National Aeronautics and Space Administration

Assessing the Impacts of Fires on Watershed Health

Part 2: Earth Observations and The Soil & Water Assessment Tool (SWAT) for Assessing Post-Fire Water Quality in Watersheds

Ibrahim Mohammed (SAIC/NASA) & Mandy Lopez (NASA-JPL)

July 11, 2023

Assessing the Impacts of Fires on Watershed Health
Overview

Training Learning Objectives

By the end of this training, participants will be able to:

- Analyze the key fire science criteria to select the appropriate data from satellites/instruments for a given watershed
- Distinguish, compare, and contrast the biophysical conditions pre- and post-fire
- Acquire land use & land cover maps for the region of interest
- Select river basin and sub-basin boundaries for their region of interest
- Recognize how to apply the Soil and Water Assessment Tool (SWAT), a river basin-scale model, to simulate the quality and quantity of surface water and groundwater

Prerequisites

- Fundamentals of Remote Sensing
- Satellite Observations and Tools for Fire Risk, Detection, and Analysis
- Using Google Earth Engine for Land Monitoring Applications
- Texas A&M Instructional Videos for SWAT

Why Study the Impacts of Fires

- Wildfires can disrupt transportation, communications, power and gas services, and water supply
- Wildfires lead to a deterioration of air quality, and loss of property, crops, resources, animals, and people.
- "Children, the elderly, and individuals with underlying health conditions are particularly vulnerable to the health effects of decreased air quality caused by wildfires." — National Institute for Occupational Safety and Health (NIOSH)

Image credit: Cameron Strandberg

Training Outline

Part 1

Satellite Observations and Tools for Fire Risk

July 6, 2023

Part 3

Using Google Earth Engine to Monitor Post-Fire Impacts

July 13, 2023

Homework

Opens July 13 – Due July 27 – Posted on Training Webpage

A **certificate of completion** will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Part 2 Objectives

By the end of Part 2, participants will be able to:

- Identify physically-based model components necessary to run a SWAT model to predict the impact of management on water and sediment in a watershed
- Ingest Earth remote sensing data into SWAT model using NASAaccess
- Recognize best practices used to conduct calibration in SWAT

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Part 2 – Trainers

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NASA GSFC HSL

Amanda (Mandy) Lopez

NPP Postdoctoral Fellow

NASA JPL

National Aeronautics and Space Administration

Earth Observations and The Soil & Water Assessment Tool (SWAT) for Assessing Post-Fire Water Quality in Watersheds

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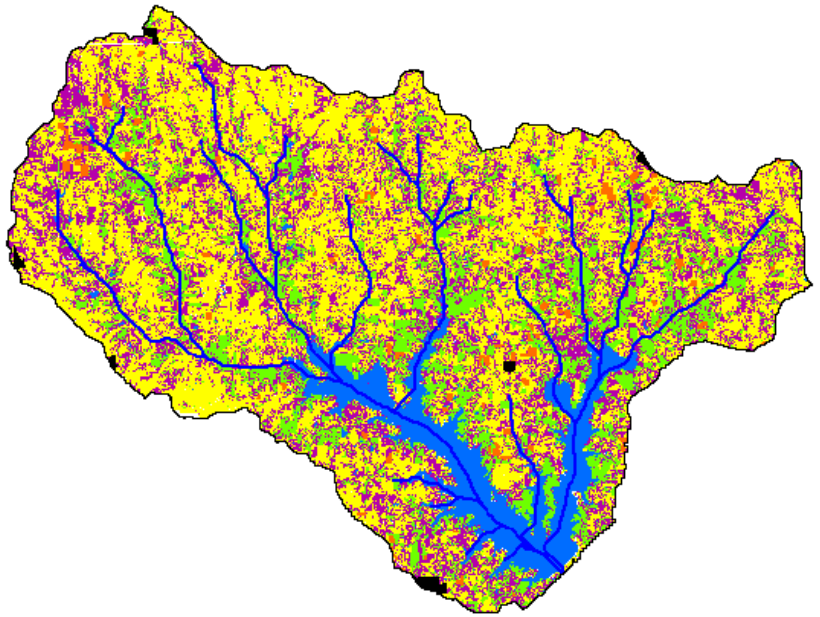
July 11, 2023

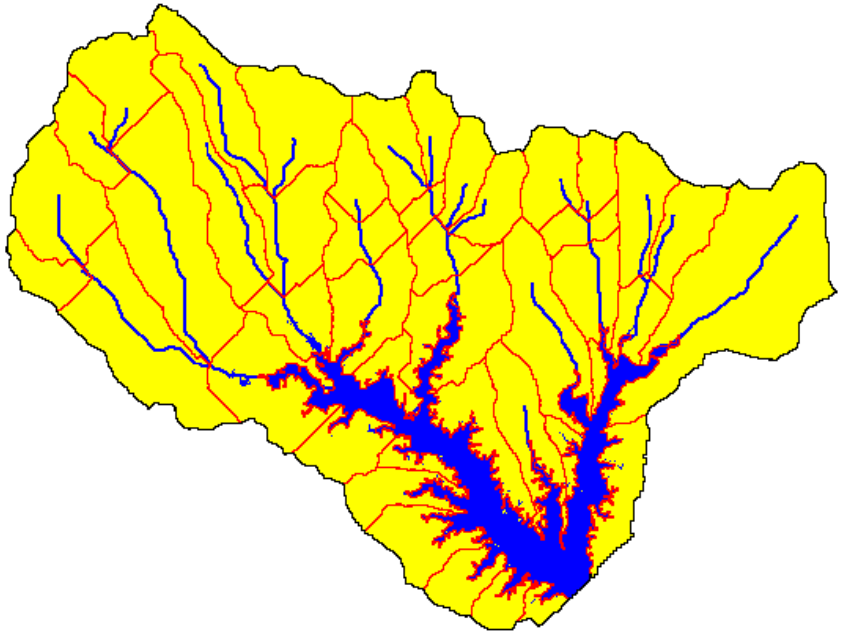
GODDARD EARTH SCIENCES

Part 1.1:
SWAT Model Overview & NASAaccess

Overview

- Setup of a SWAT model project (i.e., inputs, outputs, calibration, and verification)
- NASAaccess and its utility in processing remote sensing data for a SWAT model
- Analyze post fire water quality data simulated by a SWAT model





SWAT Configuration Examples

SWAT Overview

- A conceptual watershed-scale hydrological model designed to address water management, sediment, climate change, land use change, and agricultural chemical yield-related challenges.
- The development of SWAT is a continuation of the **USDA Agricultural Research Service (ARS)** modeling experience.
- In addition to the Agricultural Research Service and Texas A&M University, several federal agencies including the US Environmental Protection Agency, Natural Resources Conservation Service, National Oceanic and Atmospheric Administration, and Bureau of Indian Affairs have contributed to the model.

SWAT Soil & Water Assessment Tool

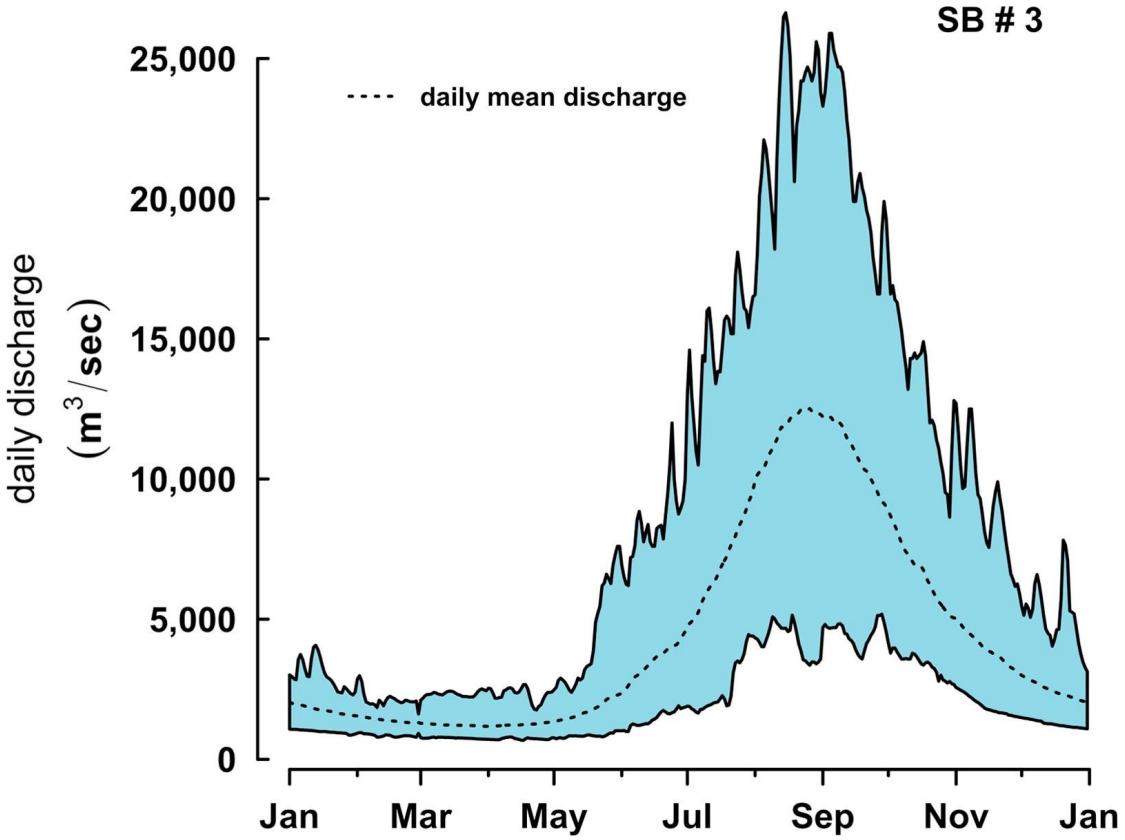
Arnold, J.G., et al., 2013

SWAT in a Few Lines…

SWAT Literature Database for Peer-Reviewed Journal Articles

- Applications range from field scale to watershed scale to continental scale.
- Components are hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management.
- Possible configurations cover cells, sub-watersheds, hydrologic response units, & point sources (e.g., treatment plants).

Hydrologic response units (HRUs) consist of homogeneous land use, management, and soil characteristics

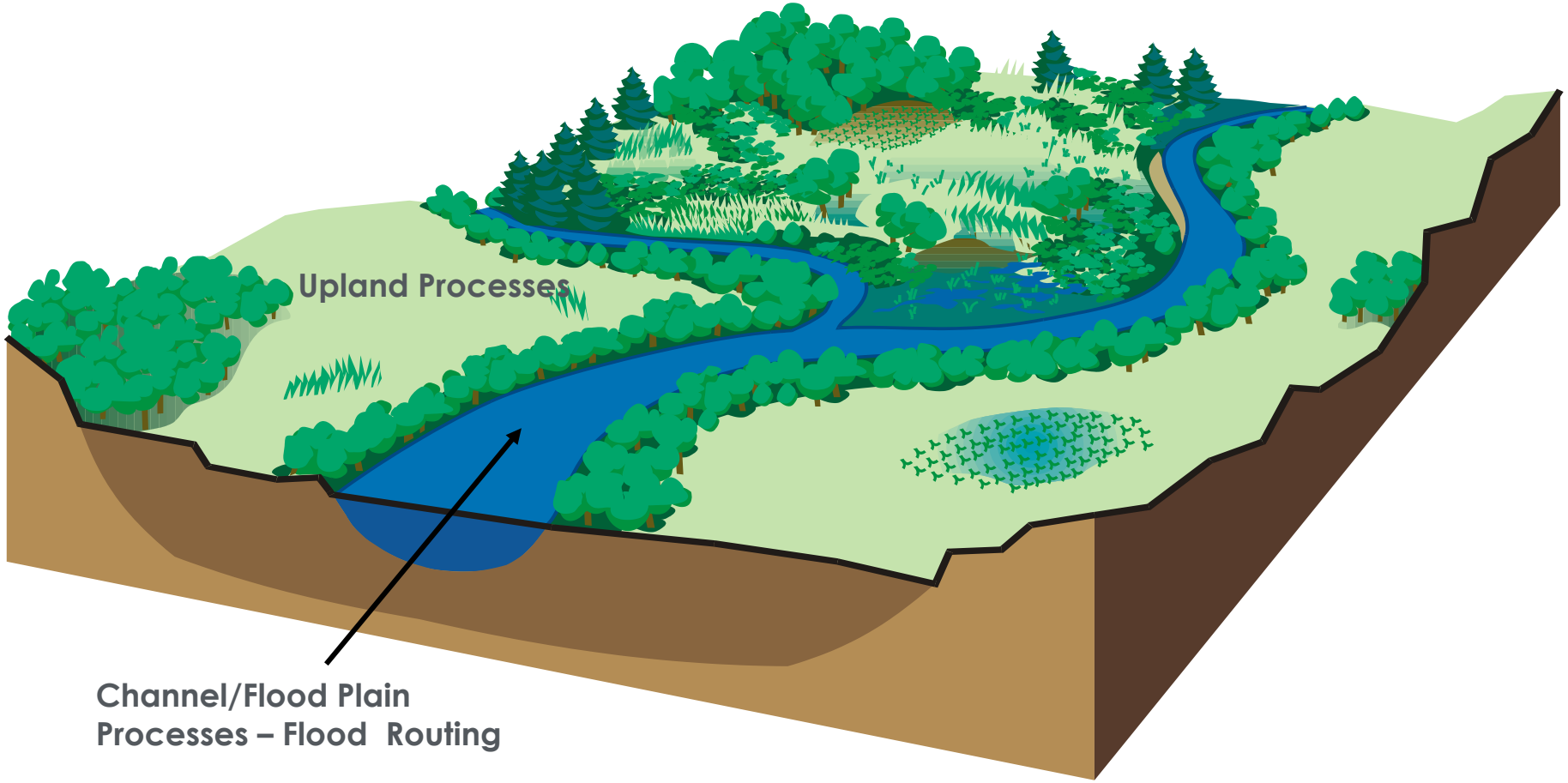


Vientiane, Laos, PDR (SB3) streamflow station hydrograph. Mean, minimum, and maximum daily discharge during 1913–2016 excerpts from (Mohammed et al., 2018).

