Practical Session Instructions

Terrestrial Water Storage
–
Drought Monitoring
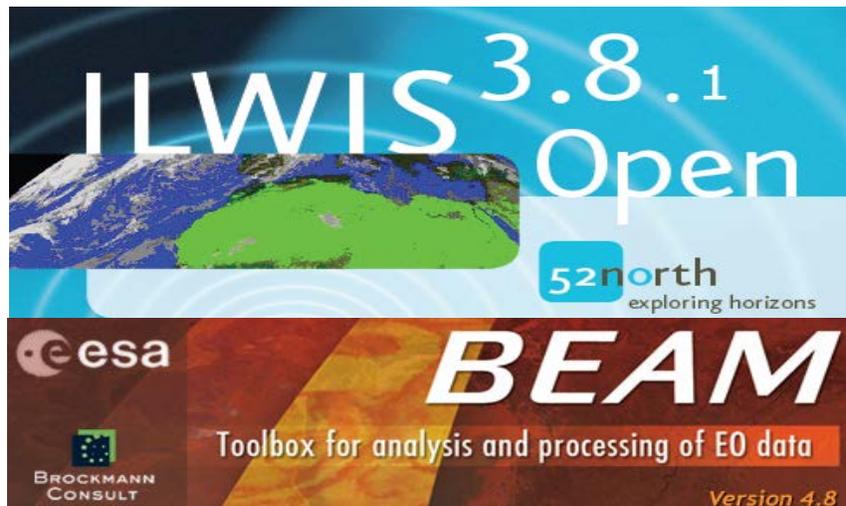
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Terrestrial water storage and Drought Monitoring using satellite and GLDAS data

This practical exercise comprises 2 parts. In part 1 of this exercise, we will study the TWS (terrestrial water storage variations using GRACE and GLDAS data. In the 2nd part of practical, we will assess the spatial and temporal variability of drought in south-west/north/north-east (e.g. Chongqing, Chengdu, Inner Mongolia, and North Plain) China for the time period of 2003-2010 using drought indicators.

Part I: Analysis of terrestrial water storage variations using GRACE and GLDAS instructions

General objectives

This exercise will guide you through the processes of analysis of terrestrial water storage variations from GRACE satellite data and GLDAS model estimates.
- To get familiar with GRACE terrestrial water storage (TWS) products
- To analyze time series TWS anomalies from GRACE.
    - To track and understand the drought and flood event in the large river basin
- To get familiar with GLDAS hydrological variables simulated by Noah land surface model.
- To compute TWS anomalies using GLDAS-based state variables.
- To compute TWS anomalies using GLDAS-based fluxes.
- To compare GRACE TWS anomalies with GLDAS-based results.
- To study the spatial and temporal patterns of TWS variations and understand how these patterns are controlled by the individual hydrological components.
- To understand if these data are suitable for drought monitoring

Data sets

GRACE estimated terrestrial water storage
- Monthly anomalies of equivalent water thickness
- File Format: NetCDF (1 NetCDF file containing 96 bands, one for each monthly anomaly data)
- Spatial coverage: 67.30S to 88.30N and 180W to 180E
- Spatial resolution: 1° x 1° (lat x lon)
- Temporal coverage: January 2003 to December 2010
- Temporal resolution: monthly anomalies
- Undefined value: 32767.0
- Unit: cm
  GRACE data is available at: *http://grace.jpl.nasa.gov/*

GLDAS Noah model data
- Monthly GLDAS/Noah model data.
- File format: NetCDF (96 netCDF files, one for each month)
- Spatial coverage: 60S to 90N and 180W to 180E
- Spatial resolution: 0.25° x 0.25° (lat x lon)
- Temporal coverage: January 2003 to December 2010
- Temporal resolution: monthly average
- Undefined value: -999
- Unit: refer to Table 1 : GLDAS land surface variables used in this exercise

- GLDAS data is available at **http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings**

River basin data
- Large river basins of the world.
- File format: ILWIS polygon map

Tools

- Drought.sav (IDL script), ILWIS 3.8, and Excel

Exercise Steps

Step 0: Obtain data

Copy files needed for the exercises
- Copy the file GRACE_GLDAS.zip to your hard disk and unzip the file to a folder e.g. D:\ TWS_input.
- Two folders named GRACE and GLDAS containing GRACE TWS and GLDAS data respectively

Copy additional ILWIS files for the exercises
- Copy TWS_out.zip to your hard disk and unzip the file to this folder e.g. D:\TWS_out.
- Use this directory as your active working directory when conducting the exercises using ILWIS.
- Always use this directory as output path when working on the provided IDL programs.

Step I: Get familiar with GRACE TWS anomaly products

a) **Process and convert GRACE TWS monthly anomalies into ILWIS**
   - Double click on Drought.sav (IDL script) application, the IDL VM may appear and ask you to click "Continue'
   - In the Drought Monitoring window that appears, select "Import GRACE Data" option and click "OK". Another window called Import GRACE Data will open asking you to specify the directory containing GRACE files and output directory (e.g. D:\TWS_out).
   - Click on OK and wait until the importing process is completed. Click on "OK" button to close the "Information" window.
   - Once the importing is completed, you will now obtain a new ILWIS map list in the catalog named "GRACE_TWS", which contains all the GRACE TWS anomalies for the period 2003 to 2008 in ILWIS.
   - Note that the map list contains 96 images (one image for per month, the GRACE-derived monthly TWS anomalies from 2003 to 2010).

b) **Start ILWIS**
   - Start ILWIS (last version) and navigate to the folder (e.g. D:\TWS_out) where contains the ILWIS maps created before. Always use this folder as your working directory for the whole exercise.

Figure 1: Object collection after import

   - Double-click on the map list file that you have just created, i.e. GRACE_TWS, a window with all the GRACE TWS bands contained in this map list will be opened. As an example, the output looks like in Figure 1. There is one image for each of GRACE derived TWS products for the period between 2003 and 2008. There are 72 maps in total.
   - Note GRACE Products are anomalies (monthly average value – time averaged value over 2003 to 2008) and expressed in cm of equivalent water thickness.
   - Display one image file and move the cursor over the image and check the coordinates displayed at the bottom of the display window.

c) **Assign georeference coordinates**
   - Right click on this map list file. Select the properties and change the georeference into GRACE (provided under working directory).
   - Display the image again and move the cursor over the image and check the coordinates displayed at the bottom of the display window.
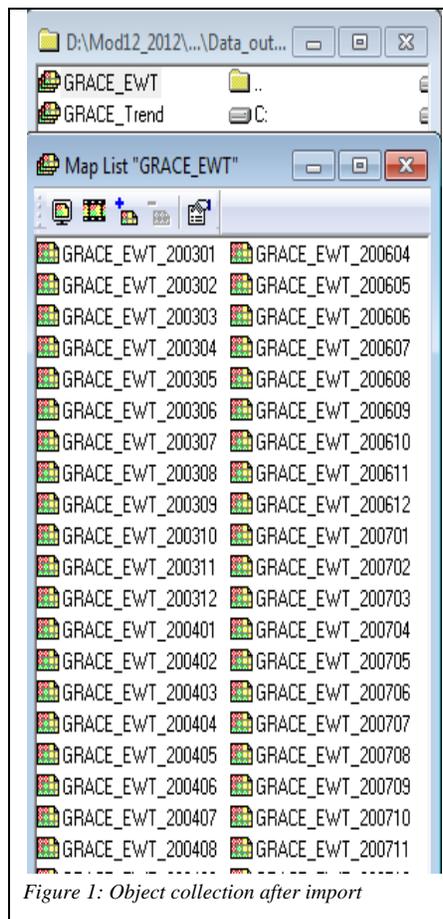
Step 2: Time series analysis of GRACE-derived TWS anomalies

a) **Display time series show and observe the spatial and temporal variations of GRACE derived TWS**

