Southeastern Asia - Oceania Flash Flood Guidance (SAOFFG) System:

Overview of Technical Development Background

Hydrologic Research Center, USA
Technical Developer

SAOFFG Steering Committee Meeting 1
10-12 July 2017
Jakarta, INDONESIA

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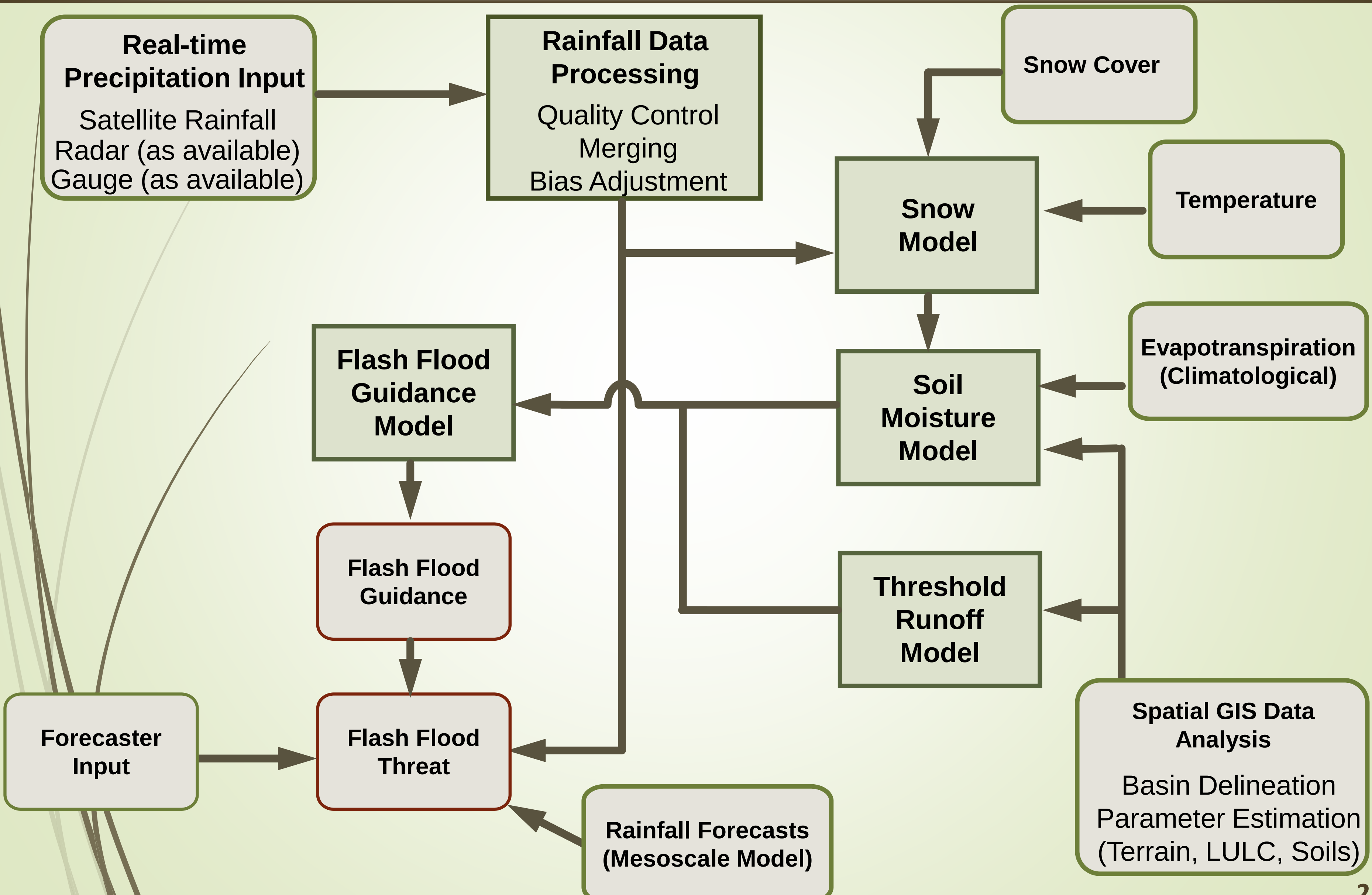
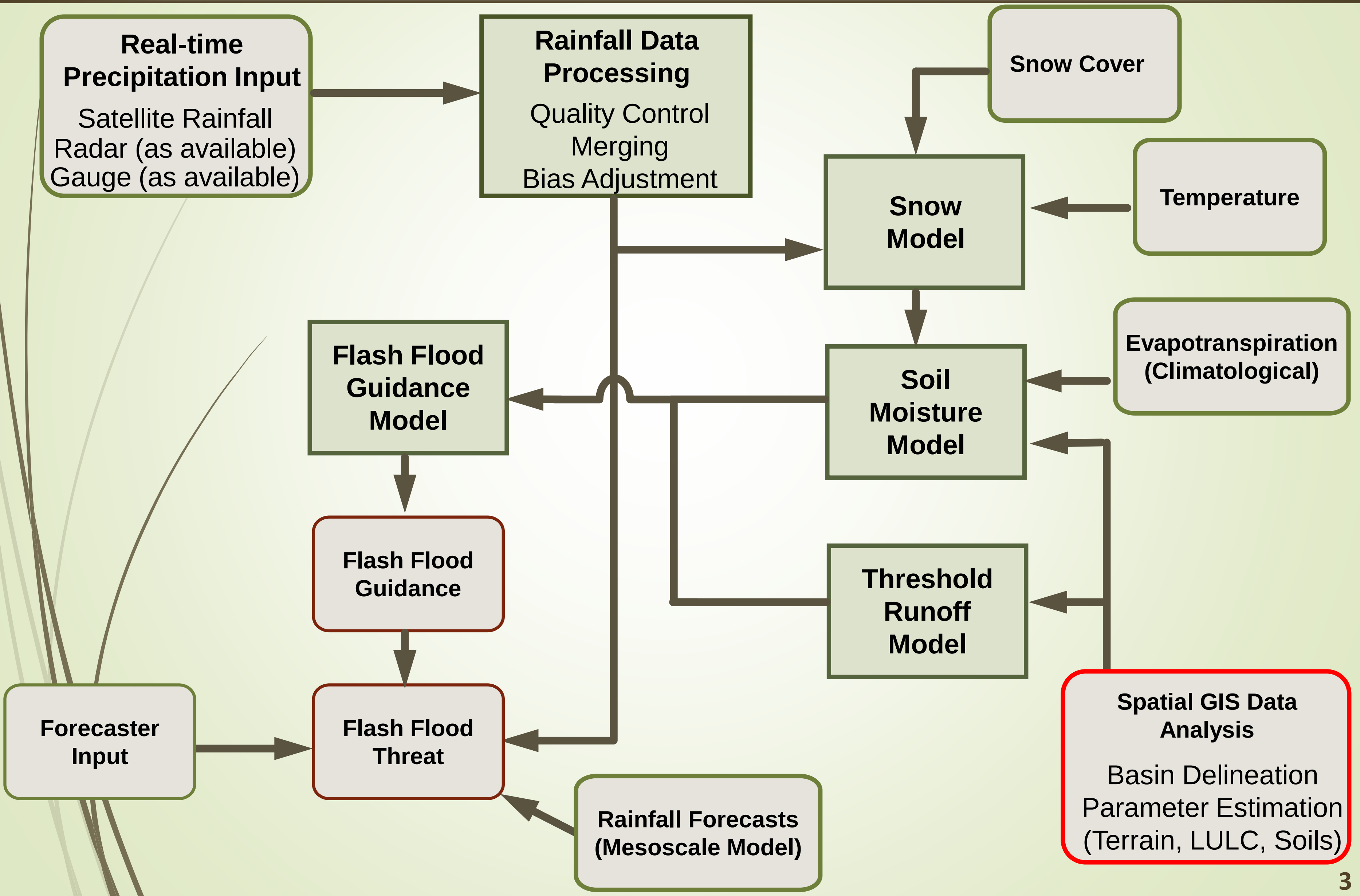
Key Technical Components of the SAOFFG System

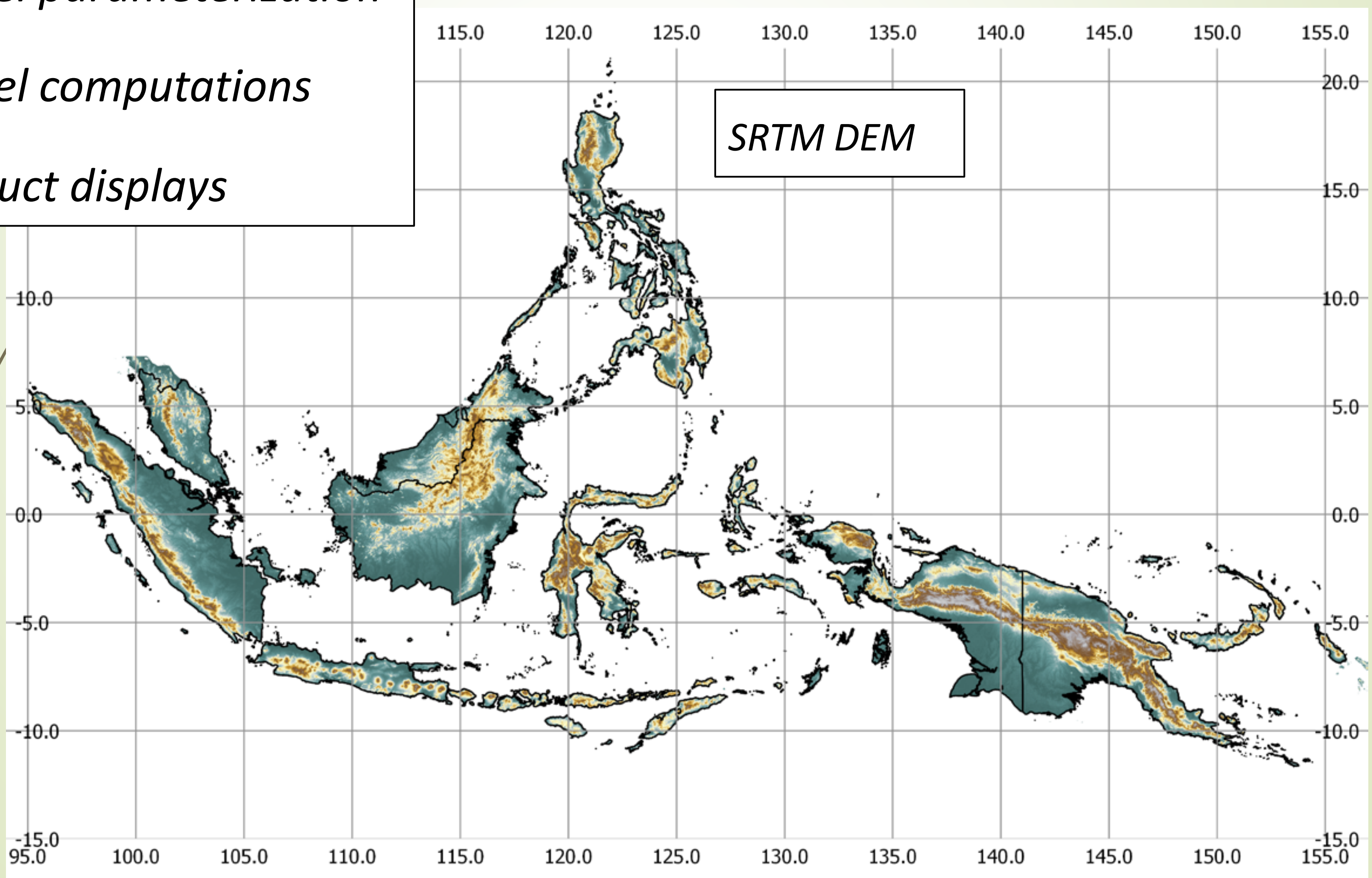


1.- Spatial Analysis



Spatial Analysis to Delineate Small Flash Flood Watersheds

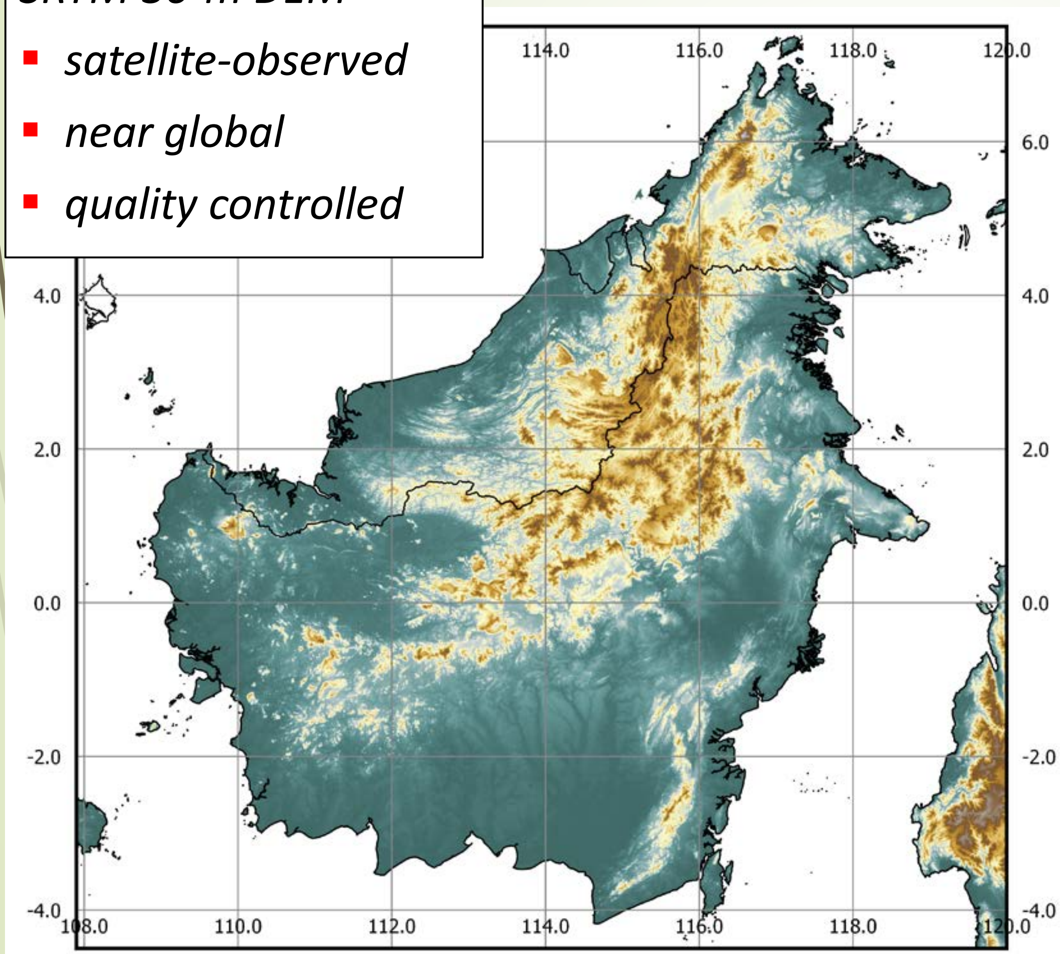
- *Objective is to define flash flood-scale watershed boundaries for SAOFFG System and compute physical properties of those watersheds.*
  - *model parameterization*
  - *model computations*
  - *product displays*



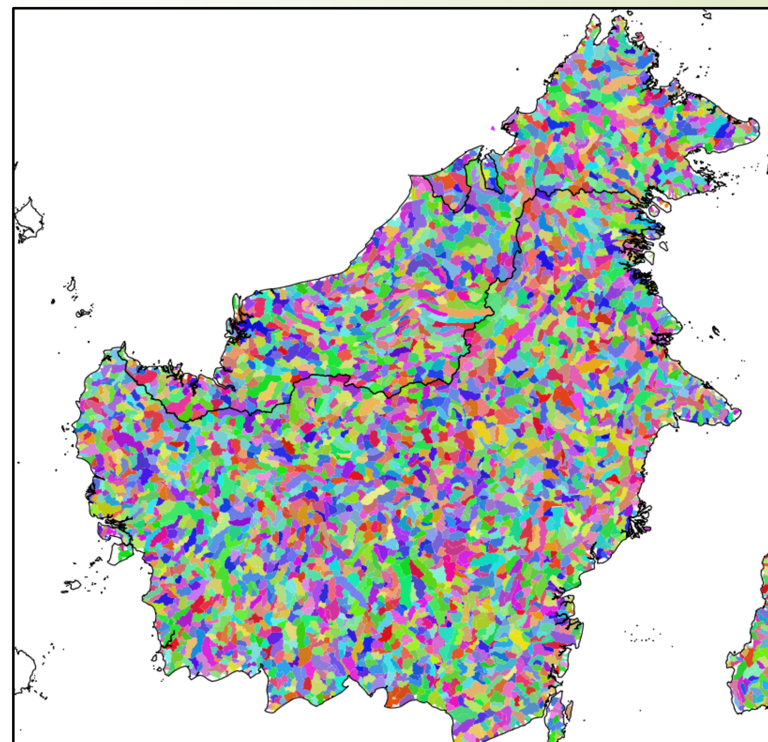
Spatial Analysis to Delineate Small Flash Flood Watersheds

❖ *GIS processing of digital elevation model data (DEM) is used to define basins*

SRTM 30-m DEM
- *satellite-observed*
- *near global*
- *quality controlled*

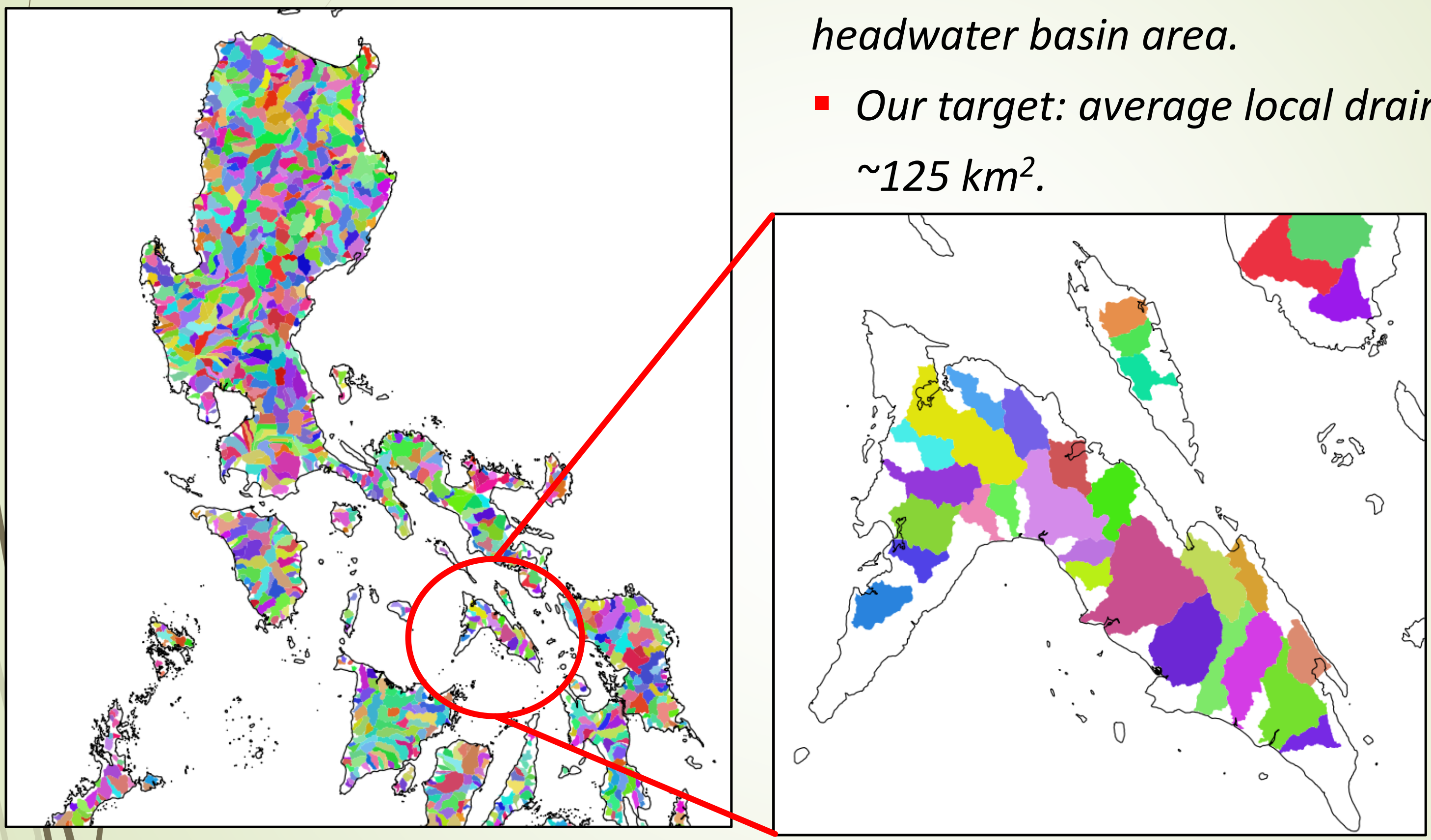


GRASS GIS Software
- *Routine for automated delineation of stream network and watersheds*



Spatial Analysis to Delineate Small Flash Flood Watersheds

INITIAL DELINEATION RESULTS



Define small watersheds based on minimum headwater basin area.

- *Our target: average local drainage area of ~125 km².*
- *Smaller basin area threshold in coastal regions*
- *Nearly 20000 basins defined in entire region*
- *Based on satellite imagery, large lakes omitted*

Output is digital stream network and watershed boundaries.

