



National Snow and Ice Data Center
World Data Center for Glaciology



EASE-Grid

A Versatile Set of Equal-Area Projections and Grids

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Introduction

The Equal-Area Scalable Earth Grid (EASE-Grid) comprises three equal-area projections, combined with an infinite number of possible grid definitions. It is based on a philosophy of digital mapping and gridding definitions that was developed at the National Snow and Ice Data Center (NSIDC), in Boulder, CO. This philosophy was used to implement a library of software routines, based on the assumption that a gridded data set is completely defined by two abstractions, the map projection and an overlaid lattice of grid points. The complete source code is available via ftp, and contains software to convert among many projections, but this paper will be restricted to an overview of the family of specific projections and grids that we have called the NSIDC EASE-Grid, or simply EASE-Grid.

The EASE-Grid is intended to be a versatile tool for users of global-scale gridded data, specifically remotely sensed data, although it is gaining popularity as a common gridding scheme for data from other sources as well. We begin with a short introduction to the abstractions used in NSIDC's generic mapping and gridding software, and proceed to the specific projections and grids that comprise the EASE-Grid family of grids. We include several short descriptions of the EASE-Grid used for different projects, as examples of the flexibility of the format. We conclude with an example of two EASE-Grid data sets that are used to study sea ice concentrations in Baffin Bay.

Defining a Gridded Data Set

NSIDC's mapping software is based on the assumption that a gridded data set is completely defined by the map projection and an overlaid lattice of grid points, often referred to as "cells". It is useful to think of the projection and the grid lattice as separate but related abstractions. The projection is simply a mathematical coordinate transformation of points on the curved surface of the Earth to points on a plane. The lattice of grid points can be imagined as a transparent piece of graph paper, overlaid on the plane of projection and anchored to it at a specified point.

Once the projection is chosen, any number of grid definitions can be used to describe the effect of changing the grid, or "graph paper," for the application at hand. For example, smaller graph cells can be used when a higher resolution is needed, or the size of the graph paper (number of columns/rows) can be reduced to study a subset area of the full projection.

An array of gridded data, then, consists of one data element for each grid "cell" or lattice point. The user has complete flexibility to define the meaning of grid cell values, according to the most appropriate sampling technique for the data and application at hand. In many cases, particularly with remotely sensed imagery, it is important for a user to think of gridded data elements as values associated with the lattice points of the graph paper, rather than as associated with the "area of the grid cell." We have found the more general lattice point concept to be more useful when the data represent regularly sampled measurements in a continuous field, for example, passive microwave brightness temperatures, or visible wavelength radiances. In the sensor swath space, the data value is simply a sample measurement from the continuous field, and may or may not have any physical relationship to the size and shape of the eventual grid "cell" surrounding the eventual lattice point in the regularly gridded data array. For example, although the sampling interval of a 19 GHz scanning passive microwave radiometer might be 25 km, the effective field of view of the antenna might be an elliptical area, 40 km x 60 km. The eventual gridded data array might be defined on a 25 km grid, with data element values chosen from the nearest neighbor of the latest swath. In this case, the data element still represents a 40 km x 60 km brightness temperature.

