SEEFFG Operations Workshop

Review of the SEEFFG System Technical Background

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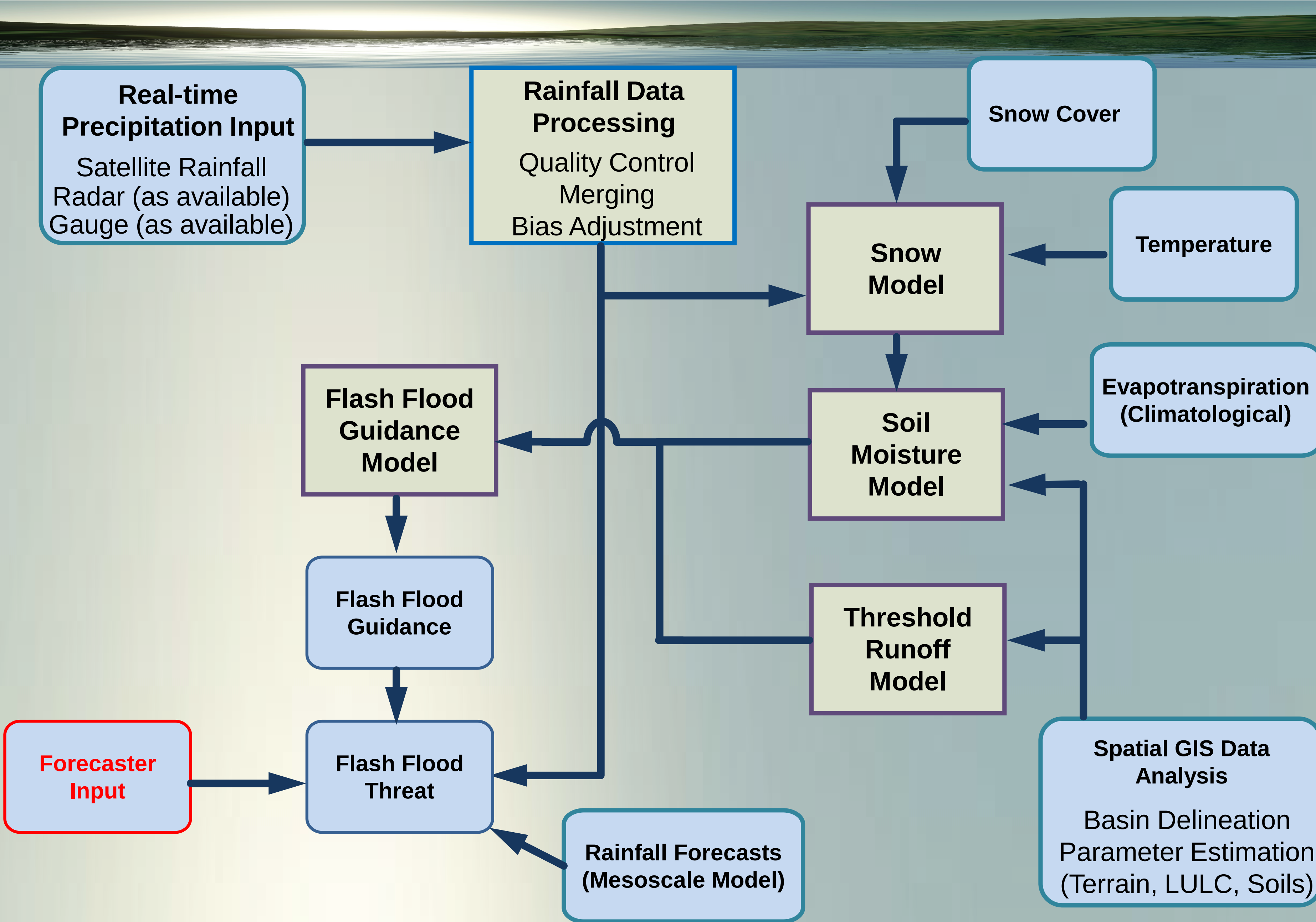
Key Technical Components for Flash Flood Guidance Systems



FFG Development Team at HRC

Kosta Georgakakos – Technical Director/Hydrometeorology

Robert Jubach - Program Management/Disaster Risk Reduction

Jason Sperfslage - IT Systems Engineering

Theresa Modrick - Hydrologic & Mesoscale Modeling and GIS Analysis

Eylon Shamir – Hydrologic modeling - Soil Water and Snow Models

Cris Spencer – IT Software Development

Aris Posner – Land Slides/EOS Data Evaluation

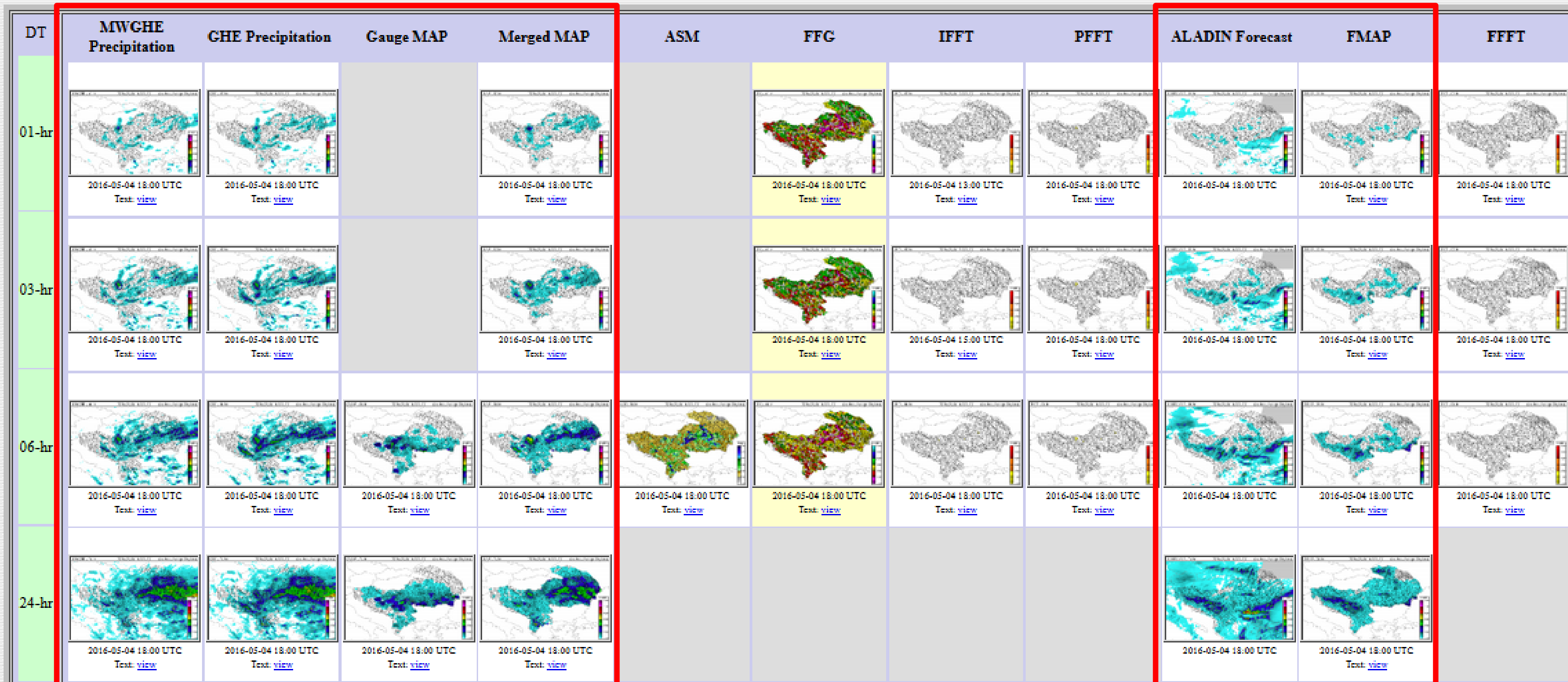
Rochelle Graham – Education and Training/Disaster Risk Reduction

Review of Technical Background
1. Precipitation Components

Nice picture of clouds and rainfall from internet article on 'best time to visit Croatia'.

SEEFFG Precipitation Products

Flash Flood Guidance Systems need up-to-date high-quality estimates of precipitation to assess current flash flood potential.



Composite Product: text, CSV, CSVT

SFTP data transfer (requires SFTP Client): EXPORTS/REGIONAL/2016/05/04

Surfmet Gauge Observations at 2016-05-04 18:00 UTC

Station Identifier	Station Name	Accumulated Precipitation (mm/06hr)	Average Temperature (C)	Snow Depth (cm)	Snow Cover (Index)	Region	Latitude	Longitude	Elevation	Enable Precipitation Flag	Enable Temperature Flag
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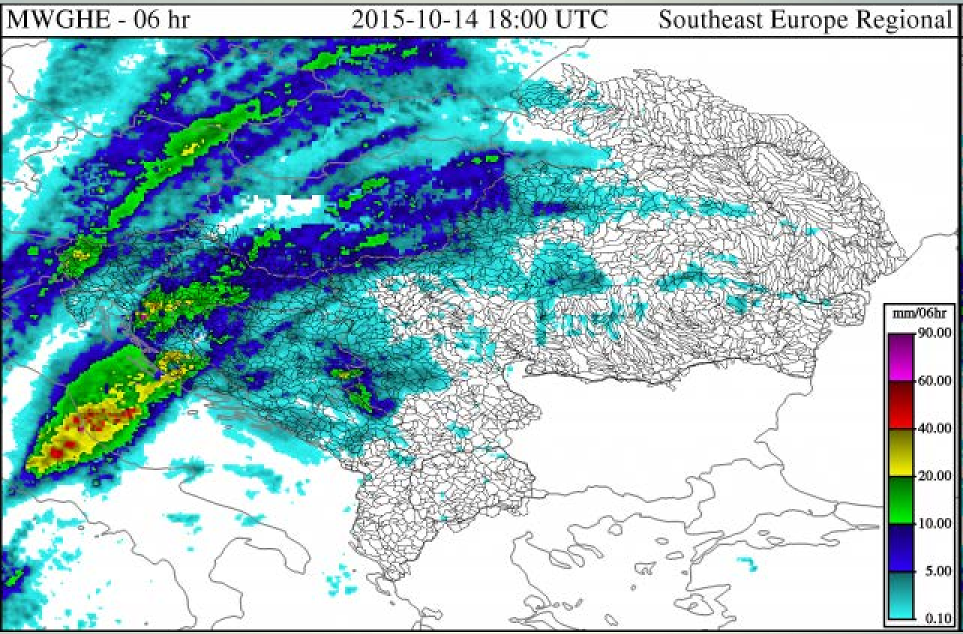
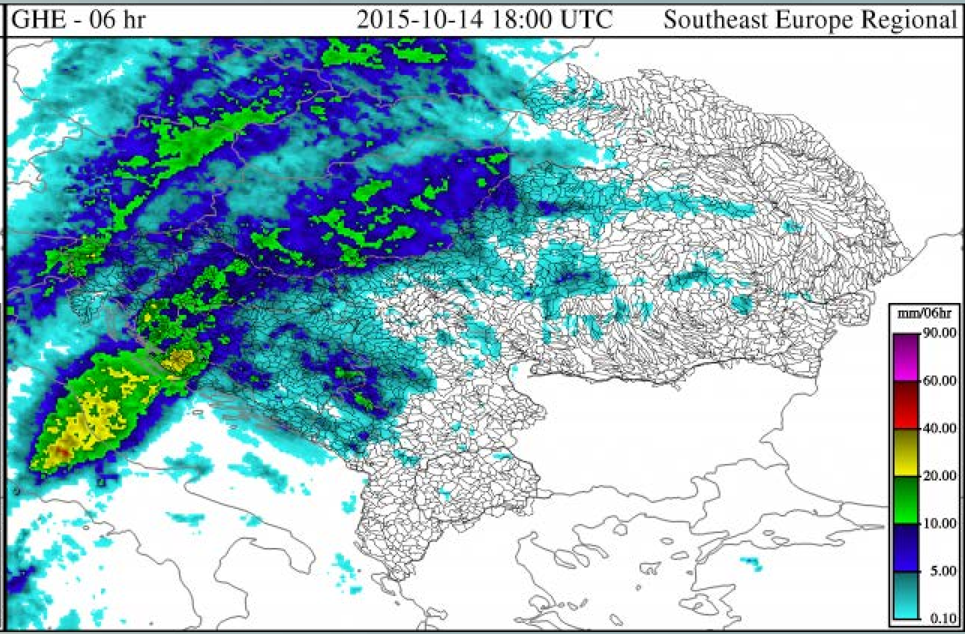
SEEFFG Satellite Precipitation



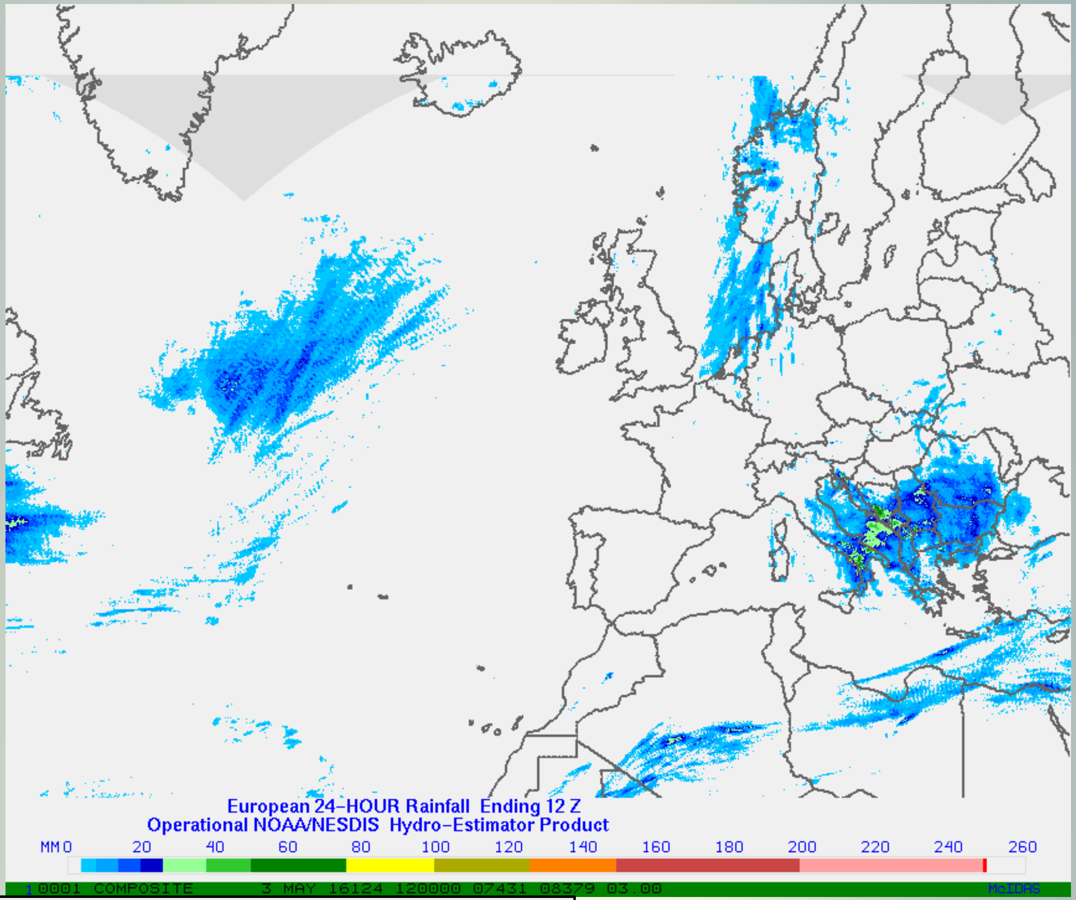


Remotely-sensed precipitation estimates provide good spatial coverage and detail. In situ observations (rain gauges) provide "ground truth" but often have sparse coverage.

However, remotely-sensed estimates do not measure precipitation!

Global Hydro-Estimator

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



NOAA/NESDIS HydroEstimator
24 Hour Rain Accum
ending 03-May-2016 12UTC

- ❖ Produced by NOAA/NESDIS
- ❖ Research on satellite precipitation
  - since late 1970s;
  - Hydro-Estimator since 2002;
  - GHE Operational in 2012.
- ❖ Infrared (IR)-based, 10.7 mm
- ❖ ** Short latency **(< ½ hour)
- ❖ ~4km resolution

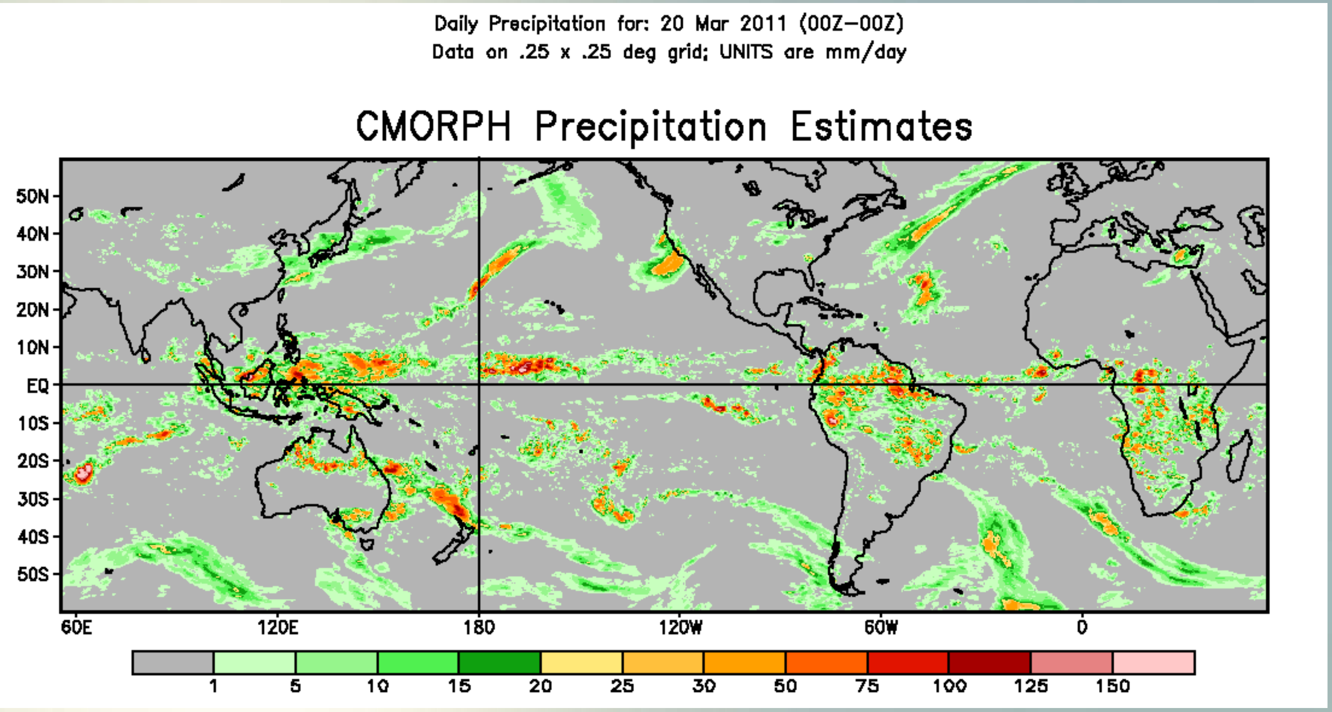
Enhanced for:

1. Atmospheric moisture effects
2. Orography (upslope/downslope)
3. Convective Eqlb. Level (warm-top convection)
4. Local pixel temperature differences
5. Convective core / no-core region

Multi-Spectral Satellite Rainfall for FFG Systems

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

CMORPH is based on measurements of microwave scattering from raindrops.
- measure of the hydrometeors in clouds
- still not observation of rainfall at surface



Multi-Spectral Satellite Rainfall for FFG Systems

GHE

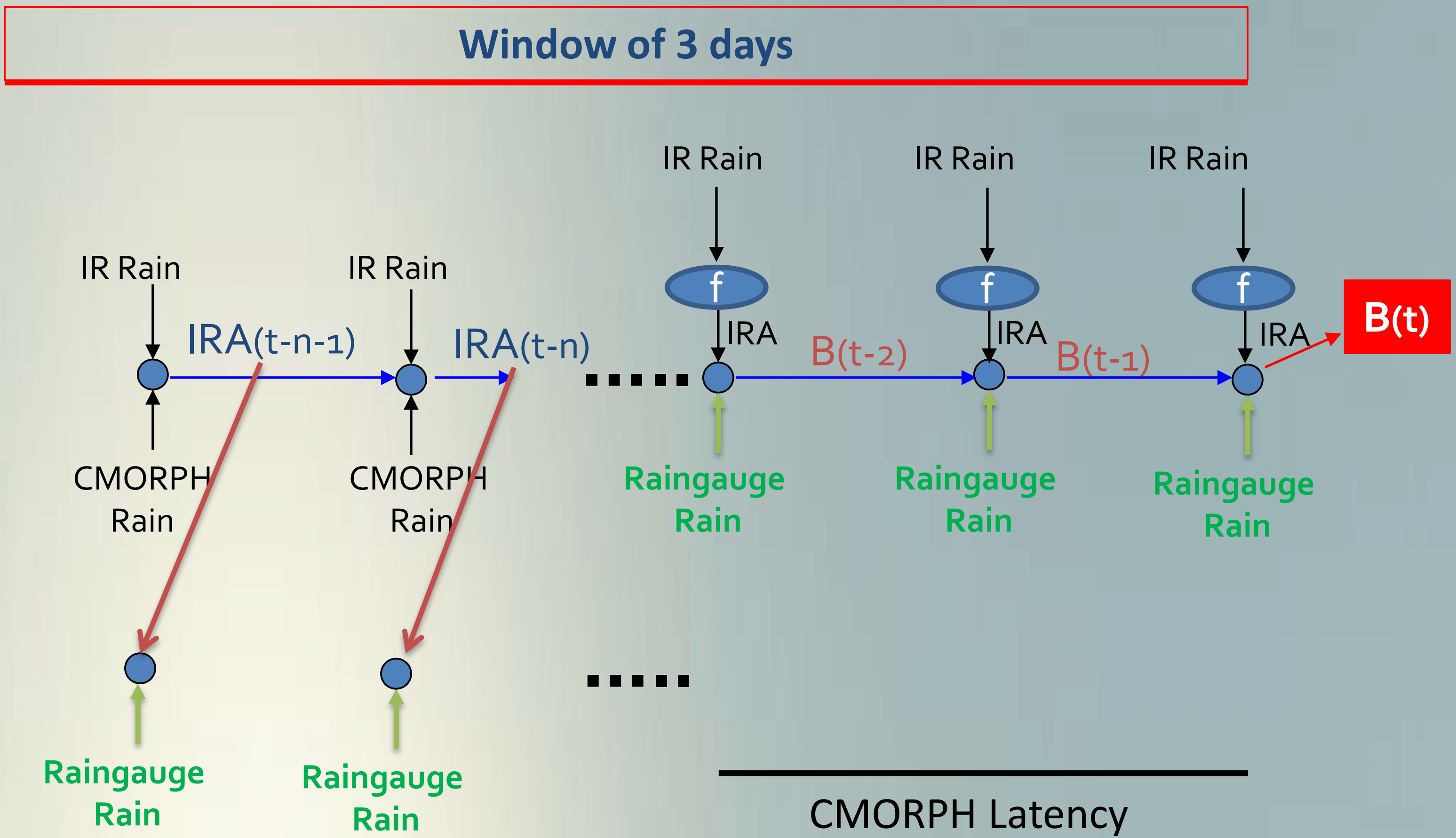
- Infrared – based
- Measurements of cloud to brightness temperature
- 30-min latency in operations
- ~4km resolution

CMORPH

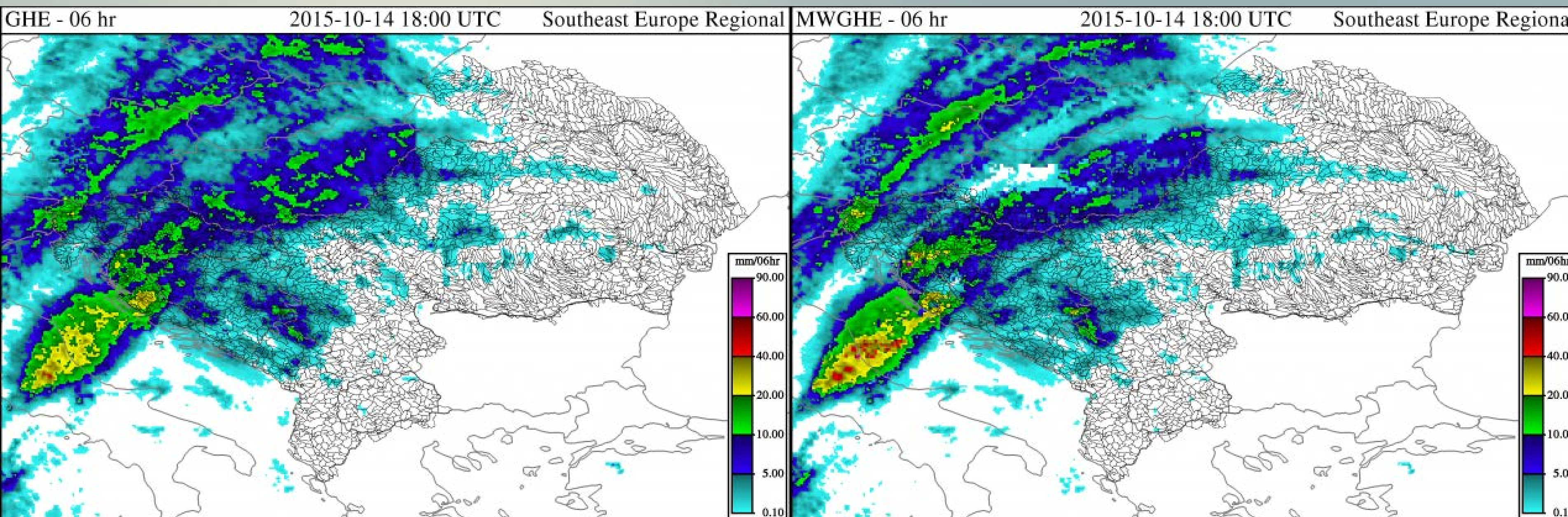
- Microwave – based
- Measurements of microwave scattering from raindrops
- 18-26 hour latency in operations
- ~ 8km resolution
- No estimation over snow

