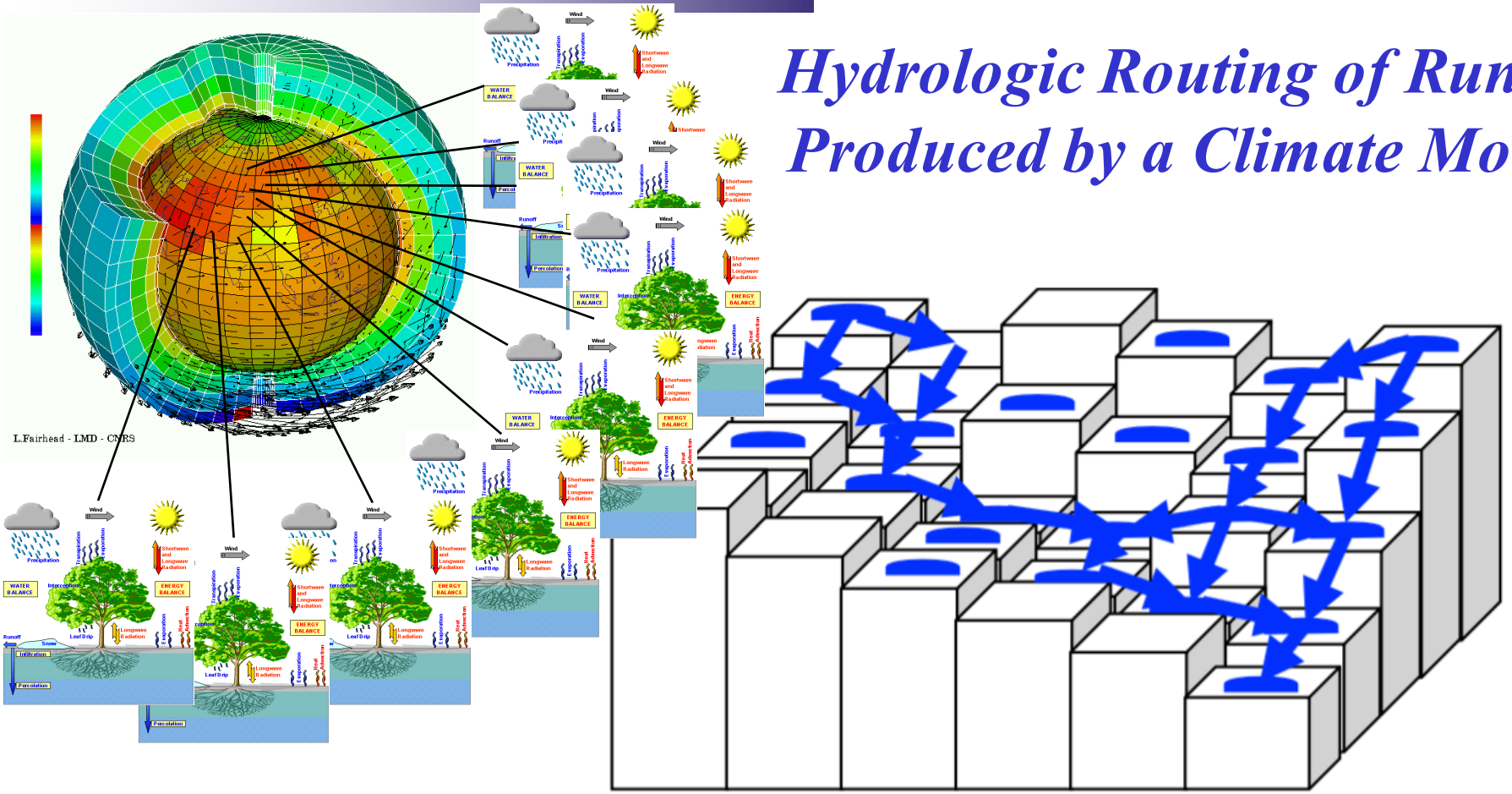
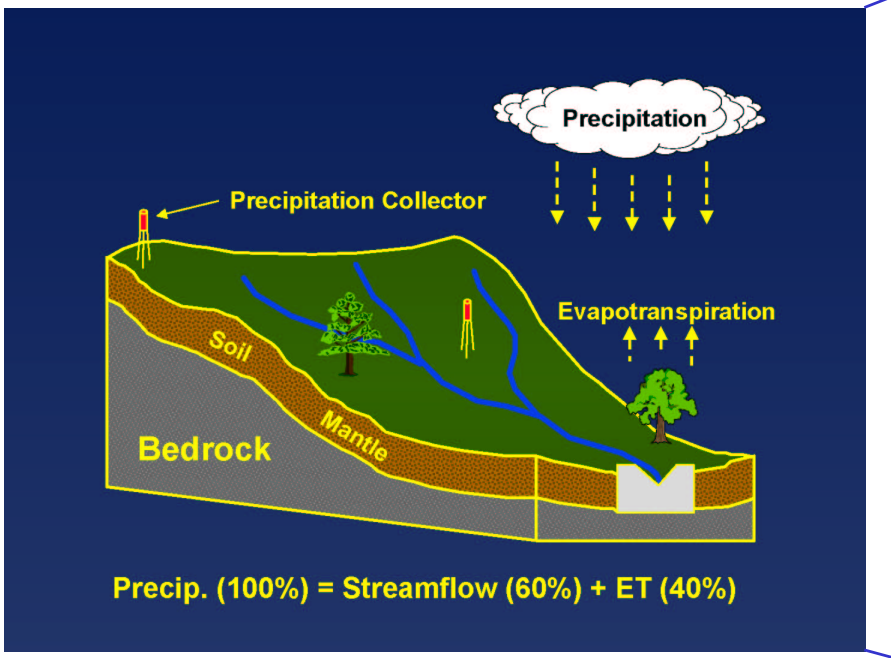


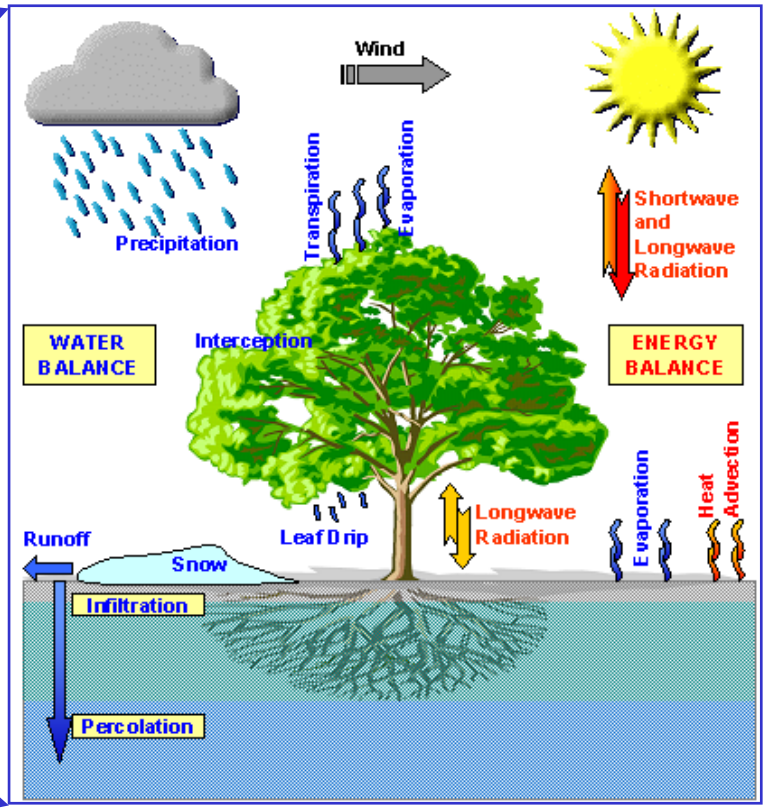
Hydrologic Routing of Runoff Produced by a Climate Model

Ömer Lütfi Şen

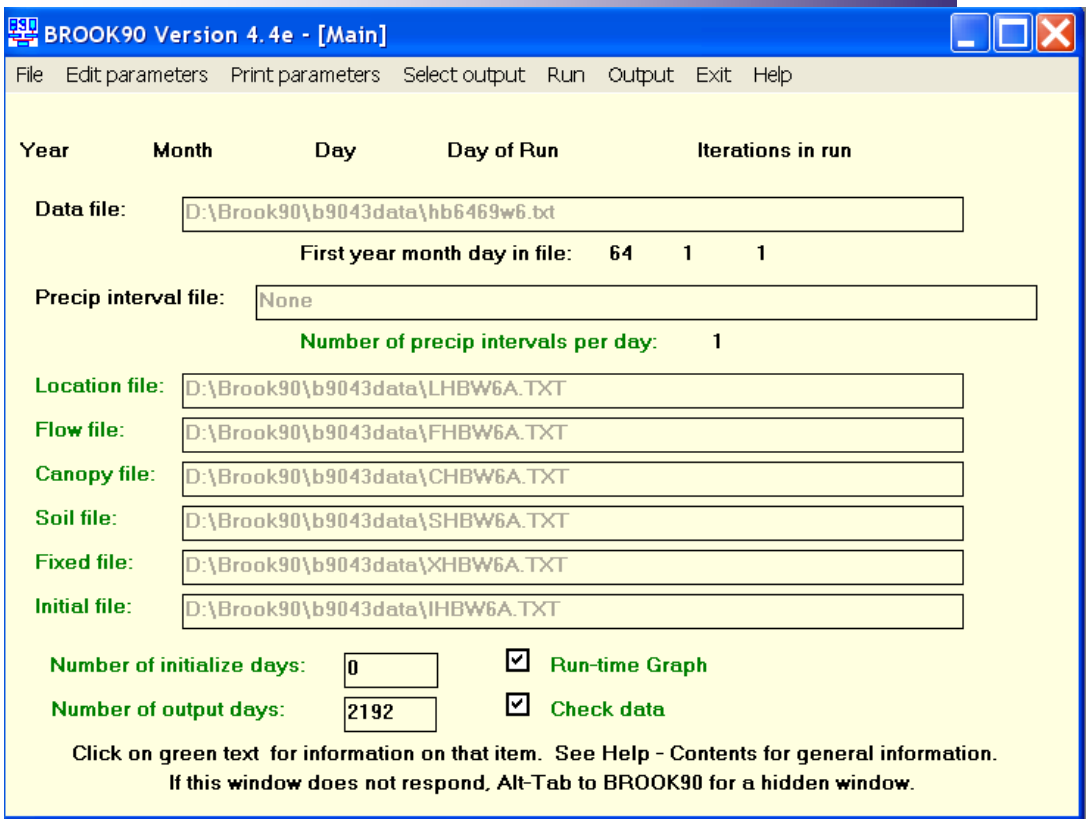
ITU Eurasia Institute of Earth Sciences

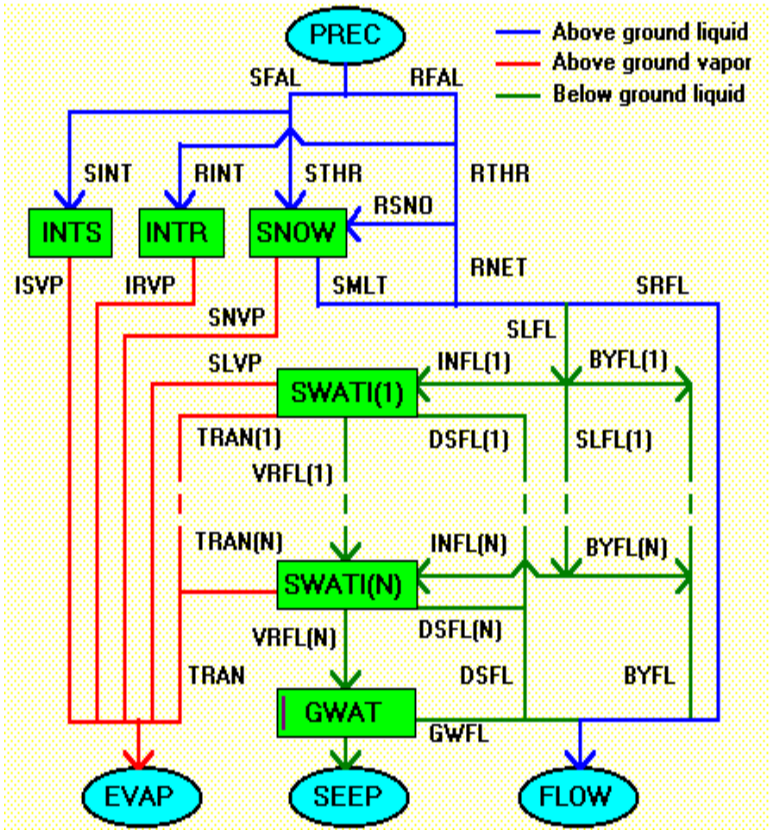
Hydrologic modeling in Small Watersheds





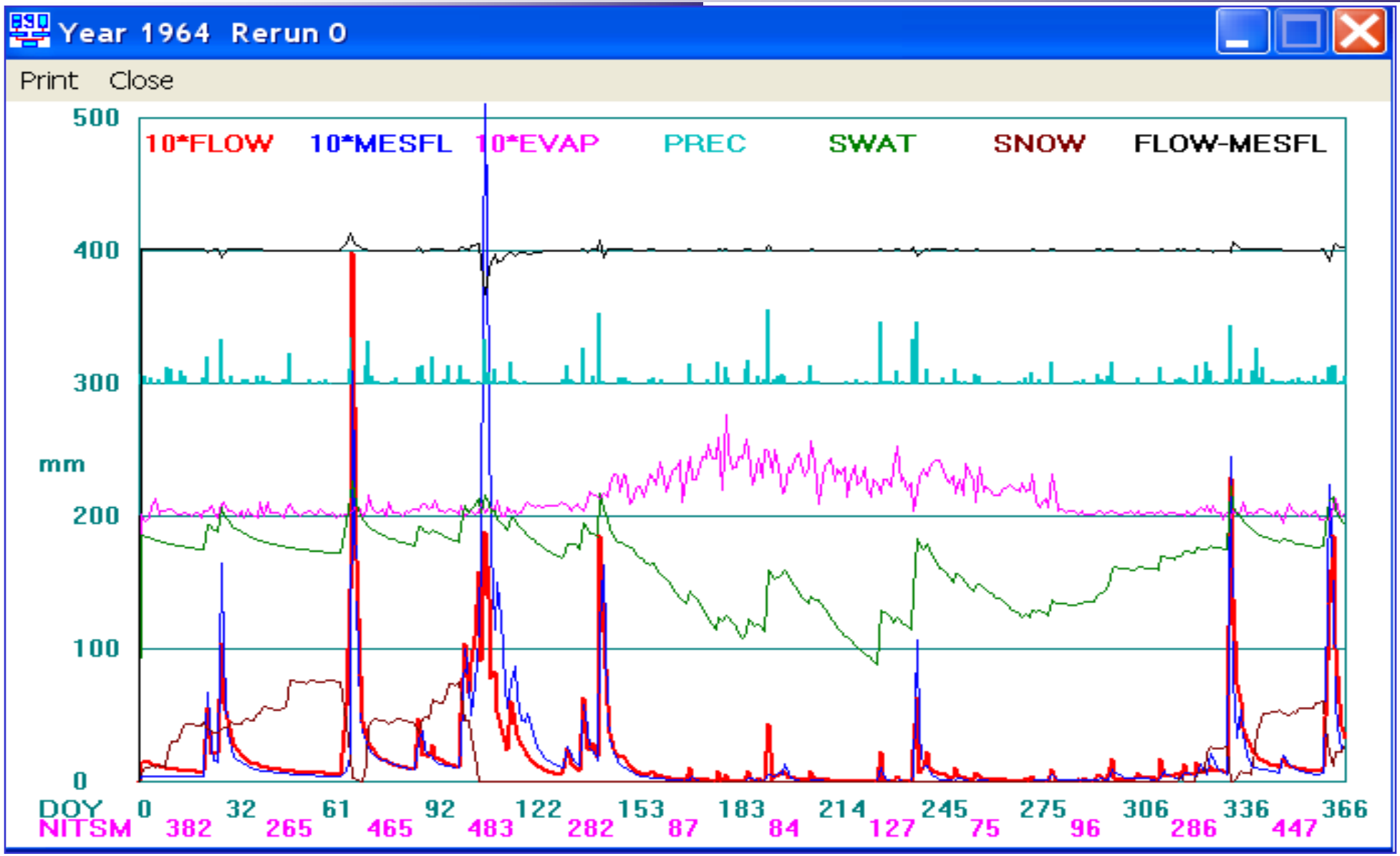
Small watershed modeling: BROOK90



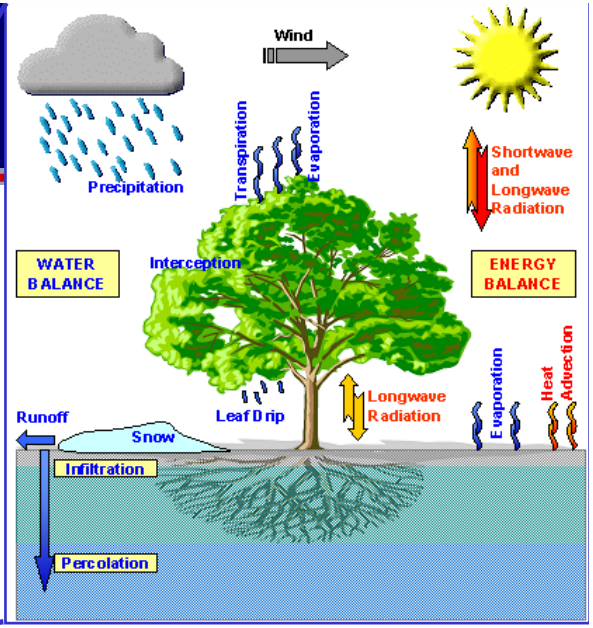


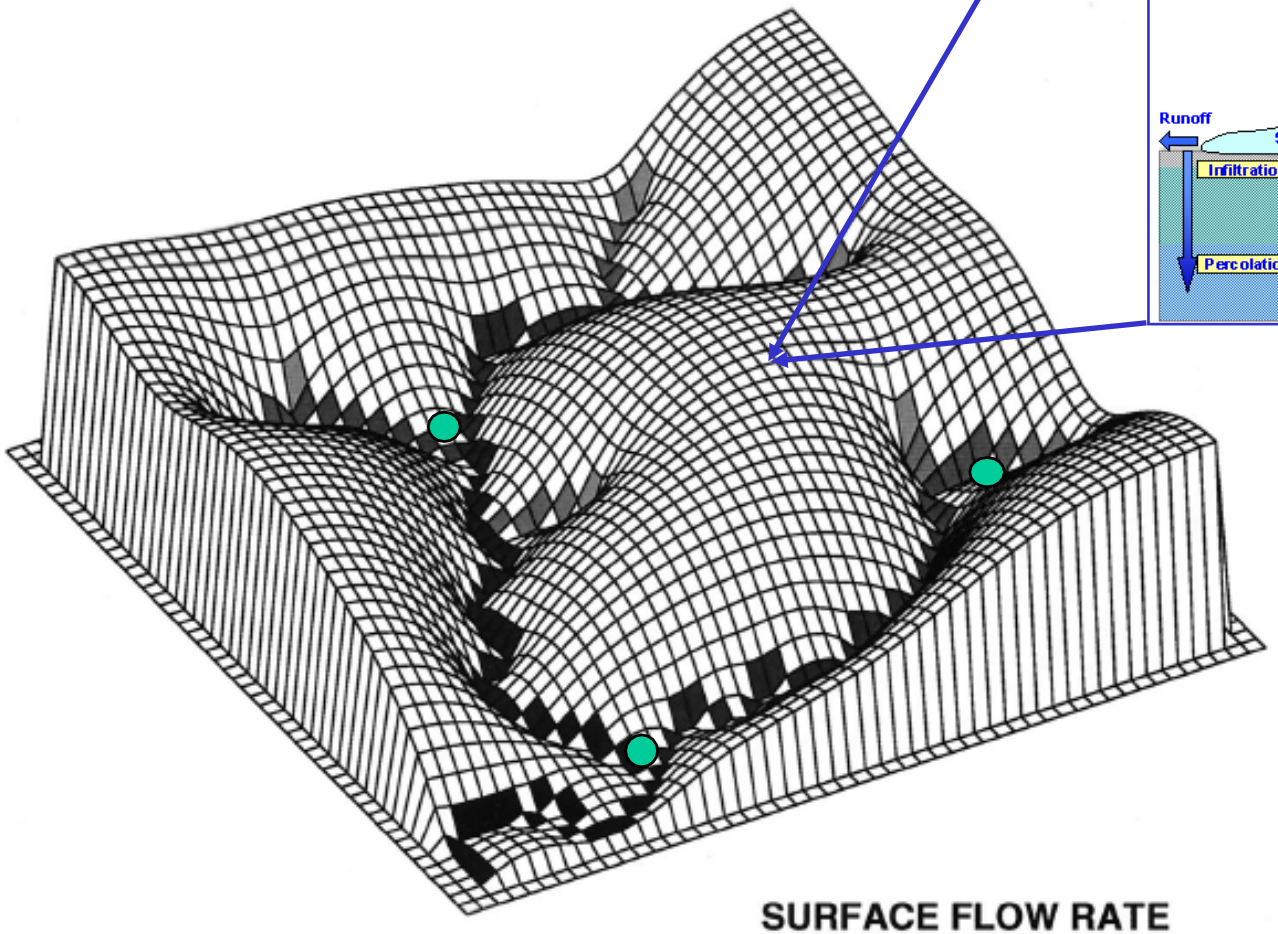
http://home.roadrunner.com/~stfederer/brook/brook90.htm

Small watershed modeling: BROOK90



Hydrologic Modeling in Large basins





SURFACE FLOW RATE
(Logarithmic scale)

