Technical Documentation

The Arctic Meteorology and Climate Atlas provides new data for a data-sparse region of the earth, and presents new and existing data products in formats that are easy to use for climate research. The meteorological atlas complements the Environmental Working Group's oceanographic and sea ice atlases and contributes to a comprehensive interpretation of the Arctic climate system. Scientific applications foreseen for these data include: investigation of evidence for climatic change over the four decades from 1951 through 1990; examination of interannual variability of climate in the coastal zone and in the central Arctic; and regional study of air mass transformation from open water to ice-covered ocean.

The technical documentation describes data products and data sources. Use the HTML interface to browse the data and see the temporal and spatial coverage of the data. All data are in ASCII files. Check the Glossary in the Primer section for unfamiliar terms or instruments. This document was written by F. Fetterer except where otherwise noted.

Data Formats

EASE-Grid format is used for ASCII data files of gridded fields. Uniformat is used for synoptic and monthly mean data from stations. These formats are described below.

EASE-Grid

All of the gridded fields on the Atlas are in EASE-Grid format. EASE-Grid is a set of equal-area projections and grids developed at the National Snow and Ice Data Center (NSIDC) to be a tool for users of global-scale gridded data. The Atlas gridded fields are in an azimuthal equal-area projection centered on the North Pole. The grid cell size is 250 km. There are a total of 529 cells in a 23- by 23- cell array, with cells numbered 0 to 22. Cell 11,11 is centered on the North Pole. The gridded field values are in ASCII files that can be accessed from the data directory, or by clicking on a browse image of a field. A "missing" data point is coded with nines (in the same format as a real value would be, for instance, "9999.99" for snow depth, or "999.999" for cloud cover).

The corners of the grid, with grid cell center coordinates, are shown in the table below.

Table 1. EASE-Grid corners.

Corner	**Row**	**Column**	**Latitude (degrees North)**	**Longitude (degrees East)**
Upper left	0	0	54.36	225.00
Upper right	0	22	54.36	135.00
Lower left	22	0	54.36	315.00
Lower right	22	22	54.36	45.00

The center latitude and longitude for each grid cell is in file /DATA/GRIDDED_FIELDS/EASE_INFO/N65-250km.latlon.dat. The grid is oriented so that the 180 degree meridian is at the top center, and the 0 degree meridian is at the bottom center. Figure 1 shows the location of the grid cell centers.

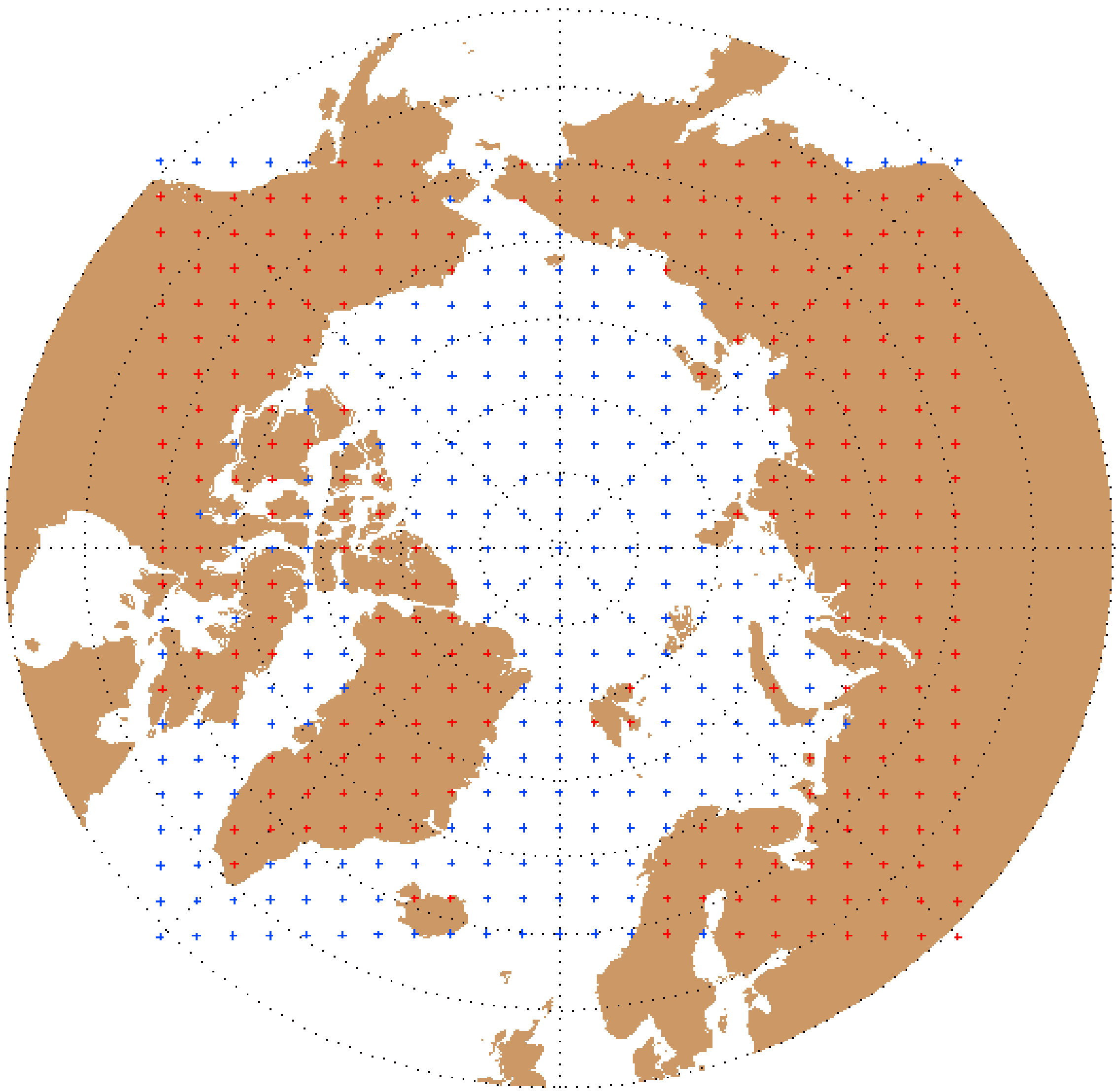


Fig. 1. EASE-Grid cell centers used for this Atlas. Red cell centers mark land cells.

The advantage of the EASE-Grid's azimuthal equal-area projection is that it combines minimal shape distortion with no areal distortion on a hemispheric scale. No areal distortion means that a grid cell at the North Pole covers the same area as one at 45 degrees North. In contrast, a polar stereographic projection is conformal (has no shape distortion) but suffers large areal distortion on a hemispheric scale. The cylindrical equal-area projection (sometimes referred to as the “latitude-longitude grid”) suffers from both shape and area distortion.

The EASE-Grid is defined by

r = 2*R/C * sin(lambda) * sin(PI/4 - phi/2) + r0
s = 2*R/C * cos(lambda) * sin(PI/4 - phi/2) + s0
h = cos(PI/4 - phi/2)
k = sec(PI/4 - phi/2)

where

r = column coordinate
s = row coordinate
h = particular scale along meridians
k = particular scale along parallels
lambda = longitude in radians
phi = latitude in radians
R = radius of the earth = 6371.228 km
C = nominal cell size
r0 = map origin column
s0 = map origin row

The values of C, r0 and s0 are determined by the grid that overlays the projection. For the Atlas EASE-Grid, r0 = 11; s0 = 11; and C = 250 km. The projection is based on a spherical model of the earth with radius R = 6371.228 km. This radius gives a sphere with the same surface area as an ellipsoid using the International Datum. *Brodzik* [1998] (http://www-nsidc.colorado.edu/NASA/GUIDE/EASE/ease_maps_info.htmland) and *Armstrong and Brodzik* [1995] have more information on the NSIDC EASE-Grid.

Uniformat - Uniform Format

All of the coastal station and floating platform data are in "uniformat", that is, as ASCII files with columns for parameters described in the table below (although none of the station types have observations for all parameters). The naming convention for the uniformat data files is uni.[station_name].dat for all stations without World Meteorological Organization (WMO) numbers, and uni.[station_name].[WMO_number].dat for those with WMO numbers.

Table 2. Uniformat file description.

Parameter Number	Parameter Name	Columns	Value for Missing	Comments
1	WMO station number	0-4	99999	For Russian coastal stations, this is the station number provided by AARI. For 21 of these stations, the number is not contained in a recent listing of WMO stations.
2	Year	5-9	Not Applicable	
3	Month	10-12	Not Applicable	
4	Day	13-15	-1	(-1 means monthly, not synoptic data)
5	Time	16-20	-1	(-1 means monthly, not synoptic data)
6	Position interpolation flag	21-22	9	Code to indicate position characteristic: 9: Missing. Used if either lat. or lon. is missing

				1: Default. Means observed, fixed position 2: Linearly interpolated. Used only for NP stations. 3: Rounded to nearest degree. Used for some western drifting station and Ice Patrol ship data. 4: Monthly mean position. Used only for monthly mean data from NP stations.
7	Latitude, decimal degrees North	23-28	99.99	For Russian coastal stations, this position is the position provided by AARI, not that provided for the station by WMO
8	Longitude, decimal degrees East	29-36	999.99	(0 - 360). As for latitude.
9	Air temperature (°C)	37-43	999.99	
10	Sea level pressure (mbar)	44-50	9999.9	
11	Wind direction (deg.)	51-56	999.9	
12	Wind speed (m/s)	57-62	999.9	
13	Total cloud amount (tenths)	63-67	99.9	Visual estimates. Note that Russian drifting stations may have "11", meaning "10, with gaps"
14	Low cloud amount (tenths)	68-72	99.9	Visual estimates. Note that Russian drifting stations may have "11", meaning "10, with gaps"
15	Relative humidity (%)	73-78	999.9	
16	Dew point (°C)	79-85	999.99	
17	Wet bulb temperature (°C)	86-92	999.99	
18	Vapor pressure (mbar)	93-99	9999.9	
19	Precipitation (millimeters)	100-106	-1.00	"Trace" precipitation is coded in uniformat files as 0.1 mm.
20	Soil or ice surface temperature (°C)	107-113	999.99	See documentation for each station type.
21	Sea surface temperature (°C)	114-120	999.99	
22	Station name	121-		Text field of varying length.

An example of uniformat records for the T-3 Western drifting station:

```
99999 1952  7 26  300 3 89.00  267.00   0.56 9999.9 999.9
999.9 10.0 99.9 999.9  -0.56   0.00 9999.9  -1.00 999.99
999.99 T-3
```

```
99999 1952  7 26  700 3 89.00  352.00   0.00 1009.4 999.9
999.9 10.0 99.9 999.9   0.56   0.00 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 26 1000 3 89.00  352.00   0.56 1007.9 999.9
999.9 10.0 99.9 999.9   0.56   0.56 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 26 1300 3 89.00  352.00   0.56 1007.6 999.9
999.9 10.0 99.9 999.9   0.56   0.56 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 26 1600 3 89.00  352.00   0.56 1007.7 999.9
999.9 10.0 99.9 999.9   0.56   0.56 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 26 1900 3 89.00  352.00   0.00 1007.8 999.9
999.9  8.0 99.9 999.9   0.00   0.00 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 26 2200 3 89.00  352.00   0.00 1008.3 999.9
999.9  9.0 99.9 999.9   0.00   0.00 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 27  500 3 89.00  347.00 999.99 9999.9 999.9
999.9  1.0 99.9 999.9 999.99 999.99 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 27  500 3 99.99  347.00  -0.56 1009.3 999.9
999.9  3.0 99.9 999.9  -1.11  -0.56 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 27  800 3 88.00  347.00   0.00 1009.9 999.9
999.9  3.0 99.9 999.9  -0.56  -0.56 9999.9  -1.00 999.99
999.99 T-3
99999 1952  7 27 1100 3 88.00  347.00   0.56 1010.7 999.9
999.9  3.0 99.9 999.9  -1.11   0.00 9999.9  -1.00 999.99
999.99 T-3
```

Gridded Fields

Climatological monthly mean fields of meteorological parameters are provided in an easy-to-use format. Decadal mean fields for those parameters with sufficient data for a decadal analysis are included. These fields are based on the best available products improved, when possible, with new data obtained for this Atlas.

Browse files are .gif format images with a color bar and contours. These allow you to quickly visualize the content of the corresponding ASCII data files. The ASCII EASE-Grid format files have a cell size of 250 km. Please read the technical documentation for the parameter of interest to find complete information on data sources and methods of compiling these fields. The documentation contains a section commenting on the seasonal cycle of the parameter written by M. Serreze. The fields are:

> **Two-meter air temperature:** Monthly means, standard deviation, and coefficient of variation for the 1980s and 1990s.

Sea level pressure: Decadal monthly means for 1950s through 1990s; long-term monthly means for 1951 through 1990; long-term monthly means for 1961 through 1990 (the WMO period); and fields of anomaly, standard deviation, and coefficient of variation.
Precipitation: Monthly mean fields for 1951 to 1990.

Cloud: Decadal monthly mean fields of total and low cloud cover (percent) for 1952 through 1995; long-term monthly mean fields of total and low cloud cover (percent) for 1952 through 1995.

Snow: Monthly mean snow depth fields for land, 1966 through 1982; monthly mean snow depth fields for the Arctic Ocean, 1954 through 1991; monthly mean snow water equivalent fields for the Arctic Ocean, 1954 through 1991.

Global solar radiation: Climatological monthly means. In addition, the "Gridded Fields" section of the Atlas contains a climatology of direct, total (or global) and net radiation compiled and scanned at the Arctic and Antarctic Research Institute (AARI) from Russian and other sources by M. S. Marshunova.

Two-meter Air Temperature

The University of Washington's International Arctic Buoy Program/Polar Exchange at the Sea Surface (IABP/POLES) temperature analysis fields are the basis for the Atlas gridded temperature fields. The IABP/POLES data set was chosen because we believe it is the best representation of the true 2–m air temperature field for the following reason: IABP/POLES unites the two most extensive sources of arctic ocean air temperature data. These are the International Arctic Buoy Program (IABP) data and the Russian North Pole (NP) drifting station data. The IABP data in IABP/POLES Temperature Data Set were carefully quality-controlled, and a warm bias was removed using the NP data as a standard.

Reanalysis products, such as those from NCEP/NCAR (see "Description of the NCEP/NCAR Global Reanalysis pressure data" section) or from the European Centre for Medium-range Weather Forecasting (ECMWF) are other sources for temperature fields. But IABP/POLES temperature fields show better correlation with NP drifting station data than do NCEP or ECMWF gridded products, particularly in the summer.

Data source for temperature fields

IABP/POLES 2-Meter Air Temperature Data Set fields can be obtained from the University of Washington web site http://iabp.apl.washington.edu/AirT/index.html. At this site, these data are available for every 12 hours, for 1979 through 1998 (with periodic updates). I. Rigor and M. Ortmeyer, with the Polar Science Center at the Applied Physics Laboratory, University of Washington, provided IABP/POLES air temperature fields to NSIDC in EASE-Grid with a 100 km cell size.

Method of constructing the temperature field products

Data (12 hour fields, 1981through 1998) obtained from the University of Washington IABP/POLES project were re-gridded from 100 km EASE-Grid to the Meteorological Atlas EASE-Grid format (250 km cell size) using cubic convolution. Decadal averages were computed prior to re-gridding.

Gridded temperature field products

Gridded temperature products are:

- Monthly mean fields for 1981 through 1990, and 1991 through 1998
- Monthly standard deviation fields for 1981 through 1990, and 1991 through 1998
- Monthly coefficient of variation fields (standard deviation divided by the 10 year mean) for 1981 through 1990, and 1991 through 1998

The browse versions of these files are shown as .gif format images with a color bar and contours every two degrees Celsius. These browse files are for the purpose of quickly visualizing the content of the corresponding ASCII data files. The IDL routine used to color-map the images gives a smooth and visually pleasing result, but keep in mind that the gridded ASCII files have one value only for every grid cell. The grid cell centers are shown as red dots. For information on the structure of the gridded files, see the section on “EASE-Grid”

A comment about the seasonal cycle of temperature

The mean seasonal cycle of temperature is simply described. During winter, temperatures decrease sharply from the northern North Atlantic to the central Arctic Ocean. The high temperatures over the Atlantic sector arise from the moderating influence of ice-free waters in this region, coupled with the frequent cyclone activity associated with the Icelandic Low transporting warm air polewards. Similarly, high temperatures are found south of Alaska associated with the Aleutian Low. The lowest winter temperatures occur over Siberia in association with the cold Siberian High. Standard deviations are also high over Siberia due to variations in the strength of the Siberian High from year to year. The low temperatures over Greenland reflect the high elevation of the ice sheet. While temperatures are of course higher everywhere in summer, the spatial variability seen in winter is much less pronounced in summer, and standard deviations are lower. Temperatures are highest over land areas in summer because the surface is snow free and can be easily heated by the strong solar radiation flux. Over the Arctic Ocean, temperatures are close to zero. This occurs because the sea ice cover is at its melting point, which keeps air temperatures near freezing. The autumn months illustrate the transition back to the winter pattern, with higher temperatures over the Atlantic and south of Alaska, and low temperatures over Siberia and the Greenland ice sheet.

Description of IABP/POLES 2-meter temperature fields

The IABP/POLES temperature data set is a gridded 12 hour, two-meter air temperature data set for the Arctic, developed at University of Washington using optimal interpolation of temperature data [*Rigor et al.*, 2000]. (An on-line version of this article can be found at http://iabp.apl.washington.edu/AirT/index.html). The IABP/POLES analysis evolved from a POLES analysis that used Russian NP drifting station, IABP, and coastal station data to produce temperature fields over the Arctic Ocean only. The development of this data product is described in *Martin and Munoz* [1997]. The IABP/POLES fields build on the earlier work by applying seasonally and spatially varying correlation length scales in the optimal interpolation. This method takes account of the fact that the correlation between observations taken at coastal stations and at ocean stations, or between coastal and interior stations, varies by season. For instance, the correlation length scale between stations of the same type is about 1000 km throughout the year, but the correlation between ocean and coastal stations drops to about 300 km in the summer. The use of these correlations allows for the inclusion of inland station data in the analysis. The data set is extended over land using data from the National Center for Atmospheric Research (NCAR) data set ds464.0, "NCEP ADP Global Sfc Obs, daily Jul 1976-on".

The IABP/POLES data set begins in 1979, when the first IABP buoys were deployed [*Untersteiner and Thorndike*, 1982]. Over the years, the IABP buoy types, types of thermistors, and the height at which they were mounted changed, making it difficult to assess accuracy. (The Russian North Pole drifting station air temperature data were acquired at a consistent height of two meters). *Martin and Munoz* [1997] estimate that overall, the temperature recorded by a thermistor on an IABP buoy should equal two-meter air temperature to within about one degree Celsius.

NCAR data set ds464.0, *NCEP ADP Global Sfc Obs, daily Jul 1976-on*, contains worldwide synoptic observations collected from the Global Telecommunications System by the National Center for Environmental Prediction (NCEP). Some quality control is applied at NCEP. Note that some but not all of the data from the 65 Russian stations included in the Coastal Stations section of this Atlas are included in this data source. The percentage of Russian coastal stations appearing in ds464.0 varies with time, but is on the order of 30 percent.

Sea Level Pressure

Monthly mean pressure fields from the NCEP/NCAR Reanalysis Project were used to create decadal and longer-term pressure fields. (For more information on the NCEP/NCAR Global Reanalysis Project, see the section titled "Description of the NCEP/NCAR Global Reanalysis pressure data".) We used Reanalysis products because the Reanalysis project employs a state-of-the-art data assimilation model. Use of a model constrains pressure values to be realistic and consistent with other assimilated data. The Reanalysis project makes use of historical data sources that may include additional data beyond what we have included on this Atlas (for instance, data from the Surface Land Synoptic Data set is included in the Reanalysis). Most of the data on this Atlas are already in the Reanalysis, through the Comprehensive Ocean-Atmosphere Data Set (COADS) and Surface Land Synoptic Data sources.

Data source for pressure fields

The data used for these fields come from the "Selected Monthly Means" from NCAR data set 090.0, *NCEP Global Reanalysis Anals, 6-hourly*. Data files were obtained from ftp://ncardata.ucar.edu/pub/reanalysis/monthly/PRES.msl.

Method of constructing the pressure field products

To construct the pressure field products, monthly reanalysis sea level pressure data from north of 54 degrees North were converted from WMO Gridded Binary (GRIB) format on a 2.5 degree latitude by 2.5 degree longitude scale, to the Atlas EASE-Grid format. Cubic convolution was used to regrid the data. Decadal and longer-term means were then calculated for each grid cell.

Gridded pressure field products

Gridded pressure field products are:

- Monthly mean fields by decade for 1951 through 1990, and 1991 through 1998
- Monthly mean fields for 1951 through 1990
- Monthly mean fields for 1961 through 1990 (the WMO period)
- Standard deviation fields (deviation from the mean for the 40-year period from 1951 through 1990)
- Coefficient of variation fields (standard deviation divided by the 40-year mean)
- Anomaly fields: $X' = X_i - X_{mean}$ where X_i are decadal means by month, and X_{mean} is the 40-year mean

The browse versions of these files are shown as .gif format images with a color bar and contours. These browse files are for the purpose of quickly visualizing the content of the corresponding ASCII data files. The IDL routine used to color map the images gives a smooth and visually pleasing result, but keep in mind that the gridded ASCII files have one value only for every grid cell. The grid cell centers are shown as red dots. For information on the structure of the gridded files, see the section on "EASE-Grid".

A comment about the seasonal cycle of air pressure

The most notable feature of sea level pressure for winter months is the low pressure over the Atlantic sector corresponding to the Icelandic Low. Standard deviations are also high in this region, due to variations in the number and strength of cyclones from year to year. (Although not within the area covered by the Atlas grid, low pressure and high standard deviation are also found south of Alaska, corresponding to the Aleutian Low.) The high winter pressures over Siberia correspond to the Siberian High. During spring the Icelandic and Aleutian lows weaken, as do the Siberian and Alaskan highs. An anticyclone develops over the Beaufort Sea. This Beaufort Sea High is strongest in March and April. In general, standard deviations are lower than for winter. The pressure field in summer is quite flat. Pressures are actually lowest over the central Arctic Ocean, as it is in this season that cyclone activity in this area is most common. The fairly high standard deviations largely manifest variations in cyclone activity in this area. The fields for autumn capture the transition back to the winter pattern. Note in particular the redevelopment of the Icelandic Low.

Description of NCEP/NCAR Global Reanalysis pressure fields

The NCEP/NCAR Global Reanalysis Project is a collaborative effort of the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental

Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) to produce an over 40-year record of global analysis of atmospheric fields. Data are recovered from a variety of sources, quality-controlled and assimilated with a data assimilation scheme that uses first guess fields, optimal interpolation, and an operational forecast model. More information can be found at NCAR's reanalysis web site (http://www.sdc.ucar.edu/dss/pub/reanalysis/index.html) and from the NOAA Climate Diagnostics Center (http://www.cdc.noaa.gov/). Currently, reanalysis products are available from 1948 through 1998.

The Reanalysis project uses pressure data from the Comprehensive Ocean Atmosphere Data Set (COADS). COADS contains data from ships, buoys, and Russian North Pole drifting stations. See the "Description of COADS" in the "Total and low cloud cover" documentation.

