Glaciers and Flooding
SD Friday Forum

James A. Rising

Columbia SIPA

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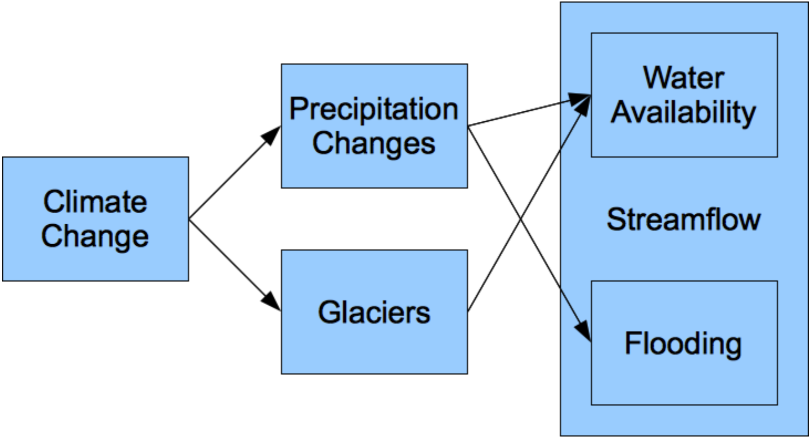
Glaciers and Flooding in Himalayan River Basins

http://existencia.org/files/sd/flooding2.pdf

Talk Plan

What contribution do glaciers and melt have to flooding in the Himalayan basins, and how will flood frequency and nature change in time, as glaciers melt and snow accumulation patterns change?

- Background and Literature ▸ Melt Contributions
- Scale Estimations (BotE and Pak2010)
- Efficient Drainage Model
- Analytic Melt Effect Model
- Bhakra Regression
- Pakistan Application
- Future Work???



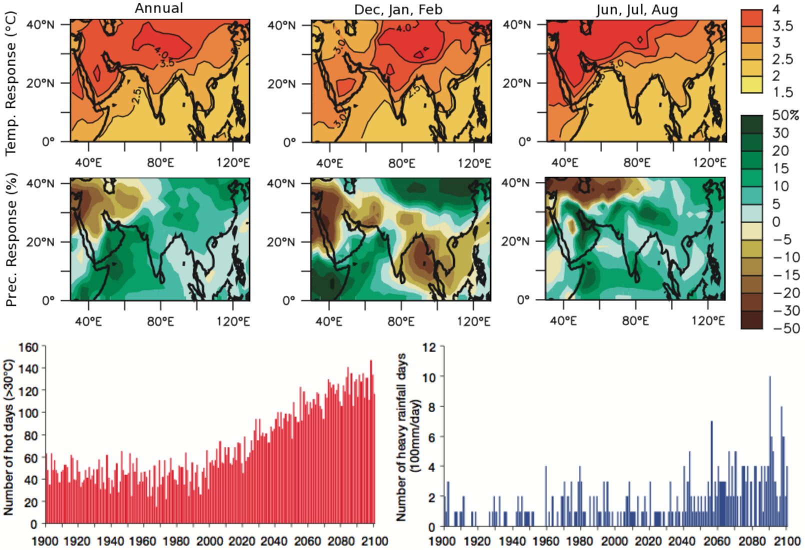
IPCC: “Glacier melt in the Himalayas is projected to increase flooding, and rock avalanches from destabilized slopes, and to affect water resources within the next two to three decades. This will be followed by decreased river flows as the glaciers recede.”

