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The Influence of Land cover changes On Atmospheric Boundary Layer and Regional Climate Characteristics, InLandOnABL&RCC

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- **Introduction and motivation**

The motivation of this project was to obtain valuable knowledge for young researchers about biosphere-atmosphere interactions and correlations between forest and meteorological characteristics at Hyytiälä station. Another motivation was to obtain transferable skills in order to apply them further to Northern Ukrainian regions due to lack of well-equipped stations and absence of complex measurements of atmosphere-biosphere interactions there.

It is known that forests which cover about 30% of total land area; 25% and 33% in the temperate and in the boreal zones respectively, are vulnerable to climate change due to negative weather conditions with combination of unfavorable factors. The impact of climate change on plants' vegetation as Gross Primary Production (GPP) can cause, e.g., forest timberline shifts, invasion of pests, etc. In turn, forests greatly impact on climate globally and regionally via plants' roughness which influences on wind speed and direction; albedo which determines solar radiation distribution, air and soil temperatures; distribution of precipitation through plant canopy interception; forests effect on air composition via aerosol emissions, e.g. volatile organic compounds (VOC) such as monoterpenes etc., and greatly regulate CO2 absorption/emission in atmospheric boundary layer (ABL) regionally and globally.

- **Scientific objectives**

To obtain valuable skills for young researchers under a guidance of experienced trainers in both aerosol measurements on modern equipment and their further application as initial data for modelling of biosphere-atmosphere interaction. To process observational data from SMEAR II archive to estimate ecosystem components' and ABL sustainability by annual cycle of climatic indicators in Boreal forest. To study and to adapt online coupled integrated meteorology-chemistry-aerosol Enviro-HIRLAM model developed in UHel for Ukraine as a part of the Enviro-PEEX on ECMWF HPC project.

- **Methodology and experimental set-up**

To study biosphere-atmosphere interactions at Hyytiälä station we used hourly data from an archive [https://avaa.tdata.fi/web/smart/smear/download] for all available periods of measurements: air temperature at height 4.2 m for period 1996-2017, photosynthetic active radiation (PAR) at 0.6 m and 18 m for 2004-2017 and precipitation for 2005-2017. We averaged air temperature and PAR, and summed up precipitation daily.

Checking temperature data has revealed some gaps in the temperature time series. We used the following methodology to fill the gaps. Depending on length of missing data 3 methods were used. Firstly, daily air temperature measured at 8.4 m or, secondly, at surface we used for data recovery in average air temperature series at 4.2 m after confirming their high consistency (Fig.1). In case of the absence of measured air temperature data (T) at all 3 levels and missing data for 2-3 days, a method of averaging of the neighboring data were used as following:

$$T = \frac{\sum_{i=1}^{n/2}(T_{db-i} + T_{de+i})}{n}$$

n – number of days of missing data ($n = n + 1$ if n is odd); T_{db} and T_{de} - daily air temperature before the first (begin) and after the last (end) days of a gap respectively.

Analysis of recovered time series (Fig.1) has revealed almost the absence of linear trend in daily air temperature.

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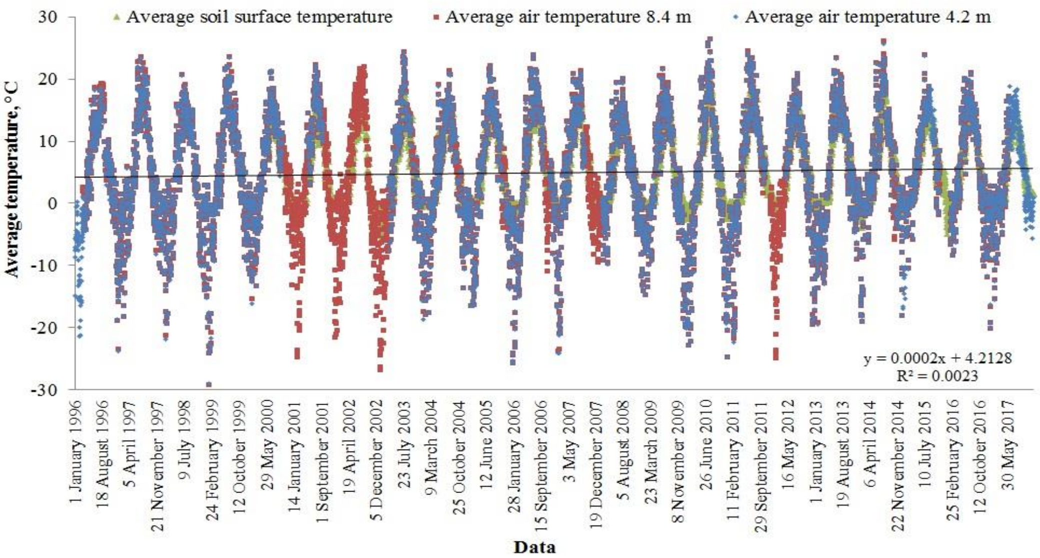