Processes Covered by SWAT

Upland Processes Cover:

- Weather
- Hydrology
- Sedimentation
- Plant Growth
- Nutrient Cycling
- Pesticide Dynamics
- Soil Temperature
- Management
- Bacteria

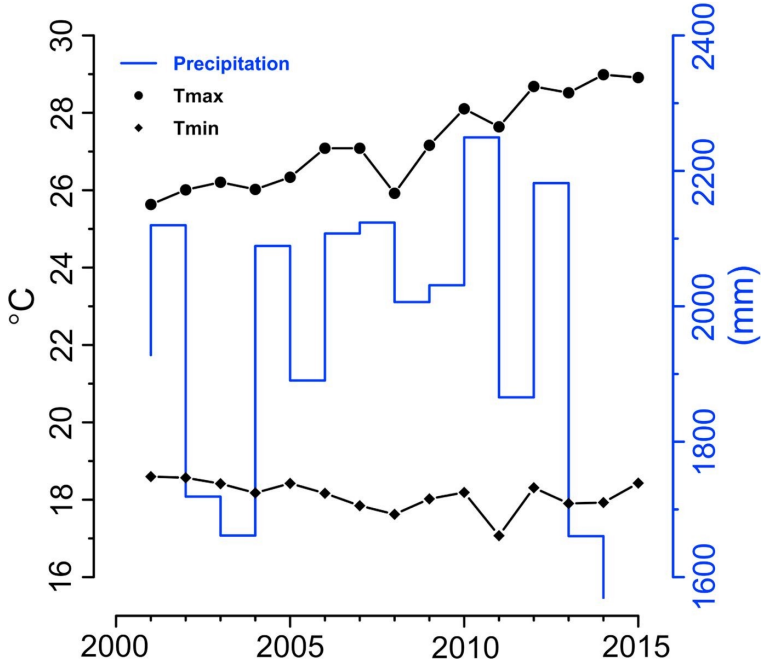


SWAT Watershed System

SWAT Input Data

- Spatial Data
  - DEM
  - Soil Information
  - Land Use Land Cover (LULC)
- Meteorological Data
  - Precipitation
  - Minimum and Maximum Air Temperatures
  - Solar Radiation
  - Wind Speed
  - Relative Humidity
  - Potential Evapotranspiration
- In-situ Observations (e.g., streamflow, sediment, reservoirs, treatment plants, etc.)

SWAT is a comprehensive model that requires a diversity of information in order to run. However, many of the inputs are used to simulate special features that are not common to all watersheds.



Lower Mekong basin time series data excerpts from Mohammed et al., 2018

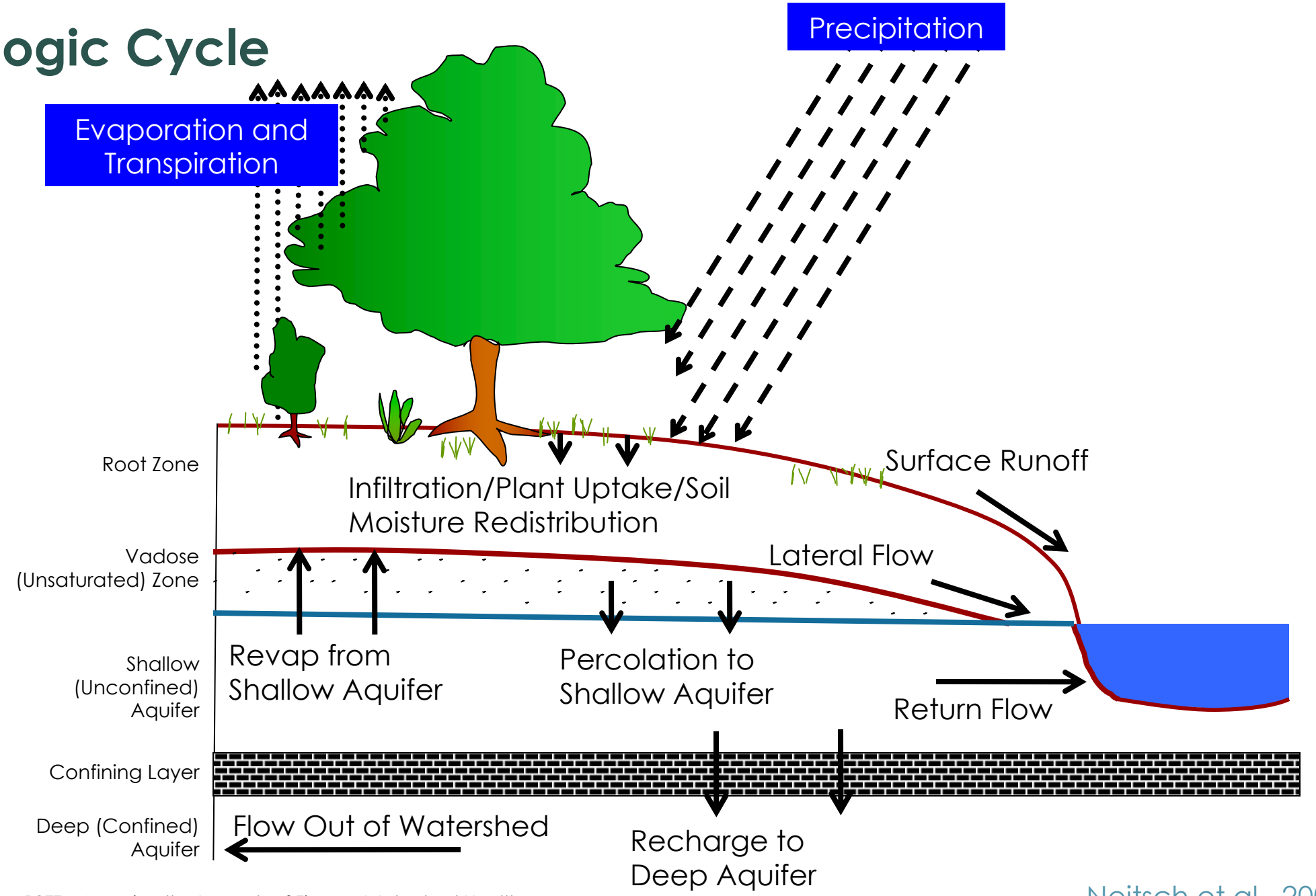
SWAT Output

- Detail of the data printed out in each file is controlled by the print codes in the master watershed file.
- Average daily values are always printed in the HRU, sub-basin, and reach files, but the time period they are summarized over will vary.
- Depending on the print code selected, the output files may include all daily values, daily amounts averaged over the month/year/entire simulation period.

File Description	File Name
Summary Input	input.std
Summary Output	output.std
HRU Output	output.hru
Sub-Basin Output	output.sub
Main Channel or Reach Output	output.rch
HRU Impoundment Output	output.wtr
Reservoir Output	output.rsv
Sediment Loads Output	output.sed

Several output files are generated in every SWAT simulation.