Literature Review

Literature on Himalayan glaciers and flooding:

- **Climate** $\rightarrow$ **Precipitation** $\rightarrow$ **Flooding**:
  Monirul Qader Mirza (2003), Mirza et al. (2003)
- **Climate** $\rightarrow$ **Glaciers** $\rightarrow$ **Streamflow**:
  Singh and Kumar (1997), Dairaku et al. (2008), Singh and Bengtsson (2005)
- **Climate** $\rightarrow$ **Glaciers**:
  Fujita et al. (1997), Dyurgerov et al. (2005)
- **Glacier Modeling**:
  Ageta (1983), Huang (1990), Ohmura (2001), Kaser et al. (2003), Fujita et al. (2007)
- GLOFs, Health, Management, Return Times, Hydrology

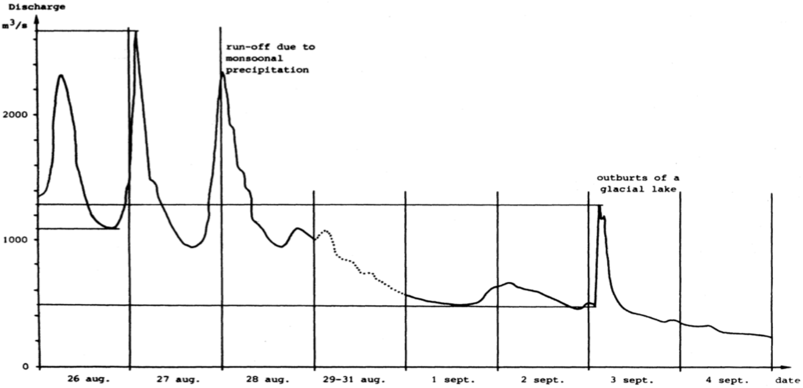
Climate Change



Climate Change

Season	Temp. Response (°C) 25%	50%	75%	Prec. Response (%) 25%	50%	75%	Extreme Seasons (%) Warm	Wet	Dry
Southern Asia (5N,64E to 50N,100E)									
DJF	3.2	3.6	3.9	-9	-5	1	99		
MAM	3.0	3.5	3.8	-2	9	18	100	14	
JJA	2.2	2.7	3.2	**4**	**11**	**16**	96	32	-1
SON	2.5	3.1	3.5	**8**	**15**	**20**	100	29	-3
Annual	2.7	3.3	3.6	**4**	**11**	**15**	100	39	-3
Tibetan Plateau (30N,50E to 75N,100E)									
DJF	3.7	4.1	4.9	**12**	**19**	**26**	95	40	0
MAM	2.9	3.6	4.3	**4**	**10**	**14**	96	34	-2
JJA	3.2	4.0	4.7	0	4	10	100	24	
SON	3.3	3.8	4.6	-4	8	14	100	20	
Annual	3.2	3.8	4.5	**2**	**10**	**13**	100	46	-1

Back of the Envelope Magnitudes



Reach L8 from Cenderelli and Wohl (2001), a point on the Dudh Kosi river: at 2580 m, serves a drainage basin of 1151 km^2.

Seasonal High Flow Floods : 205 m^3/s (grows with s^2)

Increased Melt Discharge : $Q = \mu A T = 5$ mm / day °C × 1151 km^2× 3 °C $= 200 m^3/s$ (grows with s)

1985 GLOF : 1375 m^3/s (decreases with s)

Estimating Pakistan 2010

1. **Identify flood extent**: *Spatio-Temporal Flood Analysis along the Indus River, Sindh, Punjab, KPK and Balochistan Provinces, Pakistan*
2. **Match between maps**: Geographic Matching
3. **Calculate cell areas**: 1° longitude from 178 km to 204 km
4. **Approximate water height**: Height Estimation

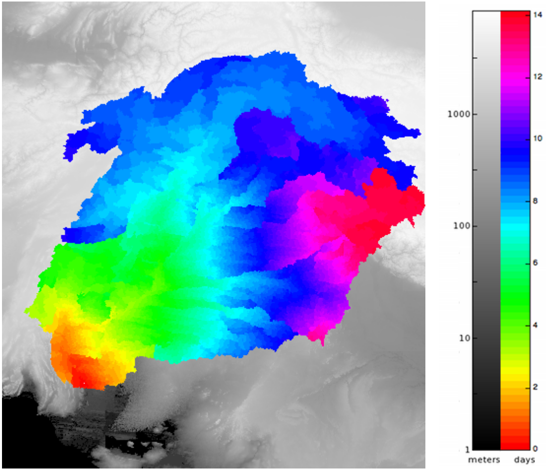
Result: 55.2 ± 1.1 km^3

1. **Model Streamflow**: (skipped for now)
2. **Aggreagate daily precipitiations** Precipitation Totals

