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SURFACE HYDROLOGY FOR USING IN CLIMATE MODEL

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Content

Introduction

In a equilibrium state, precipitation P exceeds evaporation E (or evapotranspiration) over land and the residual water runoff and results in a continental freshwater discharge into the oceans.

Within the oceans, surface net freshwater fluxes into the atmosphere are balanced by this discharge from land along with transports within the oceans.

The excess of E over P over the oceans results in atmospheric moisture that is transported to land and precipitated out, thereby completing the land–ocean water cycle.

While E and P vary spatially, the return of land runoff into the oceans is mostly concentrated at the mouths of the world's major rivers, thus providing significant freshwater inflow locally and

To study the freshwater budgets within the oceans, therefore, estimates of continental freshwater discharge into the ocean basins at each latitude are needed.

Introduction (cont.)

•Baumgartner and Reichel (1975) derived global maps of annual runoff and made estimates of annual freshwater discharge largely based on streamflow data.

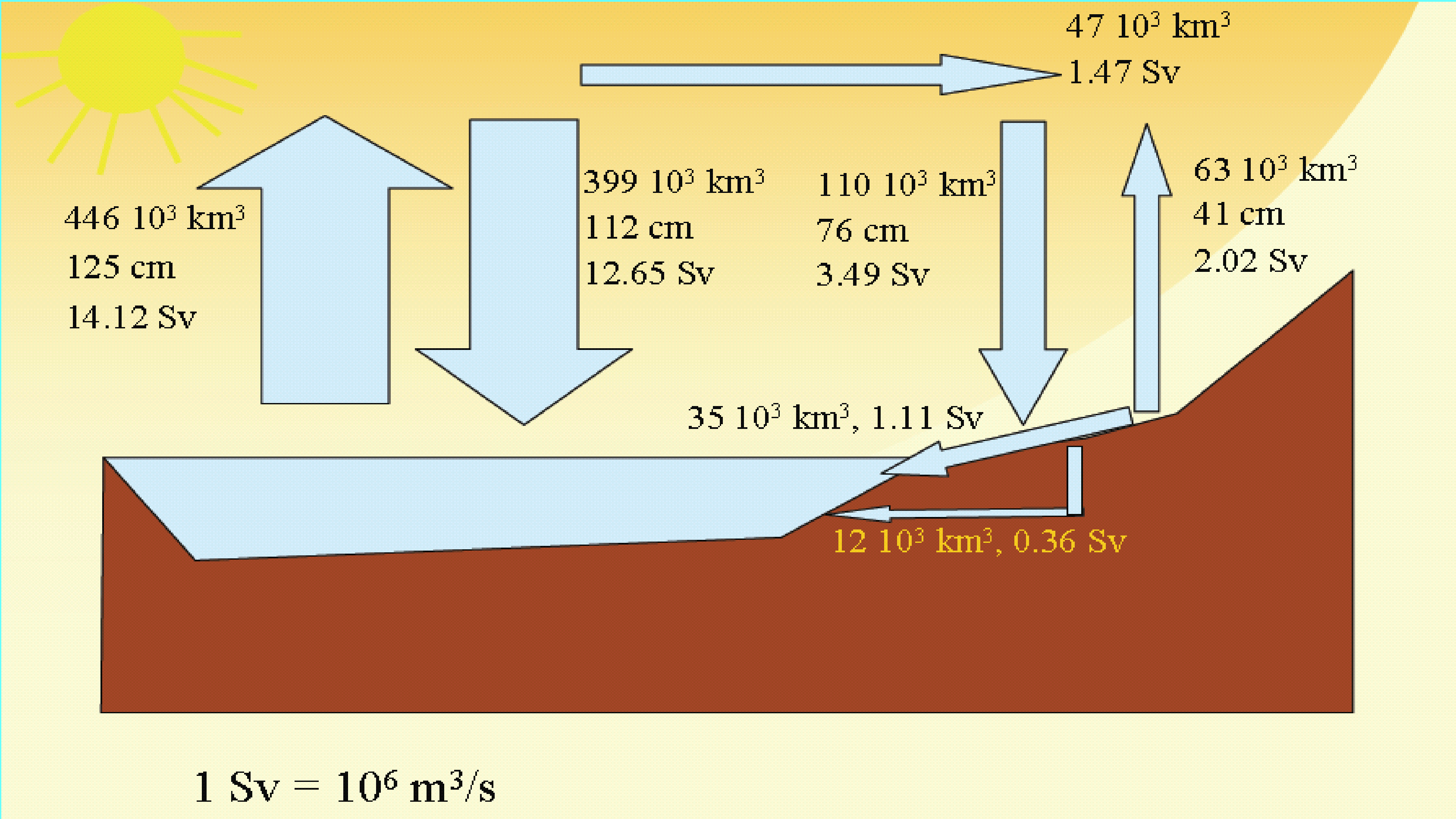
•These estimates are still used in evaluations of ocean and climate models and in estimating oceanic freshwater transport, because it becomes increasingly important in global climate system.

Introduction (cont.)

Anthropogenic changes in atmospheric composition are expected to cause climate changes, in particular an intensification of the global hydrological cycle with increase in flood risk.

M. Bierknes, H. Dolman, 2004

Global hydrological cycle (per year)

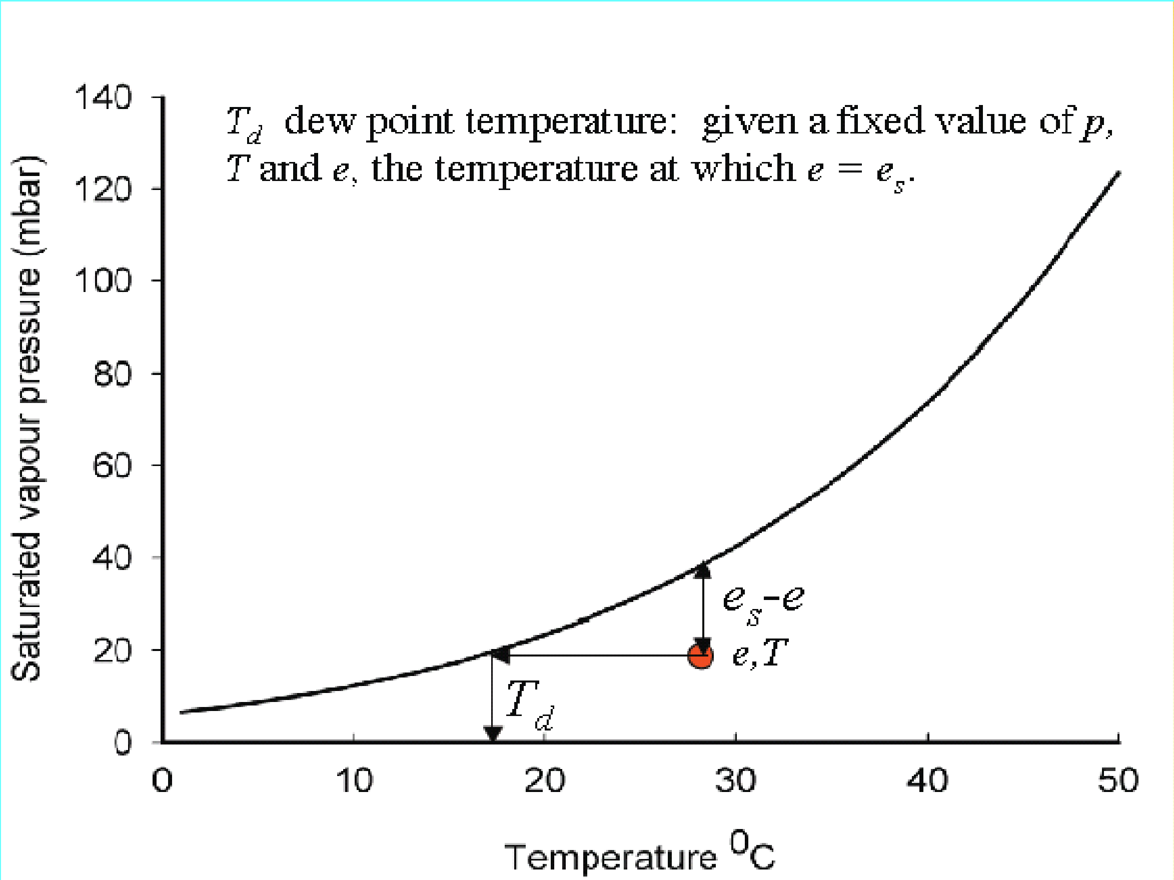


M. Bierknes, H. Dolman, 2004

Hydrology Cycle and Climate

- Вода с одной стороны “смягчает” климатические изменения - облачность сдерживает влияние парниковых газов

- С другой стороны она усиливает их - влажность увеличивается с температурой, усиливая эффект парниковых газов влажность увеличивается с температурой, усиливая эффект парниковых газов (положительная обратная связь)



Компоненты гидросферы

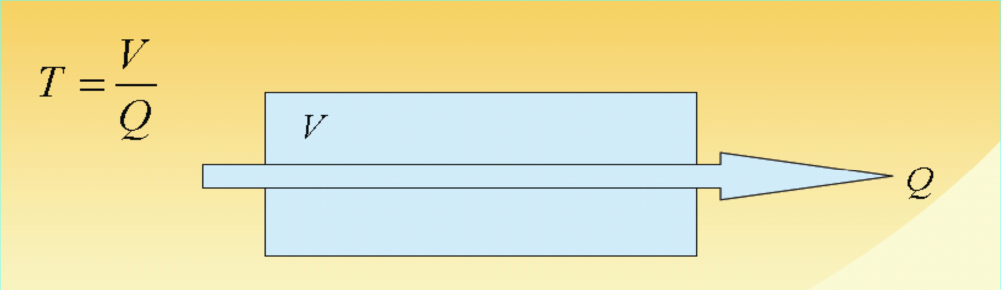
- Океаны (97 %) покрывают 70% поверхности Земли
- Криосфера (ледники и т.д.) (2%)
- Подземные воды и вода в почве (0.7%)
- Озера (0.01%)
- Атмосфера (0.001%)
- Реки (0.0001%)
- Биосфера (0.00005%)
- Пресная вода (3.5%) (в основном содержится в криосфере)

Продолжительность пребывания субстанции в водном пуле при стационарных условиях

- Время пребывания – размер водного пула, деленный на скорость втока или вытока (масса/время).
- Например, время пребывания воды в океане по отношению к речному стоку = 1.25*10**9 (км**3)/0.03*10**6(км**3/год) = **41600 лет.**
- Например, V атмосферной влаги = 13000 км3

Осадки: 0.7*112 + 0.3*76 = 101 см/год => 514389 km3/год

Время пребывания = 13000/514389 = 0.0253 лет = **9.2 суток**



Retention times

Deep groundwater	10000 year
Ice caps	8000 year
Oceans	5000 year
Moderately deep groun dwater	200 year
Lakes	100 year
Glaciers	40 year
Seasonal snow	5 months
Shallow groundwater and soil moisture	2 months
Rivers	15 days
Atmosphere	9 days

Вода в атмосфере

- Почти половина всей воды содержится в нижнем 1.5 км слое

- Не более 5% воды находится выше 5 км

- Не более 1% воды находится в стратосфере

Облака, осадки

- Облака содержат примерно 0.5 г. жидкой воды в кубическом метре воздуха
- Оказывают большое влияние на распределение радиационных потоков
- Обычно делятся на облака нижнего, среднего и верхнего яруса (26.6%, 19%, 18.7%)
- Суммарный радиационный эффект = – 28 W/m**2
- Средние глобальные осадки составляют примерно 95 – 100 см/год
- Средние над океаном осадки = 110 см/год
- Средние над сушей осадки = 75 см/год

Количество осадков

- Согласно уравнению Клаузиуса - Клайперона, «вместимость» атмосферы увеличивается примерно на 7% на градус;
- Изменение количества осадков (увеличение) контролируются не только уравнением Клазиуса – Клайперона, существует дополнительная физически согласованная связь между изменением температуры и осадков (на это указывают большинство моделей)

Влажность почвы

- Влажность почвы контролирует распределение энергии;
- Влажность почвы контролирует распределение речного стока;
- Влажность почвы является важным связующим звеном между гидрологическим и углеродным циклом.

