# Development of Sea Surface Temperature in the Baltic Sea 2016

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## Key message

The year 2016 was after 2014 and 2015 the third warmest year since 1990. February to July and September contributed by positive anomalies of up to +5 K in May, which was the warmest May since 1990. August and November were characterised by negative anomalies of up to -3 K along the west and east coast of the central Baltic induced by upwelling due to abnormal westerly and easterly winds in those months. June and September belonged to the warmest months in the southern Baltic and October in the Gulf of Bothnia. A strong cooling at the beginning of 2016 led to maximum ice coverage in the entire Baltic Sea on 23 January, while March 09 – 15 was the coldest week in the open waters of the Baltic Sea. The SST increase in late spring was more pronounced than usual, leading to positive anomalies in May and June and to an early development of cyanobacteria. A warming phase in the second half of July made 26 July to the warmest day of the year. After SST decrease beginning of August particularly in the northern Baltic, a stable situation lasted until mid-September with SSTs of 18-20°C in the southern and western Baltic. This led not only to the high anomalies in September but also to a long lasting cyanobacteria season.

## Results and assessment

Cold and heat sums of air temperature of Warnemünde (Naumann et al. 2017) were applied to derive information about the severity of winter and the course of summer. The winter 2015/16 was with a cold sum of 63.5 Kd below the long term average (102.4 Kd) since 1948. January contributed with 63 Kd mainly to this value (Average 38.9 Kd). The heat sum for summer (267 K d) exceeded the long-term average (151.7 Kd) and was the sixth warmest summer since 1948. All summer months from May to September exceeded by far the long-term means.

Anomalies of monthly mean SST for the entire Baltic Sea in Fig. 1 show the overall thermal development in 2016. The monthly mean temperatures in the central areas of the Arkona, Gotland and Bothnian Seas in Fig. 2 present the seasonal development in comparison to the long-term monthly averages (1990-2016). Daily and weekly mean SSTs are implemented for the detailed description of the temperature development.

After rather high positive anomalies in November and December 2015, the SST in January 2016 approached the long-term mean values leading to only slight positive anomalies in the southern Baltic. From February to April, anomalies increased to about +2 K. Subsequently, a strong warming led to high anomalies of +3 K to +5 K particularly in the Gulf of Finland, in the northern Bothnian Bay and in the Gotland Basin so that the May 2016 became the warmest May since 1990 in these regions. With

anomalies between +2 K and +3 K, June belonged also to the warmest in the southern Baltic Sea. The northern Baltic varied around the average.