Fig. 1. Dataset of daily air temperature for 4.2 m (blue), partially recovered from data at 8.4 m (red) and surface (green)

Data of steady air temperature transitions through 0°C (warm season), 5°C (growing season), and 10°C (season of active vegetation) were calculated by Fedorov's method for every year (1996-2017). According to it, the date of steady air temperature transition through the defined limit is the day when sum of positive deviations start to exceed sum of negative ones as temperature rises and vice versa as it decreases.

For estimation of heat accumulation, which is crucial for vegetation, we applied integrative indices as sums of daily temperatures for the above seasons.

For complex estimation warm periods we used Vorobiov's and Selianinov's hydrothermal indices which allow to analyze resources of heat and moisture for plants. Equation for calculation Vorobiov's index (*W*):

$$W = \frac{\sum R_{T>0}}{\sum T > 0} - 0{,}0286 \sum T > 0$$

where $\sum T > 0$ – sum of monthly temperatures higher 0°C; $\sum R_{T>0}$ – sum of precipitation taken for warm season. Selianinov's hydrothermal index (*HC*) was calculated as follows:

$$HC = \frac{10 * \sum R_{Tdaily>10}}{\sum T_{daily>10}}$$

where $\sum R_{Tdaily>10}$ - sum of daily precipitation for period with *T>10°C* (period of active vegetation); $\sum T_{daily>10}$ - sum of active temperatures.

Due to radiation is one of the main factors which impacts on vegetation it was necessary to evaluate which part of PAR flux is absorbed by plants potentially. Data were used at 2 different heights: above (18 m) and below canopy (0.6 m). To estimate absorbed PAR we calculated it as differences between levels in absolute values and as percentage of income PAR at the upper height.

- **Preliminary results and conclusions**

  As a summary of data archive analysis the calculated 22-yearly dynamics of start/end, lengths of warm season, growing season and season of active vegetation is presented on Fig.2. In overall, extensions of all studied seasons have been revealed. The most significant change in presented dynamics is found towards the later ending of warm season with linear trend coefficient of almost 9 days per decade. The next significant coefficient is in spring for earlier start of active vegetation season (T>10°C) with

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trend 7-8 days per decade. On the contrary, start of vegetation season (T>5°C) shifted to later dates with trend about 3 days per decade. As a result, period between 5°C and 10°C has shrunk notably indicating that heat in spring for vegetation came later but more intensively. Almost the same trends of the start of warm season and the end of active vegetation season were above 4 days per decade. Air temperature transition through 5°C was almost without changes in autumn. Note, that the most changeable date was found for the start of winter season (T<0°C) when CI=7.3 days (Fig. 2, Tabl.1).

