RECLAMATION
Managing Water in the West

Report DSO-2014-04

Gridded Snow Water Equivalent Data Set Development – Processing Methods Using the Geospatial Data Abstraction Library

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2015

1. REPORT DATE (DD-MM-YYYY) 18-09-2015	2. REPORT TYPE Data Processing Documentation	3. DATES COVERED (From - To

4. TITLE AND SUBTITLE Gridded Snow Water Equivalent Data Set Development Processing Methods Using the Geospatial Data Abstraction Library	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Jeffrey P. Niehaus, M.S., P.E.	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of the Interior Bureau of Reclamation Technical Service Center Denver, Colorado	8. PERFORMING ORGANIZATION REPORT NUMBER DSO-2014-14
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

13. SUPPLEMENTARY NOTE
   (SDG)

14. ABSTRACT
The purpose of this report is to document the data processing steps developed to convert the SNODAS SWE flat binary grids to a suitable format for input to stand-alone hydrology models and as a data set for climate change or extreme flood analysis in relation to Dam Safety Technology.

15. SUBJECT TERMS
   GIS, GDAL, geospatial, gridded spatial information, SWE, SNODAS gridded parameters, flat binary grid, data processing, distributed snowmelt modeling, hydrology models, snow depth, snow pack average temperature, cold content, snow bulk density, ASCII grid GeoTIFF, image, raster

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	a. THIS PAGE		30	19b. TELEPHONE NUMBER (Include area code)

Report DSO-2014-04

Gridded Snow Water Equivalent Data Set Development – Processing Methods Using the Geospatial Data Abstraction Library

Dam Safety Technology Development Program

Prepared by:

Jeffrey P. Niehaus, M.S., P.E.

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2015

MISSION STATEMENTS

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION
Dam Safety Technology Development Program
Flood Hydrology and Meteorology Group, 85-825000
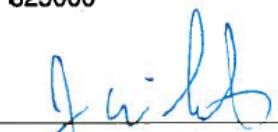
DSO-2014-04

Gridded Snow Water Equivalent Data Set Development – Processing Methods Using the Geospatial Data Abstraction Library

Prepared by: Jeffrey P. Niehaus, M.S., P.E.
Hydrologic Engineer, Flood Hydrology and Meteorology Group, 85-825000

9/18/2015
Date

Peer review: Joseph M. Wright, M.S., P.E.
Group Manager, Flood Hydrology and Meteorology Group, 85-825000

10/28/15
Date

ACRONYMS AND ABBREVIATIONS

AAIGrid	Arc/Info ASCII Grid
ASCII	American Standard Code for Information Interchange
CERN	European Council for Nuclear Research
CONUS	Contiguous United States
C_p	Specific Heat of Ice (2100 J/kg-°C)
CST	Central Standard Time
DSS	Data Storage System
EHdr	ESRI Header Labeled File
ENVI	Environment for Visualizing Images
ERDC	Engineer Research and Development Center
ESPG	European Petroleum Survey Group
ESRI	Environmental Systems Research Institute
Fermilab	Fermi National Accelerator Laboratory
Float32	A 32-bit Floating Point Quantity
Float64	A 64-bit Floating Point Quantity
FTP	File Transfer Protocol
GDAL	Geospatial Data Abstraction Library
GIS	Geographic Information System
GMT	The Generic Mapping Tools
GPS	Global Positioning System
GRASS	Geographic Resources Analysis Support System
GRS80	Geodetic Reference System 1980
GTiff	GeoTIFF File Format
HEC	Hydrologic Engineering Center
HL	Hydrology Laboratory (NWS)
HMS	Hydrologic Modeling System
h_s	Snow Depth
IDL	Interactive Data Language
Int16	A Signed 16-bit Integer Quantity
Int32	A Signed 32-bit Integer Quantity
L_f	Latent Heat of Fusion of Water (334,000 J/kg)
NAD83	North American Datum 1983
NOAA	National Oceanic and Atmospheric Administration
NOHRSC	National Operational Hydrologic Remote Sensing Center
NSIDC	National Snow and Ice Data Center
NWP	Numerical Weather Prediction
NWS	National Weather Service
QGIS	Quantum Geographic Information System
R	A Statistical Computing and Graphics Software Environment
RDHM	Research Distributed Hydrologic Model
RUC2	Rapid Update Cycle 2
SAGA	System for Automated Geoscientific Analyses
SHG	Standard Hydrologic Grid System
SL	Scientific Linux

SNODAS	SNOw Data Assimilation System
SNOTEL	SNOwpack TELemetry
SWE	Snow Water Equivalent
TIFF	Tagged Image File Format
TREX	Two-dimensional Runoff Erosion and Export Model
UInt16	A Unsigned 16-bit Integer Quantity
UInt32	A Unsigned 32-bit Integer Quantity
UTC	Universal Time Coordinated
VIC	Variable Infiltration Capacity Model
WGS	World Geodetic System

Symbols

°C	Degrees Celsius
°F	Degrees Fahrenheit
°K	Degrees Kelvin
ρ_b	Bulk Density of Snow
ρ_w	Density of Water (1 g/cm^3)
]$	Linux Command Line Prompt

CONTENTS

TABLES

FIGURES

ATTACHMENTS

Page

Introduction

Snow Water Equivalent (SWE) is the most important parameter used to initialize snow cover in stand-alone hydrology models. In the case of distributed snowmelt modeling for high-elevation watersheds, SWE in a gridded format is a requirement regardless of snowmelt modeling methodology (water-balance, energy-balance, or temperature index). Since October 2003, the National Operational Hydrologic Remote Sensing Center (NOHRSC) an organization within the National Weather Service (NWS) has been generating gridded output from their SNOw Data Assimilation System (SNODAS). SNODAS is a modeling and data assimilation system created to output the best possible estimates of SWE and seven additional snow cover variables to support hydrologic modeling and snow cover analysis for the conterminous United States. SNODAS output is supplied in a flat binary grid and archived by the National Snow and Ice Data Center (NSIDC). These flat binary grids require processing into a format that is suitable for ingestion into stand-alone rainfall-runoff models, such as HEC-HMS, TREX, VIC, HL-RDHM, etc.

Purpose

The purpose of this report is to document the data processing steps developed to convert the SNODAS SWE flat binary grids to a suitable format for ingestion into stand-alone rainfall-runoff models and as a data set for climate change or extreme flood analysis under the Dam Safety Technology Development Program.

Process Summary

The developed step by step process extracts the raw SWE, Snow Depth, and Snow Pack Average Temperature grids from the SNODAS daily archival file for both the masked (contiguous United States extending into Canada for specific watersheds) and unmasked (contiguous United States extending into Canada while outlining the coast and includes portions of Mexico) archives. Individual steps: uncompress the raw grids, corrects each grid file's extension, and creates the required header and projection files in preparation for conversion. Conversion steps include: adjustment of the NoData Value for the SWE and Snow Depth grids, convert temperatures from Kelvin to Celsius for the Snow Pack Average Temperature grid, calculate a Cold Content grid using the Snow Pack Average Temperature and SWE grids, calculate a Snow Bulk Density grid using the Snow Depth and SWE grids, and conversion of the grid file from flat binary to GeoTIFF format. Resulting files are as follows.

- SWE in a GeoTIFF format.
- Snow Depth in a GeoTIFF format.
- Cold Content in a GeoTIFF format.
- Snow Bulk Density in a GeoTIFF format.

Optional process steps were developed that produce the SWE, Snow Depth, and the Cold Content grids in an ASCII format, and re-project a given grid file from the WGS 1984 coordinate system to the CONUS Albers EPSG 5070 coordinate system. The processing was performed using binaries and python scripts from the Geospatial Data Abstraction Library (GDAL) from the Open Source Geospatial Foundation. The conversion process output was validated by

processing the input files using ESRI's ArcGIS software environment and comparing the resulting grid files with those developed using the GDAL binaries and scripts.

SNODAS Background

Beginning 1 October 2003, the NSIDC was assigned the task of archiving the output from the SNODAS system which is operated and maintained by the National Oceanic and Atmospheric Administration (NOAA) NWS NOHRSC.

SNODAS is a modeling and data assimilation system developed by NOHRSC to provide the best possible estimates of snow cover and associated parameters to support hydrologic modeling and analysis. The SNODAS system goal is to provide a physically consistent framework for integration of snow data from satellite and airborne platforms, and ground stations with model estimates of snow cover (Carroll et al. 2001). SNODAS ingests and down scales the output from the Rapid Update Cycle 2 (RUC2) Numerical Weather Prediction (NWP – mesoscale meteorological model) model and simulates snow cover over the conterminous United States and areas of Canada with contributing watersheds. Inputs from the RUC2 NWP model include temperature, wind, relative humidity, pressure and precipitation (Benjamin et al. 2002). The physically based, spatially distributed energy and mass balance model assimilates satellite, airborne and ground observations of snow cover and SWE.

At the core of the SNODAS system, is a multi-layered, grid cell based but uncoupled energy and mass balance model containing three snow and two soil layers. The thermal dynamics of the system are based on a modified version of SNTHERM.89 (Jordan 1990) developed at the U.S. Army's Cold Regions Research and Engineering Laboratory. SNTHERM.89 computes SWE, internal energy, thickness, average temperature and unfrozen fraction of water for each snow layer. Additionally, SNTHERM.89 computes the diagnostic values for total SWE in the snow pack, snow thickness, melt water runoff at the base of the pack, evaporation, condensation, and sublimation of saltated and suspension transported snow. A mass and energy balance is computed for each grid cell.

Daily, NOHRSC analysts determine if the SWE state in the model requires updating by remotely sensed and ground based observations. The difference between the modeled and observed SWE are generated and reviewed. If required, the model is rerun for the previous six hours using scaled difference values to "nudge" (Newtonian Relaxation Procedure) the model SWE estimates. A twelve hour forecast of snow cover is then developed using RUC2 NWP model output. Because the SNODAS model is updated once daily, the output for 06:00 UTC (midnight for the United States, CST) is the best estimate of the snow cover parameters and 18 out of 24 hourly time steps do not use observations to update model SWE estimates. Therefore, hourly data is only model output and not used to represent estimates of the snow cover parameters. Where no observations are available to update the model, the "best estimate" is no better than the hourly model output. Satellite data is used to identify snow-no snow boundaries when cloud free images are available. Additionally, it is worth noting that satellite observed snow data is adversely affected by the density level of forest canopy. Satellites may classify dense forested areas as being free of snow while significant amounts exist on the ground beneath the canopy. Under the forest canopy, snow cover will survive longer than on ground with no canopy resulting

in the underestimate of snow cover and volume. In the mountainous regions of the United States, large areas of drainage basins are covered by forest.

The SNODAS product is model output and should not be confused with measured observations. For measured observations and specific information regarding snowfall events or totals for specific regions see the regional or state climatology reports for a particular region or state. The NSIDC has not conducted a quality assessment of the SNODAS product. Lea and Reid conducted a successful evaluation of SNODAS data for determining the SWE on Mount St. Helens, Washington (Lea and Reid 2006). Additionally, a comparison of SNODAS gridded snow depth estimates to GPS Interferometric Reflectometry (GPS-IR) snow depth observations was performed in the Western United States (Boniface et al. 2014).