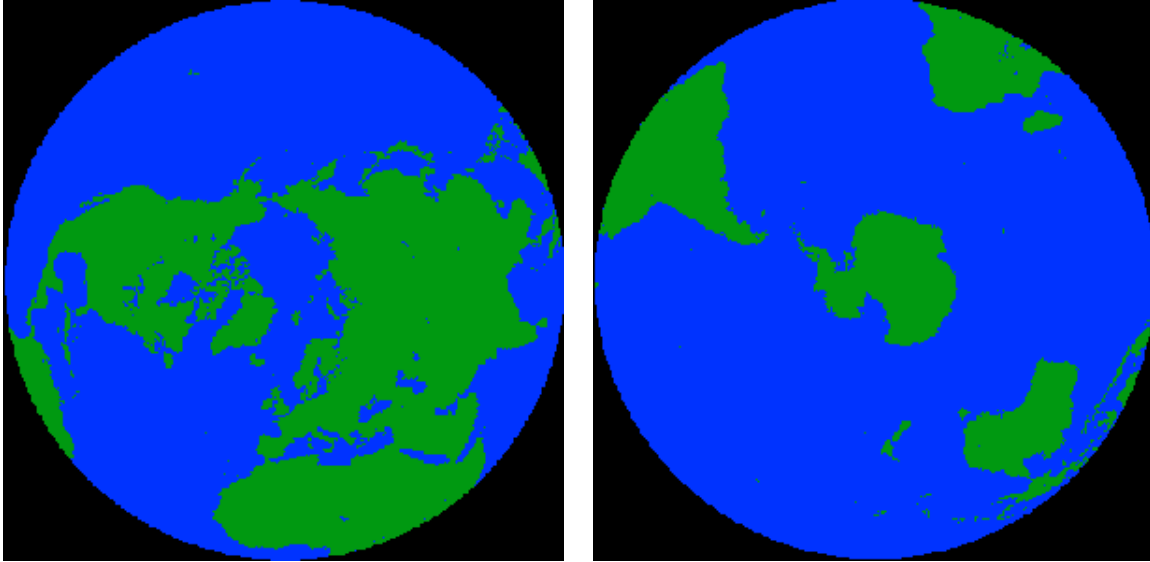
It is entirely up to the data set producer to define the meaning of a gridded data element during the sampling process. The process of sampling data to the regular grid is sometimes referred to as binning. Examples of binning techniques include averaging all data that falls into a given cell, or taking a maximum, minimum, median or latest value in the cell. The producer might choose to involve the area and shape of the cell in the definition of a data element, but is certainly not required to do so. Alternative methods include nearest neighbor, bilinear interpolation, or otherwise weighted averages of surrounding data samples.

EASE-Grid Map Parameters

The EASE-Grid was originally developed at NSIDC for the data products generated by the Special Sensor Microwave Imager (SSM/I) Level 3 Pathfinder Project, which includes gridded passive microwave brightness temperature and related geophysical products derived from the brightness temperatures at a relatively coarse 25 km resolution. However, given the flexibility of an infinite number of grid definitions for the EASE-Grid projections, the format has since been adopted by a number of other projects, with grid resolutions ranging from 1.25 km to 250 km. These include the TIROS-N Operational Vertical Sounder (TOVS) and Advanced Very High Resolution Radiometer (AVHRR) Polar Pathfinders, the AARI (Arctic and Antarctic Research Institute, St. Petersburg, Russia) Sea Ice

data, the Arctic Climatology Project Arctic Meteorology and Climate Atlas, and NSIDC's EASE-Grid versions of the Global Land Cover Classification (GLCC) data and the International Permafrost Association Permafrost and Ground Ice Map.

The three EASE-Grid projections comprise two azimuthal equal-area projections, for the Northern or Southern hemisphere, respectively, and a global cylindrical equal-area projection.



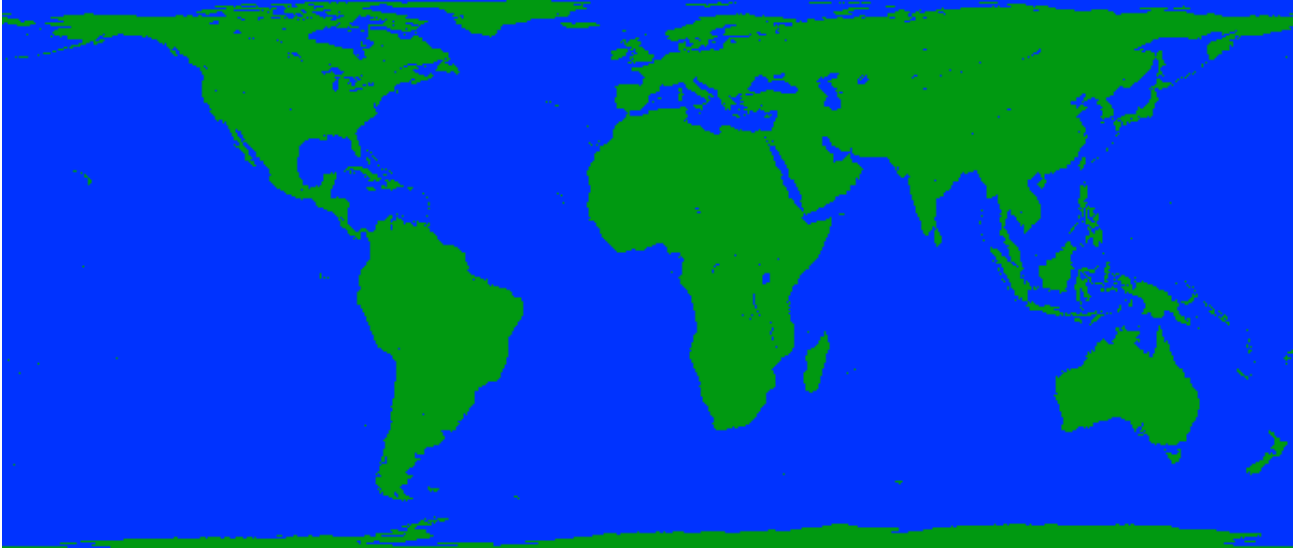
Northern Hemisphere EASE-Grid projection Southern Hemisphere EASE-Grid projection

