Introduction to Land Data Assimilation Systems (LDASs)

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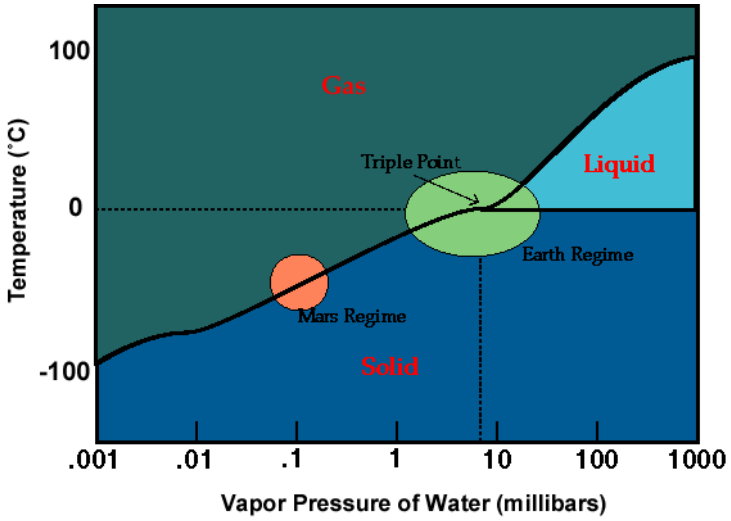
http://lis.gsfc.nasa.gov

The Hydrologic/Water Cycle

- The endless movement of water between the land, oceans and atmosphere
- Water moves across different reservoirs (ocean, rivers, atmosphere) through the physical processes of evaporation, condensation, precipitation, infiltration, runoff and subsurface flow
- Water goes through different phases during various stages of the water cycle
- Each phase change involves exchange of energy (and temperature changes)
  - Evaporation – takes up energy, cools the environment
  - Condensation – releases energy, warms the environment



Importance of Hydrology

- Fresh Water Resources and Availability
- Climate Change
- Agricultural planning
- Drought assessment
- Weather forecasting
- Water quality
- Food security
- Air quality
- Military applications









Key processes of the water cycle

Transformation of water from liquid to gas phase

Transpiration: water taken up by the plants released to the atmosphere

Difficult to separate the processes of evaporation and transpiration; often called evapotranspiration

Water escapes through the stomata (small pores on the leaves). Plants regulate the rate of transpiration by controlling the size of stomata

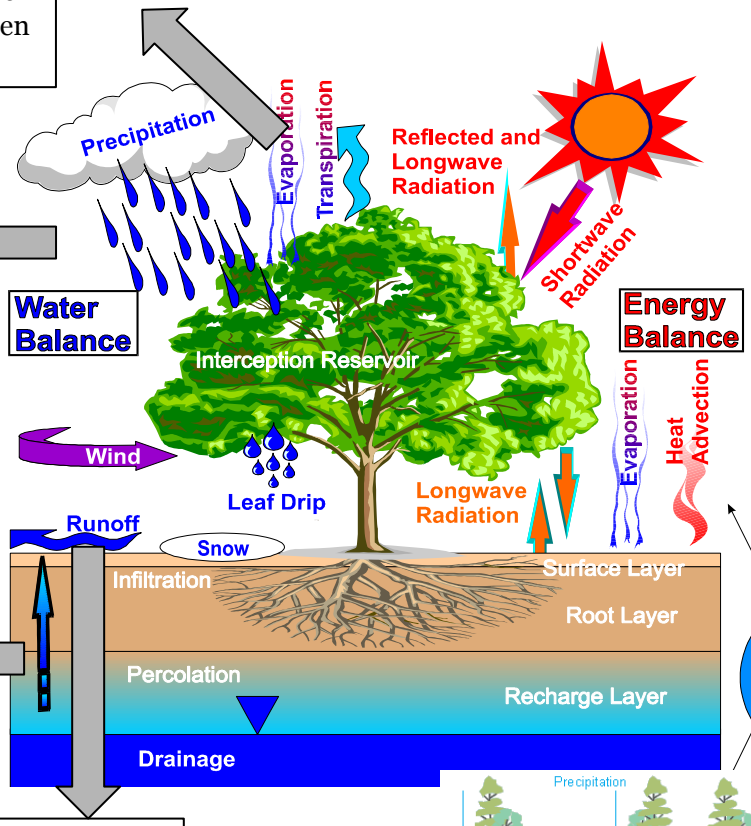
Under water stress conditions, plants would close the stomata to conserve energy

Soil moisture: Variable representing reservoir of water on land; controls the exchanges of water and energy between the land and atmosphere; affects evapotranspiration, runoff, infiltration.

Soil moisture levels are related to water resource applications; plant growth, water stress, droughts, floods

Different forms of precipitation: Rain, snow, hail, fog, drip, graupel, sleet

Many of the water related problems are related to the fact that precipitation is not evenly distributed in space and time



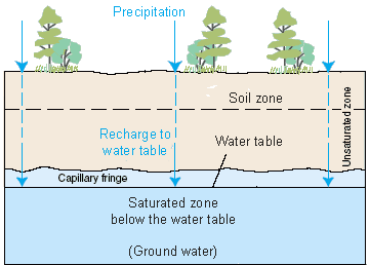
Snow: Another variable representing reservoir of water on land; intimately affects runoff, infiltration.

In many mid-latitude and high-altitude regions, the seasonal water storage and associated spring melt dominate the local hydrology.

Infiltration: Some of the precipitation on land seeps into the ground to be stored in aquifers, transported to lakes and streams through subsurface flow

Groundwater/aquifer: water stored in the saturated zone. The top of the aquifer is called water table

Groundwater accounts for almost 33% of total water withdrawals worldwide; Key as a strategic reserve in times of drought; often ignored in management decisions.



Runoff: Water that does not infiltrate the soil runs off across the surface into streams, rivers, lakes.

Runoff and infiltration contribute to natural hazards such as floods

NASA

Challenges of water cycle monitoring

Technique	Advantages	Disadvantages
In-situ measurements	“Real” data	Labor intensive; quality control issues; spatial interpolation
Remote sensing	Spatial coverage	Resolution; Sensing limitations; retrieval errors
Numerical model	Choose any region or time period; Economical	Quality limited by input; difficulty representing complex processes

Land Surface Observations: in-situ

Precipitation: Surface Gages and Doppler Radar

Radiation: DOE-ARM, Mesonets, USDA-ARS

Surface Temperature: DOE-ARM, Mesonets, NWS-ASOS,

Soil Moisture: DOE-ARM, Mesonets, Global Soil Moisture Data Bank, USDA-ARS

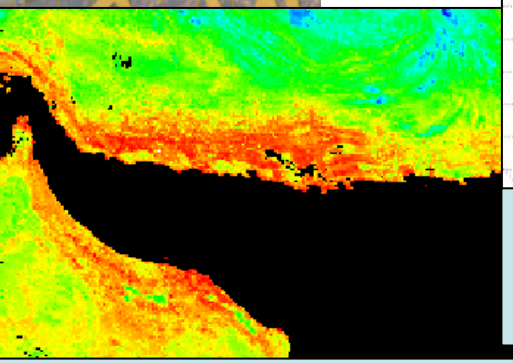
Groundwater: Well Observations

Snow Cover, Depth & Water: Field Experiments, SNOTEL

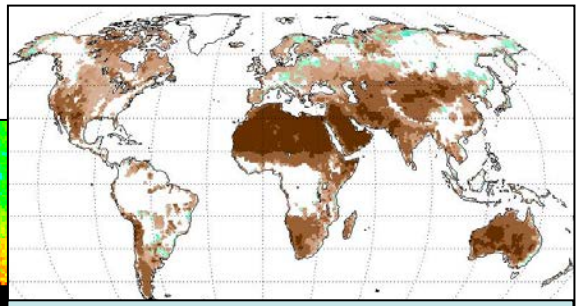
Streamflow: Real-Time Stream Gauge

Vegetation: Field Experiments

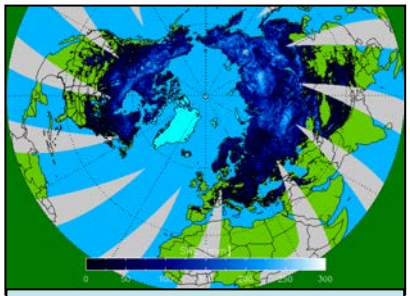
Soils: Field Experiments



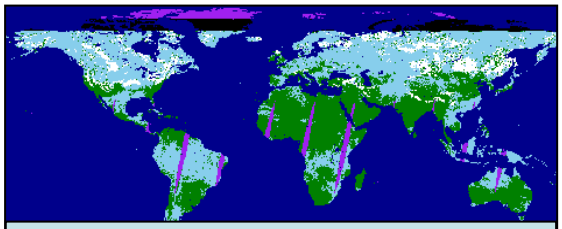
Land surface temperature
(MODIS, AVHRR,GOES,...)



Surface soil moisture
(SMMR, TRMM, AMSR-E,
SMOS, Aquarius, SMAP)

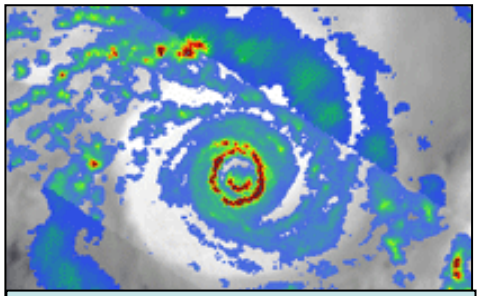


Snow water equivalent
(AMSR-E, SSM/I,
SCLP)

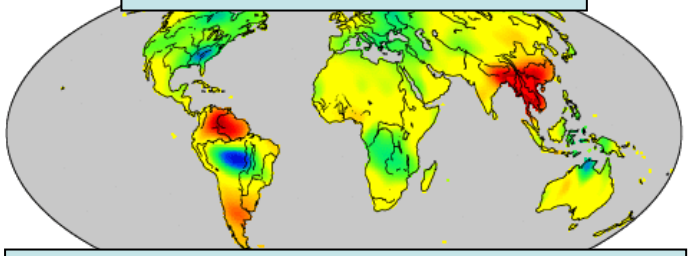


Snow cover fraction
(MODIS, *VIIRS, MIS*)

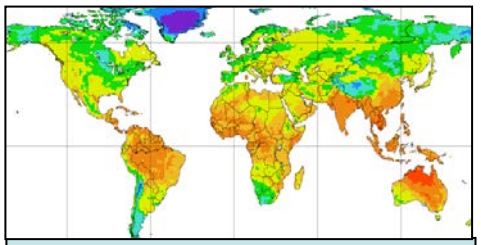
Water surface elevation
(*SWOT*)



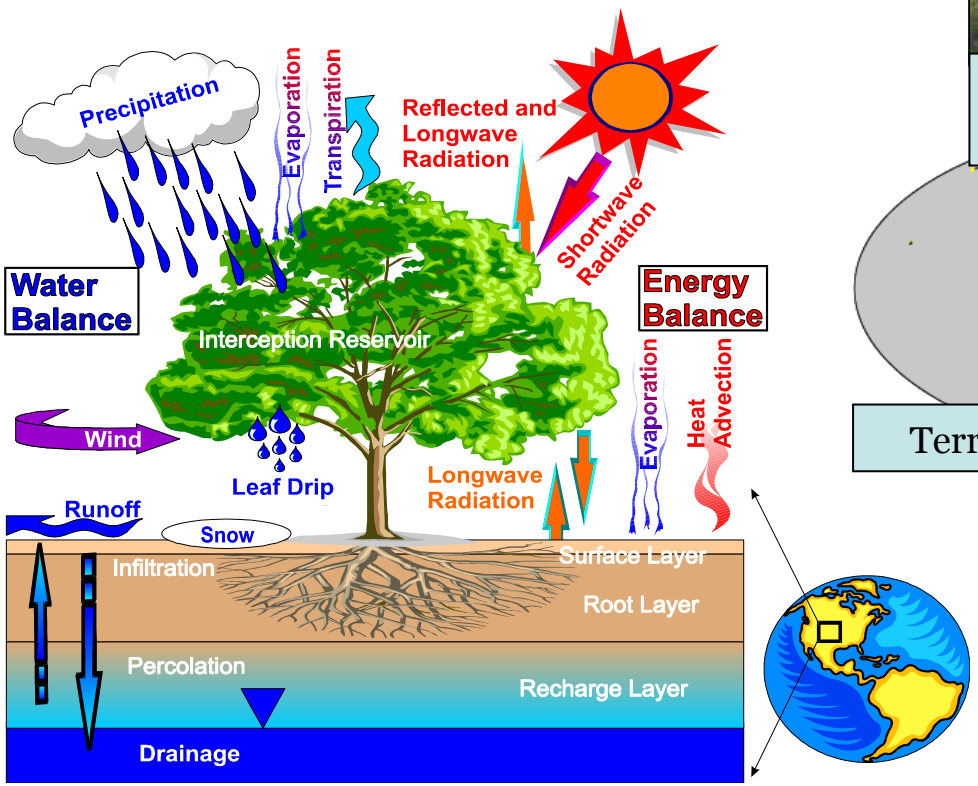
Precipitation
(TRMM, *GPM*)



Terrestrial water storage (GRACE)



Radiation
(CERES, *CLARREO*)

