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Weekly cycle in the atmosphere aerosol variations for industrial regions

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To investigate weekly cycle in aerosol parameters using recent AERONET data, we analyse the 7-days periodicity in the different regions that vary in the level of the industrial aerosol load. In the paper we are looking for the weekly cycle in atmosphere aerosol optical thickness at 440 and 870 nm (AOT440, AOT870), measured by AERONE sun-photometers in the industrial regions: Europe and North America. The possible appearance of the weekly cycle in Antarctica, where the lowest industrial aerosol load expected, was investigated as well. For each of the AERONET stations, the analysis was provided using the 8-year continuous measurement sequences data in the 2009–2016 period. Due to AERONET sun-photometers provided aerosol measurements in the daytime and cloudless conditions only, we use the weekly data overlay technique for analysis. According to this method, the initial sequence of the measurements was divided into the 7-days data segments, corresponding to a week period. The 8-year averaged values and standard deviation were calculated for an each day of week. The average Europe and North America weekend effect in the percent difference of AOT440 in the weekdays and in the weekend in the atmosphere over North America is equal 7.2 %, over Europe — 4.2 %. The lowest AOT values observed on Sunday and Monday the highest values are seen from Wednesday till Saturday. To reveal seasonal dependence of the weekend effect, the weekly variations of seasonally separated AOT440 and AOT870 data over Europe have been analysed. The results exhibit the maximum AOT values in working days and minimum in weekend similar to seasonally averaged results.

Key words: weekend cycle, aerosol, AERONET, sun-photometer

INTRODUCTION

The human activity is the major cause of the Earth atmosphere contamination for the last decades. The atmosphere composition changed significantly during the industrial development of modern society. Some of consequences are the greenhouse gases concentration increase, the water regime and the air circulation change in some regions. Over the past century, the technogenic aerosols of industry, agriculture, and transport origin, have been added to the natural sources of the aerosols. The thermal power stations that use coal with high ash-content, metallurgy, cement, magnesite plants are powerful sources of the solid and liquid aerosol particles in the atmosphere. The anthropogenic aerosol impact is significant in industrial regions that creates the global background of changes in the different parameters of the atmosphere. In addition, human activity stimulated an origin of the new cycle related to the week period. Last years the weekly variability — 'weekend effect' — in the atmosphere parameters is studied widely (e.g. [2, 9, 14, 16, 18]). The weekly cycle in atmospheric aerosol dynamics considered in many papers, for example, in [21] or [19]. The comprehensive review [21] of the weekly cycle of aerosol optical depth based on AERONET and MODIS data shows that aerosol optical thickness (AOT) during the weekday is larger about 4 % than that during the weekend in most AERONET sites in the United States and Central Europe. It was revealed that the weekly cycle in urban sites is greater than that in rural sites, which could be expected. However in some regions on the planet weekly cycle is not so obvious, for example in the Middle East and India the weekly AOT cycle is reversal and AOT weekly variations do not observe over eastern China [21].

In the paper [19] authors observed NOx, surface ozone and aerosol concentration weekly variations in the urban atmosphere. In [10] authors discuss the behaviour of weekly cycle in aerosol and cloud in the

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atmosphere over Central Europe obtained from satellite Terra/MODIS and ground-based data over the 2000–2010 period. Researchers from Portugal [14] connect electric field variations with aerosol contamination that exhibit clear 7-days cycle. The study in Helsinki [9] also shows the weekend effect in NO_2 and aerosol variations in boundary level that connected with city traffic. Authors [18] studied the dependence of aerosol parameters on the day of the week in China regions. They discussed weekly cycle in the fine mode aerosol particles of industrial nature in surface atmosphere level in large China cities. The search of 7-days aerosol variations in China was considered also in [17, 20] where aerosol contamination weekly cycle has been retrieved in Beijing.

The connections between weekly cycle in the number of thunderstorms, precipitation amount, and aerosol concentration were described in [1, 22]. The atmosphere surface level contaminants (O_3, NO_2, SO_2, CO and PM_{10}) exhibit weekend effect [23] as well, as air temperature cycles in the cities of Australia [6]. The physical models of the weekly cycle in aerosol parameters were developed recently, for example in [12] the model of Europe climate including weekly cycle in aerosol and other atmosphere parameters is considered. However, in some investigations, the weekly cycle in atmosphere constituents behaviour is not so obvious (see e.g. review by [13]).