Validation of Delineation Results

(a) HRC-internal review

comparison with Digital Chart of the World (DCW) stream database

comparison with GoogleEarth Satellite Imagery

(b) Within-Country review

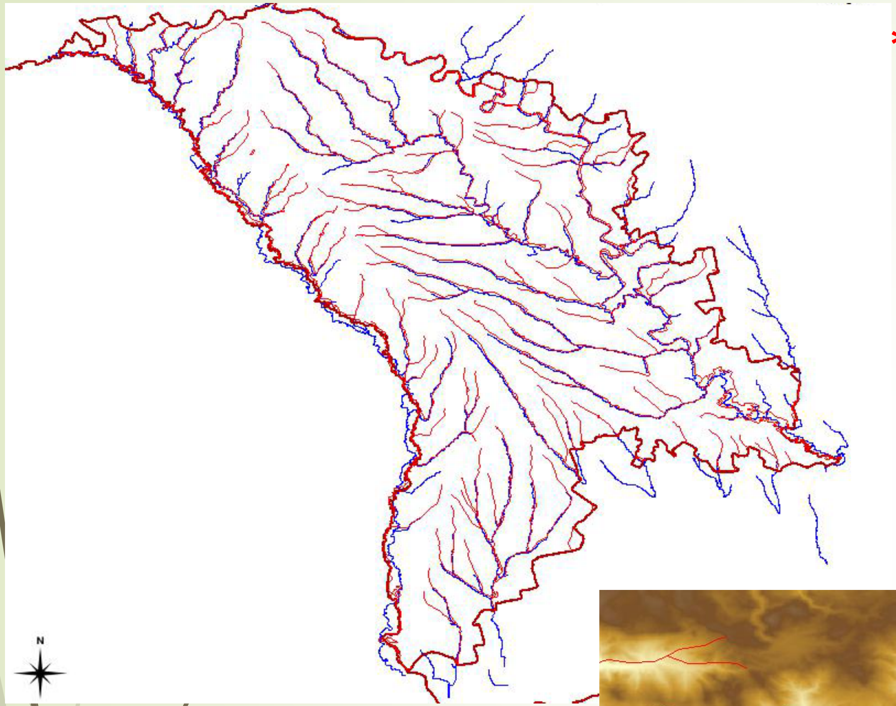
GIS layers provided to NMHSs for evaluation and comments

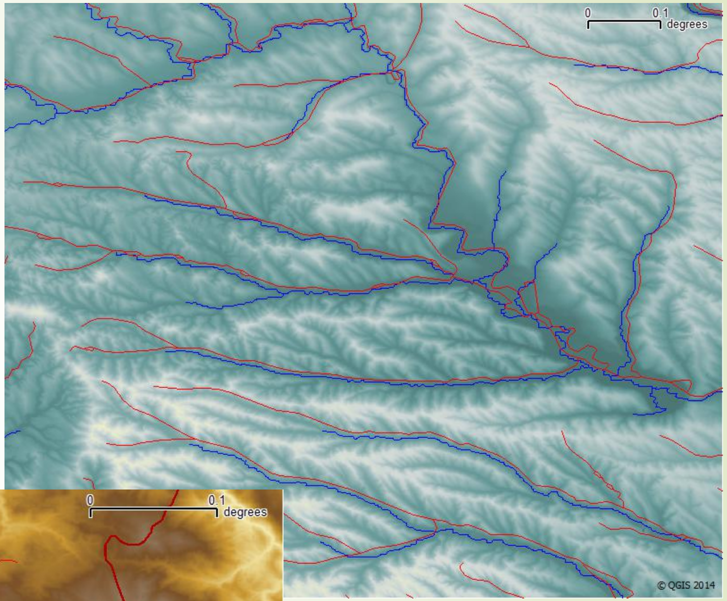
Comments and/or GIS received from 4 countries

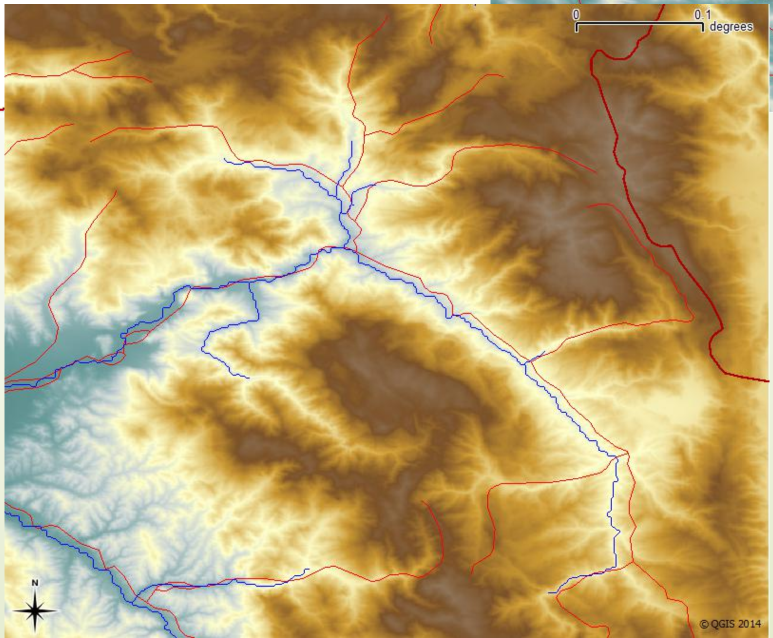
(some lacked specificity in comments)

Example Comparison with DCW Stream Data

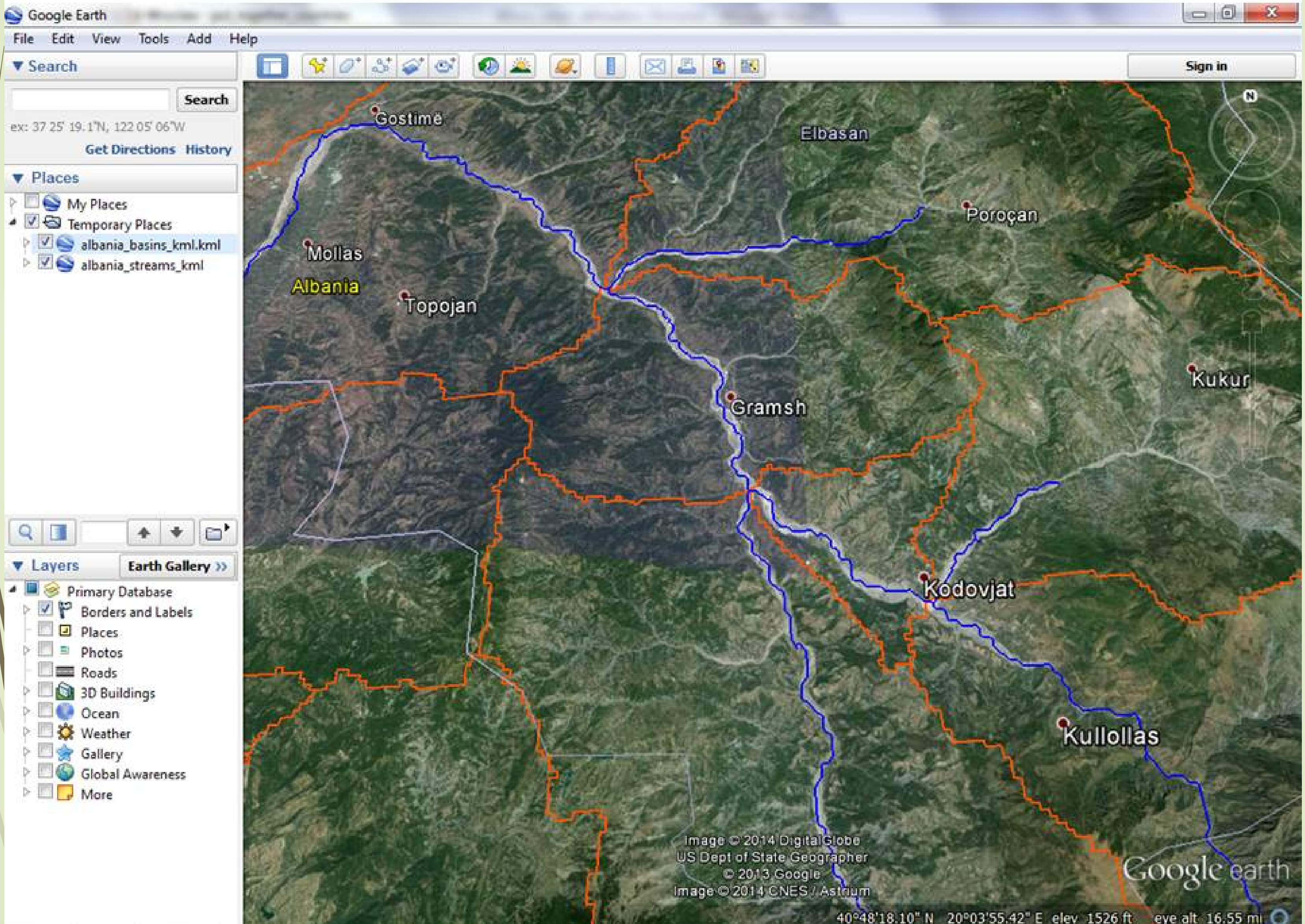
* In lieu of information on basin boundaries







Example Comparison with Satellite Imagery (GoogleEarth)



Within-Country Review of Delineation

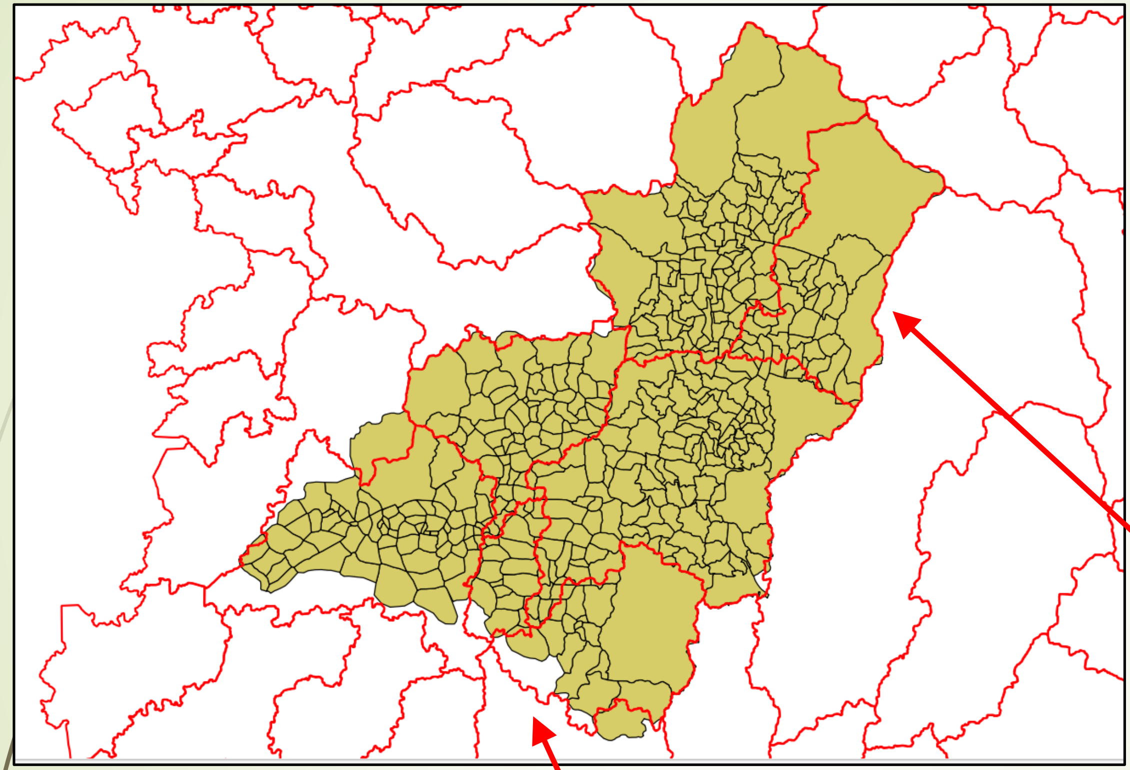
Each country provided with output of delineation processing in GIS format and comments regarding accurate representation of watersheds within country solicited.

Country representatives:

- Have local knowledge of watersheds and stream network, and can identify areas if delineation output does not reflect existing stream/watershed connectivity;
- Can specific regions of that are of concern for flash flooding;
- Can identify regions with modifications to natural drainage network;
- Can compare delineation results with local country data and provide feedback on representativeness of

Within-Country Review of Delineation

Example of local basin information for Klang River



Red outline is FFGS basin
Brown/black outline is local data.

Basin boundary matches well

Basin boundary differs from local data.

Within-Country Review of Delineation

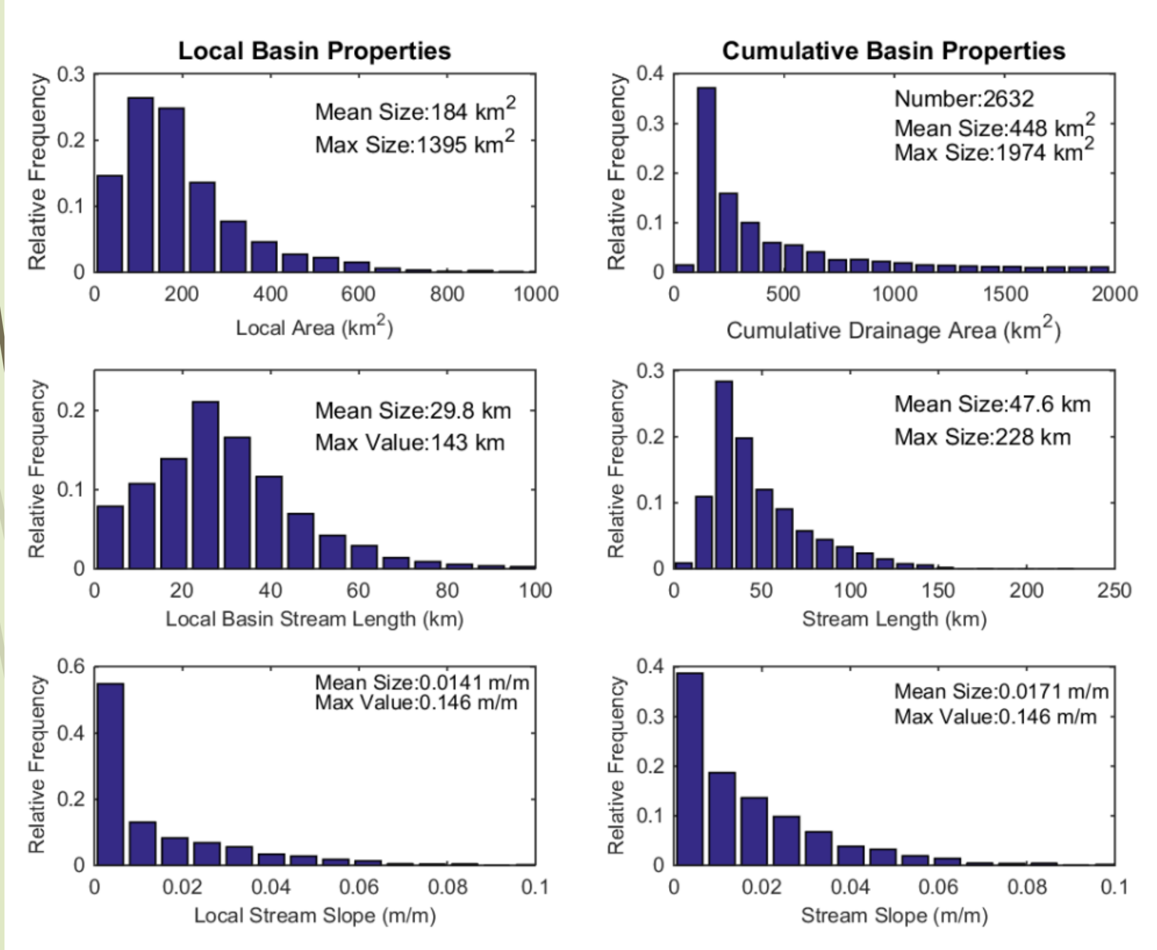
Example comparison with Satellite information

Comments should:

- Identify basin(s) involved (each basin has unique identifier in GIS file)
- State concern of local country representative
- If connectivity of basins is incorrect, provide description of correct drainage path including basin identifiers.

Spatial Analysis for Small Watershed Properties

Delineation results used with GIS software to compute geometric properties (e.g., area, stream length, stream slope) of each small watershed.



These watershed geometry properties are then used in the computation of *threshold runoff*, a characteristic parameter of FFG.

The watershed boundaries are also used to define average soils and land use properties to parameterize the hydrologic models, and to compute mean areal precipitation

Example from SEEFFG System

2. Threshold Runoff, Snow, & Soil Moisture Modeling

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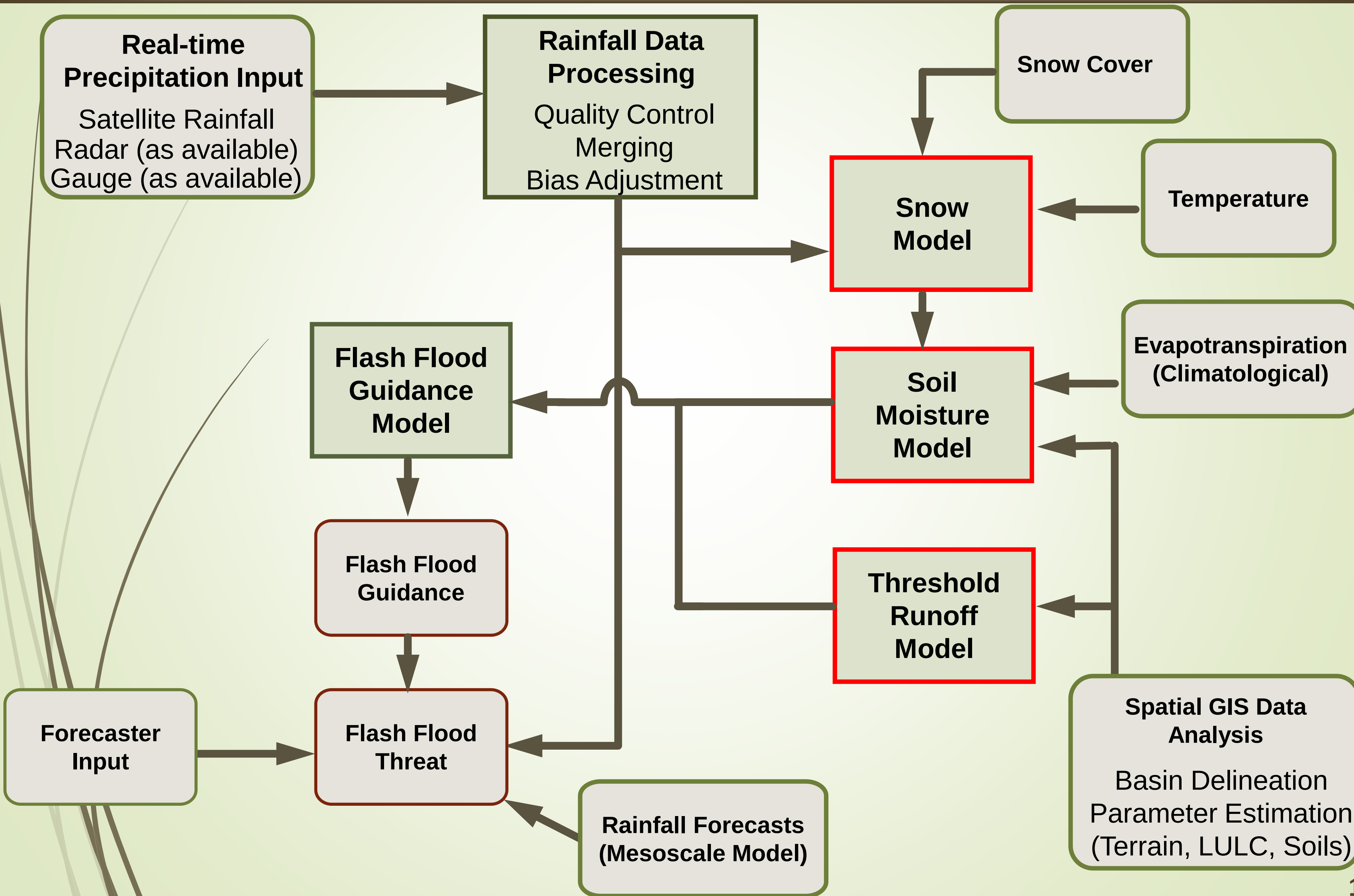
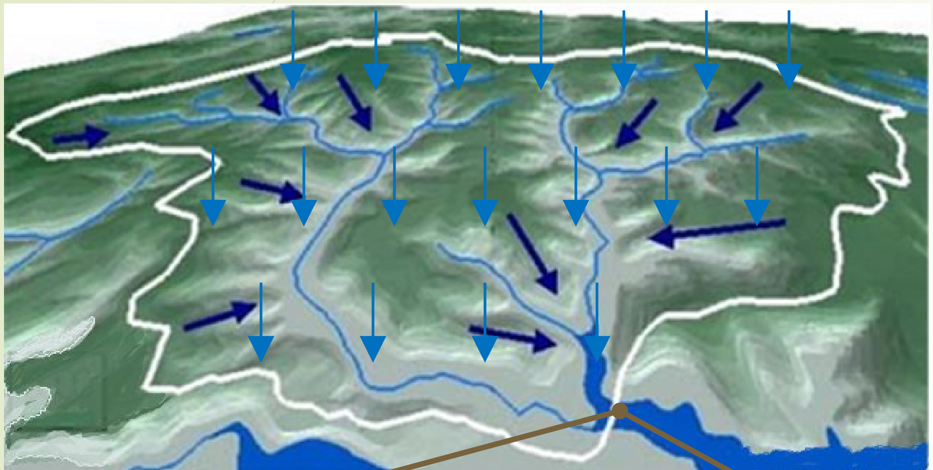
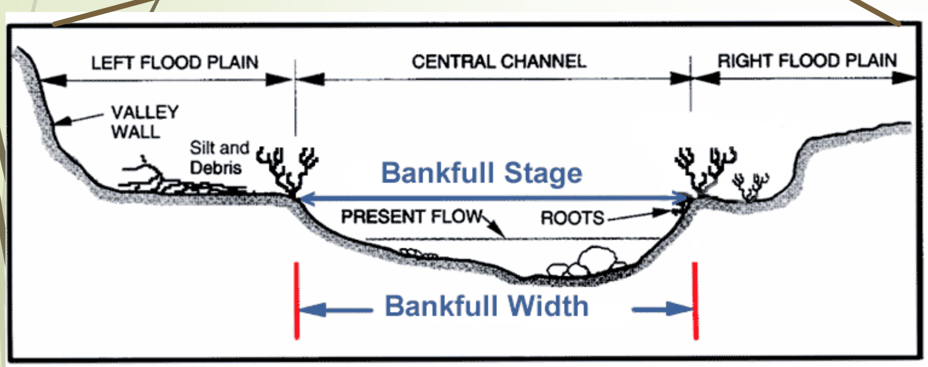


Need for Soil Water Accounting

What happens after rain falls?