- Right click on the map list containing monthly TWS anomalies (e.g. GRACE_SWT). Select the Open as Animation.
- Click on Run (See the red circles in Figure 2), animation management option will appear, leave the settings as they are and click on Start (See the red circles in Figure 2).
- Observe the spatial-temporal changes of TWS derived from GRACE.
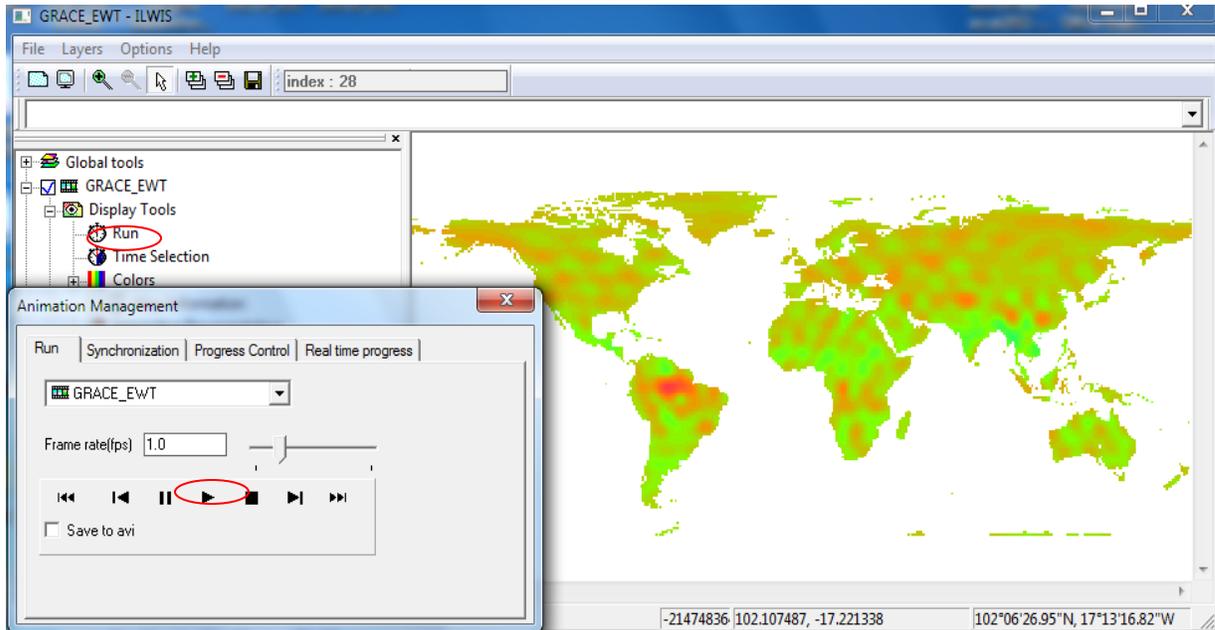
Figure 2: How to display time series show using Animation management tool in ILWIS

- Plot the temporal behavior
  - o Right click on the map list GRACE_TWS, select Statistics menu > MapList Graph.
  - o MapList Graph window will appear (see Figure 31). Select Fix Stretch option and set the value range of Y-axis from -50 to 50.
- Click mouse over the different part of World e.g. Africa, North America, South America and Asia and observe the spatial and temporal variations of GRACE derived TWS products.
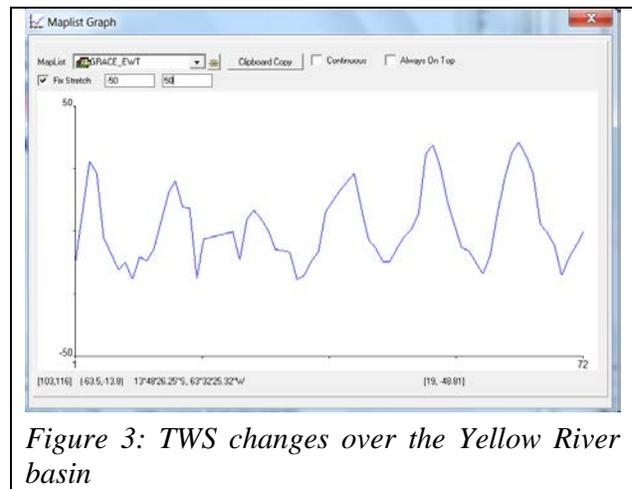
Figure 3: TWS changes over the Yellow River basin

b) **Estimate the linear trend of GRACE TWS anomalies from 2003 to 2008**
You can use the ILWIS Cross section function to compare the TWS temporal behavior in the different areas/pixels:
- Display an image, right click on the Display Tools in the left panel of the display window and select the Cross Section.
- Add the map list in the "Add data source" window that appears.

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- Click on the pixel from the area of interest, you will be able to see the temporal behavior of the selected area/pixel in the Cross section graph window.
- To compare the temporal variations in different area/pixel, Press Control key and click on the area/pixel of interest. Observe the temporal variations in different area in the Cross section graph window.
- In order to have a better show of the temporal changes, use Excel / IDL to plot the graphs.
  - ☞ Right-click on the graph area in the Cross section graph window
  - ☞ Select Open as table and click on "OK" to open the table
  - ☞ Select and copy the columns needed into an Excel file.
  - ☞ Plot the time series and estimate the linear trend using Excel/IDL.

⟹ Do the GRACE-based TWS products show a seasonal trend?

⟹ Is there a variation on the trend when you change the observation area?

⟹ What can you conclude from this trend?

c) **Track TWS deficit across the large river basins from 2003 to 2008**

- To understand the relative contributions from the large river basins to the area, add the river basins vector file:
  - ☞ In the display window, go to Layers menu > Add Layer. Select the river basins file (see Figure 4) and click OK.
  - ☞ Uncheck the Area option (see red circle in Figure 4).
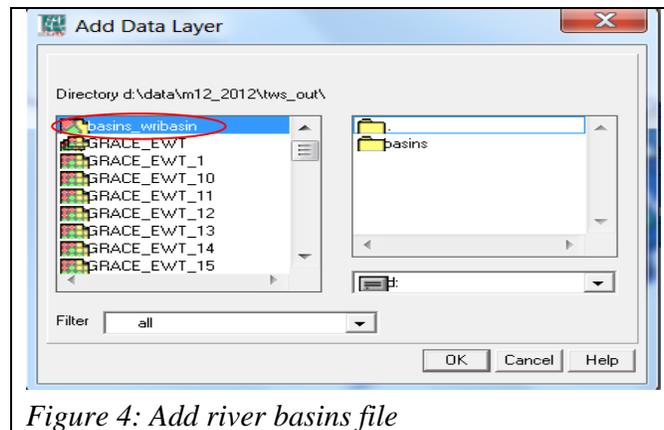
Figure 4: Add river basins file

