AWCI Training Workshop on Assessment of Climate Change Impact on Watershed Hydrology and Hydrological Modeling in Cold Region Basins, 15-17 September, 2014

Preparing Hydrological Simulation, WEB-DHM Demonstration and Analysis of Results

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Hydrological Modeling
(Basic Concepts)

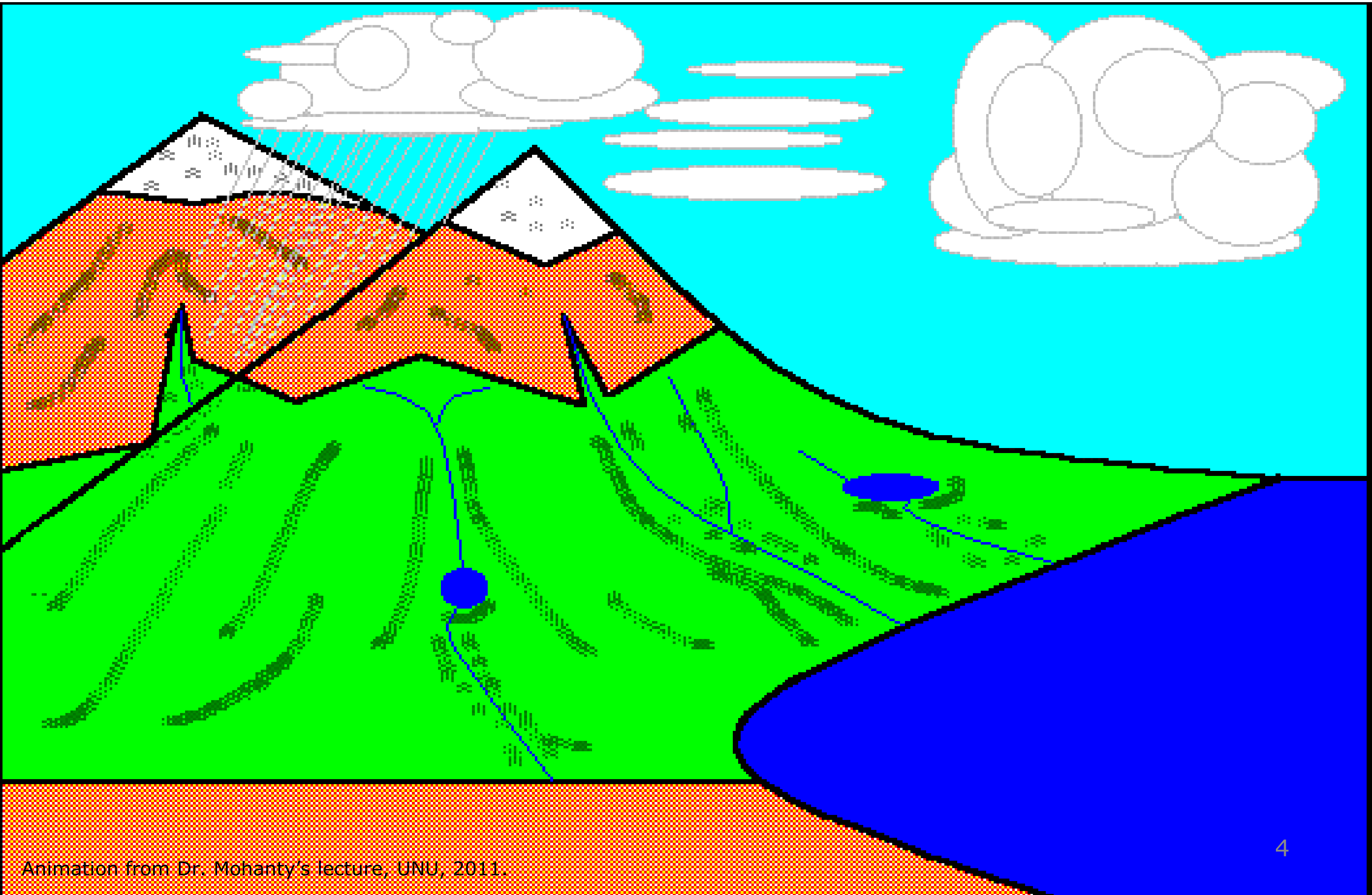
Hydrology

- comes from the greek words:
  - "hydro"—water and "logos"– science
- **As a science:**

  Hydrology is the science that treats the waters of the earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment including their relation to living things. The domain of hydrology embraces the full life history of water on the earth
- **As a profession:**

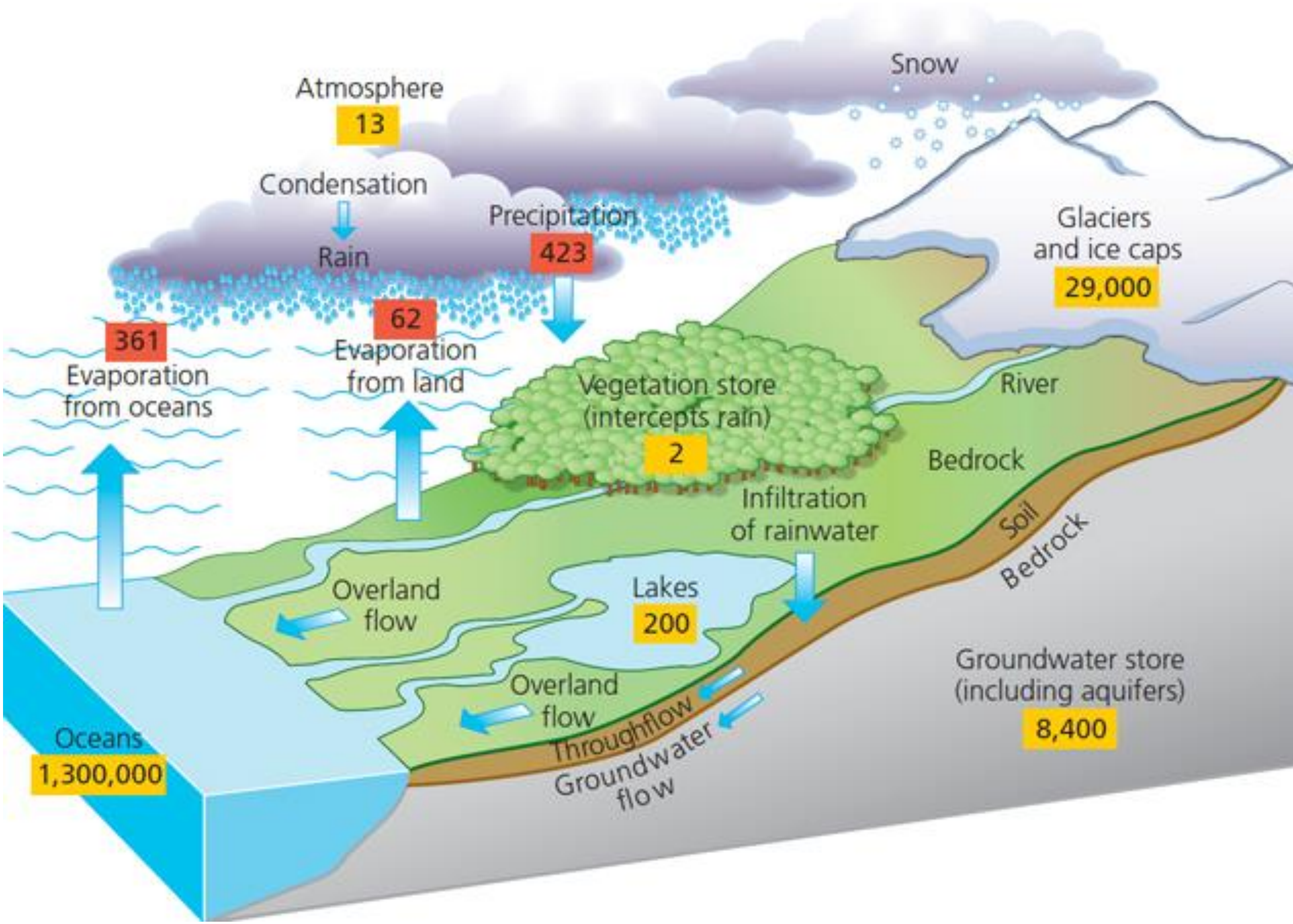
  What hydrologists do:
  - Water use: water withdrawal and in-stream uses
  - Water control: flood and drought mitigation
  - Pollution control: point and non-point sources
- Science dealing with the hydrological cycle

The Hydrological Cycle



Animation from Dr. Mohanty's lecture, UNU, 2011.

Hydrologic Cycle

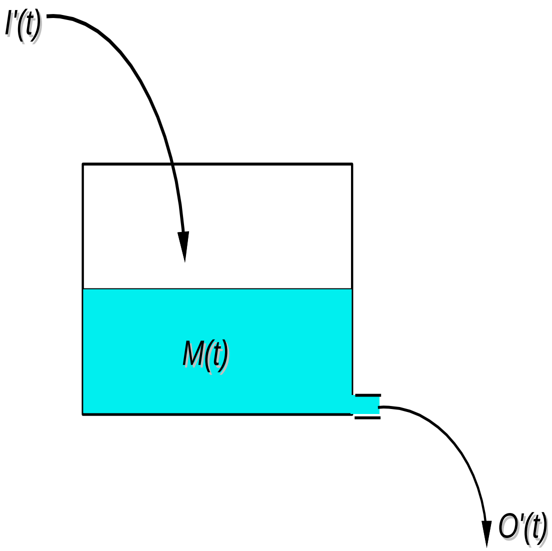


‘Basic Truths’ in Modeling Natural Systems

- Models are approximations of reality; they cannot precisely represent natural systems
- There is no single, accepted statistic or test that determines whether or not a model is valid
- Both the graphical comparisons and statistical tests are required in both model calibration and validation
- Models cannot be expected to be more accurate than the errors (confidence intervals) in the input and observed data

“All Models are wrong but some are useful…”—George E.P. Box

Water Balance

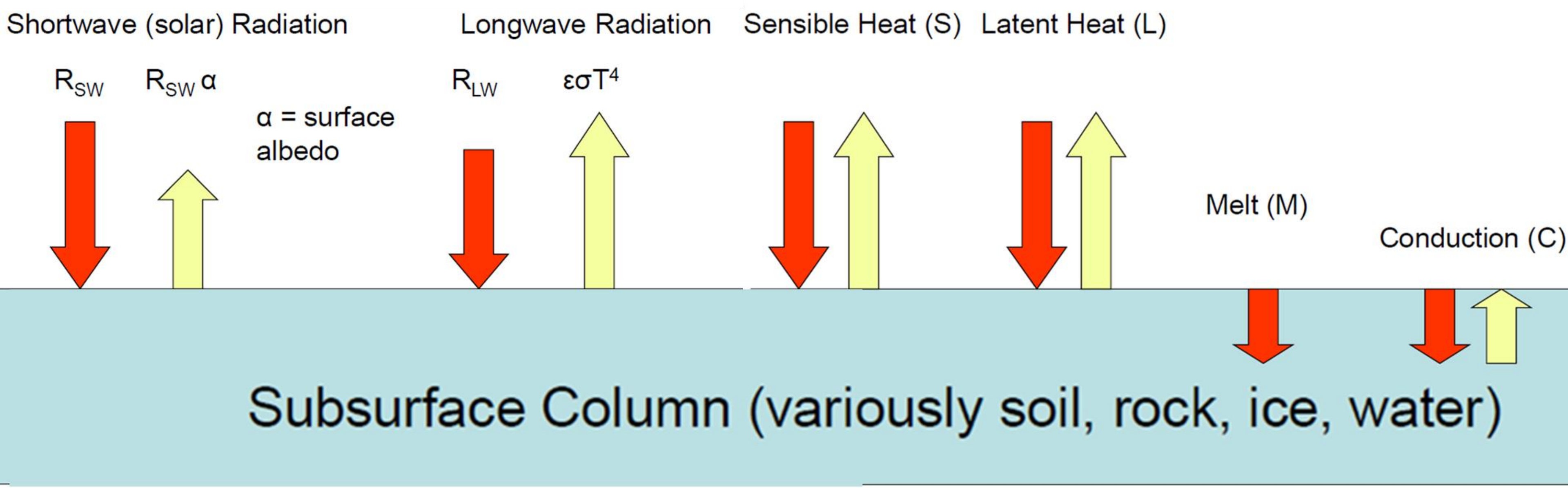


Change in mass storage = Inflow-Outflow

In Snowy/Glacierized Basin

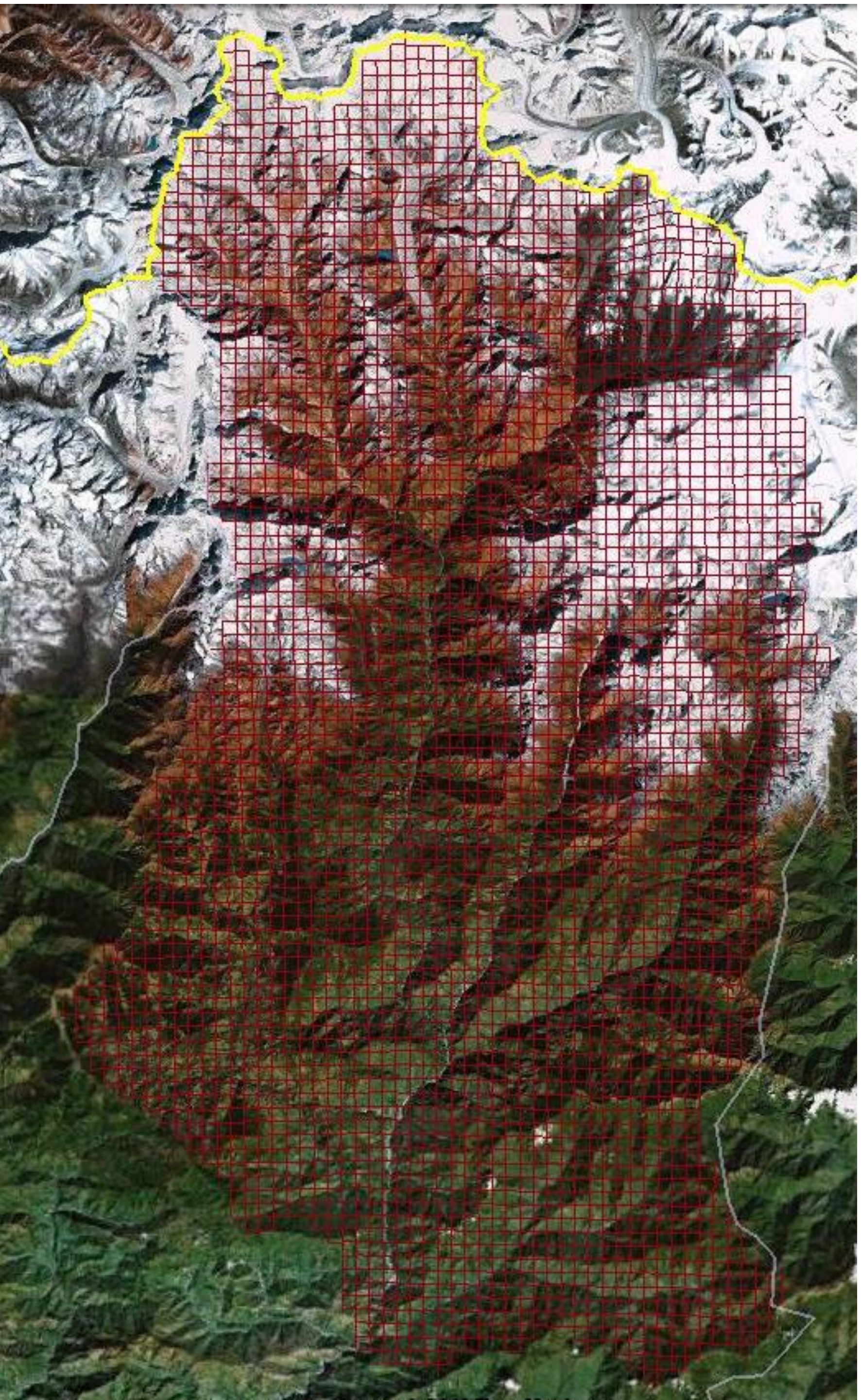
Inflow = Precipitation (Rainfall + Snowfall)
Outflow = Snowmelt/Glaciermelt+Interception+Infiltration+ Evaporation+Rainfall induced Runoff
△Storage = Inflow - Outflow

Energy Balance



Distributed Hydrological Model

- Spatial representation of basic hydrological processes.
- Mainly water balance based.
- Advancement through incorporation of energy balance by coupling sophisticated 1-D Land surface schemes or Land surface model (LSM).
- Grid-based to sub-basin unit or combination of both.