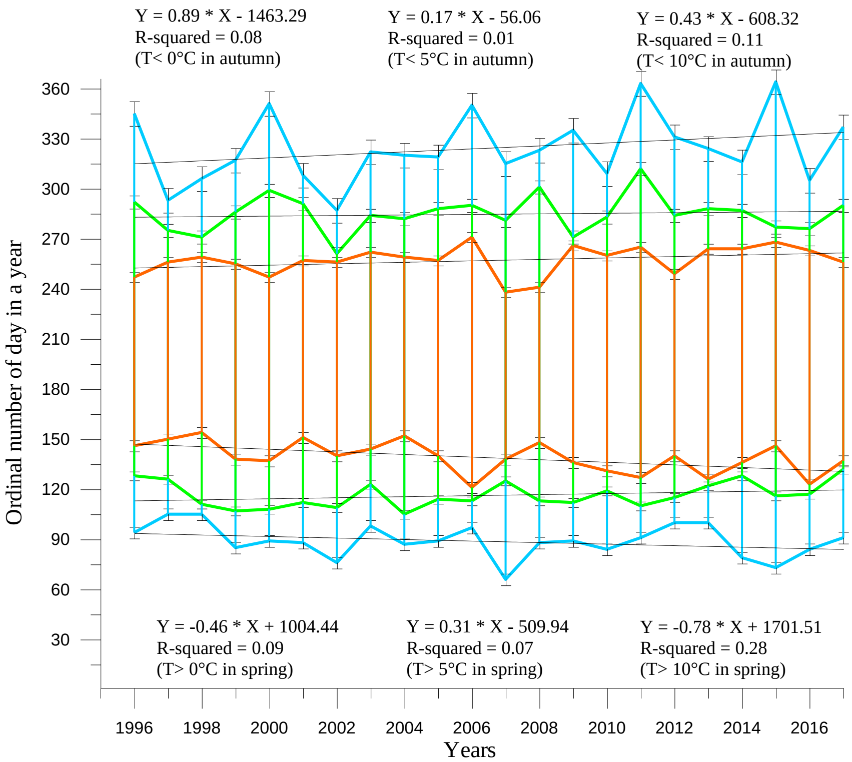

Fig. 2. Start/end, lengths of warm season, growing season and season of active vegetation with regression equations for every set of steady transition dates over 0, 5, 10°C with respective CI 90%

Vertical color lines (Fig.2) demonstrate period's duration when daily air temperature higher than defined threshold 0, 5, 10°C for every year and give a possibility to compare them. The longest warm season of 291 day with $T_{av} > 0°C$ occurred in 2015, $T_{av} > 5°C$ – 202 days in 2011, $T_{av} > 10°C$ – 150 days in 2006. The shortest seasons with $T_{av} > 0°C$ and $T_{av} > 5°C$ were in 1997 with 188 and 149 days respectively and $T_{av} > 10°C$ – 93 days in 2008 (Tabl.1). Confidence intervals 90% (CI) for air temperature transition dates, seasons' lengths were calculated and presented in Table 1.

Sums of daily temperatures and precipitation for the studied seasons 0, 5, 10°C are presented in Fig. 3 and Tabl.1. It allows evaluating heat and moisture resources during warm part of year between defined limits – 0, 5, 10°C. From both Fig.3 and Tabl. 1 these characteristics had a wide range with CI 60°C (T>0°C), 56°C (T>5°C), 82°C (T>10°C) and for precipitation CI 46 mm, 25 mm, 26 mm for respective seasons, but since 2005. The relation of the above characteristics represented as hydrothermal Vorobiov's and Selianinov's indices (Tabl.1) showed that 2006 was extremely dry and warm (*W*=2.6 and *HC*=1.0), 2008 was relatively cold and wet (*W*=8.1 and *HC*=3.4) and the highest W=8.3 was in 2017 due to pretty wet, but the coldest warm season since 1996, notwithstanding that the lengths of it exceeded the mean. Note, that 2011 year represented rather typical meteorological conditions in the region that could be determined by these average indices (*W*=5.0 and *HC*=2.5). But all lengths, heat and moisture availability in all studied in 2011 exceeded obtained mean values (Fig.3 and Tabl.1).