Land station pressure data for the Reanalysis come from Surface Land Synoptic Data. This data set is composed of data received over the GTS telecommunication system from 1967 forward. Data from 1967 to 1976 are from the Air Force; data from 1976 to present are from NCEP and are available from NCAR as data set 464.0*, NCEP ADP Global Sfc Obs, daily Jul 1976-on.* Prior to 1967, data are from Air Force Tape Deck 13, and are available from NCAR as data set ds467.0, *NCDC TD13 Global Sfc Obs, daily 1899-1970*. Surface synoptic data from 223 Soviet stations and from 300 U.S. stations for 1948 through 1966 are used in the Reanalysis. Some percentage of the data from the 65 Russian stations included in the Coastal Stations section of this Atlas is included in this data source. The percentage varies; for instance, about 30 percent of stations appear in Surface Land Synoptic Data after about 1970, with far less in earlier years.

Precipitation

Documentation written by F. Fetterer; edited by M. Serreze

The Atlas gridded precipitation fields were compiled using data from North Pole drifting stations, and from Canadian and Eurasian data sets that have been corrected for biases by the data providers. An iterated Cressman interpolation, including a first guess field, is used in creation of the gridded fields.

Measuring precipitation is particularly difficult because the measured value depends on gauge type and placement and is subject to errors from a number of sources. Blowing snow and the overall low annual precipitation make obtaining accurate precipitation values especially problematic in the Arctic. *Groisman et al.* [1991] were speaking of the precipitation record in the former Soviet Union, but his comments hold true throughout the Arctic:

> "The development of suitable methods to homogenize the precipitation measurements in the Arctic regions of the USSR remains an elusive task. In general, the measurements obtained in the Arctic are a complex function of precipitation type and intensity, wind speed, the degree of protection from the wind at the gauge site, and the gauge type….In specific episodes of solid

> precipitation, the measured precipitation can vary from the true precipitation by 100 percent or more."

We have created gridded monthly fields from data that have been corrected by the data providers as a result of painstaking study, but it is important to remember that errors in the fields are likely to be significant. This is true not only because of the biases in precipitation measurements, but because of the sparse data coverage in the Arctic. A study cited by the WMO/World Climate Research Program Arctic Climate System Study (ACSYS) Arctic Precipitation Data Archive (APDA) project finds that to achieve a relative error of about 10 percent when computing areal mean precipitation on a 100 km grid for southeast Canada, the density must be four to 10 stations per grid cell [*Rudolf et al.*, 1994]. Higher density is needed where precipitation is more variable. This density is not available in the Arctic. The ACSYS APDA project (http://www.dwd.de/research/gpcc/acsys/) will address this problem by blending model output with observations. Here, we provide monthly climatological fields by blending bias-corrected station data with a first-guess field.

Corrections to precipitation measurements

Before discussing data sources, it is helpful to review bias corrections to precipitation data. Corrections for four effects can be made:

Wind-induced undercatch

Bruce and Clark [1966], in their *Introduction to Hydrometeorology*, cite studies from as early as 1884 showing that as wind speed increases, measured precipitation is reduced. This effect is much greater for snow than for rain. Gauges are usually shielded to reduce wind undercatchment, but wind effects are still the largest source of error in precipitation measurements. *Groisman et al.* [1991] note that undercatch can be as much as 50 percent of measured precipitation. Wind loss depends on gauge type (see for example *Goodison et al.* [1998]), where the gauge is located relative to obstacles, how high the gauge is mounted, and on the type of precipitation.

Trace precipitation amounts

Trace precipitation is precipitation in amounts too small to be resolved by the collecting gauge. For example, a measure on the Tretyakov gauge of less than 0.1 mm is recorded as "trace". Corrections for trace are usually made by adding in a set amount for each day on which trace precipitation was recorded. Trace precipitation can contribute a significant amount to monthly or annual precipitation totals in regions of little precipitation. For instance, *Yang et al.* [1999] found that the yearly correction for trace precipitation was 5 percent to 11 percent of the gauge-measured annual precipitation for northern Greenland, but was a negligible 3 percent or less for southern Greenland where precipitation is much higher.

Wetting loss

Wetting loss occurs when a gauge is emptied into a measuring device to obtain a precipitation total. The small amount of precipitation that remains behind in the gauge (sticking to its sides) is the wetting loss. The size of this loss depends on how often the gauge is emptied, as well as on the type of gauge and the type of precipitation. *Yang et al.* [1999] found that for Greenland, the wetting loss is 5 percent to 6 percent of gauge-measured annual precipitation for northern Greenland, and 2 percent to 3 percent for southern Greenland.

Evaporation loss

Evaporation loss is the amount of precipitation lost from the gauge by evaporation between measurements. It depends on gauge type, the frequency of measurements, and weather conditions. While evaporation can be significant (up to 0.8 mm per day for one Finnish site for the Tretyakov gauge, it is not generally possible to apply a general correction due to the site-specific nature of the loss [*Yang et al.*, 1995].

In 1985, the WMO undertook a project to help quantify these biases, and to identify standard corrections [*WMO/CIMO*, 1985]. The data sets used for this Atlas make use of the results of this project, along with earlier work on standardizing precipitation data in the USSR documented by *Groisman et al.* [1991].

Data sources for precipitation fields

Eurasia

Monthly precipitation totals for Eurasia were taken directly from the data set *Former Soviet Union Monthly Precipitation Archive, 1891-1993*. This archive contains data from 622 stations. Work on this archive began at the State Hydrological Institute in St. Petersburg in 1977. The data are available on-line at NSIDC (http://www-nsidc.colorado.edu/NSIDC/CATALOG/ENTRIES/nsi-0059.html), along with a file containing the correction factors so that it is possible to reconstruct the uncorrected data. The stations used for the Atlas products, as well as stations from other data sources, are shown in Figure 2.

Pavel Ya. Groisman (NOAA National Climatic Data Center, Asheville, NC, and the State Hydrological Institute) and others compiled station histories and used instrument intercomparisons and field studies to arrive at methods of correcting the original data. Three corrections were applied. The following description is drawn from *Groisman et al.* [1991]. Note that all gauges in this data set were mounted two meters above ground.

In the late 1940s and early 1950s, Tretyakov gauges replaced Nipher shielded gauges to reduce wind-induced undercatch. A correction factor (K1) was determined from parallel measurements between the two gauge types, and was applied to measurements made with the Nipher gauge in order to make them compatible with the Tretyakov gauge measurements.

In 1966, the number of observations per day was increased from two to four at most stations. A correction for wetting was instituted at the station prior to archiving the data. In 1967, the method of calculating the wetting correction was changed to differentiate between solid, mixed and liquid precipitation. Coefficient K3, the wetting correction, is well correlated with the number of observations per month with solid, mixed, and liquid precipitation. Monthly values for these coefficients are recorded for each station.

In the 1960s, a field experiment was conducted to assess the absolute accuracy of precipitation measurements made with Tretyakov gauges. Based on results from the experiment, a scale correction, K2, was derived. The value of K2 is a function of climatological wind speed and temperature at the gauge site for monthly snowfall, and climatological wind speed and precipitation intensity for monthly rainfall. *Groisman et al.* [1991] caution that the values for K2 should not be applied to data from individual stations for individual years or months, since the long-term monthly means for wind speed and temperature from which K2 is derived are subject to large deviations in any given year or month.

Canada

Data for Canada were taken from NCDC data set TD-9816 *Canadian Monthly Precipitation* [*Groisman*, 1998]. The data set was prepared by P. Groisman. The original data were purchased by NCDC from the Canadian Atmospheric Environment Service (AES) in the early 1990s and then subjected to bias corrections. A total of 6692 stations are available, extending from the beginning of record to 1990, with the earliest station starting in 1874. We use data north of 60 degrees North for the period 1951 through 1990.

Earlier studies [*Metcalfe et al.,* 1997] indicate that before 1975, Canadian gauges had wetting losses of approximately 0.16 mm per measurement. It was also recommended to multiply rainfall measurements by 1.02 to account for wind-induced undercatch.

Information on the number of measurements per day (that would allow a systematic wetting correction) is not available at all stations. To provide for a more homogeneous time series, the wetting correction before 1975 made use of the mean number of days per month with rainfall at the site or, if not available, a value interpolated from nearby locations. The mean values are based on data from the early 1980s onwards, when total rainfall days began to be inserted in the original archive. A total of 2172 stations have this information for at least five years.

The total monthly rainfall prior to 1975 was taken as the measured rainfall plus the mean number of days with rain multiplied by 0.2. This adjusted total was then multiplied by 1.02 to account for wind undercatch. Subsequent to 1975 and with the adoption of the improved Type-B gauge [*Metcalfe et al*., 1997], a wetting correction was not deemed necessary and the monthly rainfall was adjusted only for wind undercatch. These adjustments increase rainfall by approximately 5 percent before 1975 and 2 percent thereafter. There are no corrections for trace rainfall events.

To obtain total precipitation, rainfall totals were added to the water equivalent of snowfall. Two instruments are used in Canada to assess snowfall water equivalent. At 85 percent of stations, a snow ruler is used to measure the depth of freshly fallen snow, which is then converted into water equivalent using a 10:1 ratio. Starting from the early 1960s, some stations were equipped with Nipher-shielded elevated snow gauges that directly measure the water equivalent of snow [*Groisman and Easterling*, 1994]. However, these measurements are prone to wind-induced error. Errors appear to be on the order of 15 percent [*Golubev et al.,* 1995], but *Groisman* [1998] notes that the errors will be site specific. While accurate corrections for gauge undercatch require wind and site exposure information, this information was not available, requiring the use of climatological adjustments.

Climatological ratios (RAT) of monthly snow water equivalent from the Nipher gauge and the snow ruler (Nipher/ruler) were computed. RAT is generally less than 1.0, and in cold climates as low at 0.6. The RAT values were increased by a factor of 10/9 to account for an average snow undercatch by the Nipher gauge (that is, the undercatch is assumed to be systematic). The RAT values were then multiplied by the water equivalent as determined from the 10:1 conversion of the ruler measurements. This procedure amounts to an adjustment of the assumed snowfall density. The adjustments were only performed where the mean monthly snowfall exceeded 3 cm. For cases in which a RAT value could not be determined due to insufficient data, a value of 1.0 was assumed. Deriving the RAT values required identification of those sites and periods for which frozen precipitation was measured by the Nipher gauge. These procedures are outlined by *Groisman* [1998].

Arctic Ocean

Monthly precipitation totals for the Arctic Ocean are North Pole drifting station data corrected for biases by Daqing Yang (currently with the Institute for Global Change Research, Tokyo, Japan). North Pole drifting station data from 1957 through 1990 from NSIDC data set *Arctic Ocean Snow and Meteorological Observations from Drifting Stations* were used. Figure 2 shows the mean monthly positions for these stations. The following description of bias corrections to this data set draws from *Yang* [1999]. For information on the Soviet North Pole drifting station program, see the Atlas documentation for the North Pole drifting stations, and the history of the program in "A Look Back". For additional information on precipitation and snow measurements on the stations, see *Colony et al.* [1998].

Precipitation was measured twice daily with a Tretyakov gauge at two meters height. To correct for trace precipitation, a value of 0.1 mm was added to the monthly total for every day on which trace was recorded. No correction for wetting was needed, because the data had already been corrected based on earlier study [*Colony et al.*, 1998]. No correction was made for daily evaporation loss.

To correct for wind-induced undercatchment, a daily catch ratio was calculated as a function of wind speed and temperature. The functional relationship was developed based on results from the WMO Solid Precipitation Measurement Intercomparison [*WMO/CIMO*, 1985]. The ratio of Tretyakov gauge catch to "true" precipitation from a reference was regressed against mean daily wind speed at the gauge height and maximum, minimum and average daily temperature. Different relations for snow, snow with rain, rain with snow, and rain were derived [*Yang et al.*, 1995].

The bias corrections adjust the overall mean monthly gauge-measured precipitation upward by from 30 percent to 100 percent (see *Yang et al.* [1995] Figure 2). Yang notes that the corrections shift the monthly maximum from July to September, which is in agreement with GCM simulations [*Walsh et al.*, 1998].

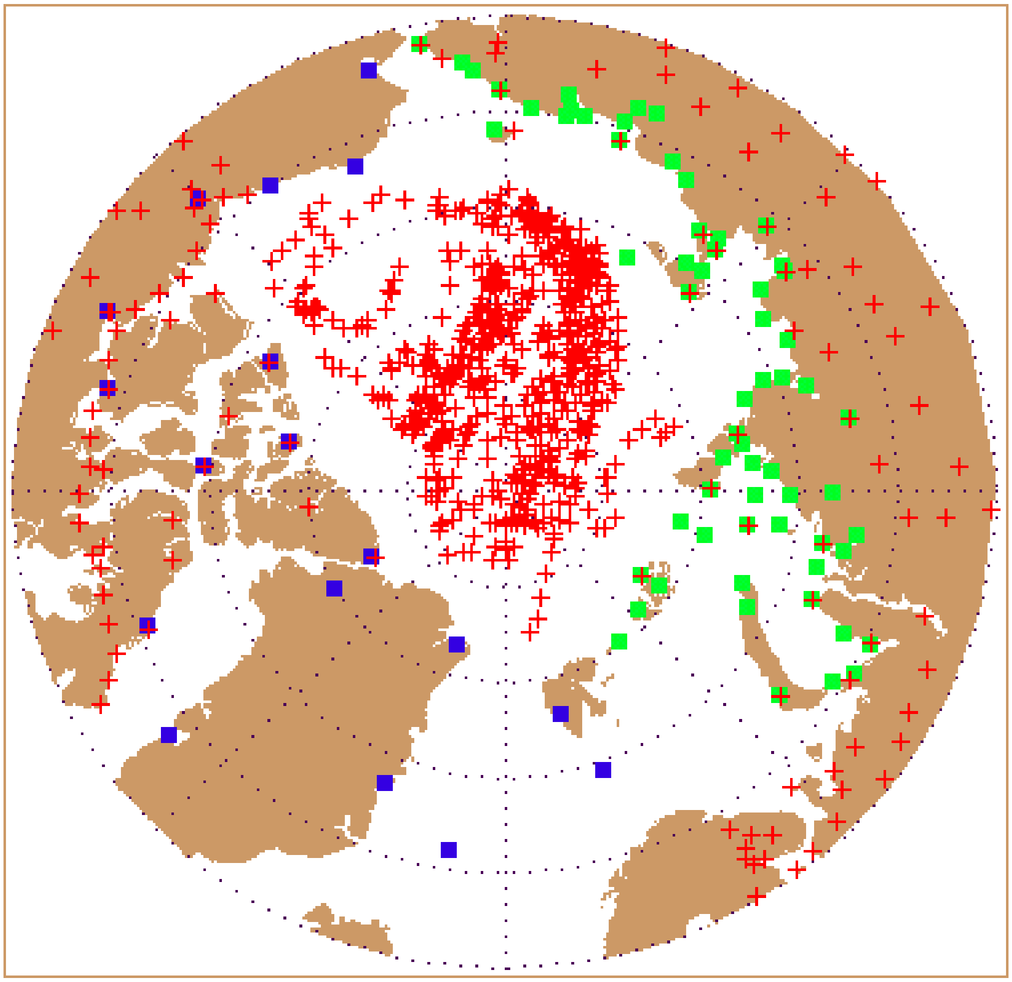


Fig. 2. Locations of stations with precipitation data that were used in constructing the interpolated precipitation fields (red crosses): Eurasian stations, Canadian stations, and all mean monthly positions for North Pole drifting stations. For comparison, the location of stations in NCAR data set 570, *World Monthly Surface Station Climatology* (blue squares) and the data set of 65 Russian coastal stations on this Atlas (green squares) are shown as well. All stations north of 50 degrees North are shown, although not all of these stations lie within the Atlas EASE-Grid.

Method of constructing the precipitation field products

Climatological monthly means of the station data (all data from stations above 55 degrees North acquired between 1951 and 1990, and with at least ten years of data) were first computed. Data from the North Pole drifting stations are from a different position each month. For compatibility with the land-based records, 11 points in the Arctic Ocean were defined. Using a drop-in-the-bucket approach, monthly precipitation means at each of these points were computed by taking any drifting station observation within 500 km of each point. If the resulting mean was based on less than three years of data, it was treated as missing.

The station data were then interpolated to the EASE-Grid using a Cressman interpolation with an iterative correction of a first guess field. For the first guess, we used the Legates and Willmott monthly climatology [*Legates and Willmott*, 1990], originally provided on a 0.5 degree by 0.5 degree grid, and interpolated to the EASE-Grid (using the Cressman equations described below, with a single 500 km search radius).

In its simplest form, the Cressman routine is given by:

$$value_{gridcell} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

where x_i is the precipitation observation at location i within a radius R of the grid location, and n is the number of stations found within the search radius. The weights w_i are given by

$$w_i = \frac{R^2 - d_i^2}{R^2 + d_i^2}$$

where d is the distance from the grid cell to the observation location.

The more complex iterative correction scheme used here is an iterated two-step process repeated using successively smaller search radii. In the first step, the operation of the Cressman routine is reversed to obtain values of the first guess at the observation locations. The difference between each observation and the first guess is then computed. In the second step, the difference values are interpolated back to the EASE-Grid using the form of the equations given above, with the gridded difference field added to the first guess field.

We now have an adjusted first-guess field. Using this adjusted first guess field, the two step process is repeated using a smaller search radius. Here, we modify the first guess four times using successively smaller search radii of 750 km, 650 km, 550 km and 450 km. The use of successively smaller search radii results in the final field being more strongly weighted by the observations in data-rich areas, while placing more reliance on the first guess where observations are sparse. More information on this method and on the Legates and Willmott climatology can be found in *Serreze and Hurst* [2000].

Gridded precipitation field products

Precipitation products are monthly mean fields for 1951 through 1990. The browse versions of these files are shown as .gif format images with a color bar and contours. These browse files are for the purpose of quickly visualizing the content of the corresponding ASCII data files. The IDL routine used to color-map the images gives a smooth and visually pleasing result, but keep in mind that the gridded ASCII files have one value only for every grid cell. The grid cell centers are shown as red dots.
For information on the structure of the gridded files, see the “EASE-Grid” Section.

A comment about the seasonal cycle of precipitation

The gridded fields illustrate the seasonal cycle of Arctic precipitation. During winter, precipitation is highest over the Atlantic sector. This represents the effect of frequent cyclone activity associated with the Icelandic Low. High precipitation totals are also found south of Alaska corresponding to the Aleutian Low. The lowest amounts are found over the central Arctic Ocean and land areas, where cyclone activity is uncommon and anticyclonic conditions are more the rule. From spring into summer, the pattern changes. The precipitation maxima over the Atlantic side and south of Alaska weaken, attended by increases in precipitation over the Arctic Ocean and land. The increases over the Arctic Ocean correspond to the seasonal increase in cyclone activity in this area. This is also true for the increase in precipitation over land. Perhaps surprisingly given the high latitude, the summer maximum in terrestrial precipitation is also contributed to by convective activity (that is, by thunderstorms). Autumn shows the transition back to the winter regime. The maxima associated with the Icelandic and Aleutian lows is reestablished, and precipitation decreases over land.

Total and Low Cloud Cover

Documentation written by F. Fetterer based on material provided by C. J. Hahn

Decadal (or near-decadal, that is, for 1952 through 1970, 1971 through 1980, 1981 through 1990, and 1991 through 1995) monthly mean values of cloud cover were prepared for this Atlas by Dr. Carole J. Hahn, Department of Atmospheric Sciences, University of Arizona, Tucson, AZ. The monthly means were re-gridded to EASE-Grid at NSIDC. The monthly mean values for total and low cloud cover are based on synoptic surface observations. Surface observers usually report cloud cover in tenths. Low clouds are those clouds with bases generally below about two km above the surface. They are encoded in the WMO synoptic code under the category "C_L". Nine different cloud types (all variations of stratus, stratocumulus, cumulus, and cumulonimbus) are included in this code. (Cumulonimbus is classified as a low cloud because of its base height, though its top may reach the tropopause.)

Data Source for Cloud Fields

The source data used for the gridded fields are from data set H99, *Extended Edited Synoptic Cloud Reports from Ships and Land Stations over the Globe, 1952-1996* available from the Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN. The data are also available from the Data Support Section, National Center for Atmospheric Research, Boulder, CO (NCAR ds292.2). See *Hahn and Warren* [1999] for a full description of H99. The source data for H99, in turn, are synoptic records: COADS data for ocean observations [*Hahn et al.*, 1992] (see the section on "Description of COADS"); the “SPOT” archive of the US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC, formerly FNOC) for 1971 through 1976 land observations, and data from the NOAA National Centers for Environmental Prediction (NCEP, formerly NMC) for 1977 through 1996. These data sets were obtained from NCAR. Land observations prior to 1971 are not used for reasons given in *Warren et al.* [1986]. Ocean observations of cloud type are considered unreliable prior to 1952 [*Warren et al.*, 1988]. Synoptic cloud data contained elsewhere on this Atlas (Russian Ice Patrol ship cloud data, western drifting station cloud data, and most North Pole drifting station data cloud data) are not part of H99.

In creating H99, raw data were checked for quality, and observations were discarded if total cloud amount was less than low cloud amount, or if total cloud amount was equal to zero, when present weather indicated rain or snow.

Average cloud cover was computed using ship observations that fell in grid "boxes" that are 5 degrees x 5 degrees (latitude by longitude) south of 50 degrees North, 5 degrees x 10 degrees between 50 degrees and 70 degrees North, 5 degrees x 20 degrees between 70 degrees and 80 degrees North, 5 degrees x 40 degrees between 80 degrees and 85 degrees North, and 5 degrees x 120 degrees between 85 degrees and 90 degrees North. For land observations, the size of the grid boxes was 2.5 degrees x 2.5°.

Sverdrup [*Sverdrup*, 1933], commenting on observations from the *Maud*, was one of the first to note that observers generally underestimate cloud cover at night: the "night detection bias". [*Hahn et al.*, 1995]. *Hahn et al.* [1994] developed criteria by which to classify nighttime observations according to the illuminance of moonlight or twilight on cloud tops, and used a threshold illuminance to screen observations that are likely to be in error. The illuminance criterion is met when the sun is at altitude greater than minus nine degrees, or the phase and altitude of the moon are such that the relative lunar illuminance (as defined in [*Hahn et al.*, 1995]) is greater than the threshold value of 0.11. Screening in this way minimizes the night detection bias but results in a monthly sampling error, since only about two weeks of data (around the time of the full moon) contribute to an average in any month. Multi-year averages reduce this error.

In computing total and low cloud amount decadal monthly averages, "daytime" observations are defined as those taken at the four synoptic hours (out of the total of eight synoptic hours: 0000, 0300, 0600, 0900, 1200, 1500, 1800, 2100 GMT) that cover times 0600 local time (LT) to 1800 LT for a box. "Nighttime" observations are defined to be those taken at the four synoptic hours that cover times 1800 LT to 0600 LT for a grid box. Averages for daytime and nighttime were computed separately and then averaged, when a sufficient number of observations were available, in order to minimize day-night sampling bias: a potential bias that results from the majority of observations used for the average coming from daytime hours. (This is because many nighttime observations are eliminated by the illuminance criterion.) The averaging method is:

> If there are at least 50 "daytime" and at least 50 "nighttime" observations for a box in an averaging period, the average total or low cloud amount is the average for "daytime" observations plus the average for "nighttime" observations divided by two. If there are less than 50 observations for either day or night, the average is computed without distinguishing between "daytime" and "nighttime" observations. If there are less than 100 observations in total for the entire averaging period, the average value for the box is set to missing prior to regridding to EASE-Grid at NSIDC.

Long-term (1952 through 1995) monthly means were produced from the decadal monthly means by taking the average of the decadal monthly mean value for each grid cell. If a grid cell was coded as "missing" for more than one out of the five "decades", the long-term monthly mean for that grid cell was set to missing.

