Precipitation, Soil Moisture, Snow, and Flash Flood Guidance Components

HYDROLOGIC RESEARCH CENTER

6 May 2015
Flash Flood Basin Delineation

*GIS processing of digital elevation data to delineate small flash flood watershed areas and determine basins characteristics (A, L, S)*

- SRTM 90-m DEM
- GRASS GIS software
- Minimum headwater stream size threshold defines basin size: targeted average area of ~150km²
BSMEFFG Basin Delineation

- Multiple processing windows
- Large rivers omitted/treated as “sink”
- Major lakes and evaporative pans
- Statistics with high resolution basins
  - A total of nearly 16,000 basins
  - A total of nearly 11,000 basins in Turkey
  - Average subcatchment basin area:
    - $\approx 250 \text{ km}^2$ (outside of Turkey)
    - $\approx 65 \text{ km}^2$ (inside of Turkey)
Key Technical Components for the FFG System
### SEEFFG - Southeast Europe Flash Flood Guidance System

**Current Date:** 2015-03-30 13:10 UTC  
**Next Date:** 2015-03-30 18:00 UTC  
**Year:** 2015  
**Month:** March  
**Day:** 30  
**Time:** 13:10 UTC  
**Region:** Regional

**MWGHE Precipitation**  
**GHE Precipitation**

<table>
<thead>
<tr>
<th>DT</th>
<th>Gauge MAP</th>
<th>Merged MAP</th>
<th>ASM</th>
<th>FFG</th>
<th>IFTT</th>
<th>PFFT</th>
<th>ALADIN Forecast</th>
<th>FMAP</th>
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<tr>
<td>01-hr</td>
<td><img src="Image1.png" alt="Image" /></td>
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**Composite Product:** Grid Cell (GSE)  
**Surface Gauge Observation:** 2015-03-30 18:00 UTC

<table>
<thead>
<tr>
<th>Station ID</th>
<th>Station Name</th>
<th>Accumulated Precipitation [mm]</th>
<th>Average Temperature [°C]</th>
<th>5-day Rainfall [mm]</th>
<th>5-day Total [mm]</th>
<th>10-day Rainfall [mm]</th>
<th>10-day Total [mm]</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation</th>
<th>Status</th>
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Satellite Rainfall - Hydroestimator

- IR based (10.7 μm)
- Short latency

Rain Rate = Function of brightness temperature

Enhanced for:
1. Atmospheric moisture effects
2. Orography (upslope/downslope)
3. Convective Eqib. Level (warm-top convection)
4. Local pixel T difference with surroundings
5. Convective core/no-core region
Bias and Log-Bias Factors

\[ \beta_t = \ln \left( \frac{\sum_{j=1}^{N_g} R_g(t, j)}{\sum_{j=1}^{N_g} R_s(t, j)} \right) \]

Bias (B)
Climatological Adjustment Using Gauges and Corresponding Satellite Pixel Data

- Historical Data for regions of uniform hydroclimatology, terrain and gauge density
- Usually done for a given month or season
- Result is bias factor for each region and month/season

Bias Factor computed from:

1. Mean values
2. Probability matching considerations

![Graph showing probability matching and bias factor for Middle East](image)
Dynamic Bias Adjustment Basics

\[ \beta_t = \ln \left( \frac{\sum_{j=1}^{N_g} R_g(t, j)}{\sum_{j=1}^{N_s} R_s(t, j)} \right) \]

\[ \beta_{t+1} = \beta_t + w_{t+1} \]

\[ z_{t+1} = \beta_{t+1} + \nu_{t+1} \]

Kalman Filter
Stochastic Approximations

- N pairs of consecutive values
- At least 20% raingauges with rain
- Conditional Mean > Threshold (mm/h)
  (satellite/radar and gauge)

Important issue:
Gauge data quality control
Multi-Spectral Satellite Rainfall

**HE**

IR – Based
30-min latency in operations
Based on measurements of top cloud brightness temperature

**CMORPH**

MW – Based
18-26 hour latency in operations
Based on measurements of microwave scattering from raindrops

New global FFGS product combines IR-based HE rainfall with MW-based CMORPH rainfall
Multi-Spectral Satellite Rainfall for FFG Systems

Window of 3 days

CMORPH Latency
Examples from BSMEFFG

Original GHE

Adjusted GHE
Rainfall Data Processing

Quality Control
Merging
Bias Adjustment

Real-time Precipitation Inputs
Satellite Rainfall Radar (as available)
Gauge (as available)

Rainfall Forecasts (Mesoscale Model)

Soil Moisture Model

Threshold Runoff Model

Snow Model

Spatial GIS Data Analyses
Basin Delineation Parameter Estimation (Terrain, LULC, soils, streams)
Evapotranspiration (Climatological)

Temperate

Snow Cover

Flash Flood Guidance Model

Flash Flood Threat

Forecaster Input

Key Technical Components for the FFG System
Soil Water Index Model: Combined Runoff - Sacramento Model Adaptation

Soil water index model:
- Saturation excess runoff
- Infiltration excess runoff
- Combined runoff

Soil Water: Depth Integrated Soil Moisture
On Site Soil Water Deficit Validation

Illinois River (Semi-Arid US)

Westville, OK Site

HRC-DHM Closest Sub-Basin Average

Reasonably good reproduction of depth-integrated soil water deficit
Average Soil Moisture (Water)

\[ \text{ASM} = \frac{\text{XT} + \text{XF}}{\text{XTo} + \text{XFo}} \]
A priori parameter estimation

Harmonized soil

Soil Texture and Hydraulic Properties

6 May 2015

HRC CAR 15
Jensen-Haise: PET - Radiation based method with 2 parameters

Pertinent References:
Jensen & Haise 1963
McGuinness & Bordne 1973
Oudin et al 2005 J. Hydrology:

For basin scale hydrologic models, PET procedures that are based on extraterrestrial radiation and climatic surface temperature outperform complex models (e.g., Penman).

