

# **The Importance of Snowmelt Runoff Modeling for Sustainable Development and Disaster Prevention**

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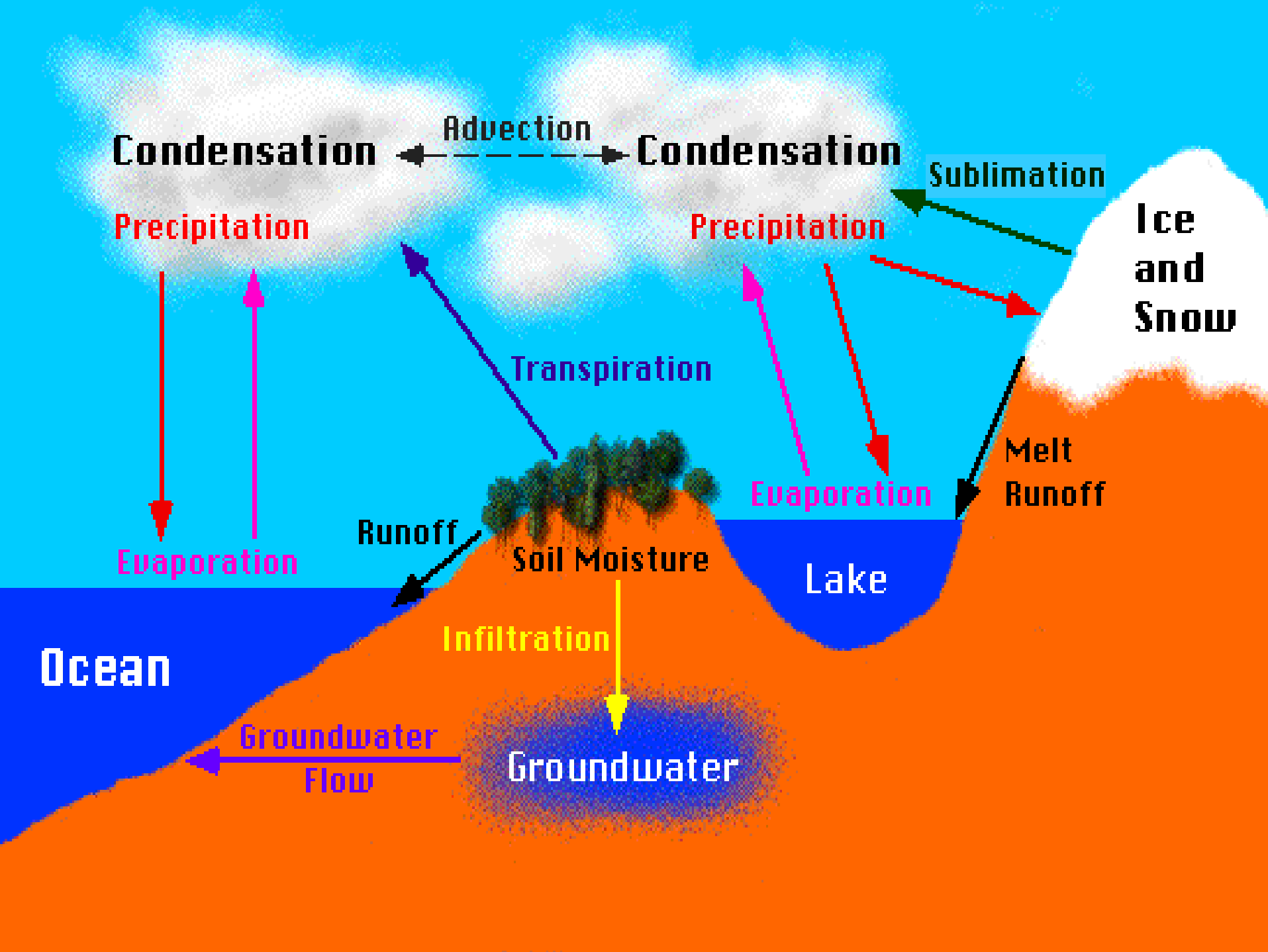
# Water

## H<sub>2</sub>O

- Gas - Water Vapor
- Liquid - Rivers and Oceans
- Solid – Ice and Snow

Very strange substance (38 anomalies)

- Water shrinks on melting
- Hot water freezes faster than cold (clustering)



**Condensation**

Advection

**Condensation**

Sublimation

**Ice and Snow**

**Precipitation**

**Precipitation**

Transpiration

Melt Runoff

**Evaporation**

Runoff

Soil Moisture

**Evaporation**

Lake

**Ocean**

Infiltration

Groundwater

Groundwater Flow

# Precipitation

## ➤ Rainfall

- Liquid water
- Produces immediate runoff
- Predictable runoff

## ➤ Snowfall

- Crystalline water
- Delayed runoff
- Difficult to predict



# Why snowmelt runoff modeling?

➤ Drinking water supply



# Why snowmelt runoff modeling?

## ➤ Flood control structures



# Why snowmelt runoff modeling?

## ➤ Irrigation



# Why snowmelt runoff modeling?

➤ Hydropower generation



# Why snowmelt runoff modeling?

## ➤ Reservoir management



# Types of models

- Physical models
  - Based on strict physical laws
  - Mass and energy balance
  - Accuracy is high
- Conceptual Index models
  - Empirical relationship to approximate mass balance
  - Requires less parameters

# Physical Models

- SNTHERM - US army corps CRREL
- LSM (land surface model)
- VIC (variable infiltration capacity) - U Washington
- WATCLASS (Watflood/class) - Env. Can
- SHE (Systeme Hydrologique Europeen)  
physically based, distributed, continuous
- Streamflow and sediment simulation, Abbott et al.

