MRCFFG System Development and Theoretical background
Soil Moisture & FFG Modeling

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Phnom Penh, Cambodia

FFGS Terminology

- **Flood** - occurrence of a flow event that overtops the natural or artificial banks in a reach of river channel.
- **Flash Flood** – a flood that follows shortly after rainfall event.
- **Bankfull Flow** - a flow in which the water level is at the top of its banks and further rise would result in inundation of the flood plain.
- **Flash Flood Guidance (FFG)** – the volume of spatially uniform precipitation of a given duration (1-6 hours) over a certain small catchment that is required to cause minor flooding in the draining outlet of the catchment.
- **Threshold Runoff** – rainfall depth in a given duration that is needed for the flow at the basin outlet to exceed bankfull flow when the basin is in near saturation conditions.
- **Flash Flood Threat** – rainfall of a given duration in excess of the corresponding Flash Flood Guidance value

Large River Flooding vs. Flash Flooding

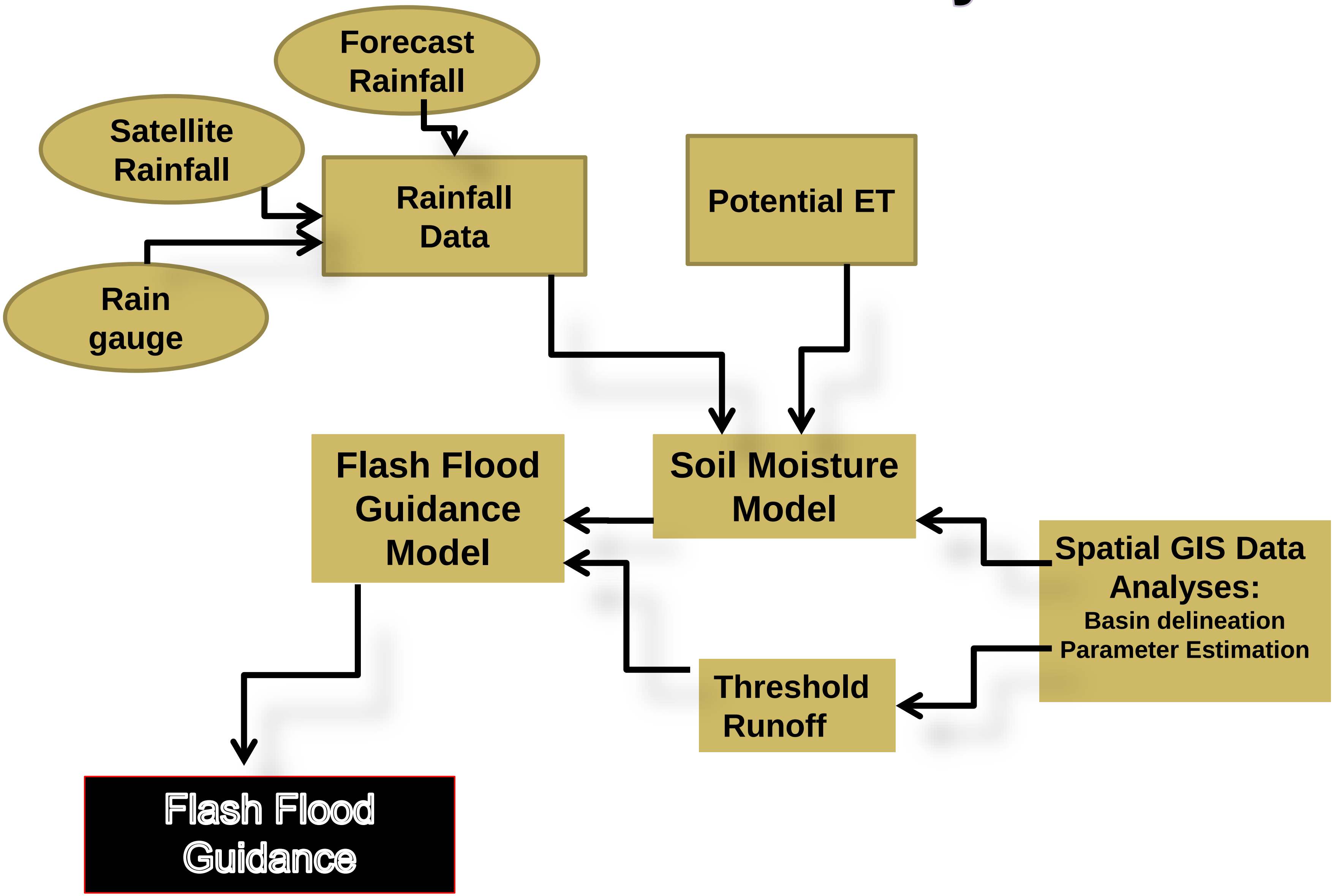
LRF

- Catchments response affords long lead times
- Entire hydrograph can be produced with low uncertainty give that a good quality data is available
- Local information is less valuable
- A hydrologic forecasting problem , primarily
- Affords time for coordination of flood response and damage mitigation

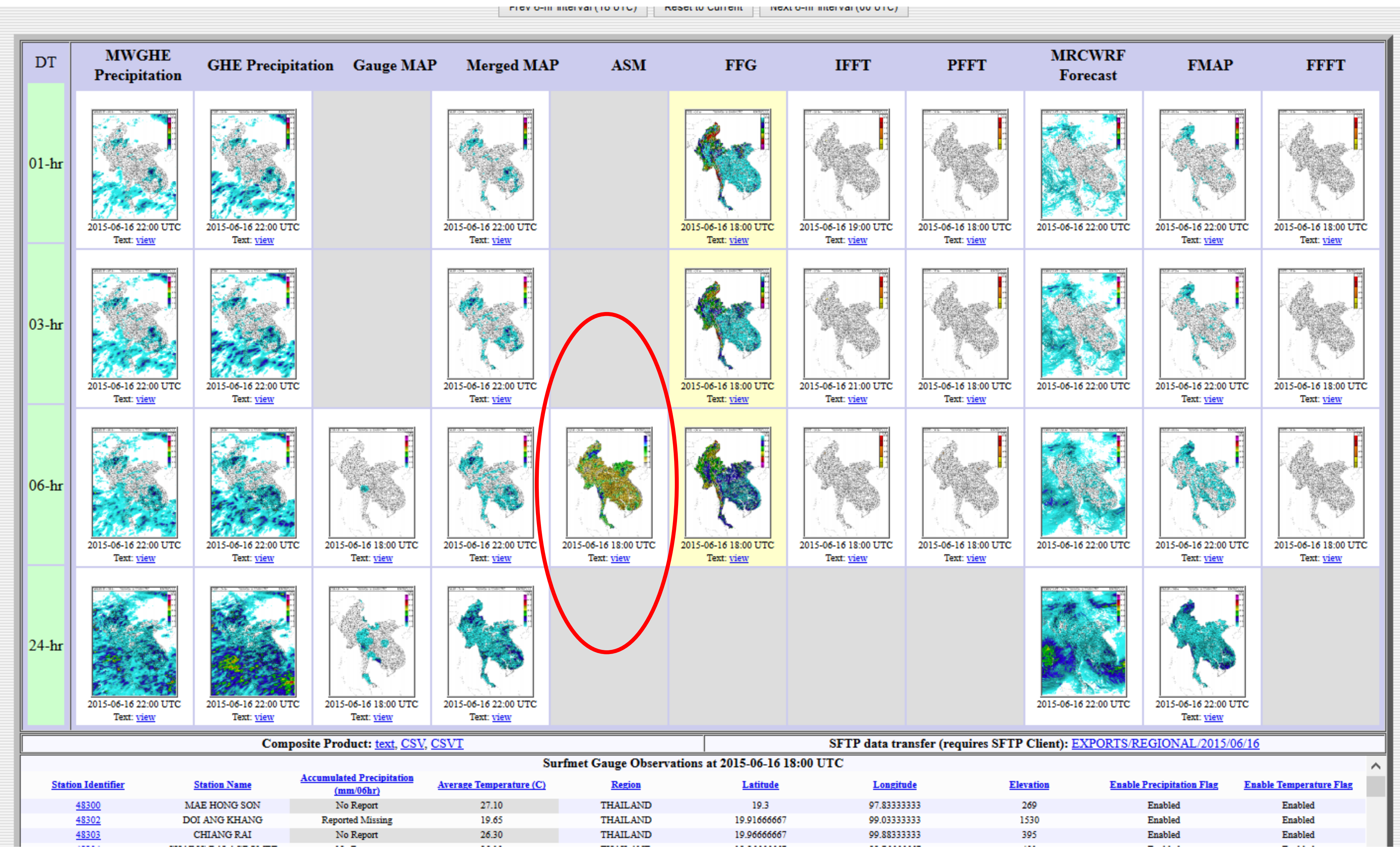
FF

- Catchment response is very fast and allows short lead times (<12 hour)
- Prediction of occurrence is of interest
- Local information is valuable
- A truly hydro-meteorological forecasting challenge
- Coordination of forecasting and response is challenging over short times

The Components of the Flash Flood Guidance System



Soil Moisture Modeling



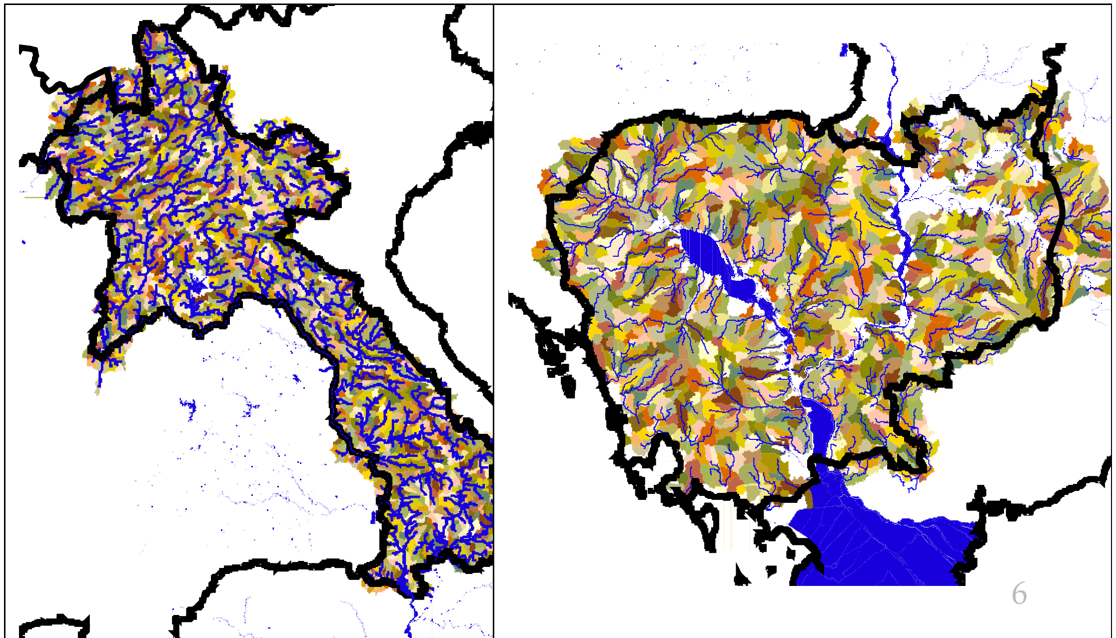
Basin Delineation

Data: DEM, stream network
Quality Control.

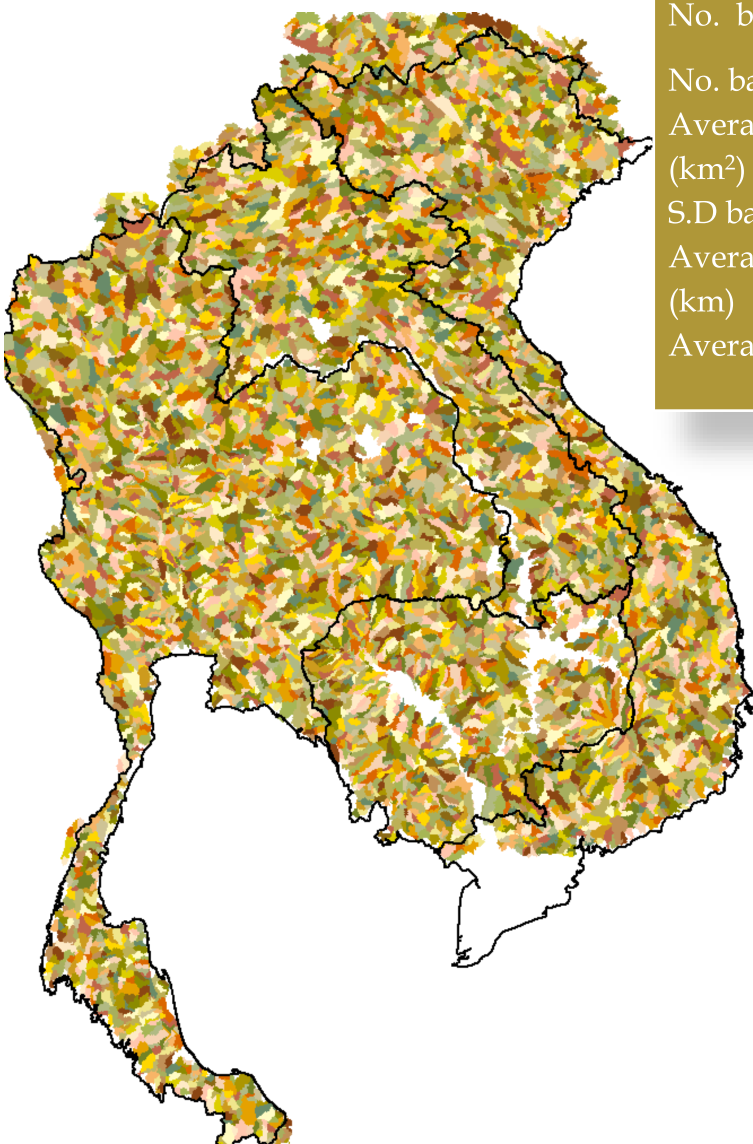
Shuttle Radar Topography Mission (SRTM)
Consultative Group for International Agriculture Research (CGIAR-CSI).