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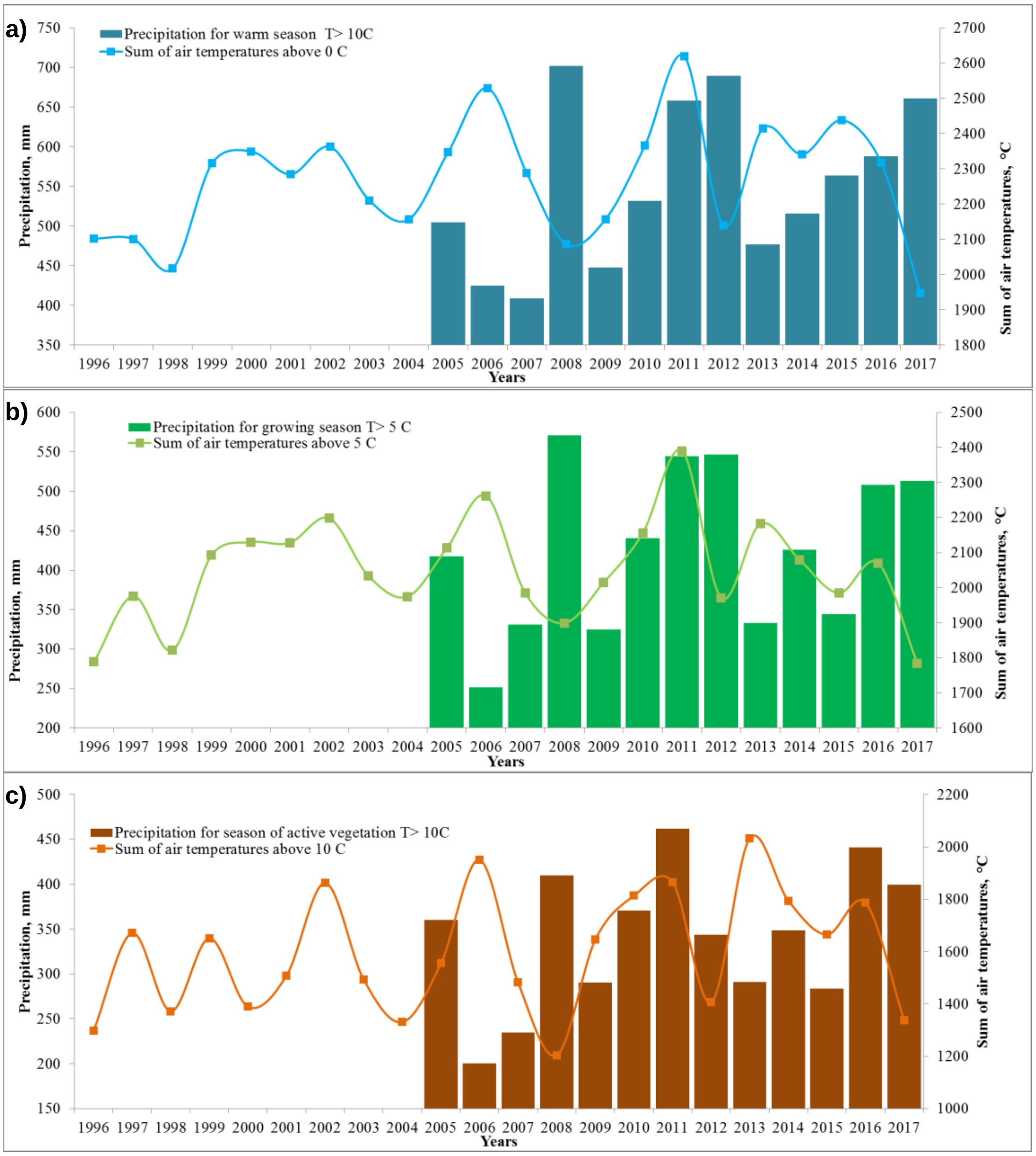

Fig.3. Sum of air temperatures and precipitation for seasons: a) Tav>0°C; b) Tav>5°C c) Tav>10°C

To study biosphere-atmosphere interaction we have chosen annual cycle of photosynthetic active radiation (PAR) as one of the crucial factors for vegetation development, particularly, GPP. We assumed that PAR is absorbed in the layer between upper level (18 m) and below canopy (0.6 m) by leaves in the process of their growth started after the threshold T>0°C, reached maximum point and declined to the cold season following simultaneously with the annual PAR cycle. Annual sums of the absorbed PAR for the investigated seasons were converted into kW/m^2 and are in Tabl.1. Their statistics have shown that the most changeable values of PAR had active vegetation season (7.61±0.51 kW/m^2). At the same time it cohered with the highest variability in sum of T>10°C (1596±82°C) confirming their high interconnection and that they are both strongly impacted by cloudiness and precipitation (Tabl.1).

We have selected 2006 as being warm and the driest one as it was pointed above and presented it as an example on Fig.4. Time series of PAR were divided by vertical lines corresponded to air temperature

thresholds, which are like heat indicators for different stages of vegetation. From the graph it can be seen that in spring PAR increased gradually but in autumn it decreased sharply to air temperature threshold through 10°C. The highest values of PAR (18 m) flux were in summer months with maximum in June ~ 670 µmol $m^{-2}s^{-1}$, PAR below canopy (0,6 m) ~ 182 µmol $m^{-2}s^{-1}$ July, absorbed PAR ~ 528 µmol$m^{-2}s^{-1}$. The most intensive absorption of PAR was between spring threshold 0°C and autumn threshold 10°C which is connected with long sunshine duration and as a consequence, increase of leaf area index and more intensive process of photosynthesis. However, PAR fluxes are very variable in time and depend on many factors, mainly on cloudiness. There is some decrease in income PAR at the ends of May, June and the second part of August and first part of September. The possible reason is clear from Fig.5 (a) where daily absorbed PAR presented together with precipitation.