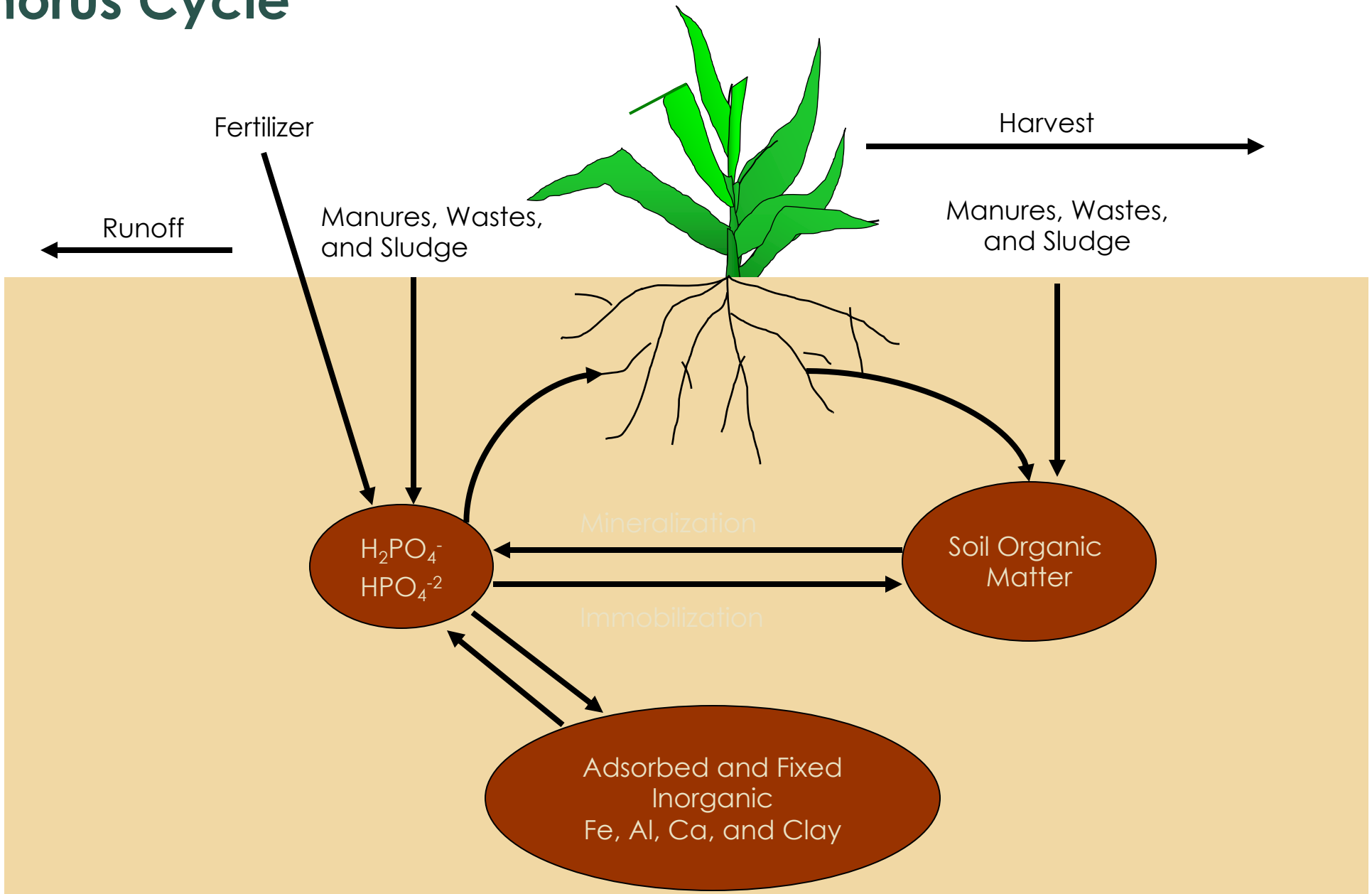
Hydrologic Cycle



Neitsch et al., 2005

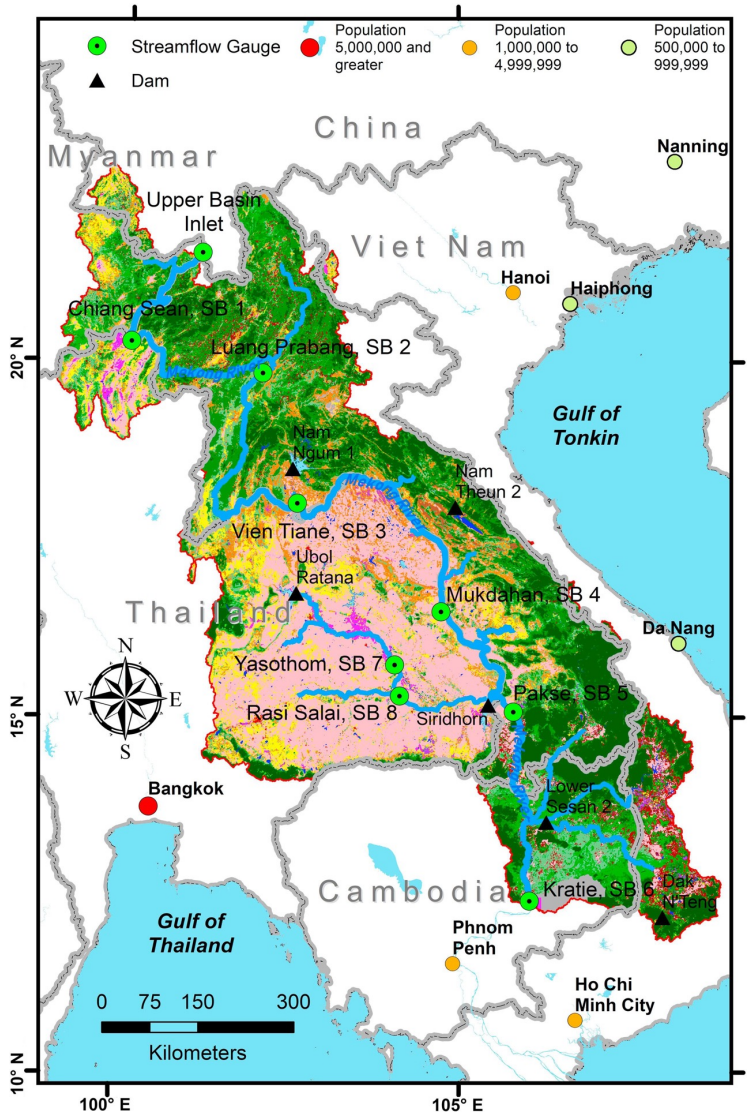
Phosphorus Cycle

Neitsch et al., 2005

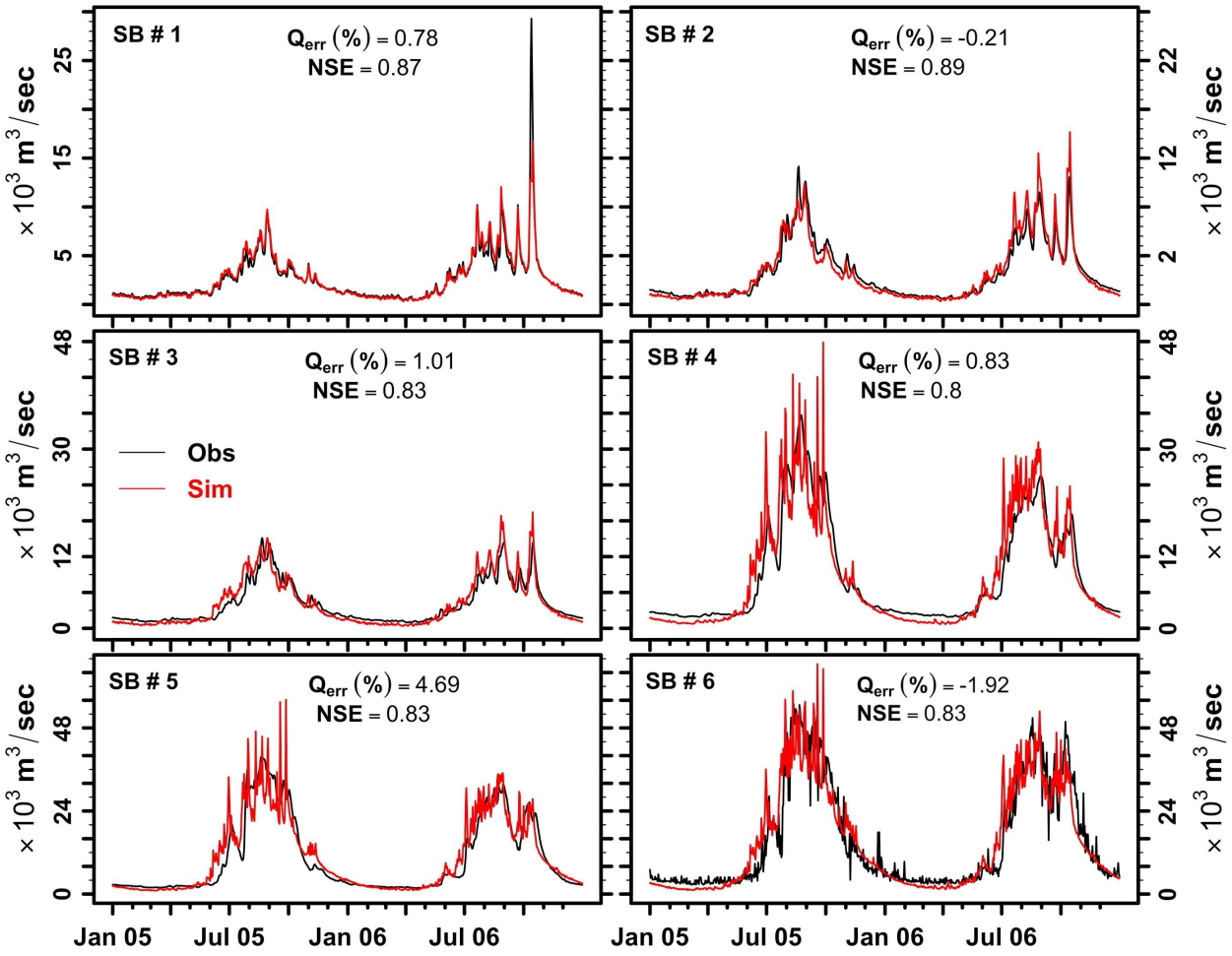


SWAT Model Calibration

SWAT uses many parameters to describe typical soil, plant growth, land cover, reservoir, and agricultural management characteristics.



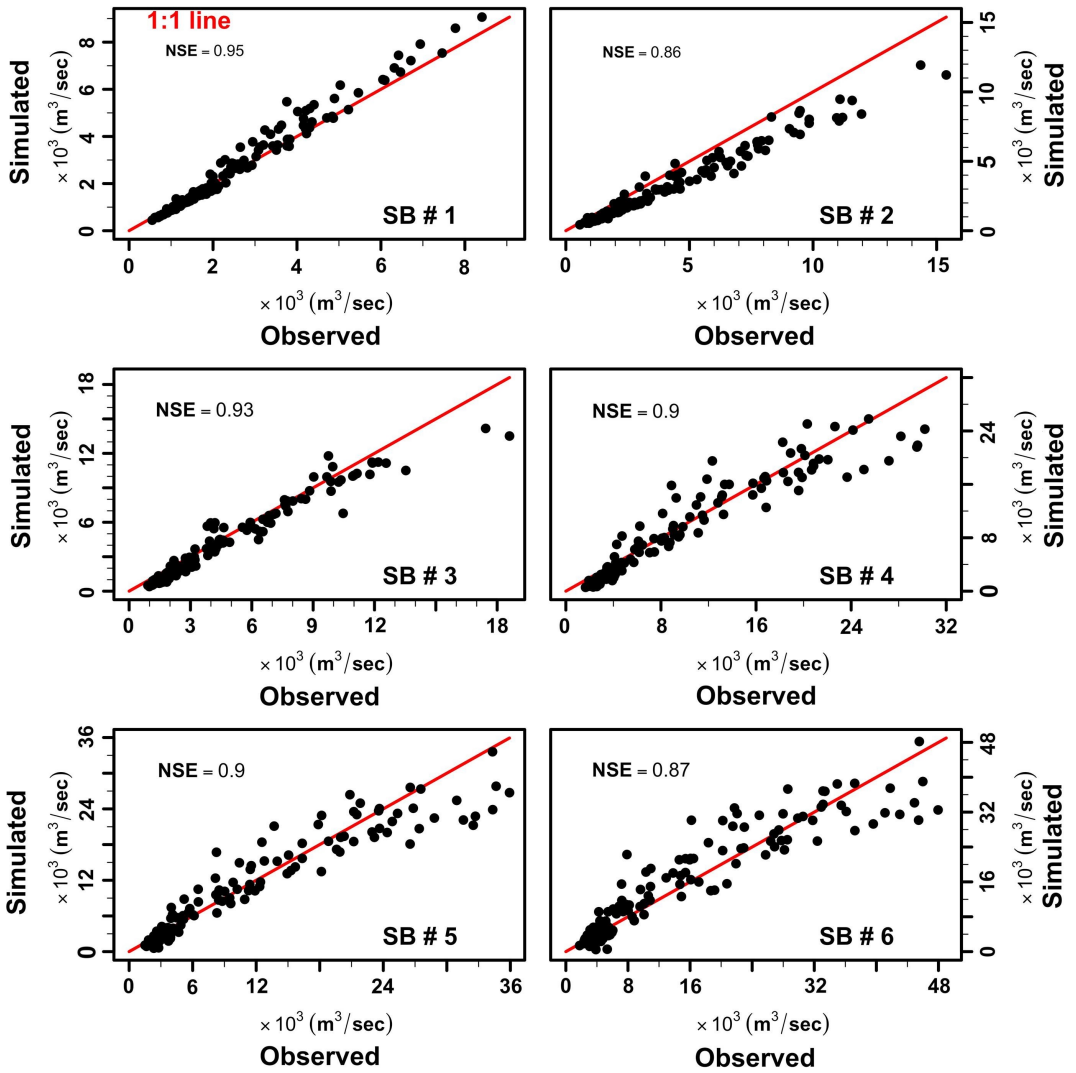
The Lower Mekong River Basin excerpts from (Mohammed et al., 2018)



Daily simulated and observed discharge in m^3/sec for the Lower Mekong River Basin (LMRB) at six sub-basin watersheds in calibration of the LMRB SWAT model excerpts from (Mohammed et al., 2018)

SWAT Model Verification

- Conducted after the SWAT model calibration step.
- Examine model behavior during times beyond the calibration period.
- Model verification gives assurance that the model is capable of simulating processes outside the training periods.

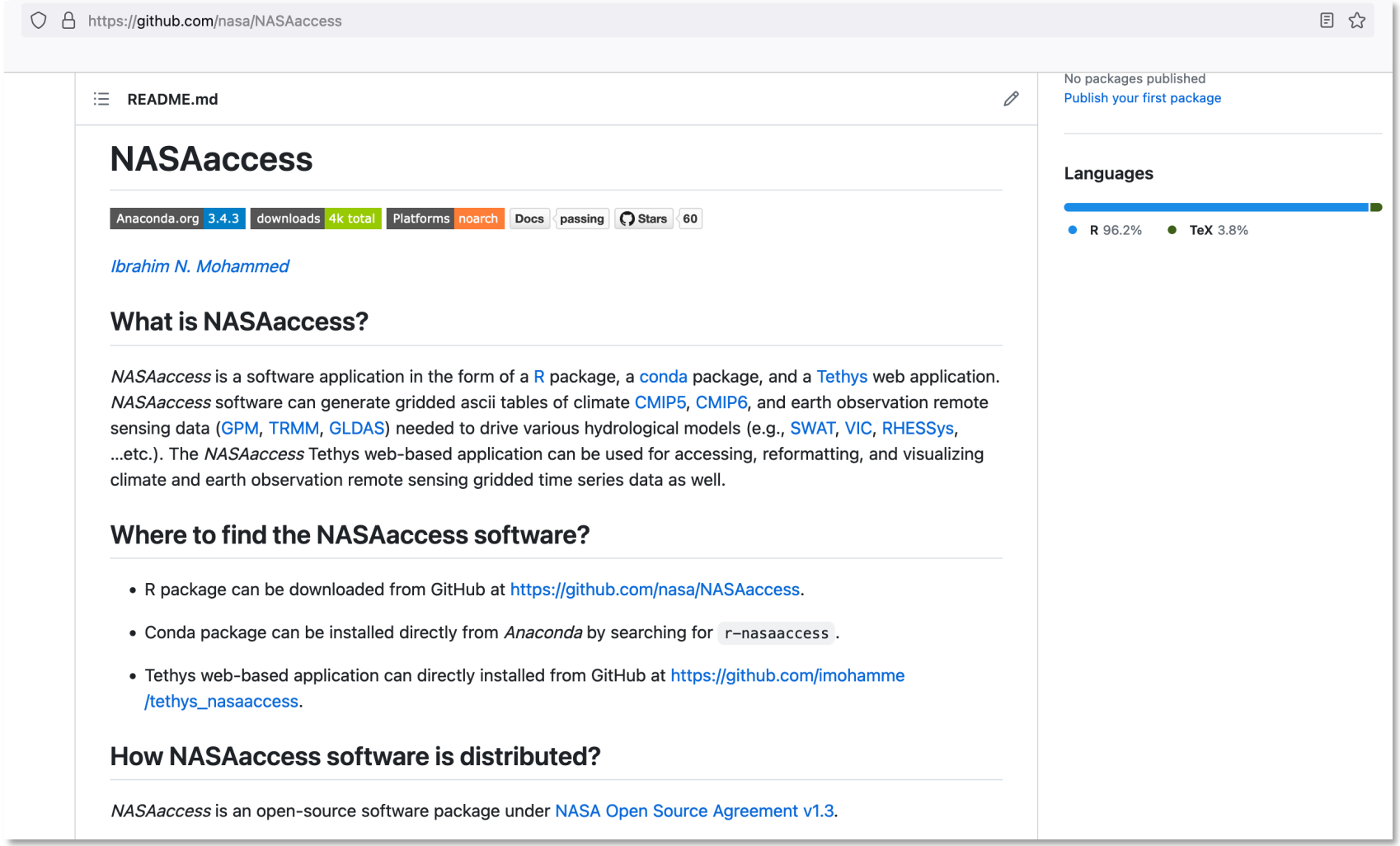


Scatterplot of monthly observed and simulated discharge in m^3/sec for the Lower Mekong River Basin (LMRB) at six sub-basin watersheds in validation of the LMRB SWAT model excerpts from (Mohammed et al., 2018)

Part 1.2:
NASAaccess

SWAT & Remote Sensing Data (NASAaccess)

- **NASAaccess** is an open-source platform for accessing and presenting quantitative remote sensing Earth observations and climate data products in an interactive format so that scientists, stakeholders, and concerned citizens can engage in the exploration, modeling, and understanding of the data.



