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Moderate-Resolution Sea Surface Temperature Data and Seasonal Pattern Analysis for the Arctic Ocean Ecoregions

Open-File Report 2011–1246

U.S. Department of the Interior
U.S. Geological Survey

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By Meredith C. Payne and Deborah A. Reusser, U.S. Geological Survey; and Henry Lee II, U.S. Environmental Protection Agency

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Conversion Factors and Datum

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32.

Datum

Horizontal and vertical coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Acronyms and Abbreviations

ArcGIS	ESRI's GIS software
AVHRR	Advanced Very High Resolution Radiometer
ESRI	Environmental Systems Research Institute, Inc.
GIS	Geographical Information System
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
JPL	Jet Propulsion Laboratory
MEOW	Marine Ecoregions of the World
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NIS	Nonindigenous species
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NSIDC	National Snow and Ice Data Center
PFSST V5x	Pathfinder Sea Surface Temperature version 5.x
POES	Polar Orbiting Environmental Satellite
PO.DAAC	Physical Oceanography Distributed Active Archive Center
SST	Sea surface temperature
WGS 84	World Geodetic System, 1984

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Abstract

Sea surface temperature (SST) is an important environmental characteristic in determining the suitability and sustainability of habitats for marine organisms. In particular, the fate of the Arctic Ocean, which provides critical habitat to commercially important fish, is in question. This poses an intriguing problem for future research of Arctic environments—one that will require examination of long-term SST records. This publication describes and provides access to an easy-to-use Arctic SST dataset for ecologists, biogeographers, oceanographers, and other scientists conducting research on habitats and/or processes in the Arctic Ocean. The data cover the Arctic ecoregions as defined by the "Marine Ecoregions of the World" (MEOW) biogeographic schema developed by The Nature Conservancy as well as the region to the north from approximately 46 °N to about 88 °N (constrained by the season and data coverage). The data span a 29-year period from September 1981 to December 2009. These SST data were derived from Advanced Very High Resolution Radiometer (AVHRR) instrument measurements that had been compiled into monthly means at 4-kilometer grid cell spatial resolution. The processed data files are available in ArcGIS geospatial datasets (raster and point shapefiles) and also are provided in text (.csv) format. All data except the raster files include attributes identifying latitude/longitude coordinates, and realm, province, and ecoregion as defined by the MEOW classification schema. A seasonal analysis of these Arctic ecoregions reveals a wide range of SSTs experienced throughout the Arctic, both over the course of an annual cycle and within each month of that cycle. Sea ice distribution plays a major role in SST regulation in all Arctic ecoregions.

Introduction

Recent research indicates there has been a warming trend in ocean temperatures over the last 50 years (Intergovernmental Panel on Climate Change, 2007). Notably, a poleward-advancing trend of warming temperatures in the Arctic has been recorded over the last few decades (Corell, 2006). Arctic Ocean regions, especially those subject to the influence of seasonal sea ice pack, are particularly sensitive to this trend. Warming waters at higher latitudes likely jeopardize fragile food webs, pushing habitability of certain ecosystems to the brink for vulnerable species, and increasing the risk of invasion by nonindigenous species (NIS) (Mueter and Norcross, 2002; Gollash, 2006; Herborg and others, 2007; Stram and Evans, 2009). *In situ* sea surface temperature (SST) measurements typically are made via buoys, or ocean-going vessels, but such measurements are irregular in both space and time. This is especially true in polar regions, where remoteness is compounded by sea ice and ice shelves, making exploration particularly dangerous and expensive. Satellite-based remote-sensing data have the advantage of extensive spatial coverage and high repeatability that is not possible with field observations. The moderate-resolution (4 km) Pathfinder versions 5.0 and 5.1 SST data (hereafter referred to as PFSST data) are derivative products of the data collected by the Advanced Very High

Resolution Radiometer (AVHRR) instrument series flown by the National Oceanic and Atmospheric Administration (NOAA) Polar Orbiting Environmental Satellites (POES). These data provide a consistent set of SST measurements of a known quality and calibration for temperature pattern analyses of marine environments in the Arctic Ocean. A value-added Arctic SST product was created by combining processed PFSST data with The Nature Conservancy's Marine Ecoregions of the World (MEOW) biogeographic schema (fig. 1) and is available for download from this open-file report (http://pubs.usgs.gov/of/2011/1246/). Additionally, these data were used to analyze seasonal SST patterns at the ecoregional scale using the MEOW geographical framework.

Figure 1. Map of Arctic realm as defined by the Marine Ecoregions of the World (MEOW; Spalding and others, 2007).

Data Description and Processing

AVHRR SST Data

The Advanced Very High Resolution Radiometer (AVHRR) is a multi-generational, 6-channel instrument that has been flown on board a series of NOAA polar-orbiting satellites, and has been returning reliable SST data since 1981. Sea surface temperature is not measured directly; rather, it is derived from a differentiation of brightness temperatures recorded by two of the sensor's infrared (IR) channels (channels 4 and 5). Furthermore, the Pathfinder algorithm used to calculate SST accounts for the non-linear relationship between surface and brightness temperatures that arises from variable atmospheric water vapor content, and also uses matchup data from *in situ* buoys aggregated within 5-month weighted windows, reducing bias due to temporal trends (Kilpatrick and others, 2001). The PFSST (and later) datasets were developed jointly by the University of Miami Rosenstiel School of Marine and Atmospheric Science and the NOAA National Oceanographic Data Center (NODC) as a more accurate, downscaled (9.28–4 km) version of a previous global AVHRR dataset (Vazquez-Cuervo and others, 1998). Importantly for the study of the Arctic, the version 5 (and later) PFSST data also were improved through the implementation of an ice mask. We obtained the version 5 (PFSST monthly mean floating point data from the NASA JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC) (ftp://podaac.jpl.nasa.gov/OceanTemperature/avhrr/L3/pathfinder_v5/). PFSST products (version 5.0 and 5.1) also are available through the NODC (ftp://data.nodc.noaa.gov/pub/data.nodc/pathfinder). For a detailed description of the AVHRR and Pathfinder algorithms, we direct the reader to Vazquez-Cuervo and others (1998; 2010) and Kilpatrick and others (2001).

AVHRR Data Quality

The PFSST data include a quality flag product in which each SST pixel is designated a value ranging from 0 (worst quality) to 7 (best quality). These quality flags convey the level of confidence attributed to the SST value calculated for each pixel location. The level of confidence is evaluated on pixel-by-pixel performance with respect to a number of tests that estimate validity and consistency of brightness temperature readings, sun angle effects, and cloudiness, which are combined to establish an overall quality rating. The version 4 Pathfinder release of the SST dataset (PFSST V41) included a standard product called "best SST," or "BSST." BSST data includes pixels with quality flags greater than 3 (Kilpatrick and others, 2001). We generated an analogous SST product from the PFSST data by disregarding SST values with corresponding quality flag values of less than 4.

Despite the rigors of the flagging algorithms, a small number of pixels with illegitimate jumps in SST gradient have been detected (Evans and others, 2009). The Arctic data presented here may potentially contain a few of these artifacts that may need to be removed by the user depending on their data requirements. Most occurrences can be eliminated by adopting a more rigorous quality standard (for example, only using data with corresponding quality flags of 7). However, this also serves to substantially reduce the amount of data available for analysis, a problem compounded by climatic conditions in the Arctic.