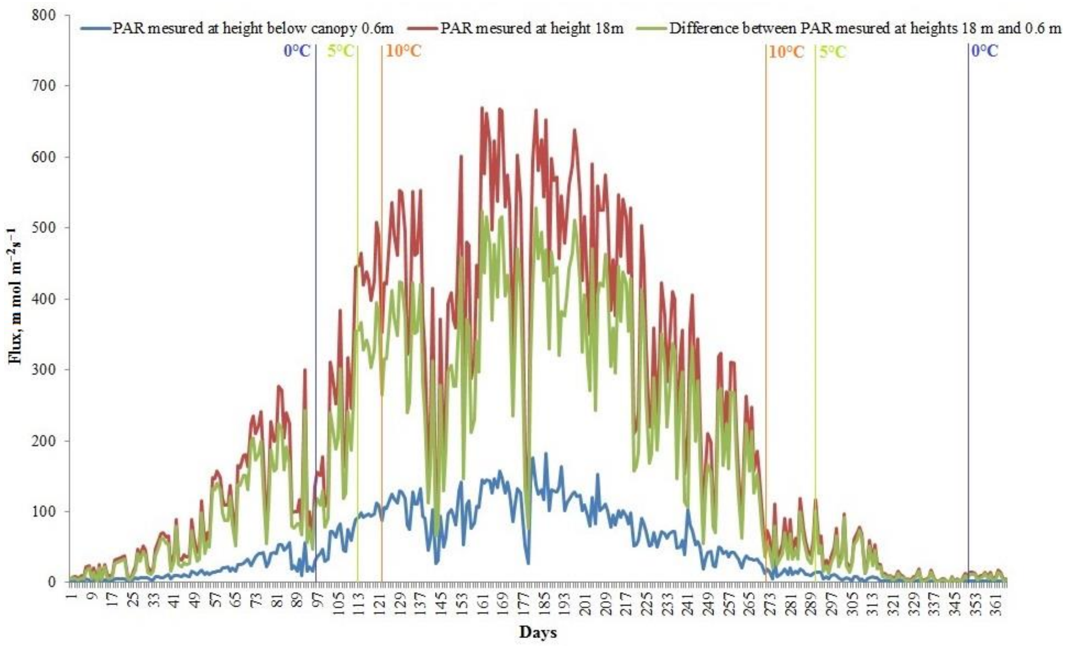

Fig. 4. Photosynthetic active radiation (2006)

On Fig. 5 (a, b, c) we presented daily absorbed PAR as the difference between PAR 18 m and PAR 0.6m in percentage for the above selected warm and dry year (2006), cold and wet year (2008) and year with relatively typical meteorological conditions (2011) respectively. Within 5°C (vegetation season) PAR absorbtion became more steady than out of this period. The total dispersion has twofold decrease in compare to cold season due to much less values of incoming PAR and consequently, higher measurement uncertainty. Within warm season all values mostly varied within 70-90% interval, the percentage of absorbed PAR grew slowly between temperature thresholds 10°C. It can be made an assumption that the leaf area was increasing gradually during this period (Fig. 5). We noted that some essential decreases in absorbed PAR were associated with intensive precipitation obviously connected with dense multilayer clouds .

