, as was observed in 1991, when mid-day temperature reached 18-20ºC. However, on average the expansion of the mid-latitude air source region from central and southern parts of Europe to the northeast is apparently gradual, and early spring gives no hint about it. Latvia starts receiving mid-latitude air masses from southern and central Europe, and from the southern part of Russia more often starting with the second half of April.

On average, the high frequency of continental (mainly cP) air and transformed maritime air masses result in very low amounts of precipitation (Table 1).

Full spring, FSP *(middle of April to the first half of May)*

During this season, the majority of migratory birds have returned, almost the entire vegetation quite evidently comes back to life and the land becomes green. The birch trees are the first to unfold their leaves, with the earliest observed cases in the second decade of April. Another early species is black-currant, which commonly stays 1-2 weeks behind the birch. The sunshine duration is already around 8 hours, reaching 50% of the possible during this season, and its increase slows down (Table 2). However, *Rn*t and *T* are still growing noticeably. On average, from April to May *Rnt* increased by 165%, and T_d from +5° to +10°C.

Full spring may be named a season with no dominant air mass. The frequency of mid-latitude (S_p) and warmed subpolar (P_s) air increases considerably while the influence of subpolar air (primarily continental type cP) decreases, so that the warm and temperate air masses become almost as frequent as the cold ones are. The coldest air mass of the season, i.e. xA air, was identified 4 years in the 11-year period, when cold spells occurred for 1-2 days. Maritime arctic air mA was identified each year with the same duration as xA air. In full spring and pre-summer, the frequency of mP air is the lowest within the year, and it is regarded as a temperate air mass for this season. Air temperatures at mid-day may rise to +10º to +14ºC, dropping at night to around +5ºC. The cloud cover, including low clouds, brings about a small diurnal temperature range. The warm air masses (even subtropical air) arrive more often (Figure 6).

It is noteworthy that transformed maritime air mass types become dominant (until late summer) and the frequency of oceanic air masses decreases while the rate of continental air masses does not change significantly. The transformed maritime air masses (xP, xP_s and xSp) occur more often. The low degree of cloudiness and the presence of relatively cold (mA, cP) air result in low night-time temperatures and frost, but in mid-day the temperature often rises to +15° to + 20°C. The spells of cold air, although short-term and less frequent than in previous seasons, are more noticeable because they occur during the growing season and stand out against the background of higher frequency warm mid-latitude and subtropical air. Both the diurnal range and the daily means of air temperature are highly variable.

As regards moisture regime, precipitation remains low and does not exceed evapotranspiration, while solar radiation and air temperature grows rapidly and the growing activity of vegetation also increases. Therefore the abundance of water on the soil surface and in soil, which is characteristic of ES landscape, disappears quite soon.

Pre-summer, PS *(the first half of May to the beginning of June)*

In this short season, the incoming short-wave radiation and the net radiation rise as high as the yearly maximum and will not change substantially during the next two phases, but the air temperature experiences seasonal growth and the precipitation starts increasing. The last migratory birds have returned, vegetation is intensively growing and ever more blooming species burst into blossom. However, this is a phase of "environmental risk" because severe night frost may occur (temperature may drop to -5°C).

In May, the warm air masses (S_p and S) are more frequent, and these comprised ca 32% of the monthly air masses (fronts excluded). The same rate remained in early summer and high summer, while the proportion between the subtypes was different and the heat content of these air masses gradually grew until the end of July. In May, the warm mid-latitude air xS_p was identified more often. At mid-day, temperatures may rise to +18°,+20°C and even higher, to +25,+26°C.

The frequency of mP air was as low as in the previous season. In PS cold/winter air masses xA, mA, cP, although less frequent, still arrive in Latvia. Transformed arctic air xA was brought infrequently (once in three years) for 1-2 days and it was identified only in the first half of May. mA air was identified briefly only from the second decade of May on,. It arrived almost each year (8:11). The relatively cold cP air was nearly of the same frequency.

PS marks the end of the transition period to summer circulation, and in Latvia it manifests itself as a return of cold weather between 21 and 28 May. It is noteworthy that in 7 years of the 11-year period, the above mentioned days were dominated either by mA, cP or xP air, the coolest air masses of this phase. Occasionally a snow layer of several centimeters may establish itself locally in mA air, but it melts within a short time. The fairly regular return of cold in Latvia in the third decade of May, when at night temperature falls to below +5°C and in mid-day does not rise much above +10°C, might be well related to the cooling of St.Cyril Metodius in Bulgaria, described by Andreeva et.al (2003). She recognized that in the period 1981-2002 a regular St. Cyril Metodius cooling was observed towards May 24, and suggested that it could be attributed to a particular atmospheric circulation over Europe.