The North azimuthal equal-area map is defined as

- $r = 2 \cdot R/C \cdot \sin(\lambda) \cdot \sin(\pi/4 - \phi/2) + r_0$
- $s = 2 \cdot R/C \cdot \cos(\lambda) \cdot \sin(\pi/4 - \phi/2) + s_0$
- $h = \cos(\pi/4 - \phi/2)$
- $k = \sec(\pi/4 - \phi/2)$

The South azimuthal equal-area map is defined as

- $r = 2 \cdot R/C \cdot \sin(\lambda) \cdot \cos(\pi/4 - \phi/2) + r_0$
- $s = -2 \cdot R/C \cdot \cos(\lambda) \cdot \cos(\pi/4 - \phi/2) + s_0$
- $h = \sin(\pi/4 - \phi/2)$
- $k = \csc(\pi/4 - \phi/2)$



Global EASE-Grid projection

The cylindrical equal-area map is defined as

- $r = r_0 + R/C * \lambda * \cos(30)$
- $s = s_0 - R/C * \sin(\phi) / \cos(30)$
- $h = \cos(\phi) / \cos(30)$
- $k = \cos(30) / \cos(\phi)$

The cylindrical equal-area map is defined as true at 30N/S.

where:

- r = column coordinate
- s = row coordinate
- h = particular scale along meridians
- k = particular scale along parallels
- λ = longitude in radians
- ϕ = latitude in radians
- R = radius of the Earth = 6371.228 km
- C = nominal cell size
- r_0 = map origin column
- s_0 = map origin row

Both projections are 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.

The values of C , r_0 and s_0 are determined by the grid that is chosen to overlay the projection.

Why "equal-area" maps?

Discussion of map projections is often unnecessarily lengthy and sidetracked by disregard for the fact

that there is no one best map projection. Each projection has different properties and thus different "best" uses. Sometimes the question is raised as to why we chose equal-area projections over the other possibilities for the EASE-Grid, and the answer relies on a basic understanding of projection characteristics, in the context of our original application: we were seeking minimal distortion over hemispheric and global scales.

"Two of the most important characteristics of maps are whether they are conformal or equal-area. No map projection is both, and some are neither" (Knowles, 1993). On equal-area maps, a small circle placed anywhere on the map will always cover the same amount of area on the globe, and, at any point on the map, the product of the scale h along a meridian of longitude and the scale k along a parallel of latitude is always one. The aspect ratio $k:h$ is a measure of shape distortion.

For the Northern and Southern hemisphere EASE-Grid projections, the aspect ratio varies from 1:1 at the pole to 1.17:1 at 45N and increases to only 2:1 at the equator. For the global EASE-Grid projection, the aspect ratio varies more widely (see details in the following table). The selection of +/-30 for the standard parallels of the cylindrical projection gives a map with minimum mean angular distortion over the continents. This projection is intended for the study of parameters in the mid- to low-latitudes.