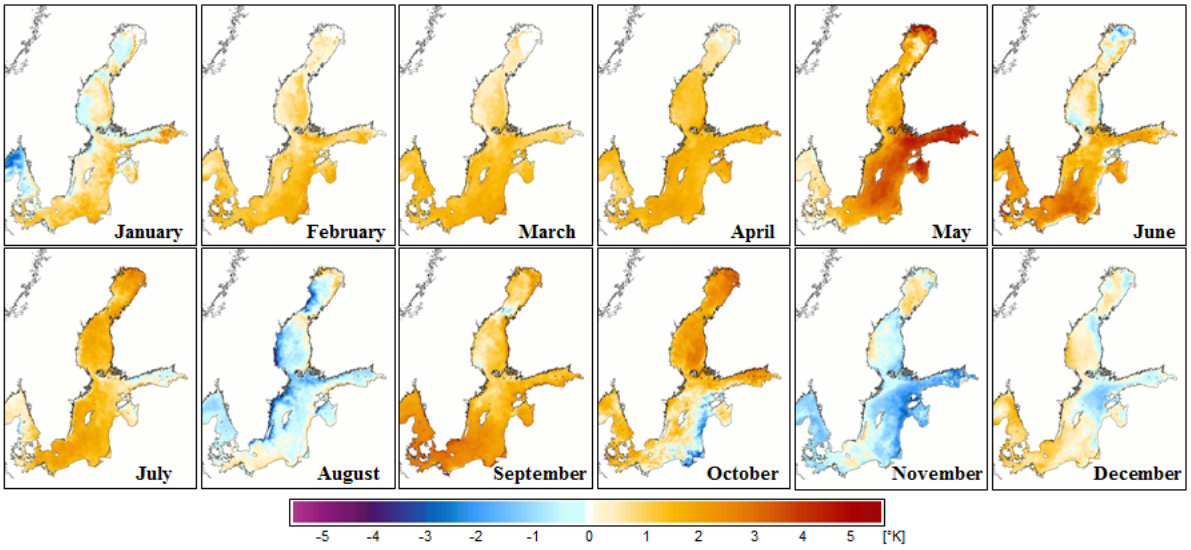


**Figure 1**. SST- Anomalies of the monthly mean temperature of the Baltic Sea in 2016 referring to the long-term means (1990-2016).

The anomalies in July are mainly between +1 K and +2 K except in the eastern and western parts, where slight negative values occurred. Deep pressure systems in August brought an abnormal high number of west- wind situations in the northern and central Baltic leading to intense upwelling of cold water along the Swedish coast and to negative SST anomalies of up to -4 K, there. September was particularly in the southern and western part warmer than the long-term mean values and belonged to the warmest since 1990 in these regions. October and November were characterised by abnormal high frequencies of easterly winds in the central Baltic leading to upwelling of cold water along the coast of the Baltic countries and anomalies of -2 K to -3 K. In the Gulf of Bothnia, the October 2016 belonged to the warmest since 1990. December was in the range of long-term mean values. The annual cycles of the Arkona Sea AS, Gotland Sea GS and Bothnian Sea BoS in Fig. 2 show that February was the coldest month in AS, but March was coldest in the GS and BoS, consistent with the long-term averages. The yearly cycle in BoS follows the averages except in July, which is the warmest month in the three regions in contrast to the averages. Further particularities occurred especially in May in the GS, in September in AS and in October in BoS. In the AS, the monthly mean SST of September was higher than in August.

