Including Water Management in Large Scale Models (2016/9/28-30)

Representation of irrigation water withdrawal in SiBUC

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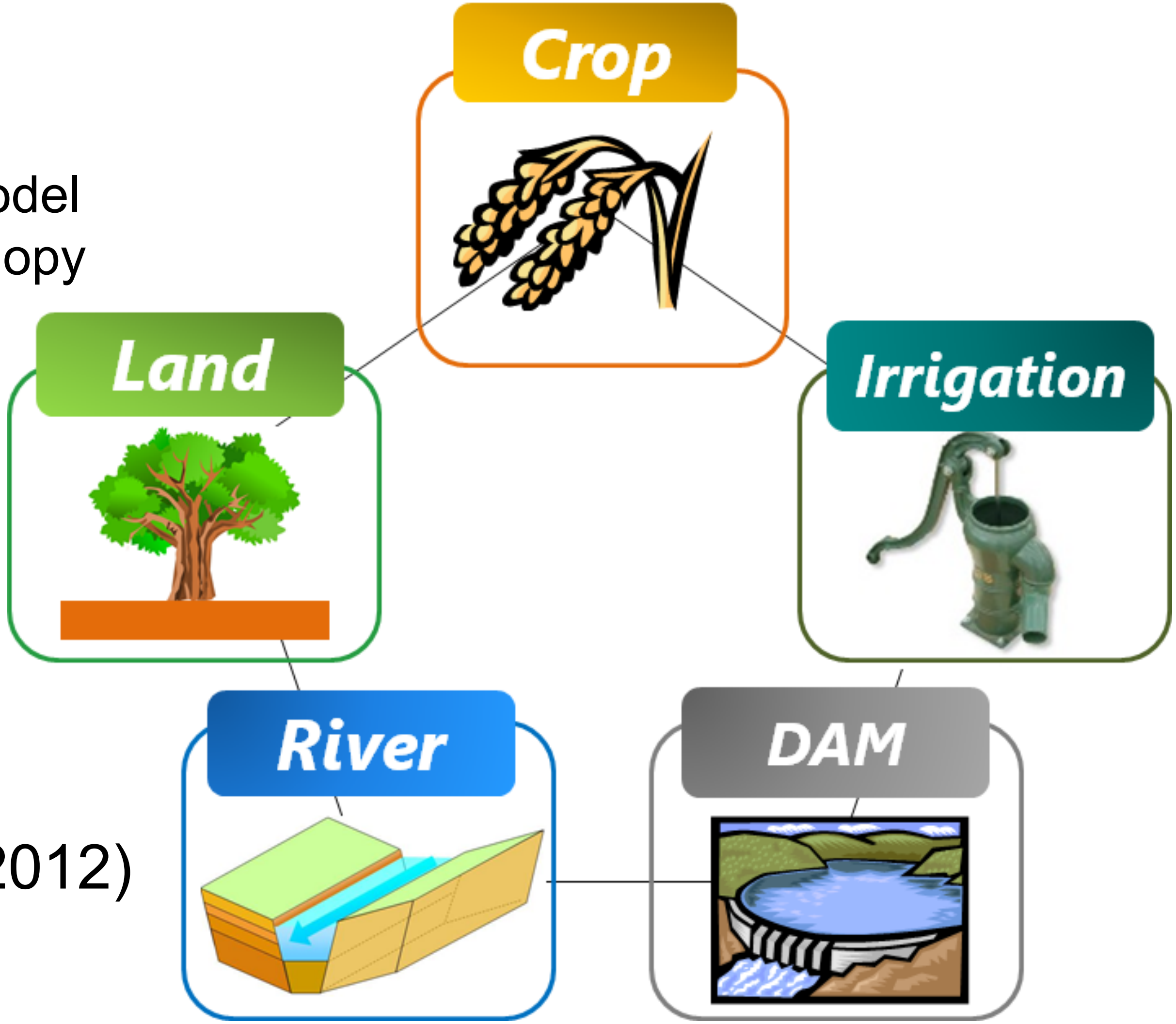
Integrated Water Resources Model