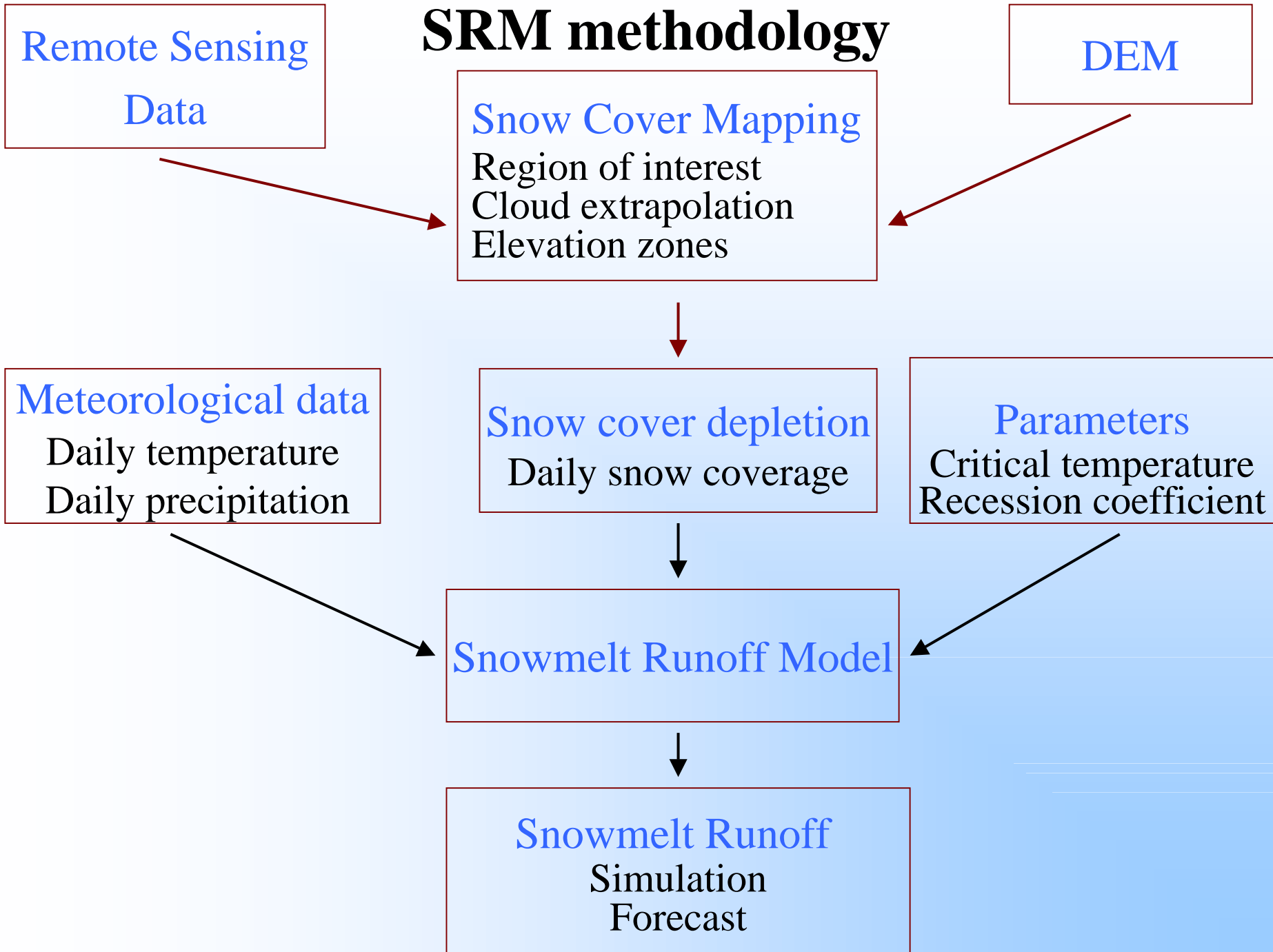
# Conceptual Index Models

- **SRM (Snowmelt Runoff Model) - USDA**
- PRMS (precipitation runoff modeling system) - USGS
- SLURP (simple lumped reservoir) - Env. Can.
- UBC Watershed Model
- TOPMODEL (hydrologic simulation model) - Beven

# Snowmelt Runoff Model

- Developed by Martinec
- Estimation of daily stream flow in Mountain basins
- Degree-day model (temperature)
- Applied in 25 countries for more than 80 basins
- Simple and Efficient

# SRM methodology



# SRM parameters

- Temperature (meteorological data)
- Precipitation (meteorological data)
- Daily Discharge
- Snow covered area (Remote Sensing data)
- DEM (topo map)

# Heart of the model

$$Q_{n+1} = [C_{sn} \cdot a_n (T_n + \Delta T_n) \cdot S_n + C_{rn} \cdot P_n] \frac{A \times 10000}{86400} \cdot (1 - k_{n+1}) + Q_n \cdot k_{n+1}$$

**Q = average daily discharge [m<sup>3</sup>s<sup>-1</sup>]**

c = runoff coefficient: losses as a ratio (runoff/precipitation), with c<sub>sn</sub> referring to snowmelt and c<sub>Rn</sub> to rain

a = degree-day factor [cm·°C<sup>-1</sup>·d<sup>-1</sup>] indicating the snowmelt depth resulting from 1 degree-day

**T = number of degree-days [°C·d]**

ΔT = the adjustment by temperature lapse rate [°C·d]

**S = ratio of the snow covered area to the total area**

**P = precipitation contributing to runoff [cm].** Threshold temperature, T<sub>CRIT</sub>, determines whether this contribution is rainfall or snowfall