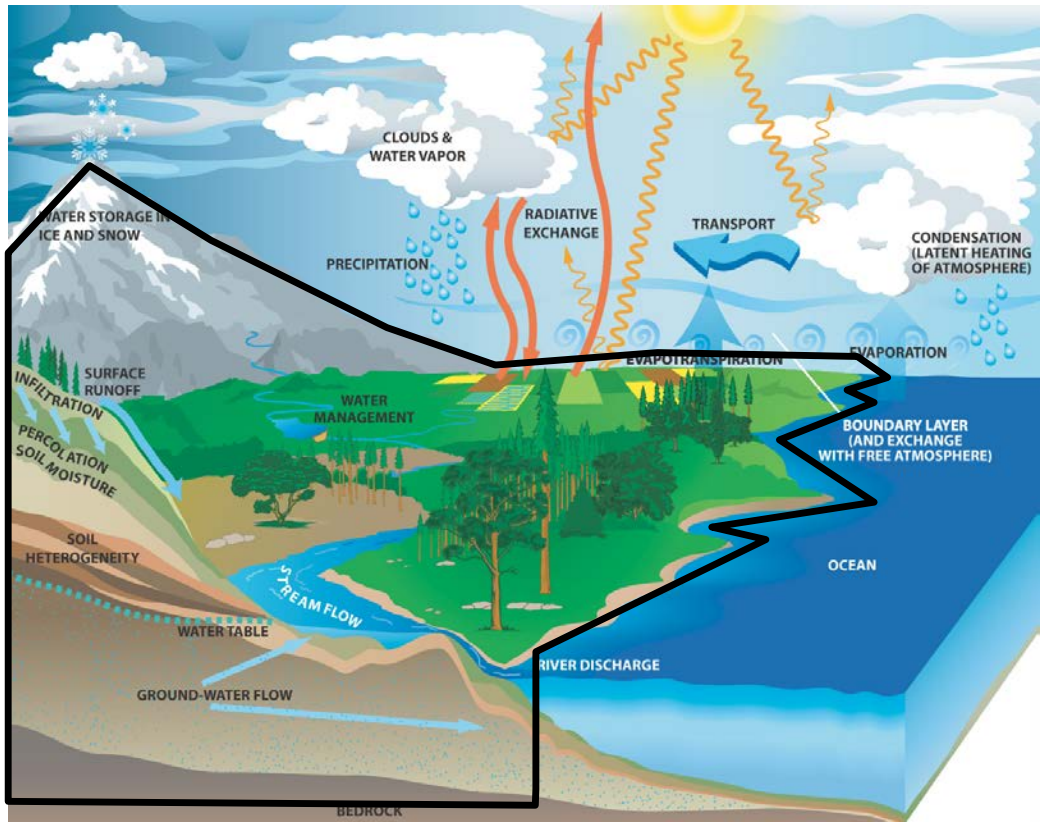


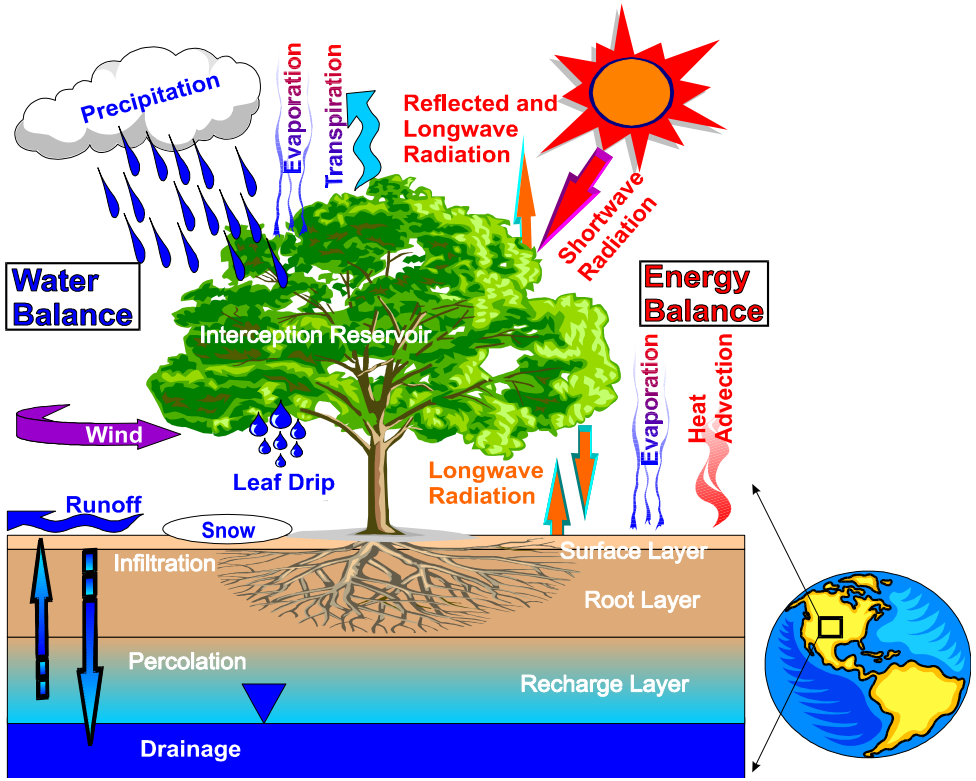
Vegetation/Carbon
(AVHRR, MODIS, *DESDynI, ICESat-II, HyspIRI, LIST, ASCENDS*)

Satellite observations

NASA

What are “Land surface models”?





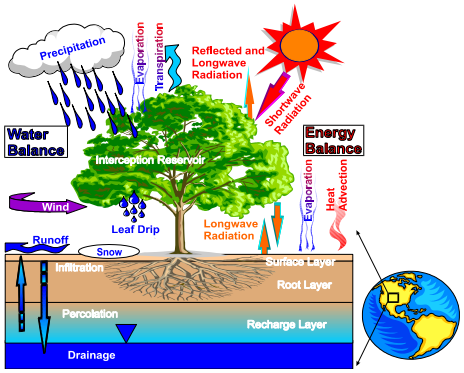
Land surface models solve for the interaction of energy, momentum and mass between the surface and the atmosphere

$$R_n = \lambda E + SH + G \qquad \frac{dS}{dt} = P - E - R$$

Estimates fluxes, land conditions (soil moisture, snow, runoff, …)

e.g. : Noah, CLM, VIC, Catchment, JULES …

How do we combine the information from satellite observations and models?



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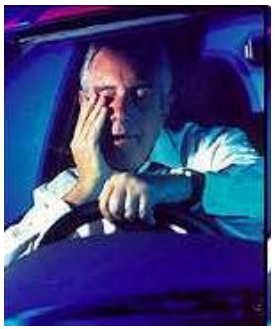
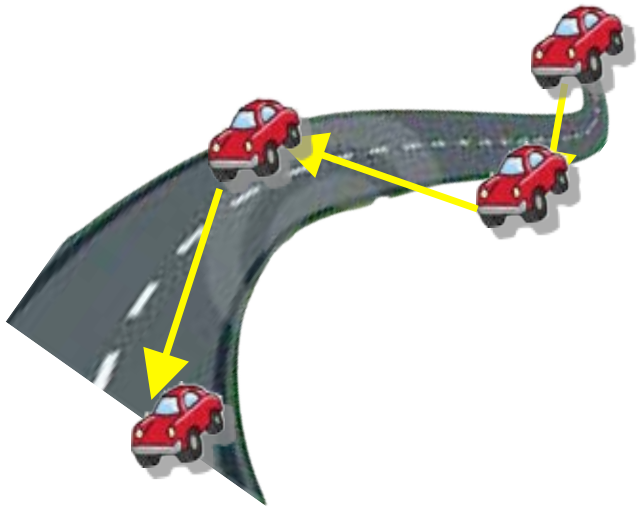
Models **Observations**

Data assimilation is the method used to incorporate observational data into model forecasts

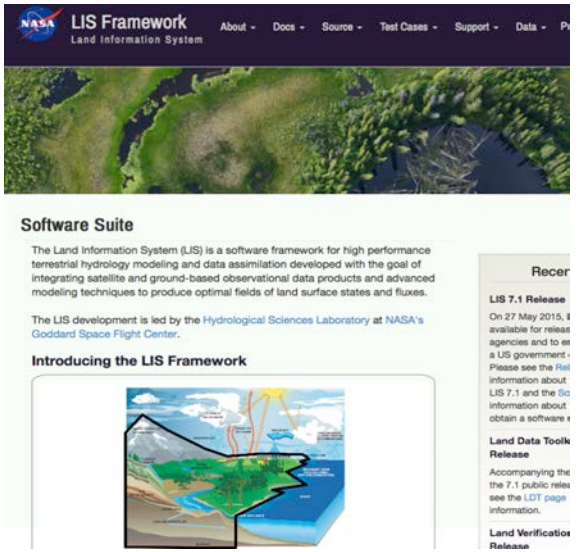


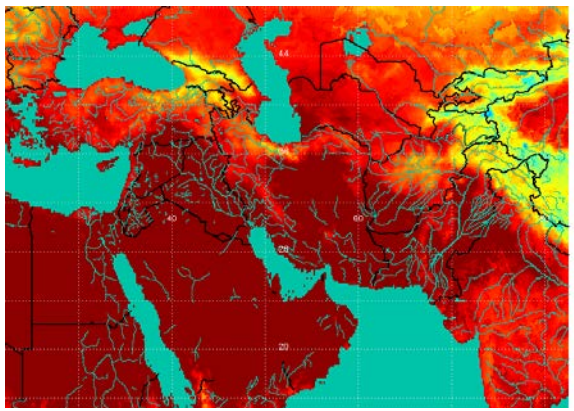
Like a “sleepy-driver” scenario

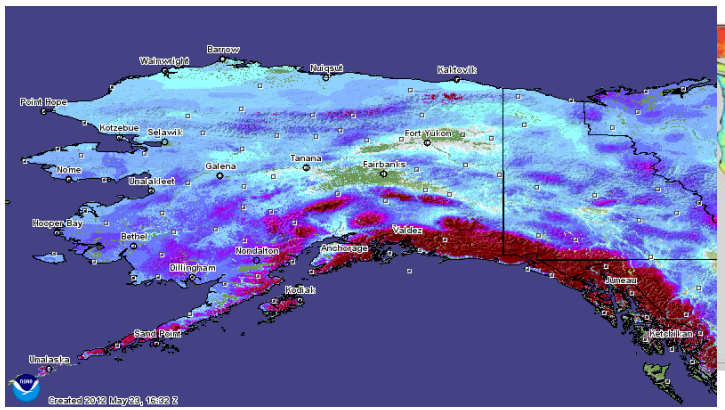


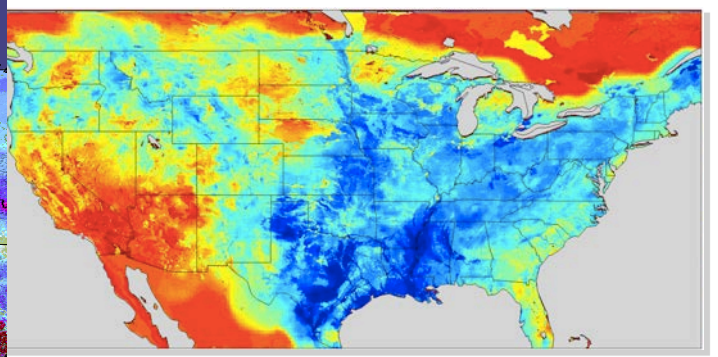
Land Data Assimilation Systems (LDASs)

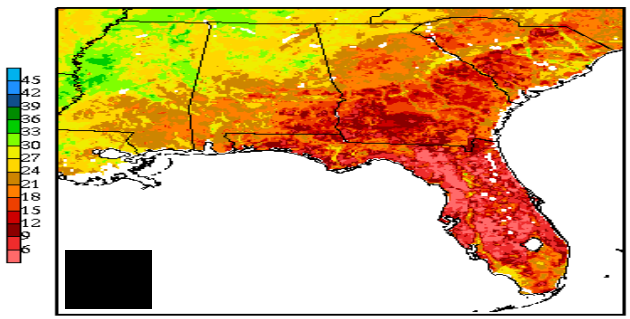
- Philosophy: Use best available observations to inform models
- NASA Land Information System (LIS; http://lis.gsfc.nasa.gov) - infrastructure that enables LDASs
- Used in several US and international agencies, universities for research and applications (Famine early warning, crop forecasts, water resources management, …)

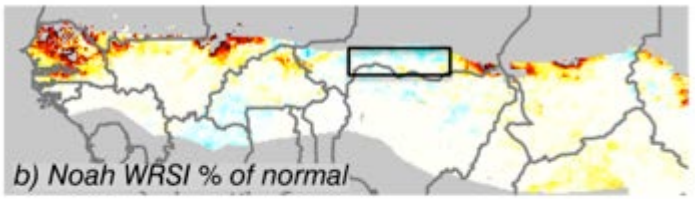


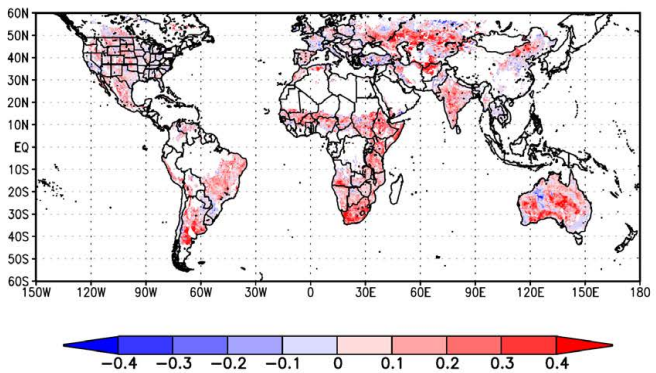








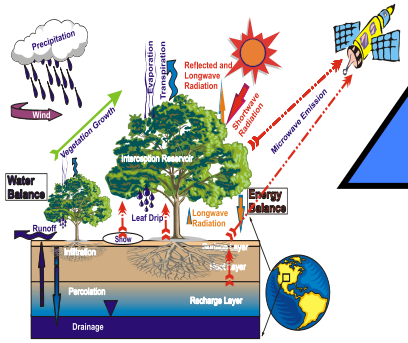




The LDAS approach

Observations

Modeling and Data Assimilation



Applications

A little bit of history..