Although the monthly mean temperature variations are decreasing as the warmest part of the year approaches, these still were high (6.1°C). For instance, in 1991, pre-summer brought only 1 day with mid-latitude air while the cold subpolar air xP prevailed 12 days, bringing dry weather and night frost. However, in the third decade maritime arctic air was identified, and, as result, the monthly temperature throughout Latvia was below +10°C. On the other hand, temperatures in May of 1993 reached record highs (even higher than in June), and weather was very dry because transformed maritime and continental mid-latitude air xS_p and cS_p was governing for 22 days and brought almost no precipitation. However, during the last week of May as a result of the passage of a cold front, temperatures dropped to typically from +°1 to +6°C at night and from +10° to +14°C at mid-day with night frost (-1° to -3°C) recorded.

Notwithstanding the high occurrence of warm air masses and almost the summer level net radiation (ca 2.5-3 times higher than in September), the air temperature in May is usually low. On the one hand, the temperature of air masses in May is lower than in September and, on the other hand, the received solar energy is richly consumed for heating up the soil, moreover the vegetation increases evapotranspiration.

Early summer, ES *(beginning of June to end of June)*

With the beginning of this phase, the increase in diurnal temperature slows down. Yet, cool nights and days are also highly possible. By the end of early summer, the maximum number of blooming species are at full bloom and perhaps the highest increase in biomass production occurs.

Early summer and the next two phases comprise together the P_s+S_p period, which shows a noticeable increase of warmed subpolar air xP_s, the first modification of maritime subpolar air in summer time. The westerly airflow is less intense because the air pressure over the continent is not so high as in winter, and the cool Atlantic air may freely intrude far over Europe. The xP_s air brings high-level and middle-level clouds, the temperatures fall as low as +11ºC during the night, and rise to around +22ºC at mid-day. The average frequency of xP_s air alone was 21%. Showers may occur, but these intersperse with sunny hours and almost clear skies. The warmed subpolar air P_s (either maritime or continental) may be regarded as relatively warm air. Almost the same temperatures are brought about by maritime mid-latitude air mS_p.

Mid-latitude air (xS_p, cS_p) and subtropical air (mS, xS) are the warmest air masses, and their occurrence was 32% (fronts excluded). In June 1999, a record high frequency of xS air of 12 days/month was observed. Inflow of transformed maritime subtropical air xS may make near-surface temperatures rise to +27º to +29ºC in midday and at night-time to around +15º to +18ºC. It is brought to Latvia by southerly winds from the Mediterranean region or in other cases from the Black Sea region and the southern part of European Russia.

The average frequency of regular subpolar air (mP, xP) masses, which are the relatively coldest in ES, was around 30%. There were two Junes in the 11-year period without a day with maritime subpolar air, and in both cases June showed the highest (1995) and the second highest (1999) average temperature of the year (+17.6ºC and +19.3ºC). Transformed maritime subpolar air xP predominantly arrives in Latvia from Scandinavia. The fresh xP air brings a low degree of cloudiness (high and middle level clouds) or almost clear skies, and the lowest June temperatures (less than +10ºC, even as low as +4ºC) at night-time and +18º to +20ºC at mid-day. The average diurnal temperatures are around +11º ÷ +15ºC. The xP air was brought into Latvia in 10 years of the 11-year period.

Starting from early June, the relatively cold mA and cP air become a rare occurrence, and towards the third decade commonly do not reach Latvia. mA air was identified in 3 years (1 day/month) of the 11-year period and cP air was identified only twice. A scattered night frost was recorded on 24 June, 1992.

The second half of early summer commonly brings a week of cool weather with frequent rainfall because of high cyclonic activity and frontal passages. A 7-day period of cool weather, when 850hPa temperatures were noticeably lower than monthly mean temperature and surface temperatures followed that pattern, was found in 30 years of the 1958-1999 42-year period, i.e. the frequency was 71%. More often the cool weather brought by mP and xP air occurred around 20-28 June. The relatively cold mP air brings cloudy and cool weather with rainfall, but xP air, arriving behind a cold front, is dryer and fresh. Night-time temperatures are only +9,+10°C, and the days are also cool (ca +13° to +16°C). Occasionally the cold air can hardly be differentiated from mA air, and under clear skies the cold air may cause local frost. Later waves of cool air are less pronounced and less regular in early, mid or late July.