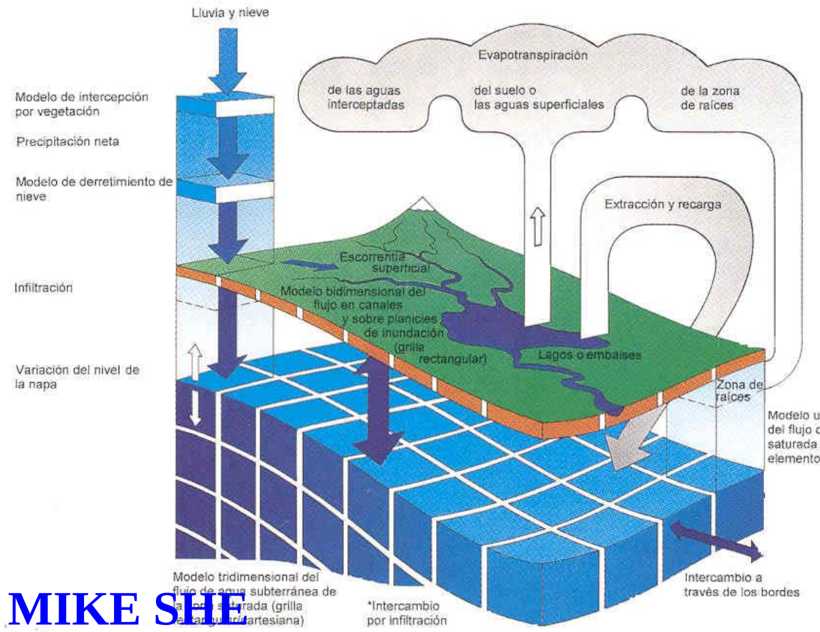
Spatial Representation

- Snowfall/Snowmelt in Forest/Baresoil
- Glacier melt
- Rainfall interception in bare soil and forest regions
- Infiltration
- Soil moisture
- Ground water
- Surface Runoff
- Subsurface Runoff
- River flow
- Elevation effect

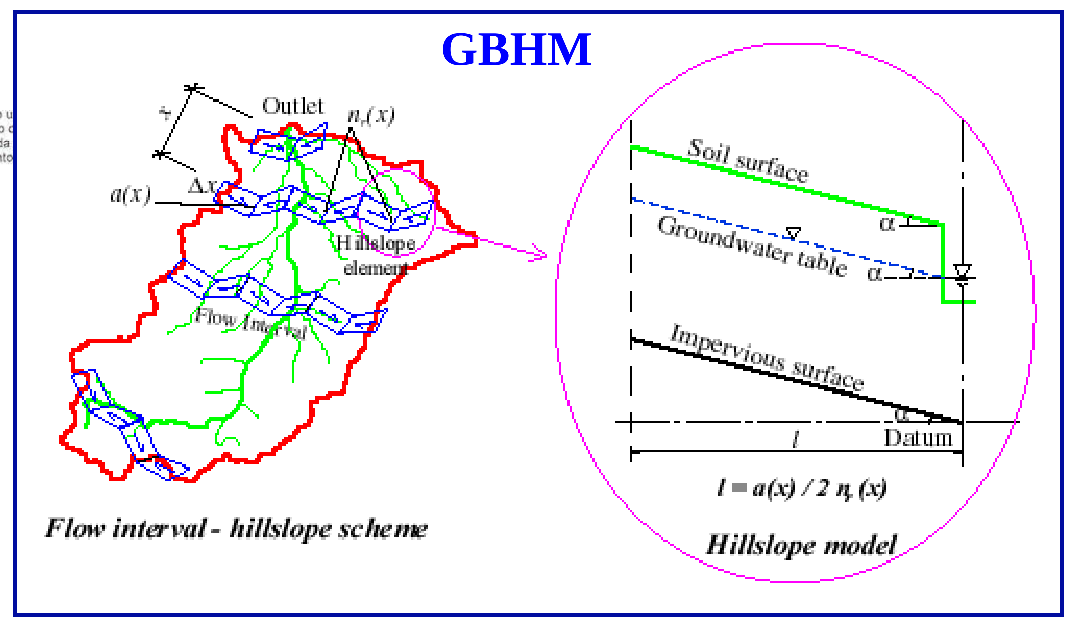
Distributed Hydrological Models (DHMs)

❖Distributed representation of spatial variation and physical descriptions of hydrological processes.

- Effective in water resources estimation.



MIKE SHE



Weakness of Traditional DHMs (no energy balance):

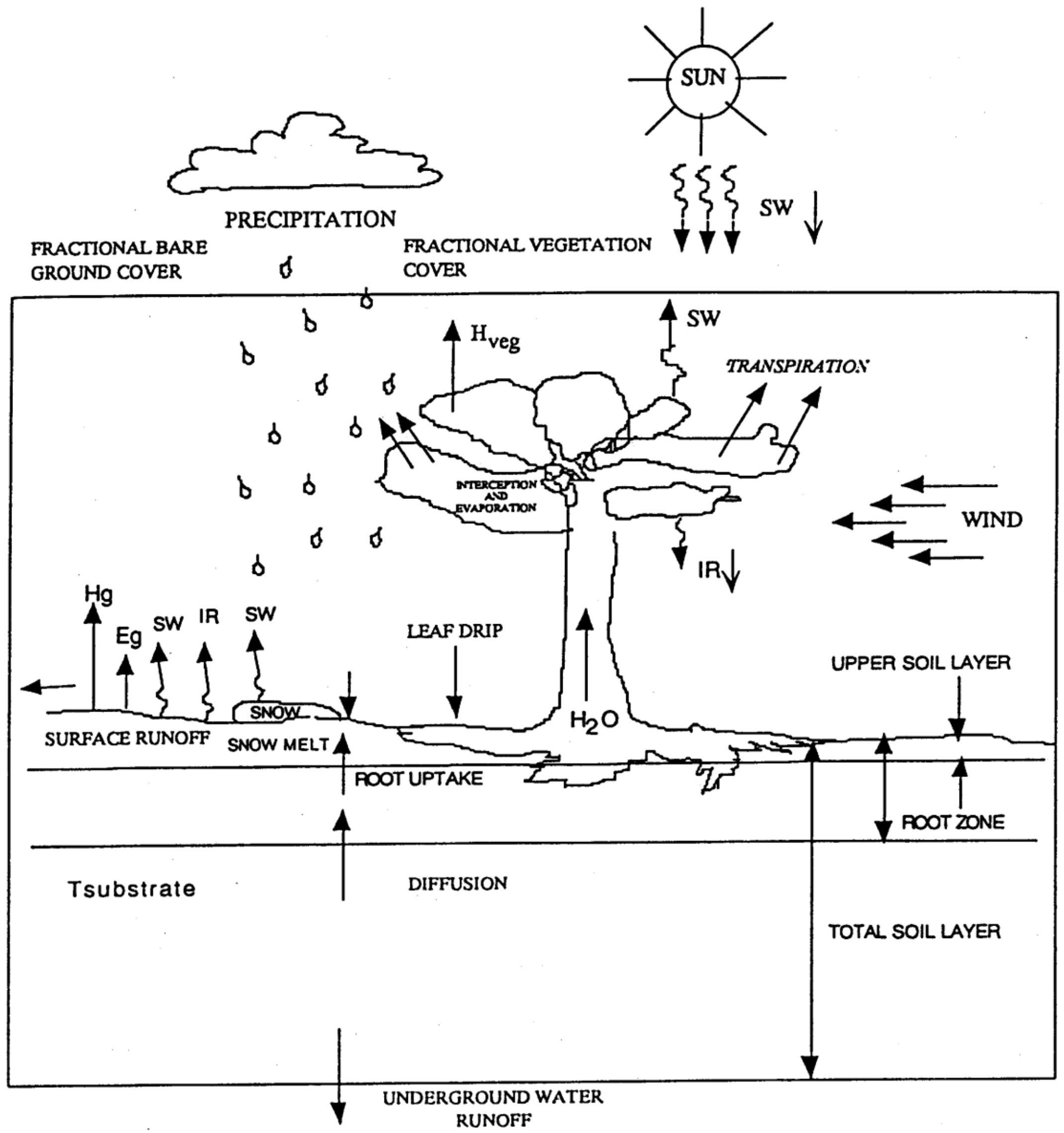
Lack of credible descriptions for land-atmosphere interactions

❑Flux:

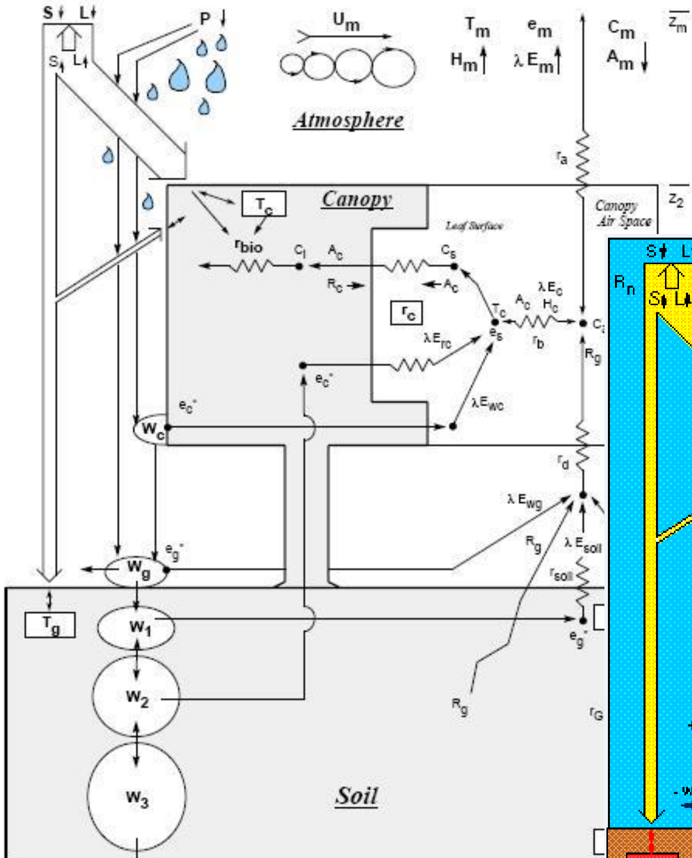
- ➢Radiation
- ➢Heat
- ➢Water vapor
- ➢Momentum
- ➢Carbon Exchange

SiB2

With advanced physics

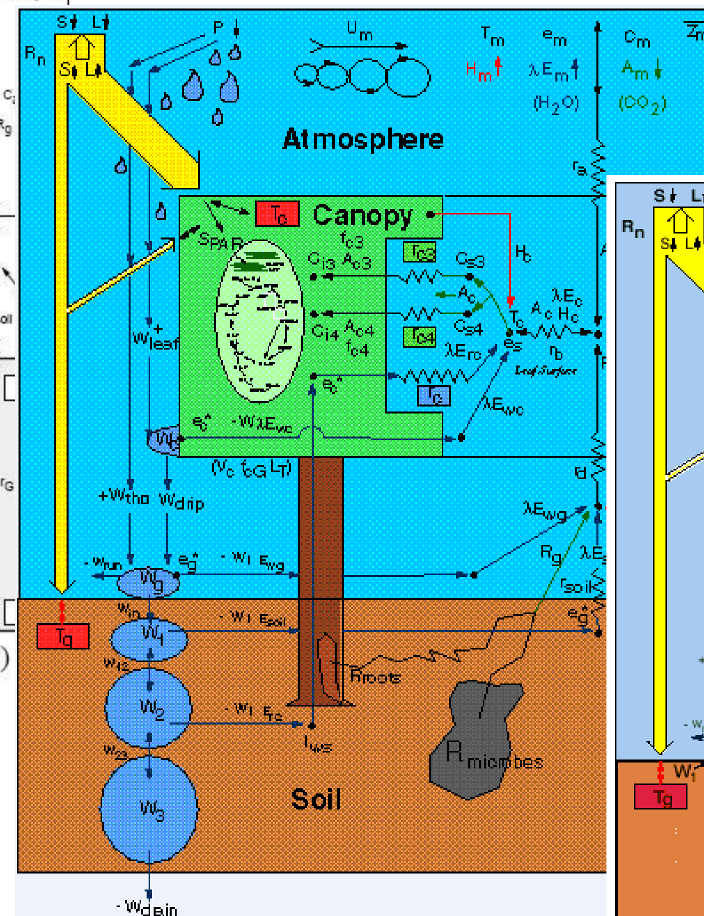


Land Surface Models

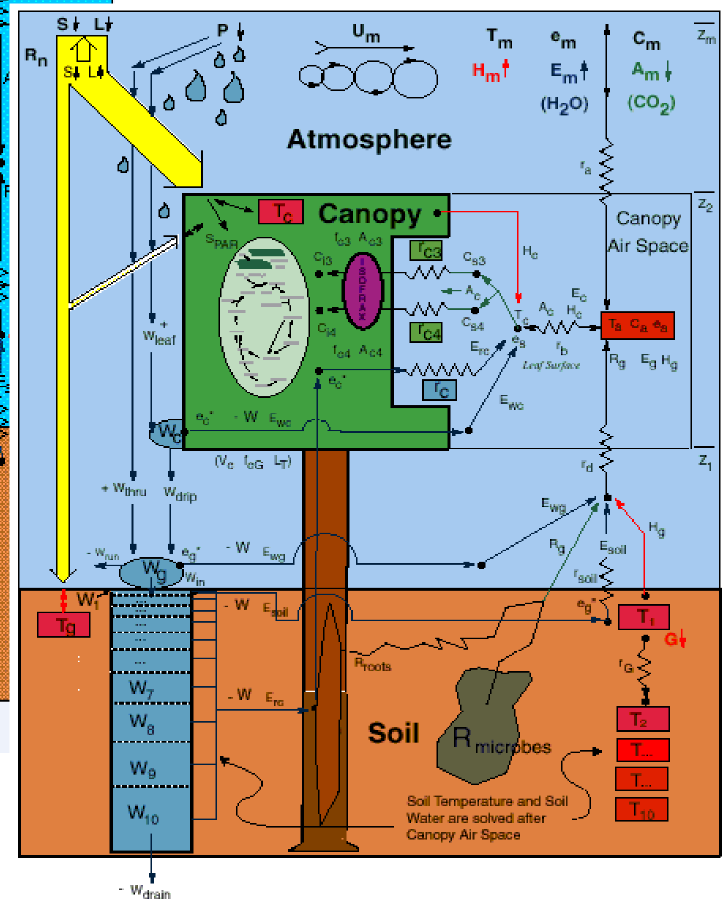


Simple Biosphere Model (SiB)