We have published in the past the results of 7-days cycle in the level of the global thunderstorm activity signal, which was retrieved from very low frequency noise at 5–25 Hz [11]. It has been shown that number of thunderstorms on the planet displays weekly periodicity that linked to human activity.

To investigate the weekly cycle in aerosol parameters using recent AERONET data we analyse the 7-days periodicity in the different regions of the planet that differ in the level of the industrial load. In the paper we are looking for a weekly periodicity in some aerosol optical characteristics — aerosol optical thickness at 440 and 870 nm (AOT440, AOT870), measured in the industrial regions of the planet — Europe and North America. The results of the 7-days periodicity in the Antarctic region, which is an area with the lowest contamination load, are presented for comparison of the weekly variations peculiarities in the regions with large aerosol contamination and the regions where this load almost negligible.

DATA AND METHOD

For study the aerosol weekly variations we use AERONET ground-based sun-photometer network data [8]. The main instrument of the network is the automatic sun tracking photometer CIMEL CE318, which measures sun and sky radiance in order to derive aerosols properties and total column precipitable water vapour. The recent instrument CE318-EDPS9 includes nine wavelengths spectral channels 340, 380, 440, 500, 675, 870, 936, 1020, 1640 nm and measures polarisation in three channels [7]. Currently the AERONET network consists of more than 1100 registered observation sites, and 500 sites are a long-term operated monitoring stations. The two AERONET sites, Kyiv site and Martova site, are operated in Ukraine since 2008 and 2013, respectively.

The measurements during 8-years period 2009–2016 of the aerosol optical thickness in two spectral channels 440 nm and 870 nm (AOT440 and AOT870) are analysed in this paper. We use `Level 2.0` cloud [15] screened and quality assured data for the analysis[1].

We have analysed measurements from two regions of the world with significant aerosol pollution – Europe and North America – using data from five AERONET sites in each region (see Table 1). The weekly cycle has been calculated for each specific site as well as for the region as a whole. To compare the aerosol weekly cycle behaviour in contaminated areas with the most clean area on the planet we calculated 7-days variations of the data from three AERONET sites in Antarctica (see Table 1). Note that sun-photometers at AERONET stations in Antarctica operate much shorter period of the year than mid- and low-latitude stations. The South Pole Obs NOAA AERONET station (S 89°59′4″, E 70°17′60″) is considered as the site with lowest anthropogenic aerosol load.

For each of the considered AERONET stations the analysis was provided using the data of continuous 8-years measurement sequences in the 2009–2016 period. Because AERONET sun-photometers provide aerosol measurements in the daytime and cloudless days only we use the weekly data overlay technique for the observation analysis. According to this method the initial sequence of the measurements was divided into 7-days data segments corresponding to a week period. Then the 8-years averaged values and standard deviation (SD) were calculated for an each day of week. The calculated AOT440, AOT870 values are presented in Figures 1–6 as a function of day-of-week from Monday to Sunday. Statistics analysis has been fulfilled using open source `Grapher 8` software[2].

We expecting that the data from monitoring sites in the Northern Hemisphere, which located in the mid-latitudinal belt, experienced similar aerosol load and close climate conditions. Therefore they could show similar weekly dynamics. To confirm the hypothesis of hemisphere range existence of 7-days variations the cross-correlation coefficients between data from two urbanised regions Europe and North America have been calculated.

[1] http://aeronet.gsfc.nasa.gov

[2] http://www.goldensoftware.com/products/grapher

Table 1: The location, altitude and number of population in the region of the AERONET sites.