- Eventually in the display window, click over the large basins of North America, South America, Africa and Asia to observe the temporal changes in the graph window and explain their occurrence. Click on the selected pixel, at the lower left side of the display window (see Figure 5) you will be able to read the pixel value and the selected basin attributes. E.g. name of the basin.
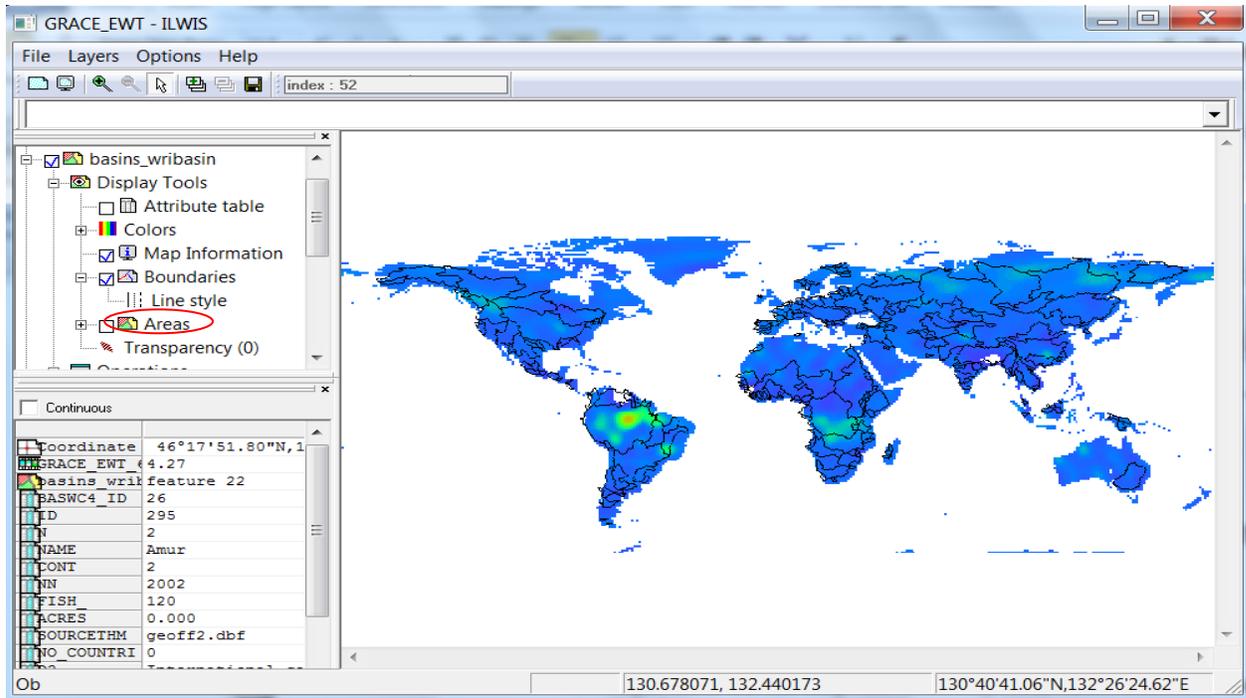
Figure 5: GRACE derived TWS overplayed with large river basins of the world. Moving over the map to see the river basin information displayed in the pixel info window (lower-left window)

- Cut the GRACE TWS to specific region covered by the selected river basin i.e. Yellow River (Huanghe).
  - ➤ Go to Operations > Spatial Reference Options > Raster > Sub Map. The input raster Map is the map list GRACE_TWS, and using the Lines and Columns option. Using the subset as defined in Figure 6 (using as first line and first column respectively 75,99 and having extent of 72 by 54 lines and columns.). Define an output map name (e.g. GRACE_EWT_HH).
  - ➤ Click on show.
  - ➤ After that, you will see the new map list GRACE_EWT_HH in the Catalog, i.e. GRACE_EWT_HH.
  - ➤ Right click on the new map list, select Properties. Check the name of the georeference used by this map list.
  - ➤ Right click on the river basin polygon map 'wribains'. Select Polygon to Raster Map. Specify the Output Raster Map, i.e.HH_basin. Select the Georeference used by the map list created before, i.e. GRACE_EWT_HH_1 and click on Show to display the result.
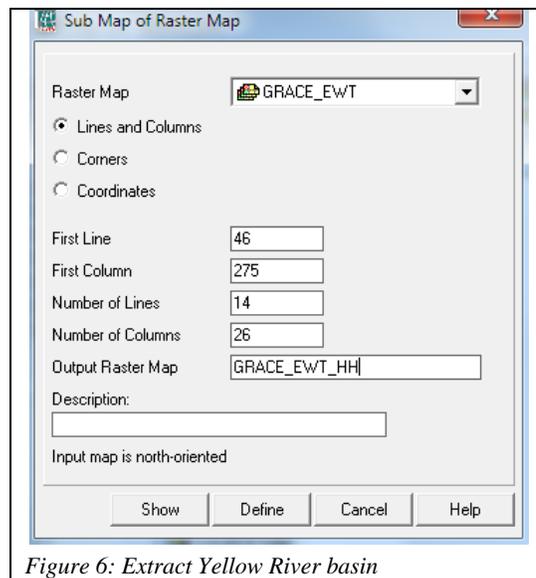
Figure 6: Extract Yellow River basin

- ➢ In the display window, click over the Yellow river basin; Use the curser to see the ID of the basin i.e. "pol 72". Take note of it. Use this map and ID to extract the area covered by the Yellow River basin:
- ➢ Type in the command line
  GRACE_HH_basin.mpl = maplistcalculate(iff(hh_basin="pol 96",@1,?),0, 71,0,GRACE_EWT_HH.mpl)
- ➢ Double click on the new map list *GRACE_HH_basin.mpl* to display the results.

- Create an attribute table containing a column with mean value for each map in the map list, i.e. *GRACE_HH_basin.mpl*

  - ➢ Go to Operations > Table Operations > Attribute column from map
  - ➢ Specify as Input *GRACE_HH_basin*, Average for method. Insert appropriate output table name, i.e. HH_basin_avg (see figure 7) and display the results.
  - ➢ Open the property window of the map list (e.g. GRACE_HH_Basin). Select HH_basin_ avg just created as Attribute table.
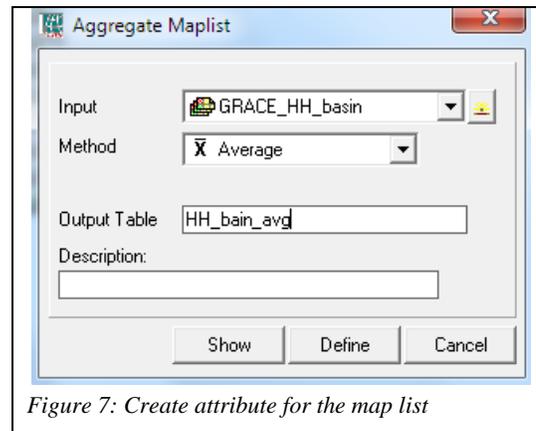
Figure 7: Create attribute for the map list