**A = area of the basin or zone [km<sup>2</sup>]**

k = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall

**n-number of days**

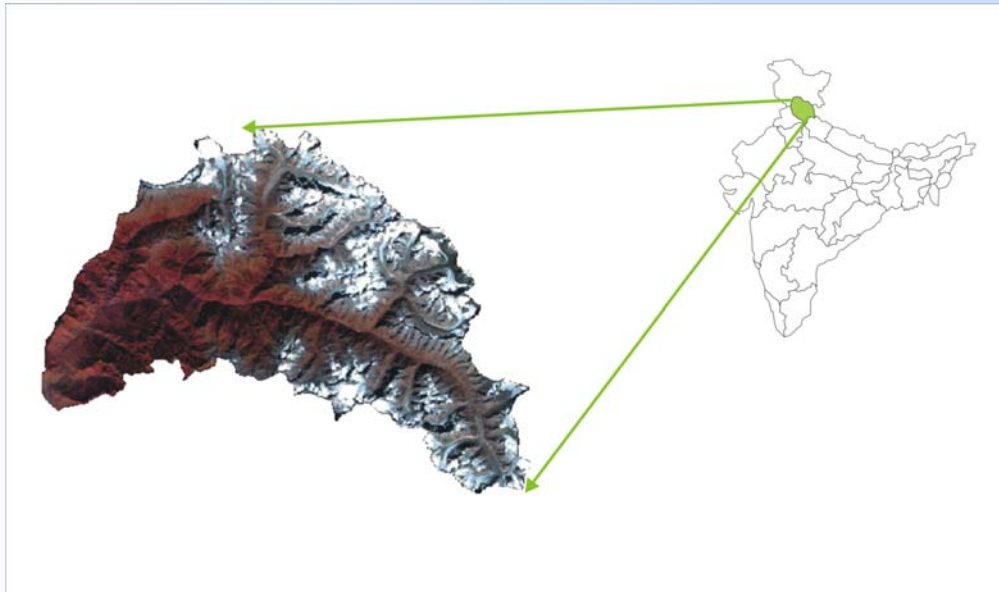
# Parameters

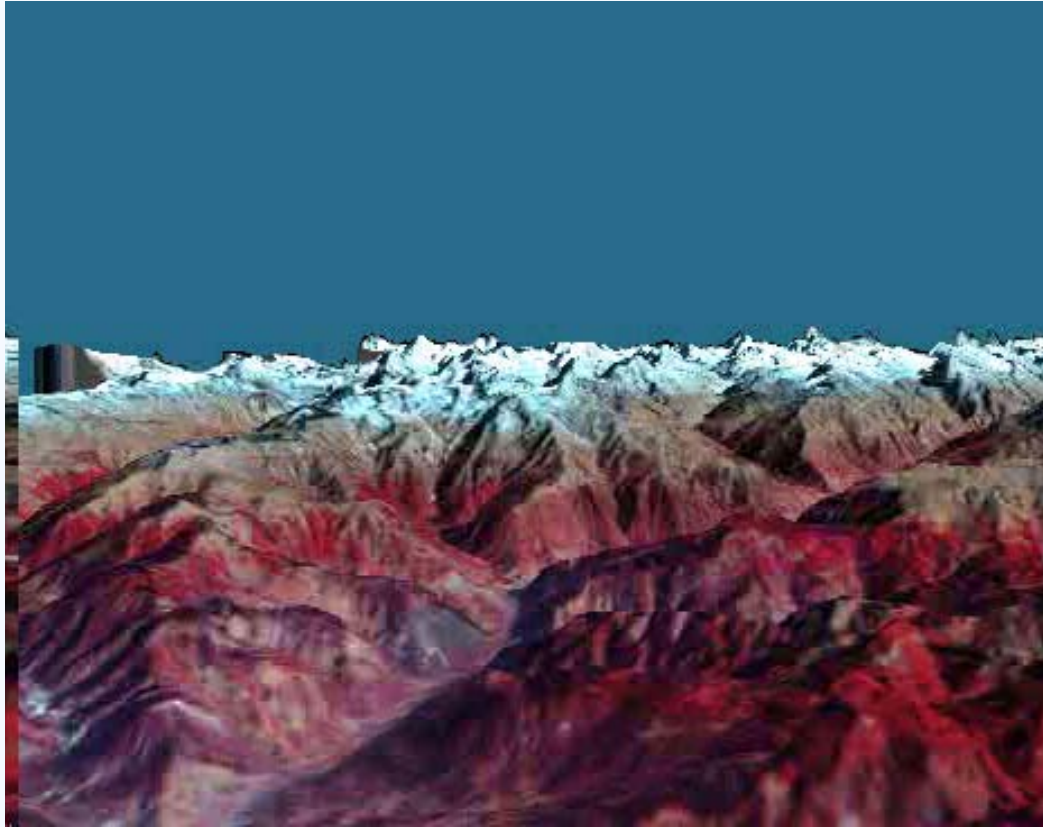
- Runoff coefficient,  $c = \frac{\textit{runoff}}{\textit{precipitation}}$
- Degree day factor,  $a$ 
  - Amount of heat for a 24 hrs with a 1 °C departure from a reference temperature. Converts number of degree-days into snowmelt depth
- Temperature lapse rate,  $\gamma$ 
  - Temperature change with the height
- Critical temperature,  $T_{\text{crit}}$ 
  - Determines whether precipitation is snow or rain
- Rainfall contributing area, RCA
- Recession coefficient,  $k$ 
  - Decline of runoff in a period without precipitation
- Time Lag,  $L$ 
  - Time elapsed between the center of mass of the effective rainfall/snowmelt and the peak of direct runoff

# Case Study

## ➤ Study Area

- Located at Kullu District Himachal Pradesh, India
- Geographical location:  $31^{\circ} 20' - 32^{\circ} 25'$  N, and  $76^{\circ} 55' - 77^{\circ} 55'$  E.
- Total area of the basin is  $1790 \text{ km}^2$ .
- Elevation difference from 800 m. to 6600 m. asl (Tichu Glacier).
- Temperature: min  $T=1^{\circ}\text{C}$ , max  $T=30^{\circ}\text{C}$  (Bhuntar 1000 m asl)
- Annual rainfall approximately 1000 mm (Bhuntar 1000 m asl)

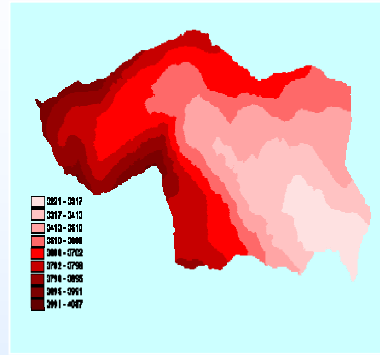




# Methodology



RS data



DEM

Attributes of Hierarchy						
Shape	Area	Area_of	Perim	AcctPerim	MeasurePer	LowerMeasure
PolyLineM	1	2	1	49144.246	3057.290	0.000
PolyLineM	2	5	2	41056.219	2564.413	0.000
PolyLineM	3	11	3	24545.643	1533.000	0.000
PolyLineM	4	3	4	46612.293	2930.042	24.960
PolyLineM	5	20	5	4507.688	255.362	0.000
PolyLineM	6	9	6	29650.640	1963.000	0.000
PolyLineM	7	17	7	11589.803	726.000	0.000
PolyLineM	8	12	8	13933.041	924.000	0.000
PolyLineM	9	13	9	22707.740	1410.000	0.000
PolyLineM	10	8	10	15695.610	972.000	0.000
PolyLineM	11	1	11	53350.620	3318.000	0.000
PolyLineM	12	4	12	46204.844	2876.000	0.000
PolyLineM	13	178	13	980.950	60.000	0.000
PolyLineM	14	270	14	445.204	46.000	0.000
PolyLineM	15	116	15	4340.443	270.000	0.000
PolyLineM	16	141	16	2503.593	170.000	0.000
PolyLineM	17	271	17	1130.167	80.000	0.000
PolyLineM	18	175	18	2520.770	140.000	0.000
PolyLineM	19	142	19	3650.790	220.000	0.000
PolyLineM	20	90	20	4389.056	270.000	0.000
PolyLineM	21	15	21	15906.307	1010.000	0.000
PolyLineM	22	117	22	3527.846	250.000	0.000
PolyLineM	23	272	23	1111.568	80.000	0.000
PolyLineM	24	118	24	3429.004	220.000	0.000
PolyLineM	25	75	25	6582.601	440.000	0.000
PolyLineM	26	273	26	3259.078	200.000	0.000

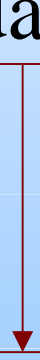
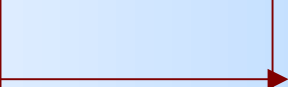
Meteorological data