SNODAS Gridded Parameters

SNODAS output parameters are stored in a flat binary (16-bit signed integer big-endian) grid file which can be manipulated by ESRI's ArcInfo and ArcGIS, GRASS, GMT, GDAL, ERDAS Imagine, IDL, Matlab and ENVI software applications. The masked grids are 6935 columns by 3351 rows and the unmasked grids 8192 columns by 4096 rows where each cell represents a 1 kilometer square ground area nominally and 24 hours temporally. Each cell value (2 byte integer) represents a point estimate for the center of the grid cell and is not an areal estimate. Each cell value is not projected but is referenced by geographic coordinates (WGS 1984 datum). For the purposes of hydrologic modeling and snow cover forecasting, each SNODAS grid cell point estimate represents a daily average value. The gridded parameters archived by the NSIDC are shown in Table 1. Driving variables are ingested from the RUC2 NWP and used to force the SNODAS model. SNODAS state variables describe the "state" of the modeled snow pack and are required to initialize the model. Diagnostic variables are SNODAS model output. We are interested in the "state" variables.

Table 1. Daily NOHRSC SNODAS Products at NSIDC.

Parameters	Units	Scale Factor[1]	Product Code	Description	Variable Type
SWE	meters	1000	1034	Snapshot at 06:00 UTC	State
Snow Depth	meters	1000	1036	Snapshot at 06:00 UTC	State
Snow Melt Runoff at the Base of the Snow Pack	meters	100,000	1044	Total of 24 per hour melt rates, 06:00 UTC-06:00 UTC	Diagnostic
Sublimation from the Snow Pack	meters	100,000	1050	Total of 24 per hour sublimation rates, 06:00 UTC-06:00 UTC	Diagnostic
Sublimation of Blowing Snow	meters	100,000	1039	Total of 24 per hour sublimation rates, 06:00 UTC-06:00 UTC	Diagnostic
Solid Precipitation	kg/m^2	10	1025 (IL01)	24 hour total, 06:00 UTC-06:00 UTC	Driving
Liquid Precipitation	kg/m^2	10	1025 (IL00)	24 hour total, 06:00 UTC-06:00 UTC	Driving
Snow Pack Average Temperature[2]	kelvin	1	1038		State
[1]To convert integers in files to model output values, divide integers in files by scale factor. [2]Please note that Snowpack Average Temperatures are integers.					

GDAL Background

The Geospatial Data Abstraction Library (GDAL, www.gdal.org) is a translator library for raster and vector geospatial data formats that is released under an X/MIT style Open Source license by the Open Source Geospatial Foundation. As a library, it presents a single raster abstract data model and vector abstract data model to the calling application for all supported formats. It also comes with a variety of useful command line utilities for data translation and processing. The current version as of September 2014 is GDAL/OGR 1.11.1. Common applications using GDAL include ESRI ArcGIS, Google Earth, Map Server, GRASS, Quantum GIS, SAGA, R, and the ERDC Flood Event Simulation Model.

Command Line Processing Using GDAL

The following command line processing steps were developed using GDAL 1.9.2 compiled on Scientific Linux (SL) Release 6.5 running on a Dell Precision T7400 workstation with two Intel E5430 Xeon (4-core) processors and 32 gigabytes of main memory. SL is a Linux release put together by the U.S. Department of Energy for the Fermi National Accelerator Laboratory (Fermilab), the European Council for Nuclear Research (CERN), and various other labs and universities around the world. The base SL distribution is basically Red Hat Enterprise Linux, recompiled from source. These processing steps can also be utilized on the Apple Mac OSX and Microsoft Windows platforms with minor alteration accounting for the differences in command line environments. Using Quantum GIS (QGIS) which is available for the Linux, Mac OSX, and Windows platforms, the resulting gridded output files can be viewed and verified.

Step 1 – Download Data

Archived daily SNODAS parameter sets (G02158) can be downloaded from the following NSIDC FTP site. This is non-subsetted data where the header file contains metadata. Masked data sets are for the conterminous United States of America and unmasked data sets include data extending into Canada and Mexico.

ftp://sidads.colorado.edu/DATASETS/NOAA/G02158/

Step 2 – File Extraction

Here we extract the file(s) of interest which include SWE (1034), Snow Depth (1036), and Snow Pack Average Temperature (1038). SWE and Snow Depth units equal meters/1000 or millimeters, and Snow Pack Average Temperature units equal kelvins (°K). The appropriate Linux command line statements are provided where "]$" represents the system prompt which is used throughout this report. The "tar" command is used for extraction and the first example represents the masked data set (SNODAS_20110119.tar) and the second the unmasked data set (SNODAS_unmasked_20110119.tar) from January 19, 2011 (NOHRSC 2004).

```
]$ tar -xvf SNODAS_20110119.tar --wildcards --no-anchored '*1034*' '*1036*' '*1038*'
```

```
]$ tar -xvf SNODAS_unmasked_20110119.tar --wildcards --no-anchored '*1034*' '*1036*' '*1038*'
```

Where,

-x   instructs tar to extract files.
-v   show progress while extracting files (verbose).
-f   specifies file name (tarball name), that which follows the f.

--wildcards   instructs tar to treat command line arguments as globbing patterns.
--no-anchored   informs tar that the patterns apply to member names after any '/' delimiter.

This produces the following files where those that begin with "us" are the masked files and those with "zz" are the unmasked files.

us_ssmv11034tS__T0001TTNATS2011011905HP001.tar.gz
us_ssmv11036tS__T0001TTNATS2011011905HP001.tar.gz
us_ssmv11038wS__A0024TTNATS2011011905DP001.tar.gz
zz_ssmv11034tS__T0001TTNATS2011011905HP001.tar.gz
zz_ssmv11036tS__T0001TTNATS2011011905HP001.tar.gz
zz_ssmv11038wS__A0024TTNATS2011011905DP001.tar.gz

Step 3 – Uncompress File

Here we uncompress the file(s) of interest using "gunzip."

]$ gunzip -v *1034* *1036* *1038*

The following files will be produced. The "dat" file contains the parameter data and the "Hdr" file contains the metadata. The metadata includes information about the creation and modification of each file, data type, geo-referencing data, maximum and minimum values, calibration and scaling information, and a time stamp for each parameter (see also Attachment 1). The minimum and maximum "x" and "y" axis coordinates are the grid cell edges that define the extents of the grid. The Benchmark "x-axis" and "y-axis" coordinates define the center of the upper left (northwest corner) grid cell where these coordinates can change over time. For example during the 2013-2014 snow season, the alignment of the product grids was adjusted by 1.5 arc seconds (1/20th of a pixel) north and east. Additionally, the minimum and maximum bounds increased positively by 0.00041666667 degrees in latitude and longitude. The Benchmark grid cell coordinates are also the "ulxmap" and "ulymap" values used in the header file(s) created in step 5 (see below). The "X-axis" and "Y-axis" offset values are the distances between the origin and the center of the pixel (grid cell) that lays over the origin. These offset values provide a way of confirming whether or not two grids are aligned.

us_ssmv11034tS__T0001TTNATS2011011905HP001.dat
us_ssmv11034tS__T0001TTNATS2011011905HP001.Hdr
us_ssmv11036tS__T0001TTNATS2011011905HP001.dat
us_ssmv11036tS__T0001TTNATS2011011905HP001.Hdr
us_ssmv11038wS__A0024TTNATS2011011905DP001.dat
us_ssmv11038wS__A0024TTNATS2011011905DP001.Hdr
zz_ssmv11034tS__T0001TTNATS2011011905HP001.dat

zz_ssmv11034tS__T0001TTNATS2011011905HP001.Hdr
zz_ssmv11036tS__T0001TTNATS2011011905HP001.dat
zz_ssmv11036tS__T0001TTNATS2011011905HP001.Hdr
zz_ssmv11038wS__A0024TTNATS2011011905DP001.dat
zz_ssmv11038wS__A0024TTNATS2011011905DP001.Hdr

Step 4 – Rename File

Here we rename the "*.dat" file(s) to "*.bil" file(s) and "*.Hdr" file(s) to "*.txt" file(s). As stated in Step 3, the "Hdr" file contains metadata. We change its extension because in Step 5 the appropriate header file (.hdr) will be created.

]$ rename .dat .bil *.dat

]$ rename .Hdr .txt *.Hdr

The following files will be produced.

us_ssmv11034tS__T0001TTNATS2011011905HP001.bil
us_ssmv11034tS__T0001TTNATS2011011905HP001.txt
us_ssmv11036tS__T0001TTNATS2011011905HP001.bil
us_ssmv11036tS__T0001TTNATS2011011905HP001.txt
us_ssmv11038wS__A0024TTNATS2011011905DP001.bil
us_ssmv11038wS__A0024TTNATS2011011905DP001.txt
zz_ssmv11034tS__T0001TTNATS2011011905HP001.bil
zz_ssmv11034tS__T0001TTNATS2011011905HP001.txt
zz_ssmv11036tS__T0001TTNATS2011011905HP001.bil
zz_ssmv11036tS__T0001TTNATS2011011905HP001.txt
zz_ssmv11038wS__A0024TTNATS2011011905DP001.bil
zz_ssmv11038wS__A0024TTNATS2011011905DP001.txt

Step 5 – Create Header File

Create the following header file (text format) in the same directory for each "bil" file. Notice how the filename is maintained for the day and type of data downloaded. The header file contains information to geo-register the grids contained in the flat binary files (.bil).

us_ssmv11034tS__T0001TTNATS2011011905HP001.hdr
us_ssmv11036tS__T0001TTNATS2011011905HP001.hdr
us_ssmv11038wS__A0024TTNATS2011011905DP001.hdr
zz_ssmv11034tS__T0001TTNATS2011011905HP001.hdr
zz_ssmv11036tS__T0001TTNATS2011011905HP001.hdr
zz_ssmv11038wS__A0024TTNATS2011011905DP001.hdr

If the file begins with "us_," paste the following text into the file.

nrows 3351
ncols 6935
nbands 1

nbits 16
byteorder M
layout bil
skipbytes 0
ulxmap -124.729583333332
ulymap 52.8704166666656
xdim 0.008333333333333
ydim 0.008333333333333
pixeltype SIGNEDINT
nodata -9999

If the file begins with "zz_" instead of "us_", then paste the following text into the file. The "zz_" files contain variable data for the contiguous United States and portions of Canada and Mexico. This data stream began on December 9, 2009.

nrows 4096
ncols 8192
nbands 1
nbits 16
byteorder M
layout bil
skipbytes 0
ulxmap -130.512916666665
ulymap 58.2287499999987
xdim 0.008333333333333
ydim 0.008333333333333
pixeltype SIGNEDINT
nodata -9999

Additional information describing the contents of the header file can be found in ESRI's ArcMap Help system under "BIL, BIP, and BSQ raster files," and in various references (ESRI 1999, Barrett 2003). The header contents may be different for the individual parameter files. See the metadata file provided with each extracted and uncompressed parameter file being processed (as described in step 3).

Step 6 – Create Projection File

Create the following ESRI compatible WGS 1984 projection file ("prj" in text format) in the same directory for each "bil" file. Notice how the filename is maintained for the day and type of data downloaded. The projection file contains information to geo-reference the grids contained in the flat binary files (.bil).

us_ssmv11034tS__T0001TTNATS2011011905HP001.prj
us_ssmv11036tS__T0001TTNATS2011011905HP001.prj
us_ssmv11038wS__A0024TTNATS2011011905DP001.prj
zz_ssmv11034tS__T0001TTNATS2011011905HP001.prj
zz_ssmv11036tS__T0001TTNATS2011011905HP001.prj

zz_ssmv11038wS__A0024TTNATS2011011905DP001.prj

The following is pasted into the projection file all on one line.

GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.017453292519943295]]

Step 7 – Basic File Information Verification (Optional)

Using the GDAL command line utility "gdalinfo," verify the file(s) basic information and force computation of image statistics if none are stored in the image or grid file. Within this report, referring to a file as an image, raster, or grid is used interchangeably.

]$ gdalinfo -stats us_ssmv11034tS__T0001TTNATS2011011905HP001.bil

Where,

-stats   read and display image statistics.

For the command line example given above, the output generated for the masked SWE file would be as follows. Note that GDAL refers to the flat binary grid file (.bil) as an ESRI Header (.hdr) Labeled (EHdr) file.

```
Driver: EHdr/ESRI .hdr Labelled
Files: us_ssmv11034tS__T0001TTNATS2011011905HP001.bil
      us_ssmv11034tS__T0001TTNATS2011011905HP001.hdr
      us_ssmv11034tS__T0001TTNATS2011011905HP001.prj
Size is 6935, 3351
Coordinate System is:
GEOGCS["GCS_WGS_1984",
  DATUM["WGS_1984",
    SPHEROID["WGS_84",6378137.0,298.257223563]],
  PRIMEM["Greenwich",0.0],
  UNIT["Degree",0.017453292519943295]]
Origin = (-124.733749999998665,52.874583333332268)
Pixel Size = (0.008333333333333,-0.008333333333333)
Corner Coordinates:
Upper Left   (-124.7337500,  52.8745833) (124d44' 1.50"W, 52d52'28.50"N)
Lower Left   (-124.7337500,  24.9495833) (124d44' 1.50"W, 24d56'58.50"N)
Upper Right ( -66.9420833,  52.8745833) ( 66d56'31.50"W, 52d52'28.50"N)
Lower Right ( -66.9420833,  24.9495833) ( 66d56'31.50"W, 24d56'58.50"N)
Center       ( -95.8379167,  38.9120833) ( 95d50'16.50"W, 38d54'43.50"N)
Band 1 Block=6935x1 Type=Int16, ColorInterp=Undefined
  Minimum=0.000, Maximum=11325.000, Mean=42.366, StdDev=95.185
  NoData Value=-9999
```

Step 8 – Change NoData Value (Optional)

Here we use the python script "val_repl.py," to change the NoData Value of -9999 to 0 for the SWE (1034) and Snow Depth (1036) files. This step is performed for presentation purposes in reference to ESRI's ArcMap application and the displaying of the SWE or Snow Depth grids when importing them from an ArcInfo ASCII Grid file. A grid cell with a SWE or Snow Depth value of -9999 or zero has the same definition in that there is no snow in the grid cell of concern. These files will be used in optional step 13. For Snow Pack Average Temperature (1038), skip this step and go to process step 9 and 10. The "val_repl.py" script can be downloaded using the following web link (see also Attachment 2). This script is known to work with Python 2.3 to 2.7 and Numpy version 1.0.0 or greater. For SL 6.5, the Python version is 2.6.6 and the Numpy version is 1.4.1.

http://svn.osgeo.org/gdal/trunk/gdal/swig/python/samples/

This python script shown in its general form below replaces specified value from the input raster file with a new one. The input file remains unchanged with the results stored in a new file. Useful in cases where it is desired to change the NoData value with another value.

```
]$ val_repl.py [-innd in_nodata_value] [-outnd out_nodata_value] [-of out_format] [-ot out_type] infile outfile
```

For the following example using the masked SWE file, the input file NoData Value is -9999, the output file NoData Value is zero, the output file format is ESRI Header Labeled (EHdr), and the output file type is a signed 16-bit integer quantity (Int16) which can represent values between -32768 and 32767 inclusive. The output file is given the name "us_1034_20110119.bil."

```
]$ val_repl.py -innd -9999 -outnd 0 -of EHdr -ot Int16 us_ssmv11034tS__T0001TTNATS2011011905HP001.bil
us_1034_20110119.bil
```

Step 9 – Convert Temperatures from Kelvin to Celsius

For the Snow Pack Average Temperature (1038) in degrees Kelvin, convert temperatures from Kelvin to Celsius using the "gdal_calc.py" python script. This script is a command line raster calculator for GDAL supported files. The general usage of the script is shown below and an example using the unmasked SWE file where the output file is named "zz_1038_20110119.bil."

```
]$ gdal_calc.py [-A...-Z filename(s)] --format=FORMAT --type=TYPE --outfile=output_file --calc=CALC --
NoDataValue=NODATAVALUE --debug
```

Where,

-A, -B, etc.   input gdal raster file or files (you can use any letter from A to Z).
--format   gdal format for output file (default GTiff).
--type   output file data type (Byte, Int16, Int32, UInt16, UInt32, Float32, or Float64).
--outfile   output file to generate or fill.
--calc   use any basic arithmetic operations supported by numpy arrays such as +, -, *, /, //, %, divmod(), ** or pow(), <<, >>, &, ^, |, ~ along with logical operators such

as ==, <, >, <=, >=, != (all files must be the same dimensions and projection). Calculations use gdalnumeric syntax.

--NoDataValue   set output no data value (defaults to data type specific values).
--debug   print debugging information to screen.

]$ gdal_calc.py -A zz_ssmv11038wS__A0024TTNATS2011011905DP001.bil --format=EHdr --type=Int16 -- outfile=zz_1038_20110119.bil --calc="A-273*(A>0)" --NoDataValue=-9999 --debug

For each raster cell value, the conversion calculation is only performed when the Snow Pack Average Temperature (1038) is greater than zero (A>0).

Step 10 – Calculate Cold Content

When the Snow Pack Average Temperature (1038, °C) is greater than or equal to 0 °C (32 °F, 273.15 °K), the Cold Content (CC) is zero. When it is less than 0 °C, the Cold Content can be calculated using the following formula. The Cold Content is the quantity of heat needed to be transferred into the snow pack in order to raise the snow pack temperature to 0 °C, the melting temperature of snow/ice. Where, C_p is the specific heat of ice (2100 J/kg-°C) and L_f is the latent heat of fusion of water (334,000 J/kg). The resulting Cold Content is in units of mm of ice.

$$CC = \frac{SWE \times C_p \times \Delta T_s}{L_f}$$

Where,

$$\Delta T_s = T_{S_{avg}} - T_{base}$$

$$T_{S_{avg}} = Snow\ Pack\ Average\ Temperature\ (1038, °C)$$

$$T_{base} = Base\ Temperature\ (Melting\ Temperature\ of\ Snow) = 0°\ C$$

Using the Snow Pack Average Temperature (1038, °C) file created in step 9 and the original SWE (1034), calculate a Cold Content raster file. The example below uses the original unmasked SWE file where the NoData Value was -9999. For each raster cell value, the Cold Content calculation is only performed when the Snow Pack Average Temperature (1038, °C) is negative (B<0).

]$ gdal_calc.py -A zz_ssmv11034tS__T0001TTNATS2011011905HP001.bil -B zz_1038_20110119.bil --format=EHdr - -type=Int16 --outfile=zz_cc_20110119.bil --calc="(A*B)/159*(B<0)" --NoDataValue=-9999 --debug

Step 11 – Calculate Bulk Density

At a given point (or grid cell), the bulk density of the snow (ρ_b) is as follows. Where, SWE and Snow Depth (h_s) are in units of mm, cm, or meters and the density of water (ρ_w) is one g/cm^3 (1000 kg/m^3, 62.4 lb./ft^3).

$$\rho_b = \frac{SWE \times \rho_w}{h_s}$$

During this step, the "gdal_translate" utility is used to convert the raster data between different formats with the option to subset the raster data in the process. The general usage of the "gdal_translate" utility is provided below.

]$ gdal_translate -ot type -of format -a_nodata value -co "NAME=VALUE" src_dataset dst_dataset

Where,

-ot	type, for the output band(s) to be of the indicated data type (Byte, Int16, UInt16, Int32, UInt32, Float32, Float64, etc.).
-of	select the output format (default is GTiff).
-projwin	ulx uly lrx lry, selects a sub window (subset) from the source image for copying with the corners given in geo-referenced coordinates.
-a_nodata	value, assign a specified no data value to output band(s). For GDAL 1.8.0 or greater, can be set to none to avoid setting a no data value to the output file if one exists for the source file.
-co	"NAME=VALUE", passes a creation option to the output format driver. "DECIMAL_PRECISION=3" for AAIGrid format (output numbers with 3 decimal places). "COMPRESS=LZW" for GTiff format (compress the output file). "TFW=YES" for GTiff format (force generation of associated ESRI world file '.tfw').
-stats	force (re)computation of the image statistics.
src_dataset	the source dataset name.
dst_dataset	the destination dataset name.

Using the original SWE (1034) file and the original Snow Depth (1036) file, calculate the Snow Bulk Density raster file. The Snow Bulk Density is in units of g/cm^3. The SWE and Snow Depth are in units of mm. The first two lines are to convert the SWE (1034) and Snow Depth (1036) files from an integer type to a floating type. In the third line, the density is then calculated by dividing the SWE by the Snow Depth when the Snow Depth is greater than zero. The fourth line converts the density file to a GeoTIFF while maintaining the no data value of -9999. Figure 1 displays the Snow Bulk Density using the "SD_20110119.tif" file in QGIS 1.8.0. Figure 2 displays the Snow Bulk Density using the "SD_20110119.tif" file in ArcMap 10.1. The Snow Bulk Density varies from 0 to 1 g/cm^3 with each grid cell containing a floating point value such as 0.322581 g/cm^3 (grid cell -94.120918, 40.838472 in decimal degrees from Figure 1 or 2).

]$ gdal_translate -ot Float32 -of EHdr -a_nodata -9999 us_ssmv11034tS__T0001TTNATS2011011905HP001.bil tmp_1034_20110119.bil

]$ gdal_translate -ot Float32 -of EHdr -a_nodata -9999 us_ssmv11036tS__T0001TTNATS2011011905HP001.bil tmp_1036_20110119.bil

```
]$ gdal_calc.py -A tmp_1034_20110119.bil -B tmp_1036_20110119.bil --format=EHdr --type=Float32 --
outfile=us_density_20110119.bil --calc="A/B*(B>0)" --NoDataValue=-9999 --debug
```

```
]$ gdal_translate -of GTiff -ot Float32 -a_nodata -9999 -co "TFW=YES" -co "COMPRESS=LZW" -stats
us_density_20110119.bil SD_20110119.tif
```
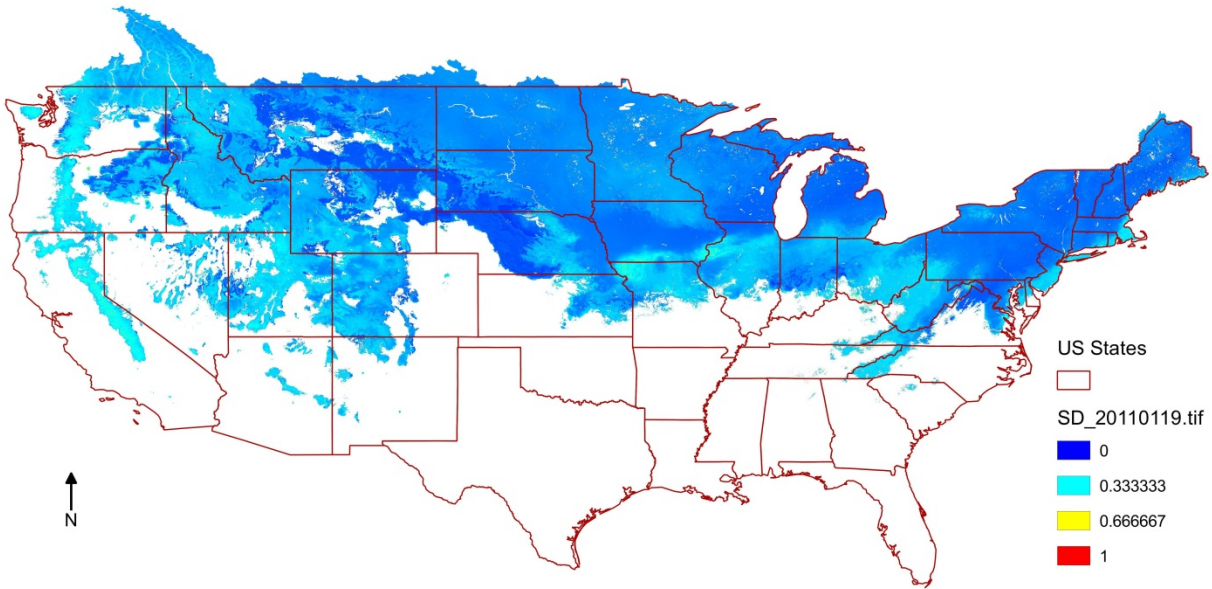