90-m resolution processed to a resolution of ~360-m

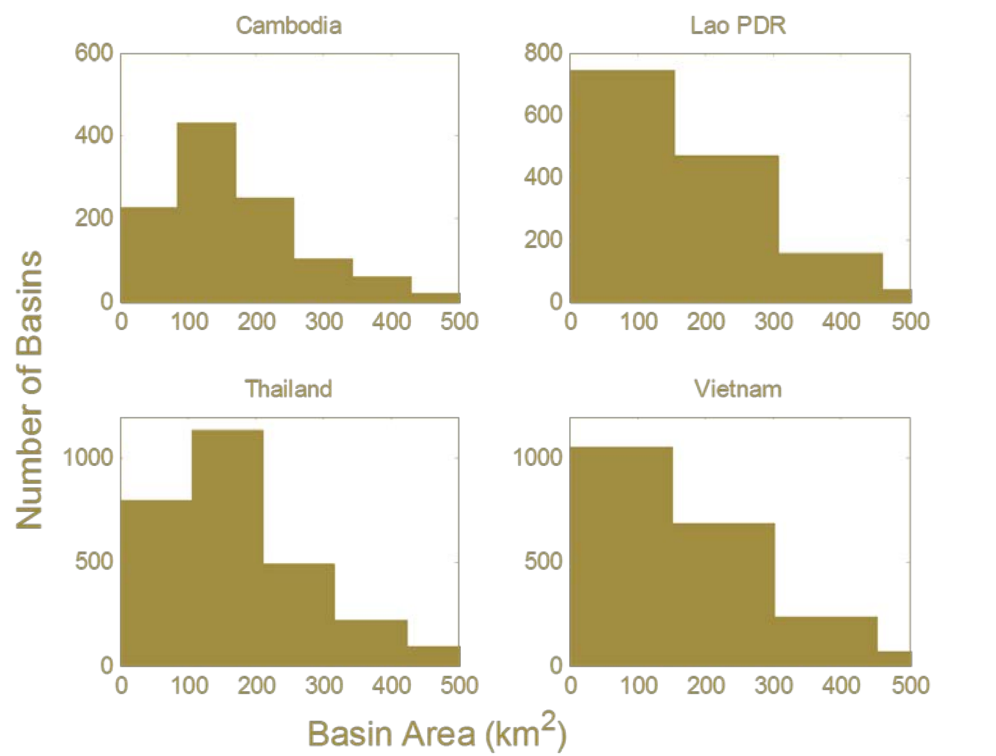
- 6372 sub-basins
- mean area 182 km2
- s.d. area 140 km2
- Mean channel length 25 km



Basin Delineation

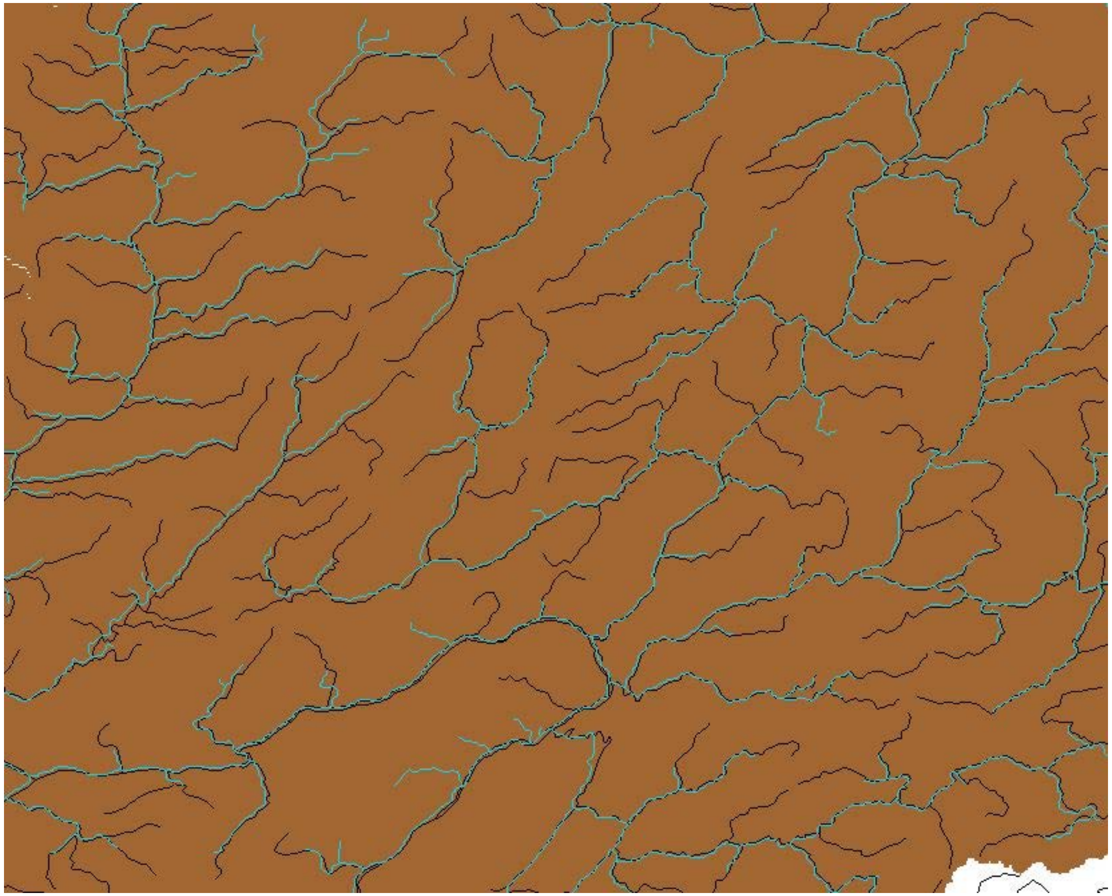


	Cambodia	Lao PDR	Thailand	Vietnam
No. basins	1113	1424	2900	2074
No. basins sm. 2000 km²	968	1115	2242	1633
Average basin local area (km²)	174 (179)	180 (187)	183 (193)	186 (193)
S.D basin Area (km²)	125 (122)	136 (139)	141 (139)	148 (141)
Average Channel Length (km)	27 (28)	23 (26)	25 (28)	25 (28)
Average slope	0.007 (0.0075)	0.017 (0.021)	0.01(0.012)	0.017 (0.021)



Delineation Quality Control

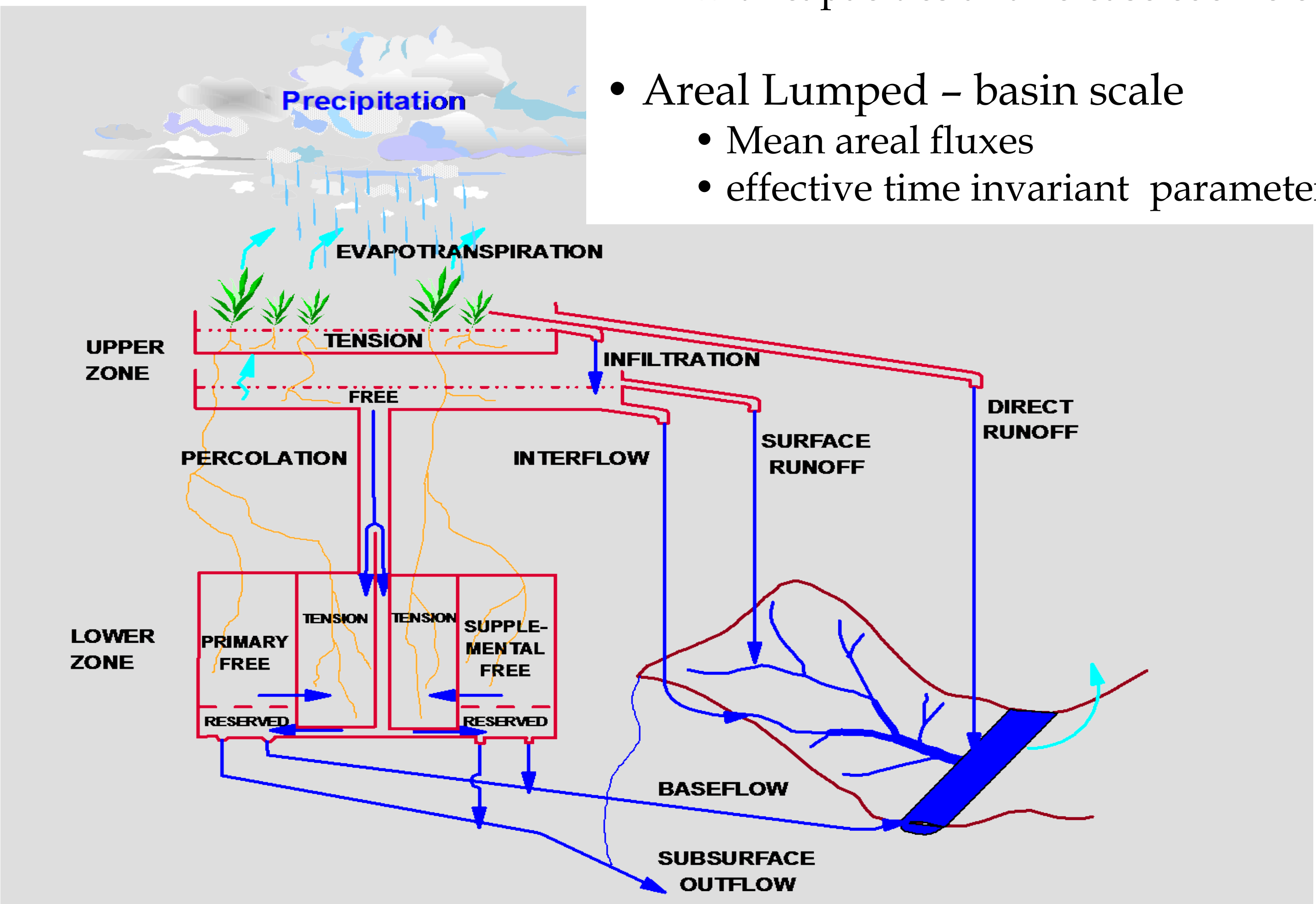
Example of the delineation verification: comparison of the delineated streams (light green) and DCW stream network (black) for a region in northern Laos.



Sacramento Soil Moisture Accounting SAC-SMA Model

- Process based conceptual model
  - A simplified description of physical processes:
  Mass balance - soil profile as a series of connected reservoirs with capacities and release coefficients

- Areal Lumped – basin scale
  - Mean areal fluxes
  - effective time invariant parameters



Three general type of soil water content that influence the runoff

Tension water

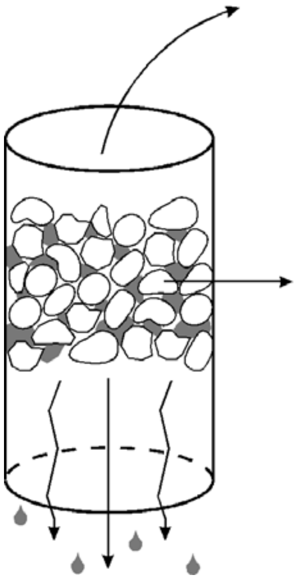
The part that can be separate from the soil and returned to the atmosphere through ET
Water that is held against gravity due to force attraction by the soil molecules
Depend on soil climate and land cover

Free water

Water in the liquid state that is free to travel
This is the water that will supply all the deficiencies in the model compartments (i.e., tension, percolation into the lower zone)
The lateral flow is generated from the free water
When rainfall intensity is larger than the percolation rate than the excess rain will generate surface flow.