Snow Cover Mapping

Elevation zones

Overlay

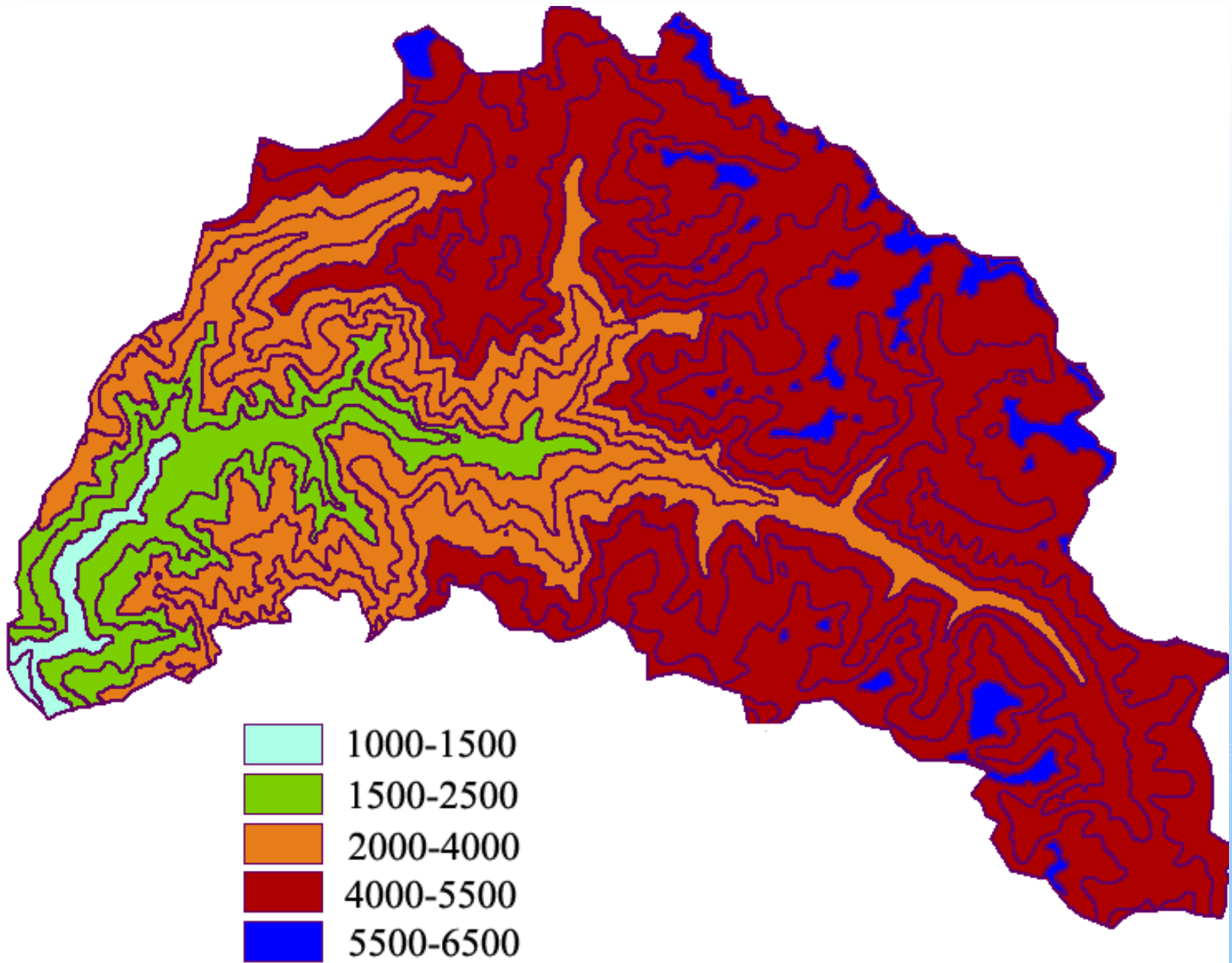
Snowmelt simulation



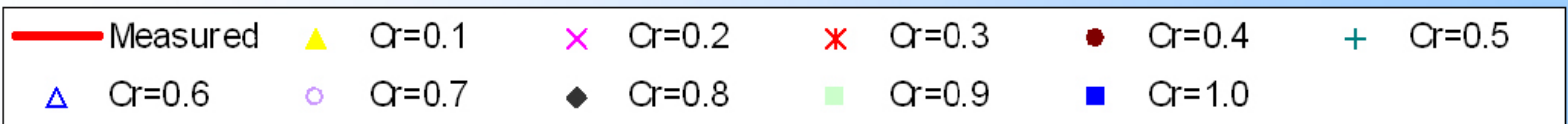
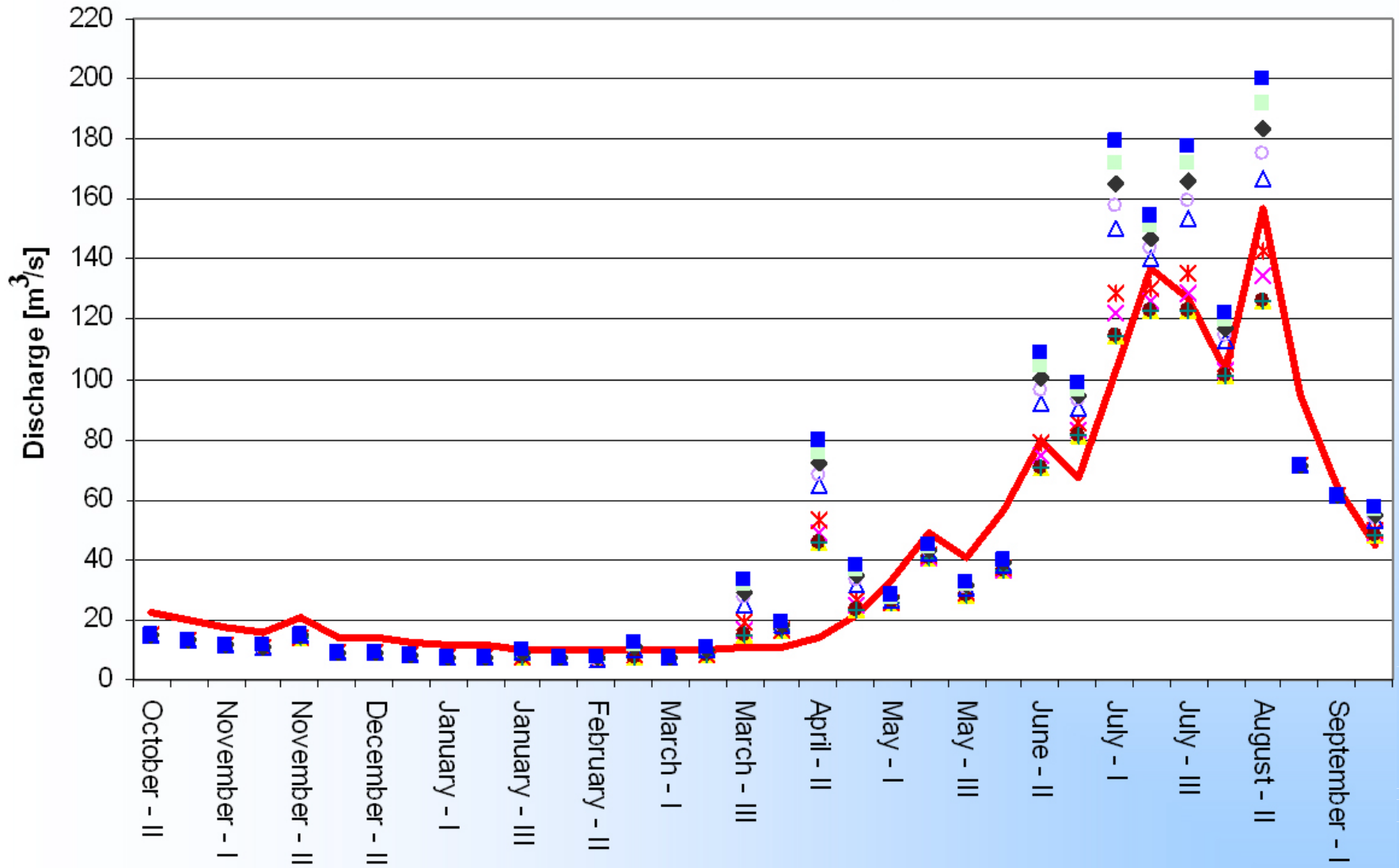
# Thematic Layers

- Elevation zones
- Snow cover maps
- Temperature distribution
- Rainfall distribution