Result: 118 km^3

An Efficient Basin Model

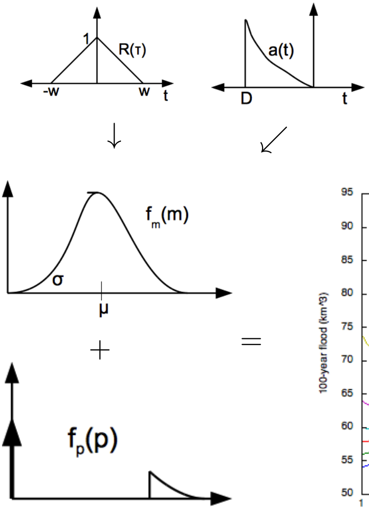
precipitation, temperature →



→ streamflow, snow/ice melt and depth

Temporal-distance map of the basin, used to map spacial quantities to aggregate regions, to support a low-dimensional discrete-time model. ▸ Map Zoom ▸ Flow Equations

Analytic Model



WSS process for temperature, and empirical melt scaling

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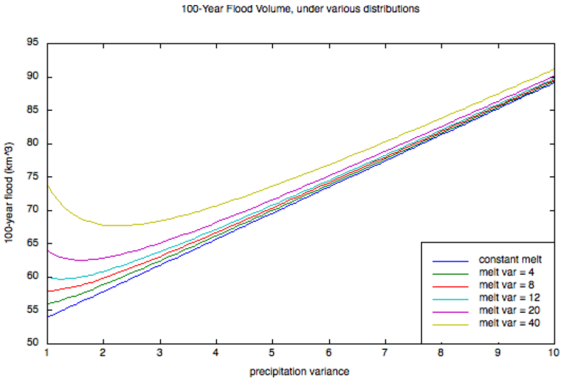
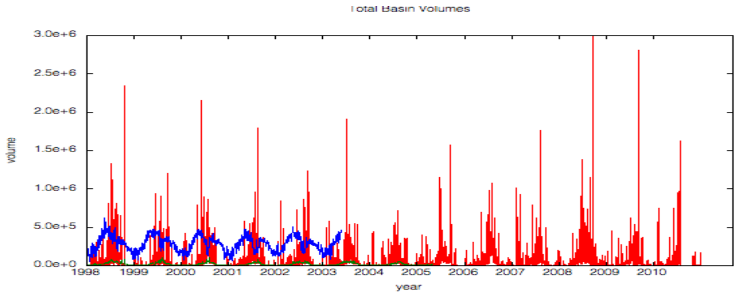
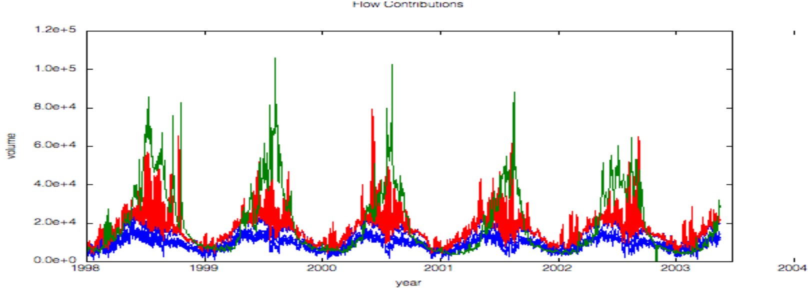


The analytic model predicts increased prevalence of 100-year floods, and very significant increases for some ranges of values. ▸ Model Derivation