Речной сток

- 50 самых крупных рек обеспечивают 57% расхода речной воды, а их общая площадь дренажа составляет 42% от глобальной площади дренажа;
- Если к ним добавить еще 150 больших рек, то эти числа увеличатся до 67% и 65%, соответственно;
- Глобальный речной сток составляет 37288 – 46930 км**3/год, для Арктики: 2600 – 5220 км**3/год;
- Имеет место большая неопределенность в оценках речного стока.

Climate Model Description

- AGCM/INM RAS 5x4 horizontal resolution and 21-level vertical resolution (Alexeev V., E.Volodin, V.Galin, V. Dymnikov, V. Lykosov, 1998)
- LSM/ICMMG SB RAS - biophysical and biochemical surface model

Atmospheric model (INM/RAS):

- Terrain-following vertical coordinate (21 σ-levels)
- Semi-implicit formulation of integration in time
- Energy conservation finite-difference schemes (5x 4) (Arakawa-Lamb,1981)
- Convection (deep, middle, shallow)
- Radiation (H_2O, CO_2, O_3, CH_4, N_2O, O_2; 18 spectral bands for SR and 10 spectral bands for LR)
- PBL (5 σ-levels)
- Gravity wave drag over irregular terrain

Land surface model(ICM&MG/SB RAS):

- **Vegetation composition, structure**
- **Radiative fluxes**
- **Momentum and energy fluxes**
- **Vegetation and ground temperature**
- **Soil and lake temperature**
- ***Surface hydrology (snow, runoff, soil water, canopy water etc.)***
- **CO_2 emissions from terrestrial vegetation**
- **CH_4 emissions from natural wetlands**

Land Surface Models

- BATS (Dickinson et al., 1993)
- LSM/NCAR (Bonan et al., 1996) – LSM/ICMMG SB RAS (Krupchatnikov V., 1998)
- CLM/NCAR (Bonan et al., 2002)
- ISBA (Decharme B., H.Douville, 2006)
- LSM/INM RAS (Lykossov V., et al.,1998)
- …

•**Runoff** is one of the major components of the **global water cycle and accounts for about 40%** of the precipitation on land. As such, it plays an important role in the global climate system by affecting **evapotranspiration and freshwater inputs to the oceans, which in turn affects the ocean thermohaline circulation.**

•A model's runoff formulation helps control its soil moisture, which influences the latent heat flux between the land surface and the atmosphere. However, its inclusion in climate models has been problematic.

•The partitioning of precipitation into evapotranspiration, surface runoff and subsurface runoff (baseflow) varies widely among these land models.

•Climate models have been adjusted so that the global, multiyear average runoff production is about 1/3 of the average precipitation.

•Runoff is divided approximately equally between surface and subsurface runoff to match the early observational estimates (Dickinson et al., 1993)

•Hydrologists introduced the concept of fractional saturated area as the dominant control on surface runoff. In such schemes, precipitation that falls over the saturated fraction of a model grid cell is immediately converted to *surface runoff.*

•More recent implementations (Stieglitz et al., 1997; Koster et al., 2000; Ducharne et al., 2000; Chen and Kumar, 2001; Yang and Niu, 2003; Niu and Yang, 2003; Gedney and Cox, 2003) define the fractional saturated area as a function of the topography and the water table depth (or water deficit depth) following TOPMODEL (Beven and Kirkby, 1979; Sivapalan et al., 1987).

•TOPMODEL incorporates topographic variation using the concept of "topographic index" or "wetness index," $\lambda = \ln(a/\tan b)$, where a is the specific catchments area, i.e., the upstream area above a point that drains through the unit contour at the point and $\tan b$ is the local surface topographic slope.

•Recent applications (Stieglitz et al., 1997; Ducharne et al., 2000; Chen and Kumar, 2001; Niu and Yang, 2003) used a three parameter gamma distribution function to represent the discrete distribution of the topographic index.

Climate models and TOPMODEL use different definitions of the soil saturated hydraulic conductivity, Ksat.

Climate models usually define Ksat as a function of soil texture, while TOPMODEL assumes that Ksat decreases with soil depth to create a water table.

In TOPMODEL, the soil surface value of Ksat is an arbitrary parameter because it is solely used to produce runoff.

The original derivations of the TOPMODEL subsurface runoff (Sivapalan et al., 1987) require much larger values for the soil surface Ksat than do climate models; researchers justified the very large Ksat with arguments about the role of macropores (Beven, 1982).

TOPMODEL's use of topographic index to explicitly use topographic data to describe the subgrid soil moisture variability captures the critical differences between upslope and downslope hydrological behavior (Koster et al., 2000).

TOPMODEL
(TOPography-based hydrological MODEL

Beven, K.J., Kirkby M.J., (1979), A physically based variable contributing area model of basin hydrology, Hydrol. Sci. Bull., 24(1), 43-69.

TOPMODEL is a conceptual rainfall-runoff model in which the predominant factors determining the formation of runoff are represented by the topography of the basin and a negative exponential law linking the transmissivity of the soil with the distance to the saturated zone below the ground level.

The authors would like to thank Professor K.J.Beven and his research group at University of Lancaster, UK, for source codes and sample data at their TOPMODEL website.

Soil Water

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial z} - e$$

$$q = -k\left[\frac{\partial(\psi + z)}{\partial z}\right]$$

Conservation of mass.

θ - volumetric soil water content

q - soil water flux,

e - soil moisture sink.

Darcy's law

ψ - soil matric potential

k - hydraulic conductivity

Description of the TOPMODEL

The mathematical starting points used to derive the fundamental TOPMODEL equations are the continuity equation and Darcy's law. The basic assumptions that govern TOPMODEL are:

(1) *the law of variation of saturated hydraulic conductivity of the soil with depth*

$$K_s(z) = K_0 e^{-fz}$$

*, where **z** is depth into the soil profile (**z**-axis pointing downwards), K_0 is hydraulic conductivity at ground surface, **f** is decay factor of K_s with **z;***

(2) *the dynamic of the saturated zone can be successive steady-state representations:*

$$a_i * R = T_0 * \tan\beta_i * e^{-fz},$$

*where **R** is spatially uniform recharge rate to the saturated zone, a_i is area draining through location **i** per unit contour length, **tan** β_i is slope of the ground surface at the location **i**, $T_0 = K_0/f$.*

It follows that

$$z_i = \bar{z} - \tfrac{1}{f}\left(\ln \frac{a_i}{\tan \beta_i} - \lambda \right), \qquad (3)$$

where $\lambda = \frac{1}{A}\int_A \ln \frac{a_i}{\tan \beta_i} dA$ *is the average value of the topographic index over the area* ***A*** *of the basin,* z_i *is the depth of water table from the ground surface. The equation* ***(3)*** *and the continuity equation* ***(4)*** *for the mean depth* $\bar{z}$ *of the saturated zone as*

$$\bar{z}^{t+1} = \bar{z}^{t} - \frac{(Q^t{}_{in} - Q^t{}_{out})}{A} * \Delta t \qquad (4)$$

present the fundamental equations of the TOPMODEL. It should be noted that if z_i***<=0*** *then the saturation condition has been reached. All points with* z_i***<=0*** *generate a basin fraction where rainfall produces direct surface runoff.*

Initial conditions

The continuity equation (4) is initialized by assuming that the simulation begins after a long dry period and the flow observed at the basin outlet has been generated only by the subsurface flow contribution:

$$Q^1{}_{in} = 0 \quad , \quad Q^1{}_{out} = Q^1{}_{obs} \; .$$

Because the quantity $\boldsymbol{Q^t{}_{out}}$ can be defined analytically as ,

$$Q^t{}_{out} = Q_0 * e^{-f\,\overline{z}^t} \; , \quad \text{where} \quad Q_0 = A * T_0 * e^{-\lambda},$$

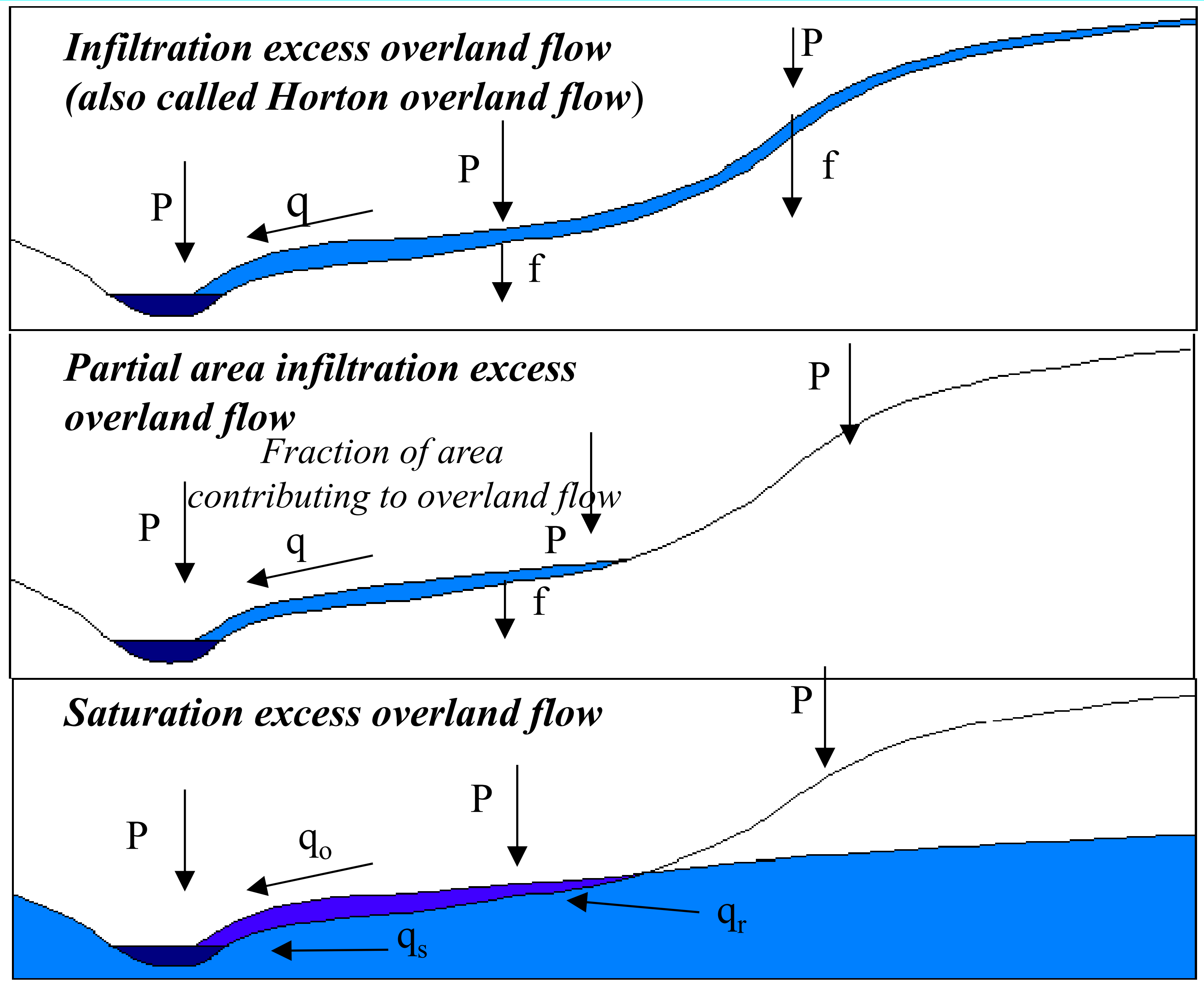
then the initial state is

$$\overline{z}^1 = -\frac{1}{f}\ln\left(\frac{Q^1{}_{obs}}{Q_0}\right) \; .$$

According to TOPMODEL the predicted hydrological responses depend upon the distribution of topographic index. The topographic index $\ln(a/\tan\beta)$ is defined on the basis by a computational procedure based on a digital elevation model (DEM) and repeated on all the DEM grid squares. The datasets include the $\ln(a/\tan\beta)$ subdivisions, the rainfall, potential evapotranspiration and observed dicharge data.