# Elevation Zones Map [m]

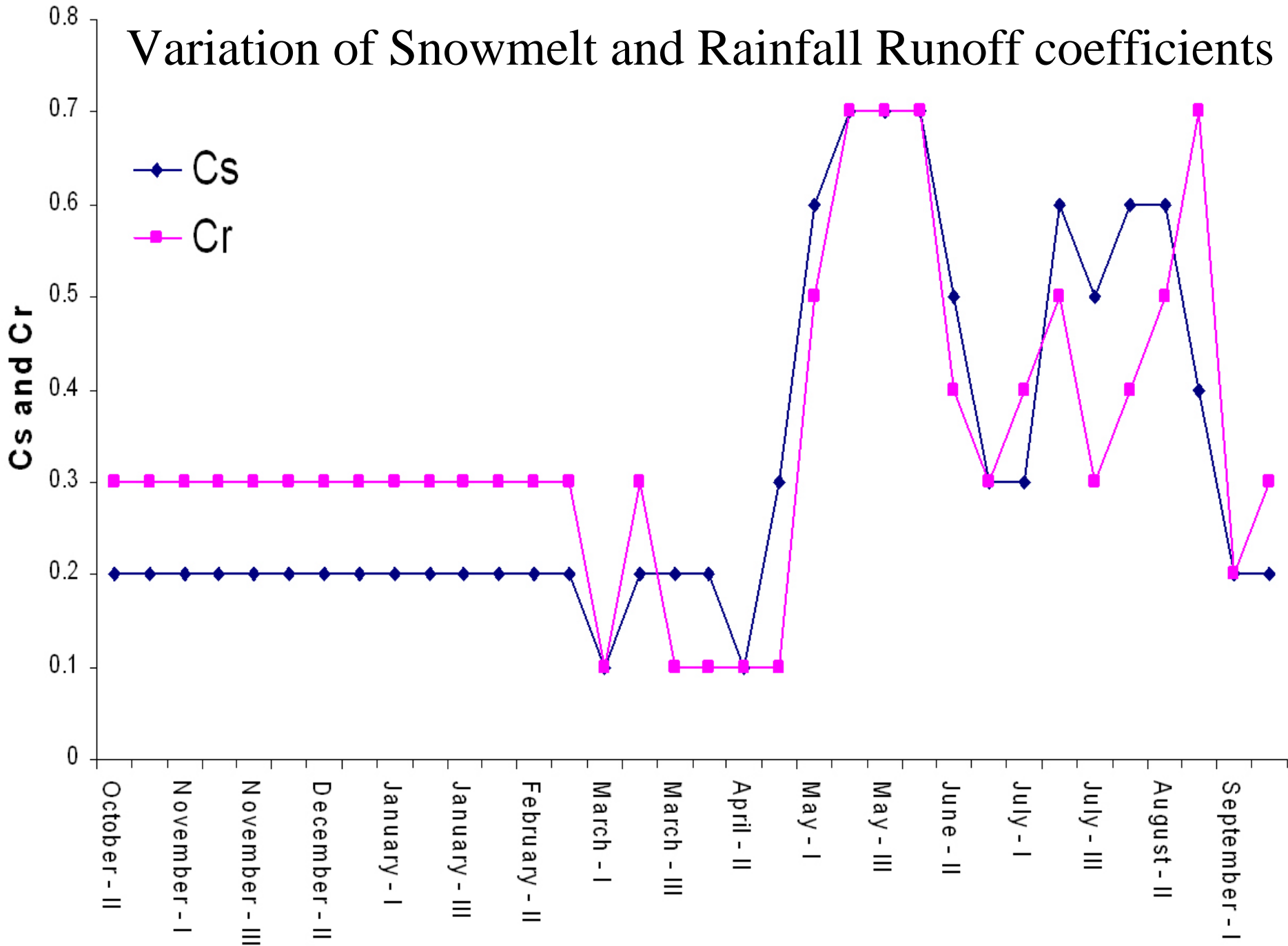


# Calibration of Cr, Cs=0.5

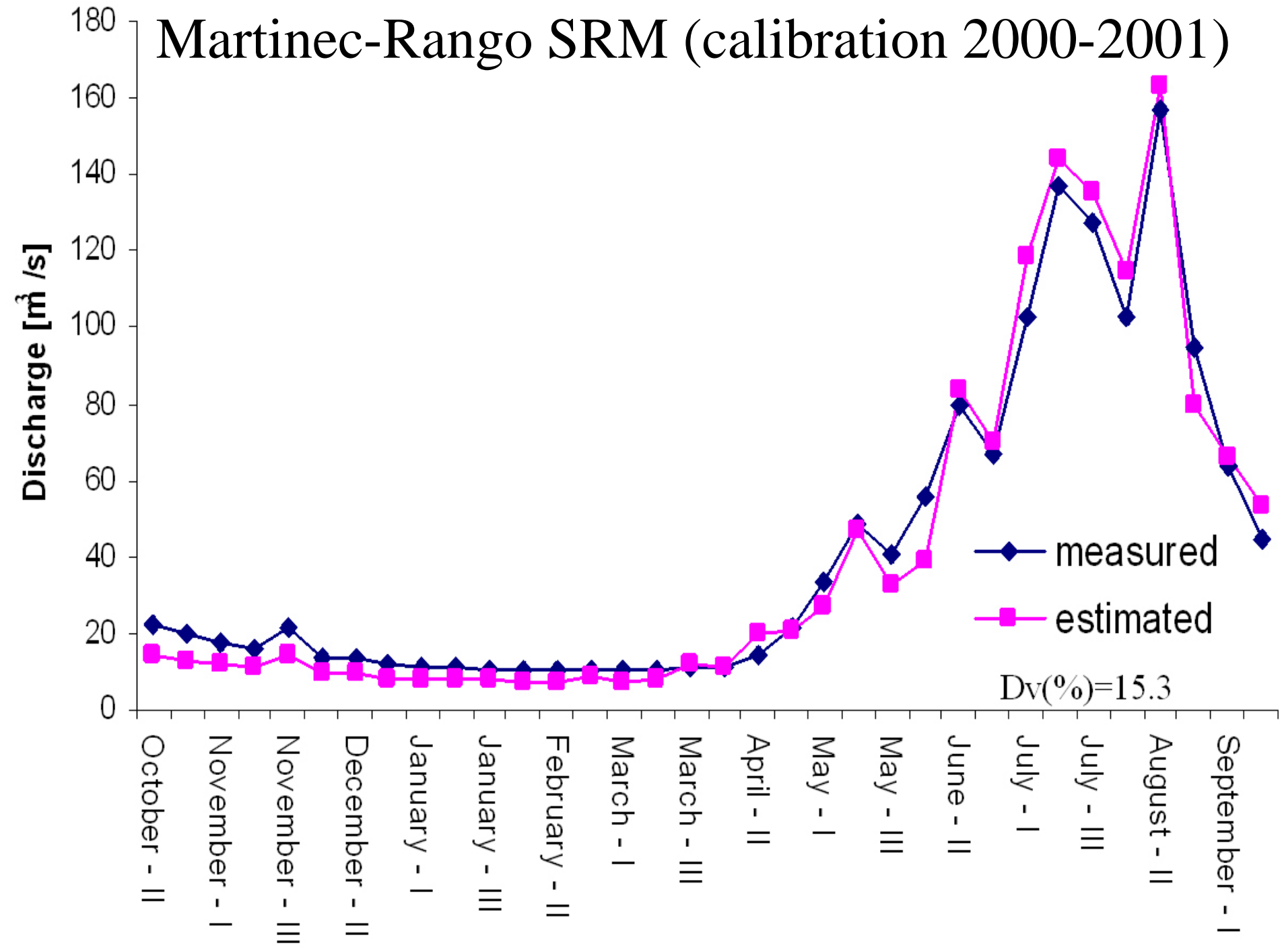




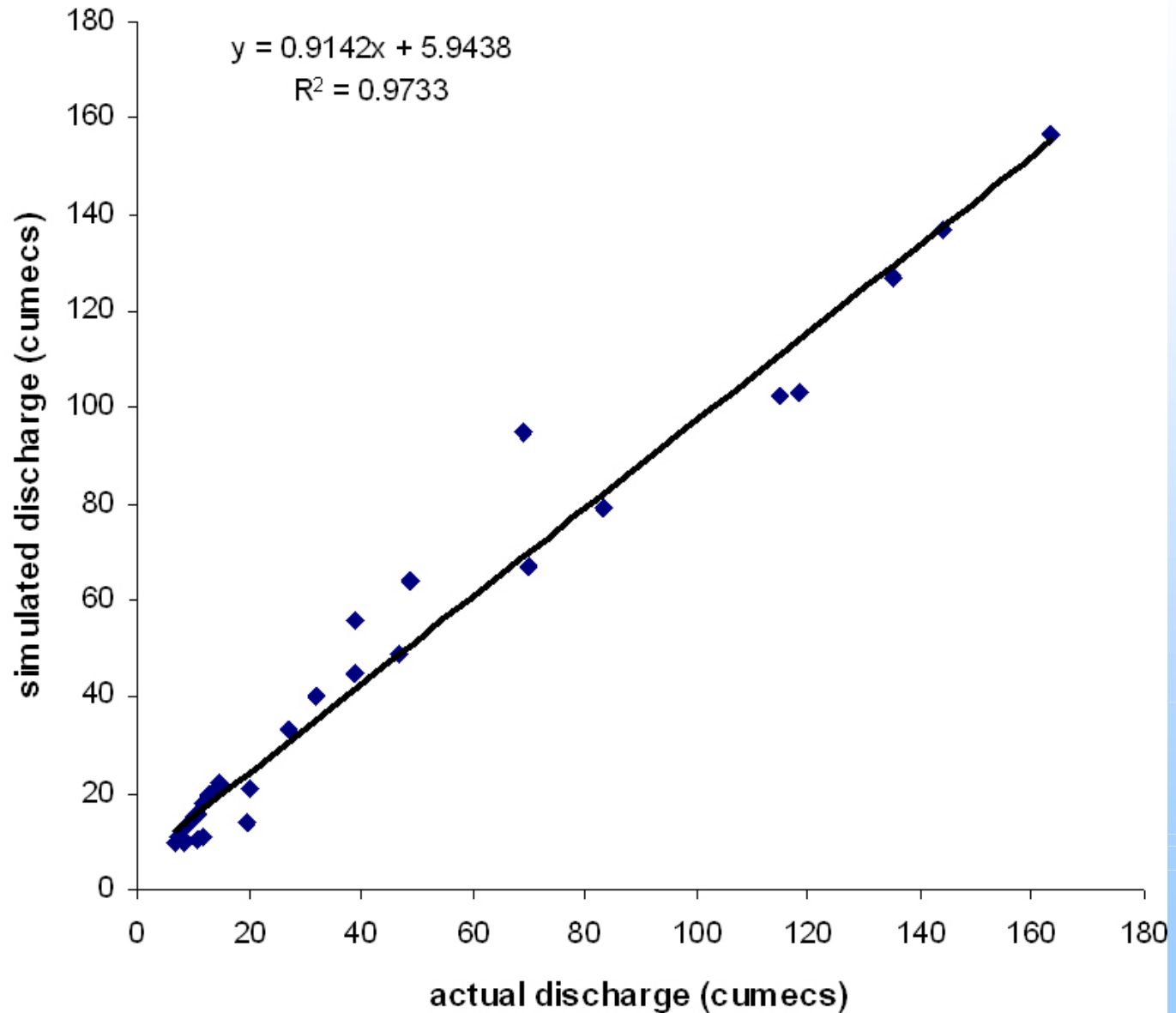