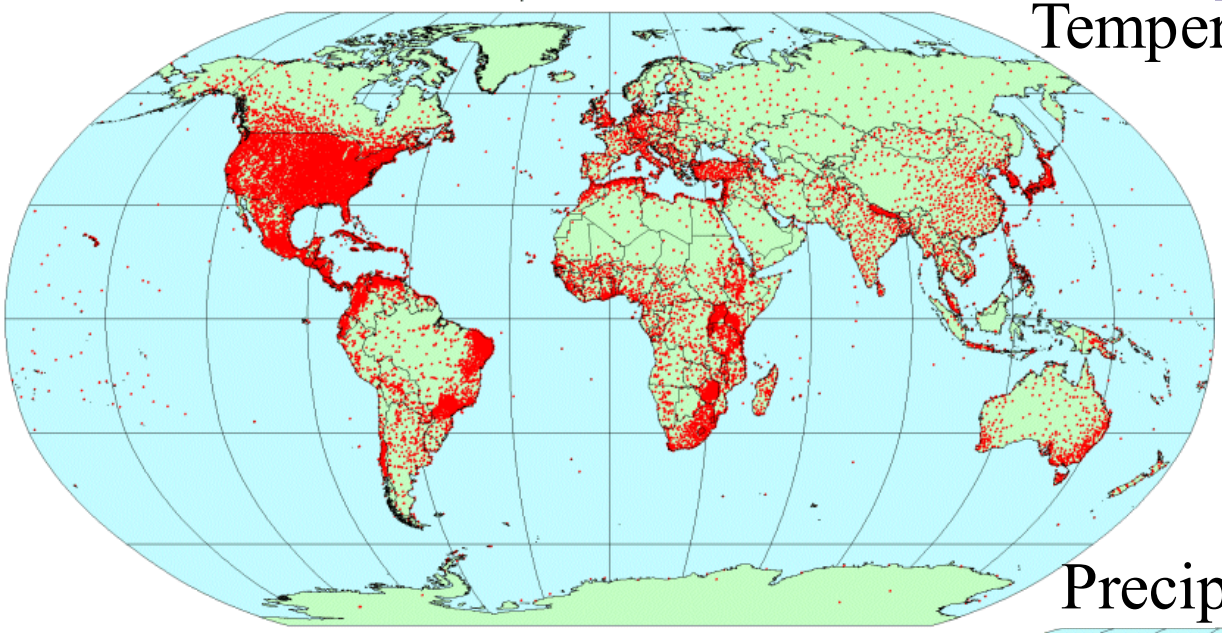
ZERO — MAX.

white = unsaturated

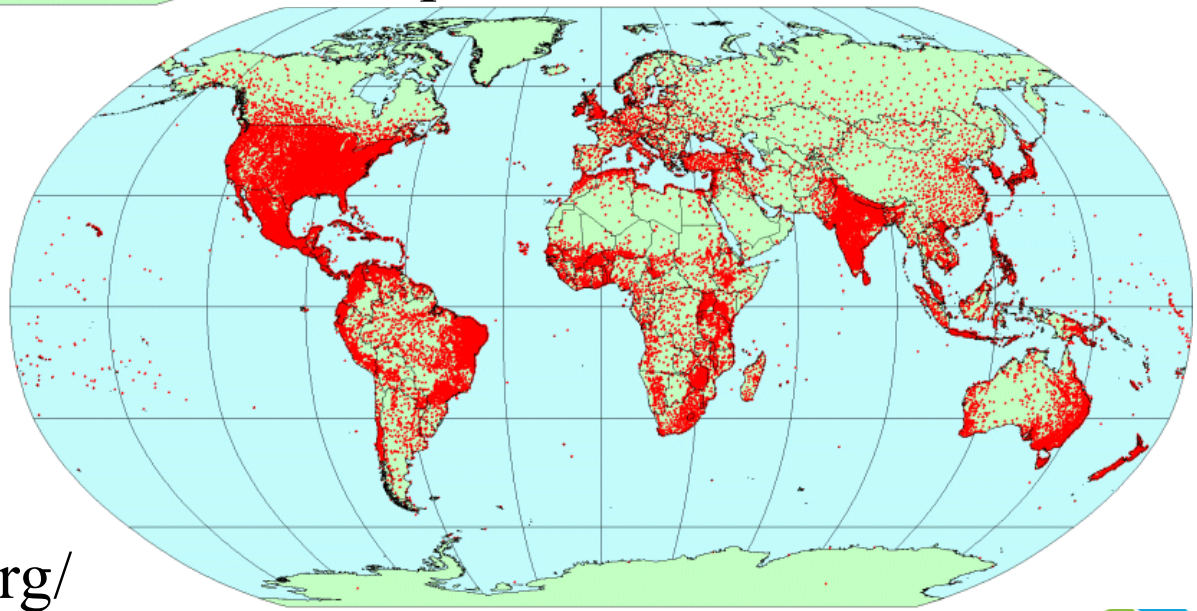
- Climate stations

World climate stations

Temperature stations

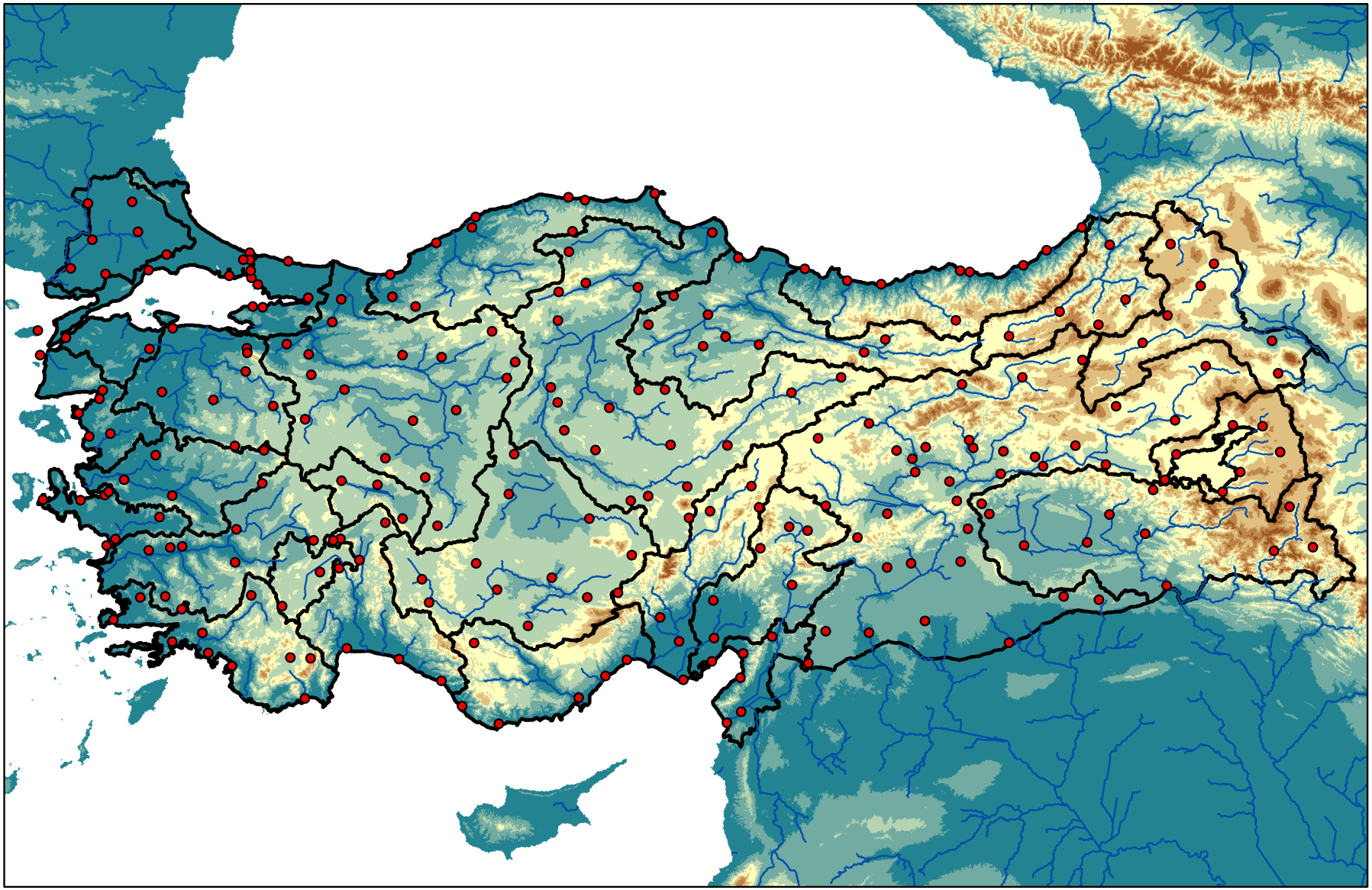


Precipitation stations

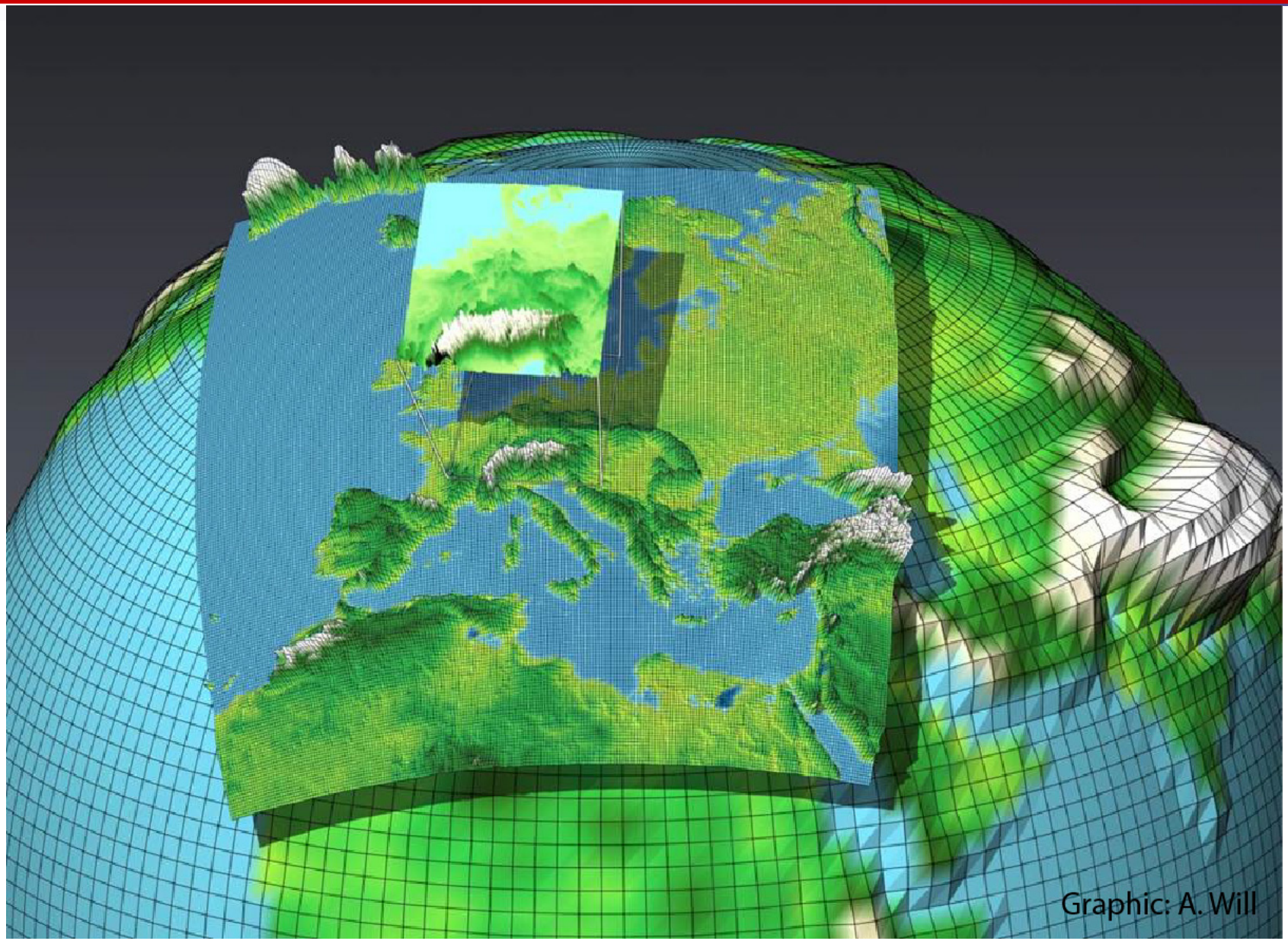


http://www.worldclim.org/

Climate stations and basins in Turkey



Global modeling and Regional Downscaling



Cell-to-Cell Routing Schemes for Climate Models

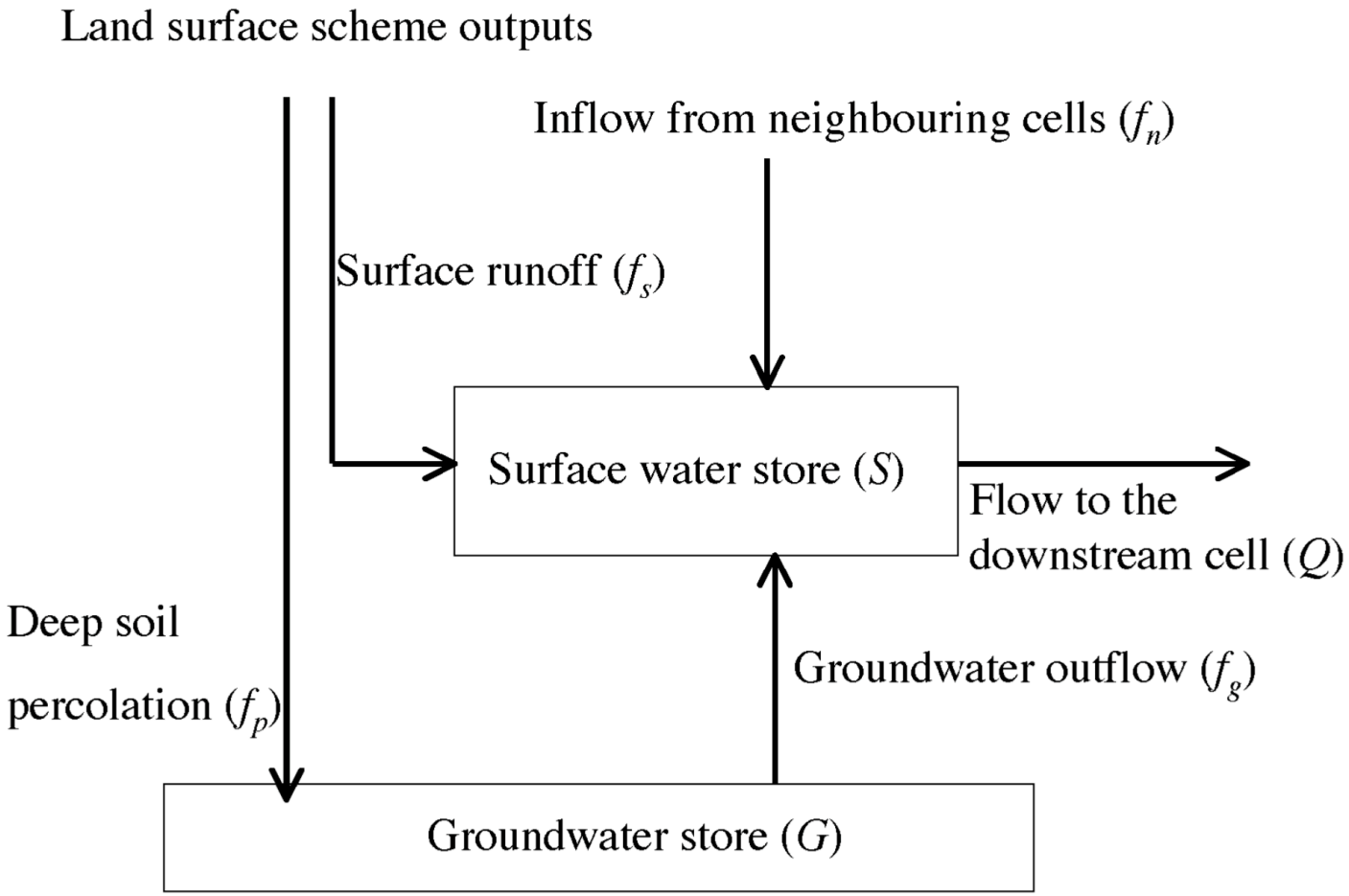


Fig. 1 Schematic representation of the cell-to-cell routing scheme.

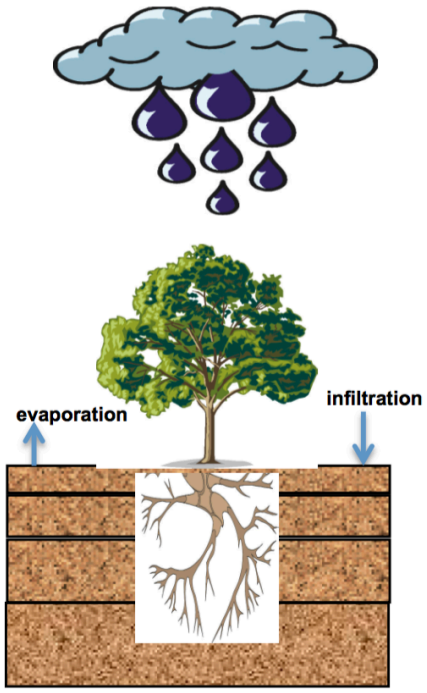
Sushama et al. (2004) Atmosphere-Ocean, 42: 221-233

WRF – Hydro model

WRF- Hydro Description

Snow melting

Single Column

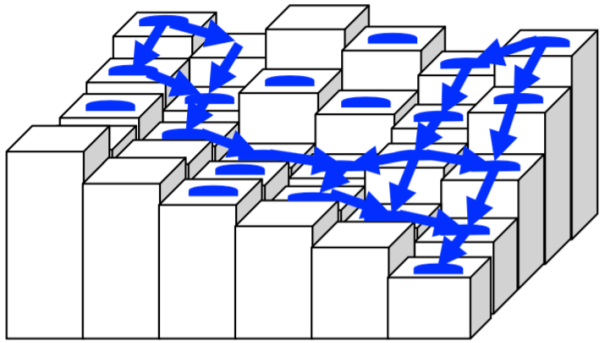


1-D Land Surface Models (e.g. 'Noah')

Run off

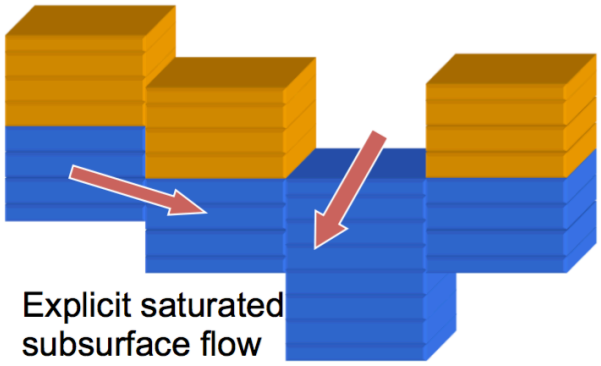
Land Surface Routing

Explicit diffusive wave overland flow



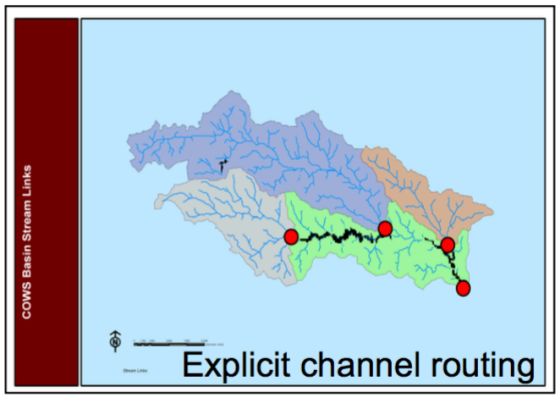
Base flow

Subsurface Routing



Explicit saturated subsurface flow

Channel Routing



Three major components for river forecasting :
Snow melting, base flow and run off

http://www2.mmm.ucar.edu/wrf/users/tutorial/201407/Friday/4_gochis_wrfhydro.pdf

Hydrology Discharge Model (HDM)

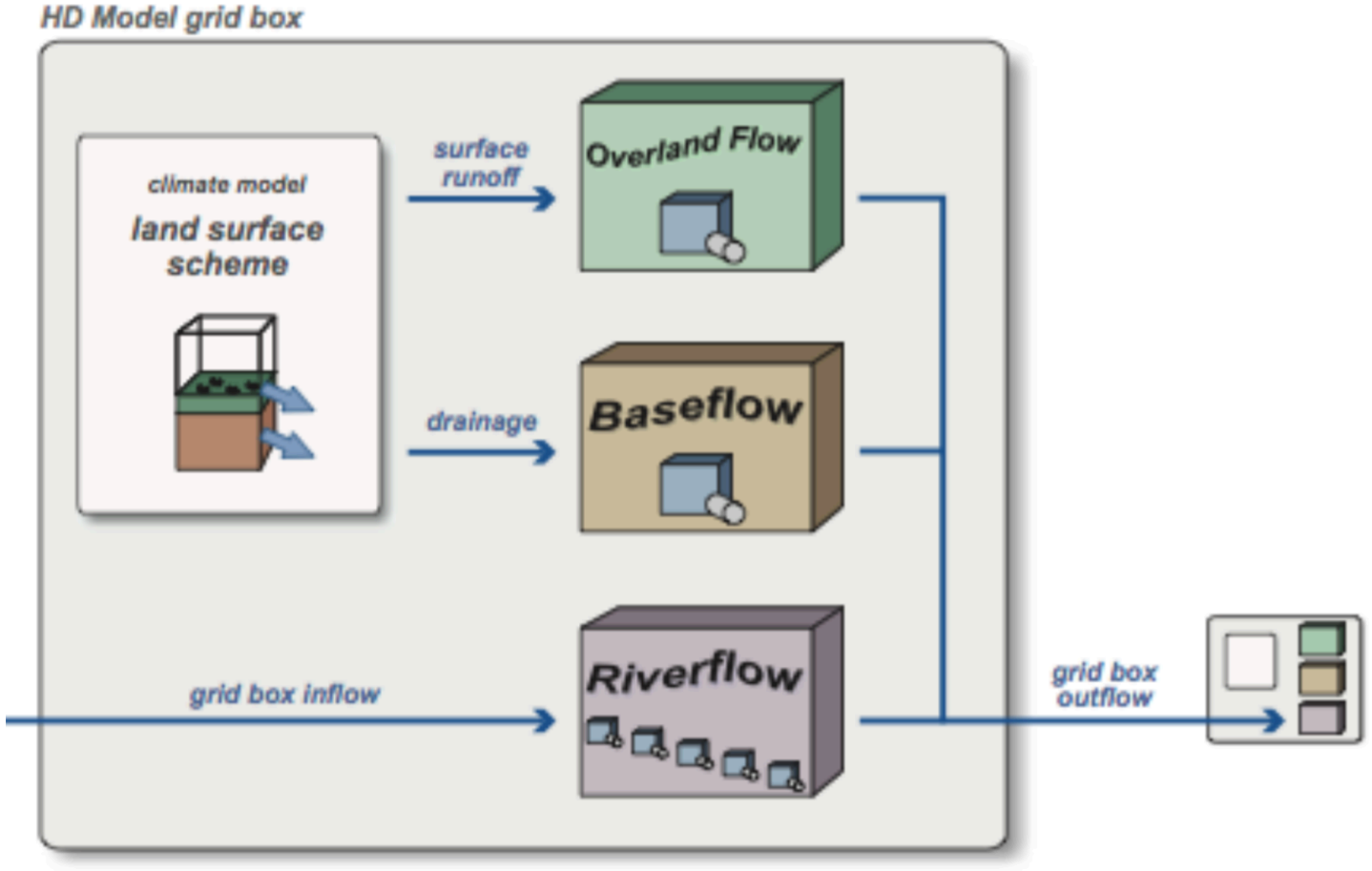


Figure 5.1 : Overview about the general structure of the HDM (Hagemann and Dümenil, 1998).

