Pan-Arctic Land Surface (PALS) model drivers and outputs:

Forcing data sets and output fields for multimodel simulations of pan-Arctic hydrology.

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Abstract

This document contains description of data sets used in the study:

Slater, A. G., T. J. Bohn, J. L. McCreight, M. C. Serreze, and D. P. Lettenmaier (2007), A multimodel simulation of pan-Arctic hydrology, *J. Geophys. Res.*, 112, G04S45, doi:10.1029/2006JG000303

The time period of the study was 1979-2001. Details are presented regarding the origins of the land surface model forcing variables (precipitation, 2-m air temperature, incoming solar and longwave radiation at the surface, 10-m winds and specific humidity at the lowest model level, temperature, and pressure) which are supplied over a subset of an equal-area grid at 3-hourly time resolution.

Outline of Documentation

I. Introduction

The following is taken from Slater et al. (2007).

3.2. Forcing Data

3.2.1. ERA-40 System

[24] As noted above, all models were forced with ERA-40 reanalysis data for the period 1979–2001. The forcing fields comprise precipitation, 2-m air temperature, incoming solar and longwave radiation at the surface, 10-m winds and specific humidity at the lowest model level, the latter calculated from dewpoint, temperature and pressure. These are available every 6 h on a grid with an approximate 125 km spacing (the so-called N80 reduced Gaussian grid). Precipitation and radiation fluxes are provided as 6-h accumulations from 6-hr forecasts. Temperature, 10-m winds, pressure and dewpoint represent instantaneous values at the 6-h analysis time.

[25] Reanalysis is a retrospective form of numerical weather prediction (NWP). Unlike NWP systems used for operational weather forecasting that are undergoing continual refinement, reanalyses like ERA-40 use fixed versions of the atmospheric model/data assimilation system. This yields more temporally consistent fields. Inconsistencies may still be present because of changes in the assimilation database through time.

[26] Overviews of ERA-40 can be found in the abstracts of the 2001 ERA-40 workshop [ECMWF, 2002] and at the ECMWF web site (www.ecmwf.int/research/era/Products). The ERA-40 model has a horizontal resolution of T-159, with 60 levels. Sea ice cover, sea surface temperature and land surface vegetation are prescribed from observations. Data sources for model

assimilation rely strongly on archives used in the companion National Centers for Environmental Prediction/NCAR (NCEP/NCAR) reanalysis [Kalnay et al., 1996; Kistler et al., 2001]. ERA-40 makes strong use of satellite data, starting with the first VTPR instrument in 1972 and continuing through the Special Sensor Microwave/Imager (SSM/I), TIROS Operational Vertical Sounder (TOVS) and Advanced TOVS (ATOVS) instruments. A significant difference with respect to the precursor ECMWF ERA-15 effort (1979–1993) is assimilation of raw satellite radiances as opposed to retrieved properties. There are numerous improvements relative to ERA-15 in the land surface scheme, many of which were driven by high-latitude concerns.

[27] ERA-40 precipitation estimates over the Arctic (both land and ocean) are known to be greatly improved over those from NCEP/NCAR [Serreze et al., 2005; Betts et al., 2003; Su et al., 2006]. Squared correlations between monthly time series of ERA-40 and observed precipitation, averaged over the four major Arctic watersheds, typically range from 0.60–0.90. Su et al. [2006] showed that ERA-40 precipitation over the same domain used here is surprisingly close to the observationally based estimates by Adam et al. [2006] when averaged over the major arctic river basins, but with some differences in seasonality.

[28] Unlike NCEP/NCAR, the ERA-40 system assimilates observations of surface temperature, humidity and winds when available. We have examined the 2-m temperature fields and find them to be of generally good quality. The temperature output for each ERA-40 grid cell from the atmospheric model (based on 6-h forecasts) is adjusted by the closest 50 stations within a 1000 km radius, but the station elevations must be within 300 m of the model's grid cell elevation to be used.