Interception

The potion of rain that is remained on the vegetation
A moisture storage that affect the rainfall-runoff regime
The intercepted water is temporarily interfere with the ET from the tension water storage.
Form modeling perspective the intercepted water is included in the tension storage.
Problem might occur in areas with large annual variability in interception



In general:

Smaller soil particles (clay) have larger tension water storage
Large soil particles (sand) have larger free water storage

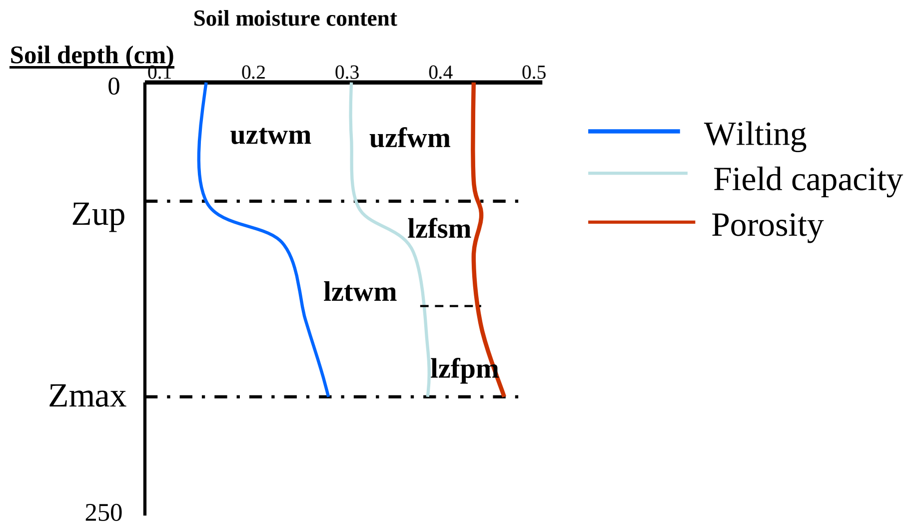
References:

http://www.nws.noaa.gov/oh/hrl/nwsrfs/users_manual/htm/formats.php

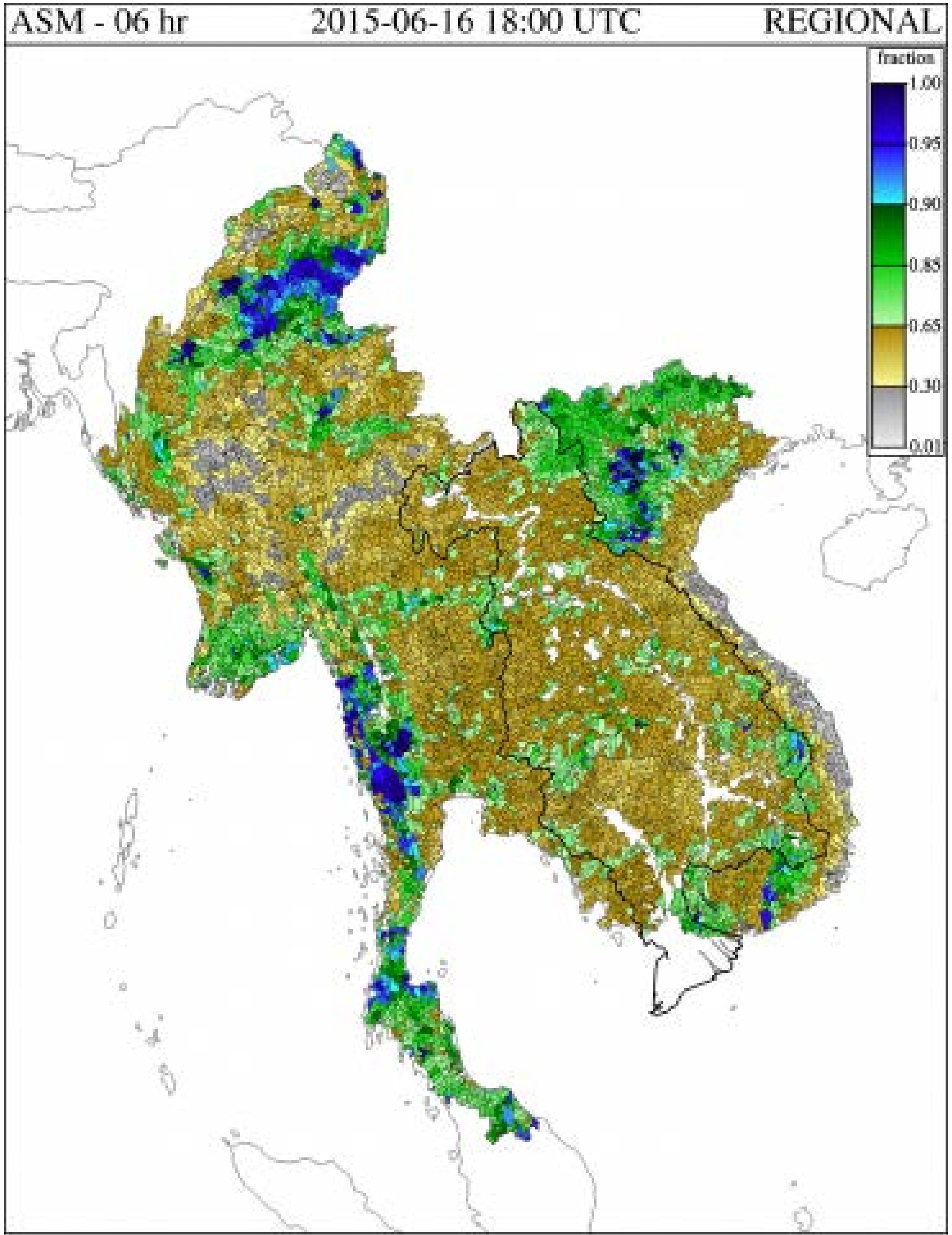
Burnash, R.J.C., 1995

A priori parameter Estimation Assumptions

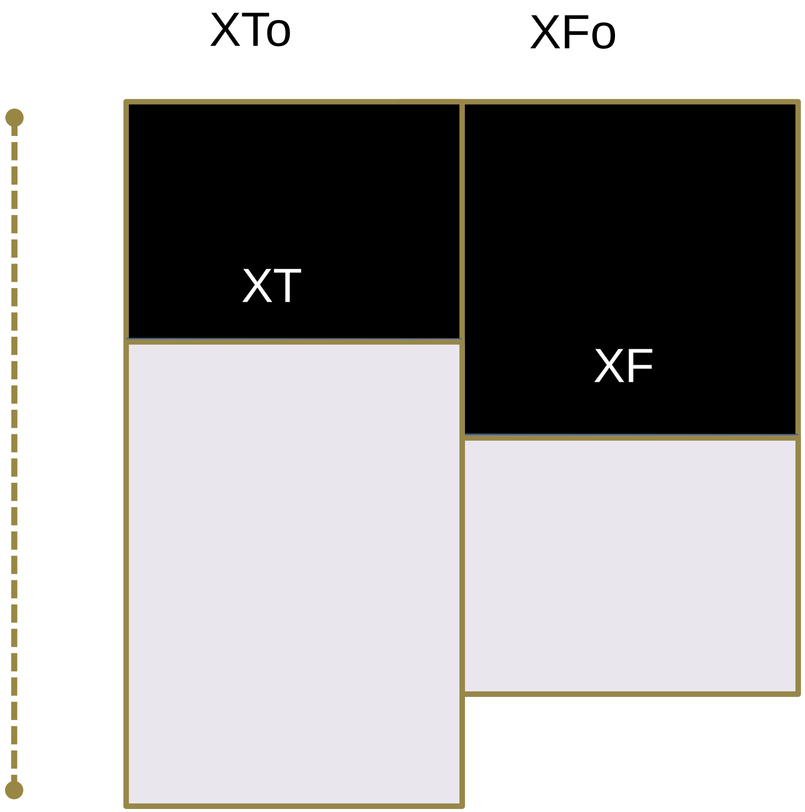
1) Tension water storages in the SAC-SMA model are related to available soil water estimated as the difference in volumetric water content between field capacity (θfld) and wilting point (θwlt).
2) The model free water storages are related to gravitational soil water estimated as the difference between porosity (θsat) and field capacity (θfld).
3) The depth of the model upper and the lower zones combined are equal to the soil profile depth (Zmax)
4) During common average soil moisture conditions the model upper tension water storage is full and the upper free water storage is empty. Thus, during rainfall events the initial losses to the soil before surface runoff is generated satisfy the upper free water storage requirements.



Average Soil Moisture [ASM]

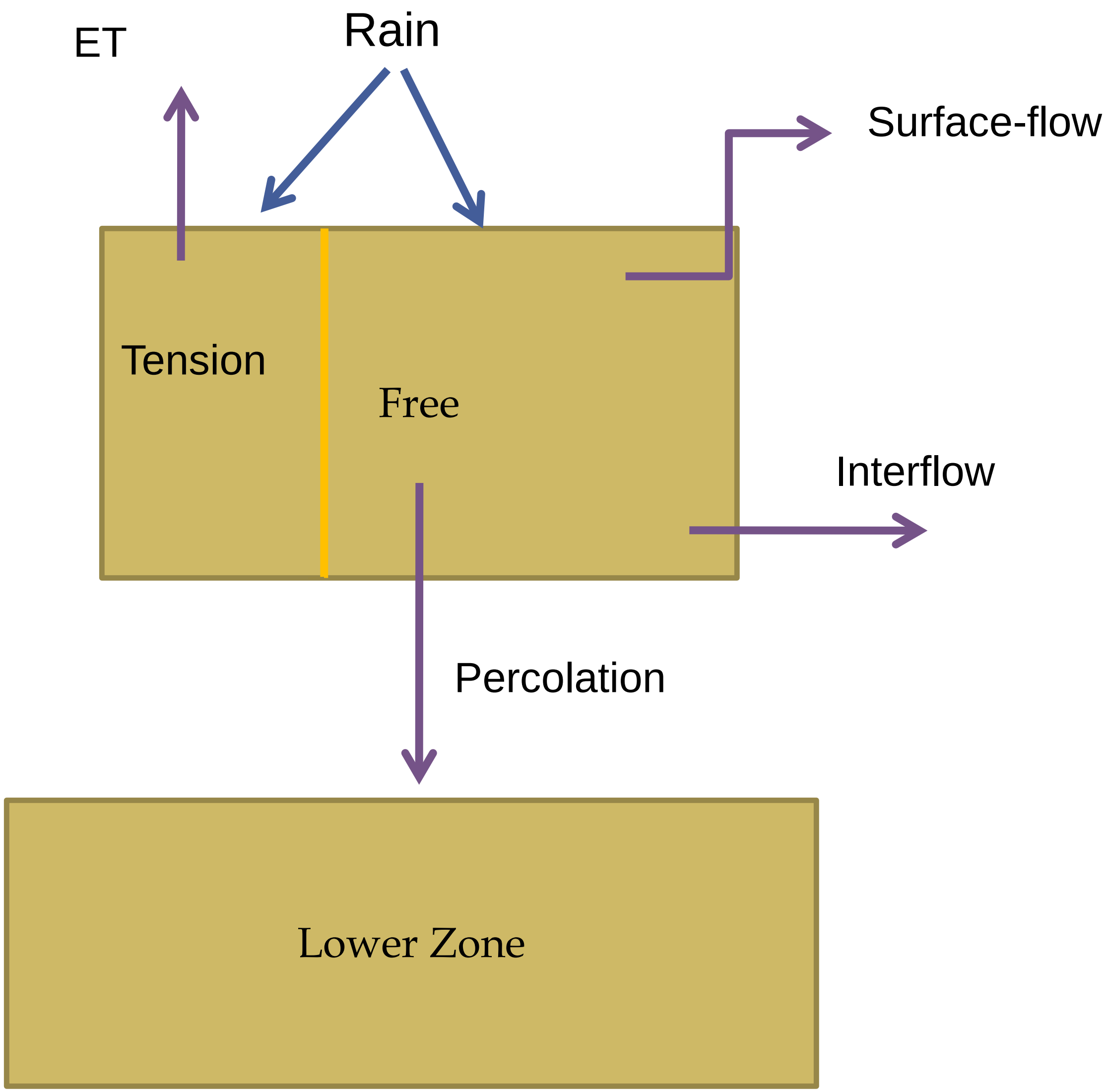


Upper Zone Soil Moisture



ASM = (XT + XF) / (XTo + XFo)

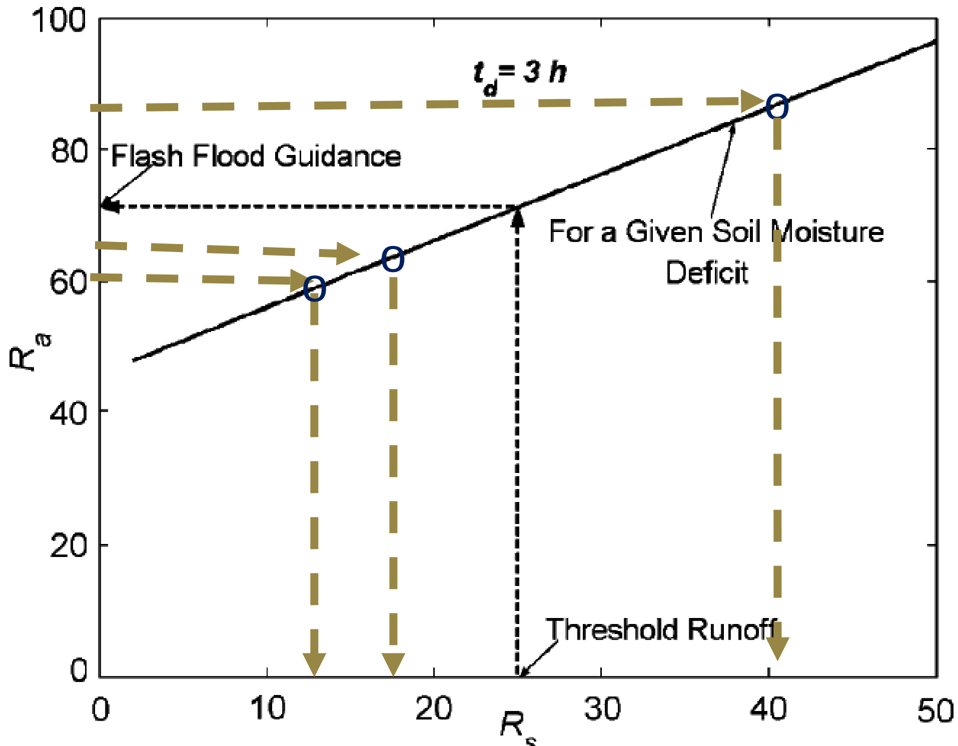
Flash Flood Sensitive parameters



Determination of FFG using thresh-R and rainfall –runoff curve

FFG

Rainfall Depth



Rainfall depth \ surface runoff

Fig. 2. Model relationship (solid line) between a given volume of rainfall, R_a, of duration t_d and the model-generated runoff R_s for a given soil moisture deficit. The relationship is used to translate the surface runoff that is just enough to cause flooding of the draining stream at the watershed outlet (called threshold runoff) to the required volume of rainfall over a given duration t_d (called flash flood guidance of duration t_d).