- Track the TWS deficit over the Yellow River basin for the period 2003 to 2010
  - ➢ Right click on map list i.e. *GRACE_HH_Basin.mpl,* double click on "Run" to start the animation management option. In the progress control tab, you see a graph (blue curves) representing the monthly average TWS anomalies of the Yellow River basin for the 2003 to 2010 period (in this case, 96 maps) and a time marker moving over those maps.
  - ➢ During an animation the image is constantly changing to track the area using a user-defined threshold that gives an indication where the area passes the threshold (on the map given as red pixels, see figure 8)
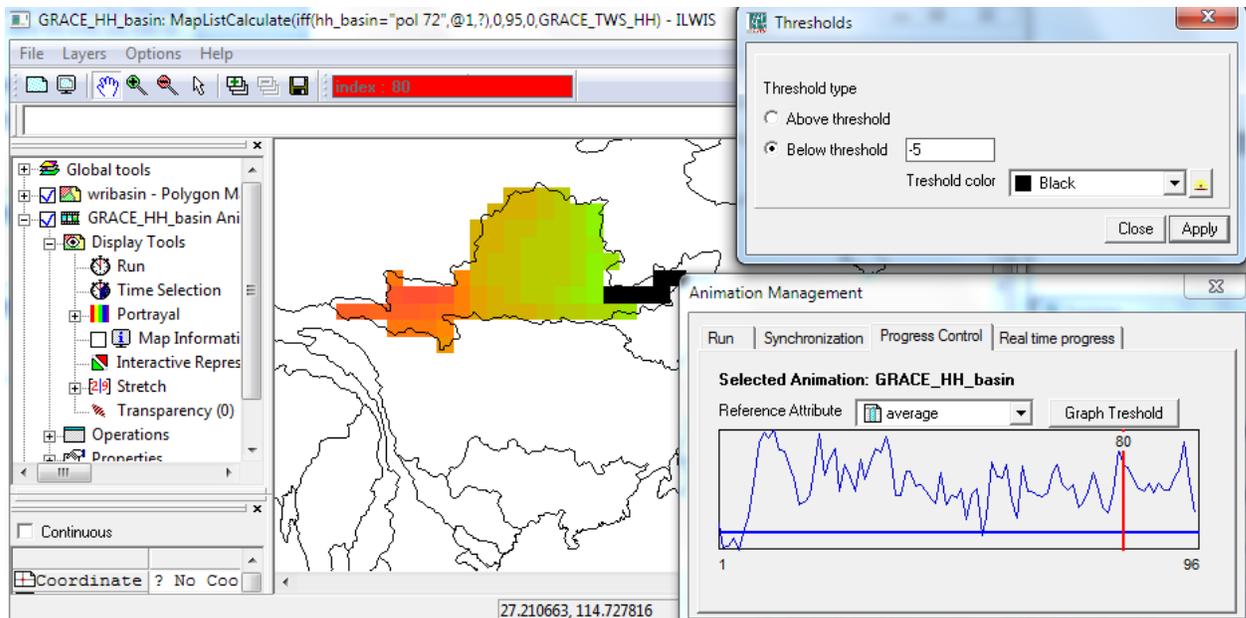
Figure 8: The graph shows the averaged TWS change of 96 maps in the yellow river area. The threshold option gives an indication where the TWS changes of a map pass the threshold.

- ➢ In order to perform the tracking of the TWS deficit for the period 2003 to 2010, you need to define a drought threshold.
- ➢ To do so, click Graph Threshold to open the Threshold option. Select "Below threshold" and insert the drought threshold. Select threshold color and click "Apply" (see Figure 8, the upper left window)
- ➢ Observe the areas change during animation and identify the TWS decrease in the Yellow River basin for the period 2003 to 2010.

⟹   Do the GRACE observations show a significant seasonal variability in the Yellow River basin?

⟹   In which periods do GRACE products show a strong TWS deficit in the Yellow River basin?

⟹   Track the flood area in the yellow river basin for the period 2003-2010 using GRACE TWS change observations.

Figure 9: GRACE averaged water storage change (in centimeters of water) in the Yellow River basin for July, August, September, October, November and December in 2005. Drought threshold -30 is applied. The values in a map during an animation exceeding the threshold are displayed in black, which provide a good measure of abnormal climate conditions, in this case, drought.
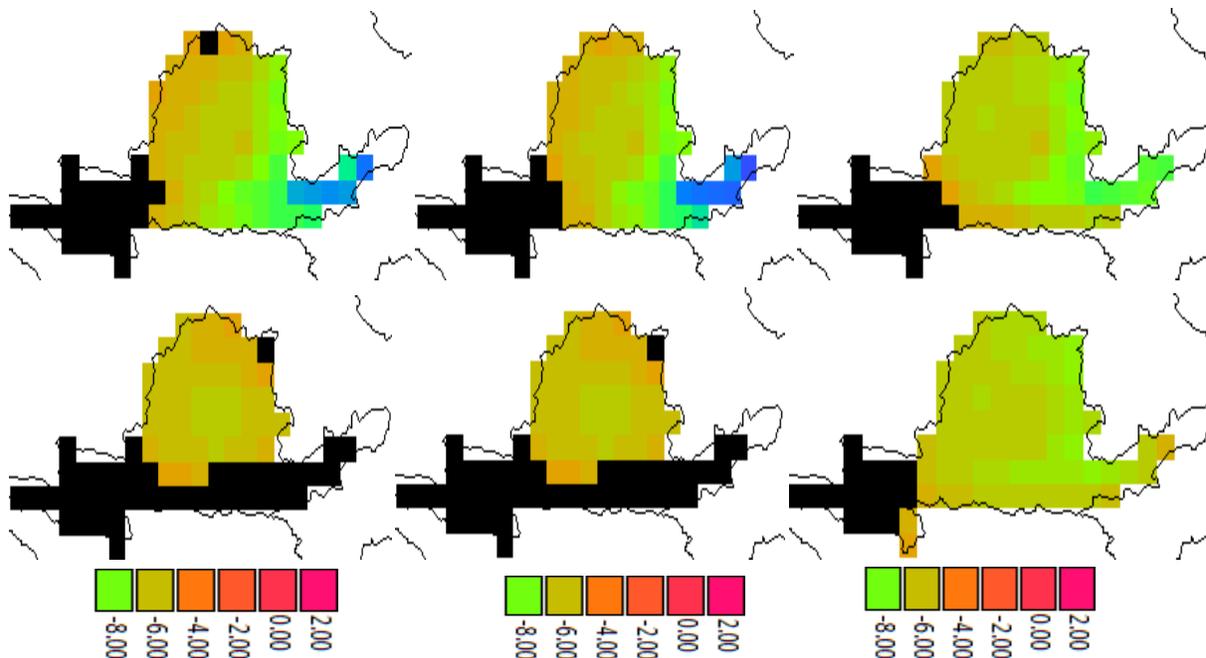
Figure 9: GRACE averaged water storage change (in centimeters of water) in the Yellow River basin for April, May, June, July, August and September in 2010. Drought threshold -10 is applied. The values in a map during an animation exceeding the threshold are displayed in black, which provide a good measure of abnormal climate conditions, in this case, drought.

Step 3: Get familiar with GLDAS/Noah model estimates

a) Process and convert GLDAS land surface states and fluxes into ILWIS

- In this exercise, we extract the GLDAS state and flux variables (see table 1 below) simulated by Noah land model. The goal is to study the capability of GLDAS to observe TWS changes in the large river basins.