3.2.2. Spatial and Temporal Interpolation

[29] The ERA-40 data on the N-80 grid were interpolated to the 100 km EASE grid array shown in Figure 1, employing the same bilinear interpolation used by ECMWF for regridding. To obtain the diurnal cycle, the 6-hourly data on the 100 km grid were then disaggregated into 3-hourly time steps. For the instantaneous values (winds, temperature, dewpoint, pressure), we employed a simple linear interpolation between the 6-hourly values. Specific humidity was then calculated via Tetens formula [Murray, 1967] from the temporally interpolated temperature, dewpoint and pressure. Temporal disaggregation of the fluxes (6-h accumulated radiation and precipitation), required a different approach. Initially, solar radiation was disaggregated on the basis of the computed cosine solar zenith angle. Humidity was used as a proxy indicator for cloud cover as well as an emitter/absorber of radiation. Therefore precipitation and longwave radiation were disaggregated assuming a positive relationship with humidity while solar radiation was further adjusted using an inverse relationship.

[30] A common set of 3-hourly forcing data was supplied for all models, though some used a finer time step in which case a linear interpolation of quantities was used. CHASM, Noah and VIC were run using time steps of 3 h, while CLM ran at hourly and ECMWF at 30 minute steps because of numerical requirements.

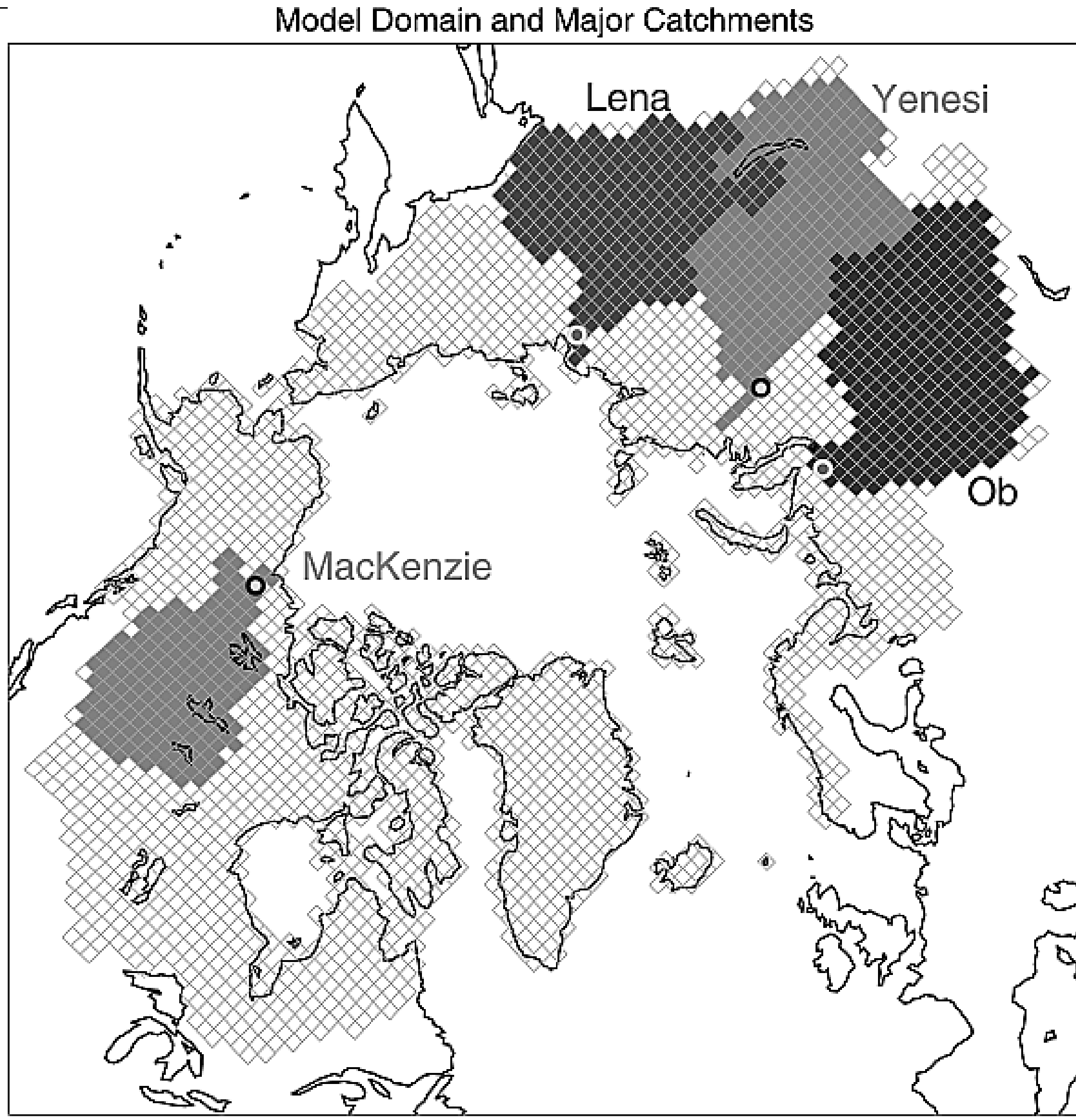

Figure 1. The Arctic terrestrial drainage as defined in this study. Also shown are the four major Arctic watersheds: the Lena, Yenisei, Ob, and Mackenzie with gauge stations shown by dots near the mouth of each river. Note that the Ob basin does not include the southern endorheic drainage areas in the Irtysh tributary system.