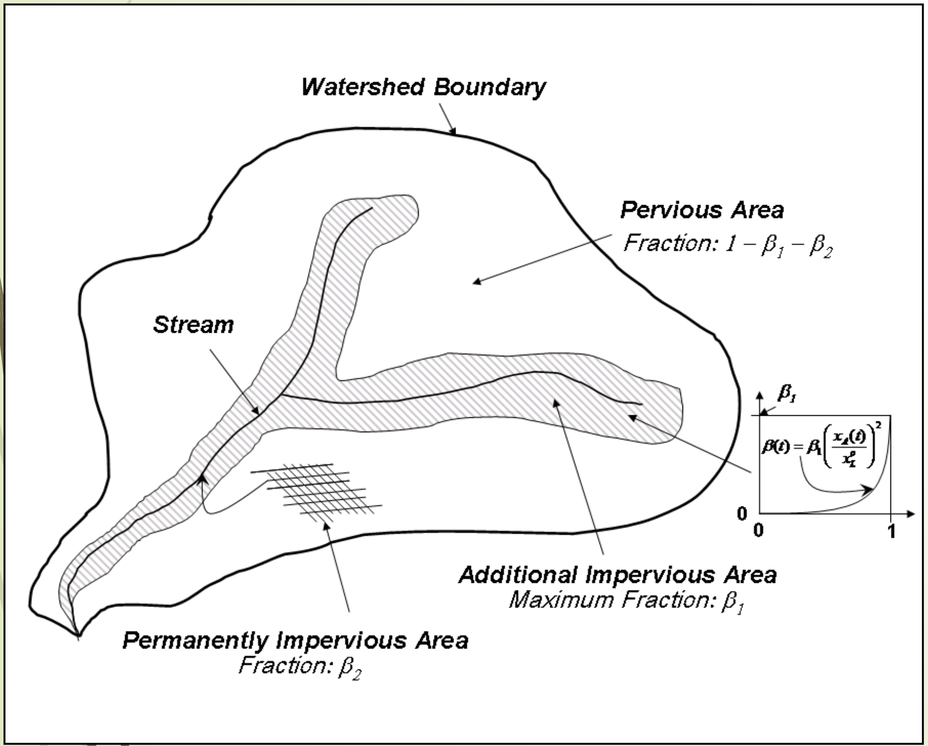


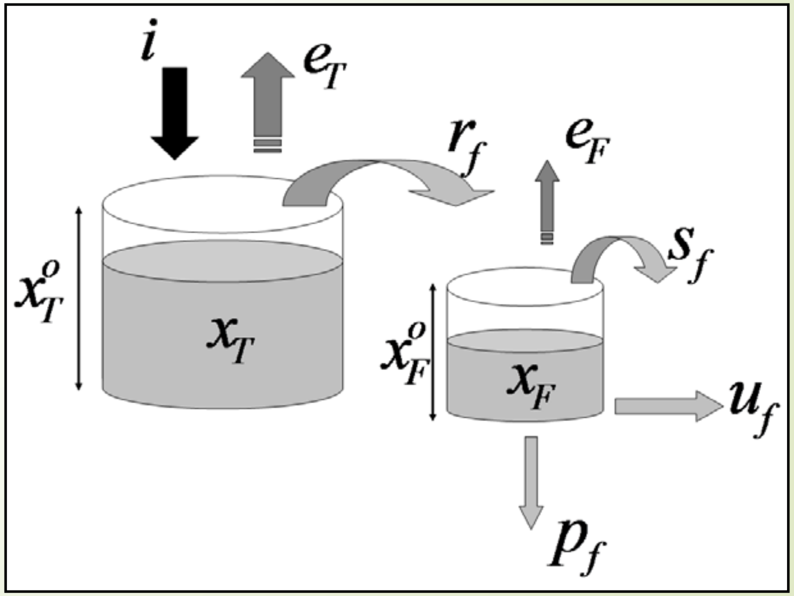
- Infiltrate into the soil and fill soil moisture storage
- Runoff from land surface into channel and fill channel storage
- Be intercepted by vegetation and evaporate

Soil Water Content Model for SAOFFG

- A conceptual hydrologic model is used for soil water modeling: Sacramento Soil Moisture Accounting Model (SAC-SMA) to estimate ability of land surface to absorb and hold moisture.

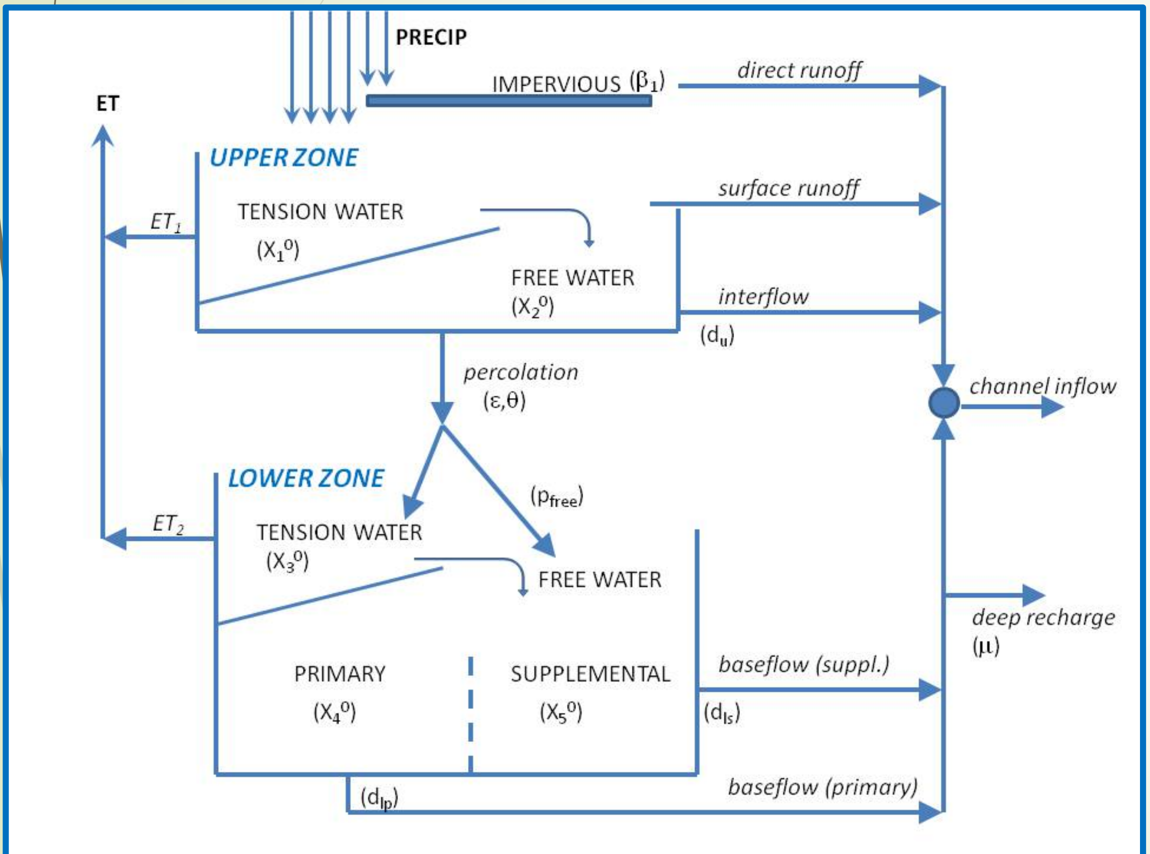
A two-layer conceptual model representing the movement of soil water through a vertical, homogeneous soil column





Soil Water Content Model for SAOFFG

Schematic of Sacramento SMA Model



INPUT:

- *Precipitation (or Rain+Snow melt)*
- *Potential Evapotranspiration*

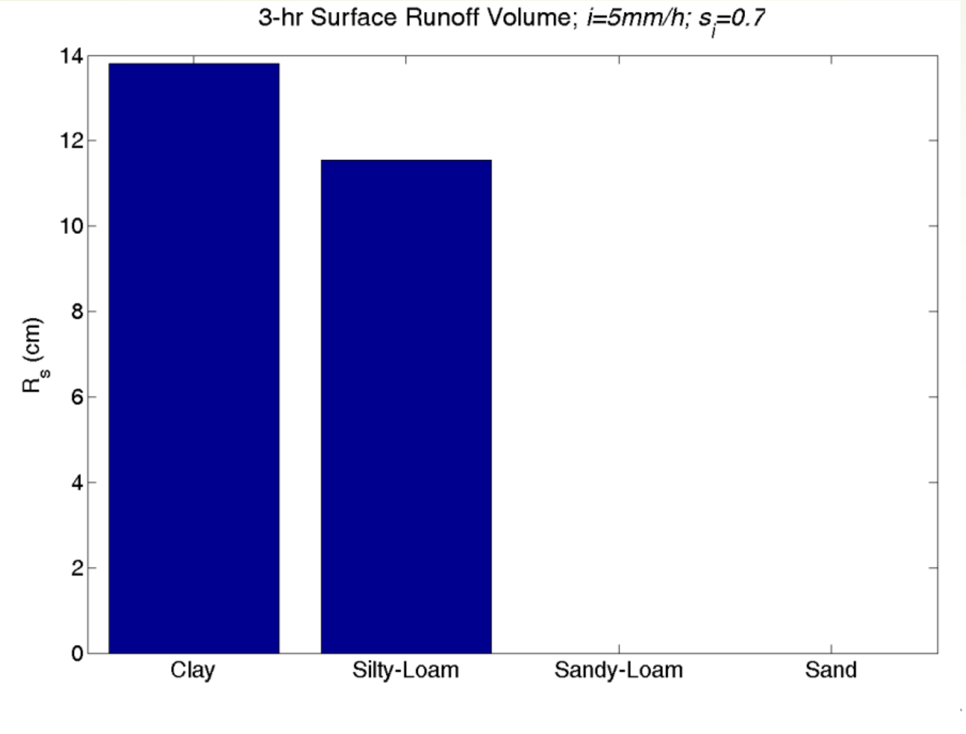
Various representations of runoff:

- *saturation excess*
- *infiltration excess*
- *combined runoff*

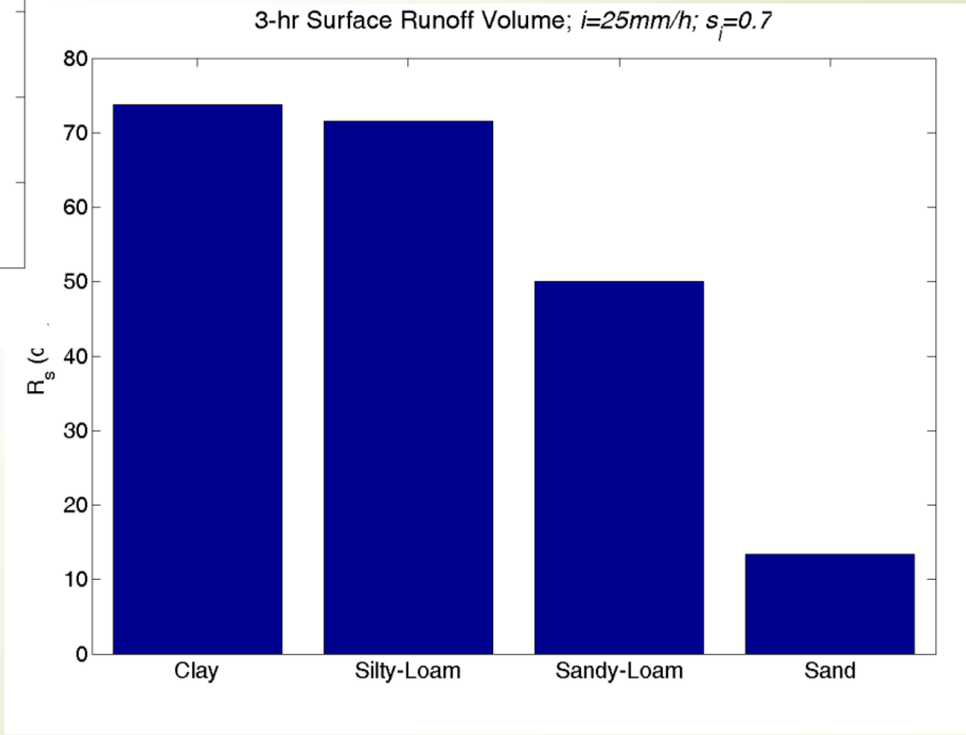
PARAMETERIZATION:

- *15 model parameters (capacities, withdrawal rates, percolation)*
- *Initial parameters based on soils and land cover*

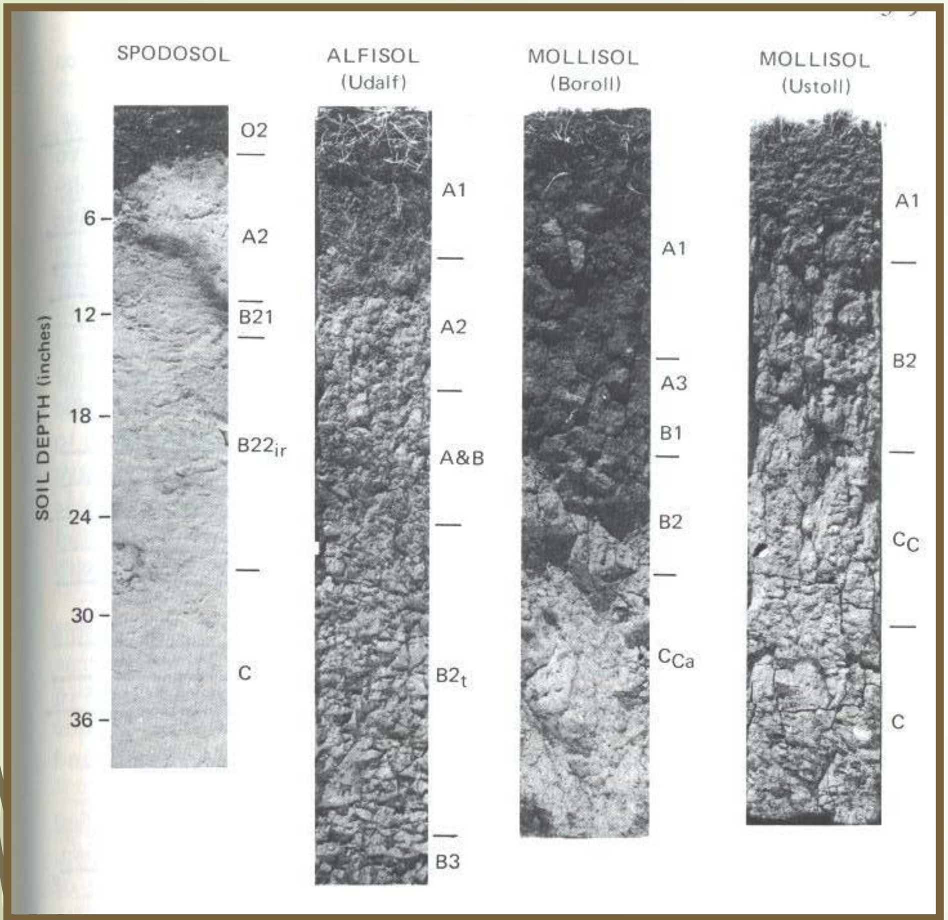
Effect of Soil Classification on Runoff Production

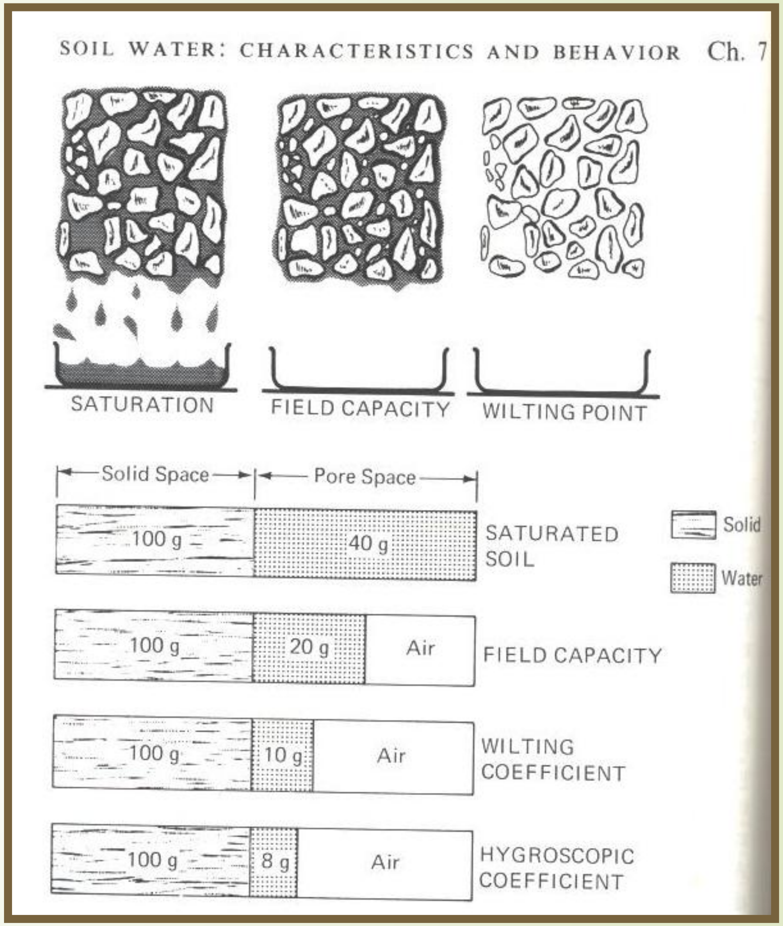


Plots of surface runoff generated over 3 hours for different soil classifications



Relating Soils Characteristics to Hydraulic Properties

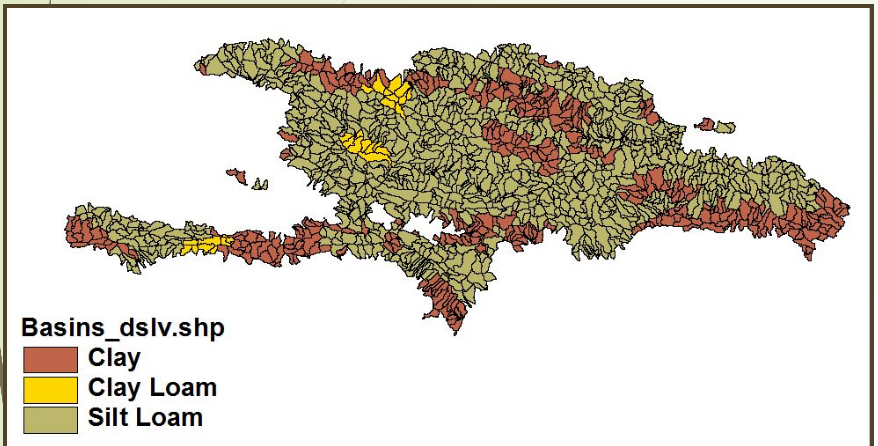




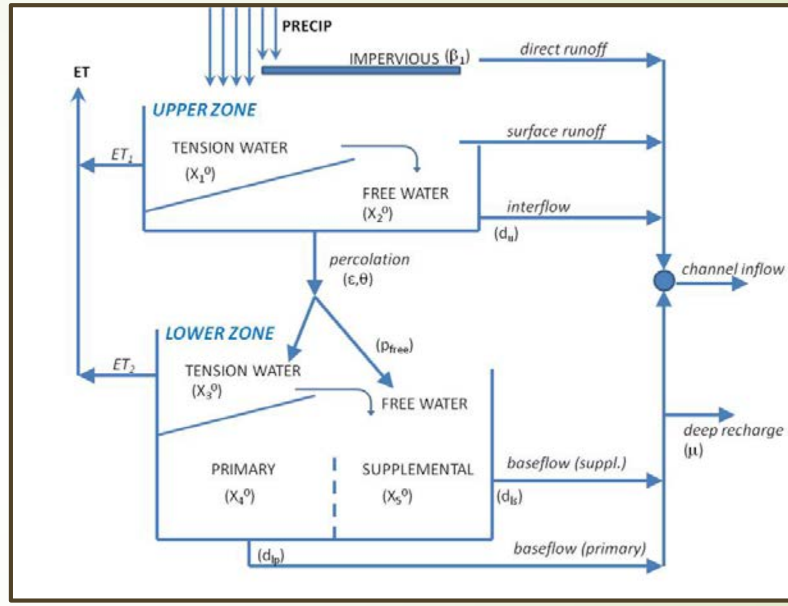
Figures from Brady, N.C., 1974: The nature and properties of soils. McMillan Publ. Co., NY