HDM application to Euphrates-Tigris basin

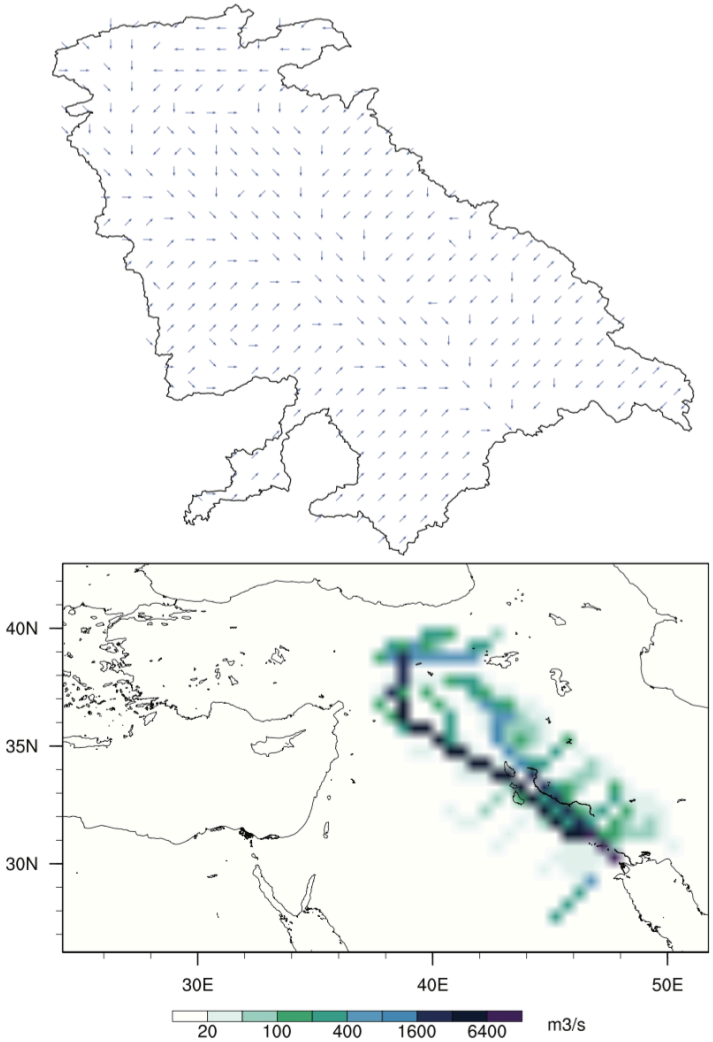


Figure 5.5 : River direction and corresponding river flow network of the ETB represented by the HDM after prescribing and changing the parameters in Experiment-2.

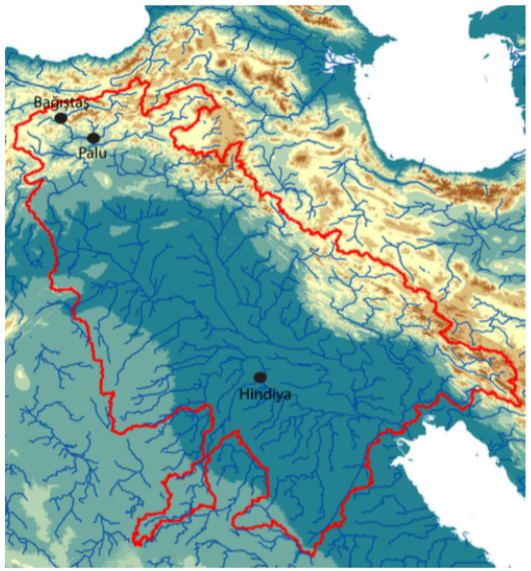


Figure 5.7 : Streamflow gauging stations used to validate the HDM.

Bozkurt, (2013) PhD Thesis

HDM application to Euphrates-Tigris basin

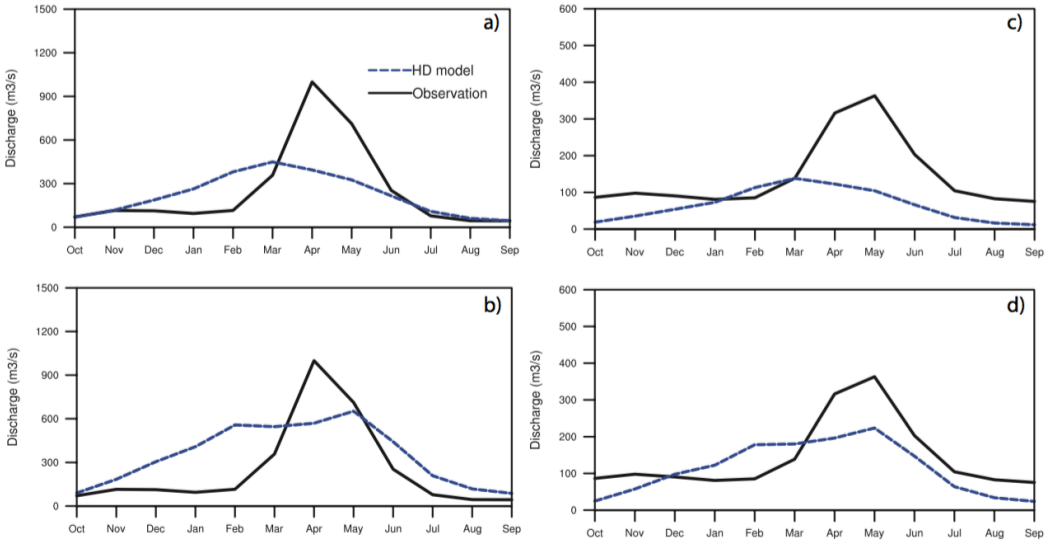


Figure 5.8 : Mean monthly discharge (m^3/s) for the Palu (left column) and Bağıştaş (right column) streamflow gauging stations (solid line) and the HD Model simulations (dashed line). Top panel corresponds to the simulations forced by ECHAM5 input fields. Bottom panel corresponds to the simulations forced by MPI-ESM-LR input fields.

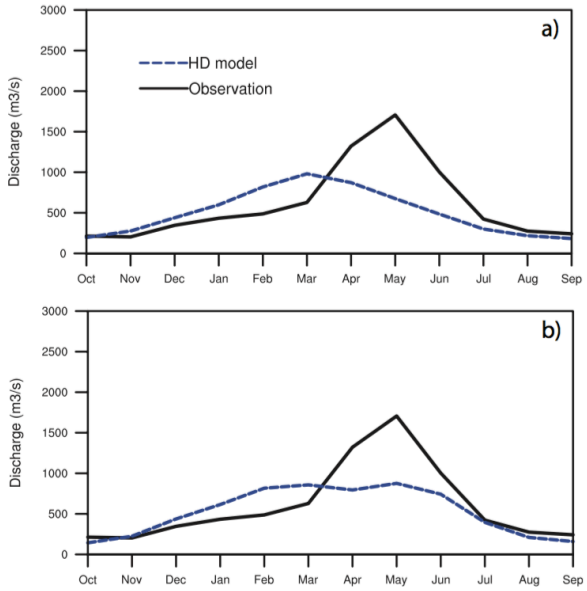
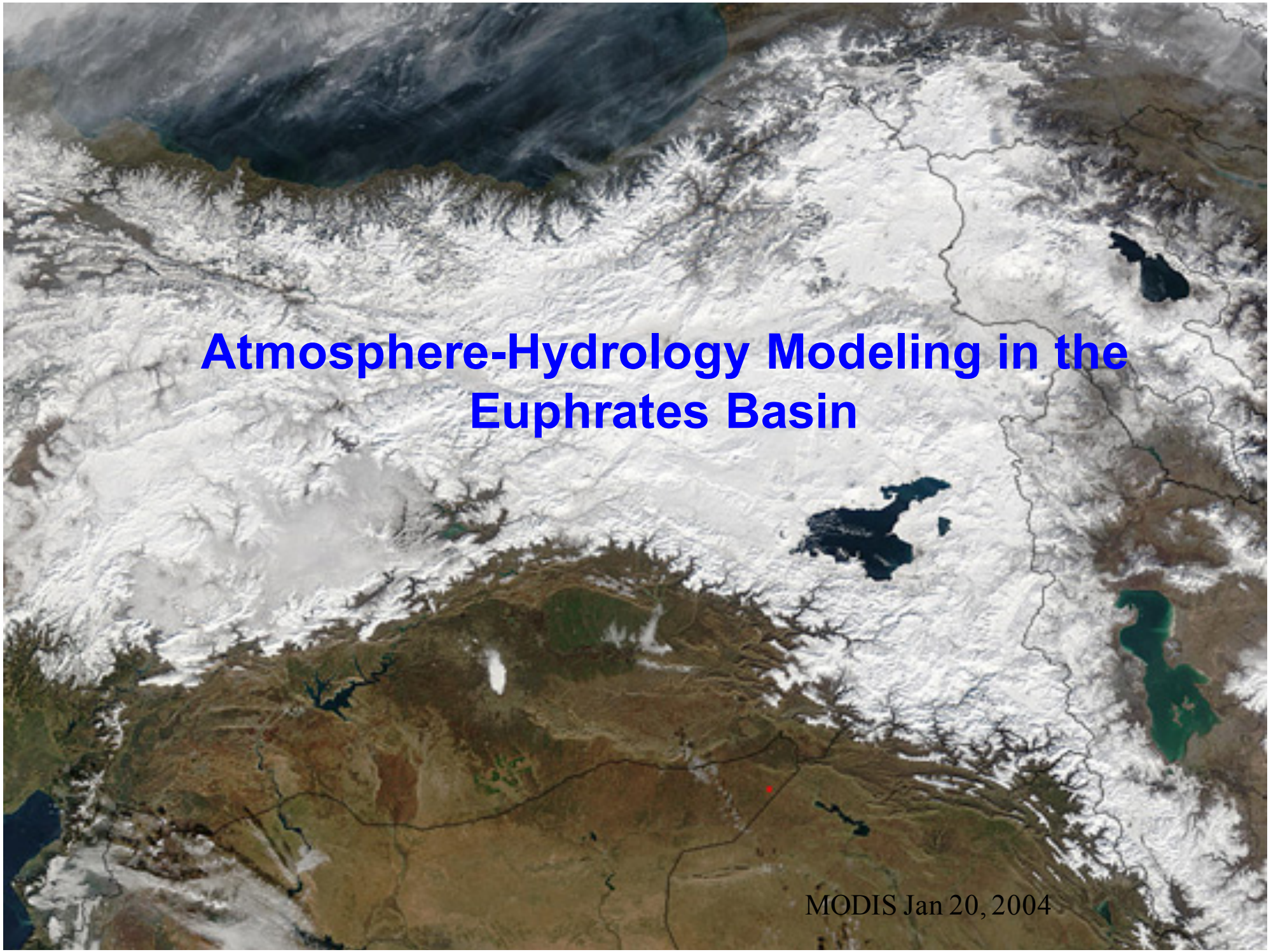


Figure 5.9 : Mean monthly discharge (m^3/s) for the Hindiya streamflow gauging station (solid line) and the HDM simulations (dashed line). Top panel corresponds to the simulations forced by ECHAM5 input fields. Bottom panel corresponds to the simulations forced by MPI-ESM-LR input fields.


Atmosphere-Hydrology Modeling in the Euphrates Basin
MODIS Jan 20, 2004

March 2004: Opening the spill gates of the dams on Euphrates

Keban hatırası...

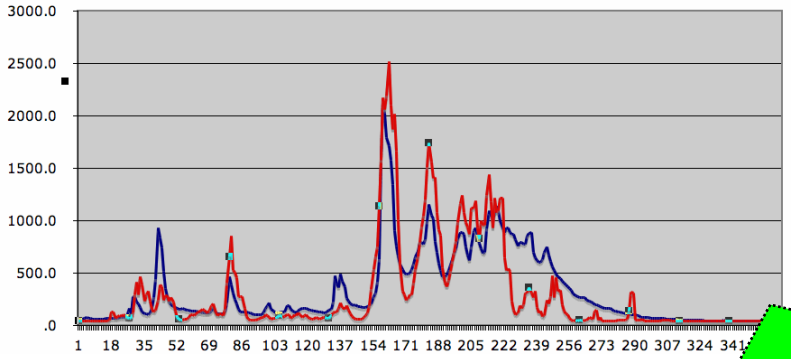
Önümüzdeki günlerde dağlardan '14 milyar metreküp su' ineceği hesaplanınca, Fırat ve Dicle üzerindeki barajların kapakları birer birer açıldı. Tahliyeler 10 gün boyunca sürecek

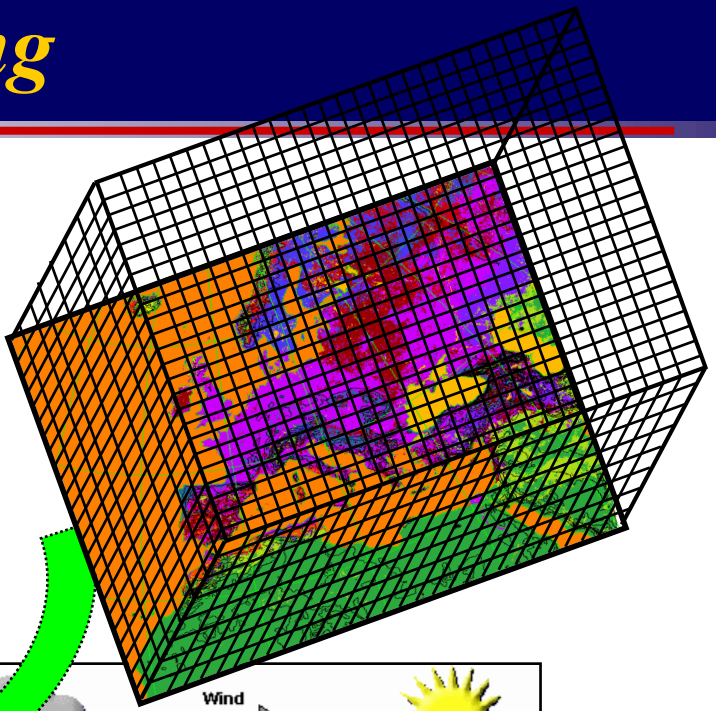
11/03/2004 (910 kişi okudu)

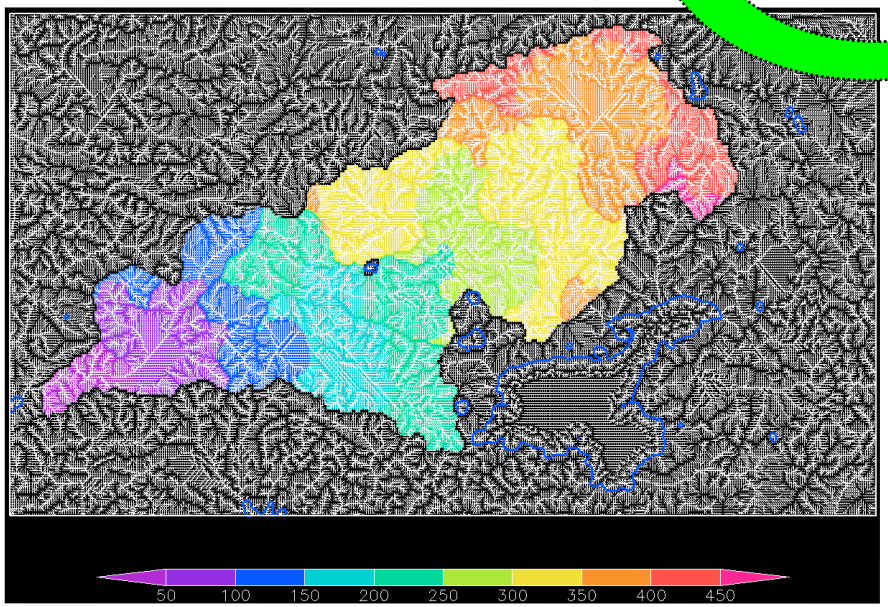
FOTOĞRAF: ÖMER FANSA/AA

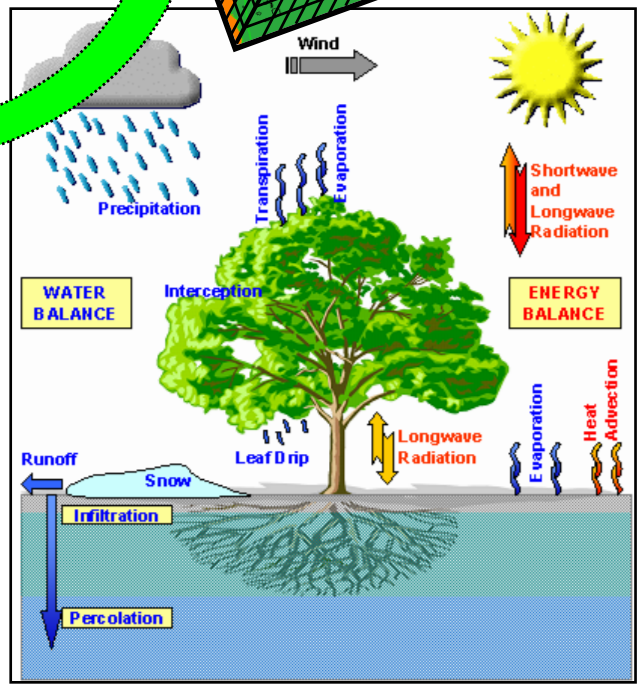
DHA - ŞANLIURFA/GAZİANTEP/ BATMAN/ELAZIĞ - Fırat üzerindeki barajlarda son yağışlar ve karların erimesiyle su seviyesi azami koda ulaşınca, 10 günlük alarm verildi. Beş barajdan, önce Suriye sınırındaki Karkamış'ta başlatılan
tahliye, dün sabahtan itibaren Keban'da da uygulandı. Keban Barajı'nda 19 yıldan beri ilk kez tahliye kapakları açılınca halk fotoğraf çekmek üzere bölgeye geldi.
Fırat ve Dicle üzerindeki barajlardaki son durum şöyle:
Keban: 1974'te hizmete giren barajın azami kodu 845. Su seviyesi 844 koduna ulaşınca, sekiz tribünde tam kapasiteyle elektrik üretimine geçildi. Önümüzdeki günlerde karların erimesiyle baraja gelecek su miktarının artacağı dikkate alınarak, dün öğleden sonra savak kapakları (barajın gövdesi üzerinde bulunan kapaklar) açılarak su tahliyesine başlandı. Saniyede 1152 metreküp su bırakılacak. Feribot seferleri iptal edildi.
Atatürk: Türkiye'nin en büyük barajında su seviyesi dün 537 kodunda ölçülünce kapakların bugün açılmasına karar verildi. Saniyede 1400 metreküp su, sekiz tribünden, 900 metreküp su da savaklardan Fırat'a bırakılacak. Tahliye 10 gün sürecek.
Batman: Dicle'deki barajda kapaklar dün açıldı. Tahliye, su seviyesi 4 metre düşene dek sürecek.
Karakaya: Saniyede 700 metreküp su bırakılacak barajdaki 10 dolu savağın kapağı, aşınma olmaması için kısmen açıldı. Su kodu 890'a ininceye kadar tahliyeye devam edilecek. Barajda, en son 1992 yılında kapaklar açılmıştı.
Birecik: Azami kodu 385 olan barajda su seviyesi 384 ölçülünce tahliyeye başlandı. Saniyede 2 bin 400 metreküp su bırakılacak.
Karkamış: Barajda tam kapasiteyle enerji üretimi yapılırken, savaklardan sırakılan sular, bazı yerleşim merkezlerinde evleri sular altında bıraktı, dolgu köprüleri aşan sular, geçit vermedi.