SiB1



SiB2



SiB3

Simple Biosphere Model

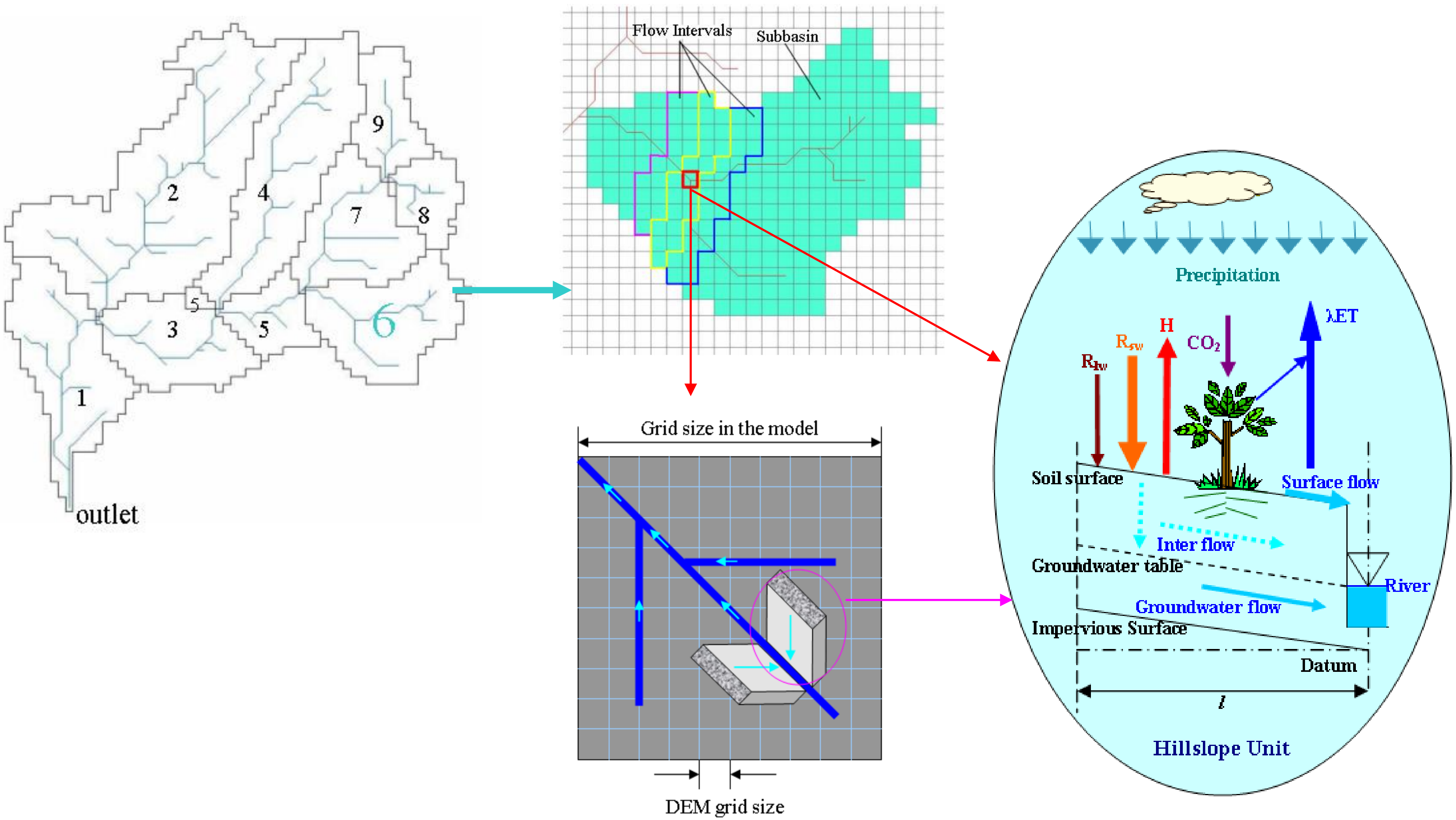
Water and Energy budget based hydrological models

Name of the Model	Snow Layers	Canopy snow process	Snow tempr.	Soil tempr.	Soil moisture	Glacier processes	Runoff routing	References
Distributed Hydrology Soils Vegetation Model (DHSVM)	2	*Yes*	*Yes*	*Yes*	*Yes*	*No*	*Yes*	*Wigmosta et al. (1994); Storck (1999)*
Variable Infiltration Capacity (VIC)	2	*Yes*	*Yes*	*Yes*	*Yes*	*No*	*Yes*	*Liang et al. (1994), Cherkauer et al. (2003)*
Utah Energy Balance (UEB) – distributed snow model	1	*No*	*Yes (Bulk)*	*Yes (Bulk)*	*No*	*No*	*No*	*Tarboton and Luce (1999)*
ISNOBAL	2	*No*	*Yes*	*No*	*No*	*No*	*No*	*Garen and Marks (2005)*
WATCLASS	1	*Yes*	*Yes(Bulk)*	*Yes(Bulk)*	*Yes*	*No*	*Yes*	*Soulis et al. (2000, 2002)*
SnowMOD	1	*Yes*	*Yes(Bulk)*	*No*	*No*	*No*	*No*	*Liston et al. (2006)*
Cold Region Hydrological Model (CRHM)	1	*Yes*	*Yes (Bulk)*	*Yes (Bulk)*	*Yes*	*No*	*Yes*	*Pomeroy et al. (2007)*
Geo-TOP	5	*No*	*Yes*	*Yes*	*Yes*	*No*	*Yes*	*Endrizzi (2007)*
Distributed Biosphere Hydrological Model (DBHM)	1	*Yes*	*Yes (Bulk)*	*Yes (Bulk)*	*Yes*	*No*	*Yes*	*Tang (2006) SiB2 - LSM*
Water and Energy Budget based Distributed Hydrological Model (WEB-DHM)	1	*Yes*	*Yes (Bulk)*	*Yes (Bulk)*	*Yes*	*No*	*Yes*	*Wang et al. (2007; 2009a,b) SiB2-LSM*
WEB-DHM with improved snow and glacier physics(WEB-DHM-S)	*3*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	***Shrestha et al.(2012) SiB2/SSiB3/BATS-LSM***

Introduction to Water and Energy Budget based Distributed Hydrological Model (WEB-DHM)

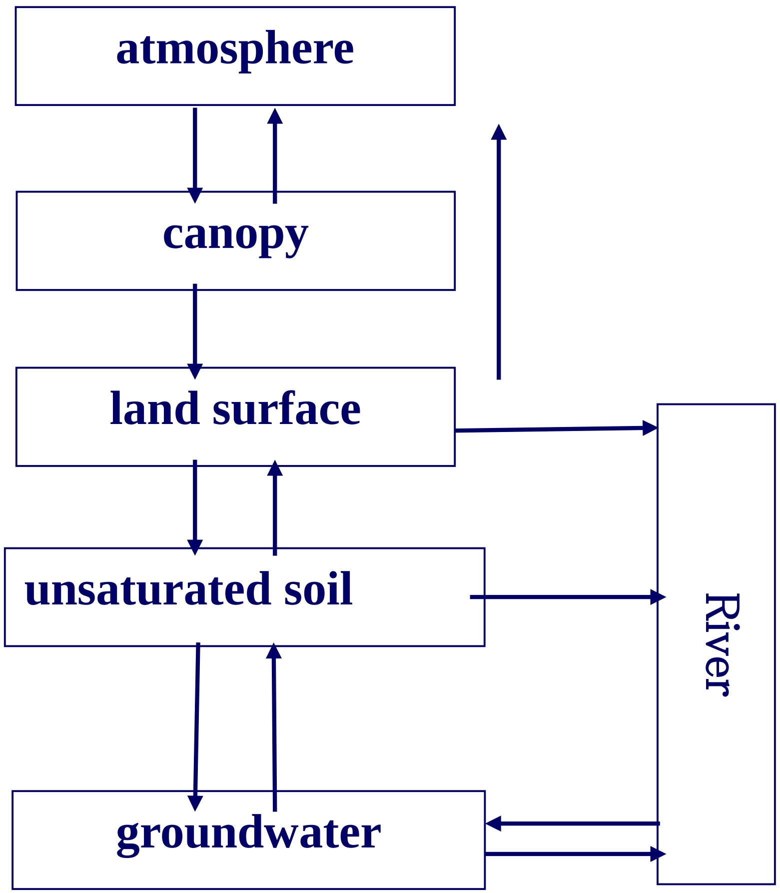
WEB-DHM

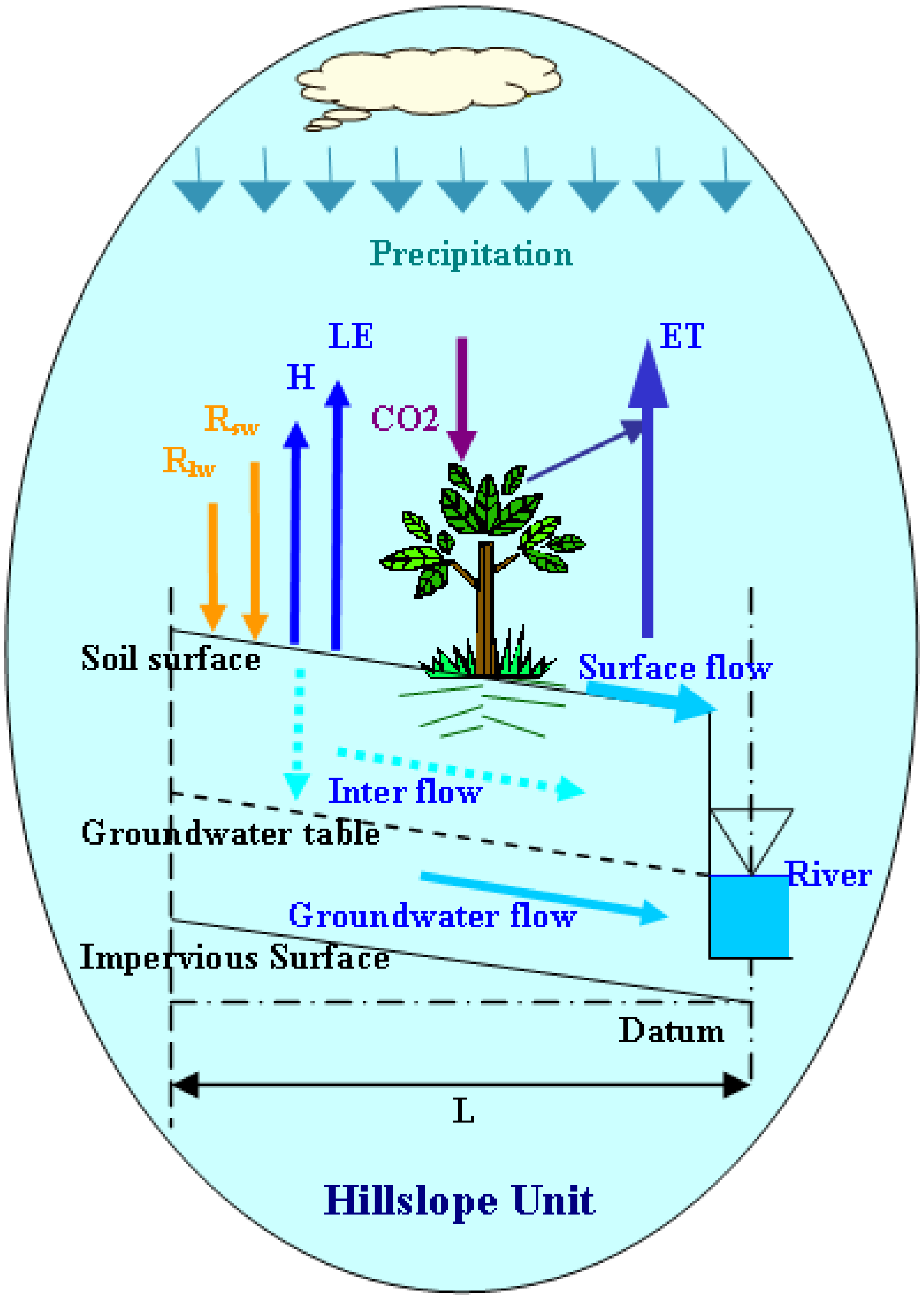
(Water and Energy Budget-based Distributed Hydrological Model)



Wang et al., 2009

Processes Description



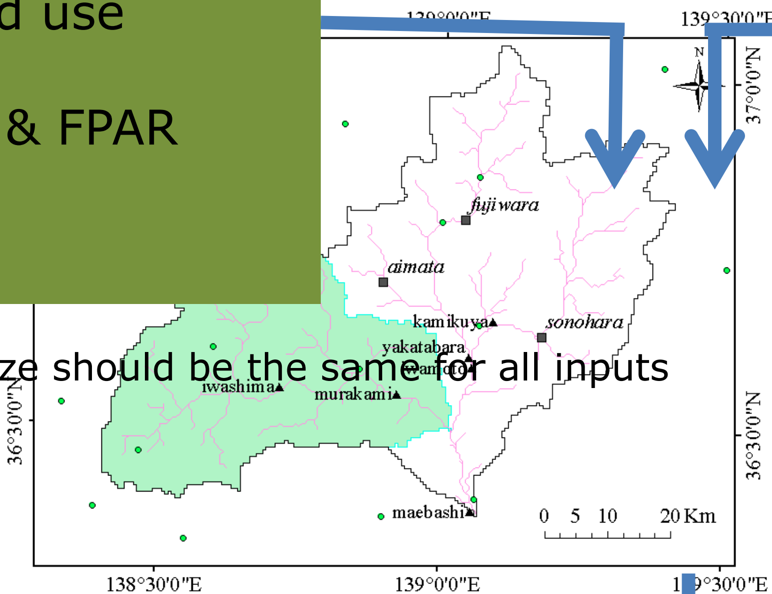


WEB-DHM Components:

Biophysical Inputs:
DEM
Hillslope
Land use
Soil
LAI & FPAR

(pre-processed at basin scale)

Meteorological inputs:
Rainfall
Air Temperature
Humidity
Wind (u,v)
Pressure
Long Wave Radiation
Short Wave Radiation

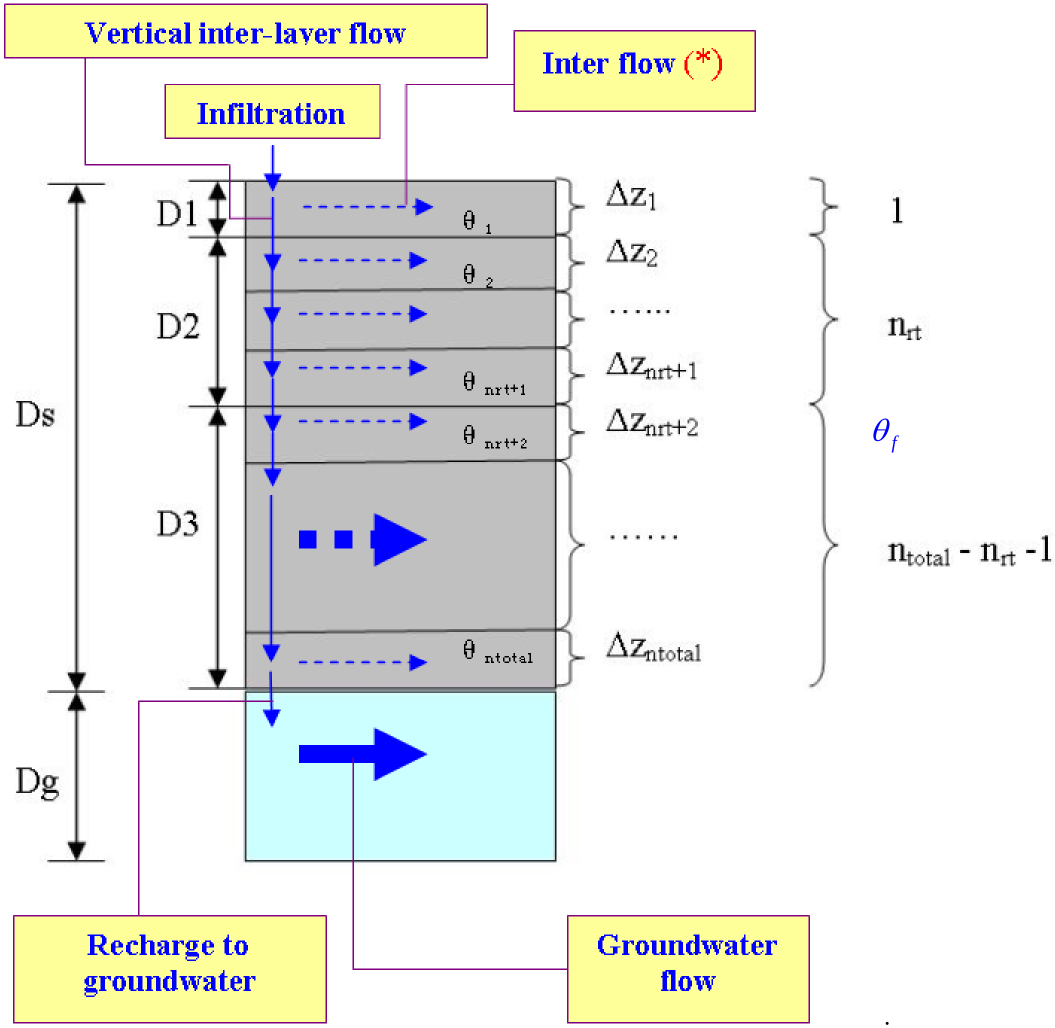


Grid size should be the same for all inputs

(usually we try to spatially distribute thes

Output
--can be spatially distributed or point scale values (hourly, daily, monthly, etc scale)

Soil Model



(*): Interflow occurs only when:

$$\theta_i > \theta_f \quad (i = 1 \sim n_{total})$$

θ_i : soil moisture content of sub-layer i

θ_f : soil moisture content at field capacity.

Initial Parameters used for setting up the hydrological model: WEB-DHM in Soan

Parameter	Data source	Global/local dataset	Static/ Dynamic
Elevation	Hydrosheds (http://hydrosheds.cr.usgs.gov/index.php)	Global	Static
Land Use	USGS Land Use (SiB2)	Global	Static
Soil	FAO soil	Global	Static
LAI/FPAR	MODIS	Global	Dynamic
Meteorological parameters (T, P, U, V, LW, SW)* *Temperature, Pressure, Wind, Long Wave and Short wave radiation	JRA-25 (Japan Reanalysis data)	Global	Dynamic
Rainfall	Aphrodite Rain for Monsoon Asia	Global and local	Dynamic

Static= does not change in time; Dynamic= changes in time; usually downscaled to hourly values inside the model

Delineating Target Basin From DEM

Digital Elevation Models (DEMs)

What is it?