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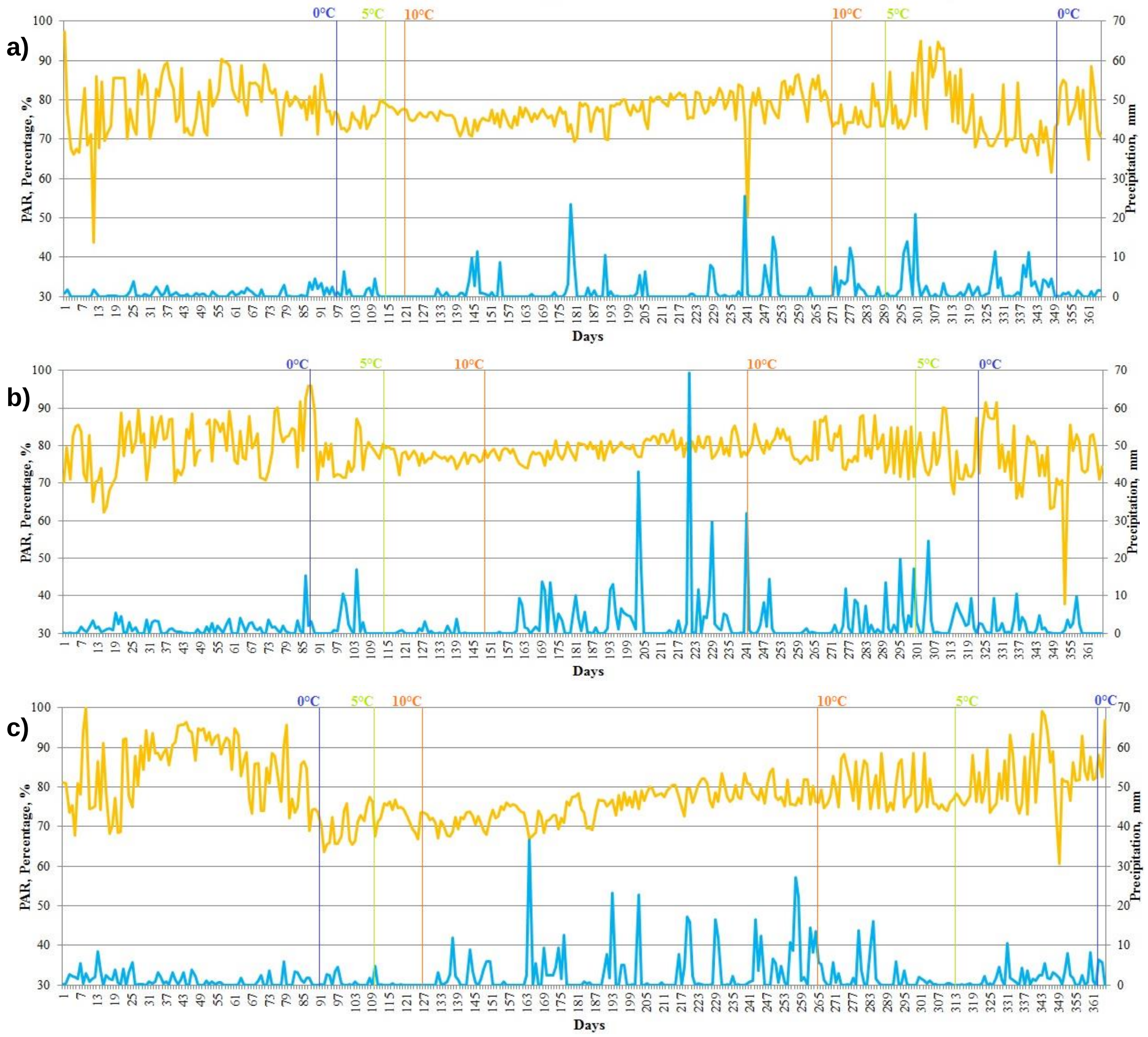

Fig. 5. Daily absorbed PAR (%) in the layer 18-0.6 m and daily sum of precipitation (mm): a) 2006; b) 2008; c)2011

Since air quality is one of the key isues of environmental probems in many countries including Ukraine, another our task was to study and to adapt meteorology-chemistry-aerosol Enviro-HIRLAM model for Ukraine. It was installed and tested for elevated pollution period in Ukraine during 7–17 August 2010, when huge amount of forest fire emissions transported over the region. Reference and direct aerosol effect modes included in the run. The model output allowed analyzing black carbon in Aitken and accumulation modes, its distribution during pollution period, and showed the transfer of main pollution from the sources from the Northeast towards Ukraine. Fig. 8 represents as an example black carbon spatial distribution at the beginning of the most polluted period during summer 2010.

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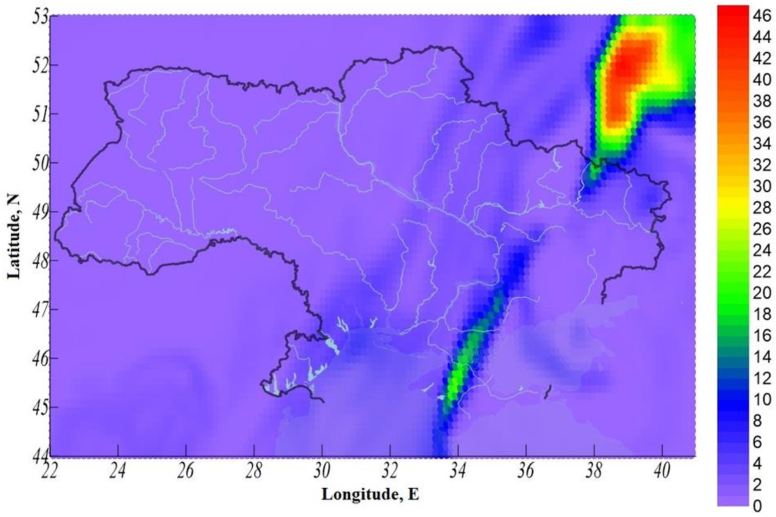