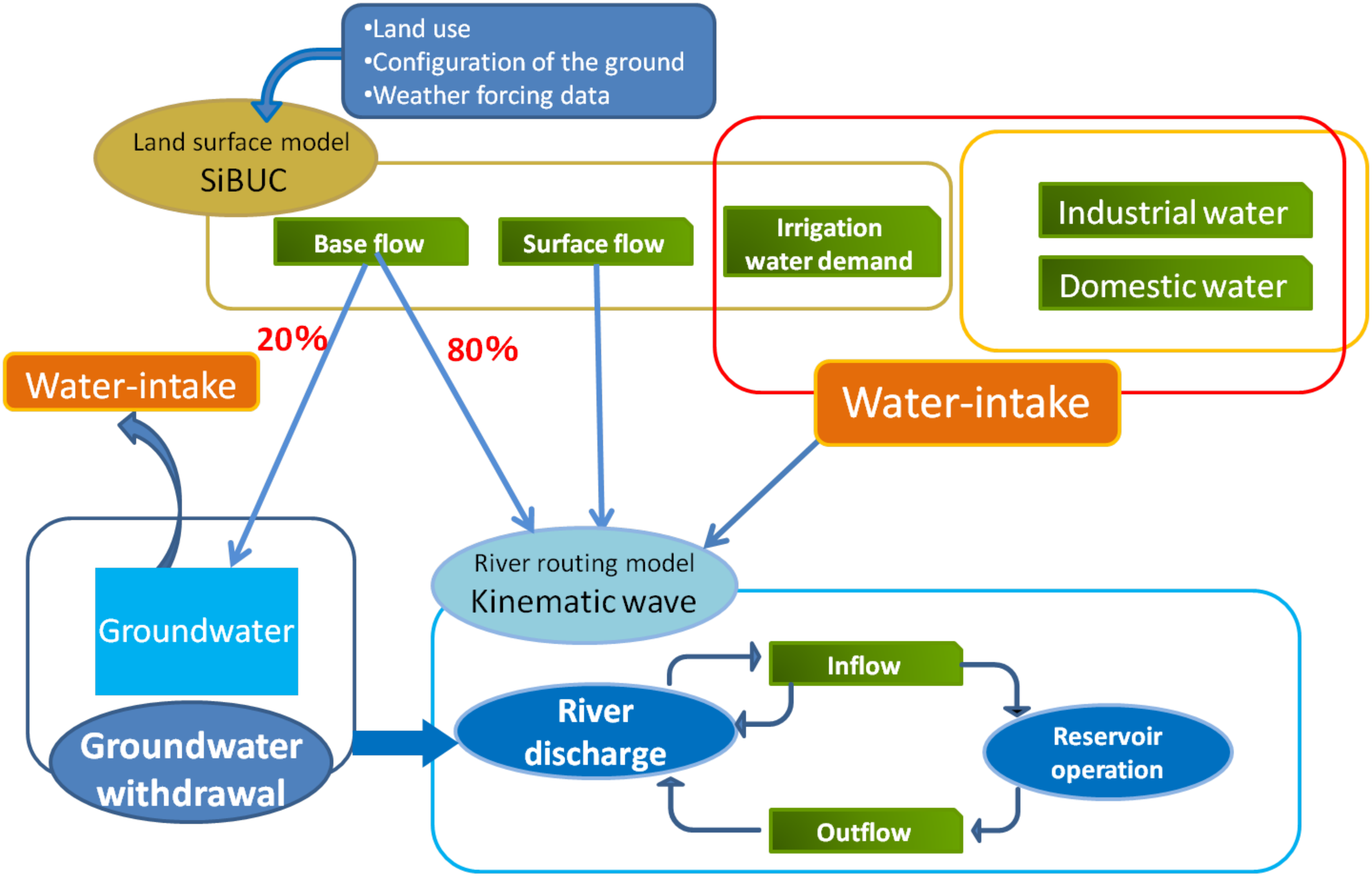
Land Surface Model
SiBUC

Simple Biosphere model including Urban Canopy



Tanaka (2004)
Kotsuki and Tanaka (2012)

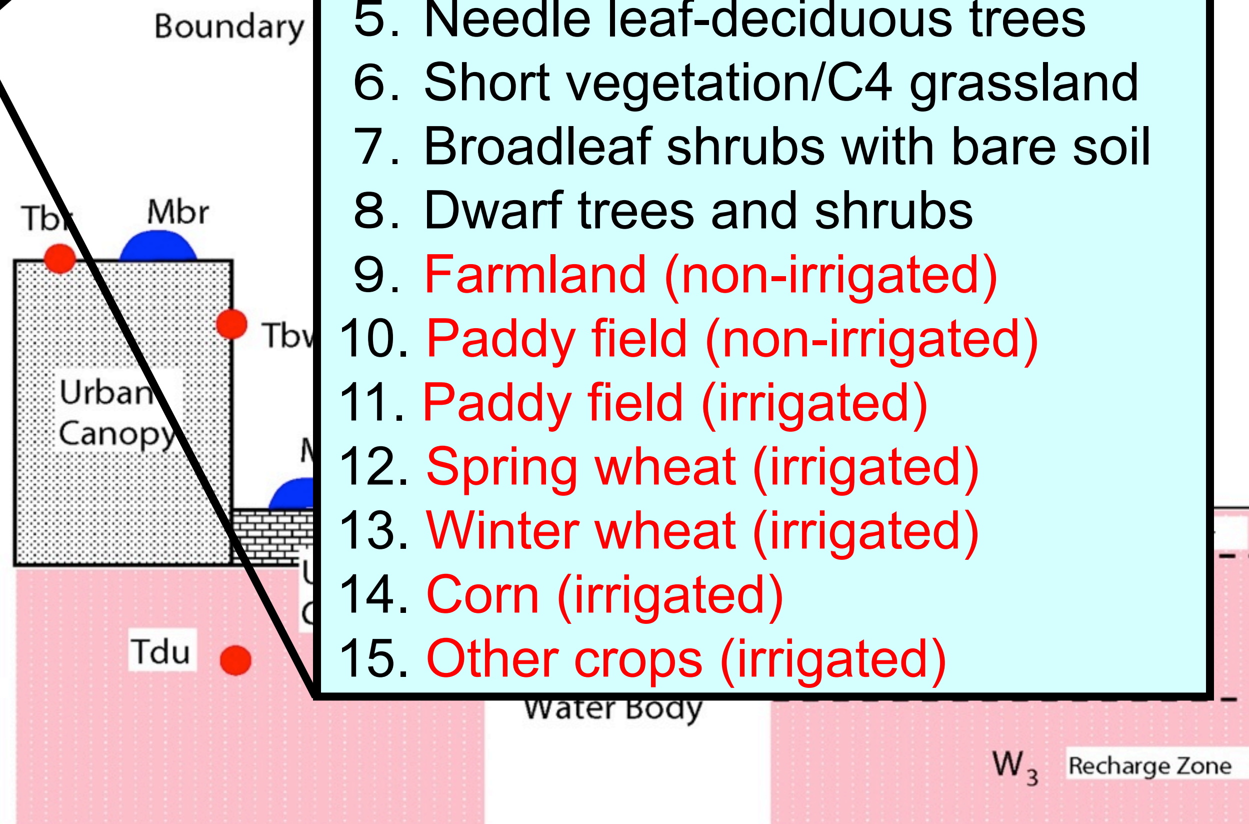
Hydrological simulation considering water withdrawal and dam operation



Land surface model (SiBUC)