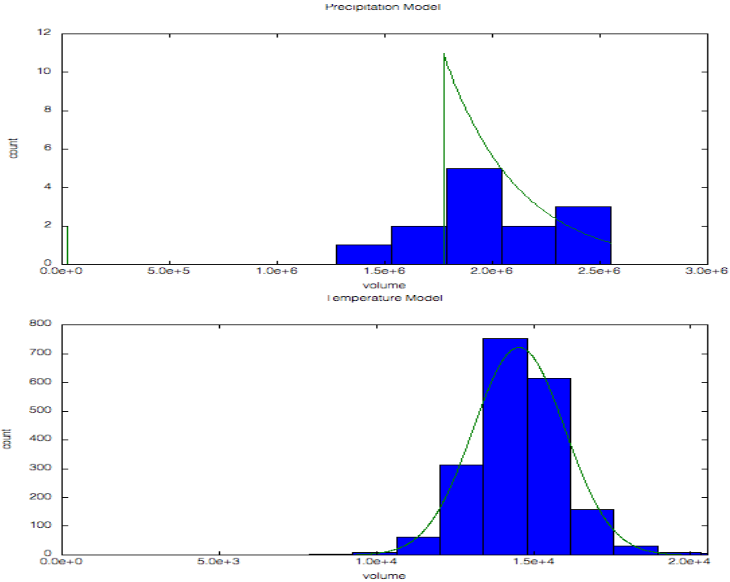
Bhakra Data





$R^2 = .758$

Bhakra Model

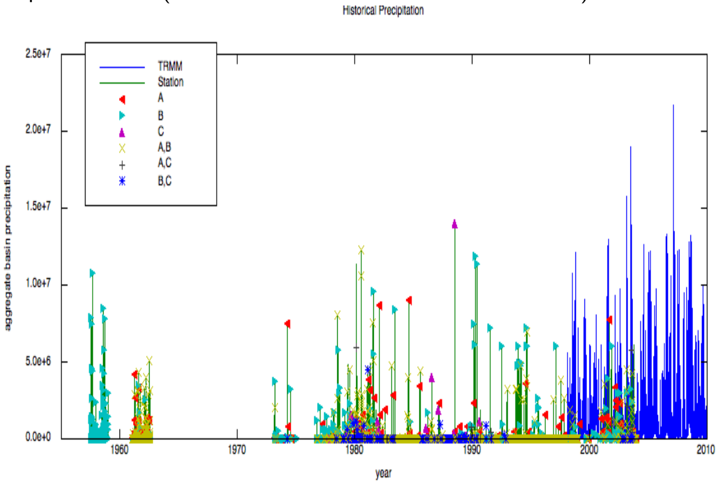


100-Year Flood: $\bar{q} = 3.2955e6$ units^3, $\tilde{q} = 6.6219e16$ units^3

Pakistan Application

1. Maximum Yearly Flood → extreme flood frequency and magnitude
2. Daily Flow/Flooding → seasonal flood shifts for agriculture

Precipitation Data (TRMM and OLS-model scaled station data)



Percipitation Data

$$Q_{TRMM}(t) = \sum_s \sum_{d=0}^{14} \alpha_{sd} P_s(t-d) + \sum_{d=0}^{14} \beta_d T_s(t-d) +$$

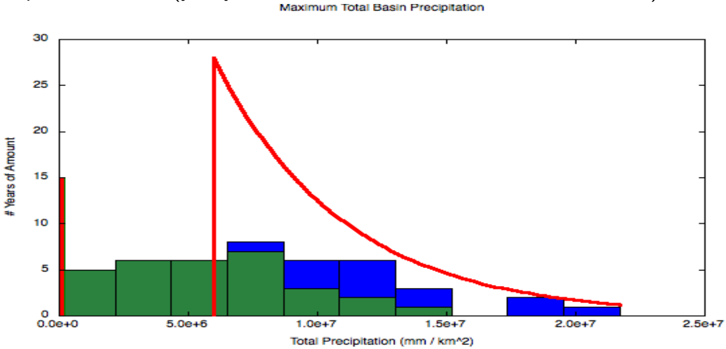
$$\sum_s \gamma_s (\sum_{d=0}^{14} T_s(t-d) \mathbf{1}\{T(t-d) > 0\})(\sum_{d=0}^{14} P_s(t-d) \mathbf{1}\{T(t-d) < 0\})$$

