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INDICATORS AND INDEXES
FOR ARCTIC CLIMATE CHANGE MONITORING AND PREDICTION

Definitions:

Indicator – representative characteristic of the state of certain part of Arctic climate system.

Indicator is selected on the basis of existing ideas about the processes that form the Arctic climate and its connection with the rest of the global climate system.

Index – quantitative value (assessment) of the indicator in a given period in a specific area, obtained from measurement data, which is added to the ongoing long-term series.

Examples of existing indicators and indexes:

Indicator: atmospheric circulation. **Indexes**: NAO, AO, PDO, etc.

Indicator: surface air temperature (SAT). **Indexes**: mean SAT north of 60°N, north of 70°N, and etc., trend of average SAT for «n» years, Arctic amplification, etc.

Indicator: sea ice, SIE. **Indexes**: min SIE, max SIE, monthly mean SIE, etc.

Indicator: sea ice, ice thickness. **Indexes** : equilibrium thickness, sea ice rate of various ages, accumulated degree-day of cold, etc.

Suggested indicators and indexes:

1 Indicator – mean SAT in the area of maximal sea ice spread in the Arctic Ocean and the adjacent North Atlantic (the marine Arctic, fig. 1).

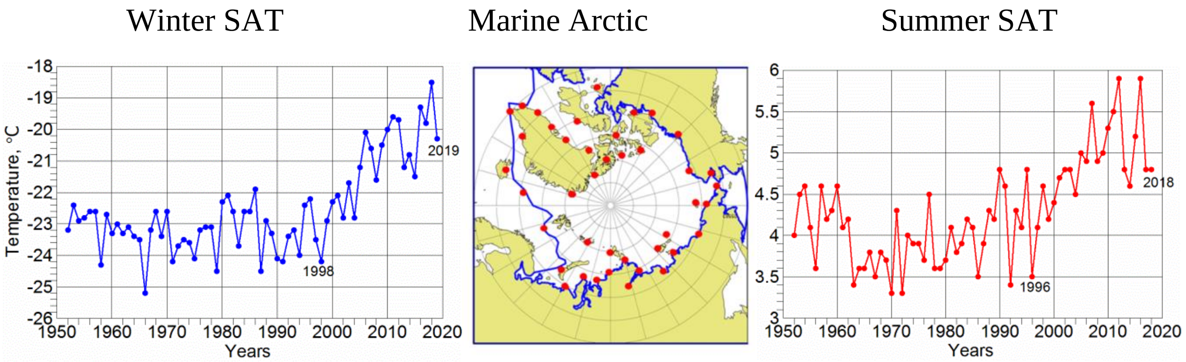

Figure 1. Changes in winter and summer SAT in the marine Arctic.

1.1 **Index – summer SAT in the marine Arctic**. It is determined by mean SAT in June-August at 41 meteorological stations.

The proposed index is closely related to the September SIE in the Arctic (fig. 2):

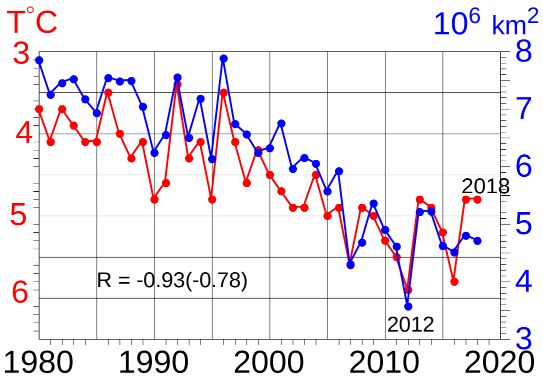

Figure 2. Mean summer SAT in the marine Arctic and sea ice extent in September. R – correlation coefficient between SAT and SIE. In brackets – between deviations from a quadratic trend. SAT scale is inverted.

1.2 **Index – mean temperature in the Atlantic sector of the marine Arctic**, reflecting the influence of Atlantic Multidecadal Oscillation (AMO) on changes in atmosphere circulation [1], water temperatures coming from the Atlantic [2], extent and thickness of sea ice [3]. Air temperature data are taken from 6 meteorological stations with the observations since 1900 (fig. 3). Data from Barrow weather station are added. This increased the representativeness of the average of 7 stations, compared with the average of 6 stations, for assessing the impact on the entire marine Arctic climate.