In addition to performing the analyses discussed here with the BSST data, we repeated the analyses using data with quality flag values of 7 only. In table 1, we show the summary R-squared statistics comparing the BSST data to Q7 data using the ecoregional aggregation of monthly mean SSTs over 29 years. The only ecoregion having significantly divergent values when using the BSST product versus the Quality 7 product is the High Arctic (essentially the Arctic Ocean). This result is to be expected, however, due to the Arctic Ocean ice cover throughout much of the year. Although both BSST and Quality 7 data have ice masks to account for this, data on the periphery of the ice mask do not typically have quality flag of 7, thereby reducing the number of Quality 7 data as compared to BSST data.

Table 1. R-squared values from simple linear regression statistics between data with quality flag values of 4-7 (BSST) and data with quality flag value of 7 only (Q7SST) for each Arctic ecoregion.

[The only significant difference between them occurs in the High Arctic ecoregion (which is essentially the open Arctic Ocean), which is covered by sea ice for most of the year. Quality flag values on the ice margin generally are lower than 7]

Ecoregion	BSST vs. Q7SST R-squared
Baffin Bay - Davis Strait	0.9933
Beaufort-Amundsen-Viscount Melville-Queen Maud	0.9828
Beaufort Sea - continental coast and shelf	0.9796
Chukchi Sea	0.9973
East Greenland Shelf	0.9745
East Siberian Sea	0.9867
Eastern Bering Sea	0.9997
High Arctic Archipelago	0.9735
High Arctic	0.6241
Hudson Complex	0.9964
Kara Sea	0.998
Lancaster Sound	0.9987
Laptev Sea	0.9894
North and East Barents Sea	0.9982
North and East Iceland	0.9999
North Greenland	0.9336
Northern Grand Banks - Southern Labrador	0.9999
Northern Labrador	0.9993
West Greenland Shelf	0.999
White Sea	0.9996

Data Accuracy

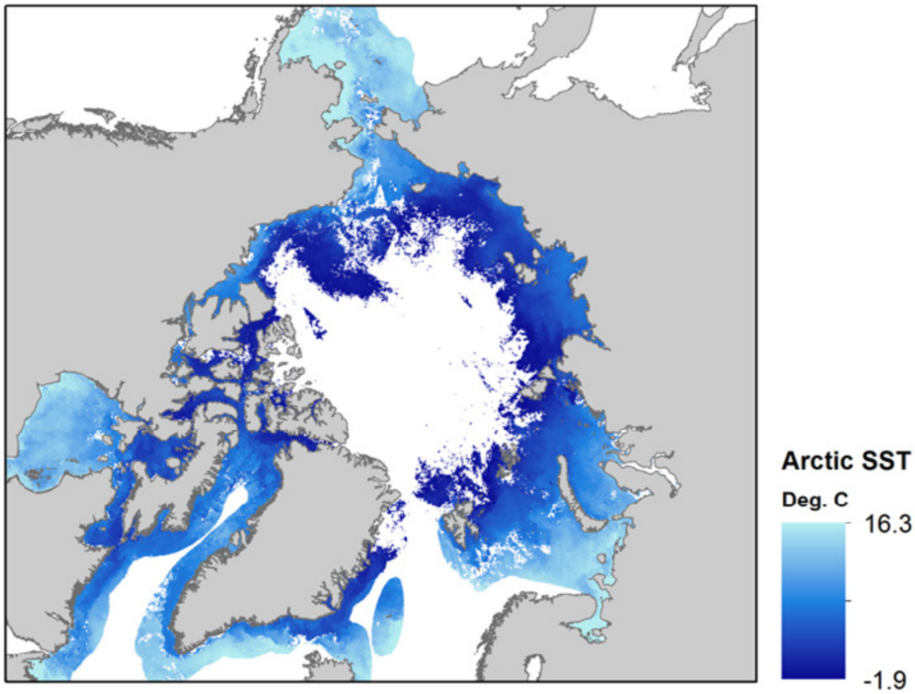
Currently (2011), the only reports on accuracy of Pathfinder SST values are linked to specific studies across a variety of spatial and temporal resolutions, pathfinder versions, and quality flag thresholds. In general, the temperature values are reported to have RMS errors between 0.1 and 1.0 °C (Kearns and others, 2000; Kilpatrick and others, 2001; Vazquez-Cuervo and others, 2010; Xu and Ignatov, 2010) when compared to *in situ* temperatures. However, it must be cautioned that *in situ* temperature data derived from multiple sources, such as moored buoys and shipboard observations, are prone to large random errors and rarely have excellent agreement amongst them (for example, Kearns and others, 2000). Furthermore, *in situ* measurements are of bulk temperatures (typically taken between 1 and 3 m depth) rather than true sea surface temperature. Lastly, comparison to *in situ* data sources, such as buoys and the National Centers for Environmental Prediction (NCEP), are not independent of PFSST data because these data (Reynolds and others, 2002) provide critical calibration and validation for the PFSST data product (Kilpatrick and others, 2001; Vazquez-Cuervo and others, 2010). When the scaling algorithm provided with the AVHRR data is applied, the resulting SST values are rounded to the nearest 10th of degree as accuracy of the SST data is approximately 0.5 °C (Jorge Vazquez-Cuervo, written commun., February 3, 2011).

Arctic SST Product

We selected AVHRR data for their global coverage at moderate resolution (4 km), their long data record (about 30 years) relative to other satellite missions and their substantial level of processing, including extensive calibration and atmospheric correction. The data represent a time-series of monthly mean sea surface temperatures over the last 29 years. Here, we provide the monthly mean SST data in three forms: (1) georeferenced ".img" raster format, (2) georeferenced ESRI point shapefile (.shp) format, and (3) plain comma-delimited text format. There is one file of each type for each month of each year in the 1981–2009 record. They are downloadable through this OFR (http://pubs.usgs.gov/of/2011/1246/) in zipped files of yearly bundles containing the GIS layers as well as the related metadata files.

In some places, the data appear jagged, or "moth-eaten," immediately adjacent to the coast and at very high latitude. Satellite data for some coastal regions are missing or are unusable due to low quality, most often due to climatic conditions. Furthermore, the Pathfinder data developers used a MOD12Q1 land mask, which has a 1-km resolution, to define their coastline. Missing data in the vicinity of the North Pole (as seen in fig. 2) is caused by several phenomena. First, the near-polar orbits of the satellites housing the AVHRR instruments never quite reach the pole. Second, sea ice plays a significant role throughout most of the year. We examined the Sea Ice Index extent product generated by the National Snow and Ice Data Center (NSIDC) (Fetterer and others, 2002, updated 2009) and found that the missing data surrounding the North Pole (for example, see fig. 2) corresponds well with the sea ice margin delineated by the NSIDC index. Third, in some instances, pixels have been eliminated due to cloud cover and to the Pathfinder SST algorithm resulting in pixels with values less than -2.0 °C that must be eliminated due to infeasibility. For all datasets, SST values are recorded in degrees Celsius.