Method of constructing the cloud products

The decadal monthly averaged, gridded data were re-gridded from the variable box size described above to equal-area EASE-Grid using Cressman interpolation [*Cressman*, 1959]. In Cressman interpolation the value at a point (the EASE-Grid cell center) is determined by the value of the nearby surrounding points (the centers of the irregularly spaced boxes) weighted by the distance of the box center from the EASE-Grid cell center:

$$value_{gridcell} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

where x_i is the value at box i within a radius R of the grid cell center, and n is the number of box centers found within radius R. Weights w_i are given by

$$w_i = \frac{R^2 - d_i^2}{R^2 + d_i^2},$$

where d is the distance from the EASE-Grid cell center to the box centers. A radius of 500 km around each EASE-Grid cell center was used. (In comparison, the average spacing between box centers is 486 km for ocean boxes and about half that for land boxes).

Gridded cloud field products

Cloud amount products are:

- Monthly mean fields of total cloud cover (percent) for the five decades (or near-decades) between 1952 and 1995.
- Long-term monthly mean fields of total cloud cover (percent) between 1952 and 1995.
- Monthly mean fields of low cloud cover (percent) for the five decades (or near-decades) between 1952 and 1995.
- Long-term monthly mean fields of low cloud cover (percent) between 1952 and 1995.
- Figures corresponding to the decadal monthly mean products above that show the number of observations at each grid box center in the original data.

Note that land observations are not included prior to 1971 (see "Data Source for Cloud Fields). Fields for periods prior to 1971 may have some cells with data over land, however, because COADS contains cloud observations from ships on large lakes, and the gridding process may spread ocean observations over land grid cells.

The browse versions of these files are shown as .gif format images with a color bar and contours. These browse files are for the purpose of quickly visualizing the content of the corresponding ASCII data files. The IDL routine used to color-map the images gives a smooth and visually pleasing result, but keep in mind that the gridded ASCII files have a value only for every grid cell. The grid cell centers are shown as red dots. For information on the structure of the gridded files, see the section on "EASE-Grid".

The re-gridding from binned data to EASE-Grid by Cressman interpolation tends to smooth over inhomogeneities in the fields that might result from the data sampling problems caused by varying station density. At the same time, real local variations are smoothed over.

Figures corresponding to the decadal monthly mean products show the number of observations in each grid box of the original data (after filtering for more than 100 observations). These are included to give an indication of the regional and temporal variability in the density of the source data. For some locations and seasons, such as over frozen oceans in winter, there are not enough observations available to produce reliable products. However in general a surprisingly large number of observations exist. Satellite imagery might be expected to provide more data than surface observations, and can be used to construct cloud climatologies (for example, the World Climate Research Programme's International Satellite Cloud Climatology Project, [*Rossow and Schiffer*, 1999]), but methods for extracting cloud properties from satellite data have unique problems in polar regions.

When graphed, cloud distributions as seen from the limited field of an observer on the surface tend to be U-shaped, with observed cloud amounts either 0-2 tenths, or 8-10 tenths, and dominated by low cloud observations. In summer (June, July, and August), distributions tend to be J-shaped (that is, with no maximum at 0-2 tenths). This is illustrated in the figure of cloud amount frequency from Ice Station Alpha (Figure 3). A year of data for NP-4 also shows a similar distribution (Figure 4).

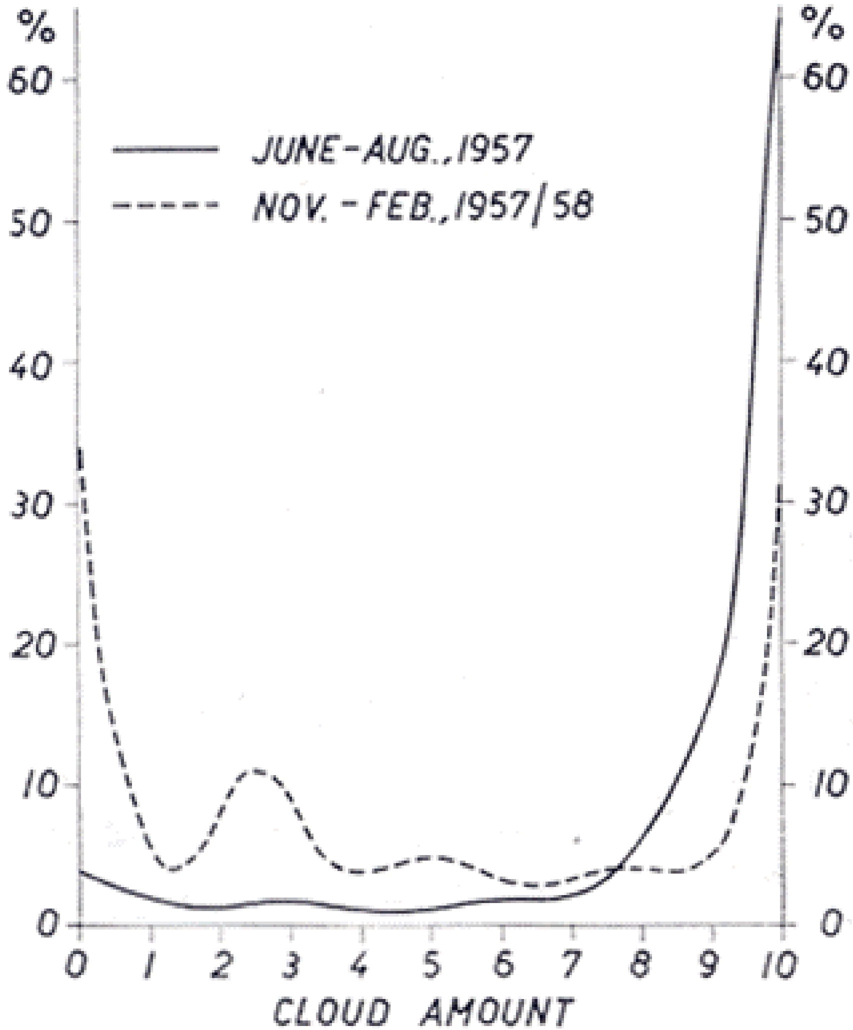


Fig. 3. Frequency of cloud amount, from three hourly observations from western drifting station Alpha (from *Untersteiner* [1961]).

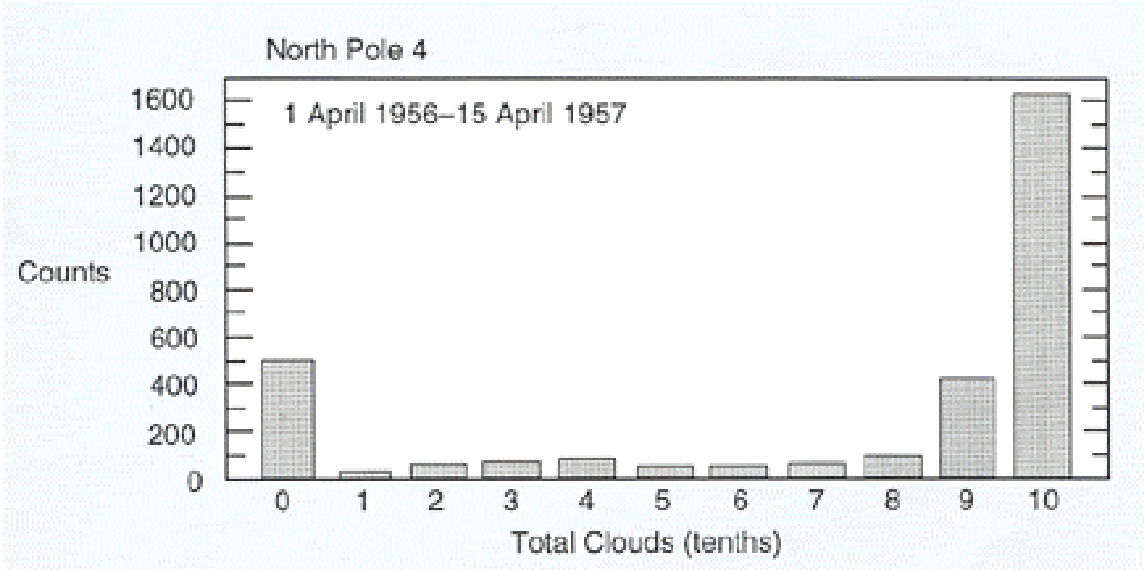


Fig. 4. Frequency of cloud amount, from observations from North Pole drifting station NP-4 (from *Makshtas et al.* [1998]).

A comment about the seasonal cycle of cloud cover

The most striking feature of low cloud cover during the winter months is the relative maximum over the northern North Atlantic. This manifests the uplift of air masses by the frequent cyclone activity in this area associated with the Icelandic Low. Low cloud cover is rather limited over central and eastern Siberia because of the general subsidence (downward motion) of air in the area of the strong Siberian high. During summer, the Icelandic Low and Siberian High weaken. Low cloud cover becomes more uniform, but with a distinct increase over the Arctic Ocean. The increase reflects the dominance of low-level stratus, which form as warm air masses moving over the ocean are chilled by the cold, melting sea ice cover. Then autumn months illustrate the transition back to the winter pattern. Total cloud cover combines low, middle and high clouds. While amounts of total cloud are hence greater than for only low cloud, it can be seen that most cloud cover is of the low variety.

Description of COADS

COADS, the Comprehensive Ocean-Atmosphere Data Set, contains global surface marine data from 1854 through 1997 (at present). Observations from ships, moored environmental buoys, and drifting buoys are quality-controlled and made available in the most extensive data set of surface marine observations ever compiled. Basic parameters are air temperature, sea surface temperature, barometric pressure, wind, humidity, cloudiness, weather, wave, and swell. COADS is a project of NOAA's Climate Diagnostics Center, the NOAA National Climatic Data Center (NCDC), the University of Colorado Cooperative Institute for Research in Environmental Science (CIRES), and the National Science Foundation's National Center for Atmospheric Research (NCAR). More information on COADS can be found on the COADS web site (http://www.cdc.noaa.gov/coads/).

Credit for the genesis of COADS is given to Joe Fletcher, who drew attention to the value of long-term marine records for climate research before it was generally recognized [*Fletcher et al.*, 1981]. International efforts at standardizing how weather observations are made, beginning with those of Lt. M. F. Maury in 1853, and now formalized in WMO resolutions, have made COADS feasible. NCDC received, consolidated, and in many cases digitized ("keyed") these data sets of early observations [*Elms et al.*, 1992; *Elms et al.,* 1993].

COADS has been made available in three major releases: Release 1 (1854 through 1979), 1a (1980 through 1997), and 1b (enhancements to 1950 through 1979). Release 2 (~1820 through 1997), with additional data, enhancements to metadata, and bias corrections for wind records, is being planned [*Woodruff et al.*, 1998; *Elms,* 1999]. Quality control in Release 1 was accomplished by "trimming", that is, by discarding observations that exceeded a 3.5-sigma level. This level was extended to 4.5 sigma in Releases 1a and 1b. An adaptive trimming approach is being considered for Release 2 [*Woodruff et al.*, 1998].

This Atlas makes indirect use of COADS for two products: cloud fields over ocean (COADS observations are the source of the cloud amount observations used) and pressure fields. (COADS observations are one data source used in constructing the gridded Reanalysis pressure fields that are used to make the products on this Atlas.) The following table notes the marine surface observation data provided with this Atlas that are in the current version of COADS or are planned for COADS.

Table 3. Relation of Atlas marine data to data in COADS

Marine Data Source on this Atlas	**Data in COADS**
AIDJEX ice stations	Planned for Release 2
Ice Station ARLIS I	Planned for Release 2
Ice Station ARLIS II	Planned for Release 2
Ice Station Alpha	Planned for Release 2
Ice Station T-3 (Ice Station Bravo)	Probably not, maybe some
Ice Station Charlie	Planned for Release 2
Maud	Planned for Release 2
Fram	Temperature and pressure, through Deck 192
Russian North Pole drifting stations	NP-1 and some other early stations, through Deck 186 (USSR Ice Station Surface Synoptic). Later stations in COADS over GTS, and through Deck 733 (Russian AARI NP stations, source was University of Washington, about 1992). For cloud data, these are total cloud only.
Ice patrol ship data	No

DARMS	No

Snow Depth and Snow Water Equivalent

There are very few measurements of snow characteristics on Arctic sea ice. The most comprehensive data set of these measurements, in terms of area and time covered, is the data set from the Russian North Pole (NP) drifting stations. *Warren et al.* [1999] interpreted these NP data in order to represent the spatial and temporal variation of snow depth on sea ice. We use the interpretation of *Warren et al.* here because the NP measurements are the only source of snow depth data complete enough to function as a climatology.

Warren et al. [1999] have represented the geographical and seasonal variation in snow depth by fitting a two-dimensional quadratic function to available data by month. The surface given by this function can be treated as a field. This representation is the best possible, in the absence of dense station coverage. Over land, coverage is more extensive. Station data from data sets available from NSIDC and NOAA, as well as station data from the Russian coastal stations on this Atlas, are used to create grids of mean snow depth.

Snow depth fields for land and for ocean are presented separately, because they represent different ranges in time and vastly different sampling densities.

Data Source for Snow Fields

Ocean

Snow depth and snow water equivalent were obtained at NP stations in accordance with methods described in the Arctic and Antarctic Research Institute (AARI) manual [*Arctic and Antarctic Research Institute*, 1985]. Daily measurements were made at the weather station at fixed stakes, and once or thrice monthly at 10 meter intervals on a survey line distant from the weather station, and 500 meters or 1000 meters long. The survey line was offset from the previous line, so that measurements were always of undisturbed snow. Snow density was measured along the survey line every 100 meters by weighing a cylinder of snow that sampled down to the ice surface. Snow water equivalent for the snow line was computed by multiplying snow depth by the ratio of the density of the snow to the density of water. See *Radionov et al.* [1996] and *Colony et al.* [1998] for more information on snow measurements at NP stations. The NP snow data are available from NSIDC (contact NSIDC User Services for information).

Measurements of snow depth from the snow lines total 499 for the years 1954 through 1991. *Warren et al.* [1999] use snow depth measurements from the snow lines rather than those from the stakes, when snow line measurements are available. They estimate the uncertainty in mean snow depth for a single snow line to be between about 0.5 cm and 2.0 cm, depending on the length of the line, the time of year, and the method used to estimate uncertainty.

An estimate of snow depth every five days for the operating life of each station was constructed with the snow line and stake data by interpolating if necessary. If snow water equivalent was not available, it was estimated using a density measurement, or if density was not available, the mean density for that month was used. These five-day values were averaged to a monthly value for each station. A two-dimensional quadratic function (six coefficients) was fitted by least squares for each month to all station data over the entire 37 year period, to produce 12 fits. There are about 70 independent data values for each month (an average of two stations reporting during each of 37 years), from which six (but no more) coefficients can be determined. See *Warren et al.* [1999] for further details.

Land

Five data sets were used to compute long-term monthly means for the snow fields over land.

Snowfall and Snow Depth for Canada, 1943-1982 has snow depth values at the end of the month. These end-of-month values were used for the Atlas fields because monthly average values were not available. Long-term monthly means were computed for each station where a given month is represented in the data record in 70 percent or more of the years from 1966 through 1982 (the period of overlap for the land data sources). The data are originally from the Atmospheric Environment Service, Canada, and from the NOAA National Climatic Data Center. The data set was compiled by J. Walsh, University of Illinois. It is available from NSIDC (http://www-nsidc.colorado.edu/NSIDC/CATALOG/ENTRIES/G00922.html)

Former Soviet Union Hydrological Snow Surveys has 10-day averages of daily snow depth at WMO stations. These data are nominally averages of the first 10 days of the month, the second ten days, and the remaining days. However, observations were not made on every day, and the distribution and number of the days on which observations were made in any one month varies significantly. To reduce bias that may result from uneven sampling, the average for a month was constructed by weighting the average snow depth for the three periods in the month by the number of days of data for that month. Thus, the average snow depth for a month with only 15 days of observations would get only half the weight of a month with 30 days of observations when the long-term monthly means were calculated. Long-term monthly means were computed for each station where a given month is represented in the data record in 70 percent or more of the years from 1966 through 1982.

Former Soviet Union Hydrological Snow Surveys snow data are from the Institute of Geography, Russian Academy of Sciences, Moscow, and were compiled by A. Krenke. The data set is available from NSIDC, (http://www-nsidc.colorado.edu/NSIDC/CATALOG/ENTRIES/G01170.html) where the data underwent quality control procedures and questionable observations were flagged. For the Atlas snow fields, only “good” (non-flagged) data were used.

Mean monthly snow-depth data from Russian coastal stations were provided by AARI. These are included in data files on this Atlas. Fifteen of these 65 coastal stations are represented in *Former Soviet Union Hydrological Snow Surveys*. Long-term monthly means were computed for each station where a given month is represented in the data record in 70 percent or more of the years from 1966 through 1982. (Data from the 50 stations not represented in *Former Soviet Union Hydrological Snow Surveys* were used).

End-of-month snow depth data for locations in Alaska were obtained from the United States Department of Agriculture (USDA) National Resource Conservation Service (NRCS) with the assistance of R. McClure, NRCS Anchorage Field Office. The NRCS Alaska homepage (http://www.ak.nrcs.usda.gov/) has information on the NRCS Alaska snow survey program. Snow course data are taken with the Standard Federal Snow Sampler according to the method described in USDA Agriculture Handbook Number 169. Most snow courses consist of five to 10 sample points. Individual measurements are averaged to give one value for the course. Measurements are generally taken at the end of the month from January through April, although measurements may be taken mid-month at some locations. Long-term monthly means were computed for each station where a given month is represented in the data record in 70 percent or more of the years from 1966 through 1982.

End-of-month snow depth data for 463 NOAA National Weather Service stations in Alaska were obtained from the Alaska Climate Research Center of the Geophysical Institute, University of Alaska, Fairbanks (UAF), with the assistance of G. Wendler and C. Rowher at UAF, and T. Zhang at NSIDC. Long-term monthly means were computed for each station where a given month is represented in the data record in 70 percent or more of the years from 1966 through 1982.

In all, the gridded snow depth fields are drawn from a total of 782 stations: the 197 stations north of 50 degrees North in *Former Soviet Union Hydrological Snow Surveys*; the 35 stations north of 50 degrees North from *Snowfall and Snow Depth for Canada, 1943-1982*, from 37 snow course locations from NRCS, from 463 stations from NWS, and from 50 Russian coastal stations. The years of overlap for these data sources are 1966 through 1982. Station locations are shown in Figure 5.

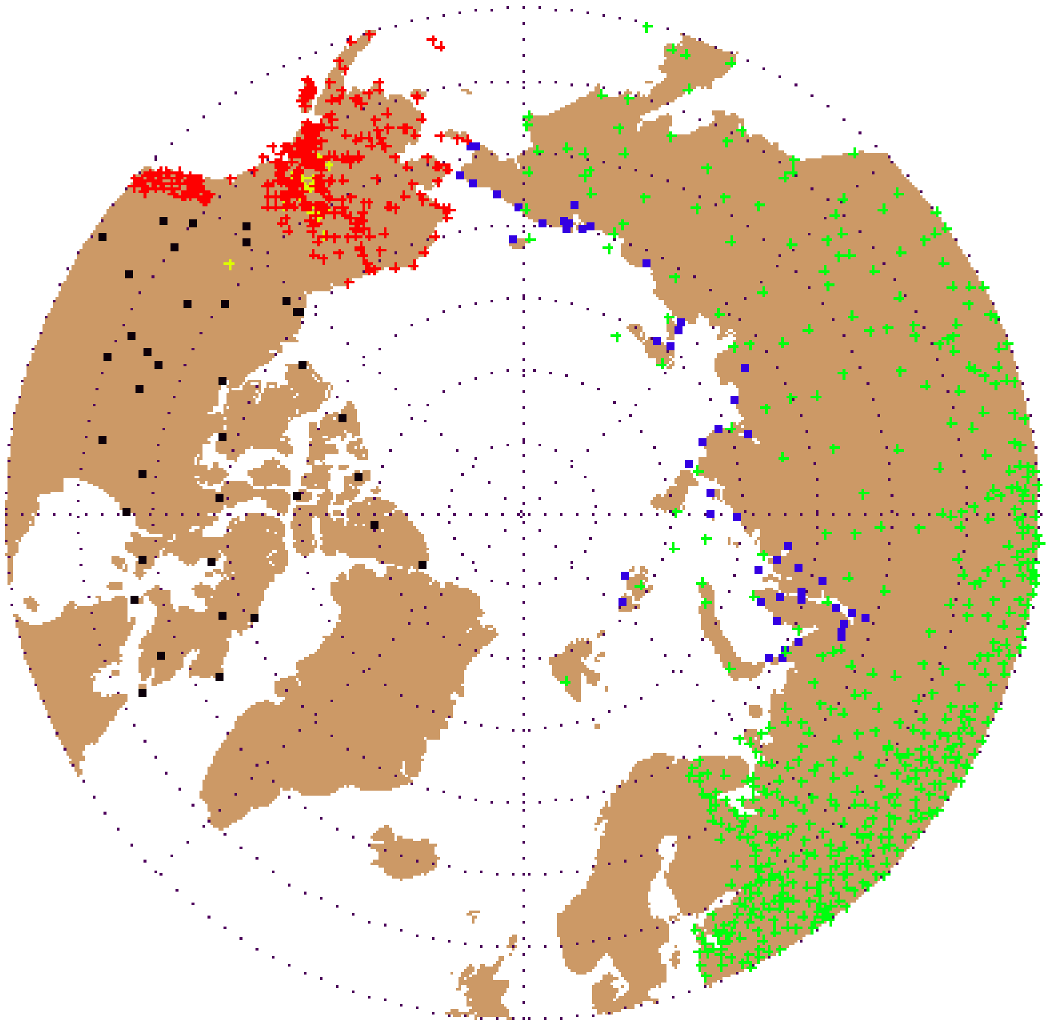


Fig. 5. Snow course locations used in the land snow depth fields. Green crosses mark stations from *Former Soviet Union Hydrological Snow Surveys*, black squares mark locations from *Snowfall and Snow Depth for Canada, 1943-1982*, yellow crosses mark NRCS snow courses, red crosses mark NWS data locations, and blue squares mark the 50 Russian coastal stations. All stations north of 55 degrees North are shown, although not all lie within the Atlas EASE-Grid.

Method of constructing the snow field products

Ocean

Warren et al. [1999] fit a two-dimensional quadratic function to all NP snow data for a particular month, irrespective of year. (Usually, only two stations were operating in any given year.) Tables 1 and 2 in *Warren et al*. give the coefficients for this fit to a rectangular grid for snow depth and snow water equivalent. To obtain snow depth and snow water equivalent for the Atlas EASE-Grid, the coefficients were used to find the snow depth at the EASE-Grid centers. The RMS error of the quadratic fit is shown in *Warren et al.* [1999].

Because NP stations were established on multiyear ice, the fields are only valid for the area of the Arctic Ocean covered by the perennial ice pack. The average ice extent for the month of September, which is generally the month of minimum ice extent and thus a reasonable proxy for mean multiyear extent, was used to mask the area outside the mean perennial ice pack. Average ice extent for September was calculated using data from 1979 through 1995 from the NSIDC data set *Northern Hemisphere EASE-Grid Weekly Snow Cover and Sea Ice Extent* (Figure 6).

Fig. 6. "Average" ice extent for September calculated using ice concentration data from satellite passive microwave brightness temperatures. The image is constructed by averaging ice concentration for 1979 through 1995, and then counting any grid cell with an average of more than 15 percent concentration as "ice-covered". This method yields a larger extent than would a method that calculates an average ice edge position.