# Variation of Snowmelt and Rainfall Runoff coefficients



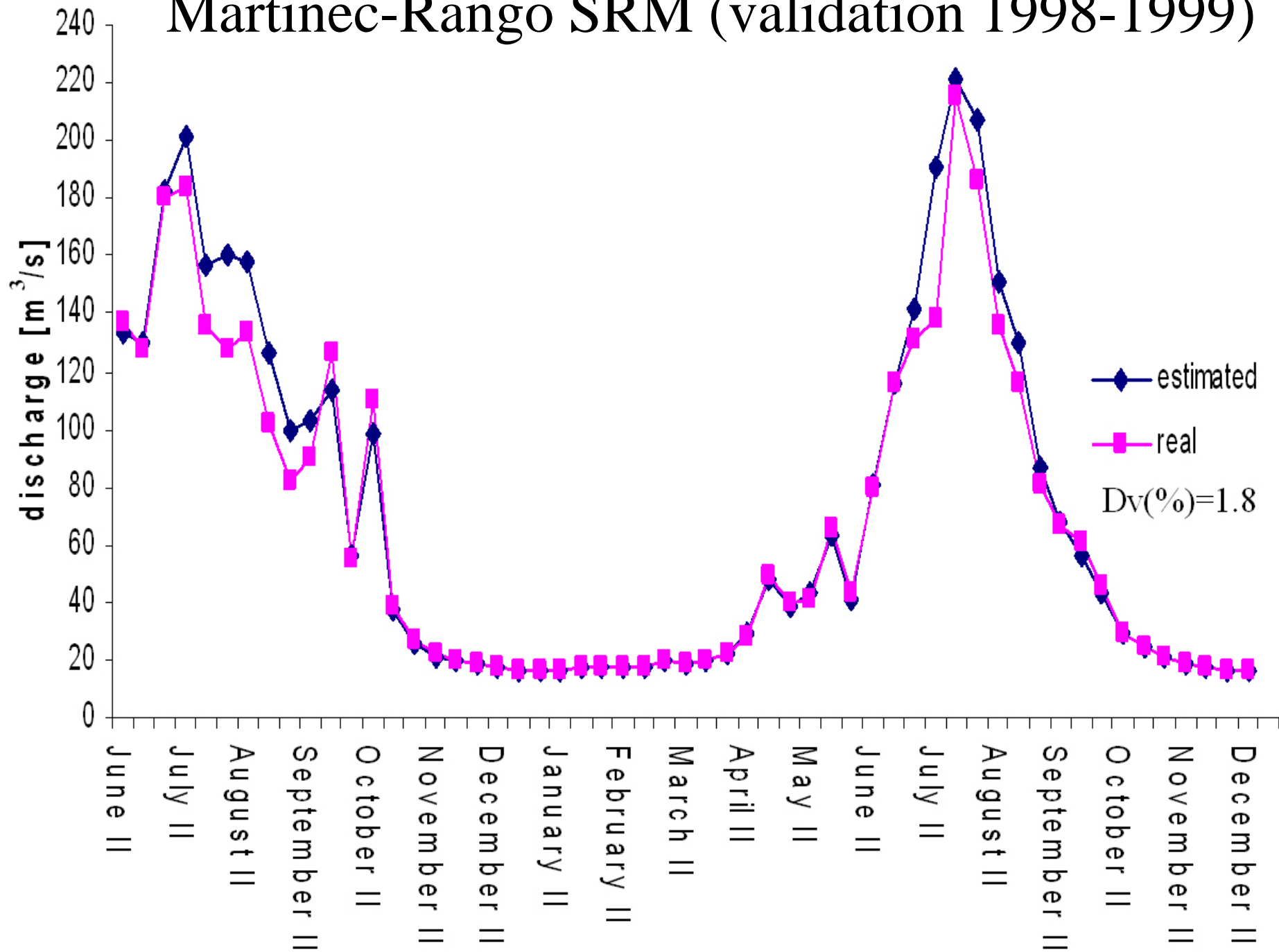
# Martinec-Rango SRM (calibration 2000-2001)