Sacramento SMA Model Parameterization

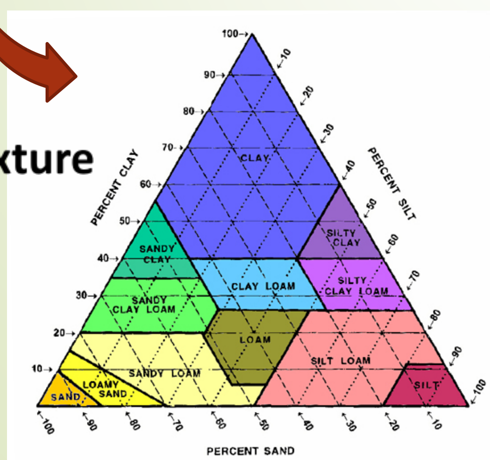
1. Soils Information



4. Parameters of SAC-SMA



2. Soils Texture

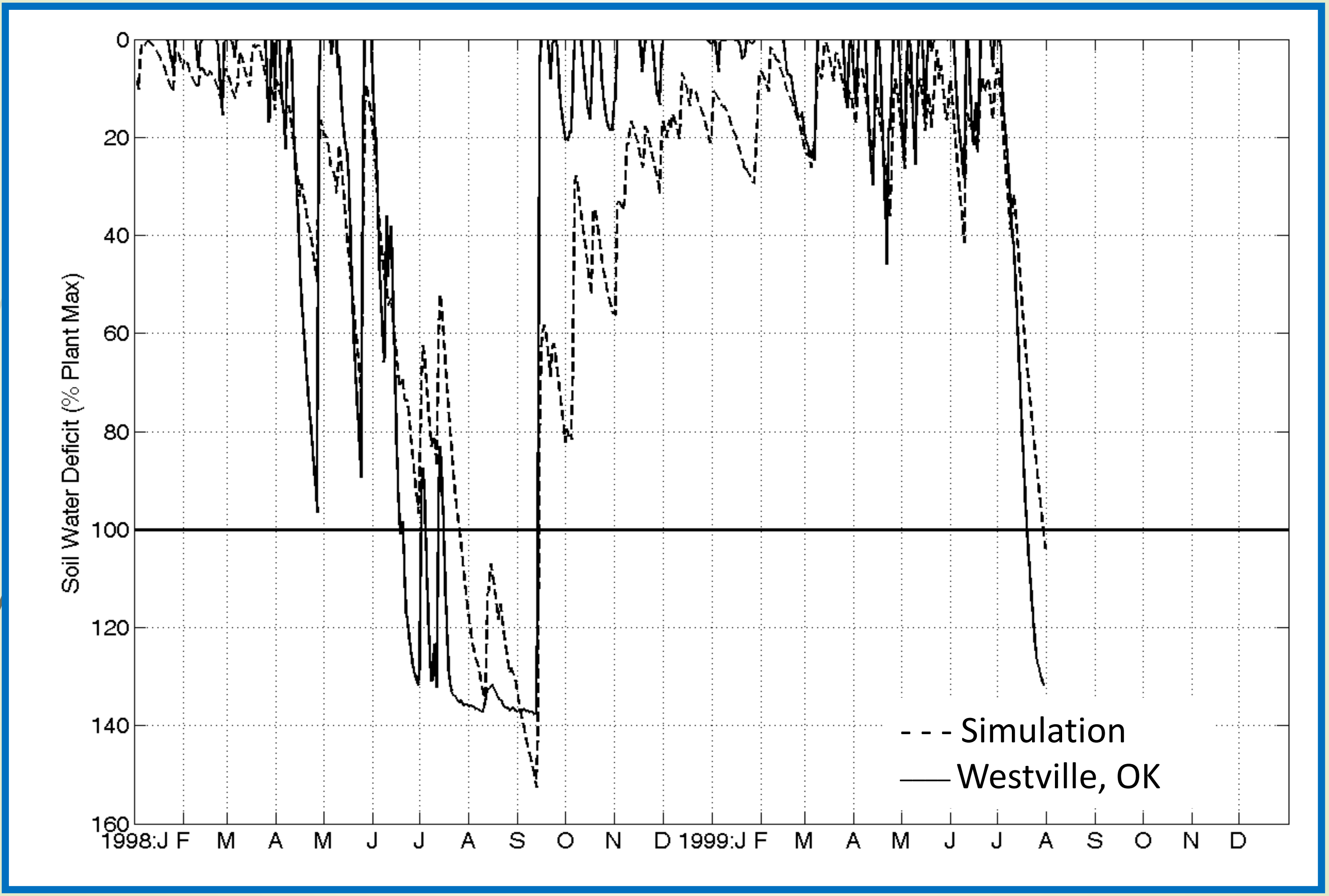


Soil Class	$\theta_s(m^3/m^3)$	$\theta_f(m^3/m^3)$	$\theta_m(m^3/m^3)$	$K_s(m/h)$	α	$\sigma_{Ks}(m/h)$
Sand	0.34	0.09	0.015	0.168	2.79	0.062
Loamy Sand	0.42	0.16	0.05	0.050	4.26	0.082
Sandy Loam	0.43	0.21	0.07	0.019	4.74	0.119
Loam	0.44	0.25	0.095	0.012	5.25	0.108
Silty Loam	0.48	0.29	0.11	0.010	5.33	0.090

3. Hydraulic Properties

Example Soil Model Output: Site-Specific Validation

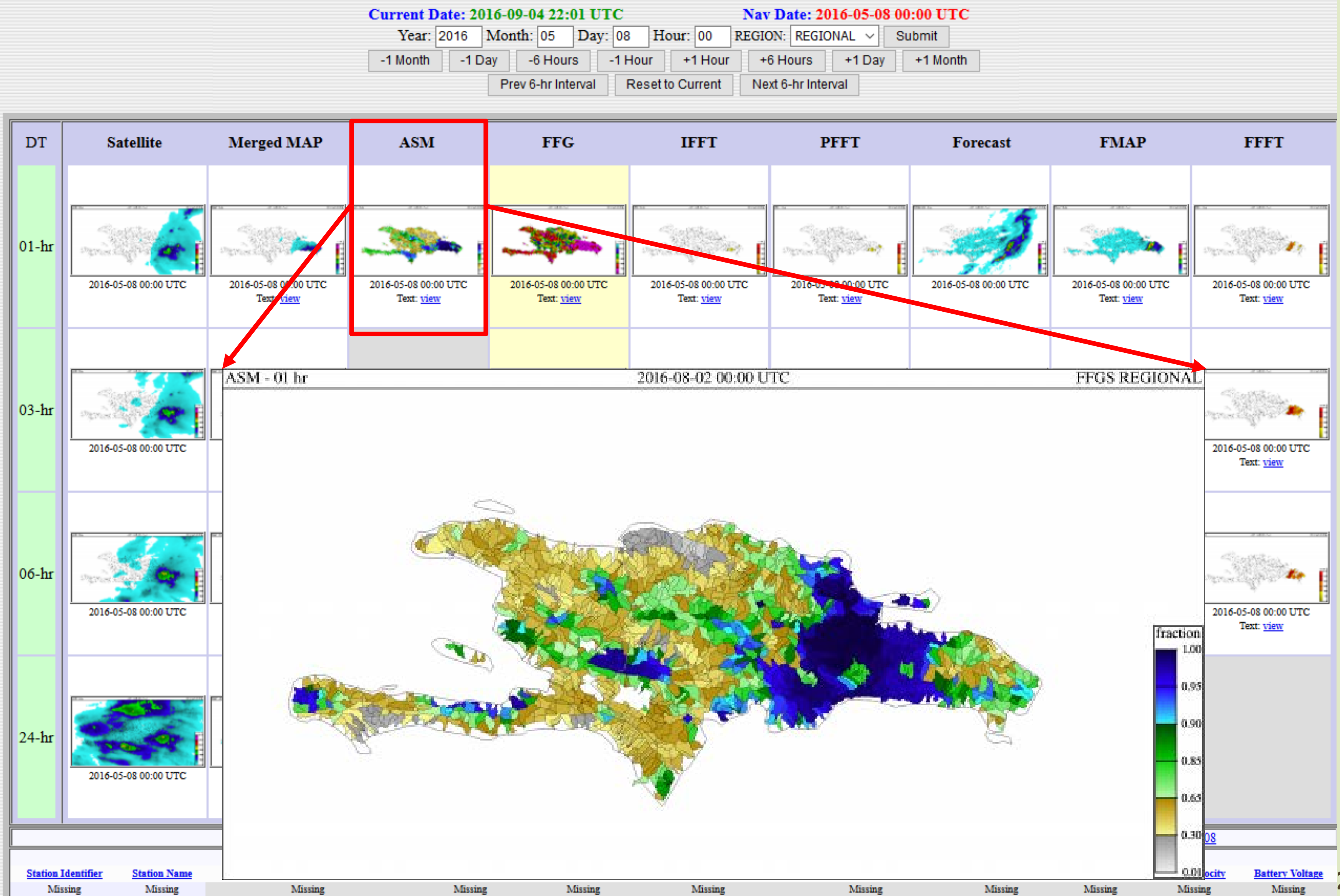
Simulation for Illinois River Basin in Oklahoma, U.S.A



Reasonably good reproduction of depth integrated soil water deficit

FFG System Products

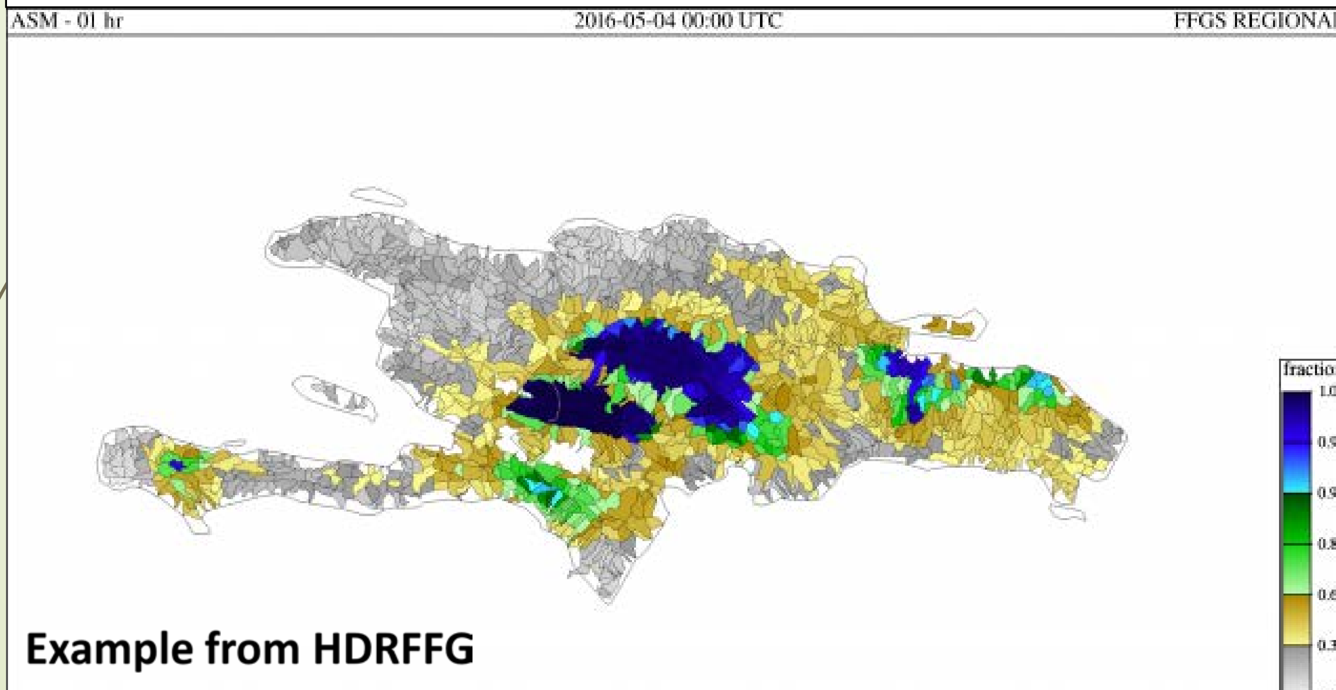
Example from: HDRFFG - Haiti and Dominican Republic Flash Flood Guidance System



Key Definitions

ASM: Average Soil Moisture

An estimate of the current soil water content in the upper soil depth layer, expressed as a fraction of saturation. The upper soil depth is most indicative for flash flood production. This is computed by the model.



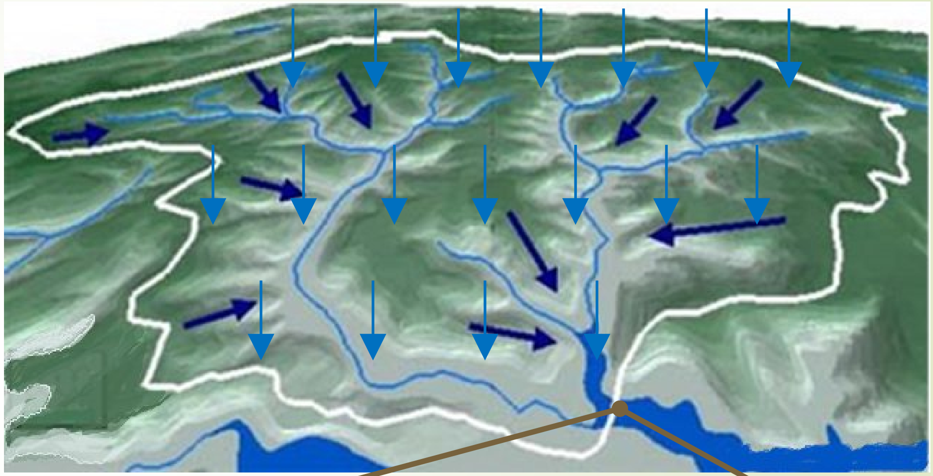
Example from HDRFFG

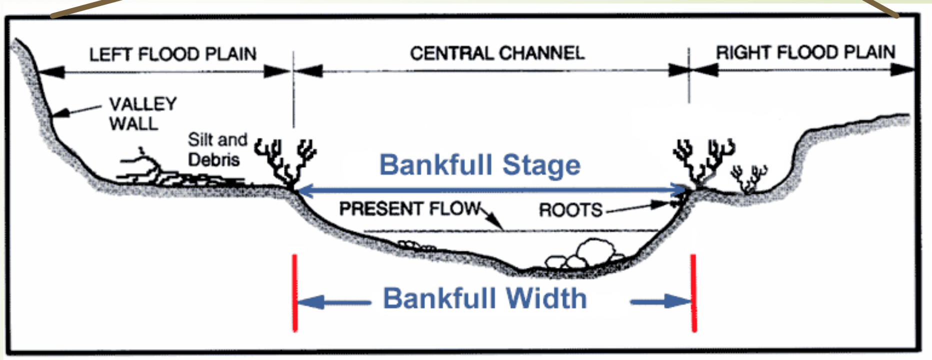
Forecasters may see changes as precipitation falls and basins (or groups of basins) become more saturated.

Definition of Threshold Runoff

Threshold Runoff (TR) is defined as the amount of *effective rainfall* of a given duration falling over a watershed that is just enough to cause *bankfull* conditions at the outlet of the draining stream.

TR is a characteristics of the watershed (constant).





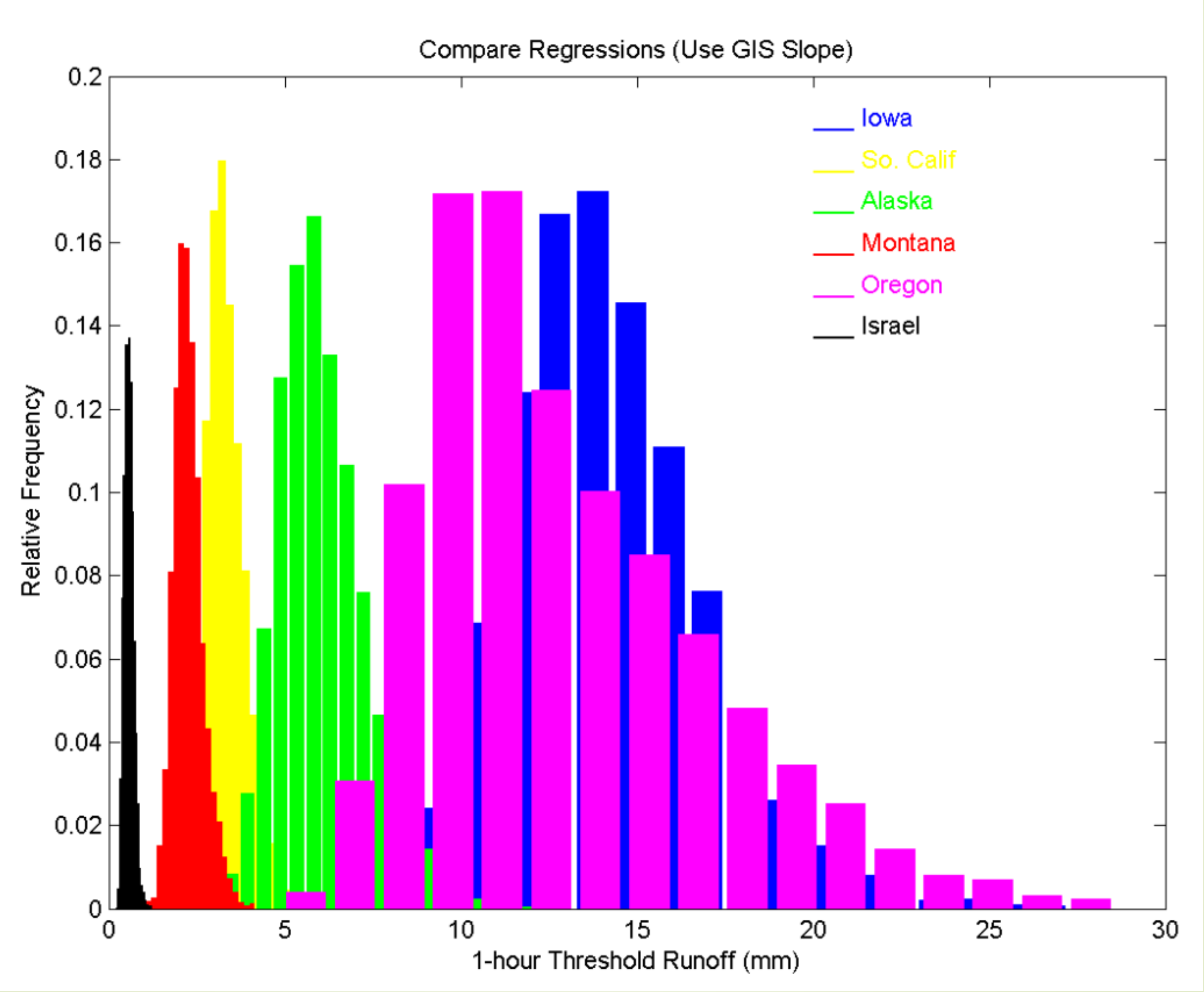
Threshold Runoff represents the amount *rainfall* that goes to filling the channel capacity at the level of bankfull conditions.

Estimation of Threshold Runoff

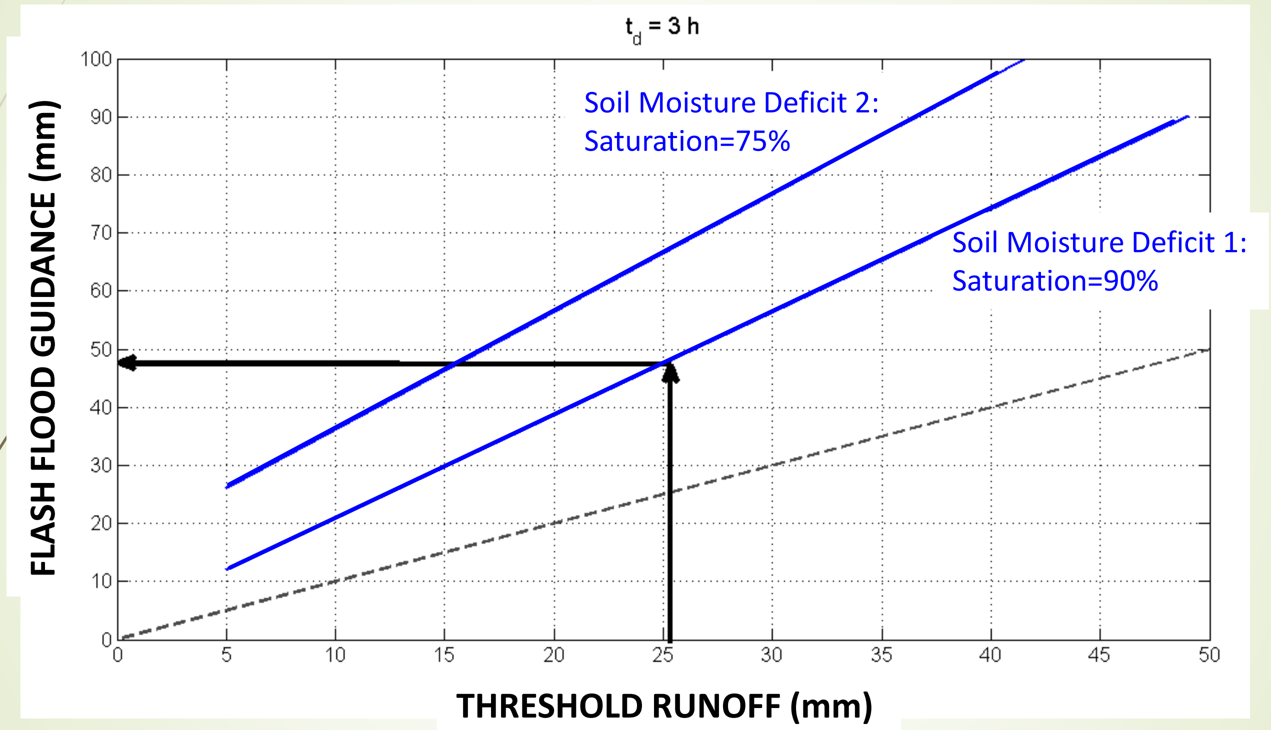
- Related to response of the watershed. Needs watershed-scale geometry properties (A, L) from spatial GIS analysis
- Related to channel capacity to carry stream flow. Needs channel *cross-sectional* properties (B_b, D_b).
  - Typically, *regional relationships* derived from country-provided channel cross-sectional survey information for small streams (limited number of locations).

$$R = f(A, L, B_b, D_b, S_c)$$

Estimation of Threshold Runoff

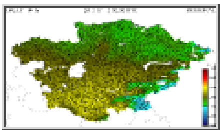
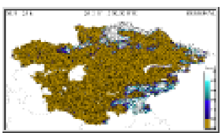
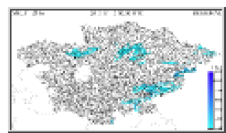
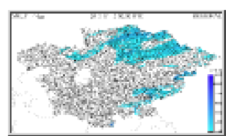


Relationship between Threshold Runoff and FFG



*Threshold Runoff is a **one-time** calculation for a given watershed (a characteristic of the watershed), whereas FFG is computed on a **real-time** basis considering up-to-date soil water content conditions. Soil water content greatly influences FFG.*

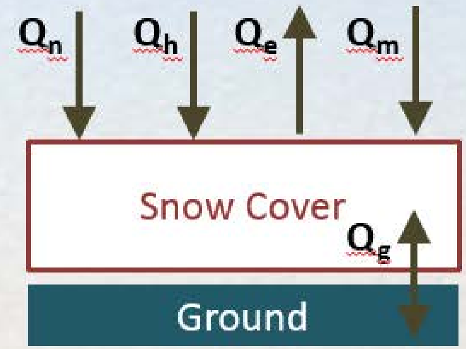
Snow Modeling

Snowpack Products				
DT	Gauge MAT	Latest IMS SCA	SWE	Melt
06-hr	 2015-04-15 00:00 UTC Text: view		 2015-04-15 00:00 UTC Text: view	
24-hr		 2015-04-15 00:00 UTC Text: view		 2015-04-15 00:00 UTC Text: view
4-day				 2015-04-15 00:00 UTC Text: view

For regions with significant snow cover, a snow model is employed to account for snow storage and snow melt impact on soil moisture.