Land

Cressman interpolation [*Cressman*, 1959] was used to grid irregularly spaced land station data to the Atlas EASE-Grid. In Cressman interpolation the value at a point (the EASE-Grid cell center) is determined by the value of the nearby surrounding observations weighted by the distance of the observation station from the cell center:

$$value_{gridcell} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

where x_i is the observation at station i within a radius R of the grid cell center, and n is the number of stations found within radius R. Weights w_i are given by

$$w_i = \frac{R^2 - d_i^2}{R^2 + d_i^2},$$

where d is the distance from the grid cell center to the station. If less than three stations were found within radius R, the grid cell value was set to missing.

Long-term monthly means from the land data sources described above were interpolated. Data from stations north of 50 degrees North, and for 1966 through 1982 (the period of overlap for the four data sources) were used. Figure 5 shows the location of the stations. A radius of 375 km around each EASE-Grid cell center was used. (In comparison, the average spacing between Canadian stations north of 60 degrees North is 286 km, and the average spacing between Russian stations north of 60 degrees North is 127 km). The radius used for Cressman interpolation determines the extent to which the station data are spatially smoothed.

Gridded snow field products

Snow field products are:

- Monthly mean snow depth fields for land, 1966 through 1982
- Monthly mean snow depth fields for the Arctic Ocean, using data from 1954 through 1991
- Monthly mean snow water equivalent fields for the Arctic Ocean, using data from 1954 through 1991

The browse versions of these files are shown as .gif format images with a color bar and contours. These browse files are for the purpose of quickly visualizing the content of the corresponding ASCII data files. The IDL routine used to color-map the images gives a smooth and visually pleasing result, but keep in mind that the gridded ASCII files have a value only for every grid cell. The grid cell centers are shown as red dots. For information on the structure of the gridded files, see the section on “EASE-Grid".

A comment about the seasonal cycle of snow

The winter fields indicate greater snow depths over the North American side of the Arctic Ocean. This is because temperatures are lower in this region, so that snow falling during the autumn months tends to more readily accumulate compared to other areas. However, March shows a tendency for deeper snow cover towards the Atlantic side of the Arctic Ocean. This is because winter snowfall is comparatively high in this area due to the northward penetration of storms associated with the Icelandic Low. Moving through spring and summer, the pattern of greater snow depths on the North American side is reestablished. Again, this is because this region tends to be colder, but here the effect is to result in slower melt. Most of the snow is melted by August. The season's first snowfall tends to occur in September. Because snow densities are broadly similar across the Arctic Ocean, the seasonal cycle of snow water equivalent is similar to that of snow depth.

Land areas with high winter snow depths correspond in part to regions with fairly high elevations (for example, Alaska and parts of Siberia). This is understood in that higher-elevation areas tend to be somewhat cooler, so snow can more easily accumulate in autumn. Snowfall may also be enhanced by orographic uplift of air masses. For other areas, such as Northwestern Eurasia, large snow depths appear to be more directly a reflection of synoptic activity. Note the low winter snow depths over east-central Siberia, where the strong Siberian High suppresses precipitation. The seasonal melt of the snow cover occurs earlier over the North American side. By July, snow cover has essentially disappeared.

Solar Radiation

Documentation written by F. Fetterer; edited by M. Serreze

Global (or total downwelling short-wave) radiation fields are constructed using measurements from the Russian North Pole drifting stations, western drifting stations, land stations, and empirically derived values from earlier Russian studies. The radiation fields are derived in the same way as those presented in *Serreze et al.* [1998], but are improved with additional data.

Data sources for global radiation fields

Ocean data sources

Radiation data from the Russian North Pole (NP) drifting stations were compiled by AARI scientists as monthly averages for the mean position of stations NP-17 through NP-31 [*Marshunova and Mishin*, 1994], and obtained from *Daily Arctic Ocean Rawinsonde Data from Soviet Drifting Ice Stations*, a CD-ROM product of AARI, University of Washington Polar Science Center, and NSIDC.

Radiation data from U.S. drifting station "T-3", primarily for the spring through autumn months of 1953, 1957 through 1959, and 1971 through 1973 were digitized from tables in *Marshunova and Chernigovskii* [1971] and *Weller and Holmgren* [1974].

Monthly radiation means and positions from U.S. drifting station "ARLIS II" for January 1964 through May 1965 were digitized from tables in *Roulet* [1969].

Measurements collected during the Surface Heat Budget of the Arctic (SHEBA) field program provided data for 1997 through 1998.

The total number of station months from these combined data sources is over 70 from June through September, and over 40 from March through May, as well as October. Very few data points are available from November through February, when polar darkness dominates most of the Arctic.

Land data sources

The Global Energy Balance Archive (GEBA; [*Gilgen and Ohmura*, 1999;*Ohmura and Gilgen*, 1991], http://bsrn.ethz.ch/gebastatus/) provided monthly means for global radiation for 57 land stations north of 60 degrees North. Station records range in length from one to 45 years. Stations in the Russian *Technological Handbook of the Climate Of Russia (Arctic Region) Solar Radiation* (provided in English on this Atlas), are for the most part represented in GEBA, but because the tables of mean monthly values in the Handbook are generally the result of more years of data than the GEBA averages, with few exceptions we used the Handbook values for a station rather than the GEBA values when both were available. Monthly values for nine Alaskan stations (1961 through 1990) were obtained from the NOAA Solar and Meteorological Surface Observations (SAMSON) archive (available from NSIDC). Monthly records of at least 20 years duration for 14 sites in the Canadian Arctic, obtained from the Atmospheric Environment Service, Ottawa, and climatological monthly means for two Eurasian sites from *Gavrilova* [1963] were also included.

Several years of monthly data from the early 1970s were obtained for the Baffin Bay region as a result of field experiments [*Muller and Coauthors*, 1976; *Jacobs et al.*, 1974]. Records of up to five years in length (1995 through 1999) for 13 stations over the Greenland ice sheet came from the National Atmospheric and Space Administration (NASA) -sponsored Program for Arctic Regional Climate Assessment (PARCA).

Ancillary data sources

The assembled archives provide poor coverage over the North Atlantic Ocean and for coastal Greenland. To obtain coverage for these areas, it was necessary to resort to calculated values provided by *Marshunova and Chernigovskii* [1971] and *Smetannikovoi* [1983]. These estimates are based on consideration of clear sky radiation and attenuation by aerosols, cloud amount, and cloud type.

Method of constructing the global radiation field products

Monthly mean global radiation values from the data sets described above were interpolated to the EASE-Grid using Cressman interpolation [*Cressman*, 1959]. The Cressman interpolation routine is given by:

$$value_{gridcell} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i}$$

where x_i is the monthly mean value of radiation at location i within a radius R of the grid location, and n is the number of stations found within the search radius. The weights w_i are given by

$$w_i = \frac{R^2 - d_i^2}{R^2 + d_i^2}$$

where d is the distance from the grid cell to the observation location.

Using the monthly mean values directly may introduce biases related to latitudinal dependencies of the flux. Therefore, prior to the application of the Cressman interpolation, an estimate of clear sky downwelling short-wave flux was subtracted from the station value. This step essentially normalizes the data with respect to latitudinal variations in solar zenith angle and day length, and with respect to associated path-length dependencies of non-cloud atmospheric absorption and scattering. The clear sky downwelling short-wave flux is added back to the gridded values after interpolation.

The clear sky downwelling short-wave flux is based on a radiative transfer model [*Schweiger and Key*, 1994]. The clear sky flux calculations use calculated or derived values for surface albedos, optical depth, month-specific total precipitable water, and total column ozone. Uncertainties in these quantities have little effect on the resulting clear sky radiance. For instance, for a 20 percent error in assumed albedo of 0.85, the resulting error in the calculated flux of 400 Wm-2 is only 5 Wm-2. See *Serreze et al.* [1998].

The record length for the land station data varies widely, and some land and ocean data are given as climatological monthly means only. Data from the North Pole drifting stations are from a different position for each month. To reduce spatial biases that would be introduced by interpolating drifting station and other data without regard to position and record length, a two-step interpolation procedure was used. First, individual monthly means at the average position for that month from the North Pole drifting stations were interpolated to the ocean EASE-Grid cell centers. The initial search radius R was set to 500 km. If data from fewer than five years were available (that is, fewer than five monthly mean values) within that radius, the search was enlarged to 750 km. The grid cell was coded as missing if fewer than five monthly mean values resulted from the enlarged search.

In the second step, climatological monthly means for land stations were calculated from the station record of monthly means. Climatological means based on less than three years were discarded. These values, plus those calculated values described in the "Ancillary data sources" section above, were combined with the ocean grid cell values from the first step of the interpolation. Land and ocean points in the combined data set were then interpolated to EASE-Grid cell centers, using a search radius of 500 km, enlarged if necessary to 750 km, 1000 km, and 1250 km, with a minimum of two values for each radius. The larger radii were necessary because of the relatively great distance between land stations.

In order to fill grid cells that would otherwise be coded as missing for months from November through February (when polar darkness dominates), grid cells where the clear sky downwelling short-wave flux is less than 15 Wm-2 were simply ascribed the clear sky value multiplied by an assumed effective cloud transmittance of 0.60. Calculations of effective cloud transmittance are described in *Serreze et al.* [1998].

Gridded radiation field products

The gridded radiation products are climatological monthly means. The browse versions of these files are shown as .gif format images with a color bar and contours. These browse files are for the purpose of quickly visualizing the content of the corresponding ASCII data files. The IDL routine used to color-map the images gives a smooth and visually pleasing result, but keep in mind that the gridded ASCII files have a value only for every grid cell. The grid cell centers are shown as red dots. For information on the structure of the gridded files, see the section on "EASE-Grid".

Limitations

The large search radius used for the Cressman interpolation tends to smooth over inhomogeneities in the fields that might result from the data sampling problems related to varying station density and caused by using records of different length. At the same time, real local variations are smoothed over. The results for the North Atlantic and coastal Greenland are based on empirically derived values and should be viewed with caution.

The data sets described above were checked for obvious outliers but were otherwise used as provided. Radiometers generally have an accuracy of ±5 to ±10 Wm-2. However, the accuracy may be less if sensors were calibrated in non-Arctic conditions. The extreme solar zenith angles of the Arctic can lead to large measurement errors, due to limitations in the cosine response of the instruments, and to multiple reflections within the radiometer domes.

A related analysis

The section of the Atlas containing gridded field data also contains a monthly climatology of direct, total (or global) and net radiation by M. S. Marshunova.

A comment about the seasonal cycle of solar radiation

The field of global radiation for March shows a primarily zonal pattern, that is, one in which radiation decreases with latitude. This occurs because in March, the amount of solar radiation at the top of the atmosphere decreases sharply with increasing latitude. From April through August, latitudinal variations in solar radiation at the top of the atmosphere are less pronounced, so that cloud cover plays a strong role in determining the flux reaching the surface. Consequently, radiation patterns from April through August are very asymmetric. Fluxes are lowest over the Atlantic sector, where cloud cover is greatest. Fluxes peak over central Greenland from May through August. In large part, this illustrates the tendency for the high central portions of the ice sheet to be above the bulk of cloud cover. The highest fluxes are found in June because radiation at the top of the atmosphere peaks in this month. Note for June the rather high fluxes over the central Arctic Ocean. This is largely explained in that cloud cover over this region is comparatively limited. From July onwards, radiation fluxes decline. September shows a zonal pattern, which as with March, arises from the strong latitudinal variation in solar flux at the top of the atmosphere for this month.

Coastal Stations

Monthly means of meteorological observation data from 65 Russian and 24 western coastal and island stations for a period that includes the early 1950s through 1990 are provided in uniformat files. The Russian station observations were provided by the Arctic and Antarctic Research Institute (AARI), St. Petersburg, and include two-meter air temperature, sea level pressure, total and low cloud amount, and relative humidity. The western station observations include sea level pressure, air temperature, and precipitation. After 1960, a moisture parameter (relative humidity or dew point temperature) is generally available. (We use the term "western" loosely to distinguish the Russian from non-Russian stations.) Use the HTML interface to see the temporal coverage of each parameter at each station. The interface can also be used to browse the data by plotting parameters.

Russian Station Data

Documentation provided by V. Radionov, edited by F. Fetterer

Overview

This Atlas includes monthly means of meteorological observation data from 65 Russian coastal and island stations for a period that includes (at a minimum) the early 1950s through 1990. (See Table 4 for details, and Table 8 for the current WMO station names for these 65 stations, as there may be differences in the transliteration of the names. Use the Atlas interface to see the length of the data record at any station for any of the parameters included in the Atlas.)

Meteorological observations were taken 24 hours a day. Observation hours were changed several times within the period of record. Observations were performed at 0700, 1300 and 2100 local solar time up to 1935; at 0100, 0700, 1300 and 1900 local solar time for 1936 through 1965; and at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 hours Moscow Local Time for 1966 through 1991. All times have been converted to GMT for the data set on this Atlas. A description of the surface parameters measured at the stations is presented in Table 5. Note that not all of these parameters are included on this Atlas. This Atlas contains monthly mean values for two-meter air temperature, surface pressure, relative humidity, surface (soil or snow) temperature, total cloud amount, and low cloud amount.

Meteorological observations were performed according to the *Manual for hydrometeorological stations and posts* [*Gidrometeoizdat*, 1985]. The meteorological site was 26 meters by 26 meters in size, and was located on relief typical of the area**.** It was more than 100 meters distant from any bodies of water, and at a distance 20 times the height of any obstruction (such as trees or a building). Station and barometer elevations as well as the dates of installation of Tretyakov precipitation gauges (which replaced Nipher shielded gauges) are presented in Table 6. The accuracy of observations is given in Table 7. In the original data tables some gaps occurred in the period of record and other gaps were introduced due to quality control.

Average daily, 10-day, monthly, seasonal, annual and long-term values of meteorological parameters were calculated from individual observations. The meteorological parameters needed for operational applications were recorded within 24 hours on paper tape. The average monthly values of air temperature taken at two meters, surface temperature, atmospheric pressure, amount of total and lower cloud, and relative humidity were recorded at the stations, and are included in the data set on this Atlas after quality control. Quality control of the coastal and island station data was performed using the methods outlined in the section “AARI quality control methods”.

WMO station names

Stations are referred to throughout this Atlas by the transliteration of their Russian name provided by AARI. This, as well as the position of the station, may vary from the WMO name for the station. Table 8 shows the names and positions used on this Atlas (from AARI) along with the corresponding WMO information. The information on WMO stations was obtained on-line from the NOAA National Weather Service (http://www.nws.noaa.gov/oso/site.html).

Table 4. Russian coastal and island stations

Synoptic number	**Station**	**Month and year the station activity started**
20026	OSTROV VICTORIYA	Sep. 1959
20034	NAGURSKAYA	Jun. 1952
20046	OSTROV HEISA	Nov. 1957
20049	OSTROV RUDOLFA	Sep. 1932
20066	OSTROV USHAKOVA	Jul. 1954
20069	OSTROV VIZE	Nov. 1945
20087	MYS GOLOMYANNYY	Jul. 1954
20186	OSTROVA KRASNOPHLOTSKIE	Oct. 1953
20274	OSTROV UEDINENIYA	Sep. 1934
20277	OSTROV ISACHENKO	Oct. 1953
20289	OSTROV RUSSKIY	Sep. 1935
20292	MYS CHELUSKIN	Sep. 1932
20294	OSTROV GEYBERGA	Jan. 1952
20353	MYS ZHELANIYA	Oct. 1931
20357	RUSSKAYA GAVAN	Sep. 1932
20388	OSTROV PRAVDY	Aug. 1940
20471	OSTROV IZVESTIY ZIK	Oct. 1953
20476	MYS STERLEGOVA	Oct. 1934
20665	OSTROV VILKITSKOGO	Mar. 1954
20667	OSTROV BELYY	Nov. 1933
20674	OSTROV DIKSON	Sep. 1916
20679	UST-TAREYA	Feb. 1954
20696	MYS KOSISTYY	Jul. 1939
20744	MALYE KARMAKULY	Jan. 1897
20766	MYS LESKINA	Oct. 1934
20856	MYS KHARASAVEY	Oct. 1953
20871	SOPOCHNAYA KARGA	Oct. 1939
20891	KHATANGA	Dec. 1928
20946	BOLVANSKIY NOS	Oct. 1947
21301	OSTROV ANDREYA	Oct. 1942
21358	OSTROV ZOKHOVA	Feb. 1955
21405	BUKHTA PRONCHISHCHEVOY	Oct. 1934

21432	OSTROV KOTELNYY	Jul. 1933
21504	OSTROV PREOBRAZHENIYA	Oct. 1934
21535	PROLIV SANNIKOVA	Dec. 1940
21541	ZEMLYA BUNGE	Oct. 1953
21611	MYS TERPYAY-TUMSA	Dec. 1959
21613	OSTROV DUNAY	Nov. 1954
21627	SAGYLLAH-ARY	Oct. 1961
21636	KIGILYAKH	Oct. 1934
21647	MYS SHALAUROVA	Nov. 1928
21733	MYS SVYATOY NOS	Jun. 1952
21824	BUKHTA TIKSI	Aug. 1932
21825	OSTROV MUOSTAKH	Sep. 1935
21849	INDIGIRSKAYA	Jun. 1955
21931	KAZACHIE	Jan. 1934
21955	ALAZEYA	Jul. 1947
21965	OSTROV CHETYREKHSTOLBOVOY	Oct. 1933
21978	VALKARKAY	Oct. 1941
21982	OSTROV VRANGELYA	Sep. 1926
23022	AMDERMA	Dec. 1933
23032	MARRE-SALE	Sep. 1914
25034	BUKHTA AMBARCHIK	Oct. 1935
25042	AYON	Jun. 1939
25051	PEVEK	Jan. 1935
25062	MYS BILLINGSA	Aug. 1935
25121	KOLYMSKAYA	Jan. 1949
25123	CHERSKIY	Nov. 1940
25151	CHAUN	Jan. 1946
25173	MYS SCHMIDTA	Sep. 1932
25282	VANKAREM	Oct. 1934
25286	OSTROV KOLUCHIN	May. 1941
25399	MYS UELEN	Sep. 1928
25594	BUKHTA PROVIDENIYA	Sep. 1934
25595	CHAPLINO	Dec. 1939

Table 5. Meteorological parameters measured at the meteorological stations

Meteorological parameter	**Observation characteristic**
Air temperature	Temperature, maximum, minimum (with thermograph)
Air pressure	Pressure, pressure tendency (with barograph)
Air humidity	Partial pressure of water vapor, relative humidity, moisture deficit (with self-recording hydrometer)
Precipitation	Measurement of amount, duration period (within 24 hours), and type of precipitation two or four times within 24 hours

Wind	Direction and wind speed (with an anemorumbograph, or recording anemometer)
Cloud	Amount of total and low cloud, its form and type (observation made visually)
Visibility	Values of horizontal meteorological visibility by devices or visually (using landmarks)
Atmospheric phenomena	Snowstorms, fogs, squalls, thundershowers, precipitation (noted by observer)
Sunlight	Duration period (by heliograph)
Sheet of glaze and rime accretion	Thickness and diameter of accretion
Temperature of soil or snow surface	Temperature, and daily maximum and minimum
Snow cover	At meteorological site: snow depth, fractional area of snow cover (daily). On snow survey course 0.5-2 km: depth and density of snow (daily and monthly)

Table 6. Station and barometer elevations (meters above sea level, or MASL) and dates of Tretyakov's precipitation gauge installation (usually replacing earlier Nipher gauge).

WMO No	Station	Station (MASL)	Barometer (MASL)	Installation of Tretyakov's precipitation gauge
20026	OSTROV VICTORIYA	8	9.2	10 Jan. 1960
20034	NAGURSKAYA	15	17.2	30 Jun. 1952
20046	OSTROV HEISA	20	21.0	1957
20049	OSTROV RUDOLFA	51	46.0	21 Sep. 1951
20066	OSTROV USHAKOVA	49	50.7	1954
20069	OSTROV VIZE	10	11.0	20 Apr. 1953
20087	MYS GOLOMYANNYY	7	8.0	14 Jun. 1954
20186	OSTROVA KRASNOPHLOTSKIE	8	5.6	25 Oct. 1953
20274	OSTROV UEDINENIYA	22	8.6	20 Sep. 1951
20277	OSTROV ISACHENKO	10	4.7	07 Oct. 1953
20289	OSTROV RUSSKIY	9	9.2	08 Sep. 1954
20292	MYS CHELUSKIN	13	14.2	10 Oct. 1949
20294	OSTROV GEYBERGA	6	7.5	24 Sep. 1951
20353	MYS ZHELANIYA	8	8.9	20 Jun. 1951
20357	RUSSKAYA GAVAN	18	9.4	18 Aug. 1949
20388	OSTROV PRAVDY	10	9.9	1954
20471	OSTROV IZVESTIY ZIK	11	11.9	1953
20476	MYS STERLEGOVA	10	9.4	31 Aug. 1951
20665	OSTROV VILKITSKOGO	3	3.6	01 Mar. 1954
20667	OSTROV BELYY	4	6.2	1954
20674	OSTROV DIKSON	42	47.2	01 Oct. 1949

20679	UST-TAREYA	14	16.9	19 Jan. 1954
20696	MYS KOSISTYY	20	9.5	26 Oct. 1954
20744	MALYE KARMAKULY	20	15.7	31 Jul. 1953
20766	MYS LESKINA	10	10.8	18 Oct. 1954
20856	MYS KHARASAVEY	10	11.7	01 Oct. 1953
20871	SOPOCHNAYA KARGA	4	5.8	09 Sep. 1954
20891	KHATANGA	30	33.4	1956
20946	BOLVANSKIY NOS	13	12.2	27 Mar. 1952
21301	OSTROV ANDREYA	6	5.4	03 Oct. 1952
21358	OSTROV ZOKHOVA	14	16.0	01 Jun. 1955
21405	BUKHTA PRONCHISHCHEVOY	15	5.7	1954
21432	OSTROV KOTELNYY	10	7.8	03 Nov. 1949
21504	OSTROV PREOBRAZHENIYA	24	10.6	01 Oct. 1949
21535	PROLIV SANNIKOVA	16	16.0	28 Feb. 1953
21541	ZEMLYA BUNGE	10	11.4	01 Oct. 1953
21611	MYS TERPYAY-TUMSA	12	9.3	17 May. 1956
21613	OSTROV DUNAY	5	3.4	20 Nov. 1954
21627	SAGYLLAH-ARY	1	2.9	12 Jul. 1963
21636	KIGILYAKH	26	24.7	06 May 1951
21647	MYS SHALAUROVA	14	21.8	10 Oct. 1953
21733	MYS SVYATOY NOS	6	6.5	01 Oct. 1953
21824	BUKHTA TIKSI	6	6.7	01 Jul. 1953
21825	OSTROV MUOSTAKH	3	4.1	04 Oct. 1953
21849	INDIGIRSKAYA	2	4.1	08 Aug. 1954
21931	KAZACHIE	25	26.2	17 May. 1955
21955	ALAZEYA	2	3.9	15 Sep. 1952
21965	OSTROV CHETYREKHSTOLBOVOY	32	15.3	13 Aug. 1953
21978	VALKARKAY	4	6.3	05 Nov. 1952
21982	OSTROV VRANGELYA	2	2.0	20 Sep. 1953
23022	AMDERMA	52	46.0	1952
23032	MARRE-SALE	24	25.4	29 Aug. 1951
25034	BUKHTA AMBARCHIK	26	22.0	25 Nov. 1955
25042	AYON	16	13.0	11 Aug. 1954
25051	PEVEK	5	5.3	1953
25062	MYS BILLINGSA	4	4.4	01 Oct. 1954
25121	KOLYMSKAYA	10	15.0	1956
25123	CHERSKIY	23	24.5	28 May 1955
25151	CHAUN	6	8.0	15 Sep. 1960
25173	MYS SCHMIDTA	3	4.4	01 Oct. 1949
25282	VANKAREM	5	6.0	23 Aug. 1954

25286	OSTROV KOLUCHIN	38	40.4	29 Aug. 1949
25399	MYS UELEN	6	7.0	1953
25594	BUKHTA PROVIDENIYA	9	11.2	04 Apr. 1950
25595	CHAPLINO	5	5.1	15 Aug. 1954

Table 7. Meteorological parameters and measurement accuracy.