A



B

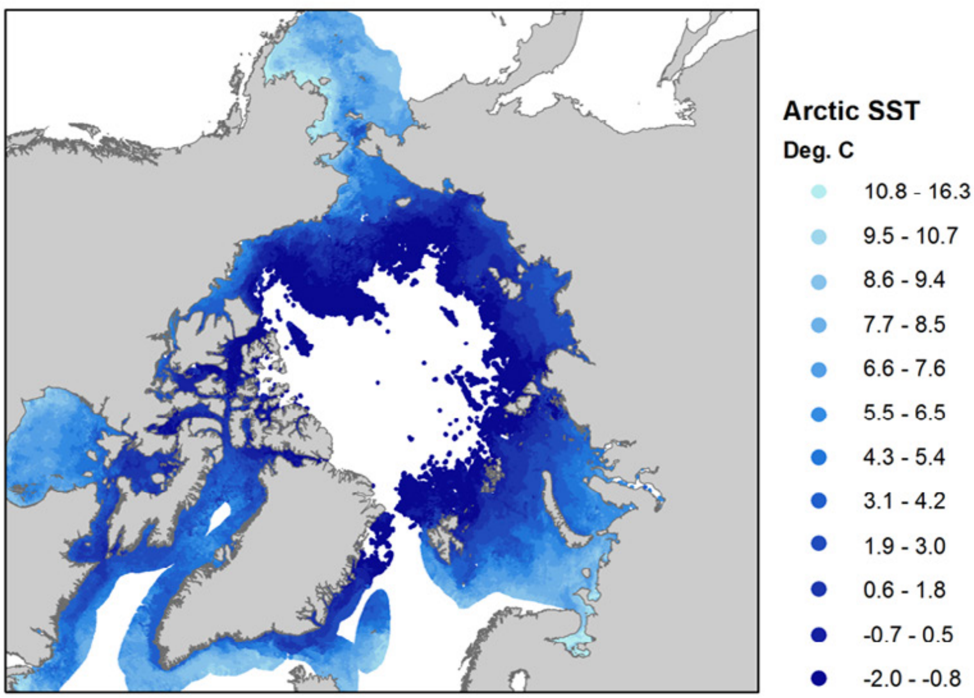


Figure 2. Map of monthly average SSTs in the Arctic Ocean ecoregions for September 2009. Figure 2A is raster format data, figure 2B is point shapefile format data. The absence of data at the pole approximately corresponds to the sea ice coverage for September 2009 (Fetterer and others, 2002, updated 2009).

Data Processing

The processes and scripts used to convert the AVHRR data to SST shapefile and text data are described in Payne and others (2011). An important difference distinguishing the Arctic data from the Northern Pacific data of the previous report is that no buffer was implemented to constrain the Arctic data to the nearshore region. Furthermore, the Python scripts provided here have been modified from the original scripts used to derive the geospatial data in order to integrate the ArcGIS 10 “arcpy” module for compatibility with ArcGIS 10 and Python v. 2.6.

Arctic raster, shapefile, and text (.csv) data are available for download from the "downloads" page of this website (click "downloads" on the left-side menu). Each point in an Arctic point shapefile was created by extracting the temperature value from the centroid of a corresponding grid cell in the Arctic raster dataset. Because the data volumes are very large, the text (.csv) files are further divided into individual ecoregions, resulting in one .csv file per month per year per ecoregion for Arctic SST data. This data partition scheme was necessary to accommodate memory constraints experienced during processing (text files were generated with R (R Development Team, 2009)). These divisions were not necessary for the shapefile and raster data.

Temperature Pattern Analysis

MEOW Framework

In the effort to characterize Arctic Ocean environments at a regional scale, we analyzed the SST measurements by marine “ecoregions” as defined by The Nature Conservancy in their MEOW biogeographic schema (Spalding and others, 2007). The MEOW schema is a global hierarchical classification system of coastal zones that divides the world’s coastal areas into 12 distinct marine “realms.” The realms are further divided into 62 marine “provinces,” which are further divided into 232 “ecoregions.” The analyses presented here focus on the 19 ecoregions within the Arctic realm (fig. 1). Additionally, the Arctic Ocean to the north of the MEOW Arctic ecoregions is included in the analyses, resulting in the creation of one additional ecoregion named “High Arctic.”

The following protocol is used to describe the SST patterns within an individual ecoregion. All 29 years of the derived SST values of mean monthly SST grid cells within an ecoregion were pooled to calculate the monthly mean SSTs for each ecoregion, as well as a suite of other metrics derived from the monthly means as summarized in tables 2 and 3.

Study Area

The Arctic and High Arctic ecoregions are shown in figure 1. We do not adhere to the strict definition of the Arctic including only the area north of the Arctic Circle (about 66.5 ºN circle of latitude). We include the entire areas of the Eastern Bering Sea and Northern Grand Banks-Southern Labrador ecoregions, which fall outside of the Arctic Circle. Much of the High Arctic is subject to perennial sea ice cover, and thus has a relatively steady annual surface temperature cycle, with little month-to-month (or within-month) variations (fig. 3). However, even lower latitude ecoregions (for example, the Bering Sea) are greatly affected by seasonal sea ice cover and have been the subject of recent research due to dramatic reductions in seasonal sea ice and multi-year sea ice, especially notable within the last decade. Presence of sea ice keeps benthic waters cold by preventing convection and mixing with surface water. Spatial sea ice cover and summer retreat is variable from year-to-year, and young ice can greatly influence the rate and potential for summer ice melt (Drobot and others, 2008). However, it is the thicker, multi-year ice that moderates long-term Arctic water temperatures, and multi-year ice is becoming progressively younger (Maslanik and others, 2007). The trend in sea ice reduction has been concurrent with a shift in biodiversity away from benthic shelf populations and towards pelagic species—a trend threatening to disrupt the stability of Arctic food-webs (Grebmeier and others, 2006; Mueter and Litzow, 2008).

Arctic Annual Cycles

Table 2 identifies and defines the metrics used in the analysis and figure 3 provides a diagrammatic description of these metrics. Table 3 provides summary statistics for most of the metrics. Figure 4 shows the mean annual SST cycles experienced within Arctic ecoregions over the 29-year period with statistical metrics that are summarized in table 2. The mean annual SST (29-year mean) among the Arctic ecoregions ranges from -1.2 °C in the High Arctic Archipelago ecoregion to a maximum of 3.8 °C in the Eastern Bering Sea. There is a significant decreasing trend of variance in SST with mean latitude. The ecoregions with the greatest variance are the White Sea, Eastern Bering Sea, and Northern Grand Banks-Southern Labrador, and those with the least variance are the High Arctic and High Arctic Archipelago ecoregions (fig. 4). Undoubtedly, this is the result of sea ice extent over the Arctic Ocean. The mean annual SST cycles in the Arctic ecoregions are shown in figure 4. Within an ecoregion, the range of the annual cycle is defined by the difference between the minimum 29-year monthly mean and the maximum 29-year monthly mean SST (see fig. 3, table 2). The minimum monthly mean SST in the Eastern Bering Sea and North and East Iceland occurs in April. The High Arctic, North and East Barents Sea, Northern Labrador, and East Greenland Shelf have minimums occurring in May, and the East Siberian Sea and Beaufort-Amundsen-Viscount Melville-Queen Maud experience SST minimums in January. The remainder of the Arctic ecoregions have minimum monthly-mean SSTs occurring in February and March. The annual cycle temperature ranges generally are greater at lower latitudes and in inland/marginal water bodies (for example, White Sea and Northern Grand Banks-Southern Labrador ranges greater than 10 °C) as opposed to ecoregions at polar latitudes (High Arctic and High Arctic Archipelago ranges less than 2 °C). The greatest annual cycle temperature range occurs in the White Sea ecoregion, which has a range of 11 °C, and the High Arctic ecoregion has the smallest range of about 0.8 °C.