- DEMs consist of an array of data representing elevation sampled at regularly spaced intervals
- Referenced horizontally either to a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system (degrees)

Digital Elevation Models (DEMs)

<u>Where can we get it? </u>USGS website

- HYDRO1k Elevation Derivative Database (1000m DEM)
- GTOPO30 (30-arc DEM : Almost 1000m DEM)
- For ASTER (30m GDEM): ASTER GDEM Explorer
- For SRTM (3-arc DEM): USGS EarthExplorer

(http://earthexplorer.usgs.gov/)

*What you need to do: sign up for an account (By yourself) in earthexplorer.usgs.gov before downloading

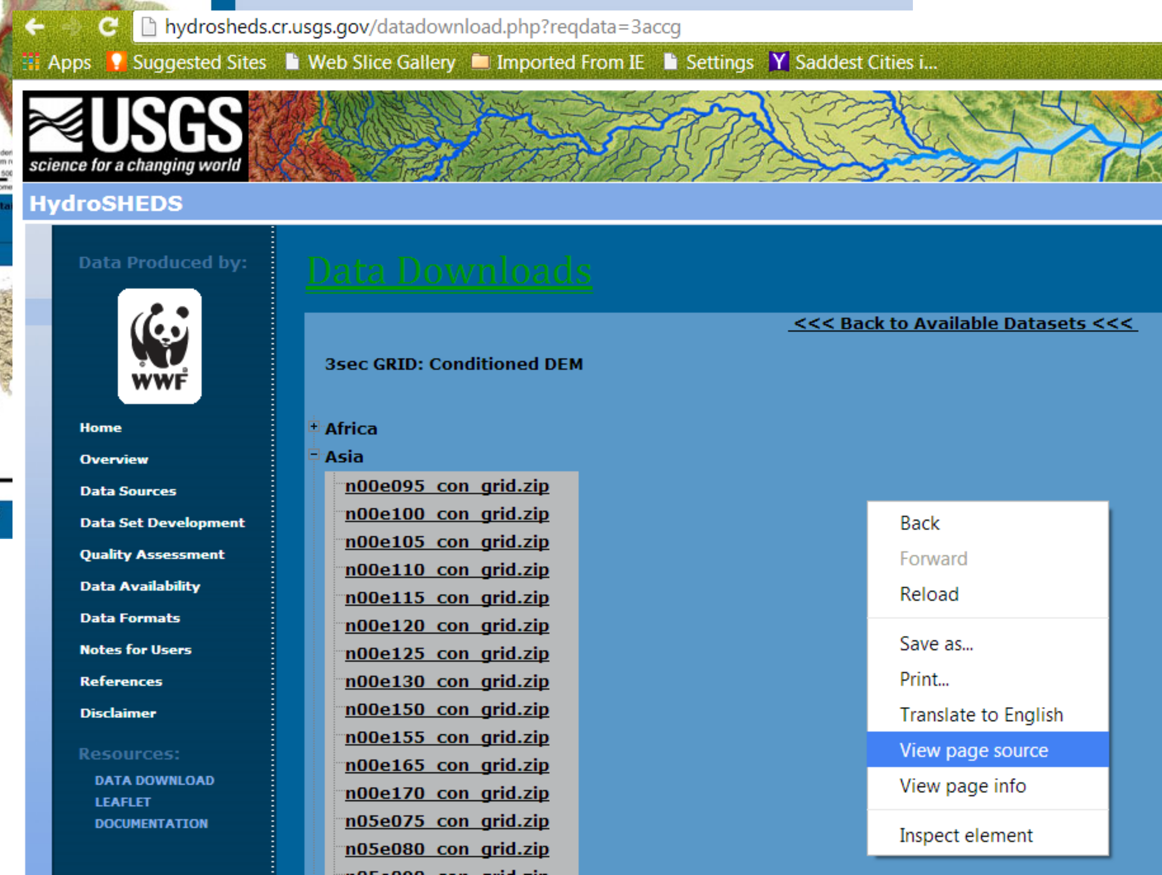
- Hydroshed-(3-arc DEM: 90m DEM)

(http://hydrosheds.cr.usgs.gov/index.php)

*What you need to do: click to download

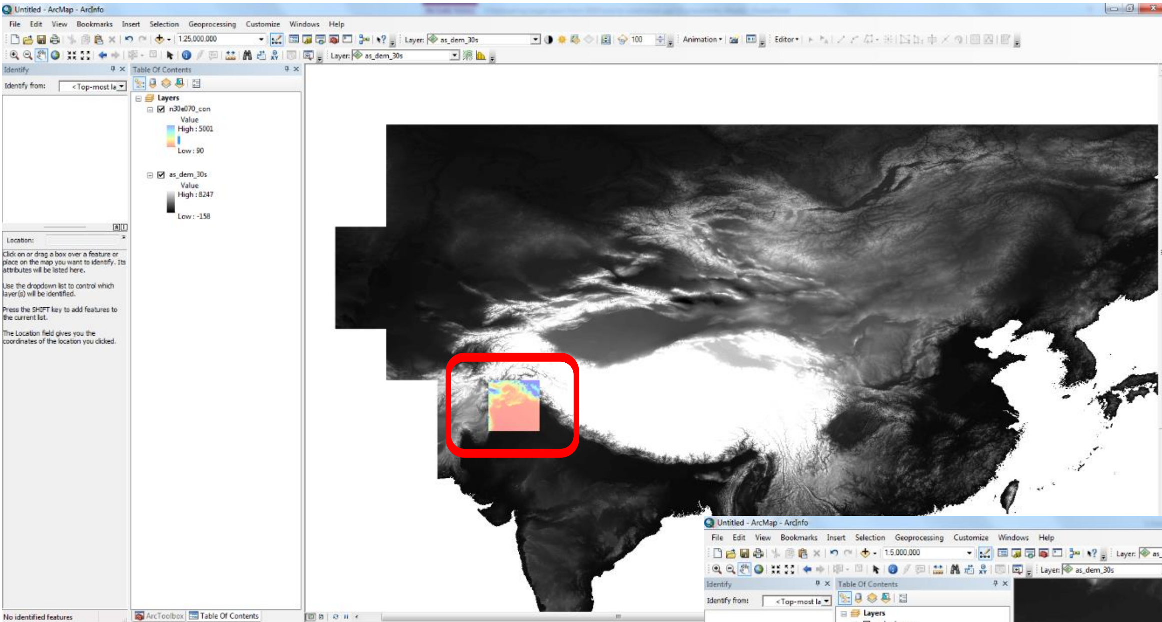
Hydroshed-(3-arc DEM: 90m DEM)

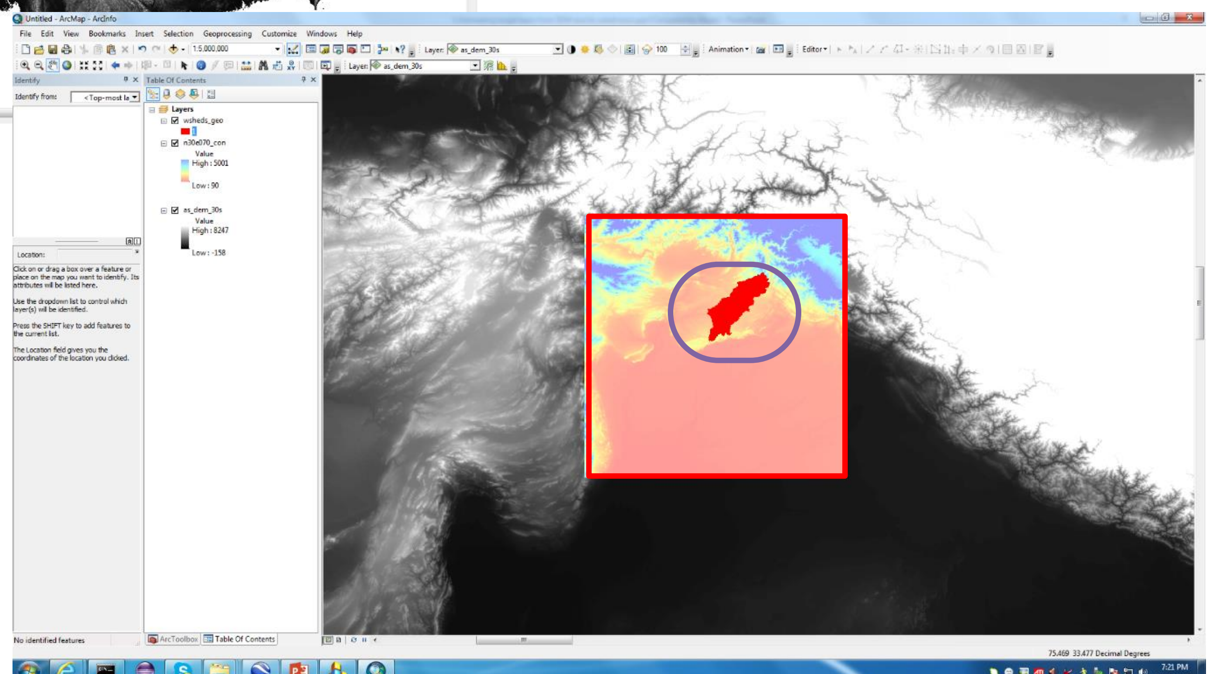
(http://hydrosheds.cr.usgs.gov/index.php)



Step 1: right click and open source
Step 2: To automatically download the files, do the following in cygwin:
C: wget –i list.txt

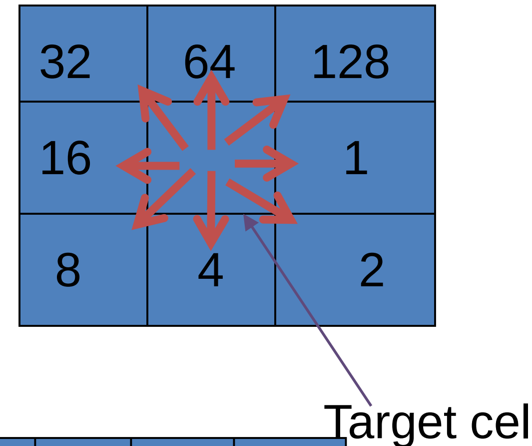
Hydroshed-(3-arc DEM: 90m DEM)





Flow direction (DIR)

- In ArcView Spatial Analyst, the output of flow direction is a grid whose values can range from 1 to 255 based on the direction water would flow from a particular cell.
- There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8) flow model and follows an approach presented in Jenson and Domingue (1988).



78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Elevation

2	2	2	4	4	8
2	2	2	4	4	8
1	1	2	4	8	4
128	128	1	2	4	8
2	2	1	4	4	4
1	1	1	1	4	16

Flow direction

Maximum drop = change in z value/distance

Flow Accumulation (ACC)

- If we know where the flow is going then we can figure out what areas (cells) have more water flowing through them than others.
- By tracing backwards up the flow direction grid we can figure the number of cells into all cells in a study area.
- Accumulated flow is calculated as the accumulated number of all cells flowing into each down slope cell.

High values==stream channels
0 values==ridges

0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	20	3
0	2	4	7	35	2

Flow accumulation

Why the basin numbering system is necessary?

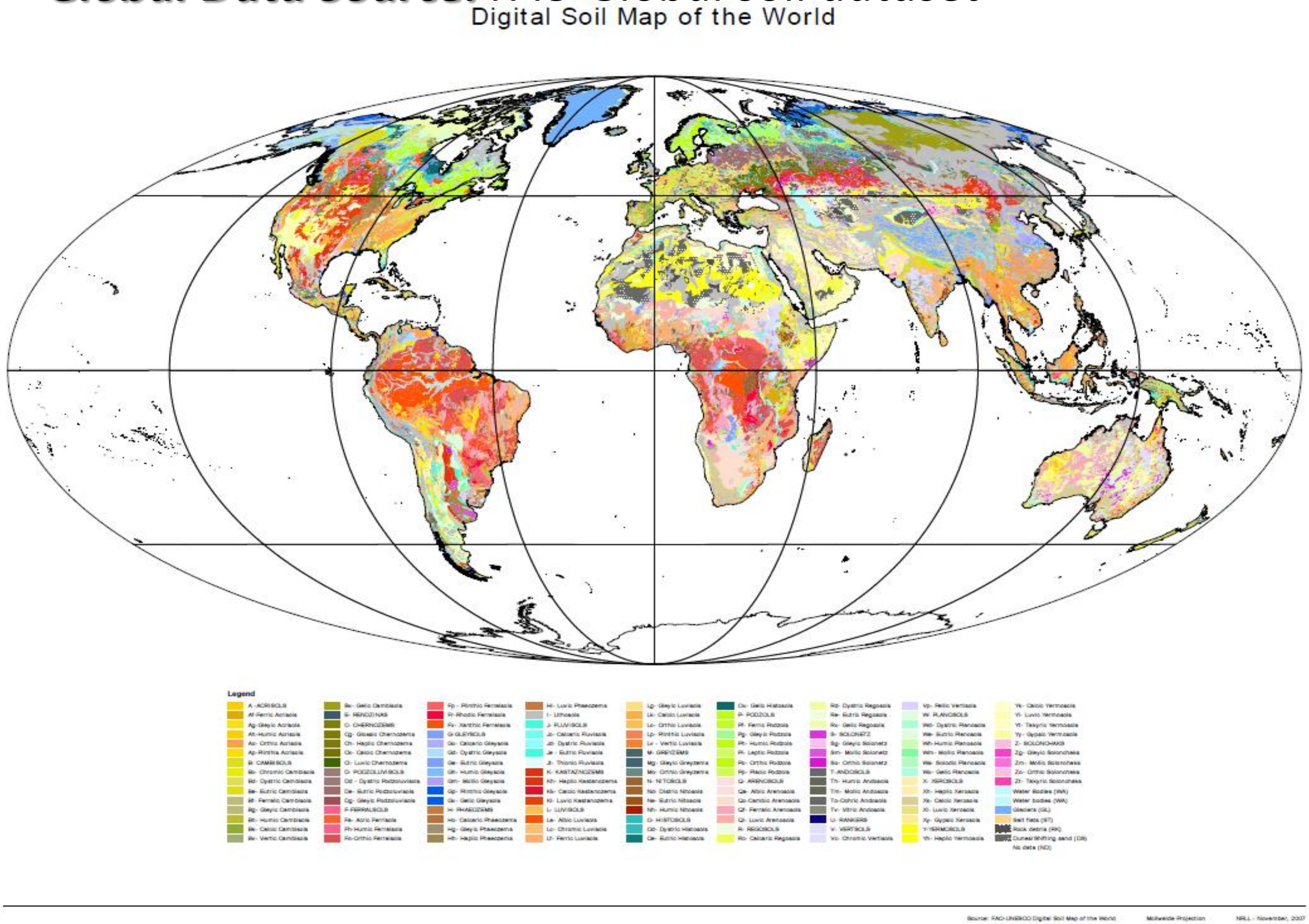
1. Hydrological modeling heavily depends on the DEMs for automatically extracting the basin and river network

2. Many hydrological models, especially physically-based models, need to subdivide the large catchment into sub-basins to achieve more accurate representation of spatial variability

3. Appropriate numbering of the sub-basins is necessary to carry out the flow accumulation in the river routing

*SOURCE: D. Yang, K. Musiake, S. Kanae, and T. Oki (I*nstitute of Industrial Science, University of Tokyo)

- ***Global Data Source:*** *FAO Global soil dataset*



Land Use Data

Data Source: USGS Global dataset

- Static (unchanging in the model; only 1 map is used for all simulations)
- Approximately 1 km resolution
- Processed parameters (land use classification :SiB2)
  - land_use grid
  - land_use.asc !this format is used in the model

Land Use Classification :SiB2

Definition of Vegetation Type	
SiB2 Type	***Vegetation Name***
1	*Broadleaf-evergreen trees*
2	*Broadleaf-deciduous trees*
3	*Broadleaf and needleleaf trees*
4	*Needleleaf-evergreen trees*
5	*Needleleaf-deciduous trees*
6	*Short vegetation/C4 grass*
7	*Broadleaf shrubs with bare soil*
8	*Dwarf trees and shrubs*
9	*Agriculture/C3 grassland*
10	*Water*
11	*Ice*

Reference *: Sellers, P.J., and Coauthors, 1996: A Revised Land Surface Parameterization (SiB2) for Atmospheric GCMS. Part I: Model Formulation. J. Climate,* ***9****, 676–705.*

Precipitation

- *Includes all forms of water deposited on the earth's surface and derived from atmospheric water vapor.*
- *Mist, rain, hail, sleet, snow frost (sometimes)*
- *(Source: Wisler and Brater,1949, Hydrology)*

Rainfall datasets:

Some rainfall data we commonly use in the lab for Asia or Globally

Asia:

- APHRODITE
- Observed gauge
- Radar

For Japan:

- AMEDAS (radar; observed)
- MLIT (observed)

- **Globally:**
- GPCP
- TRMM
- NOAA rainfall
- GSMaP
- …etc.