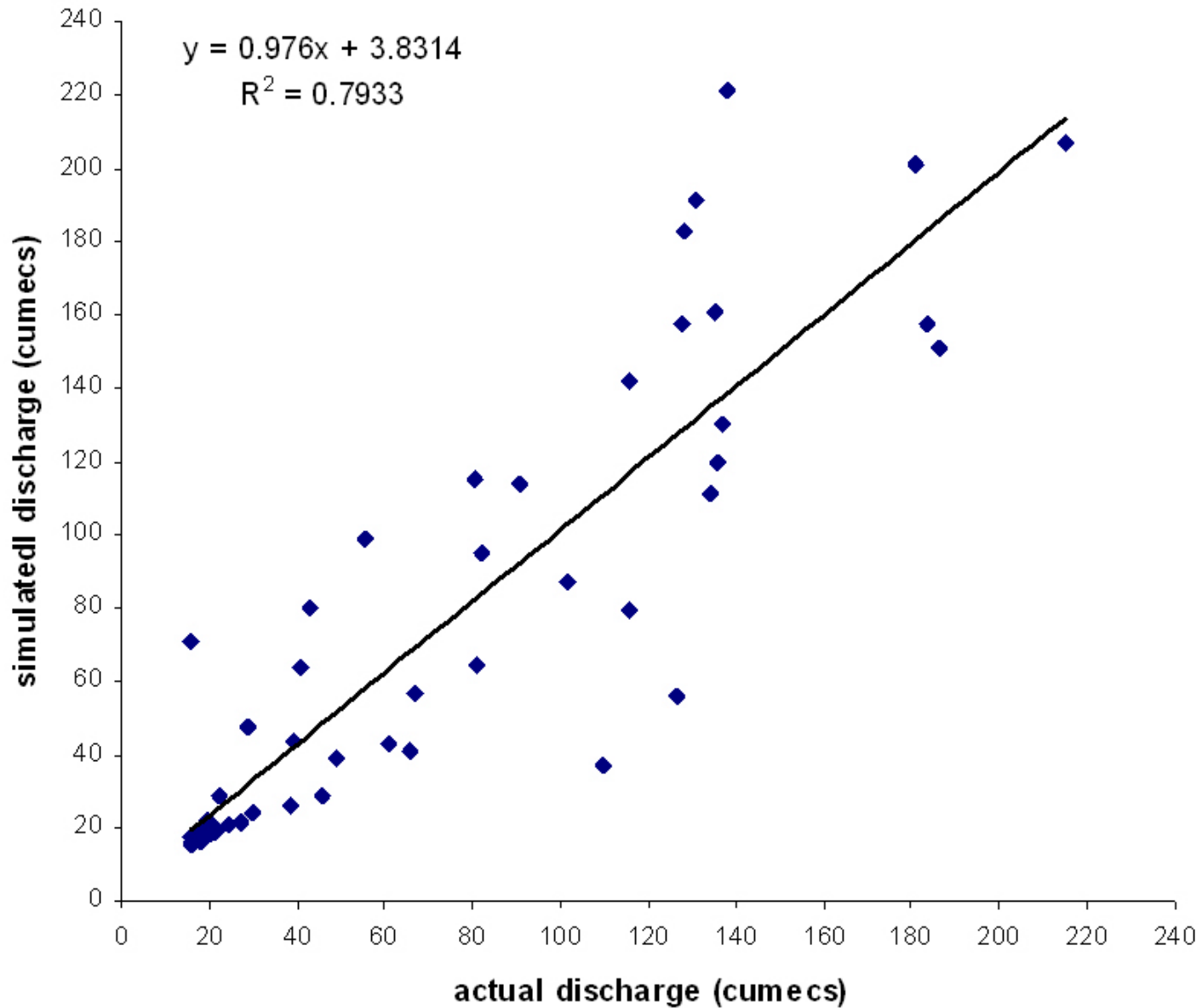
# Actual discharge vs simulated (2000-2001)



# Martinec-Rango SRM (validation 1998-1999)



# Actual discharge vs simulated (1998-1999)



# Results

- Martinec-Rango overestimates discharge during snowmelt season (10%) and underestimates in winter time (38%)
- It is possible to make short time forecasts (3-4 days), and approximate forecasts (1-2 month)