North American LDAS

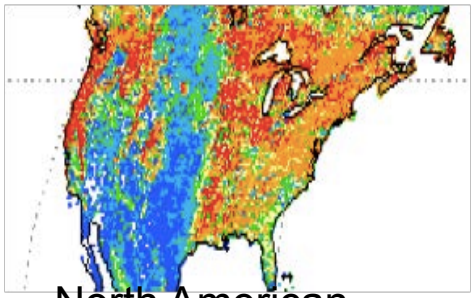
- NOAA, NASA, (and 6 other US institutions) 1998-present
- 1/8 degree resolution, central North America

Global LDAS

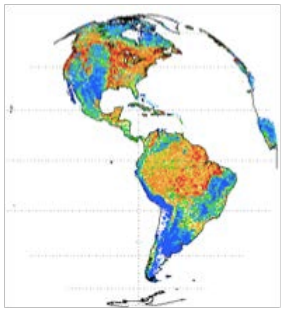
- NASA (and NOAA) 2000-present
- 1/4 and 1.0 degree resolutions, all land 60S-90N

Land Information System (LIS)

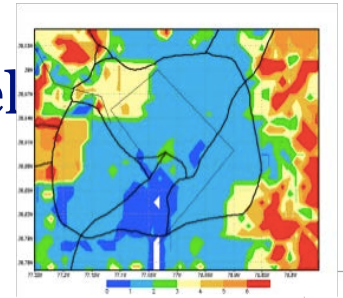
- NASA 2002-present
- Software configurable for any domain and resolution
- Multiple data assimilation options
- Can be run uncoupled or coupled to an atmospheric model



North American LDAS
1/8th degree spatial resolution



Global LDAS
1/4th degree spatial resolutio



LIS
global, regional, point
up to 1km and finer

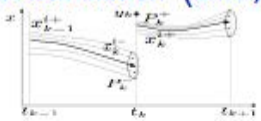
The LIS environment

LIS - OPT/UE

Optimization and Uncertainty Estimation (LM, SCE-UA,GA, RW-MCMC, DEMC)

LIS - DA

Data Assimilation (EnKF, EnKS)



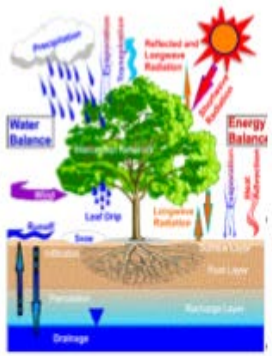
States (Soil Moisture, Snow, Skin Temperature)

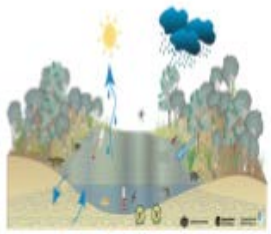
Parameters (Topography, Soil properties, vegetation properties)

Meteorological Boundary Conditions (Forcings)

LIS - LSM

Land Surface Models (Noah, CLM,VIC, Catchment, JULES, Sacramento, CABLE), Lake models (FLake)





Observations (Soil Moisture, Snow, Skin Temperature, Terrestrial Water Storage)

Water and Energy Fluxes, Soil Moisture and Temperature profiles, Land surface states

Applications

Water management

Weather and climate

Agricultural management

Hazards preparedness

Military/Mobility applications

Public Health

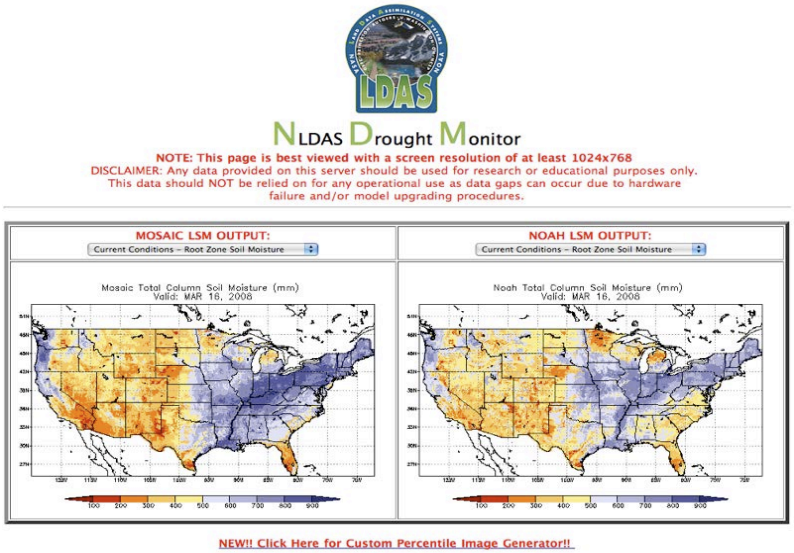
Examples of LDAS applications…

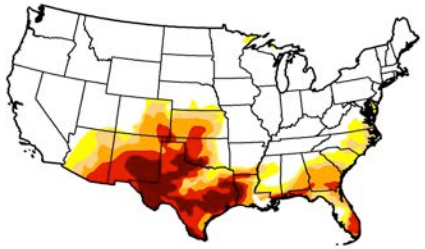
LDAS for drought monitoring

Outputs from LDASs are used for routine drought monitoring using soil moisture, evapotranspiration, streamflow, groundwater estimates

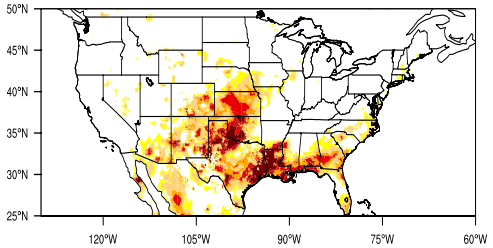
Example: NLDAS drought monitor (http://www.emc.ncep.noaa.gov/mmb/nldas/drought/)

Data assimilation can be used further improve drought estimation

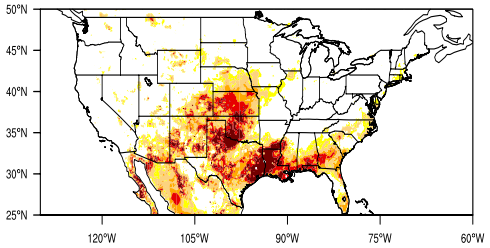




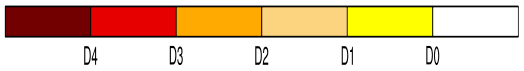
US drought monitor



LSM based drought estimate



LSM based drought estimate with data assimilation

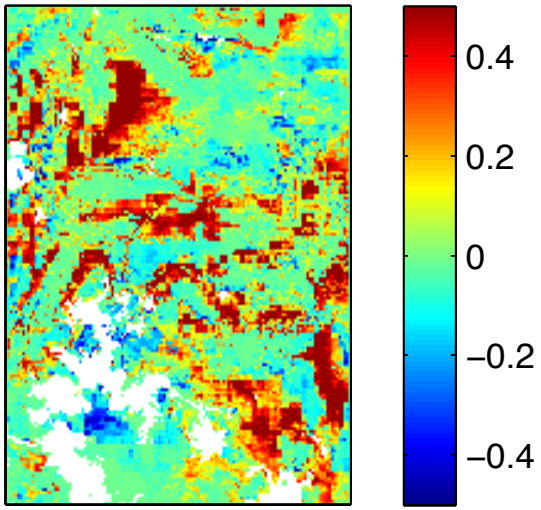


Impact of soil moisture DA on drought estimates (May 10-17, 2011).

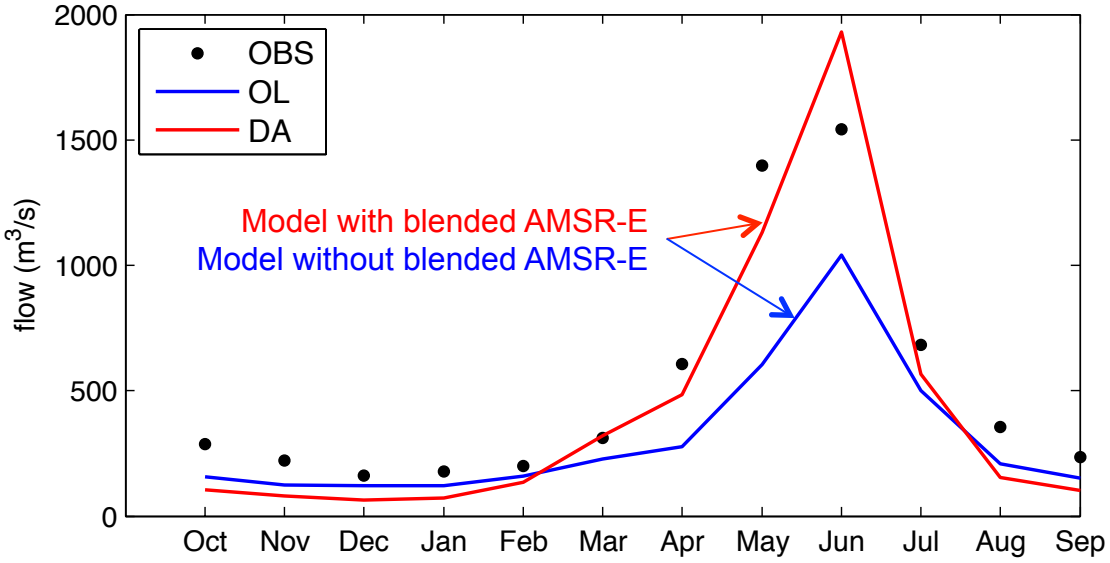
LDAS for flood monitoring

Runoff, streamflow fields from LDASs can be used for flood monitoring

Improvement in Snow Cover Probability of Detection (POD) When Assimilating satellite snow data

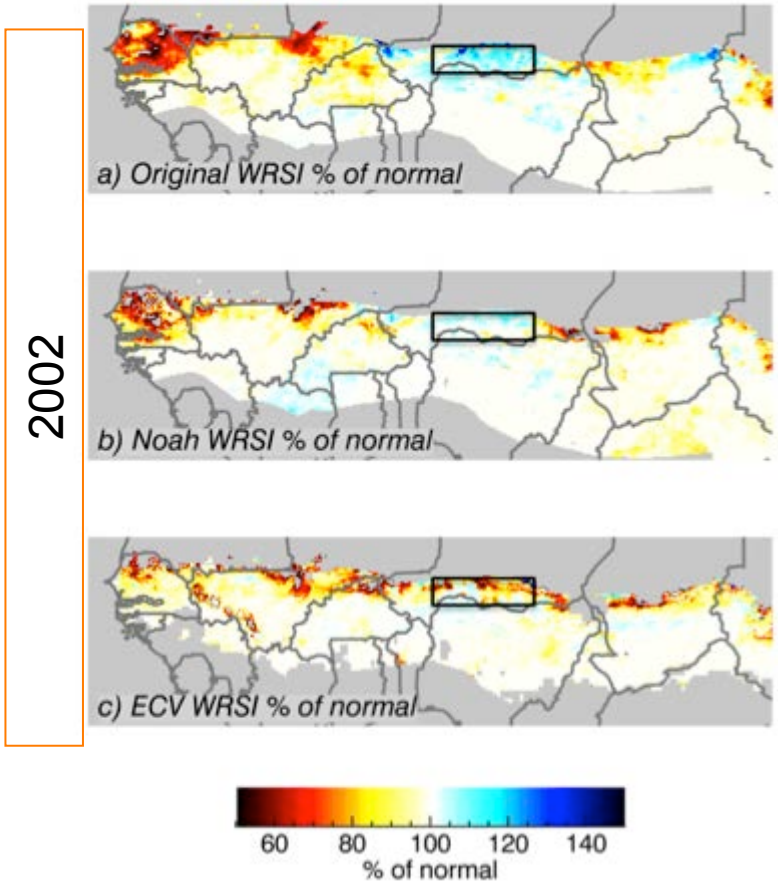


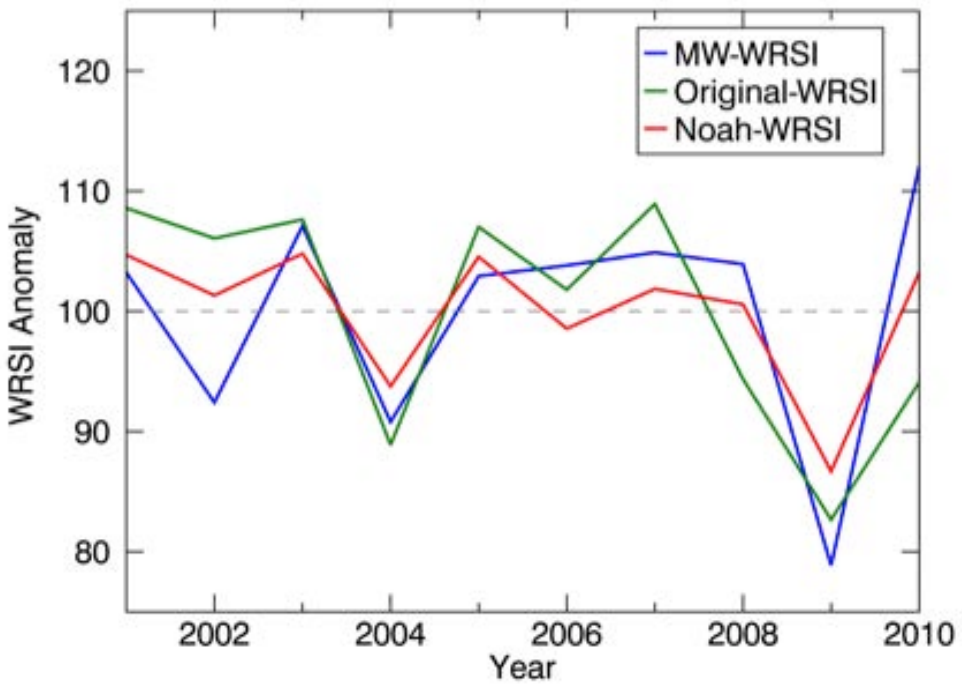
Improvement in Streamflow When Assimilating satellite snow data (Upper Colorado River at Lees Ferry)



LDAS for estimating crop water requirements

The simulated soil moisture fields from LDAS is used to compute the water requirement satisfaction index (WRSI) and is compared to satellite derived (MW) data.