Georgakakos 2006 JH 317:81-103

Relationship of Threshold Runoff to FFG

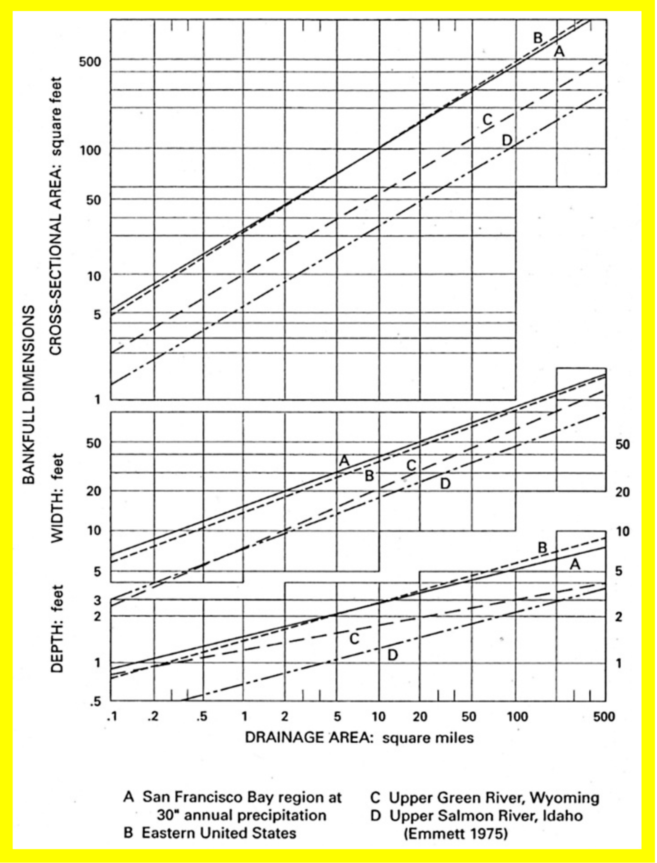
- Effective rainfall is the residual amount after accounting for all losses such as interception and soil moisture storage
- FFG is the amount of actual rainfall of a given duration falling over the watershed that causes flooding at the outlet of the drainage stream.
- FFG is derived from threshold runoff through soil moisture modeling and accounting for all losses in the transformation of rainfall to runoff
- Threshold Runoff is a one-time calculation for a given watershed whereas FFG is computed on a real-time basis

Relating Channel Cross-Sectional Properties To GIS-Computed Quantities

- Channel cross-sectional properties needed can not be resolved with current digital elevation models (DEM).
- Bankfull cross-section dimensions (top width and hydraulic depth) vary with catchment size due to sediment carrying characteristics of bankfull flow:

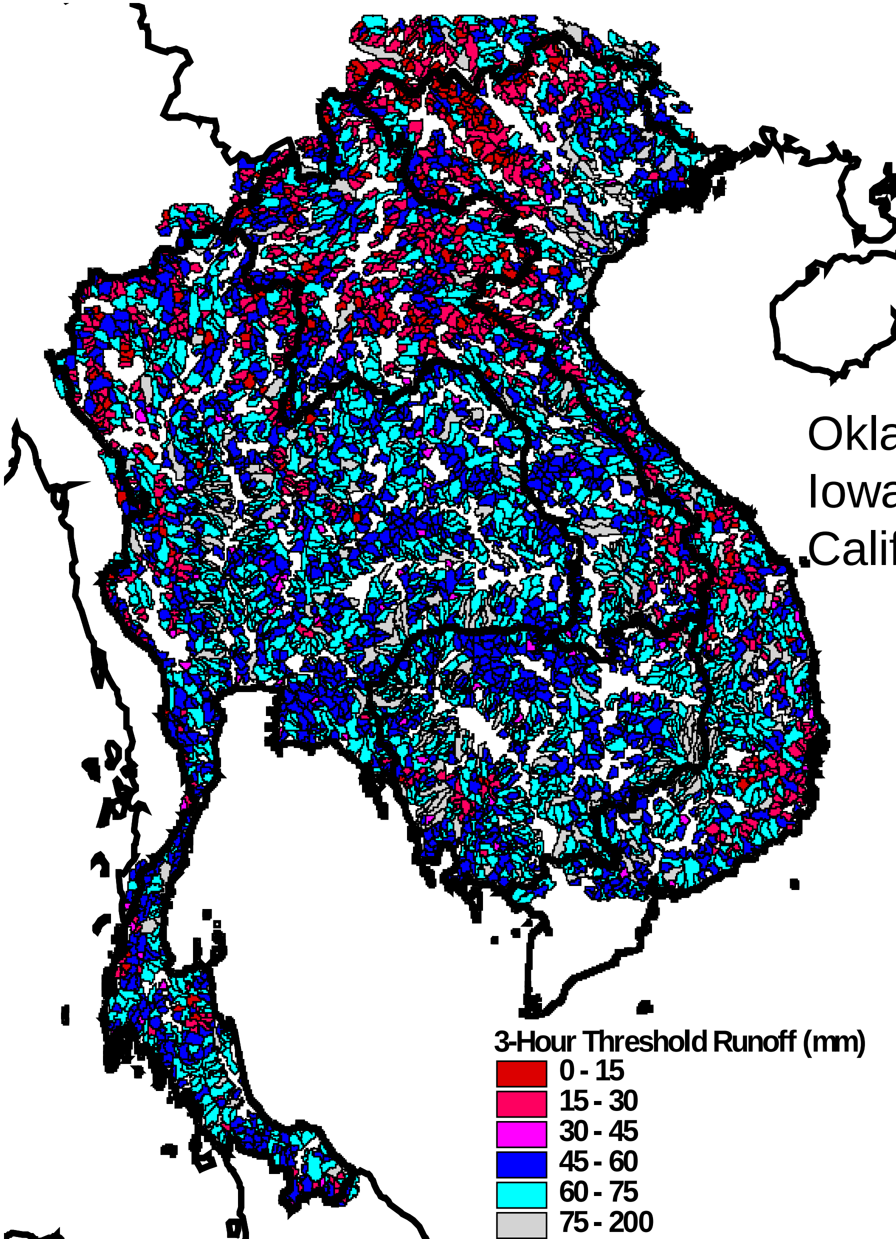
  $B_b = \alpha A^{\gamma}$ $D_b = \varepsilon A^{\lambda}$

- Develop such relationships based on channel survey data.



Source: L. Luna, 1994: *A View of the River*

Threshold Runoff



Oklahoma to basins with slopes gentler than 3%
Iowa to basins with slopes between 3-6%,
California for basins that are steeper than 6%.

Evapotranspiration Demand ETD
Jensen-Haise: Radiation-based method with two parameters

For basin scale hydrologic models and operational environments, ETD procedures that are based on extraterrestrial radiation and climatic surface temperature outperform more complex models (e.g., Penman Monteit

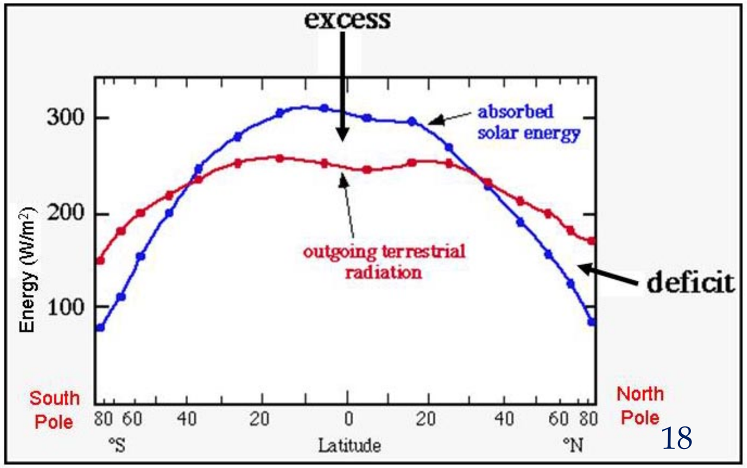
J-H Evapotranspiration Demand in a given location (mm/day):

$$PE = [Re\ (Ta - K2)] / K1(\lambda\ \rho)$$
for Ta > K2

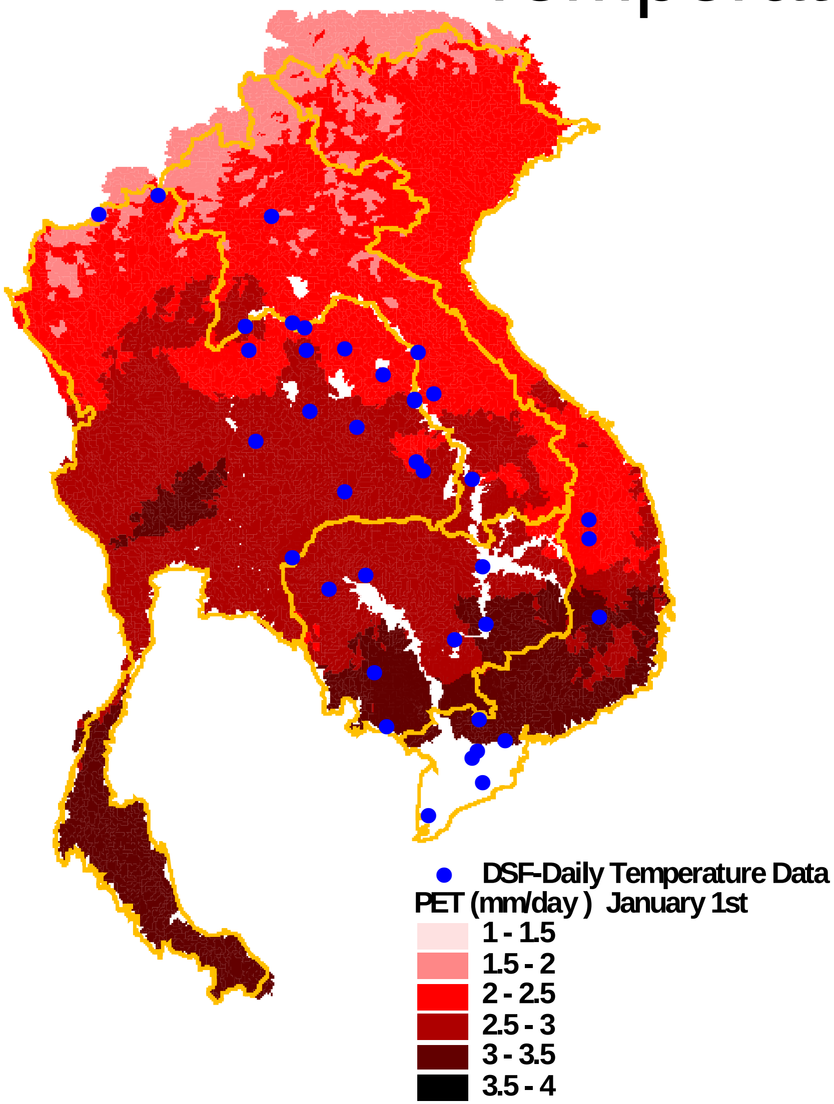
- Re - Daily potential Incoming extraterrestrial radiation (Mj m^{-2} d^{-1});
  - f{latitude, Julian date)
- Ta- Long term daily averages of surface temperature (minT+maxT)/2
  - f{Julian date, elevation)
- K2 (°C) – minimum temperature for which PE=0 (~5 ^{o}C)
- K1 (°C) – scale parameter (75-130) (assigned to 90)
- λ – Latent heat of water (Mj kg^{-1})
- ρ - density of water (kg m^{-3})

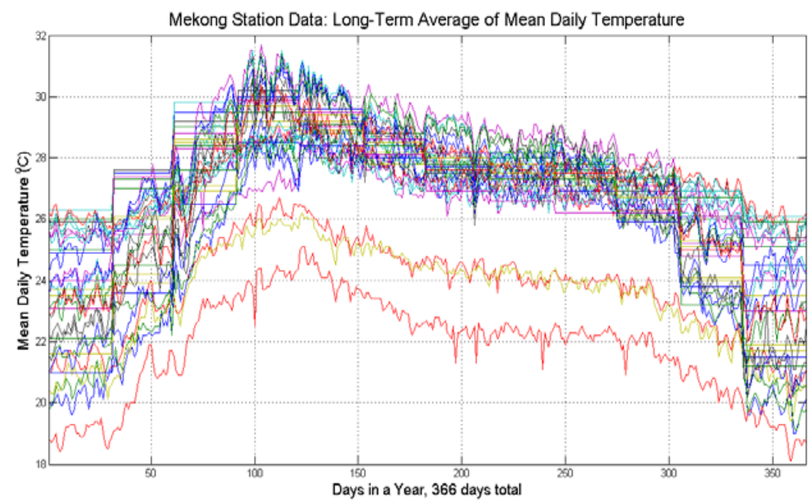
Jensen & Haise 1963
McGuinness & Borden 1973
Oudin et al 2005

