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ORIGINAL RESEARCH ARTICLE

Changing Arctic. Firm scientific evidence versus public interest in the issue. Where is the gap?

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Summary The authors provide hard evidence for a significant environmental impact of long-distance atmospheric pollution advection to the Arctic. Results from literature and of their research show that the atmospheric inflow of pollution to the Arctic has been increasing over the decades. The authors show evidence that biomass burning has a greater potential impact on radiative budget of the region than the well-known spring Arctic Haze phenomenon, which has always been regarded as the most prominent atmospheric pollution manifestation in the Arctic. Warming, which is observed in the Arctic, results in decreasing ice coverage of the region, which in turn, leads to the major changes in the ecosystem, hence affects human well-being. At the same time, the authors present results of two independent studies, dedicated to the recognition of the awareness and the level of interest of people in eight Arctic countries and among young learners in Poland. The results show that not only the level of public interest is low, but it is both decreasing or, at the best, low to societies. This is in strong contradiction to information available and the daily experience of the societies, which inhabit the region. The authors believe, that such contradiction results from a low level of knowledge and interest of the Arctic and the climate change itself. Finally, the authors provide some hints on how to

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link hard scientific evidence for Arctic environmental changes with proper communication to the general public, and hence to increase the level of interest among citizens.

1. Introduction

The Arctic is a key driver of the world ocean and climate system and plays a vital part in many environmental processes. Climate change in this region tends to be larger, especially with regard to trends and variability of surface air temperature, than for the Northern Hemisphere and globe as a whole. This problem in the Arctic, known as an Arctic Amplification, could be partly explained by the observed changes in aerosol horizontal distribution due to the changes in aerosol concentrations and their optical properties, which influence radiation balance of the region. Still, Arctic amplification has many causes operating on different time and space scales but is strongly linked to declining sea ice extent, while its extend is well beyond the Arctic region. The impact of climate change on this region is already visible with serious consequences regional, for the Arctic, and global (ACIA, 2005; Arctic Council, 2013; IPCC, 2014). The crucial issues regarding the state of the Arctic environment include:

- Arctic climate is thought to be very sensitive to any climate change, where we observe the fastest increase in temperature, known as an Arctic amplification;
- long-range transport of pollution to the Arctic. The region has become a global sink for contaminants discharged from industry, energy production, agriculture and other human activities;
- biodiversity, since ecosystems are put at risk due to the changes in the state of the environment, mostly to the global warming and increase of the pollution levels;
- environmental impacts of economic development, which pose pressure on the vulnerable Arctic environment;
- the need for knowledge and understanding of the Arctic environment.

To understand and estimate the pace of environmental change in the Arctic is one of the key challenges for a global society. Since the changes in the Arctic have global implications humans must undertake proper mitigation and adaptation measures so that future generations are fully prepared for the changing environment and hence the world around them (IPCC, 2014; Kerr, 2007; Nquyen and Williams, 2012; Stocklmayer and Bryant, 2012; Walker, 2007). A common problem for learners and all non-scientists across the world is that research results are often discussed without a wide context and the possible interactions with their own lives and thus they seem irrelevant to them. No wonder that naturally curious people often lose further interest.

Along with political involvement in the Arctic issues, the EU plays a vital role in research, monitoring and assessment of the Arctic environment and in studies on ecosystem change trends. To emphasize the magnitude of the Arctic operations it is worth adding that around four million people inhabit the Arctic region, and almost a half of a million are the European Union citizens, mostly from three EU countries, Denmark (Greenland), Finland and Sweden. Iceland and Norway are members of the European Economic Area, while Russia, USA and Canada are among core partners of the European Union (Arctic Council, 2013). The European Union is an active partner in a number of Arctic initiatives, such as Convention for the Protection of the Marine Environment of the North-west Atlantic (OSPAR) which covers about one-third of the Arctic Ocean up to the North Pole, it is a Permanent Observer on the Arctic Council and a member of the Barents Euro-Arctic Council (BEAC). Among many EU research objectives, there is one that supports studies and channels the results to create the best knowledge base, which can be used to appropriate challenge of the changes which occur in the Arctic.