Grid box is divided into three landuse categories

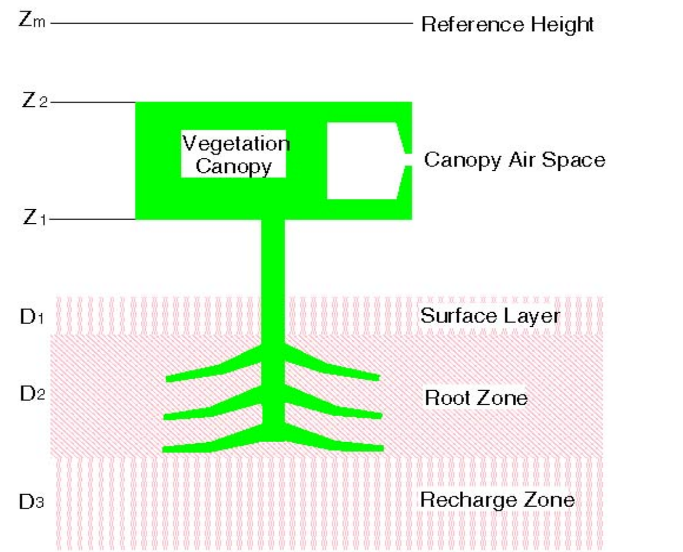
1. Green Area
2. Urban Area
3. Water Body

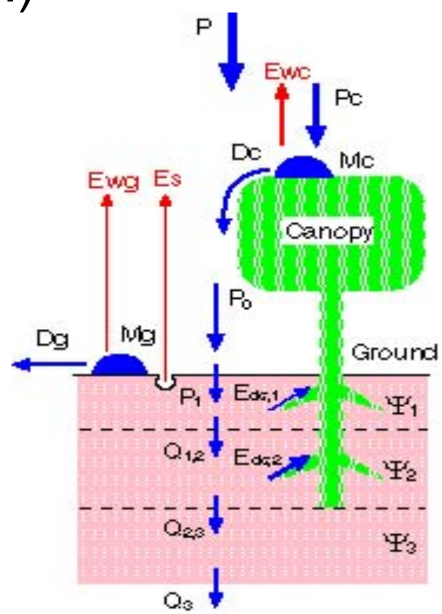


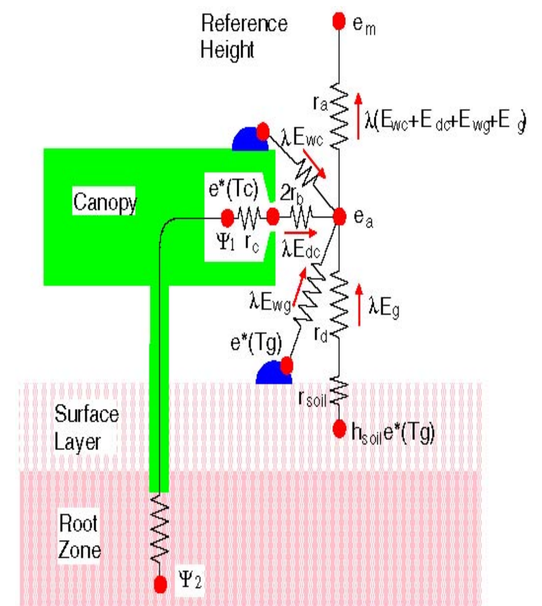
1. Broadleaf-evergreen trees
2. Broadleaf-deciduous trees
3. Broadleaf and needle leaf trees
4. Needle leaf-evergreen trees
5. Needle leaf-deciduous trees
6. Short vegetation/C4 grassland
7. Broadleaf shrubs with bare soil
8. Dwarf trees and shrubs
9. Farmland (non-irrigated)
10. Paddy field (non-irrigated)
11. Paddy field (irrigated)
12. Spring wheat (irrigated)
13. Winter wheat (irrigated)
14. Corn (irrigated)
15. Other crops (irrigated)

Green area model (SiB)

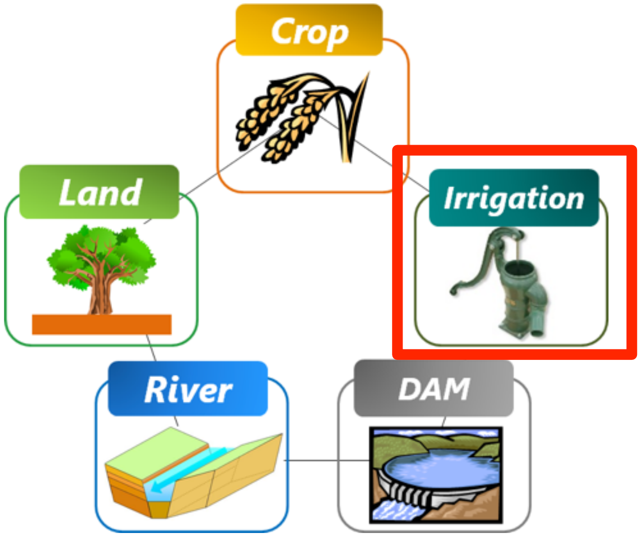
- Prognostic variables
  temperature (canopy, ground, deep soil)
  interception water (canopy, ground)
  soil wetness (surface, root zone, recharge)
- Time invariant parameter
  geometrical parameter
  optical parameter
  physiological parameter
  soil physical properties
- Time varying parameter (LAI etc.)
  estimate from satellite data
- Physical processes
  radiative transfer
  interception loss
  soil hydrology
  canopy resistance
  transpiration
  turbulent transfer,
  snow, freezing/melting,… etc.