Table 2. SST metrics used in analyses presented in this study.

[Definitions explained in this table are referred to throughout the text]

SST analysis metric	Metric description	Metric dimensions
Derived SST values	SST values derived from PFSST product. Each value represents a monthly mean for each grid cell	1 value per grid cell of acceptable quality, 1 raster per month over 29 years (340 rasters)
Monthly-mean SST per ecoregion	The 29-year average of all of the derived SST values (above product) within an ecoregion for each of the 12 months.	20 ecoregions × 12 months
Mean annual cycle	12 monthly means for each ecoregion	20 annual cycles (fig. 4)
Range of annual cycle	Difference between warmest (maximum) monthly mean and coolest (minimum) monthly mean per ecoregion	20 ranges
Mean annual SST (29-year mean)	Mean of the monthly mean SST per ecoregion over the 29-year period	1 value × 20 ecoregions
Variance in SST	Variance of all derived SST values within an ecoregion over the 29-year period	1 value × 20 ecoregions
Within-month SST variations (5th and 95th quantiles)	The 5th and 95th quantile values for each month of all derived SST values within each ecoregion.	2 values × 12 months × 20 ecoregions

Table 3. Statistical metrics for Arctic and High Arctic ecoregions.

Province	Ecoregion	Approx. Ecoregion Center Lat/Lon (°N,°W)	Temperature (°C)				29-year mean standard deviation (°C)
			29-year Mean	Min. monthly mean	Max. monthly mean	Range of annual cycle	
High Arctic	High Arctic	85.6, -178.8	-0.8	-1.2	-0.4	0.8	0.2
Arctic	North Greenland	81.3, -37.0	-1.0	-1.7	0.2	2.0	0.7
	High Arctic Archipelago	80.8, -90.8	-1.2	-1.9	-0.2	1.7	0.5
	North and East Barents Sea	76.7, +40.4	1.8	0.8	3.8	3.0	1.1
	Kara Sea	74.5, +81.4	-0.4	-1.6	1.7	3.3	1.2
	Laptev Sea	73.4, +123.0	-0.5	-2.0	1.3	3.3	1.2
	Lancaster Sound	72.8, -89.9	-0.6	-1.9	0.9	2.8	1.0
	East Siberian Sea	72.6, +159.3	-0.5	-1.4	0.6	2.0	0.7
	Baffin Bay-Davis Strait	71.8, -71.1	-0.3	-1.7	2.5	4.2	1.5
	Chukchi Sea	71.2, -169.5	0.3	-1.5	3.6	5.1	1.9
	Beaufort-Amundsen-Viscount Melville-Queen Maud	69.9, -111.8	-0.2	-1.8	1.4	3.3	1.1
	Beaufort Sea-continental coast and shelf	69.8, -142.0	-0.3	-1.5	1.7	3.2	1.2
	East Greenland Shelf	69.0, -30.4	3.4	1.9	4.6	2.6	0.7
	North and East Iceland	69.0, -12.6	2.7	0.5	6.4	5.9	2.1
	West Greenland Shelf	68.7, -53.8	1.9	0.5	4.9	4.3	1.6
	White Sea	65.6, +37.0	3.1	-1.1	9.9	11.0	4.1
	Northern Labrador	61.6, -63.3	1.0	-0.5	4.0	4.5	1.6
	Hudson Complex	60.0, -81.5	0.9	-1.2	5.4	6.6	2.3
	Eastern Bering Sea	60.0, -169.7	3.8	0.3	9.4	9.2	3.4
	Northern Grand Banks-Southern Labrador	52.2, -55.5	3.1	-0.7	9.9	10.6	3.9

The second type of temporal fluctuation experienced within each ecoregion is referred to as within-month SST variations, which is defined as the 5th and 95th quantiles and shown as the dotted envelopes in figure 3. Arctic ecoregions experience a large range of within-month temperatures. In general, this range is greatest in summer months (June–October), with some notable exceptions (for example, High Arctic). Many ecoregions have a wide span of within-month SST variability throughout the year, including North and East Barents Sea, East Greenland Shelf, North and East Iceland, West Greenland Shelf, Eastern Bering Sea, and Northern Grand Banks-Southern Labrador. These ecoregions tend to be along conduits open to the Pacific or Atlantic Ocean basins, such as the Bering Strait and Davis Strait, respectively. This flow between the Arctic Ocean and larger water bodies allows easy mixing and within-month temperature variations of as much as 10 °C.

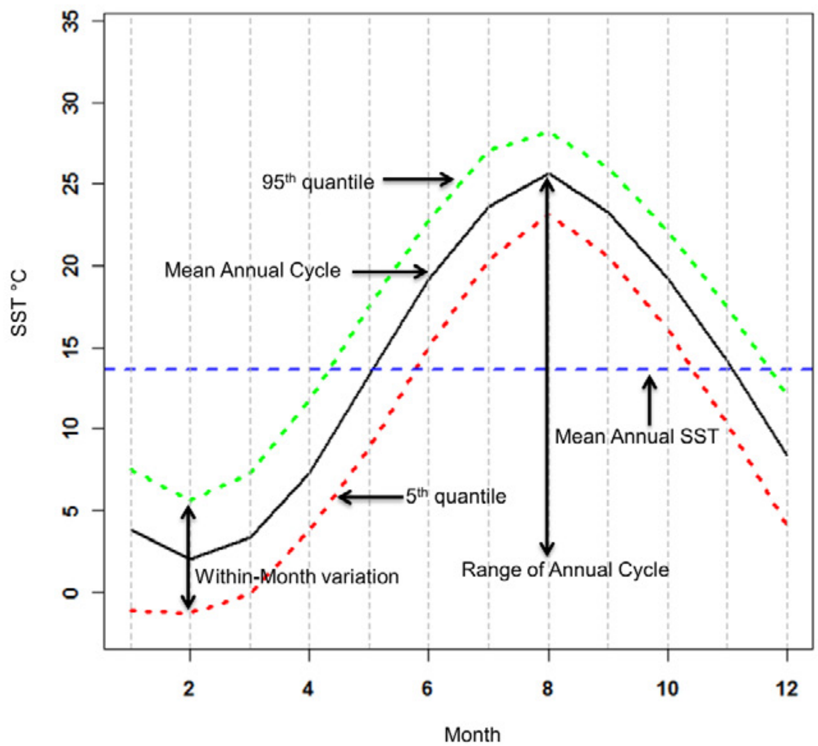


Figure 3. Legend diagram for figure 4.