II. Forcing Data Set Details

1. Description of forcing variables.

As described above, forcing data sets are derived from the ERA-40 reanalysis products using spatial and temporal interpolation. The interpolation of ERA-40 to 100km EASE grid subdomain seen in Figure 1 is described in detail in the included document *PALS_interpolation_README.pdf*. Spatial interpolation follows the bilinear approach used by ECMWF which is describted at the following URL: http://www.ecmwf.int/research/ifsdocs/CY25r1/Technical/Technical-3-04.html#wp961293
Temporal interpolation for all variables is also discussed in *PALS_interpolation_README.pdf*.

2. Description of alternative precipitation fields.

In the course of this study several alternate sets of precipitation forcing fields were developed, though these were not used in the published study of Slater et al (2007). A large set of *in-situ* observations were blended with the ERA-40 background fields via Optimal Interpolation assimilation. Two of these alternate forcing fields (BM_assim.07.06.15.12.46.07 and BM_assim.07.06.22.11.01.09) supplement this data set and are are described in the document *PALS_precip_assim_README.pdf*.

III. Format of Data Sets

1. Geolocation Directroy

There are 2 geolocation files for this data set which are found in the *PALS_geolocation* directory. The first file, *LLLSME100.nc*, contains the longitude, latitude and the percentage of land within each cell. (LLLSME100 stands for Lat-Lon-Land Surface Mask-Ease100) Also given is the index of the nearest neighbor in the N80 grid but no further information is given to make this field useful. The header dump for this netcdf file is given.

```
mccreigh@arctic2:~/geolocation/E100> ncdump -h LLLSME100.nc
netcdf LLLSME100 {
dimensions:
        ngpts = 25373 ;
variables:
        float LAT(ngpts) ;
                LAT:long_name = "Latitude                      " ;
                LAT:units = "Degrees N      " ;
        float LON(ngpts) ;
                LON:long_name = "Longitude                     " ;
                LON:units = "Degrees E      " ;
        float LSM(ngpts) ;
                LSM:long_name = "Land-Sea Mask                 " ;
                LSM:units = "Land %         " ;
        float NN(ngpts) ;
                NN:long_name = "Nearest Neighbor              " ;
                NN:units = "Index starts@ 0" ;

// global attributes:
                :description = "EASE 100km grid for NH: lat lon and land sea
mask" ;
                :author = "James McCreight - mccreigh@nsidc.org" ;
}
```

While a full EASE-100 norther hemisphere grid has 180*180 grid cells, a portion of these fall off the earth. The points off the globe have been discarded and the remaining points (25373 of them) have been stored in a linear fashion with their corresponding lon, lat, and faction of land per cell. The grid shown in figure 1 is a subset of this grid. The grid in figure 1 is known as the Pan-Arctic Land Surface grid or PALS grid and is a subset of the EASE100. The subset indices for the E100 as give above are found in the file *pals_indices.nc* which gives the following netcdf header dump:

```
mccreigh@arctic2:> ncdump -h pals_indices.nc
netcdf pals_indices {
dimensions:
        palsindex = 2988 ;
variables:
        int palspts(palsindex) ;

// global attributes:
                :Title = "Indices of PALS grid on the EASE 100km grid for
extracting the data to PALS." ;
                :Description = "The indices of the PALS grid on the EASE 100km
grid. These are for extracting data on the EASE 100km grid to the PALS grid." ;
                :Author = "James McCreight - mccreigh@nsidc.org" ;
}
```

Taking the indicies from the given E100 grid which are given in this file will give the appropriate result. NOTE, it's VERY IMPORTANT that if you are using a computer language that begins indexing at 1 and not 0, you MUST ADD 1 to the palspts indices. These indices were made for use in IDL, which begins all it's indexing at 0.