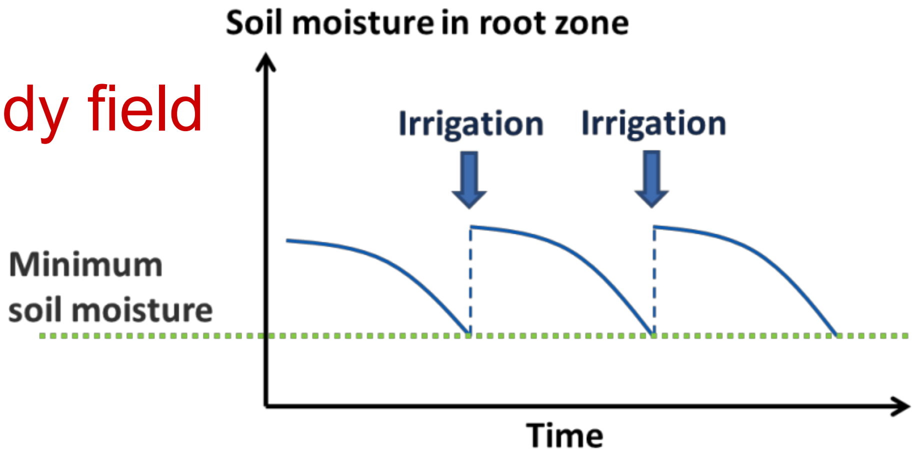




Irrigation



Basic concept is to maintain soil moisture/water depth within appropriate ranges for optimal crop growth.
Application to wheat, corn, soy bean, cotton etc…
Water layer is added to treat paddy field more accurately.



Paddy field model

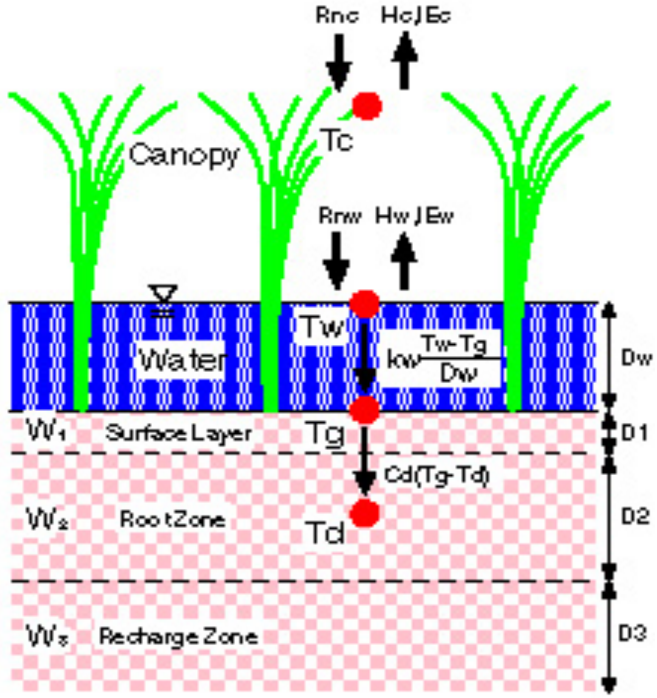
- Water depth and water temperature are added

$$C_c \frac{\partial T_c}{\partial t} = Rn_c - H_c - lE_c$$

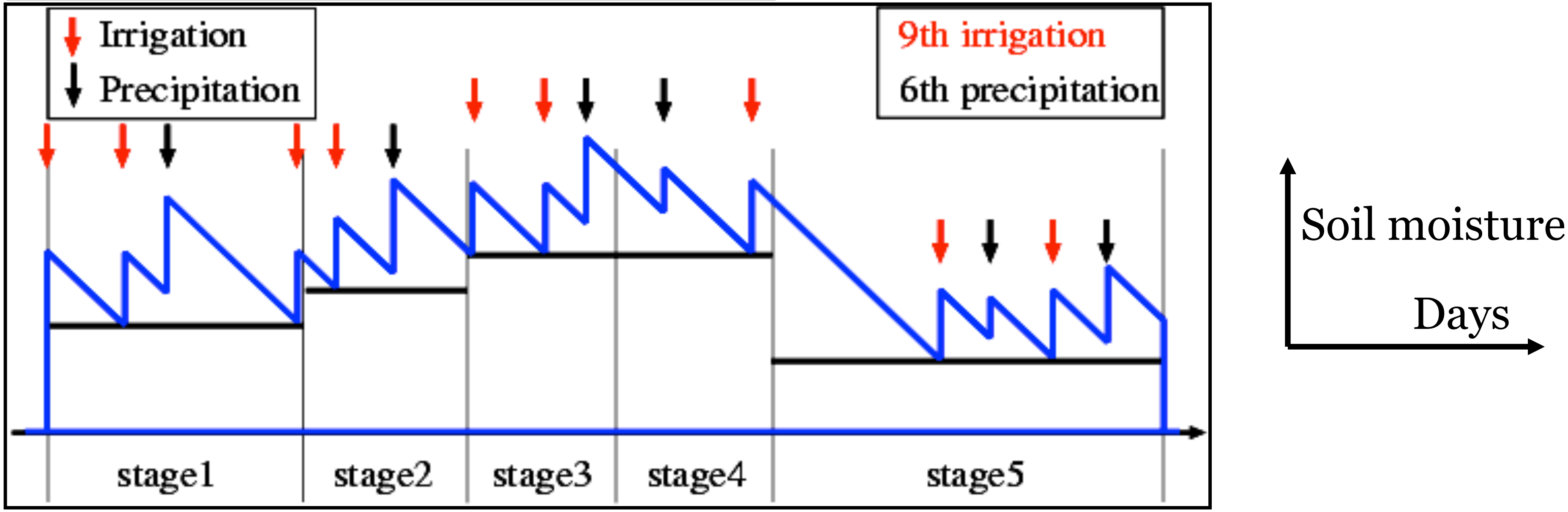
$$C_w D_w \frac{\partial T_w}{\partial t} = Rn_w - H_w - lE_w - k_w \frac{T_w - T_g}{D_w}$$

$$C_g \frac{\partial T_g}{\partial t} = k_w \frac{T_w - T_g}{D_w} - \omega C_g (T_g - T_d)$$