The Earth is experiencing global environmental changes, and thus it is critical to properly communicate research findings, and as the EU sees it, channel the information to societies of the entire world. In the process of increasing the awareness of the changes, education, at all levels, plays a crucial role (Arctic NGO Forum, 2019; Bray et al., 2012; Hovelsrud et al., 2011; Kotynska-Zielinska and Papathanasiou, 2018).

Still, despite the pan-European engagement in the Arctic issues, the social research results show, that societies in both Arctic and non-Arctic countries do not realize to what extent the climatic change influences both the Arctic and global environment and hence these societies.

This paper is a preliminary attempt to compare the scientific results regarding the changes for the Arctic ecosystem, with those regarding peoples' interest in the problem. In conclusions, the authors formulate some questions and suggestions for further discussions of this issue. The detailed description of the methodological approach and the results is provided in the subsequent sections of this paper.

2. Approach and methodology

This paper has been prepared by an interdisciplinary team of researchers, who represent both natural and social sciences, with research applied to the natural environment of the Arctic. Knowledge and understanding of the Arctic environment are essential for describing further trends and building future global and regional scenarios of the changes (Pakszys and Zielinski, 2017). The authors present strong evidence about recently increasing advection of pollution to the Arctic, related to both natural and anthropogenic activities, simply caused by global change and Arctic Amplification, and are able to presume the further adverse environmental changes in the region.

Aerosol impacts on the Arctic environment, based on data available in the literature and our own results, are described below. The authors present the changes of atmospheric aerosol and black carbon concentrations, and general behavior of aerosols in the Arctic, describing fundamental processes as well as experiments made, also with the cooling effect, shipping emissions and changes in Arctic clouds. We deal only with the long-range transport of pollution, namely various types of aerosols and we analyze yearly aerosol loads, which have been observed over Svalbard archipelago over decades. Atmospheric aerosols are among key elements of climate change and according to IPCC reports they still pose a significant unknown in determinations of the Earth radiative balance. All the analyzed aerosol events represent various sources of atmospheric pollution, from Arctic Haze phenomenon, through the event of the Eyjafjallajökull volcano eruption in spring 2010, to biomass burning events and anthropogenic events from North America (Ferrero et al., 2019a). The data presented in this work are based on sunphotometric studies using stationary sunphotometers, Cimel CE-318 (within the AERONET network) and the hand-held sunphotometers Microtops II. All data were collected in three locations, Ny-Ålesund, Longyearbyen and Hornsund. Additionally, the authors present the results from the Copernicus Atmosphere Monitoring Service (CAMS) model reanalysis, which assimilated modules of atmospheric chemistry, aerosols and greenhouse gases, also, two basic factors used in this work: Aerosol Optical Depth (AOD), which is an indirect measure of atmospheric pollution and the Angström Exponent (AE), which describes aerosol particle sizes. Then, in order to describe the air mass trajectories and the composition of the air masses the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) backward trajectories model was applied (which is not presented here, but the results are described). Such approach provided a comprehensive description of aerosol events with background information regarding sources and types of aerosol particles measured over Svalbard.

Having this strong scientific evidence of remote natural and anthropogenic activities, which are influencing the environment of Svalbard, we discuss the societal awareness of Arctic issues based on the Rethinking the Top of the World: Arctic Public Opinion Survey Report, Vol. 2, issued in 2015 by the Gordon Foundation (Rethinking the top of the world, 2015) and the results of non-formal educating project of young learners from Poland regarding their perception of the Arctic, which was run in 2017/18. We show that despite obvious and measured changes, which are quite commonly known, the level of perception of these changes among society is not high. We argue that proper education at all levels, including general public regardless of age, is the proper option to fill in the gap between hard science evidence and peoples' interest in the change of the Arctic, hence other parts of the world.