Potential Evaporation in a given location (mm/day):
\[ PE = \frac{[\text{Re} \cdot \text{Ta} + \text{K2}]}{\text{K1}(\lambda \cdot \rho)} \]
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)
- K1 (°C) – minimum temperature in which below PE=0 (~5)
- K2 (°C) – scale parameter (75-130)
- λ – Latent heat flux (Mj kg\(^{-1}\))
- ρ – density of water (kg m\(^{-3}\))
Kazakhstan Land Cover Map
PET Climatological Estimate

15 January

15 April

15 July

15 October
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)
  - \( Q_e \) = latent heat transfer
  - \( Q_h \) = sensible heat transfer
  - \( Q_g \) = heat transfer at snow-soil interface
  - \( Q_m \) = heat transfer by mass changes (e.g. advected by rain)
  - \( \Delta Q \) = change in heat storage of snow cover

\[ \begin{align*}
Q_n &= f(Q_{swr}, Q_{lw}, A, T_0) \\
Q_e &= f(e_o, u_a) \\
Q_h &= f(T_o, T_a, u_a) \\
Q_g &= f(T_g, T_s) \\
Q_m &= f(p)
\end{align*} \]

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
Data Requirements

• Surface Air Temperature
  – Index for the pack energy balance and determine the form of precipitation (rain or snow)

• Precipitation
  – determine amount of snowfall and amount of rain-on-snow (PXTEMP)
  – SCF - Multiplying factor that adjusts precipitation data for gage catch deficiencies during periods of snowfall

• Other Data (when available)
  – Snowfall
  – Snow course and/or snow sensors (water-equivalent)
  – Areal extent of snow cover (satellite)
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 (23:00 GMT) snow cover based on summary of multiple satellites at 4km x 4km resolution.
  - Geostationary satellites
  - Polar orbiter: MODIS, AVHRR & Microwave
  - Assisted by modeling, climatological maps, and personnel expertise
- Generally available within 1 day (often within several hours) following date of observation
- 4km product is Operational since 2006

- Helfrich et al., 2007 Hydrological Processes
Use of Snow Cover in BSME

- Based on fraction of snow covered area in each subbasin
  - Apportion the rain for the uncovered areas
  - Soil-snow interface leakage at the snow cover areas
  - Rain for the FFT calculations is portioned to the uncovered areas

Sub-Basin Snow Cover Area Fraction

![Map showing雪覆盖区域](image-url)
Comparison between April outlook for 2012 and 2013
Time Series from Specific Basins

Georgia 2006700402

Cumulative Net (mm per 4 days)

0 50 100 150 200 250 300
0 Mar 01 Apr 15 Apr 01 May

6-Hour - Starts at 20 March 2013

Cumulative Net (mm per 4 days)

0 200 400 600
0 Mar 01 Apr 15 Apr 01 May

6-Hour - Starts at 20 March 2013

Cumulative Net (mm per 4 days)

0 50 100
0 Mar 01 Apr 15 Apr 01 May

6-Hour - Starts at 20 March 2013

Cumulative Net (mm per 4 days)

0 500 1000
0 Mar 01 Apr 15 Apr 01 May

6-Hour - Starts at 20 March 2013

Turkey SE -2005101042

Cumulative Net (mm per 4 days)

0 500 1000
0 Mar 01 Apr 15 Apr 01 May

6-Hour - Starts at 20 March 2013

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MODIS/LST for Surface Temperature
[NASA funded Research]
MODIS/Terra 8day LST vs. SCA 2000-2014

6 May 2015
HRC CARFFG
Theory of Threshold Runoff Estimation

Following Carpenter et al (1999), under a linear response of basins to rainfall excess, threshold runoff may be calculated under the following equality:

\[ Q_p = q_{pR} R A \]  \quad (1)

- \( Q_p \) is the flow associated with flooding flow (cms)
- \( q_{pR} \) is the peak of the unit hydrograph of duration \( t_R \), normalized by catchment area (cms/km\(^2\)/mm)
- \( A \) is the catchment area (km\(^2\))
- \( R \) is \( t_R \)-hr threshold runoff (mm)
Theory of Threshold Runoff Estimation

Options to estimate parameters of threshold runoff (R):

(a) Flooding Flow, \( Q_p \)
   - Bankfull Flow (Manning’s uniform flow; uses channel cross-section)
   - Flow with given return period (statistical)

(b) Unit hydrograph response, \( q_{pR} \)
   - Synthetic Unit Hydrograph (empirical)
   - Geomorphologic Instantaneous Unit Hydrograph (physical properties)

\[
R = f(A, L, B_b, D_b, S_c)
\]
From Threshold Runoff and Soil Moisture to Flash Flood Guidance

Soil Water Model Runs

Actual time axis

forecasts of 3 - 6 hrs

Flash Flood Guidance

For a Given Soil Moisture Deficit

Threshold Runoff

$t_d = 3 \text{ h}$
FFG Uncertainty for Soil Wetness Conditions

Dry Conditions

Wet Conditions

3-hrs Actual Rainfall Volume (mm)