AERONET sites	Coordinates	Altitude above a sea level (a. s. l.), meters	Number of population, million people
		Europe	
Paris	N 48°52′01″ E 02°19′58″	50	2.3
Munich University	N 48°08′52″ E 11°34′22″	533	1.4
Leipzig	N 51°21′07″ E 12°26′06″	125	0.5
Belsk	N 51°50′13″ E 20°47′31″	190	0.007
Kyiv	N 50°21′50″ E 30°29′49″	200	208
		North America	
Cartel X	N 45°22′24″ W 71°55′51″	300	0.2
Table Mountain CA	N 40°07′30″ W 105°14′13″	1689	0.1
Toronto	N 43°46′48″ W 79°28′12″	300	2.5
University of Houston	N 29°43′04″ W 95°20′31″	65	2.3
Harvard Forest	N 42°31′55″ W 72°11′16″	322	2.8
		Antarctica	
South Pole Obs NOAA	S 89°59′45″ E 70°17′60″	2850	–
Vechernaya Hill	S 67°39′36″ E 46°09′28″	80	–
Utsteinen	S 71°57′00″4 E 23°19′58″	1396	–

DATA ANALYSIS

The features of the weekly trend behaviour of some aerosol parameters were analysed in this paper in two industrial regions of the planet. Comparison of weekly period variations of AOT440, AOT870, values averaged for industrial regions in Europe and North America were provided. It was revealed that weekly cycle features are different from region to region.

The averaged eight-years (2009–2016) data show the clear weekly progress in AOT440 for the industrial regions. The maximal values of this parameter in Europe are observed on Thursday-Friday (in Fig. 1 (left panel)), the minimal – are on weekends. The monotonous AOT440 increase is traced during the first five days of the workweek. The mean value of AOT440 is 0.26. The weekly cycle of AOT440 over the North America region (in Fig. 1 (right panel)) has different behaviour: the AOT440 value increases rapidly on Thursday to Friday and the minimum is seen on Saturday-Sunday. A mean value ~ 0.14 is about a half as much as compared to Europe.

Considering that the concentration of atmospheric aerosols is a subject of seasonal changes, we additionally calculated the 7-days cycle in winter, spring, summer and autumn (Figure 2). It was found that in winter the maximum AOT values observed on Thursday (Figure 2 (top left panel)), in spring AOT maximum is seen on Friday (Figure 2), in summer the average value of AOT increases on Wednesday, with a gradual reducing to weekend (Figure 2 (bottom left panel)), in autumn, as in spring, the AOT maximum is observed on Friday (Figure 2 (bottom right panel)). These results indicate the presence of a 7-days cycle in the AOT440 in industrial and urbanised regions of Europe. In contrast to the averaged results (Figures 1 and 3), the AOT maximum is not always observed on Friday, but in all cases it is timed to the mid-second half of the week. On weekend the steady AOT minimum is seen.

Well known that the aerosol optical thickness measured at the 870 nm wavelength is free from the molecular absorption of some gases, in comparison to AOT440, which affected by the NO_2 atmospheric molecular absorption [5]. The NO_2 influence on measured AOT440 values increases particularly over industrial or urban areas [3, 4]. Therefore AOT870 values much better correspond to aerosol contamination. From AOT870 data averaged in 2009–2016 period the weekly cycle is clear seen in the atmosphere over Europe and North America (Figure 3). AOT870 values increase from Monday to Friday over Europe and North America.

We also calculated weekly variations of the AOT870 for the four seasons of the year in Europe (Figure 4). As it is seen from figure, in spring, summer and autumn (top right, bottom left and bottom right panels, respectively), the AOT maximum values are observed on Friday, while in winter (top left panel) – on Thursday. The minimum AOT values in all cases are seen on weekends or Monday.Therefore, the 7-days cycle for AOT870 and AOT440 is clear determined for all studied regions. The separation of the measurements by seasons (Figure 2 and 4) confirms the tendency of AOT to increase during the working days and reduce in the weekend.

Therefore, the seven days cycle in AOT870 and AOT440 variations is well seen in all studied regions. Additionally, the small values of mean square deviation (MSD) confirm the weekend effect persistence in the industrially developed areas of the planet.

CORRELATION OF WEEKEND EFFECT IN NORTH AMERICA AND EUROPE

The analysis of the weekend effect for AOT aerosol parameters for some industrial regions of Earth showed that in the most cases their maximal values are observed before the end of the work week with lowering on weekends. However for the full understanding the similarity of the weekend effect for two studied parts of the world – Europe and North America, – the cross-correlation analysis was done and the correlation coefficients of the weekly cycles of AOT440 and AOT870 are calculated.