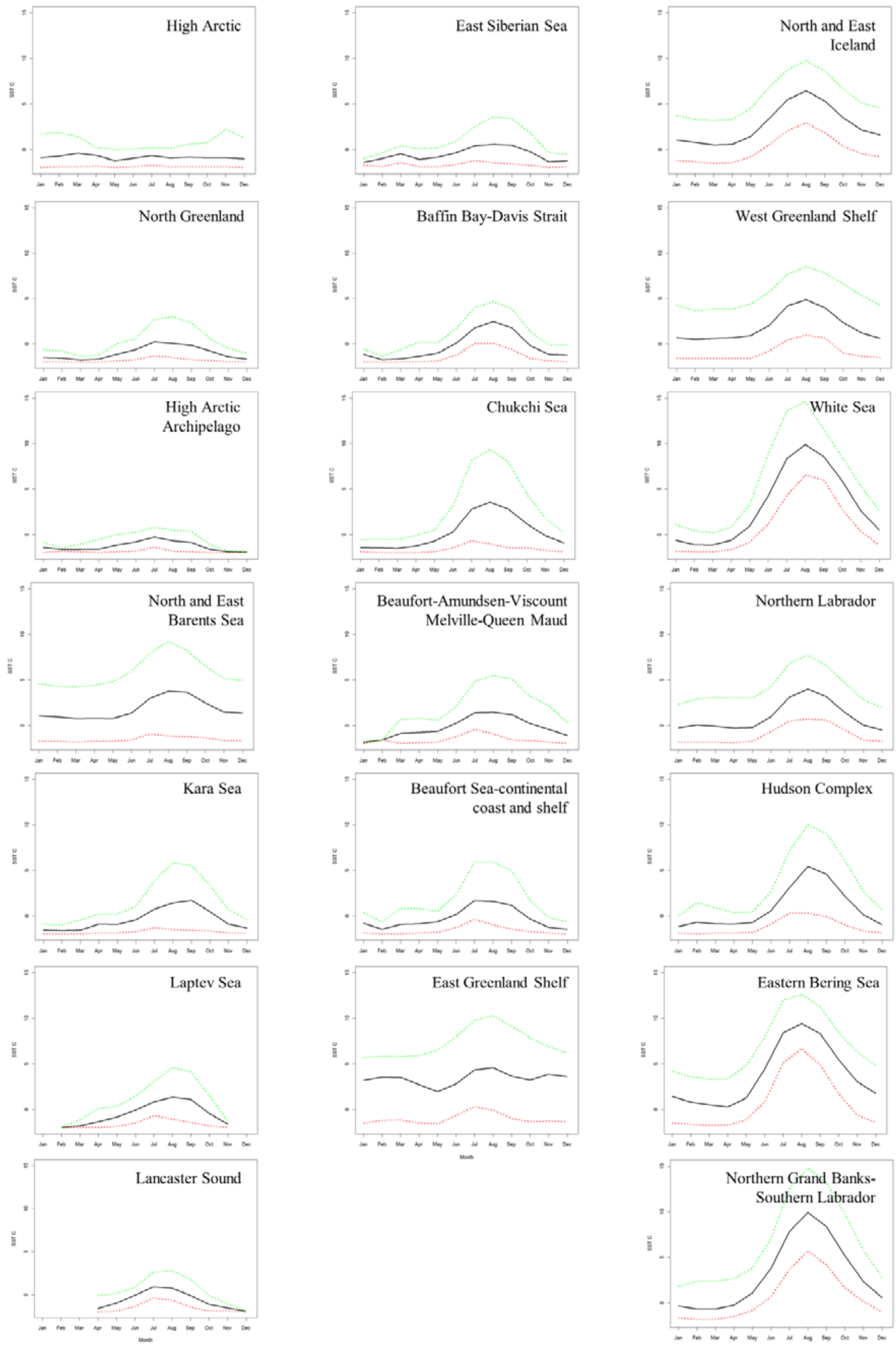


Figure 4. Arctic Ocean ecoregion plots of annual cycles of mean monthly SSTs.

Clustering Analysis

To compare the SST regimes of the ecoregions, we performed a Euclidean-distance measure hierarchical clustering analysis based on ecoregion SST means, minimums, maximums, ranges, and variances. In each case, the ecoregional SSTs group into two main branches (fig. 4), one of which contained the White Sea and Northern Grand Banks-Southern Labrador ecoregions irrespective of what SST metric was used. The High Arctic and High Arctic Archipelago ecoregions always cluster together for each SST metric, and are always grouped on the alternate branch from the White Sea and Northern Grand Banks-Southern Labrador ecoregions. Similarly, the Beaufort-Amundsen-Viscount Melville-Queen Maud and Beaufort Sea-continental coast and shelf ecoregions are nearly always grouped together by SST clustering metric and are always on the same major branch as the High Arctic and High Arctic Archipelago pair, opposing the Northern Grand Banks-Southern Labrador/White Sea at the first major clustering division. Lancaster Sound, Laptev Sea and Kara Sea are always closely related. Perhaps the most variable of the Arctic ecoregions is North Greenland, which is never found to be equivalent to any other ecoregion clustered by any of the SST metrics explored here. The Eastern Bering Sea ecoregion also shows a great deal of variation amongst the clustering metrics, but is not always uniquely discernible from all other ecoregions as is North Greenland. As seen in figure 4, which shows the Arctic ecoregions clustered based on all SST metrics simultaneously, five statistically significant cluster groups can be discerned. The red boxes denote clusters where $p > 0.95$.

The minimum, maximum, and mean SST Arctic ecoregion clusters correspond generally, but not perfectly, to latitudinal similarities between ecoregions. An exception is the Hudson Complex ecoregion, which despite its comparatively low-latitude experiences low SSTs and little within-month variation during winter, and relatively high SSTs with a vast within-month SST range in summer. The behavioral enigma of this ecoregion may be due to fresh water influence in the system, which controls the circulation by causing convective mixing in the winter, and rapid sea-ice breakup, melt, and water column stratification in summer (Galbraith and Larouche, 2011).