This animation shows rain data collected by the GPM Core Observatory and the partner satellites currently in orbit on March 17, 2014. The end of the animation focuses in on a storm system that moved over the Eastern United States, showing GPM Microwave Imager data of rain and snow rates. This is the first time a single satellite has collected simultaneous data on rain and snow for a single storm.

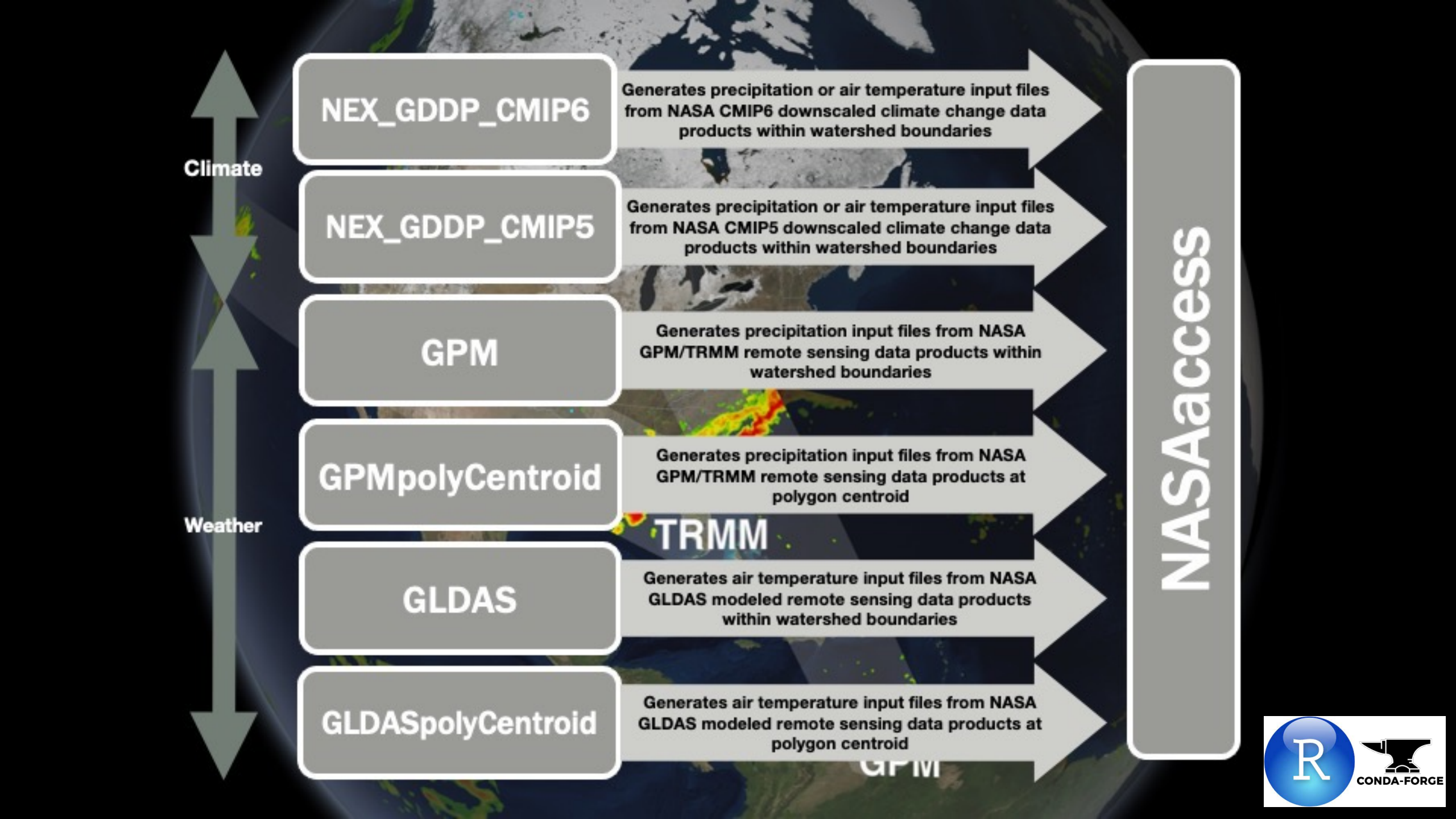
Animation Credit:

NASA's Scientific Visualization Studio
Data Provided by the joint NASA/JAXA GPM Mission

NASAaccess software program is developed for hydroclimatic applications.

- The web app and software package presented are modular and can be hosted anywhere (public or private servers).
- The NASAaccess tools presented give easy access and retrieval capabilities to weather and climate data for any watershed.
- The tools presented provide formatted data that can be seamlessly ingested into any hydrological model.

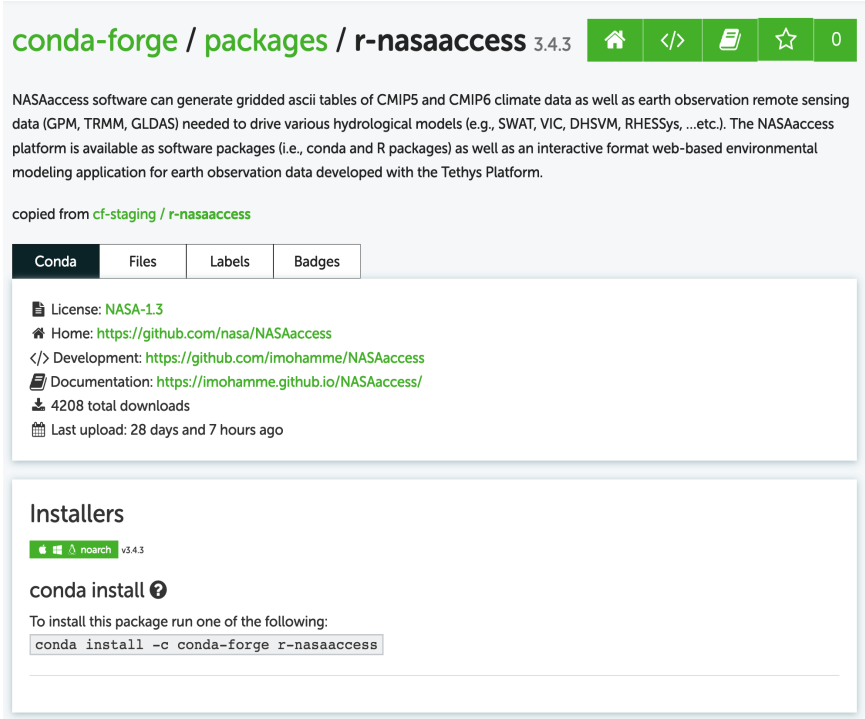
NASAaccess Tool Technical Note


Climate
Weather
NEX_GDDP_CMIP6
Generates precipitation or air temperature input files from NASA CMIP6 downscaled climate change data products within watershed boundaries
NEX_GDDP_CMIP5
Generates precipitation or air temperature input files from NASA CMIP5 downscaled climate change data products within watershed boundaries
GPM
Generates precipitation input files from NASA GPM/TRMM remote sensing data products within watershed boundaries
GPMpolyCentroid
Generates precipitation input files from NASA GPM/TRMM remote sensing data products at polygon centroid
TRMM
GLDAS
Generates air temperature input files from NASA GLDAS modeled remote sensing data products within watershed boundaries
GLDASpolyCentroid
Generates air temperature input files from NASA GLDAS modeled remote sensing data products at polygon centroid
NASAaccess
CONDA-FORGE

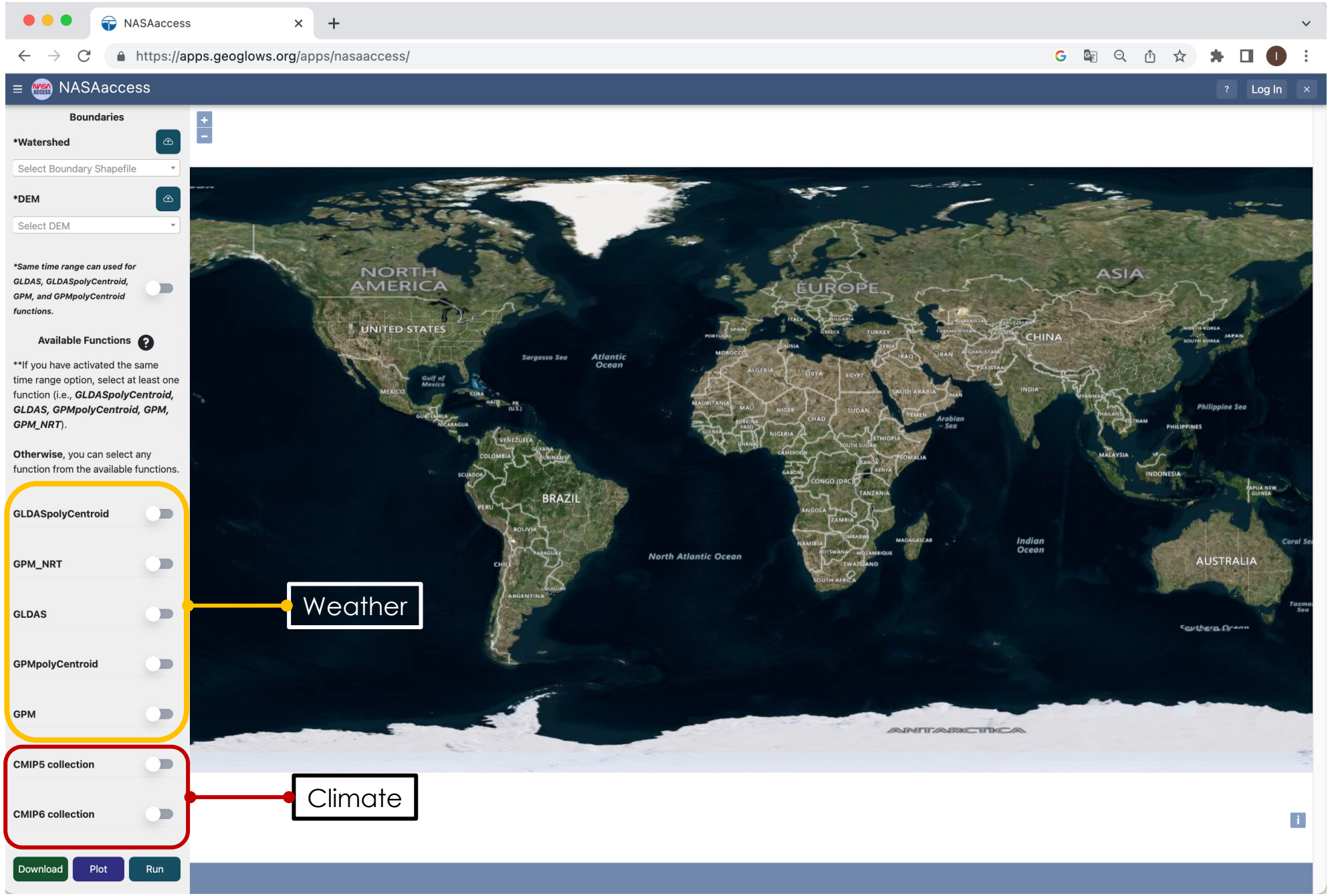
NASAaccess Benefits

- Bridging the gap for non-technically trained stakeholders and decision makers charged with water, climate, and environmental management decisions.
- Saving time for scientists tasked with analyzing weather and climate data as well as developing hydrological models.