The presented results provide an empirical perspective on how various groups of publics, from different countries, relate to the Arctic and climate change issues. In this work we discuss only the questions which relate to the state of the Arctic environment, and the awareness of institution as important as the Arctic Council.

The Polish questionnaire was run during the course of interdisciplinary workshops dedicated to young learners. The questionnaire is constructed to determine if Polish young learners have knowledge about the Arctic and if they are interested in learning something more about the mentioned region and its matters. All students were given the same anonymous questionnaire and were under uniform conditions while filling it. The study involved in total a 274 young learners aged from 8 to 19, who have been divided into 4 age groups and each group was additionally divided with a respect to the gender.

3. Data analyses and discussion

3.1. Discussion of selected natural science findings important for the Arctic ecosystem, observed by the authors

It is well known that the Arctic is subject to an amplification in which the temperatures increase faster (twice) than the global average (IPCC, 2013; Serreze and Barry, 2011; Shindell and Faluvegi, 2009). Scientific evidence showed that the "Arctic amplification" (AA) is the result of complex global feedbacks, like the perturbation of longwave radiation fluxes between ocean and atmosphere due to sea ice retreat, changes in the cloud cover (Francis and Hunter, 2006; Screen and Simmonds, 2010a, 2010b) and variation in the heat transport driven by atmosphere and oceans (Yang et al., 2010). All these processes can be altered by the deposition of black carbon on snow, and the changes in the atmospheric aerosol and black carbon concentrations (Flanner, 2013; Hansen and Nazarenko, 2004; Serreze and Barry, 2011; Shindell and Faluvegi, 2009).

Thus, several important research campaigns were carried out to unravel the processes behind the changing Arctic. First of all, the Arctic Haze phenomenon was discovered, which is related to the inflow of pollution from mid-latitudes occurring in winter/spring (Barrie and Hoff, 1985; Brock et al., 1989; Jacob et al., 2010; Radke et al., 1984; Shaw, 1995; Stohl, 2006). Stohl et al. (2006) demonstrated that atmospheric pollutants can be transported into the Arctic at low-level or with an uplift outside the Arctic followed by a descent until ground. The ARCTAS campaign results showed high altitude air pollution layers transported from North America and Asia in spring (Jacob et al., 2010), while the ARCPAC campaign went deeper clustering the aerosol pollution during the Arctic haze in four categories: from background troposphere with sulfate-rich aerosol to organic-rich biomass burning aerosol and pollution layers dominated by fossil fuel combustion (Brock et al. 2011).

Recently, Ferrero et al. (2016) classified the vertical behavior of aerosols in the Arctic, and it was reported that during springtime four types of profiles were present: 1) homogeneous profiles with constant background properties with altitude (15% of occurrence); 2) positive and negative gradient profiles due to an increase and a decrease of aerosol and black carbon concentrations with altitude influenced by long-range transport (17% and 48% of occurrence); 3) decoupled negative gradient profiles when negative gradients were located at different altitudes in function of aerosol size (20% of occurrence). They are important as homogeneous profiles are representative of Arctic background conditions, positive gradient profiles describe the long-range transported aerosols, which can influence the cloud cover and thus the longwave fluxes. Negative gradient profiles show the entrance of long-range transported aerosol inside the boundary layer: it is important because the deposited black carbon can reduce the snow/ice albedo (Hansen and Nazarenko, 2004). Finally, 4) negative gradients located at different altitudes in function of size showed ground-based locally formed secondary aerosol during snow melting, which is important as a secondary aerosol can act as cloud condensation nuclei. Kupiszewski et al. (2013) confirmed such aerosol formation reporting new particle formation events in the near-surface layer, possibly related to biological processes (ASCOS campaign). Black carbon behavior was exploited in other campaigns. PAM-ARCMIP (Stone et al., 2010) and HIPPO (Schwarz et al., 2010) projects showed elevated black carbon concentrations both at ground-level and in the upper troposphere. High black carbon ground concentrations were also measured across the whole Arctic ocean (Ferrero et al., 2019a).