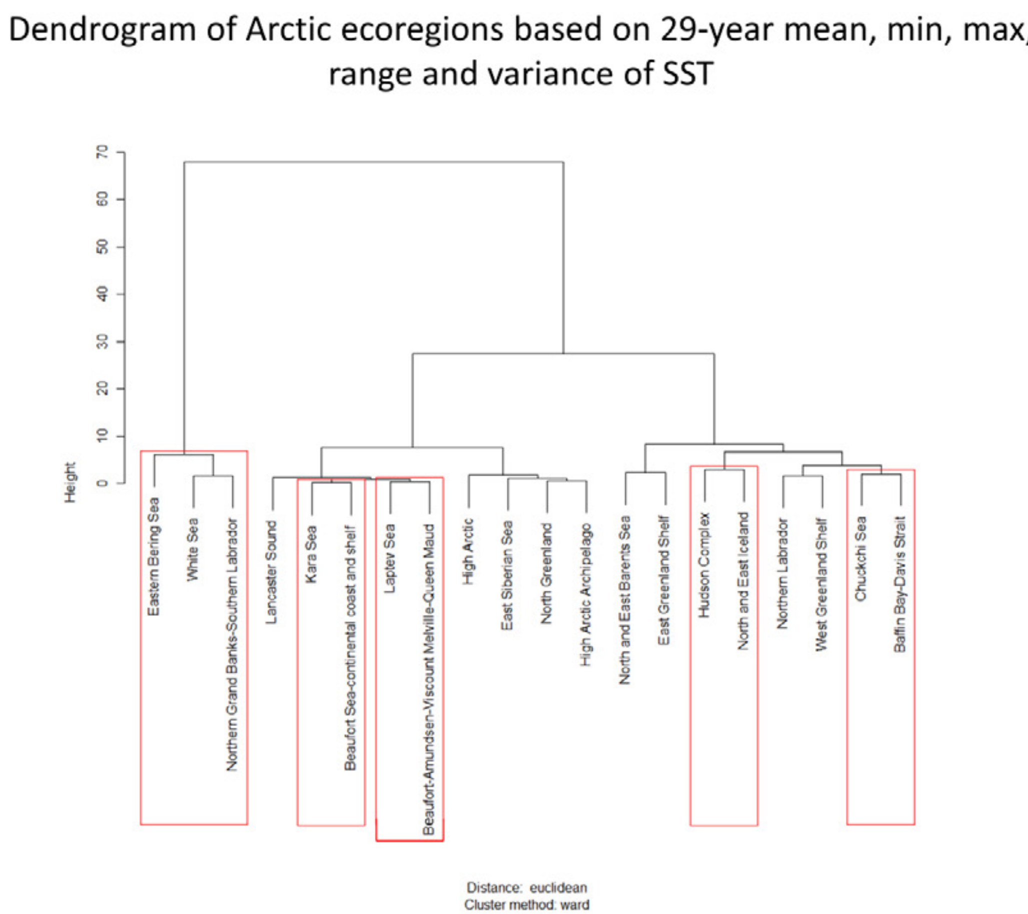


Figure 5. Euclidean distance cluster diagram for Arctic Ocean ecoregions based on 29-year mean, minimum, maximum, annual range and annual variance of SST. The red boxes denote clusters where p > 0.95.

Downloads

Data Catalog

This report contains Geographic Information System (GIS) data in georeferenced vector (point) and raster formats. The vector (point) data are available as Environmental Systems Research Institute (ESRI) shapefiles and as comma-separated text (*.csv) files. Shapefiles generally include *.shp, *.shx, *.xml, and *.dbf files at a minimum. All these data files also include the *.prj files, which contain the dataset projection information. The corresponding 4-km resolution raster data are available in Imagine *.img format.

The GIS files have been bundled by year. Each year of raster data (GRID-type) has an associated compressed WinRAR zip file. The corresponding shp and csv data types have compressed WinRAR RAR files, due to the large size capacity of RAR archives. Hence, every compressed file may contain up to 12 months of data. In addition to the spatial data, we provide Federal Geographic Data Committee (FGDC) -compliant metadata in text and HTML formats. The metadata text files are bundled with their corresponding zip files, and the metadata HTML information can be viewed in your web browser by clicking the appropriate link in the table below.

To download the data, right-click on the appropriate filename link in the '**Filename**' column (that corresponds to the desired data type) in the table below. Then select '**Save Target As...**' to save a compressed WinRAR file to your local hard drive. The download zipped file size is indicated under the '**file size**' column. All downloaded files are of type ".zip". The File Type description in the table below indicates the type of files found within the downloadable zip files.

Filename	Description	File Type	File Size	Metadata
		2009		
ArcticSST2009rast.zip	Arctic Ocean monthly mean SST data for 2009 in .img raster format.	.img	6.5 MB	Available online
ArcticSST2009pt.rar	Arctic Ocean monthly mean SST data for 2009 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	35.7 MB	Available online
ArcticSST2009csv.rar	Arctic Ocean monthly mean SST data for 2009 in .csv format.	Comma-separated text file (*.csv)	34.4 MB	Available online
		2008		
ArcticSST2008rast.zip	Arctic Ocean monthly mean SST data for 2008 in .img raster format.	.img	6.2 MB	Available online
ArcticSST2008pt.rar	Arctic Ocean monthly mean SST data for 2008 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	35.0 MB	Available online
ArcticSST2008csv.rar	Arctic Ocean monthly mean SST data for 2008 in .csv format.	Comma-separated text file (*.csv)	34.1 MB	Available online
		2007		
ArcticSST2007rast.zip	Arctic Ocean monthly mean SST data for 2007 in .img raster format.	.img	5.2 MB	Available online
ArcticSST2007pt.rar	Arctic Ocean monthly mean SST data for 2007 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	37.7 MB	Available online
ArcticSST2007csv.rar	Arctic Ocean monthly mean SST data for 2007 in .csv format.	Comma-separated text file (*.csv)	36.6 MB	Available online
		2006		
ArcticSST2006rast.zip	Arctic Ocean monthly mean SST data for 2006 in .img raster format.	.img	4.6 MB	Available online
ArcticSST2006pt.rar	Arctic Ocean monthly mean SST data for 2006 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	36.8 MB	Available online
ArcticSST2006csv.rar	Arctic Ocean monthly mean SST data for 2006 in .csv format.	Comma-separated text file (*.csv)	35.6 MB	Available online
		2005		
ArcticSST2005rast.zip	Arctic Ocean monthly mean SST data for 2005 in .img raster format.	.img	4.8 MB	Available online
ArcticSST2005pt.rar	Arctic Ocean monthly mean SST data for 2005 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	34.4 MB	Available online
ArcticSST2005csv.rar	Arctic Ocean monthly mean SST data for 2005 in .csv format.	Comma-separated text file (*.csv)	33.1 MB	Available online
		2004		
ArcticSST2004rast.zip	Arctic Ocean monthly mean SST data for 2004 in .img raster format.	.img	3.8 MB	Available online
ArcticSST2004pt.rar	Arctic Ocean monthly mean SST data for 2004 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	28.0 MB	Available online
ArcticSST2004csv.rar	Arctic Ocean monthly mean SST data for 2004 in .csv format.	Comma-separated text file (*.csv)	26.4 MB	Available online