Figure 1. Snow Bulk Density (g/cm^3) grid for January 19, 2011 displayed in QGIS 1.8.0.
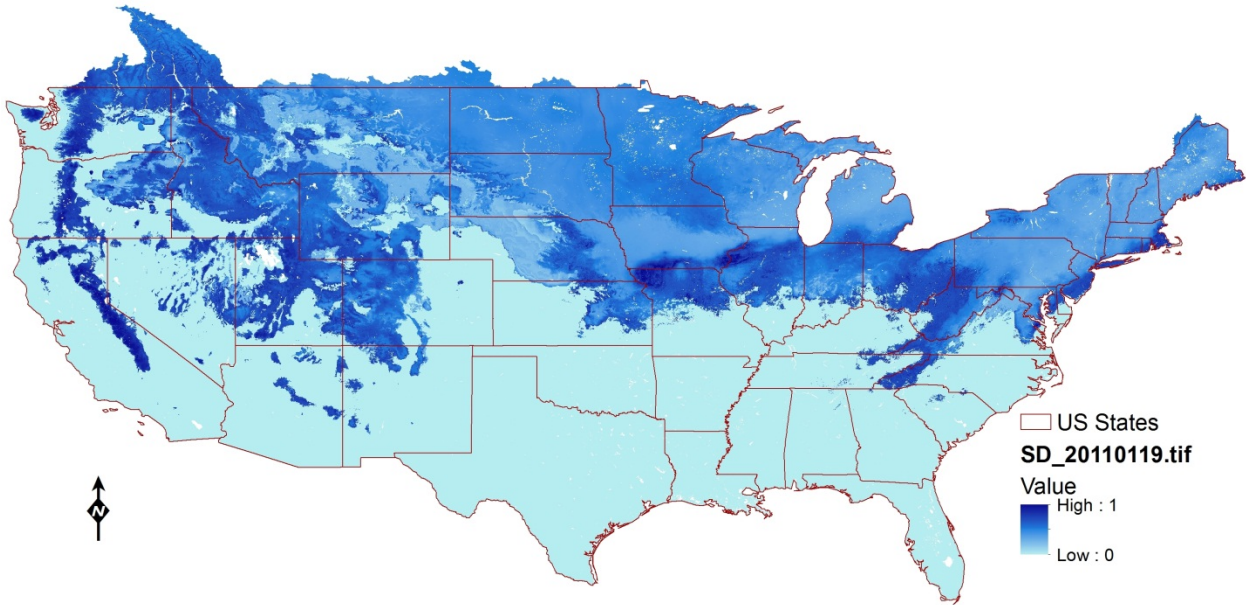

Figure 2. Snow Bulk Density (g/cm^3) grid for January 19, 2011 displayed in ArcMap 10.1.

Step 12 – Converting SNODAS File to GeoTIFF Format

As stated previously, the flat binary grids (.bil) require conversion into a format that is suitable for ingestion into stand-alone rainfall-runoff models, such as HEC-HMS, TREX, VIC, HL-RDHM, etc. Each rainfall-runoff model can directly ingest GeoTIFF or ASCII Grid files (step 13) or the model developers provide a utility program to convert one or both of the file types to a model specific format, such as the XMRG format in HL-RDHM. The GeoTIFF or ASCII Grid file formats provide the greatest flexibility for all uses at the time of this publication. It is also worth noting that a SNODAS parameter grid will usually be clipped to a specific area of interest before ingestion. For the SWE (1034) and Snow Depth (1036) files, this step can be performed directly after step 6. For the Cold Content (CC) file, this step can be performed after step 10.

For SWE (1034), use the following command.

```
]$ gdal_translate -of GTiff -ot Int16 -a_nodata -9999 -co "TFW=YES" -co "COMPRESS=LZW" -stats
us_ssmv11034tS__T0001TTNATS2011011905HP001.bil us_swe_20110119.tif
```

For Snow Depth (1036), use the following command.

```
]$ gdal_translate -of GTiff -ot Int16 -a_nodata -9999 -co "TFW=YES" -co "COMPRESS=LZW" -stats
us_ssmv11036tS__T0001TTNATS2011011905HP001.bil us_depth_20110119.tif
```

For Cold Content (CC), use the following command.

```
]$ gdal_translate -of GTiff -ot Int16 -a_nodata -9999 -co "TFW=YES" -co "COMPRESS=LZW" -stats
us_cc_20110119.bil us_cold_20110119.tif
```

Step 13 – Converting SNODAS File to ASCII Grid Format (Optional)

Here we convert the SWE (1034) and Snow Depth (1036) files produced in step 8, and the Cold Content (CC) file of step 10 from an ESRI Header Labeled file (flat binary grid) to an ArcInfo ASCII Grid (AAIGrid) file. The Snow Bulk Density file of step 11 is not converted to an ASCII Grid file because the "gdal_translate" utility does not convert a 32-bit floating point file correctly to an ArcInfo ASCII Grid file.

For SWE (1034), use the following command.

```
]$ gdal_translate -of AAIGrid us_1034_20110119.bil 1034_20110119.asc
```

For Snow Depth (1036), use the following command.

```
]$ gdal_translate -of AAIGrid us_1036_20110119.bil 1036_20110119.asc
```

For Cold Content (CC), use the following command.

```
]$ gdal_translate -of AAIGrid zz_cc_20110119.bil z_cc_20110119.asc
```

Step 14 – Re-project SNODAS File to a New Coordinate System (Optional)

If this optional process step is used, it would be implemented after step 6. A common projection for hydrologic modeling is the Standard Hydrologic Grid system (SHG). SHG is a variable-resolution square-celled map grid defined for the conterminous United States. The coordinate system of the grid is based on the Albers equal-area conic map projection with the following parameters (Table 2). Users of SHG can select a resolution suitable for the scale and scope of the study for which it is being used. For general-purpose hydrologic modeling the following grid resolutions are supported: 10,000, 5,000, 2,000, 1,000, 500, 200, 100, 50, 20, and 10 meter. The grids resulting from different resolutions are referred to as SHG-2km, SHG-1km, SHG-500m and so on (HEC 1996). Under ESRI's ArcMap, this coordinate system is titled "USA Contiguous Albers Equal Area Conic USGS version." The SNODAS grid cell size is 30 arc seconds: nominally 1000 meters on the ground. When up or down-scaling the grid cell size use the nearest neighbor resampling method which provides the best interpolation quality for discrete data.

Table 2. Standard Hydrologic Grid System.

Projection:	Albers Equal-Area
Spheroid:	GRS80
Datum:	NAD83
Prime Meridian:	Greenwich
Central Meridian:	96.0 ° West
Latitude of Origin:	23.0 ° North
1st Standard Parallel:	29.5 ° North
2nd Standard Parallel:	45.5 ° North
False Easting:	0.0
False Northing:	0.0
Linear Unit:	Meter
Angular Unit:	Degree

The "gdalwarp" utility is used to project the SNODAS file (flat binary grid) from WGS 1984 to SHG. Under GDAL, the SHG is titled "CONUS Albers EPSG:5070." The general and example usage of the "gdalwarp" utility is provided below.

```
]$ gdalwarp -s_srs srs_def -t_srs srs_def -ot type -r near -multi -of format srcfile dstfile
```

Where,

--formats	lists all raster formats supported by this "gdalwarp" build (rw+ = read-write-update formats only).
-s_srs	srs_def, source spatial reference set.
-t_srs	srs_def, target spatial reference set.
-ot	type, for the output bands to be of the indicated data type.

-r	resampling method, near, nearest neighbor resampling (default).
-multi	use multithreaded implementation performing input/output operations simultaneously.
-of	format, select the output format (default is GTiff).
-overwrite	overwrite the target dataset if it already exists.
srcfile	source file name.
dstfile	destination file name.

WGS 1984	wgs84 or '+proj=latlong +datum=wgs84'
SHG	EPSG:5070

]$ gdalwarp -s_srs wgs84 -t_srs EPSG:5070 -ot Int16 -r near -multi -of EHdr source.bil destination.bil

Process Validation Using ESRI's ArcMap

The method for importing SNODAS data into ESRI's ArcMap is well documented by the NSIDC and NOHRSC. This method can be used to validate by comparison the output generated by the process developed here in. Validation here refers to the process of conversion from a flat binary grid to an ArcInfo ASCII Grid or GeoTIFF and not an assessment of the accuracy of the SNODAS data itself. The following summary will highlight the NSIDC and NOHRSC import method providing additional detail and steps where needed for clarity and validation. The first five steps cited previously are the same except for the command line differences between Linux and Microsoft Windows which is the native operating system for ESRI's ArcMap. Here we are using ESRI ArcMap version 10.1 to perform these steps.

Step 1 – Download Data

Step 2 – File Extraction

Step 3 – Uncompress File

Under Microsoft Windows, interactive programs such "7-zip" or "WinZip" can uncompress "tar" files. If using "WinZip," ensure the "TAR file smart CR/LF conversion" option under the Options menu, Configuration, Miscellaneous is unchecked.

Step 4 – Rename File

Step 5 – Create Header File

As shown previously, create the header file (text format) in the same directory using WordPad or Notepad.

Step 6 – Converting SNODAS File to GeoTIFF Format

Start ArcCatalog and browse to the folder containing the ".bil" file(s). Select the ".bil" file of interest and right click selecting Properties. Select the Edit button (Spatial Reference). Open the Geographic Coordinate Systems folder. Open the World folder and choose the "WGS 1984.prj"

file. Click the OK button twice. Again, select the ".bil" file of interest and right click selecting Calculate Statistics. Blank out the Area of Interest and click OK. Review the results by selecting the ".bil" file of interest and right click selecting Properties. This will open the Raster Dataset Properties dialog box. Note that the cell size is 30 arc seconds (nominally 1 kilometer on the ground), the data type is a 16-bit signed integer, the no data value is -9999, and the minimum cell value is zero with the maximum cell value being 11325 for the masked SWE (1034, mm) file of January 19, 2011. For the masked Snow Depth (1036, mm) file, the minimum cell value is zero with the maximum cell value being 24411. For the masked Snow Pack Average Temperature (1038, °K) file, the minimum cell value is 252 with the maximum cell value being 273. These values will match the information given in each SNODAS parameter metadata file (see example Attachment 1). Exit ArcCatalog.