Parameter	**Measurement (observation) accuracy**
Air temperature	Air temperature is measured by mercury thermometer placed in psychrometric box at a meteorological site. Measurement accuracy is equal to 0.1 °C.
Air pressure	Atmospheric air pressure is measured by mercury barometer placed in stationary room at 50 to 60 cm height from floor (barometric cistern). Corrected record is written in hPa with accuracy up to 0.1 hPa. (This is given as mbar in the data set on this Atlas).
Air humidity	Relative humidity is calculated by records of dry-bulb and wet-bulb thermometers (in summer) and by data of dry thermometer and hair hygrometer (when temperature is below -10 °C). Calculation accuracy is 1%.
Cloud	Cloud is defined visually. Cloud amount is given in tenths; cloud forms are defined by the international Atlas of clouds; base height of low cloud border is defined visually or by IVO device with accuracy up to 50 m.
Precipitation	Precipitation amount is measured by "O-1" precipitation gauge (Tretyakov precipitation gauge) twice daily (0000 and 0600 hours local time) to an accuracy of 0.1 mm.
Surface temperature	Temperature of the soil or snow surface is measured by mercury thermometer and recorded to the nearest whole degree.

Table 8. Station information from AARI compared with WMO station information. Dashes indicate no match.

AARI Station Number	**WMO Station Number**	**AARI Station Name**	**WMO Station Name**	**AARI Station Lat. (dec. deg. N.)**	**WMO Station Lat. (dec. deg. N.)**	**AARI Station Long. (dec. deg. E.)**	**WMO Station Long. (dec. deg. E.)**
20026	20026	Ostrov Victoriya	Viktoriya Island	80.15	80.17	36.77	36.75
20034	-----	Nagurskaya	-	80.8	-----	47.63	------
20046	20046	Ostrov Heisa	Polargmo Im. E. T. Krenkelja	80.62	80.62	58.05	58.05

20049	20049	Ostrov Rudolfa	Tikhaya Bay	81.8	80.37	57.97	52.92
20066	20066	Ostrov Ushakova	Ushakova Island	80.82	80.83	79.55	79.7
20069	20069	Ostrov Vize	Ostrov Vize	79.5	79.5	76.98	76.98
20087	20087	Mys Golomyannyy	Ostrov Golomjannyj	79.55	79.55	90.62	90.62
20186	-----	Ostrova Krasnophlotskie	-	78.63	-----	98.72	------
20274	20274	Ostrov Uedineniya	Ostrov Uedinenija	77.5	77.5	82.23	82.2
20277	20277	Ostrov Isachenko	Isachenko Island	77.15	77.28	89.2	89.67
20289	20289	Ostrov Russkiy	Russkiy Island	77.17	77.18	96.43	96.58
20292	20292	Mys Cheluskin	Gmo Im. E. K. Fedorova	77.72	77.72	104.3	104.3
20294	-----	Ostrov Geyberga	-	77.6	-----	101.52	------
20353	20353	Mys Zhelaniya	Mys Zelanija	76.95	76.95	68.58	68.55
20357	20357	Russkaya Gavan	Russkaya Gavan	76.18	76.18	63.57	63.57
20388	20388	Ostrov Pravdy	Pravdy Island	76.27	76.28	94.28	94.73
20471	20471	Ostrov Izvestiy Zik	Troynoy Island	75.92	75.92	83.08	83.25
20476	20476	Mys Sterlegova	Cape Sterlegova	75.42	75.4	88.9	88.78
20665	20665	Ostrov Vilkitskogo	Vilkickogo Island	73.52	73.5	75.77	76
20667	20667	Ostrov Belyy	Im. M. V. Popova	73.33	73.33	70.05	70.05
20674	20674	Ostrov	Ostrov	73.5	73.5	80.23	80.4

		Dikson	Dikson				
20679	20679	Ust-Tareya	Tareya Stream	73.22	73.25	89.72	90.92
20696	-----	Mys Kosistyy	-	73.67	-----	109.73	------
20744	20744	Malye Karmakuly	Malye Karmakuly	72.38	72.37	52.73	52.7
20766	20766	Mys Leskina	Leskino	72.35	72.33	79.55	79.5
20856	20856	Mys Kharasavey	Cape Kharasovoy	71.13	71.4	66.75	67.63
20871	20871	Sopochnaya Karga	Sopochnaya Karga	71.87	71.9	82.7	82.72
20891	20891	Khatanga	Hatanga	71.97	71.98	102.47	102.47
20946	20946	Bolvanskiy Nos	Cape Bolvanskij	70.45	70.45	59.07	59.07
21301	21301	Ostrov Andreya	Andreya Island	76.82	76.8	111.45	110.83
21358	-----	Ostrov Zokhova	-	76.15	-----	152.83	------
21405	-----	Bukhta Pronchishchevoy	-	75.53	-----	113.43	------
21432	21432	Ostrov Kotelnyy	Ostrov Kotel'Nyj	76	76	137.9	137.87
21504	21504	Ostrov Preobrazheniya	Ostrov Preobrazenija	74.67	74.67	112.93	112.93
21535	-----	Proliv Sannikova	-	74.67	-----	138.9	------
21541	-----	Zemlya Bunge	-	74.88	-----	142.12	------
21611	-----	Mys Terpyay-Tumsa	-	73.55	-----	118.67	------
21613	-----	Ostrov Dunay	-	73.93	-----	124.5	------
21627	-----	Sagyllah-Ary	-	73.15	-----	128.9	------
21636	-----	Kigilyakh	-	73.35	-----	139.88	------
21647	21647	Mys	Mys	73.18	73.18	143.93	143.23

		Shalaurova	Shalaurova				
21733	-----	Mys Svyatoy	-	72.83	-----	140.73	------
21824	21824	Bukhta Tiksi	Tiksi	71.58	71.58	128.92	128.92
21825	21825	Ostrov Muostakh	Mostakh Island	71.55	71.53	130.02	129.92
21849	-----	Indigirskaya	-	71.27	-----	150.28	------
21931	21931	Kazachie	Jubilejnaja	70.75	70.77	136.22	136.22
21955	-----	Alazeya	-	70.67	-----	154	------
21965	21965	Ostrov Chetyrekhstolbovoy	Ostrov Chetyreh-Stolbovoy	70.63	70.63	162.48	162.48
21978	-----	Valkarkay	-	70.08	-----	170.93	------
21982	21982	Ostrov Vrangelya	Ostrov Vrangelja	70.97	70.98	181.52	178.48
23022	23022	Amderma	Amderma	69.77	69.75	61.68	61.7
23032	23032	Marre-Sale	Maresale	69.72	69.72	66.8	66.8
25034	25034	Bukhta Ambarchik	Buhta Ambarcik	69.63	69.62	162.3	162.3
25042	25042	Ayon	Ajon Island	69.93	69.83	167.98	168.67
25051	-----	Pevek	-	69.7	-----	170.25	------
25062	-----	Mys Billingsa	-	69.88	-----	175.77	------
25121	25121	Kolymskaya	Koljmskaja	68.68	68.73	158.72	158.73
25123	25123	Cherskiy	Cherskij	68.8	68.75	161.28	161.28
25151	25151	Chaun	Caun	68.88	68.8	170.78	170.67
25173	25173	Mys Schmidta	Mys Shmidta	68.92	68.9	180.53	179.37
25282	-----	Vankarem	-	67.83	-----	184.17	------
25286	-----	Ostrov Koluchin	-	67.48	-----	185.37	------
25399	25399	Mys Uelen	Mys Uelen	66.17	66.17	190.17	169.83

25594	25594	Bukhta Provideniya	Buhta Providenja	64.42	64.42	186.77	173.23
25595	-----	Chaplino	-	64.4	-----	187.75	------

Western Station Data

This Atlas contains monthly means of meteorological observation data from 24 western coastal and island stations for a period that generally includes the early 1950s through 1990. The data are in uniformat files. (See Table 9 for the WMO station names and other information for these stations, and for the starting month and year for which data are available. Use the Atlas interface to see the length of the data record at any station for any of the parameters included in the Atlas.)

Stations were selected based on length of record and coastal location, and to complement the Russian coastal station data and provide circumpolar coastal data. The western station data are from National Center for Atmospheric Research (NCAR) data set 570.0, *World Monthly Station Data Climatology*. For two stations, Vardo and Isfjord Radio, data are from the NCDC Global Historical Climate Network (GHCN).

Table 9. Western coastal stations on the Atlas. Station location and number are from a WMO station listing rather than from information in data set 570. Starting month and year is for data on this Atlas.

Station Name	WMO Station Number	Latitude (deg. N)	Longitude (deg. E.)	Elevation (m)	Data starting month, year
AKLAVIK	71968	68.2	225.2	56	Jul. 1926
ALERT	71082	82.5	297.4	63	Jan. 1951
BARROW	70026	71.4	203.7	13	Jan. 1921
BARTER ISLAND	70086	70.1	216.4	2	Jan. 1948
BJORNOYA	1028	74.5	19.0	16	Jan. 1951
CAMBRIDGE BAY	71925	69.1	255.0	23	Jan. 1941
CLYDE	71090	70.5	291.4	25	Jan.,1943
COPPERMINE	71938	67.8	244.8	22	Jan. 1931
EGEDESMINDE	4220	68.7	307.2	43	Jan. 1951
EUREKA	71917	80.0	301.1	10	May, 1947
ISACHSEN	71074	78.8	256.5	58	May, 1948
ISFJORD RADIO	1005	78.0	14.2	missing	Jan. 1912
JAN MAYEN	1001	71.0	351.6	10	Jan. 1921
KOTZEBUE	70133	66.9	197.4	3	Oct. 1928

MOULD BAY	71072	76.3	240.5	15	Jun. 1948
MYGGBUKTA	99900	73.5	338.5	899	Jan. 1932
NOME	70200	64.5	194.6	11	Jan. 1907
NORD	4310	81.6	343.3	36	Apr. 1952
RESOLUTE	71924	74.7	265.1	67	Jan. 1948
SACHS HARBOUR	71051	72.0	235.3	88	Nov. 1955
SCORESBY SUND	4339	70.5	338.0	65	Nov. 1980
THULE	4202	76.5	291.2	77	Sep. 1946
UPERNAVIK	4210	72.8	303.9	120	Sep. 1873
VARDO	1098	70.4	31.1	14	Jan. 1941

NCAR data set 570.0, *World Monthly Station Data Climatology*, is a product of the Data Support Section at NCAR. Most of these data came from NCDC's *Monthly Climate Data of the World*. Other data sources were World Weather Records from the Smithsonian Institution, the U. S. Weather Bureau, and the Department of Commerce. Standard parameters are sea level pressure, station pressure, temperature, and precipitation. After 1960, moisture parameters and percent sunshine are available. Documentation by W. Spangler and R. Jenne (available from ftp://ncardata.ucar.edu/datasets/ds570.0/format) provides information on the entire data set, which contains data from more than 3900 stations. Data were quality controlled at NCAR by looking for deviations of greater than four or five standard deviations from the long period monthly mean. These extreme values were then manually inspected and either accepted, or set to missing.

The Global Historical Climatology Network (GHCN, http://www.ncdc.noaa.gov/ol/climate/research/ghcn/ghcnoverview.html) contains monthly temperature and precipitation data. Version 2 contains temperature data from over 7000 stations. They have been quality controlled by a variety of methods, as documented in "Quality Control of Monthly Temperature Data: the GHCN Experience", by T.C. Peterson, R. Vose, R. Schmoyer, and V. Razuvaev (http://www.ncdc.noaa.gov/ol/climate/research/ghcn/ghcnqc.html). Extensive metadata are available. In addition to the quality controlled monthly data, a quality controlled and homogeneity adjusted version is available. This version makes historical data homogenous with present day observations by adjusting for non-climatic discontinuities [*Peterson and Vose*, 1997]. The GHCN incorporates data from data set 570.0, and from many additional sources. The GHCN was used for the records on this Atlas from Vardo and Isfjord Radio.

For any given station, the GHCN may have more than one time series [*Peterson and Vose* 1997], and each time series taken singly may not cover the entire history of that station (the average number of time series for the stations selected for the Atlas is three). Data set 570.0, *World Monthly Station Data Climatology,* has only one time series for each station that generally covers the entire history of the station. Therefore we used data set 570.0 for the Atlas, but to obtain some of the benefit of the extensive quality control that GHCN data have been subjected to, we compared the temperature data from data set

570.0 with both homogeneity adjusted and non-homogeneity adjusted GHCN temperature data.

For almost all stations, the data set 570.0 records were identical, or very close, to the non-homogeneity adjusted data in the GHCN. In comparing the homogeneity adjusted GHCN data with data set 570.0 records, we found that the two data sources were often offset by 1 degrees Celsius to 3 degrees Celsius early in the record. Data from the two sources agreed for most stations beginning in the late 1950s. For five stations, data set 570.0 values closely agreed with GHCN homogeneity adjusted data for the entire period of record (these stations were Jan Mayan, Kotzbue, Myggbukta, Nord, and Resolute).

To avoid having to choose and piece multiple time series from a single station together, we used data set 570.0 rather than GHCN for temperature (and other parameter) records. Two exceptions are station records for Vardo and Isfjord Radio, where we used GHCN because the GHCN records are considerably longer than that in data set 570.0. Those interested in regional, rather than arctic-wide, analysis of climate trends may wish to use homogeneity adjusted GHCN data from NCDC.

Parameters included on the Atlas are two-meter air temperature, sea level pressure, and precipitation. Precipitation coded as "trace" in data set 570.0 is reported as 0.1 mm in the Atlas uniformat files. Relative humidity is generally available only in the early 1960s, with vapor pressure available after the late 1960s. Time series of other parameters such as cloud amount were not included because they are not available in daily or monthly summarized form. Some hourly data are available from various sources, but summarizing them would require resources beyond those available to us. These sources include a U.S. Air Force data base (DATSAV2) with hourly data from airport reporting stations starting in the 1970s; *International Surface Weather Observations*, a CD-ROM product available from NCAR, with hourly data from 1982 through 1997, and NCDC data set 464.0, *NCEP ADP Global Sfc Obs, daily Jul 1976-con* (although data set 464.0 does not include two-meter air temperature and relative humidity). Other data sets of synoptic observations can be found at NCAR (http://www.ncar.ucar.edu/) and NCDC (http://www.ncdc.noaa.gov/).

The method of observation used at the stations, and the accuracy of the synoptic observations from which the monthly means were compiled, cannot be documented without station histories that include instrumentation types and details of instrument placement. Compiling this documentation is beyond the scope of this project. In general, observation methods would have followed those outlined in WMO publication 8, *Guide to Meteorological Instruments and Methods of Observation*, and, for NOAA National Weather Service stations in the United States, the *Federal Meteorological Handbook vol. I*. Station inventories are available from NCDC (http://www.ncdc.noaa.gov/ol/climate/surfaceinventories.html). Unfortunately, the method of calculating the monthly mean temperature at a station is not readily available, and as *Peterson and Vose* [1997] point out, differences in temperature attributable to calculating the mean using two different methods at a particular station can be greater than the temperature difference between two neighboring stations.

(Thomas Peterson, NCDC, Scott Stephen, NCDC, and Dennis Joseph, NCAR, kindly provided information on data sources)

Floating Platforms

The data in this section of the Atlas are from floating platforms: ships, manned drifting stations, and unmanned drifting stations. These data, taken together, provide observations with better spatial and temporal coverage of the Arctic Ocean than has generally been available in the past. These data are three or six hourly synoptic data, monthly means, or in the case of Drifting Automatic Radiometeorological Stations (DARMS), once daily observations. Data are from:

> **Russian "North Pole" drifting stations:** Two-meter air temperature, sea level pressure, total and low cloud, surface temperature, and wind velocity, for years spanning 1938 to 1991.
>
> **Western drifting stations:** The earliest data are from the *Fram* in 1893, and the latest are from the AIDJEX experiment in 1975 and 1976. Parameters vary but all stations include air temperature, pressure, wind, and humidity data. (We use the term "western" loosely to distinguish the Russian from non-Russian stations.)
>
> **DARMS:** Wind, pressure and temperature data from 1958 through 1975 from the Russian program.
>
> **Ice patrol ships:** Wind, pressure, air temperature, sea surface temperature, total cloud amount, low cloud amount, and relative humidity for voyages of Russian ships from 1952 through 1982.

To view the time coverage for any parameter from any station, and to see a plot of the individual station track, use the Atlas HTML interface. (These options are not available for DARMS data due to the large number of stations.) The data are in uniformat files.

Overview

The relation of these data to data in previously published data sets, if any, is given in this overview section. See the documentation section for each platform type for technical documentation. The Arctic and Antarctic Research Institute (AARI), St. Petersburg, provided all data except the western drifting station data.

Russian Drifting Station Data: Data from the "North Pole", or NP, series of 31 drifting stations, plus three subsidiary stations (NP 13f, NP 15f, and NP 18f), include three or six hourly observations of two-meter air temperature, sea level pressure, total and low cloud, surface temperature, and wind velocity. Each station drifted for about two years, and generally at least two stations were operational at any one time. NSIDC, University of Washington, and AARI published these data (with the exception of the subsidiary station data) jointly in 1996. The new version of the data on this Atlas corrects errors in positions and observation times, and adds to the length of the data record in many cases. Older versions of these data are in COADS: NP01 and some other early station data are in Deck 186 (USSR Ice Station Sfc. Synoptic) and in Global Telecommunications System (GTS) -based data sets, and all 31 stations are in Deck 733 (Russian AARI NP Stations). (A description of COADS can be found in the documentation section for gridded cloud fields). In addition to synoptic data, files of monthly mean data are included. Figure 7 shows "North Pole" drifting station tracks.

The article "North Pole Drifting Stations", by Romanov, Konstantinov, and Kornilov, is a comprehensive history of the NP program. It can be found under "Expeditions in the Russian Arctic", in "A Look Back" (the history section of the Atlas). "Historical Photos", also in "A Look Back", illustrate life on a NP station.

Western Drifting Station Data: Historical drifting station synoptic observations from ice islands, sea ice floes or from ships drifting in the ice were digitized at NCDC. Data from the *Fram* were obtained from the German Weather Service. Figure 7 shows drifting station tracks. With the exception of some data from T-3 and *Fram* that are in COADS, these data have not been readily available in the past.

DARMS Data: AARI has prepared wind, pressure and temperature data from the Russian DARMS (Drifting Automatic Radiometeorological Stations) program for 1958 through 1975. In this period a total of 164 stations reported, with an average of nine deployed in any one year. Once-daily values are provided. The position data (Figure 7) are part of the International Arctic Buoy Program (http://iabp.apl.washington.edu/) data set, but the meteorological data have not been published in digital form prior to this Atlas.

Ice Patrol Ship Data: As part of Northern Sea Route (sometimes referred to as the Northeast Passage) patrols, 14 Russian ships made observations on 58 cruises between 1952 and 1970 (cruise tracks are shown in Figure 7). These cruises were from three to five months in duration. Measurements were taken four times a day of air temperature, pressure, relative humidity, sea surface temperature, wind velocity, and total cloud amount. These measurements have been prepared at AARI for the Atlas.

Fig. 7. Russian "North Pole" drifting station tracks, (upper left), Western drifting station tracks (upper right), DARMS drift tracks, 1958 through 1975 (lower left), Ice Patrol ship cruise tracks, 1952 through 1970 (lower right).

Russian Drifting Stations

Documentation provided by V. Radionov, with additions from a previous edition of these data (see "Related data products"); edited by F. Fetterer

The history of the "North Pole" (NP) drifting station program is described in "A Look Back", in the manuscript titled "North Pole Drifting Stations". This document has detailed information on each station. NP drifting stations were established on multiyear ice floes less than 2 km^2 in diameter and 3 meters to 5 meters thick. Usually, a starting location to the northeast of Wrangel Island (about 175 degrees West) was chosen for the station. Station personnel generally debarked on the ice in spring (March through May) after being transported by air, but sometimes personnel were delivered to the site by icebreaker in autumn.

Use the Atlas HTML interface to see the length of the data record at any station for any of the parameters included in the Atlas, as well as the drift track of the station for which data are included on the Atlas.

Some NP data were reported on the Global Telecommunication System (GTS). The radio call letters for some of the NP stations were: NP12-RGAB; NP13-ROBB; NP19-RRDA; NP20-RTAU; NP21-ROBB; NP22-RGAB; NP23-RRDA; NP 24-ROBB; NP25-ROBB; NP26-RGAB and EMIO; NP27-UYAI and ROBB; NP28-EMIO; NP29-UFRF, NP30 UYAJ; and NP31-UFRE.

Meteorological observations at drifting stations

Meteorological observations at drifting stations were performed by the methods described *Gidrometeoizdat* [1969] and *Gidrometeoizdat* [1985]. AARI instructions made some changes to these standard observation methods related to the peculiarities of making observations on drifting ice.

Usually, meteorological observations were performed eight times daily (at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 Moscow Local Time (MLT). (MLT is three hours later than GMT). However sometimes observations were performed four times daily (at 0300, 0900, 1500 and 2100 MLT) during times of ice breakup when new personnel arrived, so that some stations have observations at both three- and six-hourly observation periods. The observation record was kept at the meteorological site in a KM-1 log book. TM-1 tables were developed every month after laboratory processing.

The meteorological site was selected on level ice at a distance of not less than 70 meters to 100 meters away from hummocks and living accommodations. Devices and equipment were situated according to the standard plan of a 26 meter by 26 meter meteorological site. On site there was a psychrometric box with thermometers, hygrometers, and a box for recorders with thermometer and self-recording hygrometer, masts with wind vanes, and masts with an anemorumbometer. The thermometers to measure the snow surface temperature were located near the psychrometric box. During the polar night the meteorological site was electrically lighted. Flashlights were used to read the instruments when power outages occurred.

This Atlas contains data for the meteorological parameters described below. Parameters are available in uniformat synoptic data and as monthly averages. (Monthly averages for wind speed and wind direction are not given). Note that observations of additional parameters were taken, and some of these data are available on the related data products described in the section "Related data products".

Air pressure

Air pressures were measured by barograph and by using two mercury barometers located in the main meteorological building: one as the main instrument, and the other as a control. Pressure measurements from the control (calibration) barometer were taken at regular intervals; readings from the main barometer are provided on this Atlas. Air pressure was recorded in hPa referred to a temperature of zero degrees Celsius and standard gravity force, that is, gravity at a latitude of 45 degrees and at sea level.

A station cistern mercury barometer (SP-A) and an inspector's mercury siphon-cistern barometer (IP) were used.