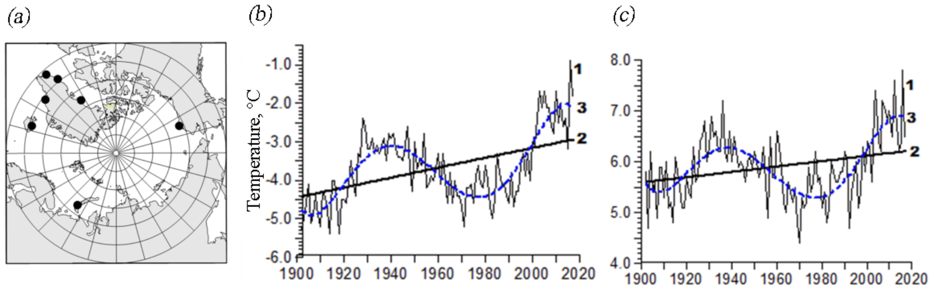

Figure 3. Air temperature at 7 Arctic stations with long-term observations.

a) — meteorological stations in the marine Arctic with long-term observations; *b*) — average annual temperature at 7 stations; *c*) — summer temperature (1 —row values, 2 — trend, 3 — low frequency oscillation).

There is a close relationship between the average air temperature at 7 stations and sea ice (tabl.1).

Table 1. The correlation between the summer air temperature at 7 stations and the average monthly ice extent and area in the Arctic Ocean for 1979–2017

Month / Season	1	2	3	4	5	6	7	8	9	10	11	12
	Sea ice area (concentration more than 15 %)											
June	-0,71	-0,73	-0,66	-0,63	-0,70	-0,78	-0,77	-0,78	**-0,79**	**-0,79**	-0,76	-0,68
July	-0,65	-0,70	-0,65	-0,63	-0,61	-0,68	-0,74	-0,77	**-0,80**	**-0,80**	-0,76	-0,73
Summer	-0,64	-0,68	-0,61	-0,60	-0,64	-0,75	-0,78	**-0,80**	**-0,83**	**-0,84**	**-0,80**	-0,75
	Sea ice extent											
June	-0,68	-0,69	-0,64	-0,69	-0,78	-0,80	-0,79	-0,76	**-0,79**	**-0,79**	-0,73	-0,70
July	-0,62	-0,68	-0,64	-0,67	-0,68	-0,72	-0,74	-0,77	**-0,81**	**-0,80**	-0,74	-0,71
Summer	-0,60	-0,63	-0,57	-0,65	-0,73	-0,78	**-0,80**	**-0,80**	**-0,83**	**-0,83**	-0,76	-0,73
Note. Bold font ratios of 0.79 or more												

Extrapolated summer air temperature at 7 stations can be used for the predictive estimate of the sea ice extent in the Arctic Ocean (fig.4).

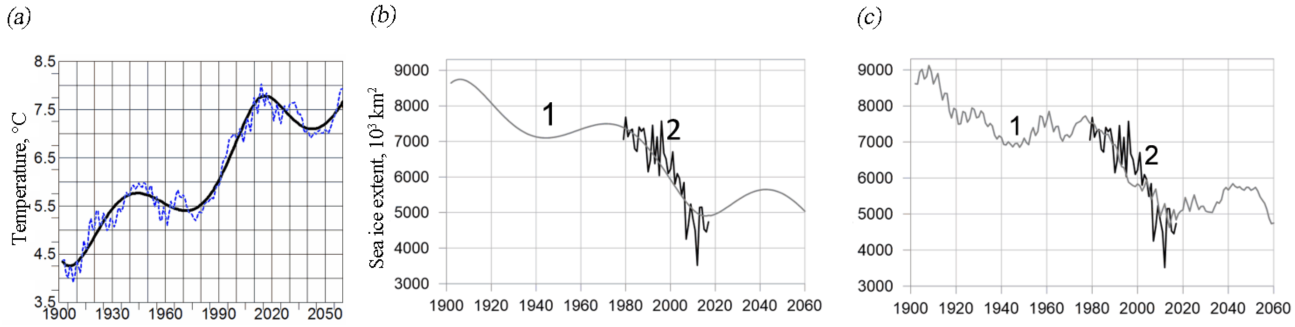

Figure 4. Predictive values of sea ice extent in the Arctic Ocean until 2060.

a) - extrapolated summer air temperature (predictor) with added noise; *b*) - the ice extent calculated by the regression model without adding noise to the predictor (1) and the observed ice extent (2); *c*) - the same as (*b*), but with the addition of noise to the predictor.

1.3 **Index – accumulated degree-day of cold** at weather stations along the Northern Sea Route (fig. 5a) which reflects changes in the maximum thickness of first-year ice in the Arctic seas (fig. 5b).