Atmoshere-Hydrology Modeling





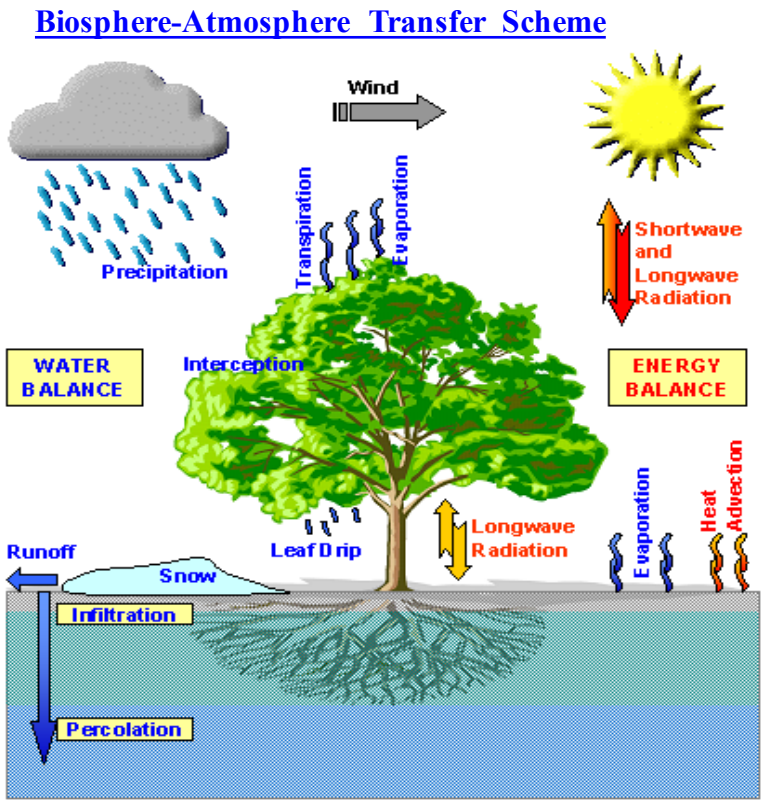




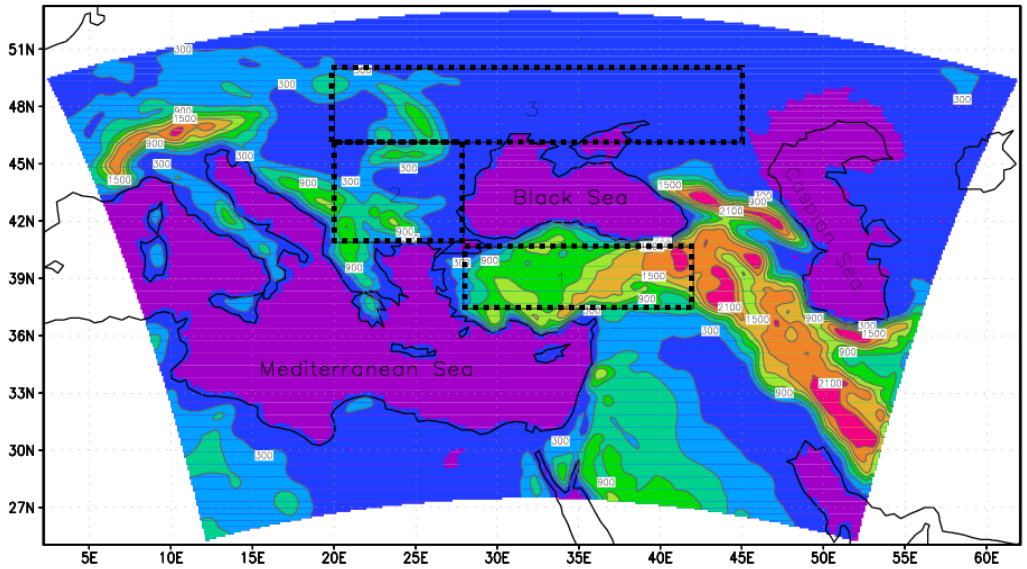
Atmospheric Modeling

RegCM3: Regional Climate Model

- Dynamics ➔ Two options:
  - ✓ 1. MM5 Hydrostatic Dynamics (Grell et al. 1994);
  - ✓ 2. Non-hydrostatic (Bi)
- Radiation ➔ CCM3 (Kiehl 1996)
- Large-Scale Clouds & Precipitation ➔ SUBEX (Pal et al 2000)
- Cumulus convection ➔ Four options:
  - ✓ 1. Grell (1993);
  - ✓ 2. Anthes-Kuo (1977);
  - ✓ 3. Emanuel (1991);
  - ✓ 4. Bets-Miller (?)
- Tracers/Aerosols ➔ Qian et al (2001)
- Boundary Layer ➔ Holtslag (1990)
- Land Surface ➔ Two options:
  - ✓ 1. BATS (Dickinson et al. 1986);
  - ✓ 2. Subgrid BATS (Giorgi et al 2003)
- Ocean Fluxes ➔ Two options:
  - ✓ 1. Zeng et al (1998);
  - ✓ 2. BATS (Dickinson et al. 1986)



Design of the experiment



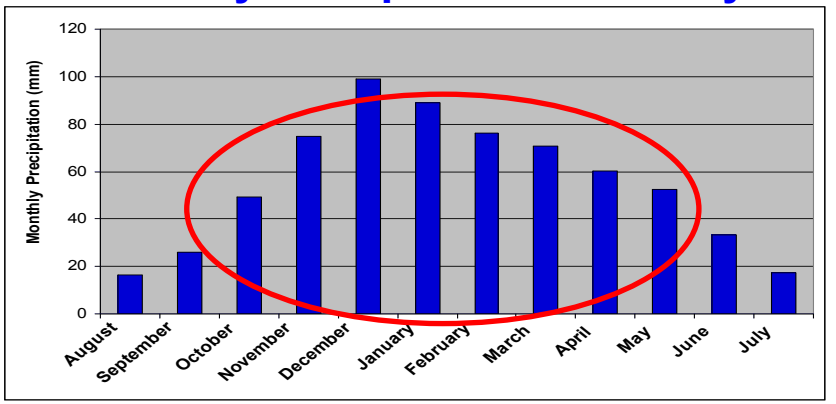
Simulation Period

OCT 1 — SEP 30

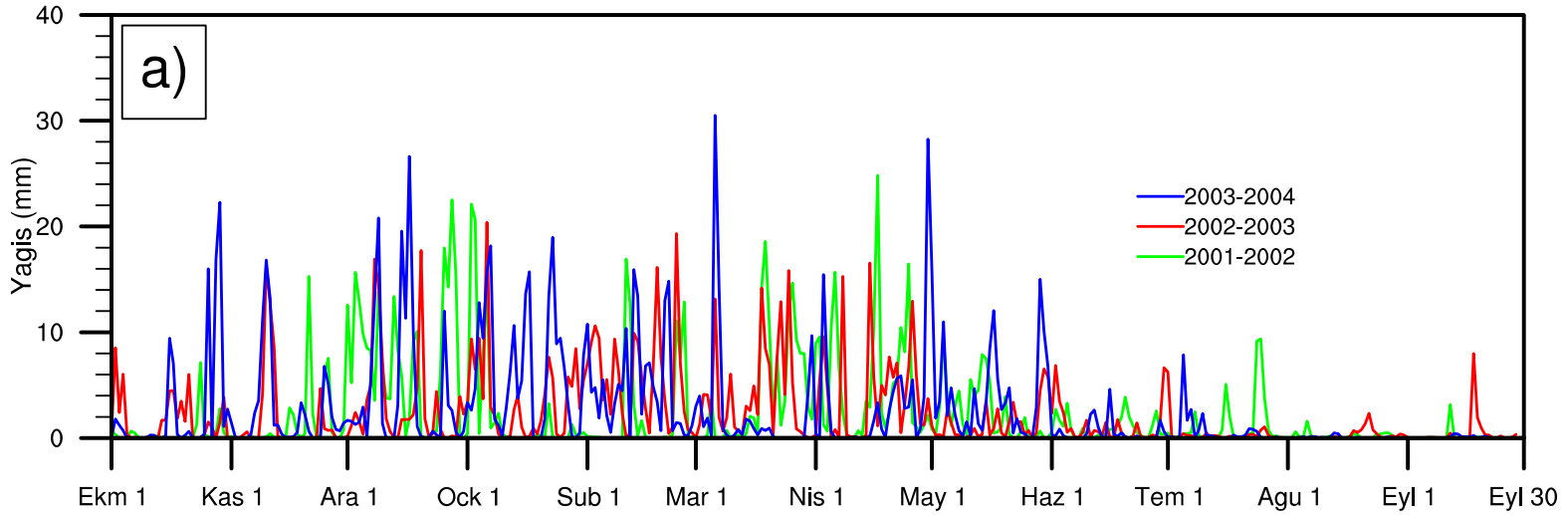
2001 — 2004

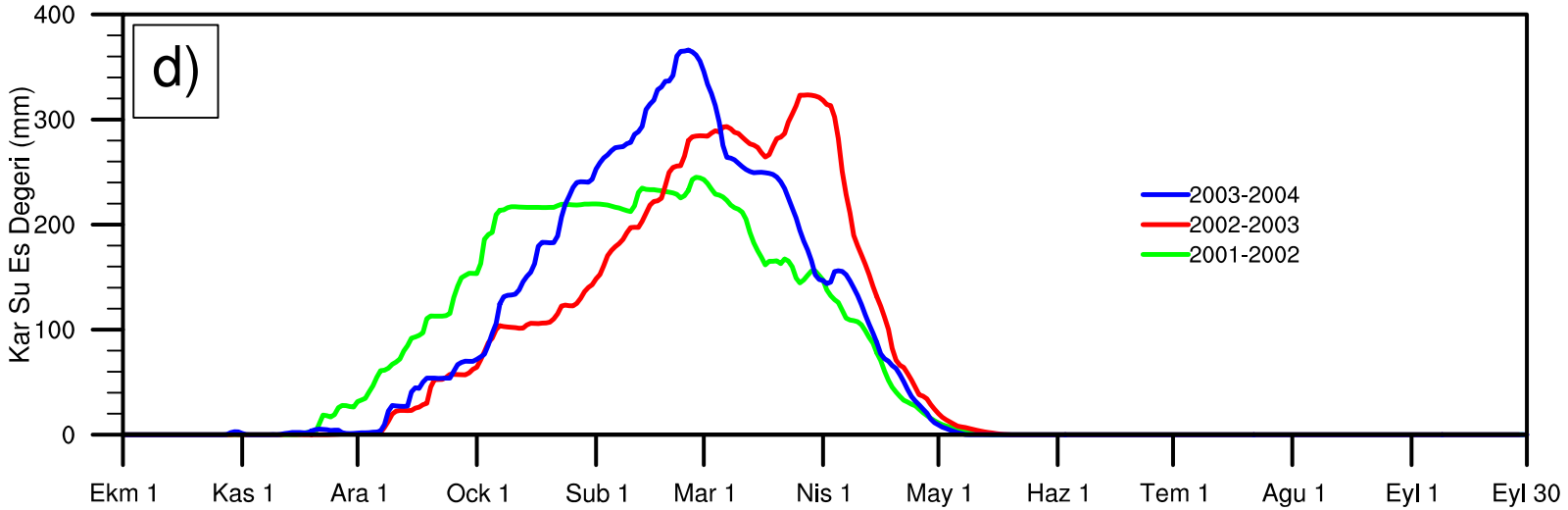
- **Grids**: 171x117 grids in x and y directions
- **Spatial Resolution**: 24 km
- **Topography** : USGS GTOPO30 data
- **Land Cover** : USGS GLCC data
- **Sea Surface Temperature** : Reynolds SST
- **Initial & Boundary Conditions** : NCEP/NCAR

Monthly Precipitation in Turkey

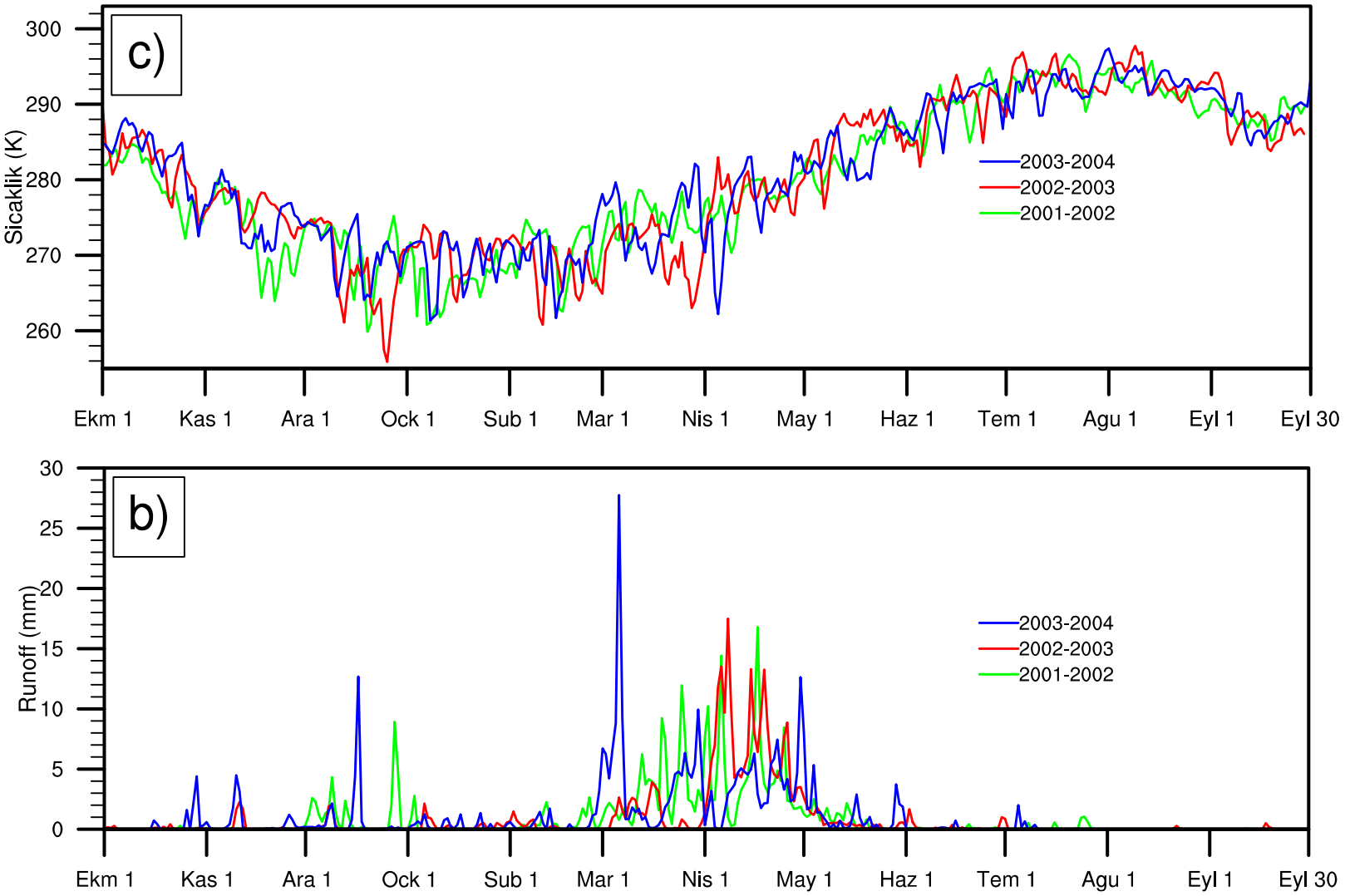


Model outputs for the Middle Euphrates Basin

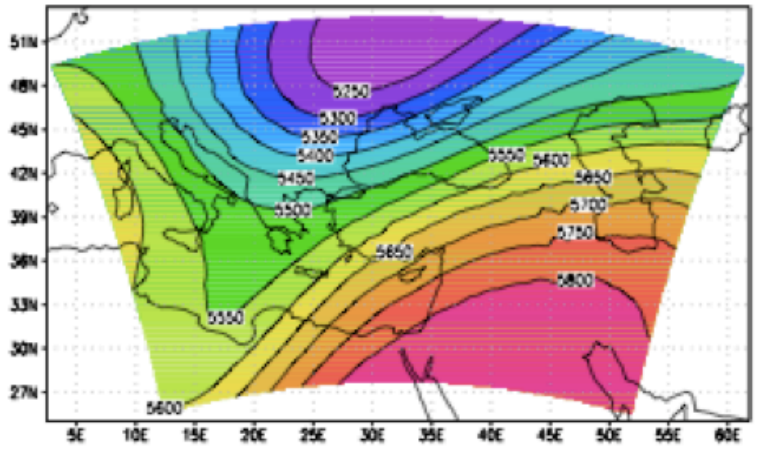


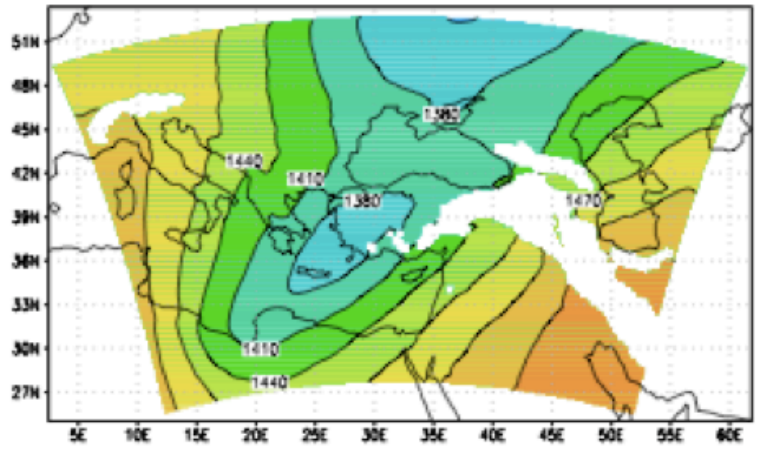


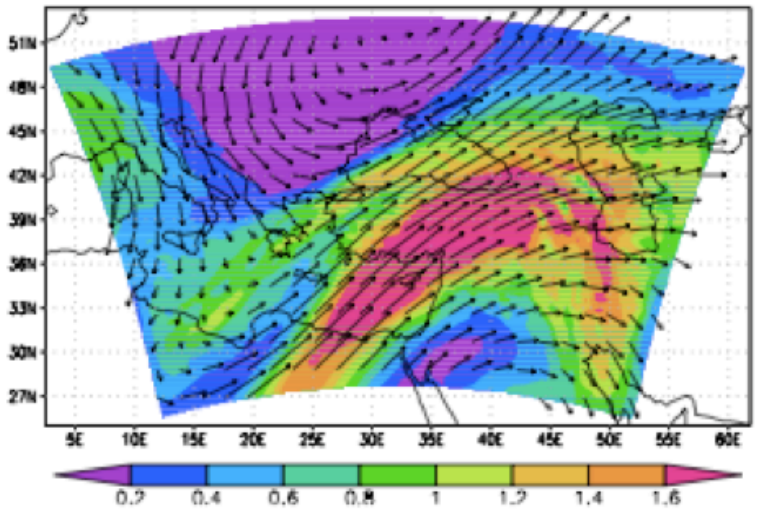
Model outputs for the Middle Euphrates Basin

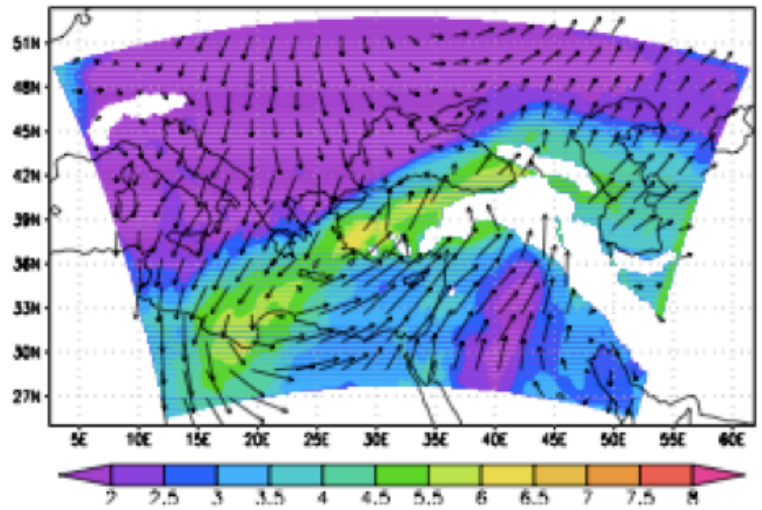


4 March 2004: Atmospheric Circulation



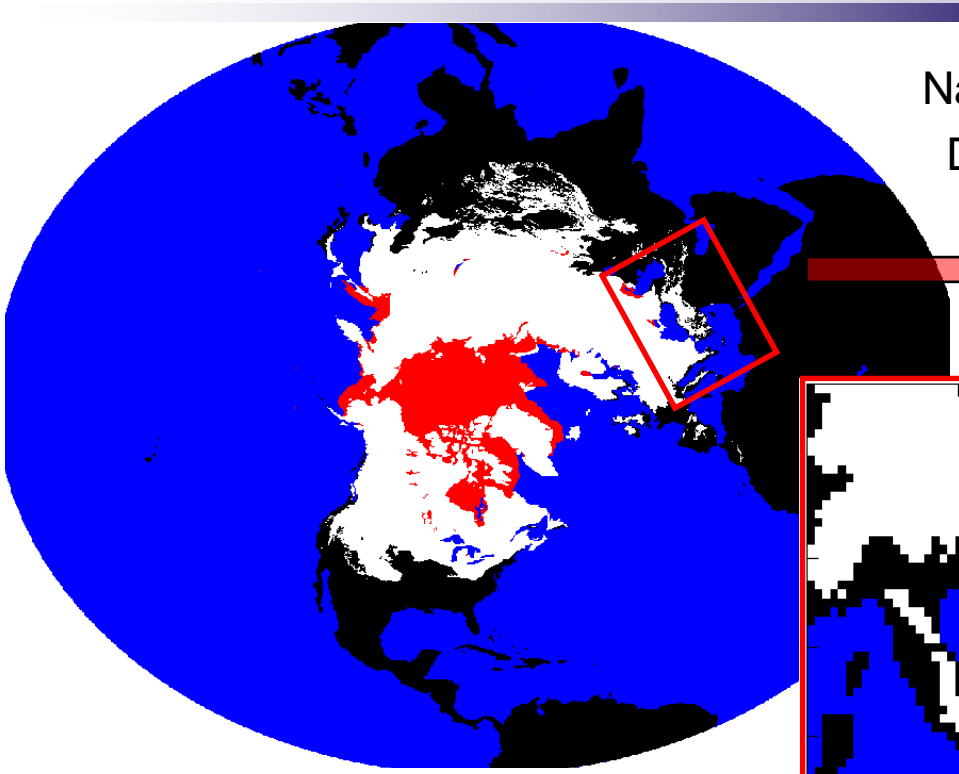




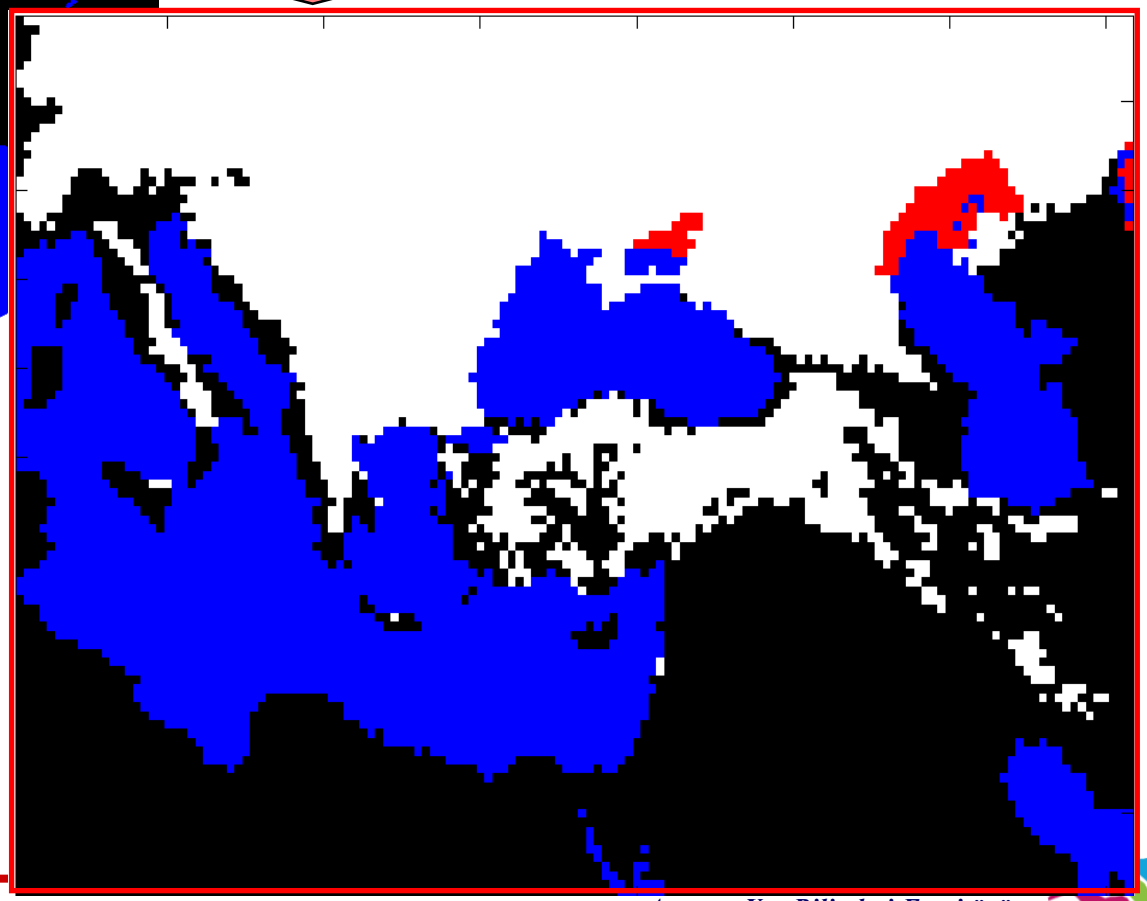


Performance of Atmosphere Model

Interpolation of satellite snow cover into model grids



National Weather Service, Climate Prediction Center
Daily 1024x1024 NH snow cover (2000 - present)
http://www.cpc.ncep.noaa.gov/data/daily_snow/