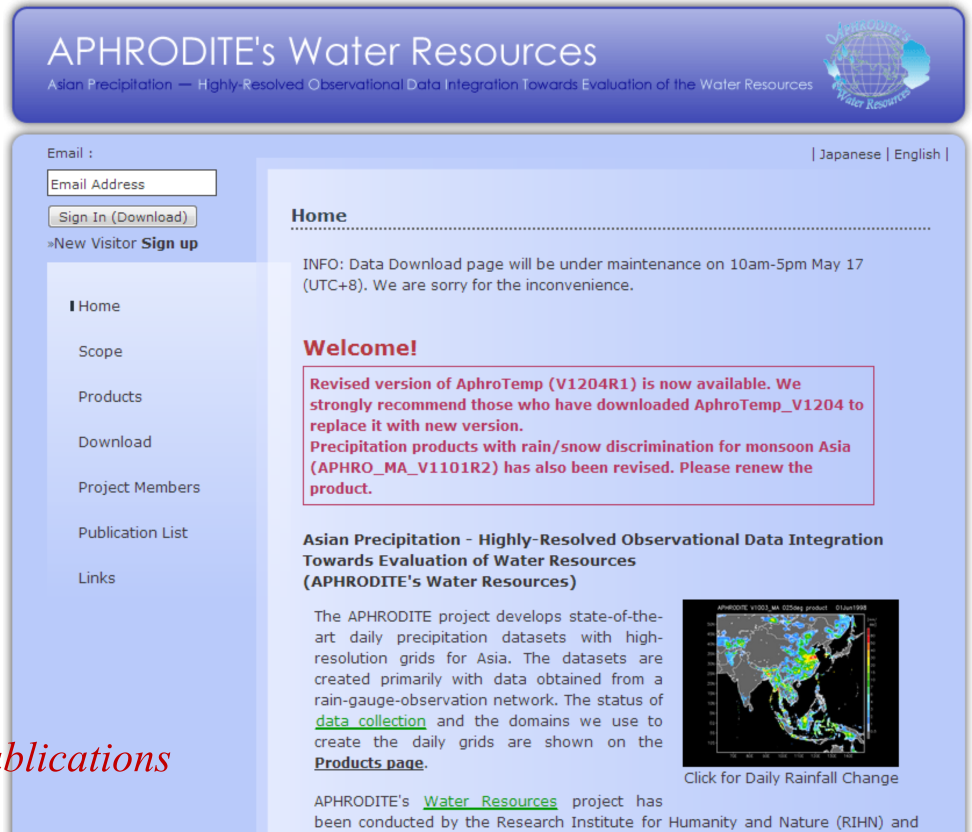
APHRODITE rainfall data

Asian precipitation-highly resolved observational data integration towards the evaluation of water resources management (APHRODITE) dataset.

•contains a dense network of daily rain-gauge data for Asia including the Himalayas, South and Southeast Asia and mountainous areas in the Middle East. The number of valid stations was between 5000 and 12,000, representing 2.3 to 4.5 times the data available through the Global Telecommunication System network, which were used for most daily grid precipitation products.

- Long-term, continental scale 52-year gridded ($0.25^o \times 0.25^o$; $0.5^o \times 0.5^o$) daily precipitation dataset (1951-2007)—in the website
- $0.05^o \times 0.05$v for Japan and data providers

For WEB-DHM input: Interpolation Method to downscale to watershed grid size (e.g. 1000m x 1000m grid): Equal Distance Weighing Method



For more details check out Yatagai-sensei's publications especially the one from SOLA

JRA project

Japanese >>

JRA-55 : Japanese 55-year Reanalysis

News | About | Usage | Manual | Contact | Application

3 hourly at about 50 km grid

1. Downward Shortwave radiation
2. Downward Longwave radiation
3. Specific Humidity
4. Large scale precipitation
5. Convective Precipitation
6. Air Temperature
7. Wind speed (U-component)
8. Wind speed (V-component)
9. Air Pressure
10. Cloud Amount

Latest News

Important notice:

The change password and email address service is currently out of order.
If you receive an email "Your Password will expire in a few days." from <JDDS_admin>, please contact us with specifying your ID at the following email address.

Email: jra@met.kishou.go.jp

We apologize for any inconvenience this may cause, and appreciate your kind understanding.

10 March 2014

The JRA-55 manual 1.25-degree latitude/longitude grid data is updated. *New / Update !*

The JRA-55 manual model grid data (TL319L60) is released. *New / Update !*

The JRA-55 model grid data (TL319L60) distribution has been started. *New / Update !*

6 February 2014

Please take part in a Reanalysis User and Application Survey (closing 28 February 2014) to better understand your needs.

29 January 2014

The near real-time JRA-55 latitude/logitude gridded data distribution has been started.

The JRA-55 latitude/longitude gridded data (year 2013) distribution has been started.

25 December 2013

Release schedule for the JRA-55 data and a plan for ceasing provisions of the JRA-25/JCDAS data (changed)

MODIS

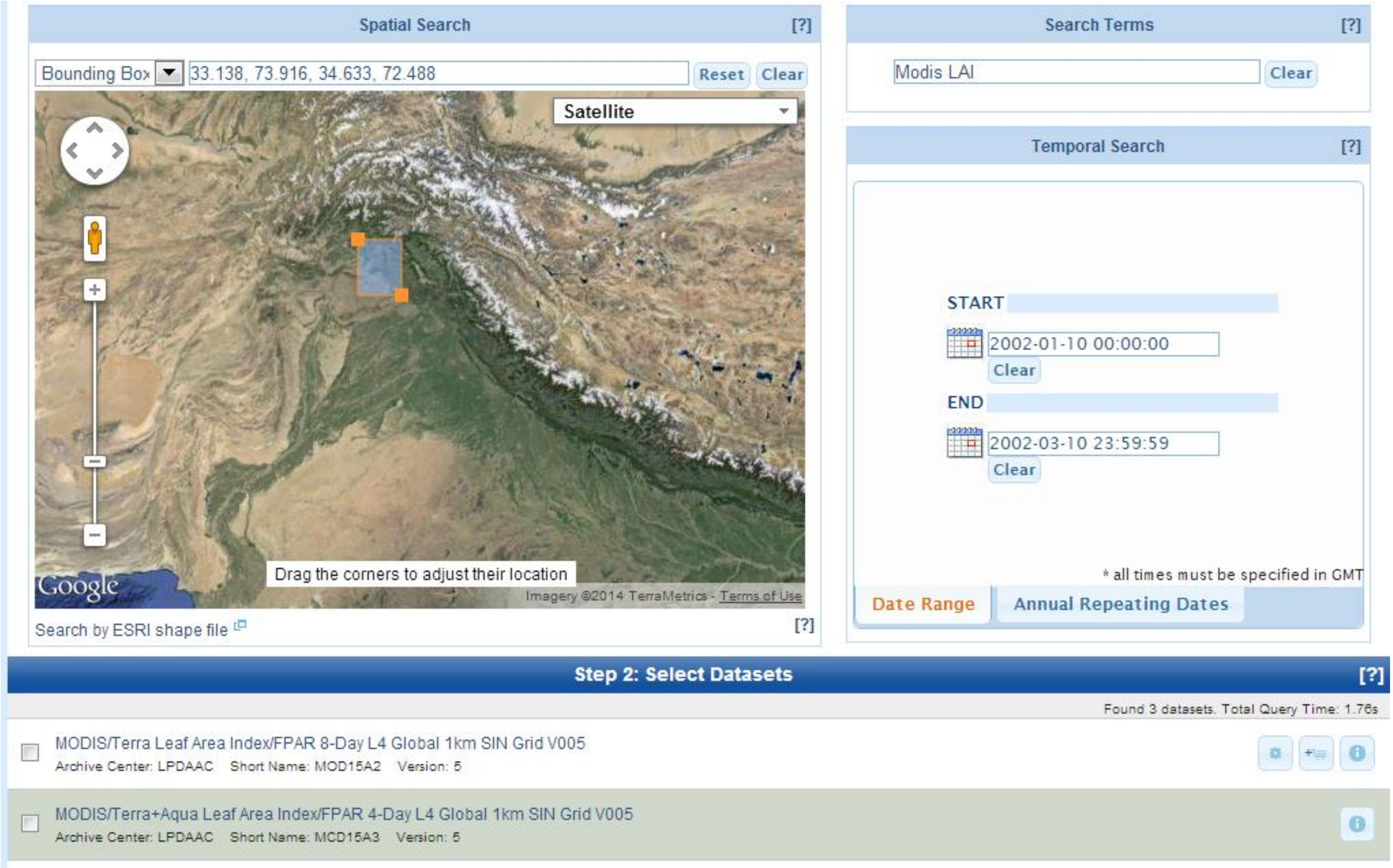
(Moderate-resolution Imaging Spectroradiometer)

Order Data through the reverb of NASA

(http://reverb.echo.nasa.gov /)

Create your own account and login to order the data


Reverb | ECHO
How to print screen
Use Snipping Tool to
reverb.echo.nasa.gov/reverb/#utf8=%E2%9C%93&spatial_map=satellite&spatial_type=rectangle
National Aeronautics and Space Administration
EOSDIS NASA's Earth Observing System Data and Information System
Reverb | ECHO
The Next Generation Earth Science Discovery Tool
EOSDIS Home
Reverb Home
About
Tutorial
Shopping Cart (0)
Order Status
Service Request Status
Sign In
Search Options
Spatial
Search Terms
Temporal
Platforms & Instruments [?]
Campaigns [?]
Processing Levels [?]
Science Keywords [?]
Save Query
Clear Criteria
Feedback? Tell us what you think.
Availability [?]
ASTER GDEM V2 Tutorial
Mon Oct 17 2011 17:00:00 GMT+0900 (Japan Standard Time) (GMT+9:00) to (End Date Not Provided)
More
Notices [?]
NSIDC scheduled downtime
Thu Jan 16 2014 02:00:00
Step 1: Select Search Criteria [?]
Spatial Search [?]
Bounding Box
e.g. -50.736, 163.477, -11.144, 105.680 (S,E,N,W)
Reset
Clear
Satellite
61.939, 29.883
Click and drag to set a bounding rectangle
Imagery ©2014 NASA - Terms of Use Report a map error
Search by ESRI shape file [?]
Search Terms [?]
e.g. MODIS Fire AST_L1A
Clear
Temporal Search [?]
START
YYYY-MM-DD HH:MM:SS
Clear
END
YYYY-MM-DD HH:MM:SS
Clear
* all times must be specified in GMT
Date Range
Annual Repeating Dates
Step 2: Select Datasets [?]
Found 3397 datasets. Total Query Time: 0.56s
15 Minute Stream Flow Data: USGS (FIFE)
Archive Center: ORNL_DAAC Short Name: doi:10.3334/ORNLDAAC/1 Version: 1
9:18
2014/01/10


Spatial Search
[?]
Bounding Box
33.138, 73.916, 34.633, 72.488
Reset
Clear
Satellite
Drag the corners to adjust their location
Google
Imagery ©2014 TerraMetrics - Terms of Use
Search by ESRI shape file
[?]
Search Terms
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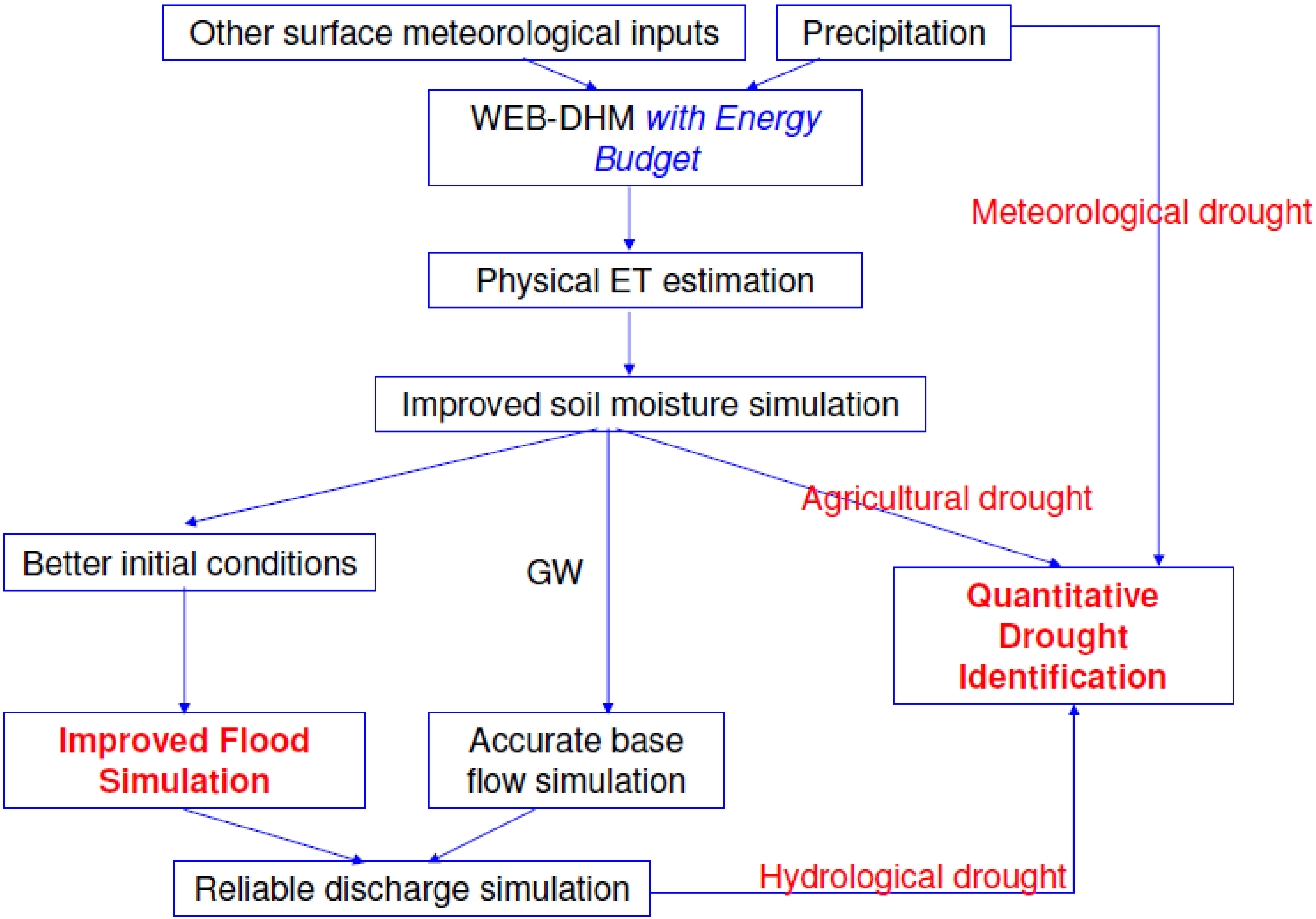
Modis LAI
Clear
Temporal Search
[?]
START
2002-01-10 00:00:00
Clear
END
2002-03-10 23:59:59
Clear
* all times must be specified in GMT
Date Range
Annual Repeating Dates
Step 2: Select Datasets
[?]
Found 3 datasets. Total Query Time: 1.76s
MODIS/Terra Leaf Area Index/FPAR 8-Day L4 Global 1km SIN Grid V005
Archive Center: LPDAAC Short Name: MOD15A2 Version: 5
MODIS/Terra+Aqua Leaf Area Index/FPAR 4-Day L4 Global 1km SIN Grid V005
Archive Center: LPDAAC Short Name: MCD15A3 Version: 5

WEB-DHM is a solution for flood and drought



Advantages of WEB-DHM

- A distributed biosphere hydrological model, which can give continuous, spatially-distributed descriptions of water and energy balance, as well as CO_2 flux for river basins.
- More reliable estimation of Evapotranspiration (ET)