Aspect ratios (a measure of shape distortion) of the EASE-Grid projections:

Azimuthal Equal-Area		Cylindrical Equal-Area	
latitude	k/h	latitude	k/h
90	1.00	80	24.90
75	1.02	75	11.20
60	1.07	60	3.00
45	1.17	45	1.50
30	1.33	30	1.00
15	1.59	15	0.80
0	2.00	0	0.75

In contrast, on conformal maps, angles within a small area are reproduced accurately, so a small circle on the globe will look like a small circle on the map. At any point on the map, the scale h along a meridian of longitude is equal to the scale k along a parallel of latitude, and $hk - 1$ is a measure of areal distortion. For example, NSIDC produces other polar gridded data products using a polar stereographic map true at 70N. The projection is a conformal map. By definition, the aspect ratio remains 1:1 everywhere, however, the areal distortion of this map varies from -6% at the pole to +29% at 45N and increases to +276% at the equator.

Areal distortion of the Polar Stereographic map true at 70N:

Polar Stereographic, (true at 70N)	
latitude	kh - 1
90	-6%
45	29%
0	276%

A very popular map that is neither equal-area nor conformal is the cylindrical equidistant map, also known as the "lat-lon grid." This map suffers from both areal and shape distortion, as follows:

	Shape Distortion	Areal Distortion
latitude	k/h	kh - 1
89	57	5630%
80	6	476%
60	2	100%
45	1.4	41%
0	1	0%

In summary, given the choices of either shape distortion or areal distortion or both, we decided in favor of the equal-area projections for the EASE-Grid because they minimized the amount of distortion over the hemispheric and global scale we were attempting to portray. One convenient side effect of this choice is that calculations of areal statistics are reduced to simply summing pixels and multiplying by a constant area per pixel, so the acronym, "EASE-" takes on a secondary meaning, as in "easy to use."

Why a Spherical Earth Model?

Another question that is sometimes raised is why we chose to use a spherical earth model over an elliptical model, and how much "error" this introduces in the gridding geolocation. The answer is that no error is introduced by this model choice.

Representation of the gridded data as a fixed array of values is accomplished with a set of equations to map from geographic coordinates (latitude, longitude) to grid coordinates (column, row). In this sense, the location (column and row) of each grid "cell" can just be considered an entry in a look-up table, i.e. a place to store the data (Brightness Temperature, albedo, time stamp, etc.) for a specific, implicitly defined, geographic location. As long as the transformation back from grid coordinates (column,row) to geographic coordinates (latitude, longitude) is performed with the inverse transformation that uses the same Earth model, there is no error introduced by using a spherical Earth model. Choice of an elliptical model would only slow down the transformation calculations, (geographic to grid and back), with no gain in accuracy.

EASE-Grid Family of Grid Definitions

A grid is always defined in relation to a specific map projection. It is essentially the parameters necessary to define a rectangular coordinate system overlaid on a flat map and anchored to it at the map origin. The following four elements completely describe a grid:

- the map projection
- the numbers of columns and rows
- the number of grid cells per map unit (the map unit is part of the projection parameters)
- the grid cell coordinates of the map's origin

The EASE-Grid family of grid definitions includes, but is not limited to, the following specific grids.

The Original SSM/I Grids

The original 25 kilometer grids were defined for the data products generated by the SSM/I Level 3 Pathfinder Project at NSIDC. These grids have a nominal cell size of 25 km x 25 km. A slightly larger actual cell size $C=25.067525$ km was chosen to make the full global (ML), 25 km grid exactly span the equator, and was then used for all three projections for the sake of data product consistency. Of course, few cells actually have these dimensions, but they all have the same area.

By convention, grid coordinates (r,s) start in the upper left corner, at cell (0,0), with r increasing to the right and s increasing downward. Rounding the grid coordinates up at .5 yields the grid cell number. A grid cell is centered at grid coordinates (j,i) and bounded by: $(j - .5) \leq r < (j + .5)$ and $(i - .5) \leq s < (i + .5)$.

The 25 km hemispheric grids for the North and South azimuthal projections (aka "NL" and "SL") are defined with 721 columns, 721 rows, and the respective pole anchored at cell (360.0,360.0). The ML grid for the cylindrical projection is defined with 1383 columns, 586 rows, and is defined with the point where the equator crosses the prime meridian at cell location (691.0,292.5).