These above-discussed experimental pieces of evidence are fundamental since the same kinds of aerosol particles can produce opposite effects on climate (from warming to cooling) depending on their vertical location (Ferrero et al., 2019b; Flanner, 2013; Sand et al., 2013; Shindell and Faluvegi, 2009; Zielinski et al., 2016). The black aerosols absorb the incoming shortwave radiation heating the surrounding atmosphere (Ferrero et al., 2011a, b, 2014, 2018; Ramana et al., 2007; Samset et al., 2013, 2014), but the final surface temperature response is influenced by the altitude of the black carbon layer. While they warm the Arctic if deposited above snow and ice, they have a cooling effect when located in the free troposphere (Brock et al., 2011; Flanner, 2013; Hansen and Nazarenko, 2004; Seinfeld and Pandis, 2016). Not only black carbon is important, but the total aerosol properties are also fundamental as aerosols can trigger the cloud formation promoting an indirect effect. Changes in the Arctic cloud cover, especially low-level Arctic stratus, increase the downward longwave flux (Francis and Hunter; 2006; Serreze and Barry, 2011) mainly warming the Arctic surface (Intrieri et al., 2002; Vavrus et al., 2009).

The net effect of the whole ensemble of these processes is the warming Arctic in which the first complete opening of the Northwest Passage was observed in 2007 (Serreze et al., 2007). This brings attention to new commercial routes into the Arctic. Particularly, the importance of increasing shipping emissions has been recently underlined (Corbett et al., 2010; Eckhardt et al., 2013; Granier et al., 2006). It has been reported that during summer a considerable impact of ship emissions is observed in the Arctic, particularly, during ship passage in the Arctic, aerosol and black carbon concentrations reached values usually measured in urban continental areas (Ferrero et al., 2016). The impact of increased ship presence is just one of the anthropogenic impacts locally occurring in the Arctic. Other local emissions like the residential heating and gas flaring also showed huge impacts. Increasing anthropic emissions in the Arctic could significantly increase the aerosol effect on the climate change that the Arctic is already experiencing. However, as aerosols are short-lived pollutants (~few weeks of residence time) they act as short-lived climate forcers. Their reduction could be employed in short-term climate strategies (Jacobson, 2010; Ødemark et al., 2012; Quinn et al., 2008; Shindell et al., 2012).

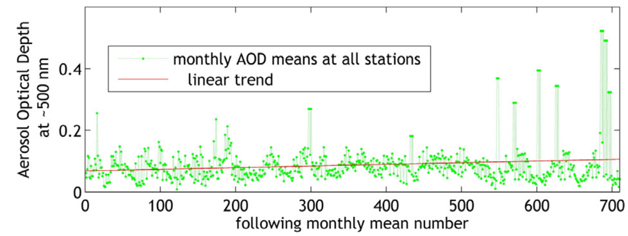

Figure 1 Timeseries of monthly mean AODs for all measurement datasets.

In 2018, Paulina Pakszys, in her Ph.D. dissertation (Pakszys, 2018) provided a thorough analysis of aerosol processes, which were observed during research campaigns in the Arctic, based on information collected by an international team of researchers and from her CAMS analyses. The analyses of data and model results showed a noticeable increase in AOD between 2000 and 2015, leading to the alteration in the state of the Arctic atmosphere, as certain differences between stations can be observed. Monthly averages of AOD values showed an increasing trend with some local maxima. The overall increase was from 0.07 to 0.11 (Figure 1). AOD increase in Ny-Ålesund was from 0.07 to 0.11 (Figure 2a), in Hornsund (Figure 2b), from 0.08 to 0.12, and the largest increase was recorded in Longyearbyen from 0.05 to 0.12 (Figure 2c).