During early summer, the amount of precipitation is growing, and in some years June has been the wettest month.

In the 11-year period, the average heat content of June air masses expressed by equivalent potential temperature θ_{850} was 35ºC, which was lower than in July-August. On the whole, June's average temperatures (1990-2000) varied within the limits of 6ºC and the standard deviation of near surface air temperature and average equivalent potential temperature was falling.

High summer, HS *(end of June to end of July)*

High summer is a season when the air temperature reaches the maximum while the day-length starts gradually decreasing. During the 11-year period, the net radiation does not show any hint of falling back, in most cases it is still higher than in June. Even at night, the air temperature is commonly above +10°C. By the third decade of July, all air masses, including the coolest ones, finally reach their highest temperature. High summer is generally reserved for late bloomers. It starts with blooming of lime trees. On the one hand, the number of blooming species and the biomass production is still very high. On the other hand, an increasing number of species is running to seed or ripening the fruits. The vegetation gradually loses the bright-green colour, fades and becomes drab. On average, the amount of precipitation is higher than in the previous season, and the yearly maximum often occurs in July.

In addition to the highest air mass temperatures and the highest heat content, the highest occurrence of xP_s air and the warm xS_p was identified. In high summer transformed air masses are very often arriving in Latvia. The occurrence of warm mid-latitude and subtropical air was of the same frequency (ca 32%) as in early summer, yet these air masses were warmer. High summer showed a very low frequency of continental air masses, and at the same time it showed the lowest occurrence of the cold xP and mP air masses, thus justifying the “high” title. Periods of cool weather are usually less pronounced than in ES and occur with varying regularity at different times during HS.

The xP air, which is the relatively coldest air mass of high summer, was identified on average on 9% of days, and arrived in Latvia with northerly and north-easterly winds, when anticyclones developed behind a cold front in maritime arctic air over Scandinavia. For instance, on 6 July 1992, when transformed maritime subpolar air affected Latvia, there was frost at grass level (-1º to -2ºC) in the eastern part of Latvia. In the xP air, the night-time temperatures commonly are as low as +6º to +12ºC and at mid-day +16º to +21ºC. The weather is dry or a light rainfall may occur. The xP air was identified 10 years in 11-year period.

However, occasionally July is both the hottest and driest month. July 1994 was an unusually dry month. In the 2nd-3rd decades of July 1994, continental subtropical air cS was brought to Latvia. Mid-day temperatures rose to +º33 to +36ºC, and even at night-time the temperature was a very warm +15º to +20ºC. The diurnal temperature range was very large. Thunderstorms developed, particularly in the afternoon hours.

In the 11-year period, the average heat content of July air masses expressed by equivalent potential temperature θ_{850} was 38ºC, which was the yearly maximum. On the whole, average July temperatures (1990-2000) varied within the limits of 4.2ºC above or below the mean, and the standard deviation of near surface air temperature and average equivalent potential temperature θ_{850} were the lowest. The amount of precipitation showed just the opposite, i.e. the standard deviation was the highest in July. On average, July was the second wettest month after October.

Late summer, LS *(end of July to end of August)*

The beginning of August clearly shows that the incoming short-wave radiation and the net radiation starts to fall rapidly, but the decrease of air temperature is less significant or does not even occur. The prevailing process for vegetation is running to seeds and ripening of fruits. The first flowers of the heather show themselves, thus heralding that the phenological year is at its turning point. The green colour of vegetation fades even more, uncut and depastured grasslands become dun, and the trees, primarily birch trees, show first signs of colouring. A characteristic feature of the landscape is the activity of migratory birds before their flying away.

In the first decade of August the 850 hPa temperatures and pseudopotential temperatures of the airmasses are still at their maximum and start declining gradually in the coming decades (Figures 7, 8). Yet, the warm mid-latitude air, primarily xS_p, doesn’t arrive as often as in HS, and the same refers to warmed subpolar air xP_s. The frequency of relatively cool air masses (xP, mP) increased slightly, in particular xP air arrived more often.

In some years August may be warmer than July. For instance, very sunny, warm, even hot, and unusually dry weather was observed in August of 1996 and 1997, when the amount of precipitation was less than 30 mm. The fine summer weather was due to governance of mid-latitude and subtropical air masses associated with high-pressure conditions over central and western Europe and Scandinavia. The frequency of occurrence of the latter air masses was 12 and 14 days (in 1997 and 1996, respectively). However, on average the arrival of mid-latitude and subtropical air was noticeably less frequent than in high summer.