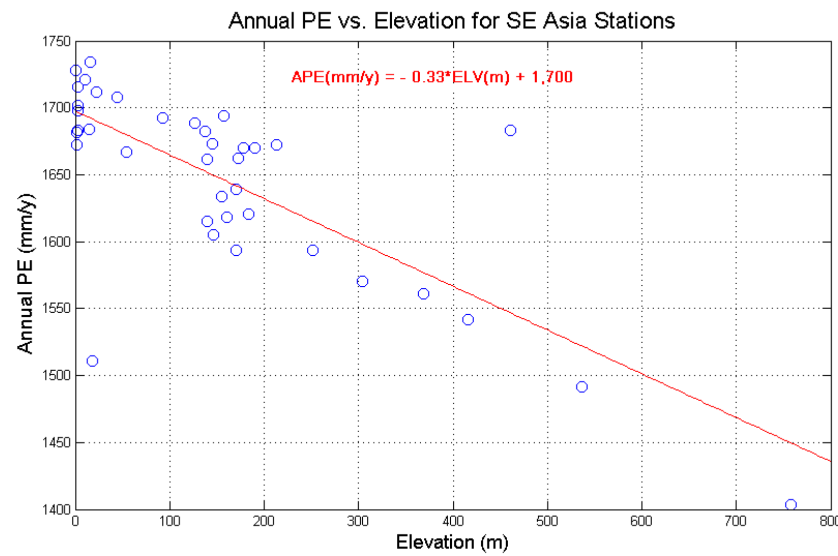
CRU-U of East Anglia, UK
Monthly climatology of mean daily
Ta and diurnal Ta range
(1961-1990; 10 min scale)
New et al. 2002



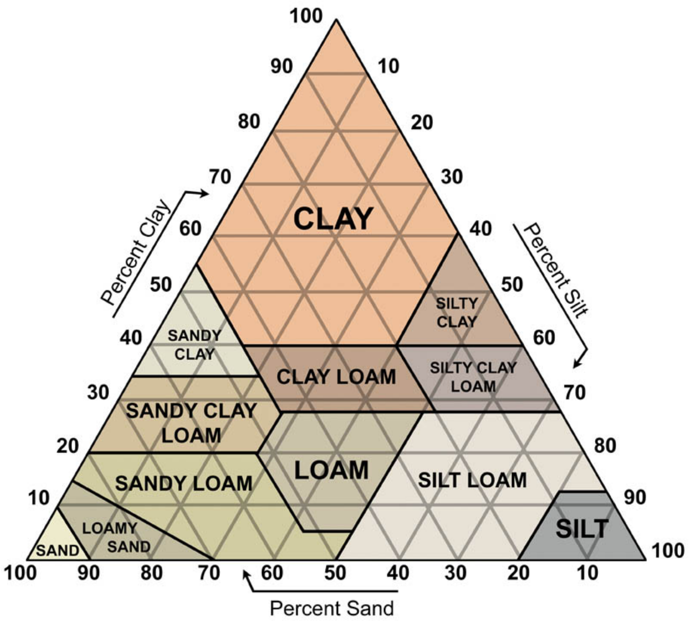
PET Interpolated from DSF Surface Temperature Data







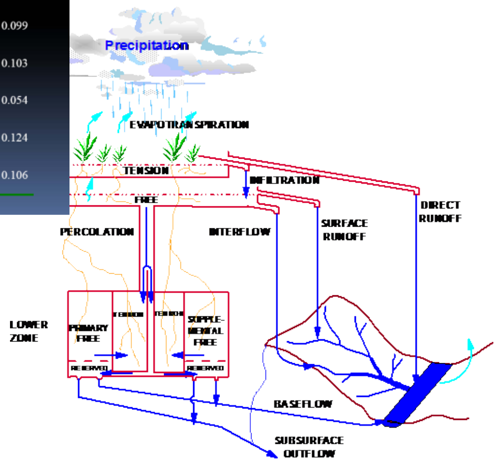
Soil Moisture Accounting Model A priori Parameter Estimation



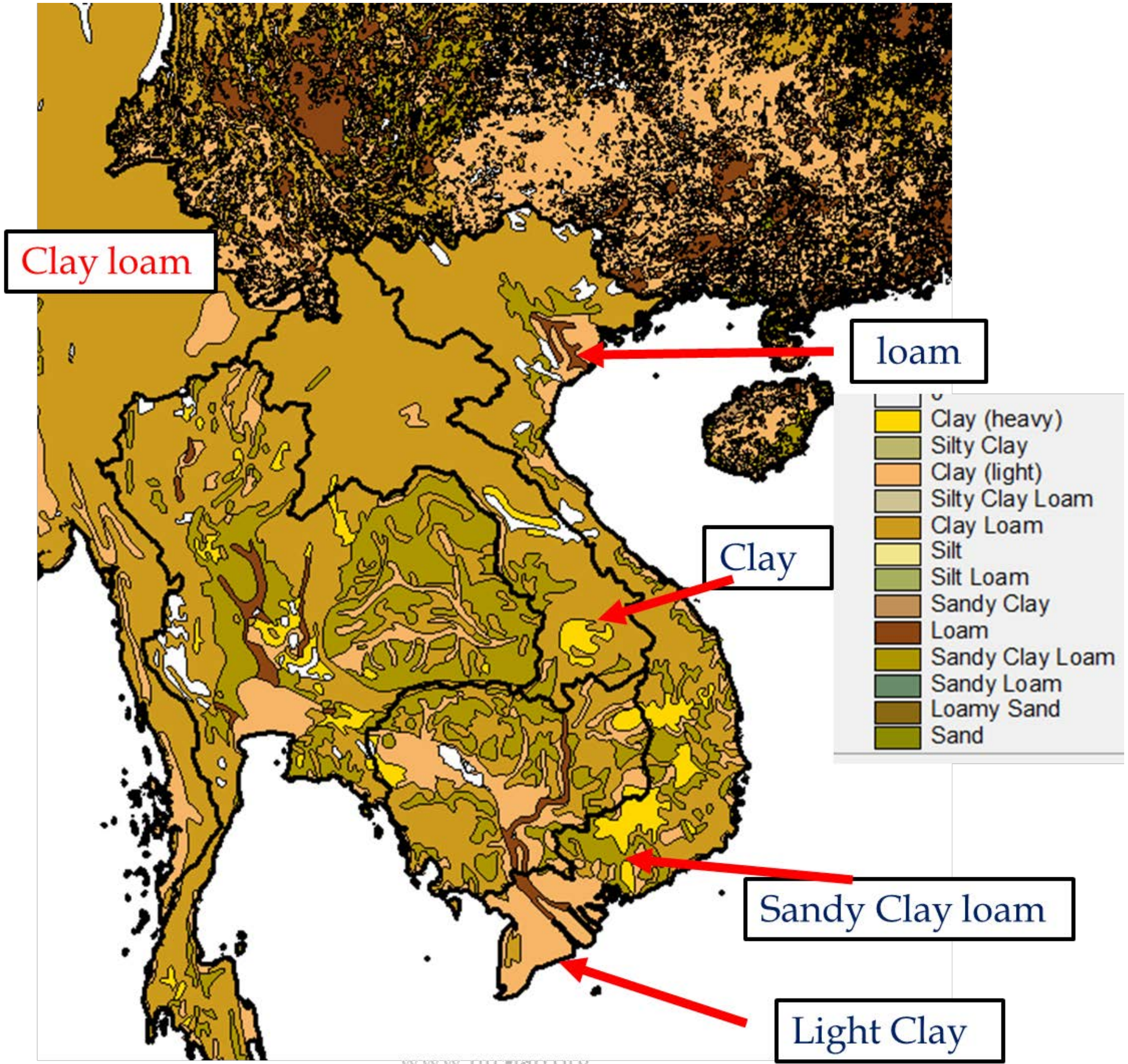
Soil Texture and Hydraulic Properties

Soil Class	$\theta_s (m^3/m^3)$	$\theta_f (m^3/m^3)$	$\theta_m (m^3/m^3)$	$K_s (m/h)$	α	$\sigma_{Ks} (m/h)$
Sand	0.34	0.09	0.015	0.168	2.79	0.062
Loamy Sand	0.42	0.16	0.05	0.050	4.26	0.082
Sandy Loam	0.43	0.21	0.07	0.019	4.74	0.119
Loam	0.44	0.25	0.095	0.012	5.25	0.108
Silty Loam	0.48	0.29	0.11	0.010	5.33	0.090
Sandy Clay Loam	0.40	0.24	0.11	0.016	6.77	0.088
Clay Loam	0.47	0.32	0.17	0.009	8.17	0.099
Silty Clay Loam	0.46	0.33	0.19	0.007	8.72	0.103
Sandy Clay	0.41	0.29	0.18	0.026	10.73	0.054
Silty Clay	0.47	0.35	0.21	0.005	10.39	0.124
Clay	0.47	0.36	0.24	0.004	11.55	0.106

Values are from Cosby et al. 1984

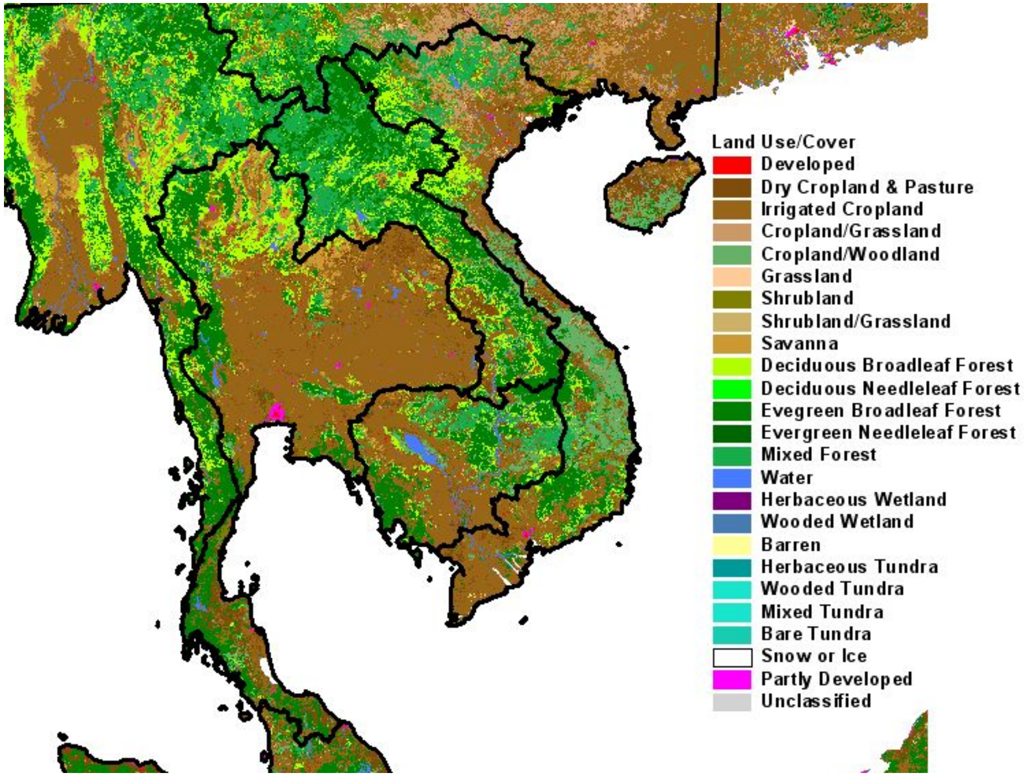


FOOD AGRICULTURE ORGANIZATION [FAO]
Harmonized Soil Texture

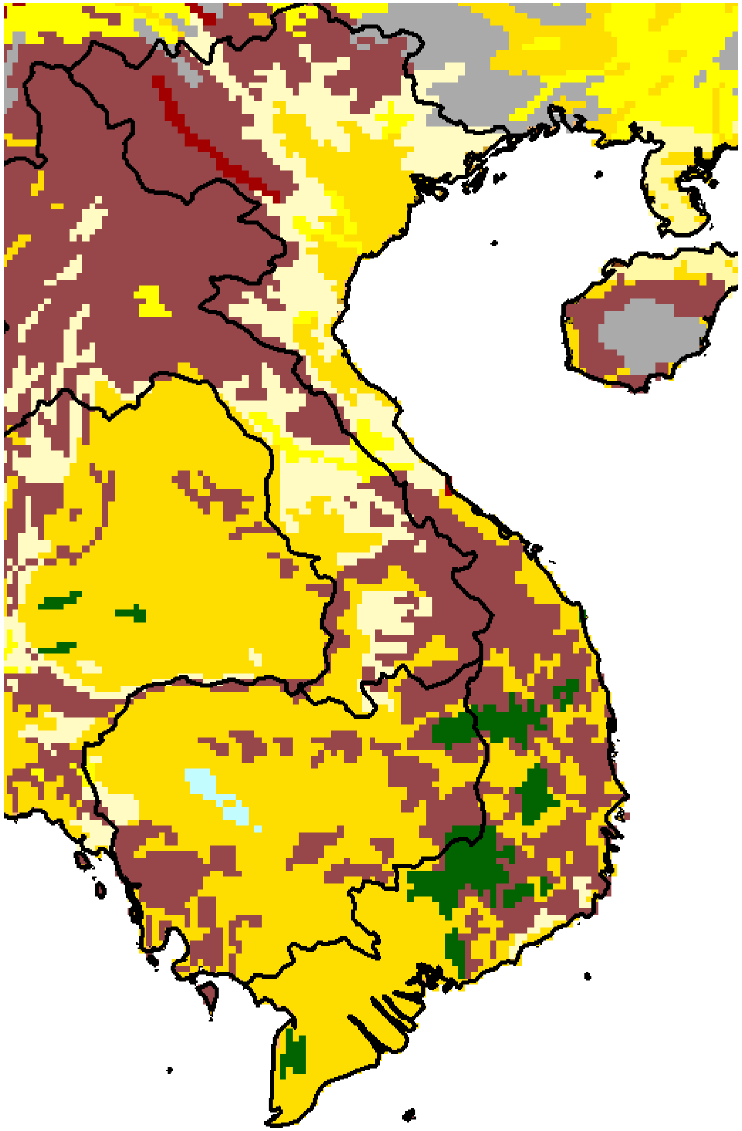


Land Use/Cover

- Land Cover Database is derived from the U.S. Geological Survey's (USGS) Global Land Cover Characteristics (GLCC) database at 30 arc second resolution in a common grid for the entire globe.