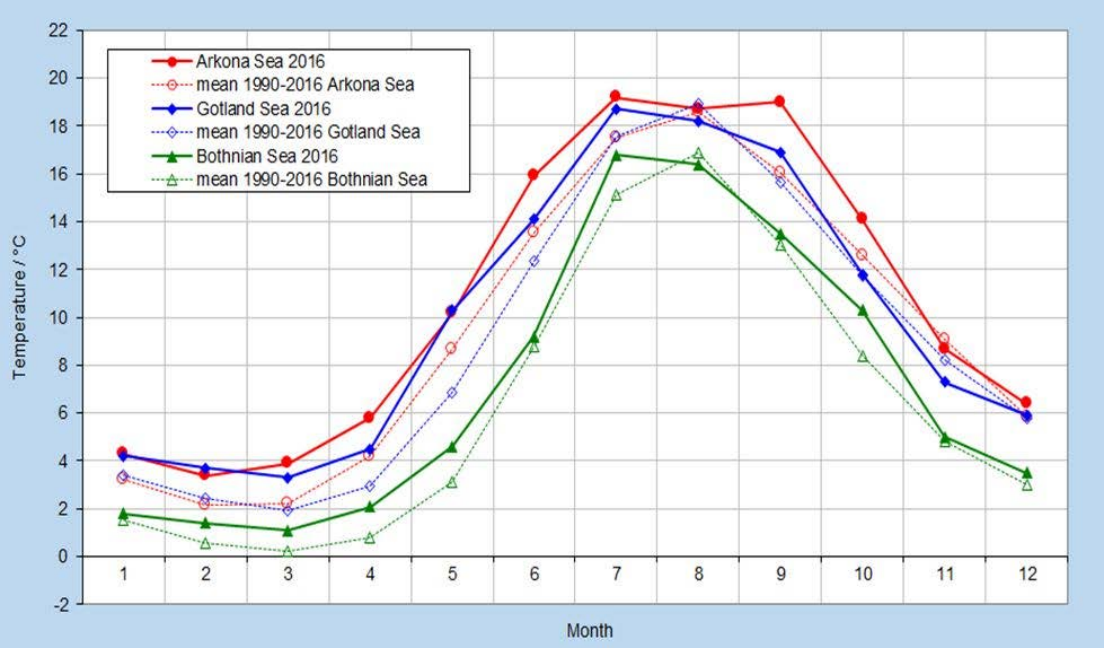


**Figure 2.** Seasonal cycle of SST in the central Arkona-, Gotland- and Bothnian Sea in 2016 in comparison to the mean values (1990-2016).

A strong cooling beginning of 2016 induced ice development not only in the northern Baltic but also in inner coastal waters in the south and an early maximum ice coverage of the entire Baltic on 23 January (Naumann et al. 2017; Schwegmann, Holfort 2016). Until 28 January, the SST increased and the ice disappeared in the German waters. The minimum of monthly mean SST in central GS and BoS was reached in March and March, 09 – 15, was the coldest week in the entire Baltic (Fig. 3, left image). After 20 March, slight SST increase started and reached 5-6°C in the western Baltic and 0-2 °C in BoS. The transect of mean SST through the entire Baltic in the coldest month, March, is presented in relation to long-term average (1990-2016), previous year, and range of variation in Fig. 4. SST of entire Baltic was higher than the long-term mean values and reached between Bornholm and Gotland Sea partly the upper limit of the variation range.