Energy Balance Methods for Snow Modeling

- Energy Balance for Snow Cover



$$Q_n + Q_e + Q_h + Q_g + Q_m = \Delta Q$$

where
- Q_n = net radiation (solar – longwave) $= f(Q_{sw}, Q_{lw}, A, T_o)$
- Q_e = latent heat transfer $= f(e_o, u_a)$
- Q_h = sensible heat transfer $= f(T_o, T_a, u_a)$
- Q_g = heat transfer at snow-soil interface $= f(T_g, T_s)$
- Q_m = heat transfer by mass changes (e.g. advected by rain) $= f(p)$
- ΔQ = change in heat storage of snow cover

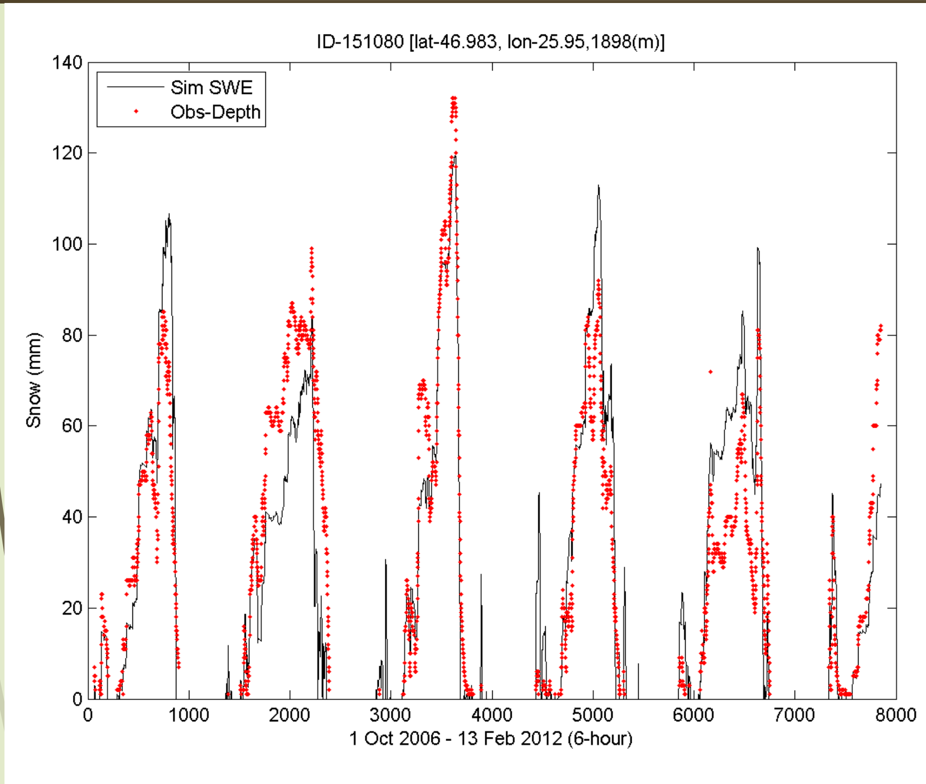
Energy Balance solution is data intensive!

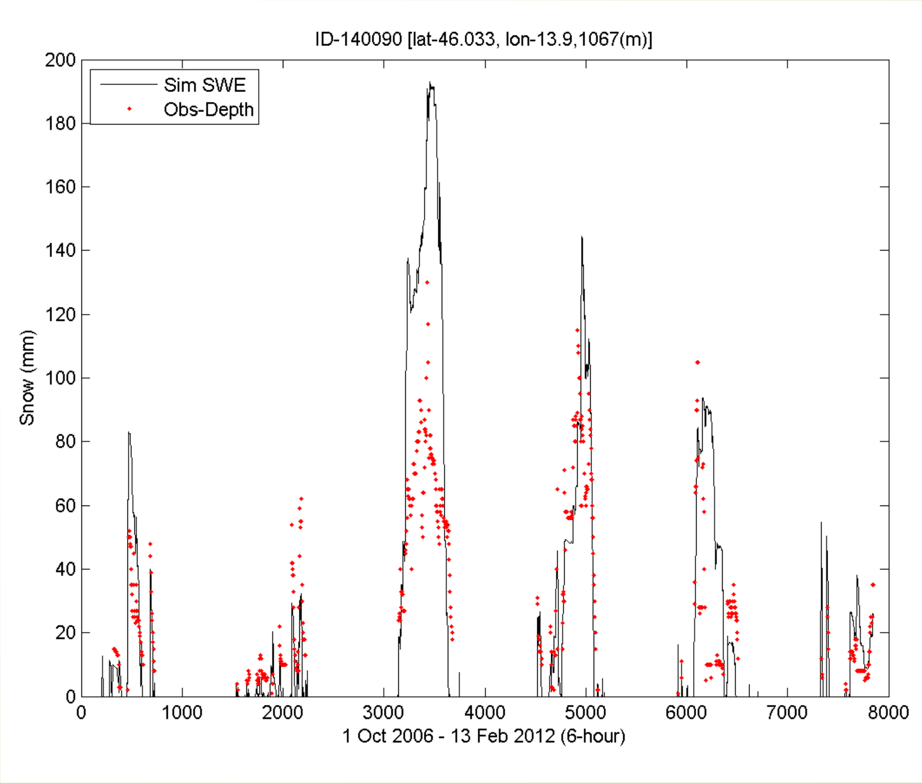
Snow Model – SNOW 17

- Snow Accumulation and Ablation Model (SNOW-17) of the U.S. NWS (Anderson, 1973)
- Designed to use readily available operational data
- A conceptual areal lumped energy and mass balance model
- *Air Temperature* used as an index for pack energy and division of precipitation as rain or snow
- Considers: melt during no rain; melt during rain; no melt
- Model states track: snow water equivalent (SWE), heat deficit, pack temperature, liquid content.
- Single vertical layer
- Three modules:
  - Melt during rain
  - Melt during no rain
  - Heat accounting during no melt

Describe the snow cover extent using the Snow Depletion Curve

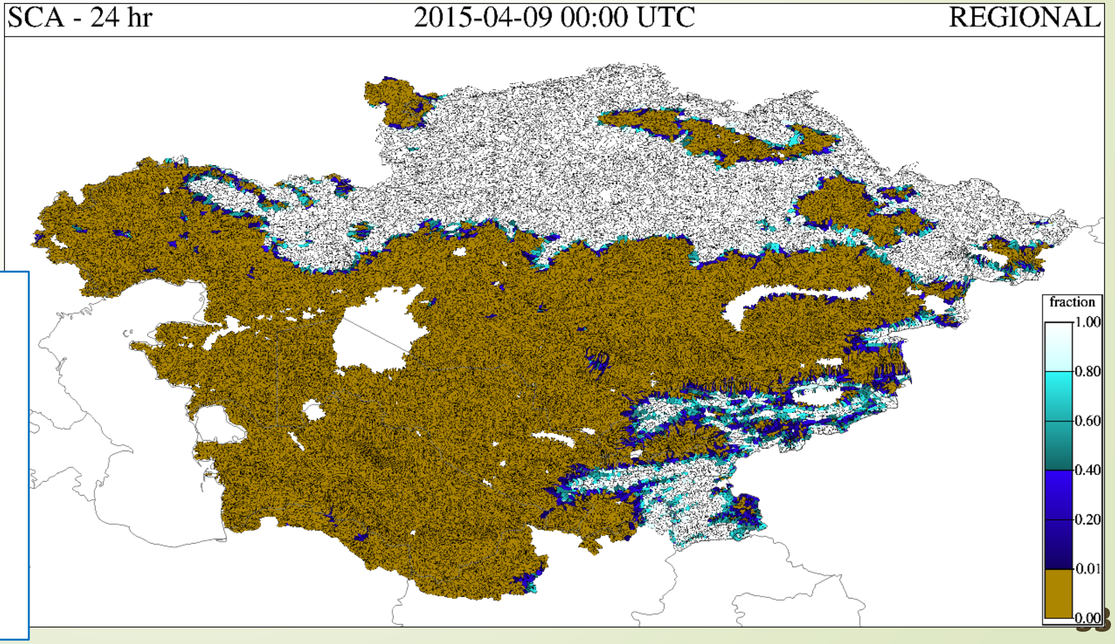
Comparison of modeled SWE with Observed Snow Depth





Satellite Snow Covered Area

- Interactive Multisensor Snow and Ice Mapping System (IMS), made available through National Snow and Ice Data Center, NOAA.
  http://nsidc.org/data/docs/noaa/g02156_ims_snow_ice_analysis/index.html
- Daily snow cover based on summary of multiple satellites at 4km x 4km resolution.
  - Geostationary & Polar orbiter satellites
  - Assisted by modeling , climatological maps, and personnel expertise
- Generally available within 1 day (often within several hours) after date of observation
- 4km product is Operational since 2006-2011



Example from CARFFG:
presented as fraction of snow cover in each basin.

- *Apportion rain for uncovered areas*
- *Soil-snow interface leakage for snow covered areas*

3. Flash Flood Guidance

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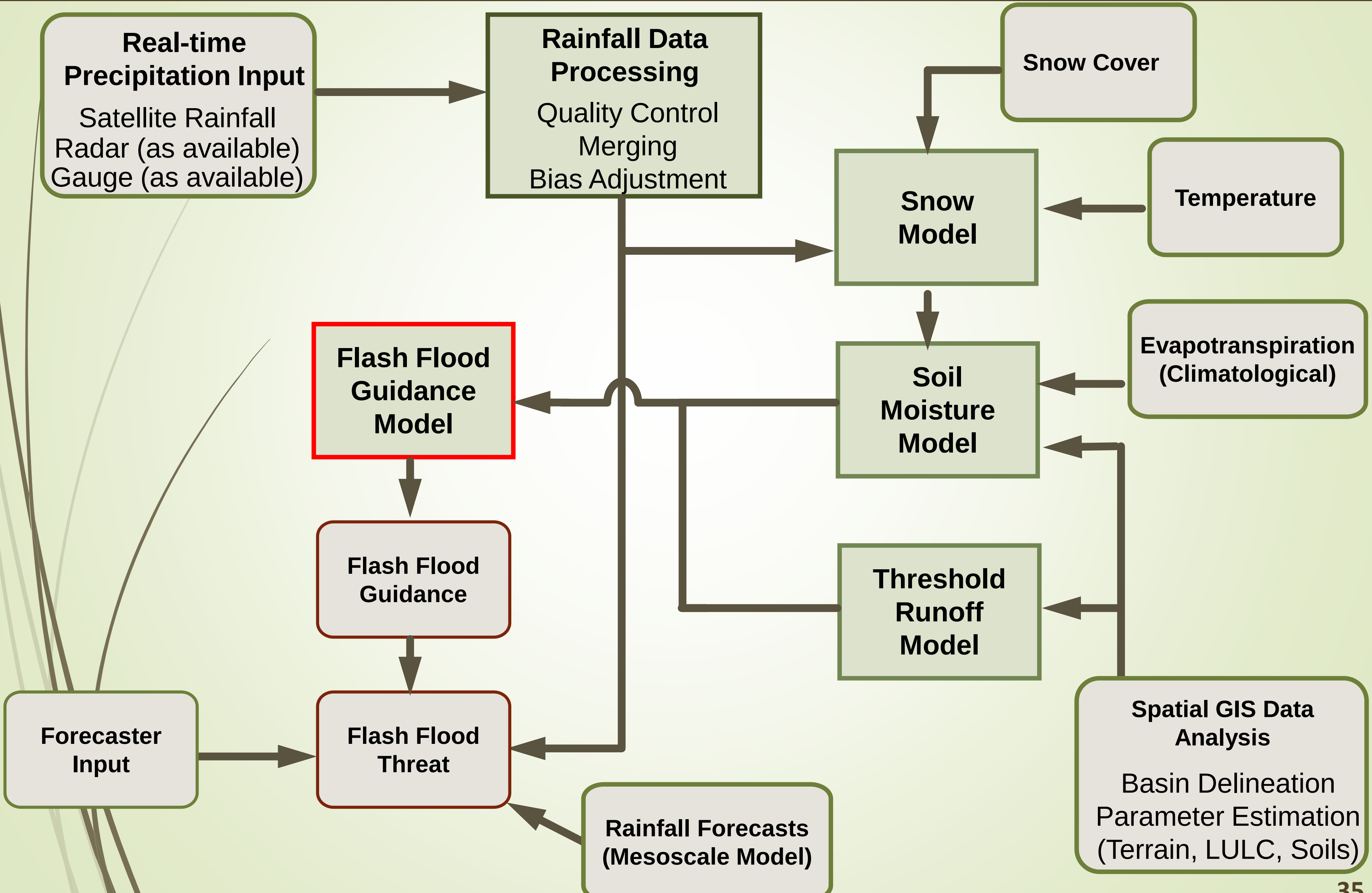
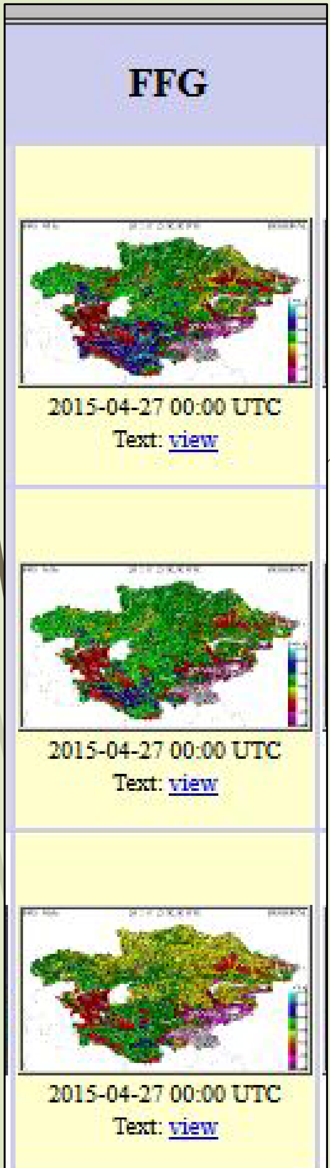


Flash Flood Guidance



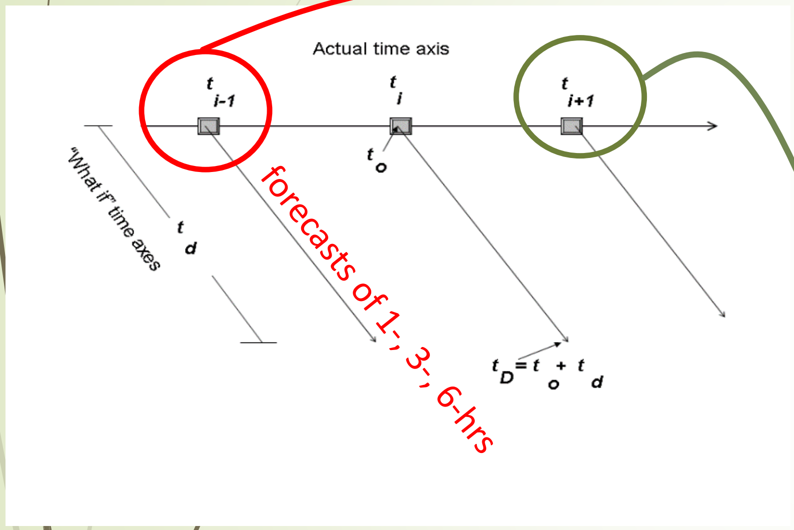
Flash Flood Guidance (FFG) is an estimate of the amount of ***actual rainfall*** of a given duration over a given small watershed which is enough to produce bankfull flow in the stream channel at the outlet of the watershed.

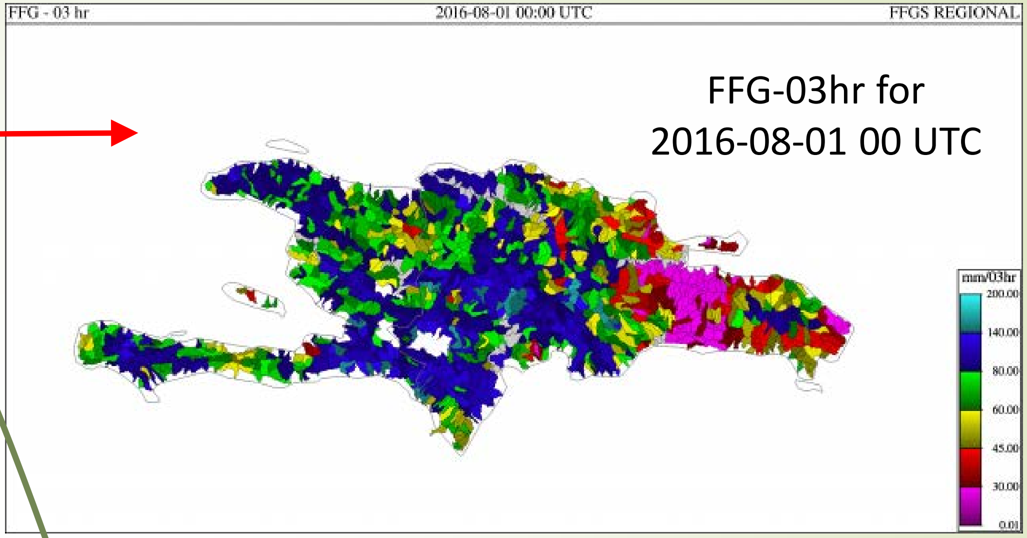
FFG integrates information from threshold runoff, soil water content, and current precipitation.

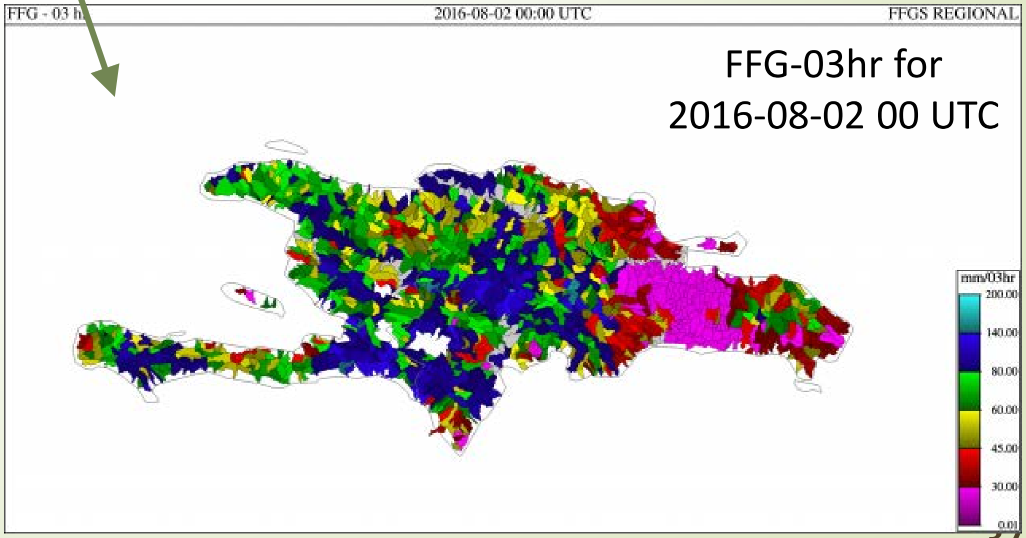
FFG is updated every six-hour in SAOFFG System.