Figure 3 presents monthly means for AOD, during several years at various Spitsbergen stations. Some outliers in AOD are visible and these high peaks are connected with the events in the atmosphere that occurred in high Arctic. The peaks were observed mostly during spring (around 120 day of year), in 2006, 2008, 2010 in Hornsund, 2003 in Longyearbyen and in 2006 in Ny-Ålesund. The highest peak occurred in summer of 2015, in Hornsund during the biomass burning event. Some months in certain years show very high values of AOD due to strong aerosol events such as the Arctic Haze (spring 2004, spring 2005, May 2006, March 2008 and 2011), forest fires (summer 2004, June 2015) and volcano eruptions (August and September 2008, April and May 2010, May 2011).

One of the most recent Biomass Burning events, from North American intense fires occurred in July 2015 (according to the Global News Canada and Natural Resources Canada 2016, it was one of the worst within the last five years in terms of the number of forest fires). This event caused a record high AOD values, that at times were 10 times higher than expected (Figure 4).

Intensive wild fires in North America started in middle May 2015, while the culmination was observed on 28 June 2015. Fire spots were active continuously until late June 2015 and the number of forest fires was the highest over a long period of time (Global News Canada, 2015). MODIS-derived AODs significantly increased on 10 July 2015 around Spitsbergen Island reaching 0.7 AOD (0.6 at 550 nm), increaseswere observed during two following days in the region of Svalbard. AOD values of more than 1 (c. 10 times higher than expected) were recorded by SP1A sunphotometer in Ny-Ålesund, while simultaneous measurements

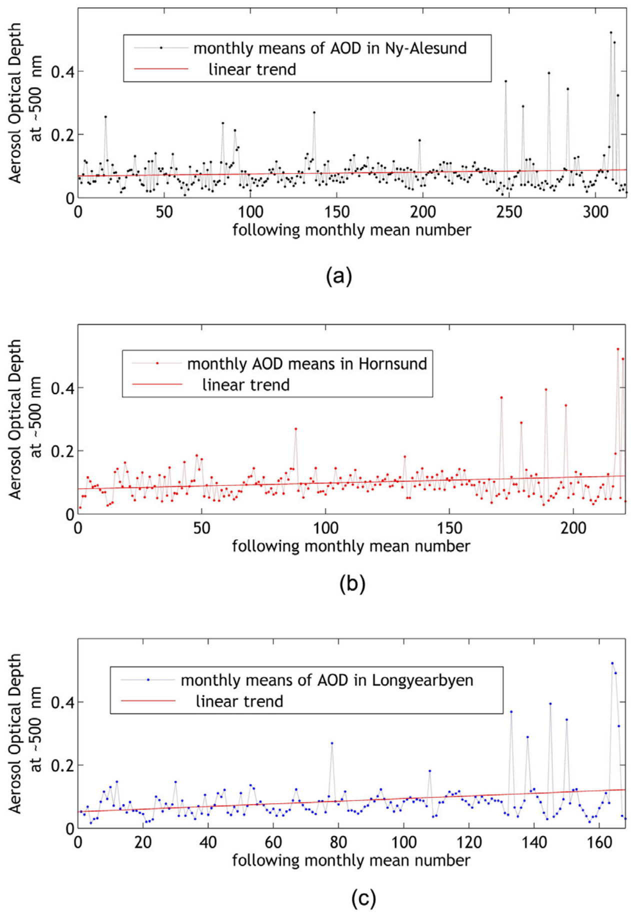

Figure 2 Timeseries of monthly mean AOD for all datasets in Ny-Ålesund (Fig. 2a), Hornsund (Fig. 2b) and Longyearbyen (Fig. 2c).