2. Forcing Files
The model forcing files are found in PALS_FORCING.tar, which is a tar-ed archive. When this archive is un-tar-ed, it becomes the directory PALS_FORCING and contains gnu-zipped netcdf files with the filename convention as follows: era40.PALS.E100.3hr.bilinr.YYYYMM.nc.gz. The gunzip command must be run on these files to uncompress them to their original netcdf format. Data is netcdf format and should be self-explanatory. An example netcdf header dump:

```
netcdf era40.PALS.E100.3hr.bilinr.197901 {
dimensions:
        tstep = 248 ;
        land = 2988 ;
        z = 1 ;
variables:
        float nav_lon(land) ;
                nav_lon:units = "degrees_east" ;
                nav_lon:valid_min = -178.66f ;
                nav_lon:valid_max = 179.275f ;
                nav_lon:long_name = "Longitude" ;
        float nav_lat(land) ;
                nav_lat:units = "degrees_north" ;
                nav_lat:valid_min = 45.23f ;
                nav_lat:valid_max = 83.603f ;
                nav_lat:long_name = "Latitude" ;
        int level(z) ;
                level:units = "m" ;
                level:valid_min = 2.f ;
                level:valid_max = 2.f ;
                level:long_name = "Vertical levels" ;
                level:Notice = "Wind Components are at 10m as in the orig. ERA40
data. They should be interpolated down." ;
        int land(land) ;
                land:compress = "na" ;
        float time(tstep) ;
                time:units = "seconds since 1979-01-01 00:00:00" ;
                time:calendar = "gregorian" ;
                time:Title = "Time" ;
                time:long_name = "Time axis" ;
                time:time_origin = "1979-01-01 00:00:00" ;
        int timestp(tstep) ;
                timestp:units = "timesteps since 1979-01-01 00:00:00" ;
                timestp:Title = "Time steps" ;
                timestp:tstep_sec = 10800.f ;
                timestp:long_name = "Time step axis" ;
                timestp:time_origin = "1979-01-01 00:00:00" ;
        float SWdown(tstep, land) ;
                SWdown:axis = "TL" ;
                SWdown:units = "W/m^2    " ;
                SWdown:long_name = "Surface incident shortwave radiation
" ;
                SWdown:associate = "time (nav_lat nav_lon)" ;
                SWdown:missing_value = 2.656331e+21f ;
        float LSRainf(tstep, land) ;
                LSRainf:axis = "TL" ;
                LSRainf:units = "kg/(m^2s)" ;
                LSRainf:long_name = "Large-Scale rainfall rate
```

```
" ;
                LSRainf:associate = "time (nav_lat nav_lon)" ;
                LSRainf:missing_value = 2.656331e+21f ;
        float CRainf(tstep, land) ;
                CRainf:axis = "TL" ;
                CRainf:units = "kg/(m^2s)" ;
                CRainf:long_name = "Convective rainfall rate
" ;
                CRainf:associate = "time (nav_lat nav_lon)" ;
                CRainf:missing_value = 2.656331e+21f ;
        float Snowf(tstep, land) ;
                Snowf:axis = "TL" ;
                Snowf:units = "kg/(m^2s)" ;
                Snowf:long_name = "Snowfall rate
" ;
                Snowf:associate = "time (nav_lat nav_lon)" ;
                Snowf:missing_value = 2.656331e+21f ;
        float LWdown(tstep, land) ;
                LWdown:axis = "TL" ;
                LWdown:units = "W/m^2    " ;
                LWdown:long_name = "Surface incident longwave radiation
" ;
                LWdown:associate = "time (nav_lat nav_lon)" ;
                LWdown:missing_value = 2.656331e+21f ;
        float PSurf(tstep, land) ;
                PSurf:axis = "TL" ;
                PSurf:units = "Pa       " ;
                PSurf:long_name = "Surface pressure
" ;
                PSurf:associate = "time (nav_lat nav_lon)" ;
                PSurf:missing_value = 2.656331e+21f ;
        float Tair(tstep, z, land) ;
                Tair:axis = "TZL" ;
                Tair:units = "K        " ;
                Tair:long_name = "Near surface air temperature (2m)
" ;
                Tair:associate = "time level (nav_lat nav_lon)" ;
                Tair:missing_value = 2.656331e+21f ;
        float Qair(tstep, z, land) ;
                Qair:axis = "TZL" ;
                Qair:units = "kg/kg    " ;
                Qair:long_name = "Near surface specific humidity (2m)
" ;
                Qair:associate = "time level (nav_lat nav_lon)" ;
                Qair:missing_value = 2.656331e+21f ;
        float Wind_N(tstep, z, land) ;
                Wind_N:axis = "TZL" ;
                Wind_N:units = "m/s      " ;
                Wind_N:long_name = "Near surface northward directed wind
component (10m)" ;
                Wind_N:associate = "time level (nav_lat nav_lon)" ;
                Wind_N:missing_value = 2.656331e+21f ;
        float Wind_E(tstep, z, land) ;
                Wind_E:axis = "TZL" ;
                Wind_E:units = "m/s      " ;
                Wind_E:long_name = "Near surface eastward directed wind component
(10m) " ;
                Wind_E:associate = "time level (nav_lat nav_lon)" ;
                Wind_E:missing_value = 2.656331e+21f ;

// global attributes:
                :Conventions = "GDT 1.2" ;
                :file_name =
"/arc_hive/PALS/bilinear/era40.PALS.E100.3hr.bilinr.197901.nc �?�" ;
                :year = "1979" ;
                :month = "01" ;
```

```
                :description = "3 hourly ERA40 on the EASE 100km grid. Regridded
from orig. resolution using biline interpolation with radius 0000 km and
downscaling to 3 hourly timesteps" ;
                :creator = "James McCreight - mccreigh@nsidc.org" ;
}
```