GLDAS Variables	From Units	TR	SR	To units
Soil moisture of 4 layer (with 2 m column depth) (SM)	kg/m^2	Monthly average	0.25°*0.25°	cm
Snow water equivalent (SWE)	kg/m^2	Monthly average	0.25°*0.25°	cm
Canopy water storage (CWS)	kg/m^2	Monthly average	0.25°*0.25°	cm
Precipitation (P)	kg/m^2/s	Monthly sum	0.25°*0.25°	cm
Evapotranspiration (ET)	kg/m^2/s	Monthly sum	0.25°*0.25°	cm
Runoff (R)	kg/m^2/s	Monthly sum	0.25°*0.25°	cm

Table 1: GLDAS variables used in this exercise; SR: spatial resolution. TR: temporal resolution
Note:
1). Total precipitation will be the sum of rainfall and snowfall.
2). Total runoff will be the sum of subsurface runoff and surface runoff.
3) Monthly average files contain straight averages of 3-hourly data, so that each monthly average has units PER 3 HOURS. For example, to compute total evapotranspiration (ET) use this formula:
*Total monthly ET (April) = evapsfc (April) * 10800 {sec/3hr} * 8{3hr/day}* 30{days}*

4) The depths of the four soil layers are 0-10 cm, 10-40 cm, 40-100 cm, and 100-200 cm.
5) GLDAS results used here are for the same period from 2003 to 2008 as the GRACE TWS anomalies.

- To convert the GLDAS variables to ILWIS using the provided IDL script Drought.sav
- Double click on Drought application, the IDL VM may appear and ask you to click "Continue'
- In the Drought Monitoring window that appears, select "Import GLDAS variable" option and click "OK". Another window called Import GLDAS Variables will open asking you to specify the directory containing GLDAS files, output folder (e.g. D:\TWS_out).
- Select "Soil Moisture" option and click "OK"
- Wait until the conversion is completed and then another window (information window) will open. Click on "OK" button in this window.
- After this step, you will now obtain a new ILWIS map list in the catalog named "GLDAS_SM", which contains soil moisture maps for the period 2003 to 2010 in ILWIS. (See figure 10).
- Note that the map list contains 96 images (one image for per month, the GLDAS-derived monthly soil moisture values from 2003 to 2010).

- Repeating step 3 a) to import "SWE" and "CWS" variables.
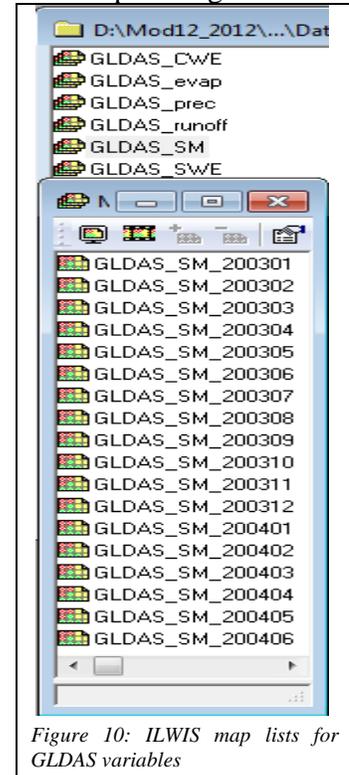
Figure 10: ILWIS map lists for GLDAS variables

b) ILWIS part
- Check the results just created (under step 3a). Check at least one image file at each map list to understand the value ranges, image size, spatial resolution. Display the image and move the cursor over the image and check the coordinates at the corners.
- Assign georeference coordinates
    - Right click on SM map list file, e.g. GLDAS_SM. Select the properties and change the georeference into GLDAS (provided under the working directory).
    - Display the image and move the cursor over the image and check the coordinates displayed at the bottom of the display window.
    - Repeat the procedure to other map lists. (e.g. GLDAS_CWS, GLDAS_SWE) and check the results.
- Convert the units of CWS in mm into centimeter
    - For this study, all units are in cm. The units of CWS are in mm, converted into cm. In ILWIS main window, select from the ILWIS main Operations > Raster Operations > MapList Calculation. The input MapList is GLDAS CWS e.g. GLDAS_CWS just created before (under step 4 –a)
    - Type the expression and use the settings as shown in figure 11.
    - Perform the calculation and check the results.
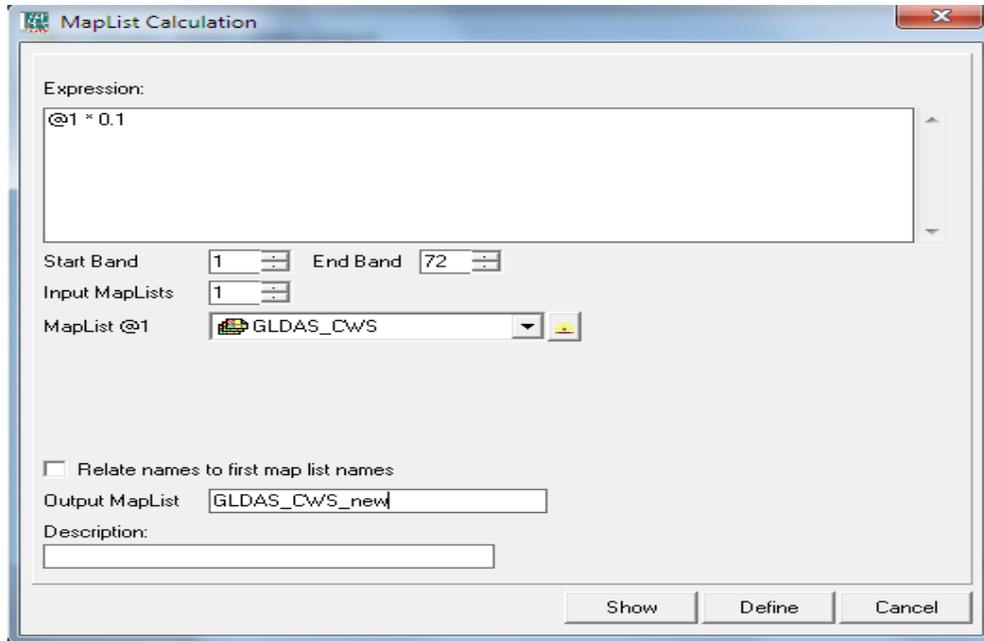
Figure 11: MapList calculation function in ILWIS to convert CWS into centimeters

c) **Plot a time series and understand the temporal patterns and variations of GLDAS variables**
   - Display an image in the map list. e.g. gldas_sm
   - Go to Operations > Statistics menu > MapList Graph. Select a maplist e.g. GLDAS_SM. Assign proper graph stretching values.
   - Click over the different areas of the World e.g. Africa, North America, South America and Asia and observe the temporal variations of the GLDAS variable e.g. GLDAS_SM
   - Repeat the procedure for other 5 map lists (see figure 12)
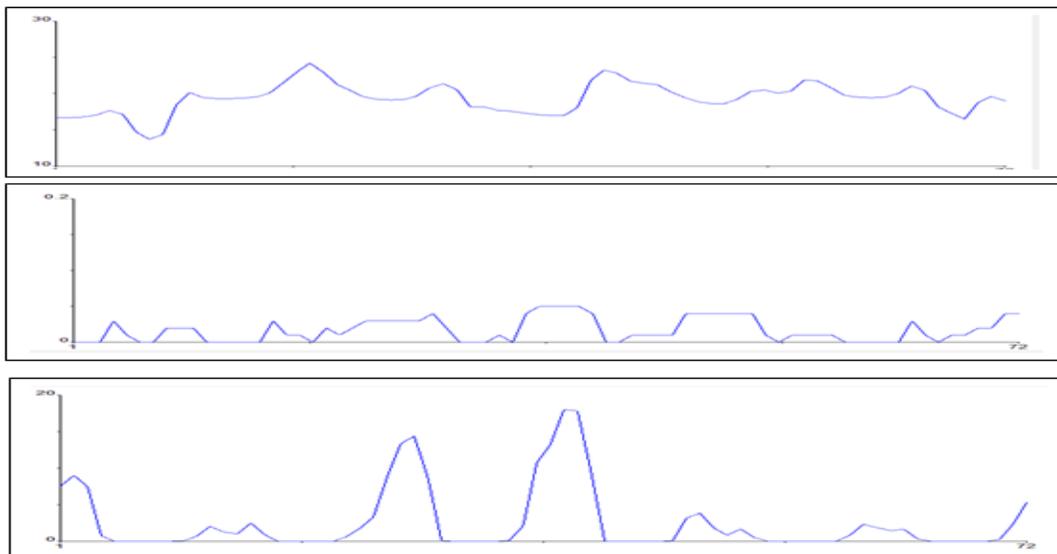
Figure 12: GLDAS SM (upper panel), CWS (middle panel) and SWE (lower panel) variables (in centimeters of water) in Amur basin (53° 43' 07.50" N, 139° 47' 50.51" E).