The main parameters of the SP-A are:

Range of the instrument:	810 to 1070 hPa
Maximum error:	< or = 0.5 hPa
Accuracy of reading:	0.1 hPa
Scale spacing of cosine:	0.1 hPa
Scale spacing:	1.0 hPa
Range of the barometric thermometer:	-5 °C to +45 °C
Error of the barometric thermometer:	0.5 °C

The main parameters of the IP are:

Range of the instrument:	570 to 1070 hPa
Maximum error:	0.3 hPa
Accuracy of reading:	0.05 hPa
Scale spacing of cosine:	0.05 hPa
Scale spacing:	1.0 hPa
Range of the barometer thermometer:	-5 °C to +45 °C

If these barometers failed to operate, the atmospheric pressure was measured by aneroid-barometer with an accuracy of 1 mmHg and a maximum measurement error of not more than 0.8 mmHg. Aneroid-barometers were used exclusively on NP-5, NP-8, NP-9, and NP16.

Air temperature and relative humidity

Air temperature and relative humidity were measured using instruments in a psychrometric box (similar to a Stevenson's Screen) 2.0 meters over ice surface. When the temperature was higher than minus 30 degrees Celsius, mercury meteorological thermometers (TM-4) were used, otherwise, alcohol meteorological thermometers (TM-9) were used.

The main parameters of the TM-4 are:

Range of the instrument:	-35 °C to +40 °C
Scale spacing:	0.2 °C
Measurement error over the range from	
+0 °C to +50C:	< or = 0.2 °C
< 0 °C:	< or = 0.3 °C

The main parameters of the TM-9 are:

Range of the instrument:	-65 °C to +25 °C
Scale spacing:	0.5 °C
Measurement error over the range from	
+20 °C to -20 °C:	0.5 °C
-30 °C to -40 °C:	0.8 °C
-40 °C to -50 °C:	1.0 °C
-50 °C to -60 °C:	1.5 °C

Starting with NP-21, copper wire resistance thermometers (MT-102) were used as the wet-bulb thermometer as well as to measure the air and snow-ice surface temperature.

At temperatures above minus 10 degrees Celsius, relative humidity was determined by psychrometry, which is based on measuring the difference between air temperature and the temperature of a wet-bulb thermometer. Values of relative humidity were calculated using the psychrometric table, and the results obtained using psychrometry were compared with a hair hygrometer in order to check and correct the hygrometer reading at regular intervals.

At air temperatures below minus 10 degrees Celsius, the model MV-1 meteorological hygrometer used to measure relative air humidity. The main parameters of the MV-1 are:

Range of the instrument:	30% to 100%
Measurement error:	up to 10%
Scale spacing:	1%
Operating temperature range:	-50 °C to +55 °C

Surface temperature

The temperature of snow cover was usually measured from September to the end of April, but sometimes as late as mid-May, depending on the length of the period with stable negative temperatures. To measure snow surface temperature when the air temperature was higher than minus 30 degrees Celsius, the TM-3 mercury thermometer with a scale spacing of 0.5 degrees Celsius was used. The accuracy of the TM-3 measurement is ± 0.5 degrees Celsius when temperature is higher than minus 20 degrees Celsius and is ± 0.7 degrees Celsius when temperature is below minus 20 degrees Celsius. If temperature is below minus 30 degrees Celsius, an alcohol thermometer with scale spacing of 0.5 degrees Celsius was used. The accuracy of the alcohol thermometer is given in the following table:

Temperature range:	Error
Greater than -20 °C:	± 0.5 °C
-30 °C to -20 °C:	± 0.5 °C
-40 °C to -30 °C:	± 0.8 °C
-50 °C to -40 °C:	± 1.0 °C
-60 °C to -50 °C:	± 2 °C

Cloud amount

Cloud amount is defined visually on a ten-point scale, and the quantity of clouds (both total and low cloud cover) was recorded in tenths of coverage. Coverage that was almost complete ("10" with gaps) was coded as "11". The following devices were used to measure cloud height: cloud searchlight (up to 1963), pilot balloons, and radio sounding data. IVO-1, a device to measure cloud height, was used from 1969 on. Cloud height was defined visually in a case when the instrumental measurements could not be performed.

Wind direction and speed

Until 1962 wind direction and speed were measured by Wild's wind vane with heavy and light boards and also by meteorological devices DMS-49 or DMS-53. From 1963 on M-47 and M-49 type anemorumbometers and M-12 and M-64 type anemorumbographs were used. Table 10 lists the instrument types and heights of installation of the wind velocity sensors. Table 11 provides the main parameters of the instruments.

Table 10. Instruments and installation heights used for the measurement of wind velocity and direction.

Station	**Instrument(s)**	**Height (m)**	**(Dates)**
NP-1	MS-13	2	
NP-2	8I0001M	8	
NP-3	MS-13; 8I0001M	8	
NP-4	8I0001M; FVL	8	
NP-5	FVL	6	
NP-6	FVL; FVT	8	
NP-7	FVL; FVT	10	
NP-8	FVL; FVT	8	
NP-9	FVL; FVT	8	
NP-10	M-49	6	
NP-11	FVL; FVT; M-47	8	
NP-12	M-49	10	
NP-13	M-47; M12	6	
NP-14	M-47;M-63	8	
NP-15	M-63	6	
NP-16	M-49	10	
NP-17	M-63	10	
NP-18	M-49; M-12	6.4	(11/68 - 05/69)
		8.5	(05/69 - 10/71)
NP-19	M-64; M-63M	6.4	(12/69 - 10/70)
		7.5	(11/70 - 01/71)
		9.5	(02/71 - 11/72)
		12	(11/72 - 03/73)
NP-20	M-47	8	(05/70 - 04/71)
		6	(05/71 - 05/72)
NP-21	M-47	10	
NP-22	M-64; M-63M	10	
NP-23	M-63M	10	
NP-24	M-63M	10	
NP-25	M-63M	10	
NP-26	M-63M	11	
NP-27	M-63M	10	
NP-28	M-63M	10	
NP-29	M-63M	10	
NP-30	M-63M	10	
NP-31	M-63M	10	

Table 11. Main characteristics of the instruments used for the measurement of wind velocity and direction.

Instrument	Speed range (m/s)	Direction range (degrees)	Accuracy of measurement of speed (m/s)	Accuracy of measurement of direction (deg)	Threshold sensitivity for speed/ direction (m/s)
MS-13	1.0 - 20	-	(0.3+0.06V)	-	0.8/-
810001M	1.0 - 15	0-360	1.0	10	1.0/1.0
FVL	1.0 - 20	0-360 (16 compass points)			
FVT	1.0 - 40	0-360			
M-49	1.5-59	0-360	(0.5+0.05V)	10	1.2/1.2
M-47	1.5-50	0-360	(0.5+0.05V)	10	1.2/1.2
M-64	1.0-40	0-360	(0.5+0.05V)	10	0.8/1.5
M-12	1.0-40	0-360 (16 compass points)	(0.5+0.05V)	11.25	0.7/0.9
M-63	1.0-40	0 -360	(0.5+0.05V)	10	0.8/1.5
M-63M	1.0-40	0 -360	(0.5+0.05V)	10	0.6/1.0

Notes for Table 11:
1. MS-13 measures only wind speed.
2. The choice of a light (FVL, 200 g) board or a heavy (FVT, 800 g) board depended on the observer's experience. Measurement error is not less than ±1 m/s for speed and ±0.5 point (11 degrees) for direction.
3. M-12, M-47, M-64, M-63, and M-63M record the wind velocity averaged over 10 minutes; MS-13 records velocity averaged over 2 to 10 minutes.
4. V in formulas for velocity measurement precision is the measured wind velocity in m/s.

Accuracy of meteorological observations

Typical ranges in accuracy for the measurement of most of the parameters listed above are given in Table 12.

Table 12. Accuracy of meteorological observations.

Parameter	Devices (methods) and units of error	Error			
		Single Observation		24 hours (daily)	
		average	max	average	max
Air pressure	Mercury barometer, mbar (mm)	0.2	0.5	0.2	0.4

Wind speed	Wind vane, m/s	1-2	4-6	1-2	2-4
Wind direction	Wind vane, points (22.5 degrees)	1	2	0.5	1
Air temperature	Psychrometric thermometer, °C	0.3 - 0.4	1.0	0.3 -0.4	0.6 - 0.8
Air temperature max. over 3 or 6 hour period	Thermometer for measuring maximum temperature, °C	0.4 - 0.6	2.0	0.4	0.8 - 1.0
Air temperature min. over 3 or 6 hour period	Thermometer for measuring minimum temperature, °C	0.5	2.0	0.5	1.0
Relative humidity	Psychrometer or self-recording hygrometer, mbar	0.2	0.4	0.2	0.4

Station positions

Positions of drifting stations NP-1 to NP-24 were determined primarily by celestial navigation. Sun fixes and star observations were made daily as season and weather permitted. Positioning errors are estimated to have been 3 km to 5 km. Starting with NP-25, positions were determined using satellite technology. NP-31 used the Satellite Navigation system.

The position data files received from AARI contained only observations that were actually made. After quality control, these positions were linearly interpolated to provide an approximate position for each meteorological observation. J. Comeaux, NCAR Data Support Section, provided the quality-controlled, interpolated positions for this Atlas.

Quality control of NP data

Meteorological data were checked at AARI as described in the section "AARI quality control methods", and following *Drozdov* [1989]. Data underwent further quality control by J. Comeaux, NCAR Data Support Section, as follows.

These checks were performed on the position files:

- Checked for computed drift velocities that were greater than two km per hour. These were usually the result of typographical errors in latitudes or longitudes, or in dates.
- Checked for out of range values in latitudes or longitudes.
- Checked the range of dates and times. Missing observation times were filled with 1200, unless the date had two observation times missing, in which case 0300 and 1800 were used. These times are consistent with other observations, at the station under consideration, for which times are not missing.
- Interpolated positions to the observation times of the meteorological data, and compared positions to those in a 1996 version of the data set: *Arctic Ocean Snow and Meteorological Observations from Drifting Stations 1937, 1950-1991* (see "Related data products"). Position differences greater than 5 km were checked.

Meteorological data files were checked for dates out of order, missing observation times, and out of range values on all data fields.

Related data products

The NP data set on this Atlas corrects previous data and position records, and adds additional data records to the data set on CD-ROM published by AARI, the University of Washington Polar Science Center, and NSIDC in 1996 titled *Arctic Ocean Snow and Meteorological Observations from Drifting Stations 1937, 1950-1991*. (The 1996 CD-ROM includes snow and radiation data from the NP stations that are not included in this Atlas). Specifically, this new version of the NP meteorological observations contains corrected latitude and longitudes for NP-18 and NP-26, includes data from NP-4 that are missing from the 1996 CD-ROM, and contains more data records. For a complete inventory of differences with the earlier version, contact NSIDC User Services. AARI, NCAR's Data Support Section, the University of Washington Polar Science Center, and NSIDC have cooperated in publishing this new edition of the NP meteorological data. This version of the data set is also available from NCAR's DSS, where it has been prepared for inclusion in the update to the Comprehensive Ocean-Atmosphere Data Set (COADS), and in the NCEP/NCAR and ECMWF Reanalysis projects.

Earlier versions of NP drifting station data were used in the following data products available from NSIDC:

Arctic Water Vapor Characteristics from Rawinsondes
http://www-nsidc.colorado.edu/NSIDC/CATALOG/ENTRIES/nsi-0033.html

Daily Arctic Ocean Rawinsonde Data from Soviet Drifting Ice Stations
http://www-nsidc.colorado.edu/NSIDC/CATALOG/ENTRIES/nsi-0060.html

Comprehensive Ocean - Atmosphere Data Set LMRF Arctic Subset
http://www-nsidc.colorado.edu/NSIDC/CATALOG/ENTRIES/nsi-0057.html

Russian Ice Patrol Ships

Documentation provided by V. Radionov; edited by F. Fetterer

Meteorological observations from ice patrol ships

Meteorological data from ice patrol ships have been used in the past only for operational navigation services along the Northern Sea Route. To create the archive of observation data from ice patrol ships for this Atlas, data from 14 ships in the seas of the western, central and eastern sections of the Russian Arctic between 1952 and 1982 were used. These ships had standard areas and months of operation (see Table 13).

Table 13. Year and area of operation of ice patrol ships.

Year	Ship names, months of operation (represented by Roman numerals), and expedition region

	Western section of the Russian Arctic (generally Barents and Kara Seas)	Central section of the Russian Arctic (generally the Laptev Sea)	Eastern section of the Russian Arctic (generally the East Siberian and Chukchi Seas)
1952	Lag (VII-X)		
1953	Toros (VII-X)	Polyarnik (VII-X)	
1954	Toros (VII-X)	Polyarnik (VIII-X)	
1955	Toros (VII-X)	Polyarnik (VII-IX)	
1956	Toros (VII-X)	Polyarnik (VII-X)	
1957	Toros (VII-X)	Polyarnik (VII-IX)	
1958	Toros (VII-X)	Polyarnik (VII-X)	Lomonosov (VI-X)
1959	Toros (VII-X)	Polyarnik (VII-IX)	Lomonosov (VI-X)
1960	Priboy (VI-X)	Lomonosov (VII-X)	Azimut (VII-X)
1961	Priboy (VII-X)	Shtorm (VII-X)	Azimut (VIII-X)
1962	Priboy (VI-X)	Shtorm (VII-X)	Lomonosov (VII-X)
1963	Priboy (VII-X)	Shtorm (VII-X) Azimut (VIII-IX)	
1965	Priboy (VII-XI)	Shtorm (VII-X)	Azimut (VII-X)
1966	Priboy (VII-X)	Shtorm (VII-X)	Azimut (VII-X)
1967	Priboy (VIII-X)	Shtorm (VII-X)	Azimut (VII-X)
1968	Priboy (VII-IX)	Iney (VII-X)	Azimut (VII-X)
1969	Shqual (VIII-IX)	Yana (VII-IX)	
1970	Shqual (VIII-IX)	Yana (VII-IX)	
1972	Polyarnik (VI-VIII)		
1976	Aisberg (IV-VI)		
1979	Majak (VIII-X)	Shtorm (VIII-X)	Stvor (VII-IX)
1980	Dmitry Laptev (IX-X)	Shtorm (VIII-X)	
1981	Dmitry Laptev (VIII-X)	Stvor (IX)	
1982	Dmitry Laptev (IX-X)		

A typical ice patrol ship plan is shown in Figure 8, and the meteorological equipment carried aboard the ships is presented in Table 14. Note that all the meteorological devices were calibrated before an expedition and were given special certificates with information about all essential instrument corrections.

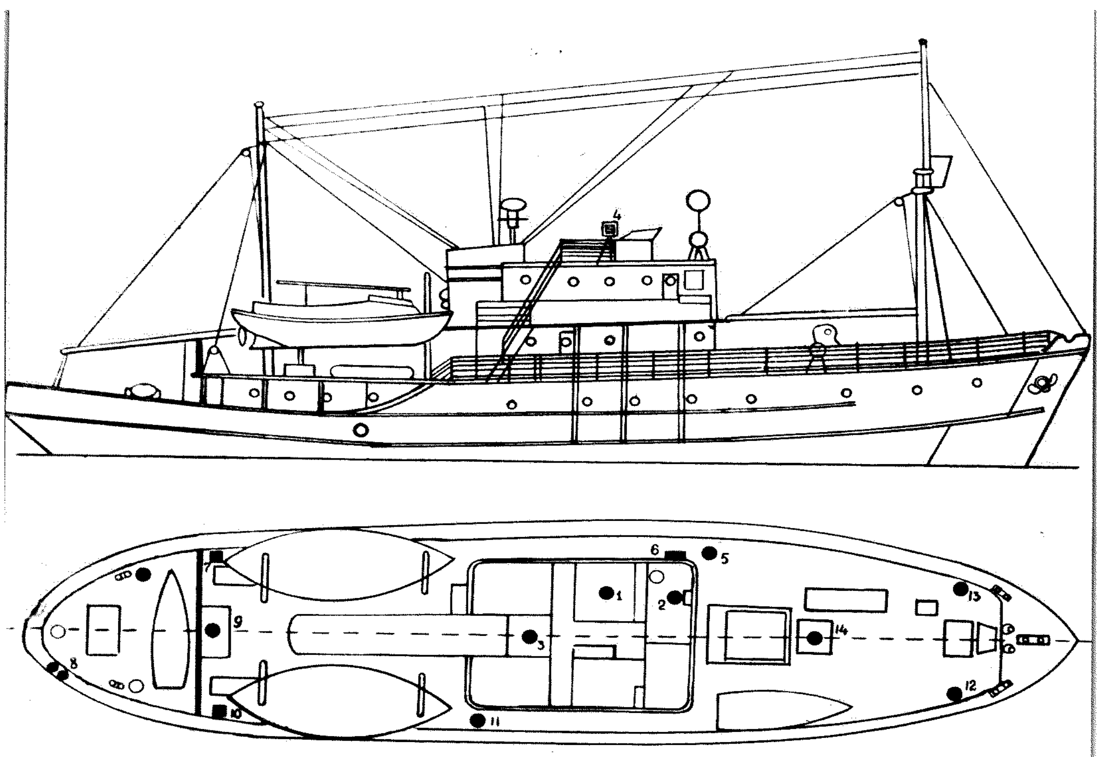


Fig. 8. A typical ice patrol ship plan. "1" marks the room for hydrological measurements (in the central part of the ship on the port side), "4" marks the meteorological instrumentation box (on the centerline aft of the forward mast).

Table 14. Meteorological equipment on ice patrol ships.

Ships	Devices
Azimut, Aisberg, Iney, Shqual	Aneroid-barometer, daily barograph, Assman psychrometer, MS-13 hand anemometer, ARI-49 induction hand anemometer,

	thermometer to measure water temperature in Schpandler's cover
Lag, Lomonosov, Polyarnik, Yana	Aneroid-barometer, week barograph, MS-13 hand anemometer, ARI-49 induction hand anemometer, psychrometric thermometers, thermometer to measure water temperature in Schpandler's cover
Dmitry Laptev	Aneroid-barometer, week barograph, Assman psychrometer, MS-13 hand anemometer, ARI-49 induction hand anemometer, M-63 anemorumbometer, thermometer to measure water temperature in Schpandler's cover
Majak	Aneroid-barometer, Assman psychrometer, psychrometric thermometers in meteorological box, MS-13 hand anemometer, ARI-49 induction hand anemometer, thermometer to measure water temperature in Schpandler's cover, GM-6 aboard distant reading type meteorological station
Priboy, Stvor	Aneroid-barometer, daily barograph, MS-13 hand anemometer, ARI-49 induction hand anemometer, psychrometric thermometers in meteorological box, Assman psychrometer, thermometer to measure water temperature in Schpandler's cover
Toros	Aneroid-barometer, daily barograph, Assman psychrometer , MS-13 hand anemometer, ARME-1m anemorumbometer, thermometer to measure water temperature in Schpandler's cover
Shtorm	Aneroid-barometer, daily barograph, Assman psychrometer, MS-13 hand anemometer, ARI-49 induction hand anemometer, thermometer to measure water temperature in Schpandler's cover, GM-6 aboard distant reading type meteorological station

Hydrometeorological observations were performed at standard times (see Table 3) according to "Instruction for hydrometeorological stations and posts" (Iss. 9, Part III, 1955, 1967, 1976) and "Instruction for hydrometeorological stations and posts" (Iss. 9, Hydrometeorological observations over seas. *Part II, Hydrometeorological observations at aboard stations for staff observers*, Leningrad, Gidrometeoizdat, 1964, 367 pp.) Instrumental and visual observations were taken instrumentally (for atmospheric pressure, air temperature and humidity, wind direction and speed, and sea surface temperature) and visually (for cloud amount, and atmospheric phenomena) .These observations were performed while a ship was underway. No measurements were taken while at anchor.

Table 15. Ice patrol ship operation period and observation times**.**

Ship/operation period	**Observation times** *(MT indicates Moscow time. All observations on this Atlas were converted to GMT)*
Azimut	
13 Jul - 04 Oct 1960	00, 06, 12, 18 GMT
09 Aug - 03 Oct 1961	00, 06, 12, 18 GMT
05 Aug - 26 Sep 1962	00, 06, 12, 18 GMT
18 Jul - 01 Oct 1964	00, 06, 12, 18 GMT

21 Jul - 11 Oct 1965 18 Jul - 02 Oct 1966 31 Jul - 07 Oct 1967 26 Jul - 06 Oct 1968	00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 03, 09, 15, 21 MT
Aisberg 13 Apr - 14 Jun 1976	 00, 03, 06, 09, 12, 15, 18, 21 GMT
Dmitry Laptev 06 Jun - 03 Oct 1980 19 Aug - 26 Sep 1981 23 Sep - 16 Oct 1982	 00, 03, 06, 09, 12, 15, 18, 21 GMT 00, 03, 06, 09, 12, 15, 18, 21 GMT 00, 03, 06, 09, 12, 15, 18, 21 GMT
Iney 31 Jul - 01 Oct 1968	from 31 Jul 68: 03, 07, 11, 15, 19, 23 MT from 6 Aug 68: 02, 06, 10, 14, 18, 22 MT from 23 Sep 68: 01, 05, 09, 13, 17, 21 MT
Lag 03 Aug - 10 Oct 1952 30 Aug - 26 Sep 1953	 00, 06, 12, 18 GMT 03, 07, 11, 15, 19, 23 MT
Lomonosov 21 Jun - 21 Oct 1958 19 Jun - 11 Oct 1959 09 Jul - 12 Oct 1960 04 Jul - 14 Oct 1962	 0, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT
Majak 28 Aug - 14 Oct 1979	 00, 06, 12, 18 GMT
Polyarnik 29 Jul - 02 Oct 1953 01 Aug - 30 Oct 1954 21 Jul - 29 Sep 1955 21 Jul - 04 Oct 1956 24 Jul - 21 Sep 1957 24 Jul - 02 Oct 1958 22 Jul - 02 Oct 1959 21 Jun - 28 Aug 1972	 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT
Priboy 19 Jun - 16 Oct 1960 12 Jul - 22 Oct 1961 27 Jun - 12 Oct 1962 17 Jul - 19 Oct 1963 31 Jul - 26 Oct 1964 09 Jul - 07 Nov 1965 27 Jul - 23 Oct 1966 14 Aug - 8 Aug 1967	 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT 00, 06, 12, 18 GMT
Stvor 30 Jul - 24 Sep 1979 15 Aug - 03 Oct 1980 01 Sep - 26 Sep 1981	 00, 03, 06, 09, 12, 15, 18, 21 GMT 00, 03, 06, 09, 12, 15, 18, 21 GMT 00, 03, 06, 09, 12, 15, 18, 21 GMT

Toros	
17 Jul - 28 Oct 1953	00, 06, 12, 18 GMT
16 Jul - 12 Oct 1954	00, 06, 12, 18 GMT
12 Jul - 14 Oct 1955	00, 06, 12, 18 GMT
01 Jul - 15 Oct 1956	00, 06, 12, 18 GMT
02 Jul - 10 Oct 1957	00, 06, 12, 18 GMT
15 Jul - 27 Sep 1958	00, 06, 12, 18 GMT
20 Jul - 12 Oct 1959	00, 06, 12, 18 GMT
Shtorm	
26 Apr - 14 Jun 1959	00, 06, 12, 18 GMT
20 Jul - 11 Oct 1961	00, 06, 12, 18 GMT
08 Jul - 15 Oct 1962	00, 06, 12, 18 GMT
27 Jul - 21 Oct 1963	00, 06, 12, 18 GMT
06 Jul - 22 Oct 1964	00, 06, 12, 18 GMT
08 Jul - 24 Oct 1965	00, 06, 12, 18 GMT
06 Jul - 17 Oct 1966	00, 06, 12, 18 GMT
08 Jul - 17 Oct 1967	00, 06, 12, 18 GMT
Shqual	
27 Aug - 27 Sep 1959	03, 07, 11, 15, 19, 23 MT
05 Aug - 29 Sep 1960	03, 07, 11, 15, 19, 23 MT
01 Aug - 03 Oct 1961	03, 07, 11, 15, 19, 23 MT
13 Aug - 21 Sep 1963	03, 07, 11, 15, 19, 23 MT
03 Aug - 28 Sep 1964	03, 07, 11, 15, 19, 23 MT
31 Jul - 01 Oct 1969	03, 07, 11, 15, 19, 23 MT
Yana	
24 Jul - 30 Sep 1969	03, 07, 11, 15, 19, 23 MT
15 Jul - 03 Oct 1970	03, 07, 11, 15, 19, 23 MT

The main sources of observation error while a ship is underway, are the low measurement accuracy of most parameters in comparison with measurements performed at stationary and drifting stations, and the inability to repeat observations due to changes in measuring characteristics when the ship location changes.