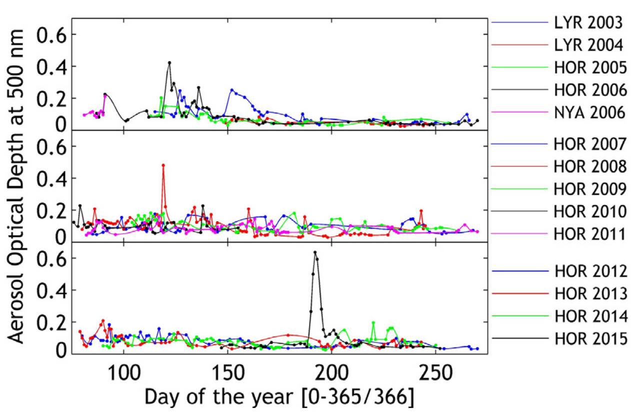

Figure 3 Inhomogeneity in AOD during the period 2003—2015, between years and stations based on AERONET dataset.

in Hornsund showed very high values (0.9) using CIMEL and lower (0.7) using Microtops II Sunphotometer. The CAMS model calculated AOD at 550 nm and showed that the maximum values occurred on 10 July 2015 and this peak lasted until 16 July at all three stations.

Changes in the Arctic climate are important because the Arctic acts as a refrigerator for the rest of the world. This rapid warming trend is anticipated to continue into the next

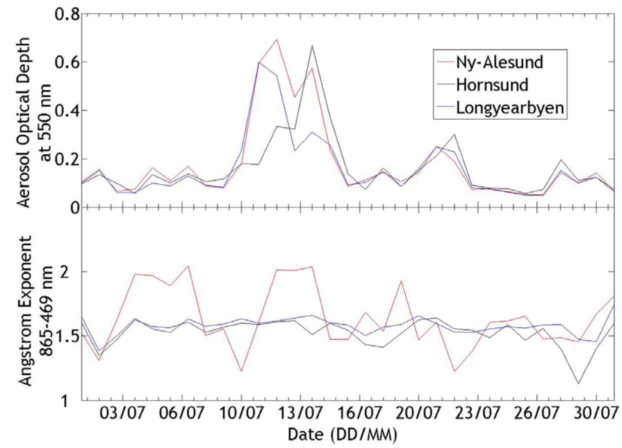

Figure 4 AOD values at 550 nm (upper plot) and AE from 865 nm—460 nm (lower plot) in Ny-Ålesund (red lines), Hornsund (black lines) and Longyearbyen (blue lines) during biomass burning event in July 2015 based on CAMS model.

century with temperature increases exceeding those predicted in the rest of the Northern Hemisphere and will result in accelerated loss of land and sea ice, and an increased rate of sea level rise, with global consequences. These changes affect both local and distant communities, and they can be profoundly observed in many environmental aspects. These changes are leading to significant economic and cultural upheaval particularly for the indigenous peoples of the Arctic.

3.2. Data regarding societal attitudes towards the Arctic issues

The first study, which is discussed in this paper, has been conducted in 2015 within the framework of the Arctic Public Opinion Survey. The results of the study, which was conducted in 8 Arctic countries, and additionally in Canada and USA, with division to the region of the country. In case of the Arctic Council, the results are compared to the first such survey, which was conducted in 2010.

The selected results from the survey are presented in the Table 1 and 2 below. Only questions regarding interest in environmental issues and the awareness of the Arctic Council are presented in this work.

The numbers of respondents varied from 866 in Iceland up to 3000 in Canada, while other countries have been represented by over a 1000 respondents. In the first analyzed question, which is *What do you think is the greatest threat facing the Arctic region today?* authors use only the environmental issues. The majority number of responses noticed the climate change and global warming as an Arctic threat, however, the interest do not exceeds 50% of responses in any given country. The lowest number has been recorded in Russia (20%) while the highest in Denmark (46%). These relatively numerous responses were not followed in the second question, connected to the ice cap and permafrost melting. Only 2 to 19% of people in the investigated countries consider those problems as Arctic threats. Interestingly, the highest number of climate change issue responses came from Russia while the lowest from North Canada (2%), where the issue is expected to be the most obvious. Environmen-

Table 1 Responses to selected questions regarding environmental issues, from the Arctic countries (Modified from Rethinking the top of the world (2015)).