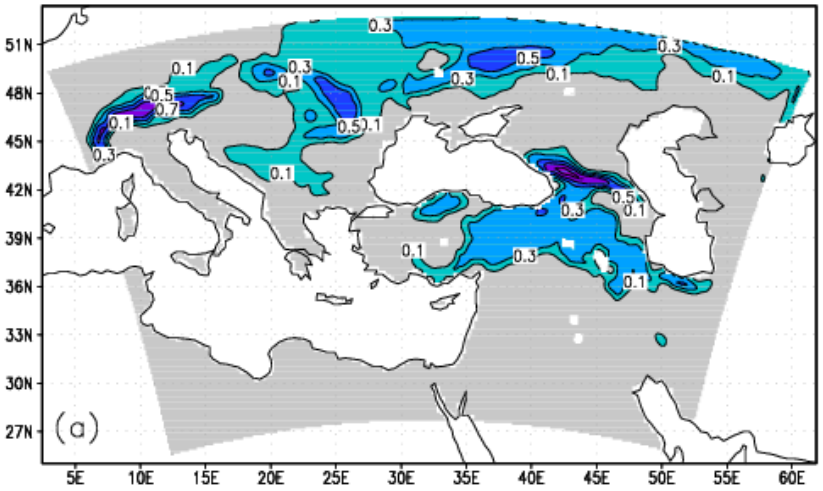
It is assumed that the modeled snow cover becomes comparable to the satellite snow cover when the modeled snow water equivalent is at least **5 mm** at which the surface albedo is modified.