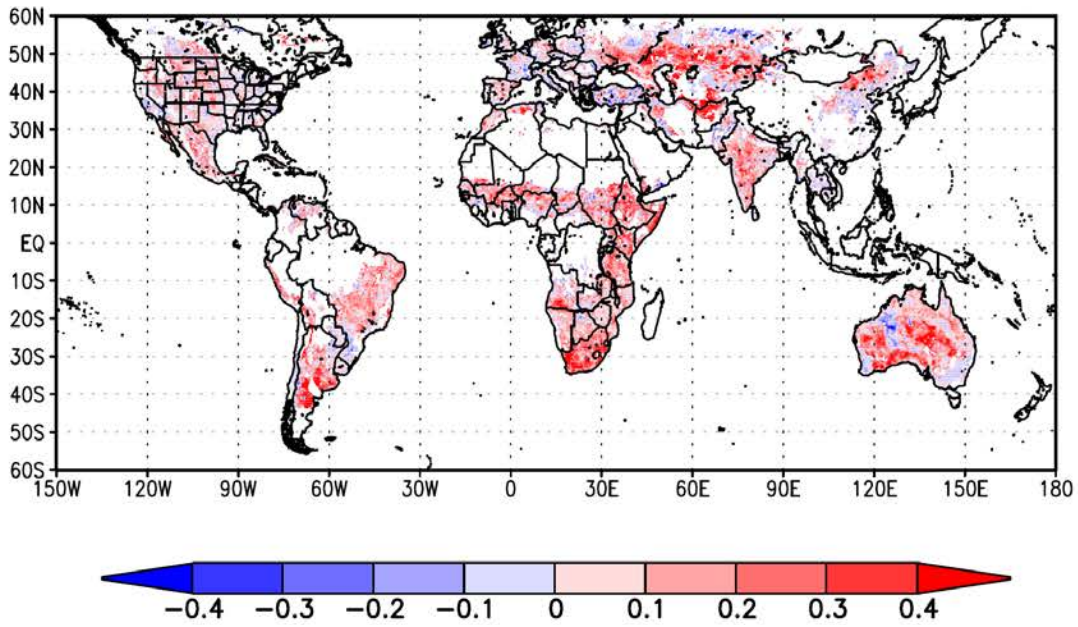




LDAS for global crop product decision support system

The US Department of Agriculture uses soil moisture outputs from LDAS towards crop product decision support

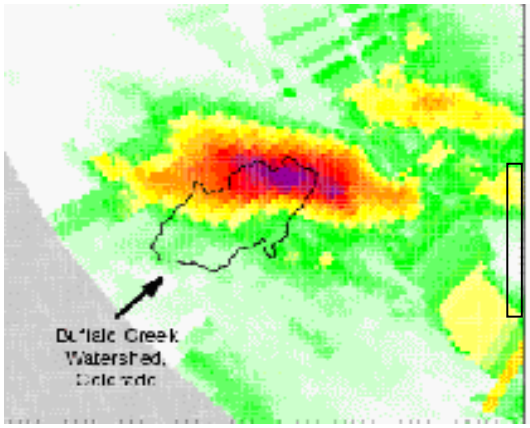
Soil moisture data from satellites (SMOS, SMAP) are incorporated into the land surface models for improved simulation of soil moisture states.



Skill improvements in soil moisture fields from incorporating satellite soil moisture observations (warm colors indicate skill improvements, cool colors denote skill degradations)

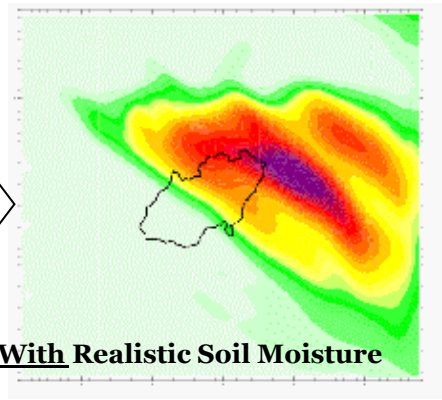
LDAS for improving weather forecasts

Realistic simulation of land conditions from a LDAS can be used to initial weather and climate models, leading to improved weather forecasts

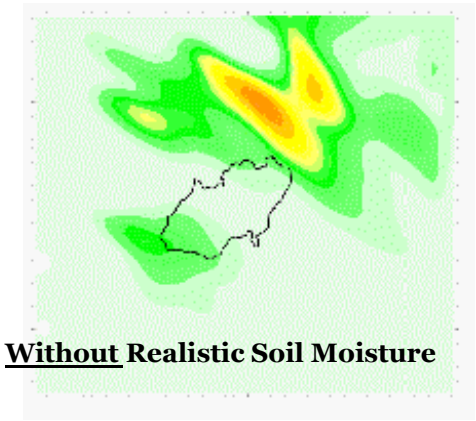


Observed Rainfall for Colorado Flood Event
0000Z to 0400Z 13/7/96
(Chen et al., NCAR)

Example 24-Hours Ahead Atmospheric Model Forecasts



With Realistic Soil Moisture



Without Realistic Soil Moisture

NLDAS & GLDAS Data Availability

http://disc.gsfc.nasa.gov/hydrology

- Access via GDS, FTP, or quick-look visualization in Giovanni (below right)
- GRIB and NetCDF formats
- 3-hourly and monthly; 1.0° and 0.25° global grids
- On-the-fly subsetting (below left)
- Full documentation
- NLDAS & GLDAS support a growing number of national and international hydrometeorological investigations and water resources applications

<u>NLDAS</u>

0.125°, 1979-present (operational at NOAA/NCEP, 3.5 day latency), to 53N, -125 to -67W, hourly/monthly: Noah, Mosaic, VIC

<u>GLDAS v1</u>

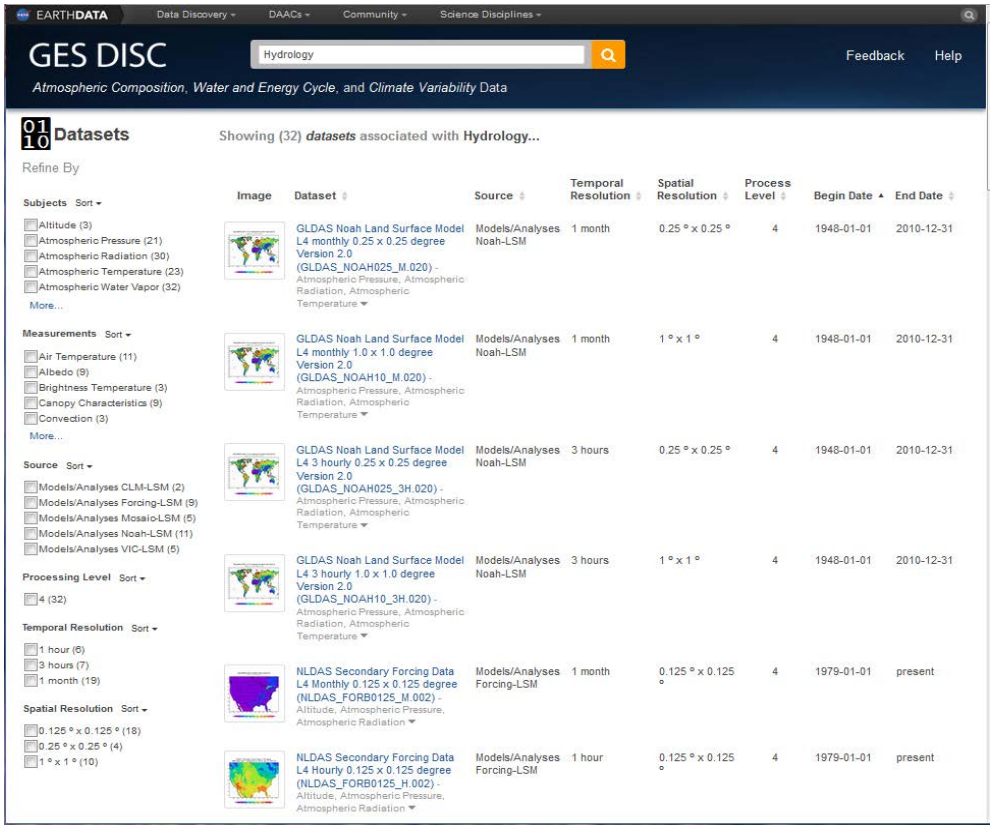
1.0°, 1979-present (1-2 month latency): Noah, Mosaic, VIC, CLM2
0.25°, 2000-present: Noah w/ MODIS snow cover assimilation

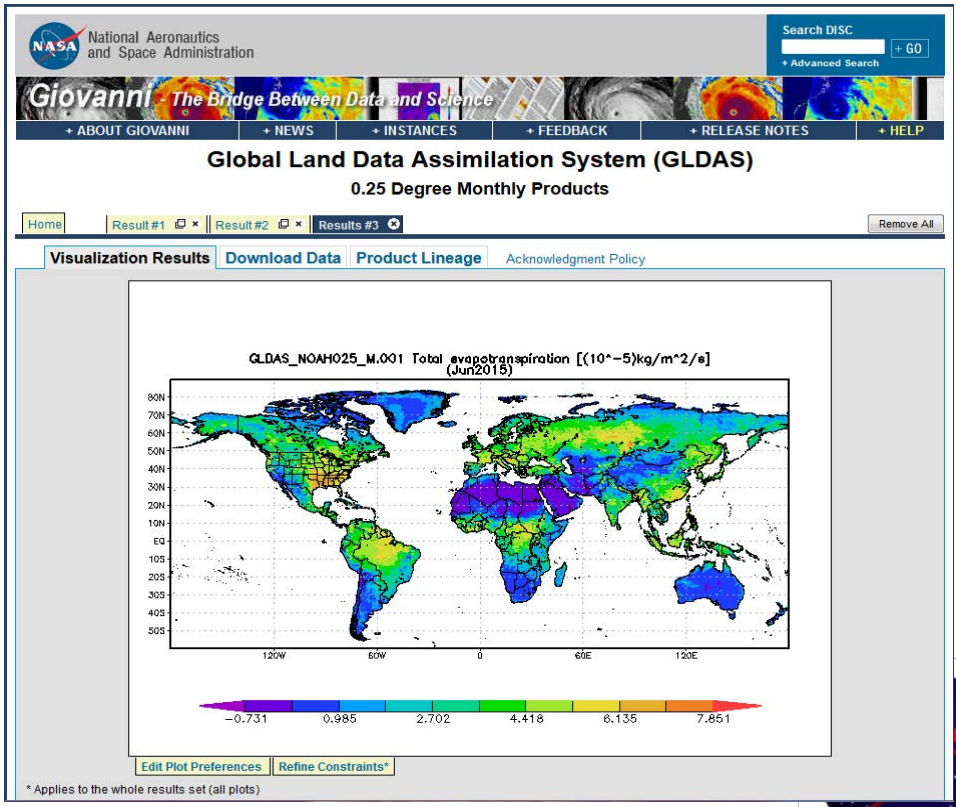
<u>GLDAS v2</u>

1.0° & 0.25°, 1948-2012: Noah

<u>GLDAS v2.1 & v2.2</u> (coming soon)

1.0° & 0.25°, 1948-present, with multivariate data assimilation: Noah, Catchment, VIC, CLM4.5





Summary

- Land Data Assimilation Systems have been developed for central North America (NLDAS), Europe (ELDAS), South America (SALDAS), Middle East North Africa (MENA-LDAS) and the globe (GLDAS)

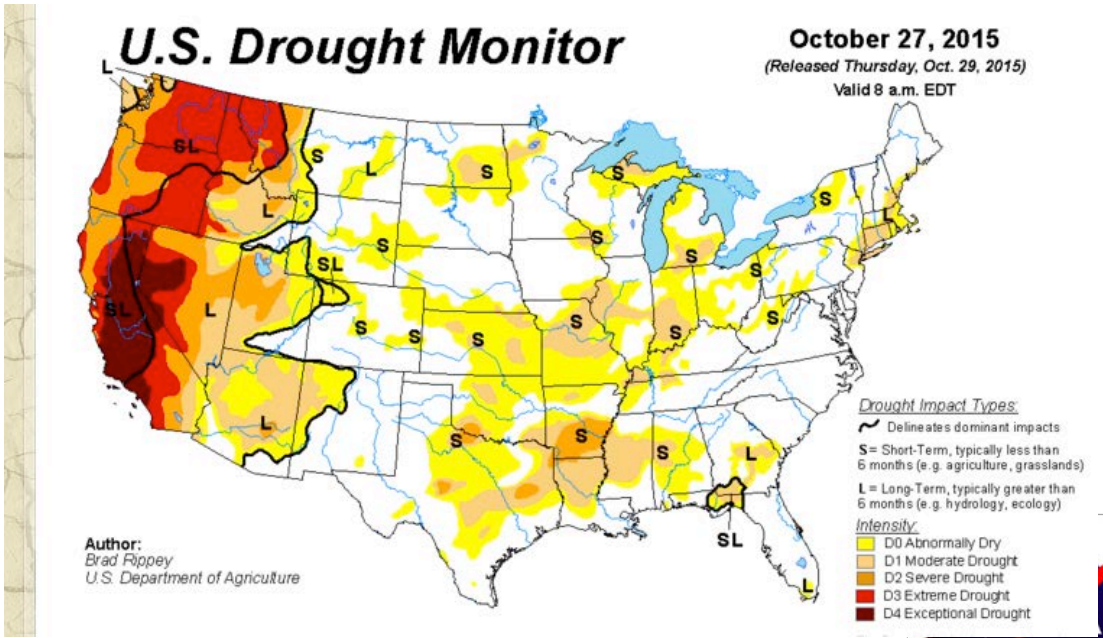
- The common goal of these projects is to integrate all relevant data in a physically consistent manner within sophisticated land surface models to produce optimal estimates of hydrological states (e.g. soil moisture, surface temperature) and fluxes (e.g. runoff, evapotranspiration)

- The Land Information System (LIS) is an efficient and configurable software that can be used to specify an instance of LDAS

- LDASs have been used for water availability applications including drought/flood monitoring, agricultural management, weather and climate initialization.