Flash Flood Guidance

Model Run Time (6-hours)

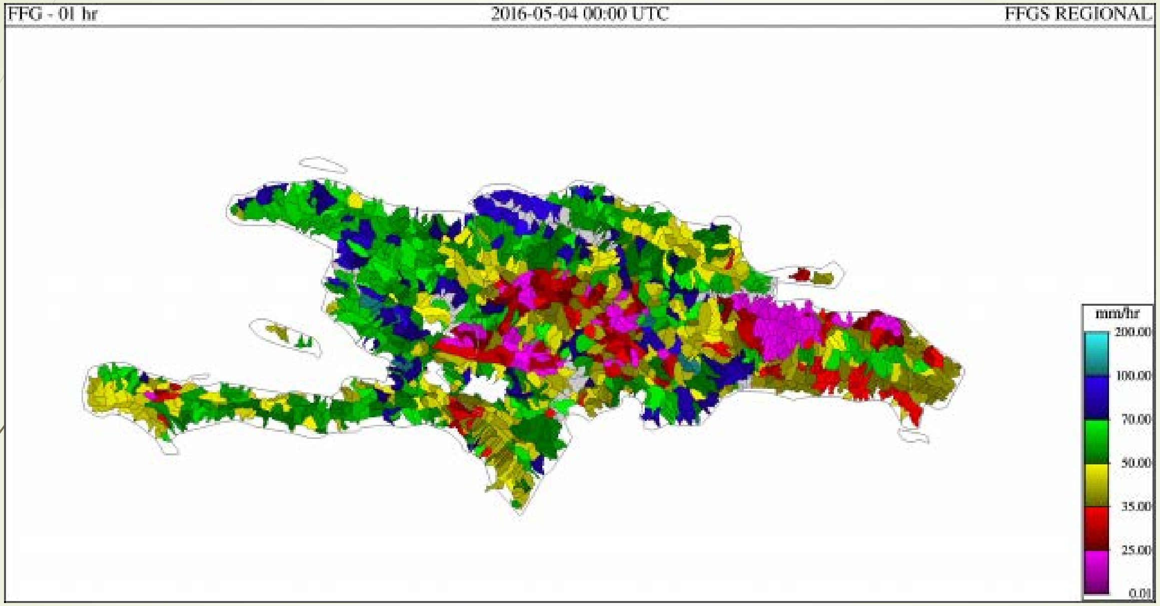






Fundamental Concept of FFG Use

FFG: How much rain is *needed* to reach flooding conditions?



4. Precipitation Input

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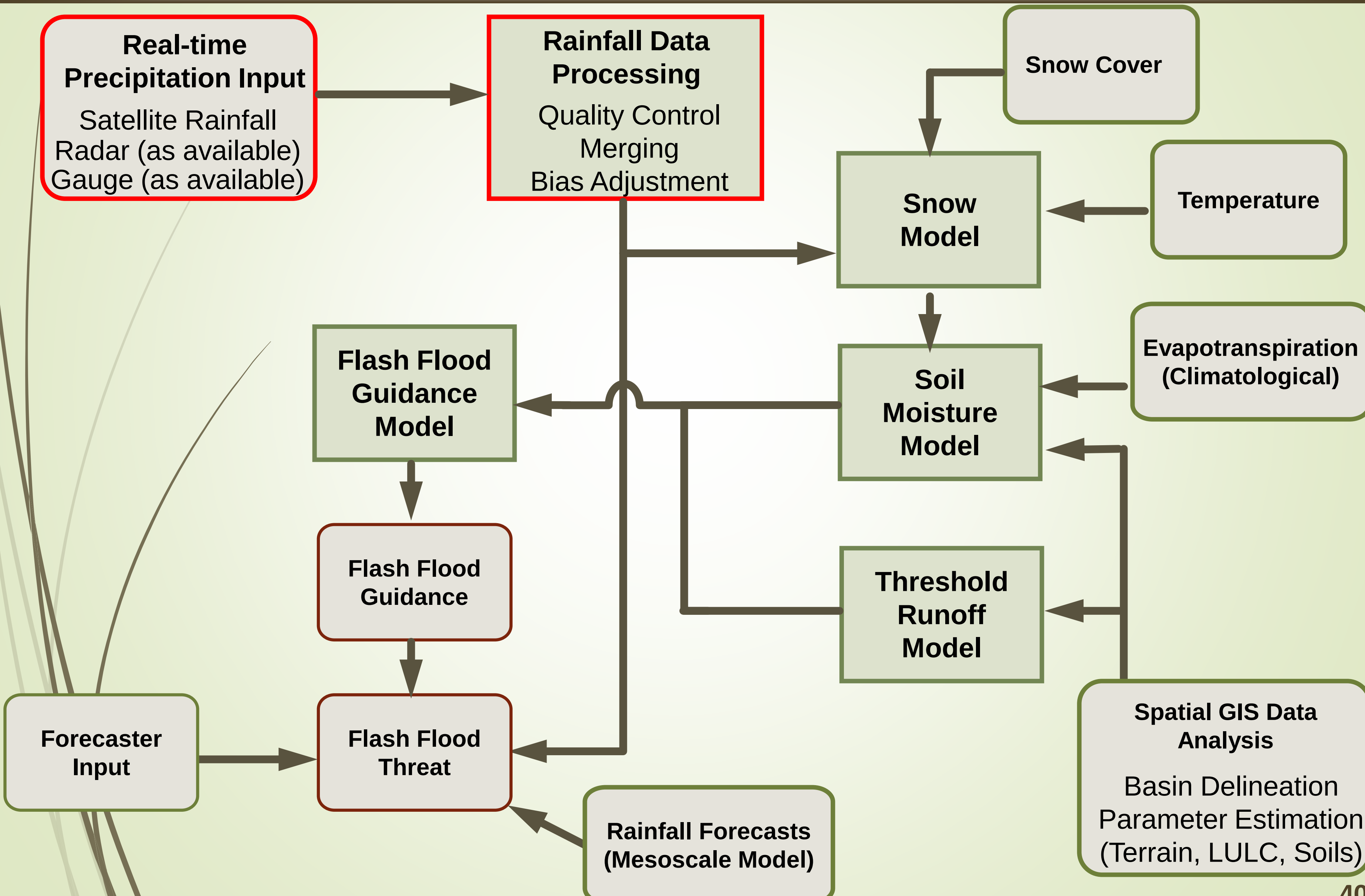
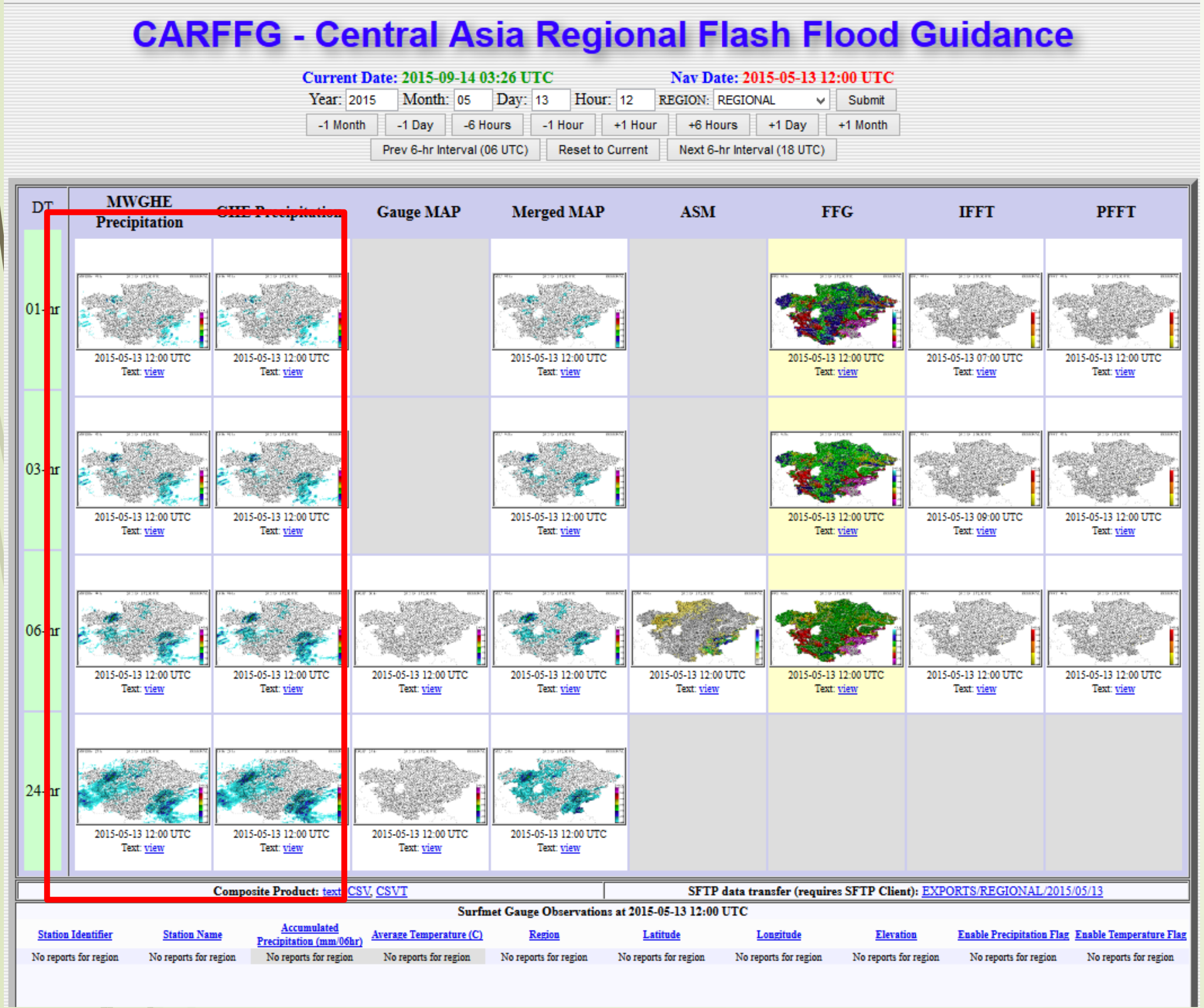


Satellite Precipitation Estimation

Satellite Precipitation estimates provide critical information in regions with sparse coverage by traditional gauge or radar networks.



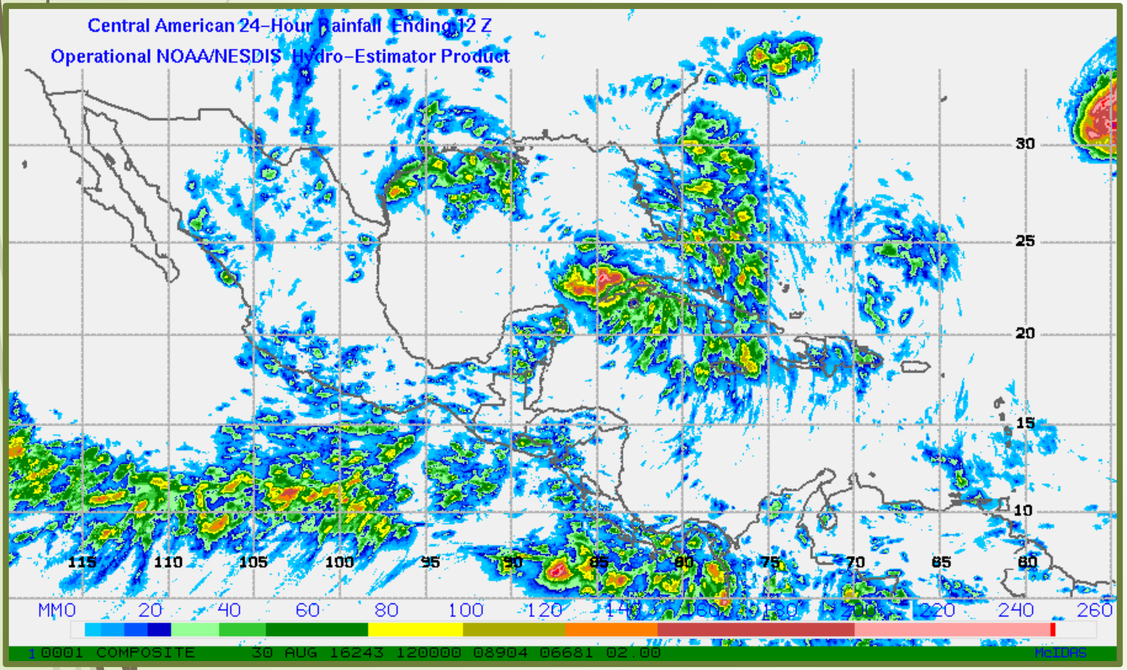
In this section:

- Describe satellite products
- Introduce procedures to handle bias in precipitation estimates

Satellite Precipitation – HydroEstimator (GHE)

Remotely-sensed precipitation estimates provide good spatial coverage and detail.
In situ observations (rain gauges) provide "ground truth" but often have sparse coverage.

NOAA/NESDIS Hydro-Estimator
24-hr rainfall ending 31-Aug-2016 @ 12 UTC



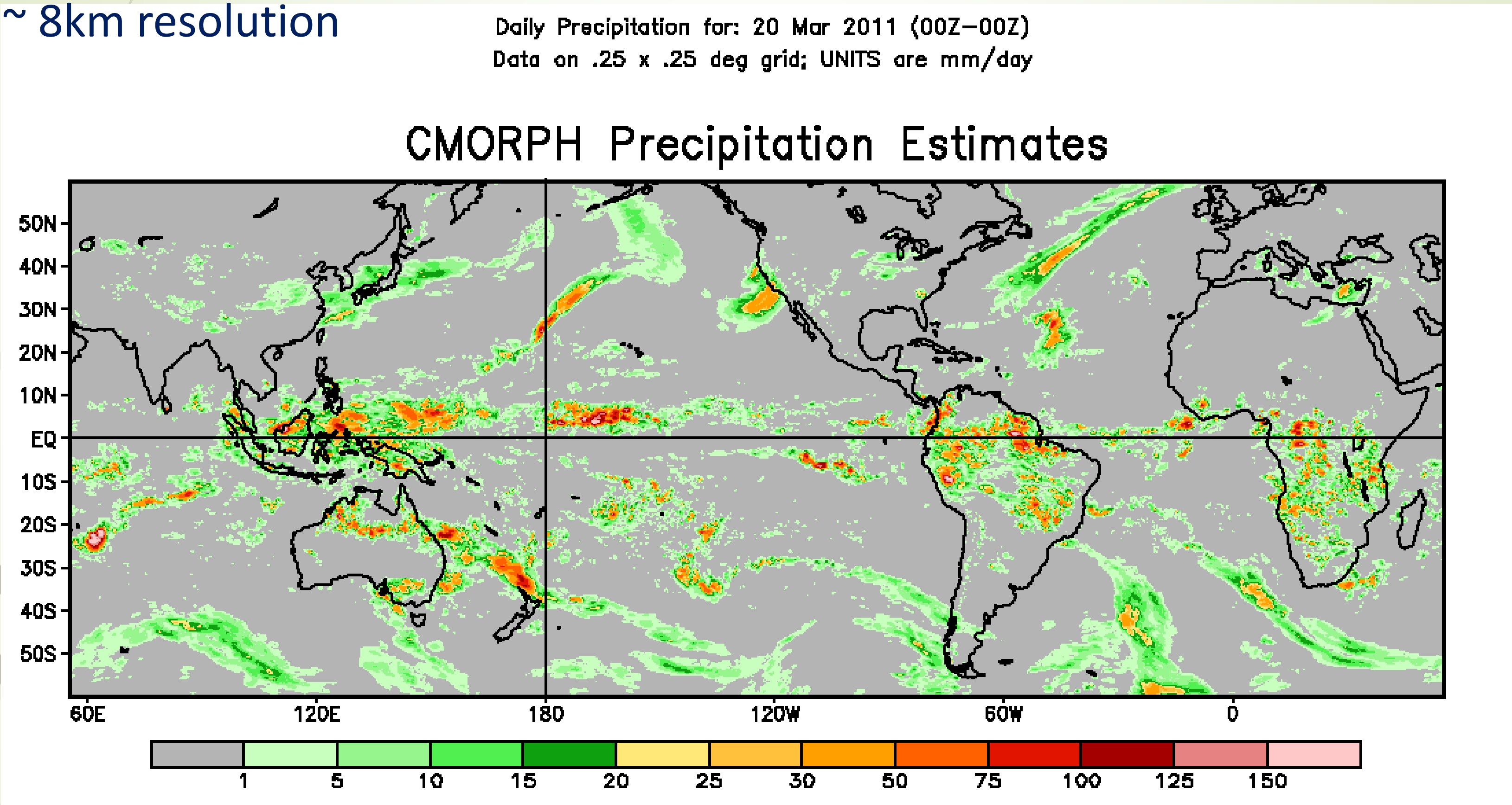
- Satellite estimates since late 1970s; Hydro-Estimator since 2002; GHE operational in 2012.
- Provide critical data in data sparse regions!
- Infrared (IR) based (10.7 µm)
- **Short latency**(< ½ hour)
- ~4 km resolution

GHE: Rainfall rate based on Cloud Top Brightness Temperature (*indirect measurement*)

Microwave Estimate: CMORPH

CMORPH

- Based on measurements of microwave scattering from raindrops
  Produced by NOAA/CPC
- 18-26 hour latency in operations
- ~ 8km resolution



Multi-Spectral Satellite Precipitation for FFG Systems

HRC effort to combine IR-based GHE rainfall with MW-based CMORPH rainfall

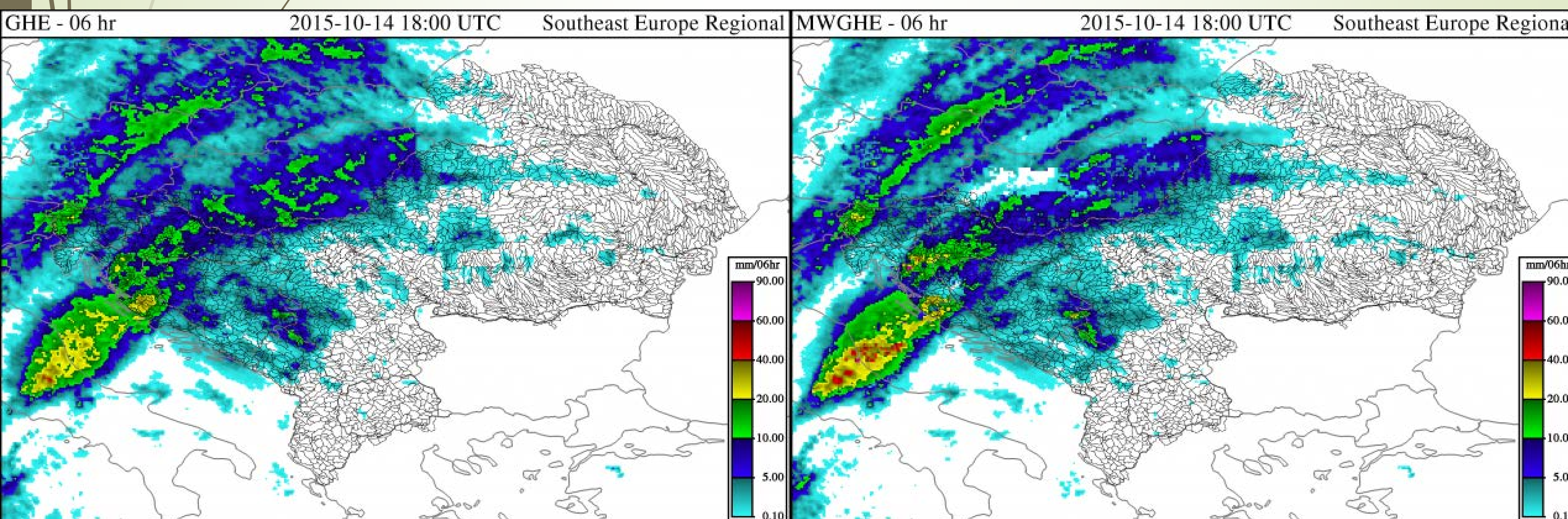
HRC-developed method which:

(a) compares IR-based GHE and MW-based CMORPH for period (2-3 days) up to last CMORPH observation,

(b) develops an adjustment factor based on differences within region,

(c) applies adjustment to GHE up to current observation.

FFGS Product MWGHE

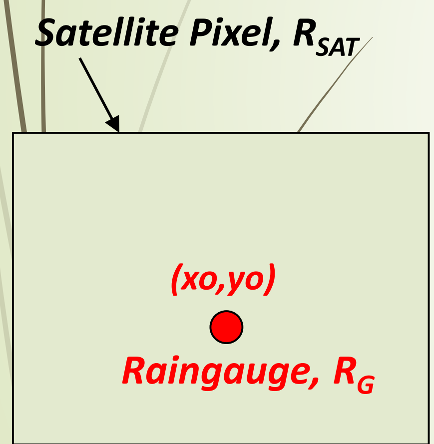


Example from South East Europe (SEEFFGS)

Satellite Precipitation Bias Adjustment

Remotely-sensed precipitation estimates provide good spatial coverage, but surface observations provide “ground truth”.

Bias may exist in remotely sensed precipitation and should be removed for “best estimate” to provide input to hydrologic models.