Country/Region	North Canada	South Canada	Alaska	South USA	Russia	Sweden	Finland	Norway	Denmark	Iceland
Number of respondents	770	2042	500	1016	1011	1003	1002	1002	1000	866
What do you think is the greatest threat facing the Arctic region today?										
Global warming, climate change	37%	40%	30%	37%	20%	32%	43%	26%	46%	30%
Ice caps melting, melting of sea ice/ permafrost	2%	8%	3%	14%	19%	12%	8%	4%	5%	3%
Environmental damage/degradation (negatives to flora/fauna/pollution/land...)	8%	7%	5%	1%	5%	7%	5%	7%	7%	11%
Human/outsider interference/intrusions, negative effects on land/North, lack of understanding/ignorance of area, lack of respect for the North	2%	1%	3%	2%	4%	1%	3%	2%	3%	3%
Do not know/refuse	14%	15%	26%	35%	38%	35%	28%	49%	29%	36%

Table 2 Responses to the question regarding recognition of the Arctic Council, from the Arctic countries (Modified from Rethinking the top of the world (2015)).

Country/Region	North Canada	South Canada	Alaska	South USA	Russia	Sweden	Finland	Norway	Denmark	Iceland
Number of respondents	770	2042	500	1016	1011	1003	1002	1002	1000	866
Have you ever heard of an intergovernmental forum or group called the Arctic Council that is made up of eight countries with Arctic regions?										
Yes, vaguely.	27%	26%	20%	20%	42%	28%	36%	34%	29%	21%
Yes, clearly.	32%	8%	15%	12%	12%	11%	8%	12%	28%	49%
Yes, clearly as in 2010	35%	15%	-	2%	7%	9%	17%	20%	30%	36%

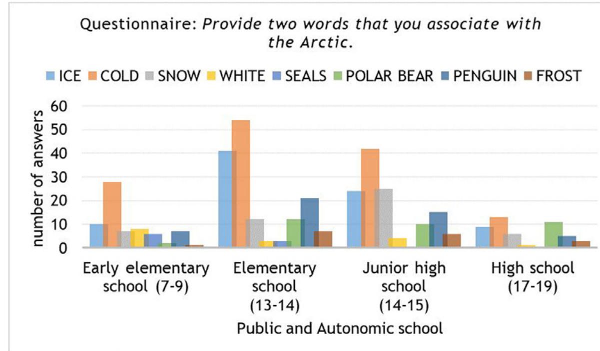

Figure 5 Responses of Polish young learners to the question: *Provide two words that you associate with the Arctic.*

tal damage is also not perceived as an important issue and the percentages range from 1% (South USA) to 11% (Iceland). Another interesting result came regarding the human interference with the environment of the region. The highest number of answers to the mentioned issue were reported in Russia (4%), while in South Canada it was only 1%. Relatively high percentages of responses refer to the question: *Don't know/refuse*, with lowest 14% in North Canada up to 49% in Norway. These answers can be summarized as: *I am not interested*. This assumption can be supported by the results presented in Table 1, where respondents refer to their knowledge about the Arctic Council. The positive answers with good recognition of the Arctic Council were given by less than 50% of respondents in each country/region. The highest percentage (49%) of those answers came from Denmark and the lowest 8% was reported in Finland and in South Canada. Compared with the survey from 2010, the percentages of the responses are in 6 cases lower than in 2015, 3 were slightly higher (South USA, Russia, Sweden) and in one case there are no data from 2010 (Alaska).