Import Water Budget Data into GIS

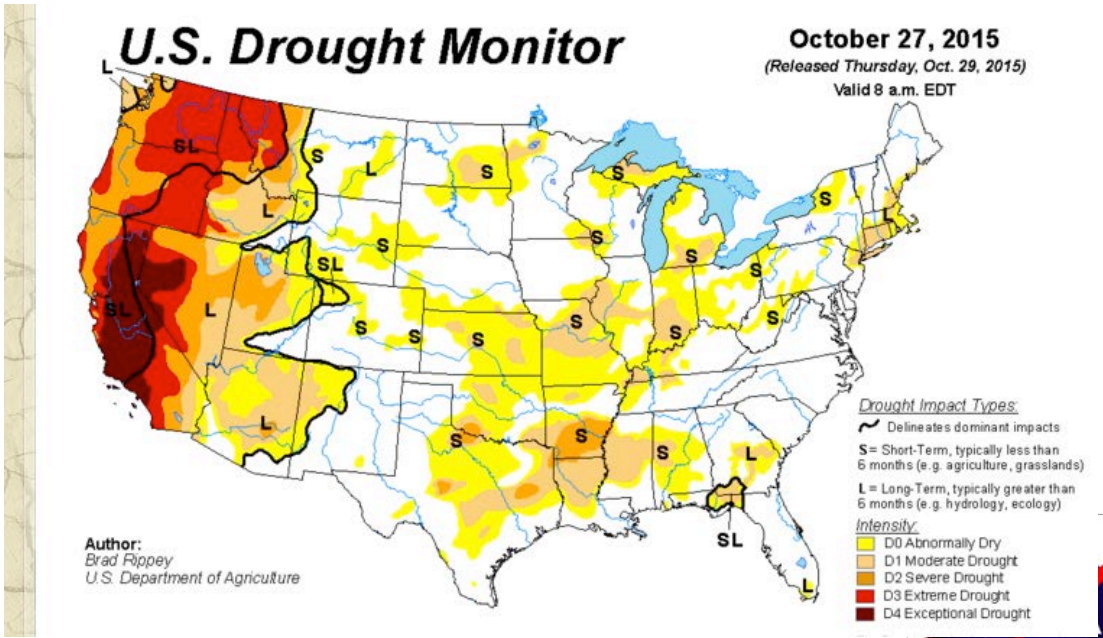
Live demonstration of Giovanni water budget data access, GIS import and analysis



Reference, US Drought Monitor (2015 October 27)

Giovanni Version 4

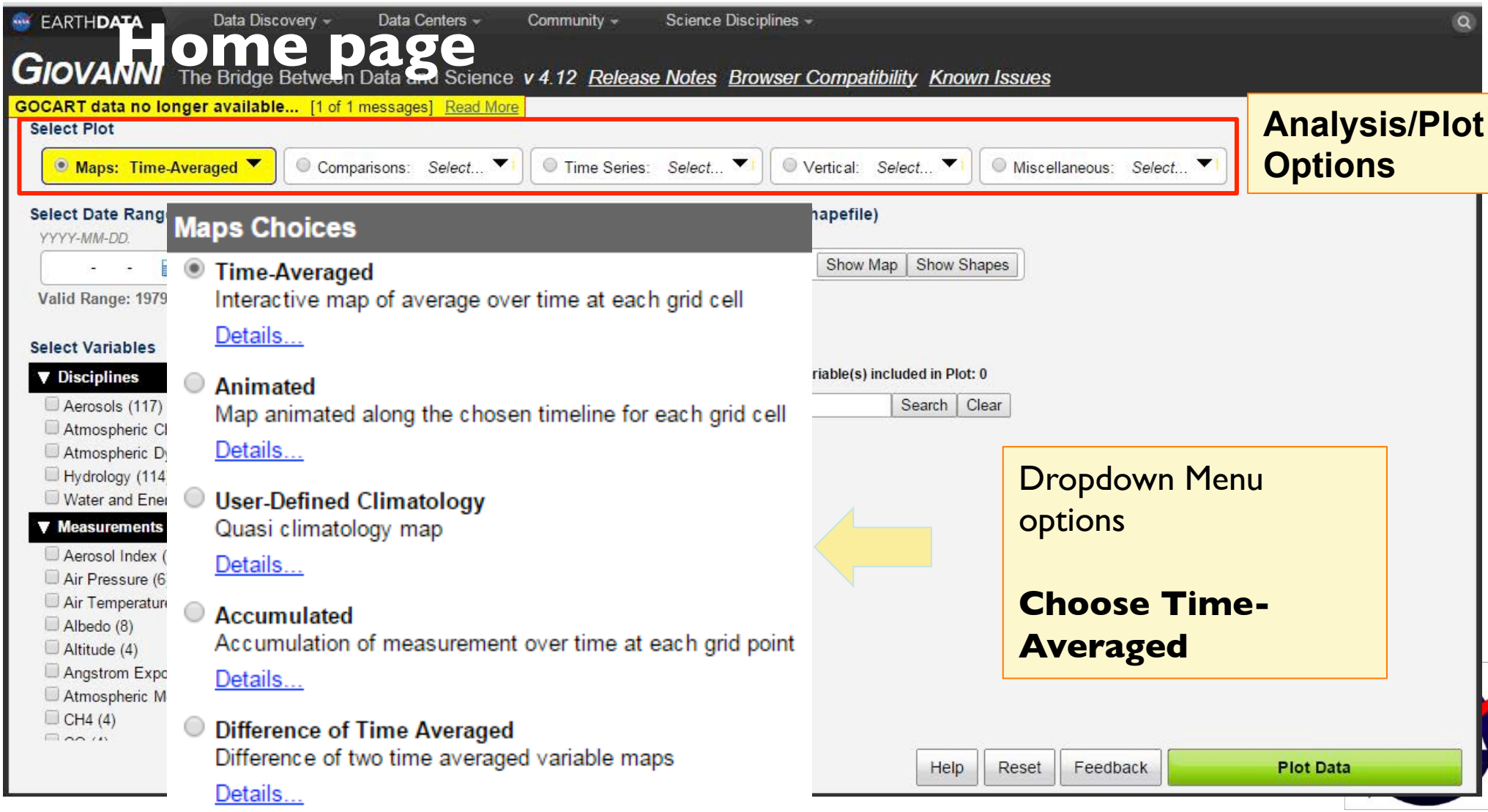
http://giovanni.gsfc.nasa.gov/giovanni/



Reference, US Drought Monitor (2015 October 27)

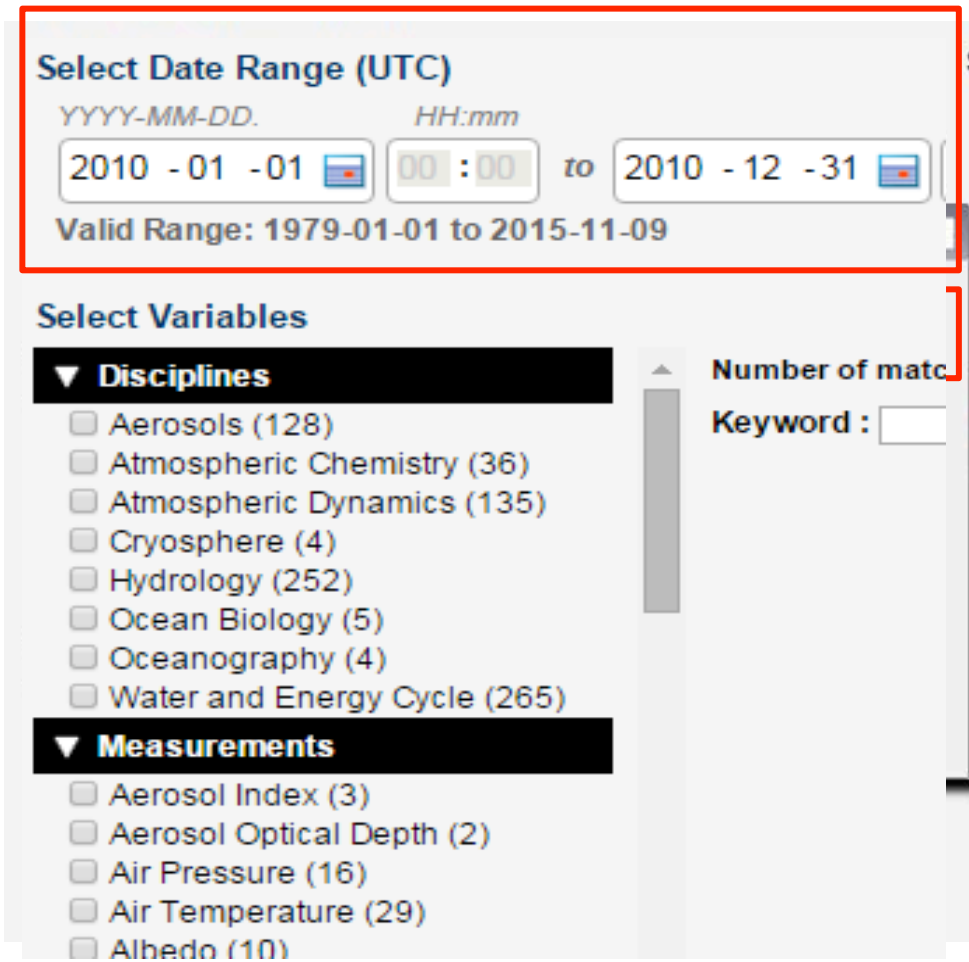
NLDAS Data Access - Giovanni Version 4 data portal