Bias Error Model:

$$g(R_{SAT}) = \alpha g(R_G) + B + \varepsilon$$

Transformation for Normality — *Regional Bias* — *Random Error*

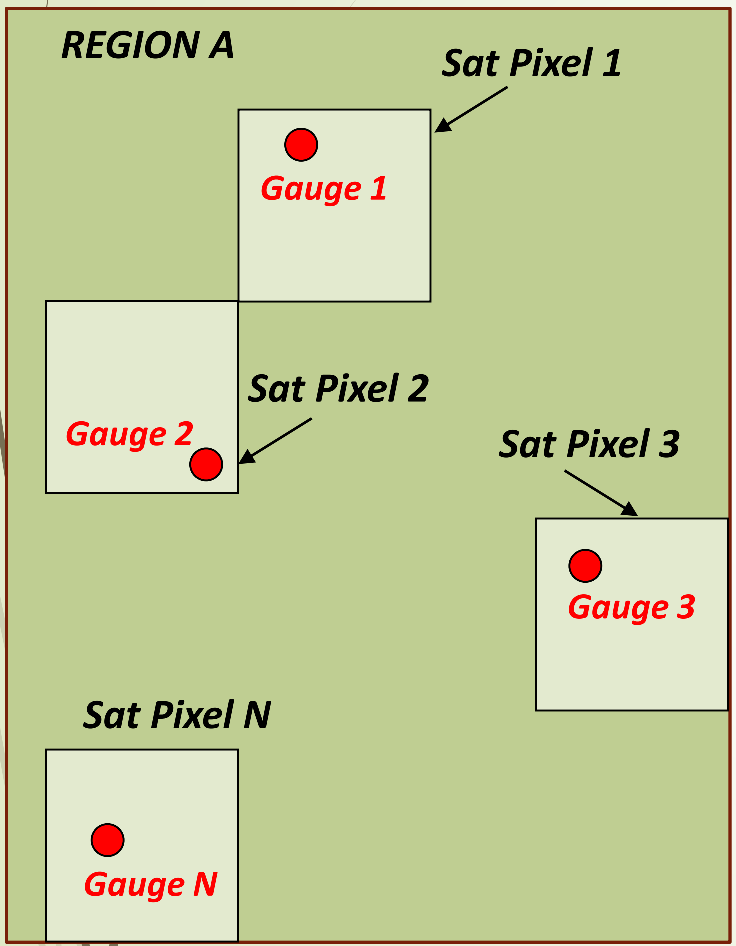
Two applications of bias adjustment within FFG Systems

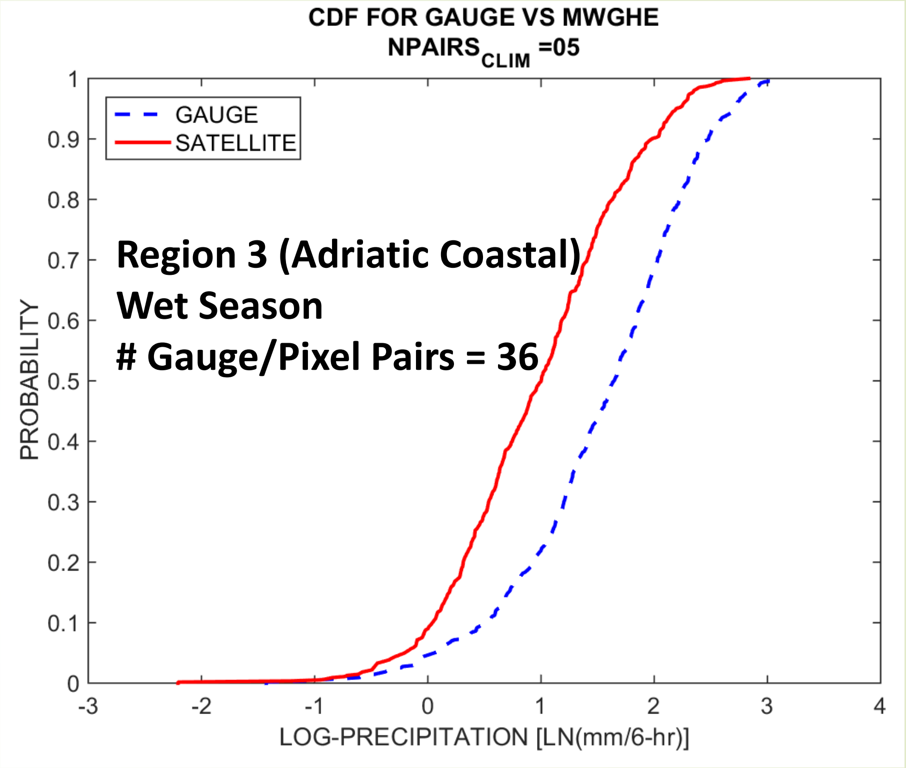
(Applied to each remotely sense product prior to merge MAP)

- Climatological bias adjustment

- Dynamic (real-time) bias adjustment

Bias Adjustment for Satellite Precipitation





Log Bias:

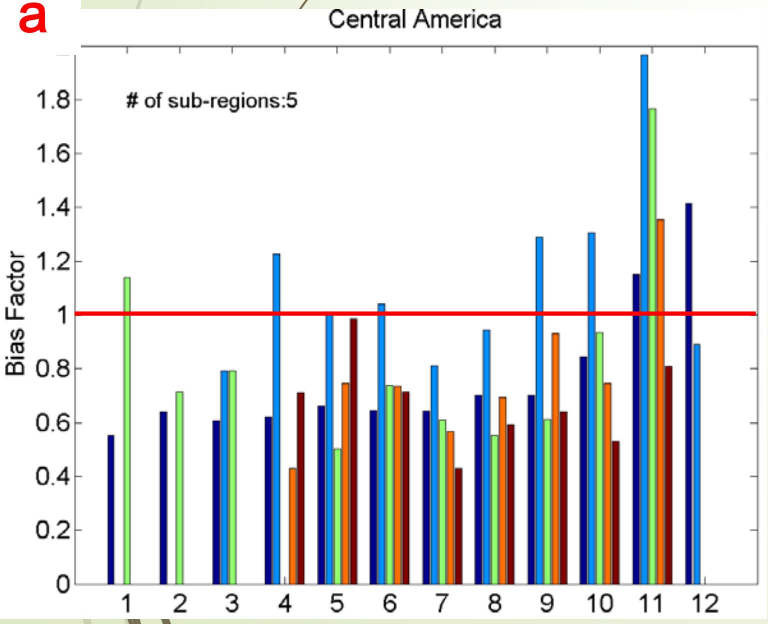
$$\beta_t = \ln\left\{\frac{\sum_{j=1}^{N_G} R_G(j,t)/NG}{\sum_{j=1}^{N_G} R_{SAT}(j,t)/NG}\right\}$$

Climatological Bias Adjustment Basics

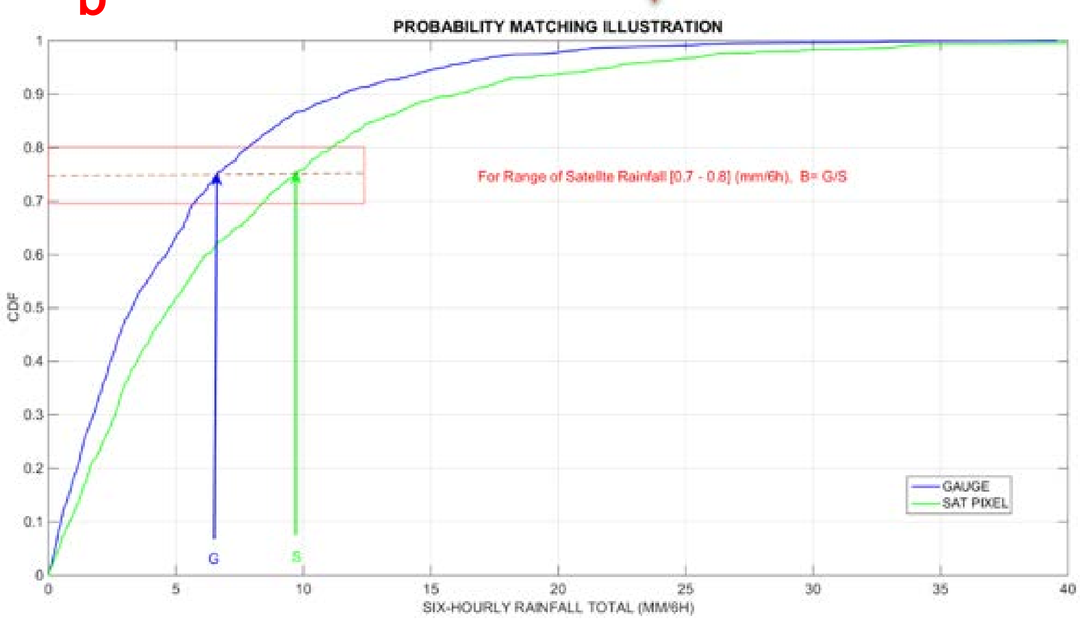
Goal is to determine long-term bias in satellite precipitation within a given region using historical records

- Uses historical data for regions of uniform hydro-climatology, terrain, and gauge density
- Usually done for given month or season (depending on historical record)
- Results in a "bias factor" that can be applied to satellite estimates for each region & month
- May be computed based on (a) mean values or (b) probability matching

a



b



Dynamic Bias Adjustment Basics

Employs Kalman Filter with Stochastic Approximations

$$\beta_t = \ln\left\{\frac{\sum_{j=1}^{N_G} R_G(j,t)}{\sum_{j=1}^{N_G} R_{SAT}(j,t)}\right\}$$

$$\beta_{t+1} = \beta_t + w_{t+1}$$

- Uses available real-time gauge precipitation to compute current bias with conditions for:
  - Minimum # pairs of consecutive values
  - Minimum # pairs with rain
  - Conditional Mean > Threshold (mm/h) for both satellite and gauge)

Prediction/Update cycle assimilates observations and tracks variance of Errors

Prediction:

$$\hat{\beta}_{t+1}^{-} = \hat{\beta}_t^{+}$$

$$P_{t+1}^{-} = P_t^{+} + Q_{t+1}$$

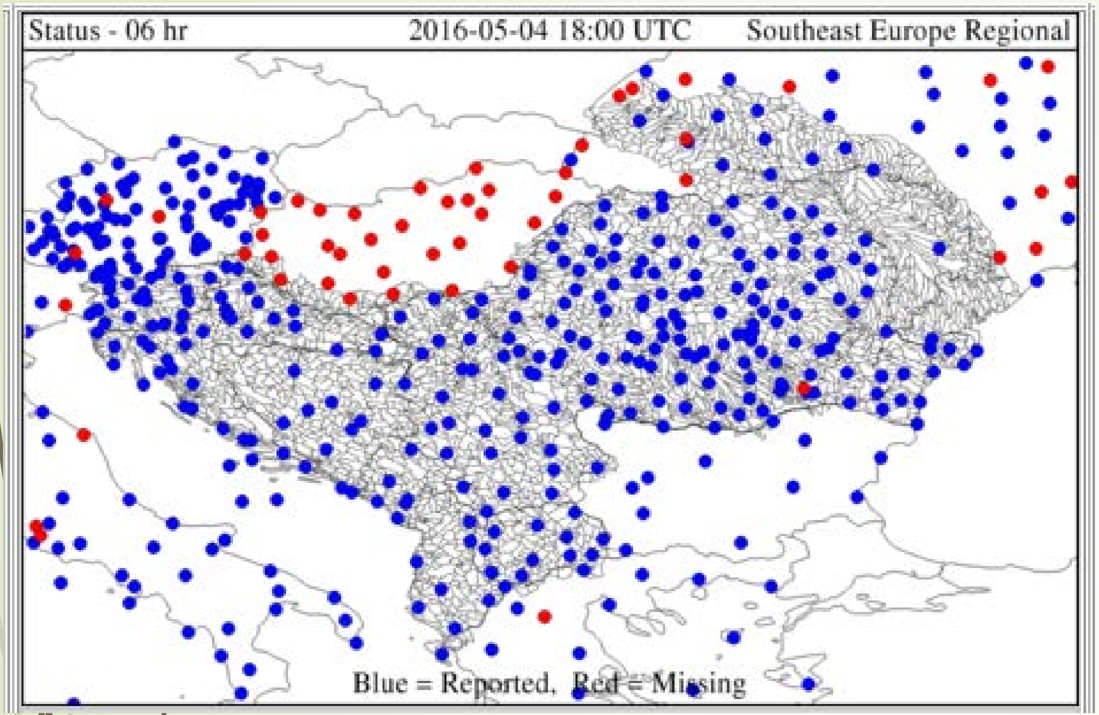
Stochastic Approximations Algorithm

Updating:

$$\hat{\beta}_{t+1}^{+} = \hat{\beta}_{t+1}^{-} + K_{t+1}(z_{t+1} - \hat{\beta}_{t+1}^{-})$$

Kalman Gain

Real-Time Gauge Data



Gauge data quality control is important!

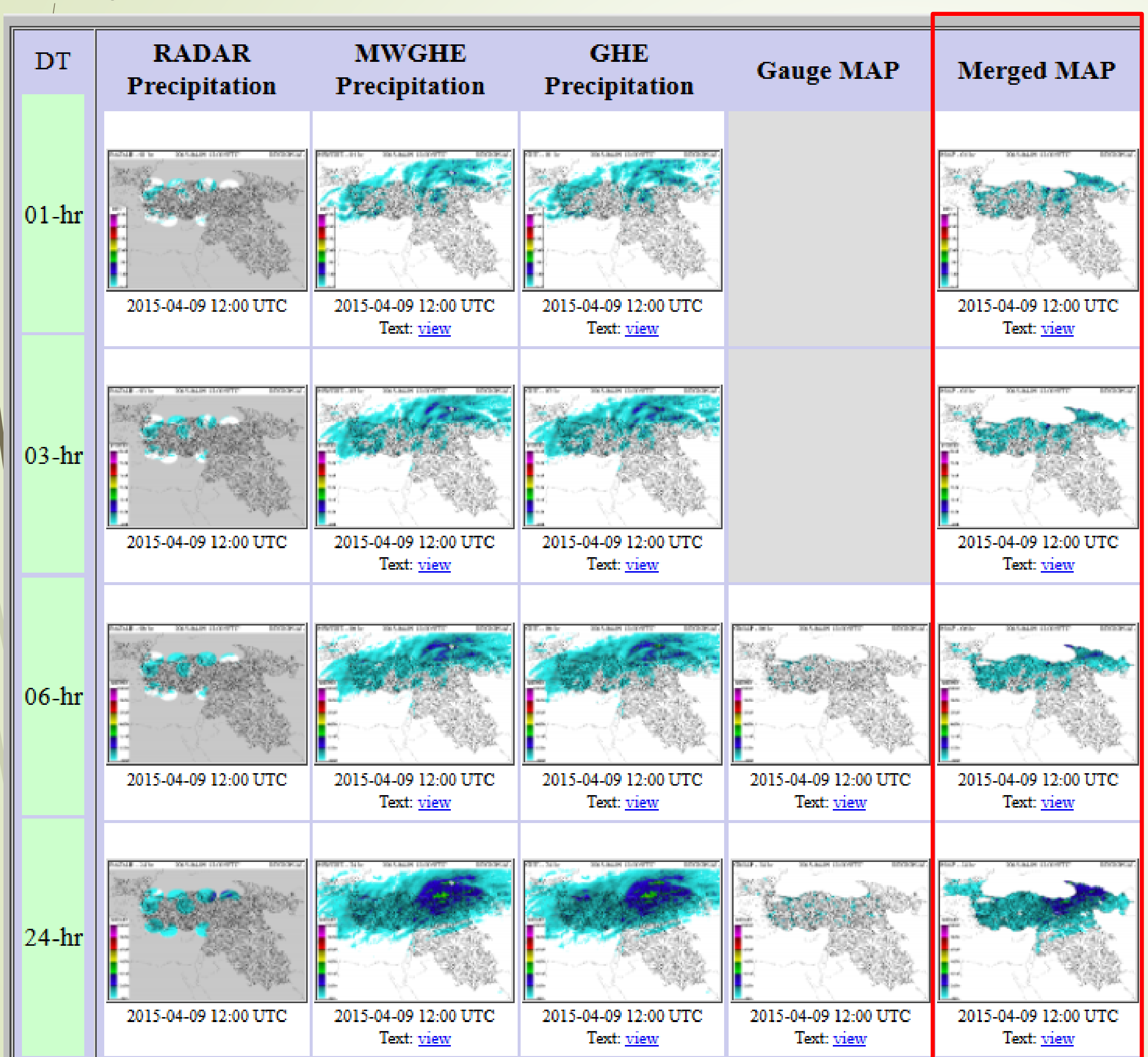
Composite Product: text, CSV, CSVT | SFTP data transfer (requires SFTP Client): EXPORTS/REGIONAL/2015/09/12

Surfmet Gauge Observations at 2015-09-12 12:00 UTC

Station Identifier	Station Name	Accumulated Precipitation (mm/06hr)	Average Temperature (C)	Region	Latitude	Longitude	Elevation	Enable Precipitation Flag	Enable Temperature Flag
28676	PETROPAVLOVSK	0.00	9.45	KAZAKHSTAN	54.8	69.1	100	Enabled	Enabled
28678	MAMLUTKA	0.00	11.50	KAZAKHSTAN	54.5	68.3	136	Enabled	Enabled
28764	PRESNOGORKOVKA	0.00	9.35	KAZAKHSTAN	54.2	65.4	160	Enabled	Enabled
28766	BLAGOVESHCHENKA	0.00	8.95	KAZAKHSTAN	54.2	67	150	Enabled	Enabled
28775	YAVLENKA	0.00	9.20	KAZAKHSTAN	54.2	68.2	113	Enabled	Enabled
28776	SMIRNOVO	0.00	9.10	KAZAKHSTAN	54.3	69.2	138	Enabled	Enabled
28785	VOZVYSHENKA	Reported Missing	9.80	KAZAKHSTAN	54.2	70.5	125	Enabled	Enabled
28843	KARABALYK	0.00	11.30	KAZAKHSTAN	53.4	62	177	Enabled	Enabled

Merged MAP Product

Example from Black Sea Middle East (BSMEFFGS)



DT	RADAR Precipitation	MWGHE Precipitation	GHE Precipitation	Gauge MAP	Merged MAP
01-hr	2015-04-09 12:00 UTC	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view		2015-04-09 12:00 UTC Text: view
03-hr	2015-04-09 12:00 UTC	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view		2015-04-09 12:00 UTC Text: view
06-hr	2015-04-09 12:00 UTC	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view
24-hr	2015-04-09 12:00 UTC	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view	2015-04-09 12:00 UTC Text: view

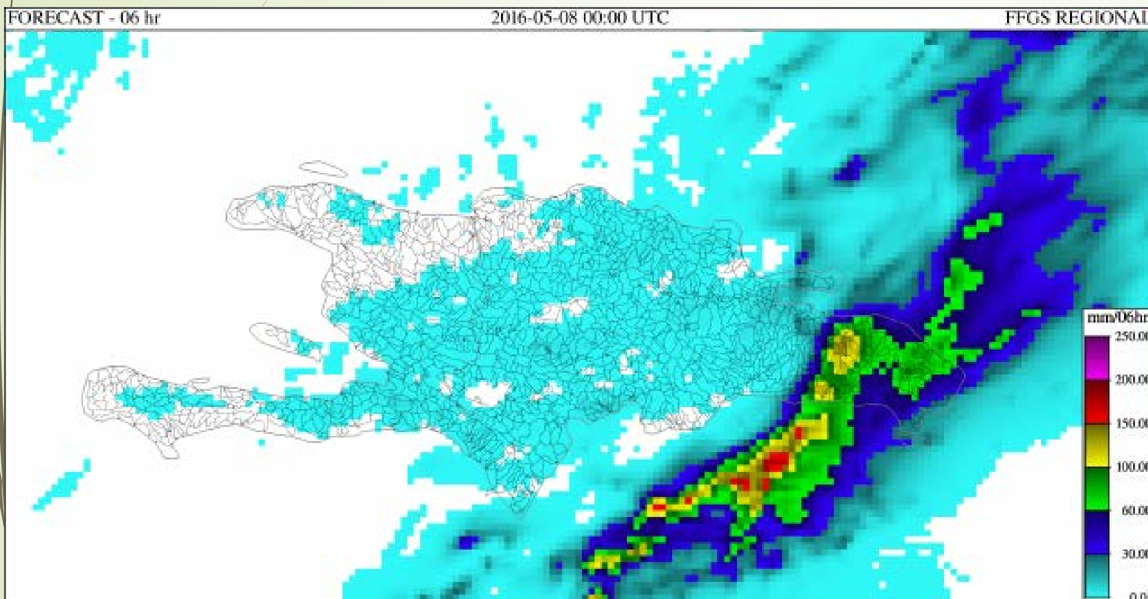
Merged MAP is the *best estimate* of Mean Areal Precipitation over each small watershed for previous 1-, 3-, 6- and 24- hour periods.