Calculations showed statistically significant correlation of averaged aerosol parameters in the data for monitoring sites in Europe and North America: for AOT870 the correlation is 0.74, for AOT440 — 0.61.

WEEKLY CYCLE OF AEROSOL PARAMETERS IN THE ANTARCTIC REGION

For more complete understanding the rates of anthropogenic influence on the concentration of aerosols in the Earth atmosphere, and also for the effective working of hypothesis about an origin weekend effect in the investigated parameters, for comparison the search of seven days recurrence was done in a region with minimal anthropogenic influence. Data of the monitoring site AERONET South Pole were used. The variations illustrating expected weekly cycle of AOT440, AOT870 in this region, are presented in Fig. 5.

The sun-photometer measurements at the South Pole Obs NOAA station are available during only 2–3 months in a year due to the geographical position of this AERONET station. However, the weekend effect presence in those measurements can be checked. Analysis shows that the AOT values in Antarctica don't depend on the day of the week. We should also note that aerosol load in the atmosphere above Antarctica is very low in comparison to other industrial regions of the world. For example the AOT440 values in the average are 0.02, AOT870 — 0.01, which is from 5 to 10 times less than in industrial regions of Europe and North America. The analysis of 7-days cycle variations in AOT values at the two coastal Antarctic AERONET stations in Fig. 5) shows the absence of the weekend cycle in the behaviour of AOT440 and AOT870 (left and right panels in Fig. 5), and the values for both parameters of the AOT vary from 0.03 to 0.07.

The larger standard deviations in data shown in Figure 5 are also supportive evidence of the absence of any regularity in the behaviour of aerosol parameters in the Antarctica coastal region stations and the South Pole Obs NOAA station. Comparison of the variations seen in Figure 5 and Figure 6 shows the difference of the atmosphere properties over the coastal regions of the Antarctic continent and of the South Pole area. At the coastal regions the AOT440, AOT870 are significantly higher than in the centre of Antarctic continent. These differences are due to diverse climate conditions, as well as different elevations of the location of the Antarctic AERONET stations. The value of the aerosol optical thickness in the coastal regions is larger in about 3–4 times than in South Pole area.

DISCUSSION AND CONCLUSIONS

The analysis of AOT440, AOT870 resulted in a clear 7-days cycle for regions with the intensive anthropogenic load and no visible weekly cycle for Antarctic area. Taking into account the possible seasonal dependence of the weekend effect, we calculated the weekly variations of AOT440 and AOT870 for Europe stations separately for every season. In all cases we obtained maximum values on midweek and minimum – on weekends. The average percentage difference between AOT values in the weekdays and in the weekend for Europe and North America are listed in Table 2. Comparison with results for AOT440 calculated by [21] shows that its weekly periodicity over North America is higher in our data: 7.2 %, against 3.8 %, in [21]. This difference for North America can be caused by choice for analysis in this paper of AERONET stations with large aerosol contamination load. The average weekend effect over Europe is 4.2 %, comparing to 4.0 % [21].

As the result of analysis we conclude that the 7-days cycle is persistent in atmospheric aerosol AOT values for Europe and North America. Seven days cycle in a different parts of the world has the similar features of a weekly trend. Practically for all aerosol parameters there is a maximal value at the end of workweek and minimum on weekends. The high enough correlation coefficients were received between North America and Europe. In the South Pole region, which can be considered as the area with lowest industrial aerosol load, weekend effect in the parameters of AOT440 and AOT870 is not seen. This result confirms anthropogenic nature of weekly variations in the concentration of the atmospheric aerosols.