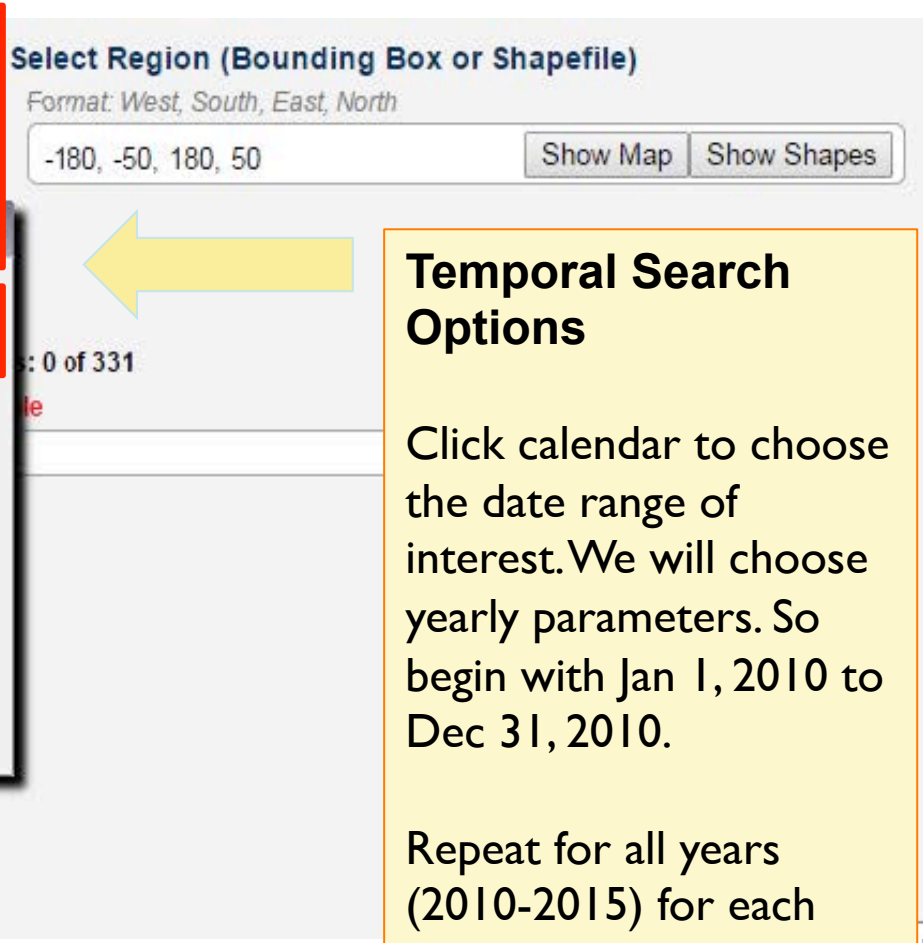
http://giovanni.gsfc.nasa.gov/giovanni/



Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/





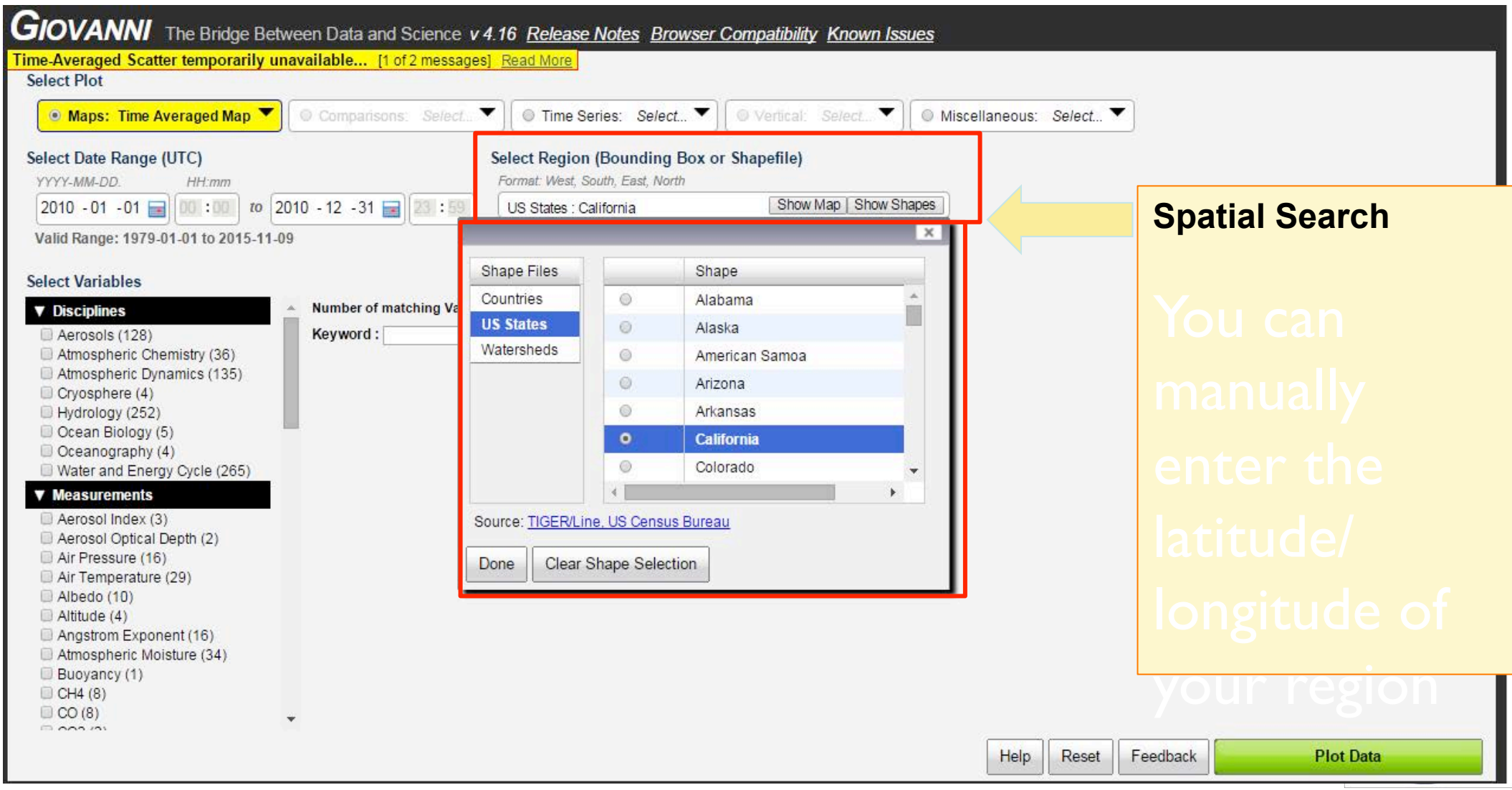
Temporal Search Options

Click calendar to choose the date range of interest. We will choose yearly parameters. So begin with Jan 1, 2010 to Dec 31, 2010.

Repeat for all years (2010-2015) for each parameter.

Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

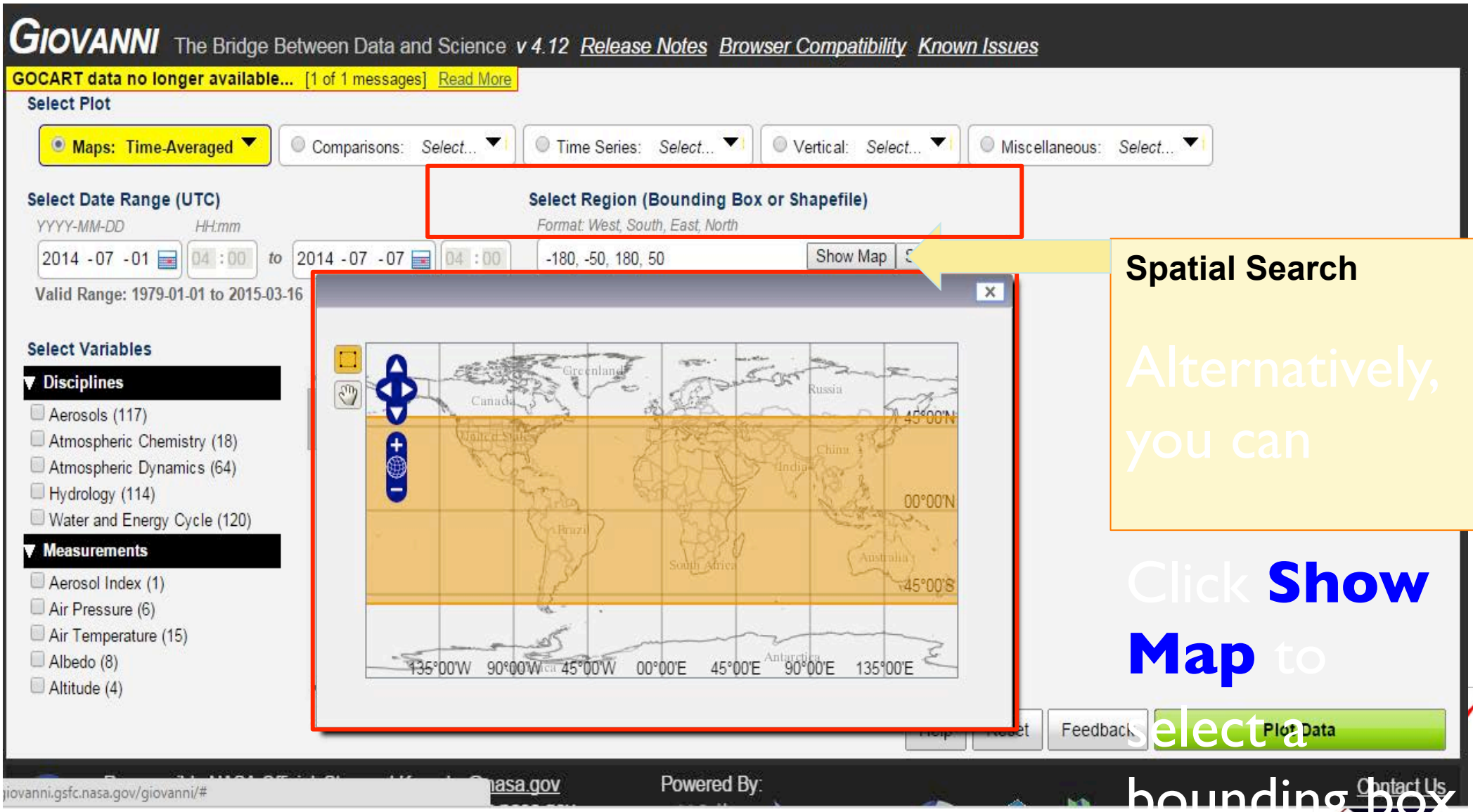


Spatial Search

You can manually enter the latitude/ longitude of your region

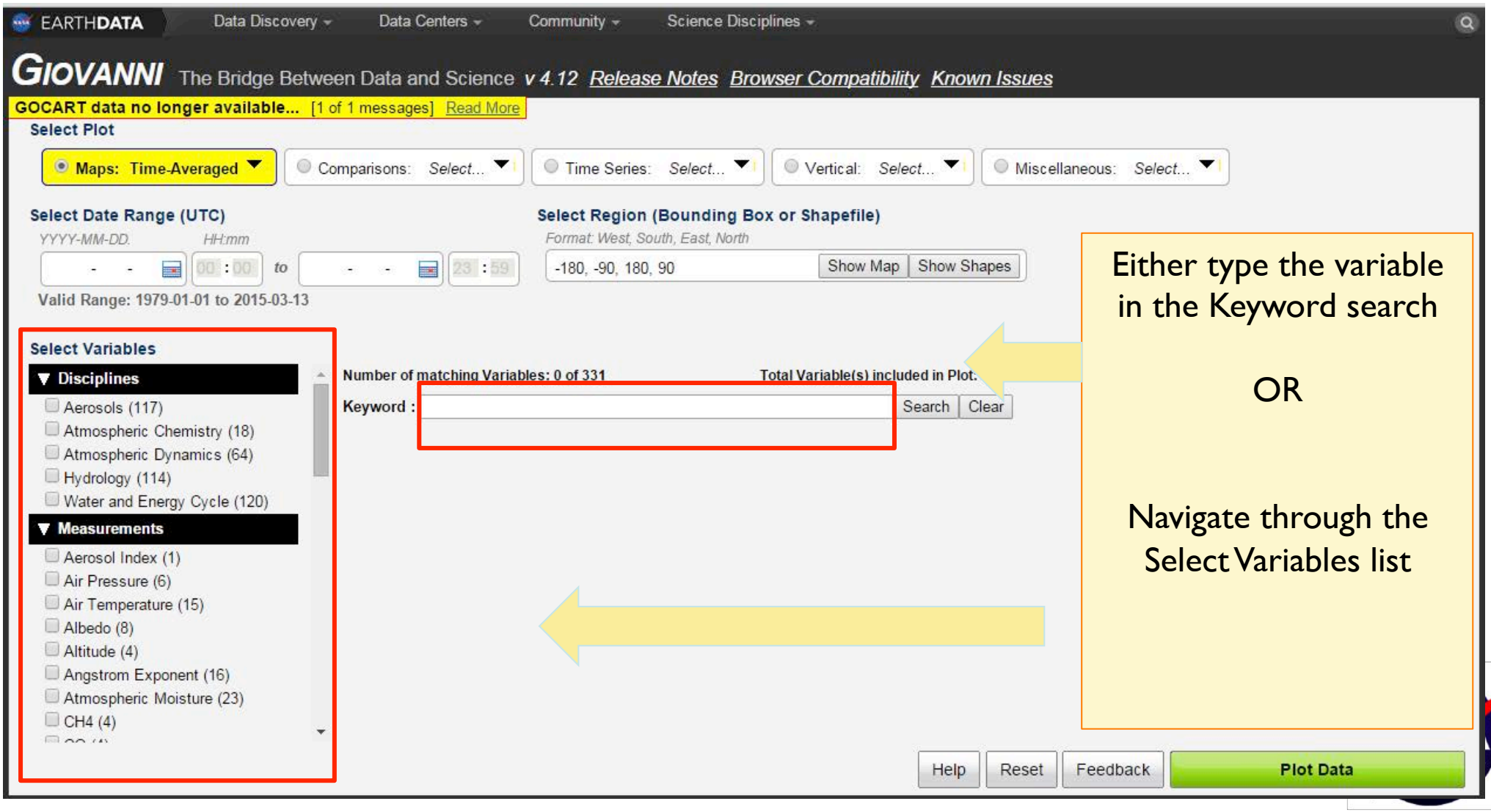
Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/



Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/



Either type the variable in the Keyword search

OR

Navigate through the Select Variables list

Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

Scroll down and select

Rainfall (unfrozen) and Total evapotranspiration (NLDAS VIC Annually Temporal Resolution)

(there are more variables to acquire here as well, including runoff, soil moisture, snow water equivalent, etc. The variables you will need to calculate your water budget will depend upon the complexity of your model).

GPM IMERG data will also be appropriate to obtain here.