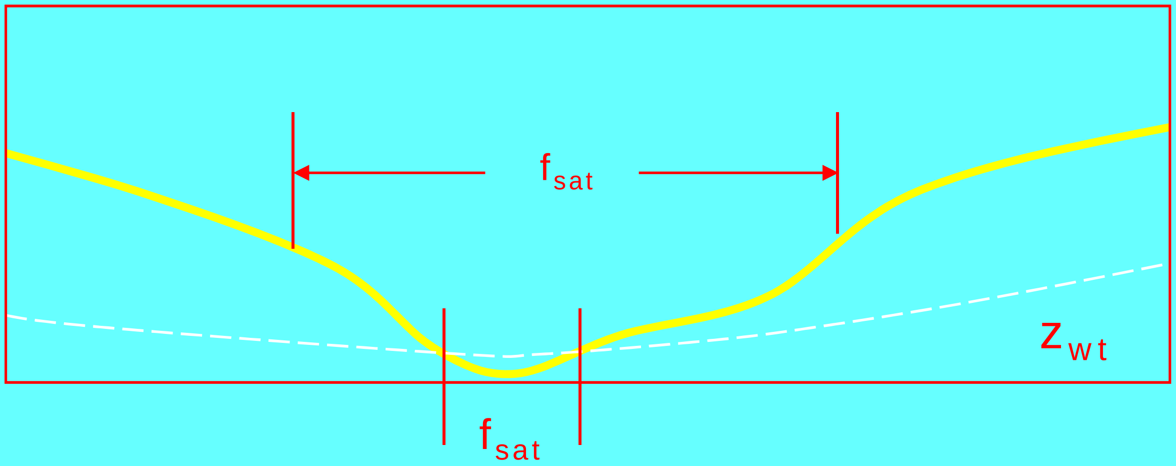
In this model the total flow is calculated as the sum of two terms: surface runoff and flow in the saturated zone. The surface runoff is in turn the sum of two component, the first generated by infiltration excess (Horton mechanism) and the second, referring to a variable contributing area, by saturation from below excess.

Model runoff generation processes



Relationship Between the Saturated Area and Water Table Depth

Expansion during a single rainstorm. (Dunne and Leopold, 1978)



$$f_{sat} = F_{max}(\lambda)\, e^{-C\, f\, zwt}$$

The Saturated Fraction the Grid-Cell

(Z.-L. Yang, G.-Y. Niu and R. Dickinson, 2006)

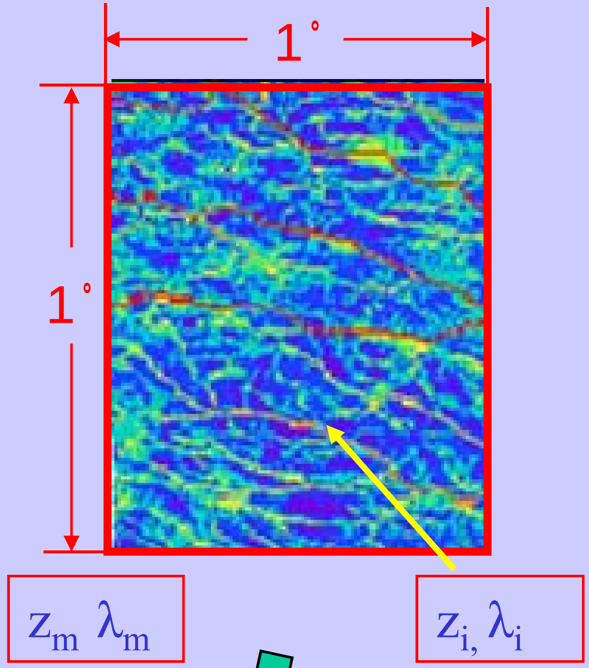
(Beven and Kirkby, 1979; Sivapalan et al., 1987):

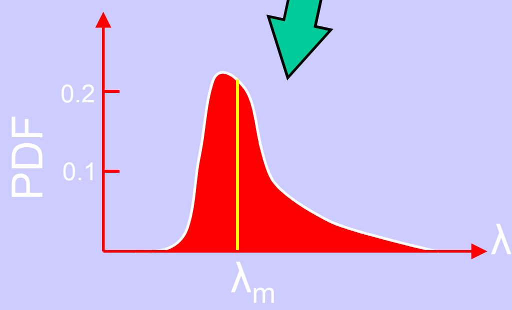
zi – zm = – (λi – λm) / f, where zi and λi are water table depth and topographic index at a pixel; while zm and λm are their grid-cell (catchment) mean values.