In cool nights of late summer, the night minimum in the air and on the soil surface may drop to +2° to 5°C, but in the 1990s frost was not observed.

Since the mean 850 hPa pseudopotential temperature of August air masses over Latvia was almost as high as in July (+37.9°C), the average heat content of August air masses was almost the same. On the whole, August’s average temperatures (1990-2000) varied within the limits of 4.4ºC from the mean and the standard deviation of near surface air temperature. The amount of precipitation was almost as high as in HS.

Early autumn, EA *(end of August to second half of September)*

In September, the incoming short-wave radiation decreases, and in September it was just a half of that received in June-July. Toward the autumnal equinox the steepness of monthly air temperature curve is the same as that of the incoming short-wave radiation or net radiation. However, in the mid-day (10-13 local time) the received short-wave radiation was, on average, nearly as high as in June. The first frosts may occur and the leaf colouring begins, which comes about with a significant drop in temperature. The frost-free period comes gradually to an end.

Early autumn is a short phase of transition from the summer air mass pattern P_s+S_p to winter P+A pattern. Starting from early autumn the equator-pole temperature gradient gradually gets stronger and, as a result, the westerly circulation starts strengthening and moving equatorward, i.e. a transition to winter circulation occurs. The frequency of subpolar air increases to a considerable extent and in the 11-year period comprised on average 25% (fronts excluded) or 13 days/month. The increase occurred at the expense of mid-latitude S_p and warmed subpolar P_s air, the frequency of which decreased 1.5-2 times. In early autumn, cold air masses (mA, cP) start arriving in Latvia, and their frequency in the 11-year period was almost 20%. Maritime arctic air mA and continental subpolar air was identified in 8 years out of 11 years with average frequency of 2-3 days. A couple of episodes with transformed maritime arctic air xA were noted in the third decade of 1993 and 1996. Yet, these were associated with the inflow of maritime arctic air mA, which briefly showed particularly low values of 850 hPa temperature and pseudopotential temperature, which could be related to xA air. The above cold air masses are those to cause the first killing frosts.

It is noteworthy that the frequencies of maritime air (different air mass types) increased, and, along with the decrease of the frequency of continental air masses, the frequency of transformed maritime air masses decreased noticeably. The amount of precipitation was slightly higher compared to August.

Toward the end of September, after the first frosts, a period of calm, sunny weather with warm days, but cold nights and misty mornings may set in, yet it does not occur every year. This weather singularity, which is named “Old Wives’ summer” or summer-in-autumn, usually caused by an independent anticyclone formed either over European part of Russia or central Europe, lasts for at least three days (in Latvia, the longest period was around 14 days). Sometimes such weather may set in during the first half of October. Regardless of the exact timing of the return of summer, this period is governed by mid-latitude and subtropical air, primarily, xS_p, cS_p, xS or even cS air. The diurnal temperatures vary greatly.

Conclusions

The location of Latvia in the area where on the one hand the boreal and nemoral zones and on the other hand the regions of oceanic and continental climate meet causes the landscapes to go through 12 seasonal states or seasons, which depend both on the annual cycle of insolation and air mass occurrence. Regarding the seasonal patterns of Latvia’s boreo-nemoral landscapes, the most notable conclusions are as follows.

The period of positive net radiation is two times longer than the period of negative net radiation, and during 2.5 months (middle of May to end of July) the curve of mean annual net radiation has reached the highest values and stays at this level. This period of time (pre-summer, early summer and high summer) coincides with the main portion of the vegetation period and is typified by a large amount of precipitation. During this same period, in early summer, evaporation reaches yearly maximum and the time of minimum runoff sets in.

The season with the highest upward gradients of net radiation and air temperature are early spring (starts just after vernal equinox or even before it) and full spring (second half of April to beginning of May). Yet, it is the time of the lowest amount of precipitation and the highest runoff, too. On the other hand, autumn equinox, which coincides with a steep downward gradient of net radiation and air temperature, opens the autumn season of maximum precipitation, very low evaporation and gradual increase of runoff, designated full autumn (October).

In Latvia, just as throughout the whole boreo-nemoral ecotone, which belongs to the area of humid climate, on average 4 months/year (April-July) evaporation exceeds the amount of precipitation, 4 months/year (August-October, March) it is less than the amount of precipitation and the remaining 4 months (November-February) evaporation is small and may be considered as zero, but precipitated water is accumulated in the form of snow (and ice). Besides, 1-2 months a year (April and part of March) the runoff exceeds precipitation and evaporation. Thus, the mean annual water balance of Latvia's landscapes viewed from a time dimension is a diachronous cycle of three essentially different periods: "overconsumption", "compensation" and "conservation" of water (Figure 4).