Start ArcMap and load the ".bil" file(s) of interest into the Layers view. Do build the pyramids at this time using Nearest Neighbor method for discrete data. For display purposes, select the ".bil" file of interest and right click selecting Properties then the Symbology tab. This will open the Layer Properties dialog box. Check the Display Background Value (0) as No Color and under Stretch Type select Standard Deviations. Choose a Color Ramp of choice and click OK (See Figure 3).
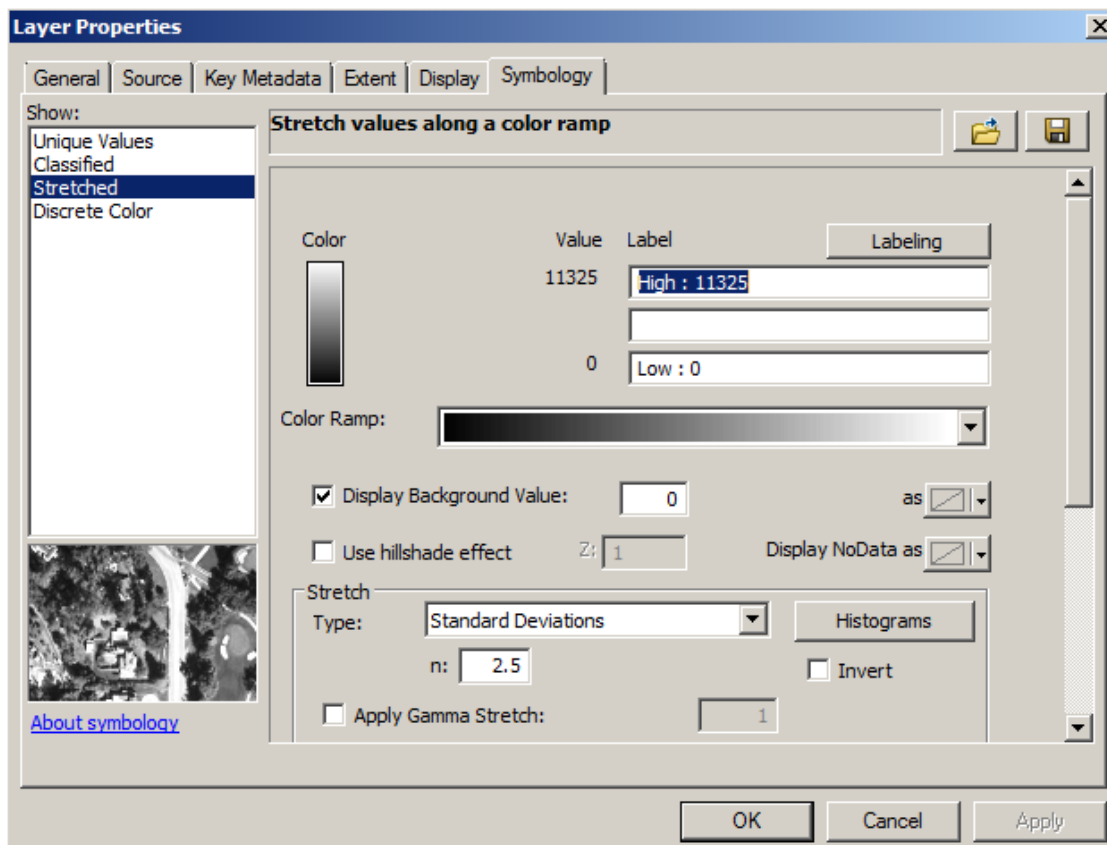

Figure 3. The Layer Properties dialog box in ArcMap 10.1.

Open ArcToolbox and select Conversion Tools | To Raster | Raster to Other Format (multiple). In the Input Rasters box, browse and select the filename(s) with the ".bil" extension. In the

Output Workspace box, select the folder to store the new file(s). In the Raster Format (optional) box, choose the TIFF format which is equivalent to GDAL's GeoTIFF format and click OK. Load the created TIFF file(s) into the Layers view. Right click the TIFF file of interest and select Properties and change the Symbology as before. In the Source tab, note the data type is 16-bit signed integer, the no data value is -9999, and the minimum and maximum cell values are as before.

Step 7 – Convert Temperatures from Kelvin to Celsius

The following commands will convert the Snow Pack Average Temperature (1038) from degrees Kelvin to degrees Celsius. Open ArcToolbox, select Spatial Analyst Tools | Map Algebra | Raster Calculator. In the Raster Calculator Map Algebra expression box, create the following expression and in the Output raster box create a file name with associated path (see Figure 4). Click OK and after processing the output raster will be loaded into the Layers view.

Con("us_ssmv11038wS__A0024TTNATS2011011905DP001.tif" >= 0,"us_ssmv11038wS__A0024TTNATS2011011905DP001.tif" - 273,"us_ssmv11038wS__A0024TTNATS2011011905DP001.tif")
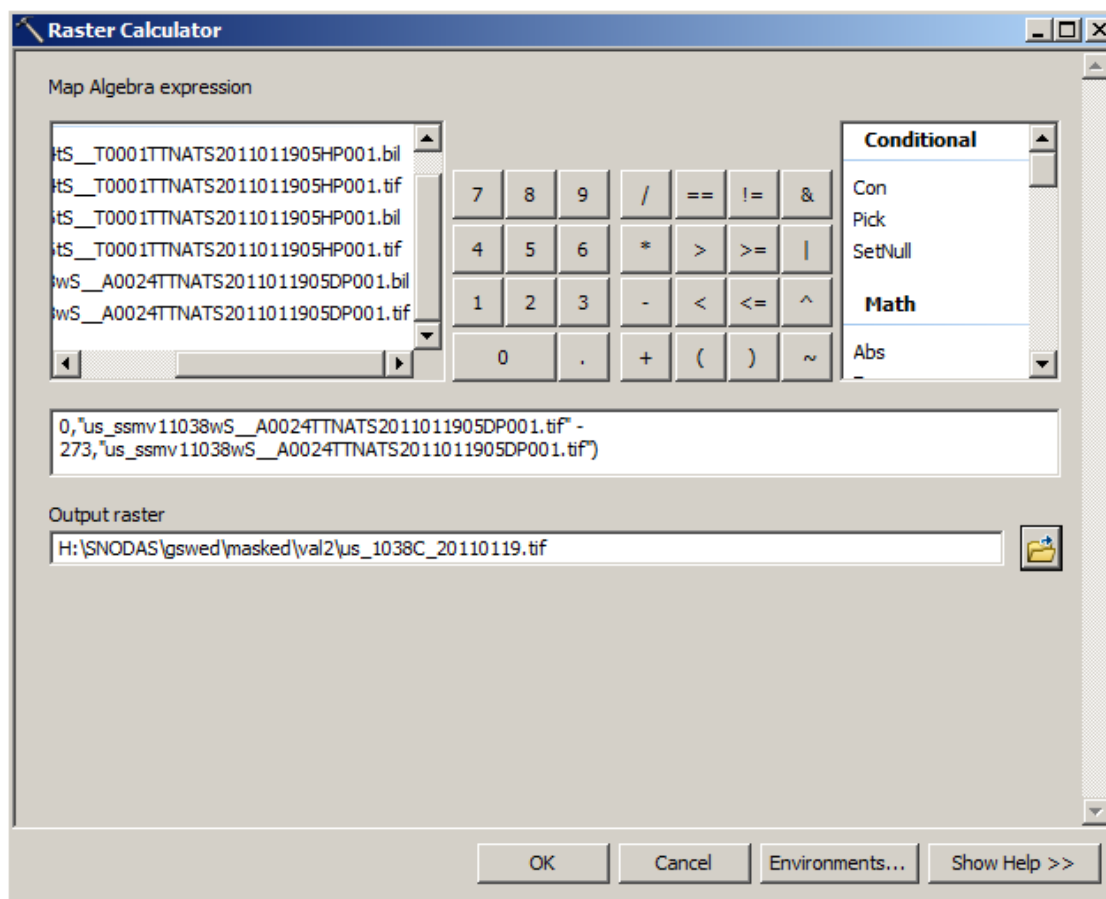

Figure 4. The Raster Calculator dialog box in ArcMap 10.1.

For the TIFF just created, the no data value must be redefined. Use the "SetNull" expression to define the NoData Value. Open ArcToolbox, select Spatial Analyst Tools | Map Algebra | Raster Calculator. In the Raster Calculator Map Algebra expression box, create the following expression and in the Output raster box create a file name with associated path (see example below). Click OK and after processing the output raster will be loaded into the Layers view.

SetNull("us_1038C_20110119.tif" == - 9999,"us_1038C_20110119.tif")

H:\SNODAS\gswed\masked\val2\us_n1038C_20110119.tif

Right click the TIFF file and select Properties then the Source tab. Note the data type is 32-bit signed integer, the no data value is -2147483648, and the minimum cell value is -21. The no data value listed is the default value for a 32-bit signed integer file. Additionally, all -9999 grid cell values have been defined as a no data value using the "SetNull" expression. This was done so that the grid cells containing -9999 would not be used in the calculation of Cold Content in step 8. The Symbology can be changed from Unique Values to Stretched as before while the Display Background Value (0) would be unchecked to prevent the valid value of 0 °C from not being displayed.

Step 8 – Calculate Cold Content

Using the Snow Pack Average Temperature (1038, °C) file created in step 7 and the SWE (1034, mm), calculate a Cold Content (mm) raster file. Open ArcToolbox, select Spatial Analyst Tools | Map Algebra | Raster Calculator. In the Raster Calculator Map Algebra expression box, create the following expression and in the Output raster box create a file name with associated path (see example below). Click OK and after processing the output raster will be loaded into the Layers view.