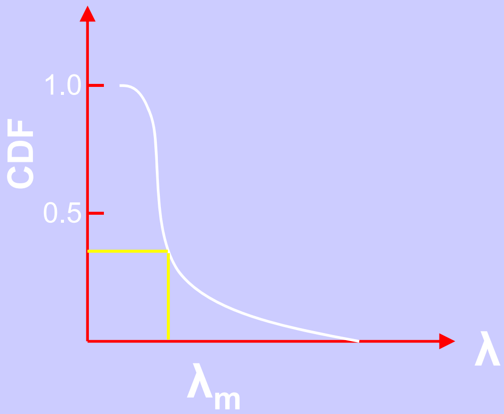
Fsat = Prob { zi < 0 }

or

Prob { λi > λm – fzm }

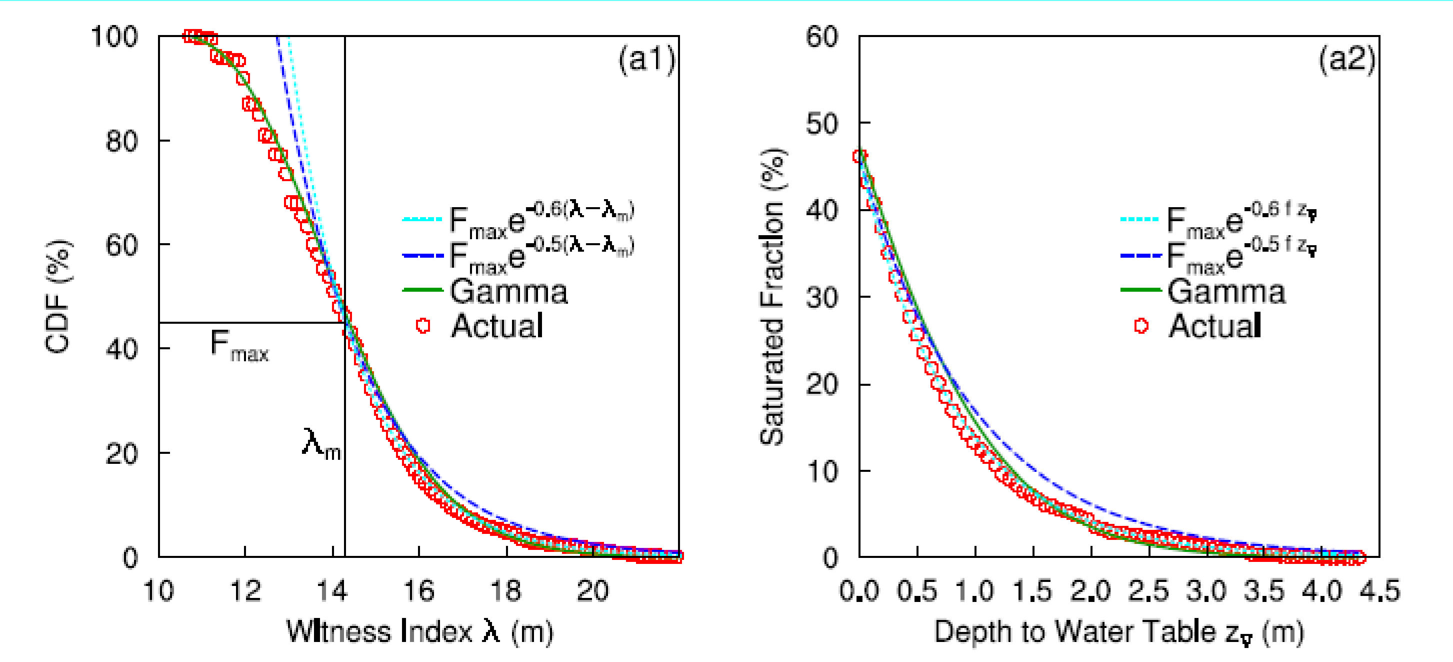


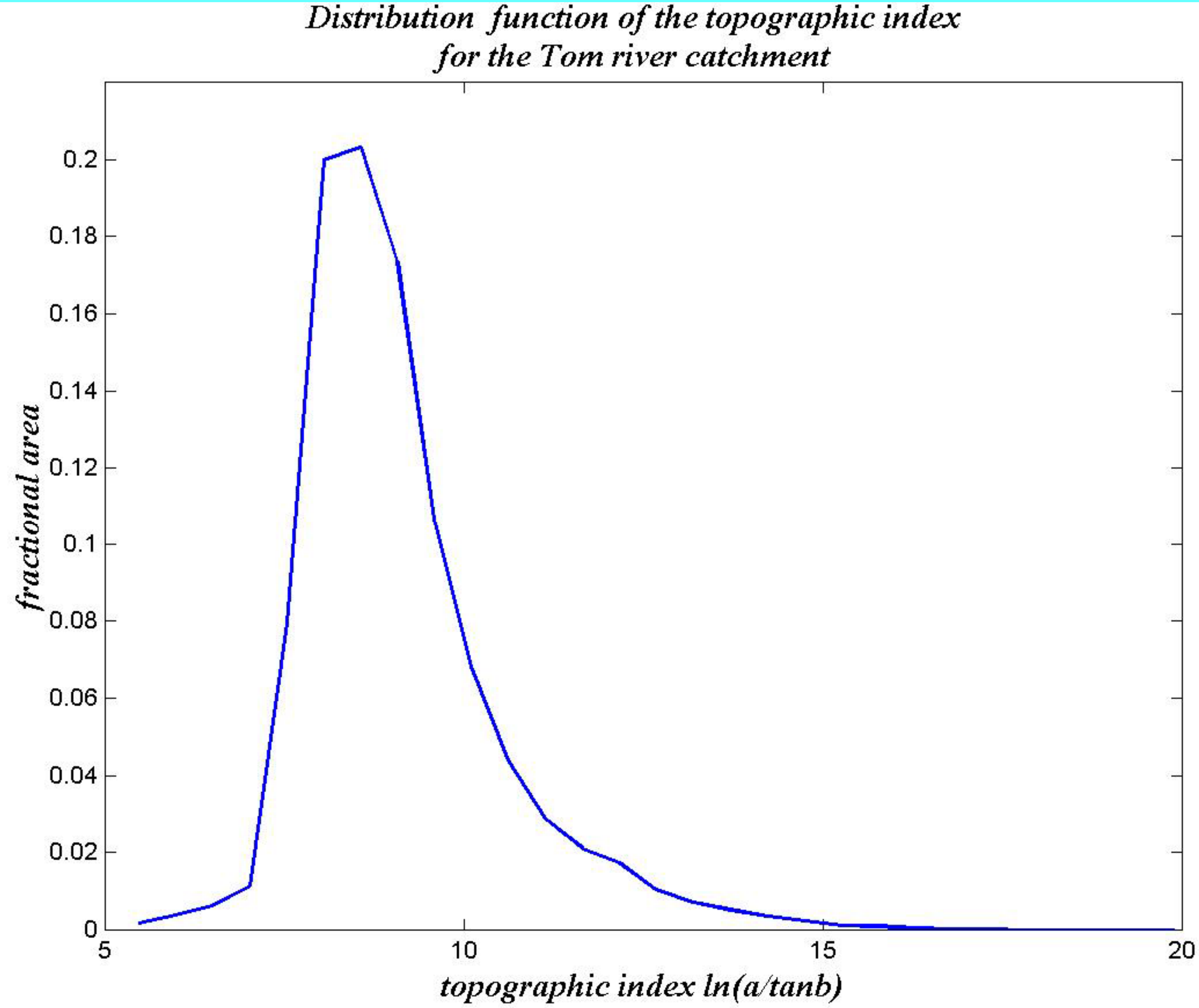




1 °x 1° arid-cell in the Amazon River basin

(Z.-L. Yang, G.-Y. Niu and R. Dickinson, 2006)




Distribution function of the topographic index
for the Tom river catchment
fractional area
topographic index ln(a/tanb)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
5
10
15
20

TOPMODEL

(TOPography-based hydrological MODEL

The use of TOPMODEL is considered a suitable starting point toward a proper representation of subgrid soil moisture variability at the land surface. Beven and Kirkby (1979) proposed TOPMODEL based on contributing area concept in hillslope hydrology.

The mathematical starting points used to derive the TOPMODEL equations are the continuity equation and Darcy's law. The basic assumptions that govern TOPMODEL are:

1. **the water table is nearly parallel to the soil surface so that the local hydraulic gradient is close to $\tan\beta$, where β is the local slope angle;**
2. **2) the saturated hydraulic conductivity of soil falls off exponentially with depth: $K_s(z) = K_0 e^{-fz}$, where z is the depth into the soil profile (z-axis pointing downwards), K_0 is hydraulic conductivity at ground surface, f is decay factor of K_s with z;**
3. **3) the water table is recharged at a spatially uniform, steady rate that is slow enough (relative to the response time of the catchment) to allow a water table distribution is always at equilibrium**

TOPMODEL

(TOPography-based hydrological MODEL

Given these assumptions an analytic equation can be derived between the catchment mean table depth $\overline{z}$ and the local water table z_i:

$$z_i = \overline{z} - \frac{1}{f}\left[\ln\frac{a_i}{\tan\beta_i} - \lambda\right], \qquad (1)$$

where

$$\lambda = \frac{1}{A}\int_A \ln\frac{a_i}{\tan\beta_i}\,dA,$$

$\ln\frac{a_i}{\tan\beta_i}$ is called the topographic index.

TOPMODEL
(TOPography-based hydrological MODEL

Equation (??) shows that the position of the i-th point is not important, but the value of the corresponding topographic index $\ln(a_i/\tan\beta_i)$ as an index of hydrological similarity. If λ^* is the value of $\ln(a_i/\tan\beta_i)$ which produces $z_i = 0$, then all the points with $\ln(a_i/\tan\beta_i) \geq \lambda^*$ are in a saturated condition. The basin percentage with $\ln(a_i/\tan\beta_i) \geq \lambda^*$ is then defined on the basis of the index curve. This curve represents the probability distribution of the variable

$\ln(a_i/\tan\beta_i)$. The value of $\overline{z}$ is updated at every Δt on the basis of the following equation:

$$\overline{z}^{t+1} = \overline{z}^t - \frac{(Q_v^t - Q_b^t)}{A}\Delta t,$$

where Q_v^t is recharge rate of the saturated zone from the unsaturated zone over the time interval $[t, t+1]$, Q_b^t is groundwater discharge to the stream over all grids over the time interval Δt, A is total area of the basin.

Groundwater discharge is determined analytically as $Q_v = AT_0 e^{\ \lambda} e^{\ f\overline{z}^t}$. Discharge is composed of overland flow and baseflow. Overland flow from grid cell i , Q_{ofi}^t can be given as follows

$$Q_{ofi}^t = S_{uzi}^t - S_i^t,$$

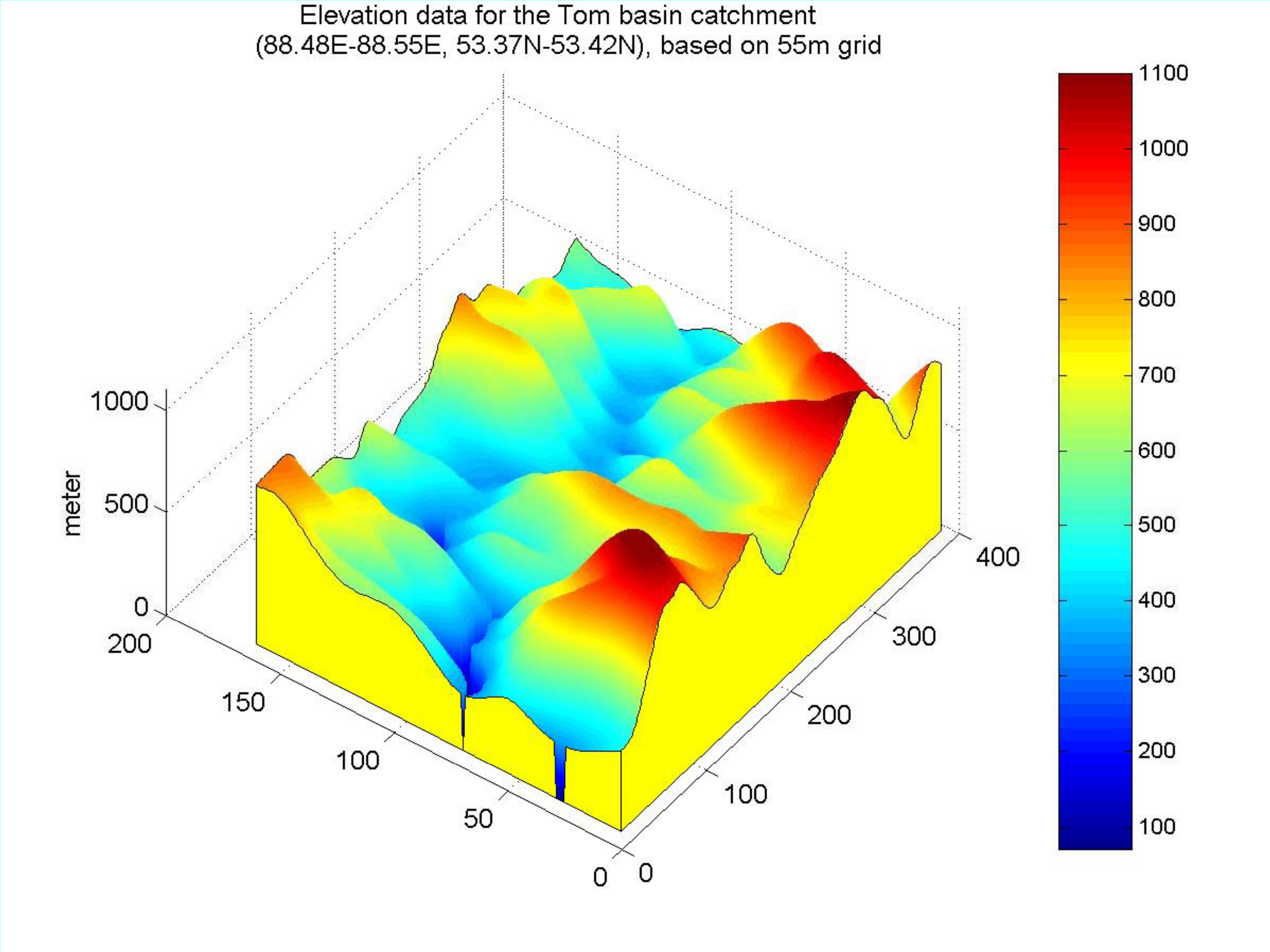
where S_i^t is local saturation deficit ($S_i = z_i(\vartheta_s - \theta_r)$, θ_s and θ_r are the moisture content in the saturated soil and the residual moisture content, respectively); S_{uzi} is the unsaturated zone storage . The discharge from grid cell i to the stream unit width is the sum of Q_{ofi}^t and Q_{bi}^t.

TOPMODEL
(TOPography-based hydrological MODEL

The $\ln(a/\tan\beta)$ values are calculated from a digital elevation model (DEM) for every single grid cell of the catchment using the algorithm of multidirectional flow in 8 directions. In order to suppress the generation of very large $\ln(a/\tan\beta)$ values, the upslope drainage area for each cell can be limited by a threshold which supports the creation of a river net. Input data for TOPMODEL are DEMs and time series data for precipitation and potential evapotranspiration. Data for measured discharges can be used for validation. Output data include simulated discharges, actual evapotranspiration and information on the build-up of soil moisture and averages of soil moisture deficit.

The example of application of TOPMODEL refers to the small forested catchment of Tom river basin (88.48^0 E– 88.55^0 E, 53.37^0 N– 53.42^0 N, area approximately 90 km^2).

The data available for this basin are the hourly rainfall values over the period 1 January – 31 December 1978, as well as the DEM with a spatial resolution of 30 arcseconds. Figure 1 shows (a) the distribution function of the $\ln(a/\tan\beta)$ topographic index for the Tom river catchment, corresponding to (b) the map based on 55 m grid model.