Fig. 8. Black carbon accumulation mode (ppbm) distribution over Ukraine on Aug. 8, 2010

- **Multidisciplinary approach**

The conducted project InLandOnABL&RCC has been fulfilled intentionally at the multi-disciplinary RI platform Hyytiälä forestry station and continued with further access to its dataset aiming on mutual analysis of meteorological and vegetation-related characteristics in order to establish their interconnection. Revealed interconnections could promote further collaboration between UHMI and UHel; experts in atmosphere physics and chemistry and forestry.

- **Outcome and future studies**

The project sought to answer some questions about atmosphere-biosphere interactions, namely finding correlations between meteorological parameters and plant's development. In this report were calculated air temperature transitions through 0, 5, 10°C and their seasons' lengths: warm season, growing season and season of active vegetation for 1996-2017. In overall, extensions of all studied seasons have been revealed. The most significant changes are found towards the later ending of warm season of almost 9 days per decade and for earlier start of active vegetation season (T>10°C) of 7-8 days per decade. On the contrary, start of vegetation season (T>5°C) shifted to later dates about 3 days per decade and as a result, period between 5°C and 10°C has shrunk notably. Hydrothermal Vorobiov's and Selianinov's indices were calculated for estimating heat and moisture availability for vegetation. The most intensive absorption of PAR was after T>0°C and before T<10°C which is connected with long sunshine duration and as a consequence, increase of leaf area index and more intensive process of photosynthesis. Absorbed PAR variated within 70-90% and had less variability in warm season in compare to cold one. Also, a slight increase in PAR absorbing was within season T >10°C. It can be connected with leaf area increase. Some essential decreases in absorbed PAR were associated with intensive precipitation obviously connected with dense multilayer clouds.

We realize that the obtained results need discussions with experts in forestry for further application and have to be supplemented with phenological data and possibly atmosphere-chemistry data from Finnish models, such as Enviro-HIRLAM. We plan to extend the conducted project towards further investigation on interconnections between PAR, CO_2 and monoterpene fluxes with meteorological characteristics.

Obtained valuable experience at RI platform for Ukrainian project's participants in measurements, processing, analyzing of SMEAR-II data, modeling by ENVIRO-HIRLAM is definitely transferable knowledge. The next step of project's participants should be the preparation of at least one peer-reviewed publication and a few presentations for International conferences in collaboration with UHel experts. In the future received outcome and obtained knowledge and skills in InLandOnABL&RCC project in addition with modelling ENVIRO-HIRLAM will be an essential part for PI's PhD thesis.