Con("us_n1038C_20110119.tif" <= 0,"us_n1038C_20110119.tif" *
"us_ssmv11034tS__T0001TTNATS2011011905HP001.tif" * 0.006287425,"us_n1038C_20110119.tif")

H:\SNODAS\gswed\masked\val2\us_CC_20110119.tif

Right click the TIFF file and select Properties then the Source tab. Note the data type is 32-bit floating point and the minimum cell value is -154.526. The no data value listed is the default value for a 32-bit floating point file. The Symbology can be changed as before. The Display Background Value (0) would be unchecked to prevent the valid Cold Content value of zero millimeters from not being displayed (No Color). Figure 5 shows the Cold Content produced using ArcMap and Figure 6 shows the Cold Content developed with the GDAL process.
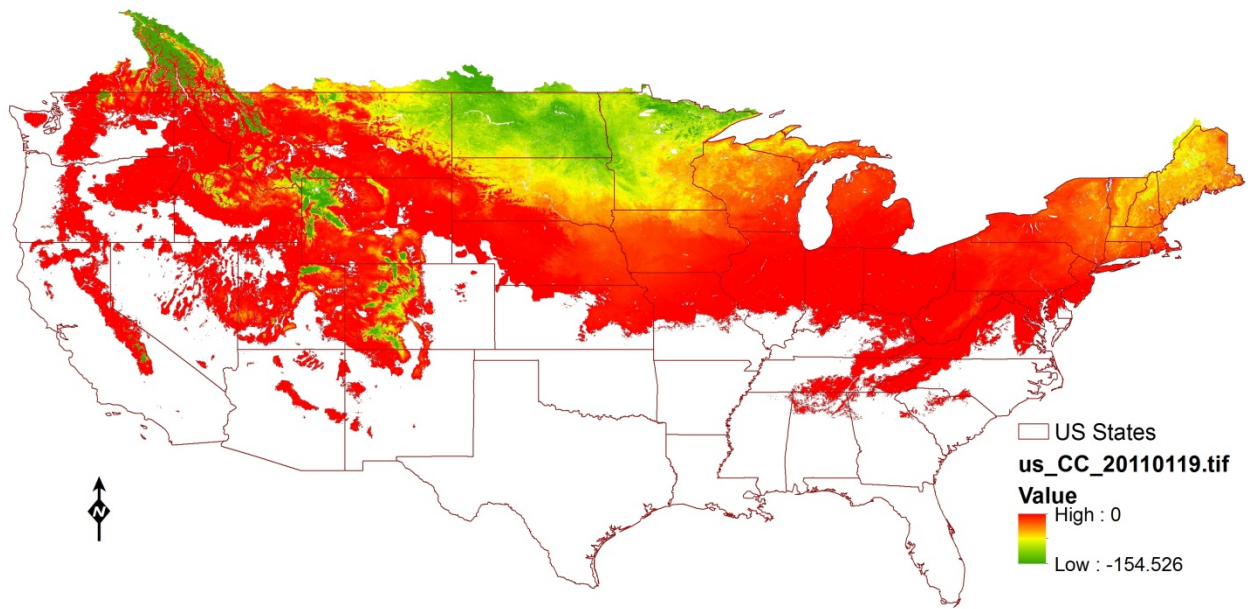
Figure 5. Cold Content (mm) grid for January 19, 2011 created in ArcMap 10.1.
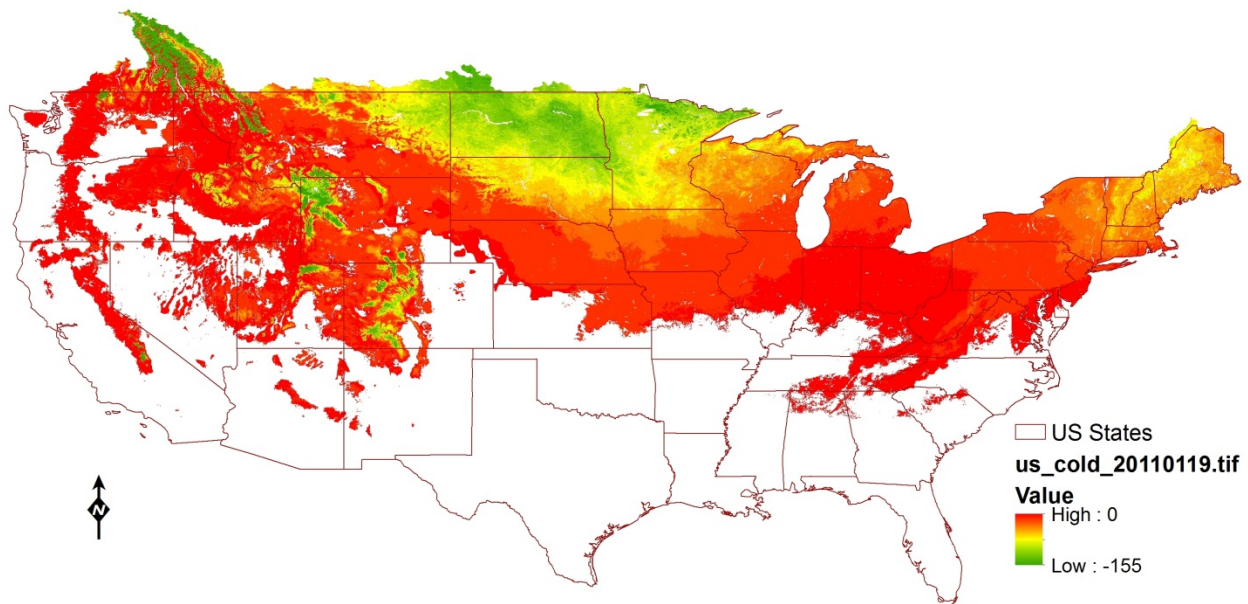

Figure 6. Cold Content (mm) grid for January 19, 2011 created using GDAL 1.9.2.

For the SNODAS data user, it is worth noting that the Cold Content (mm) will appear in grid cells where there is no snow (see Figure 7). In Figure 7, the Cold Content grid represented by a green gradient is overlaid by the SWE (1034, mm) grid represented by a blue gradient showing this discrepancy (zero SWE values shown using No Color). This is the result of the Snow Pack Average Temperature (1038, ° C) grid containing temperature values where the SWE has a zero

value therefore producing a Cold Content of zero. For the snow modeler, this anomaly does not present a problem because grid cells that have a zero SWE value will not calculate snow melt and accumulation of snow will only occur if there is new snow fall in which case the Cold Content will initialize at zero.
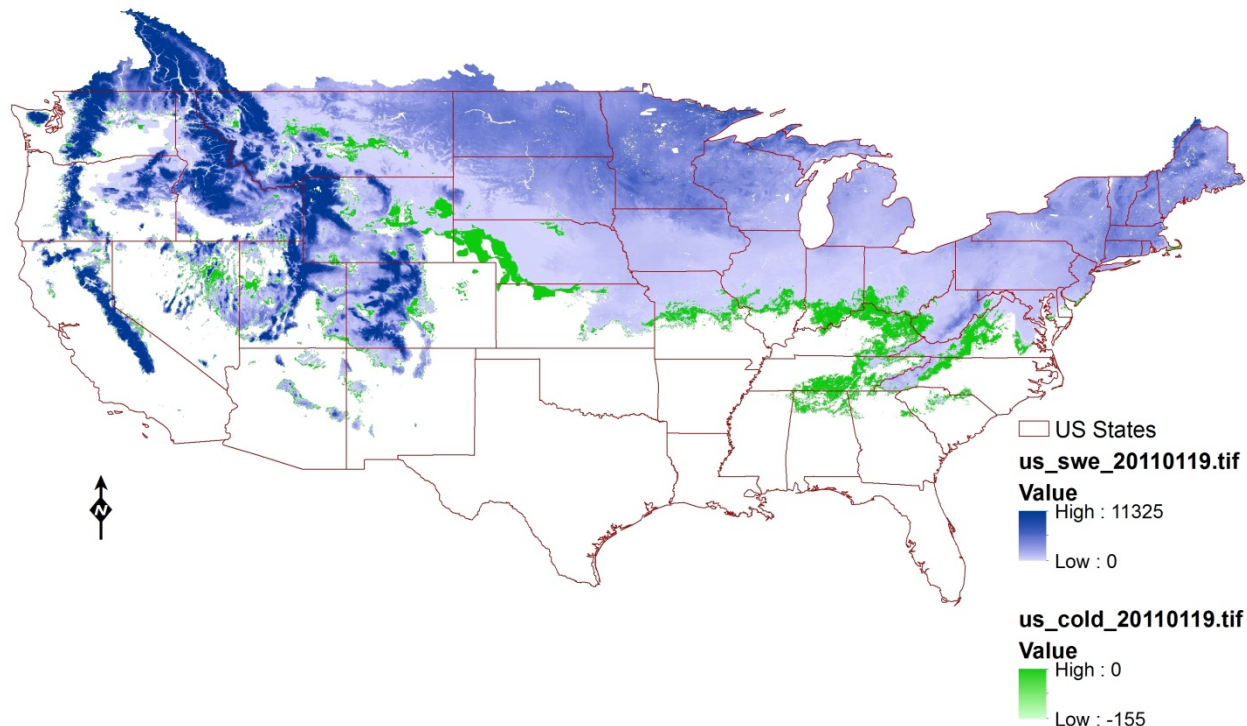

Figure 7. Cold Content (mm) grid overlaid by SWE (mm) grid for January 19, 2011.

Step 9 – Calculate Bulk Density

In order to create a bulk Snow Density grid in g/cm^3, open ArcToolbox, select Spatial Analyst Tools | Map Algebra | Raster Calculator and in the Raster Calculator Map Algebra expression box create the following expression and in the Output raster box create a file name with associated path (see example below). Click OK and after processing the output raster will be loaded into the Layers view.

```
Con("us_ssmv11036tS__T0001TTNATS2011011905HP001.tif" >
0,Float("us_ssmv11034tS__T0001TTNATS2011011905HP001.tif") /
Float("us_ssmv11036tS__T0001TTNATS2011011905HP001.tif"),Float("us_ssmv11036tS__T0001TTNATS
2011011905HP001.tif"))

H:\SNODAS\gswed\masked\val2\us_density_20110119.tif
```

Right click the TIFF file and select Properties then the Source tab. Note the data type is 32-bit floating point. The no data value listed is the default value for a 32-bit floating point file. The Symbology can be changed as before. In comparison with Figures 1 and 2, Figure 8 shows the Snow Bulk Density grid created using ESRI's ArcMap. Figures 9 and 10 provide a comparison

of the unmasked SWE created in ArcMap and with the GDAL process, respectively. Figures 11 and 12 provide a comparison of the masked Snow Depth created in ArcMap and with the GDAL process, respectively.
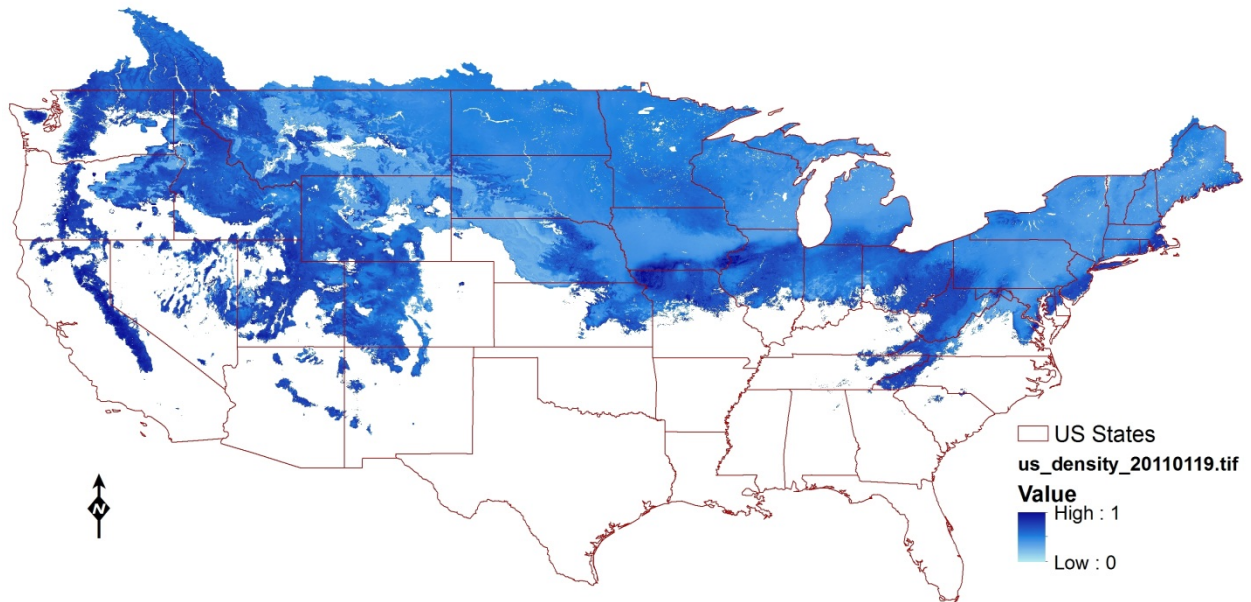