Elevation data for the Tom basin catchment
(88.48E-88.55E, 53.37N-53.42N), based on 55m grid
meter
1000
500
0
200
150
100
50
0
0
100
200
300
400
1100
1000
900
800
700
600
500
400
300
200
100

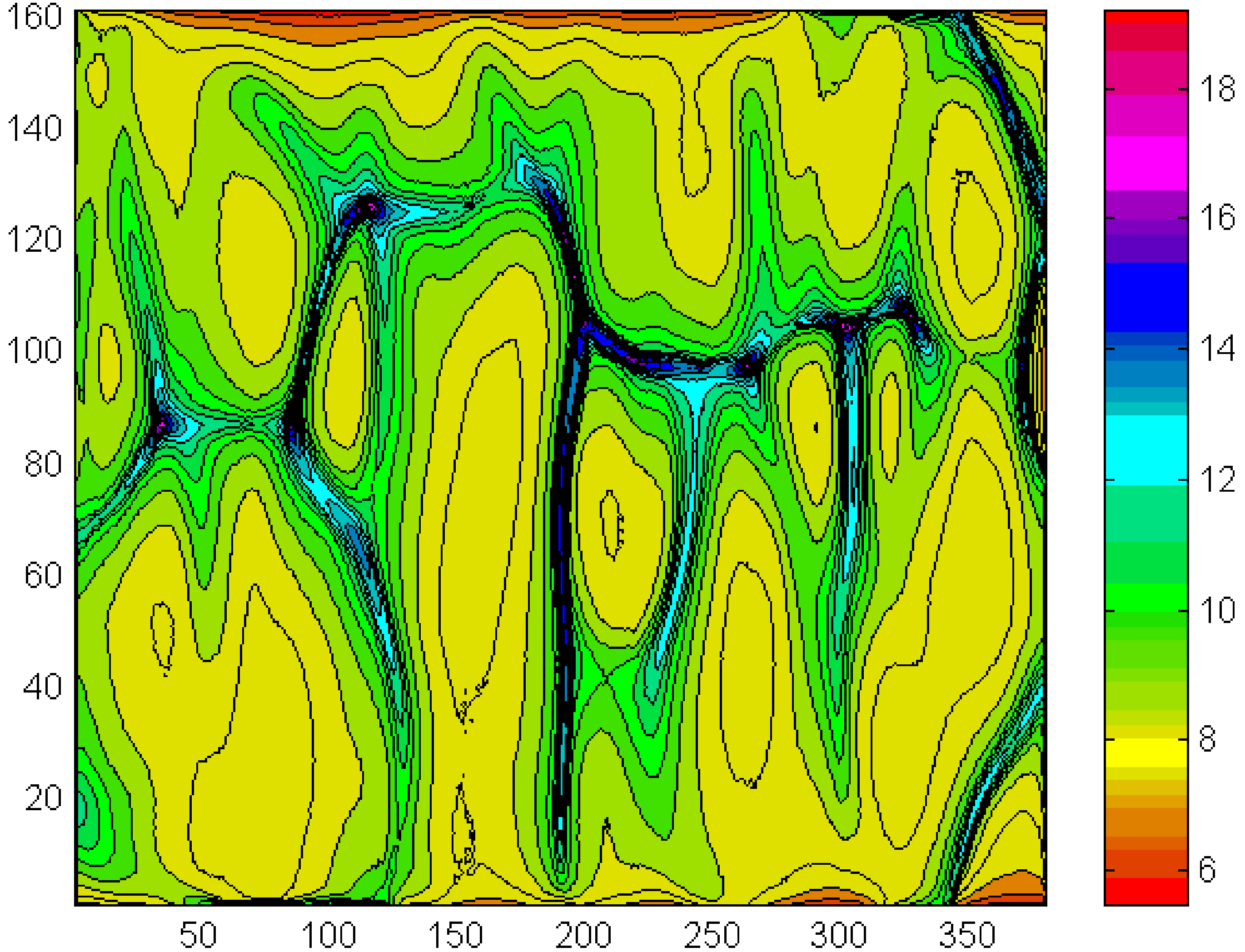
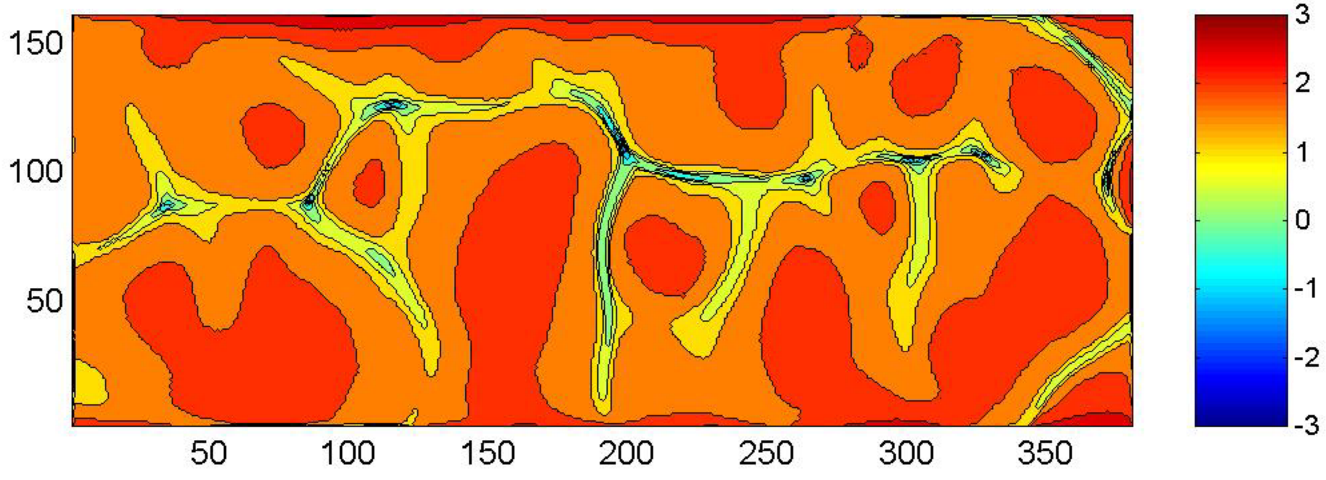
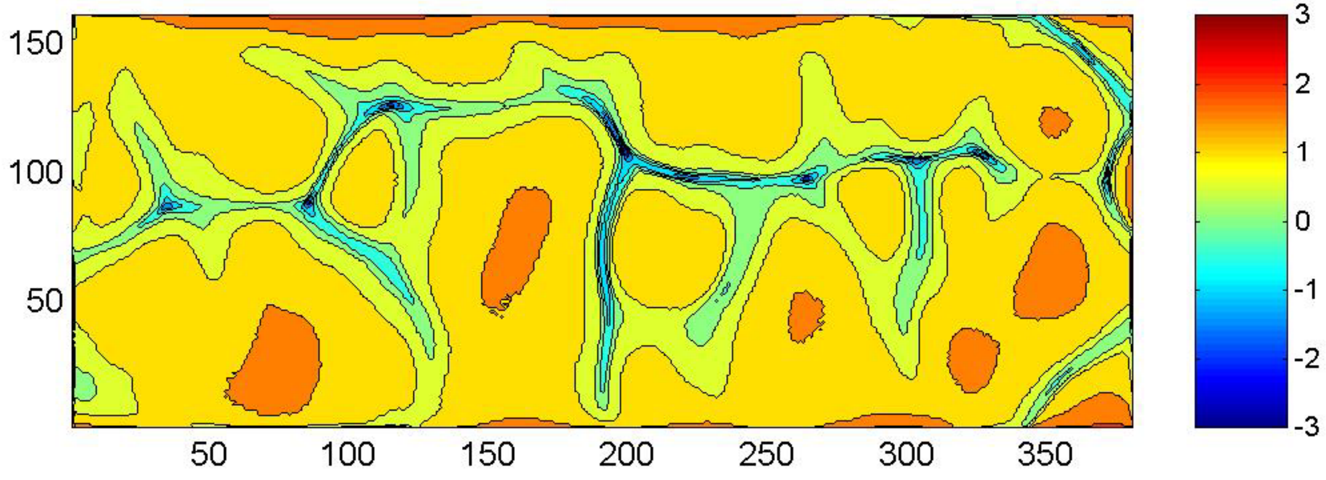


Figure . Map of the topographic index for Tom river catchment, based on 55m grid

A 2D map of the saturation status. 1-st day.



The same, only for the 31-st day.



Topography-related runoff model

The hydrologic cycle over land includes interception of water by plant foliage and wood, throughfall and stemflow, infiltration, runoff, soil water, and snow. These are directly linked to the biogeophysics and also affect temperature, precipitation, and runoff.

Total water balance of the soil column is

$$\Delta W_{can} + \Delta W_{sno} + \sum_i \Delta\theta_i \Delta z_i = (q_{prec} - e_{vevap} - e_{gevap} - q_{over} - q_{drai})\Delta t, \quad (2)$$

where W_{can} is canopy water, Δt is time step, q_{prec} is total precipitation, e_{vevap} is vegetation evapotraspiration, e_{gevap} is ground evaporation, q_{over} is surface runoff (overland flow), q_{drai} is subsurface drainage.

Topography-related runoff model

We assume that soil is saturated ($\frac{\theta}{\theta_{sat}} = 1$) for lakes and wetland.

Surface runoff and infiltration

The water at the soil surface either infiltrates (mm/s) into soil column or is lost as surface runoff (mm/s). Surface runoff is (ignoring spatial heterogeneity)

$$R = \begin{cases} (P+Q), P > 0, \frac{\theta_1}{\theta_{sat}} \geq 1, (Dunne\_runoff) \\ (P+Q-I_{\max}), P > 0, \frac{\theta_1}{\theta_{sat}} < 1, Q > I_{\max}, (Horton\_runoff) \\ (P+Q-I_{\max}), P > I_{\max} - Q, \frac{\theta_1}{\theta_{sat}} \leq 1, Q < I_{\max}, (Horton\_runoff) \end{cases}$$

where P is precipitation rate (mm/s) , $Q = q_{melt} + q_{sdew} (mm/s)$, $I_{\max}$ is infiltration capacity (mm/s) which depends of $\frac{\theta_1}{\theta_{sat}}$. All surface water (P+Q) is lost as Dunne runoff when the soil is saturated ($\frac{\theta_1}{\theta_{sat}}$ >1). Horton runoff occurs when soil is not saturated and when P+Q > $I_{\max}$. Infiltration is

$$I = P + Q - R$$

Topography-related runoff model

Saturated hydraulic conductivity

The parameterizations follows closely the TOPMODEL framework [Beven &Kirkby, 1979] and work of Stieglitz et al. (1997). The saturated hydraulic conductivity decreases with depth according to

$$K_{sat}(z) = K_{sat}(0)e^{-fz},$$

where z is soil depth, $K_{sat}(0)$ is the surface value of saturated hydraulic conductivity, and $1/f$ - e-folding depth of K_{sat} can be determined through the procedure of optimization.