Regressed Stations	Coefficient(s)	Overlap (N)	All Points	Additions
Station A only	1.5474e5	457	3916	1191
RMS Error:	2.0235e6	R^2:	0.0679	
Station B only	1.1974e5	612	5770	2863
RMS Error:	2.1131e6	R^2:	0.0835	
Station C only	1.0984e5	39	389	97
RMS Error:	2.1448e6	R^2:	0.2306	
Stations A and B	1.9041e5, 6.451e4	325	2566	2069
RMS Error:	1.7899e6	R^2:	0.0863	
Stations B and C	1.8656e5, 9.543e4	34	260	54
RMS Error:	1.6859e6	R^2:	0.3305	
Stations A and C	3.7336e5, 1.0151e5	31	230	199
RMS Error:	1.0415e6	R^2:	0.7135	

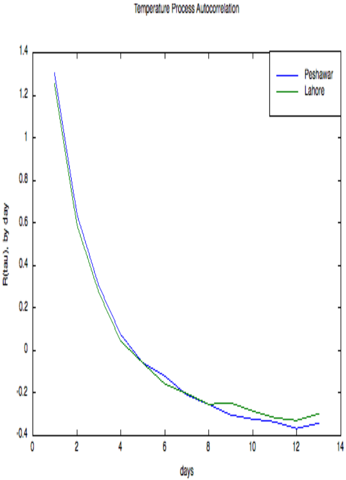
Percipitation Model

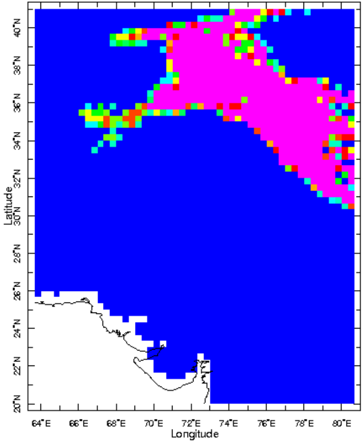
$$\rho = \frac{\displaystyle\sum_{p_i \geq p_0} (p_i - p_0)}{n} \rightarrow score_{p_0} = |Var(P_i) - \rho^2|$$

Precipitation Model (yearly maximum, with method of moments model)



Temperature and Snow Data



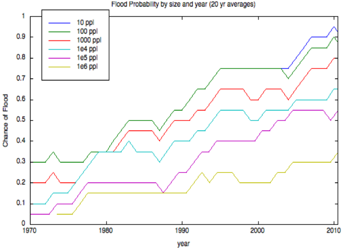


14-20 May 2003

How to calculate $a(t)$?

Implications

Increasing Floods



Agriculture

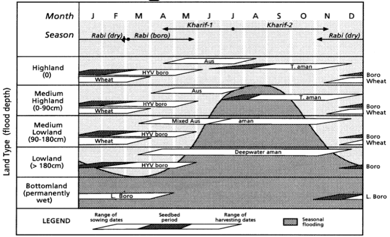
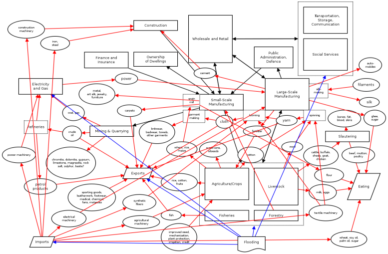


Fig. 10. Crop calendar in relation to monsoon flooding.