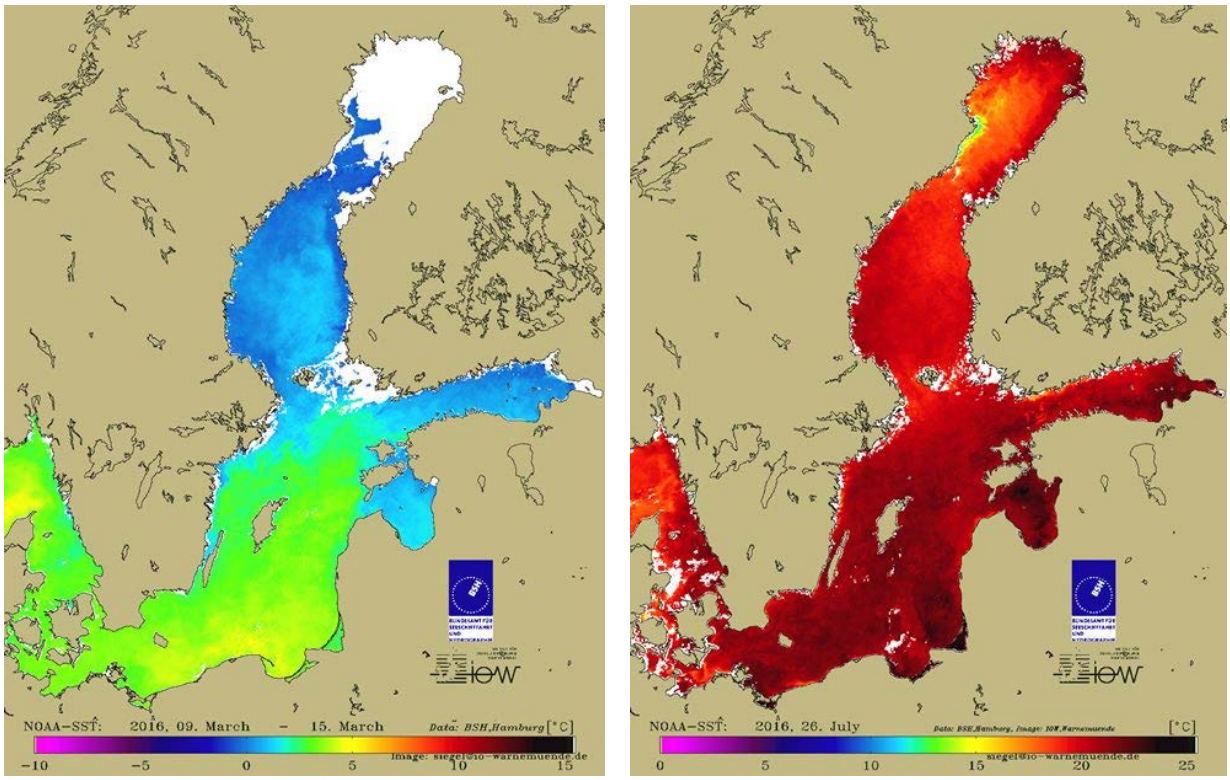


**Figure 3.** Weekly mean SST of the Baltic Sea for 09 - 15 March (coldest week) and SST on July 26, the warmest day of year 2016.

In April, the SST increase continued with only short interruptions that end of the month SST reached 6-8 °C in the western and southern Baltic (WB, SB) and about 3 °C in the BoS.

May was very special in the SST development as described in the monthly anomalies and in the yearly cycle. A first strong warming took place until 10 May with maximum SST of 15 °C. A deep pressure system until about 20 May induced cooling by cloudy conditions and wind mixing. After that, a further warming from the coast led to temperatures of 13-16 °C in the central parts of WB and SB outside of upwelling influence leading to this relatively warm month. These high surface temperatures und calm conditions supported the early development of cyanobacteria as derived from MODIS data and confirmed during the monitoring cruise in the third decade of May. In Fig. 4 (lower panel), the transect of mean SST through the entire Baltic in this special May is presented in relation to long-term average (1990-2016), previous year, and range of variation. Particularly in the GS, the SSTs are up to 3 K higher than the long-term averages and determined the upper limit of the variation range.

In the first decade of June, a further warming took place leading to 18 °C in south- eastern Baltic before a wind mixing reduced the SST again to 13-16 °C. After 20 June, a low wind period supported a strong heating until 25 June with SSTs of 16-19 °C in the central and western Baltic. A stagnation period followed until the end of the month.