ICMMG Land Surface model (LSM – NCAR, 1996)

In the ICMMG land-surface model the soil moisture is calculated at the interface level of the model layers

$$k_{i+\frac{1}{2}} = \frac{2\Delta z_{i+\frac{1}{2}}}{\left(\frac{\Delta z_i}{k_i} + \frac{\Delta z_{i+1}}{k_{i+1}}\right)} q_{i+\frac{1}{2}} = -k_{i+\frac{1}{2}}\left[\frac{(\psi_{i+1} - \psi_i)}{\Delta z_{i+\frac{1}{2}}} - 1\right]$$

$q_{i+\frac{1}{2}}$ is the soil moisture flux at the interface level between layers $i$and $i+1$, ψ_i, Δz_i are matrix potential and layer thickness at layers i and $i+1$. Hydraulic conductivity k and soil matrix potential ψ depends on volumetric soil water content θ $(\mathrm{m}^3/\mathrm{m}^3)$ and soil texture. For the i- th layer (Cosby et al., 1984)

$$k_i = k_{sat}\left(\frac{\theta_i}{\theta_{sat}}\right), \quad \psi_i = \psi_{sat}\left(\frac{\theta_i}{\theta_{sat}}\right)^{-b} ,$$

where k_{sat} - hydraulic conductivity at saturation k_{sat} (mm/s), ψ_{sat} - matrix potential at saturation (mm), water content at saturation θ_{sat} (porosity), and b are empirically related to perant of sand and clay. Hydraulic conductivity at saturation k_{sat} vary with percent of sand according to Clapp&Hornbergor (1978): $k_{sat}(0) = 0.0070556 * 10^{-\alpha+\beta(\%sand)}$, where α and β can be determined through optimization procedures.

Water table

The soil water may exceed the physical constraints. Any soil in excess of saturation

$$\sum(\theta_i - \theta_{sat})\Delta z_i = W_{ex}$$

is added to the soil, starting at the top of the soil layer. Any remaining excess water is added to the **subsurface drainage** $q_{i,drain}$ **(subsurface runoff).** This saturation excess is used to recharge the soil layers above water table.

If the column becomes oversaturated, subsurface runoff due to saturation excess is

$$R_{sat,sb} = \max\left[0, \left(\sum(\theta_i - \theta_{sat}\right)/\Delta t)\right].$$

Water table

The water table depth z_w is used to determine saturated function, surface runoff and baseflow. The method of Chen&Kumar (2001) can be used here to evaluate water table. After the soil moisture is obtained, the soil moisture deficit for column is given by (8). Assuming that there is no vertical moisture flux, then total head must be conserved within the soil column

$$\psi(z) - z = \psi_{sat} - z_w \quad , \tag{3}$$

or

$$\psi_{sat}\left(\frac{\theta(z)}{\theta_{sat}}\right)^{-b} - z = \psi_{sat} - z_w . \tag{4}$$

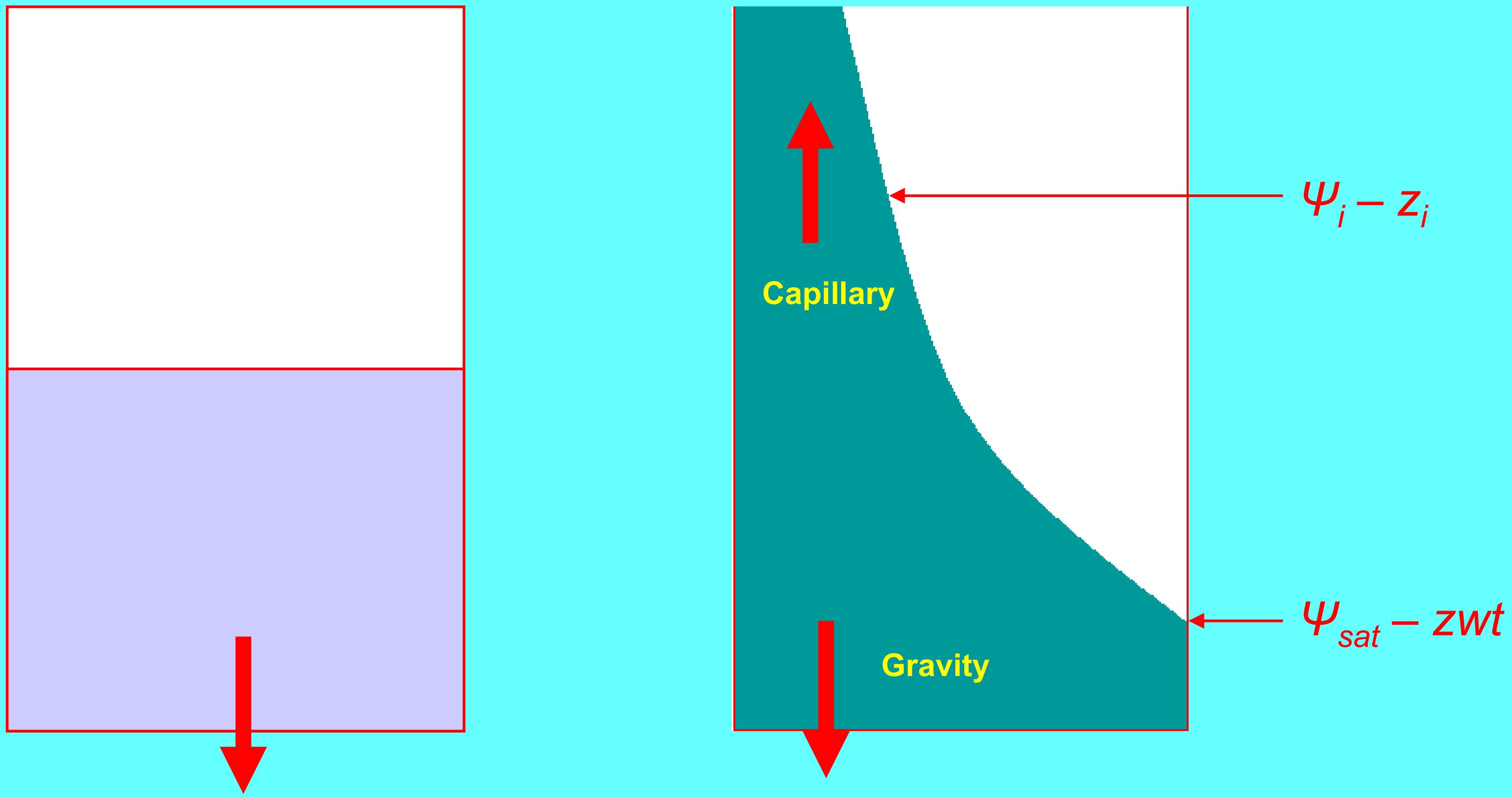
Therefore, soil moisture profile is

$$\theta(z) = \theta_{sat}\left(\frac{\psi_{sat} - (z - z_w)}{\psi_{sat}}\right)^{-\frac{1}{b}} . \tag{5}$$

Water table depth z_w is then computed by solving the equality

$$W_{ex} = \int_0^{z_w} (\theta_{sat} - \theta(z))dz$$

iteratively.

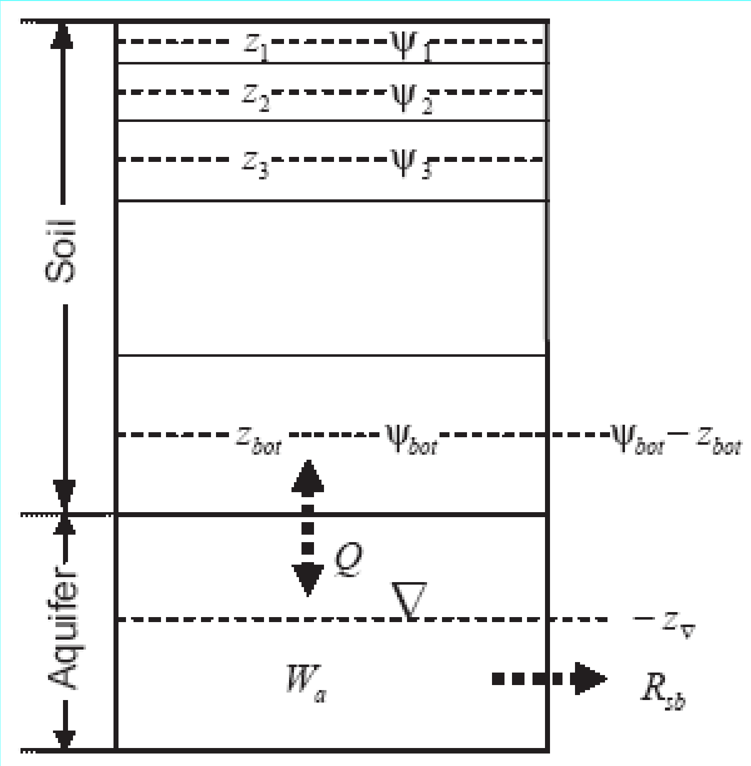


Water profile under gravity

Soil water profile when gravity equals to capillary force

Simple groundwater model (SIMGM) for use in GCMs

(Z.-L. Yang, G.-Y. Niu and R. Dickinson, 2006)



$$\frac{dW_a}{dt} = Q - R_{sb}$$

$$Q = -K_a \frac{-z_\nabla - (\psi_{bot} - z_{bot})}{z_\nabla - z_{bot}}$$

$$= K_a \left(1 + \frac{\psi_{bot}}{z_\nabla - z_{bot}}\right)$$

Gravitational Drainage

Upward Flow under capillary forces

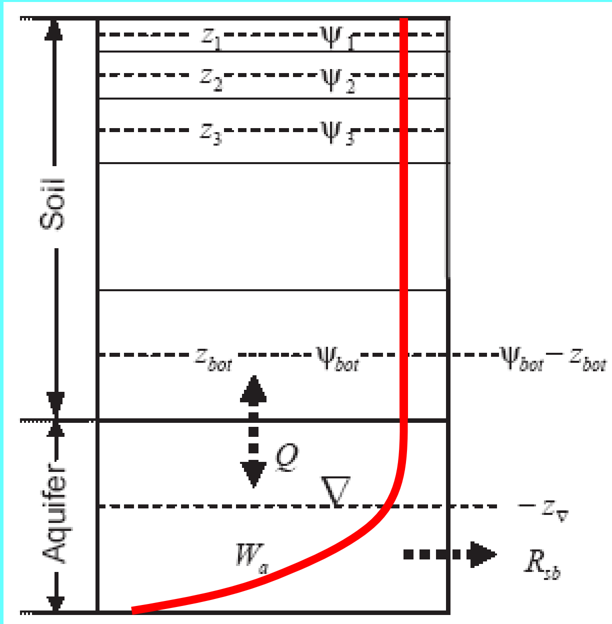
Simple groundwater model (SIMGM) for use in GCMs

Groundwater Discharge

$$R_{sb} = R_{sb,\max} e^{-f z_{\nabla}}$$

Properties of the Aquifer
Hydraulic Conductivity:

$$K_{sat} = K_{sat,bot} e^{-f(z - z_{bot})}$$



Topographic effect of new version LSM

In order to focus on topographic effect of new version land-surface model, we describe only modified surface and subsurface runoff components of the land hydrology model.