Direct Effects

Trickle-Down



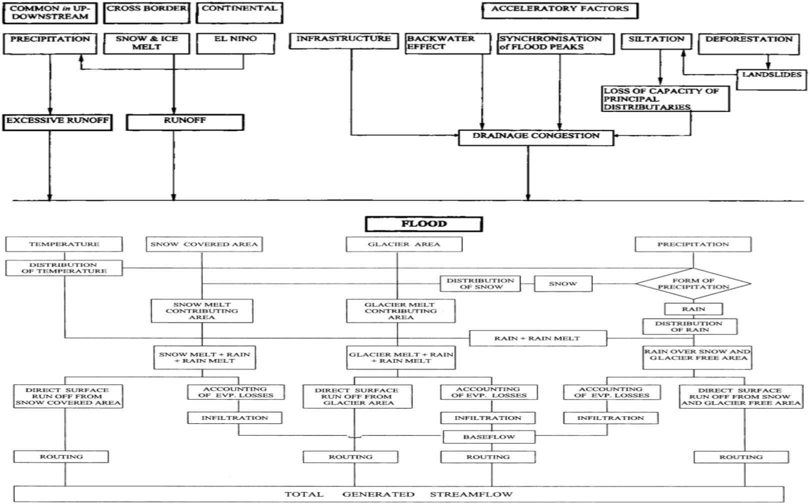
Future Work

Additional and Unanswered Questions:

- What effects will seasonal flood timing shifts have on flood magnitude?
- How will flood timing and mangitude affect crops?
- Can the glaciation area affect be incorporated in the model?
- Do I need detailed information about monsoons and the structure of hydrological basins into a model of flood probability?
- How many people are affected by seasonal flooding?
- Use Pakistan data of previous extreme floods to improve calibration.

Future Work

- Get a calibrated civil hydrological model of the Pakistan basin.



Melt Contributions

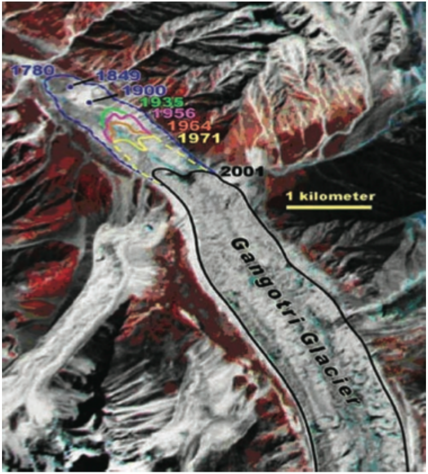
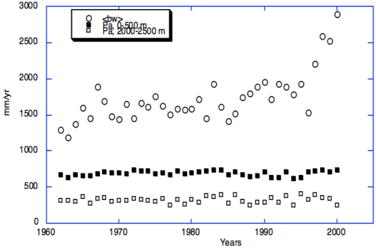


Figure 10.6. *Composite satellite image showing how the Gangotri Glacier terminus has retracted since 1780 (courtesy of NASA EROS Data Center, 9 September 2001).*

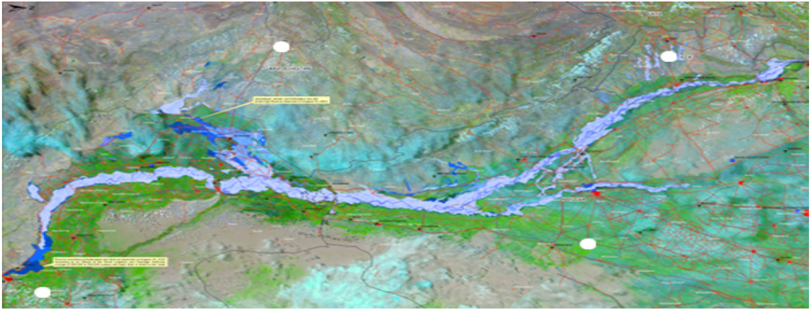
Return

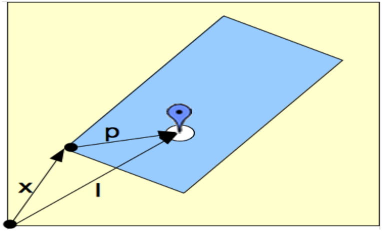
Winter Accumulation (and precipitation)