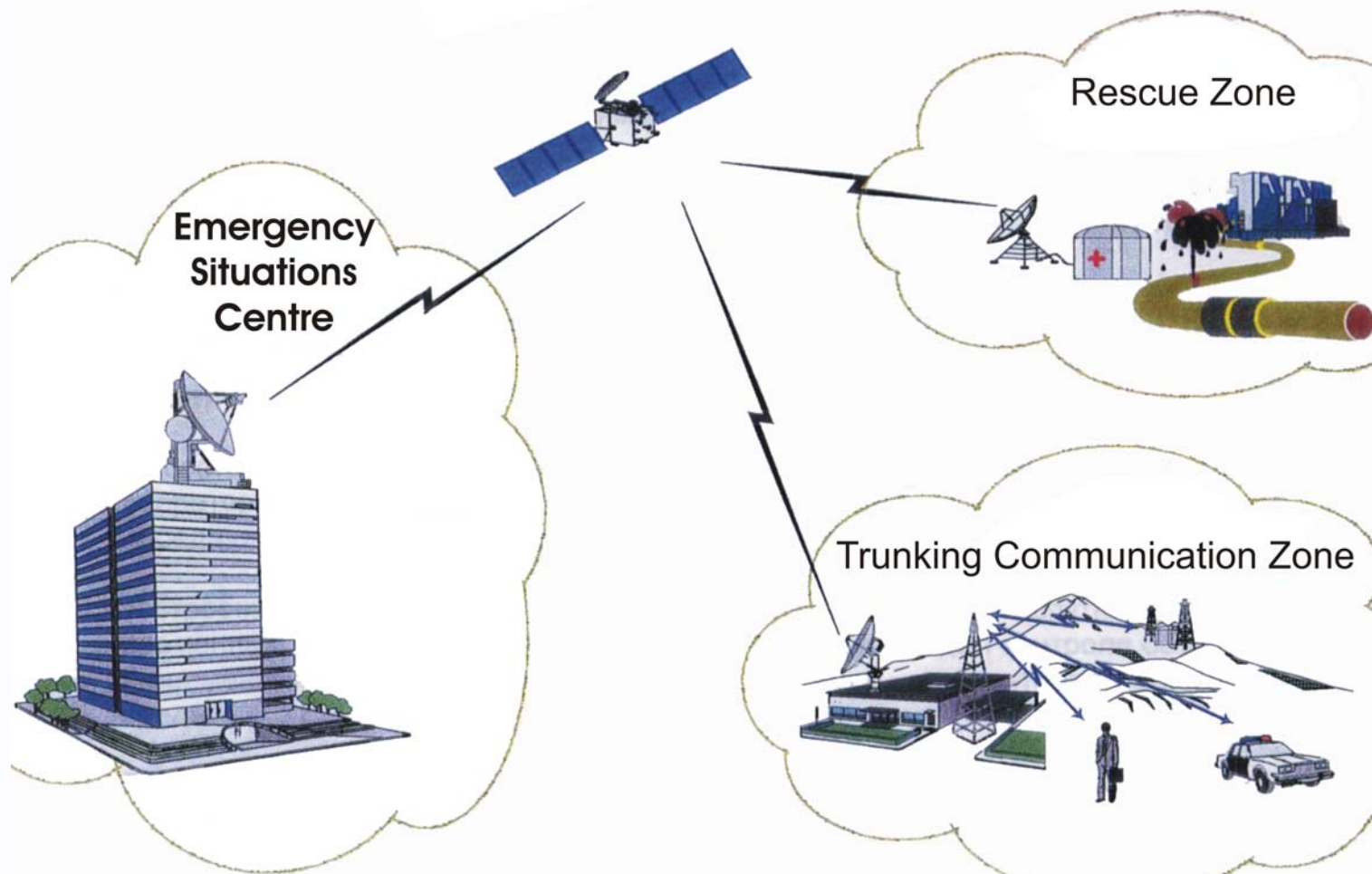
## **Limitations of Present Study**

1. Snowmelt Runoff Model was developed for small European basins, but watersheds are highly varying all over the world.
2. Gauging stations are very less (Bhuntar)
3. Lapse rate is a good approximation of temperature variation vs elevation
4. Often discharge data is not available.
5. Very less snow gauging stations are available
6. Interpolation of Snow Cover Area

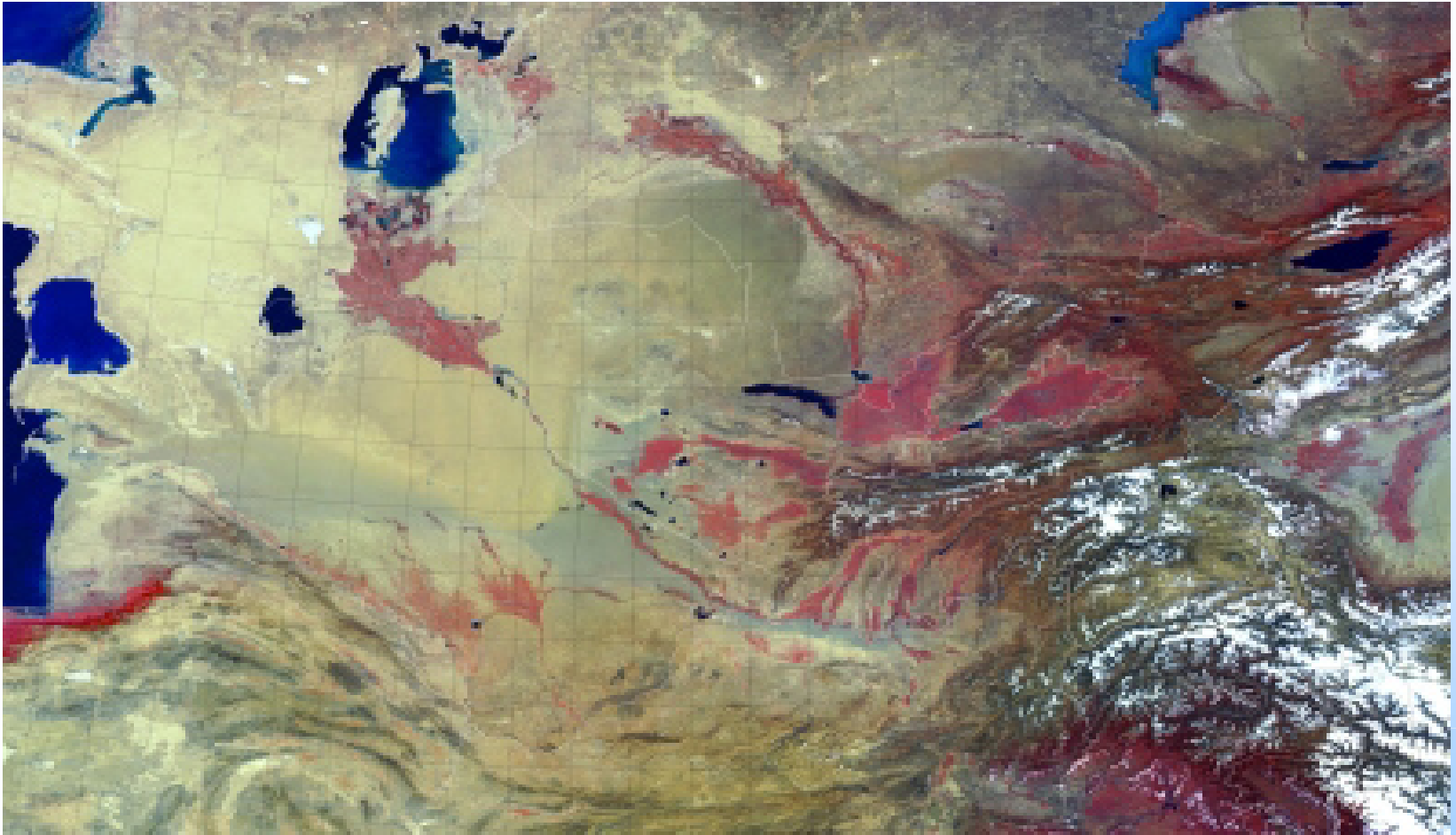
## **Future Scope of Work**

1. Reasonable temporal resolution of SRM inputs would significantly increase the accuracy of the model and allow SRM working in forecasting mode.
2. Weather simulation - long-term forecasts
3. Cost factor

# System of Notification in Emergency Situations



# Scenario of Central Asia



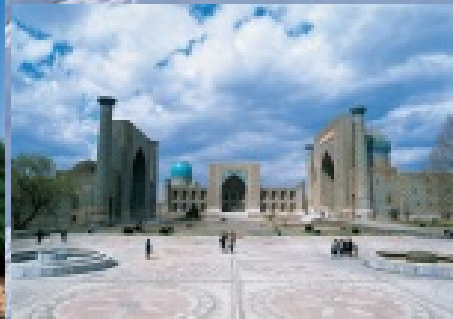
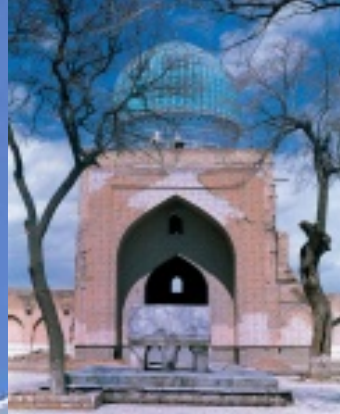
SPOT 4

September 2001

- Melt water is the major source of water
- Hydropower, Irrigation

# What is being done?

- Data collection for similar project in Uzbekistan
  - Practical application
  - Higher temporary resolution of satellite imagery
  - Availability of discharge data
- Close cooperation with interested ministries
  - Ministry of Water and Agriculture
    - Around 100 000 sq km are under agriculture
  - Ministry of Nature Protection
  - Ministry of Emergency Situations
    - More than 20 large water bodies
  - Meteorological service



Thank You