FFGS Product combines IR-based GHE with MW-based CMORPH: MWGHE

Multi-Spectral Satellite Rainfall for FFG Systems



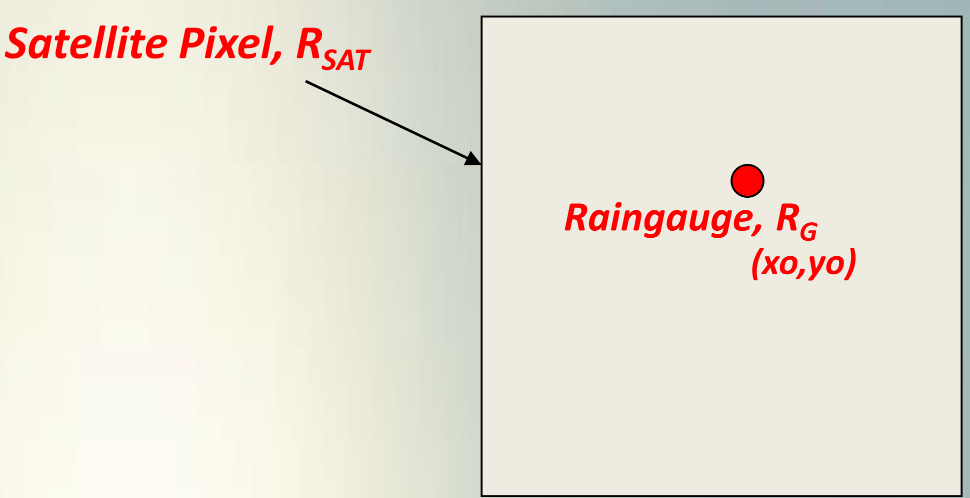
SEEFFG Satellite Precipitation



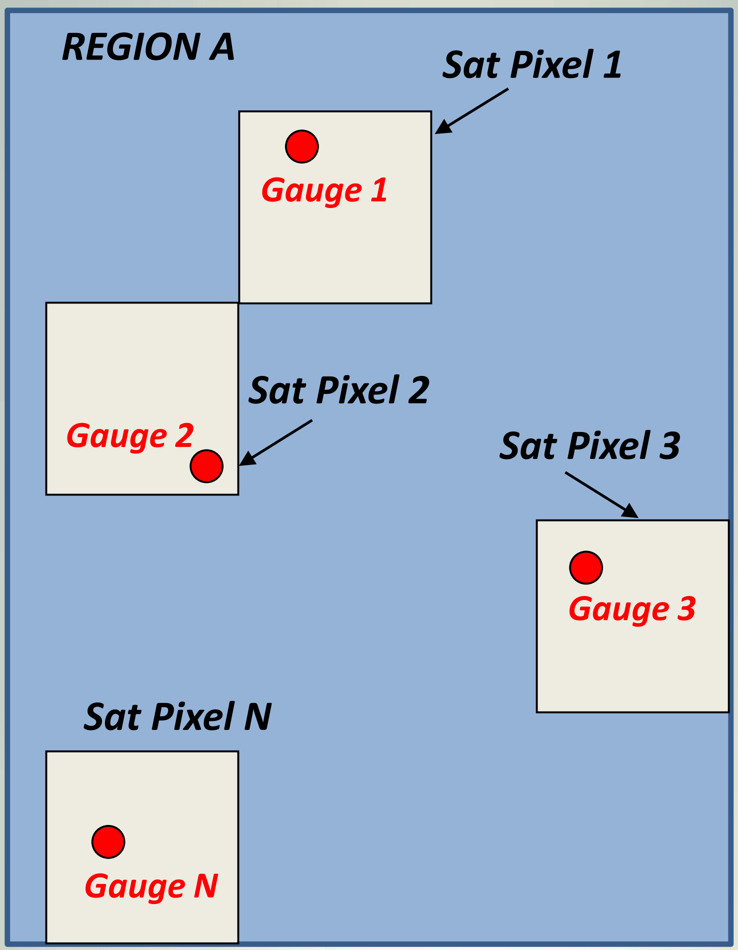
Reasons for Satellite Precipitation Bias

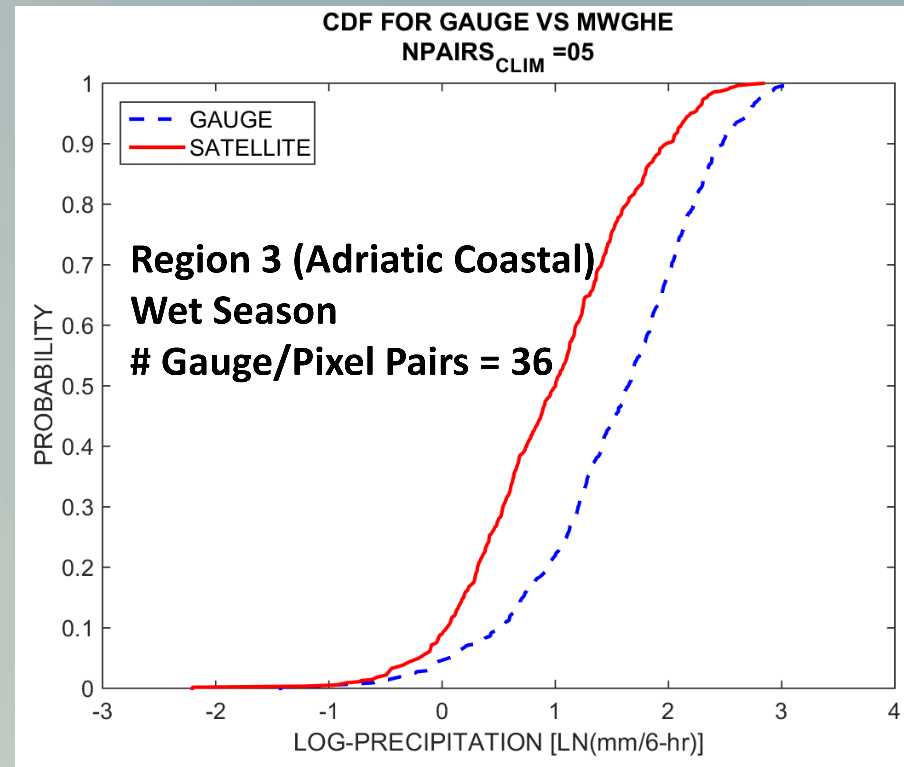
Bias may exist in the remotely sensed precipitation estimates relative to gauges. This should be removed before inputting to hydrologic models.

- Vastly different scales of satellite pixel and rain gauge area
- Orography organizes surface rainfall according to prevailing winds
- Satellite estimates do not directly measure rainfall at surface
- There may be significant misregistration errors in satellite data



Bias Adjustment for Satellite Precipitation





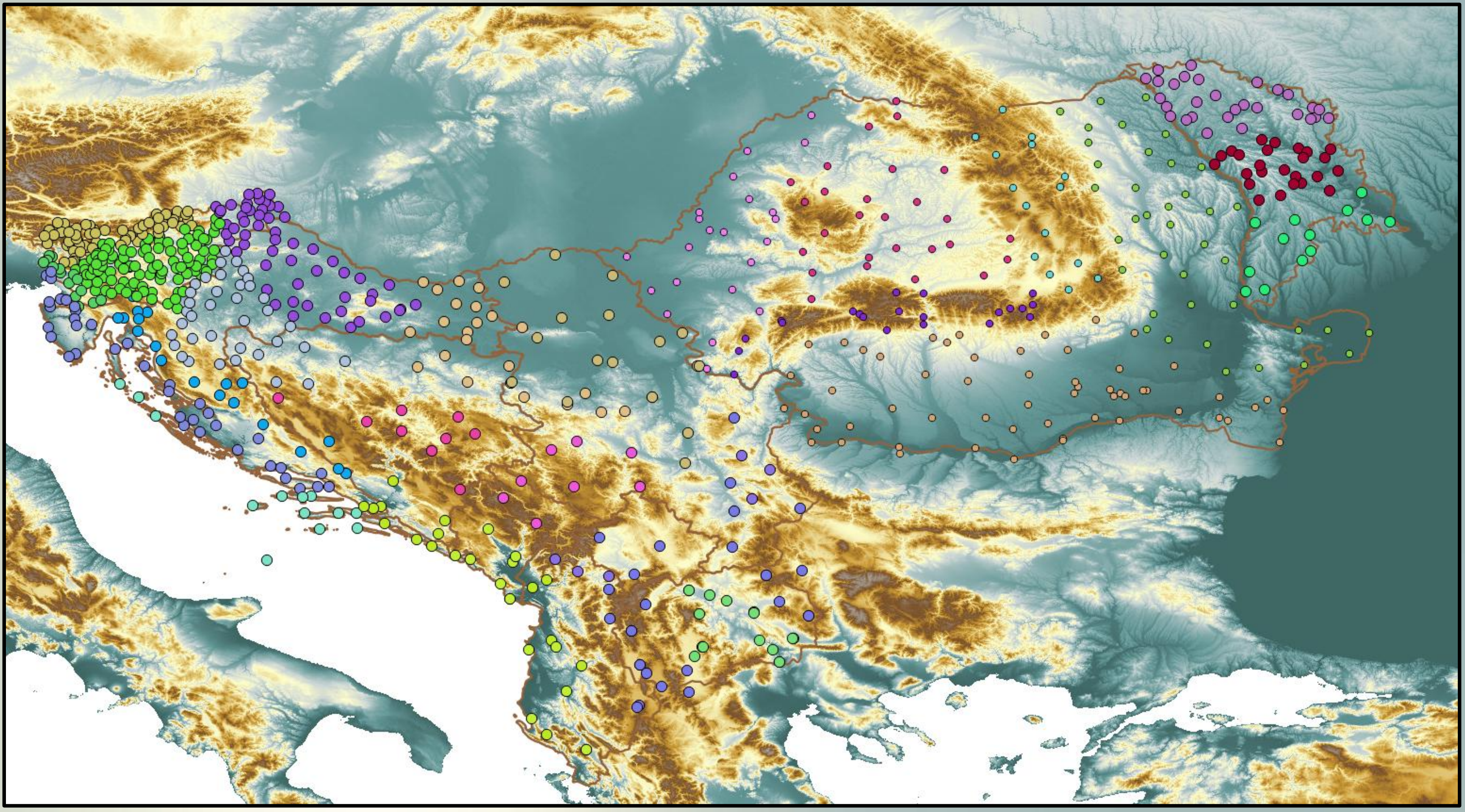
Log Bias:

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

Approach for both climatological and real-time bias.

Climatological Bias Adjustment for Satellite Precipitation

During "on-site" training at HRC, country participants performed bias analysis for satellite data using country-provided gauge precipitation data for period 2012-2015.



Climatological Bias Adjustment for Satellite Precipitation

During "on-site" training at HRC, country participants performed bias analysis for satellite data using country-provided gauge precipitation data for period 2012-2015.

SEE Region04 (Croatia)

4.1 WINTER (DJF) MWGHE then GHE

MWGHE Bias Factors Table

0.00,	0.23,	0.0841494
0.23,	0.45,	0.2157738
0.45,	0.80,	0.3032894
0.80,	1.58,	0.3670615
1.58,	2.24,	0.6091672
2.24,	2.81,	1.0409994
2.81,	3.52,	1.1707244
3.52,	4.78,	1.4309652
4.78,	6.30,	1.5983874
6.30,	1000.00,	1.5962369

GHE Bias Factors Table

0.00,	0.41,	0.0476108
0.41,	0.75,	0.1285461
0.75,	1.56,	0.1552676
1.56,	3.22,	0.1804308
3.22,	5.22,	0.2617467
5.22,	8.05,	0.3628667
8.05,	10.05,	0.4103636
10.05,	14.14,	0.4840811
14.14,	20.39,	0.4937991
20.39,	1000.00,	0.4201858

SEE Region22 (Moldova)

WARM SEASON (Apr-Sep) MWGHE then GHE

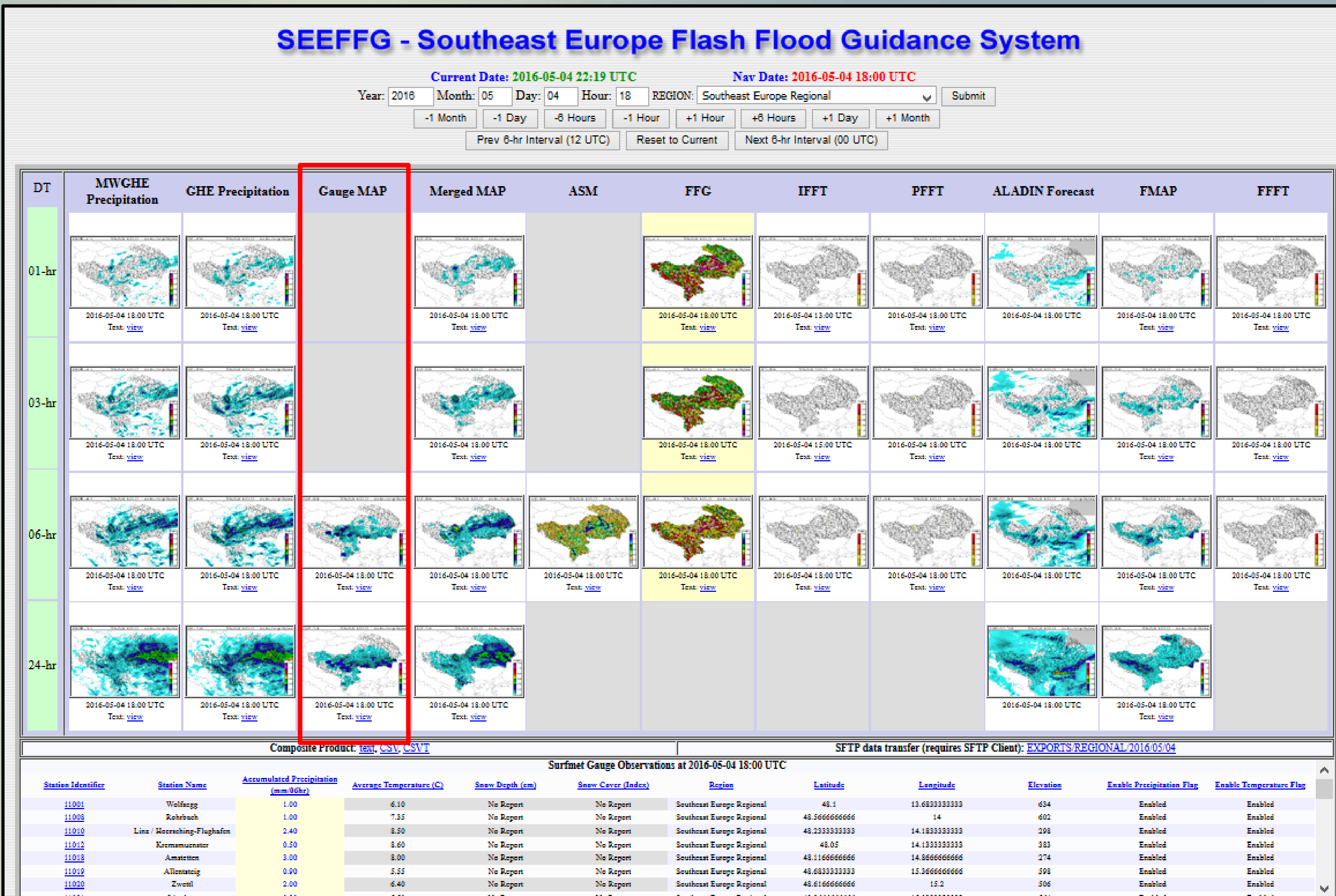
MWGHE Bias Factors Table

0.00,	0.15,	0.7049152
0.15,	0.42,	0.7708208
0.42,	0.82,	0.9300191
0.82,	1.32,	0.8420643
1.32,	2.08,	0.8892119
2.08,	2.95,	0.8074777
2.95,	4.58,	0.7961481
4.58,	7.31,	0.7584821
7.31,	11.97,	0.7148458
11.97,	1000.00,	0.7999887

GHE Bias Factors Table

0.00,	0.12,	1.0289515
0.12,	0.30,	1.0770354
0.30,	0.51,	1.4947053
0.51,	0.96,	1.4353465
0.96,	1.52,	1.2703668
1.52,	2.71,	0.9923241
2.71,	3.98,	0.9506581
3.98,	5.28,	1.0095724
5.28,	11.27,	0.9000618
11.27,	1000.00,	0.7736117

SEEFFG Precipitation Products



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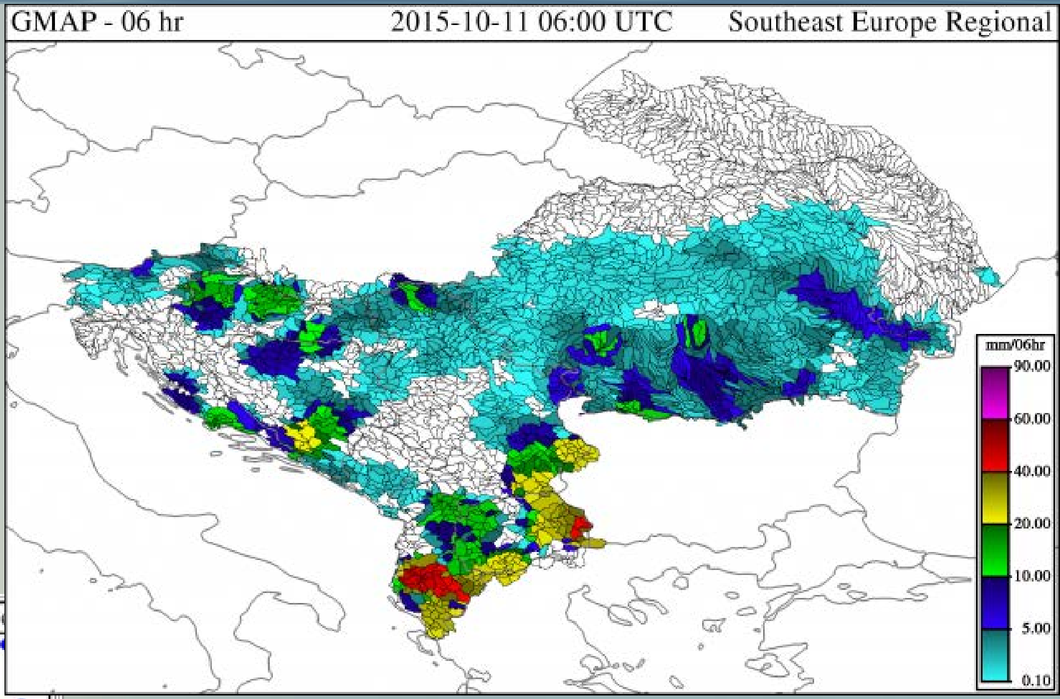
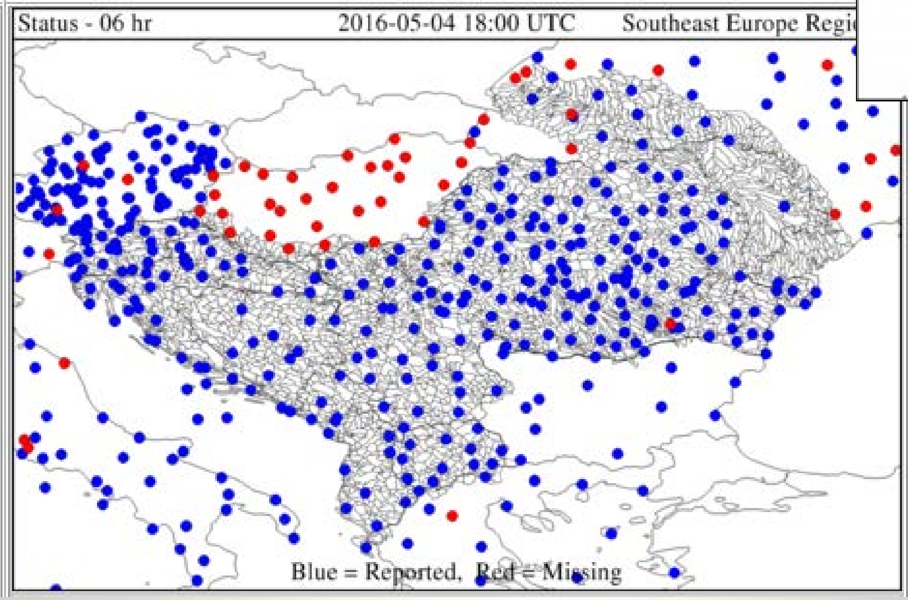
Gauge MAP

GMAP is interpolation of real-time gauge precipitation to flash flood basins. Updated every 6 hours.



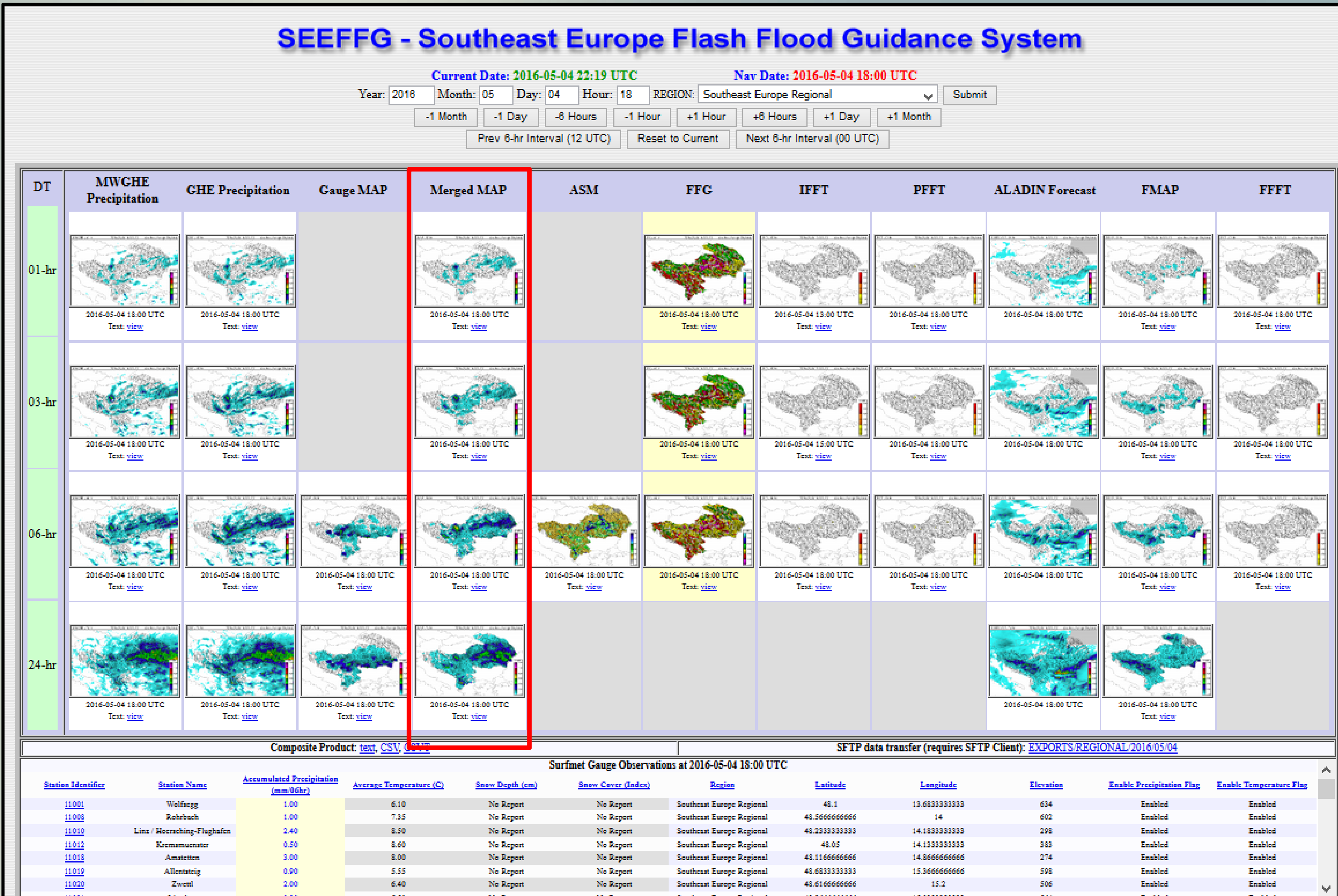
Real-time data quality is important!



The dashboard shows status of stations reporting to system in real-time.

- notify RC if stations are erroneous
- always working to add more stations if available in real-time.