d) Resample 0.25° x 0.25° GLDAS variables to the size and resolution of GRACE data (1° x 1°)
- For comparison with GRACE later on in the exercise, transform GLDAS model outputs in 0.25 deg to 1 deg X 1deg gridded data. To do so, right click on the GLDAS_SM map list that you have created before.
- Go to Spatial Reference Operations > Resample. The input map is GLDAS_SM and the output map is GLDAS_SM_re. Use a nearest neighbor resampling! Use as GeoReference GRACE!
- Perform the resample and display the results. Check the coordinates; especially those of the corners of the map (should have the same coordinates as GRACE data).

e) Repeat the procedure (under Step 3-d) for other GLDAS variables that you have created before (e.g. GLDAS_CWS, GLDAS_SWE,), and check the results.

Step 4: Compute TWS anomalies from GLDAS

a) Compute the time series mean value averaged over the period 2003-2007.

- Right click on the resample map list e.g. GLDAS_SM
- Go to Raster Operations > Aggregate MapList. The input map list is GLDAS_SM_re and the output map is GLDAS_SM_mean. Use Average method!
- Perform the aggregate map list calculation and display the newly calculated map and check the map values.

Figure13:Compute the mean of the maps in a map list

- Repeat the above procedure (under step 4-a) to other resampled GLDAS variables. (i.e. GLDAS_swe_re, GLDAS_cws_re,).

b) Generate anomalies of GLDAS-derived maps (deviations from the time mean)
- To perform the anomaly calculation, select from the ILWIS main Operations > Raster Operations > MapList Calculation. The input MapList is the resampled GLDAS variables (e.g. GLDAS_SM_re) just created before (under step 4 –a)
- Type the expression and use the settings as shown in figure 14.
- Perform the calculation and check the results.
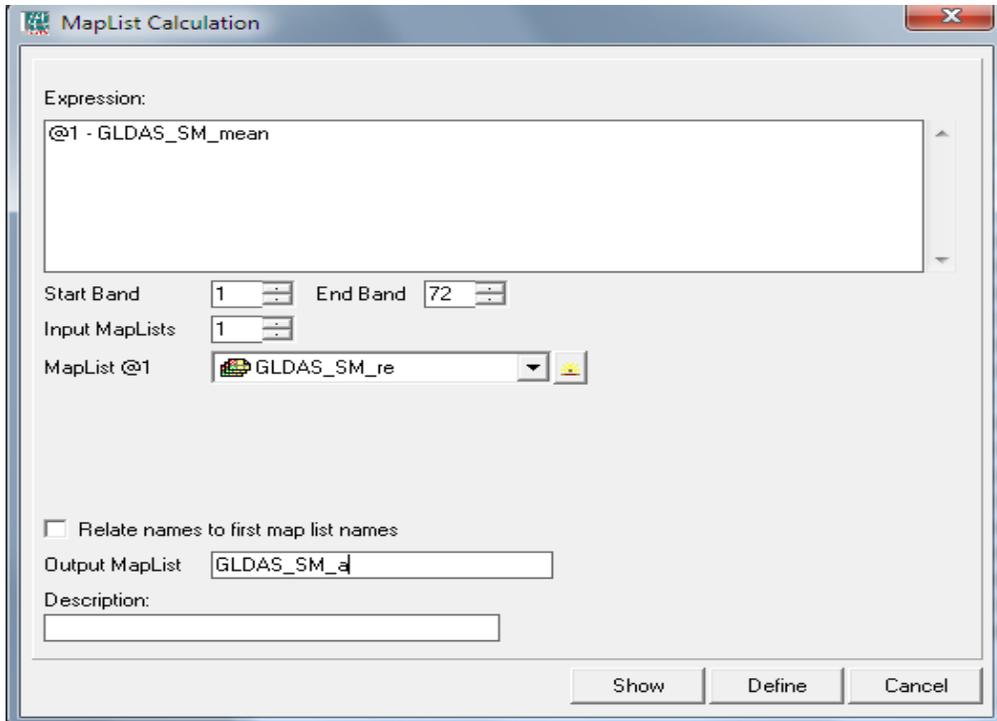
Figure 14: MapList calculation function in ILWIS to calculate the GLDAS SM anomalies

- Repeat the above procedure (under step 4-b) to other GLDAS land surface variables (e.g. SWE, CWS)
- Note that in the MapList Calculation window, replace the time mean value with e.g. GLDAS_SWE_mean, GLDAS_CWS_mean that you have created under step 4-a respectively.
- After this step, the following maps should be created (see table 2 below):

GLDAS Variables	Time series mean	Anomalies	SP	unit
Soil moisture (with 2 m column depth) (SM)	GLDAS_SM_mean	GLDAS_SM_a	1° x 1°	Cm
Snow water equivalent (SWE)	GLDAS_SWE_mean	GLDAS_SWE_a	1° x 1°	Cm
Canopy water storage (CWS)	GLDAS_CWS_mean	GLDAS_CWS_a	1° x 1°	Cm

Table 2: list of map lists containing anomalies of GLDAS land surface variables

c) **Mask out the large SWE in Greenland and a few other area**
- Display GLDAS_SWE_a. Move curser over Greenland and check the values.
  ➢ Do you see abnormally large SWE anomalies?
- Mask out the large SWE in Greenland and a few other areas
  ➢ To perform the masking, go to Operations > Raster Operations > MapList Calculation
  ➢ Type the expression and use the settings as shown in figure 15.
  ➢ Perform the calculation and check the results especially over Greenland.
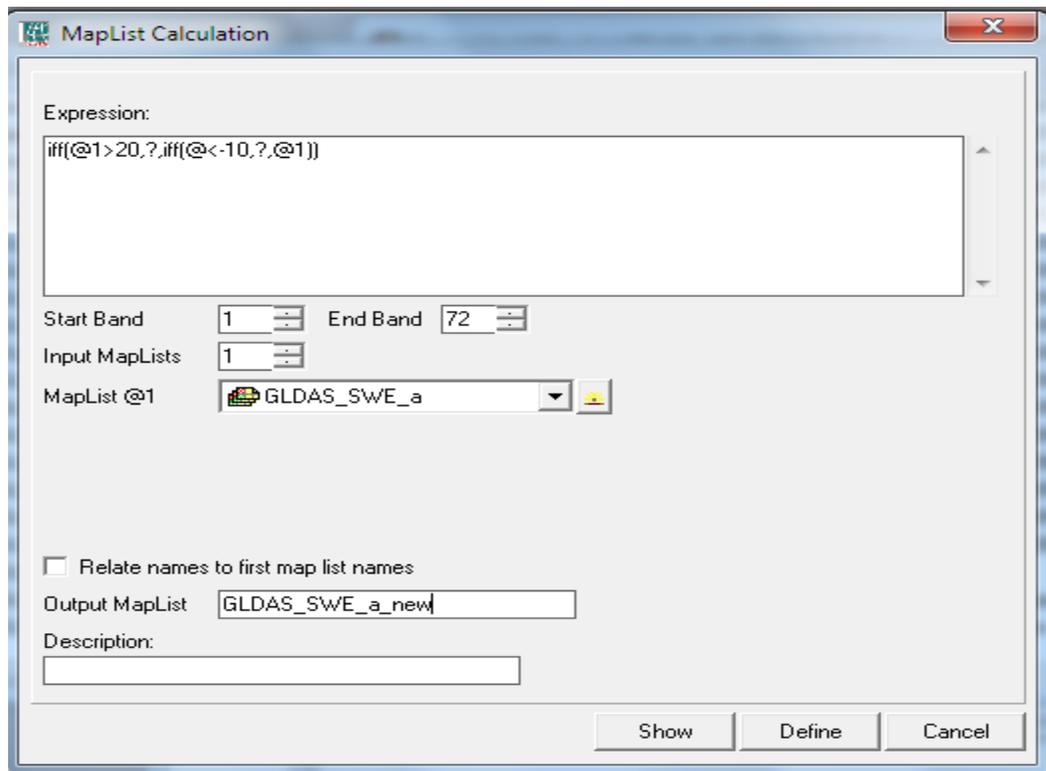
Figure 15: Mask out the abnormally large SWE values