Glacial Lake Outburst Floods (and Lewis Pugh)

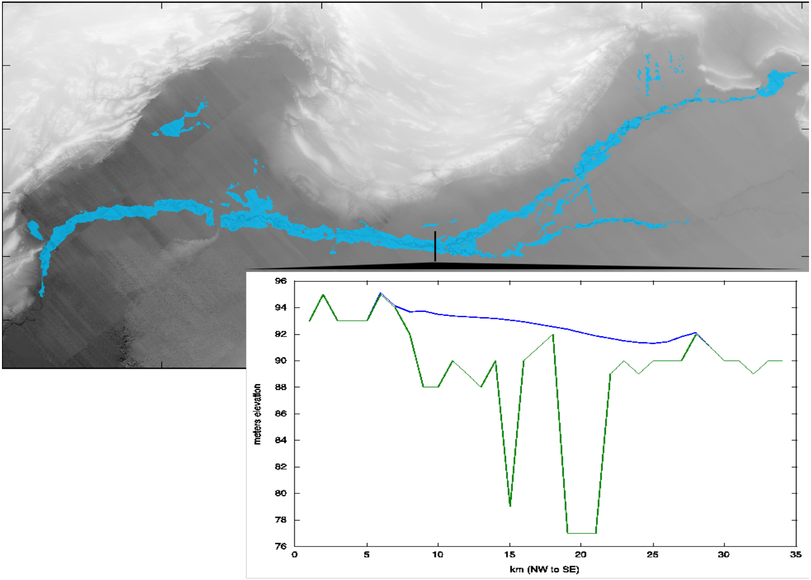
Matching Between Maps





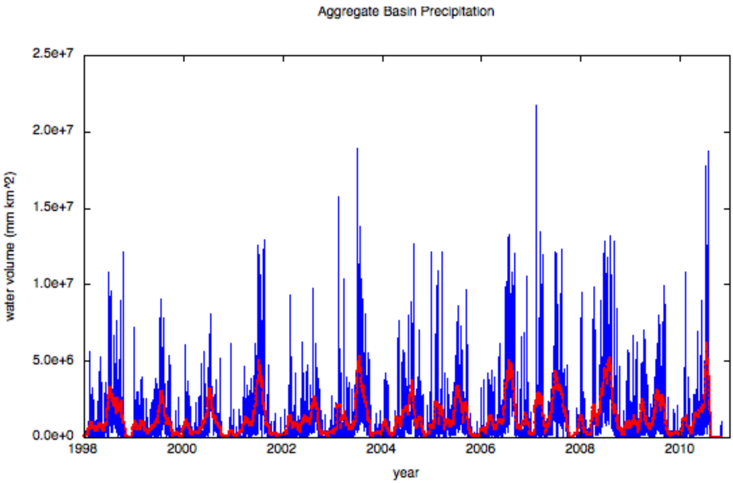
Return

Flood Mapping

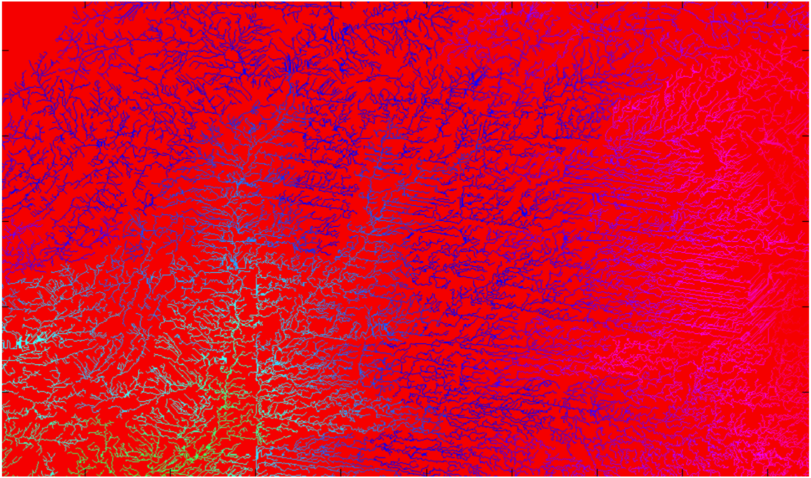


Return

Pakistan Precipitation Totals



Return



Return

- $P(t, x, y)$, the precipitation, in $\frac{w.e.}{m^2 hr}$.
- $T(t, x, y)$, the temperature, in $^\circ C$.
- $\xi(x, y)$, the elevation at a point.
- $\mu_s(\xi)$ and $\mu_i(\xi)$, the melt coefficient of snow and ice at an altitude, in $\frac{w.e.}{^\circ C hr}$.

Define the snow melt at a point, $M_s(t, x, y)$, as a linear response to temperature, and total snow depth, $S(t, x, y)$:

$$M_s(t,x,y) = \mu_s(\xi(x,y)) T(t,x,y) \mathbf{1}\{T(t,x,y) > 0, S(t,x,y) > 0\}$$

$$S(t,x,y) = \int_{-\inf}^{t} P(\tau,x,y)\mathbf{1}\{T(\tau,x,y) \leq 0\} - M_s(\tau,x,y) d\tau$$

Analogously, define the glacier melt, $M_i(t, x, y)$ and glacier height $G(t, x, y)$.

$$M_i(t,x,y) = \mu_i(\xi(x,y)) T(t,x,y) \mathbf{1}\{G(t,x,y) > 0, T(t,x) > 0, S(t,x) = 0\}$$

$$G(t,x,y) = \int_{-\inf}^{t} -M_i(\tau,x,y) d\tau$$