SEEFFG Precipitation Products



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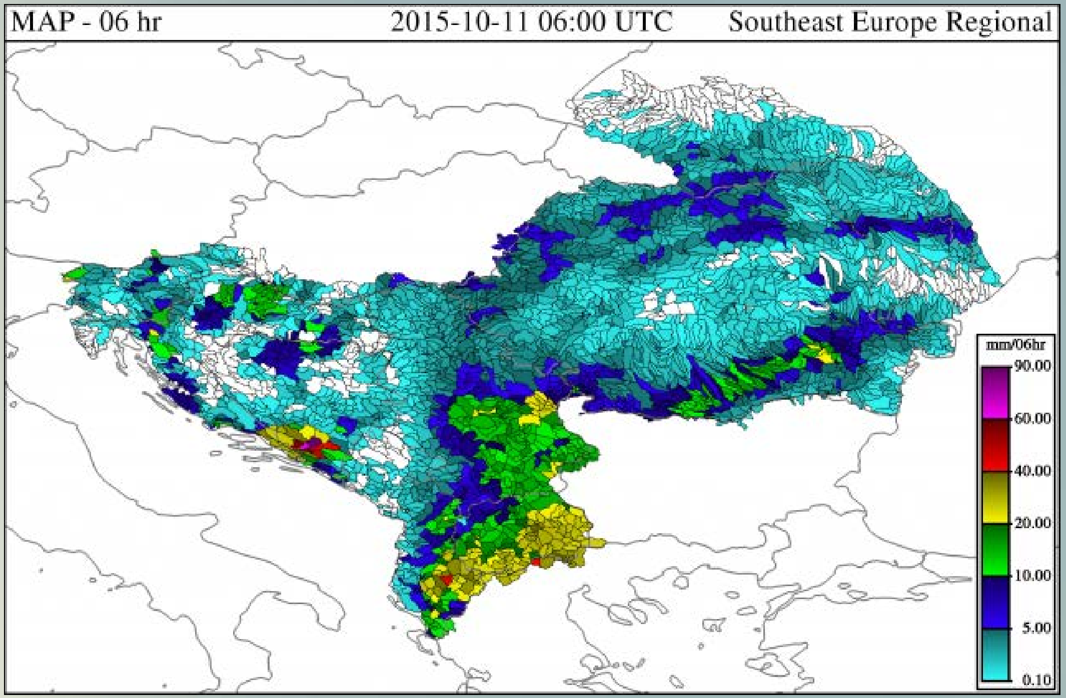
Merged MAP

Merged MAP:

The “best estimate” of current mean areal precipitation over each watershed

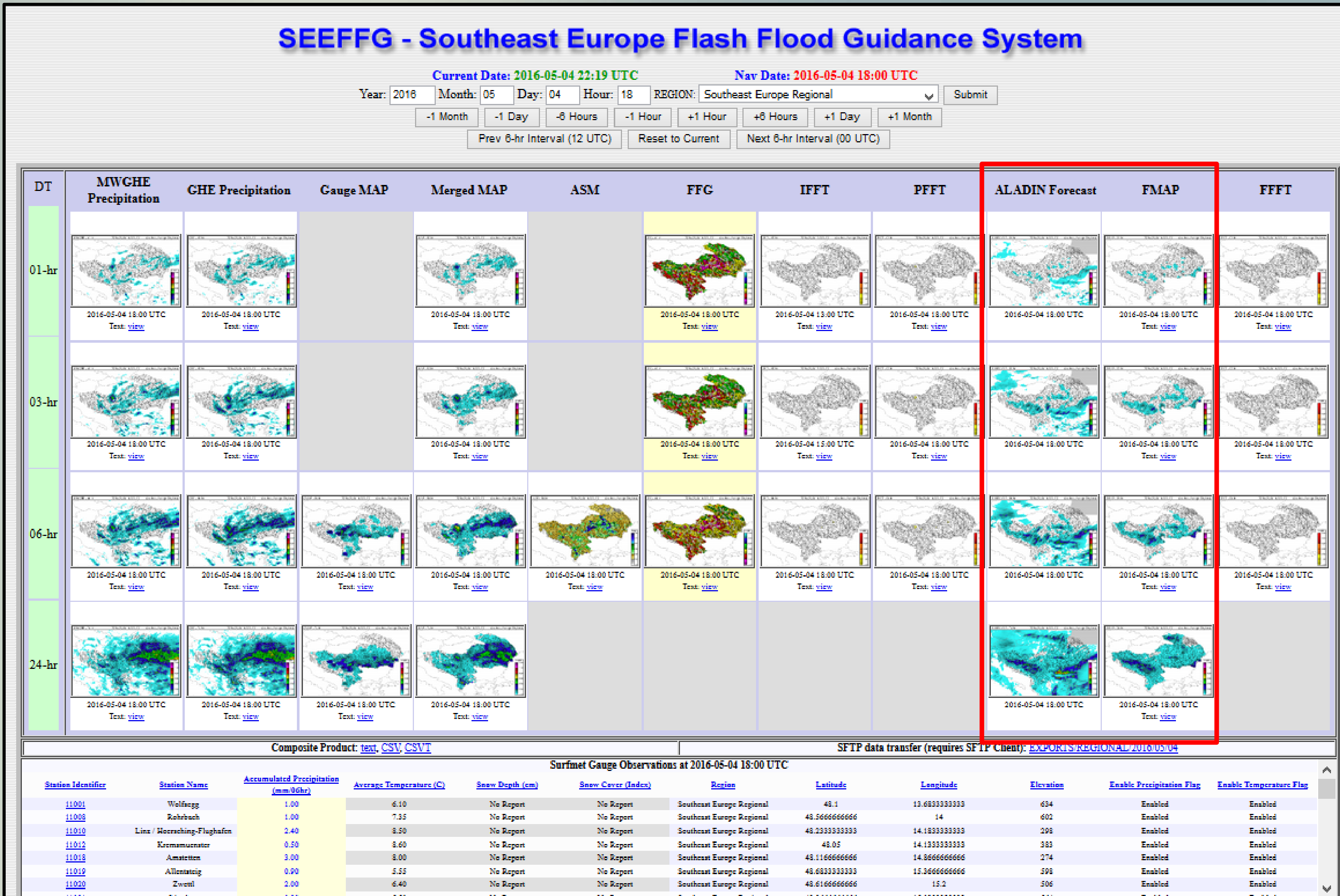
- MWGHE
- GHE
- real-time gauges



Accounts for ‘long-term’ bias (climatological bias applied) as well as event-specific (real-time) bias.

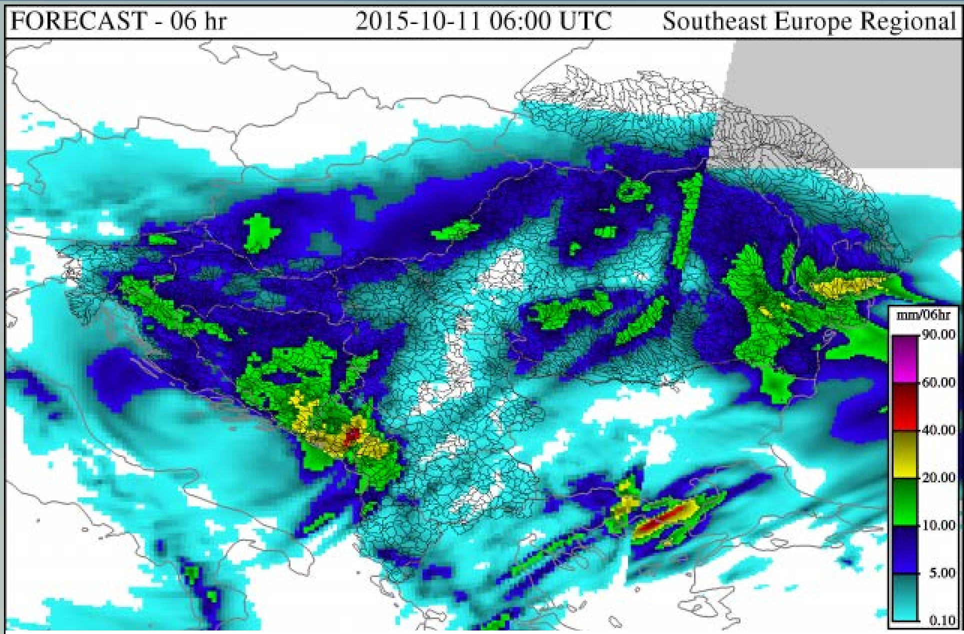
Merged MAP is input to hydrologic modeling components and used for IFFT/PFFT comparisons.

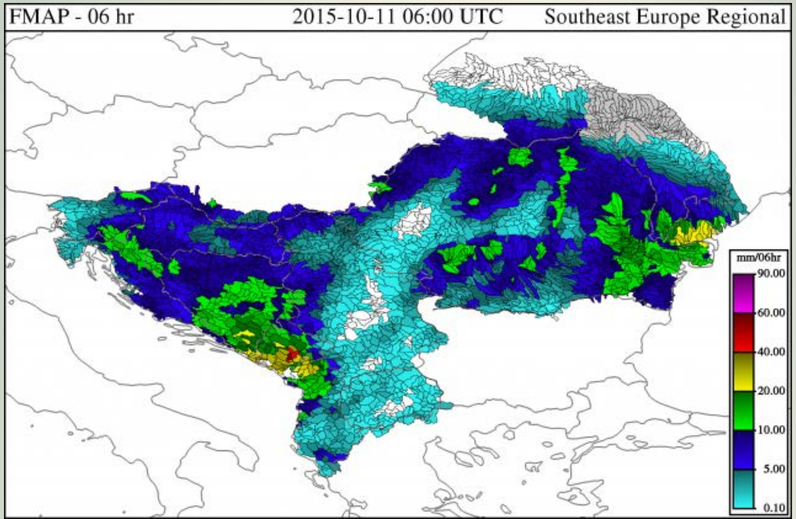
SEEFFG Precipitation Products

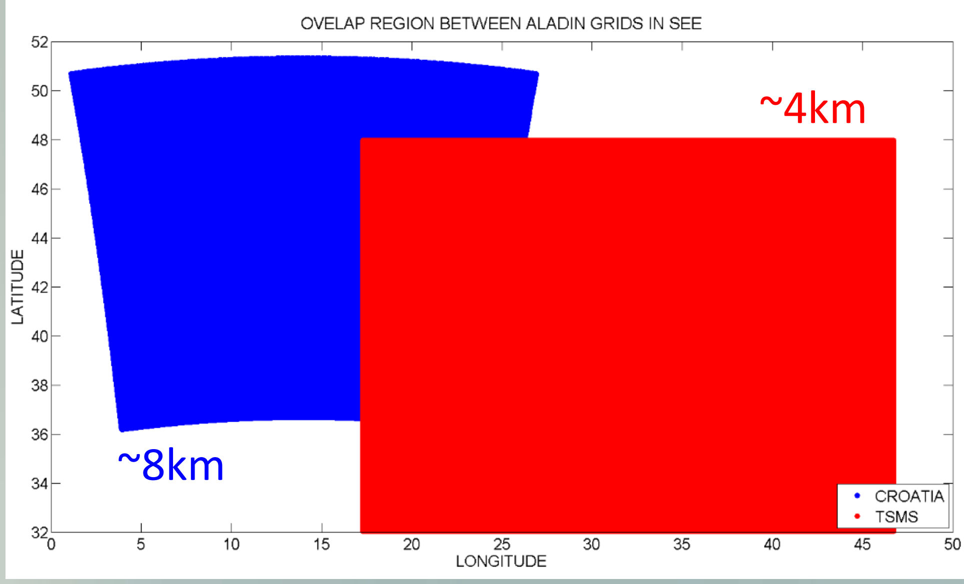


Forecast Precipitation Products

- Two ALADIN forecast models
  - Croatia DHMZ
  - Turkey (TSMS) as RC
- Single composite forecast grid is produced
  (Croatia first, TSMS second)
- Area in NE not covered (Moldova)
- FMAP is computed as average of grids within each basin (*no adjust.*)

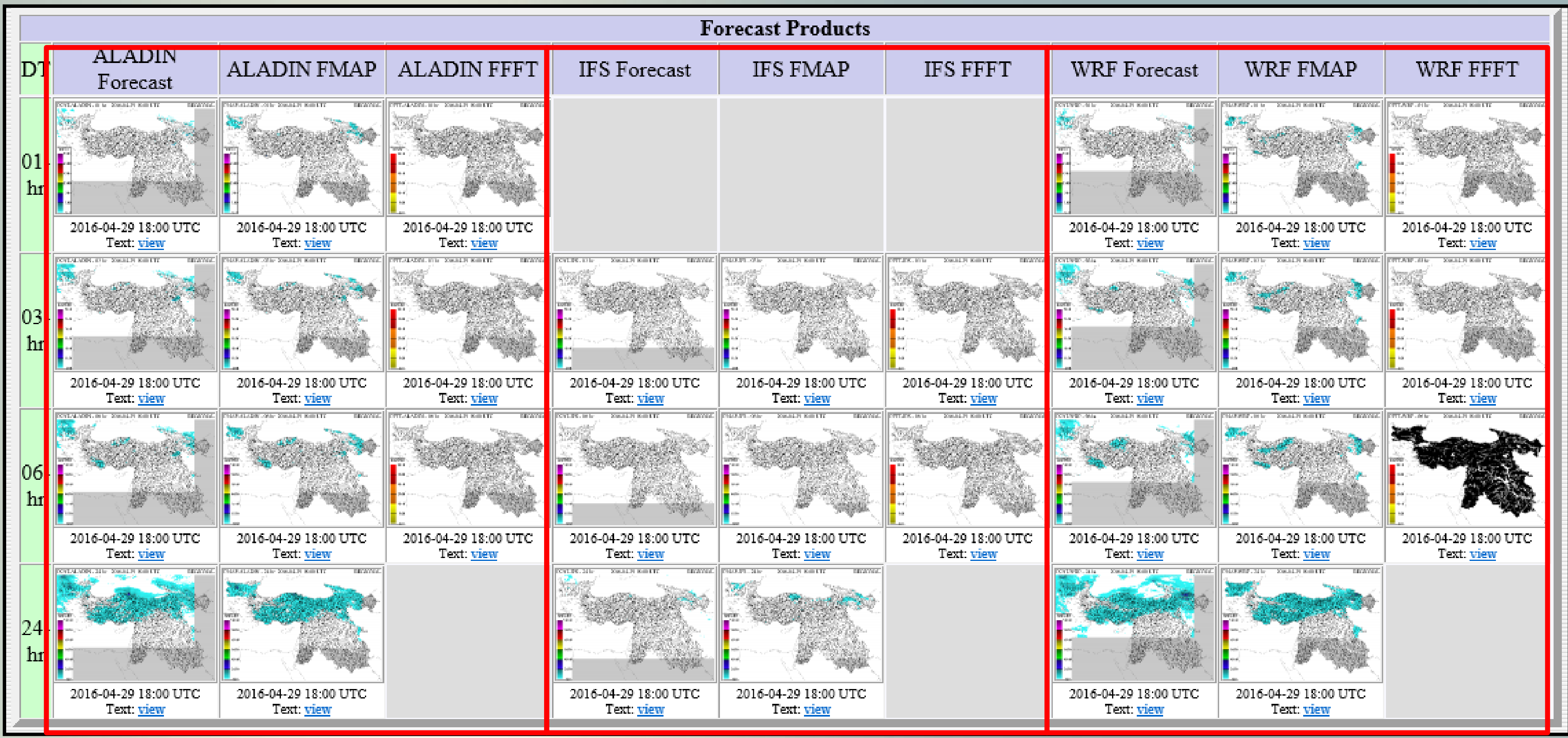






Future: Multi-model Forecast Precipitation

Currently under development, capability to ingest precipitation forecasts from multiple NWP models and generate FMAP and FFFT products (prototyped in BSMEFFGS).



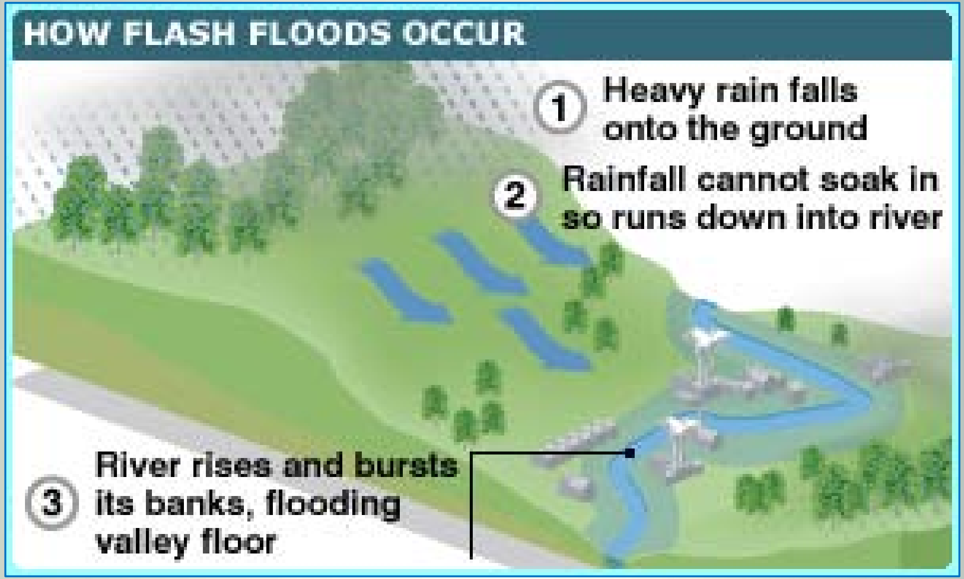
Review of Technical Background
2. Spatial Analysis / GIS and Soil Model Components

Southern California mountain stream

Motivation

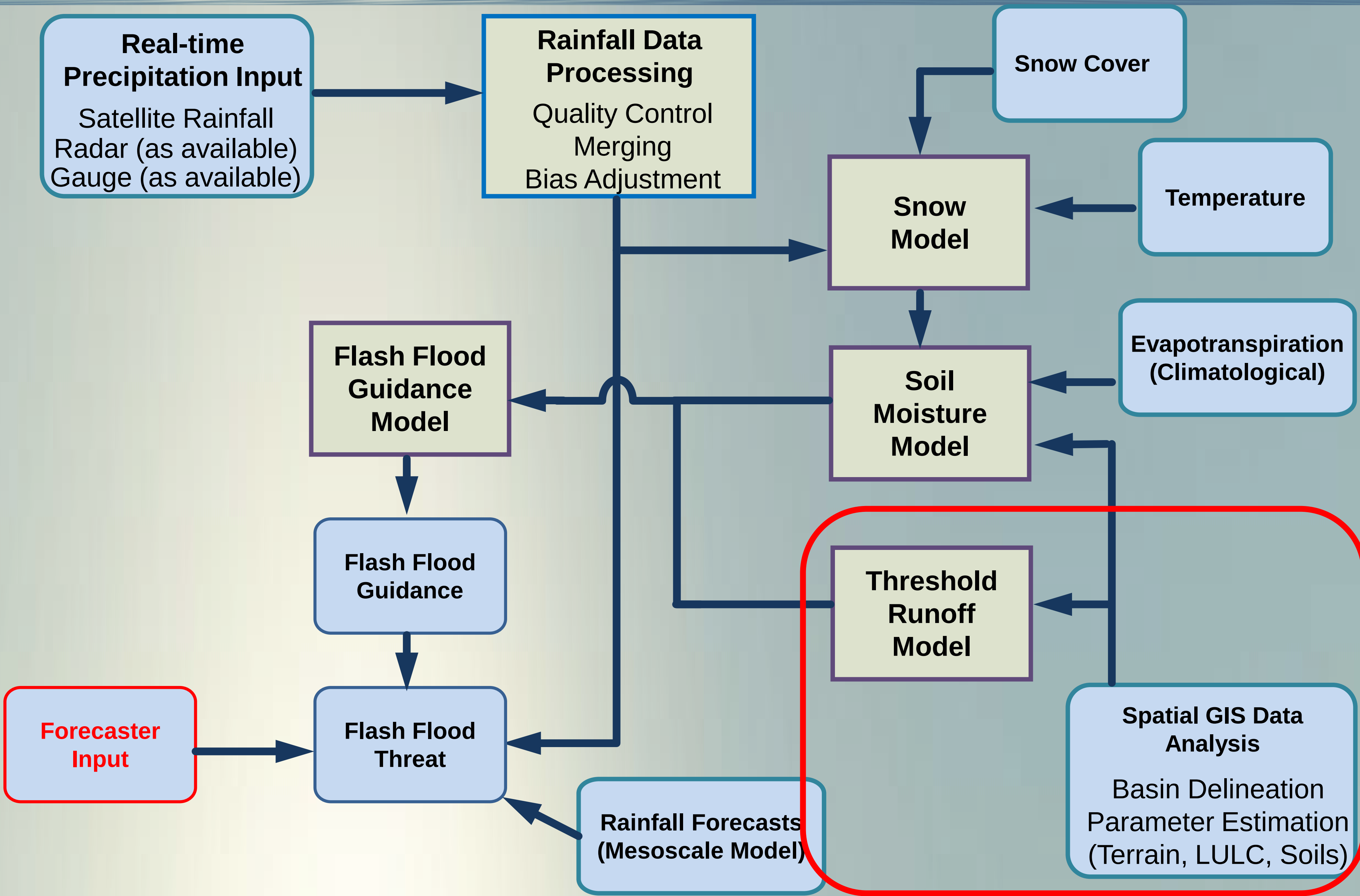
Hydrologic Components of SEEFFG System account for land surface processes in production of flash floods.

- *infiltration of rainfall into soil and storage of moisture in soil*
- *Accumulation and ablation of snow, and snow melt contribution to soil*
- *production of runoff into channels*
- *evapotranspiration*



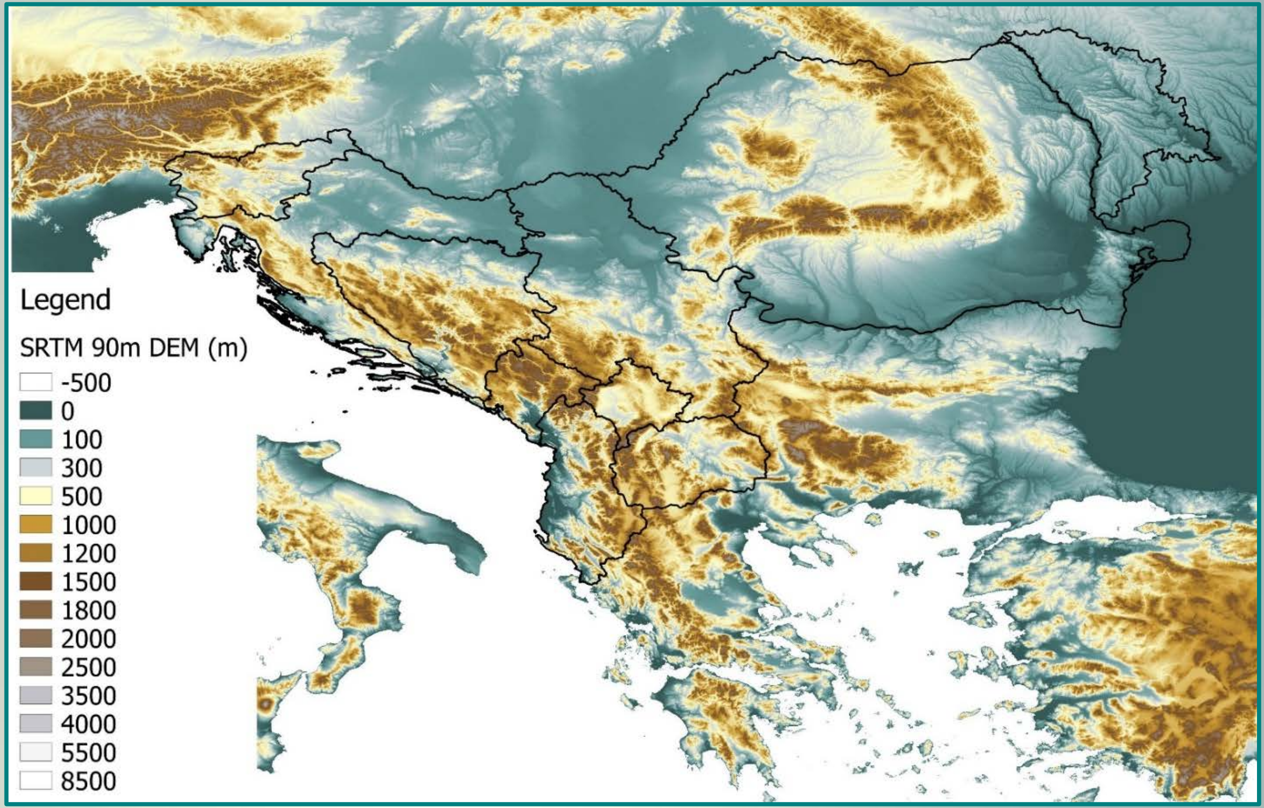
From BBC news

Key Technical Components for Flash Flood Guidance Systems



GIS Processing to Delineate Small Flash Flood Watersheds

- *GIS processing of digital elevation data (SRTM)*
- *Define watershed boundaries*
- *Estimate watershed characteristics (A, L, S) used in calculations*
- *Spatial analysis for model parameterizations and MAP calculations*



GRASS GIS software

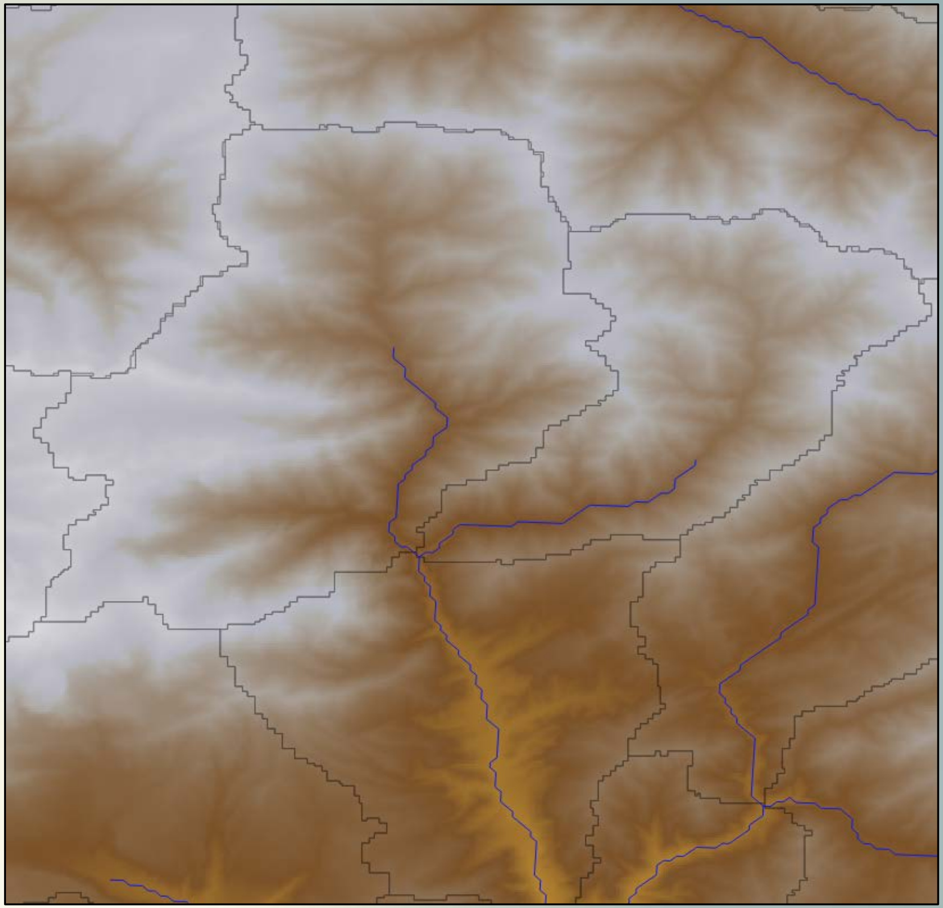
- *r.watershed routine*

SRTM 90-m DEM

- *satellite-observed*
- *near global*
- *quality controlled*

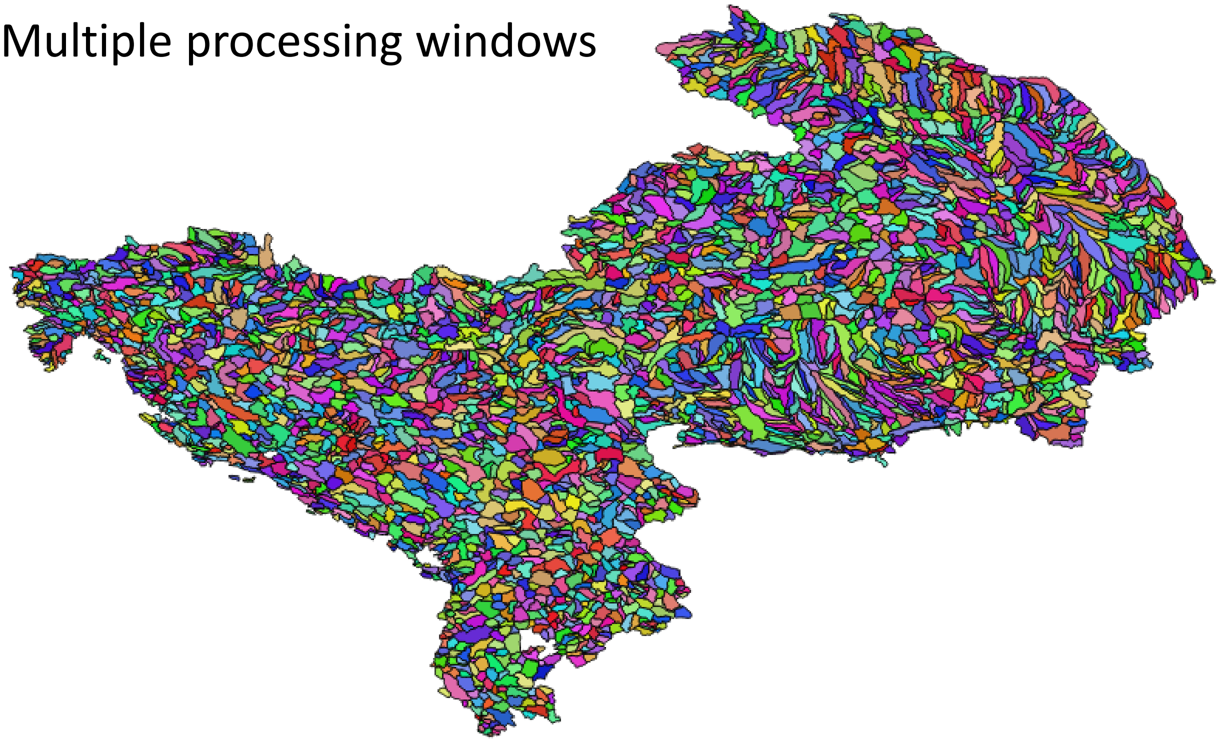
GIS Processing to Delineate Small Flash Flood Watersheds