3. Alternate precipitation files.
The tar-ed archive PALS_ALT_PRECIP.tar will produce the directory PALS_ALT_PRECIP which contains the 2 subdirectories, BM_assim.07.06.15.12.46.07 and BM_assim.07.06.22.11.01.09. The difference between the data in these directories is described in *PALS_assim_precip_README.pdf*. The files in these subdirectories are again gzipped netcdf files and must be gunzip-ed to restore them to netcdf form. The filename convention follows:
era40.PALS.E100.3hr.bilinr.YYYYMM.nc.assim_precip.nc.gz
The netcdf header dump for an example alternative precipitation fields file is given.

```
netcdf era40.PALS.E100.3hr.bilinr.200011.nc.assim_precip {
dimensions:
        ntimesteps = 240 ;
        ngpts = 2988 ;
variables:
        float LSRainf(ntimesteps, ngpts) ;
                LSRainf:units = "kg/(m^2s)" ;
                LSRainf:long_name = "Large-Scale rainfall rate " ;
        float CRainf(ntimesteps, ngpts) ;
                CRainf:units = "kg/(m^2s)" ;
                CRainf:long_name = "Convective rainfall rate" ;
        float Snowf(ntimesteps, ngpts) ;
                Snowf:units = "kg/(m^2s)" ;
                Snowf:long_name = "Snowfall rate" ;
        float Day(ntimesteps) ;
                Day:desc = "day of month" ;
        float Time(ntimesteps) ;
                Time:desc = "time of day" ;

// global attributes:
                :Description = "Big Merge/ERA40 assimilated precip data on PALS
grid at 3-hourly timestep." ;
                :creator = "James McCreight - mccreigh@nsidc.org" ;
                :year = "2000" ;
                :month = "11" ;
}
```

4. Model output.
The tar archive PALS_OUTPUT.tar can be extracted to the PALS_OUTPUT which contains the following subdirectories:
CHASM CLM ECMWF FORCING NOAH VIC and the README file. The directories all contain gzipped netcdf files. The content of the README file is repeated now.

Model output is stored in NetCDF files that largely comply with the ALMA standards. There are 5 files for each model for each month from January 1979 to December 2001. The stored values are DAILY MEANS and the month's woth of data is stored in each file.

File name conventions are as : MODELNAME_FILETYPE_YYYYMM.nc

MODELNAME : CHASM, NOAH, ECMWF, CLM, VIC

FILETYPE : COLD, EBAL, EVAP, SURF, WBAL
YYYYMM : year and month, e.g. 198001 = January 1980

Details of the 5 models are given in Slater et al., 2007
Different sets of variables are stored in each "Filetype" and some variables may be repreted in some of the different Filetypes.

COLD = Cold season processes, maily snow variables
EBAL = energy balance components e.g. sensible heat flux
EVAP = evaporation variables (e.g. canopy or bare soil)
SURF = Surface variables, e.g. surface temperatures
WBAL = Water balance components e.g. precip, runoff

A sample of headers for each filetype is given below.

