17. SUMMARY

In this monograph the current state of development of the meteorological and climatic studies programme of the Polish Polar Station at Hornsund and its region has been presented. Results of the observations at Hornsund are representative of south-western Spitsbergen, which is situated in the central part of the Atlantic Arctic. In the recording period, 1978–2009, climatic conditions in this area were not stationary, as is proven by the results of the research.

The climate changes in south-western Spitsbergen over the last 25–30 years have been large in their scale and rapid. Statistically significant increase of air temperature is evident: it is especially strong in the autumn and winter, so that the annual amplitude of air temperature has been decreased. There were statistically insignificant but consistent increases of mean temperatures of the two warmest months of year also – July and August. Over the year the air temperature regime has clearly changed to one of increasing "oceanicity". Changes of many other climatic parameters have been coherent with those of air temperature, confirming the oceanicity trend in this part of Spitsbergen. Increase of precipitation totals has been part of the trend, in summer and autumn particularly the amount of liquid precipitation has gradually increased, as has the frequency of precipitation with high daily totals. The duration of snow cover is shortening. General cloudiness is increasing, sunshine duration decreasing. Annual mean wind velocity is increasing and atmospheric pressure decreasing. These changes are recorded very well by the series of measurements at Hornsund. As analysis of the data shows, in the last 5–7 years the rate of the climatic changes at Hornsund underwent a further acceleration when compared to the already significant rate of changes that were recorded in the preceding period.

The climate changes at other Spitsbergen stations and their vicinity are quite similar to those at Hornsund and thus are indicative of conditions in the Atlantic Arctic region in general. They are accompanied by extensive changes at sea. The area of sea ice is decreasing, especially markedly in its minimum extent; water temperature is increasing, both on the surface and below the surface layers of the West Spitsbergen Current. Sea surface temperatures in the other bodies of water around Spitsbergen are increasing also, although at different rates than in the West Spitsbergen Current.

The findings of both earlier research (Styszyńska 2005, 2007) and that presented in this monograph show that the main factor driving the climatic changes observed in the Atlantic Arctic is the increase of heat resources introduced with the Atlantic water by oceanic circulation. The fact of increase of heat flux to the Atlantic Arctic together with its transport through these waters is confirmed and documented, by the research of Institute of Oceanology PAS (Piechura *et al*. 2001, Walczowski *et al*. 2005, Walczowski and Piechura 2006, 2007) and other sources. The increase of heat resources in the water, via a complicated chain of interrelationships activated and supports the processes of climatic changes. The key role is played by processes in the ocean, leading to decrease of sea ice cover.

Increased areas of ice-free water during the polar night, together with increase of heat resources in the sea, cause greater flow of heat and water vapour from the ocean to the atmosphere, contributing to increase of air temperature. This increase of air temperature then reduces the extent of sea ice during the winter. After a milder winter the greater area of water without ice cover during the spring and summer allows for an earlier beginning of net heat accumulation in the water and extends the duration of the accumulation, contributing to increase of water surface temperature and therefore also of the air temperature. Solar radiation reaching the sea surface in such conditions is much more efficiently "used" to increase temperature both in the water and the air over it, than when it falls on sea ice cover with high albedo and great amounts of heat must be used for to bring about phase changes in the water.

During the autumn the delayed formation of ice cover in these warmer waters also contributes to increase of air temperatures and of precipitation. Especially strong horizontal temperature gradients developing during the autumn and the first half of winter in the middle troposphere between areas over warm, ice-free waters of the West Spitsbergen Current and cooled air over glaciated Greenland and the belt of ice extending along its eastern coast cause strong baroclinity in the atmosphere. The effect of this is to increase frequency of cyclogenetic processes in the region and re-invigoration of low pressure systems from the North Atlantic. This causes fall of atmospheric pressure and increase of cloudiness that in turn reduces drops in air temperature. Increase of intensity of the cyclogenesis processes contributes to increase of frequency of warm air mass advection over the Atlantic Arctic. All this together leads to further diminishing of the ice cover and decrease of the amounts of multiannual ice that can become nuclei in the formation of new sea ice. These feedback loops are closed entities. Such inflow of heat and salt with the Atlantic water is required to delay the formation of ice, so that there may be intensive streams of heat from the ocean to the atmosphere during the polar night.

It appears to be of great importance to continue meteorological measurements and observations at the Polish Polar Station at Hornsund and to publish their results immediately or make them available to researchers in other ways. This will allow scientists to track the continuation of the processes of climate evolution of this part of the Arctic in which the changes that are occurring appear to be of great importance for the climate of the entire Arctic region. The geographic location of the Polish Polar Station at Hornsund is exceptionally beneficial for this purpose.