Output of GIS processing is delineation of stream network and watershed boundaries



SEEFFG Delineated Basins

Multiple processing windows



Quality Control

- *HRC review with DCW*
- *Comparison with*
- *Country review and comments*
- *Re-delineation after comments (check with SRTM 30m DEM)*

Result: 3757 basins

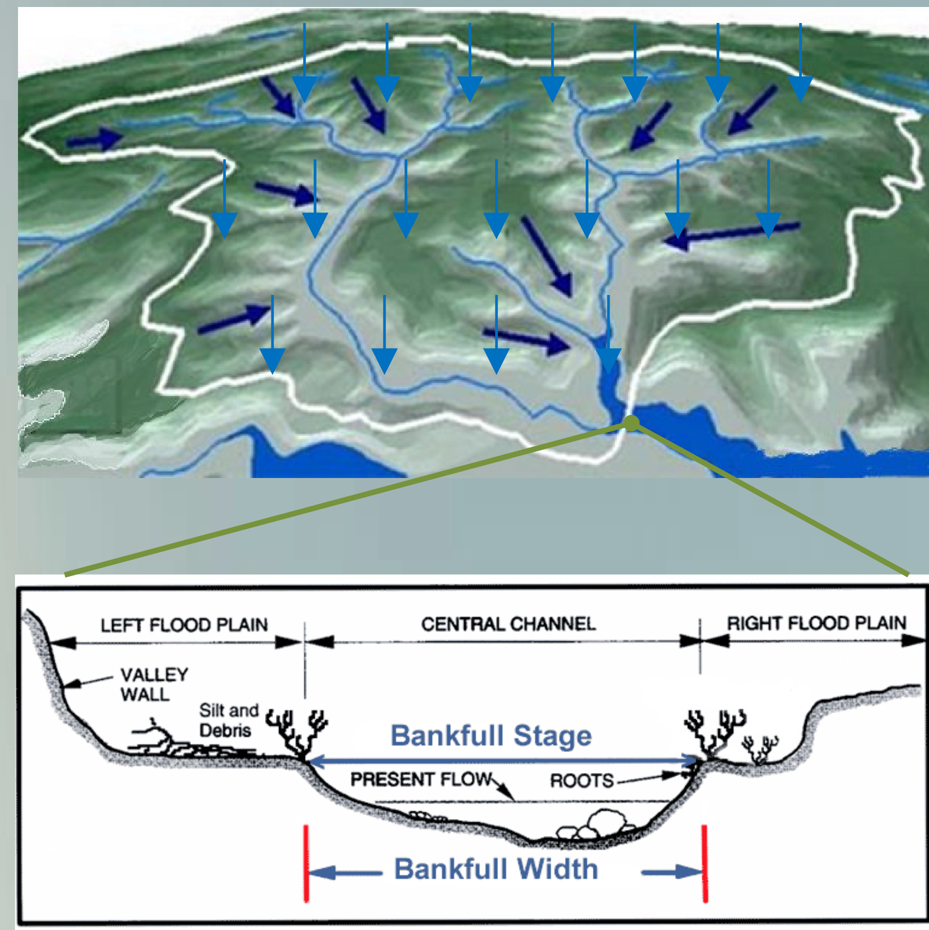
Average A = ~175km^2

Comments on GIS-based Watershed Delineation

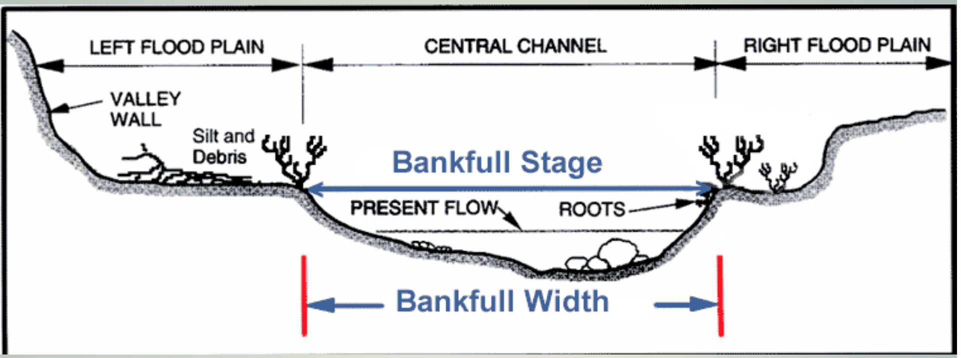
- Watershed delineation is based on topography only
  - Represents *natural* drainage system
  - SRTM “sees” top of canopy
  - Known difficulties in very mildly sloping regions and regions with small terrain undulations.
- Multiple “processing windows”, which are “patched” together to create regional GIS file.
- Watersheds defined throughout region.
  Soil/snow models applied throughout but FFG computed only for watersheds with cumulative area < 2000km^2.

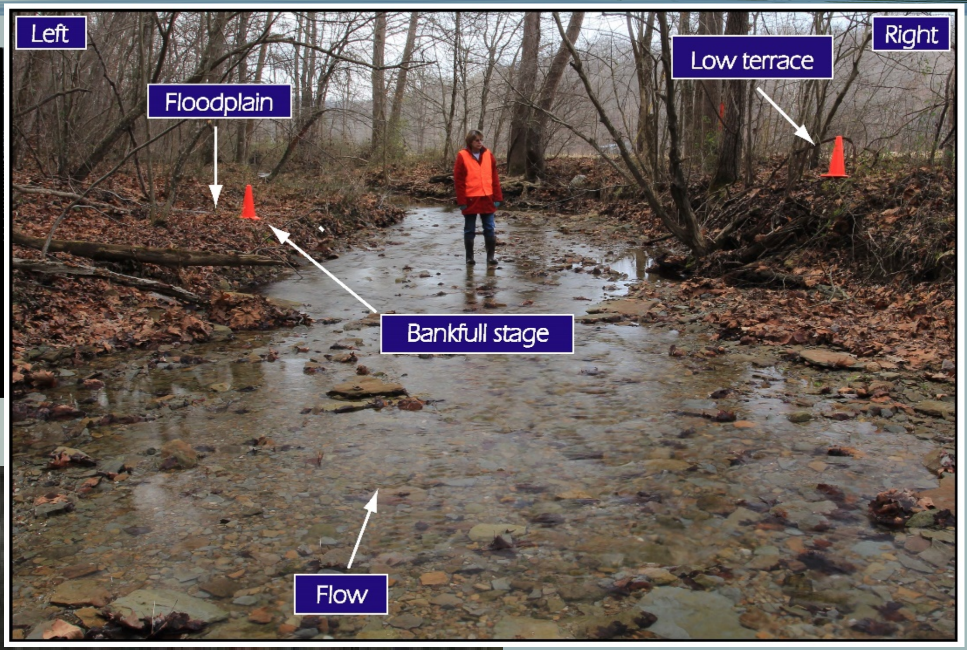
Definition of Threshold Runoff

Threshold Runoff 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.



Definition of Threshold Runoff





Threshold runoff represents the storage capacity of the stream to accept runoff at a level of minor flooding.

Estimation of Threshold Runoff

Under assumption that watersheds respond linearly to rainfall excess, ***threshold runoff*** found by equating peak catchment runoff to flow at outlet associated with flooding (“flooding flow”).

Carpenter et al., J. Hydrology, 1999.

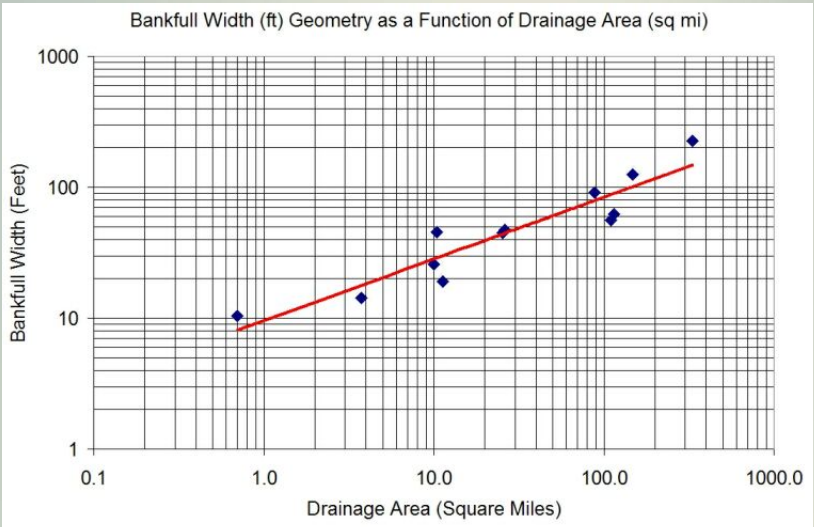
- “Flooding flow”, Q_p = bankfull flow as calculated from hydraulic principles (Mannings’ steady uniform resistance formula).
  $Q_p = f$(channel cross-sectional characteristics: B_b, D_b, S_c)

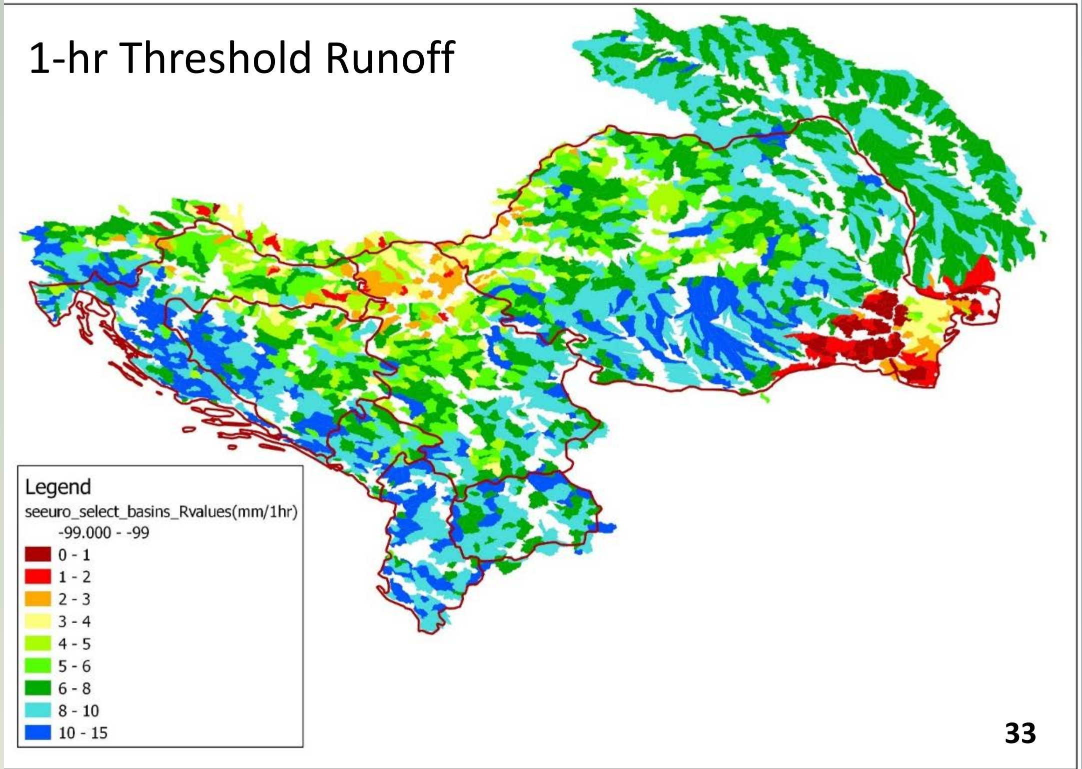
- Peak of unit hydrograph is based on Geomorphologic Instantaneous Unit Hydrograph (GIUH) theory.
  Unit hydrograph peak response, $q_{pR} = f$(catchment & channel characteristics, rainfall rate)

- *Threshold Runoff, R = nonlinear function of catchment and channel characteristics (A,L, R_L, B_b, D_b, S_c)*

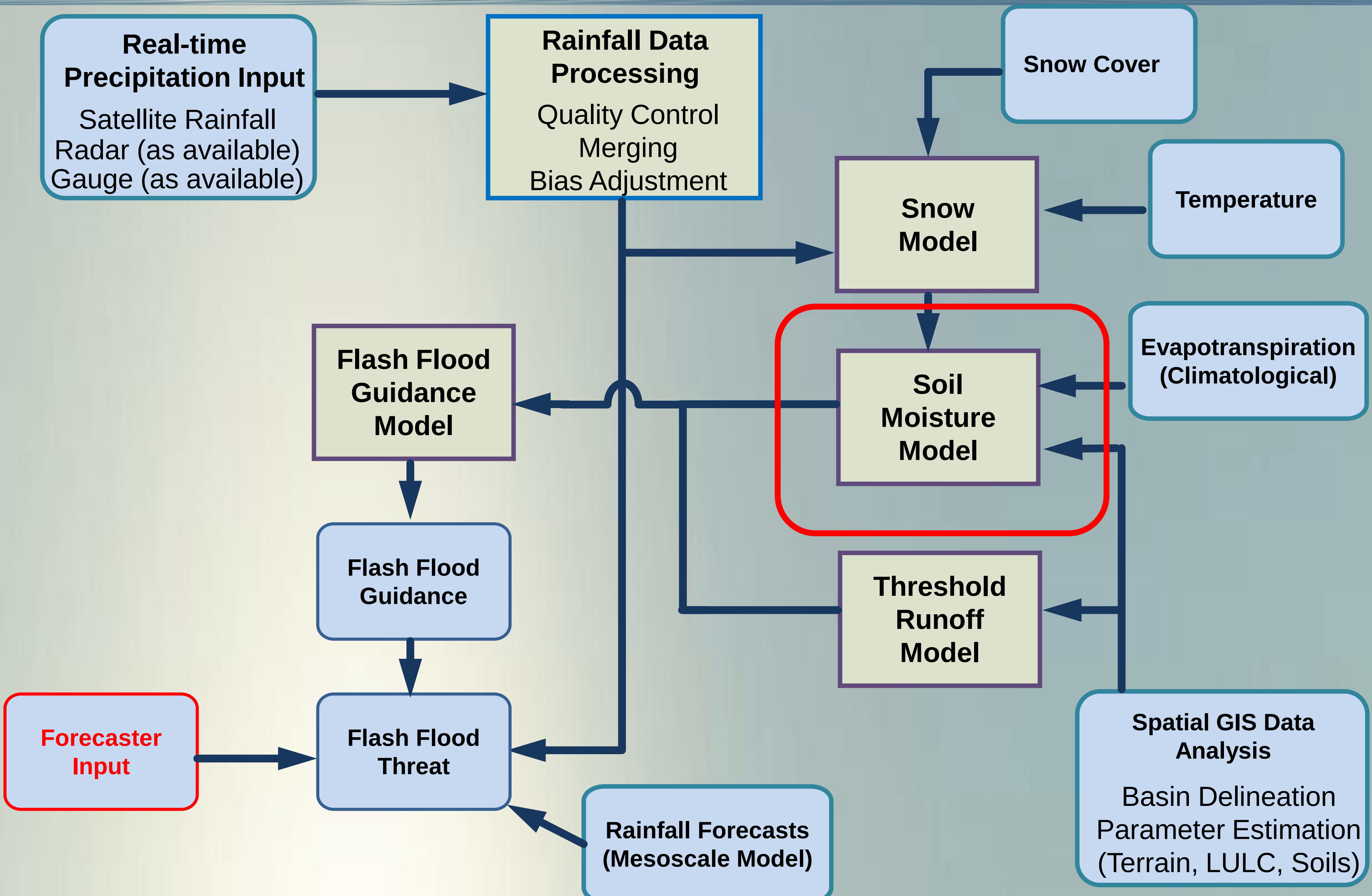
Method to Estimate Threshold Runoff

(1) Define watershed boundaries
(2) Compute watershed properties (A, L, S)
(3) Estimate channel cross-section from regional regressions (Romania)
(4) Compute ***threshold runoff***





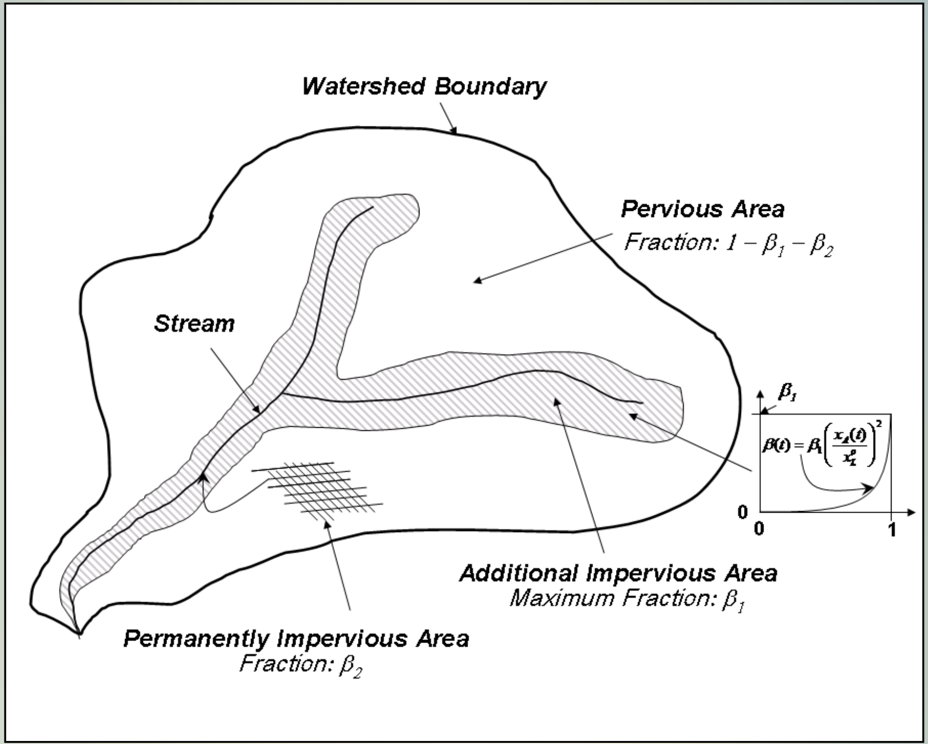
Key Technical Components for Flash Flood Guidance Systems

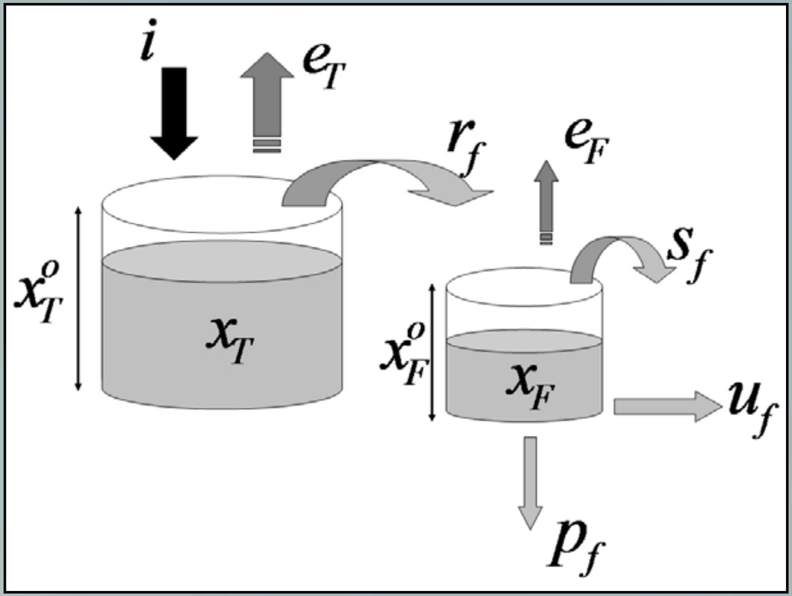


Soil Model for SEEFFG

- 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.