Table 2: The average weekend effect in percent difference of AOT values in the weekdays and in the weekend for different regions

	Europe (%)	North America (%)
AOT440	4.2 ± 4.2	7.2 ± 4.2
AOT870	3.1 ± 2.6	8.5 ± 2.3

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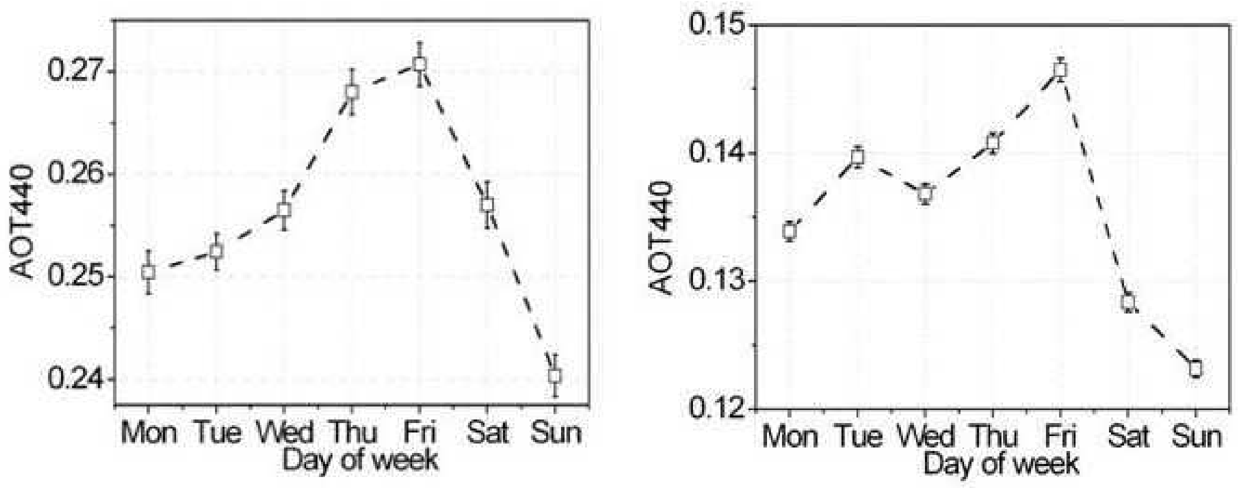

Fig. 1: AOT440 weekly cycle for Europe (left), North America (right) averaged over the period 2009–2016.