Cold processes

```
netcdf CHASM_COLD_198001 {
dimensions:
        ntstp = UNLIMITED ; // (31 currently)
        land = 2988 ;
        z = 5 ;
        nsnow = 1 ;
variables:
        float nav_lon(land) ;
                nav_lon:units = "degrees_east" ;
                nav_lon:valid_min = -178.66f ;
                nav_lon:valid_max = 179.275f ;
                nav_lon:long_name = "Longitude" ;
        float nav_lat(land) ;
                nav_lat:units = "degrees_north" ;
                nav_lat:valid_min = 45.23f ;
                nav_lat:valid_max = 83.603f ;
                nav_lat:long_name = "Latitude" ;
        float SnowFrac(ntstp, land, nsnow) ;
                SnowFrac:long_name = "Snow Cover Fraction
              " ;
                SnowFrac:units = "-              " ;
        float SAlbedo(ntstp, land) ;
                SAlbedo:long_name = "Snow Albedo
             " ;
                SAlbedo:units = "-              " ;
        float SnowDepth(ntstp, land) ;
                SnowDepth:long_name = "3D Depth of Snow Layers
               " ;
                SnowDepth:units = "m              " ;

// global attributes:
                :Model = "CHASM" ;
                :Year = 1980 ;
                :Month = 1 ;
                :missing_value = -9999.99f ;
                :time_origin = "1979-01-01 00:00:00" ;
                :time_units = "s" ;
                :time_step_len = 86400 ;
                :model_time_units = "s" ;
                :model_time_step_len = 10800 ;
                :Creator = "Andrew Slater - aslater@cires.colorado.edu" ;
}
```

Energy Balance components

```
netcdf CHASM_EBAL_198001 {
dimensions:
        ntstp = UNLIMITED ; // (31 currently)
        land = 2988 ;
variables:
        float nav_lon(land) ;
                nav_lon:units = "degrees_east" ;
                nav_lon:valid_min = -178.66f ;
                nav_lon:valid_max = 179.275f ;
                nav_lon:long_name = "Longitude" ;
        float nav_lat(land) ;
                nav_lat:units = "degrees_north" ;
                nav_lat:valid_min = 45.23f ;
                nav_lat:valid_max = 83.603f ;
                nav_lat:long_name = "Latitude" ;
        float SWnet(ntstp, land) ;
                SWnet:long_name = "Net S/W radiation
          " ;
                SWnet:units = "W m^-2         " ;
        float LWnet(ntstp, land) ;
                LWnet:long_name = "Net L/W radiation
          " ;
                LWnet:units = "W m^-2         " ;
        float Qle(ntstp, land) ;
                Qle:long_name = "Latent heat flux
        " ;
                Qle:units = "W m^-2         " ;
        float Qh(ntstp, land) ;
                Qh:long_name = "Sensible heat flux
       " ;
                Qh:units = "W m^-2         " ;
        float Qg(ntstp, land) ;
                Qg:long_name = "Ground heat flux
       " ;
                Qg:units = "W m^-2         " ;
        float Qf(ntstp, land) ;
                Qf:long_name = "Energy of fusion
       " ;
                Qf:units = "W m^-2         " ;
        float Qv(ntstp, land) ;
                Qv:long_name = "Energy of sublimation
       " ;
                Qv:units = "W m^-2         " ;
        float Qa(ntstp, land) ;
                Qa:long_name = "Advective energy*
       " ;
                Qa:units = "W m^-2         " ;
        float DelSurfHeat(ntstp, land) ;
                DelSurfHeat:long_name = "Change in surface layer heat
                " ;
                DelSurfHeat:units = "J m-2          " ;
        float DelColdCont(ntstp, land) ;
                DelColdCont:long_name = "Change in snow surface layer cold conte
nt              " ;
                DelColdCont:units = "J m-2          " ;

// global attributes:
                :Model = "CHASM" ;
                :Year = 1980 ;
                :Month = 1 ;
                :missing_value = -9999.99f ;
                :time_origin = "1979-01-01 00:00:00" ;
```

```
                :time_units = "s" ;
                :time_step_len = 86400 ;
                :model_time_units = "s" ;
                :model_time_step_len = 10800 ;
                :Creator = "Andrew Slater - aslater@cires.colorado.edu" ;
}
```