		2003		
ArcticSST2003rast.zip	Arctic Ocean monthly mean SST data for 2003 in .img raster format.	.img	3.3 MB	Available online
ArcticSST2003pt.rar	Arctic Ocean monthly mean SST data for 2003 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	23.4 MB	Available online
ArcticSST2003csv.rar	Arctic Ocean monthly mean SST data for 2003 in .csv format.	Comma-separated text file (*.csv)	21.8 MB	Available online
		2002		
ArcticSST2002rast.zip	Arctic Ocean monthly mean SST data for 2002 in .img raster format.	.img	4.3 MB	Available online
ArcticSST2002pt.rar	Arctic Ocean monthly mean SST data for 2002 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	29.5 MB	Available online
ArcticSST2002csv.rar	Arctic Ocean monthly mean SST data for 2002 in .csv format.	Comma-separated text file (*.csv)	28.2 MB	Available online
		2001		
ArcticSST2001rast.zip	Arctic Ocean monthly mean SST data for 2001 in .img raster format.	.img	3.2 MB	Available online
ArcticSST2001pt.rar	Arctic Ocean monthly mean SST data for 2001 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	22.5 MB	Available online
ArcticSST2001csv.rar	Arctic Ocean monthly mean SST data for 2001 in .csv format.	Comma-separated text file (*.csv)	20.1 MB	Available online
		2000		
ArcticSST2000rast.zip	Arctic Ocean monthly mean SST data for 2000 in .img raster format.	.img	7.0 MB	Available online
ArcticSST2000pt.rar	Arctic Ocean monthly mean SST data for 2000 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	67.3 MB	Available online
ArcticSST2000csv.rar	Arctic Ocean monthly mean SST data for 2000 in .csv format.	Comma-separated text file (*.csv)	67.6 MB	Available online
		1999		
ArcticSST1999rast.zip	Arctic Ocean monthly mean SST data for 1999 in .img raster format.	.img	3.9 MB	Available online
ArcticSST1999pt.rar	Arctic Ocean monthly mean SST data for 1999 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	29.2 MB	Available online
ArcticSST1999csv.rar	Arctic Ocean monthly mean SST data for 1999 in .csv format.	Comma-separated text file (*.csv)	27.3 MB	Available online
		1998		
ArcticSST1998rast.zip	Arctic Ocean monthly mean SST data for 1998 in .img raster format.	.img	3.8 MB	Available online
ArcticSST1998pt.rar	Arctic Ocean monthly mean SST data for 1998 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	27.6 MB	Available online
ArcticSST1998csv.rar	Arctic Ocean monthly mean SST data for 1998 in .csv format.	Comma-separated text file (*.csv)	25.8 MB	Available online
		1997		
ArcticSST1997rast.zip	Arctic Ocean monthly mean SST data for 1997 in .img raster format.	.img	3.9 MB	Available online
ArcticSST1997pt.rar	Arctic Ocean monthly mean SST data for 1997 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	29.5 MB	Available online
ArcticSST1997csv.rar	Arctic Ocean monthly mean SST data for 1997 in .csv format.	Comma-separated text file (*.csv)	28.1 MB	Available online

		1996		
ArcticSST1996rast.zip	Arctic Ocean monthly mean SST data for 1996 in .img raster format.	.img	3.7 MB	Available online
ArcticSST1996pt.rar	Arctic Ocean monthly mean SST data for 1996 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	27.2 MB	Available online
ArcticSST1996csv.rar	Arctic Ocean monthly mean SST data for 1996 in .csv format.	Comma-separated text file (*.csv)	26.2 MB	Available online
		1995		
ArcticSST1995rast.zip	Arctic Ocean monthly mean SST data for 1995 in .img raster format.	.img	1.6 MB	Available online
ArcticSST1995pt.rar	Arctic Ocean monthly mean SST data for 1995 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	8.7 MB	Available online
ArcticSST1995csv.rar	Arctic Ocean monthly mean SST data for 1995 in .csv format.	Comma-separated text file (*.csv)	6.4 MB	Available online
		1994		
ArcticSST1994rast.zip	Arctic Ocean monthly mean SST data for 1994 in .img raster format.	.img	5.3 MB	Available online
ArcticSST1994pt.rar	Arctic Ocean monthly mean SST data for 1994 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	56.4 MB	Available online
ArcticSST1994csv.rar	Arctic Ocean monthly mean SST data for 1994 in .csv format.	Comma-separated text file (*.csv)	54.3 MB	Available online
		1993		
ArcticSST1993rast.zip	Arctic Ocean monthly mean SST data for 1993 in .img raster format.	.img	5.7 MB	Available online
ArcticSST1993pt.rar	Arctic Ocean monthly mean SST data for 1993 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	54.8 MB	Available online
ArcticSST1993csv.rar	Arctic Ocean monthly mean SST data for 1993 in .csv format.	Comma-separated text file (*.csv)	54.0 MB	Available online
		1992		
ArcticSST1992rast.zip	Arctic Ocean monthly mean SST data for 1992 in .img raster format.	.img	5.2 MB	Available online
ArcticSST1992pt.rar	Arctic Ocean monthly mean SST data for 1992 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	53.7 MB	Available online
ArcticSST1992csv.rar	Arctic Ocean monthly mean SST data for 1992 in .csv format.	Comma-separated text file (*.csv)	51.3 MB	Available online
		1991		
ArcticSST1991rast.zip	Arctic Ocean monthly mean SST data for 1991 in .img raster format.	.img	6.3 MB	Available online
ArcticSST1991pt.rar	Arctic Ocean monthly mean SST data for 1991 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	63.4 MB	Available online
ArcticSST1991csv.rar	Arctic Ocean monthly mean SST data for 1991 in .csv format.	Comma-separated text file (*.csv)	62.6 MB	Available online
		1990		
ArcticSST1990rast.zip	Arctic Ocean monthly mean SST data for 1990 in .img raster format.	.img	5.7 MB	Available online
ArcticSST1990pt.rar	Arctic Ocean monthly mean SST data for 1990 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	60.5 MB	Available online
ArcticSST1990csv.rar	Arctic Ocean monthly mean SST data for 1990 in .csv format.	Comma-separated text file (*.csv)	60.8 MB	Available online

		1989		
ArcticSST1989rast.zip	Arctic Ocean monthly mean SST data for 1989 in .img raster format.	.img	5.4 MB	Available online
ArcticSST1989pt.rar	Arctic Ocean monthly mean SST data for 1989 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	52.4 MB	Available online
ArcticSST1989csv.rar	Arctic Ocean monthly mean SST data for 1989 in .csv format.	Comma-separated text file (*.csv)	51.2 MB	Available online
		1988		
ArcticSST1988rast.zip	Arctic Ocean monthly mean SST data for 1988 in .img raster format.	.img	5.5 MB	Available online
ArcticSST1988pt.rar	Arctic Ocean monthly mean SST data for 1988 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	57.2 MB	Available online
ArcticSST1988csv.rar	Arctic Ocean monthly mean SST data for 1988 in .csv format.	Comma-separated text file (*.csv)	55.4 MB	Available online
		1987		
ArcticSST1987rast.zip	Arctic Ocean monthly mean SST data for 1987 in .img raster format.	.img	5.7 MB	Available online
ArcticSST1987pt.rar	Arctic Ocean monthly mean SST data for 1987 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	56.5 MB	Available online
ArcticSST1987csv.rar	Arctic Ocean monthly mean SST data for 1987 in .csv format.	Comma-separated text file (*.csv)	55.3 MB	Available online
		1986		
ArcticSST1986rast.zip	Arctic Ocean monthly mean SST data for 1986 in .img raster format.	.img	5.7 MB	Available online
ArcticSST1986pt.rar	Arctic Ocean monthly mean SST data for 1986 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	54.4 MB	Available online
ArcticSST1986csv.rar	Arctic Ocean monthly mean SST data for 1986 in .csv format.	Comma-separated text file (*.csv)	53.1 MB	Available online
		1985		
ArcticSST1985rast.zip	Arctic Ocean monthly mean SST data for 1985 in .img raster format.	.img	5.8 MB	Available online
ArcticSST1985pt.rar	Arctic Ocean monthly mean SST data for 1985 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	59.1 MB	Available online
ArcticSST1985csv.rar	Arctic Ocean monthly mean SST data for 1985 in .csv format.	Comma-separated text file (*.csv)	59.0 MB	Available online
		1984		
ArcticSST1984rast.zip	Arctic Ocean monthly mean SST data for 1984 in .img raster format.	.img	5.3 MB	Available online
ArcticSST1984pt.rar	Arctic Ocean monthly mean SST data for 1984 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	49.1 MB	Available online
ArcticSST1984csv.rar	Arctic Ocean monthly mean SST data for 1984 in .csv format.	Comma-separated text file (*.csv)	49.2 MB	Available online
		1983		
ArcticSST1983rast.zip	Arctic Ocean monthly mean SST data for 1983 in .img raster format.	.img	4.9 MB	Available online
ArcticSST1983pt.rar	Arctic Ocean monthly mean SST data for 1983 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	52.6 MB	Available online
ArcticSST1983csv.rar	Arctic Ocean monthly mean SST data for 1983 in .csv format.	Comma-separated text file (*.csv)	51.5 MB	Available online