The climate of the Atlantic Arctic still evolves, not only under the influence of the processes described in the present work but also those that function elsewhere in the Arctic. We do not know the future progression of this evolution, we cannot predict in a reliable way even using the most advanced prognostic techniques such as computer modelling. Numerous papers presenting results of modelling of climate changes in the Arctic convince us of this (e.g. Moritz et al., 2002, Przybylak 2007), also the numerous models of evolution of sea ice cover (e.g. Holland *et al*., 2006, Stroeve *et al*., 2007, Holland *et al*., 2008).

On the one hand, rapid decrease of sea ice cover in the Arctic and change of its structure is observed. Multiannual ice, six to ten or more years in age, at present (in 2010) is only few percent of Arctic ice cover. In 1988 this ice made up as much as 40–45% of the total area of Arctic sea ice (Maslanik *et al*., 2007). The decrease of sea ice cover in the Arctic in September is especially strong. In September 2010 sea ice cover in the Arctic was around 4.9 million km^2. Since shrinking to its smallest recorded area of 4.1 million km^2 in September 2007 there has been some slow and irregular increase of ice cover at the annual minimum; however, it is considerably smaller area than average minimum for 1979-2004, which was slightly above 7.2 million km^2.

Based on their analysis of the minimum extent of sea ice, 1988–2003, Lindsay and Zhang (2005) posed an important question – Can the Arctic sea ice minimum pass some "point without return", from which its rebuilding to the previous state in the following winter seasons will be not possible? Reaching such point would mean that the Arctic and its climate would pass from the state of "cool Arctic" to the state of "warm Arctic" (Polyakov *et al.*, 2005), approaching the so-called "ice free regime"[1]. May be we may observe *in statu nascendi* process of change of the Arctic climate from one state to the other. Undoubtedly we may say that the second phase[2] of intense warming of the Arctic is being observed now. Will be this warming permanent?

On the other hand, results of research by Styszyńska (2005, 2007) as well as Marsz and Styszyńska (2009) show that the intensity of inflow of the warm Atlantic water to the Norwegian Current and its further transport to the Atlantic Arctic is a function of processes in the Gulf Stream Delta. Increase of intensity of the transport of warm and salt tropical water to the northern branch of the Delta, from which water is transported by the North Atlantic Current and onwards to the Norwegian Current, is correlated with increase of water temperature in the northern part of the Delta. The pattern of temperature in this part of the Gulf Stream- Delta investigated in 1890–2009 seems to show strong periodicity with low frequency. Two minima in this pattern are known to have occurred, approximately in 1904 and 1973, and one maximum in 1937–1939, which suggests a periodicity of 65–70 years. The same periodicity in the patterns of global temperature was discovered by Schlesinger and Ramankutty (1994). Numerous researchers associate this periodicity with AMO (e.g. Kerr 2000, Enfield *et al.*, 2001, Sutton and Hodson, 2005, Trenberth and Shea, 2006, Li and Bates, 2007). The temperature in the northern part of the Gulf Stream Delta increased smoothly again after 1973–1974. The trends in the index characterizing heat resources in the Atlantic water flowing into the Atlantic Arctic ($LF_{1\text{-}4}$ index), as well as amazingly smooth trends of the annual air temperatures at Svalbard-Lufthavn station (1917–2009) and Björnöya station (1923–2009) are correlated with it, and also air temperature anomalies for the whole Arctic (Marsz and Styszyńska, 2009). From the values of the ocean surface temperature in the Gulf Stream Delta Marsz and Styszyńska (2005) modelled the pattern of annual air temperature at Svalbard-Lufthavn, which conforms well with the observed pattern.

If the intensity of transport of the warm Gulf Stream water by the northern current actually has some stable periodicity of around 70 years it means that at present we are in the time around culmination (2008–2009), after which there will be a decrease of transport intensity, or just after the culmination. In both cases in the near future, although with few years delay, gradual cooling of the Atlantic Arctic would begin, extending gradually to other regions of the Arctic. Some symptoms of changes of the surface temperature field in the North Atlantic, the Norwegian Sea and water of the Greenland Sea adjacent to Spitsbergen seem to show the beginning of such decrease of heat transport to the Arctic by oceanic circulation.

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[1] No-ice regime should be understand as a state in which during the summer sea ice in the Arctic melts out nearly completely whereas during the winter the sea ice formed may cover an area close to that observed at present. In the ice structure ice older than one year will be not observed, except limited areas of the Arctic (e.g. in the Canadian Arctic).

Regardless which of the described scenarios of climatic changes will be realized, the location of the Polish Polar Station at Hornsund ensures that this kind of climatic change in the Atlantic Arctic oceanic processes will be recorded there first. Observations at the Hornsund station will allow us to discover and diagnose the character of these changes and next may provide data for explaining mechanisms and causes of them.