d) Compute TWS anomalies using GLDAS state variables

In this exercise the land surface states from GLDAS obtained will be used to estimate the TWS anomalies. The following equation (1), estimates of TWS anomalies from GLDAS is applied.

TWSC(t) = SMC(t)+SWEC(t)+CWSC(t)   (1)

The terms on the right side are monthly soil moisture anomalies (SMC), monthly snow water equivalent anomalies (SWEC) and monthly canopy water storage anomalies (CWSC) respectively. t is time.

TWSC Terrestrial water storage anomaly considered here is the sum of soil moisture anomaly in all layers (SM), snow water equivalent anomaly, and plant canopy surface water storage anomaly. Note that ground water storage is not represented in the GLDAS model simulation and hence can be a source of error in this estimation.

- To perform the TWSC from GLDAS states anomalies, go to Operations > Raster Operations > MapList Calculation
- To perform the TWS anomalies from GLDAS states, select from the ILWIS main Operations > Raster Operations > MapList Calculation
- Type the expression and use the settings as shown in figure 16.
- Perform the calculation and check the results.
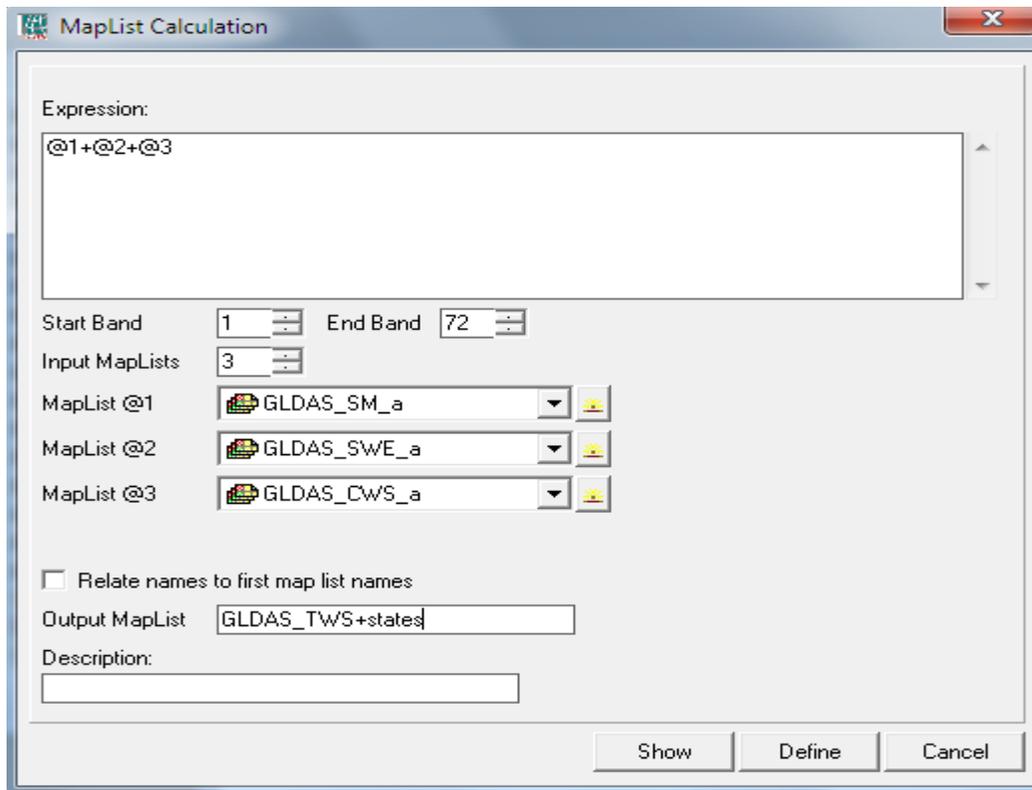
Figure 16: Calculate TWS anomalies from GLDAS states anomalies

e) Compute TWS anomalies using GLDAS fluxes

- Repeat step 2 a) reading GLDAS fluxes: Precipitation, evapotranspiration, and runoff

- Repeat the steps from step 3 b) to step 4 b) for GLDAS fluxes (precipitation, evapotranspiration, and runoff)

- Use the water balance equation below to compute the TWS anomalies

TWSC(t) = P(t) – ET(t) – R(t)   (2)

Where, P is rainfall and R is runoff and ET is evapotranspiration, and t is time. TWSC is the change of water storage in a vertical column expressed in centimeters of water.

- After that, the following map lists should be created (see table below)

GLDAS Variables	Time series mean	Anomalies	SP	unit
Precipitation (the sum of the rainfall and snowfall) (P)	GLDAS_P_mean	GLDAS_P_a	1° x 1°	Cm
Evapotranspiration (ET)	GLDAS_E_mean	GLDAS_ET_a	1° x 1°	Cm
Runoff (the sum of	GLDAS_R_mean	GLDAS_R_a	1° x 1°	Cm

subsurface runoff and surface runoff) (R)				

Table 3: list of map lists containing anomalies of GLDAS flux variables

Step 5: Time series analysis of GLDAS derived TWS anomalies

- Repeat step 2: analysis of time series anomalies of TWS, state and flux components from GLDAS
- Plot time series anomalies of TWS from equation 1, and states of SM, SWE and, CWS from GLDAS
- Plot time series anomalies of TWS from equation 2, and fluxes of P, ET, R from GLDAS
- Understand the GLDAS-based flux and state components contributing to TWS variations for the selected river basin and explain the reasons.

Step 6: Compare GRACE-derived TWS anomalies with those from GLDAS

- Compare spatial distribution of TWS anomalies from GRACE and GLDAS
- Compare temporal behavior of TWS anomalies from GRACE and GLDAS
  - Plot the time series of TWSC of GRACE and GLDAS for a selected pixel and compare them
- Plot time series TWS anomalies from GRACE and GLDAS of the large river basins
- Estimate the linear anomaly trends of TWS from 2003 to 2008
- Compare TWSC trends
- Compare seasonal estimates from GRACE to those from GLDAS
- Plots of seasonal TWS change estimates
- Compare spatial distribution of seasonally averaged anomalies of TWS in the selected river basin.