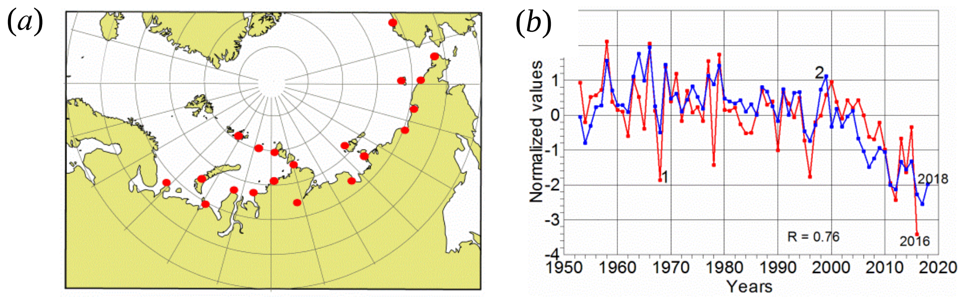

Figure 5. Mean accumulated degree-day of cold (1,b) at the stations along Northern Sea Route (a) compared to the average ice thickness at these stations in May (2, b). R – correlation coefficient between (1) and (2).

2. **Indicator – inflow of water from the Atlantic** to the Norwegian, Greenland and Barents Seas. It has a strong effect on sea ice extent in the Atlantic sector of Arctic in winter (fig. 6).

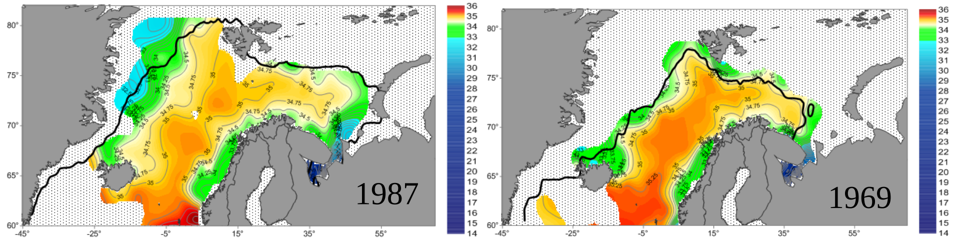

Figure 6. Sea surface salinity and ice edge in June 1969 and 1987 (http://www.nodc.noaa.gov/OC5/nordic-seas/, HadSST)

2.1 **Index - AW temperatures in 50-200 m layer along 33°30' E in the Barents Sea**.

Data from PINRO website (http://www.pinro.ru). Average for the year available since 1901, monthly average since 1951.

There is strong correlation between the temperature in the 50–200m layer on the Kola section and SIE in the Barents Sea (Table 2):

	1	2	3	4	5	6	7	8	9	10	11	12
К-т	**-0.83**	**-0.82**	**-0.70**	**-0.78**	**-0.87**	**-0.83**	-0.67	-0.48	-0.26	-0.28	-0.44	-0.70

This index closely associated with SIE in the Arctic Ocean (fig. 7)

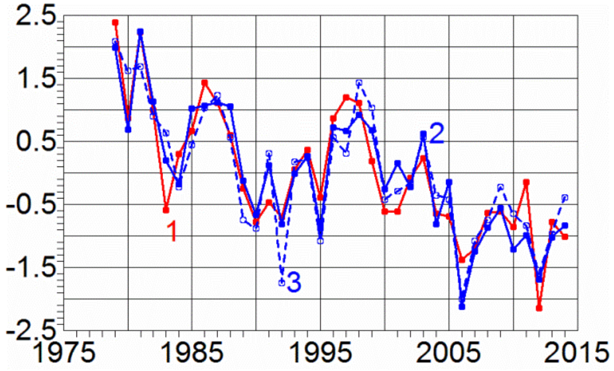

Figure 7. Normalized values of water temperature at the Kola section (1), SIE in the Arctic (2) and in the Barents Sea (3) in May. The correlation between (1) and (2) is -0.92 (-0.83), between (1) and (3) is -0.87 (-0.76). Sign of water temperature anomaly was changed.

Statistical forecast of monthly average Arctic SIE in June - September 2018 and 2019

The forecast is performed using linear regression equations with two predictors:

1. SIE in February
2. SST in the tropical North Atlantic in October 2 yr earlier

Month	Monthly SIE, 10^6 km^2 2018	Observed	Monthly SIE, 10^6 km^2 2019	Observed
June	11,01	10,72	11,00	
July	8,19	8,24	8,26	
August	5,54	5,62	5,35	
September	4,57	4,72	4,95	

CONCLUSIONS

- The proposed indicators and indexes reflect relationships in the Arctic climate system between the atmosphere, sea ice and the ocean;
- The data of direct observations of the air temperature at the Arctic meteorological stations and the water temperature at the oceanographic section (monitoring since the beginning of the 20th century) are used for indices calculation;
- Prolongation of the multi-year series of proposed indices provides the necessary historical context of monitoring climate change in the Arctic and the demand for direct observations and measurements at a network of meteorological stations and oceanographic sections.

References

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2. Park H. S., Lee S., Son S. W., Feldstein S. B., Kosaka Y. The impact of poleward moisture and sensible heat flux on arctic winter sea ice variability. J. Climate, 2015, vol. 28, no. 13, pp. 5030–5040.
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