Although winter (period of negative net radiation) in Latvia lasts only 4 months (end of October to end of February), for 9 months the most frequent air masses are these of subpolar (subarctic) origin and arctic air arrives. Only three summer months show a slight prevalence of warmed subpolar air, which occurs relatively often during other seasons (including winter), too. Another air mass type characteristic of spring and summer seasons – mid-latitude air – is a rare air mass from autumn till early spring, and subtropical air is brought to Latvia almost only in summer (Figure 9). Apparently, such pattern of air mass frequency may be explained by the location of Latvia on the northern edge of the mid-latitudes.

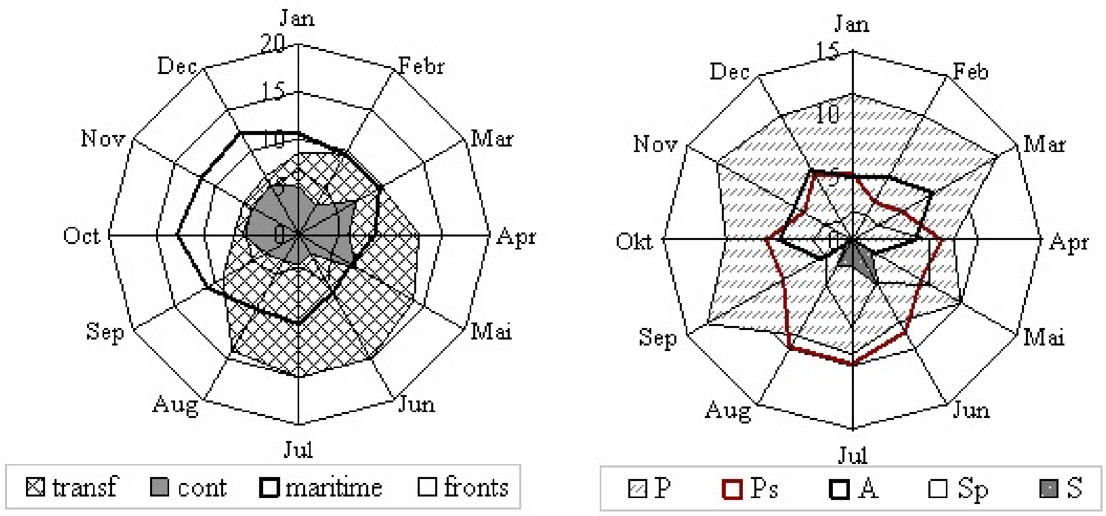


Figure 9. Monthly mean frequency (number of days) of air mass types in Riga (1990-2000). *Left*: transformed maritime, continental and maritime types and fronts; *right*: arctic (A), subpolar (P), warmed subpolar (P_s), mid-latitude (S_p) and subtropical (S) air masses.

The location of Latvia between the oceanic and inner continental regions brings about the prevalence of transformed maritime air masses over maritime and continental air. Yet, from a seasonal viewpoint, transformed maritime air masses prevail only in spring and summer, reaching the highest frequency in early summer, but in autumn and winter, maritime air masses prevail and their occurrrence is the highest in full autumn. Typical continental air does not occur often in Latvia (particularly in late winter and early summer), and a slightly higher occurrence was observed only at the beginning and the end of spring.

In general, each season may be distinguished by a definite pattern of solar radiation, distinctive state of heat and water balance, biological turnover, phenological phase of animate nature and a distinctive occurrence of different air mass types and their particular "association". During each season these variables show a particular combination on numerical values and a distinctive landscape image. Every season has an effect on the state of landscape in the following seasons (theoretically – throughout the year). Transitions between the seasons are both gradual and sharp, but in all cases these may be clearly identified by several quantitative and qualitative features.

The presented conclusions still would need to be studied in greater detail, adjusted and better interpreted from a geographical viewpoint. In this regard, systematic measurements of energy and mass exchange, and phenological observations in long-term terrestrial research stations, combined with an efficient application of data obtained by remote sensing would be necessary [Krauklis 2003]. At the same time both the idea and results of the study would be useful for launching basic research in landscape ecology and climatology. Moreover, these might contribute to advancing the UNESCO Program *Man and Biosphere*, the UN International *Geosphere-Biosphere* Program and to implementing the *European Landscape Convention* accepted by the Council of Europe in 2000.

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