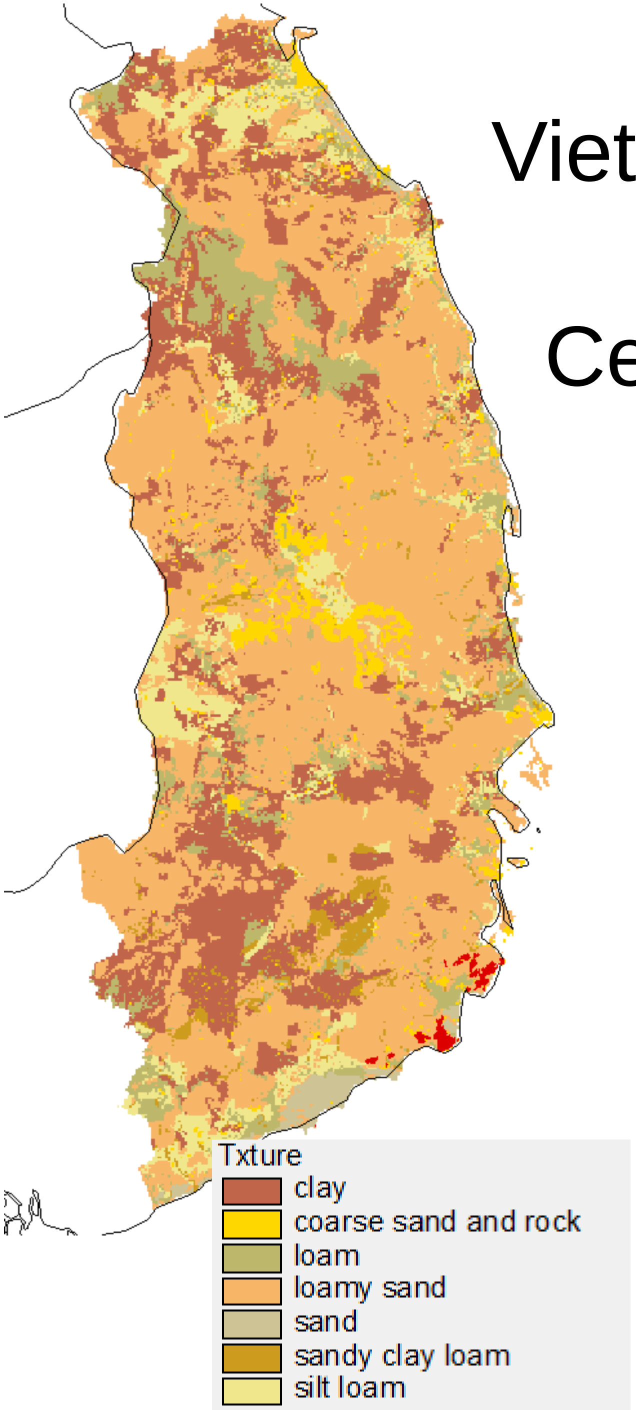
FOOD AGRICULTURE ORGANIZATION [FAO]
Soil Depth

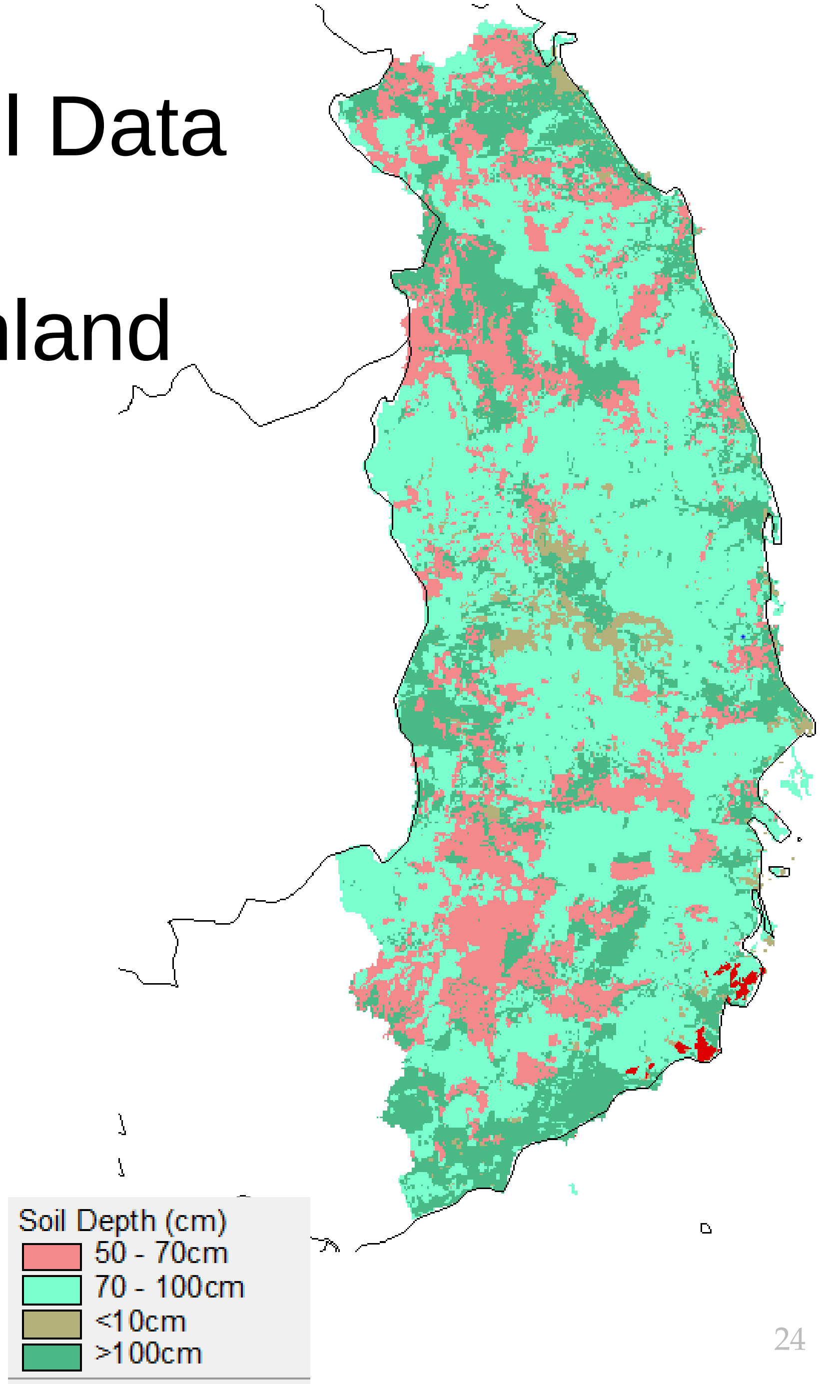


Depth

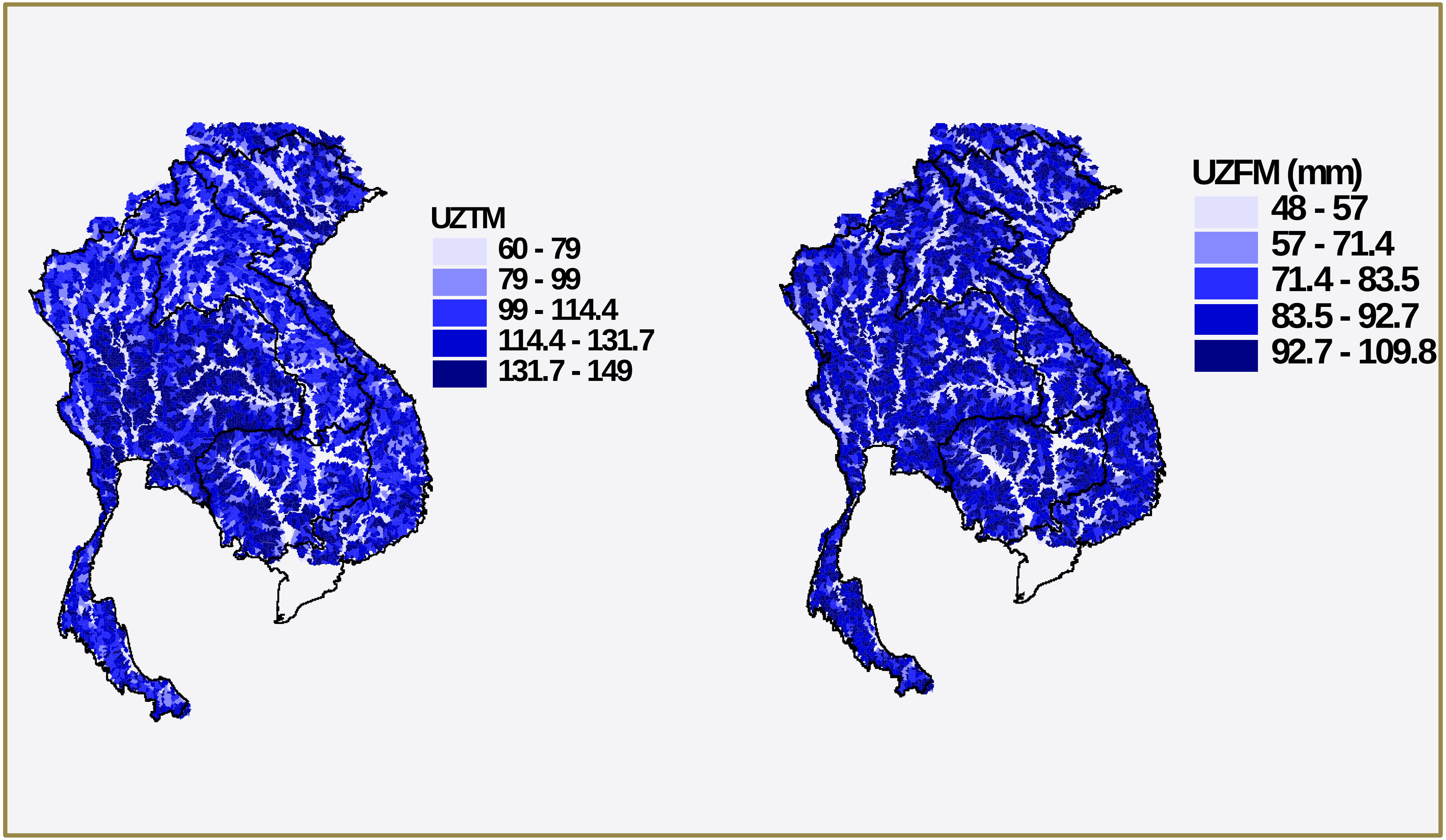
10	Very shallow (<10 cm)	
12	Very shallow (<10 cm)	Shallow (10-50 cm)
13	Very shallow (<10 cm)	Moderately deep (50-100 cm)
14	Very shallow (<10 cm)	Deep (100-150 cm)
15	Very shallow (<10 cm)	Very deep (150-300 cm)
20	Shallow (10-50 cm)	
21	Shallow (10-50 cm)	Very shallow (<10 cm)
23	Shallow (10-50 cm)	Moderately deep (50-100 cm)
24	Shallow (10-50 cm)	Deep (100-150 cm)
25	Shallow (10-50 cm)	Very deep (150-300 cm)
34	Moderately deep (50-100 cm)	Deep (100-150 cm)
40	Deep (100-150 cm)	
41	Deep (100-150 cm)	Very shallow (<10 cm)
42	Deep (100-150 cm)	Shallow (10-50 cm)
43	Deep (100-150 cm)	Moderately deep (50-100 cm)
45	Deep (100-150 cm)	Very deep (150-300 cm)
50	Very deep (150-300 cm)	
51	Very deep (150-300 cm)	Very shallow (<10 cm)
52	Very deep (150-300 cm)	Shallow (10-50 cm)
53	Very deep (150-300 cm)	Moderately deep (50-100 cm)
54	Very deep (150-300 cm)	Deep (100-150 cm)
97	Water	