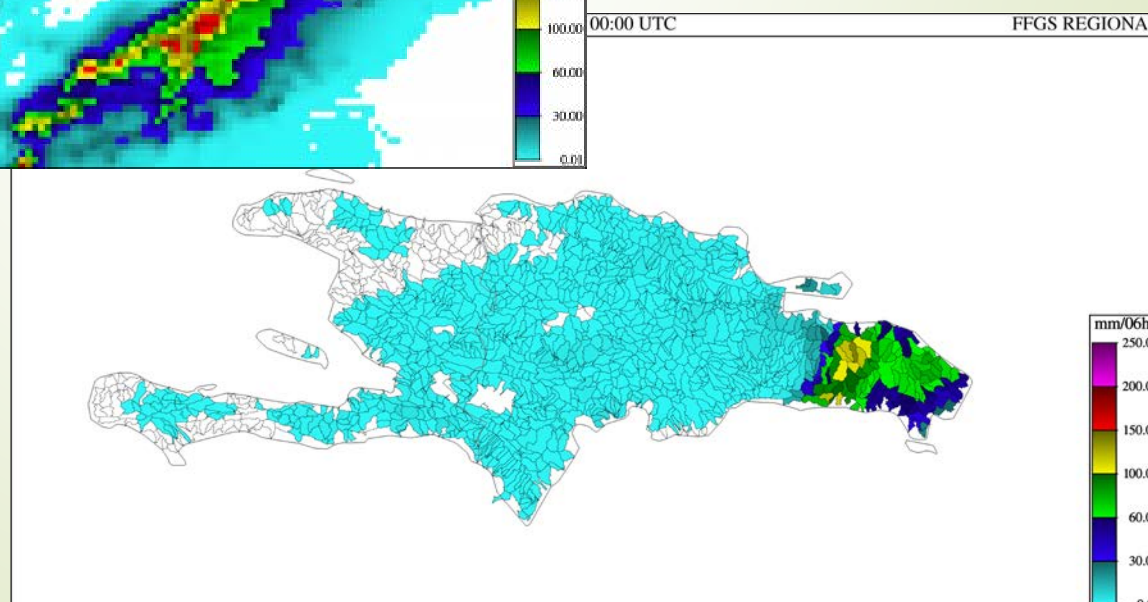
- Satellite
- Real-time gauges
- Radar (if available)

* Includes bias adjustment

FFG System Products: Forecast Precipitation

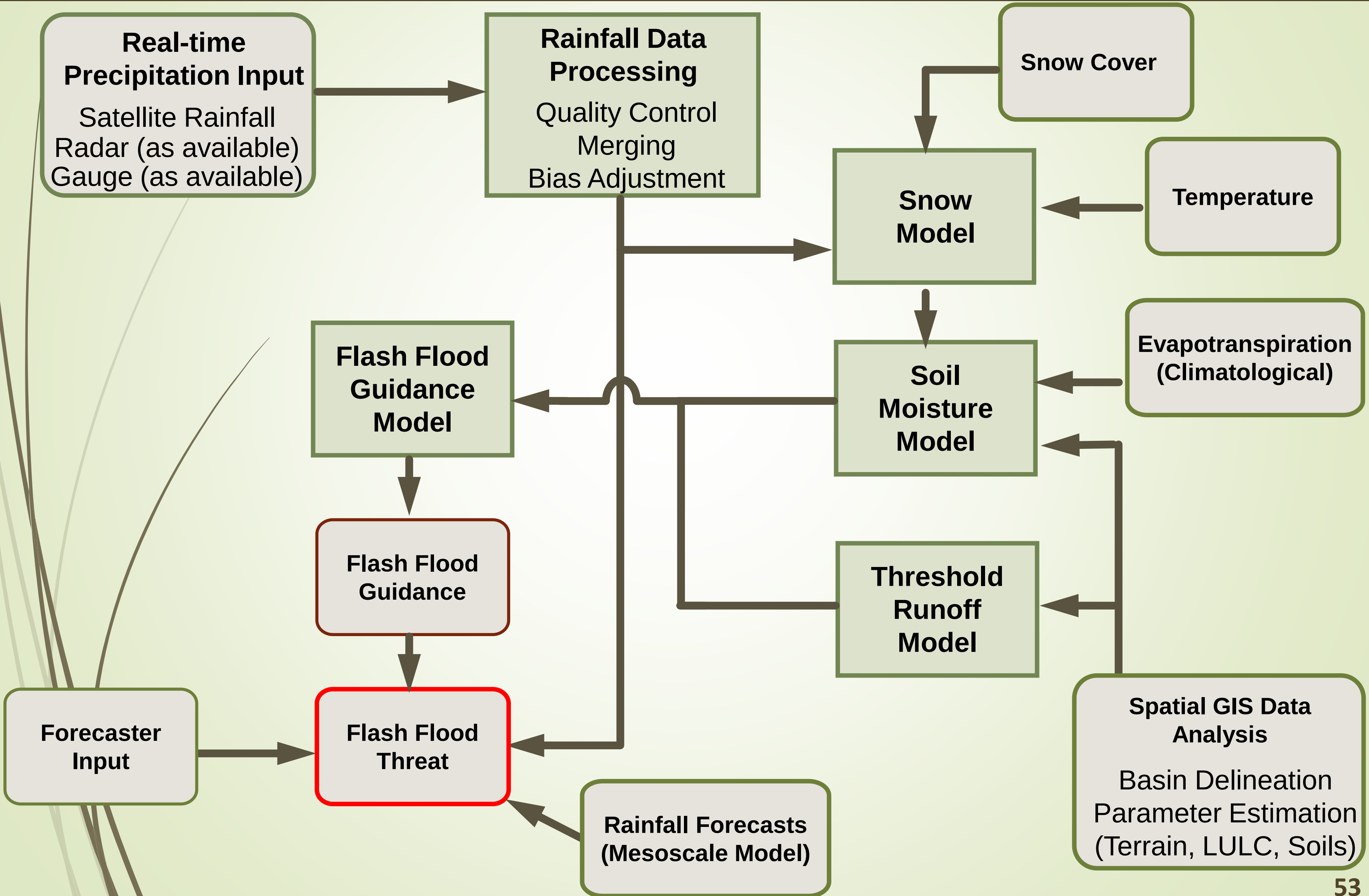
FORECAST PRECIPITATION: How much precipitation is expected based on NWP model QPF. This is ingest into the FFG System based on existing NWP models that may be provided by participating countries.





4. Flash Flood Threat Products

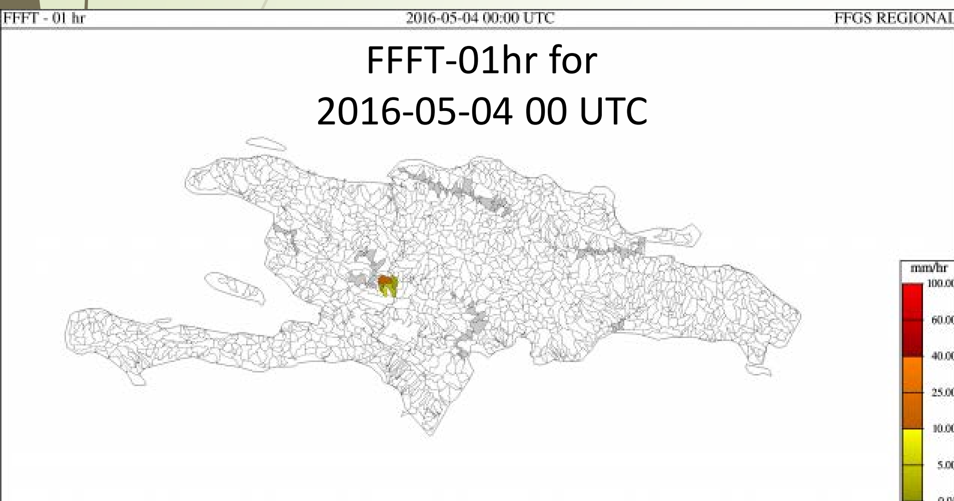
4. Precipitation Input

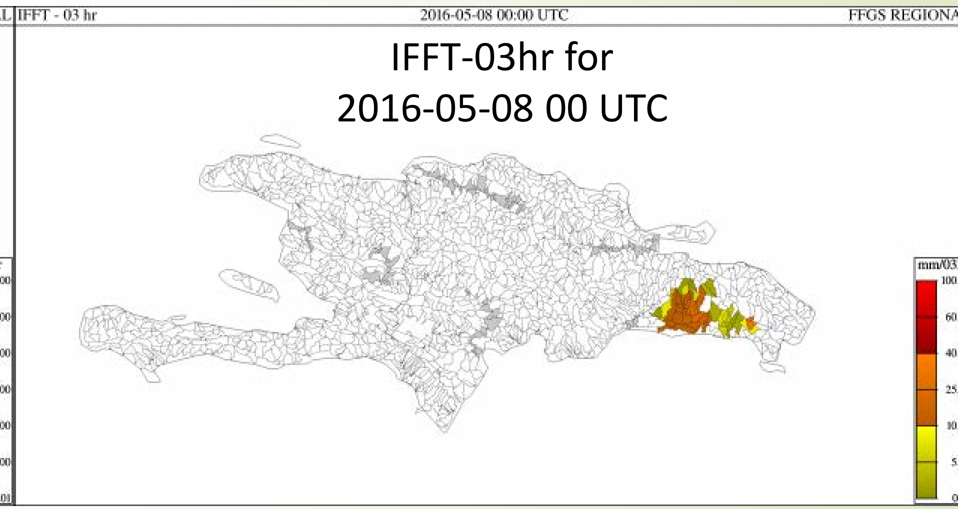


Flash Flood Threat Products

Potential for flash flooding is increased when ***PRECIPITATION > FFG***.

Flash Flood Threat, FFT, defined: ***FFT = MAP – FFG***
FFT products are computed by FFG System automatically

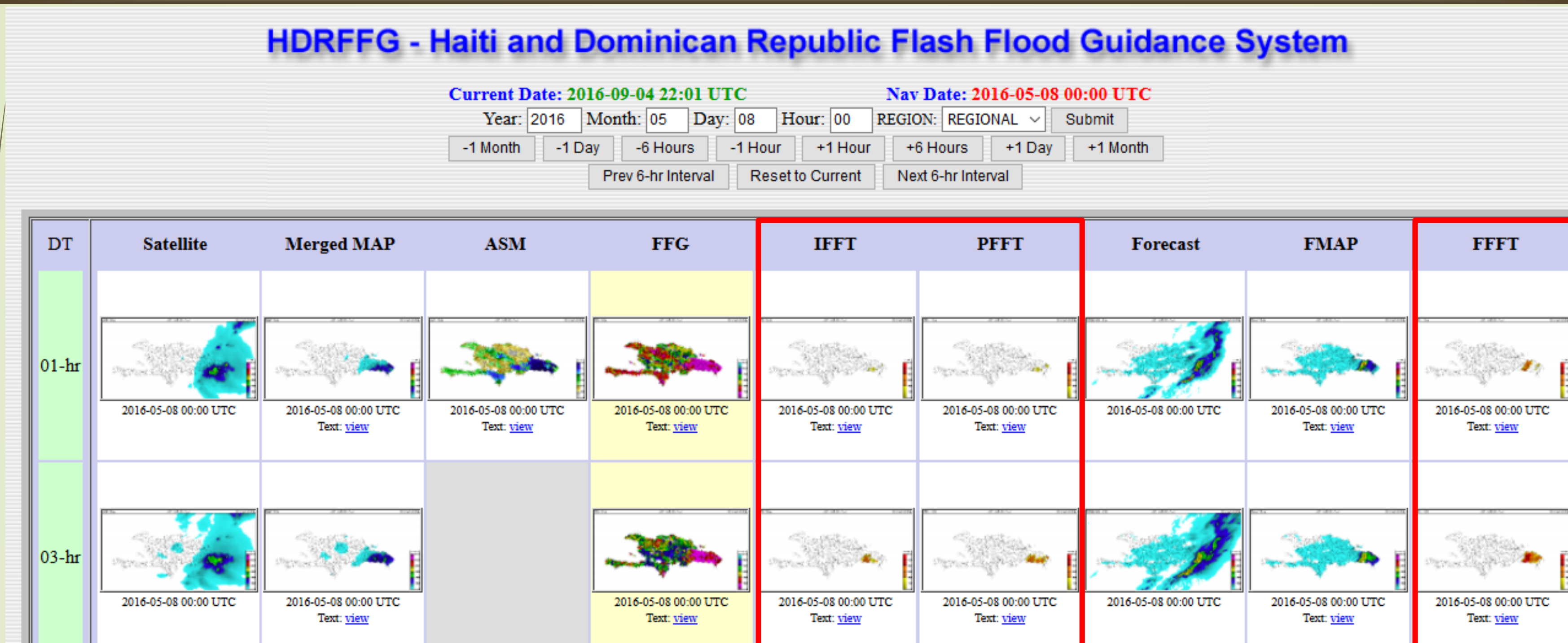




FFT provides indication of regions of potential concern.

Like FFG, FFT products for computed for 1, 3, and 6-hour durations.

FFG System Products: FFTs

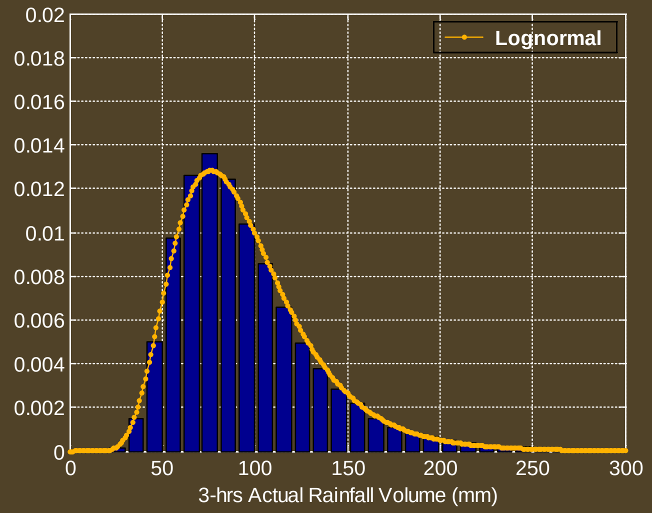


Different FFT products are provided, based on observed or forecasted precipitation and timing.

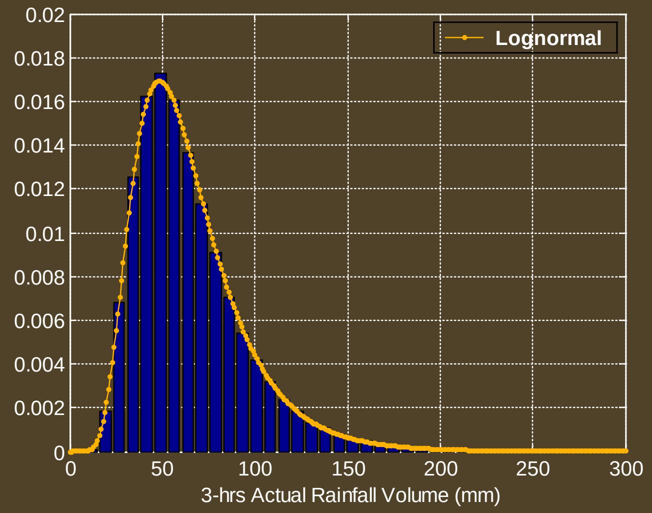
- IFFT: imminent, based on observed precipitation that has fallen.
  Flash flooding may be occurring!
- PFFT: forecast of persistence – *IF* rainfall continues at current rate
- FFFT: based on forecast precipitation.

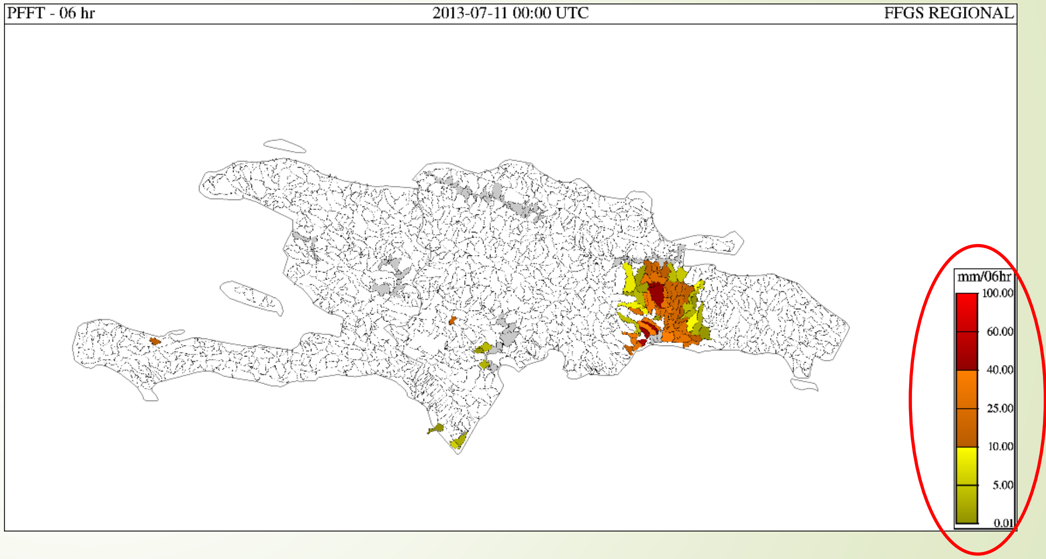
Uncertainty in FFG

Dry Conditions

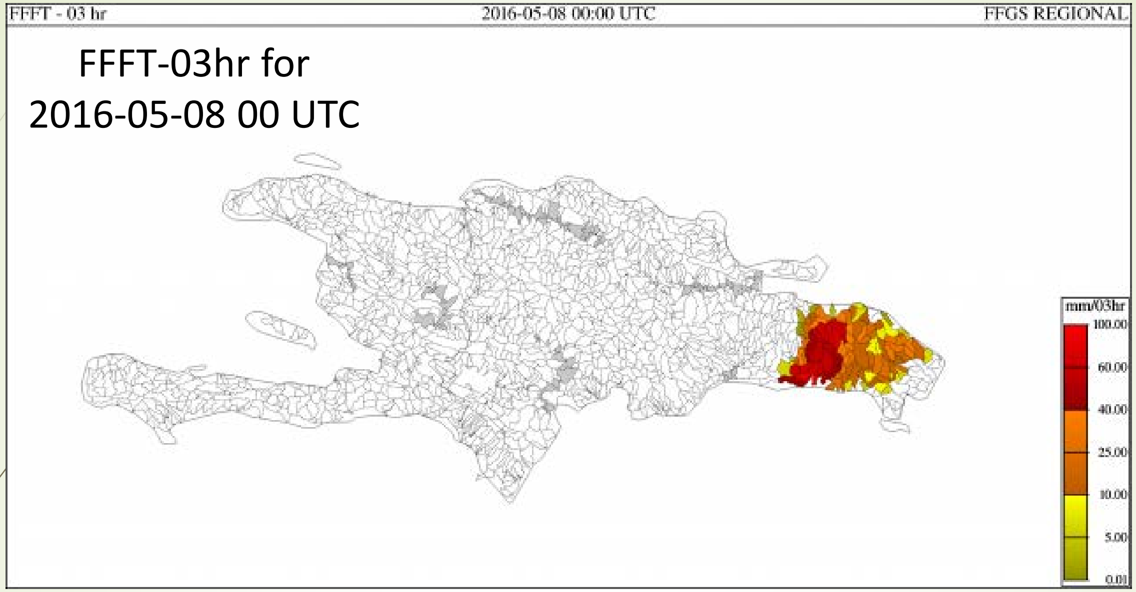


WetConditions





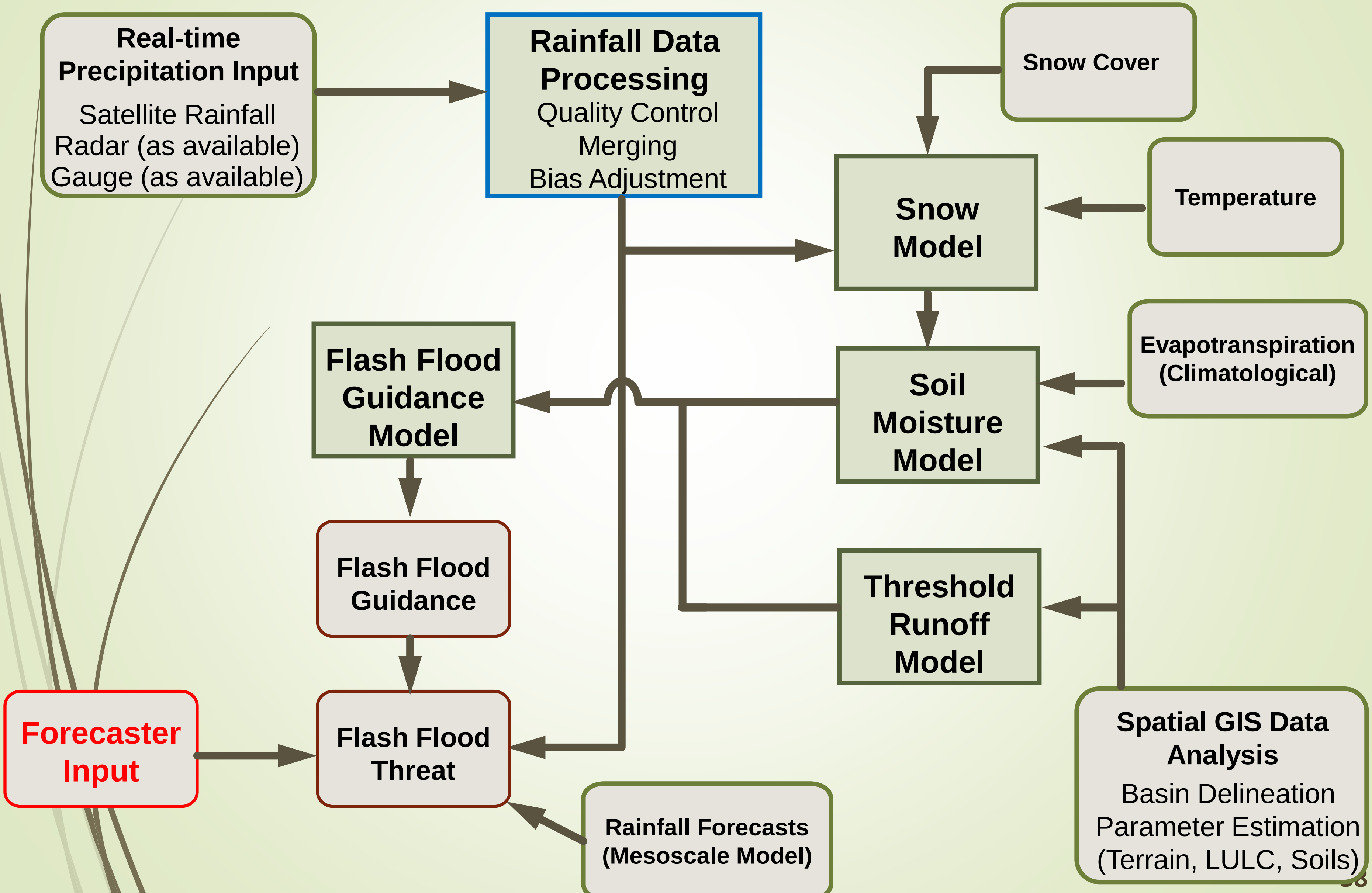
Flash Flood Threat Products



Operational forecasters recognize FFG System products and precipitation forecasts carry uncertainty, and must evaluate the current situation and forecast.

*FFT products are *__not__* intended to be the forecast, but are system indicators of potential concern. The role of the forecaster in evaluating available information is __critical__.*

Key Technical Components for Flash Flood Guidance Systems



Overview of the Development of FFG Systems

In summary:

- FFG Systems are designed to provide operational hydro-meteorological forecasters with quality information relevant to the assessment of flash flood potential toward the generation of warnings.
- Flash flood guidance concept provides estimate of the amount of precipitation necessary to produce initiation of flooding (bankfull condition).
- FFG System ingest high resolution satellite estimates of precipitation in real time with short latency.
- Development of the technical and modeling components was reviewed. This included:
  - precipitation data ingest, quality control, and adjustment
  - accounting of the hydrologic state of the land surface and ability of the land surface to accept precipitation
  - estimation of threshold runoff as an indicator of channel storage
  - system-computed indications of regions with precipitation exceeding flash flood guidance

Overview of the Development of FFG System Products

THANK YOU