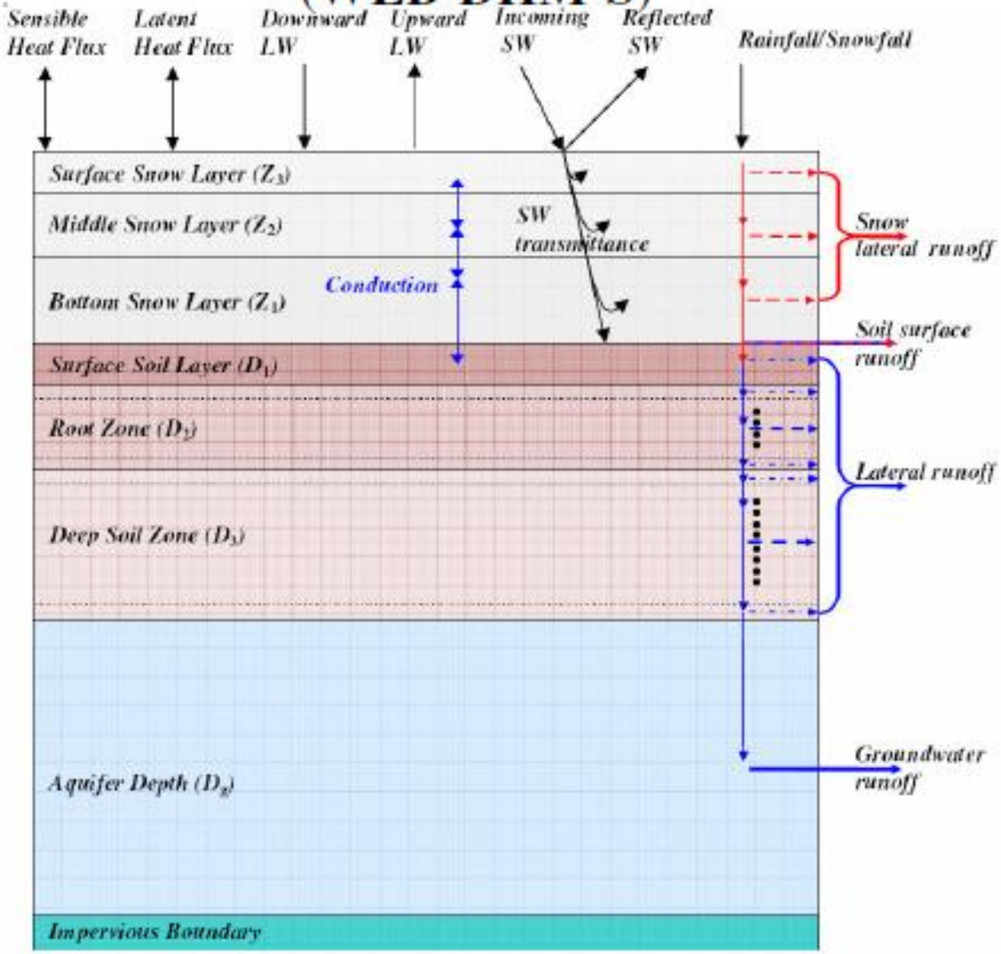
  (by using a biophysical land surface scheme for simulation of heat and moisture fluxes in the SVAT processes)
- Satellite data *is used to describe the vegetation and phenology*
- Can be coupled with GCMs and forecasting data for flood and drought prediction
- Applicability to large river basins.

  (by simplification of a model grid to a hillslope element, and simplification of river routing process)

Improving the snow physics of WEB-DHM

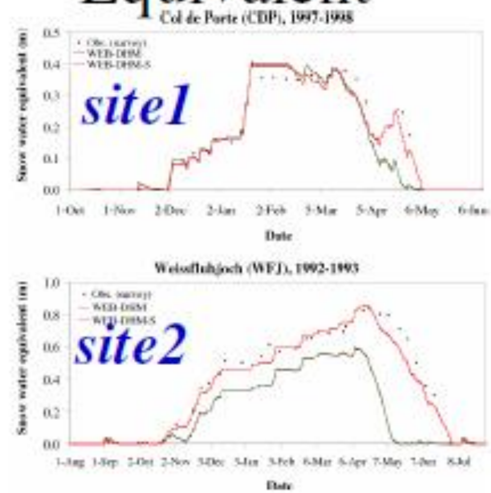
A three-layer snow model is added

(WEB-DHM-S)

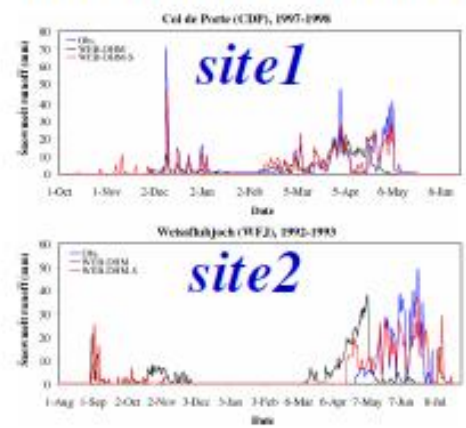


Shrestha, Wang, Koike et al., 2010, HESS

Snow Water Equivalent



Snowmelt Runoff



Hydrology and Earth System Sciences, 5(1), *1-12* (2001) © EGS

Hydrology & Earth System Sciences

The Dalton Lecture

THE EGS DALTON MEDAL HAS BEEN AWARDED TO KEITH JOHN BEVEN FOR HIS OUTSTANDING CONTRIBUTIONS TO THE UNDERSTANDING OF HYDROLOGICAL PROCESSES AND HYDROLOGICAL MODELLING

How far can we go in distributed hydrological modelling?

Keith Beven*

Climate Threats

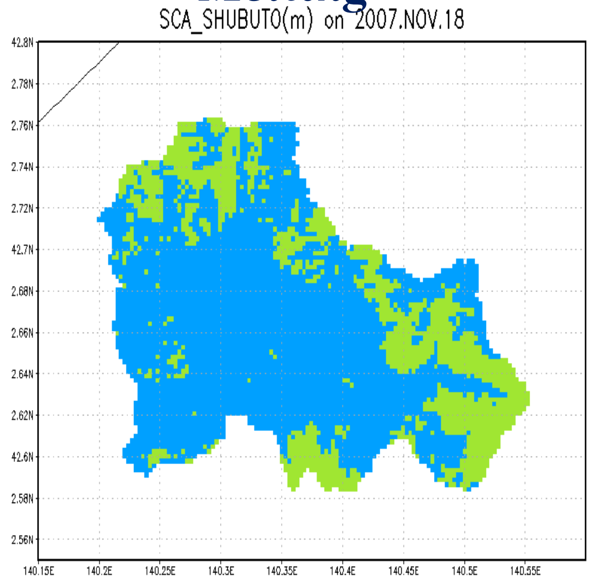
MOST OF THREADS EMERGE IN THE FORM OF "WATER"

Heavy Rain

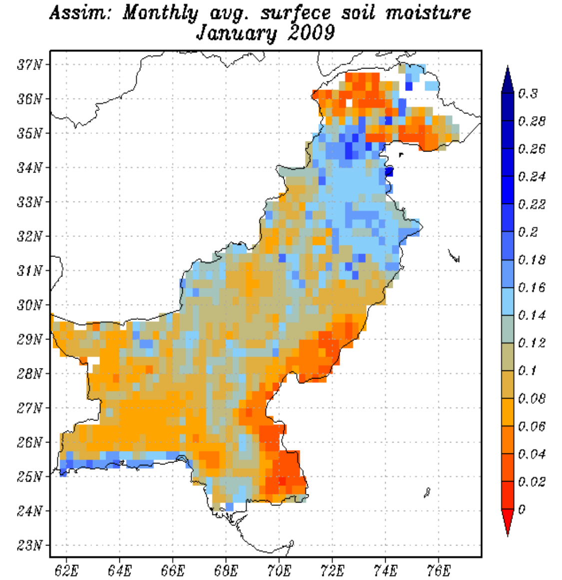
Flood

Drought

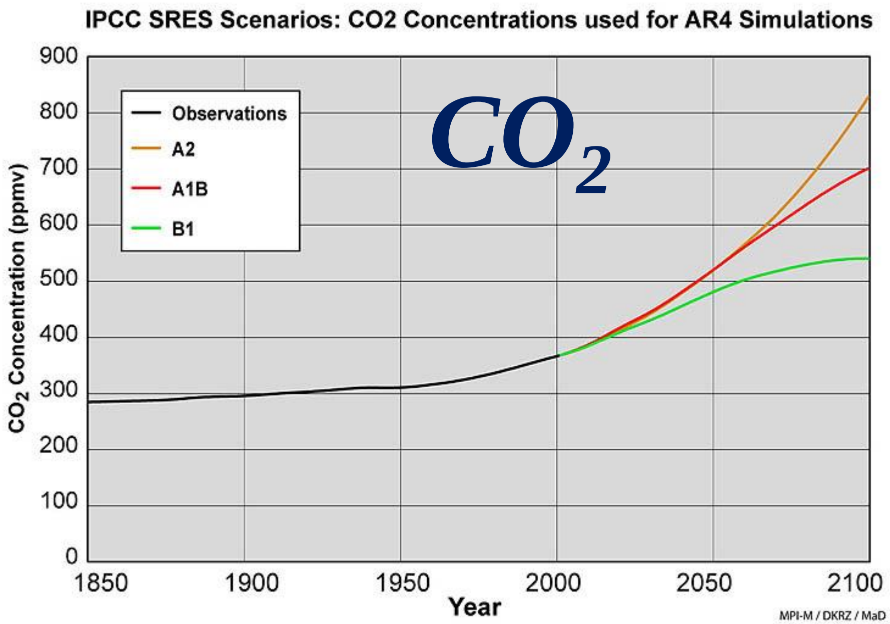
Hydrological Drought: Snow Melting

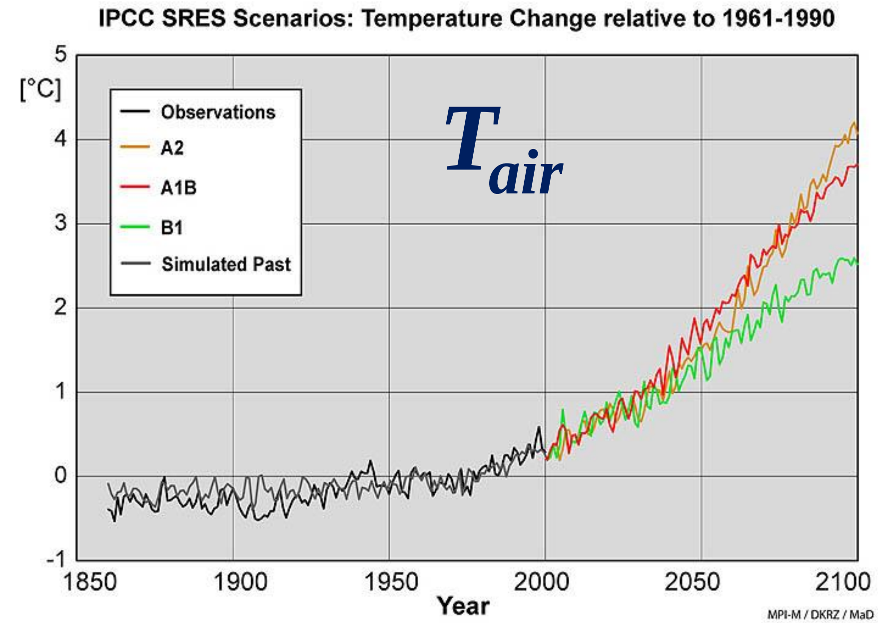


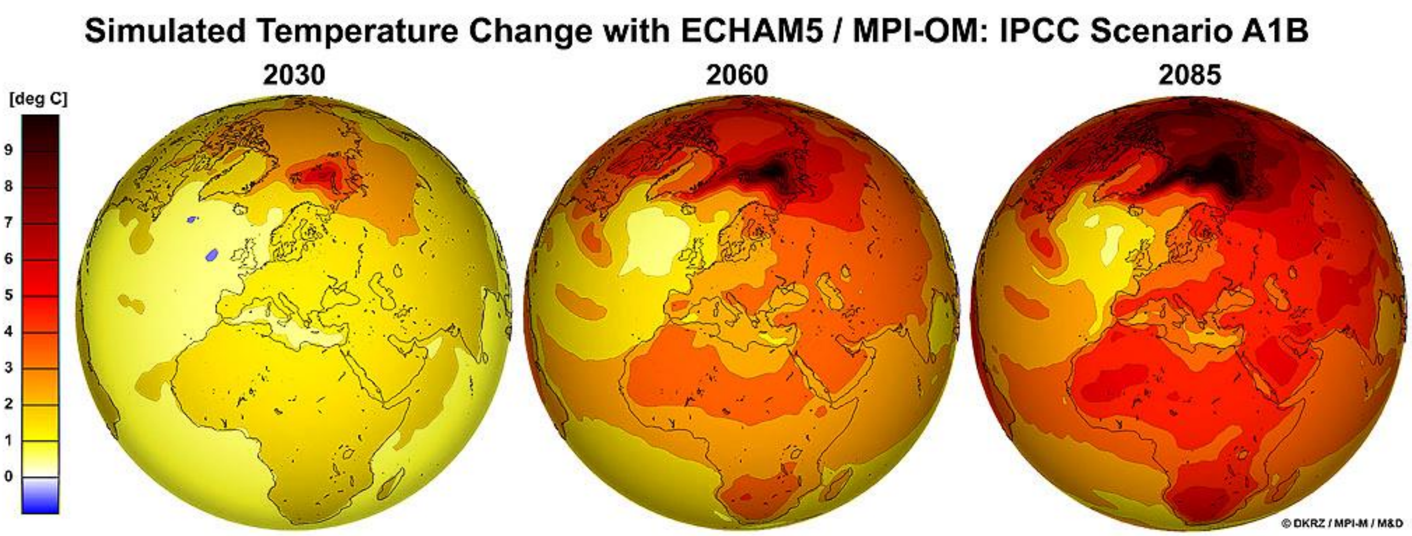
Agriculture Drought : Soil Moisture



Simulations of Climate Change (IPCC AR4, 2007)







Climate Change Impact Assessment

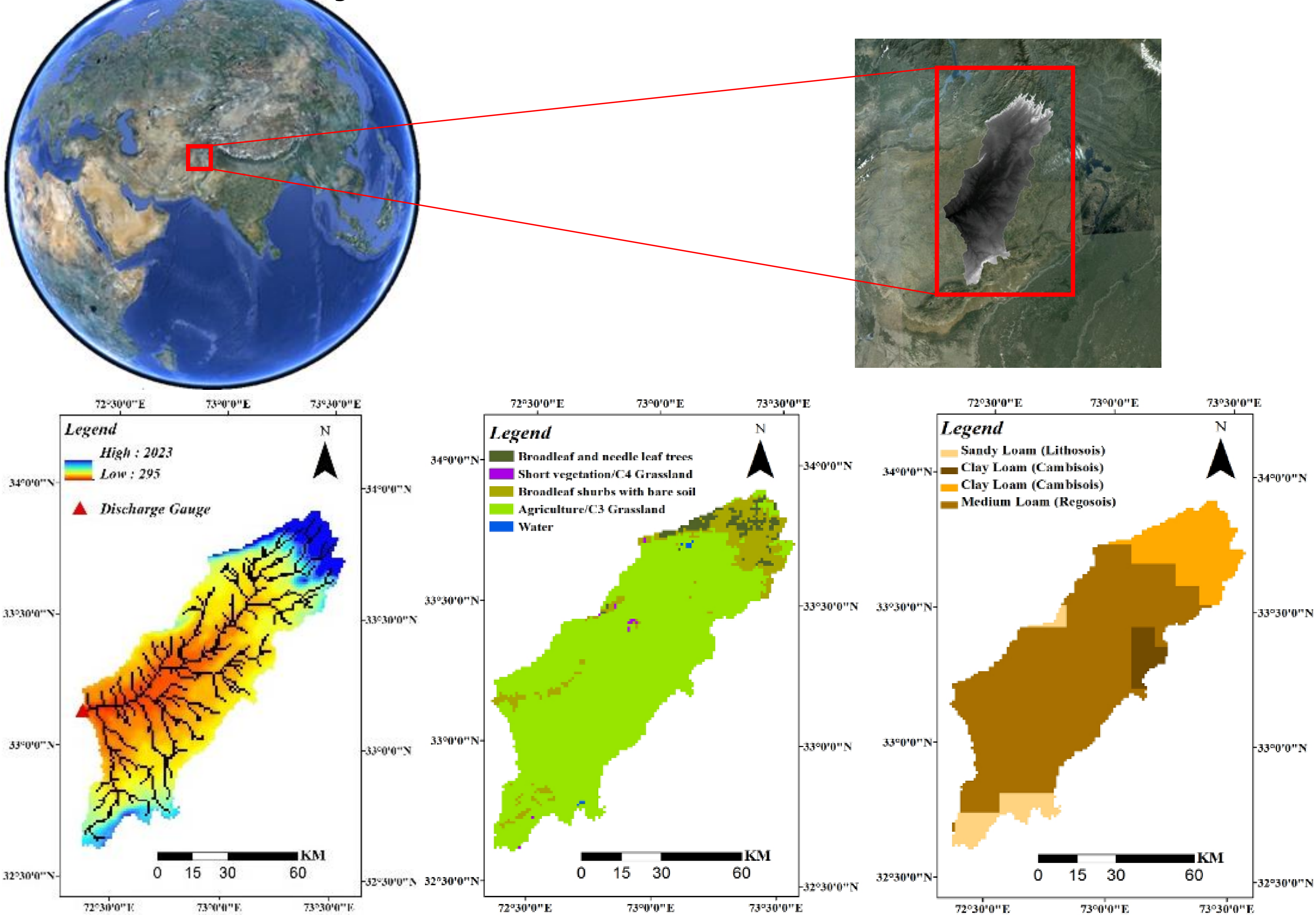
Does climate change really affect basins hydrological processes?