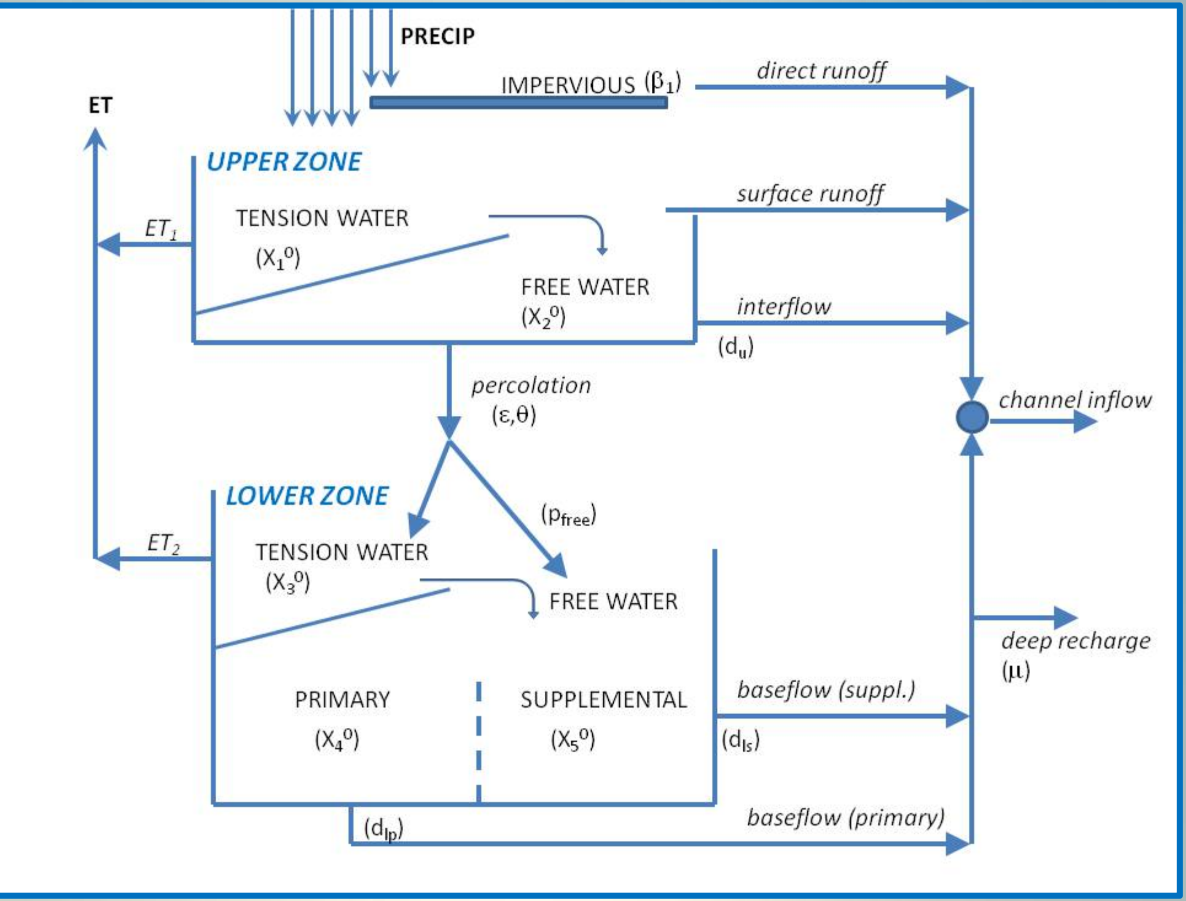
A two-layer conceptual model representing the movement of soil water through a vertical, homogeneous soil column





Soil moisture storage in two sub-surface layers; "tension" and "free" water"

Sacramento Soil Moisture Accounting Model



INPUT:

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

Various representations of runoff:

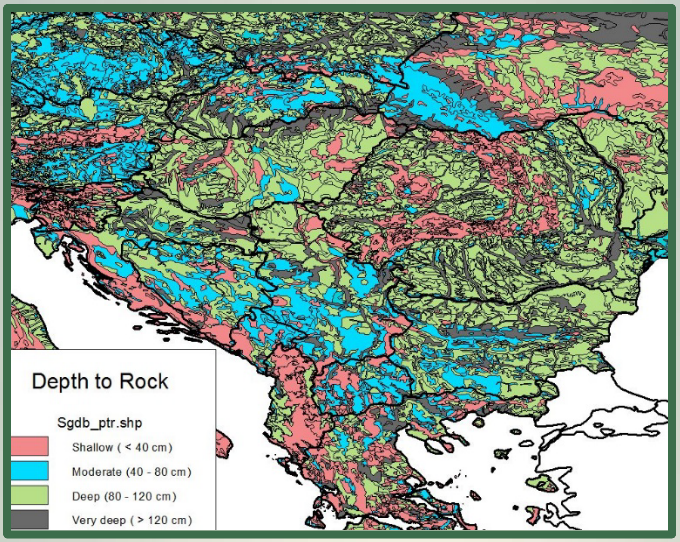
- *saturation excess*
- *infiltration excess*
- *combined runoff*

PARAMETERIZATION:

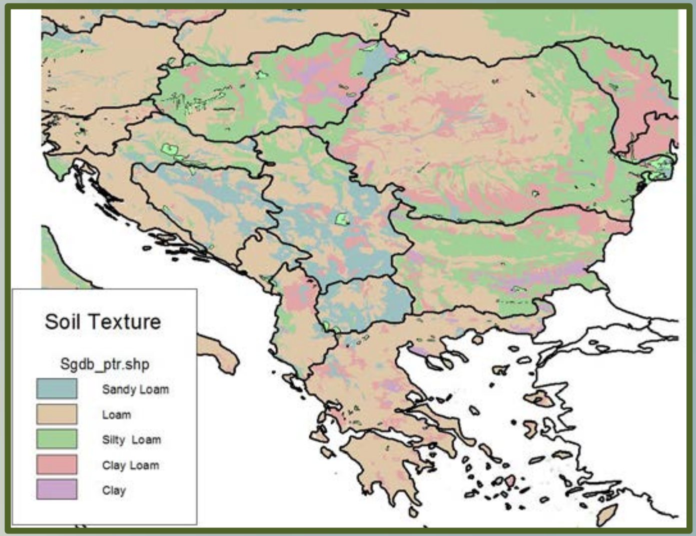
- *15 model parameters (capacities, withdrawal rates, percolation)*
- *Initial parameters based on soils and land cover*

Initial Spatial Datasets for Model Parameterization

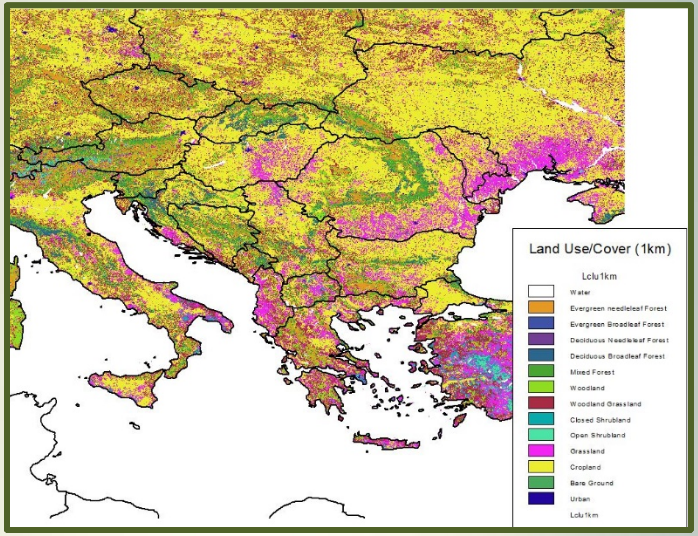
European Soils Database
Depth to Bedrock



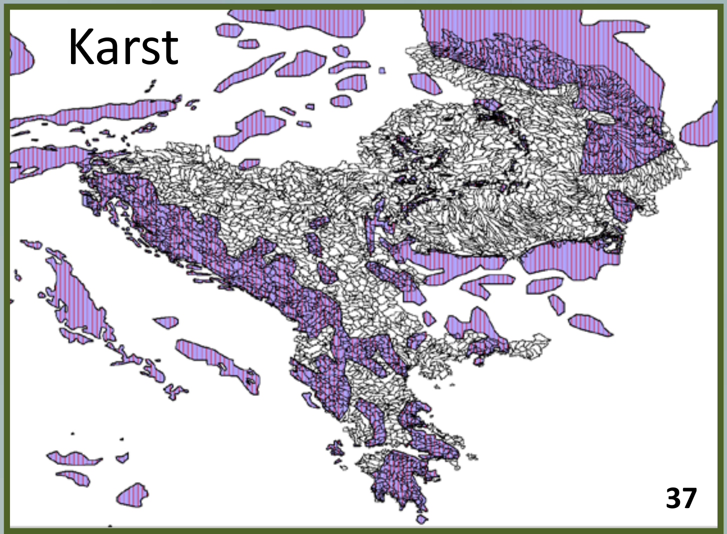
European Soils Database
Soil Texture



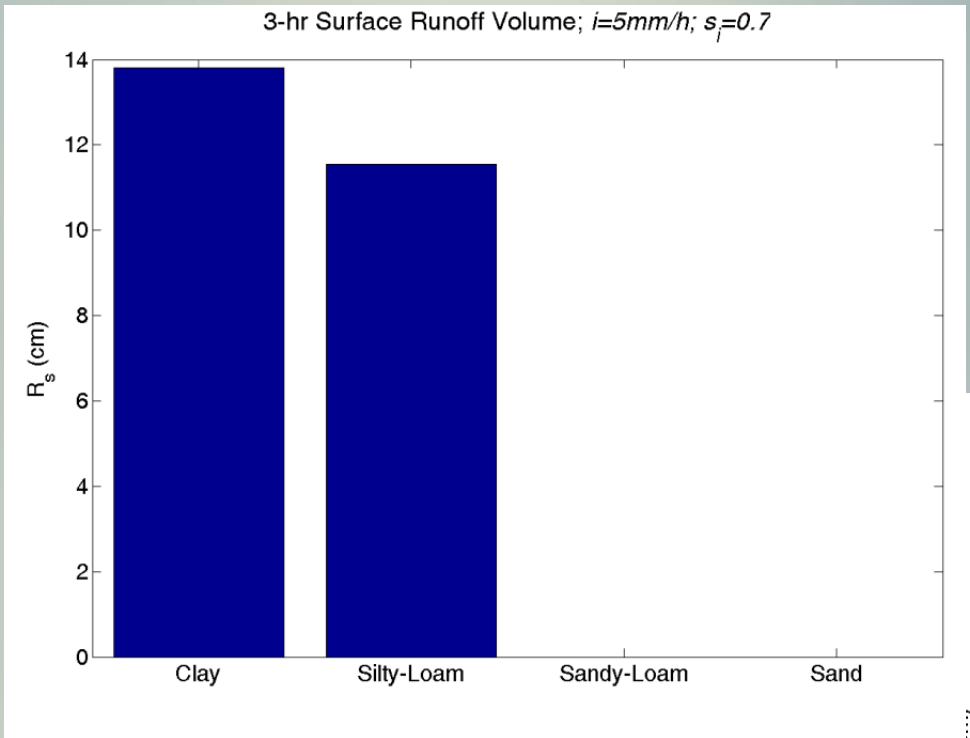
Land Use/
Land Cover



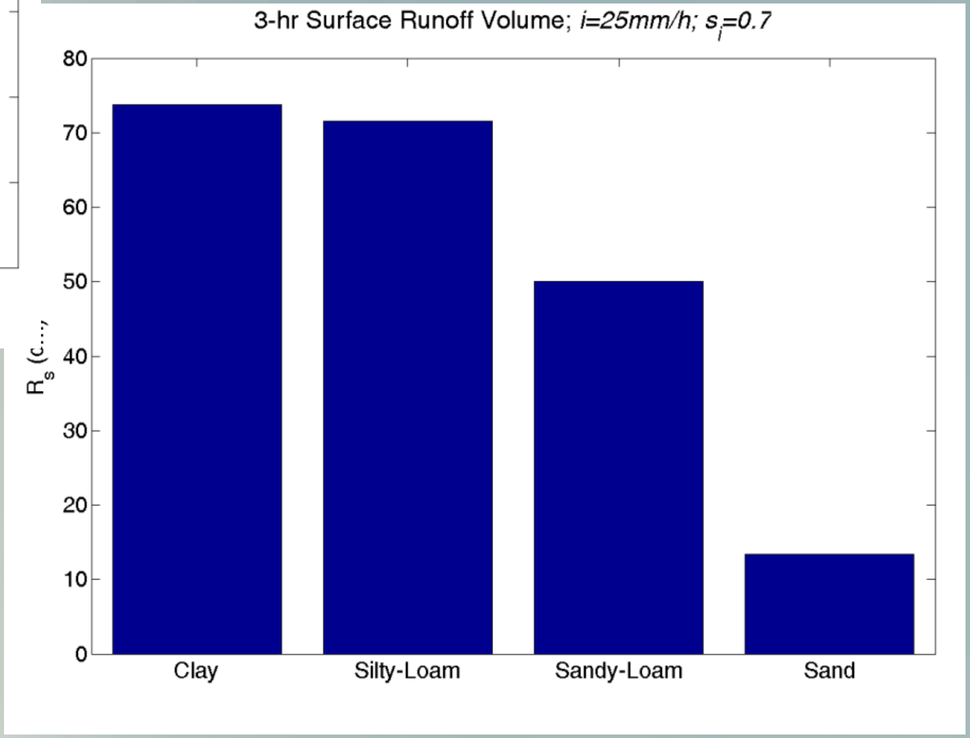
Karst



Effect of Soil Classification on Runoff Generation

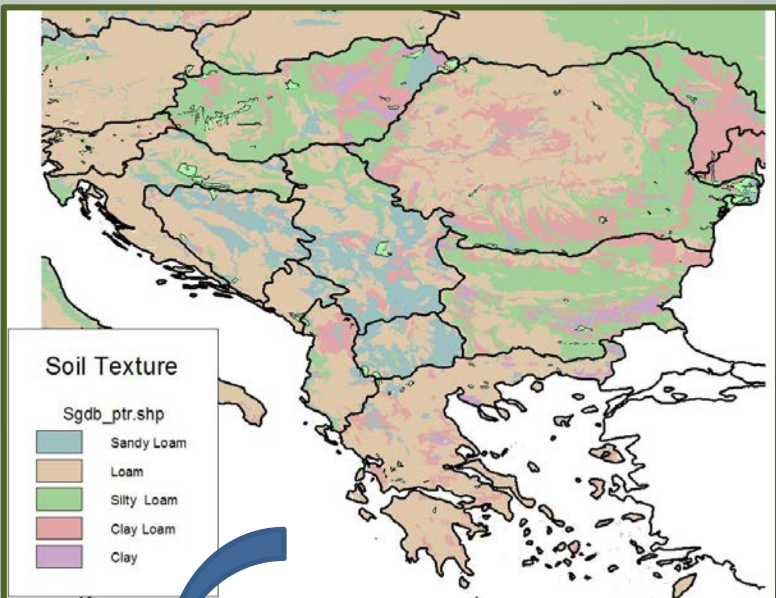


Plots of surface runoff generated over 3 hours for different soil classifications

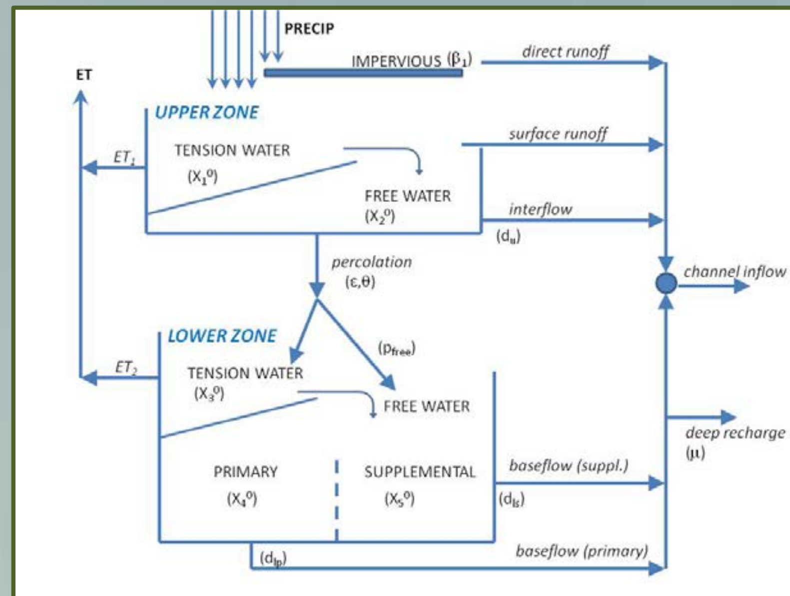


Sacramento SMA Model Parameterization

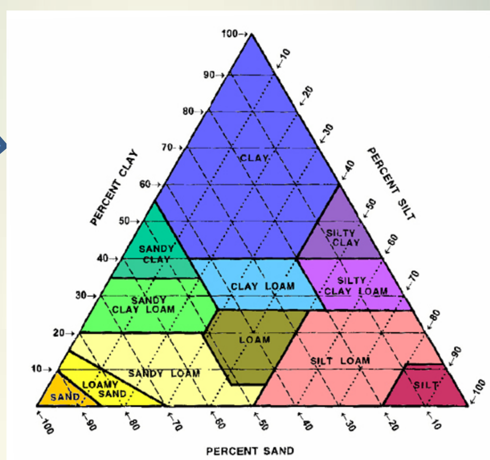
1. Soils Information



4. Parameters of SAC-SMA



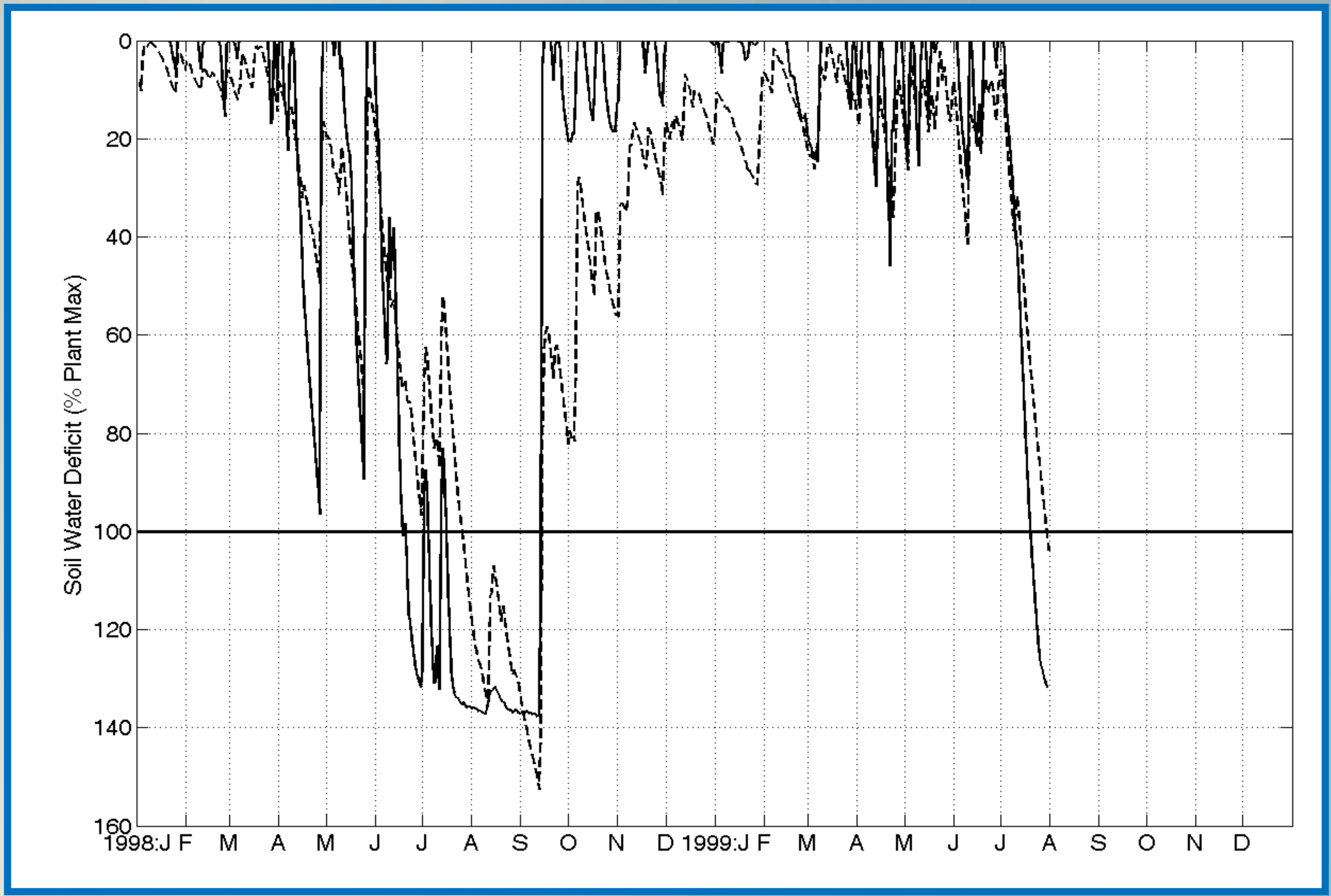
2. Soils Texture



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

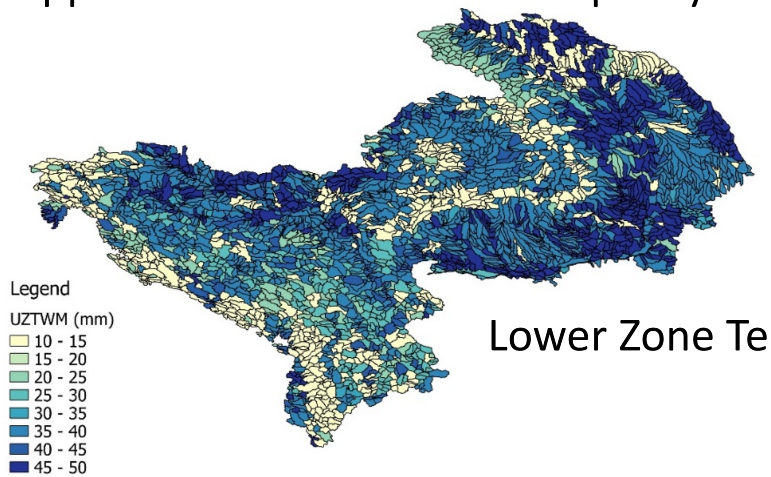
Example of SAC-SMA Output: Site Soil Moisture Validation



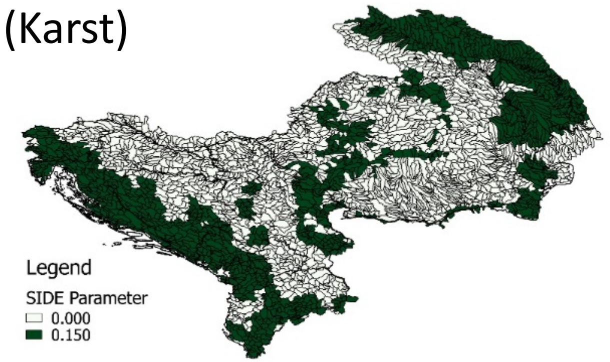
Reasonably good reproduction of depth integrated soil water deficit

Model Parameterization

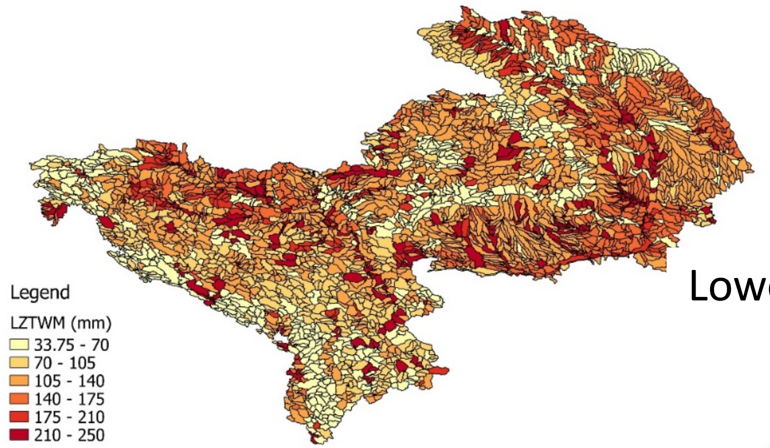
Upper Zone Tension Water Capacity



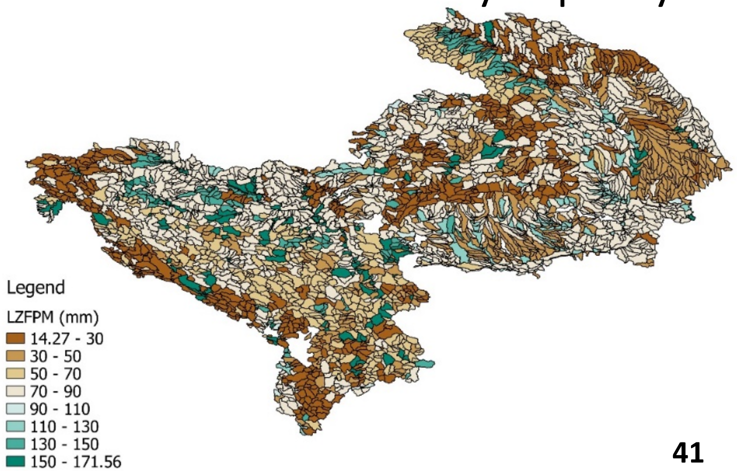
SIDE parameter (loss)
(Karst)



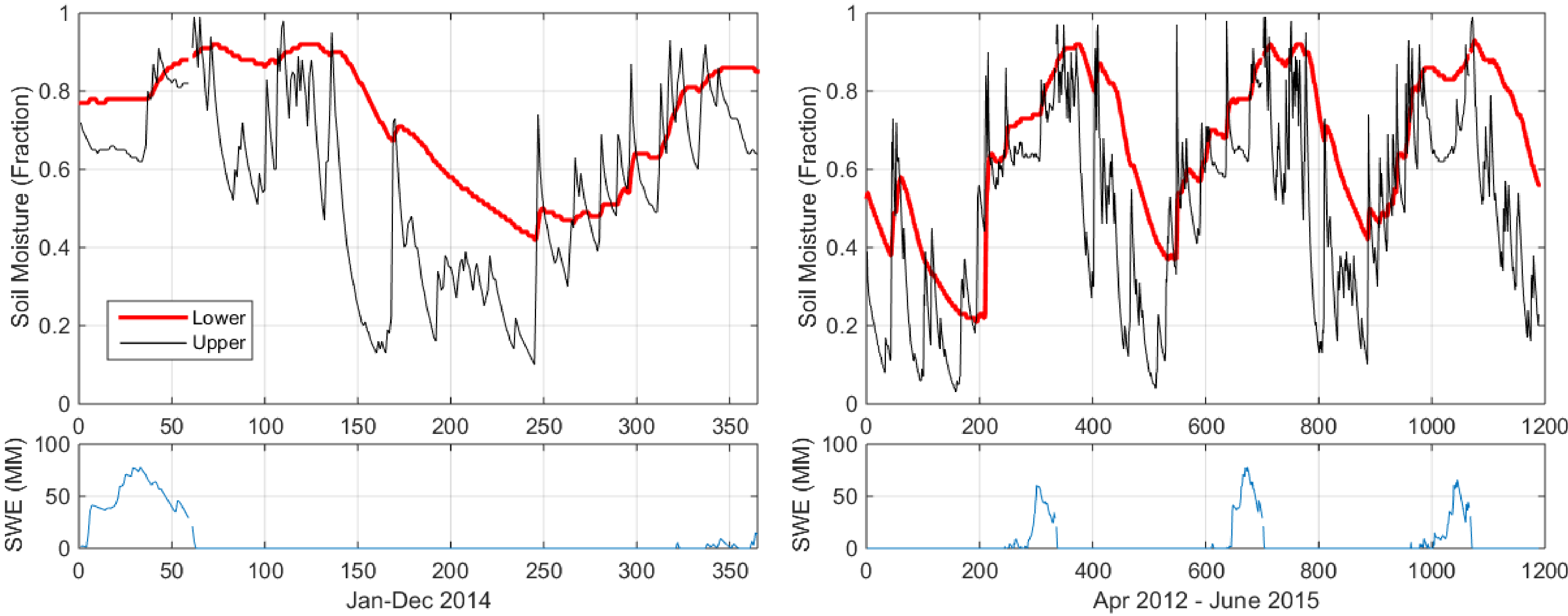
Lower Zone Tension Water Capacity



Lower Zone Free Primary Capacity

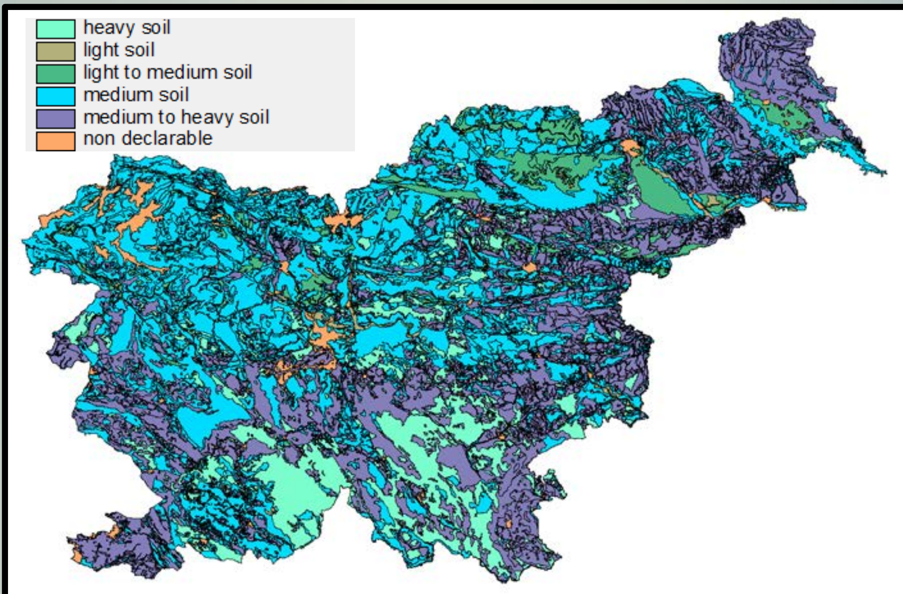


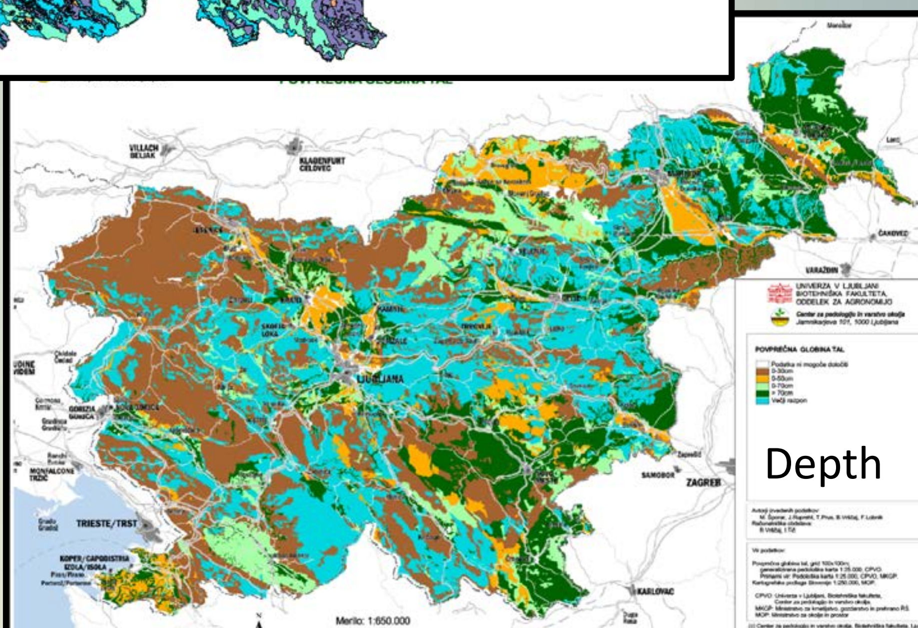
Timeseries of Soil Moisture



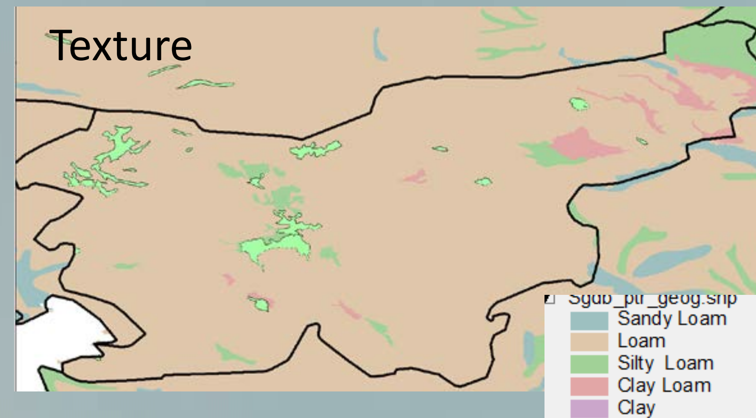
Local Spatial Datasets (During On-Site Training)