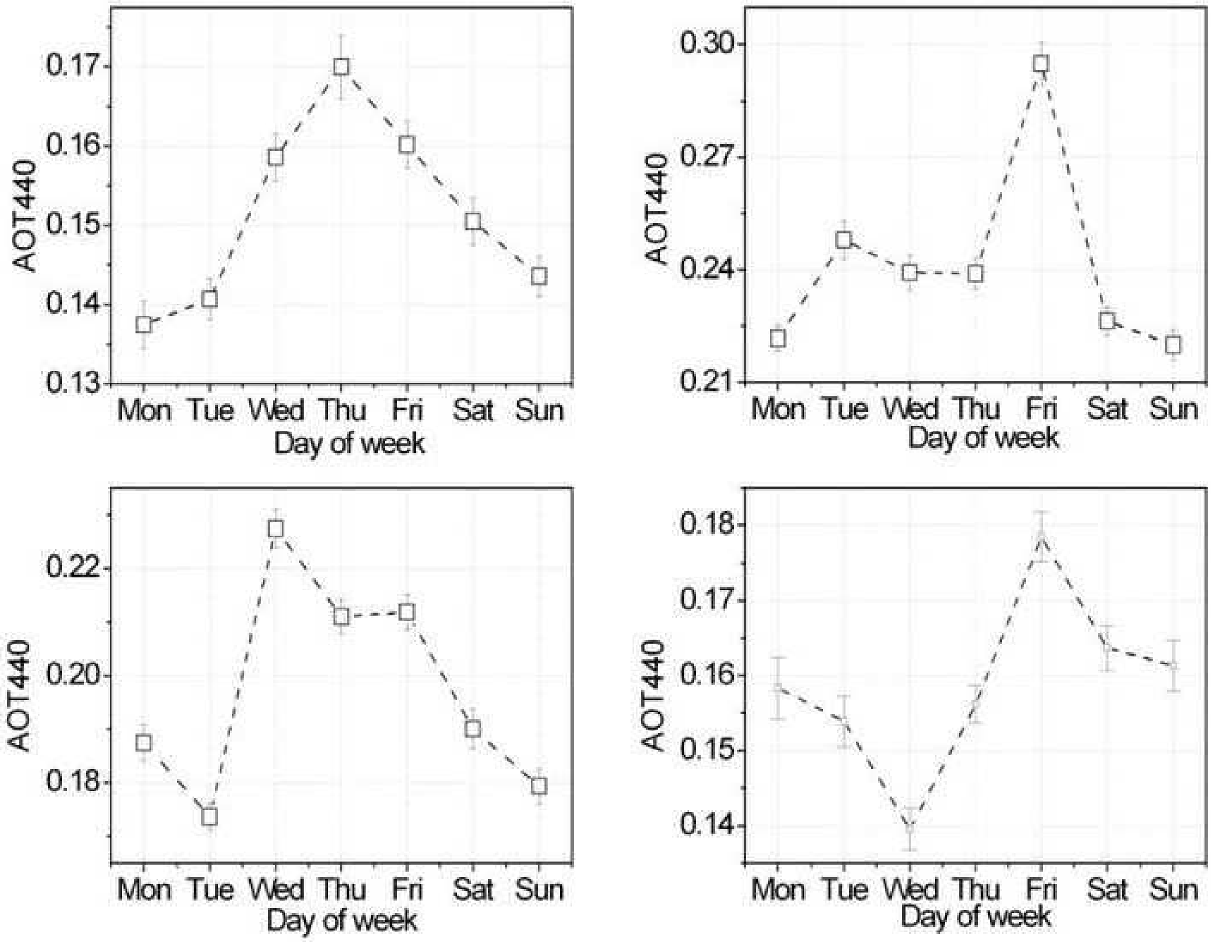

Fig. 2: Weekend effect in AOT440 for Europe by season. On the top panel: winter (left), spring (right) and on the bottom panel: summer (left) and autumn (right).

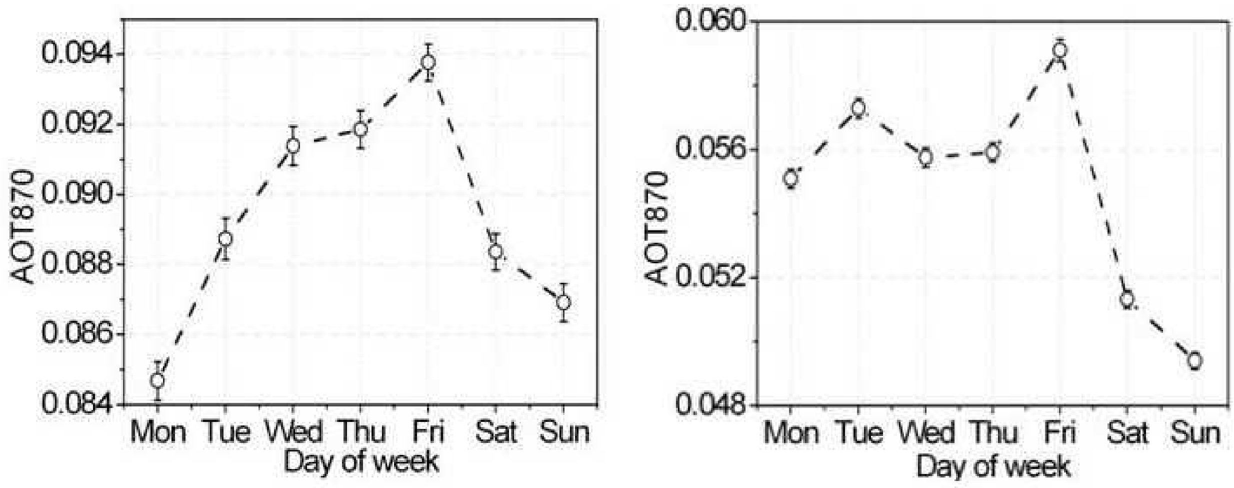

Fig. 3: AOT870 weekly cycles for Europe (left), North America (right) averaged over the period 2009–2016.