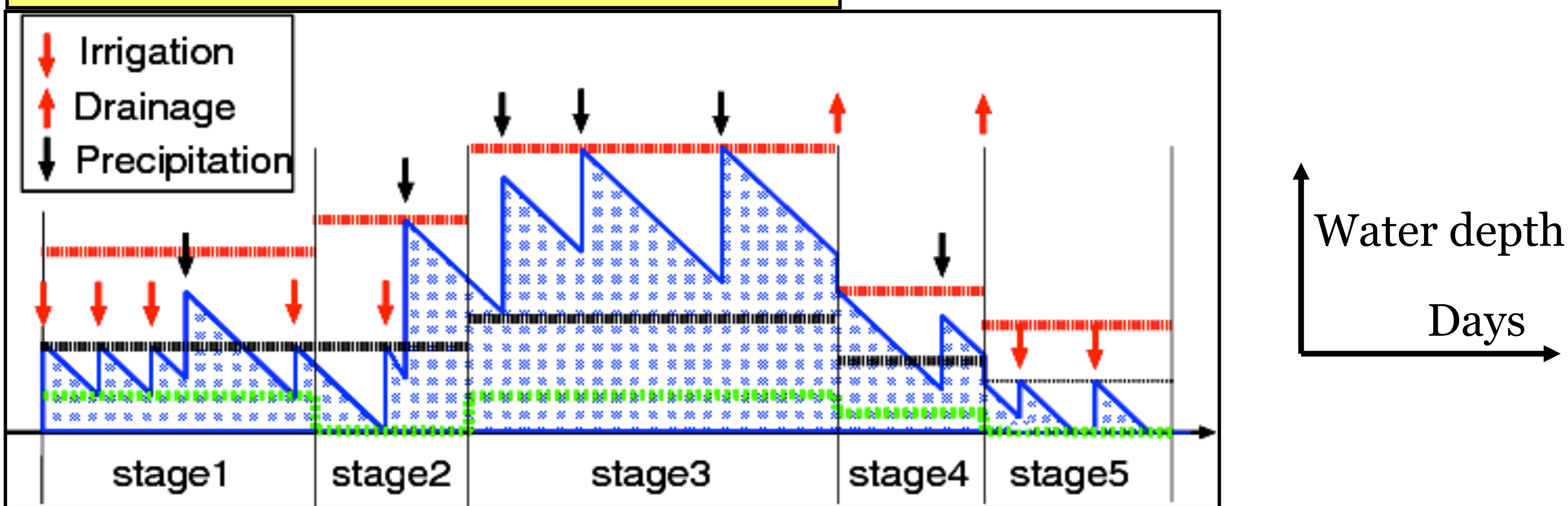
$$C_d \frac{\partial T_d}{\partial t} = \omega C_d (T_g - T_d)$$