NASAaccess R Library

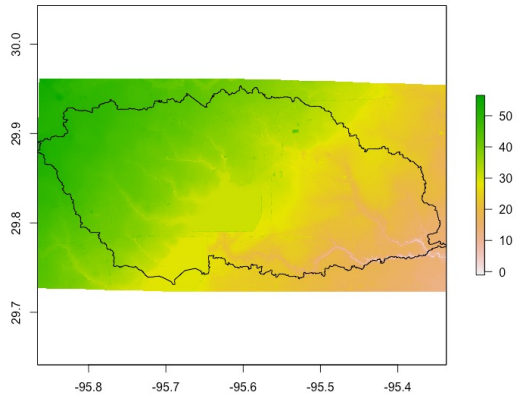


NASAaccess Conda Package


NASAaccess
https://apps.geoglows.org/apps/nasaaccess/
NASAaccess
Log In
Boundaries
*Watershed
Select Boundary Shapefile
*DEM
Select DEM
*Same time range can used for GLDAS, GLDASpolyCentroid, GPM, and GPMpolyCentroid functions.
Available Functions
**If you have activated the same time range option, select at least one function (i.e., GLDASpolyCentroid, GLDAS, GPMpolyCentroid, GPM, GPM_NRT).
Otherwise, you can select any function from the available functions.
GLDASpolyCentroid
GPM_NRT
GLDAS
GPMpolyCentroid
GPM
CMIP5 collection
CMIP6 collection
Download
Plot
Run
Weather
Climate
NORTH AMERICA
UNITED STATES
EUROPE
ASIA
CHINA
BRAZIL
AUSTRALIA
ANTARCTICA
North Atlantic Ocean
Indian Ocean
Atlantic Ocean
Sargasso Sea
Gulf of Mexico
Arabian Sea
Philippine Sea

GPM NRT Function Example

```
GPM_NRT
(
Dir = "./INPUT/",
watershed =
"./basin.shp",
DEM = "./dem.tif",
start = "2023-3-1",
end = "2023-3-19"
 )
```



EARTHDATA Find a DAAC

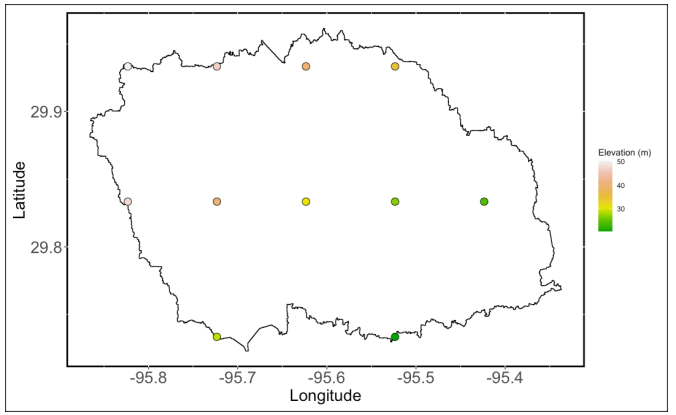
GES DISC

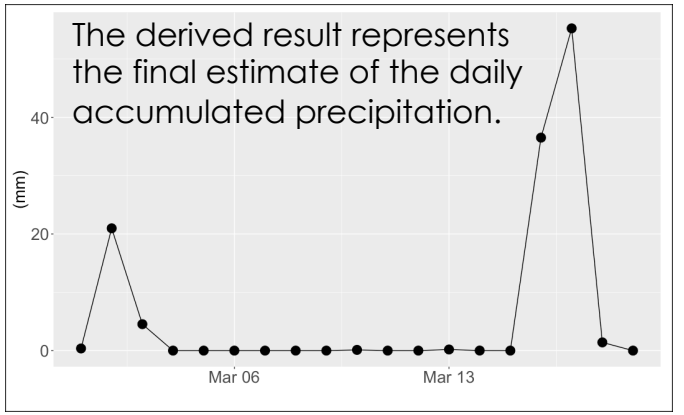
Atmospheric Composition, *Water & Energy Cycles* and *Climate Variability*

https://gpm1.gesdisc.eosdisc.nasa.gov/data/GPM_L3/GPM_3IMERGDE.06//2023/03/3B-DAY-E.MS.MRG.3IMERG.20230319-S000000-E235959.V06.nc4

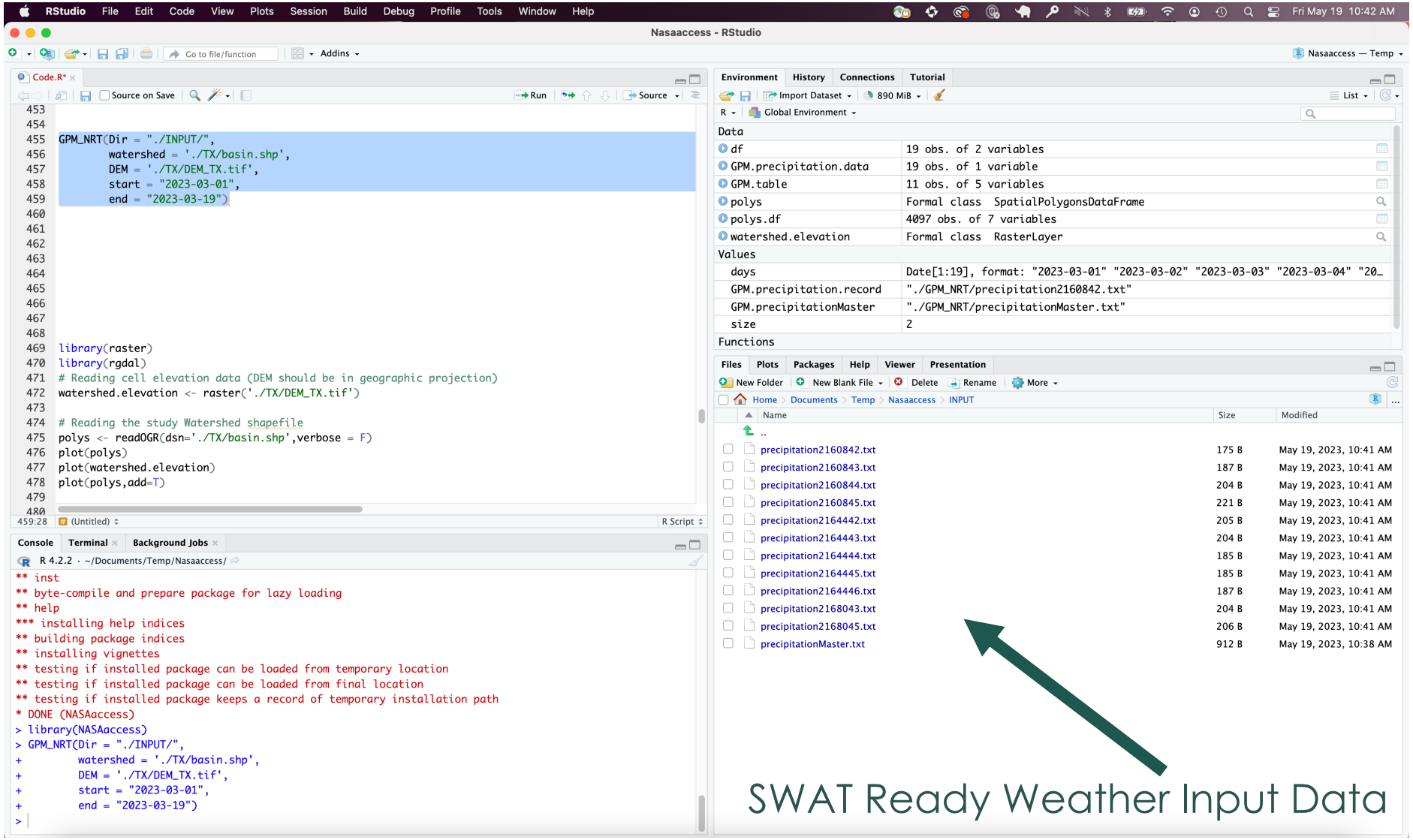
```
download.file
(
quiet = T,
method = "curl",
        url = paste(myurl, filenames[ll], sep = "") ,
destfile = paste("./temp/", filenames[ll], sep = ""),
mode = "wb",
        extra = "-n -c ~/.urs_cookies -b ~/.urs_cookies
-L"
)
```

GPM Level 3 IMERG *Early* Daily 0.1 x 0.1 deg (GPM_3IMERGDE) derived from the half-hourly GPM_3IMERGHHE.

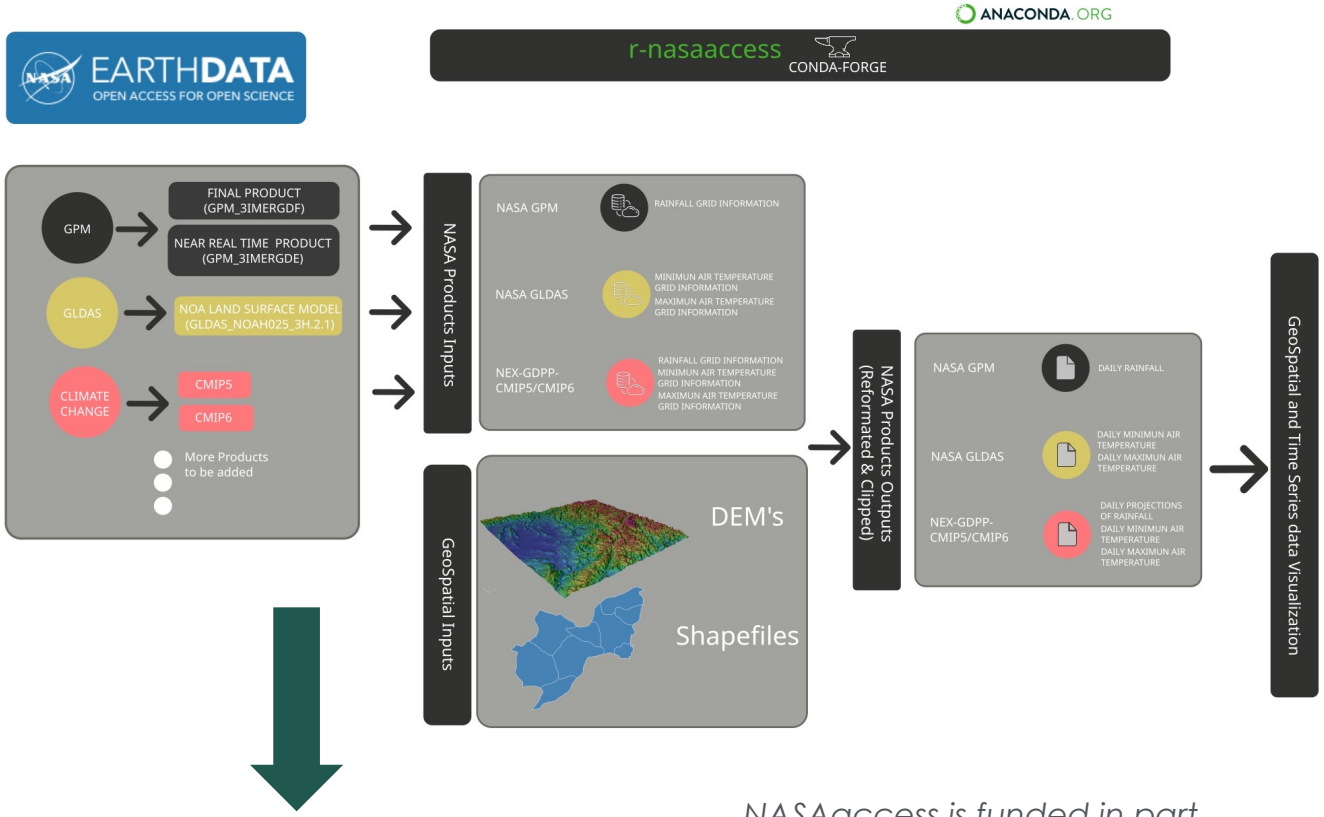




GPM NRT Function Example (2)



NASAaccess Flow Chart

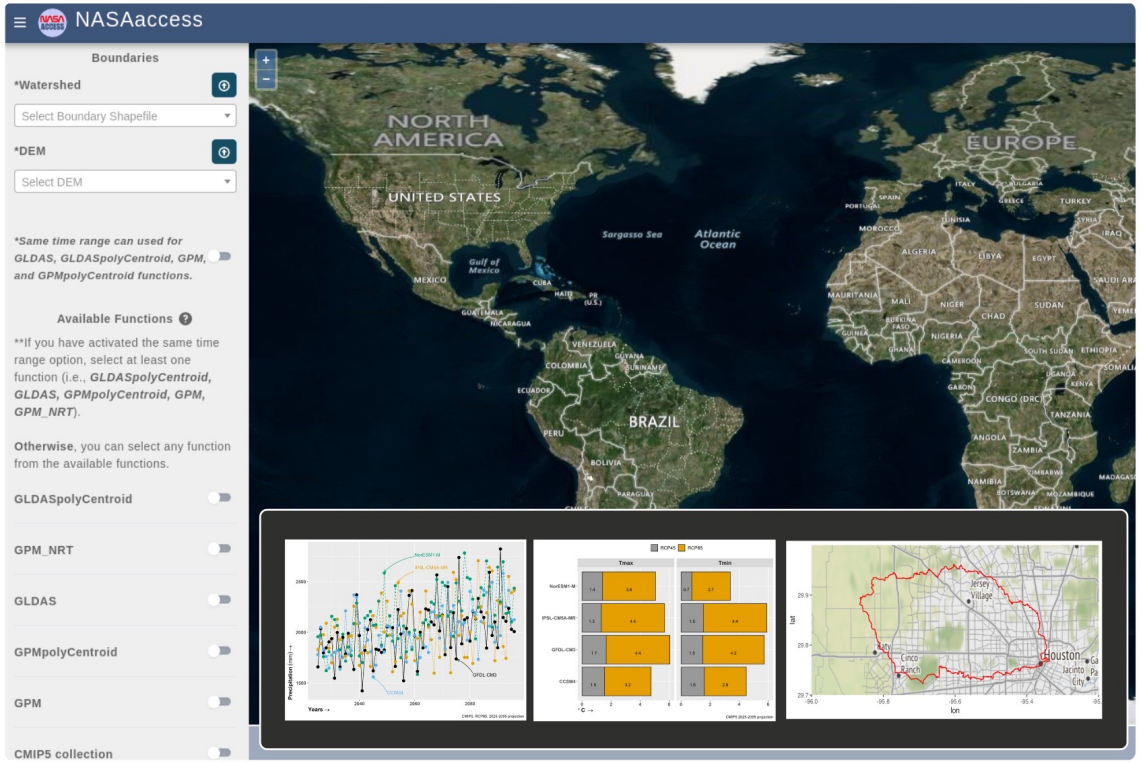


[Guide & Materials]

NASAaccess is funded in part by SERVIR, and NASA SHARE.