Evaporation processes

```
netcdf CHASM_EVAP_198001 {
dimensions:
        ntstp = UNLIMITED ; // (31 currently)
        land = 2988 ;
variables:
        float nav_lon(land) ;
                nav_lon:units = "degrees_east" ;
                nav_lon:valid_min = -178.66f ;
                nav_lon:valid_max = 179.275f ;
                nav_lon:long_name = "Longitude" ;
        float nav_lat(land) ;
                nav_lat:units = "degrees_north" ;
                nav_lat:valid_min = 45.23f ;
                nav_lat:valid_max = 83.603f ;
                nav_lat:long_name = "Latitude" ;
        float PotEvap(ntstp, land) ;
                PotEvap:long_name = "Potential evapotranspiration
            " ;
                PotEvap:units = "kg m^-2 s^-1   " ;
        float ECanop(ntstp, land) ;
                ECanop:long_name = "Evaporation of canopy interception
           " ;
                ECanop:units = "kg m^-2 s^-1   " ;
        float TVeg(ntstp, land) ;
                TVeg:long_name = "Vegetation Transpiration
         " ;
                TVeg:units = "kg m^-2 s^-1   " ;
        float ESoil(ntstp, land) ;
                ESoil:long_name = "Bare soil evaporation
          " ;
                ESoil:units = "kg m^-2 s^-1   " ;
        float EWater(ntstp, land) ;
                EWater:long_name = "Open Water evaporation
           " ;
                EWater:units = "kg m^-2 s^-1   " ;
        float RootMoist(ntstp, land) ;
                RootMoist:long_name = "Root zone soil soil moisture
              " ;
                RootMoist:units = "kg m^-2        " ;
        float CanopInt(ntstp, land) ;
                CanopInt:long_name = "Total Canopy Water Storage
             " ;
                CanopInt:units = "kg m^-2        " ;
        float EvapSnow(ntstp, land) ;
                EvapSnow:long_name = "Evaporation of liquid water from snowpack
             " ;
                EvapSnow:units = "kg m^-2 s^-1   " ;
        float SubSnow(ntstp, land) ;
                SubSnow:long_name = "Snow Sublimation
            " ;
                SubSnow:units = "kg m^-2 s^-1   " ;
        float SubSurf(ntstp, land) ;
                SubSurf:long_name = "Sublimation of ice from soil and canopy int
ercation    " ;
                SubSurf:units = "kg m^-2 s^-1   " ;
```

```
        float ACond(ntstp, land) ;
                ACond:long_name = "Aerodynamic conductance
          " ;
                ACond:units = "m s^-1         " ;
        float Ccond(ntstp, land) ;
                Ccond:long_name = "Canopy (Stomatal) conductance
          " ;
                Ccond:units = "m s^-1         " ;

// global attributes:
                :Model = "CHASM" ;
                :Year = 1980 ;
                :Month = 1 ;
                :missing_value = -9999.99f ;
                :time_origin = "1979-01-01 00:00:00" ;
                :time_units = "s" ;
                :time_step_len = 86400 ;
                :model_time_units = "s" ;
                :model_time_step_len = 10800 ;
                :Creator = "Andrew Slater - aslater@cires.colorado.edu" ;
}
```

Surface characteristics

```
netcdf CHASM_SURF_198001 {
dimensions:
        ntstp = UNLIMITED ; // (31 currently)
        land = 2988 ;
        z = 5 ;
        nsnow = 1 ;
variables:
        float nav_lon(land) ;
                nav_lon:units = "degrees_east" ;
                nav_lon:valid_min = -178.66f ;
                nav_lon:valid_max = 179.275f ;
                nav_lon:long_name = "Longitude" ;
        float nav_lat(land) ;
                nav_lat:units = "degrees_north" ;
                nav_lat:valid_min = 45.23f ;
                nav_lat:valid_max = 83.603f ;
                nav_lat:long_name = "Latitude" ;
        float SnowT(ntstp, land) ;
                SnowT:long_name = "Snow surface temperature
          " ;
                SnowT:units = "K              " ;
        float VegT(ntstp, land) ;
                VegT:long_name = "Vegetation/canopy temperature
         " ;
                VegT:units = "K              " ;
        float BearsoilT(ntstp, land) ;
                BearsoilT:long_name = "Bare soil temperature
              " ;
                BearsoilT:units = "K              " ;
        float AvgSurfT(ntstp, land) ;
                AvgSurfT:long_name = "Area weighted average surface temperature
             " ;
                AvgSurfT:units = "K              " ;
        float RadT(ntstp, land) ;
                RadT:long_name = "Surface radiative temperature
         " ;
                RadT:units = "K              " ;
        float Albedo(ntstp, land) ;
                Albedo:long_name = "Surface Albedo
           " ;
```

```
                Albedo:units = "-               " ;
        float SWE(ntstp, land, nsnow) ;
                SWE:long_name = "3D snow water equivalent
        " ;
                SWE:units = "kg m^-2        " ;
        float SWEVeg(ntstp, land) ;
                SWEVeg:long_name = "Snow water equivqlent in canopy interception
           " ;
                SWEVeg:units = "kg m^-2        " ;
        float SurfStor(ntstp, land) ;
                SurfStor:long_name = "Surface water storage
             " ;
                SurfStor:units = "kg m^-2        " ;

// global attributes:
                :Model = "CHASM" ;
                :Year = 1980 ;
                :Month = 1 ;
                :missing_value = -9999.99f ;
                :time_origin = "1979-01-01 00:00:00" ;
                :time_units = "s" ;
                :time_step_len = 86400 ;
                :model_time_units = "s" ;
                :model_time_step_len = 10800 ;
                :Creator = "Andrew Slater - aslater@cires.colorado.edu" ;
}
```