Air temperature and humidity were usually measured on the upper bridge of the ship either by an Assman psychrometer or psychrometric thermometers. The psychrometer was put out on a special rod to take measurements (Table 16). Absolute and relative air humidity were calculated using standard psychrometric tables. Sea surface temperature was measured by thermometer in Schpandler's cover.

Air pressure was measured by an MD-49-2 aneroid barometer, placed in a room for hydrological measurements. Baric tendency (change in pressure) was defined by a daily or weekly barograph.

Table 16. Location of barometer and its height above sea level. Location and height of wind and temperature measurements.

Ship	**Place of**	**Height**	**Location of**	**Height of**

	barometer	above sea level, m	temperature-wind equipment	equipment above sea level, m
Azimut	Hydrological room	6	upper bridge	9.5
Aisberg	Hydrological room	6	upper bridge	9.5
Dmitry Laptev	Hydrological room	8	upper bridge	12
Iney	Hydrological room	6	upper bridge	9.5
Lag	Rudder house	5	upper bridge	9
Lomonosov	Rudder house	5	upper bridge	9
Majak	Hydrological room	6	upper bridge	10
Polyarnik	Rudder house	5	upper bridge	9
Priboy	Hydrological room	6	upper bridge	10
Stvor	Hydrological room	6	upper bridge	10
Toros	Rudder house	5	conning bridge	6
Shtorm	Hydrological room	6	upper bridge	10
Shqual	Hydrological room	6	upper bridge	9.5
Yana	Rudder house	4	upper bridge	4-5

Wind direction and speed were observed from the upper bridge. Wind speed was measured as a rule by hand anemometer (100 s exposure time). Wind direction was measured by a wind cone on the upper bridge and by a compass repeater. Sometimes wind direction and speed was measured by GM-6 type meteorological station if it was aboard the ship. Clouds were observed visually from the upper bridge.

Observation procedure

Cloud cover

The amount and form of clouds were observed visually from the upper bridge 10 to 12 minutes before the synoptic observation time. Visibility was defined by scale in miles. Atmospheric phenomena were noted in the observer book.

Wind

Wind speed was measured by MS-13 hand anemometer (for wind speeds from 1 m/s to 20 m/s), or by ARI-49 induction hand anemometer (for wind speeds more than 20 m/s) five to six minutes before the observation time.

Air temperature

The psychrometer was put up on a special rack of 1.5 meter height on the windward side of the upper bridge 10 to 15 minutes before the observation time. (When air temperature was below zero, this was changed to 20 to 25 minutes before the observation time). The cambric of the wet-bulb thermometer was moistened by distilled water and the suction apparatus was started four minutes before an observation. In frost conditions, the cambric was moistened and the suction apparatus was started 10 minutes before the observation time. Four minutes before the observation time, the suction apparatus was started once more. When the wind was strong a wind shield was used. At the observation time, temperature readings from both thermometers (with accuracy of 0.1 degrees Celsius) were recorded. The cambric was changed every two weeks.

Sea surface temperature

After air temperature was recorded sea surface temperature was measured. A bucket was lowered overboard and filled with water, then put in shadow on deck. A covered thermometer was put in the bucket so that it did not contact the walls. The water was stirred by the thermometer until three nearly identical temperature readings were obtained. The last consistent temperature was entered into an observer book. The average thermometer exposure time in water was about three minutes. When the ship was anchored, temperature was measured directly by lowering a thermometer overboard into the water.

Atmospheric pressure

Atmospheric pressure and barometric tendency value (that is, the difference of pressure values measured at two successive observation times) were measured five to seven minutes after the synoptic observation time.

Initial processing

Meteorological observations were processed immediately after the observation time, and wind direction and speed calculated. The values of relative and absolute air humidity and dew point were calculated using standard psychrometric tables, taking into account the instrumental temperature correction for each individual thermometer. An instrumental correction to the water surface temperature reading was made when necessary. The four corrections taken into account in reading the aneroid barometer were: instrumental, temperature, height above sea level (MASL), and a constant correction for the individual barometer.

After the initial processing, TGM-15 tables were compiled, from which the data archive was formed.

Processing data for this Atlas

Synoptic observations from the TGM-15 tables of surface air pressure, air temperature, relative humidity, sea surface temperature, wind speed and direction and total cloud cover were digitized for this Atlas. Data were checked at AARI as described in "AARI quality control methods".

General parameters of meteorological devices

Barometer-aneroid: Measuring range, 600-800 mmHg; Measuring error due to temperature (from -10 °C up to +50 °C), ±0.8 mmHg; Scale spacing, 1 mmHg.

TM-4 psychrometric thermometers: Scale limits, –35 to +40 and –25 to +50 °C ; Scale spacing, 0.2 °C ; Measuring error: when temperature range is +0 °C up to +50 °C not more than ±0.2 °C; when temperature is below zero not more than ±0.3 °C; when temperature is - 35 °C not more than ±0.4 °C.

Thermometer to measure water temperature in Schpandler's cover: Scale limits, –2 to +32 °C; Scale spacing, 0.2 °C ; Measuring error, ±0.3 °C.

Aspiration psychrometer: The table below shows the error (percent) relative to air temperature and measured value of relative humidity.

Table 17. Error in measured relative humidity as a function of temperature and humidity.

Air temperature, °C	Relative humidity, %			
	100	80	20	10
30	1.5	2	5	9
20	2	3	7	14
10	3	4	11	20
0	4	6	17	35
-5	5	9	25	50
-10	7	12	35	70

MC-13 hand anemometer: Measuring range, 1 – 20 m/s; Initial sensitivity, 0.8 m/s; Measuring error, m/s, 0.3+0.06V (V is average wind speed, m/s).

ARI-49 induction hand anemometer: Measuring range, 2 – 30 m/s; Precision, 1 m/s; Measuring error, m/s 0.5+0.05V; (V is average wind speed, m/s); Initial sensitivity, 1.5 m/s.

ARME-1m anemorumbometer: Measuring range: Speed, 1.5 – 50 m/s; direction, 0 to 360 degrees; Measuring error: speed, m/s, 0.5+0.05V (V is average wind speed, m/s); Direction, ±10 degrees; Initial sensitivity of wind sensor for speed and direction, 1.2 m/s.

M-63M anemorumbometer: Measuring range: instantaneous speed, 1.5 – 60 m/s; maximum speed, 3 – 60 m/s; average (within 10 minutes) speed, 1 – 40 m/s. Direction, 0 – 360 degrees. Measuring error: instantaneous speed, ± (0.5+0.05V) m/s; maximum speed, ± (0.5+0.05V) m/s; average (within 10 minutes) speed, ± (0.5+0.05V) m/s (where V is average wind speed, m/s); Direction, ±10 degrees; Initial sensitivity: to speed, 0.6 m/s; to direction, ±10°.

The GM-6 meteorological station was used to measure wind speed and direction, air temperature and humidity, water temperature (of overboard water aboard). Measuring range: average wind speed, 1.5 – 40 m/s; direction, 32 compass points; air humidity, 30 – 100%; air temperature, –32 to +32 °C; water temperature, 2 to 32 °C. Measuring error: average wind speed less than 12 m/s, ±1 m/s; more than 12 m/s, ± (0.5+0.05V) m/s (V-average wind speed, m/s). Wind direction ±1 of 32 points of compass. Air humidity, when temperature is above zero, ±10%; when temperature is between 0 °C and -10 °C, ±15%. Air temperature, ±0.5 °C; water temperature, ±0.3 °C.

Drifting Automatic Radiometeorological Stations

Documentation provided by V. Radionov; edited by F. Fetterer

Overview, observations of ice drift and meteorological parameters from DARMS

The Drifting Automatic Radiometeorological Station (DARMS) for weather and sea ice drift data recording was developed at the Arctic and Antarctic Research Institute (AARI) by Yu. K. Alexeyev for operation in remote and otherwise inaccessible sites in the Arctic Ocean. Placed on the pack ice of the Arctic Ocean by aircraft or icebreaker, DARMS automatically transmitted information on wind speed and direction, air pressure and temperature. From 1957 through 1976, AARI continuously had DARMS units in operation.

Figure 9 shows the structure of a DARMS unit. A hollow steel bar that passed through ice was the principal feature of the station design. A hermetically closed container housed batteries and a clock mechanism, and was fixed to the lower end of the bar under ice. The station antenna, a 12 meter duraluminum mast, was supported by three stays. These were fixed by anchors frozen into ice. The anchors were fitted with guide runners, in which the supporting tripod could move freely. This design decreased the possibility of station damage due to ice cracking. DARMS units were equipped with a special tent, stretched above the ice surface, to prevent anchors from melting out of ice due to solar heating. The duration of autonomous DARMS operation on ice with daily data transmission was about 1 year.

A radio transmitter and receiver, as well as meteorological unit, were mounted at a height of two meters over ice surface. The DARMS meteorological unit (Figure 9, right) measured air temperature, air pressure, and wind direction and speed.

A bimetallic thermometer measured air temperature. An aneroid barometer with temperature compensation by the bimetallic strip was used as pressure sensor. A large weathervane turned the meteorological unit around the vertical axis into the wind direction. Wind direction was determined by magnetic compass reading. Two smaller weathervanes measured wind speed. For that purpose the dynamic anemometer principle was used.

The mechanical systems of the sensors were damped. This excluded the influence of vibrations that came with high wind speeds on the temperature and pressure sensor readings. Wind speed and direction were averaged automatically over an eight or 10 minute period.

The DARMS units measured meteorological data within the following ranges:

> Air pressure from 960 mbar up to 1050 mbar, with a precision of 1 mbar.
> Air temperature from -55 °C up to +30 °C with a precision of 1 degree.
> Wind speed from 1 m/s up to 25 m/s with a precision of 1 m/s.
> Wind direction through 16 points (360 degrees) with a precision of 22.5 degrees (1 point).

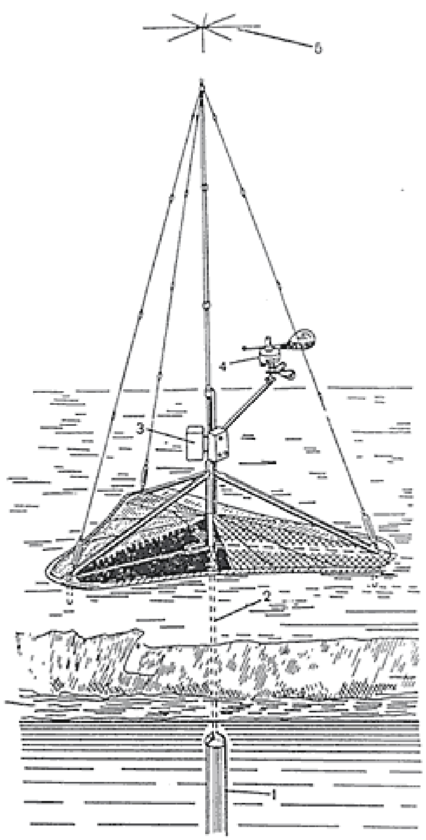
The data were transformed into radio signals by means of a code block and transmitted by Morse code on fixed frequency in the 551- 584 kHz range. The signals were received by American radio transmitting and bearing stations DAN-2. Nine stations were mounted in the Arctic during the Second World War to guide the transit flights of airplanes from the USA (Alaska) through the Arctic and Siberia to the Soviet-German front. High-frequency radio waves were used to fix position of the DARMS unit by triangulation. The sensitivity of the antenna was 1 μV, and bearing accuracy was ±1 degree. Signals were received from distances up to 1500 kilometers.

The long term (1957 through 1976) of the observation program for ice drift and meteorological parameters was due to the very dependable DARMS equipment and excellent radio bearing capabilities.

At the time of their acquisition, DARMS data were used in weather forecasting. Now the weather observations obtained by these stations supplement the information collected by the Russian North Pole drifting stations.

Preparation of DARMS data for the Atlas

Daily values of surface air pressure, two-meter air temperature, wind speed, wind direction, and DARMS positions were prepared for this Atlas. The time of daily values is given as 0000 GMT. Values from the archive at AARI for position and the meteorological observations were quality controlled by checking them against the original daily synoptic chart.



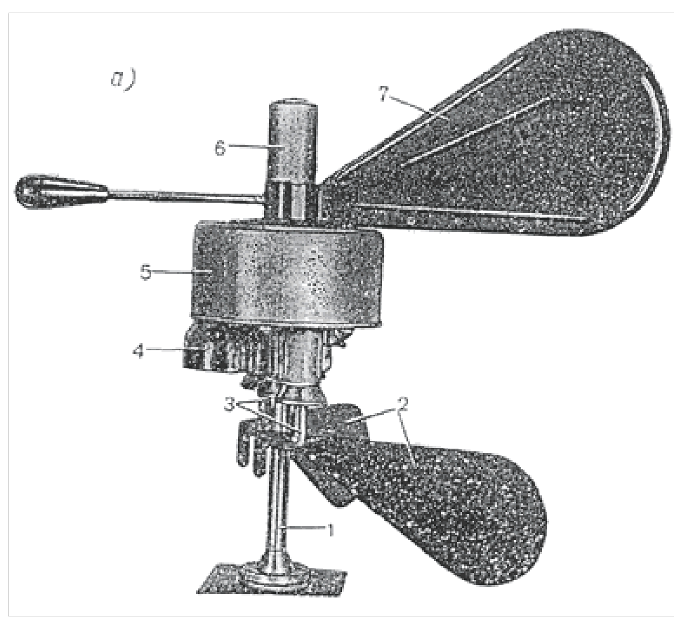


Fig. 9. (Left) A DARMS station. 1. Container for batteries and a clock mechanism. 2. Hollow steel bar. 3. Radio transmitter and receiver. 4. Meteorological unit. 5. Antenna. (Right) DARMS meteorological unit. 1. Axis 2. Wind speed vanes. 4. Temperature sensor with cover. 6. Cover of magnetic compass 7. Wind direction vane.

Western Drifting Stations

Historical drifting station synoptic observations from ice islands, sea ice floes or from ships drifting in pack ice were digitized at NOAA's National Climatic Data Center (NCDC). Data from the *Fram* were obtained from the German Weather Service. With the exception of some data from drifting ice station T-3 and the *Fram* that are in COADS (see "Description of COADS" under "Total and Low Cloud Cover" in the gridded fields section of the documentation) these data have not been readily available in the past. Table 18 gives the time period and parameters for each station. Use the Atlas HTML interface to see the length of the data record at any station for any of the parameters included in the Atlas, as well as the drift track of the station.

Data were keyed (digitized) at NCDC from the original or photocopies of the original records, or in the case of T-3, using some previously digitized sources. Each station's data were in a different format. Data were converted to standard units at NSIDC where necessary (with the aid of documentation provided by NCDC), sorted by time, and put in uniformat files (see "Uniformat - uniform format" under "Data Formats"). Generally, positions had to be converted to decimal degrees, longitude to degrees east, and time to UTC (for *Maud* data and parts of the T-3 data record). For ice stations Alpha, Charlie, and T-3, precipitation was converted from inches to millimeters.

While drifting stations are sometimes referred to as ice islands, an ice island is ice of land origin that has broken off an ice shelf. Most ice islands originate from the Ellesmere ice shelf. Of the drifting stations on this Atlas, only ARLIS II, T-3, and the Russian drifting stations NP-19, NP-22, NP-23, and NP-24 were on ice islands. Typically, stations were on multiyear ice floes.

This section of the Atlas is not a comprehensive catalogue of all western drifting stations. Only the major drifting stations, from T-3 (the first major, non-Russian, drifting station) through the AIDJEX program (the last western drifting stations prior to the SHEBA experiment of 1997 and 1998) are included. Data acquired during the drift of the Norwegian ships *Fram* and *Maud* are also included.

Table 18. Western drifting station, date range for data on the Atlas, and all parameters available in digital form. Uniformat parameters are included in uniformat files; all available parameters are included in data files in "raw" form (see text).

Station	Dates	Parameters

AIDJEX (4 stations)	4/1975-4/1976	Press, Air Temp, Wind Dir/Spd, DewTemp
ARLIS I	9/1960 - 3/1961	Press, Air Temp, Precip*, Sky Cover, Wind Dir/Spd, Weather, Visibility, Wet Bulb Temp, Cloud Layers, Min Temp
ARLIS II	6/1961 – 9/1962	Press, Air Temp, Precip*, Sky Cover, Wind Dir/Spd, Weather, Visibility, Wet Bulb Temp, Cloud Layers, Min/Max Temp (
Ice Station Alpha	5/1957 – 11/1958	Press, Air Temp, Precip, Sky Cover, Wind Dir/Spd, Weather, Visibility, Dew Temp, Cloud Layers
Ice Station Charlie	5/1959 – 1/1960	Press, Air Temp, Precip, Sky Cover, Wind Dir/Spd, Weather, Visibility, Dew Temp, Cloud Layers - Daily Summary: Min/Max Temp, 24 Hour Precip, 24 Hour Snowfall, Snow Depth, Peak Wind Dir/Spd
T-3 (called Ice Station Bravo in IGY)	1952-1971 (with gaps)	Press, Air Temp, Precip, Sky Cover, Wind Dir/Spd, Weather, Visibility, Dew Temp, Cloud Layers
Maud	9/1922 – 8/1924	Press, Air Temp, Precip, Sky Cover, Wind Dir/Force, Weather, Cloud Layers
Fram	1893-1896	Press, Air Temp, Wind Dir, Total Cloud, Low Cloud, Rel Humid., Dew Temp, Wet Bulb Temp

* Note: Precipitation data from ARLIS I and ARLIS II are not included in the uniformat files for these stations, because the data were determined to be unreliable by NCDC.

The literature resulting from drifting station studies is extensive. As a starting point, *Cabaniss*, [1962] summarizes much of the work done at Alpha, Bravo and Charlie. *Crary* [1958] summarizes characteristics of T-3. The proceedings of the Airlie Symposium on Arctic Drifting Stations [*Salter*, 1968] compiles research results from all the ice station programs that received funding from the U. S. Office of Naval Research (ONR). *Jeffries*, [1992] reviews the physical characteristics of ice islands and gives an overview of the history of their discovery and use as research stations.

For a historical perspective, *Fletcher* [1966] provides an account of early Soviet and U.S. ice station activities with an emphasis on the role of air support. *Leary and LeSchack* [1996] relates the development of U. S. interest in ice stations for military advantage, culminating in the story of a secret mission to an abandoned Soviet North Pole drifting station. Articles in National Geographic present interesting accounts of life on T-3 [*Fletcher*, 1953] and ARLIS II [*Thomas*, 1965].

Data sources

Ice station data were keyed at NCDC under the direction of J. Elms, in a project initiated in 1992 for COADS. The University of Washington Polar Science Center and NSIDC assisted by helping to locate data, and NOAA's National Geophysical Data Center (NGDC) provided funding. The project is documented in *Elms et al.* [1993], with additional information in *Elms* [1992] and *Elms* [1999]. The objective of the project was to key data that were then missing from COADS.

Data were assembled from all sources that could be located. These included manuscripts, teletype, some digital data, and published data. NSIDC provided NCDC with copies of handwritten logs from AIDJEX (originals are at the University of Washington), and with messages printed on teletype paper for T-3 from 1963 through 1966. The University of Washington provided NCDC with copies of logs from the *Maud* (published in *Sverdrup* [1933]). Records from T-3 came from a variety of sources collected at NCDC, including synoptic teletype messages, "plain language" messages, and WBAN hourly surface observations.

Data from the *Fram* were obtained by NSIDC from the Deutscher Wetterdienst (the German Weather Service) with the assistance of V. Wagner.

Some of the ice stations reported parameters that are not included in the uniformat files (see Table 18 for the complete list of parameters available in digital form). These observations are included on this Atlas in files containing all the data as digitized by NCDC from the original records, and prior to any quality control at NSIDC. Files are in the directory FLOATING_PLATFORMS/WESTERN_DRIFT/ORIGINAL_DATA/. Supporting documentation was scanned and is included with the "raw" data files (00SUMMARY.htm). These additional data may be difficult to use, and we are including them on the Atlas only for completeness and because they are historical records that may not have been published elsewhere.

Positions

Records digitized at NCDC included station positions. When necessary, positions were inserted in records at NCDC by locating the needed positions in manuscripts. For some stations (ARLIS II, Ice Station Alpha, *Fram*, and parts of T-3) we used position data from the data set *Arctic Ocean Drift Tracks from Ships, Buoys and Manned Research Stations*, available from NSIDC (http://www-nsidc.colorado.edu/NSIDC/CATALOG/ENTRIES/G01358.html) for the Atlas instead of positions in the NCDC records. These data are smoothed and interpolated from data sets of observations at the Polar Science Center, University of Washington [*Colony and Thorndike*, 1984] to give a position every two days. The position nearest in time to the observation time is used in the uniformat file. Sea ice drift speeds in the Arctic seldom exceed a few kilometers per day, so little error is introduced by this practice.

For the four stations named above, the Colony and Thorndike data set provided data that were not readily available elsewhere (for the *Fram*), or provided a smoother track where data had been recorded only to the nearest degree (for Alpha, ARLIS II, and parts of T-3). Still, at least part of the position record for ARLIS I, Alpha, Charlie, and T-3 is available only to the nearest degree. The positions have not been quality controlled beyond measures taken at NCDC. They are given on the Atlas as they were received from NCDC or as they appear in the Colony and Thorndike data set. The position flag for the western drifting station data is set to "1", even though some positions may have been interpolated (see "Uniformat - uniform format" under "Data Formats").

Quality control

Elms et al. [1993] note that data continuity problems plagued the effort to collect and digitize the arctic ice station records. Date and time were often miscoded, for example. Usually these problems were corrected in quality control procedures at NCDC.

After conversion to uniformat data, station meteorological data underwent further testing at NSIDC. Data points that exceeded minimum and maximum values suggested by a meteorologist were visually inspected and discarded if suspected to be erroneous. Parameters that do not vary smoothly, such as wind direction, wind speed, precipitation, and cloud, were checked for gross errors by plotting the data and looking for evidence of problems such as stuck gauges, or factor-of-ten jumps.

Air temperature was checked for out of range values (greater than 10 degrees Celsius, less than minus 55 degrees Celsius). Relative humidity was converted to vapor pressure, which is less sensitive to temperature, before quality control. For smoothly varying parameters, such as air temperature, pressure, and humidity, a difference method was used to identify bad points. The difference in adjacent measurements, (x_{n+1}-x_n), was found. This difference was compared with a "standard" difference, and if the tested point created a difference greater than the standard, it was visually inspected and a decision was made whether or not to discard the point. The standard differences were obtained by finding the maximum differences for each parameter in records from each of the 31 Russian North Pole drifting station data sets. The average of the 31 maximum differences was then taken to produce a "standard" maximum expected difference. The Russian North Pole drifting station data were used because the time series is very long, while the western drifting station data sets are generally too short to provide a reliable estimate of the maximum expected deviation between adjacent measurements.