If Yes….
Then
To what extent it affect Natural Infrastructure

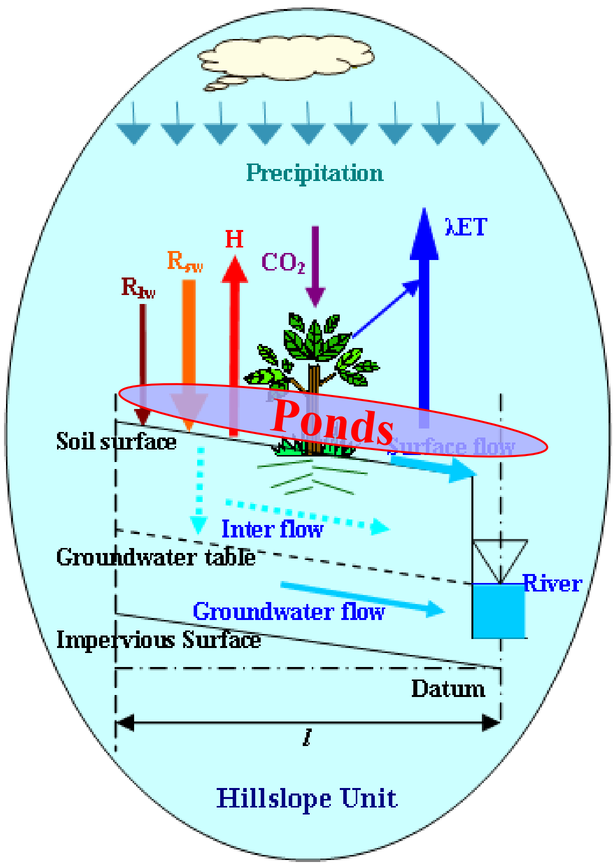
In modern hydrology, how far we have achieved to elucidate the impact of climate change on natural infrastructure

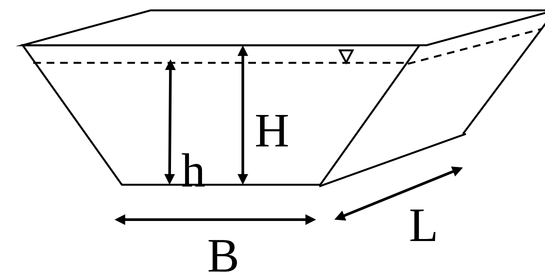
How to forecast climate change impact in PGBs located in semi arid regions

Case Study: Soan River Watershed, Pakistan



Storage Ponds in the Basin : Introducing Pond Model in the WEB-DHM





$$Surface\ Area = (B + 2nh)(L + 2nh) = BL + 2nhB + 2nhL + 4n^2h^2$$

$$Volume = \frac{h}{3}\left[3BL + 3nh(B + L) + 4n^2h^2\right]$$

Water Balance in Reservoir

$$ST_{end} = ST_{start} - E - S - Water\ Used$$

Where:

ST_{end} is the pond Storage at the end (m^3)

ST_{start} is the pond Storage at the start (m^3)

E is the Evaporation (m^3)

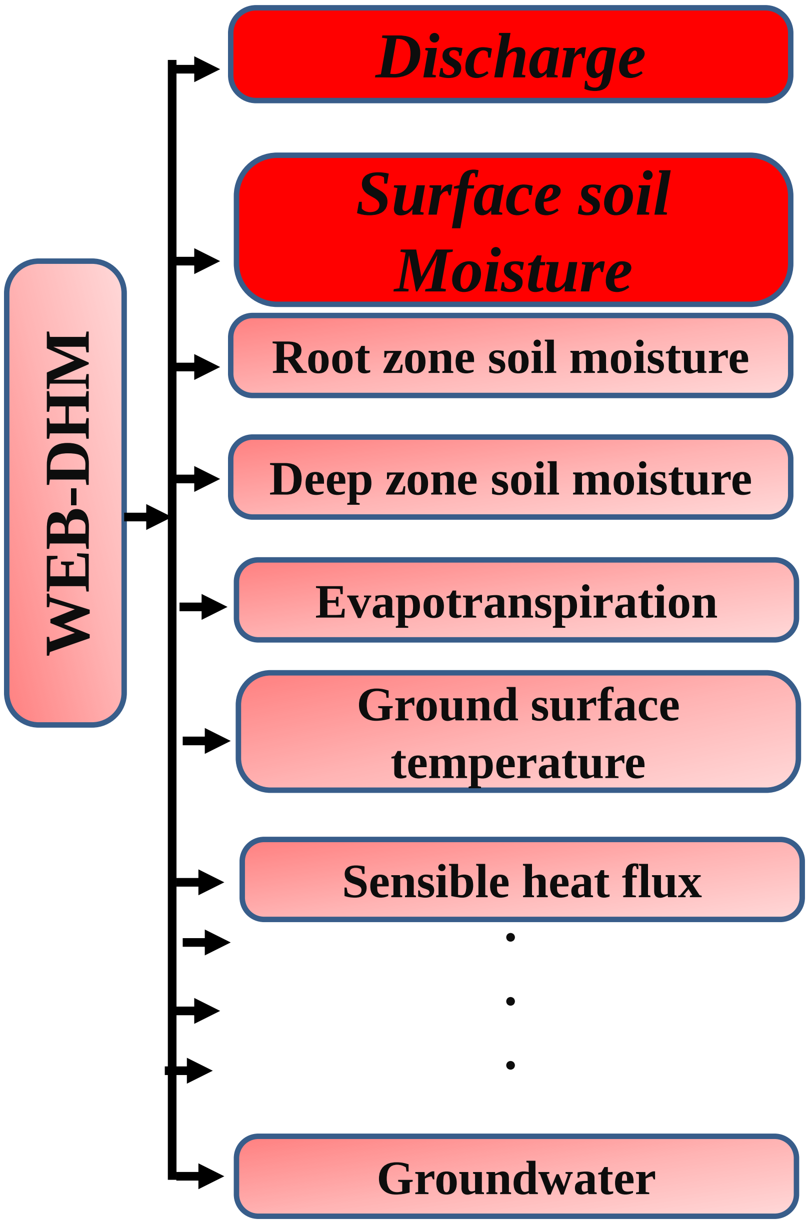
S is the Seepage (m^3)

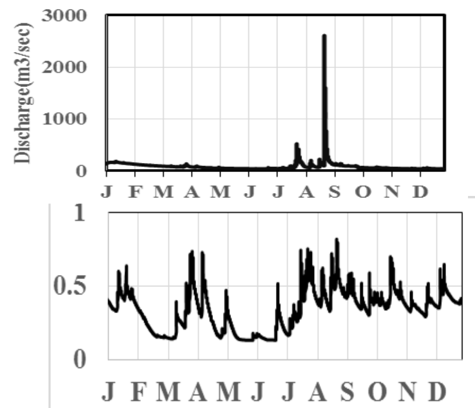
WEB-DHM : Model Inputs

(Model grid size : 1000m)

Data	***Spatial Resolution***	***Temporal Resolution***	***Source***
Spatial Information			
DEM	Grid (50 m)	Static	SRTM
Land use	1000 m	Static	Global, USGS
Soil type/local	1000m	Static	FAO
Time series forcing data			
Discharge	Gauge data	Daily	At Dhok Pathan : PMD
Precipitation	Gridded (0.25 degree) Daily Rainfall	APHRODITE	Japan Metrological Agency (JMA)
Meteorological data (Shortwave and longwave radiation, wind speed, humidity, air pressure, air temperature)	Point	Dynamic : 6 Hourly	JRA-25, JMA
Vegetation indices: LAI & FPAR	Grid (1 km)	Dynamic : 8 day average	MODIS Terra (MOD15A2) – MRT@500m

WEB-DHM : Model Output





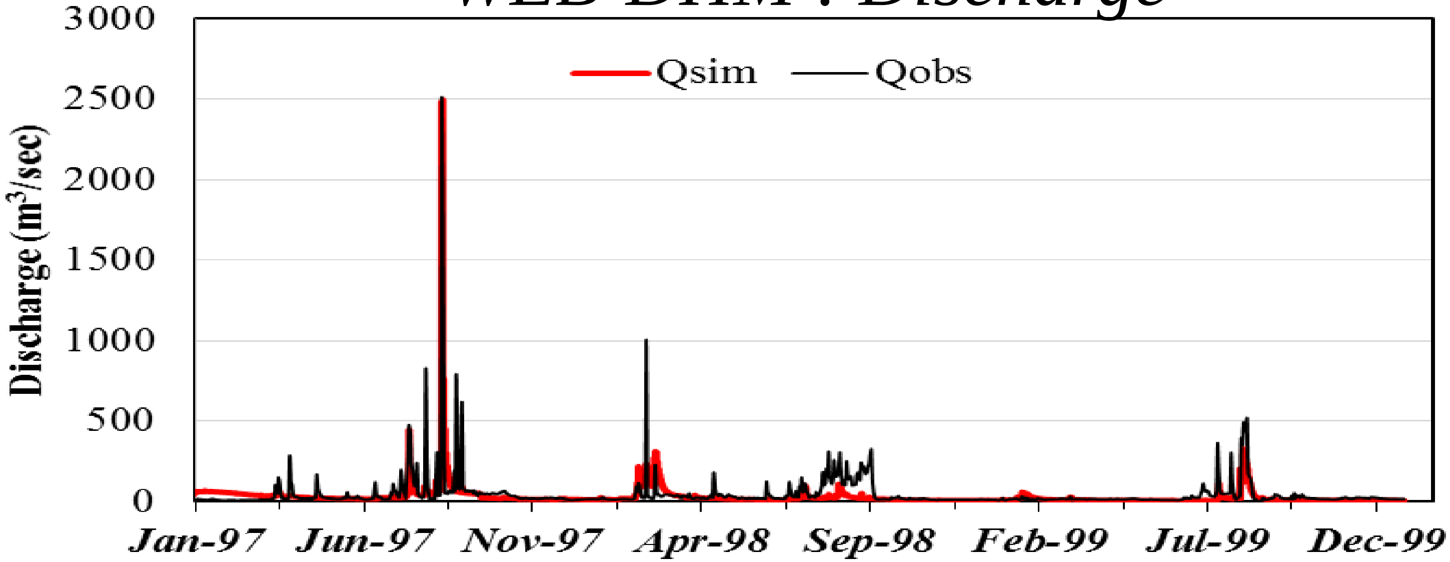
Model calibration and validation : Observed Discharge

Model validation: No Observed data

- ***The model has ability to address all major processes in the basin hydrological cycle over a range of space-time scales and climates.***
- ***The model is capable for long-term continuous simulation of hydrological processes and can simulate floods, low flow and other aspects of hydrological cycle very well.***

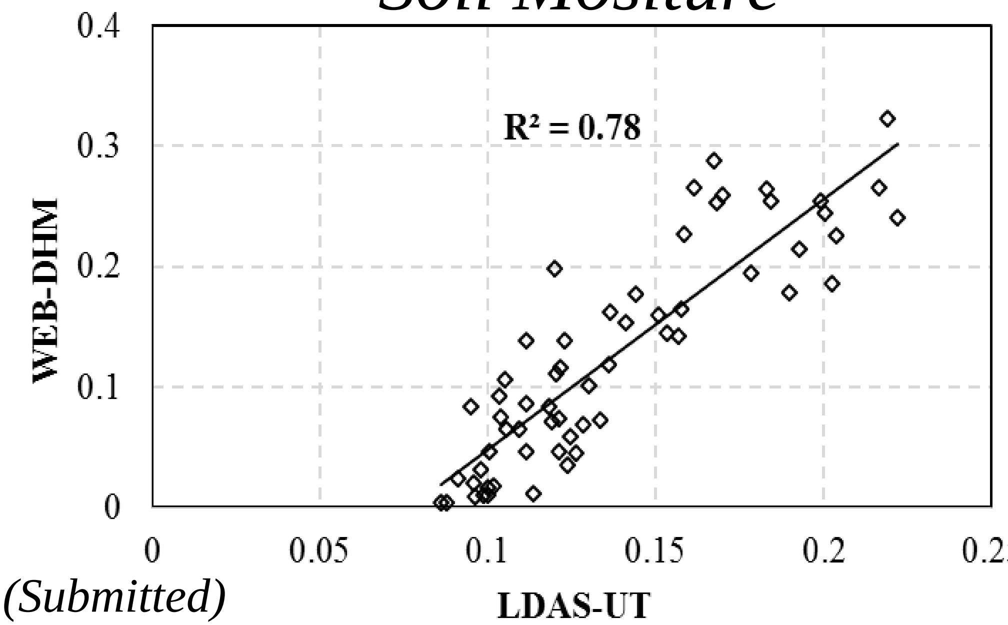
Model Calibration & Validation

WEB-DHM : Discharge



Soil Mositure

Comparison of basin average daily surface soil moisture from LDAS-UT and WEB-DHM



Reference : Bhatti A. M., et al., JSCE (Submitted)

Climate Change Assessment

Selection of SRES Scenario

SRES-A1B using 24 AOGCMs

↓

Obtaining the daily parameters of GCMs from CMIP3

↓

GCM Model Selection

↓

Bias Correction of the rainfall parameter from selected GCMs

↓

Incorporation of bias corrected GCM into the Hydrological Model

↓

Analysis of Discharges for floods and droughts

GCM Selections

GCM Data DIAS Data Integration & Analysis System

Inter-comparison: Re-analysis/Observation Data vs. CMIP3 Model Output
Earth Observation Data Integration and Fusion Research Initiative (EDITORIA), The University of Tokyo. http://dias.tkl.iis.u-tokyo.ac.jp/model-eval/beta.html

Small scale meteorological consideration

Area: 71ºE-76ºE,31ºN-36ºN

- Precipitation

Large scale circulations

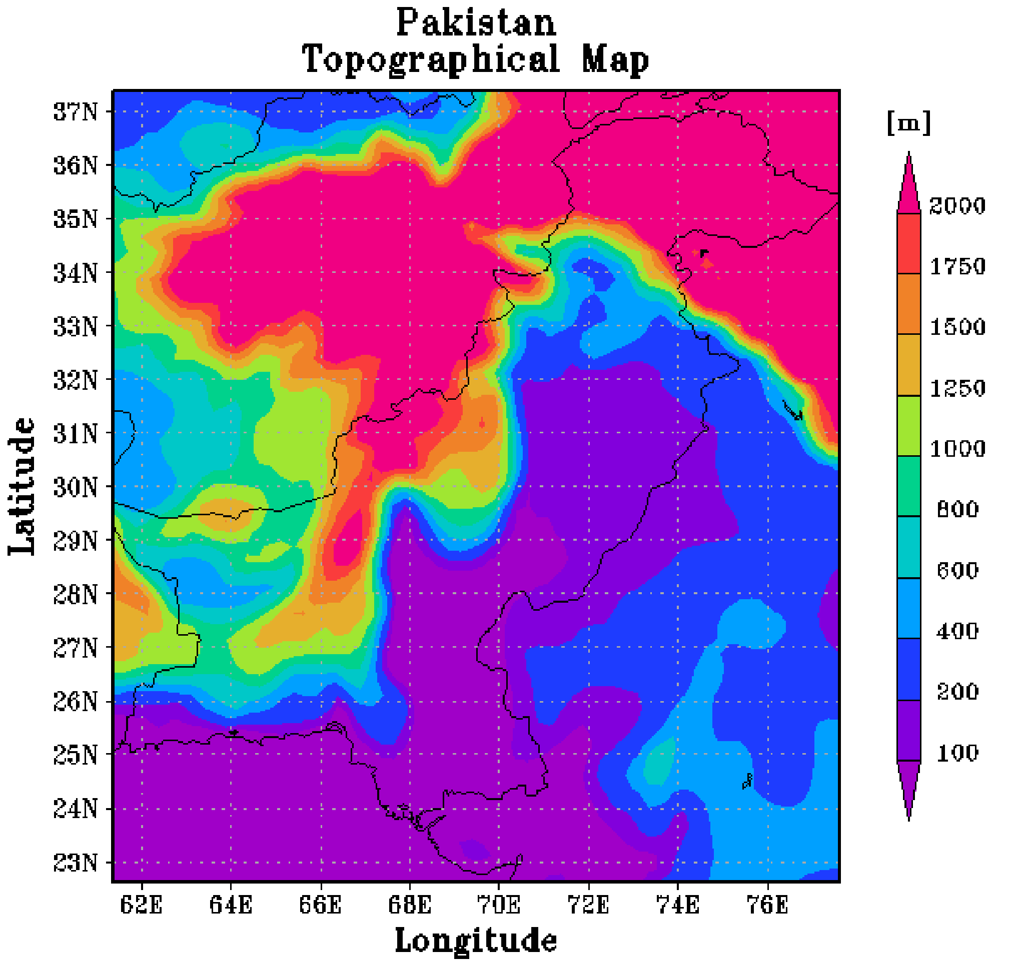
- Air temperature
- Outgoing Long wave Radiation (OLR)
- Sea surface temperature (SST)
- Sea Level pressure (SLP)
- Meridonial Wind
- Zonal Wind