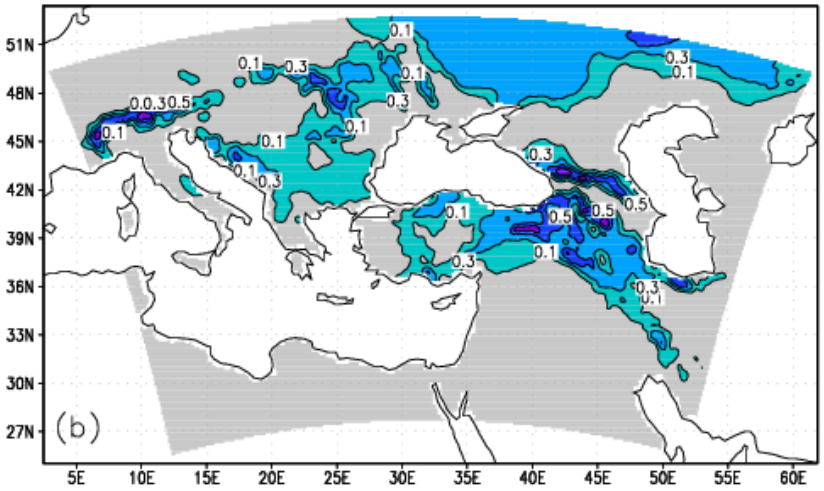
Monthly Snow Cover

MODELED

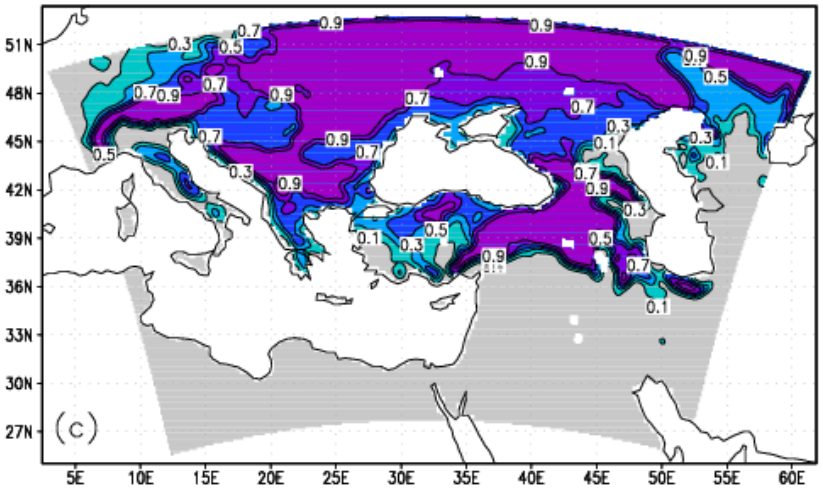
OBSERVED

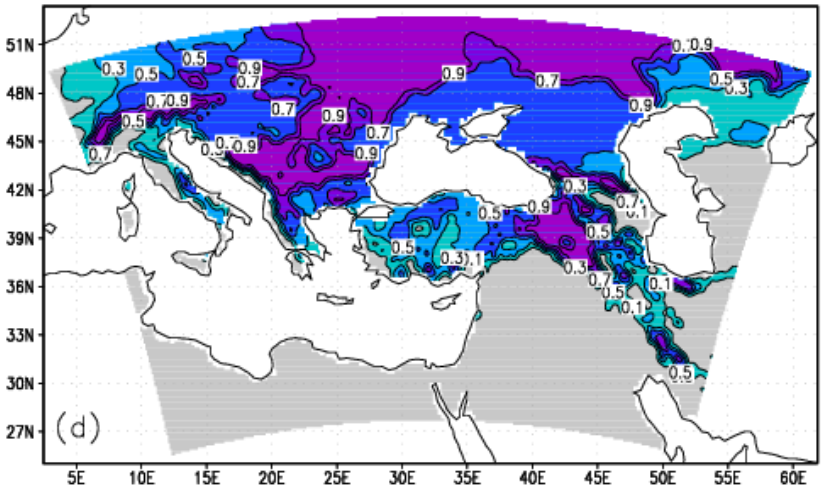
NOVEMBER





DECEMBER

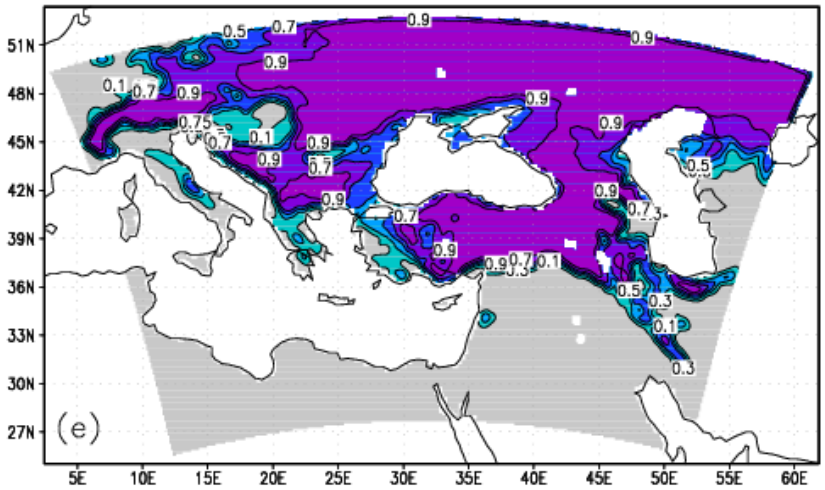


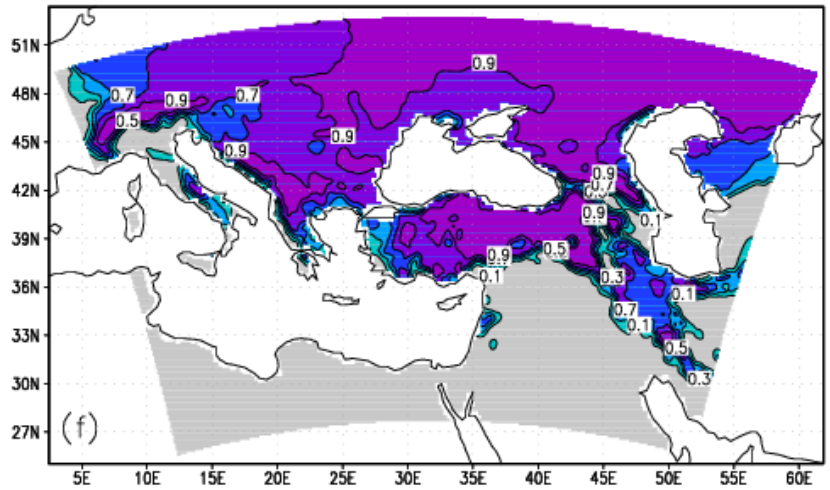


Monthly snow cover

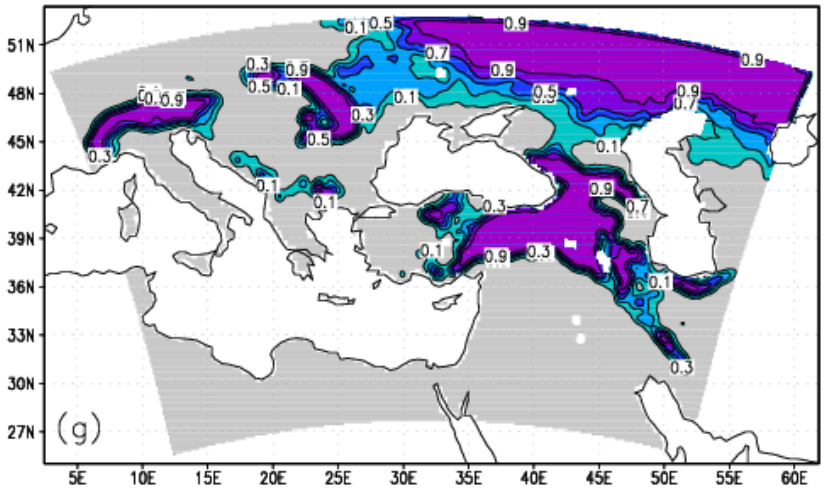
MODELED **OBSERVED**

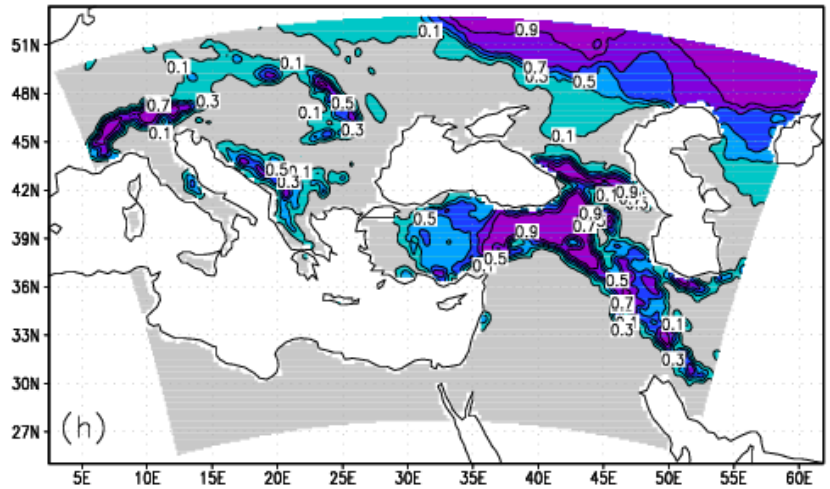
JANUARY





FEBRUARY



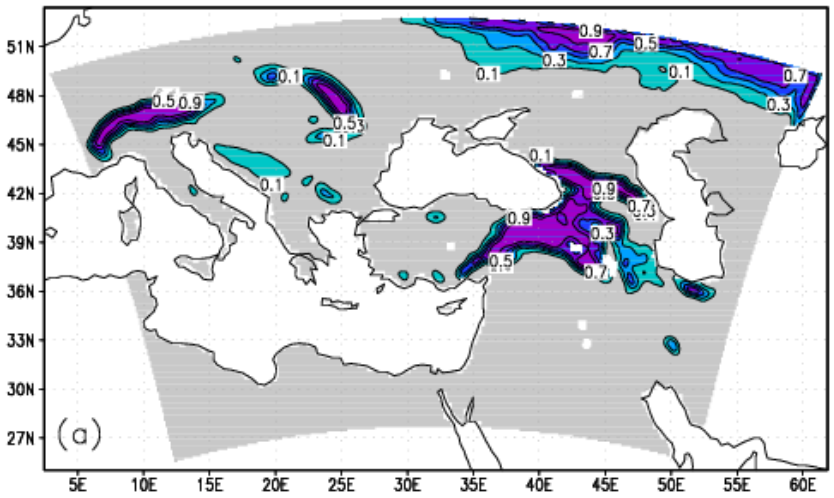


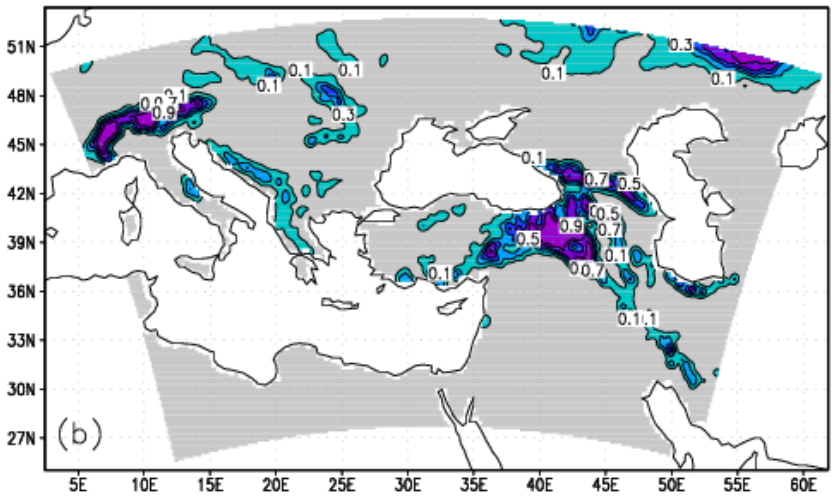
Monthly snow cover

MODELED

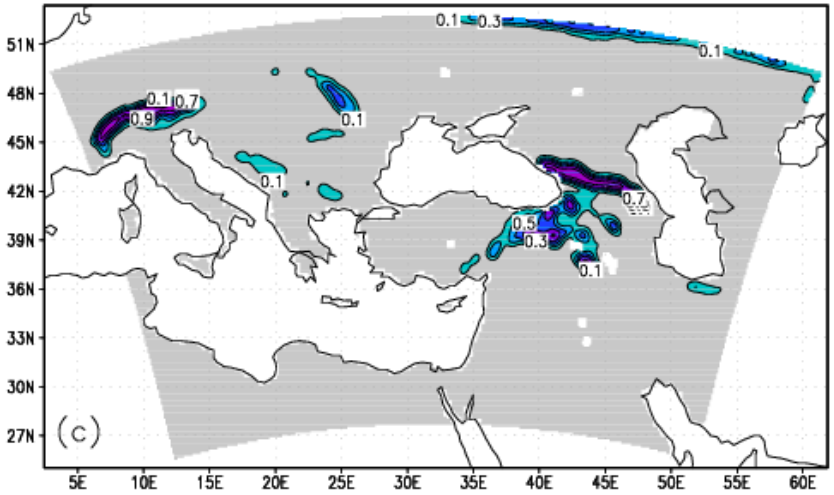
OBSERVED

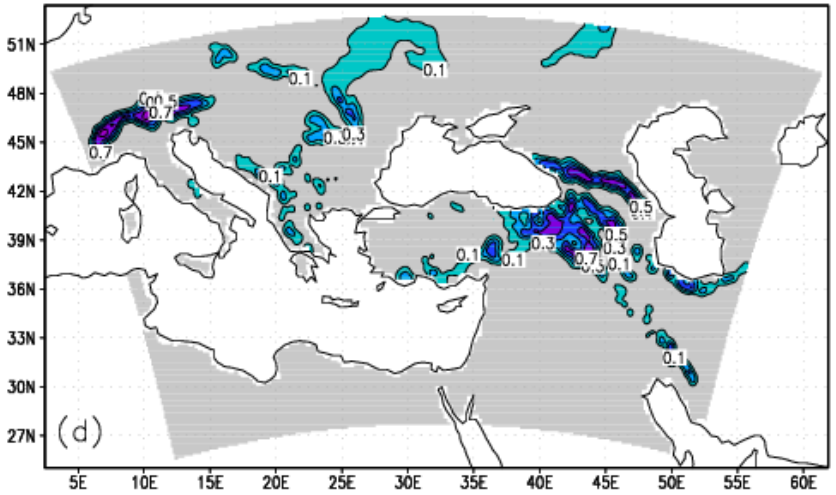
MARCH



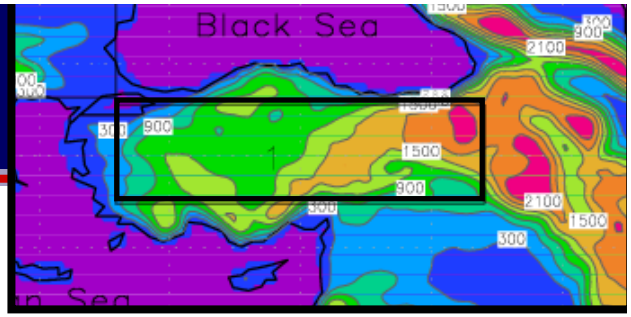


APRIL

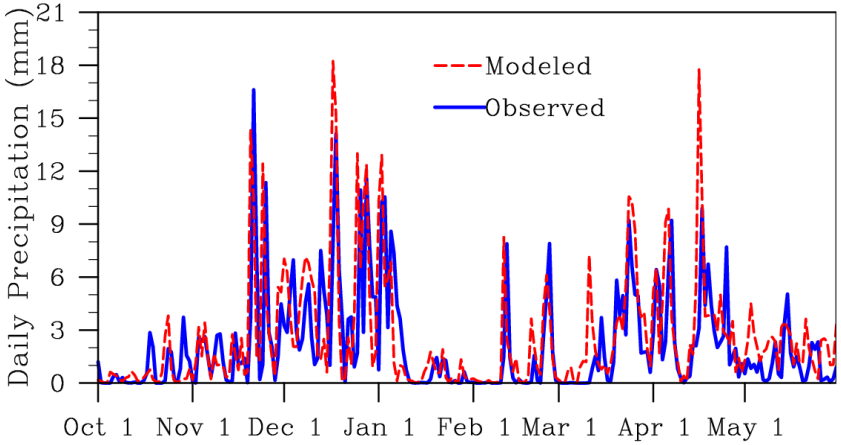


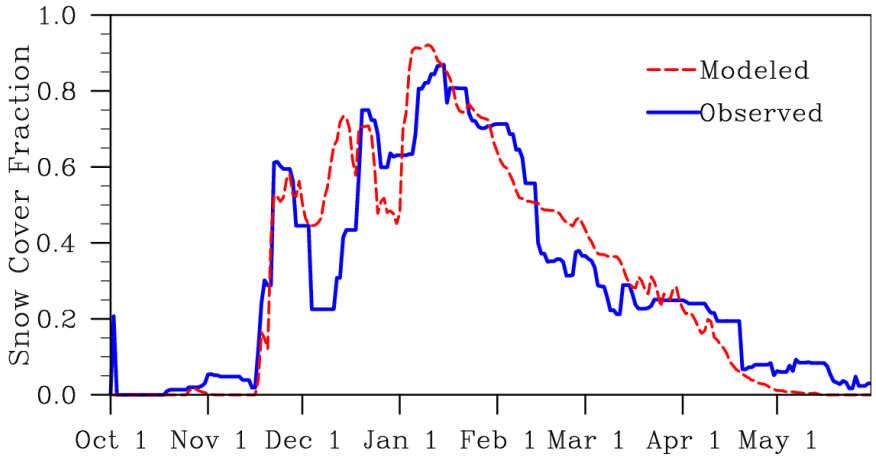


Daily change



2001-2002





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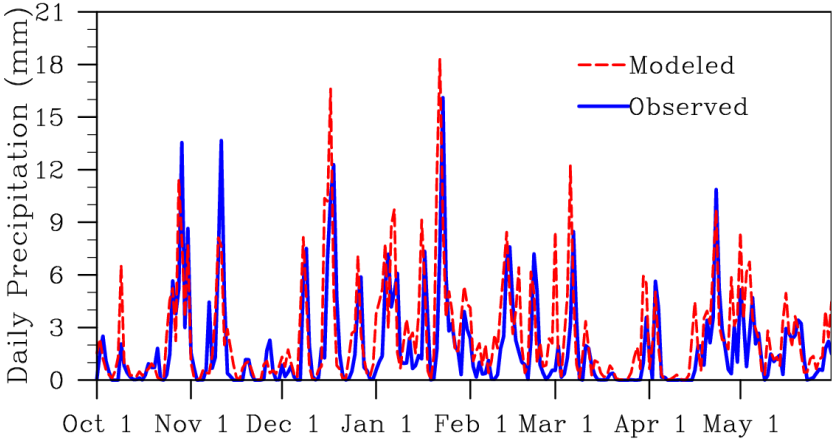
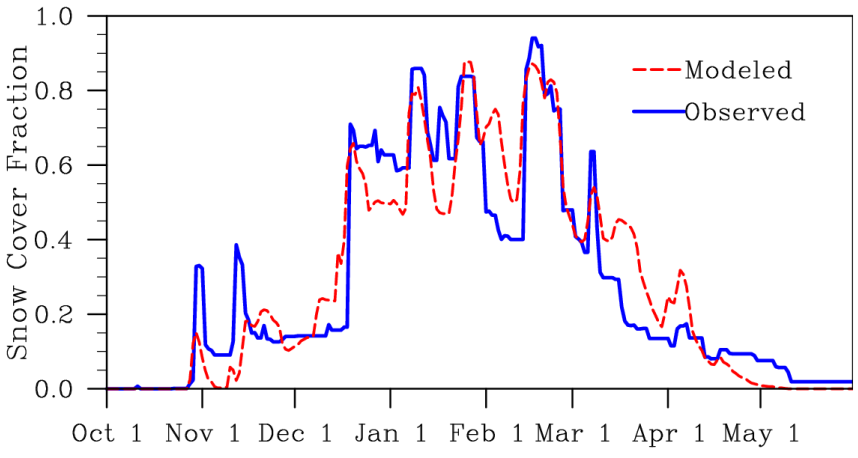
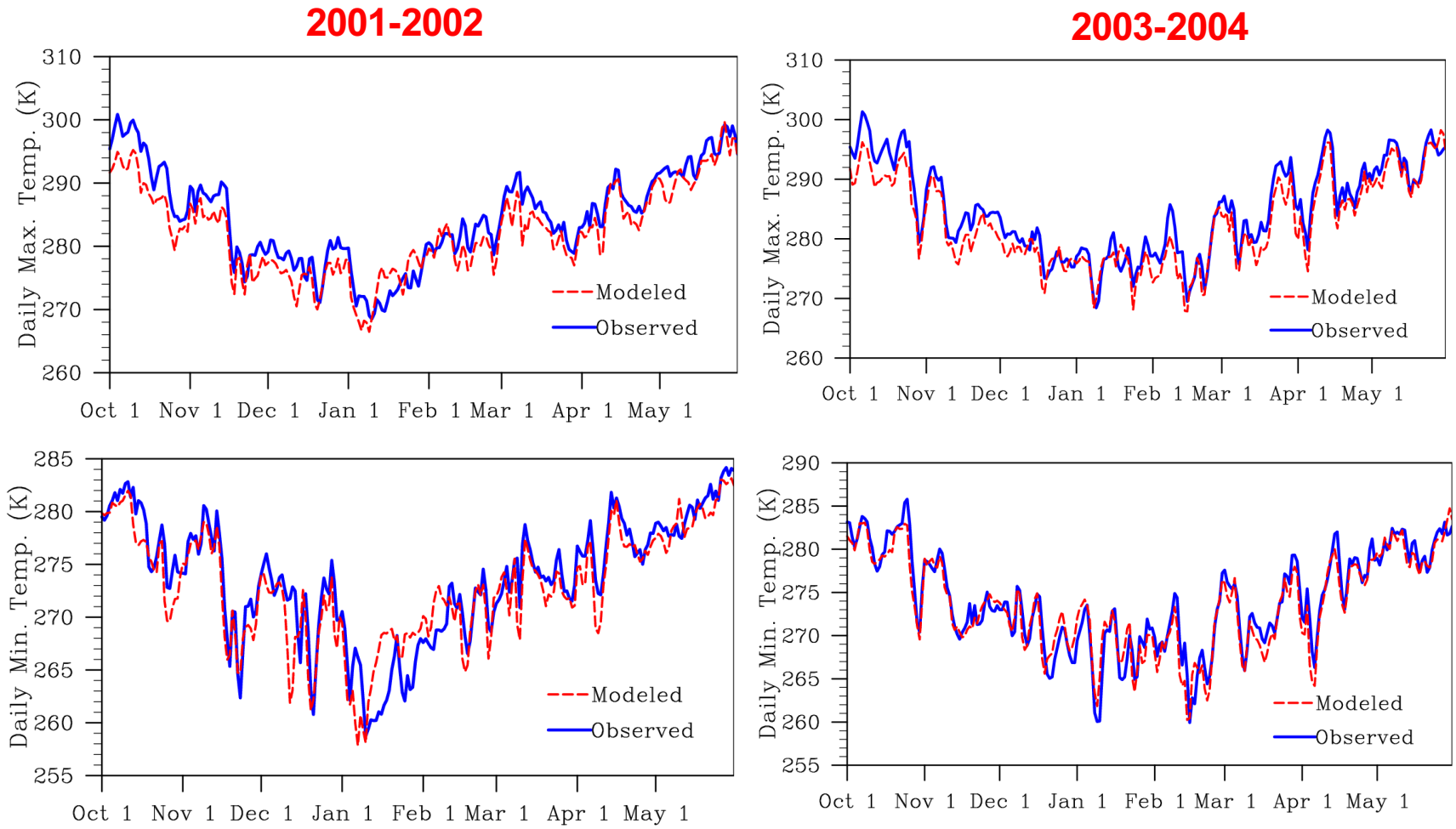
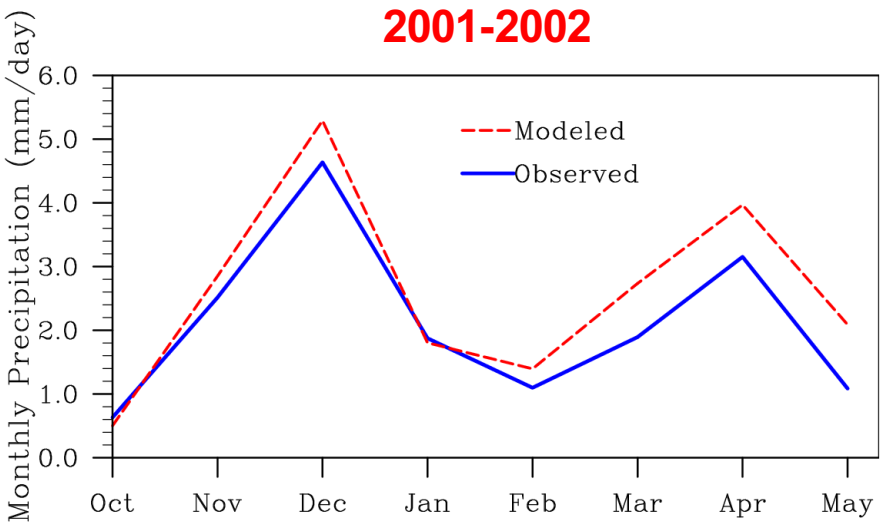


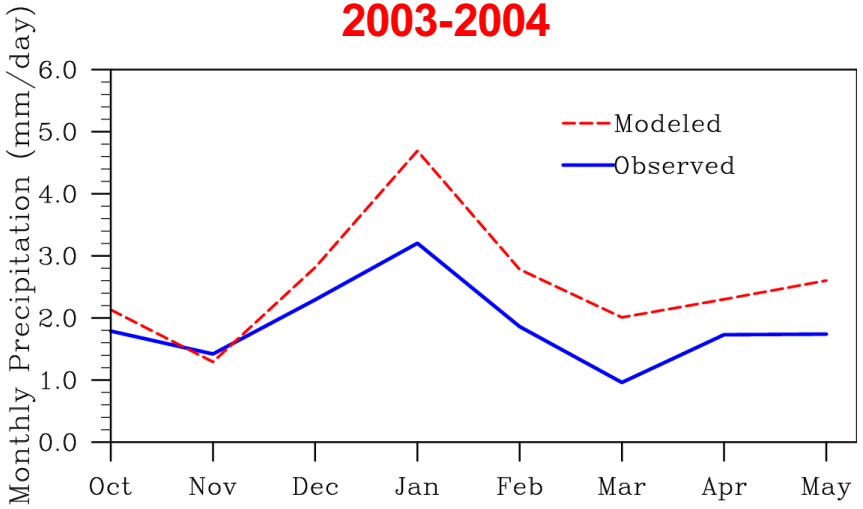


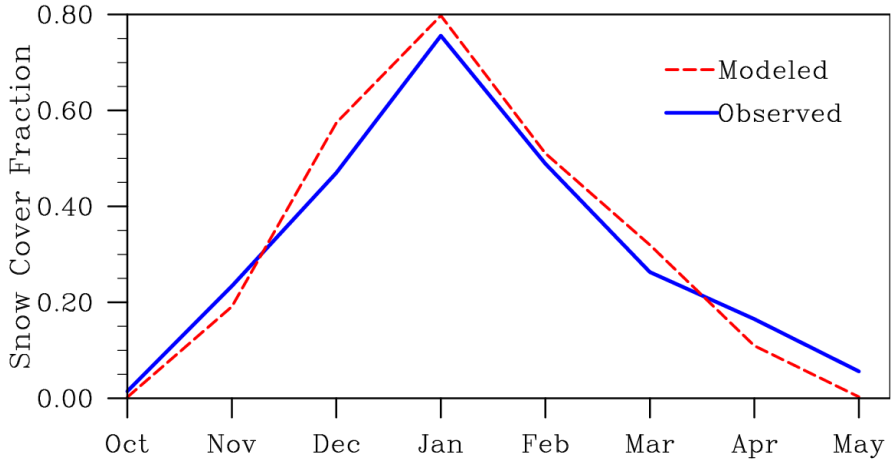
Daily change

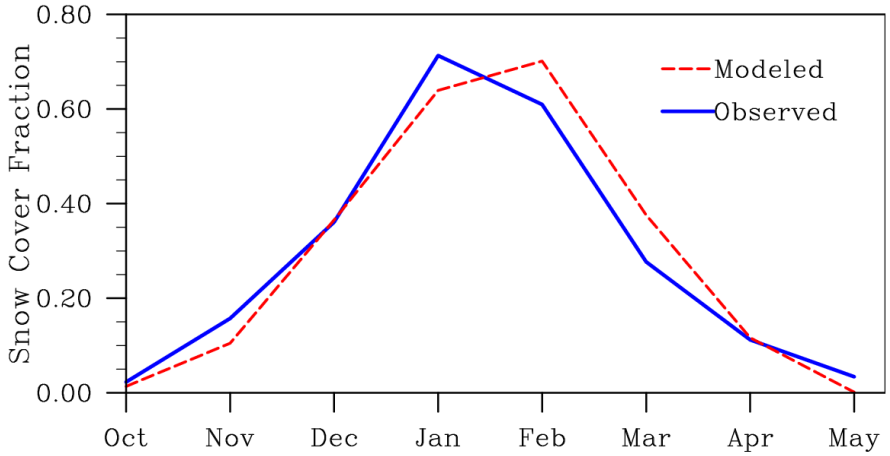


Monthly change

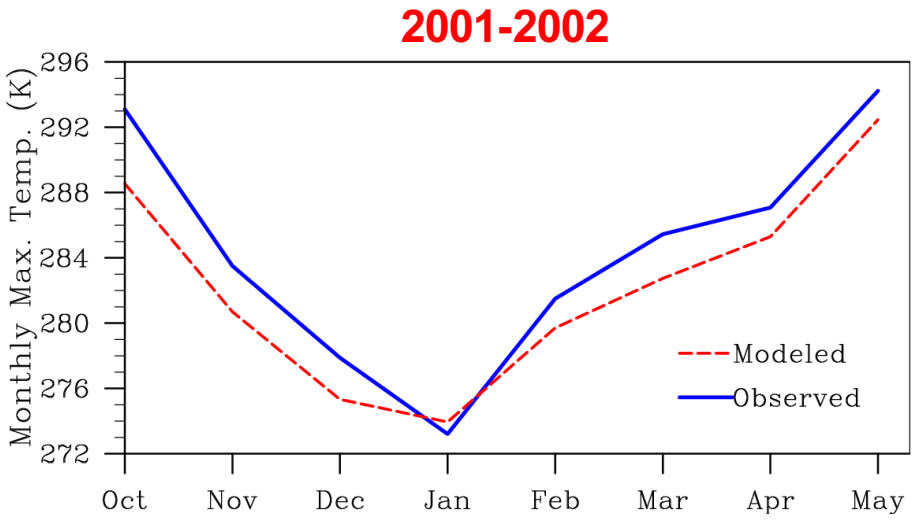


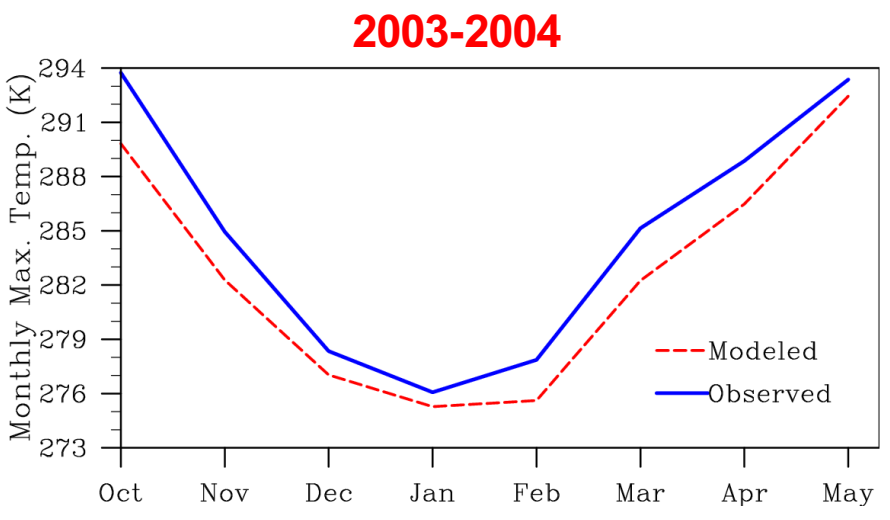


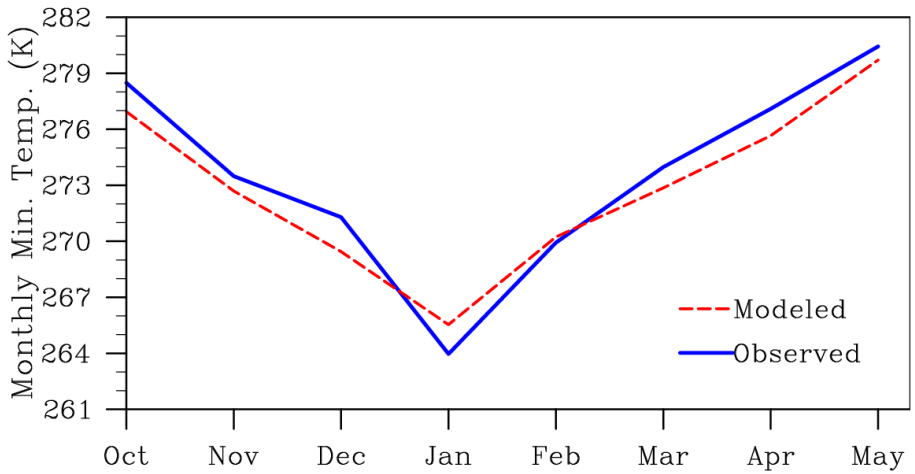


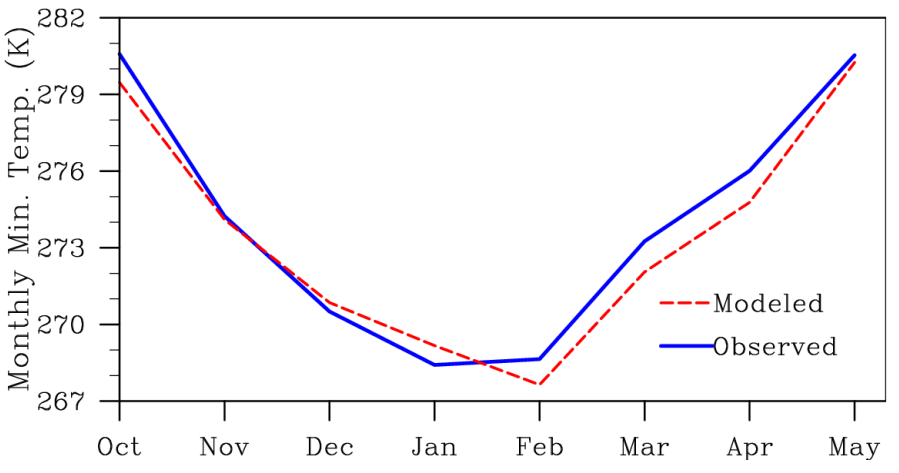


Monthly change



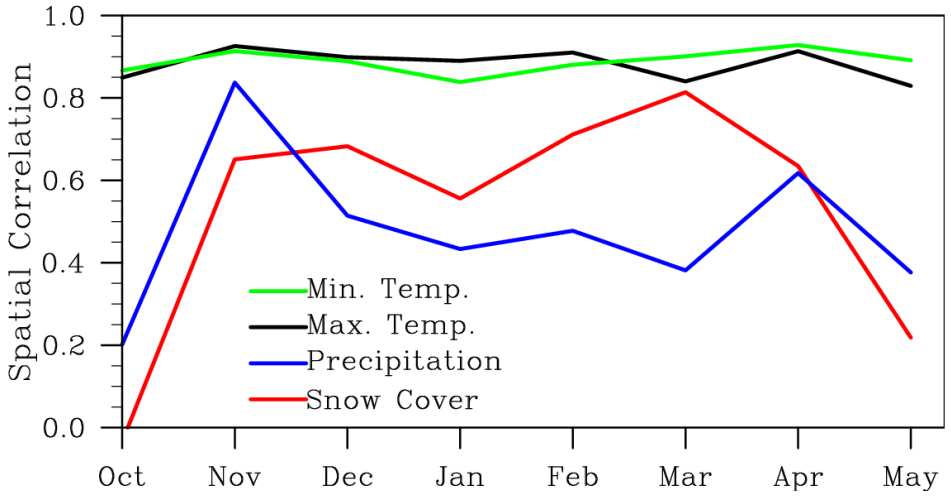




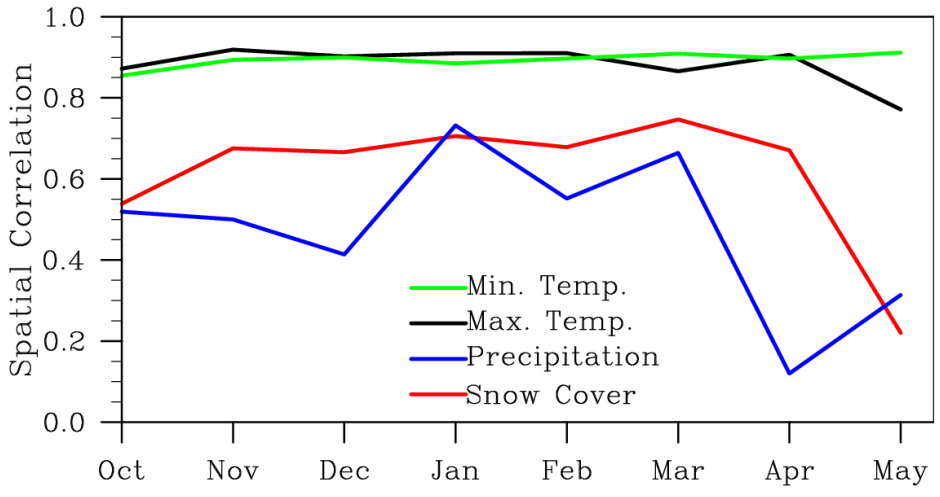


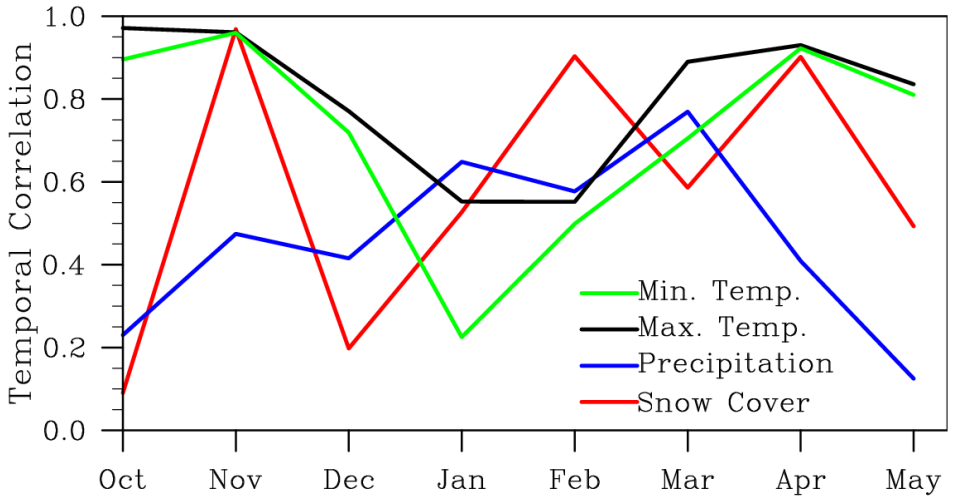
Monthly spatial and temporal correlations