For each 25 km grid, the set of corresponding 12.5 km grids was defined such that the grid coordinates are coincident (aka. "bore-centered") and exactly double the lower resolution grid coordinates. The ML grid is symmetrical about the prime meridian, but the MH grid is not. The 25 km ML grid exactly spans the equator, from 180 W to 180 E, with 1383 grid cells. The 12.5 km grid, (aka MH), also exactly spans the equator, with 2766 grid cells. However, since the center of the ML column 0 is coincident with the ML column 0, the western edge of the Mh grid cell in column 0 row 293 (at the equator) is slightly east of 180 W, and the eastern edge of the Mh grid cell in column 2765 is slightly east of 180 E.

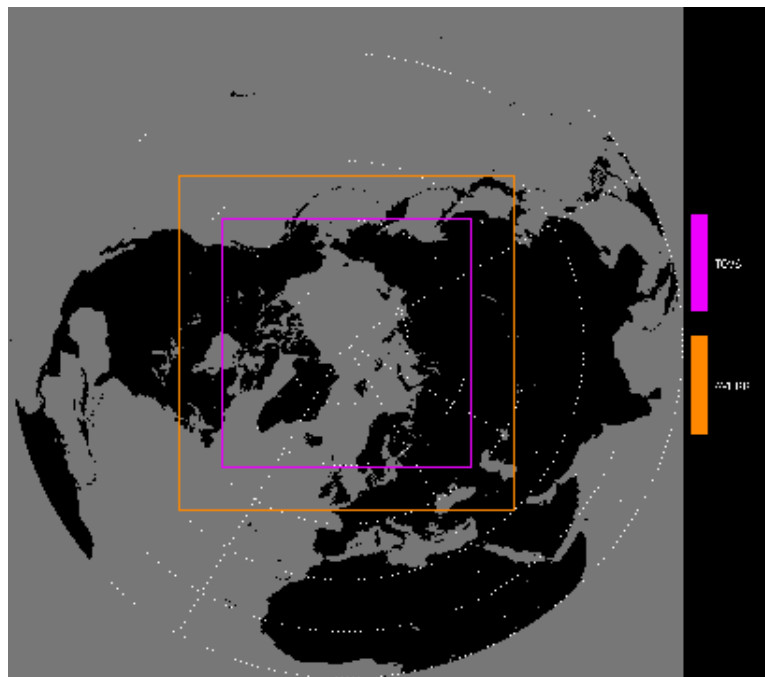
The dimensions, center, and extent of the original SSM/I grids are summarized below. It is important to remember that there is nothing specific to the SSM/I data in these definitions. If these grid definitions are considered appropriate for another data set, they can be used with no changes.

Original 25 and 12.5 km Grids										
Grid	Dimensions		Map Origin		Map Origin		Grid Extent			
	Name	Width	Height	Column (r0)	Row (s0)	Latitude	Longitude	Minimum Latitude	Maximum Latitude	Minimum Longitude
ML	1383	586	691.0	292.5	0.0	0.0	86.72S	86.72N	180.00W	180.00E
MH	2766	1171	1382.0	585.0	0.0	0.0	85.95S	85.95N	179.93W	180.00E
NL	721	721	360.0	360.0	90.0N	0.0	0.34S	90.00N	180.00W	180.00E
NH	1441	1441	720.0	720.0	90.0N	0.0	0.26S	90.00N	180.00W	180.00E
SL	721	721	360.0	360.0	90.0S	0.0	90.00S	0.34N	180.00W	180.00E
SH	1441	1441	720.0	720.0	90.0S	0.0	90.00S	0.26N	180.00W	180.00E

Other Grid Definitions in the EASE-Grid Family

The Polar Pathfinders

Users of the NSIDC EASE-Grid are not limited to the grid orientation, size and resolution described above, and are free to define grids that are more appropriate to a given data set. For example, the TOVS Polar Pathfinder data were defined with the EASE-Grid Northern hemisphere map projection parameters, and a polar subset of the original hemisphere at a 100 kilometer resolution. The AVHRR Polar Pathfinder data were defined for both Northern and Southern hemisphere maps, as subsets of each, at 1.25 km, 5 km, and 25 km resolutions. The figure below shows the Northern hemisphere grid extent for SSM/I (the full hemisphere), TOVS Polar, and AVHRR Polar grids (respective subsets).