These answers go well with the responses provided by Polish young learners regarding their perception of the Arctic. Figure 5 shows the division of responses to the question: *Provide two words that you associate with the Arctic.*

When we look at the responses, we can observe that Polish young respondents of all age groups, think about the Arctic in a rather typical (cliché?) manner, since the majority of responses independent of age group and gender mostly mention: cold, ice, snow and penguins. None of the respondents provided such associations as: climate change, degrading Arctic environment or melting glaciers. Some respondents mentioned polar bears. However, quite a number of respondents mentioned penguins, which shows that the knowledge about the Arctic is at their best not too clear.

The next question of the survey: *Would you like to enhance your knowledge about the Arctic?* provides information about the level of interest and potential concern about the Arctic among the young learners. The results are presented in Figure 6.

In all cases, there is a great number of students in all four groups of ages who are simply not interested in the Arctic issues or cannot decide if they want to learn anything about this region. The number of uninterested students is relatively low in young ages and becomes more dominating among older students.

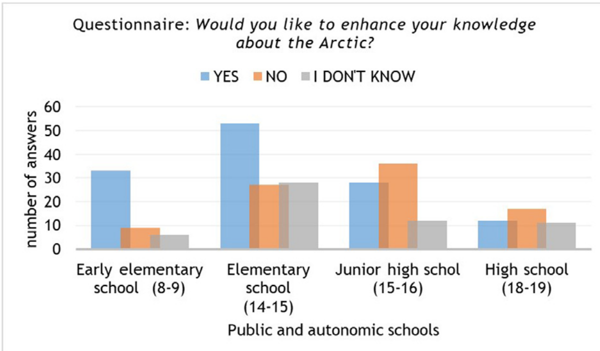

Figure 6 Responses of Polish young learners in public and autonomic schools to the question: *Would you like to enhance your knowledge about the Arctic?*

The results of the questionnaire in these two independent studies, which concern eight Arctic countries and Poland, a country without geographical connection with the Arctic, but with long-lasting presence (exploration and research) in the region, show that in all cases investigated members of each society do not seem to be very much interested and concerned about the Arctic, its changes, problems and hazards. People do not seem to realize what role we have in modifications of the state of the Arctic and what consequences they pose on the region.

4. Conclusions

The following conclusions can be formulated based on the findings presented in this paper.

1. There is no doubt that the environment of the Arctic is under an increasing pressure (both natural and anthropogenic) and that this pressure is concerned with pollution advected to the region from distant sources.
2. Over the last decade, the dramatic summer biomass burning events in Canada, Greenland and Siberia have become a major source of atmospheric pollution to the Arctic. The amounts of chemical compounds and dust from these events are so vast, that they have serious impact on the radiative balance of the region.
3. These events are connected with increasing global warming, due to lack of moisture in the soils and progressive drying, many regions become very vulnerable to wild fire outbreaks. We should expect that this process will only continue to worsen.
4. Still, recent studies on society perception of the Arctic issues among citizens of eight Arctic states and among young learners in Poland show that the Arctic environmental issues are not well understood and people are not interested in learning much about the region and its problems, regardless of age.
5. Very few people are aware of the environmental damage, which is happening in the Arctic and about the human role in this process. Unfortunately, certain issues are less important to people (survey in 2015) than they were in 2010, i.e. perception of the Arctic Council and its role.
6. It is evident from the Polish survey, that young people of various age groups and independent of gender are not too aware of the Arctic issues and they are not too interested in learning much more over what they know now.
7. However, Polish young learners, best absorb knowledge using Internet and during non-formal education activities, such as interactive workshops.
8. Therefore, the authors believe, that the scientists together with educators of all types, formal and non-formal, should join forces and create interesting offers (materials and set of classes/workshops), which can be available online for any educator or any interested party to use them in educational activities, available to the general public.

9 We think that the SIOS Knowledge Center could become such an information/education hub for the Arctic issues.

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