Slovenia Local Dataset

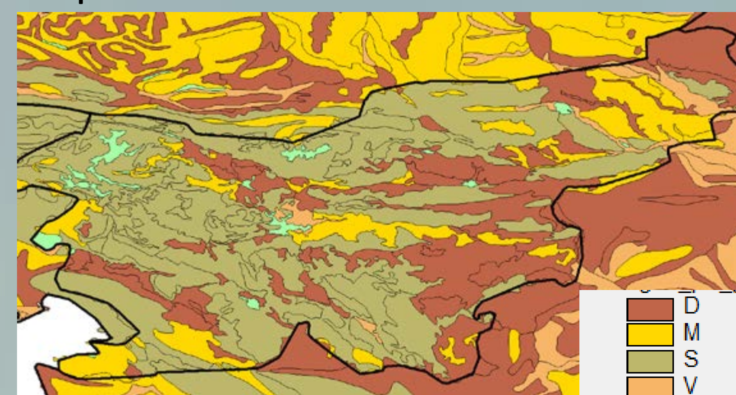




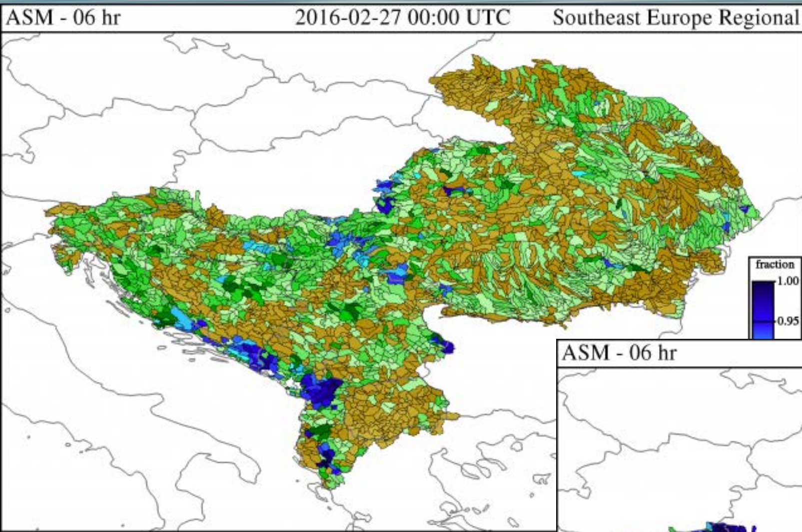
European Dataset

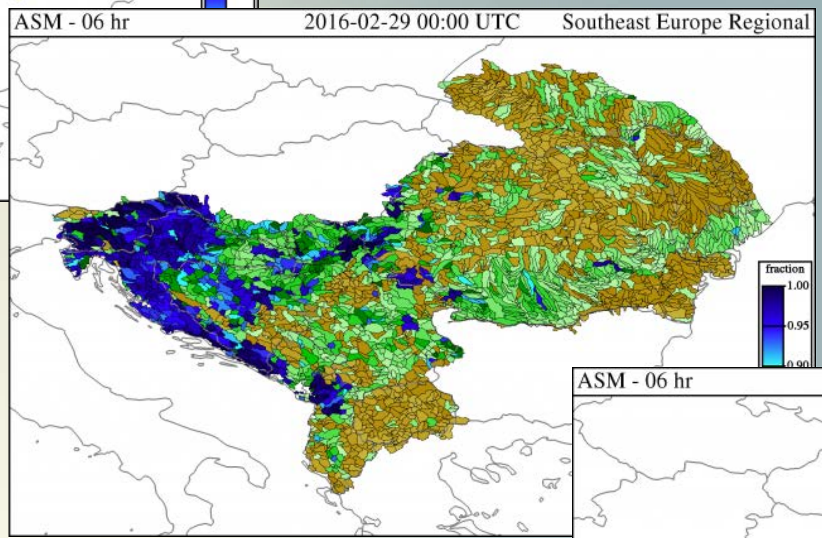


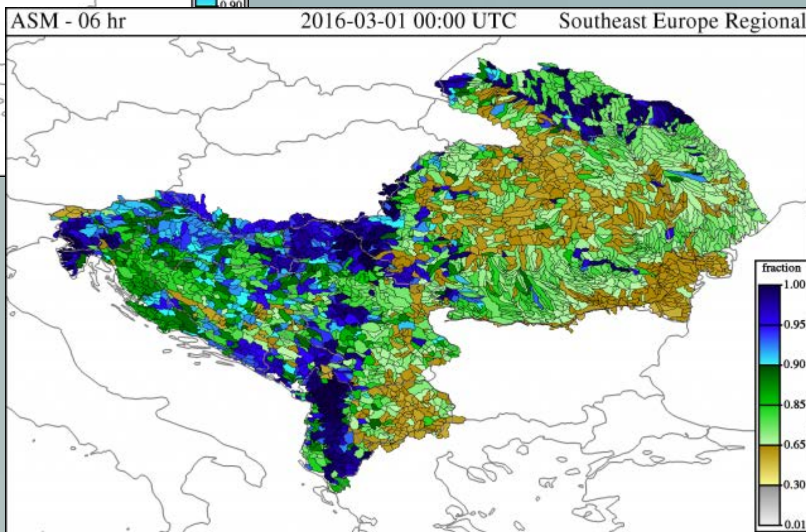
Depth



SEEFFG Product: ASM



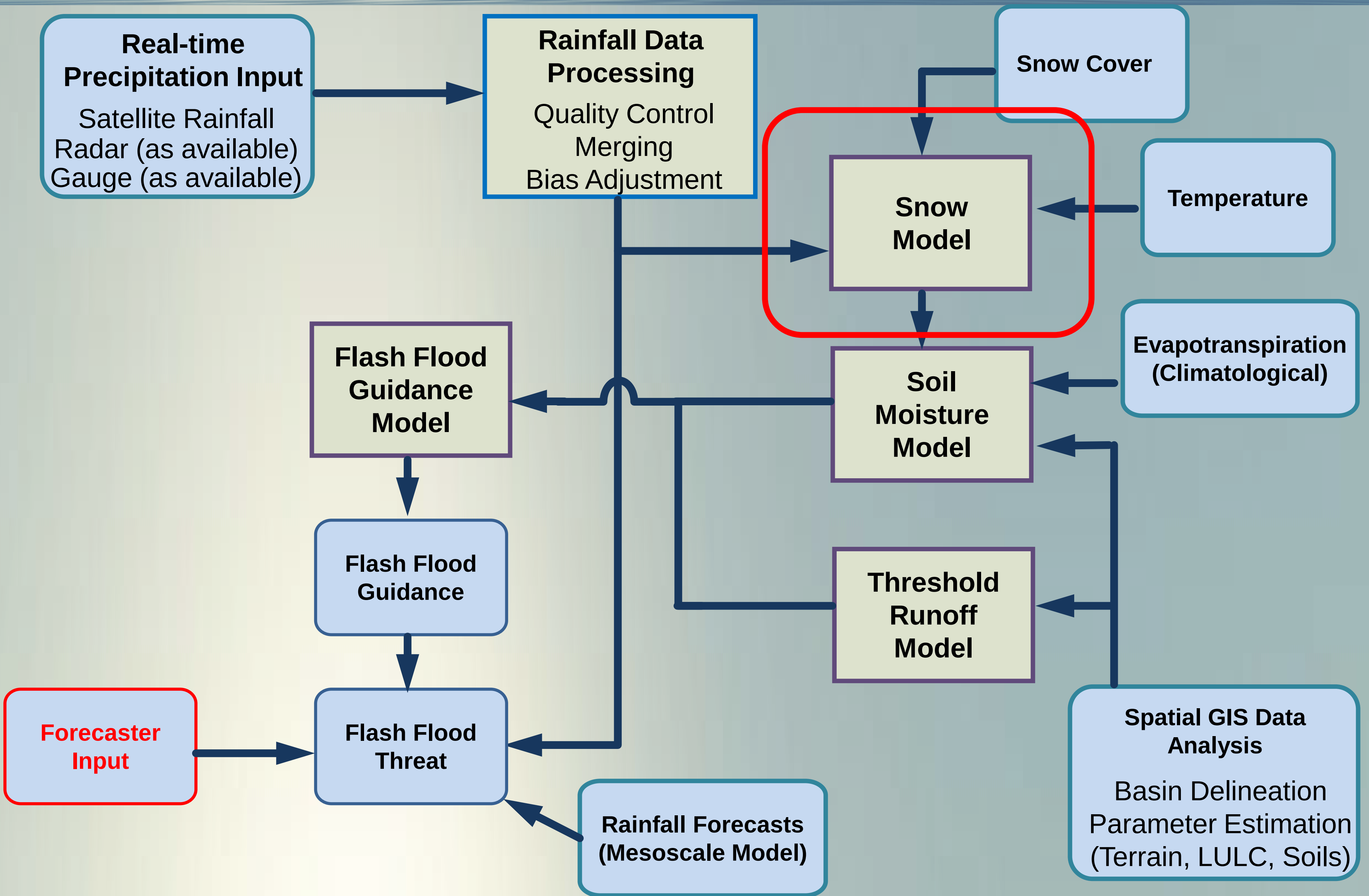




Review of Technical Background
3. Snow Model and Snow Products

Carpathian Mountains, Bucovina, Romania

Key Technical Components for Flash Flood Guidance Systems

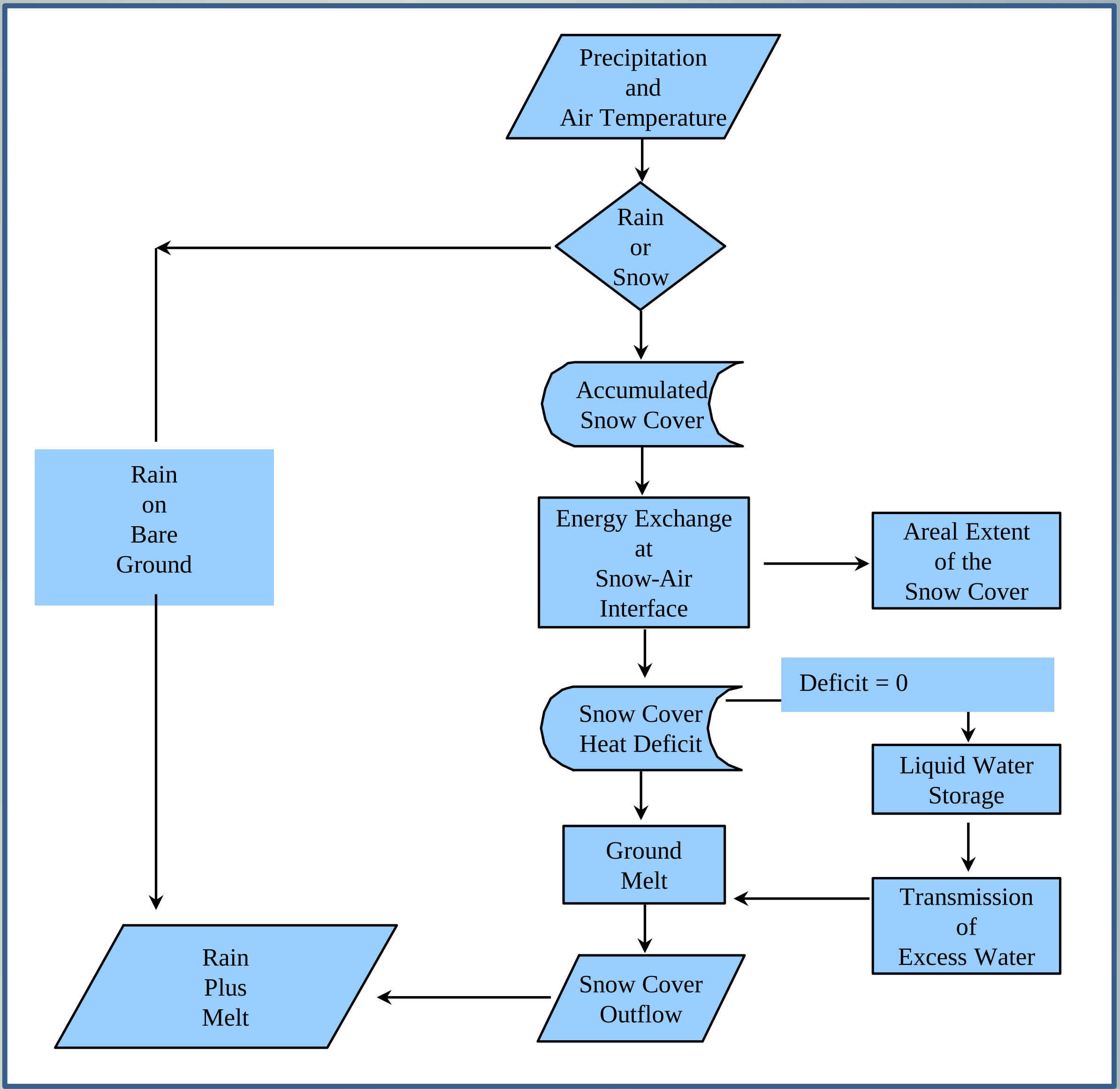


Snow Model for SEEFFG

- Employs conceptual lumped energy and mass balance model, SNOW-17

- Treat as single vertical layer for each watershed
- Considers:
  - Melt during rain
  - Melt during no rain
  - No Melt (heat accounting)
- Used operationally by U.S. National Weather Service (Anderson, 1973; Anderson, 2005)
- Air temperature index for division of rain versus snow
- Snow Depletion Curve describe snow cover extent within model

Snow-17 Model



INPUT:

- *Surface Air Temperature*
- *Precipitation (MAT and MAP)*

MODEL STATES:

- *snow water equivalent (SWE)*
- *liquid content*
- *heat deficit*
- *antecedent temperature index (ATI)*
- *snow cover area (SCA)*
- *snow pack depth (opt.)*

OUTPUT:

- *rain + melt*

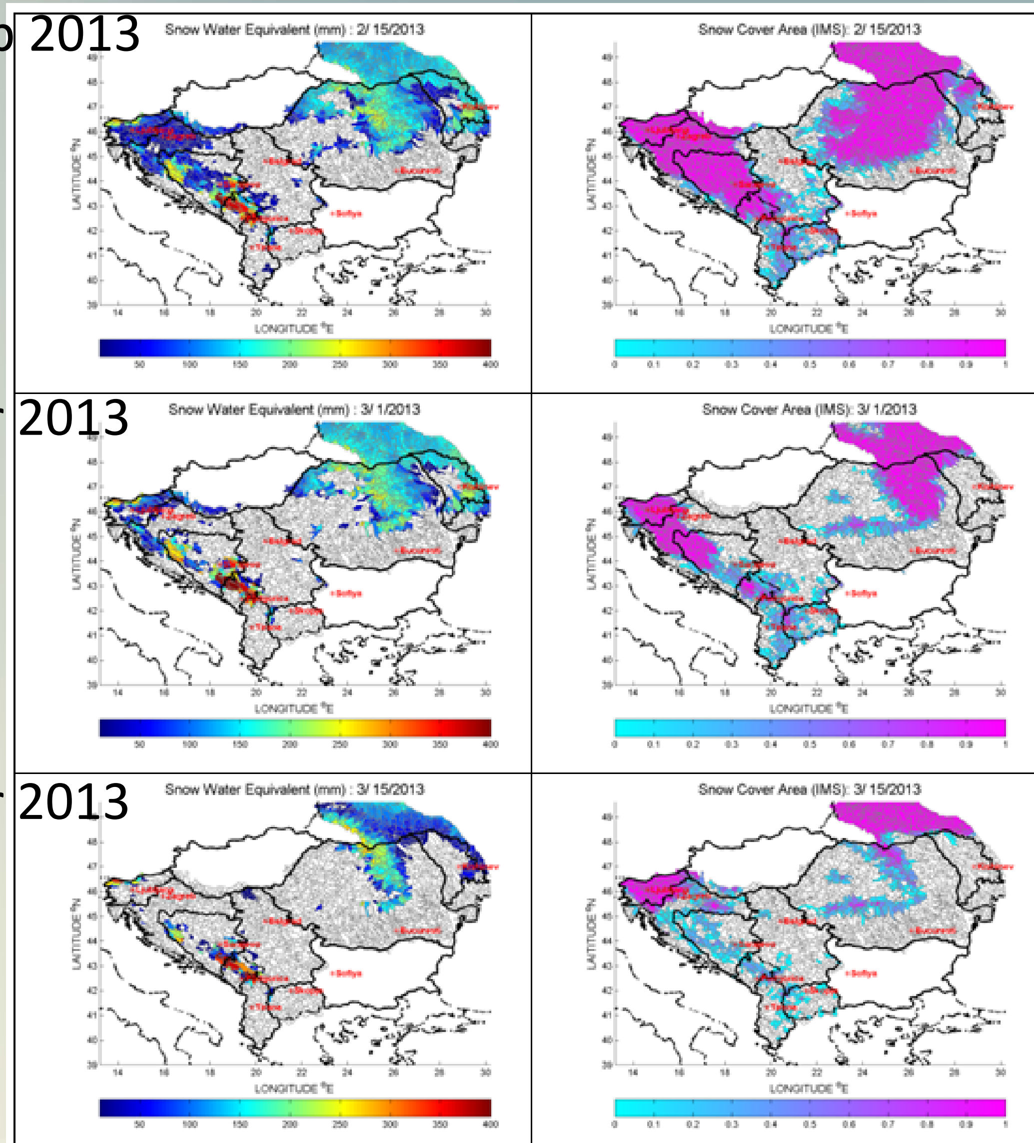
SNOW-17 Output

Comparison of SWE (mm) with Snow Cover Extent from NOAA IMS Satellite Product

15 Feb 2013

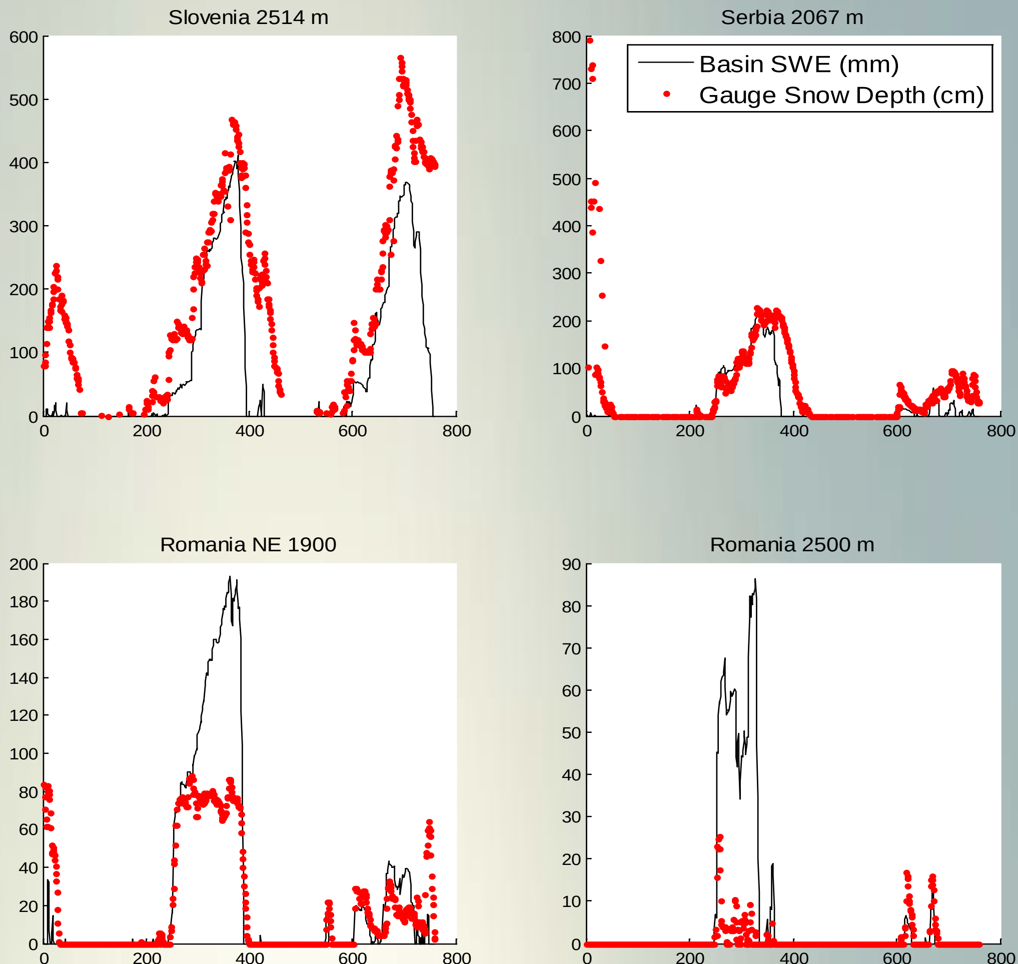
01 Mar 2013

15 Mar 2013

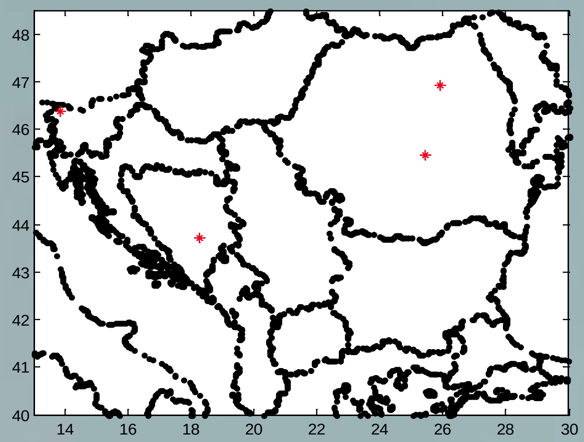


SNOW-17 Output

Comparison of SWE (mm) with observed Snow Depth Measurements



1 April 2012 -30 April 2014



Surface Temperature Input (MAT)

Computation from:

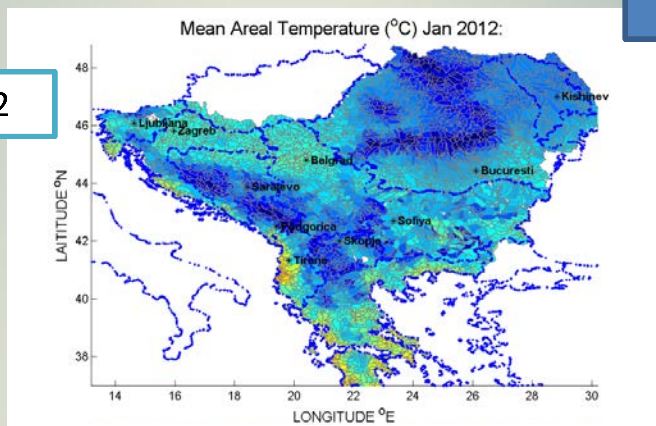
- Surface gauges
- Climatology
- GFS foreast