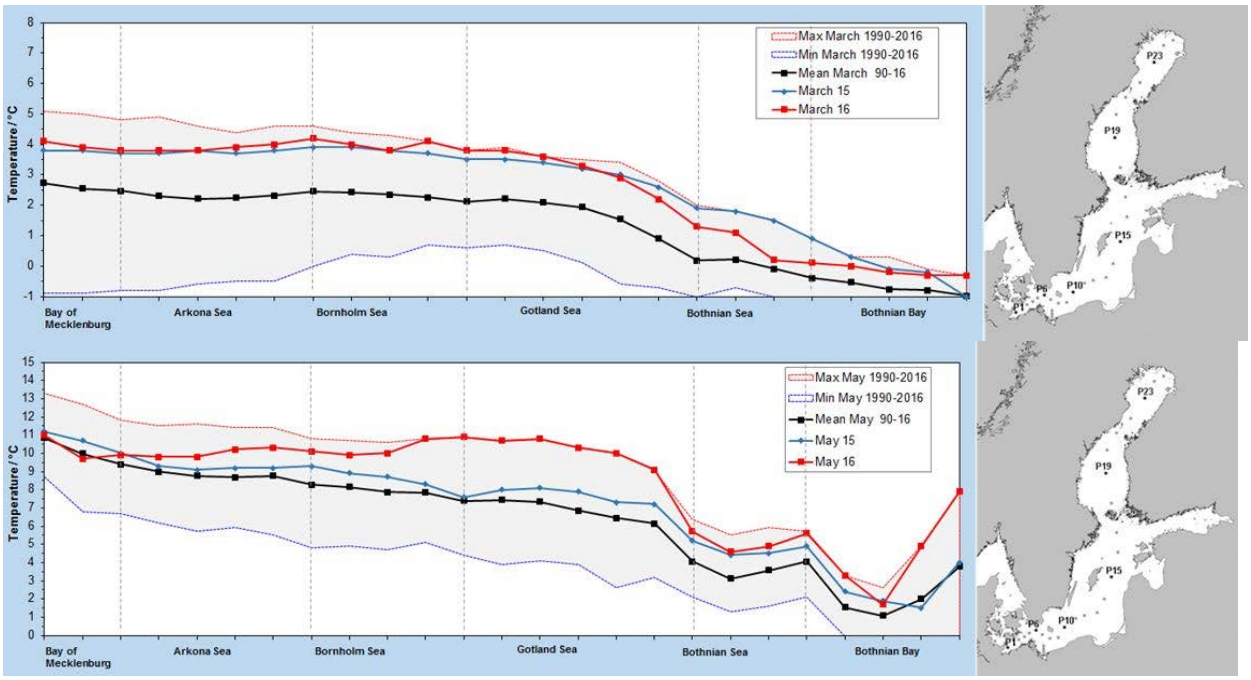


**Figure 4.** Temperature distribution along the transect through the central basins of the Baltic Sea in March and in May 2016 in comparison to the previous year, the long-term mean value of 1990-2016 and the variation range.

After a period of 5 days of calm weather conditions, deep pressure systems passed the Baltic Sea area partly with wind speeds of up to 17 $ms^{-1}$, which reduced the maximum SST from 18-19 °C to around 16 °C. This situation lasted until the next warming in the third decade of July, which made 26 July to the warmest day of the year (Fig. 3).

After a slow SST decrease beginning of August, a stronger one followed between 10 and 15 August particularly in the northern Baltic. The resulting situation was more or less stable until mid of September with a SST maximum of 18-20 °C in the southern and western Baltic.

A slight cooling to the end of the month reduced the temperatures to up to 16-17 °C. These high temperatures due to low wind conditions led not only to the high anomalies in September but also to a long cyanobacteria season. The transect of mean SST through the entire Baltic in the months August and September are presented in relation to long-term average (1990-2016), previous year, and range of variation. In August (Fig. 5, upper panel), the SST is in the central parts in the range of the long-term mean values. In September (Fig. 5, lower panel), the SST is in the entire Baltic above the long term mean values and particularly in the southern and western parts with values of up to +2.5 K above the averages.  End of September strong westerly winds induced upwelling of cold water along the Swedish coast in the northern and central Baltic. In the southern and eastern central Baltic SSTs of 15-17 °C still exist.

From 5 October, passages of low-pressure systems with changing wind and cloud conditions accelerated the cooling. End of October, SSTs of 7-9 °C characterise the northern Baltic and 10-12 °C the southern part.