GitHub

Tethys Software Development Kit



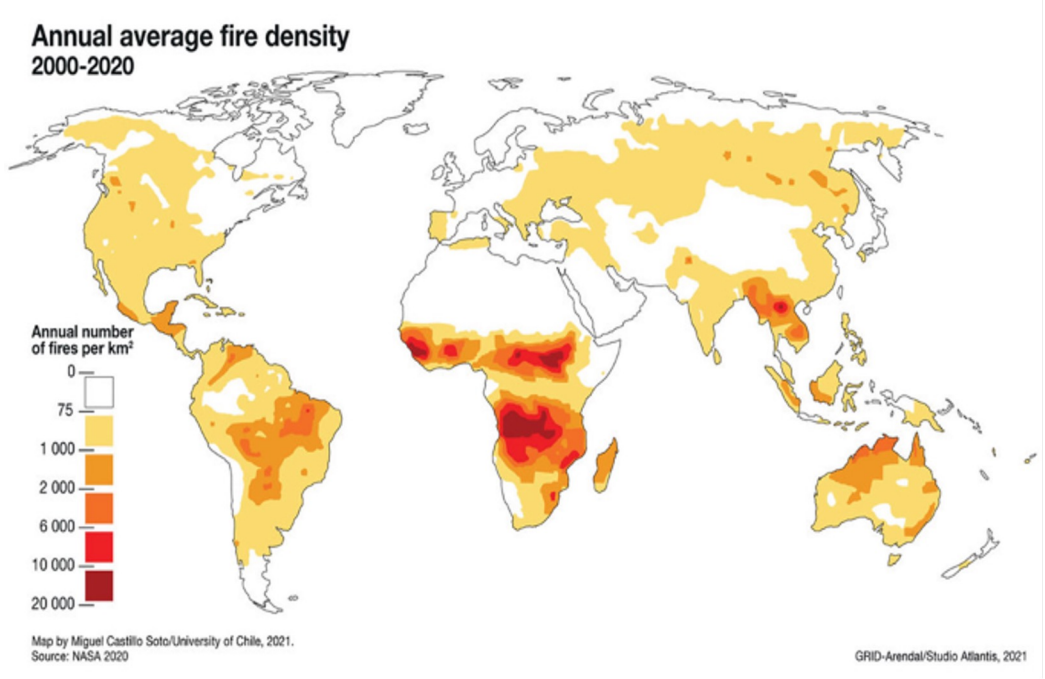
- *NASAaccess* is a software application in the form of an R package, a conda package, and a web application.
- *NASAaccess* software can generate gridded ascii tables of climate CMIP5, CMIP6, and weather data (GPM, GLDAS) needed to drive various hydrological models (e.g., DHSVM, SWAT, VIC, RHESSys, …etc.).
- NASAaccess web application has visualization capabilities that can aid users to examine various NASA remote sensing products.

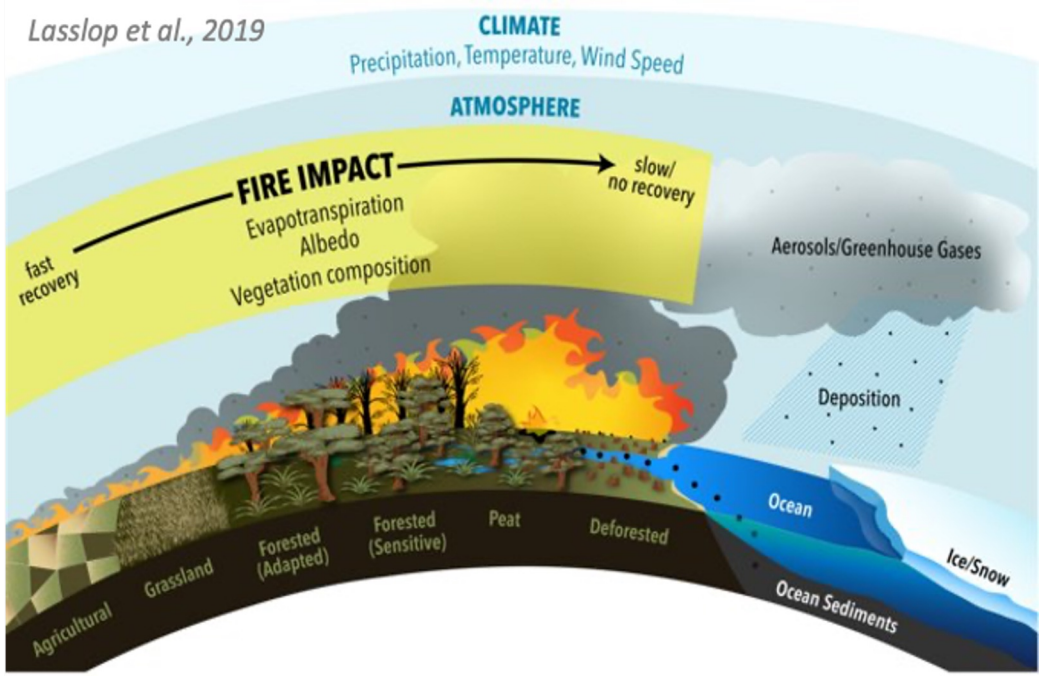
Part 1: Summary

- The Soil & Water Assessment Tool (SWAT) is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change.
- SWAT is physically based, computationally efficient, and capable of continuous simulation over long time periods.
- SWAT is a comprehensive model that requires a diversity of information in order to run. However, many of the inputs are used to simulate special features that are not common to all watersheds.
- NASAaccess is an open-source platform for accessing and presenting quantitative remote sensing earth observations and climate data products. NASAaccess can be used to ingest Earth remote sensing data into a SWAT model.

Part 2:
Fire Impacts on Watershed Health

Fire Impact





- Wildfires are increasing in frequency and severity globally.
- **Burned Watersheds:** Reduced vegetation cover/infiltration and increased erosion/runoff
- How are hydrologic processes impacted by wildfire?

Soil and Water Assessment Tool

- Watershed Model: Soil and Water Assessment Tool (SWAT)
- Simulate discharge & sediment loads
- In situ data used for model calibration/validation

Step 1 Covered in This Session

Model Inputs 1
- Elevation
- Land & soil cover
- Climate data (precipitation, air temperature)

Model Outputs 2
- Discharge
- Sediment loads

Model Calibration 3
- *In situ* & simulated data compared
- Model parameters tuned until sufficient matchup is achieved

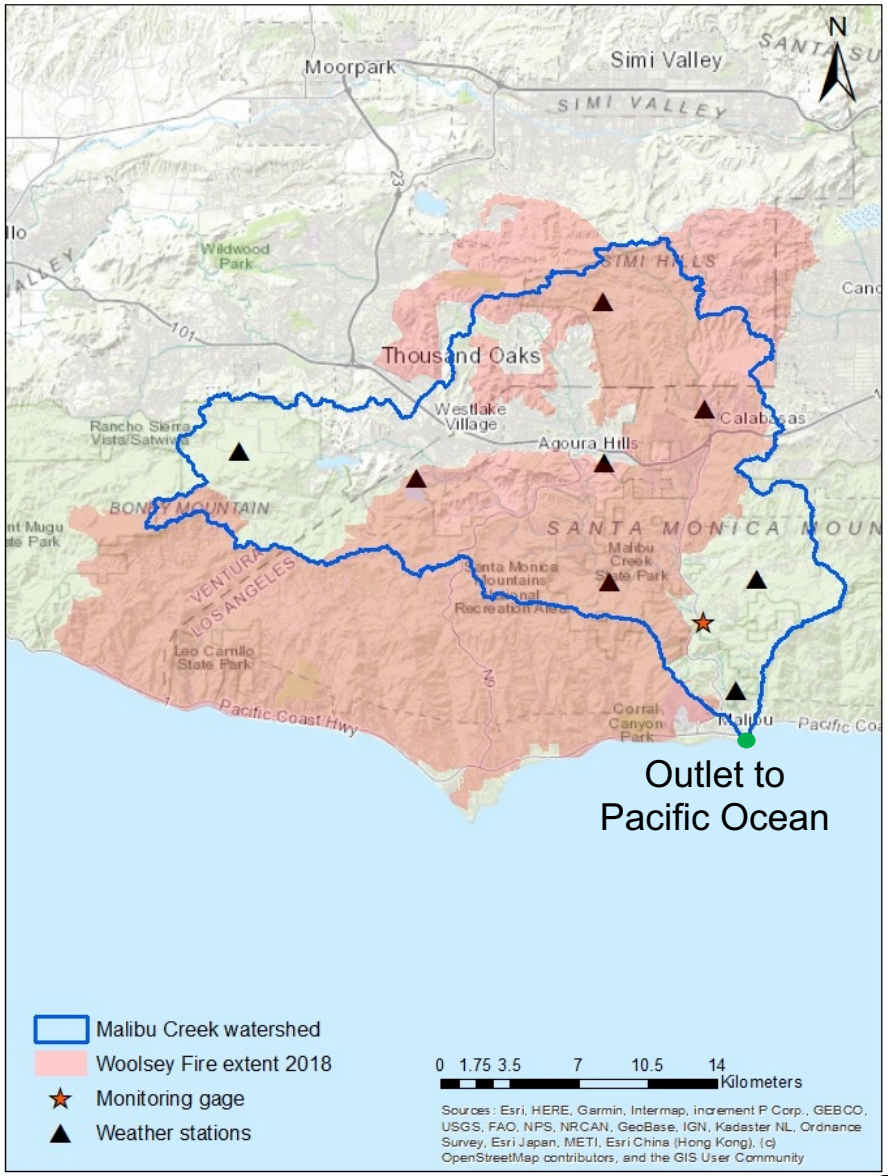
Model Validation 4
- *In situ* & simulated data compared
- No model parameters tuned
- Confirm sufficient matchup is achieved