Gauge → Surface Temperature MAT

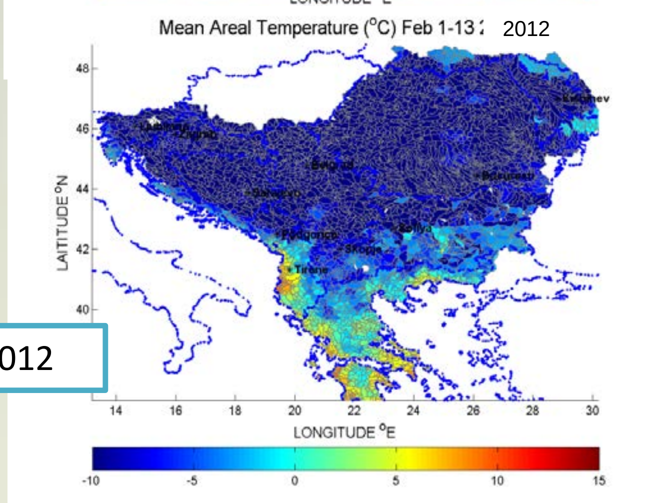
GFS → Surface Temperature MAT

Climate → Surface Temperature MAT

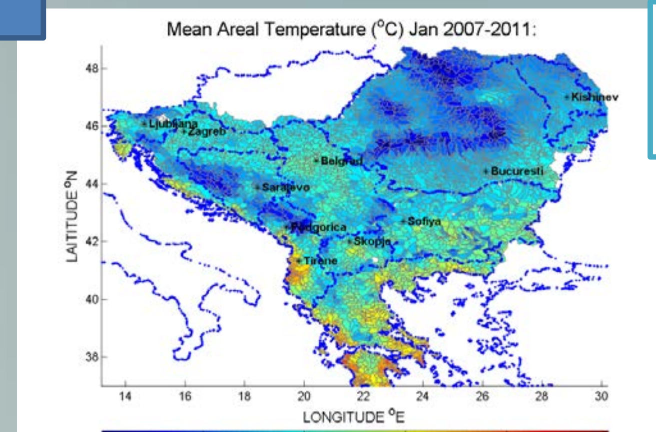
Jan 2012



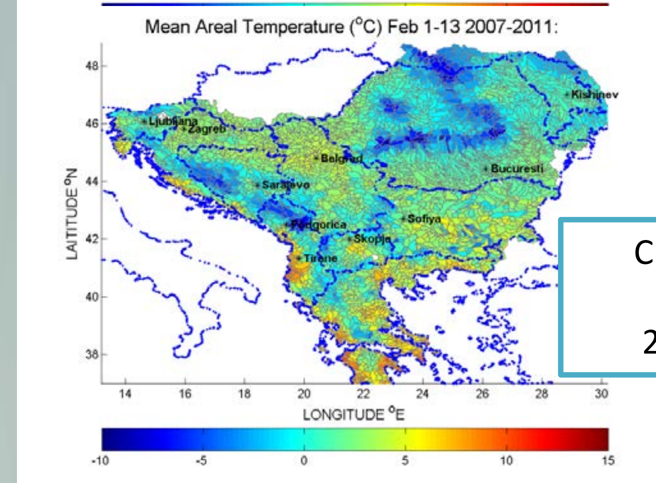
1-13 Feb 2012



Climatology Jan 2007-2011

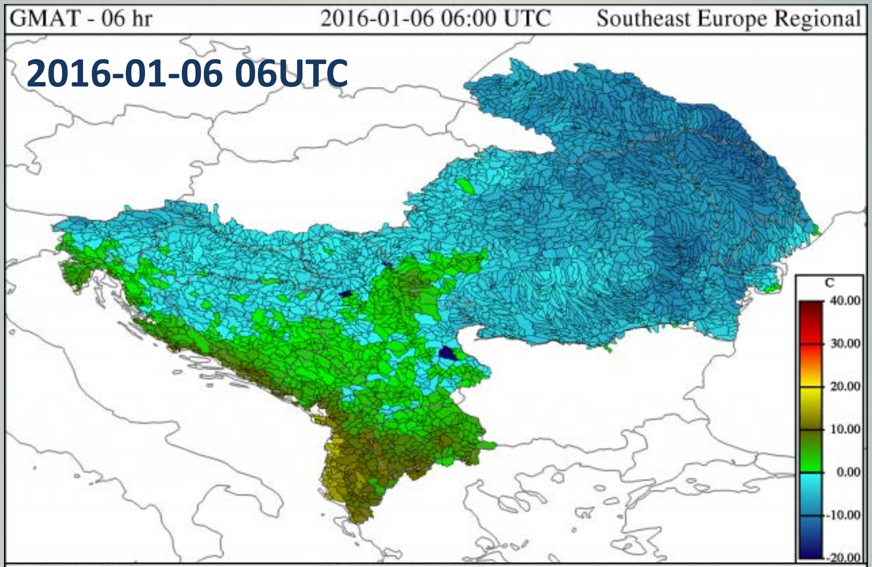


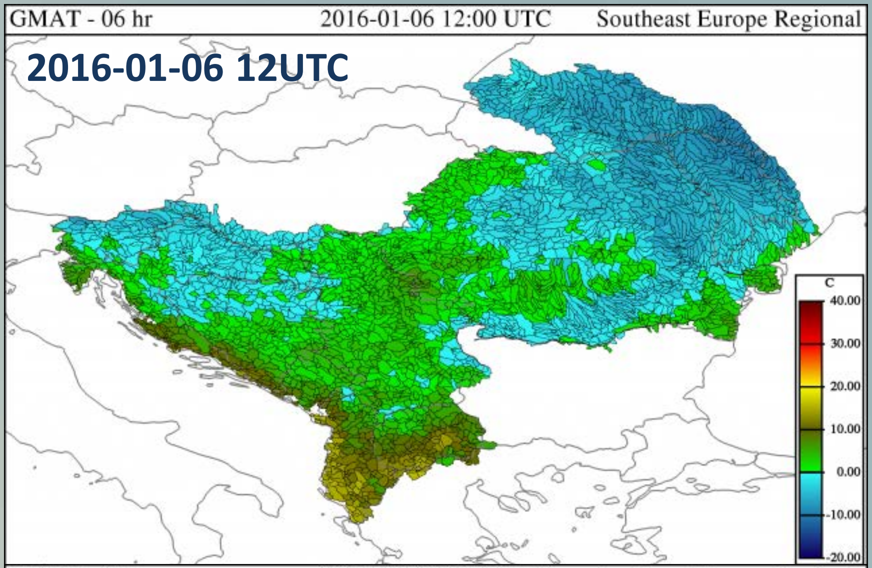
Climatology 1-13 Feb 2007-2011

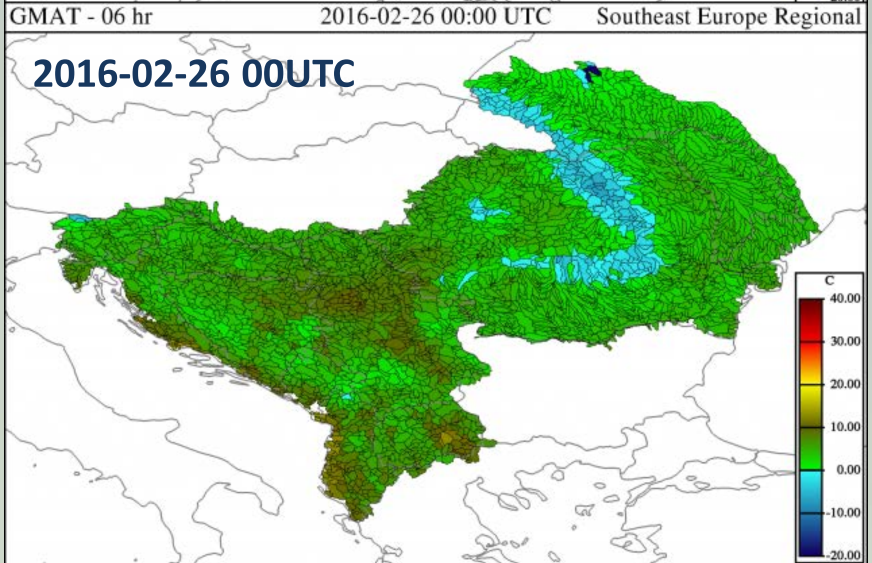


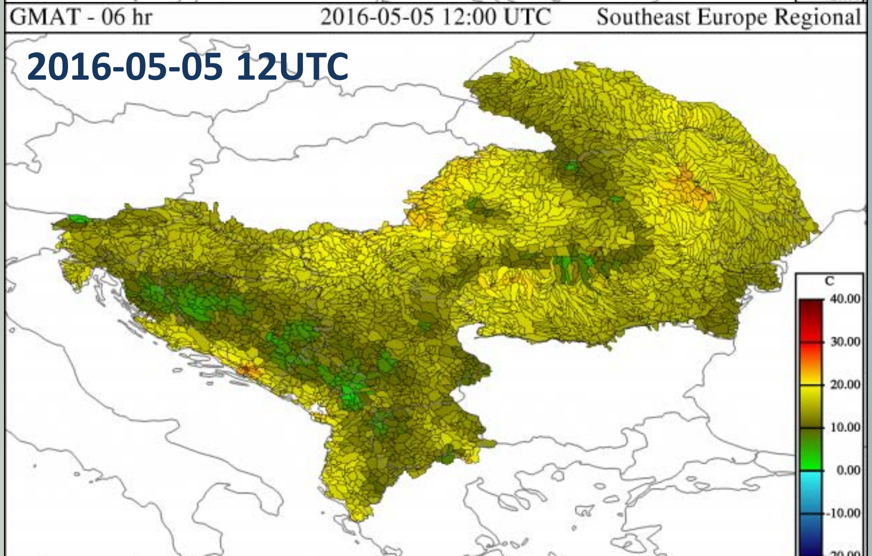
SEEFFG Snow Product (MAT)

❖ Updated every 6-hours





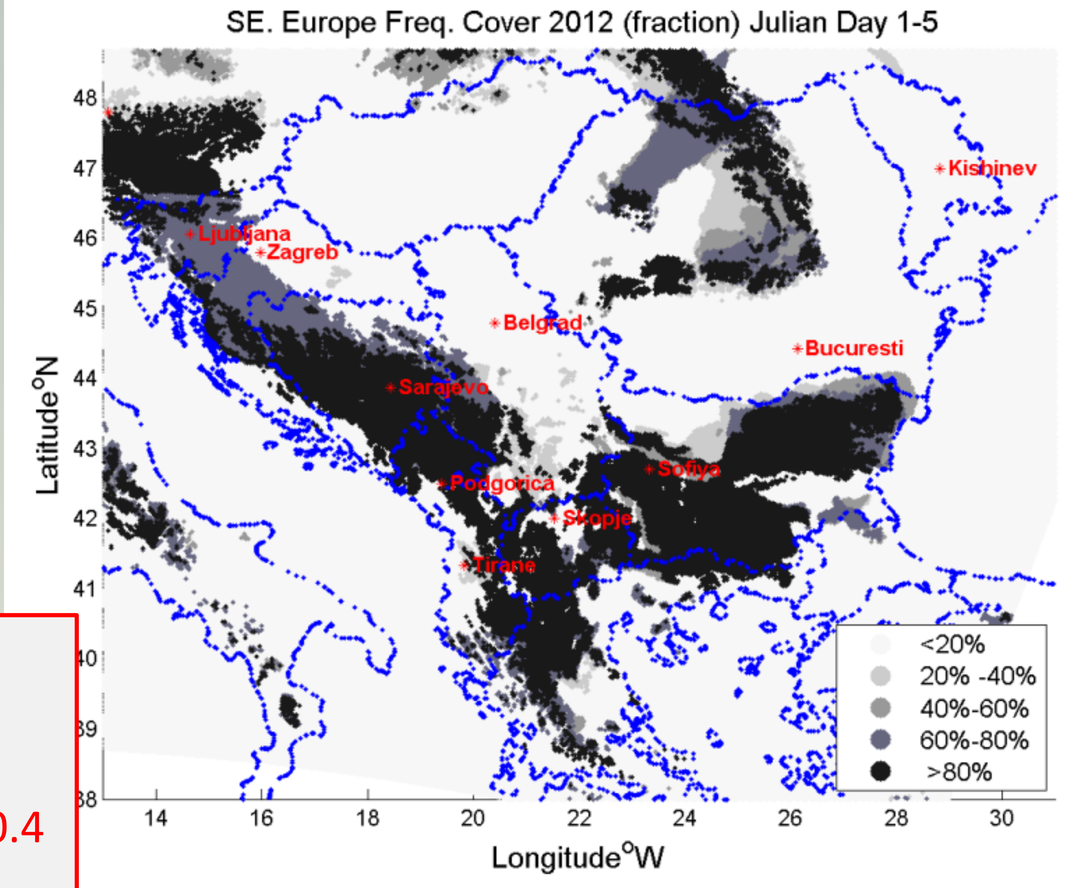




Satellite Snow Covered Area

❖ SEEFFG System ingests snow cover information from Interactive Multisensor Snow and Ice Mapping System (IMS) (NOAA)

- 1km x 1 km snow covered area (since 2014)
- 4km x 4km snow depth
- Available within 1 day
- Multiple satellites
- Helfrich et al, 2007 (Hydro. Processes)

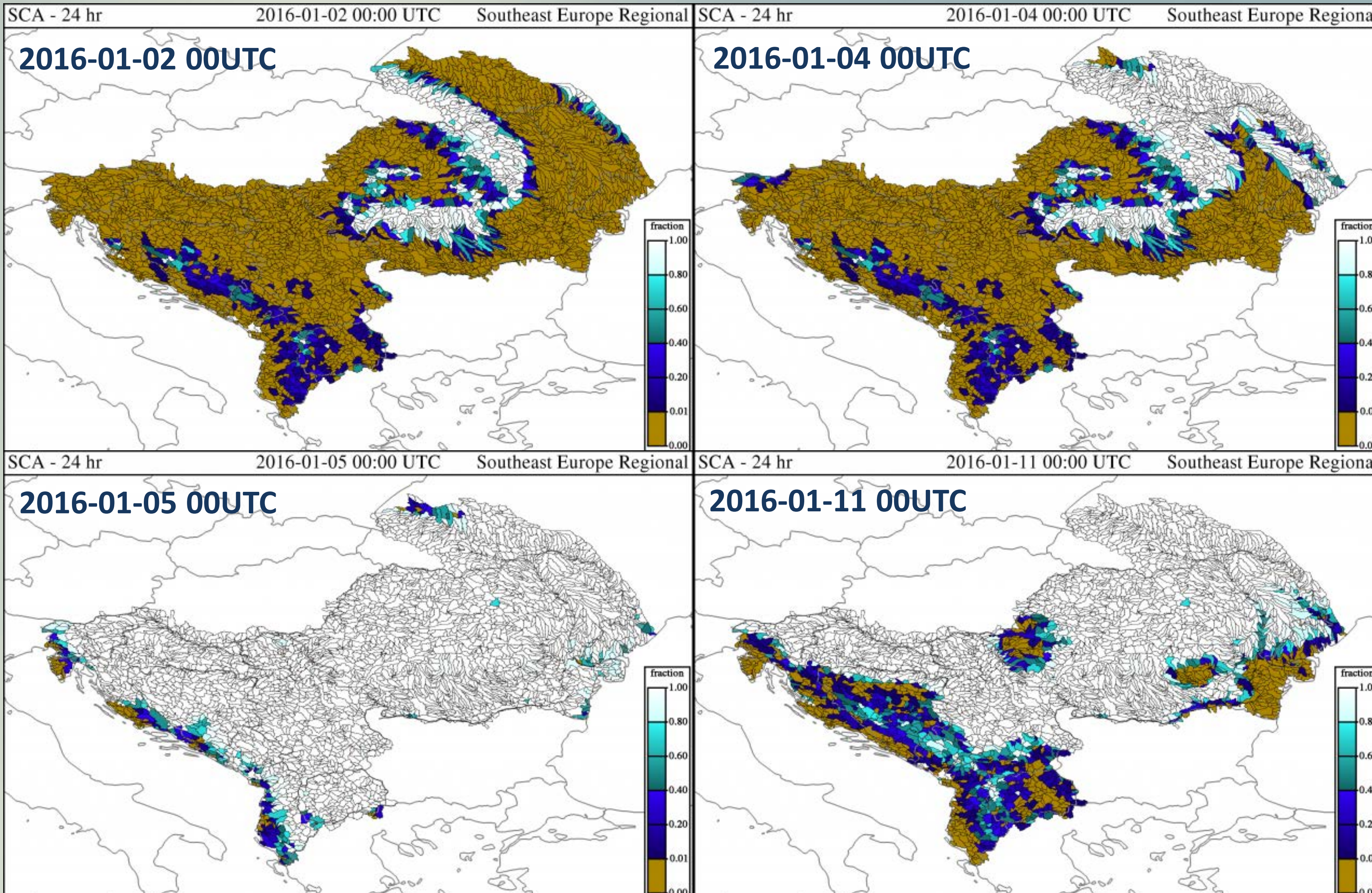


Imposed conditions:

- FFG is *not* computed for basins with SCA > 0.4
- Input = (Rain+Melt)*(1-SCA) for SCA < 0.4