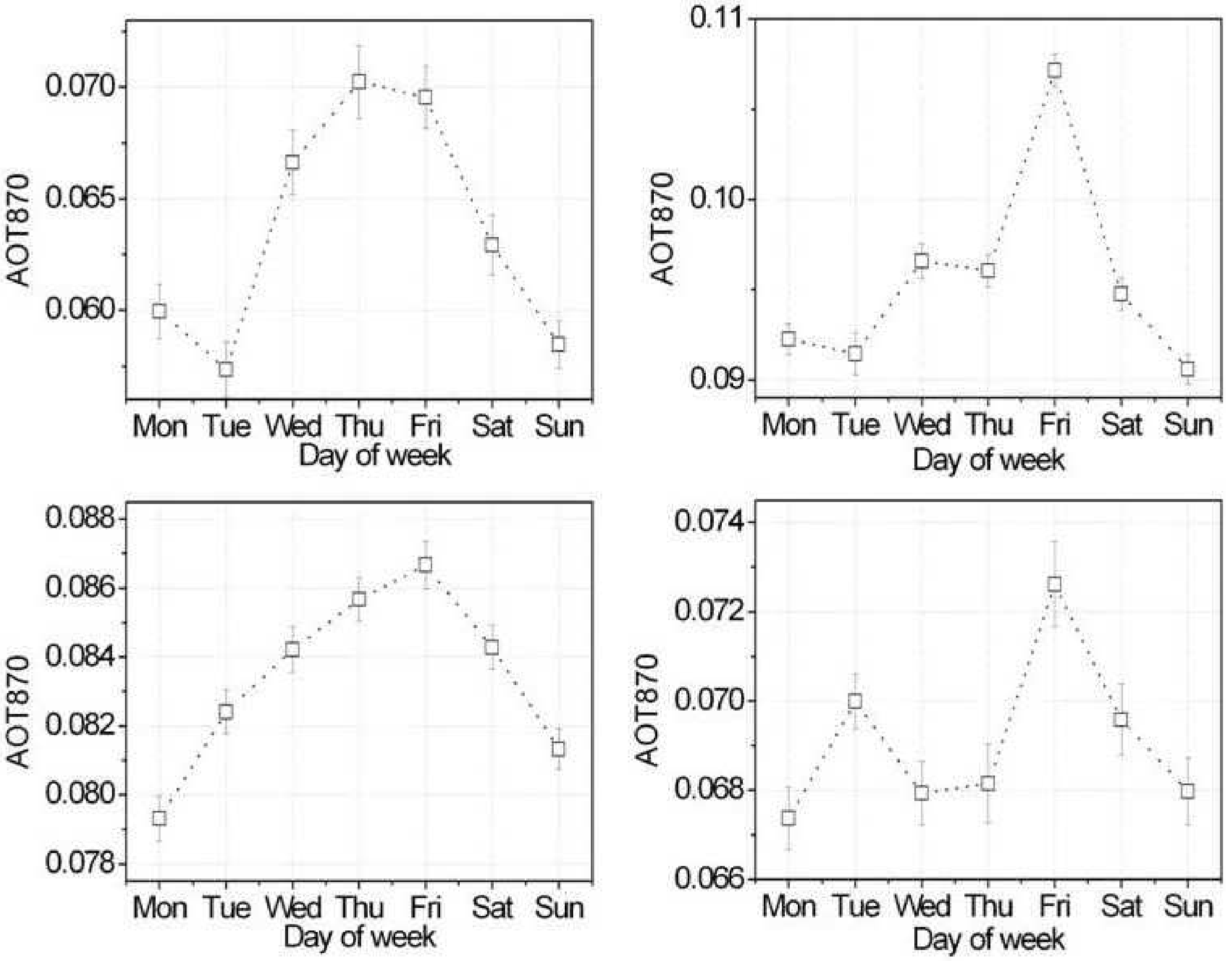

Fig. 4: Weekend effect in AOT870 for Europe by season. On the top panel: winter (left), spring (right) and on the bottom panel: summer (left) and autumn (right).