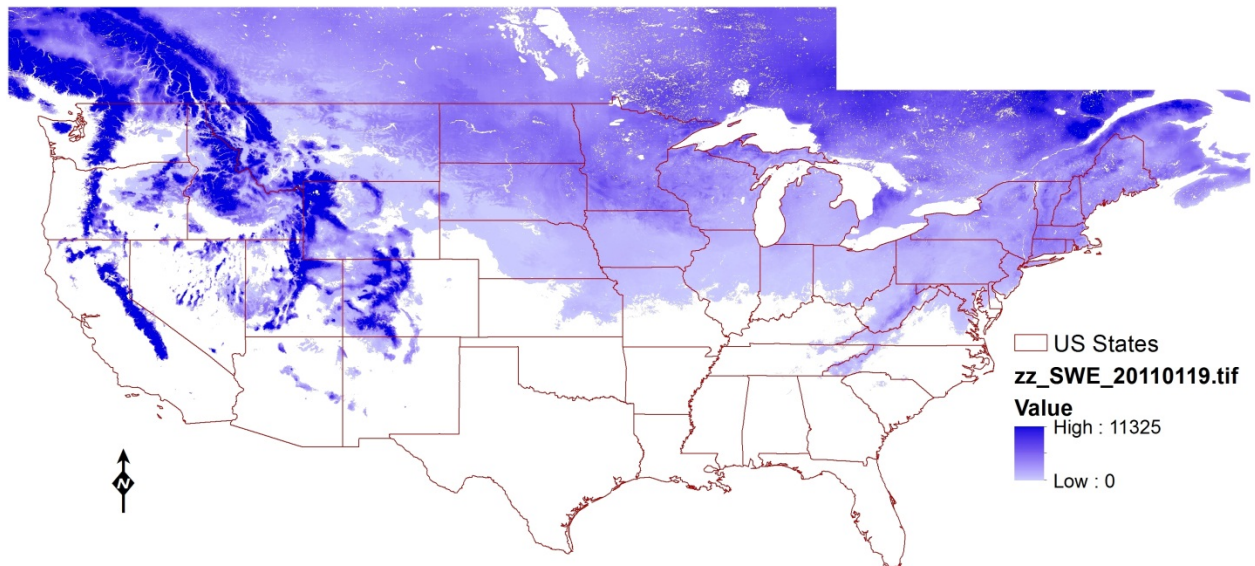**Figure 8.** Snow Bulk Density (g/cm^3) grid for January 19, 2011 created in ArcMap 10.1.

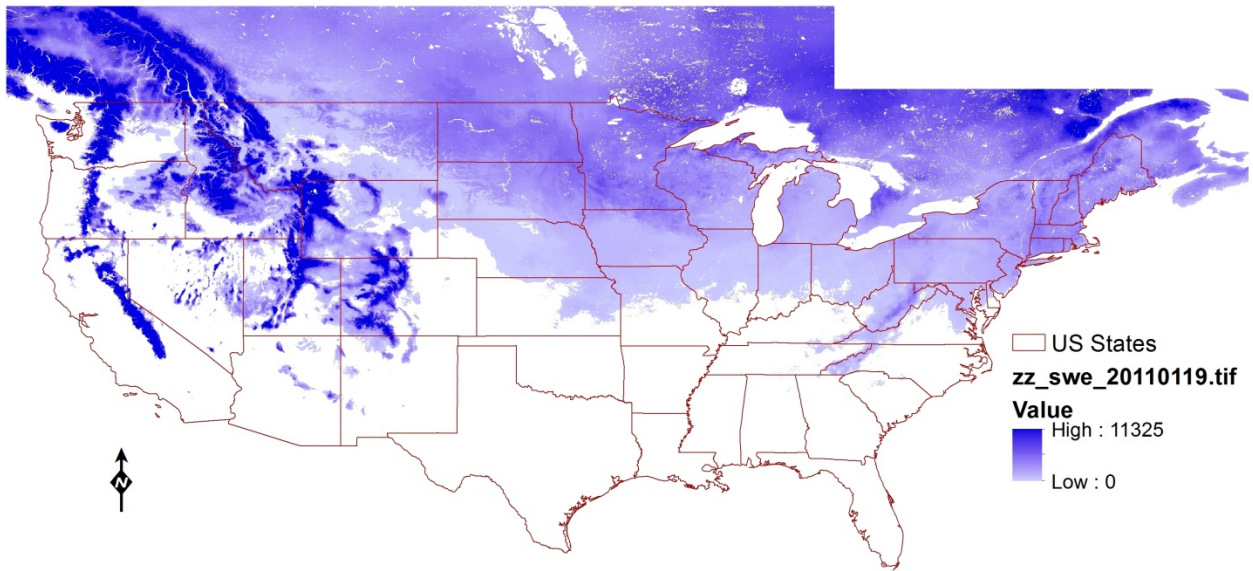**Figure 9.** Unmasked SWE (mm) grid for January 19, 2011 created in ArcMap 10.1.

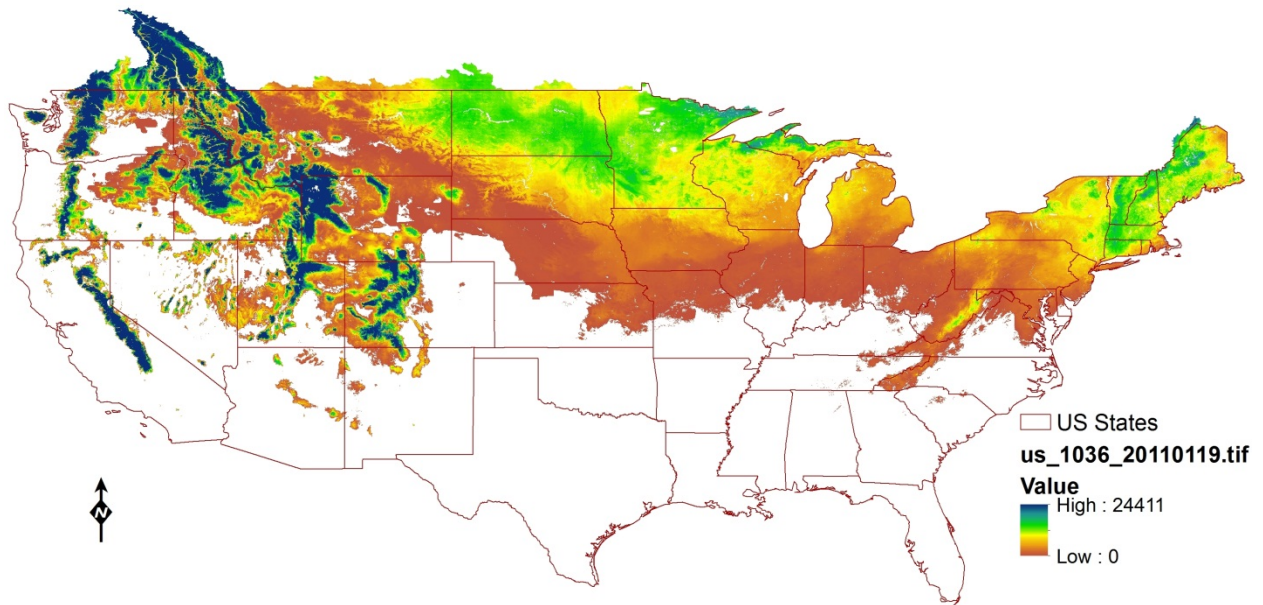**Figure 10.** Unmasked SWE (mm) grid for January 19, 2011 created using GDAL 1.9.2.

Figure 11. Snow Depth (mm) grid for January 19, 2011 created in ArcMap 10.1.
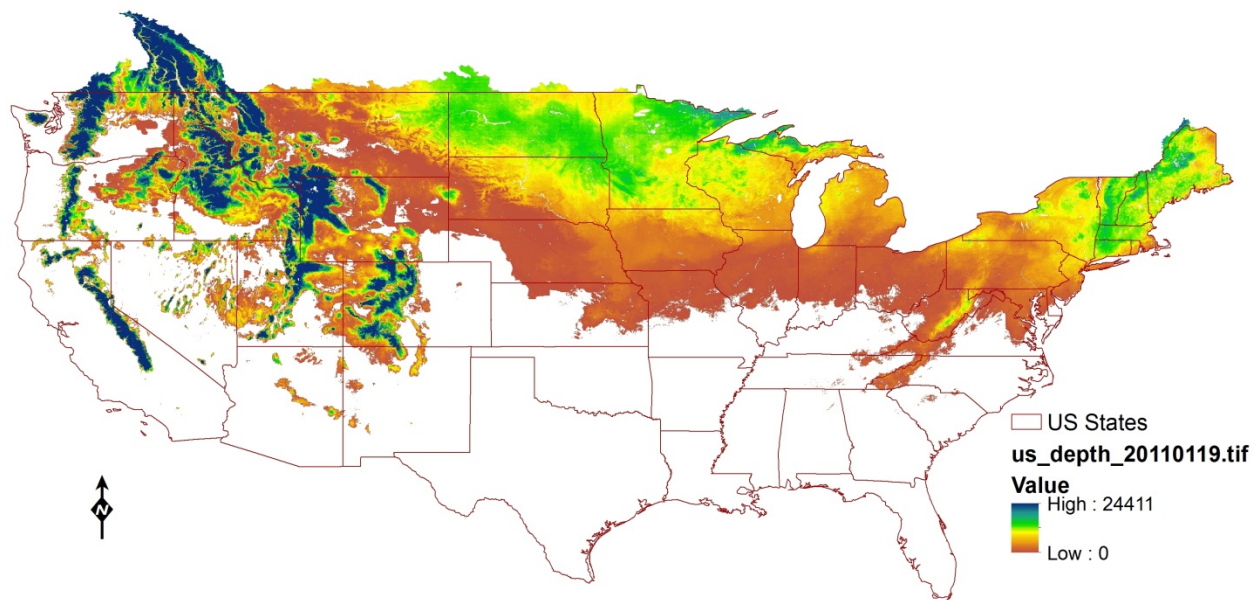
Figure 12. Snow Depth (mm) grid for January 19, 2011 created using GDAL 1.9.2.

Future Processing Improvements

Using the Perl 5 programming language automate the developed process providing the ability to process multiple archived daily SNODAS parameter sets. Perl 5 provides the capability to combine the GDAL binaries, Python scripts, and text manipulation into a single object-oriented, procedural program. Perl 5 is Open Source and available on the Linux, Mac OS X, and Microsoft Windows platforms. Automation is the key to efficiently process the large SNODAS dataset, and have a straightforward way to periodically update and process the data for each new year of information. After process automation is complete and tested, the resulting gridded output can be spot verified using ESRI's ArcMap.

Add a process step that permits the SNODAS parameter grid to be clipped to a polygon shapefile representing a particular user defined or 8-digit Hydrologic Unit Code (HUC) watershed. Additionally, develop the processing steps using the capabilities of R that will overlay a shapefile's polygons onto a SNODAS parameter grid calculating the daily mean raster value for each polygon thus permitting the calculation of a daily SWE volume using the watershed area.