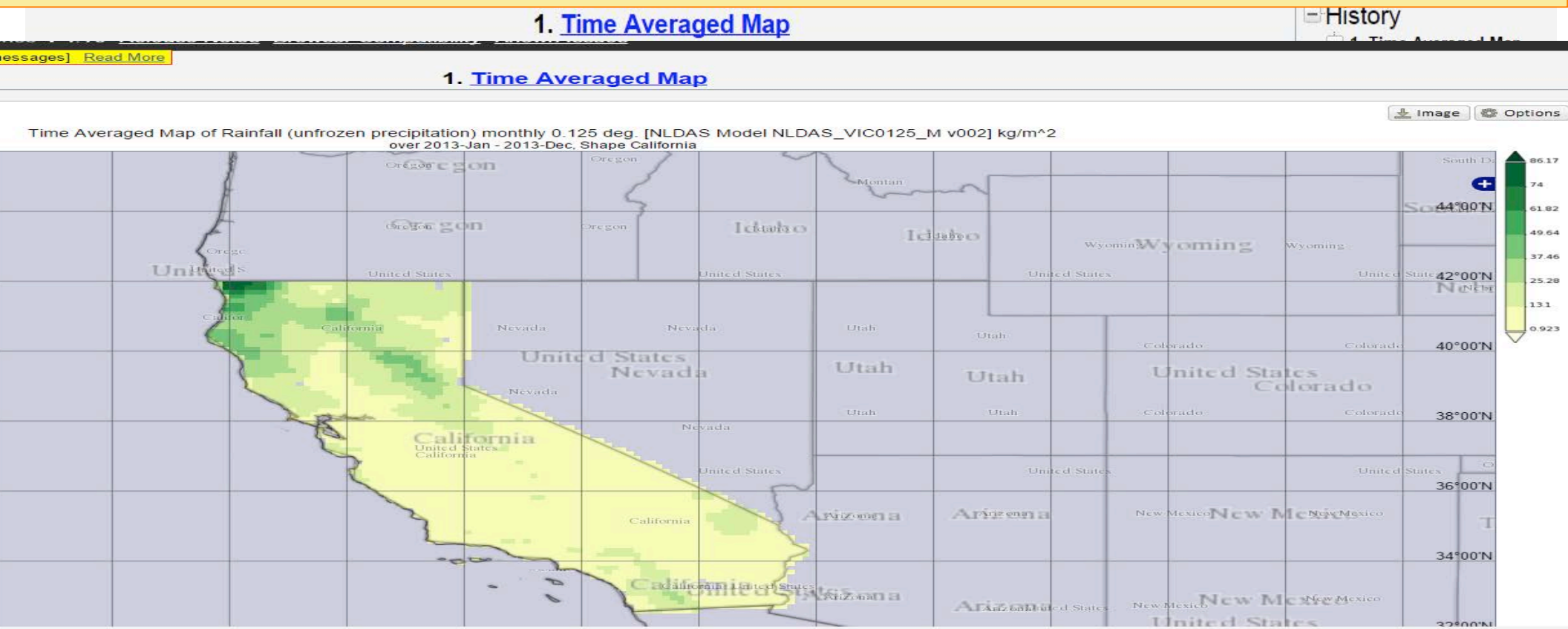
When finished,

Click **Plot Data**

Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

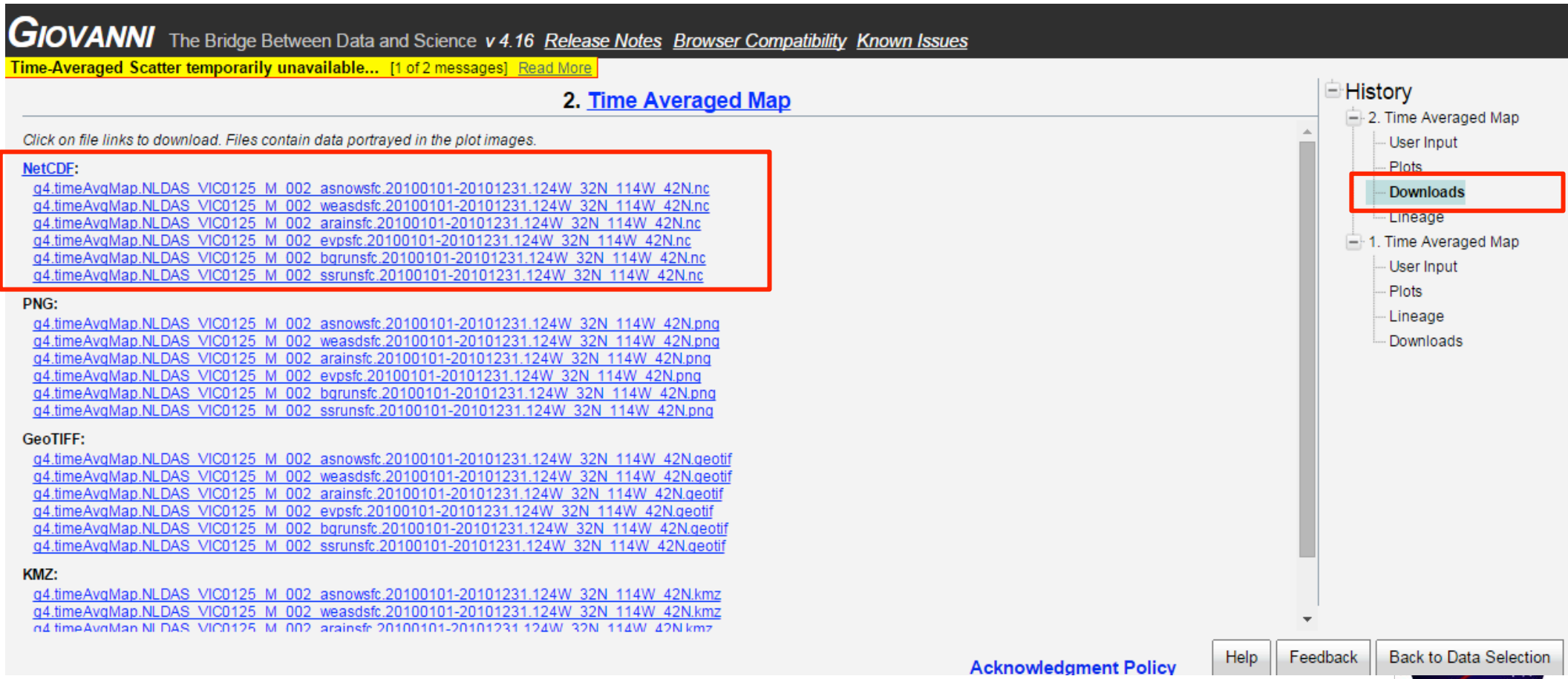
Time Averaged Maps will be generated with the variables displayed for the year 2010 in region



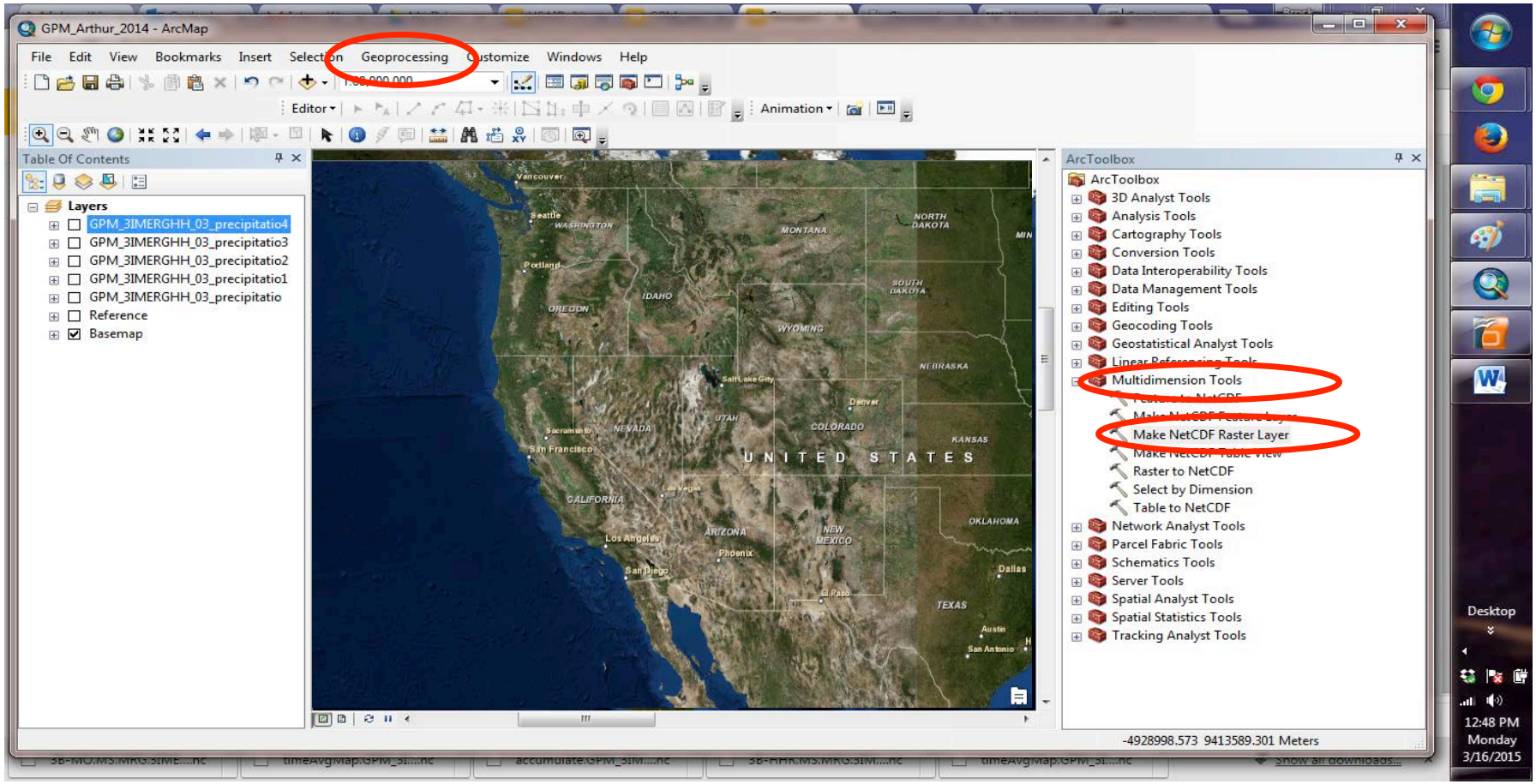
Giovanni Version 4

http://giovanni.gsfc.nasa.gov/giovanni/

You can download the data files in either NetCDF, GeoTIFF or PNG formats.
NetCDF format is easily imported into ArcMap.
Click the links to download to your desired location on your computer.

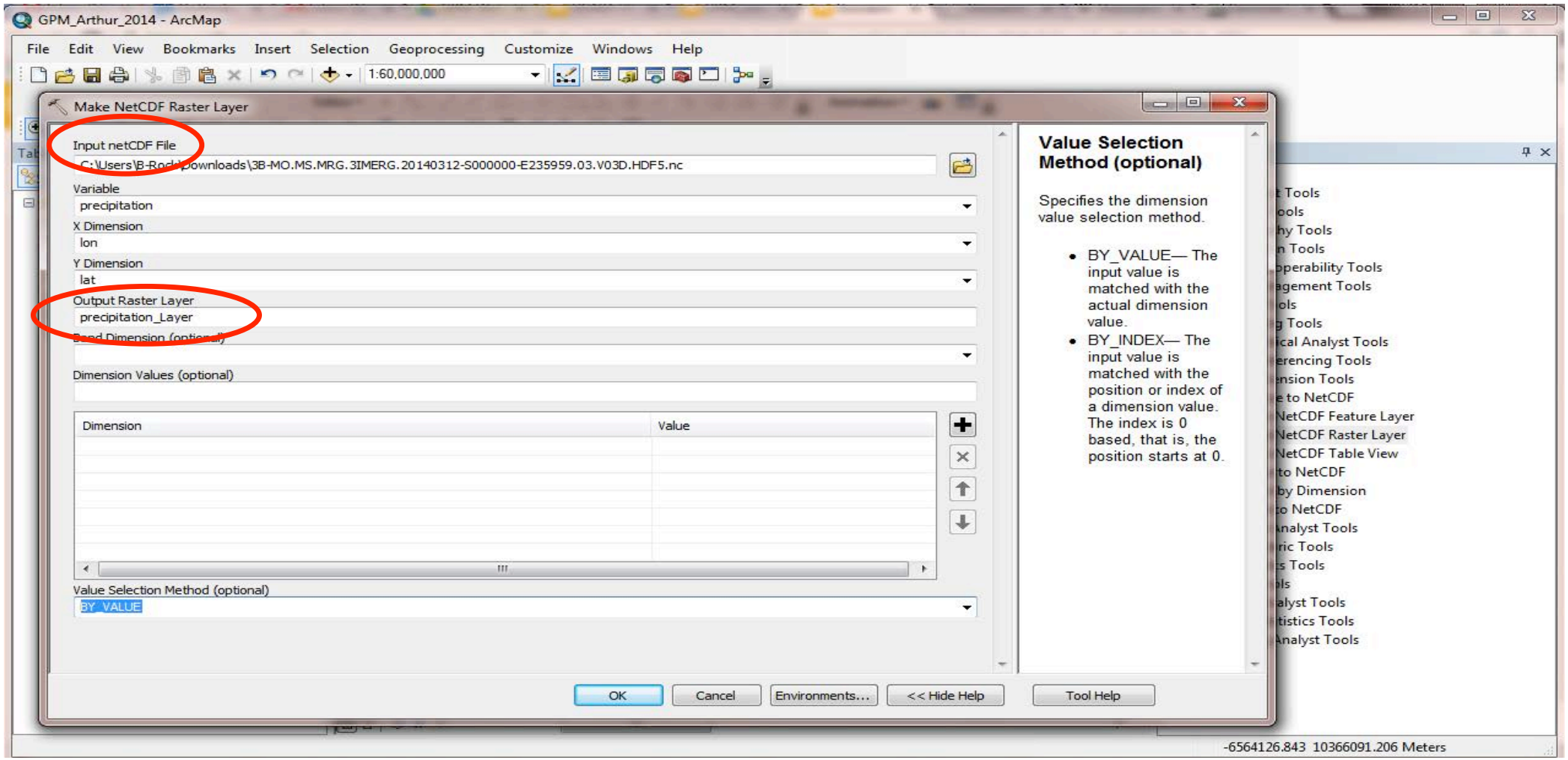


Import into GIS (ArcMAP)