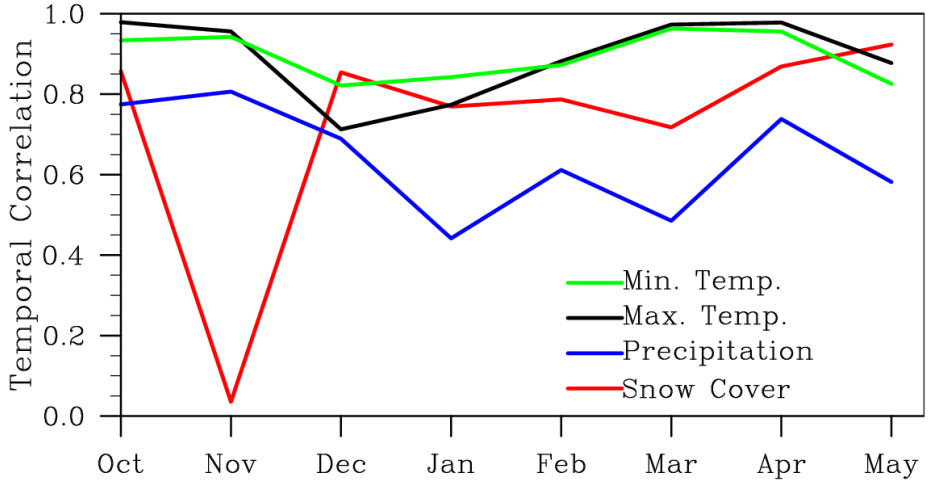
2001-2002



2003-2004

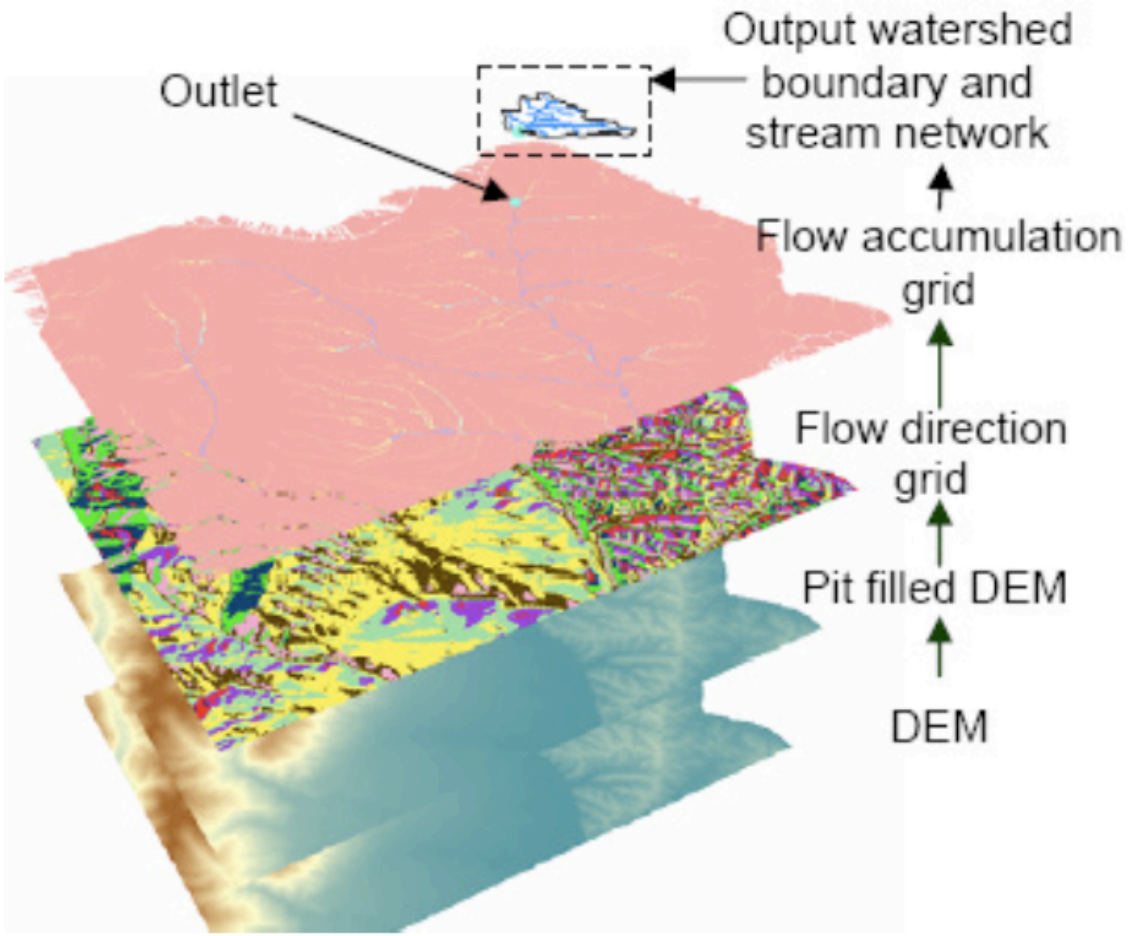






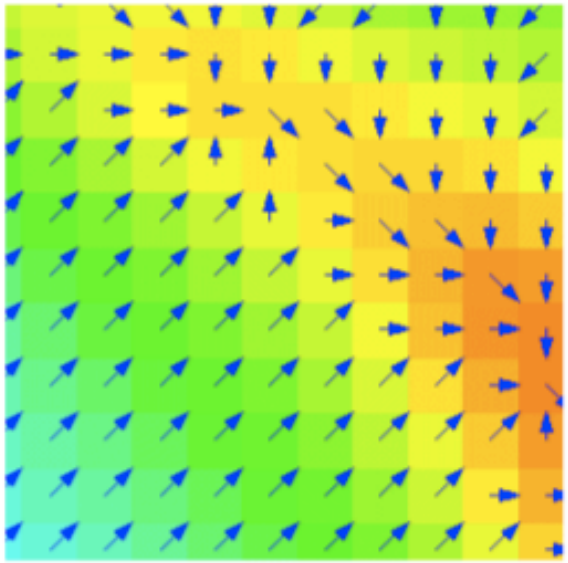
Hidrolojik Modelleme

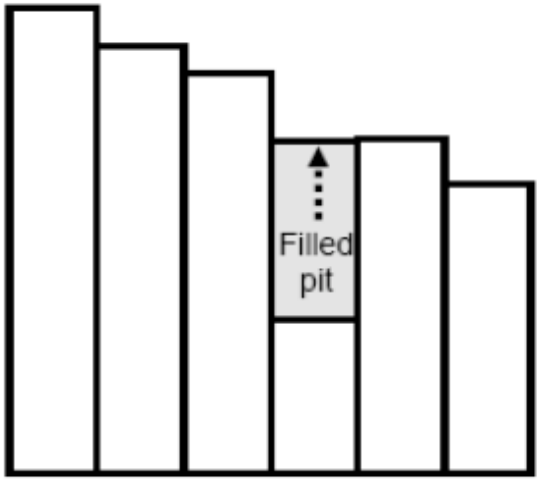
Before hydrologic routing

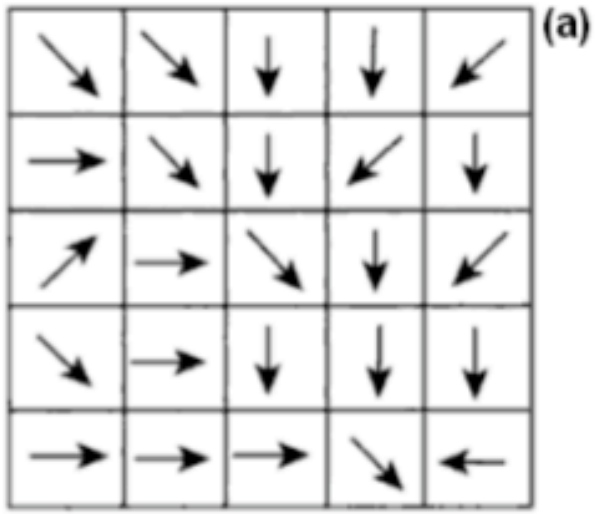


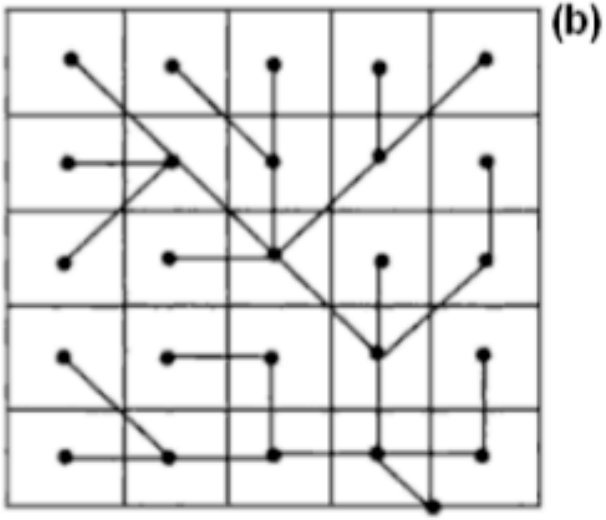
Extracting flow direction and accumulation, stream network and basins
(Chinnayakanahalli et al., 2006)

Before hydrologic routing



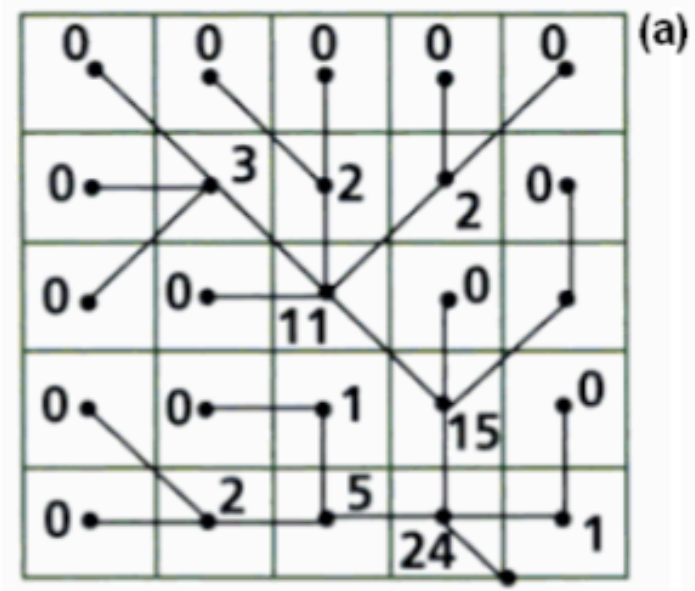






Eriş (2011)

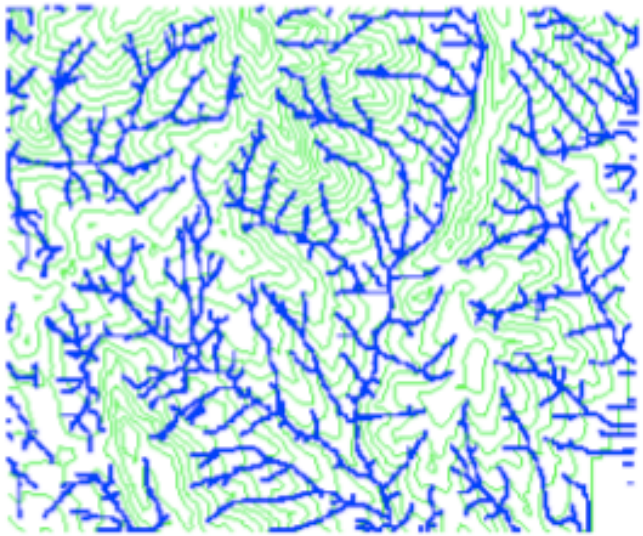
Before hydrologic routing



(b)

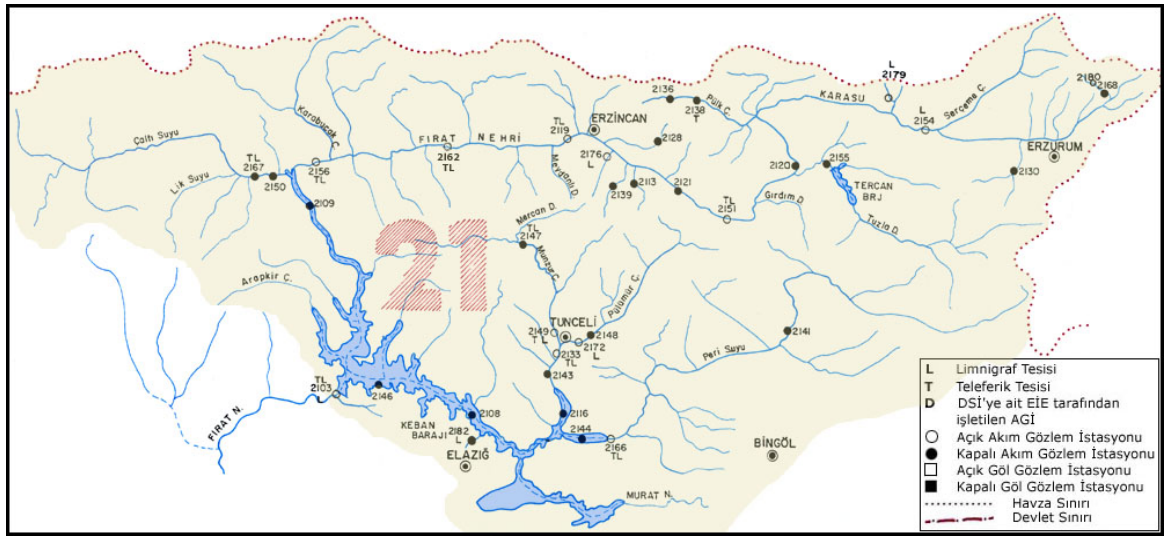
0	0	0	0	0
0	3	2	2	0
0	0	11	0	1
0	0	1	15	0
0	2	5	24	0

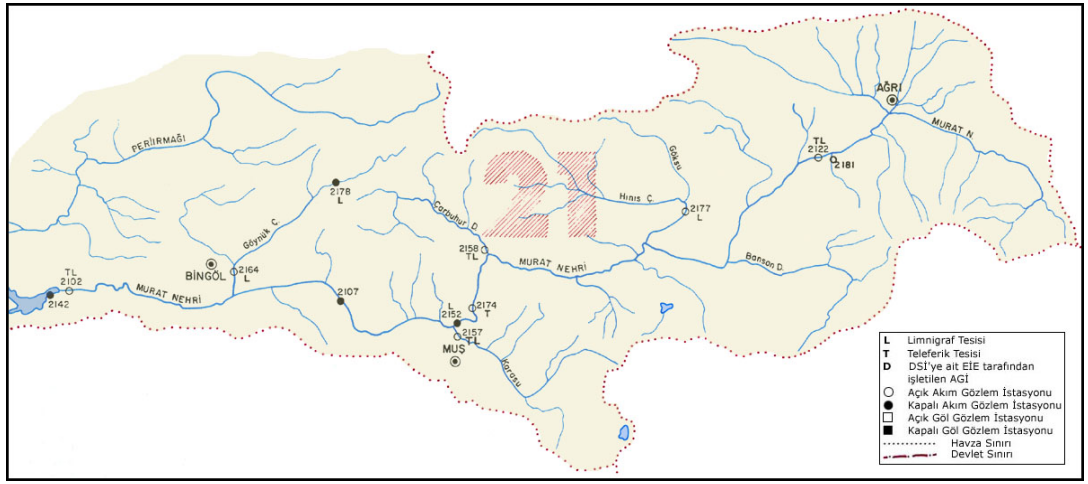
(c)



Eriş (2011)

Upper and middle Euphrates basins



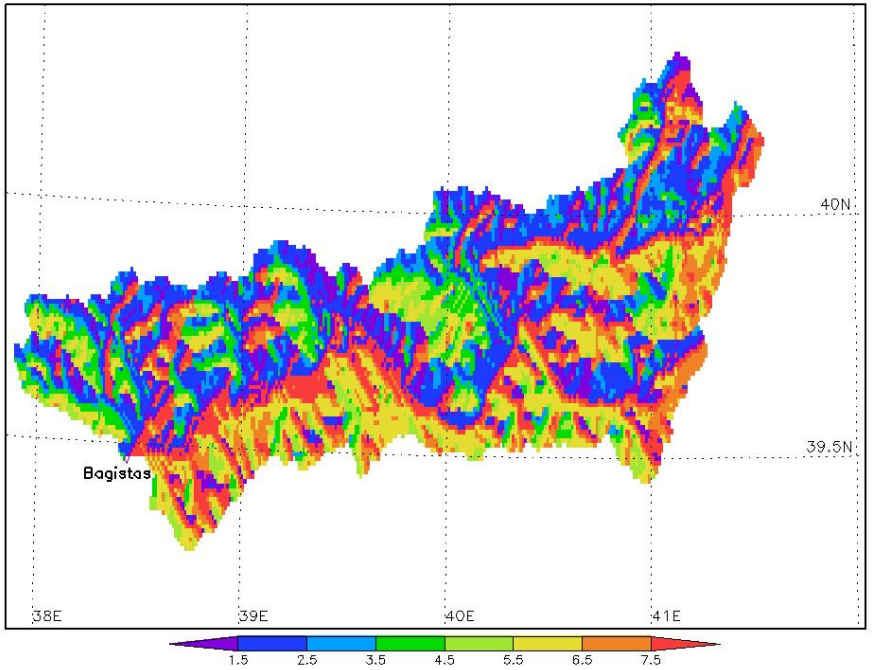


Algorithm to calculate basin characteristics

model1km_described.f

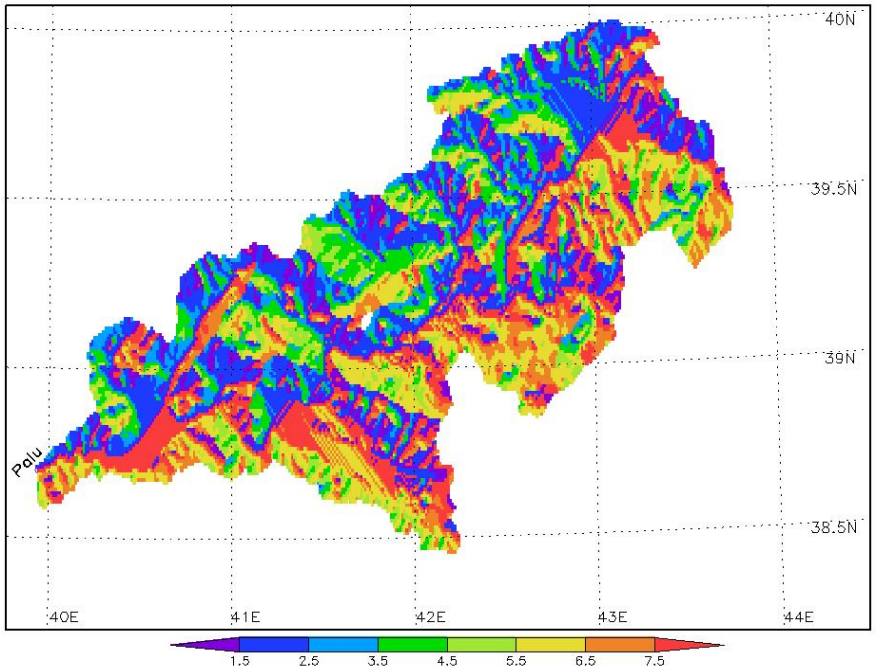
```
      Program RiverNetwork
!
!     Given the topography, latitude, longitude and land-sea mask data and
!     the basin outlet coordinates (latitude and longitude), this algorithm
!     provides the basin map, slopes, river flow directions, distances of
!     each grid to the basin outlet. The latter is used to calculate
!     the daily streamflow in another algorithm.
!
!     This algorithm is compiled and run using the following commands:
!      f77 -convert big_endian model1km_described.f
!      or
!      ifort -convert big_endian model1km_described.f
!      ./a.out
!     Note: It may take 10s of minutes to finish the job.
!
!     Definition of the variables:
!     jmx:   Number of grids in x direction in 1km data from MM5
!     imx:   Number of grids in y direction in 1km data from MM5
!     htt:   Height data (1km resolution) from MM5
!     xlat:  Latitude data (1km resolution) from MM5
!     xlon:  Longitude data (1km resolution) from MM5
!     htsd:  Height standard deviation data (1km resolution) from MM5
!     mask:  Land Sea mask data (1km resolution) from MM5
!     jmax:  Number of grids in x direction for the basin
!     imax:  Number of grids in y direction for the basin
!     ht:    Height data for a rectangle consisting of the basin
!     xlt:   Latitude data for a rectangle consisting of the basin
!     xln:   Longitude data for a rectangle consisting of the basin
!     hts:   Height standard deviation data for a rectangle consisting of the basin
!     msk:   Land Sea mask data for a rectangle consisting of the basin
!     idir:  Direction (1=southwest,2=south,3=southeast,4=east,5=northeast,
!                       6=north,7=northwest,8=west)
!     sest:  Used to find the largest slope
!     slop:  Slopes of the grid towards 8 directions
!     slope: Highest slope (where water is expected to flow)
!     dist:  Distances of the grid to the grids surrounding it
!     dista: Distance to the grid that forms the largest slope
!     uu:    Flow direction component in x direction (analogous to the winds)
!     vv:    Flow direction component in y direction (analogous to the winds)
!     tdist: Total distance of a grid to the basin outlet (along watercourse)
!     tslop: Slope between any grid and the grid at the basin outlet
!     ydis:  Distance between two grids in km in y direction
!     xdis:  Distance between two grids in km in x direction
!     xlati: Latitude of basin outlet
!     xloni: Longitude of basin outlet
!
```