Water control in farmland

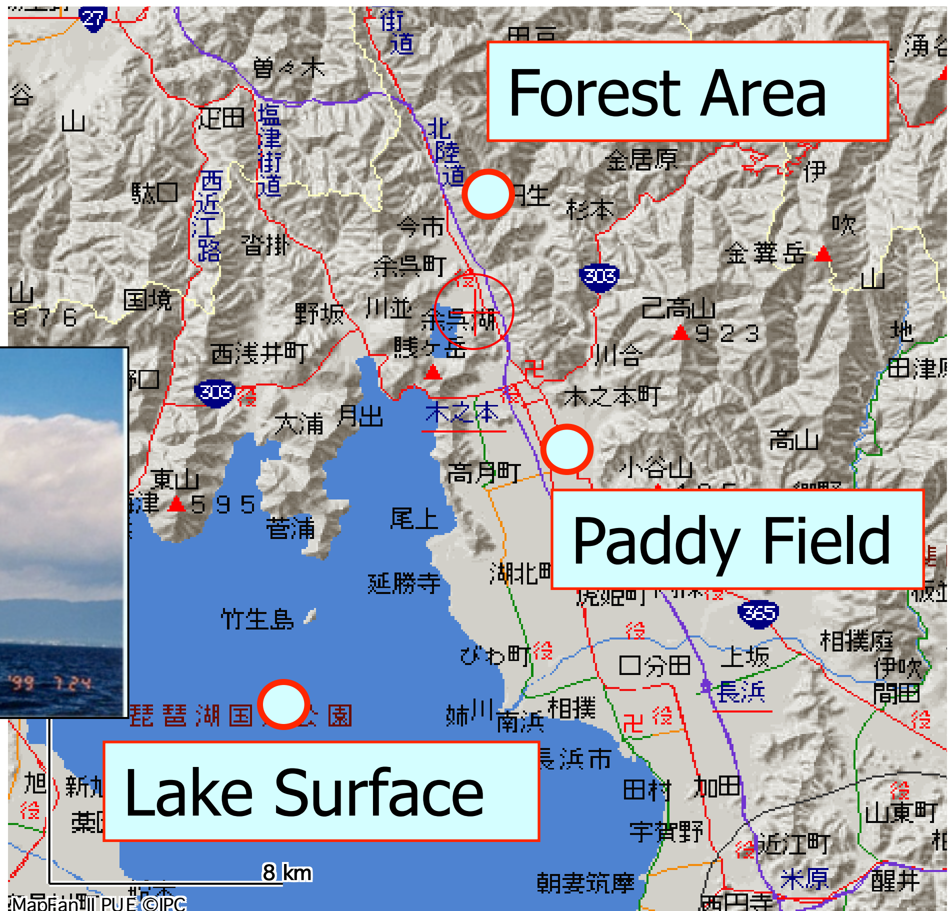


Water control in paddy field

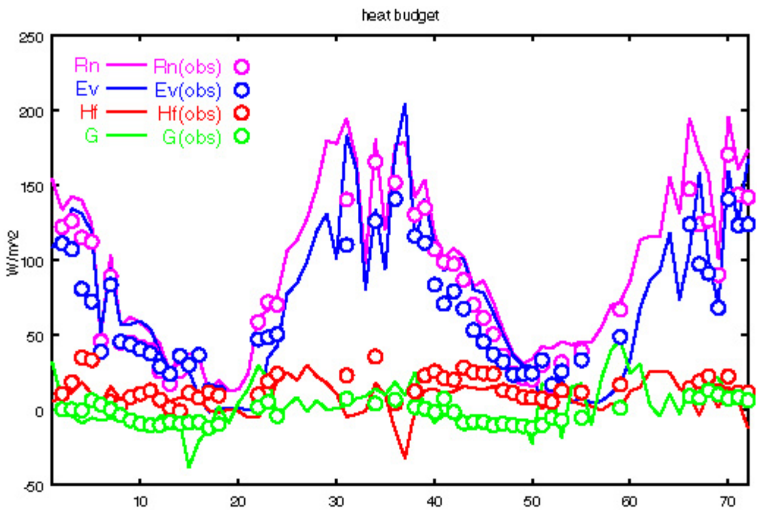


In-situ Flux station (Lake Biwa Project)

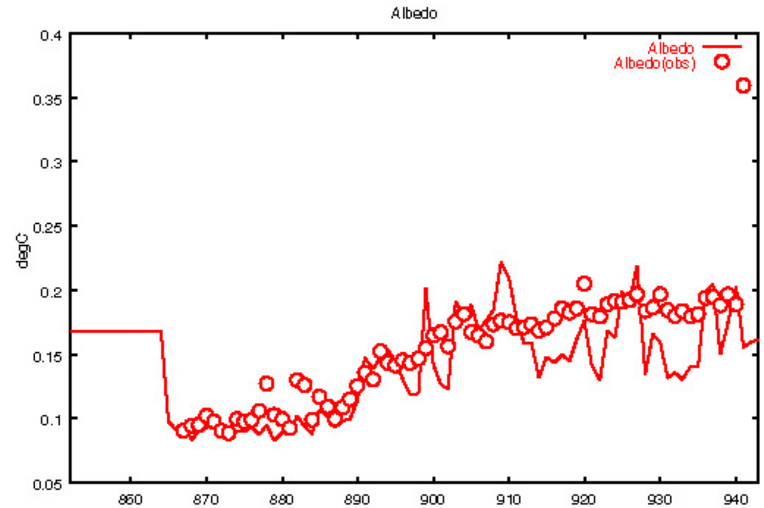
- Three sites from the Lake Biwa Project
  Fluxes of radiation budget and heat budget component and related meteorological and hydrological variables can be used from these datasets.
- Two sites from the snow depth observation station



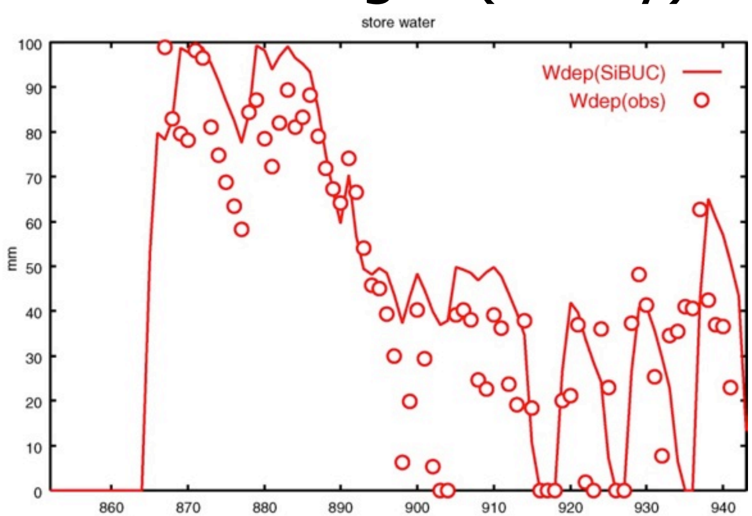
Grid P (paddy field)



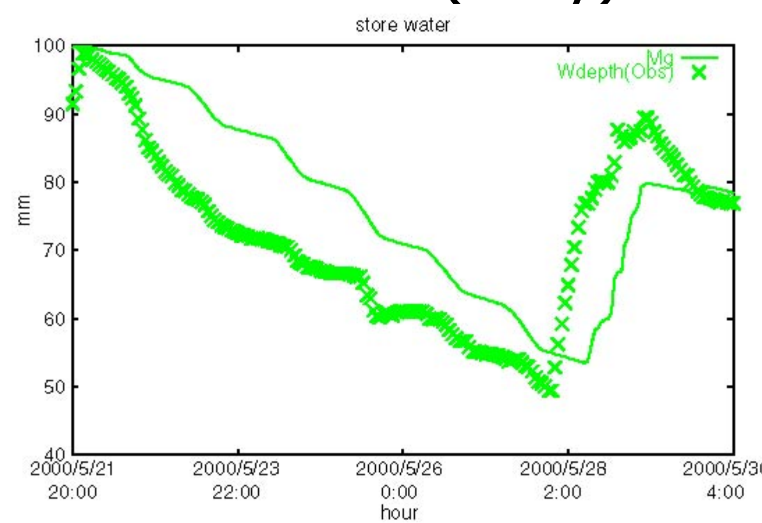
Heat budget (10day)



albedo (1day)