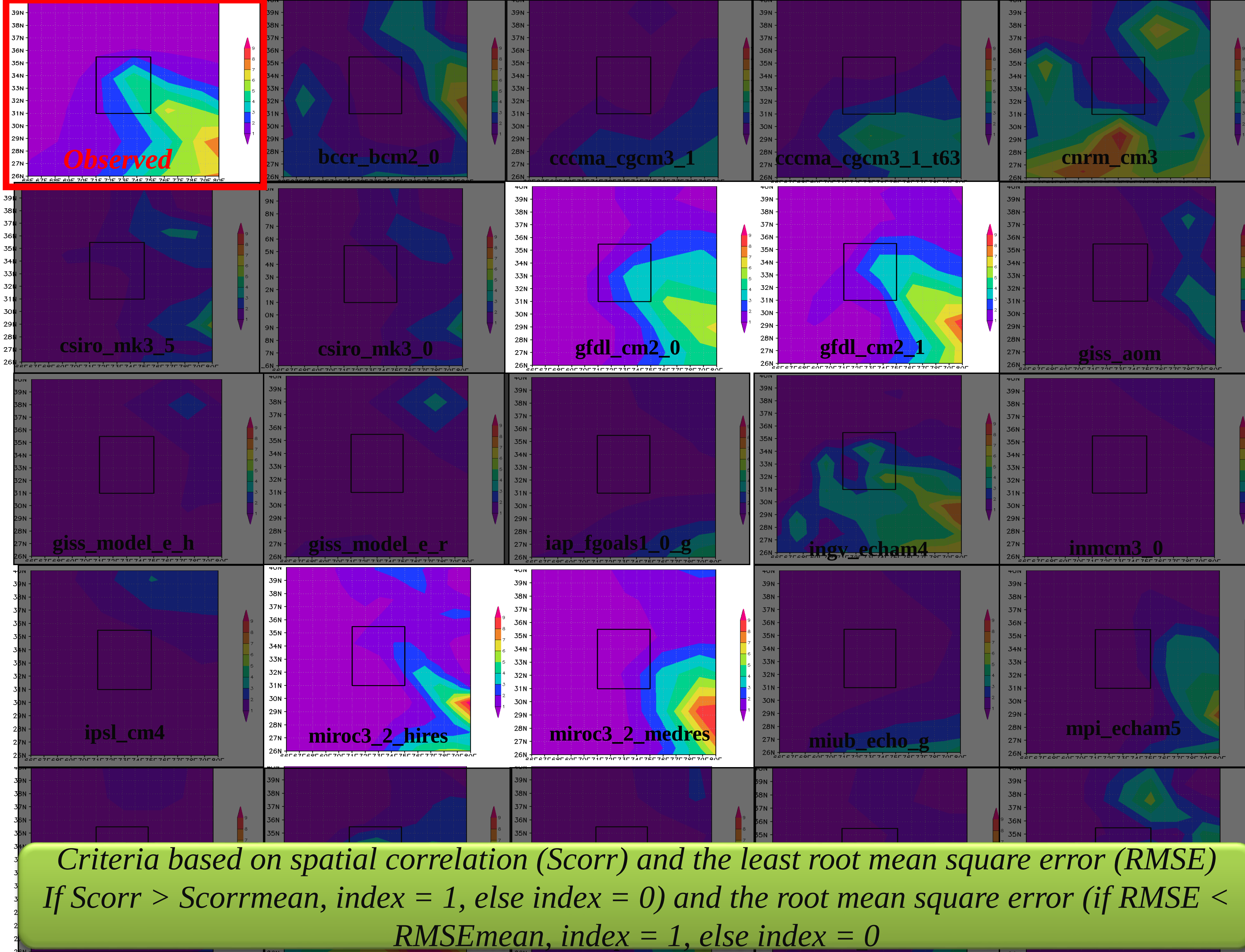
Selected Parameters - 7 Nos.

- Precipitation
- Air temperature
- Outgoing Long wave Radiation (OLR)
- Meridonial Wind
- Zonal Wind
- Sea surface temperature (SST)
- Sea Level pressure (SLP)

Target Season

June to September *(Rainy Season)*





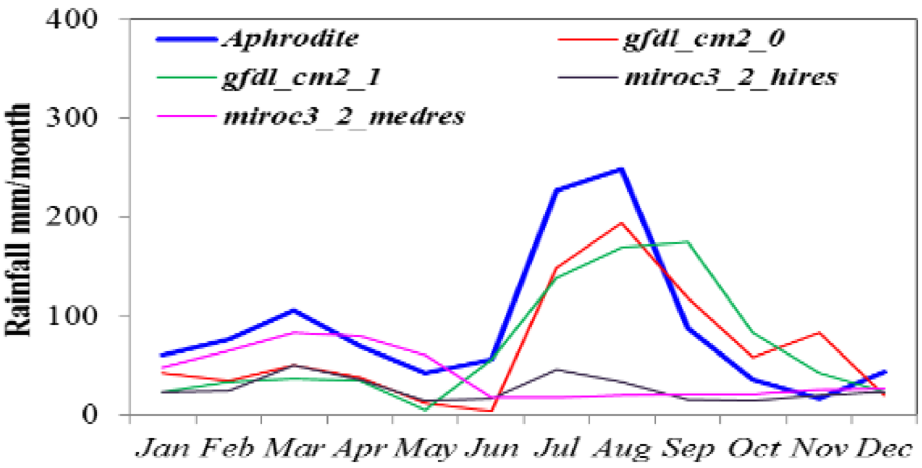
Criteria based on spatial correlation (Scorr) and the least root mean square error (RMSE) If Scorr > Scorrmean, index = 1, else index = 0) and the root mean square error (if RMSE < RMSEmean, index = 1, else index = 0

Statistical Downscaling

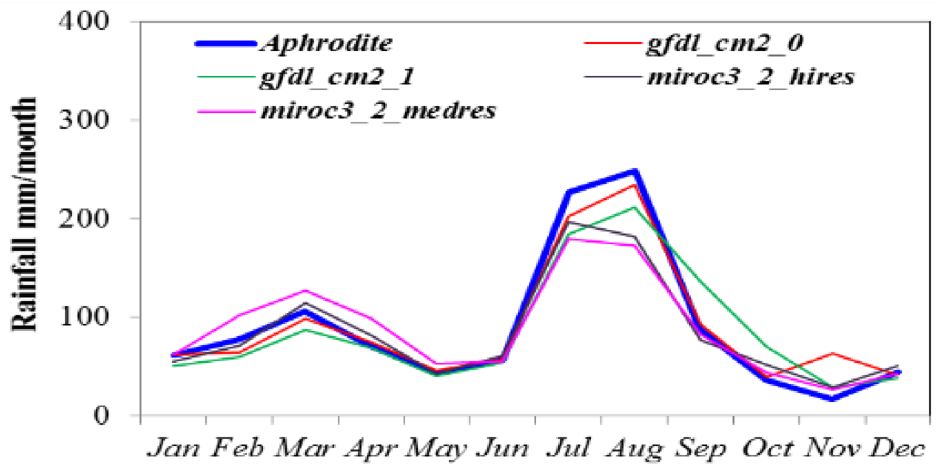
Statistical or dynamics downscaling is proved to be a useful tool to bridge the scale gap.

An improved three step statistical bias correction method was applied to correct precipitation.

GCM raw seasonal precipitation (1981-2000)



GCM corrected seasonal rainfall (1981-2000)



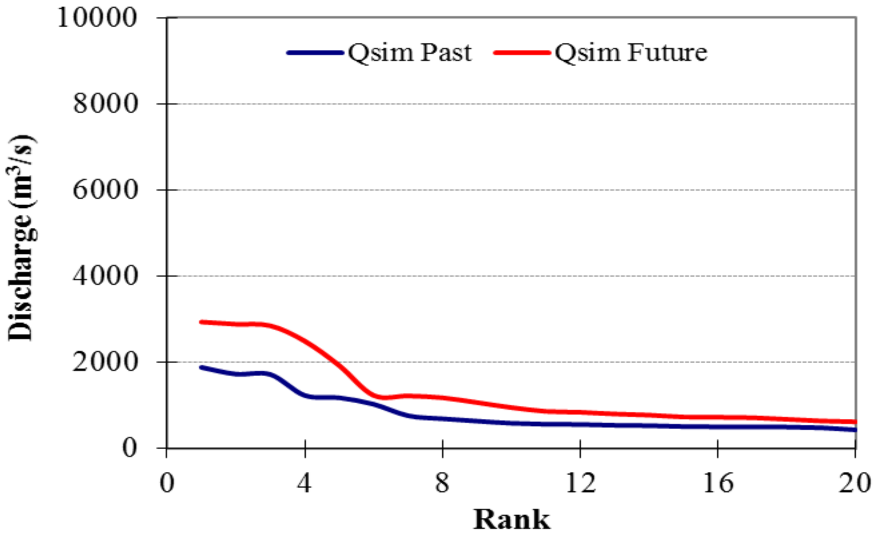
Reference : Nyunt C. T. et al., JSCE, 2013

CLIMATE CHANGE IMPACTS:PEAK FLOW TRENDS

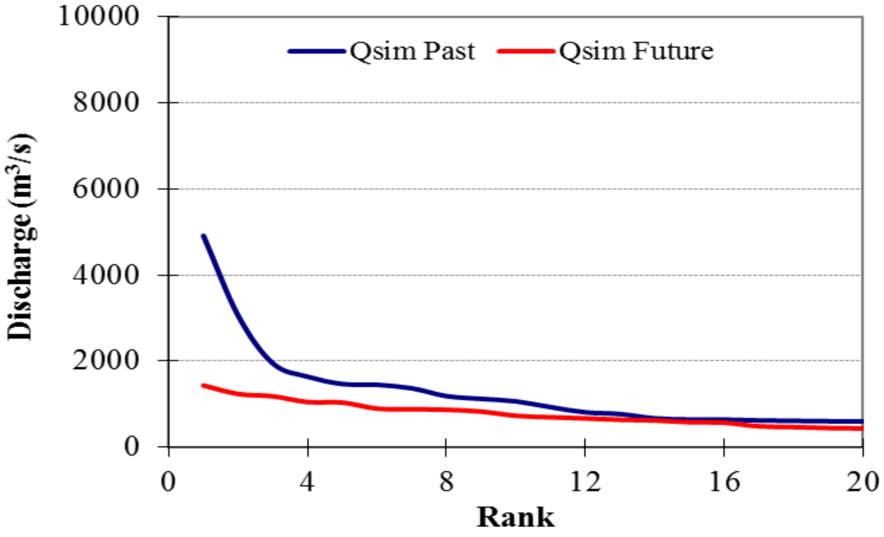
An extreme value analysis based on yearly maxima of twenty (20) years daily discharge was performed.

PEAK FLOW TRENDS

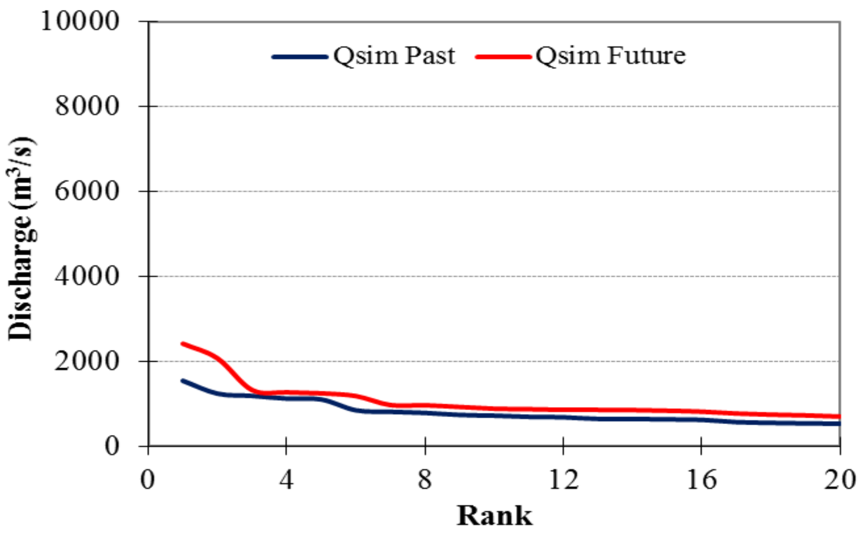
GFDL_CM2_0



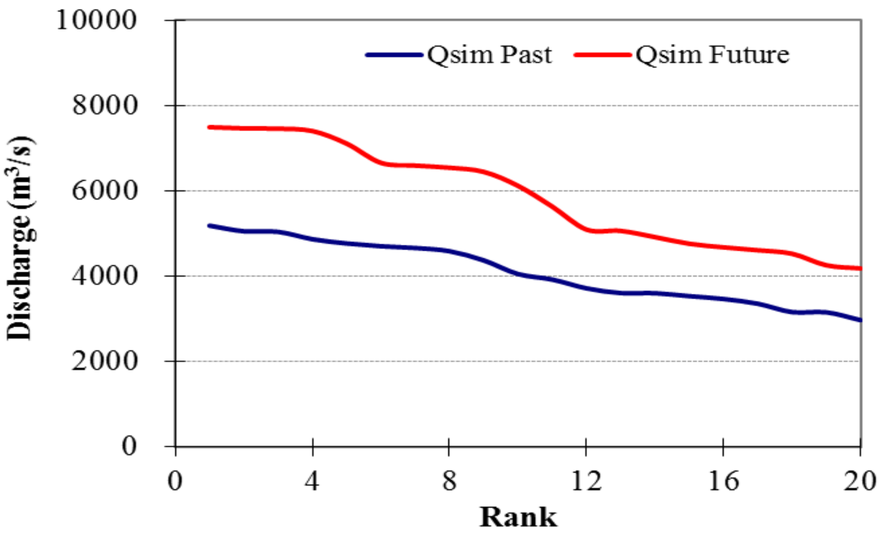
GFDL_CM2_1



MIROC3_2_MEDRES



MIROC3_2_HIRES



Drought Indices

The 364th rank of the past and future climatologically daily discharge simulations, arranged in descending order, was considered as the basis of ***drought discharge (DD).***

Average of DD for twenty year past and twenty year future is termed as past ***DDavg*** *and future* ***DDavg*** *respectively.*

Four indices defined to examine the climate change impact on drought in the basin as follow;

i) Drought discharge average (DDavg) for twenty years

ii) Average number of days during twenty years below DDavg is used as a basis to characterize how frequent the daily discharge for the past twenty years goes below past and future DDavg

iii) Maximal drought discharge during twenty years in the past and future

iv) Longest number of days per year when daily discharge was less than past and future DD

Conclusion

Peak Flow Trends: ***According to the IPCC Fourth Assessment Report criteria for likelihood scale, our analysis predicted that it is likely that floods will increase with high magnitude in future in the basin.***

Drought Trends: ***It is about as likely as not that the drought will intensify in the future; however, the number of drought days are uncertain.***

We are at the mercy of the nature, shift towards green growth, green economy and green water supported by green societies is pathway to address water scarcity.

"Change is something that happens gradually"

Thanks

Email: asif@hydra.t.u-tokyo.ac.jp