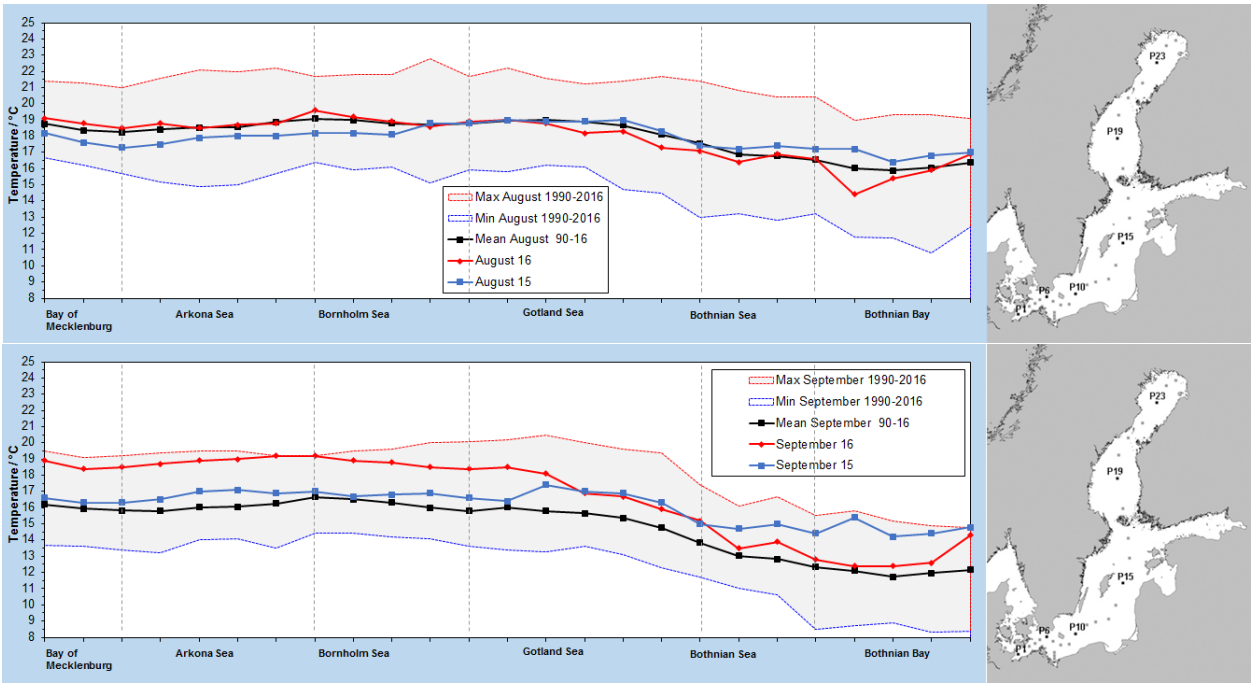


**Figure 5.** Temperature distribution along the transect through the central basins of the Baltic Sea in August and September 2016 in comparison to the previous year, the long-term mean value of 1990-2016 and the variation range.

The cooling continued in November particularly in the northern Baltic that end of the month temperatures of 0-5 °C occurred in Gulf of Bothnia and 7-10 °C from WB to GS. In the first decade of November, the first ice developed in the northern Bothnian Bay.

In December, the SST decreased very slowly that there were 0-3 °C in Gulf of Bothnia and 3-6 °C in the southern Baltic. After the comparatively warm September in the southern and October in the northern Baltic, the strong cooling in November led to monthly mean temperatures of November and December in the range of the long-term mean values.

Overall, 2016 was after 2014 and 2015 the third warmest year since 1990 (Fig. 6). The annual temperature average throughout the Baltic Sea was about 0.9 K higher than the long-term average, and only 0.3 K below the warmest year 2014. February to July and September contributed by their positive anomalies. With up to +5 K May was the warmest since 1990. June and September belonged to the warmest months in the southern Baltic and October in the Gulf of Bothnia. The resulting temperature trend was 0.6 K per decade.

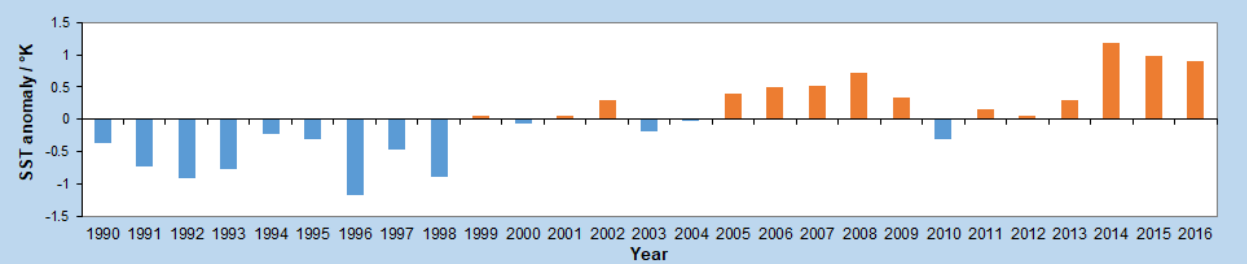


**Figure 6.** Anomalies of the annual mean sea surface temperature of the entire Baltic Sea during the last 27 years (1990-2016).