IMHAN
Vietnam's Soil Data for Central Highland

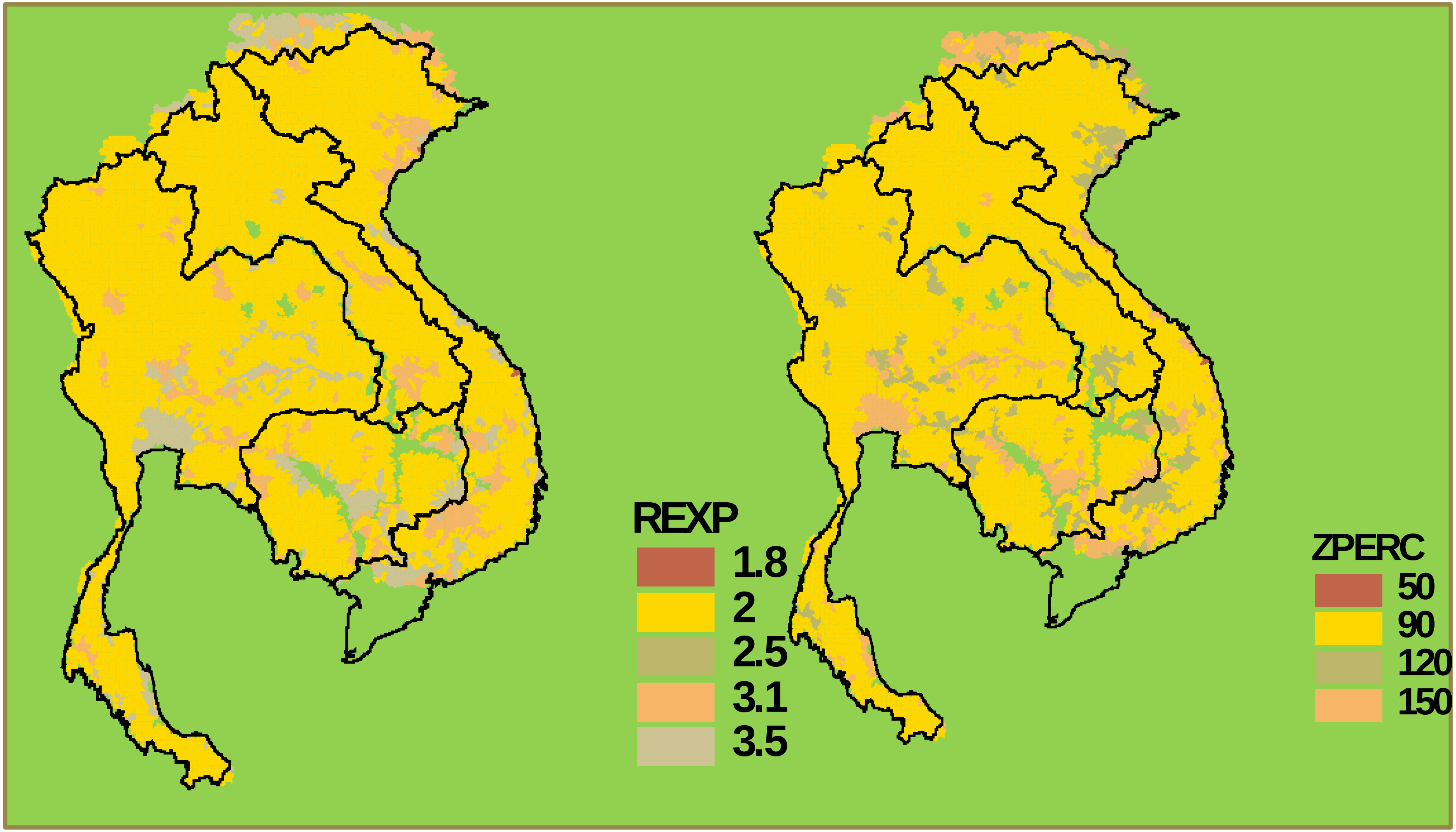




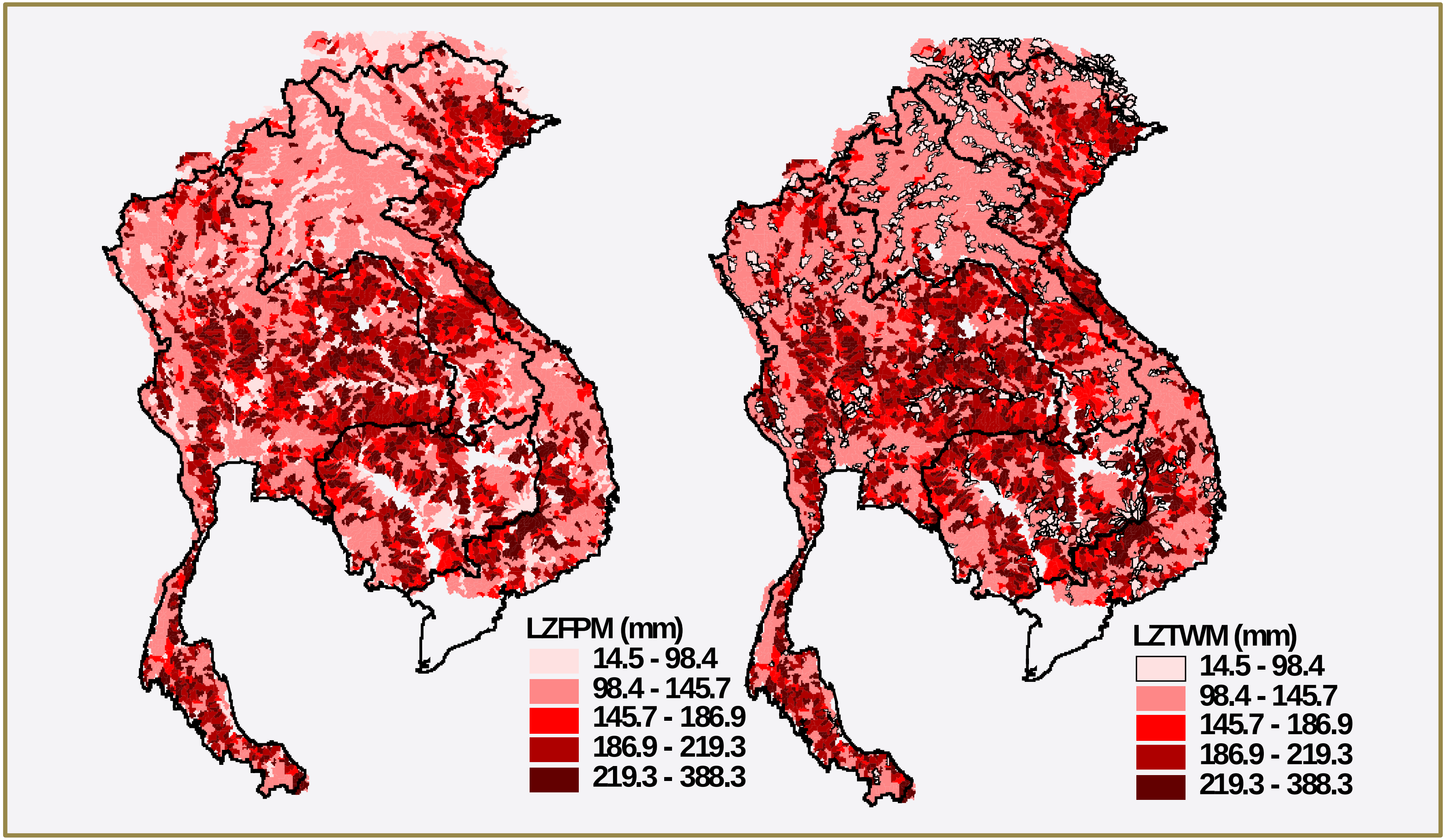
Upper Zone Parameters



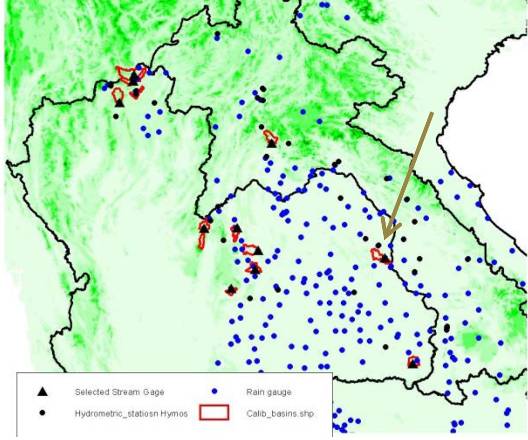
Percolation Equation Parameters



Lower Zone Parameters

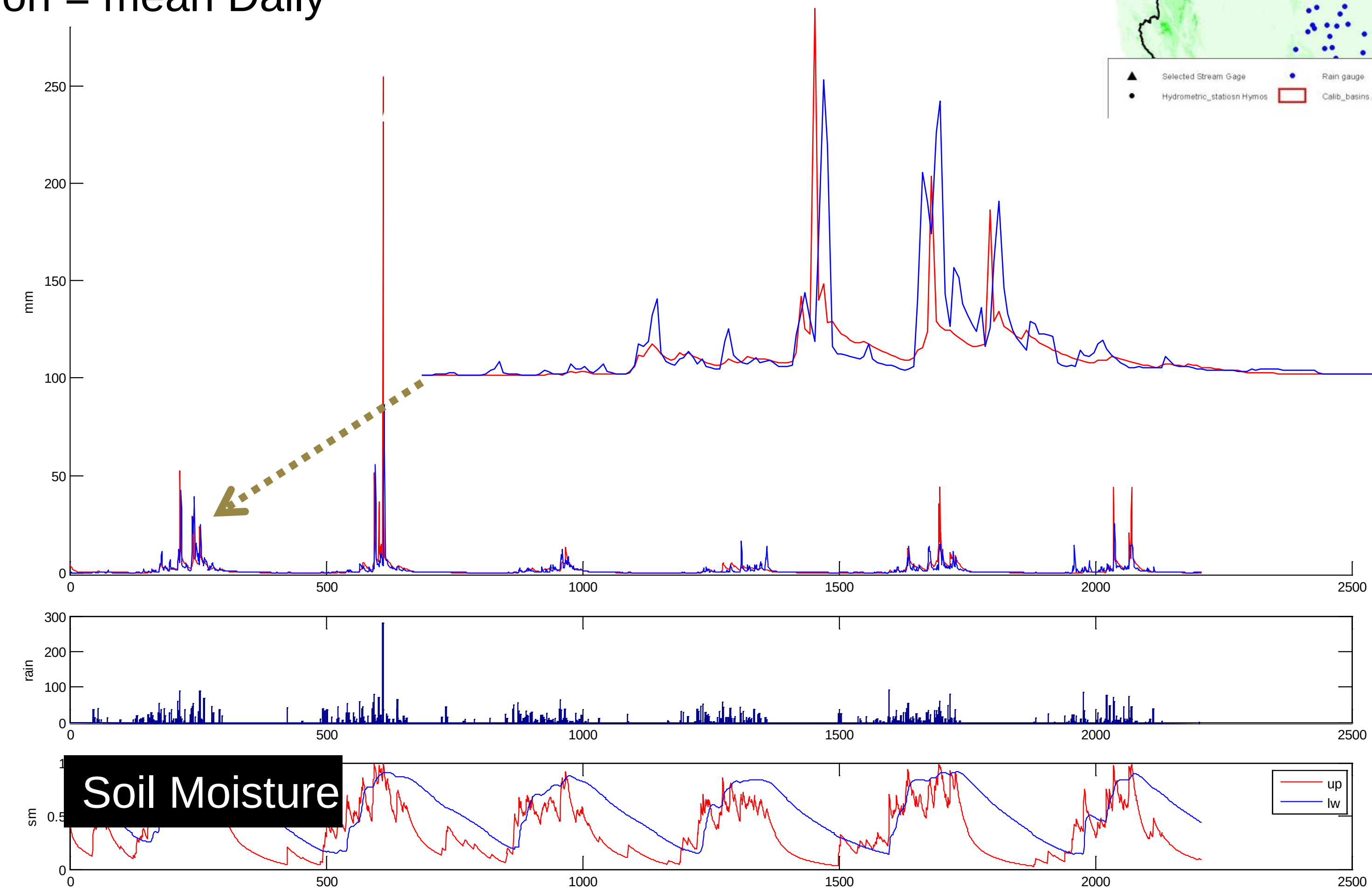


Huai Bang Sai (Thailand)