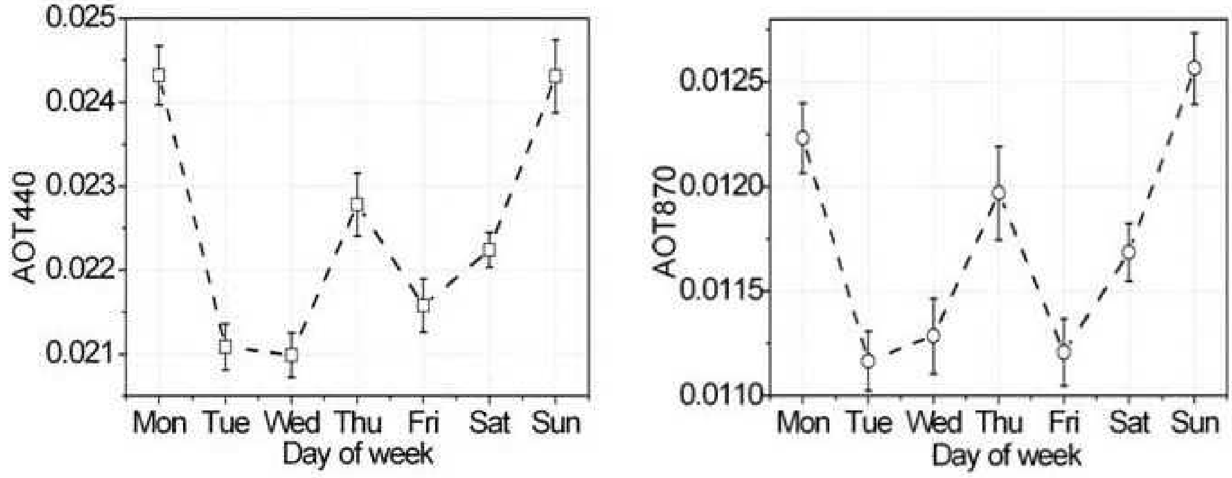

Fig. 5: Weekly cycle of aerosol parameters at the South Pole Obs NOAA station AOT440 (left) and AOT870 (right).

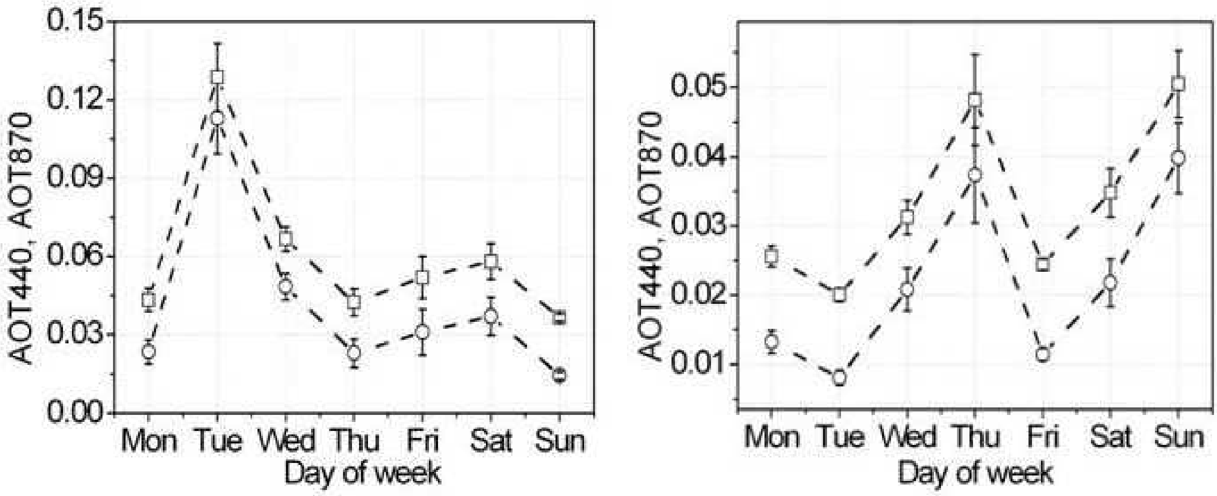

Fig. 6: Weekly aerosol behaviour in the Antarctic coastal region AEROET stations Vechernaya Hill (left) and Utsteinen (right) by data analysis the 2009–2016 period: AOT440 (squares), AOT870 (circles).