Topographic effect of new version LSM

Surface runoff consists of overland flow by Dunne and Horton mechanism that was described before, topographic effect on runoff processes have mathematical representation. The mathematical representation of the surface runoff takes in the form of

$$R = \eta_s R_{s>1} + (1 - \eta_s) R_{s<1} \quad ,$$

where

$$\eta_s = \int_{|\overline{\chi} + f z_w| < \chi} \varphi(\chi) d\chi;$$

$\chi = \ln(a/\tan\beta)$ is topographic index, a is cumulative area, $\tan\beta$ is local slope; $\overline{\chi}$ is mean value of χ in the grid cell; $\varphi(\chi)$ is probability density function of χ; z_w is grid cell mean water table depth. Subsurface runoff is parameterized in form

$$R_{sub} = R_{sub,\chi} + R_{sub,drain} + R_{sub,ex},$$

where $R_{sub,\chi}$ is subsurface runoff due to topographic control, $R_{sub,drain}$ is bottom drainage and $R_{sub,ex}$ is saturation excess. Subsurface runoff due to topographic control is given by

$$R_{sub,\chi} = \alpha \frac{K_{sat}(0)}{f} e^{-(\overline{\chi} + f z_w)},$$

where α is factor accounting for the difference in the saturated hydraulic conductivity in lateral and vertical directions (Chen&Kumar, 2001).

$$\chi_{10'} = -0.07 + 1.62 \cdot \chi_{30''}$$

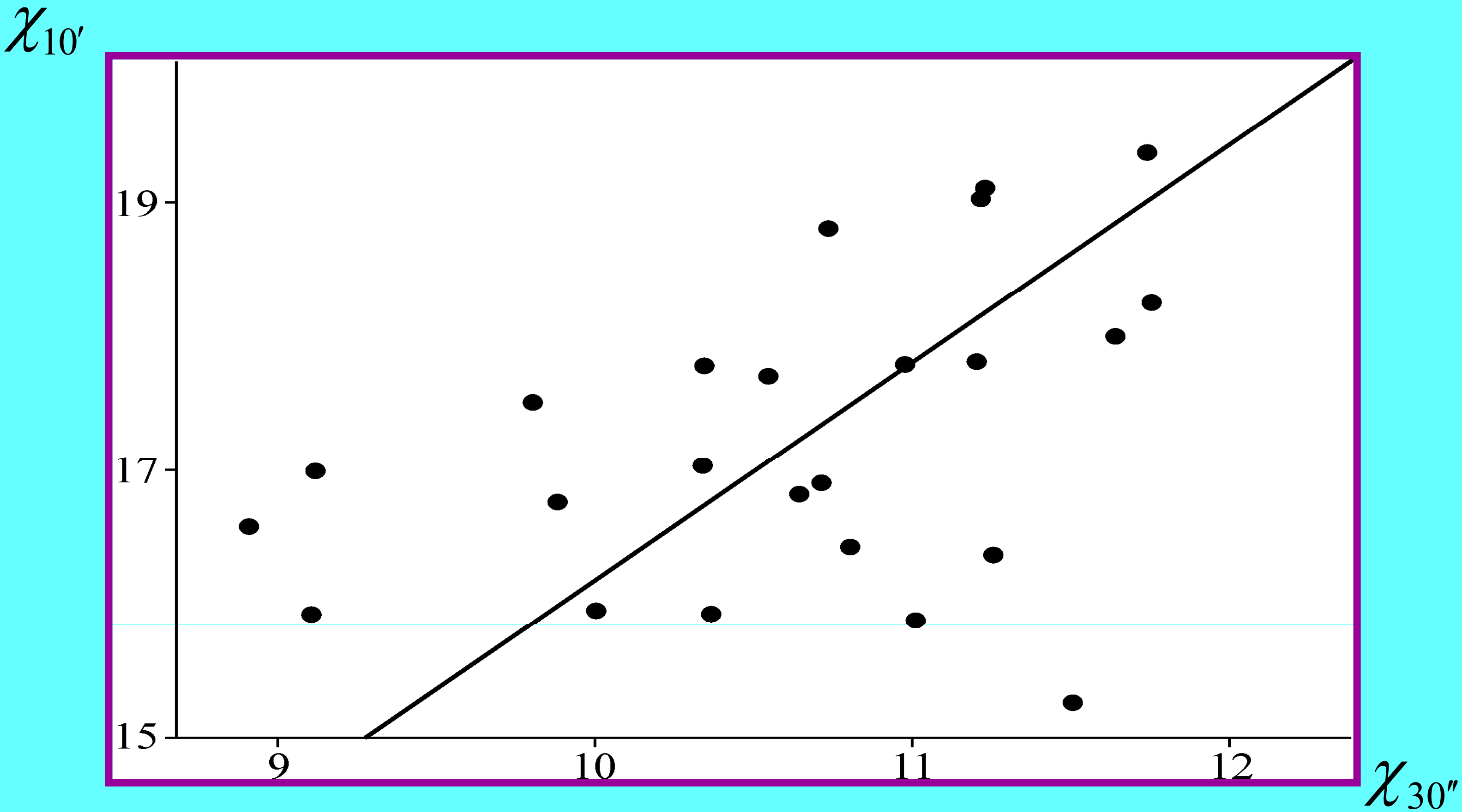
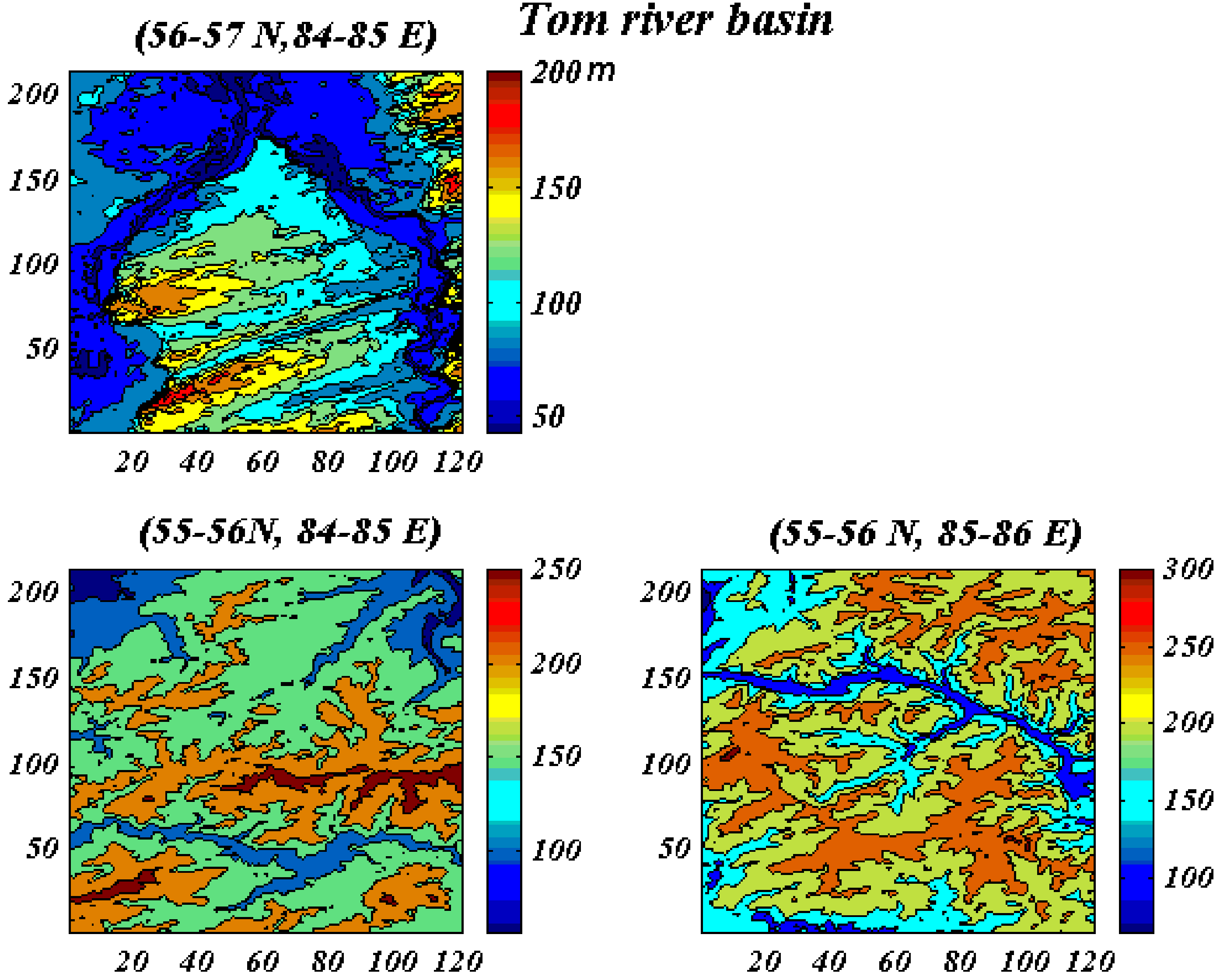


Figure 2. Upscaling function for obtaining 10' equivalent of a topographic index from its values for 30-arc-second DEM

Tom river basin



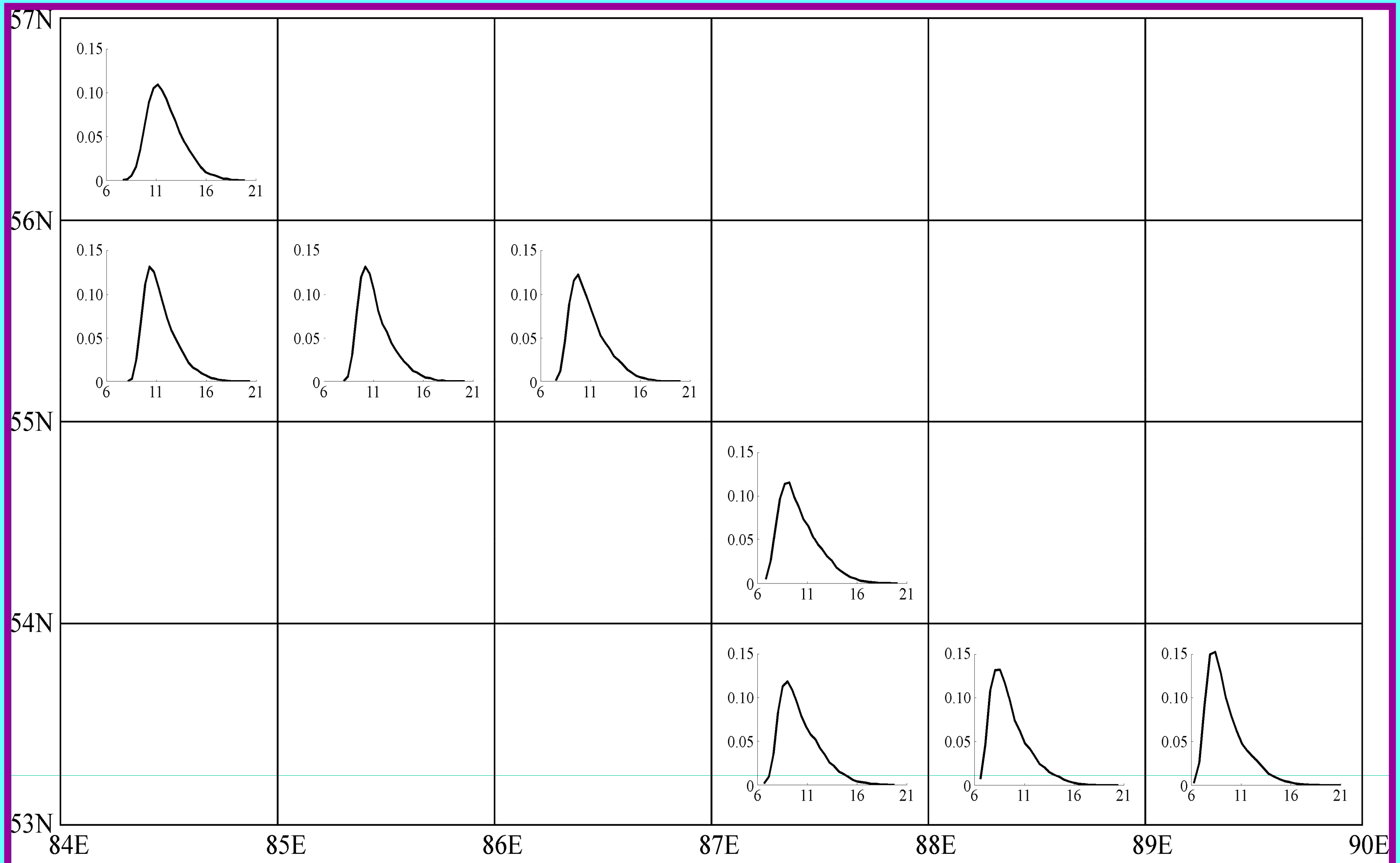


Figure 1. The topographic index computed from GTOPO30 DEMs for the Tom river basin

Figure 1. ln(a/tan b) distribution function computed from GTOPO30 DEMs for the Tom river basin

Model of river discharge

The total discharge into the Arctic peaks in June, whereas the peak is in May for the Atlantic Ocean and in August for the Indian Ocean.