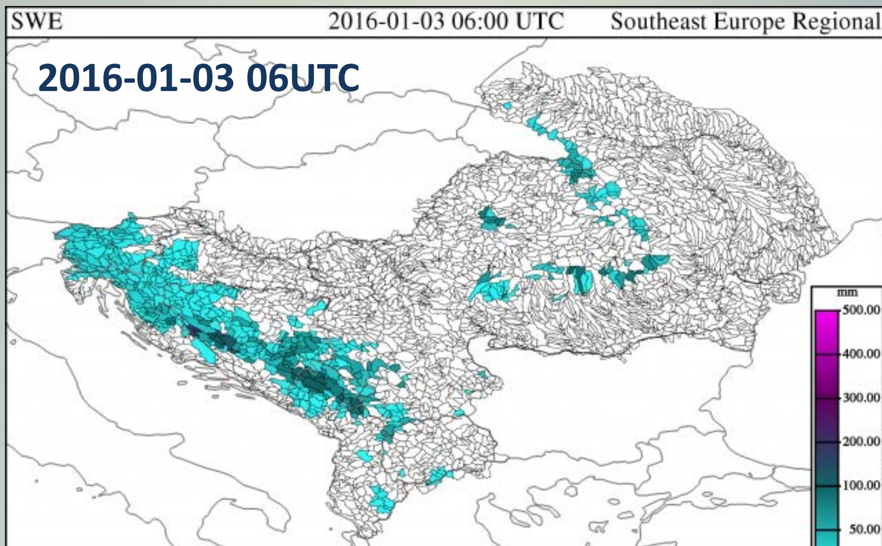
SEEFFG Snow Products: SCA

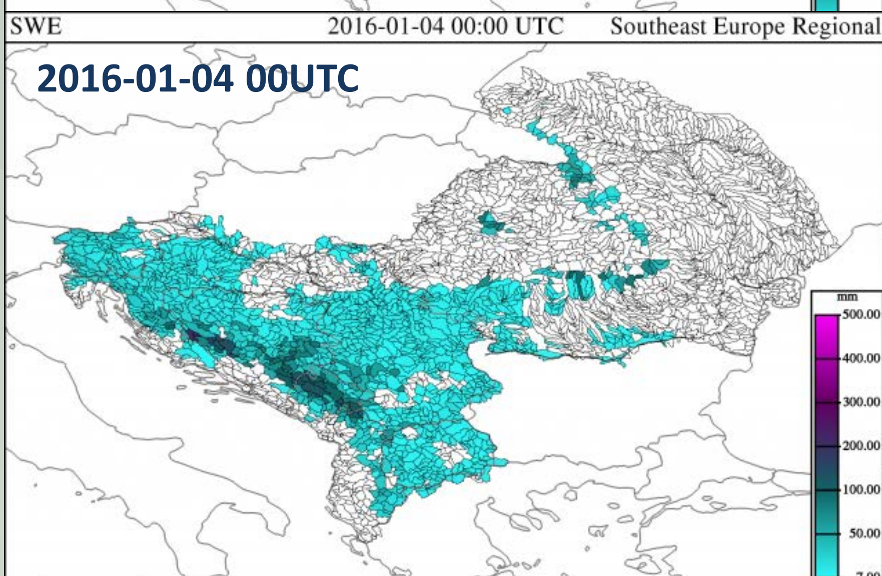
- Updated every 24-hours



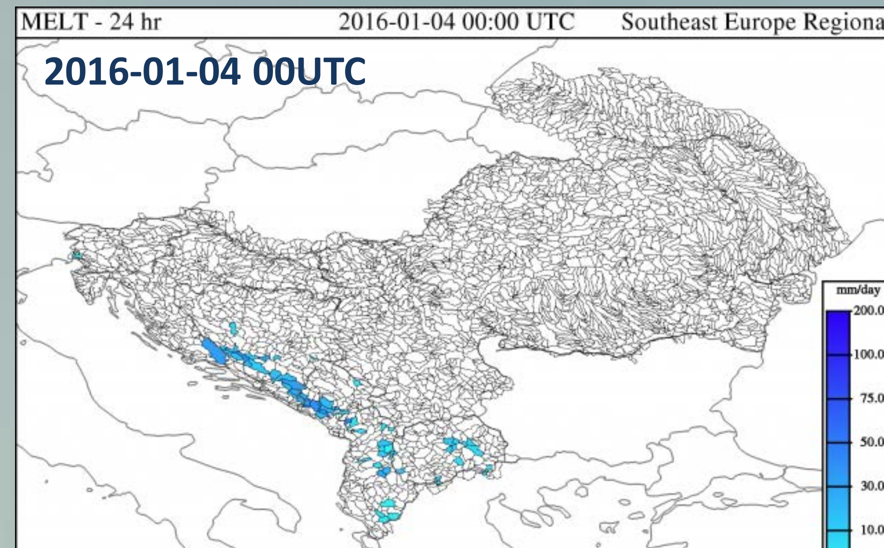
SEEFFG Snow Products: SWE & Melt

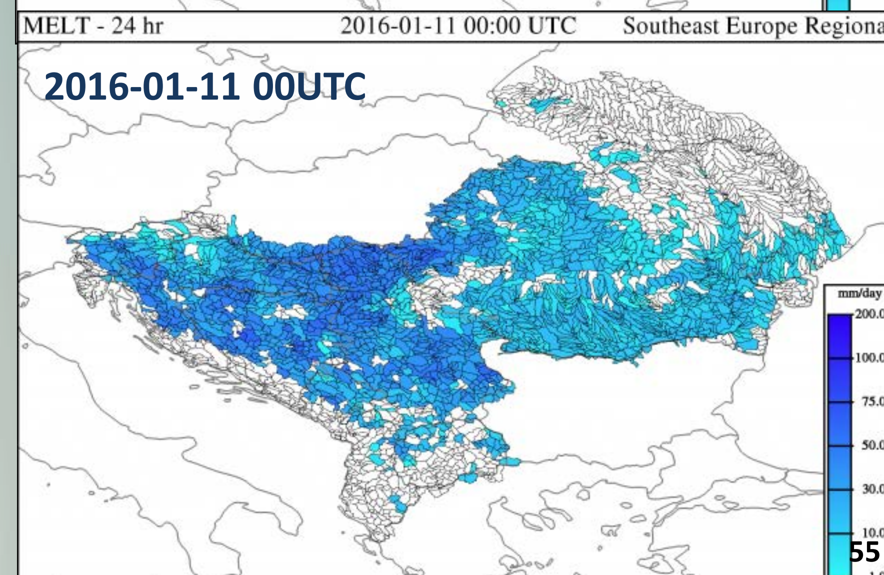
❖ SWE – updated every 6 hours



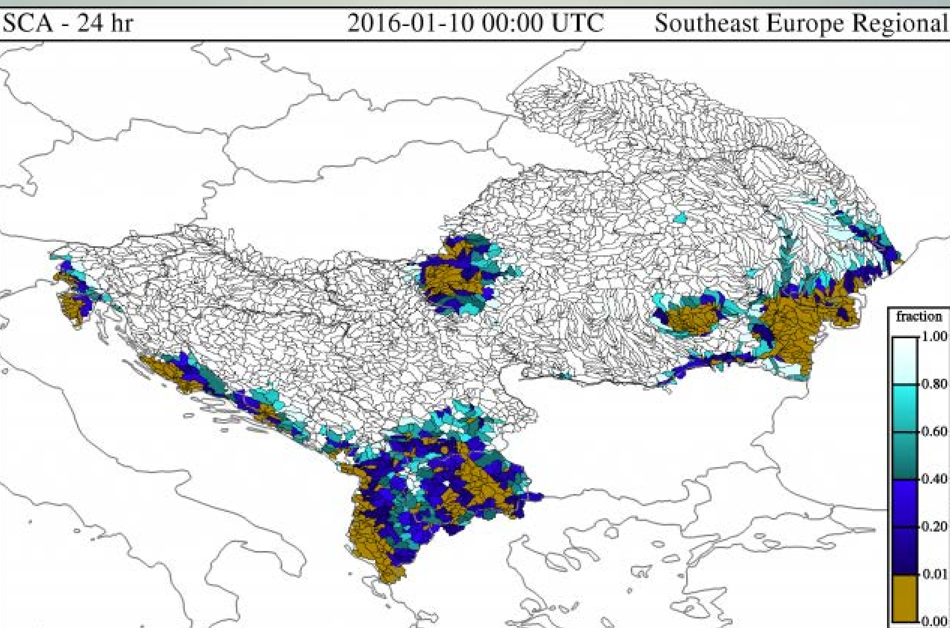


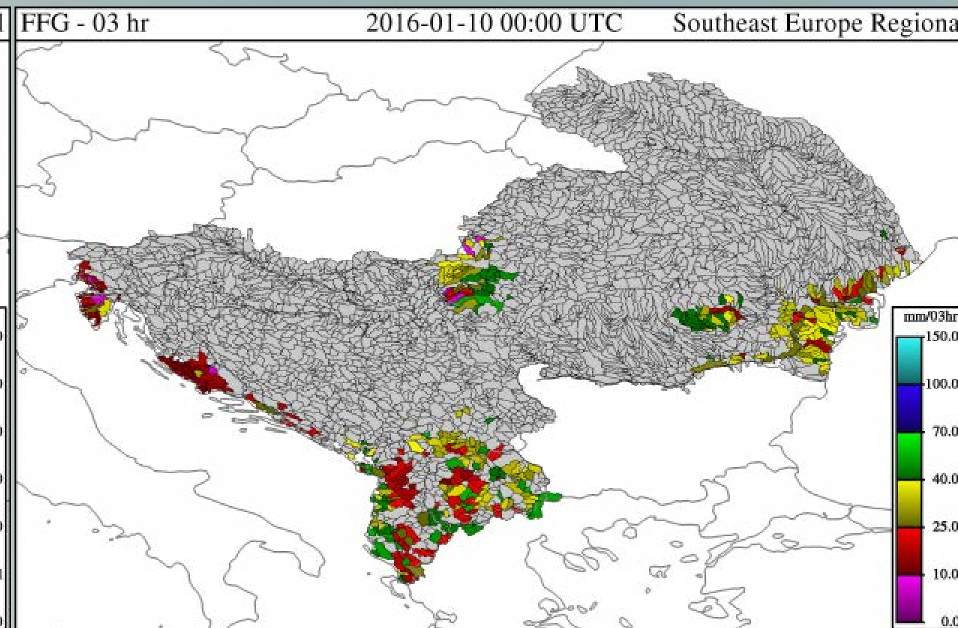
❖ MELT – computed every 24 / 96 hours

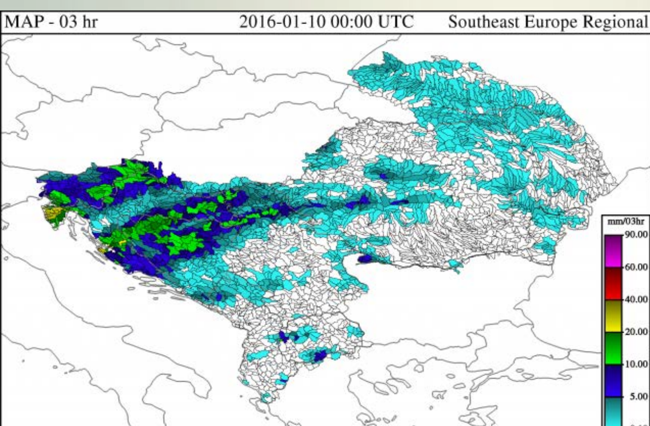


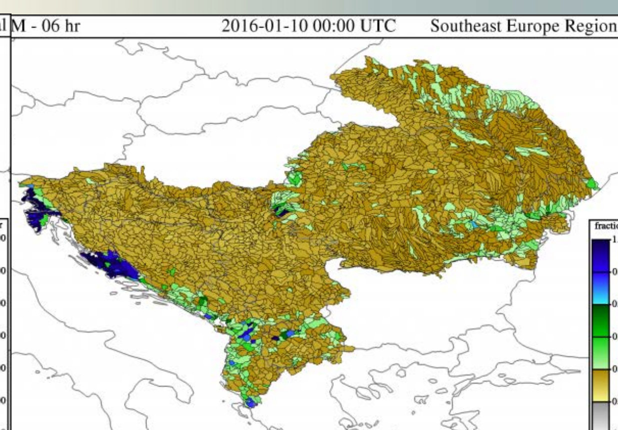


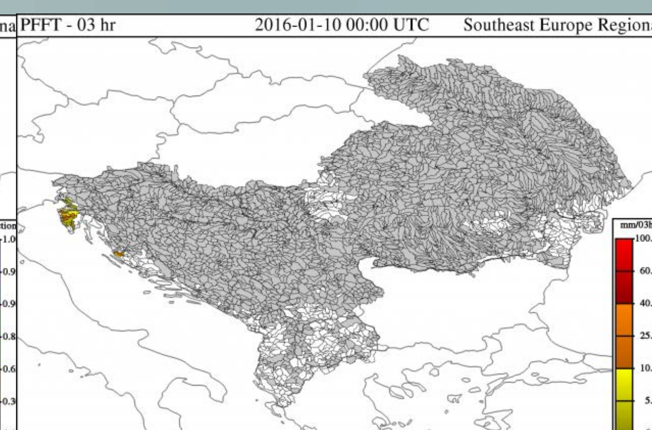
Example of SCA on FFG Calculation



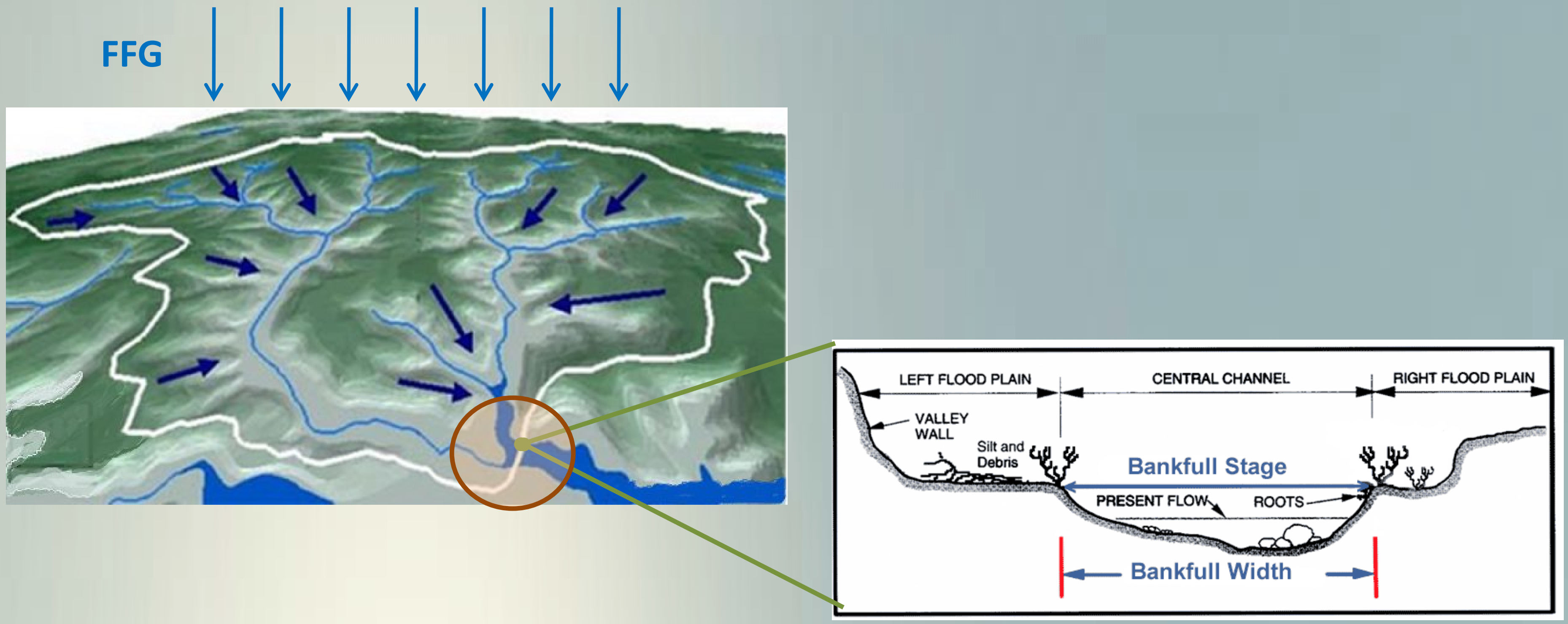








Review of Technical Background
4. Flash Flood Guidance and Flash Flood Threat Products



Flash Flood Guidance (FFG): The amount of **rainfall** of a given duration and over a given catchment that is just enough to cause **flooding conditions** at the outlet of the draining stream

Relationship of Threshold Runoff, Soil Moisture & FFG

*Threshold Runoff is a characteristic (non-varying) of the watershed. This is a **one-time** calculation for a given watershed.*

TR is computed for:

Rainfall durations of 1-, 3-, and 6-hours.

*FFG is computed on a **real-time** basis considering up-to-date soil water content. Soil water content greatly influences FFG.*

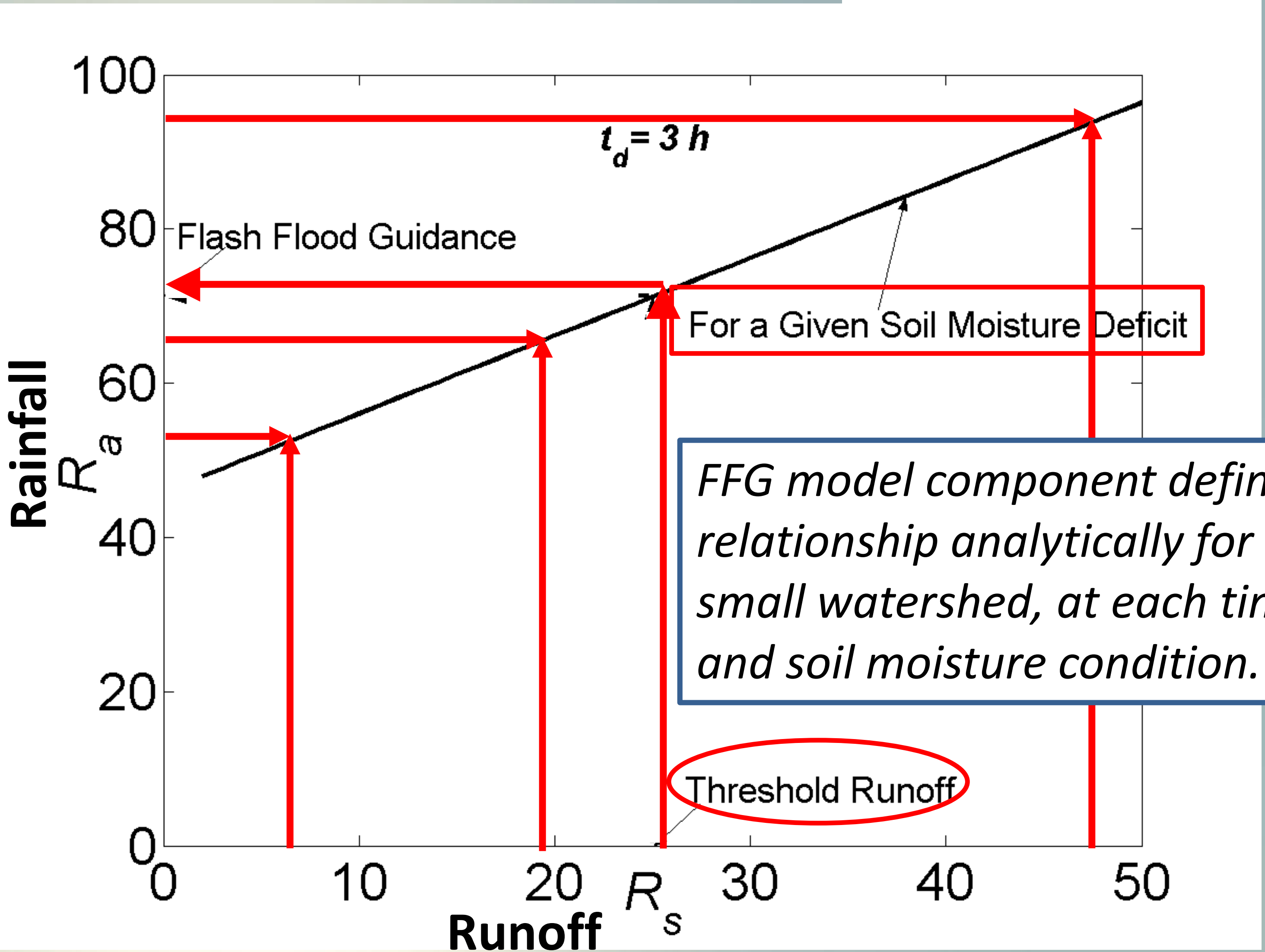
FFG is updated:

every 6-hours and for rainfall durations of 1-, 3-, 6-hours.

Relationship of Threshold Runoff to FFG

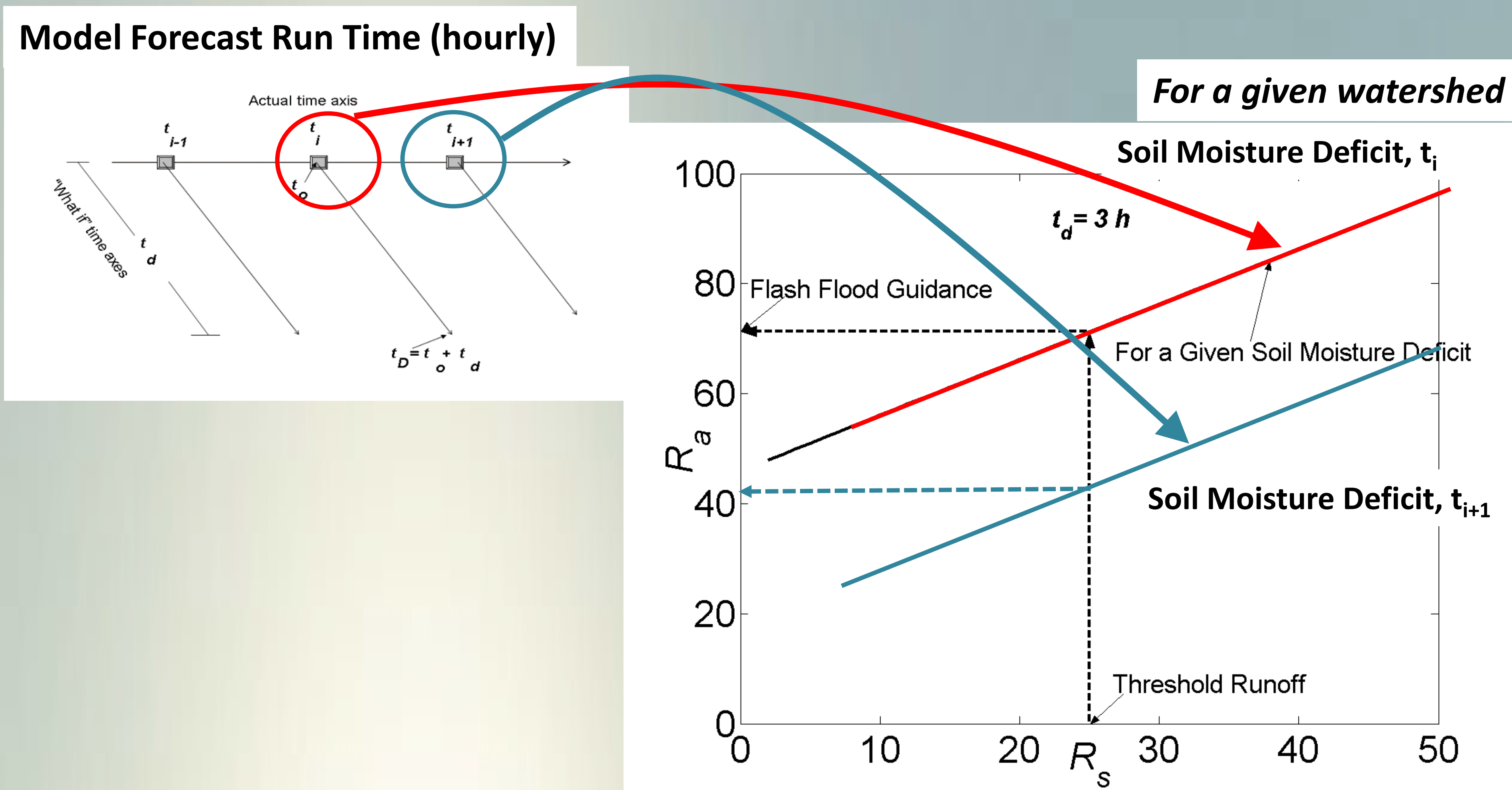
A) "What if" scenario

For a given watershed



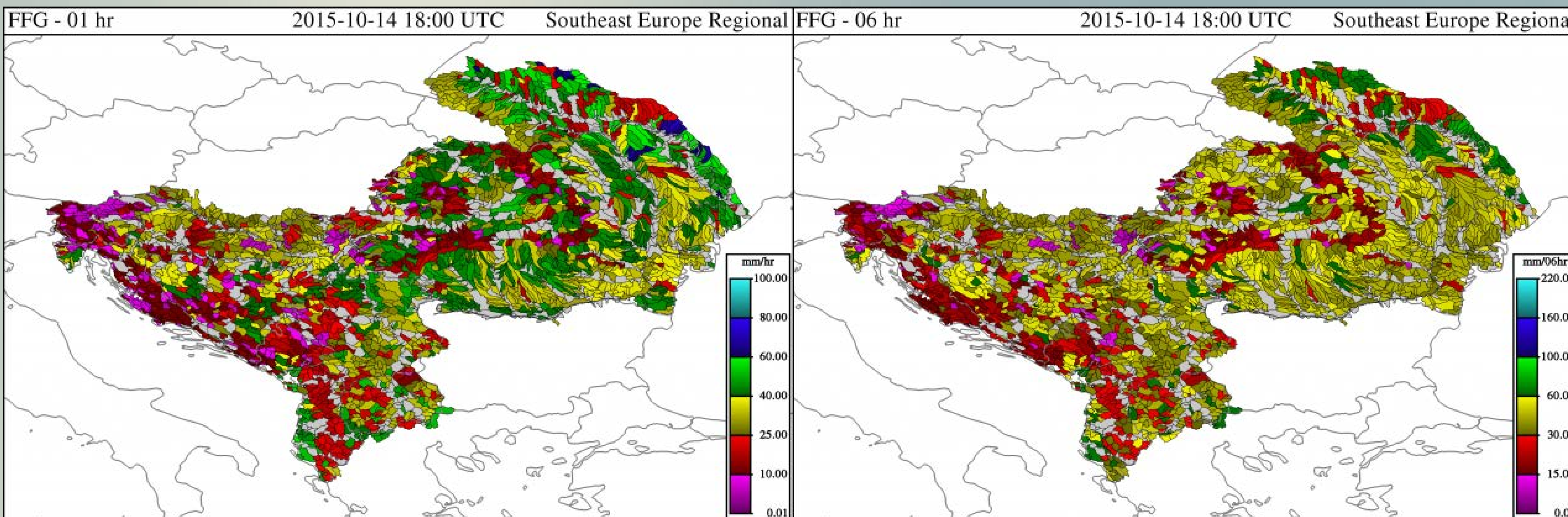
FFG model component defines this relationship analytically for each small watershed, at each time step, and soil moisture condition.

From Threshold Runoff and Soil Moisture to FFG



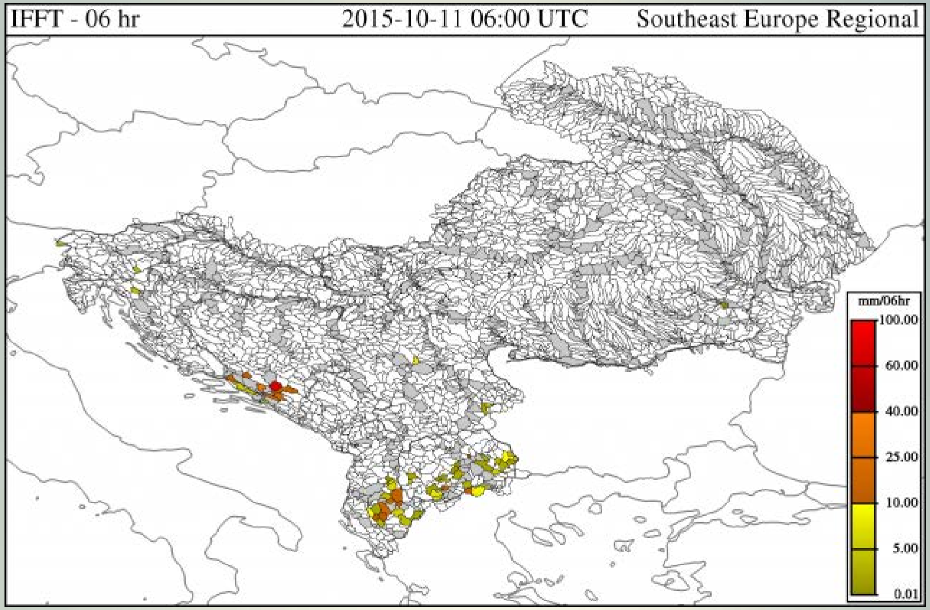
FFG Products

FFG is computed for 1-, 3-, and 6-hour rainfall durations and updated every 6 hours.



Flash Flood Threat Products

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



Flash Flood Threat, FFT, defined:

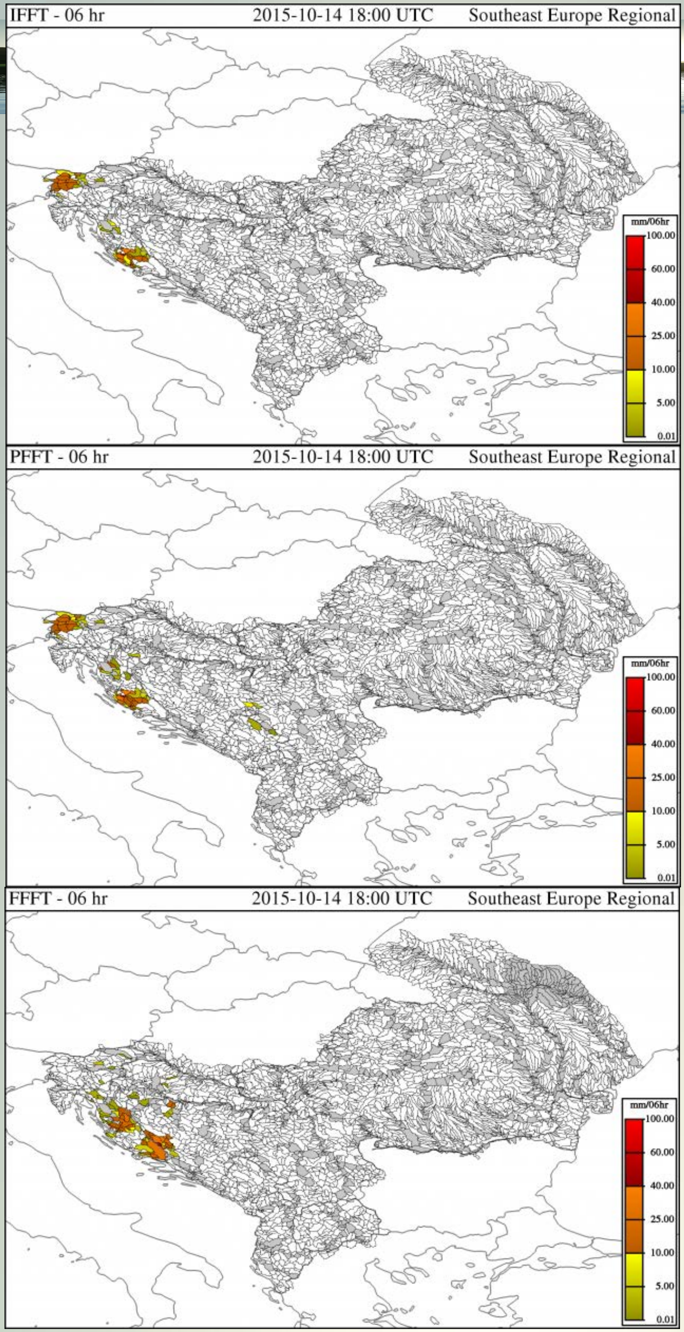
FFT = MAP - FFG

FFT provides indication of regions of potential concern.

Color bar provides magnitude of FFT.

Like FFG, FFT products are computed for 1-, 3-, and 6- hour durations and updated every 6 hours.

Flash Flood Threat Products



IFFT: Imminent

- based on *observed* precipitation (merged MAP) and prior FFG
- Flash flooding may be occurring!

PFFT: Persistence

- most recent *observed* precipitation (merged MAP) and current FFG
- forecast of persistence: *IF* rainfall continues at current rate

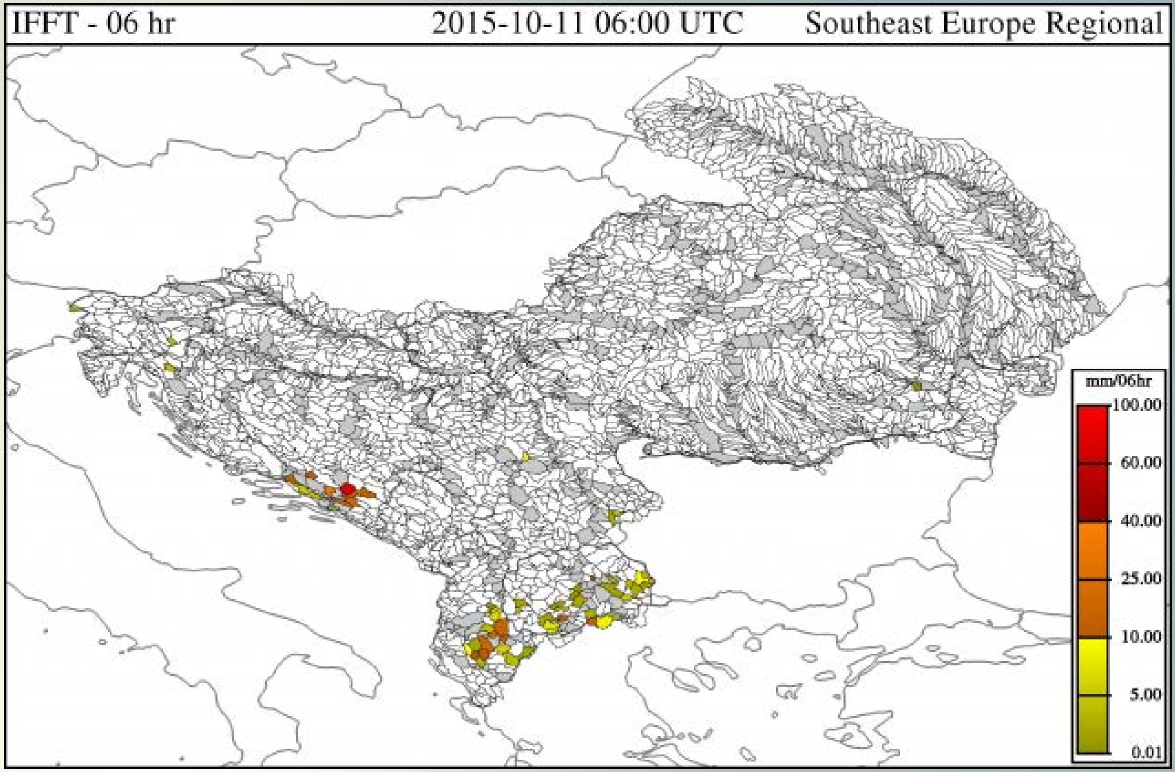
FFFT: Forecast

- based on *forecast* precipitation (FMAP) and current FFG
- Forecaster must evaluate in FMAP

Flash Flood Threat Products

*FFT products are *__not__* intended to be the forecast.*

Rather, these are indicators of regions of potential concern that the forecaster should review.




THANK YOU