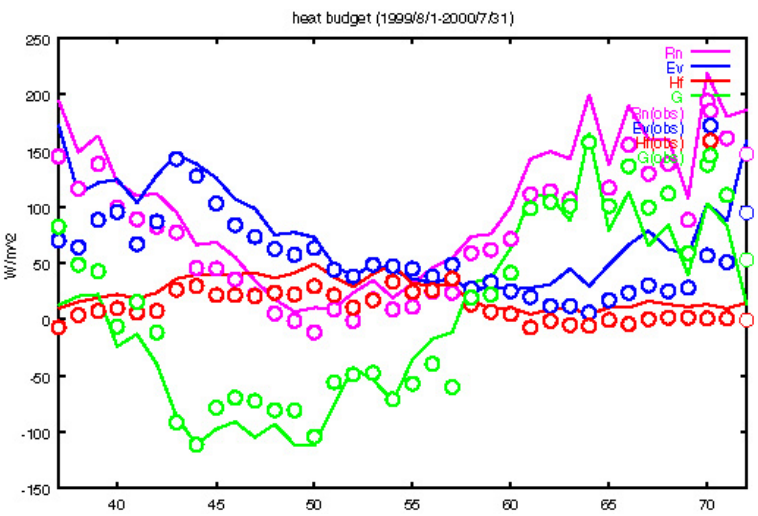


Water depth (1day)

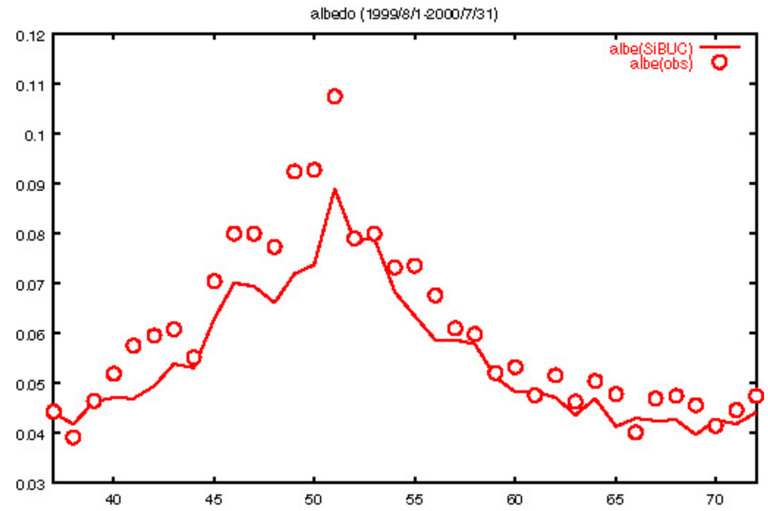


Water depth (1hr)

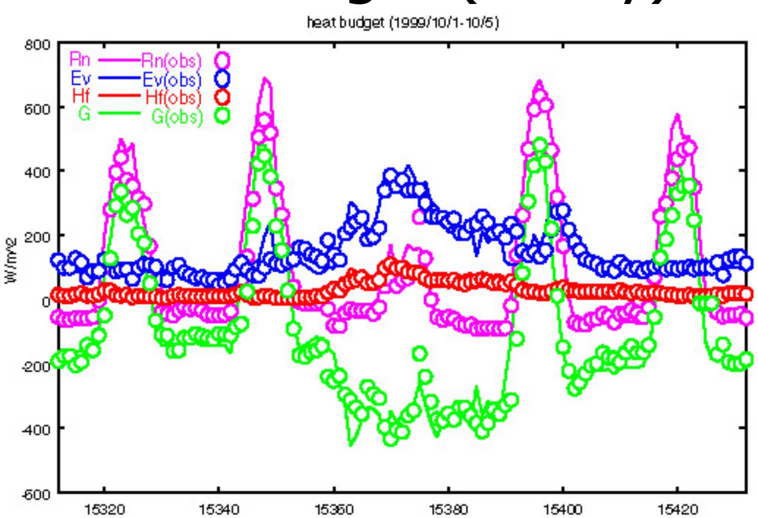
Grid L (lake surface)



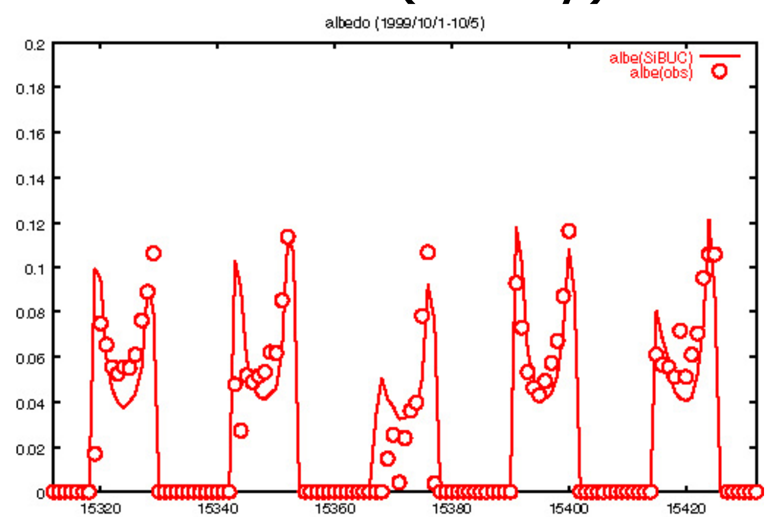
Heat budget (10day)



Albedo (10day)



Heat Budget (1hr)



Albedo (1hr)