$$Q_d(t) = \iint_D (P(t,x,y) + M_s(t,x,y) + M_i(t,x,y)) \mathbf{1}\{T(t,x,y) > 0\} \mathrm{d}x\mathrm{d}y + Q_{d+1}(t) \star d(t)$$

Q_0 is the flow through the drainage point. Return

For a constant melt of $A\bar{T}$, the size of a 100-year flood is,

$$P(\bar{Q} \geq q) = \int_q^\infty \frac{(1-\alpha)}{\rho} e^{-\frac{p'-p_0-A\bar{T}}{\rho}} dp' = .01$$
$$\implies q = p_0 + A\bar{T} - \rho ln(\frac{.01}{1-\alpha})$$

For melt following a normal distribution with μ and σ,

$$P(\tilde{Q} \geq q) = \int_q^\infty \frac{(1-\alpha)}{\rho} e^{-\frac{p'-p_0}{\rho}} \star n(\mu, \sigma^2) dp'$$
$$= \int_q^\infty \int_{-\infty}^\infty \frac{1-\alpha}{\rho} e^{-\frac{p'-p''-p_0}{\rho}} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(p''-\mu)^2}{2\sigma^2}} dp'' dp'$$
$$\implies q = p_0 - \rho[ln(\frac{.01}{1-\alpha}) - \frac{1}{2\sigma^2}[(\frac{\sigma^2}{\rho} + \mu)^2 - \mu^2]]$$

σ can be calculate from $a(t)$ and $R(\tau)$:

$$E(Q_T - A\bar{T})^2 = E \int_{-\infty}^\infty \int_{-\infty}^\infty a(\tau, t) a(\tau', t) T(\tau) T(\tau') d\tau d\tau'$$
$$= \int_{-\infty}^\infty b(v, t) R(v) dv \text{ where } b(v, t) = \int_{-\infty}^\infty a(\tau' + v, t) a(\tau', t) d\tau'$$

◂ Return