Water Balance components

```
netcdf CHASM_WBAL_198001 {
dimensions:
        ntstp = UNLIMITED ; // (31 currently)
        land = 2988 ;
variables:
        float nav_lon(land) ;
                nav_lon:units = "degrees_east" ;
                nav_lon:valid_min = -178.66f ;
                nav_lon:valid_max = 179.275f ;
                nav_lon:long_name = "Longitude" ;
        float nav_lat(land) ;
                nav_lat:units = "degrees_north" ;
                nav_lat:valid_min = 45.23f ;
                nav_lat:valid_max = 83.603f ;
                nav_lat:long_name = "Latitude" ;
        float Snowf(ntstp, land) ;
                Snowf:long_name = "Snowfall rate
          " ;
                Snowf:units = "kg m^-2 s^-1   " ;
        float Rainf(ntstp, land) ;
                Rainf:long_name = "Rainfall rate
          " ;
                Rainf:units = "kg m^-2 s^-1   " ;
        float Evap(ntstp, land) ;
                Evap:long_name = "Total evapotranspiration
         " ;
                Evap:units = "kg m^-2 s^-1   " ;
        float Qs(ntstp, land) ;
                Qs:long_name = "Surface runoff
       " ;
                Qs:units = "kg m^-2 s^-1   " ;
        float Qsb(ntstp, land) ;
                Qsb:long_name = "Subsurface runoff
        " ;
                Qsb:units = "kg m^-2 s^-1   " ;
```

```
        float Qsm(ntstp, land) ;
                Qsm:long_name = "Snowmelt
        " ;
                Qsm:units = "kg m^-2 s^-1   " ;
        float Qfz(ntstp, land) ;
                Qfz:long_name = "Refreezing of water in snowpack
        " ;
                Qfz:units = "kg m^-2 s^-1   " ;
        float Qst(ntstp, land) ;
                Qst:long_name = "Water flowing out of snowpack
        " ;
                Qst:units = "kg m^-2 s^-1   " ;
        float DelSoilMoist(ntstp, land) ;
                DelSoilMoist:long_name = "Change in column soil moisture
                 " ;
                DelSoilMoist:units = "kg m^-2        " ;
        float DelSWE(ntstp, land) ;
                DelSWE:long_name = "Change in SWE
           " ;
                DelSWE:units = "kg m^-2        " ;
        float DelSurfStor(ntstp, land) ;
                DelSurfStor:long_name = "Change in surface liquid water storage
                " ;
                DelSurfStor:units = "kg m^-2        " ;
        float DelIntercept(ntstp, land) ;
                DelIntercept:long_name = "Change in canopy interception storage
                 " ;
                DelIntercept:units = "kg m^-2        " ;

// global attributes:
                :Model = "CHASM" ;
                :Year = 1980 ;
                :Month = 1 ;
                :missing_value = -9999.99f ;
                :time_origin = "1979-01-01 00:00:00" ;
                :time_units = "s" ;
                :time_step_len = 86400 ;
                :model_time_units = "s" ;
                :model_time_step_len = 10800 ;
                :Creator = "Andrew Slater - aslater@cires.colorado.edu" ;
}
```