Relative Northern hemisphere grid extents of Polar Pathfinders

(SSM/I (full hemisphere), AVHRR and TOVS).

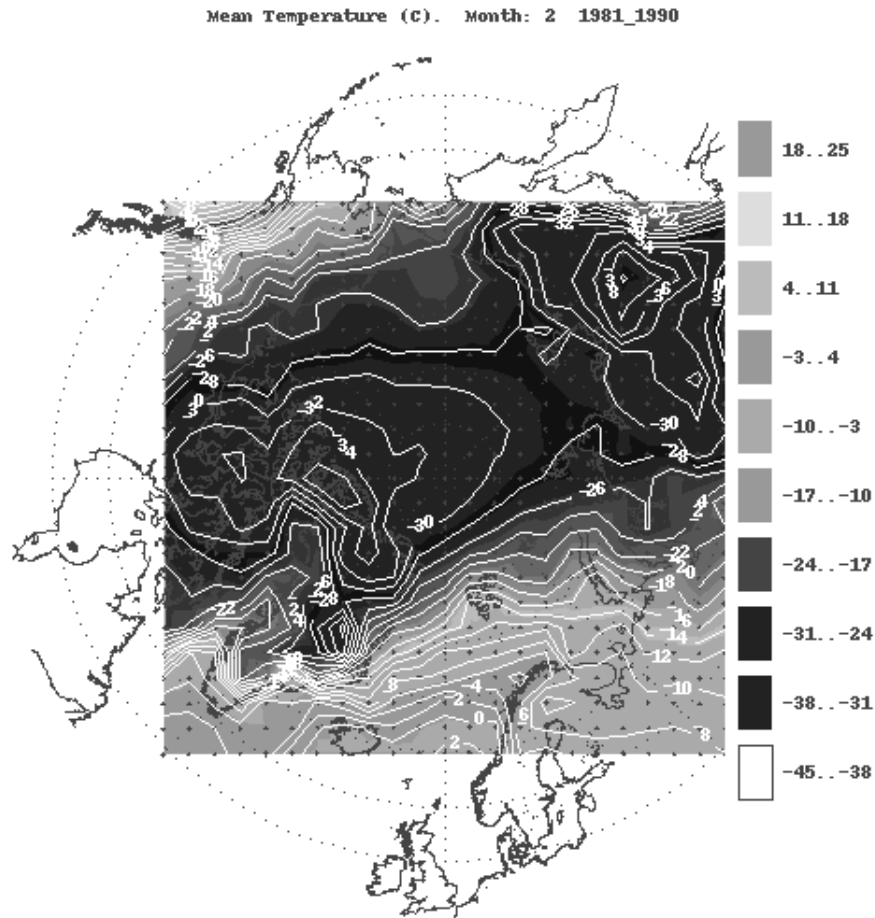
The AARI Sea Ice Data in EASE-Grid

The AARI EASE-Grid sea ice data provide another example. These data did not require hemispheric coverage, but the data set producers at NSIDC wanted to provide them in a grid that would facilitate intercomparison with sea ice data derived from SSM/I. Therefore the AARI EASE-Grid was defined to be the subset of the SSM/I Pathfinder NH grid (Northern hemisphere, 12.5 km resolution) defined by columns 360 through 1080 and rows 360 through 1080. The resulting AARI EASE-Grid is 721 columns and 721 rows. This, in turn, relates the AARI EASE-Grid definition to the 25 km AVHRR EASE-grid (aka "NA25") subset via the following simple relationship:

- $AARI_{column} = 2 * NA25_{column}$
- $AARI_{row} = 2 * NA25_{row}$

The Arctic Climatology Project Arctic Meteorology and Climate Atlas in EASE-Grid

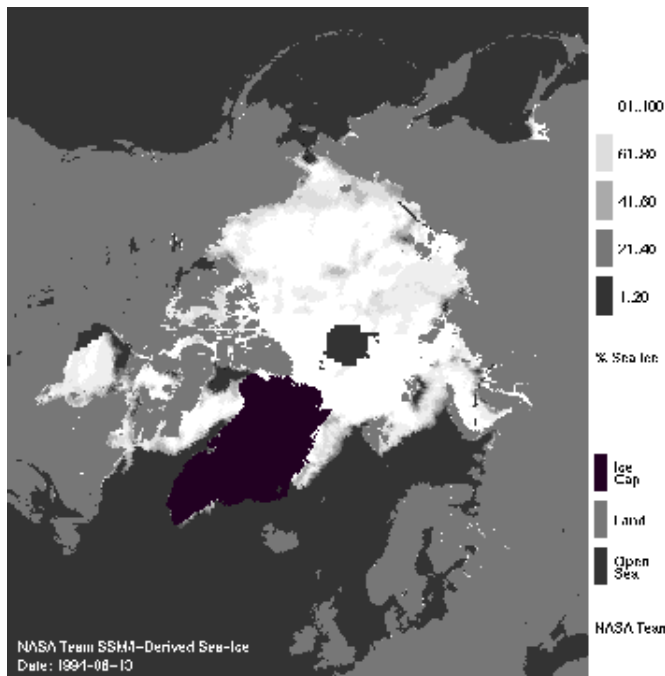
NSIDC has produced an atlas of Arctic meteorology and climatology under the auspices of the U.S.-Russian Joint Commission on Economic and Technological Cooperation's Environmental Working Group (EWG). The gridded fields produced for this atlas are defined for a subset of the full northern hemisphere above 65N, at a 250 km grid spacing. Data arrays are 23 columns by 23 rows. An example temperature field is included below.



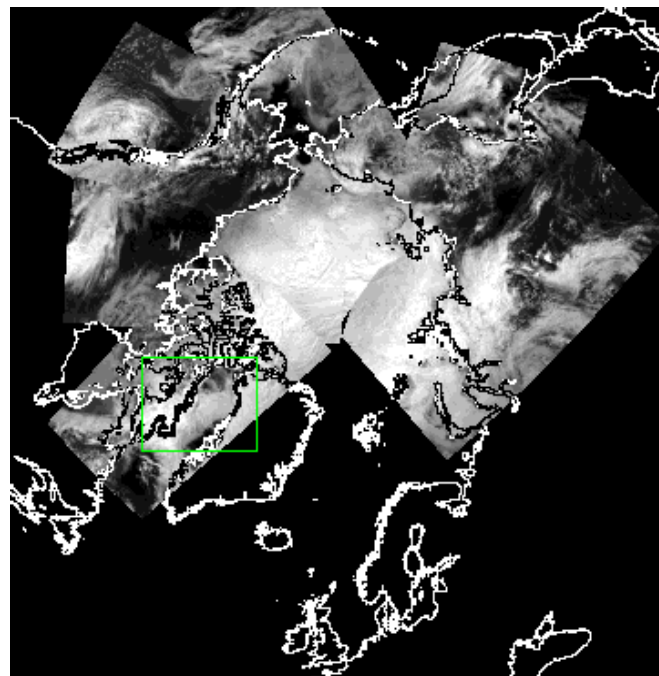
Mean air temperature (degrees Centigrade), February, 1981 - 1990.
(Dots indicate the EWG EASE-Grid lattice points.)