Provide an optional processing step that imports ArcInfo ASCII Grid files of SNODAS parameters into a HEC-DSS database file. The HEC Data Storage System (DSS) stores data in a fashion convenient for inventory, retrieval, archiving and model use (HEC 1995) such as the Hydrologic Modeling System (HEC-HMS). The DSS was designed for water resource applications and the efficient storage and retrieval of scientific data that is typically sequential. Such data types include, but are not limited to, time series data, curve data, spatial-oriented gridded data, textual data, and others (HEC 2009).

References

Barrett, A.P., 2003, *National Operational Hydrologic Remote Sensing Center SNOw Data Assimilation System (SNODAS) Products at NSIDC, Special Report No. 11*: National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, Digital Media, 19 p.

Benjamin, S.G., Brown, J.M., Brundage, K.J., Devenyi, D., Grell, G.A., Kim, D., Schwartz, B.E., Smirnova, T.G., Smith, T.L., Weygandt, S., and Manikin, G.S., 2002, *The 20-km version of the Rapid Update Cycle (RUC20)*: NWS Technical Procedures Bulletin No. 490.

Boniface, K., Braun, J.J., McCreight, J.L., and Nievinski, F.G., 2014, *Comparison of SNODAS to GPS Reflectometry Snow Depth in the Western United States*: Accepted Article, Hydrological Processes, John Wiley & Sons, Inc.

Carroll, T., Cline, D., Fall, G., Nilsson, A., Li, L., and Rost, A., 2001, *NOHRSC Operations and the Simulation of Snow Cover Properties for the Conterminous U.S.*: Proceedings of the 69th Annual Meeting of the Western Snow Conference, pp. 1-14.

ESRI, 1999, *Extendable Image Formats for ArcView GIS 3.1 and 3.2, An ESRI White Paper*: Environmental Systems Research Institute, Inc., Redlands, CA, 19 p.

Hydrologic Engineering Center (HEC), 1995, *Overview HEC Data Storage System*: U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA, 31 p.

Hydrologic Engineering Center, 1996, *GridParm, Procedures for Deriving Grid Cell Parameters for the ModClark Rainfall-Runoff Model (CPD-71)*: U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, Davis, CA, 62 p.

Hydrologic Engineering Center, 2009, *HEC-DSSVue, HEC Data Storage System, Visual Utility Engine, User's Manual, Version 2.0 (CPD-79)*: U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center, Davis, CA, 490 p.

Jordan, R., 1990, *A One Dimensional Temperature Model for a Snow Cover (Technical Documentation for SNTHERM.89)*: CRREL Special Report 91-16, 64 p.

Lea, J., and Reid, I., 2006, *An Evaluation of SNODAS for Determining Snow Water Equivalent on Mount St. Helens, Washington (Western Snow Conference)*: United States Department of Agriculture, Natural Resources Conservation Service, Portland, OR, pp. 165-169.

National Operational Hydrologic Remote Sensing Center (NOHRSC), 2004, *Snow Data Assimilation System (SNODAS) Data Products at NSIDC, 19-JAN-2011*: National Snow and Ice Data Center, Boulder, Colorado.

Acknowledgements

Attachments

Attachment 1 – us_ssmv11034tS__T0001TTNATS2011011905HP001.Hdr

Format version: NOHRSC GIS/RS raster file v1.1
Data source: RUC2, NESDIS, etc.
Created by module: sm_products
Created by module comment: number BARD codes: 0000000024 BARD codes: 447200641 453379106 363670475
  448507164 447201002 447200999 448507161 447201003 447200647 458956735 449198303 447201000 12222
  226921937 194762463 194750795 120043862 319955379 194761059 244392413 324899530 445116660
  445116661 445116662
Created year: 2011
Created month: 1
Created day: 19
Created hour: 5
Created minute: 42
Created second: 8
Last modified by module: sm_products
Last modified by module comment: Not applicable
Last modified year: 2011
Last modified month: 1
Last modified day: 19
Last modified hour: 5
Last modified minute: 42
Last modified second: 8
Satellite data: no
Satellite name: Not applicable
Satellite channel: 0
Satellite data calibrated: no
Description: Modeled snow water equivalent, total of snow layers
Thematic: no
Theme file: Not applicable
Data units: Meters / 1000.000000
Product code: 465707251
Attribute table: Not applicable
Data file pathname: us_ssmv11034tS__T0001TTNATS2011011905HP001.dat
Data type: integer
Data bytes per pixel: 2
Data intercept: 0.00000000000000
Data slope: 1.00000000000000
Minimum data value: 0.00000000000000
Maximum data value: 11325.0000000000
No data value: -9999.00000000000
Number of columns: 6935
Number of rows: 3351
Geographically corrected: yes
Projected: no
Projection file: Not applicable
Horizontal datum: WGS84
Horizontal precision: 0.00833333333333300
Elevation above datum: no
Vertical datum: Not applicable
Vertical precision: 0.00000000000000
Benchmark column: 0
Benchmark row: 0
Benchmark x-axis coordinate: -124.729583333332
Benchmark y-axis coordinate: 52.8704166666656
X-axis resolution: 0.00833333333333300
Y-axis resolution: 0.00833333333333300
X-axis offset: 0.00374999999670214

Y-axis offset: 0.00375000000107451
Minimum x-axis coordinate: -124.733749999999
Maximum x-axis coordinate: -66.9420833333342
Minimum y-axis coordinate: 24.9495833333334
Maximum y-axis coordinate: 52.8745833333322
Start year: 2011
Start month: 1
Start day: 19
Start hour: 6
Start minute: 0
Start second: 0
Stop year: 2011
Stop month: 1
Stop day: 19
Stop hour: 6
Stop minute: 0
Stop second: 0
Compressed: no
Compression file: Not applicable
Number of color tables: 0
Color table 01 descriptor: Not applicable
Color table 02 descriptor: Not applicable
Color table 03 descriptor: Not applicable
Color table 04 descriptor: Not applicable
Color table 05 descriptor: Not applicable
Color table 06 descriptor: Not applicable
Color table 07 descriptor: Not applicable
Color table 08 descriptor: Not applicable
Color table 09 descriptor: Not applicable
Color table 10 descriptor: Not applicable
Color table 11 descriptor: Not applicable
Color table 12 descriptor: Not applicable
Color table 13 descriptor: Not applicable
Color table 14 descriptor: Not applicable
Color table 15 descriptor: Not applicable
Color table 16 descriptor: Not applicable
Color table 01 file: Not applicable
Color table 02 file: Not applicable
Color table 03 file: Not applicable
Color table 04 file: Not applicable
Color table 05 file: Not applicable
Color table 06 file: Not applicable
Color table 07 file: Not applicable
Color table 08 file: Not applicable
Color table 09 file: Not applicable
Color table 10 file: Not applicable
Color table 11 file: Not applicable
Color table 12 file: Not applicable
Color table 13 file: Not applicable
Color table 14 file: Not applicable
Color table 15 file: Not applicable
Color table 16 file: Not applicable
Histogram: no
Histogram file: Not applicable

Attachment 2 – val_repl.py

```
#!/usr/bin/env python
###############################################################################
# $Id$
#
# Project:  GDAL Python samples
# Purpose:  Script to replace specified values from the input raster file
#           with the new ones. May be useful in cases when you don't like
#           value, used for NoData indication and want replace it with other
#           value. Input file remains unchanged, results stored in other file.
# Author:   Andrey Kiselev, dron@remotesensing.org
#
###############################################################################
# Copyright (c) 2003, Andrey Kiselev <dron@remotesensing.org>
#
# Permission is hereby granted, free of charge, to any person obtaining a
# copy of this software and associated documentation files (the "Software"),
# to deal in the Software without restriction, including without limitation
# the rights to use, copy, modify, merge, publish, distribute, sublicense,
# and/or sell copies of the Software, and to permit persons to whom the
# Software is furnished to do so, subject to the following conditions:
#
# The above copyright notice and this permission notice shall be included
# in all copies or substantial portions of the Software.
#
# THE SOFTWARE IS PROVIDED "AS IS", WITHOUT WARRANTY OF ANY KIND, EXPRESS
# OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE WARRANTIES OF MERCHANTABILITY,
# FITNESS FOR A PARTICULAR PURPOSE AND NONINFRINGEMENT. IN NO EVENT SHALL
# THE AUTHORS OR COPYRIGHT HOLDERS BE LIABLE FOR ANY CLAIM, DAMAGES OR OTHER
# LIABILITY, WHETHER IN AN ACTION OF CONTRACT, TORT OR OTHERWISE, ARISING
# FROM, OUT OF OR IN CONNECTION WITH THE SOFTWARE OR THE USE OR OTHER
# DEALINGS IN THE SOFTWARE.
###############################################################################


try:
    from osgeo import gdal
    from osgeo.gdalconst import *
    gdal.TermProgress = gdal.TermProgress_nocb
except ImportError:
    import gdal
    from gdalconst import *

try:
    import numpy
except ImportError:
    import Numeric as numpy


import sys

# =============================================================================
def Usage():
    print('Usage: val_repl.py -innd in_nodata_value -outnd out_nodata_value')
    print('                   [-of out_format] [-ot out_type] infile outfile')
    print('')
    sys.exit( 1 )


# =============================================================================

# =============================================================================
def ParseType(type):
    gdal_dt = gdal.GetDataTypeByName(type)
```

```
    if gdal_dt is GDT_Unknown:
        gdal_dt = GDT_Byte
    return gdal_dt

# ============================================================================

inNoData = None
outNoData = None
infile = None
outfile = None
format = 'GTiff'
type = GDT_Byte

# Parse command line arguments.
i = 1
while i < len(sys.argv):
    arg = sys.argv[i]

    if arg == '-innd':
        i = i + 1
        inNoData = float(sys.argv[i])

    elif arg == '-outnd':
        i = i + 1
        outNoData = float(sys.argv[i])

    elif arg == '-of':
        i = i + 1
        format = sys.argv[i]

    elif arg == '-ot':
        i = i + 1
        type = ParseType(sys.argv[i])

    elif infile is None:
        infile = arg

    elif outfile is None:
        outfile = arg

    else:
        Usage()

    i = i + 1

if infile is None:
    Usage()
if  outfile is None:
    Usage()
if inNoData is None:
    Usage()
if outNoData is None:
    Usage()

indataset = gdal.Open( infile, GA_ReadOnly )

out_driver = gdal.GetDriverByName(format)
outdataset = out_driver.Create(outfile, indataset.RasterXSize, indataset.RasterYSize, indataset.RasterCount, type)

gt = indataset.GetGeoTransform()
if gt is not None and gt != (0.0, 1.0, 0.0, 0.0, 0.0, 1.0):
```

```
    outdataset.SetGeoTransform(gt)

prj = indataset.GetProjectionRef()
if prj is not None and len(prj) > 0:
    outdataset.SetProjection(prj)

for iBand in range(1, indataset.RasterCount + 1):
    inband = indataset.GetRasterBand(iBand)
    outband = outdataset.GetRasterBand(iBand)

    for i in range(inband.YSize - 1, -1, -1):
        scanline = inband.ReadAsArray(0, i, inband.XSize, 1, inband.XSize, 1)
        scanline = numpy.choose( numpy.equal( scanline, inNoData),
                                 (scanline, outNoData) )
        outband.WriteArray(scanline, 0, i)
```