Snow accumulation and melt have large effects on the annual cycle of discharge into the Arctic, Atlantic, Pacific, and global oceans, but little influence on the discharge into the Indian Ocean and the Mediterranean and Black Seas.

To estimate continental discharge into each ocean basin we must sum up the river outflow within each ocean basin. We decide to use some ideas of river routes water models to estimate river outflow. Using linear advection scheme at 1^0 resolution river rout water model from one cell to its downstream neighboring cell by considering balance of horizontal water inflows and outflows:

$$\frac{\Delta W_{riv}}{\Delta t} = \sum F_{in,i} - F_{out} + R$$

$F_{out} = v_m / r \; W_{riv}$;

v_m is the effective water flow velocity (Miller et al.,1994) ($v_m \approx 0.5$ m/s)

W_{riv} is storage of stream water within the cell (m3);

F_{out} is the water flux leaving the cell in the downstream direction (m3/s);

$\sum F_{in,i}$ is the sum of inflows of water from upstream cells (m3/s);

r is distance between centers of the cell and its downstream neighboring cell (m).

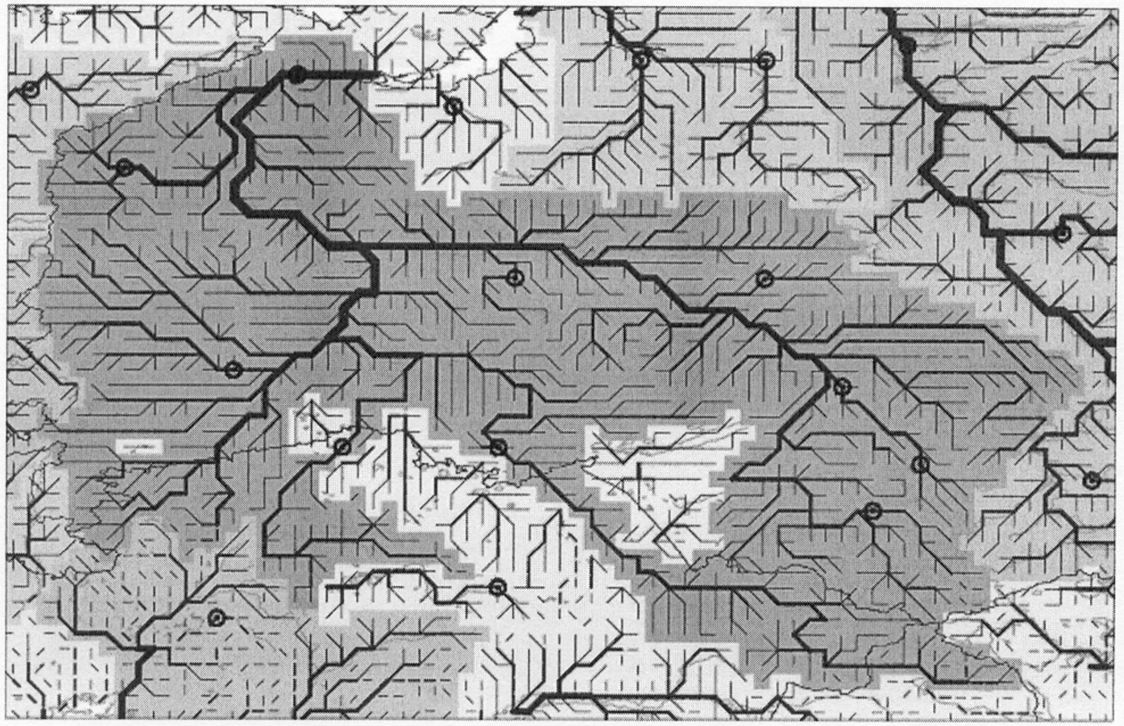
It takes some time to reach equilibrium under constant runoff field.

Estimation of this time is about 5-6 months with v_m = 0.5 m/s starting from empty river channel.

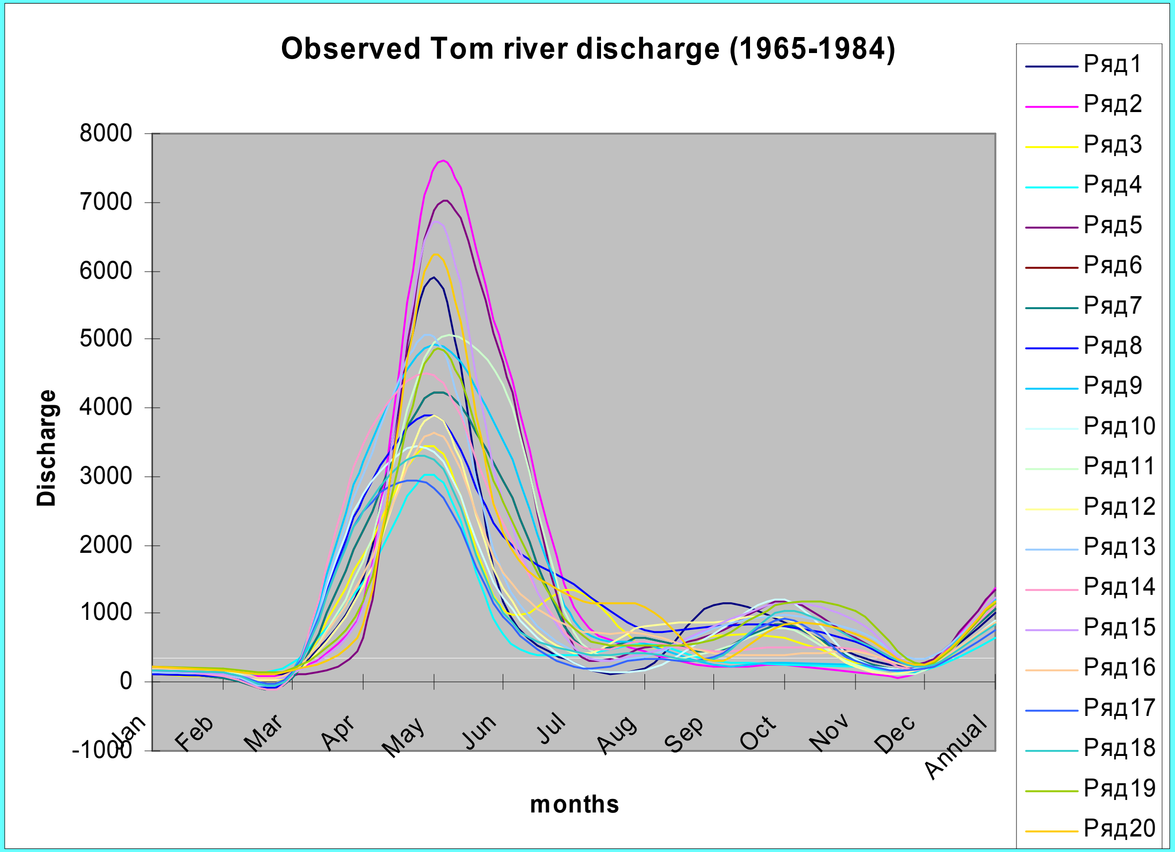
Therefore we must used river flow after 1500 model days in annual simulations.

Total Runoff Integrating Pathways (TRIP) - A Global River Channel Network (1997)
Taikan Oki and Y.C. Sud

Ob river basin



Results


Observed Tom river discharge (1965-1984)
Discharge
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Annual
months
Ряд1
Ряд2
Ряд3
Ряд4
Ряд5
Ряд6
Ряд7
Ряд8
Ряд9
Ряд10
Ряд11
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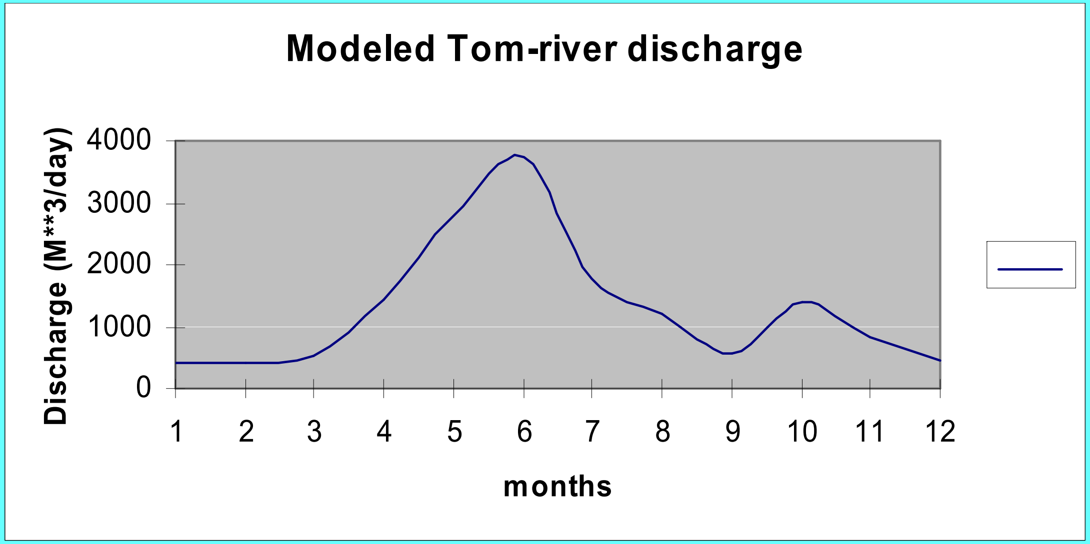
Ряд17
Ряд18
Ряд19
Ряд20



Modeled Tom-river discharge
Discharge (M**3/day)
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9
10
11
12
months

Conclusion

- **Total runoff (surface and sub-surface drainage) is routed downstream to oceans using a river routing model. River routing model is based on TOPMODEL ideas**

- **A river routing model is coupled to the Land Surface Model (ICMMG SB RAS) for hydrological applications and for improved land-ocean-sea ice-atmosphere coupling in the Climate System Model (CSM).**

- **We have implemented this model (off-line) on a 1-degree grid. Land model interpolates the total runoff from the column hydrology (2.8 by 2.8 degree) to the river routing 1-degree grid.**

- **Pictures we shown here are results from a regional 1° by 1° simulation (River Tom basin) using global ICMMG LSM. The model is driven with AMIP data from 1979 to 1993.**

- **Acknowledgements. The work was supported by RFFI № 05-05 – 94989a**