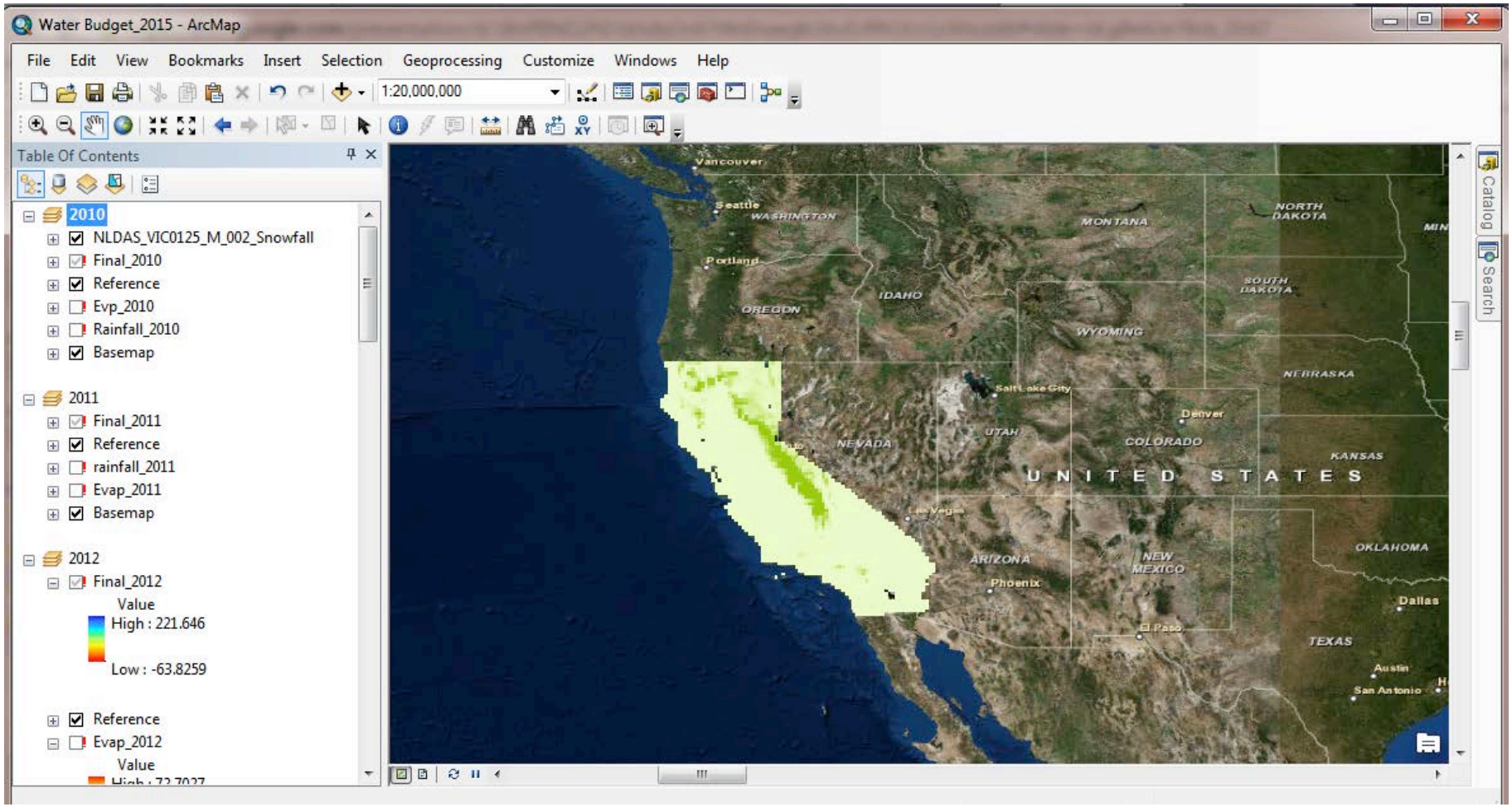
Import our hydrology data - Under the Geoprocessing Tab, Open the ArcToolbox.Open the Multidimensional toolbox, choose the **Make NetCDF Raster Layer tool**

Import into GIS (ArcMAP)



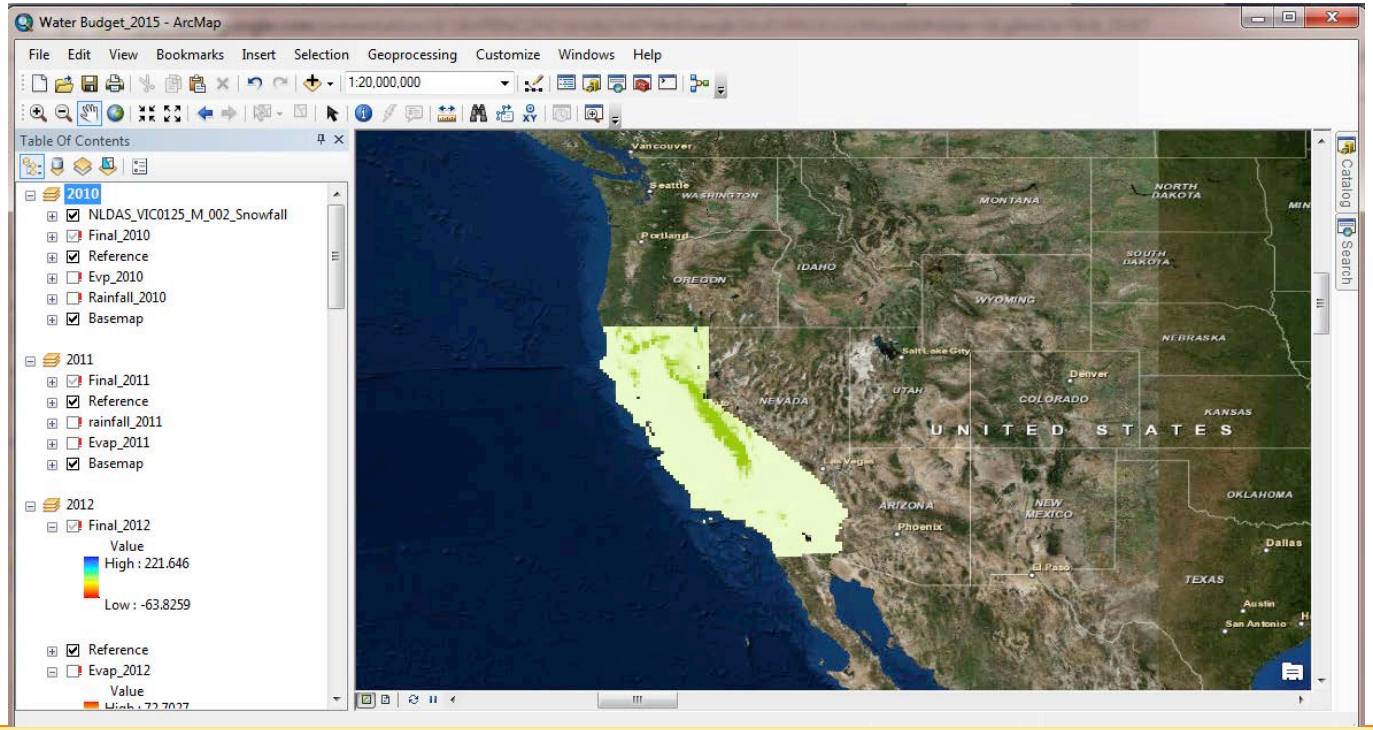
For the input field, **Input netCDF File:** Navigate to and click on the previously downloaded files (one by one). The remaining fields will fill in accordingly, KEEP the default values. You may change the output file name if you choose. Click OK.

Import into GIS (ArcMAP)



The result will be in raster format in ArcMAP.
This is the area averaged snowfall for the state of California for 2010.
Raster files are ideal for spatial analysis tools and for model input.

Import into GIS (ArcMAP)

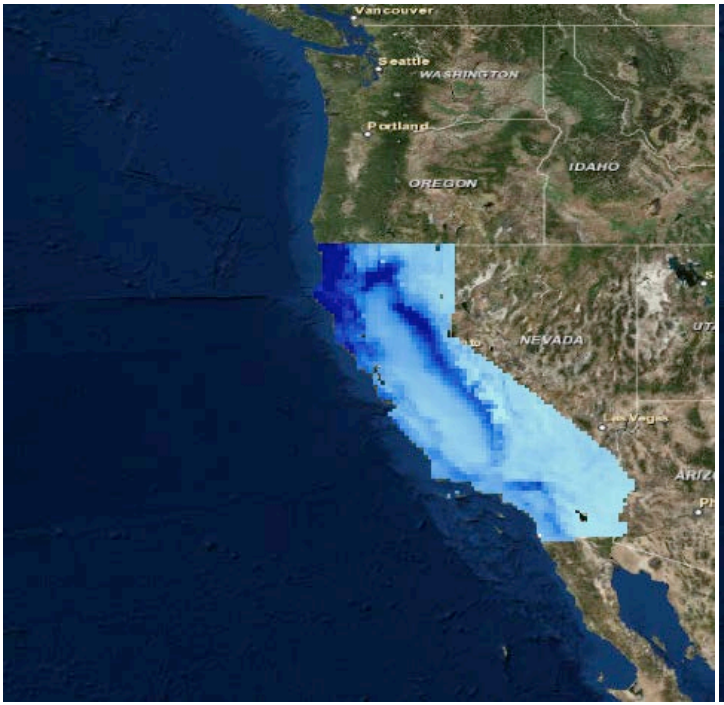


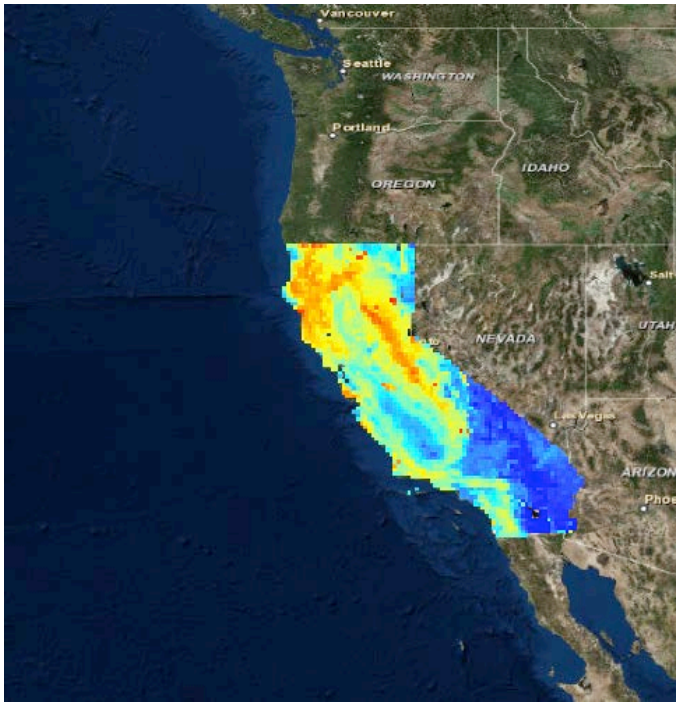
You will want to import all variables of interest for all years to prepare for the spatial analysis of your water budget.

For reference upon importing, the naming conventions for the NLDAS variable files are below:

Subsurface runoff: g4.timeAvgMap.NLDAS_VIC0125_M_002_**bgrunsfc**
Rainfall (unfrozen precipitation): g4.timeAvgMap.NLDAS_VIC0125_M_002_**arainsfc**
Rainfall (frozen precipitation): g4.timeAvgMap.NLDAS_VIC0125_M_002_**asnowsfc**
Total Evapotranspiration: g4.timeAvgMap.NLDAS_VIC0125_M_002_**evpsfc.**
Surface runoff (non-infiltrating): g4.timeAvgMap.NLDAS_VIC0125_M_002_**ssrunsfc.**
Accumulated snow water-equivalent: g4.timeAvgMap.NLDAS_VIC0125_M_002_**weasdsfc.**

Spatial Analysis





Once all variables are imported into your GIS, given the different complexities to the various models and raster calculations needed to derive a water budget, please refer to relevant literature to determine the appropriate model inputs and variables needed for your region, watershed or basin.

Common GIS Data Layers and locations to find them

Rivers/Basins	USGS HydroSHEDS	http://hydrosheds.cr.usgs.gov/
Population	NASA Socioeconomic Data and Applications Center (SEDAC)	http://sedac.ciesin.columbia.edu/
Elevation	Consortium for Spatial Information (CGIAR-CSI)	http://srtm.csi.cgiar.org/
Reservoirs	NASA Socioeconomic Data and Applications Center (SEDAC)	http://sedac.ciesin.columbia.edu/
Soil Type	ISRIC - World Soil Information	http://www.isric.org/
Dams	NASA Socioeconomic Data and Applications Center (SEDAC)	http://sedac.ciesin.columbia.edu/
Infrastructure	See various local/state/regional GIS data sites	
Land Use	Waterbase	http://www.waterbase.org