Interpret Model Output 5

SWAT Example

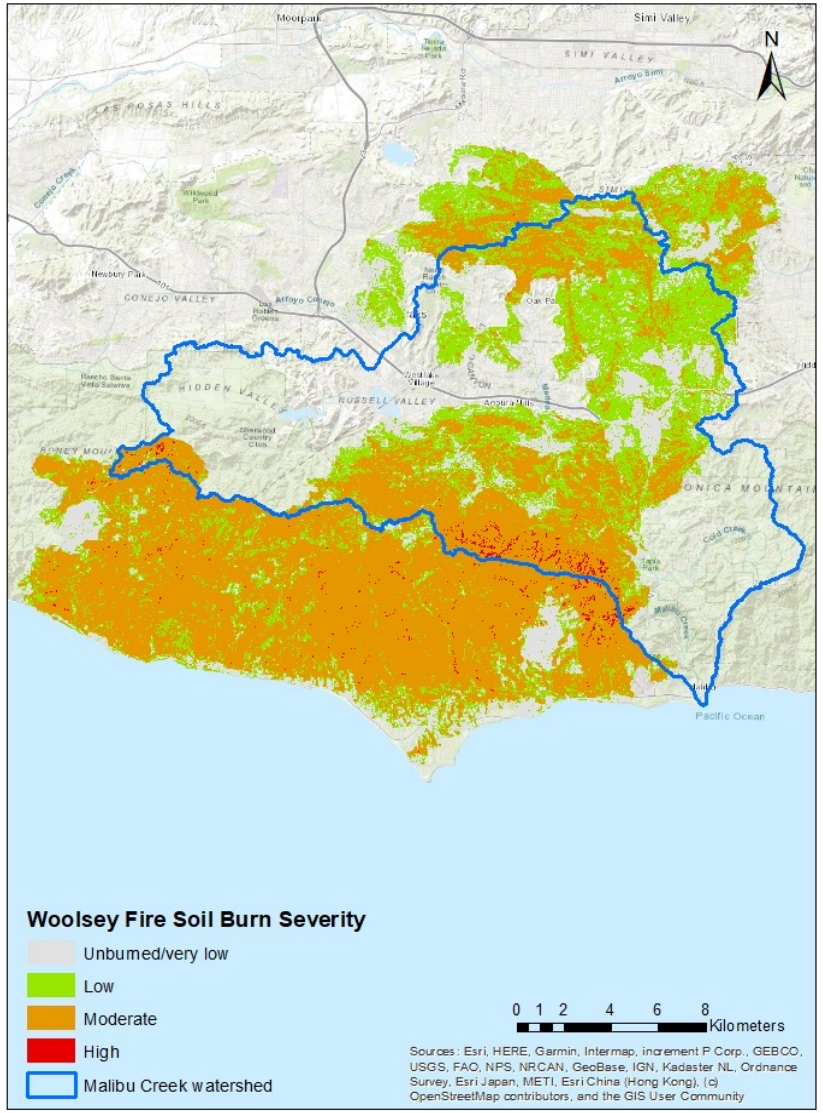
- Woolsey Fire November 2018 near Malibu, CA
- Malibu Creek watershed
- SWAT Input Datasets:

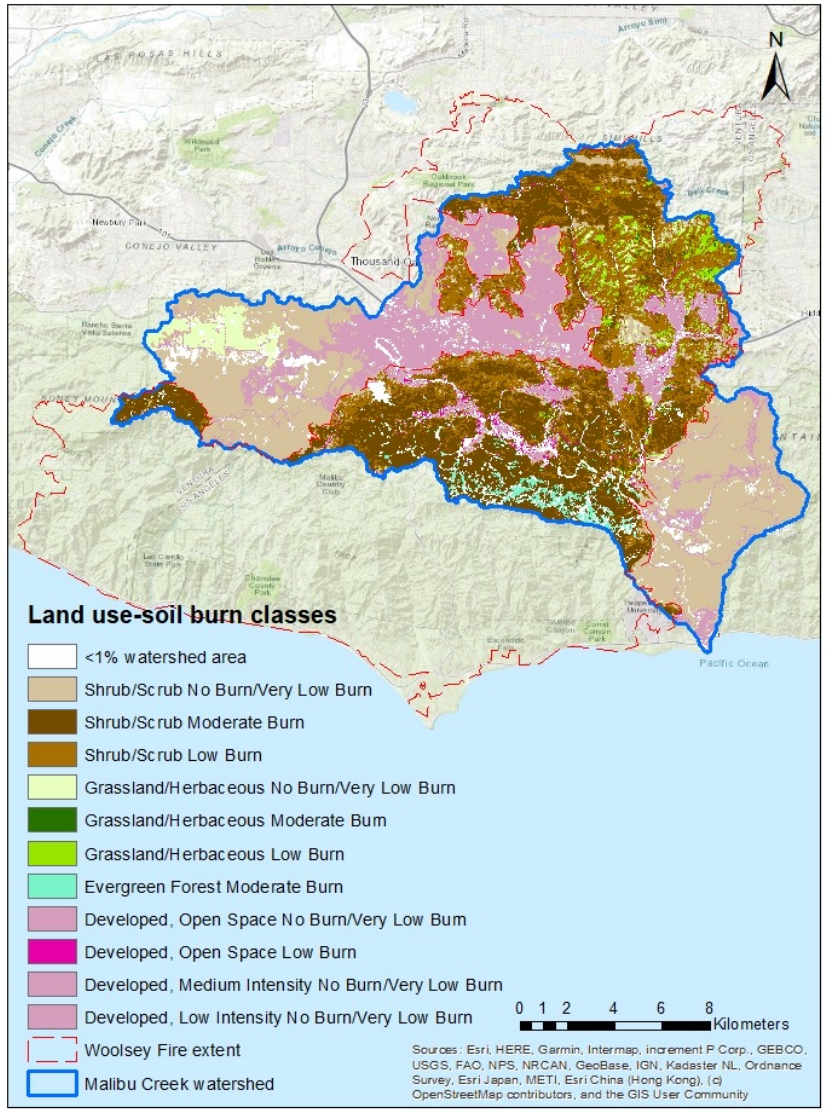
SWAT Input	Data Source
Elevation (digital elevation model)	USGS National Elevation Dataset
Pre-fire land cover	USGS National Land Cover Database (2016)
Post-fire land cover	National Land Cover Database 2016 **plus** California Geological Survey **Soil Burn Severity**
Soil cover	STATSGO2 USDA Natural Resources Conservation Service
Precipitation (mm)	PRISM Climate Group Oregon State University
Temperature (Celsius)	PRISM Climate Group Oregon State University



Create Post-Fire Land Cover Layer

- Overlay pre-fire land cover layer and burn severity map to **create post-fire land cover layer**
- Re-classify land covers to include burn severity identifier where applicable
- **Example:** Pre-fire "Forest" that was low burned would become "Forest Low Burn"





Modify SWAT Parameters to Reflect Fire

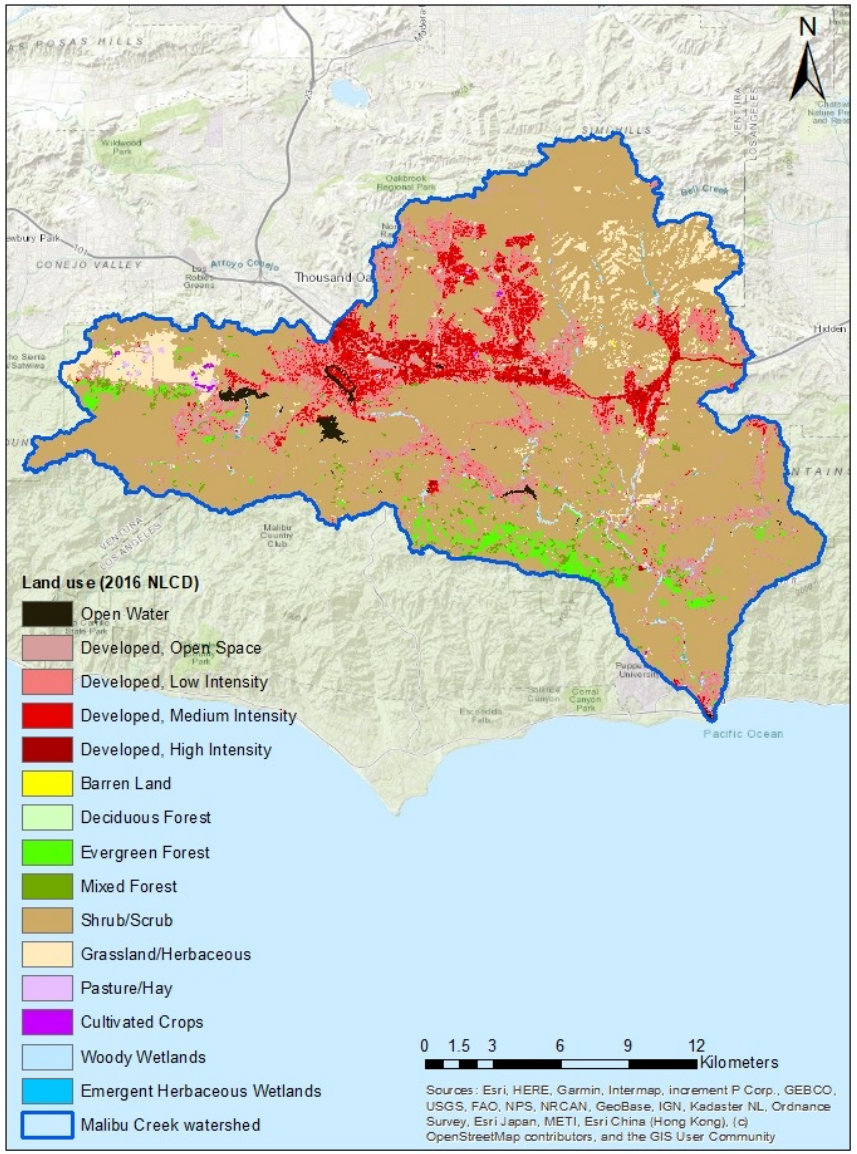
- Modify parameters in burned land cover classes included in the post-fire land cover layer
  1. Curve Number (CN) – Soil Permeability, Land Use, Soil Moisture
  2. K Factor in Modified Universal Soil Loss Equation – Soil Erodibility
  3. Leaf Area Index (LAI) – Evapotranspiration/Plant Canopy Cover

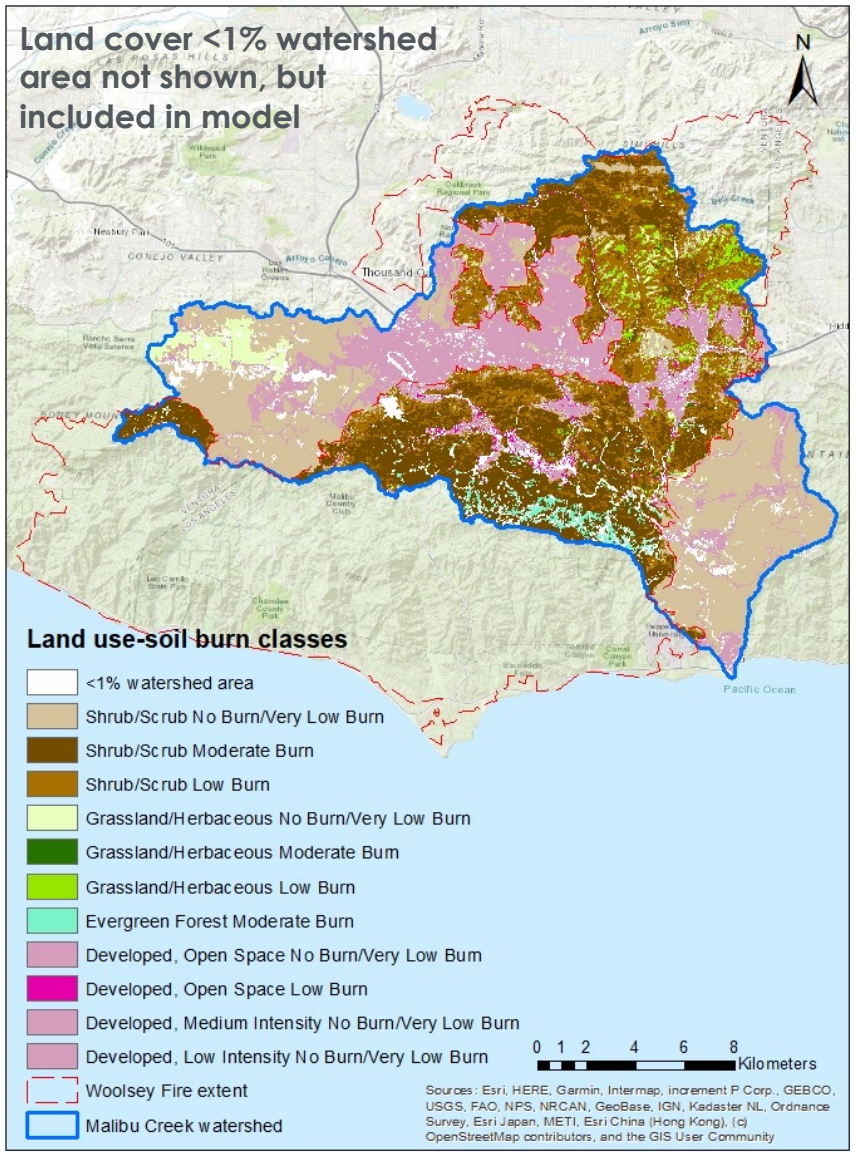
- Increase CN and K Factor: Increase Surface Erosion and Runoff

- Reduce LAI Parameters: Vegetation Loss
  - Maximum Potential LAI (BLAI)
  - Initial LAI (LAI_INIT)
  - Minimum LAI for Plant During Dormant Period (ALAI_MIN)