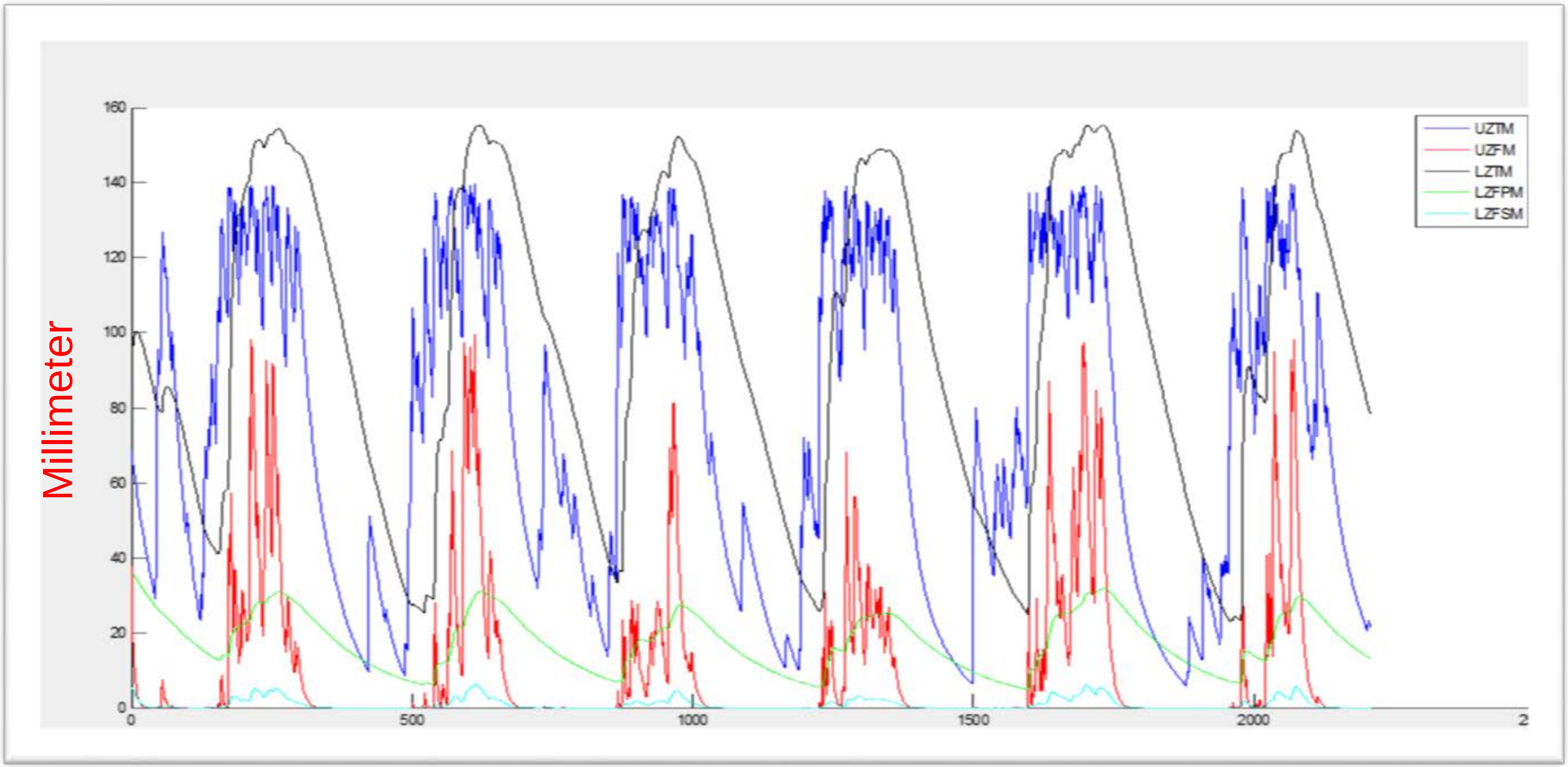


Observed = instantaneous
Simulation = mean Daily

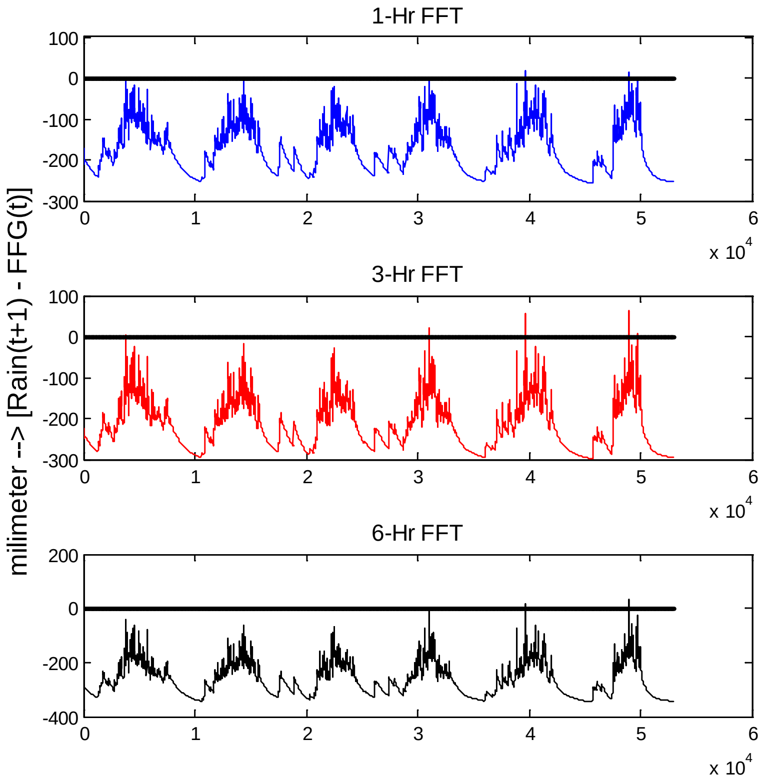
Mm/Day

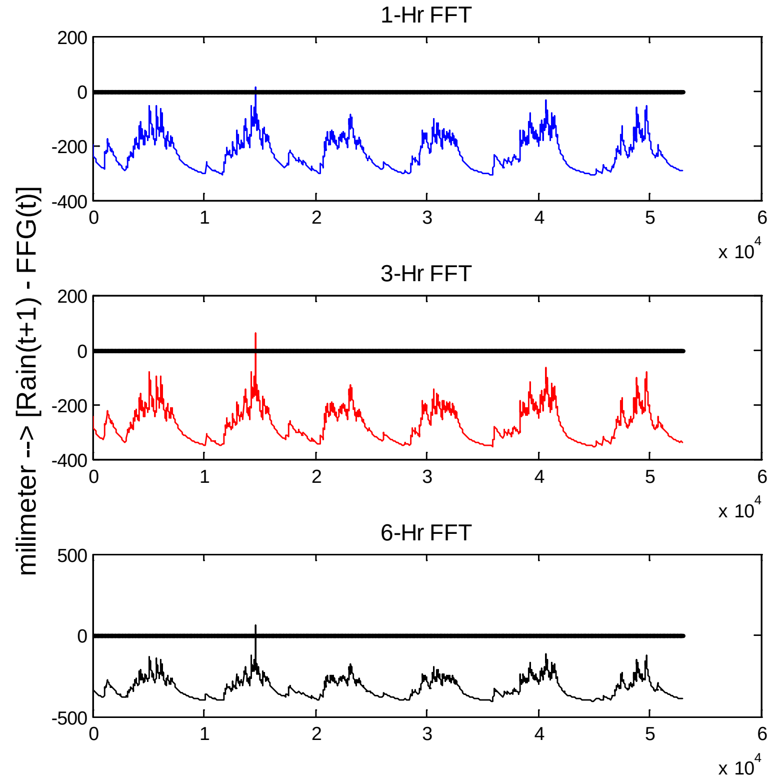


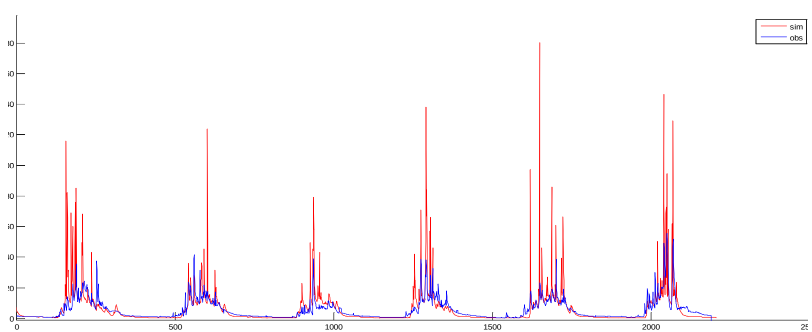
Model States

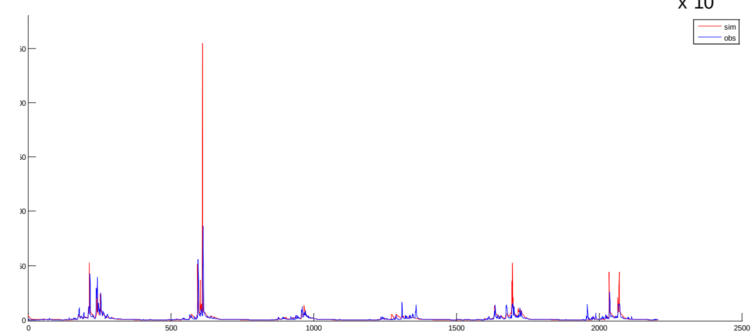


FFT Evaluation

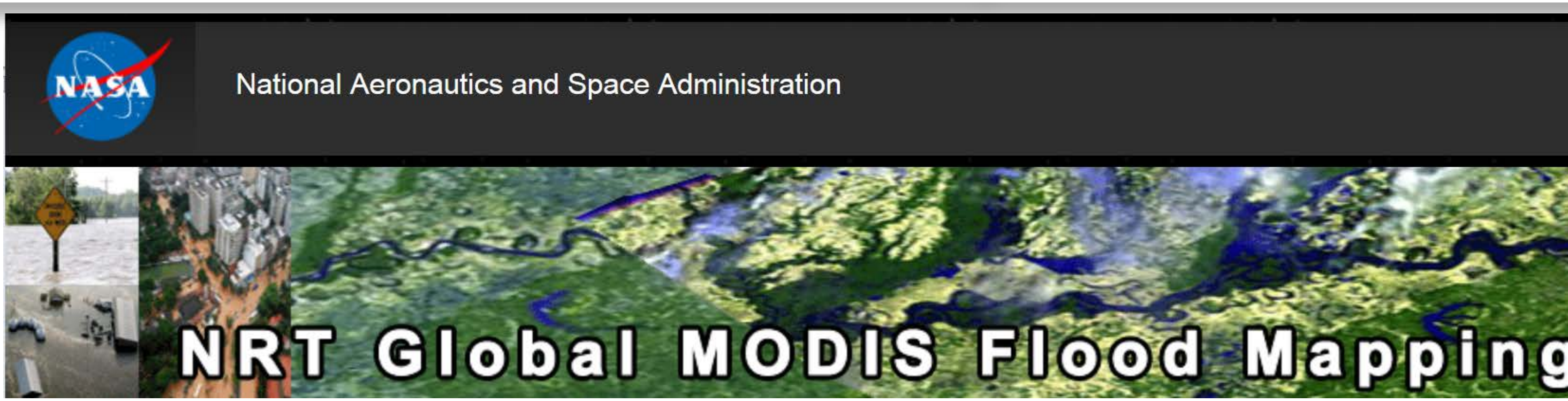






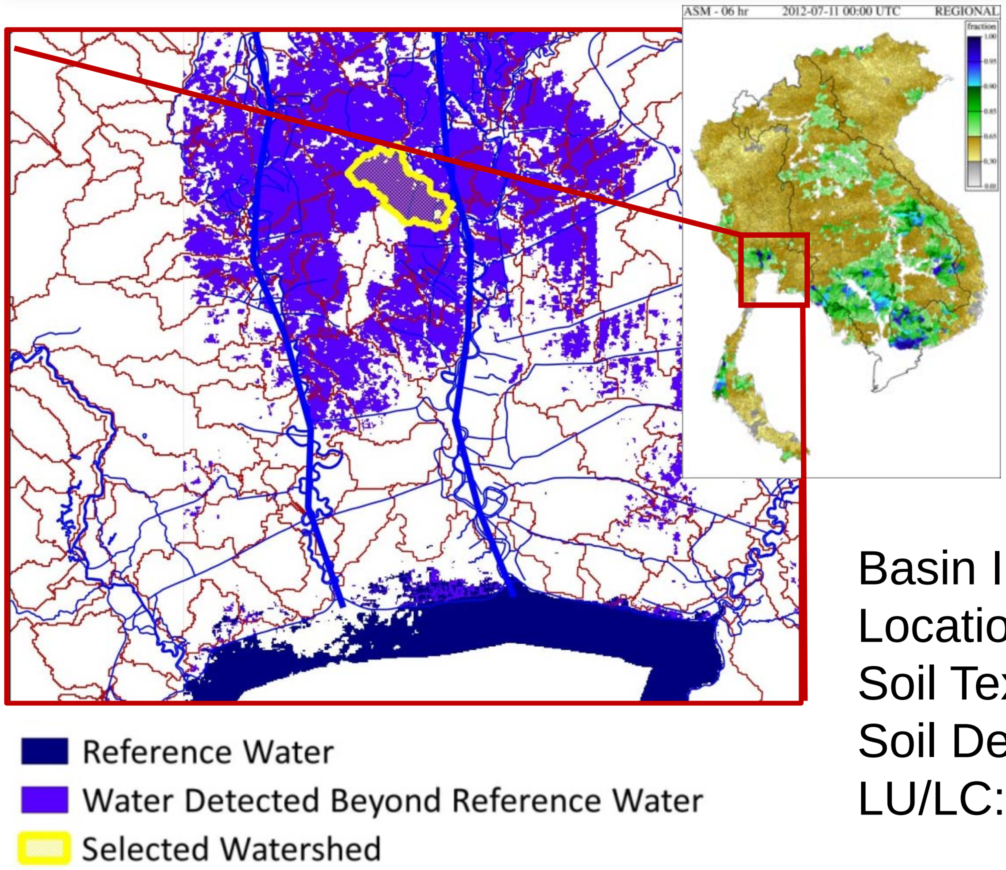


Product Description



- MODIS Instrument onboard Terra & Aqua satellites
- Daily product
- 250m grid resolution
- 10X10 degree tiles
- False detections eliminated by requiring the 3 last consecutive days and Terrain shadow masking, to designate as inundated
- http://oas.gsfc.nasa.gov/floodmap/home.html
- NRT Staff (esp. Dr. Dan Slayback & Frederick Policelli) generated historic products for analysis

Basin Case Studies



Basin ID: 31245
Location: Bangkok
Soil Texture: Silty Clay
Soil Depth: V. Deep
LU/LC: Cropland/Woodland/Grassland
Elevation (m): 6
Area (km^2): 162
Channel Length (km): 32.2
Channel Slope (%): 0.31

Problem Statement

Many basins in Southeast Asia experience large inundation extents.

Does soil saturation fraction (ASM) reflect actual conditions,

when inundation occurs?