1982				
ArcticSST1982rast.zip	Arctic Ocean monthly mean SST data for 1982 in .img raster format.	.img	8.5 MB	Available online
ArcticSST1982pt.rar	Arctic Ocean monthly mean SST data for 1982 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	51.6 MB	Available online
ArcticSST1982csv.rar	Arctic Ocean monthly mean SST data for 1982 in .csv format.	Comma-separated text file (*.csv)	51.8 MB	Available online
1981‡				
ArcticSST1981rast.zip	Arctic Ocean monthly mean SST data for 1981 in .img raster format.	.img	2.7 MB	Available online
ArcticSST1981pt.rar	Arctic Ocean monthly mean SST data for 1981 in ESRI (point) shapefile format.	ESRI shapefile (*.shp)	14.9 MB	Available online
ArcticSST1981csv.rar	Arctic Ocean monthly mean SST data for 1981 in .csv format.	Comma-separated text file (*.csv)	14.3 MB	Available online

‡These files contain only the 4 months of data that are available for 1981. 09/1981 – 12/1981.

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References Cited

Corell, R.W., 2006, Challenges of Climate Change: An Arctic Perspective: AMBIO: A Journal of the Human Environment, v. 35, no. 4, p. 148-152.

Drobot, S., Stroeve, J., Maslanik, J., Emery, W., Fowler, C., and Kay, J., 2008, Evolution of the 2007-2008 Arctic sea ice cover and prospects for a new record in 2008: Geophys. Res. Lett., v. 35, no. 19, p. L19501.

Evans, R.H., Vasquez, J., and Casey, K.S., 2009, 4 km Pathfinder Version 5 User Guide, United States Department of Commerce, National Oceanographic Data Center. PDF available at http://www.nodc.noaa.gov/sog/pathfinder4km/userguide.html.

Fetterer, F., Knowles, K., Meier, W., and Savoie, M., 2002, updated 2009, Sea Ice Index: Boulder, CO, National Snow and Ice Data Center. Digital media.

Galbraith, P.S., and Larouche, P., 2011, Sea-surface temperature in Hudson Bay and Hudson Strait in relation to air temperature and ice cover breakup, 1985-2009: Journal of Marine Systems, v. 87, no. 1, p. 66-78.

Gollash, S., 2006, Assessment of the introduction potential of aquatic alien species in new environments, in Koike, F., Clout, M.N., Kawamichi, M., De Poorter, M., and Iwatsuki, K., eds., Assessment and Control of Biological Invasion Risks: Kyoto, Japan; Gland, Switzerland, Shoukadoh Book Sellers, IUCN, p. 88-91.

Grebmeier, J.M., Overland, J.E., Moore, S.E., Farley, E.V., Carmack, E.C., Cooper, L.W., Frey, K.E., Helle, J.H., McLaughlin, F.A., and McNutt, S.L., 2006, A Major Ecosystem Shift in the Northern Bering Sea: Science, v. 311, no. 5766, p. 1461-1464.

Herborg, L.-M., Jerde, C.L., Lodge, D.M., Ruiz, G.M., and Macisaac, H.J., 2007, Predicting invasion risk using measures of introduction effort and environmental niche models: Ecological Applications, v. 17, p. 663-674.

Intergovernmental Panel on Climate Change, 2007, Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climage Change, 976 p.

Kearns, E.J., Hanafin, J.A., Evans, R.H., Minnett, P.J., and Brown, O.B., 2000, An Independent Assessment of Pathfinder AVHRR Sea Surface Temperature Accuracy Using the Marine Atmosphere Emitted Radiance Interferometer (MAERI): Bulletin of the American Meteorological Society, v. 81, no. 7, p. 1525-1536.

Kilpatrick, K.A., Podesta, G.P., and Evans, R., 2001, Overview of the NOAA/NASA advanced very high resolution radiometer Pathfinder algorithm for sea surface temperature and associated matchup database: Journal of Geophysical Research-Oceans, v. 106, no. C5, p. 9179-9197.

Maslanik, J.A., Fowler, C., Stroeve, J., Drobot, S., Zwally, J., Yi, D., and Emery, W., 2007, A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss: Geophys. Res. Lett., v. 34, no. 24, p. L24501.

Mueter, F.J., and Litzow, M.A., 2008, Sea ice retreat alters the biogeography of the Bering Sea continental shelf: Ecological Applications, v. 18, no. 2, p. 309-320.

Mueter, F.J., and Norcross, B.L., 2002, Spatial and temporal patterns in the demersal fish community on the shelf and upper slope regions of the Gulf of Alaska: Fishery Bulletin, v. 100, p. 559-581.

Payne, M.C., Reusser, D.A., Lee II, H., and Brown, C.A., 2011, Moderate-resolution sea surface temperature data for the nearshore North Pacific: U.S. Geological Survey Open-File Report 2010-1251, available at *http://pubs.usgs.gov/of/2010/1251/*, 16 p.

Reynolds, R.W., Rayner, N.A., Smith, T.M., Stokes, D.C., and Wang, W., 2002, An Improved In Situ and Satellite SST Analysis for Climate: Journal of Climate, v. 15, no. 13, p. 1609-1625.

Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdana, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., McManus, E., Molnar, J., Recchia, C.A., and Robertson, J., 2007, Marine ecoregions of the world: a bioregionalization of coastal and shelf areas: BioScience, v. 57, no. 7, p. 573-583.

Stram, D.L., and Evans, D.C.K., 2009, Fishery management responses to climate change in the North Pacific: ICES Journal of Marine Science: Journal du Conseil, v. 66, no. 7, p. 1633-1639.

Vazquez-Cuervo, J., Armstrong, E.M., Casey, K.S., Evans, R., and Kilpatrick, K., 2010, Comparison between the Pathfinder Versions 5.0 and 4.1 Sea Surface Temperature Datasets: A Case Study for High Resolution: Journal of Climate, v. 23, no. 5, p. 1047-1059.

Vazquez-Cuervo, J., Perry, K., and Kilpatrick, K., 1998, NOAA/NASA AVHRR Oceans Pathfinder sea surface temperature data set user's reference manual version 4.0: JPL Publication D-14070.

Xu, F., and Ignatov, A., 2010, Evaluation of in situ sea surface temperatures for use in the calibration and validation of satellite retrievals: Journal of Geophysical Research-Oceans, v. 115.

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