Tabl. 1. Calculated characteristics for period 1996-2017

	Air T transitions in spring			Air T transitions in autumn			Period's duration and Σ T, days and °C			Precipitation, mm			Indices		Sum of absorbed PAR between 18 and 0.6m, kW/m2		
Years	0°C	5°C	10°C	10°C	5°C	0°C	0°C	5°C	10°C	0°C	5°C	10°C	0°C (Vorobjov)	10°C (Selianinov)	0°C	5°C	10°C
1996	04.04.96	08.05.96	26.05.96	04.09.96	19.10.96	11.12.96	251/2102	164/1788	101/1297	no data	no data	no data	no data	no data	no data	no data	no data
1997	16.04.97	07.05.97	31.05.97	14.09.97	03.10.97	21.10.97	188/2101	149/1976	106/1670	no data	no data	no data	no data	no data	no data	no data	no data
1998	16.04.98	22.04.98	04.06.98	17.09.98	29.09.98	03.11.98	201/2017	160/1821	105/1372	no data	no data	no data	no data	no data	no data	no data	no data
1999	27.03.99	18.04.99	19.05.99	13.09.99	14.10.99	14.11.99	232/2316	179/2092	117/1651	no data	no data	no data	no data	no data	no data	no data	no data
2000	30.03.00	18.04.00	17.05.00	04.09.00	26.10.00	17.12.00	262/2350	191/2130	110/1389	no data	no data	no data	no data	no data	no data	no data	no data
2001	30.03.01	23.04.01	01.06.01	15.09.01	19.10.01	05.11.01	220/2285	179/2128	106/1508	no data	no data	no data	no data	no data	no data	no data	no data
2002	18.03.02	20.04.02	21.05.02	14.09.02	19.09.02	15.10.02	211/2363	152/2198	116/1862	no data	no data	no data	no data	no data	no data	no data	no data
2003	09.04.03	04.05.03	25.05.03	20.09.03	12.10.03	19.11.03	224/2211	161/2034	118/1492	no data	no data	no data	no data	no data	no data	no data	no data
2004	28.03.04	15.04.04	01.06.04	16.09.04	09.10.04	16.11.04	233/2157	177/1974	107/1331	no data	no data	no data	no data	no data	10.34	8.94	5.74
2005	31.03.05	25.04.05	21.05.05	15.09.05	16.10.05	16.11.05	230/2347	174/2113	117/1555	505	417	360	4.2	2.3	11.53	10.08	7.75
2006	08.04.06	24.04.06	02.05.06	29.09.06	18.10.06	17.12.06	253/2529	177/2262	150/1950	425	251	200	2.6	1.0	11.67	10.71	9.91
2007	08.03.07	06.05.07	19.05.07	27.08.07	09.10.07	12.11.07	249/2288	156/1985	100/1481	409	331	235	3.2	1.6	11.72	8.81	6.60
2008	29.03.08	23.04.08	28.05.08	29.08.08	28.10.08	19.11.08	235/2087	188/1899	93/1204	702	571	410	8.1	3.4	10.68	9.60	5.84
2009	31.03.09	23.04.09	17.05.09	24.09.09	29.09.09	02.12.09	246/2157	159/2014	130/1645	448	324	290	4.2	1.6	11.74	10.11	8.30
2010	26.03.10	30.04.10	12.05.10	18.09.10	11.10.10	06.11.10	225/2366	164/2156	129/1813	532	441	371	4.5	2.0	10.50	8.95	7.95
2011	02.04.11	21.04.11	08.05.11	23.09.11	09.11.11	30.12.11	272/2619	202/2390	138/1866	658	544	462	5.0	2.5	10.46	9.69	7.95
2012	10.04.12	25.04.12	20.05.12	06.09.12	11.10.12	27.11.12	231/2140	169/1971	109/1406	690	546	343	7.6	2.4	9.87	9.03	6.88
2013	11.04.13	03.05.13	07.05.13	22.09.13	16.10.13	21.11.13	224/2415	166/2182	138/2033	477	333	291	3.6	1.4	10.75	9.44	8.73
2014	21.03.14	09.05.14	17.05.14	22.09.14	15.10.14	13.11.14	237/2341	159/2079	128/1794	516	426	349	4.4	1.9	11.74	9.02	8.25
2015	15.03.15	27.04.15	27.05.15	26.09.15	05.10.15	31.12.15	291/2439	161/1985	122/1665	564	344	283	4.6	1.7	11.70	9.48	7.63
2016	25.03.16	27.04.16	03.05.16	20.09.16	03.10.16	01.11.16	221/2318	159/2070	140/1786	588	508	441	5.4	2.5			
2017	02.04.17	16.05.17	18.05.17	14.09.17	18.10.17	04.12.17	246/1947	158/1785	119/1338	661	513	399	8.3	3.0	11.22	8.49	7.44
Max	16.04.17	13.05.17	04.06.17	29.09.17	09.11.17	31.12.17	291/2619	202/2390	150/2033	702	571	462	8.3	3.4	11.74	10.71	9.91
Min	08.03.17	16.04.17	02.05.17	27.08.17	19.09.17	15.10.17	188/1947	149/1785	93/1204	409	251	200	2.6	1.0	9.87	8.49	5.74
Average	31.03.17	27.04.17	20.05.17	15.09.17	12.10.17	21.11.17	235/2268	168/2047	118/1596	552	427	341	5.1	2.1	11.07	9.41	7.61
CI 90%	3.5	2.7	3.3	3.0	3.9	7.3	8.1/60	4.7/56	5.2/82	46	25	26	0.8	0.3	0.29	0.28	0.51

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