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Arctic environmental change research and Antarctic studies have mutual benefits

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Arctic environmental change research and Antarctic studies have mutual benefits for increasing understanding of climate and environmental change in the polar regions. Two examples of bipolar environmental research questions with mutual benefit are presented here. First, climate change and climatically significant cryospheric changes are introduced, and then the roles of albedo feedback mechanism and light absorbing impurities are discussed. Second, the challenge of polar stratospheric ozone depletion is discussed in connection with the increase in the harmful ultraviolet solar irradiance reaching the Earth.

1 Climatically significant polar cryospheric changes and snow albedo

Eunice Foote, an American amateur scientist, demonstrated experimentally in 1856 the interaction between the Sun's radiation and different gases and theorized how those gases could affect atmospheric temperature (Foote, 1856). Her findings are the first to refer to climate warming, one of the biggest challenges of our time. Swedish professor Svante Arrhenius hypothesized in 1896 that climate warming would be greater in the polar regions, with greater warming in both the Arctic and the Antarctic regions than elsewhere. He suggested albedo feedback as the main reason for this difference (Arrhenius, 1896). Currently, over 120 years later, we know with the help of modern technology, satellite data included, that Arrhenius was correct and that climate change is more pronounced in the Arctic and Antarctic regions. The warming is stronger in the North and is called "Arctic amplification." Arctic amplification has been identified more recently to be due primarily to temperature feedbacks, with albedo feedbacks as the second most important cause (Pithan and Mauritsen, 2014). Various additional causes of different temporal and spatial scales have also been identified, including, e.g., heat absorbing aerosols in the atmosphere and their deposition to the cryosphere (Serreze and Barry, 2011; IPCC, 2019).

Albedo decrease can be due to cryospheric melt or to darkening due to light absorbing impurities, most often linked to black carbon (BC). Yet, dust and organic carbon (OC), as well as various microorganisms that reside in snow and ice, can have similar albedo effects (AMAP, 2015; IPCC, 2019). Finnish explorer Adolf Erik Nordenskiöld reported red snow in Greenland as early as 1883 (Nordenskiöld, 1883). The measured albedo of clean snow is higher in the Antarctic than in the Arctic. The reasons for this, as discussed first by Wiscombe and Warren (1980) and Warren and Wiscombe (1980), are that the clean snow albedo is mostly related to grain size, which is smaller in Antarctica due to stronger winds. The

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lower amount of impurities in the cleaner Antarctic air, as well as snow grain shape and topography, as discussed, e.g., by Meinander et al. (2008, 2013), also contribute to different albedo values. Differences in precipitated snow grain shapes can be due to differences in atmospheric moisture (Antarctic air is dryer). The Antarctic atmosphere is also colder than the Arctic, and sometimes stratospheric air masses reach down into the troposphere.

The reduction in the spectral albedo due to black carbon on snow varies also as a function not only of snow grain size and wavelength but also of the impurity concentration and the impurity's absorption properties (Hadley and Kirchtetter, 2012; Flanner et al., 2013). High latitude dust refers to dust particles produced in high latitudes (⩾ 50°N and ⩾ 40°S), and more dust sources and dust impacts have recently been documented in the Arctic (Bullard et al., 2016). For example, Icelandic dust and ash particles are dark in color, and their impact on the cryosphere can be significant due to their light-absorbing properties (Peltoniemi et al., 2015). Dragosics et al. (2016) showed that a thin Icelandic ash layer increased the snow and ice melt, but an ash layer exceeding a certain critical thickness caused insulation and prevented snow and ice from melting. Additional effects related to dust are, e.g., atmospheric heating, cloud formation and ocean fertilization. The melting of snow and ice could result in new dust sources in the future. Hence, while some of the interactions and feedbacks (Boy et al., 2019) are the same for Arctic and Antarctic snow (and for snow in high mountain cold areas, too), others may be different.

2 Solar UV irradiance research in the Antarctic and Arctic regions

The springtime depletion of stratospheric ozone and the increase in the harmful ultraviolet solar irradiance reaching the Earth's surface is an additional bipolar environmental question. The discovery of the ozone hole by British physicist Joe Farman (Farman et al., 1986) highlighted one of the 20th century's most important environmental challenges. The 1995 Nobel Prize in Chemistry was awarded jointly to Paul J. Crutzen, Mario J. Molina and F. Sherwood Rowland "for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone" (The Nobel Prize in Chemistry 1995). The stratospheric ozone layer protects the Earth from harmful ultraviolet radiation, and the biological effectiveness depends on the wavelength (e.g., McKinlay and Diffey, 1987). The ozone hole is linked to human-made chlorofluorocarbons and with the surface chemistry on and in polar stratospheric clouds (PSCs) that form during extreme cold conditions (Solomon et al., 1986). Fundamental differences between Arctic and Antarctic ozone depletion have been recently discussed in Solomon et al. (2014) with unique insights into the contrasts between Arctic and Antarctic ozone chemistry. Similar challenges in making ground measurements of ultraviolet radiation in the Arctic (e.g., Meinander et al., 2013) and Antarctica (e.g., Lakkala et al., 2018) include low Sun azimuth, harsh winter and changing cloudiness. Arctic measurements closer to inhabited areas can more easily determine corrections for Solar Zenith Angle dependency, temperature corrections and the effect of defrosting systems. The QA/QC of the data are important also for using satellite instruments, which need ground-based data for their validation. An important scientific research question is whether recent Arctic ozone depletion (Manney et al., 2011) is, in fact, an impact of climate change (Solomon et al., 2014).

3 Conclusions

The research topics of Arctic and Antarctic snow albedo and solar UV irradiance reaching the ground were discussed here with their mutual benefits for increasing understanding of climate and environmental change in the polar regions. For example, Arctic and Antarctic snow albedo values differ due to snow grain properties, which again differ due to different climate conditions and impurity deposition rates. Yet, surface-melt-induced, diurnally asymmetric albedo has been found with the same magnitude of 10% decline from morning to evening despite the different snow and environmental conditions (e.g., Pirazzini, 2004; Meinander et al., 2013). The measured Arctic and Antarctic solar UV irradiances at the corresponding northern and southern latitudes, in turn, differ due to the differences in atmospheric conditions that control ozone chemistry. The benefits from their similarities include, for example, similar challenges in measuring ultraviolet radiation by ground measurements in the Arctic and the Antarctic, which might be more easily solved with Arctic measurements closer to inhabited areas. Knowing and understanding the history of the Arctic and Antarctic environmental change research forms the basis to understand past, current and future challenges and to find their solutions. Moreover, the differences between the Arctic and Antarctic provide a wider range of natural conditions over which to study and understand the key atmospheric, cryospheric, hydrospheric, and biospheric (also lithospheric) processes and feedbacks.

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Note: Queries and discussions on this article should be made by E-mail directly with the corresponding author.

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