Flow directions

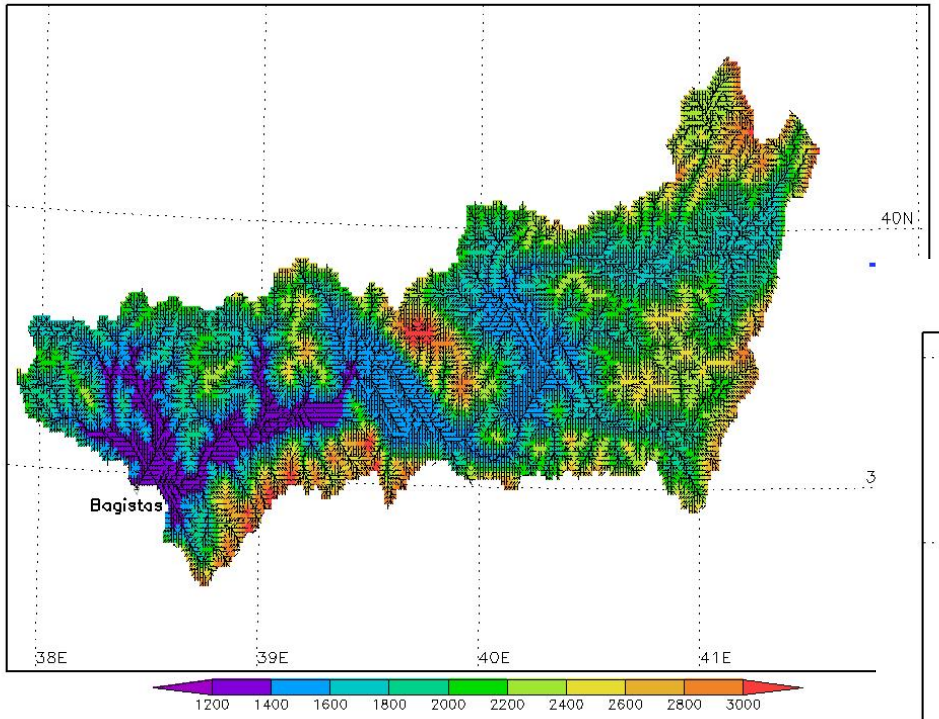


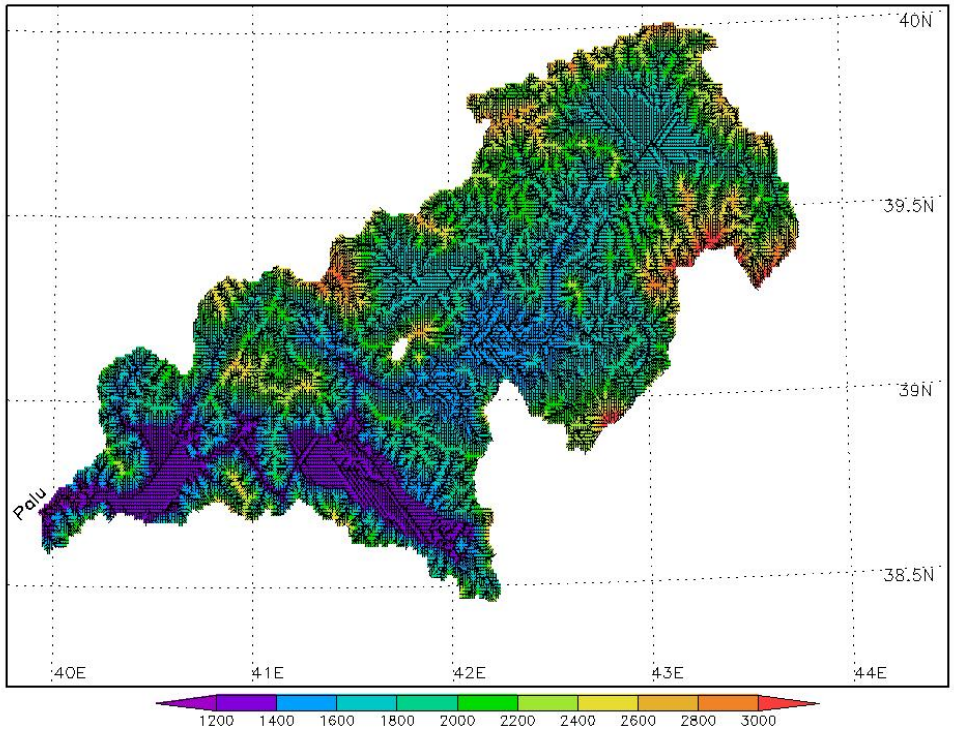
Directions for X grid

7 6 5
8 X 4
1 2 3

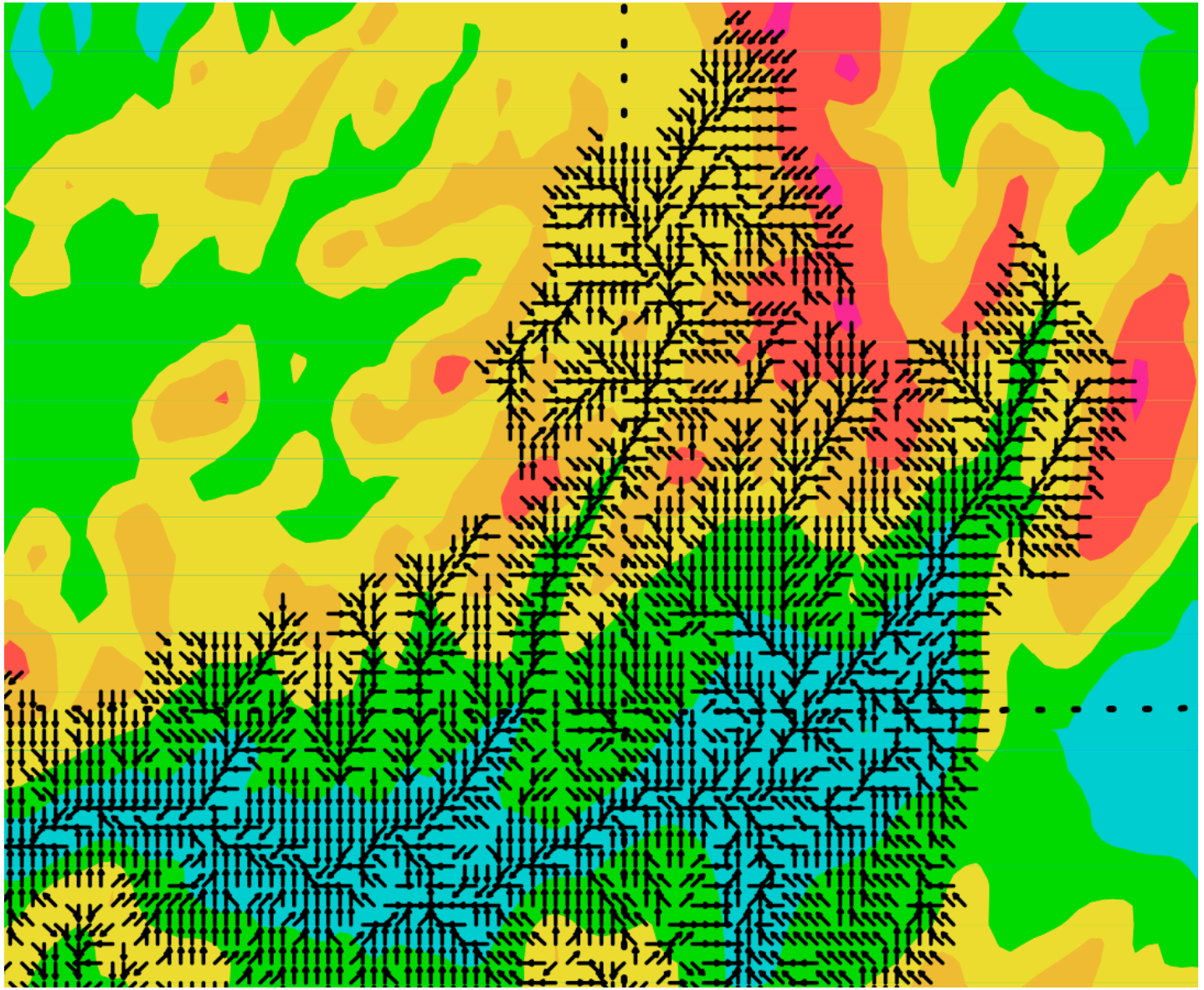


Flow directions

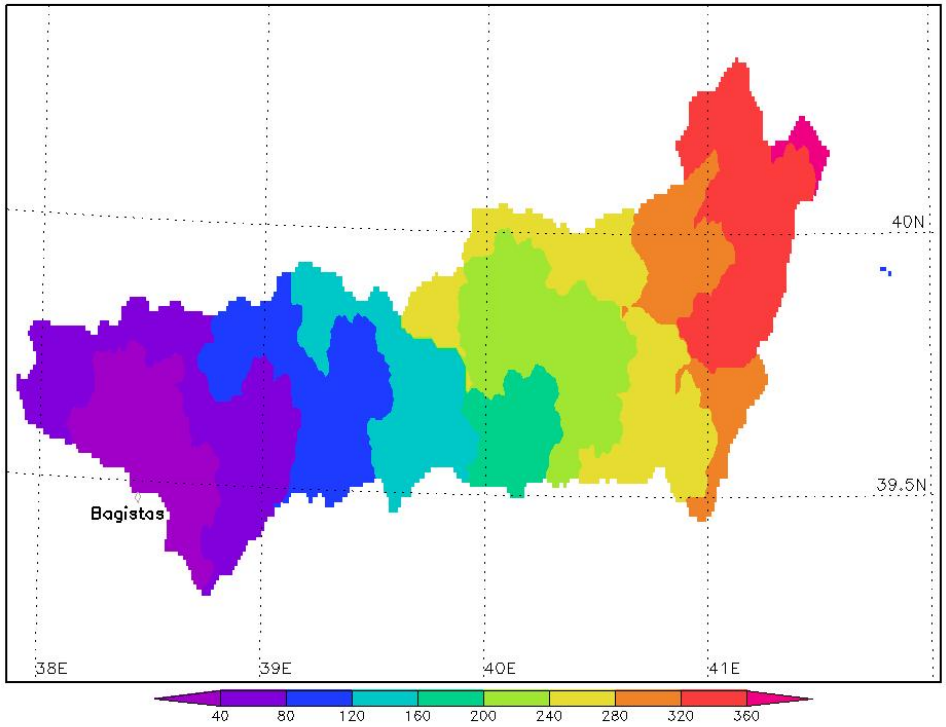


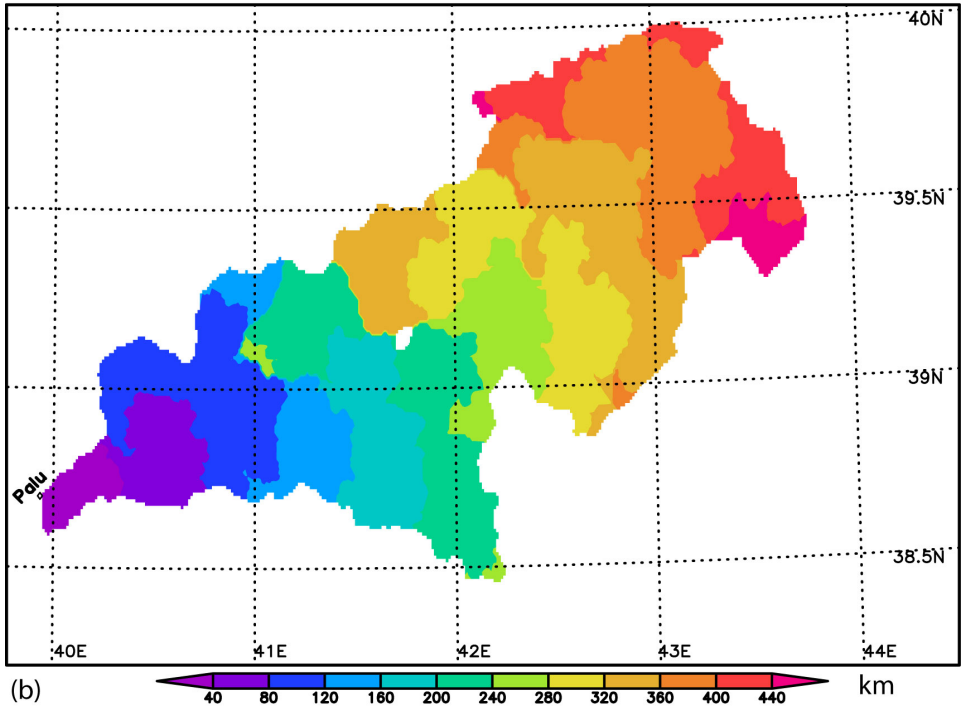


Flow directions

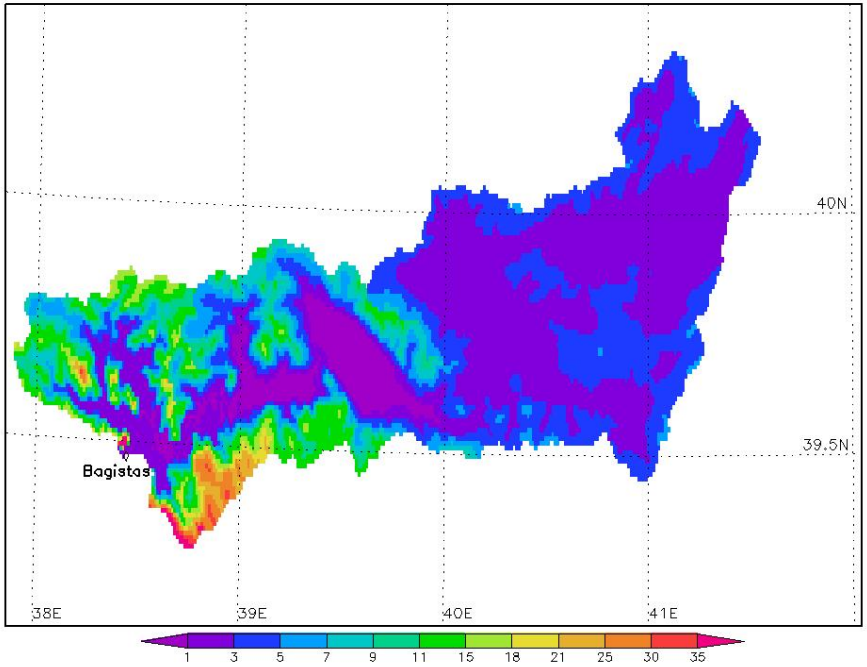


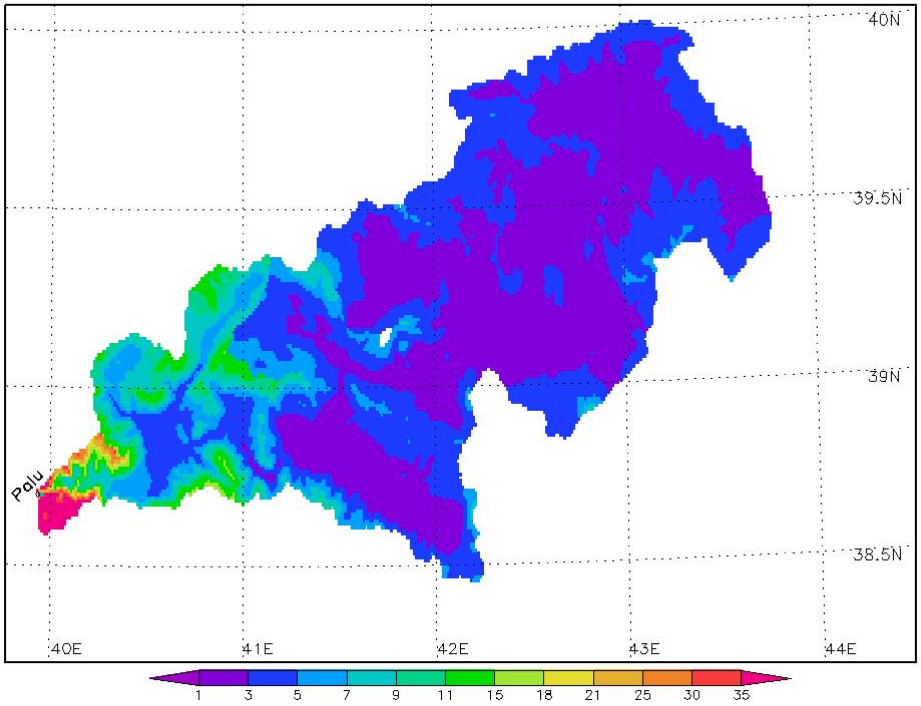
Distances of grids to basin outlet





Slope maps



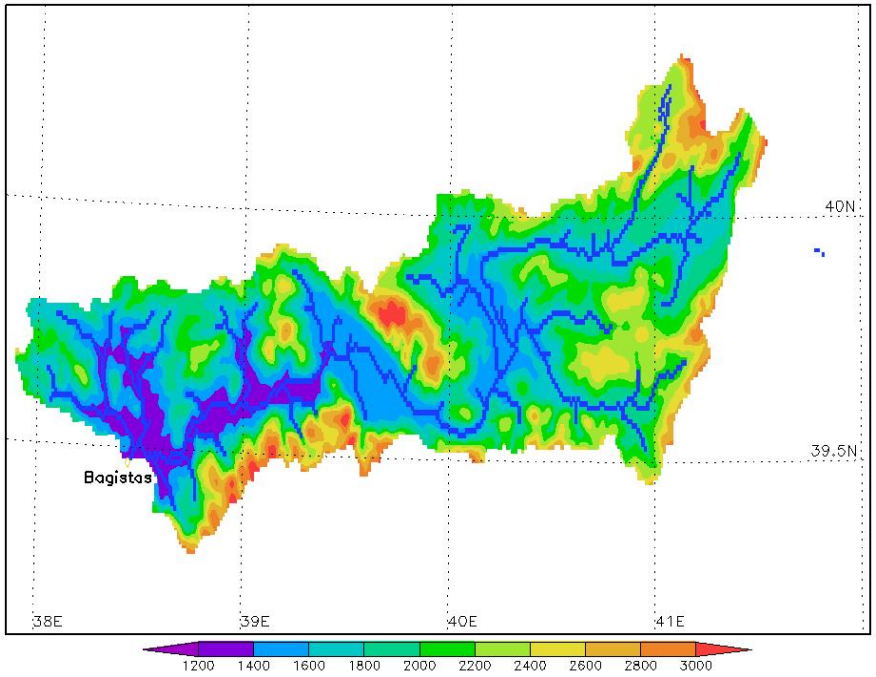


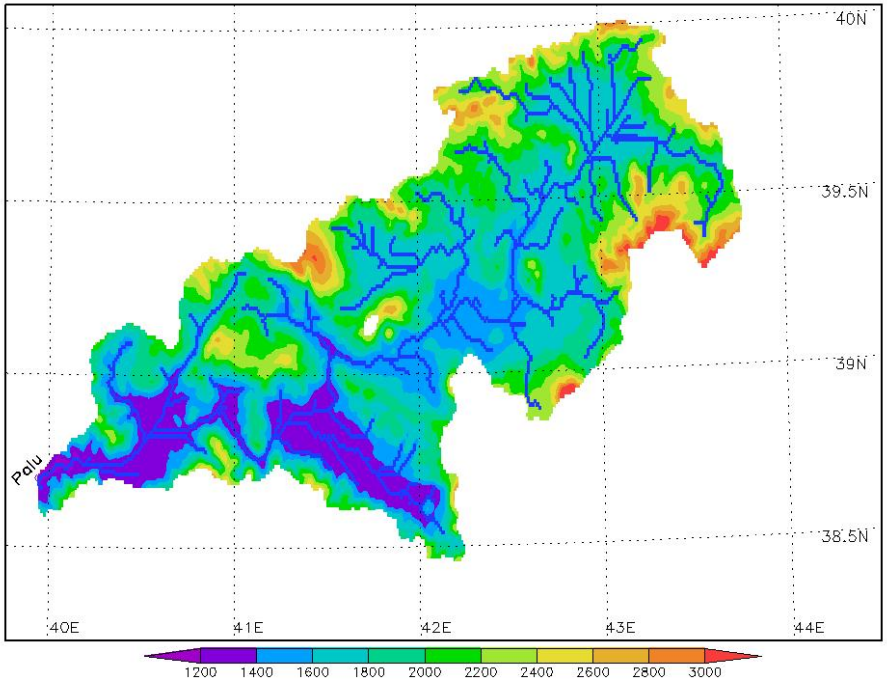
Manning eşitliği açık kanal akım hızını (m/s) belirlemek için kullanılmakta olup aşağıdaki gibi tanımlanmaktadır:

$$V = (1/n)\, R^{2/3}\, S^{1/2}$$

Eşitlikte, n Manning pürüzlülük katsayısı, R hidrolik yarıçap (R=A/P, A kesitte akım alanı ve P ıslak çeperin uzunluğu) ve S ise eğimdir (Chow vd. 1988).

River network





Routing algorithm

runoff2discharge_2001_04_described_calib.f

```
      Program Runoff2discharge
!
!     This algorithm uses the watershed characteristics determined
!     in another algoritm (model1km_described.f ==> uv.dat) to
!     estimate the daily stream discharge at the streamgage of
!     interest. Based on the distance of each grid to the basin outlet
!     it calculates the time it should take water to reach to the
!     basin outlet. Using the runoff data from an atmosphere model,
!     it, then, estimates the discharge by assigning the runoff data
!     to the appropriate day.
!
!     jmax    : Number of grids in x direction in watershed file (uv.dat)
!     imax    : Number of grids in y direction in watershed file (uv.dat)
!     jmx     : Number of grids in x direction in lat&lon data (model)
!     imx     : Number of grids in y direction in lat&lon data (model)
!     jmx1    : Number of grids in x direction in runoff data (modeled)
!     imx1    : Number of grids in y direction in runoff data (modeled)
!     numday  : Number of days being modeled
!     numdisc : numday + 60 (travel time cannot be longer than 60 days!)
!     roff9km : Runoff from the model
!     xlat    : Latitude from the model
!     xlon    : Longitude from the model
!     roff    : Runoff from the model (number of grids are slightly different
!               from those of lat and lon, but adjusted in the algorithm
!     idir    : Direction of flow for each grid (from uv.dat)
!     msk     : Mask of water bodies (from uv.dat)
!     tcon    : Travel time (in days) for water from grid to outlet
!     ht      : Elevation of the grid (from uv.dat)
!     xlt     : Latitude (from uv.dat)
!     xln     : Longitude (from uv.dat)
!     hts     : Standard deviation of the elevations
!     wspeed  : Average speed in overland flow (in km/day)
!     uu      : Flow direction component in x direction (analogous to the winds)
!     vv      : Flow direction component in y direction (analogous to the winds)
!     dista   : Distance to the grid that forms the largest slope
!     tdist   : Total distance of a grid to the basin outlet (along watercourse)
!     tslop   : Slope between any grid and the grid at the basin outlet
!     wshed   : Watershed area (=1 watershed grid)
!     xnumb   : River network (a grid fed by how many grids)
!     disc    : Daily discharge
!     check   :
!
```

Modeled and observed discharges