Step 7: Calculate ground water anomalies using GRACE and GLDAS output fields

- We will apply the following equation to estimate the ground water storage change GWC.

GWC(t) = TWSC(t) - (SMC(t) + SWEC(t))   (3)

Where:
TWSC: Total water storage anomalies derived from GRACE.
SMC: Soil moisture anomalies taken from GLDAS output field.
SWEC: Monthly snow water equivalent anomalies taken from GLDAS.
t is time
GWC: Ground water anomalies
  - ☞ Compute ground water anomalies for the period 2003 to 2008
  - ☞ Observe the obtained time series spatial and temporal patterns over selected river basin.

- Plot the time series ground water anomalies and study the trends.

Part II: Drought monitoring using remote-sensing and GLDAS data

General objectives

In this exercise, we will assess the spatial and temporal variability of drought in south-west/north/north-east China (e.g. Chongqing, Chengdu, Inner Mongolia, and North Plain) for the time period from 2003 to 2010 using drought indicators derived from satellite and GLDAS data. For this you need to perform the following tasks:

- calculate the drought indices:
  - Rainfall anomaly index (RAI)
  - Cumulative precipitation anomaly (CPA)
  - Standardized precipitation index (SPI)
  - Soil moisture anomaly SMA
  - Soil moisture deficit index (SMDI)
  - Standardized soil moisture index (SSMI)
- Identify the drought occurrence in the given region
  - Spatial analysis in GIS environment
  - Temporal behavior by time series plots
- Assess and compare the monitoring capabilities among the drought indices calculated.

Study area

- South-west/north/north-east China (e.g. Chongqing, Chengdu, Inner Mongolia, and North Plain).

Data sets

TRMM precipitation data
- File format: NetCDF (96 netCDF files, one for each month)
- Spatial coverage: 50S to 50N and 180W to 180E
- Spatial resolution: 0.25° x 0.25° (lat x lon) grid
- Temporal coverage: January 2003 to December 2010
- Temporal resolution: monthly data
- Undefined value: -9999.900390625
- Unit: mm/hour (hourly rain rate)

GLDAS/Noah model outputs
- File format: NetCDF (96 netCDF files, one for each month)
- Spatial coverage: 60S to 90N and 180W to 180E
- Spatial resolution: 0.25° x 0.25° (lat x lon)
- Temporal coverage: January 2003 to December 2010
- Temporal resolution: monthly average

Tools

- Drought.sav (IDL script), ILWIS 3.8, and Excel

Exercise Steps

Step 1: Calculate drought indices

a) Rainfall Anomaly Index (RAI)

1) Double click on Drought application, the IDL VM may appear and ask you to click "Continue'
2) In the Drought Monitoring window that appears, select "Drought Indices" option and click "OK". Another window called Calculate Drought Indices will open asking you to specify the directory containing TRMM monthly precipitation images, on a 0.25 degrees lat-lon grid, in NetCDF for the period from 2003 to 2010, output folder (use the same folder used in the previous exercises).
3) Select Rainfall anomaly Index option and click "OK"
4) Wait for the calculation to take a short time and then another window (information) will open. Click on "OK" button in this window.
5) After this step, you will now obtain an ILWIS map list "RAI", which contains RAI for the period 2003 to 2010 in ILWIS.
6) Note that the map list contains 96 images (one image per month, the TRMM-derived monthly RAI from 2003 to 2010).
7) RAI (Δy) is created by subtracting a climatological mean from observed monthly rainfall data.

$$\Delta y = y(t) - u$$

u = a climatological mean over a long-period
y = a given variable (t = a specific period, month in this case)
Climatology mean is defined as the long-term average of a given variable, often over time   periods longer than 30 years.
A monthly climatology mean, for example will produce a mean value for each month and a daily climatology will produce a mean value for each day, over a specified time-period.

b) Calculate standardized precipitation index (SPI)

Repeat above steps for SPI.
SPI is defined by :

$$SPI = \Delta P_{ijk} / P(std)$$

Where: P(std) = standard deviation of long term precipitation for pixel i in month j (climatology standard deviation)

$$\Delta P_{ijk} = P_{ijk} - P(mean)_{ij}$$

P_{ijk} = monthly precipitation for pixel I in month j for year k
$P(mean)_{ij}$ = multiyear average precipitation for pixel I in month j

- Long lasted negative rainfall anomaly leads to severe drought.
- Short-term shortage of precipitation is not necessary to result in drought.

c) Cumulative precipitation anomaly (CPA)

Repeat above steps for CPA.
CPA is calculated:

$$\Delta P_{acc} = \sum(P_j - P_j(mean)) \quad (j = \text{a specific period, week, month, year, etc })$$

d) Calculate soil moisture deficit index (SMDI)

Repeat above steps for SMDI
Note to Specify the input directory containing GLDAS data

SMDI$_j$ = 0.5SMDIj-1 + SD$_j$/50 (Narasimhan and Srinivasan, 2005)
Where:
SD$_{i,j}$= (SW$_{i,j}$ – MSW$_j$)/(MSW$_j$ – minSW$_j$)   if SW$_{i,j}$ = MSW$_j$
SD$_{i,j}$ = (SW$_{i,j}$ – MSW$_j$)/(maxSW$_j$ – SW$_j$)   if SW$_{i,j}$ > MSW$_j$
SMDI$_1$ = SD$_1$/50 for initial month
SMDI j = monthly SMDI in a pixel in month j
SD$_{i,j}$ = monthly soil deficit in pixel I for month j
SW$_{i,j}$ = monthly soil moisture in pixel I for month j
MSWj= multiyear median available soil water in a pixel for month j
 maxSW$_j$= multiyear maximum available soil water in a pixel for month j
 minSW$_j$ = multiyear minimum available soil water in a pixel for month j

e) **Calculate soil moisture anomaly (SMA)**
   Repeat above steps for SMA
   Note that Specify the input directory containing GLDAS data

f) **Calculate standard soil moisture index (SSMI)**
   Repeat above steps for SSMI
   Note that Specify the input directory containing GLDAS data

Step 2: Start ILWIS

a) Start ILWIS3.8 and navigate to the folder (e.g. D:\Exe_out) where contains the drought Index "products" that you have created in Step 1. Always use this folder as your working directory for the whole exercise.
b) Assign georeference coordinates to the map lists created in step 1. Use georeference "China" for GLDAS derived drought index products and TRMM_China for TRMM derived drought products.

Step 3: Assess and compare the monitoring capabilities of the calculated drought indices

a) Open as Animation to:

$\Longrightarrow$ observe the spatial and temporal variations of RAI,SPI,CPA, SMA,SMDI and SSMI in different part of China;

$\Longrightarrow$ Determine the spatial extent of drought;

$\Longrightarrow$ Identify the driest and wettest areas from the different drought index products.

b) Use Cross section graph to:

$\Longrightarrow$ plot a time series drought index product;

$\Longrightarrow$ Compare two different drought indicators for the specific pixels of your choice (in south-west/north/north-east China, e.g. Chongqing, Chengdu, Inner Mongolia, and North Plain).

c) For the students who like to do more

$\Rightarrow$ Copy all information in to an Excel file to:

$\Rightarrow$ Plot the drought index values of two drought indicators;

$\Rightarrow$ Plot the linear trend and correlate between;

$\Rightarrow$ Calculate drought class maps