An Example Application

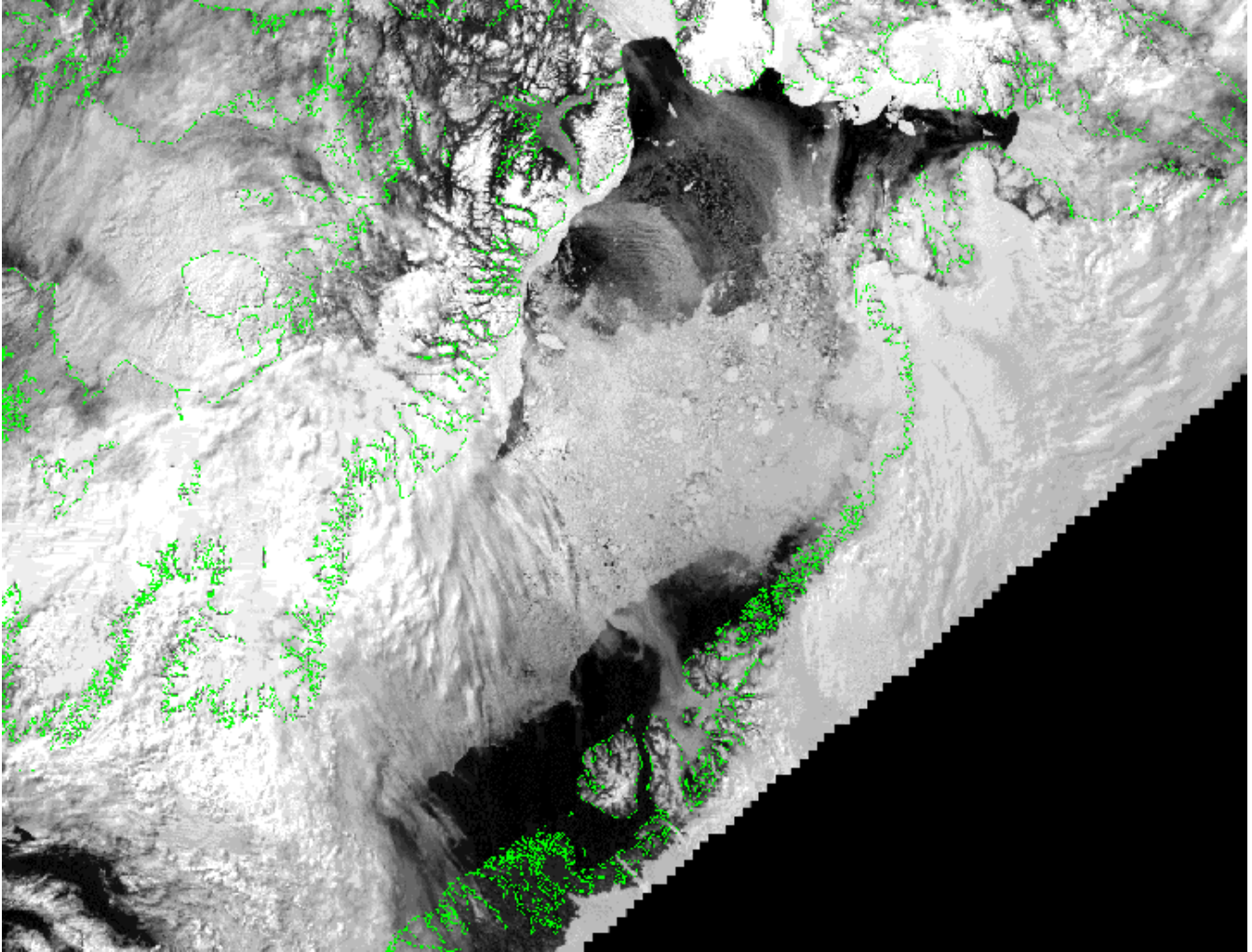
The following series of images illustrates a comparison of SSM/I-derived sea ice in Baffin Bay with AVHRR-derived albedo for June 13, 1994. Since all images are derived from various resolution grids of the same NL EASE-Grid projection, the reader can easily visually compare the ice edge. Digital comparison and analysis are likewise easily performed using the user's favorite graphical analysis package.



Arctic 25 km Sea Ice Concentration
 Derived from SSM/I, June 13, 1994.



Arctic 25 km AVHRR Albedo Product
 Browse Image, June 13, 1994.



Zoomed area of Baffin Bay, AVHRR Albedo Product Image, full resolution (1.25 km), June 13, 1994.

Conclusions

While originally intended for use with a single data product, the EASE-Grid has proven to be flexible and extensible to other global, gridded applications. The projection and gridding abstractions are simple and easy to apply to the requirements of a new data set. Data from diverse sources can be resampled and expressed as digital arrays of varying resolutions, which are defined in relation to one of three possible projections. Storage as a simple digital array facilitates portability and ability to be imported into a user's favorite analysis package. Users find that visualization and intercomparison operations are then greatly simplified, and that the tasks of analysis and intercomparison can be more readily accomplished.

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- National Snow and Ice Data Center. Complete source code for mapping and gridding software. <<ftp://baikal.colorado.edu/pub/NSIDC/>>.