The contribution of different regions becomes visible in the summary in table 1, which includes the annual mean SSTs of the entire Baltic Sea of the last years, the warmest year 2014 and the coldest year 1996 as well as the means of single points representing the central Arkona, Bornholm, Gotland, and Bothnian Seas and the standard deviation. The year 2016 was with 10.8 °C in the Arkona and Bornholm Sea the second warmest year after 2014 (11-11.6 °C). In the Gotland Sea, 2016 and 2015 were slightly warmer than 2014 and the Bothnian Sea was similar in SST as in 2014 and 2015 (7.6 °C) and warmer than in 2016 (7.1 °C). In 2016, the standard deviations were higher than 2015 in all regions and again in the range of the other years.

**Table 1:** Annual mean SSTs of the entire Baltic Sea of the last 5 years including the warmest year 2014 and the coldest year 1996 as well as the means of single points representing the central parts of Arkona, Bornholm, Gotland and Bothnian Seas and the standard deviation.

| year | Baltic | Arkona Sea | | Bornholm Sea | | Gotland Sea | | Bothnian Sea | |
|---|---|---|---|---|---|---|---|---|---|
| | mean | mean | stdv | mean | stdv | mean | stdv | mean | stdv |
| 1996 | 6.6 | 8.0 | ± 6.6 | 8.0 | ± 5.9 | 7.6 | ± 6.3 | 5.8 | ± 6.4 |
| 2012 | 7.8 | 9.0 | ± 5.8 | 9.2 | ± 6.2 | 9.1 | ± 5.6 | 6.4 | ± 5.5 |
| 2013 | 8.1 | 9.4 | ± 6.7 | 9.6 | ± 6.8 | 9.1 | ± 6.7 | 6.8 | ± 6.4 |
| 2014 | 9.0 | 11.6 | ± 6.4 | 11.0 | ± 6.3 | 9.7 | ± 6.3 | 7.6 | ± 6.7 |
| 2015 | 8.8 | 10.4 | ± 5.3 | 10.3 | ± 5.2 | 9.9 | ± 5.7 | 7.6 | ± 5.5 |
| 2016 | 8.7 | 10.8 | ± 6.3 | 10.8 | ± 6.2 | 9.9 | ± 5.9 | 7.1 | ± 5.9 |

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## Acknowledgement

The authors thank Mrs. G. Tschersich and the BSH Hamburg for providing the satellite data.

## Data and metadata

This HELCOM Baltic Sea Environmental fact sheet is based on satellite derived Sea Surface Temperature (SST) and heat and cold sum of air temperature measured in Warnemünde. Sea Surface Temperature of the Baltic Sea was derived from data of the Advanced Very High Resolution Radiometer (AVHRR) of

weather satellites of the National Oceanic and Atmospheric Administration (NOAA) and from the European MetOp-2. The Federal Maritime and Hydrographic Agency (BSH) Hamburg provided up to eight daily satellite scenes since 1990. Evaluation methods and methodological investigations are discussed in Siegel et al. (2008). The annual assessment of the development of SST in the Baltic Sea is summarized in Naumann et al. 2017 and in HELCOM Environment Fact Sheets (Siegel & Gerth, 2015). Reflections on long-term development of SST since 1990 are presented in Siegel et al. (1999, 2006, 2008). The air temperature data of Warnemünde provided by the German Weather Service was used to calculate the heat and cold sum, which permits to evaluate the intensity of summer and winter.

**For reference purposes, please cite this Baltic Sea environment fact sheet as follows:**

[Author's name(s)], [Year]. [Baltic Sea environment fact sheet title]. HELCOM Baltic Sea Environment Fact Sheets. Online. [Date Viewed], http://www.helcom.fi/baltic-sea-trends/environment-fact-sheets/.

*Last updated 12.10.2017*