The difference method was preferred over simply flagging points outside a few standard deviations from the mean. It assumes little about the data distribution, and it was found to work better on temperature data, where large temperature excursions in winter resulted in a standard deviation too large to properly screen data in summer. Figure 10 shows an example of how the difference method worked for pressure data from Ice Station Charlie.

All changes to data digitized at NCDC for the uniformat files were noted, and an inventory of changes is available from NSIDC.

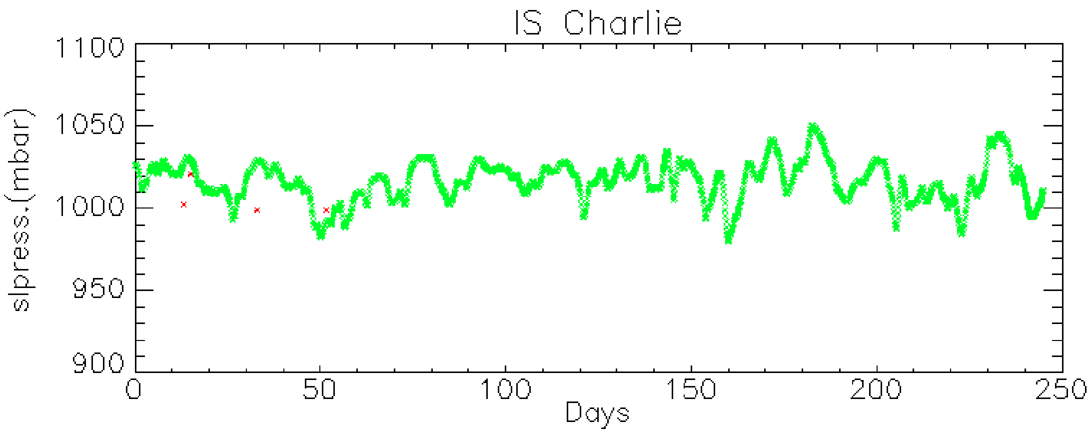


Fig. 10. Data points in red are those flagged as questionable by the difference method of quality control in the record of sea level pressure from Ice Station Charlie.

Notes on individual stations

Fram

The North Polar Expedition of 1893 through 1896 was conducted on board the *Fram*. Norwegian researcher and explorer Fridtjof Nansen originated the idea of using a ship, beset in ice and drifting, as a research station after pieces of wreckage from the *USS Jeannette*, crushed in the ice of the Laptev Sea, washed up on the southwest coast of Greenland after three years. To Nansen, this event suggested the existence of a trans-Arctic current. The *Fram*, designed specifically for the expedition by naval architect Colin Archer, drifted from a starting point in ice north of the New Siberian Islands to Svalbard in what was later named the Transpolar Drift Stream.

The meteorological observation program for the expedition was the responsibility of H. Mohn. The instruments used, their characteristics, and the observations themselves are in "Meteorology", by H. Mohn, published as Volume VI of the Scientific Results [*Nansen*, 1900-1906]. Observations were taken every two hours, and recorded with the local time (converted to UTC at the German Weather Service). Following are brief summaries of measurement methods for the parameters for which we have digital data, obtained from Mohn's account.

Wind direction was reported on a 32-point compass scale (that is, points have 11.25 degrees of separation). Wind direction was noted to the nearest compass point in degrees True. Wind speed was measured with a Mohn hand-held anemometer and recorded in meters per second. (The wind data for *Fram* received at NSIDC were in knots. We converted these values to m/s).

Atmospheric pressure was measured with three mercury barometers, one of which served as a standard. The observations were corrected to the height of the mercury at zero degrees Celsius and at sea level, and reduced to standard gravity.

Air temperature was measured with a variety of mercury, alcohol and toluol thermometers, as well as two thermographs. When the ship was frozen in the ice, the thermometer for air temperature and the hygrometer were placed on the ice in a Stevenson screen at a height of about 1.2 m.

Air humidity was measured using a psychrometer and a hair hygrometer. Absolute humidity and relative humidity were computed from the corrected readings of the dry and wet-bulb thermometer using psychrometric tables. When the wet-bulb temperature reading was below zero, its reading was corrected following Ekholm's recommendation (as cited by [*Nansen*, 1900-1906]).

Cloud amount was recorded on a scale of 0 to 10, and cloud form was noted.

Ship positions were interpolated to the time of each meteorological observation.

Maud

Following the success of the *Fram* expedition, Norwegian researcher and explorer Roald Amundsen organized an expedition of the *Maud* to perform a similar drift. The scientific program was lead by H. Sverdrup, and meteorological observations were published in *Sverdrup* [1933].

The expedition lasted from 1918 to 1925, but most of the observations from 1918 through 1919 were lost when two members of the expedition set forth along the coast, carrying the records. They died in the attempt to reach the Russian station at Dikson, and the records were destroyed by animals [*Sverdrup*, 1933].

The observations on this Atlas are from 1922 to 1924, when the ship was in the ice. Observations were taken every two hours, and recorded with the local time (converted to UTC at NSIDC).

Air pressure was reduced to zero degrees Celsius, standard gravity and sea level. Air temperature was measured by sling thermometer or Assman psychrometer at about 5 meters above sea level. Relative humidity was calculated from readings of the Assman psychrometer.

Maud data include "shelter" and "masthead" temperatures. The shelter readings were used for the Atlas uniformat files. The shelter was about 4 to 5 meters above the ice surface.

Wind speed observations from the *Maud* used the Beaufort scale. NSIDC converted the Beaufort force number to the middle of its corresponding range in knots, and then converted to m/s. The anemometer was mounted about 5 meters above the surface of the ice. Wind direction was recorded to the nearest 16 point compass direction (that is, points have 22.5 degrees of separation).

Daily precipitation was recorded. Cloud cover was generally recorded six times a day prior to June 1, 1923, and every two hours after then, on a scale of 0 to 10.

The ship position was recorded at noon in tables separate from the meteorological data. NCDC assigned the position nearest in time to the meteorological observation time to each meteorological record.

T-3

The ice island that was later designated T-3 (T stands for Target) was sighted for the first time by North Americans when the crew of an U.S. Airforce B-29 flew over it on 27 April 1947 [*Wood*, 1956]. Lt. Col. J. O. Fletcher established the station on T-3 in March, 1952. A. P. Crary, Air Force Cambridge Research Center, soon joined the station to conduct geophysical investigations. Over more than 20 years of drift, T-3 served as a base for weather observations and research programs sponsored primarily by the U.S. Office of Naval Research and the U.S. Air Force. In an interesting footnote to the scientific work carried on at the station, complicated issues of jurisdiction were raised after a murder on T-3 in 1970 [*Wilkes*, 1973]. T-3 has also been called Fletcher's Ice Island and, during the International Geophysical Year (IGY, 1957 through 1958), the station on the ice island was called IGY-B or Ice Station Bravo.

T-3 was occupied continuously between March 1952 and May 1954 as a weather station operated by the Air Weather Service, and then reoccupied in spring and summer of 1955 to continue geophysical investigations [*Cottell*, 1960]. Beginning in 1957 the U. S. Weather Bureau took over responsibility for meteorological observations [*Crary*, 1966]. The station was continuously occupied from 1957 until 1971, with the exception of October 1961 to October 1962 [*Wilkes*, 1972].

Drifting station positions were obtained by theodolite using the stars in winter and the sun in summer. The Lamont-Doherty Geological Observatory recalculated positions using a computer for the period from 1962 through 1970, and estimated the error in resulting coordinates to be less than 0.05 nautical miles. In 1967, a Doppler-based satellite positioning system was installed. The positions from this system were no more accurate than celestial navigation, but the system allowed more fixes for a smoother track [*Hunkins and Hall*, 1971].

A device dropped on the ice island in May 1976 allowed the island to be tracked by the NASA Nimbus satellite for four months, and again for a short time in July 1977 [*Anonymous*, 1977]. The ice island was visible in NOAA polar orbitor satellite images, and in Seasat synthetic aperture radar imagery from 1978 (Figure 11). After 1979 T-3 was not tracked, but in 1984 what was believed to be a remnant of T-3 was sighted at the southern tip of Greenland [*Jeffries*, 1992]. T-3 had made three circuits in the Beaufort Gyre before exiting the Arctic through the Fram Strait via the Transpolar Drift Stream.

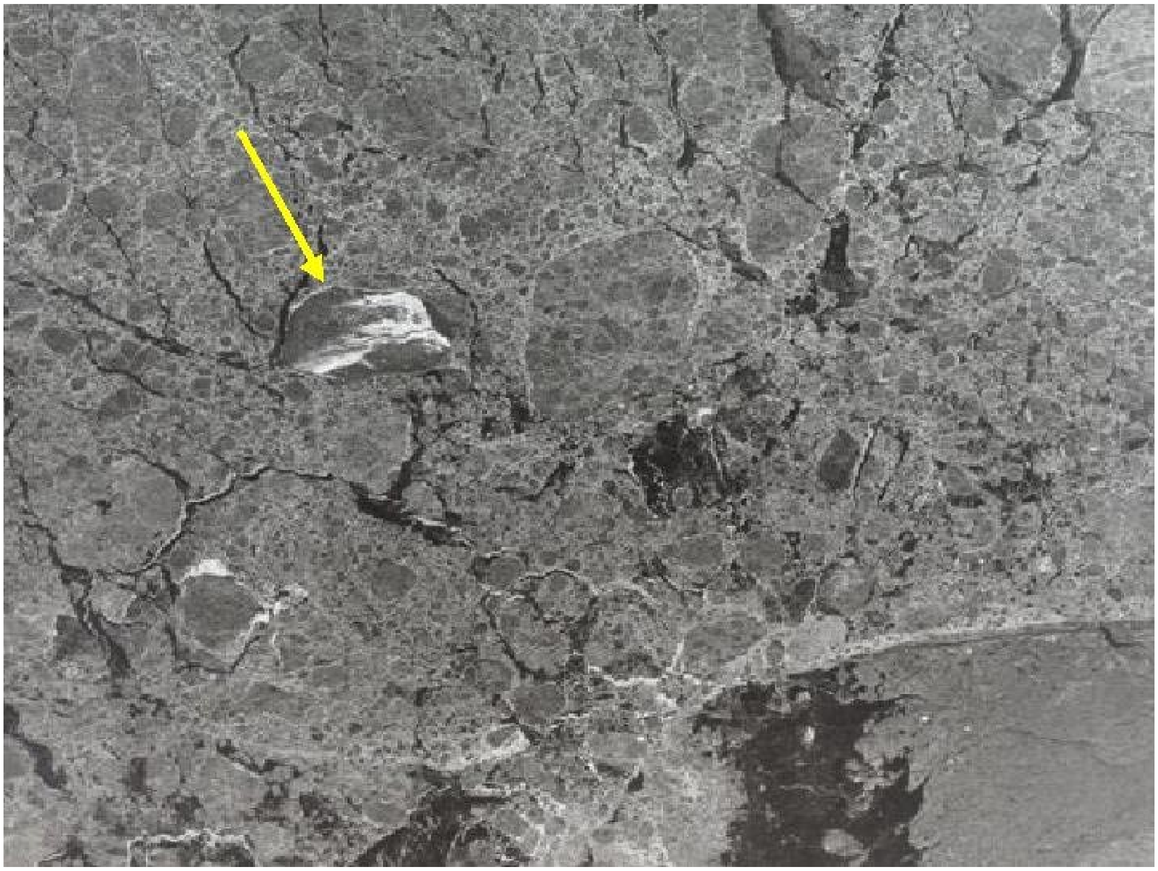


Fig. 11. T-3 as it appeared in a Seasat synthetic aperture radar image on Oct. 3, 1978. The island was about 12 km long and 7 km wide. The high backscatter is thought to be due to the low corrugated ridges of rock debris [*Fu and Holt*, 1982]. Banks Island, in the Canadian archipelago, is at lower right. (Image provided by Benjamin Holt, Jet Propulsion Laboratory, Pasadena, CA).

Alpha, Bravo, and Charlie

Information on ice stations Alpha, Bravo, and Charlie was drawn from *Cottell* [1960], and *Leary and LeSchack* [1996]. Alpha, Bravo (the re-occupied T-3), and Charlie were established under Project Ice Skate through the agency of the U. S. National Committee for the International Geophysical Year (IGY). The U. S. Air Force provided logistic support, and the U. S. Weather Bureau directed the meteorological observations. These included upper air data, radiation, carbon dioxide, and ozone studies as well as synoptic observations.

The scientific program included heat budget studies, ice physics, magnetics, oceanography, and geology, and was carried out by a number of U.S. universities and agencies with participation by Canadian and Japanese agencies as well. After IGY, many of these studies continued under sponsorship of the U. S. Office of Naval Research (ONR) and the U. S. Geophysics Research Directorate. One significant bathymetric discovery from the program at Alpha was the existence of the "Alpha Rise", which parallels the Lomonosov Ridge.

Positions were determined from observations of sun, moon, and stars with precision theodolites or transits. The recorded positions were estimated to be accurate within one-half a nautical mile.

Ice Station Alpha was set up in April 1957, and the scientific program lasted from June 1957 to November 1958, when the station was abandoned due to the ice breaking up. ONR had agreed to run Alpha after IGY, and after Alpha's premature abandonment, ONR supported the establishment of Ice Station Charlie in April 1959. Observations at Charlie began in May 1959 and lasted until January 1960, when the station was abandoned due to the ice breaking up.

Ice Station Bravo was established by re-occupying T-3 in March 1957. Signals from the Sputnik satellites were monitored on Bravo for a time in 1957, when the position of the drifting station north of Ellesmere Island was advantageous for reception.

ARLIS I and ARLIS II

The Arctic Research Laboratory Ice Stations (ARLIS I and ARLIS II) were supported by the Arctic Research Laboratory (ARL) established near Barrow, Alaska, by the newly formed U. S. Office of Naval Research in 1947. In 1956, M. Brewer, the director of ARL, and M. Britton, director of arctic research at ONR, were successful in obtaining support for a program to establish drifting stations at relatively low cost. ARLIS I was established by icebreaker in September 1960, but abandoned in March 1961. ARLIS II was established on an ice island in May 1961 and operated until May 1965 [*Thomas*, 1965].

Of the four ARLIS stations, only data from ARLIS I and ARLIS II were located and keyed at NCDC. ARLIS II swept west in the Beaufort Gyre, and left the Arctic Basin through the Fram Strait via the Transpolar Drift Stream. ARLIS I had a much shorter track.

AIDJEX

The Arctic Ice Dynamics Joint Experiment (AIDJEX) grew out of an initial experiment design prepared by N. Untersteiner and K. Hunkins at the request of the U. S. Office of Naval Research and the U. S. Naval Oceanographic Office. The experiment was designed to collect, for the first time in the West, coordinated measurements of wind stress, ice strain, water motion, and water stress over at least one year, in order to have the right combination of data with which to understand atmosphere and ice interactions. Canadian and U.S. scientists collaborated in planning and carrying out the experiment, which included pilot studies in 1971 and 1972 as well as the main experiment in 1975 and 1976. J. Fletcher served as AIDJEX coordinator, 1970 through 1971, followed by N. Untersteiner for the remainder of the program (1971 through 1977). The National Science Foundation, the Office of Naval Research, and other U. S. and Canadian agencies funded AIDJEX.

All AIDJEX science and logistics activities are documented in the AIDJEX Bulletin series. Forty volumes were published between September 1970 and June 1978. Volumes 3, 16, and 17 were devoted to translations from Russian: evidence that AIDJEX scientists were intensely interested in Arctic research performed by Russian scientists. *Pritchard* [1980] has a wealth of information on AIDJEX science.

The main objective of AIDJEX was to improve understanding of ice dynamics, and meteorological observations were important for estimating wind stress. Observations of wind, temperature, pressure and radiation were taken at the main camp (Big Bear), and at three satellite camps (Caribou, Blue Fox and Snowbird) established 60 km from the main camp. Figure 12 is an aerial view of Big Bear. Data were acquired from April 1975 through April 1976.

AIDJEX was the first major project in the Arctic Basin to employ navigation by the highly accurate satellite navigation methods that had become available at that time. All previous station positions were taken by the traditional methods of celestial navigation. The positions of the AIDJEX camps were acquired approximately 10 times per day using the Transit navigational satellite or the NOAA Nimbus F satellite.

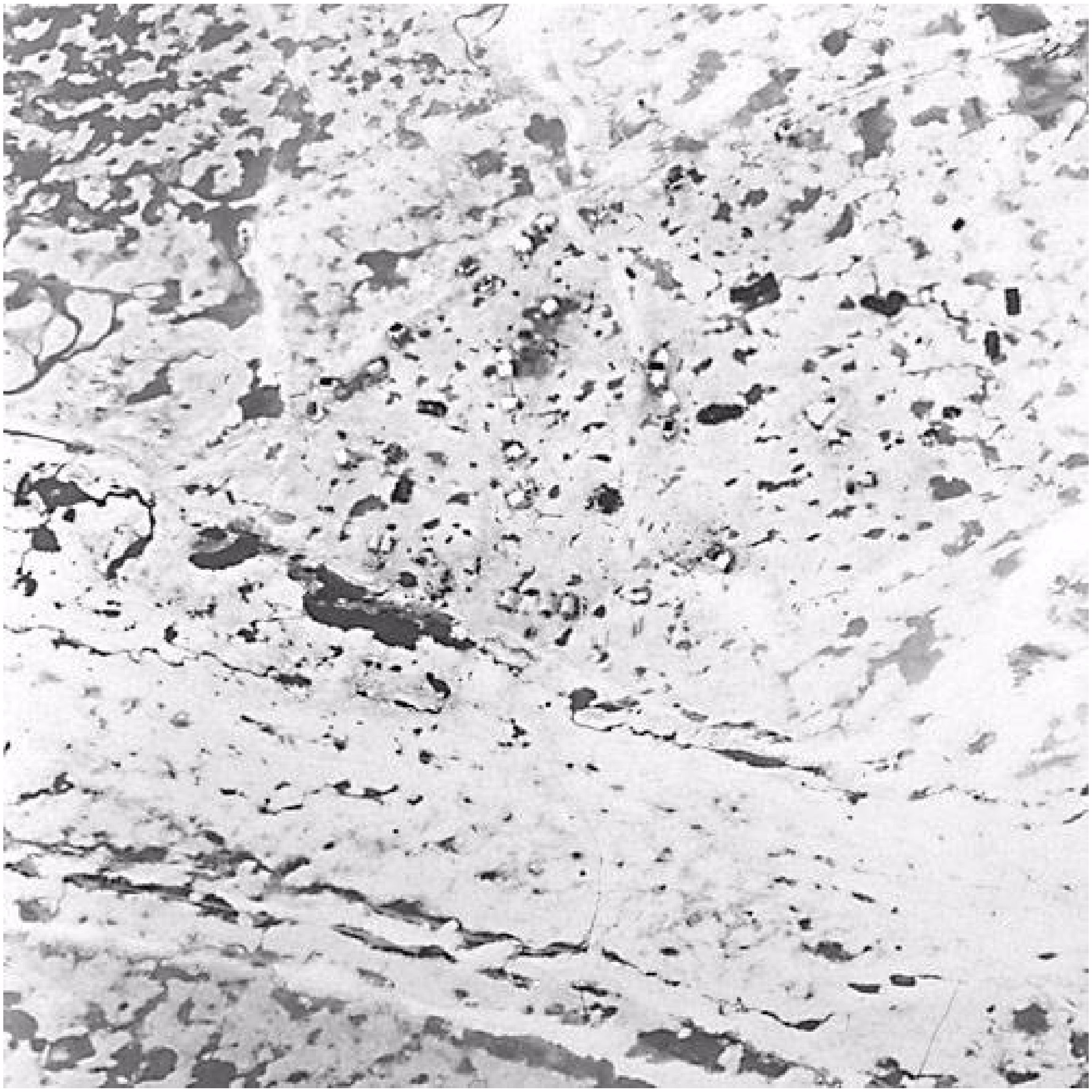


Fig. 12. A view of Big Bear taken from a helicopter at an altitude of about 1000 meters on 12 July 1975. The runway, covered with melt ponds as is the rest of the ice floe, runs across the bottom of the image.

Paulson and Bell [1975] describe routine observations taken at the manned camps. At each camp a 10 meter tower was instrumented to measure wind speed and wind direction at 10 meters, and air temperature at 1 meter and 9 meters (the 1 meter observations are included in this Atlas). The tower was located away from large ridges, and 100 meters from the hut housing the data recording instruments.

Wind was measured with a vane and cup anemometer calibrated before and after the experiment. Air temperature was measured with platinum resistance elements inside aspirated radiation shields. Surface pressure was recorded with two microbarographs at each station, and also measured twice-daily using mercury barometers.

Humidity was measured with an Assman ventilated psychrometer three times per day when conditions permitted (that is, when dry bulb temperatures were above minus 10 degrees Celsius). At very low temperatures the difference between dry and "wet" temperature becomes too small to be measured by ordinary thermometers.

Sky cover, cloud type, visibility, precipitation, ablation, and radiation were also measured, but these observations are not included on the Atlas because they are not readily available. See *Paulson and Bell* [1975] for more information.

AARI Quality Control Methods

Documentation provided by V. Radionov

The following describes general methods of quality control used at AARI.

Stage I: Data that were not already in digital form were digitized from logbooks, bulletins, or charts. Data quality control was performed for three or six hourly data from North Pole drifting stations and Ice Patrol ships, for once-daily DARMS data values, and for monthly means at coastal and island stations as follows:

1. Each observation or monthly mean (monthly means were calculated at each station by an observer) was evaluated based on the likelihood and consistency of individual parameter values. This excluded most large errors.
2. For individual meteorological parameters, where the distribution is close to normal, statistical estimates of the mean and extremes can be used for testing. These parameters generally include pressure, air temperature, relative humidity, and surface temperature.

    a. Grubbs' criterion [*Grubbs*, 1950] was used to detect individual extrema. If a point exceeded a threshold based on the mean, one may assume the hypothesis of over-estimation. Points that exceeded ±2.5 standard deviations from the monthly mean were marked.
    b. The modified criteria of *Tietjen and Moore* [1972] was sometimes used for testing outliers.

Values exceeding the thresholds were noted as questionable. As an additional quality control, a parameter may have been temporarily changed by interpolation of the tested parameter with observational data of this parameter across two adjacent intervals. Discrepancies between tested and interpolated parameter values were estimated as extreme deviations (Kolmogoroff deviation) and each evaluated by an expert, who made the ultimate decision. Additionally, all questionable observations were tested by an expert specialist from AARI who made the ultimate decision about the rejection of questionable values.

Stage II: Testing during Stage I will exclude crude errors. In Stage II, systematic errors connected with instrument function, improper operation, or with incorrect data processing are considered. These are errors that would not necessarily be routinely noticed.

Horizontal control between stations:
Within a 40-year period, there may appear changes in the climatic homogeneity of time series. These may result from changes in the meteorological station location, or in the station surroundings, and from natural climatic changes. The most common analysis methods of climatic homogeneity, the difference and ratio methods [*Drozdov*, 1989] are used in this test. This procedure makes it possible to identify shifts in parameter value. Other cases of climatic heterogeneity of temporal sets will not be identified during these threshold tests because it is impossible to distinguish the causes of heterogeneity without carrying out a sophisticated analysis. The data record of the 65 Russian coastal stations was tested by this method.

As in all preceding steps, an expert made the final decisions regarding quality control, including the advisability of testing observations at adjacent stations. Observations that passed all stages of the testing are included in the Atlas data base.

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