Fire Simulation in SWAT

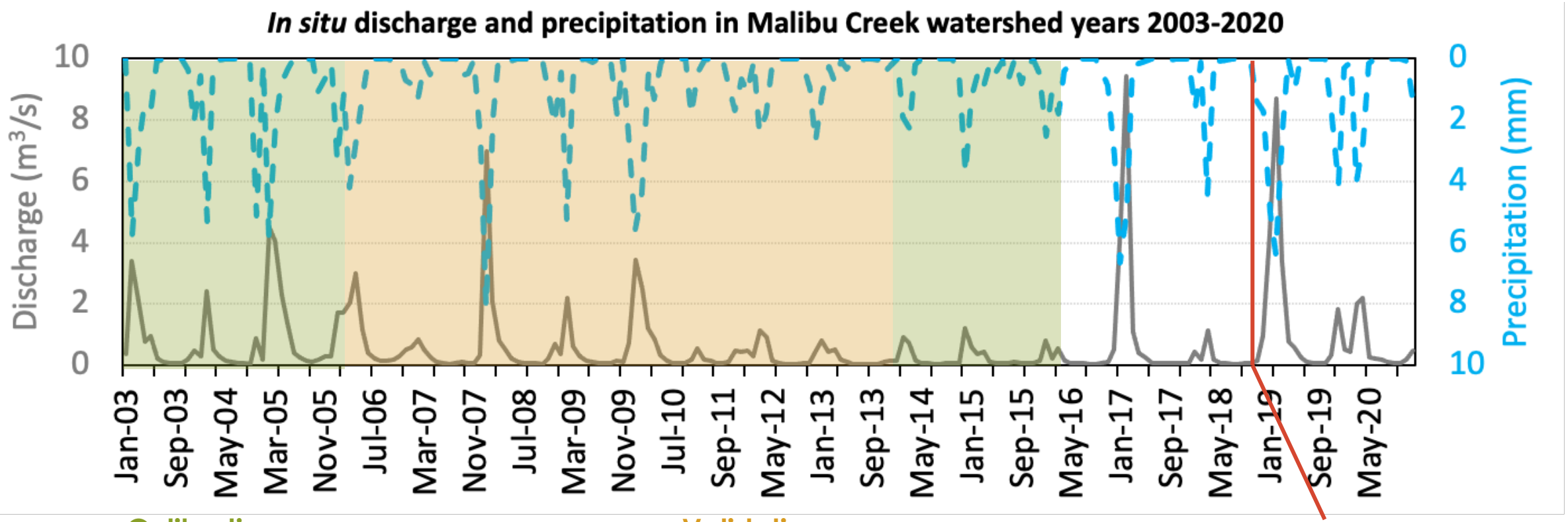
- SWAT Land Use Update Tool
- Switches land cover input from pre-fire to post-fire during model simulation
- Requires creation of land use change input/output files
  - SWAT_LUC
  - Purdue SWAT Tools LUU
  - SWAT LUT





Best Practices for Calibrating/Validating SWAT Model

- Separate in situ data into two groups, one for calibration and one for validation
- Groups should have similar wet/dry seasonality and discharge



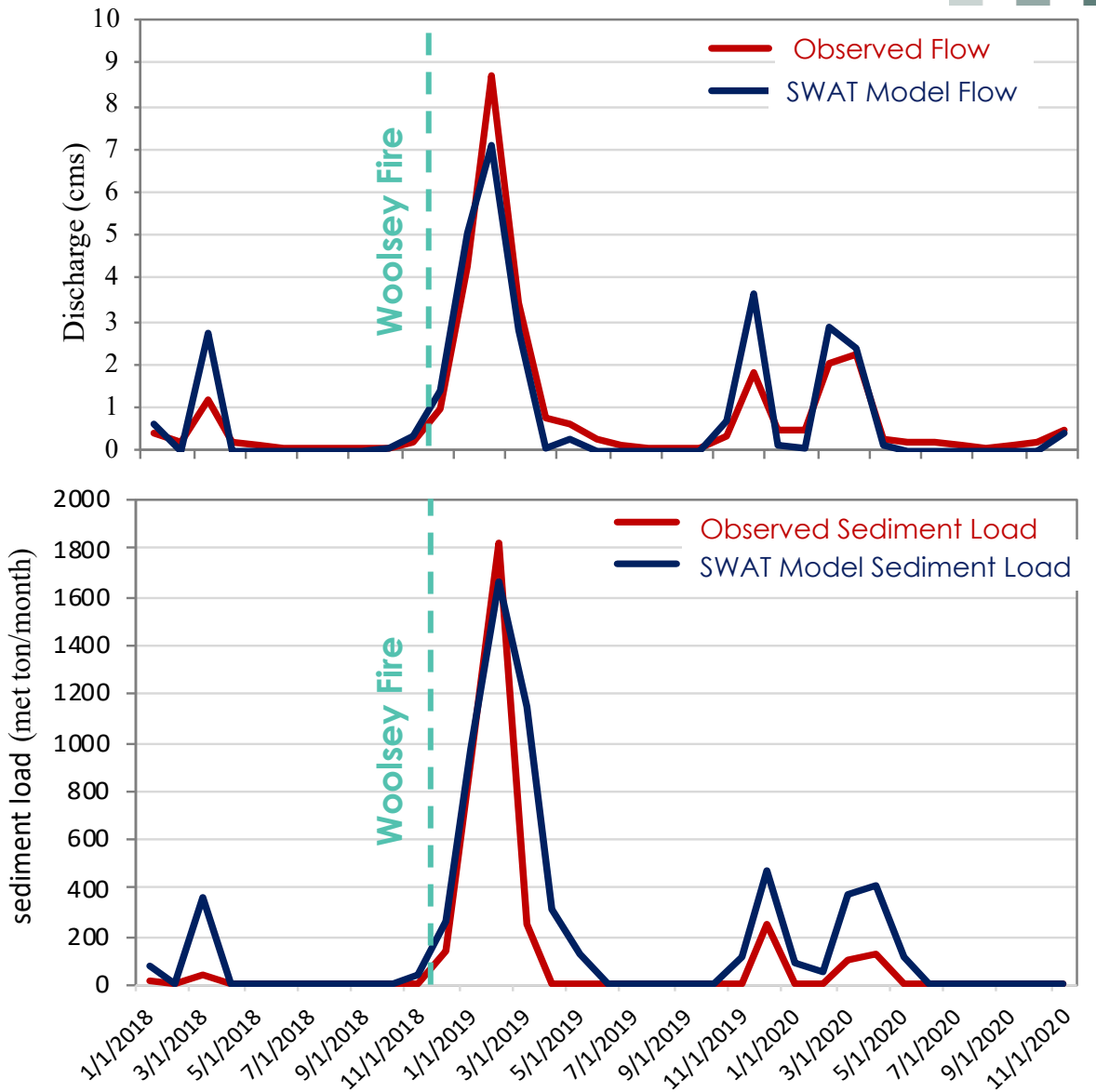
Calibration
Average Discharge: 0.58 m^3/s
Std. Deviation Discharge: 0.97 m^3/s

Validation
Average Discharge: 0.55 m^3/s
Std. Deviation Discharge: 0.96 m^3/s

Woolsey Fire
November 2018

Post-Woolsey Fire SWAT results

- Post-fire rain event
- Increased discharge and sediment loads
- SWAT captures fire-related changes in the first ~1 year following fire (2019)
- SWAT overestimates peaks in discharge and sediment in 2020
  - **Potential fire recovery?**
  - Re-tune model parameters for 2020?



Using SWAT to Evaluate Fire Impacts on Watershed Health

- Previous work demonstrated increases in SWAT estimated post-fire stream discharge, sediment loads, and other water quality parameters.
- 2017 Fires, Zezere River, Portugal (Basso et al., 2020)
  - Nitrate and phosphate increased near and/or above regulatory limits
- Cache la Poudre Watershed, Colorado, USA (Havel et al., 2018)
  - Increased runoff, particularly peak flows post-fire

TABLE 4 Soil water assessment tool (SWAT) predictions of hydrological processes (annual amounts) under the scenarios with and without wildfire, at the subbasin and at the watershed scale

	Subbasin		Watershed (inflow to the reservoir)	
	Unburned	Wildfire	Unburned	Wildfire
Annual runoff (mm)	72	177	349	542
Annual total streamflow ($m^3\ yr^{-1}$)	6.598×10^{10}	7.108×10^{10}	9.954×10^{11}	9.979×10^{11}
Runoff coefficient (–)	6%	16%	–	–
Annual erosion (ton yr^{-1} ha^{-1})	1.53	1.74	0.75	1.44
Average nitrate concentration (mg NO_3-N L^{-1})	0.035	0.214	0.039	1.721
Annual nitrate export (mg NO_3–N L^{-1})	12.72	78.08	14.38	628.53
Average phosphate concentration (mg P L^{-1})	0.001	0.010	0.032	0.257
Annual phosphate export (mg P L^{-1})	0.36	3.55	11.71	94.15

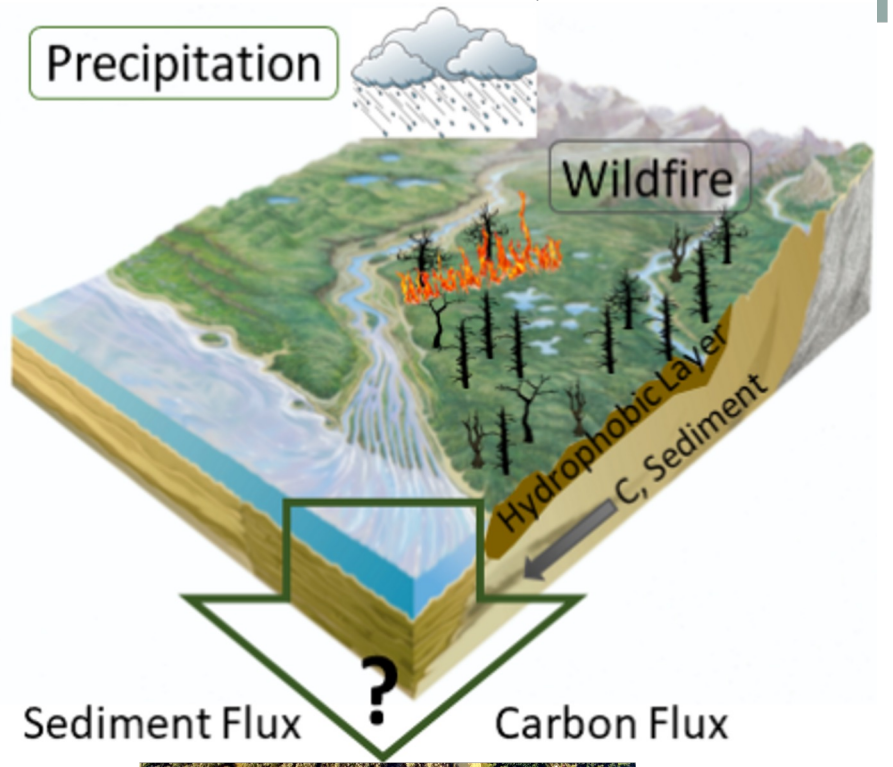
Basso et al., 2020

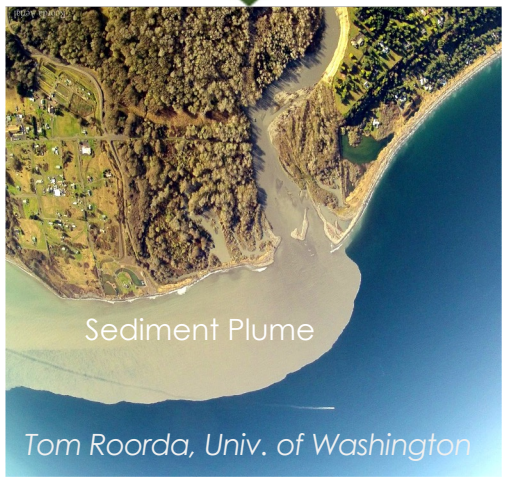
Part 2:
Summary

Summary

- Fires have been shown to increase streamflow, sediment loads, and nutrient loads (i.e., nitrogen, phosphorous) in watersheds.
- SWAT can be used to quantitatively constrain fire-related increases in water quantity and quality parameters.
- **This application of SWAT is relatively new. There is the potential to continue development.**

Modified from D. Avouris and E. Hestir, UC Merced





Looking Ahead to Part 3

Part 3 will focus on:

- Identifying global socioeconomic datasets and land cover products useful for assessing the impact of fire on population, infrastructure, and land use & land cover types
- Acquiring land use & land cover maps for a watershed of interest
- Evaluating the severity of post-fire burns within a watershed of interest

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on July 13, 2023
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by July 27, 2023**
  - Parts 1 and 3 will include hands-on exercises to assess pre-fire risk and post-fire impact on a watershed using Google Earth Engine. **You will be instructed to submit results of these exercises via Google Folder by July 27, 2023.**

- **Certificate of Completion:**
  - Attend all three live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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- ARSET Website
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Resources

- SWAT Model Home page
- SWAT 2012 Input/Output Documentation
- SWAT Literature Database
- SWAT LUC
- Purdue SWAT Tools LUU
- SWAT LUT
- SWAT-CUP for SWAT model calibration
- NASAaccess Tool
- NASAaccess Tool Technical Note

Prerequisites

- SWAT Model Software and Documentation
- Create Earthdata Account & Link GES DISC with your Account
- NASAaccess Data Tool


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!