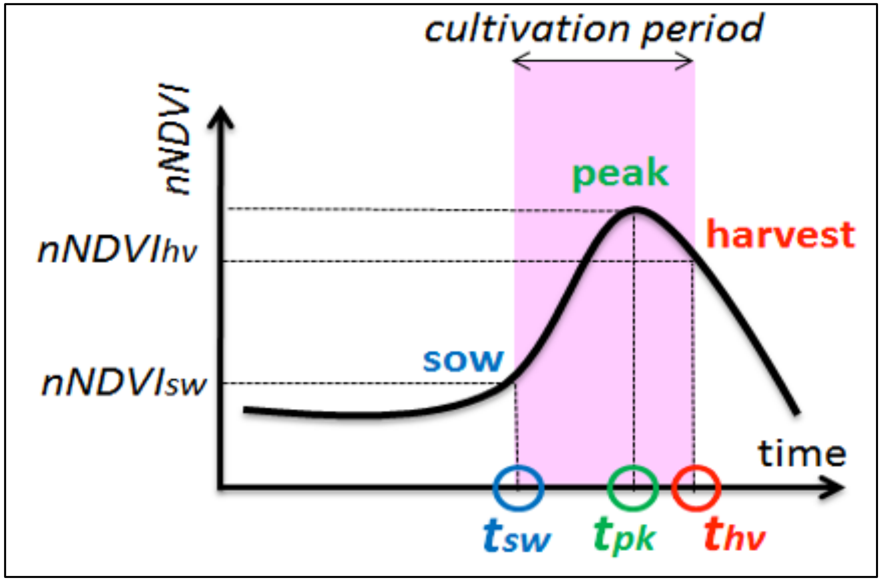
Applied condition

Crop type	Growing stage	1st	2nd	3rd	4th	5th
Spring wheat	Periods(%)	23	14	14	14	35
	Soil wetness	0.70	0.60	0.80	0.80	0.55
Winter wheat	Periods(%)	25	20	22	13	20
	Soil wetness	0.70	0.70	0.80	0.80	0.55
Corn	Periods(%)	8	48	6	14	24
	Soil wetness	0.75	0.65	0.70	0.75	0.65
Rice	Periods(%)	25	13	33	13	16
	Water depth (mm)	20-50	none	20-60	moistening	intermittent
soy bean	Periods(%)	3	26	16	28	27
	Soil wetness	0.75	0.65	0.65	0.70	0.65
cotton	Periods(%)	4	21	13	26	36
	Soil wetness	none	0.5	0.55	0.55	0.5

Chart by required water for cultivation in China

Satellite-derived crop calendar (SACRA)

Kotsuki S. and K. Tanaka (2015):
SACRA - a method for the estimation of global high-resolution crop calendars from a satellite-sensed NDVI. Hydrology and Earth System Sciences, 19, 4441-4461.

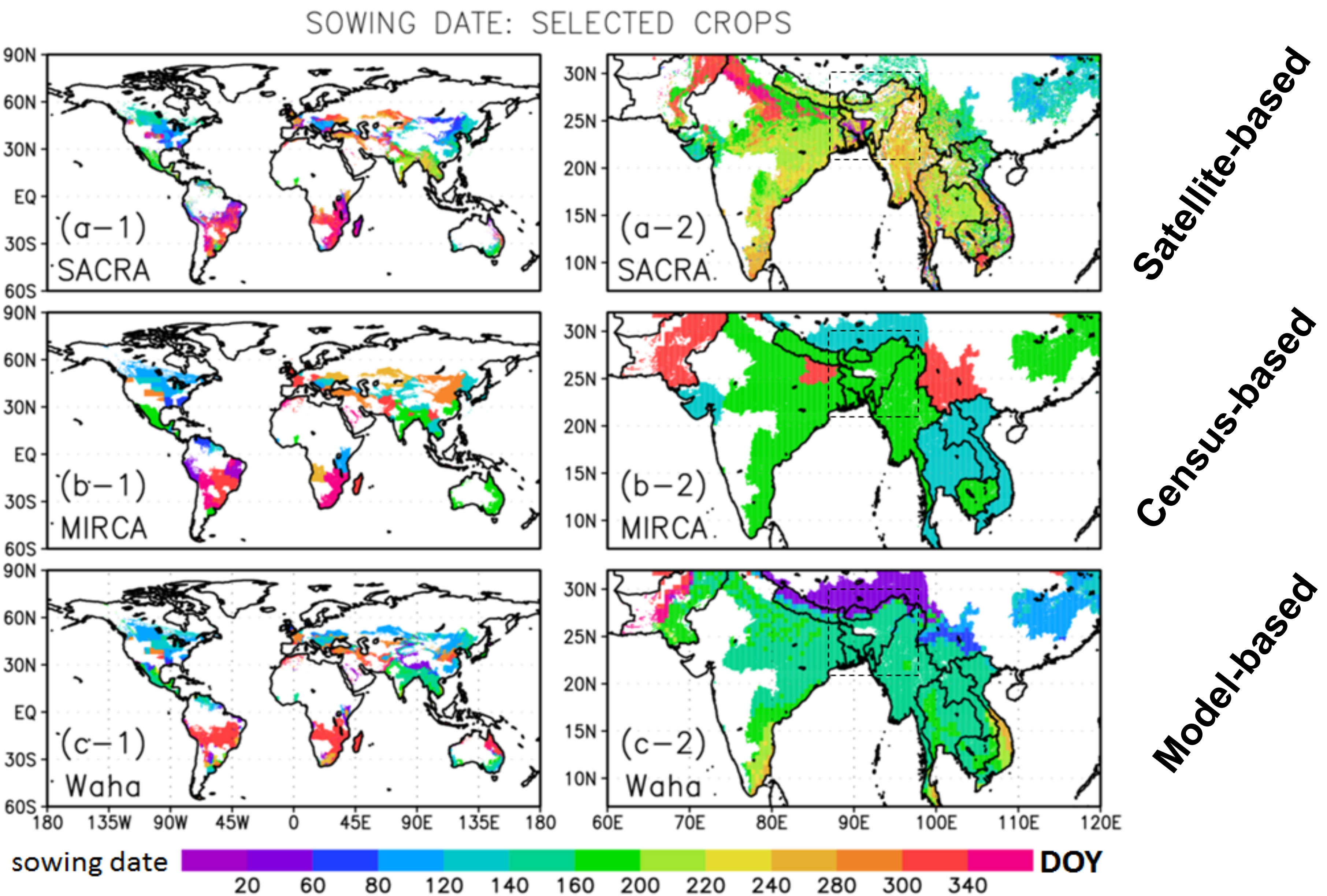


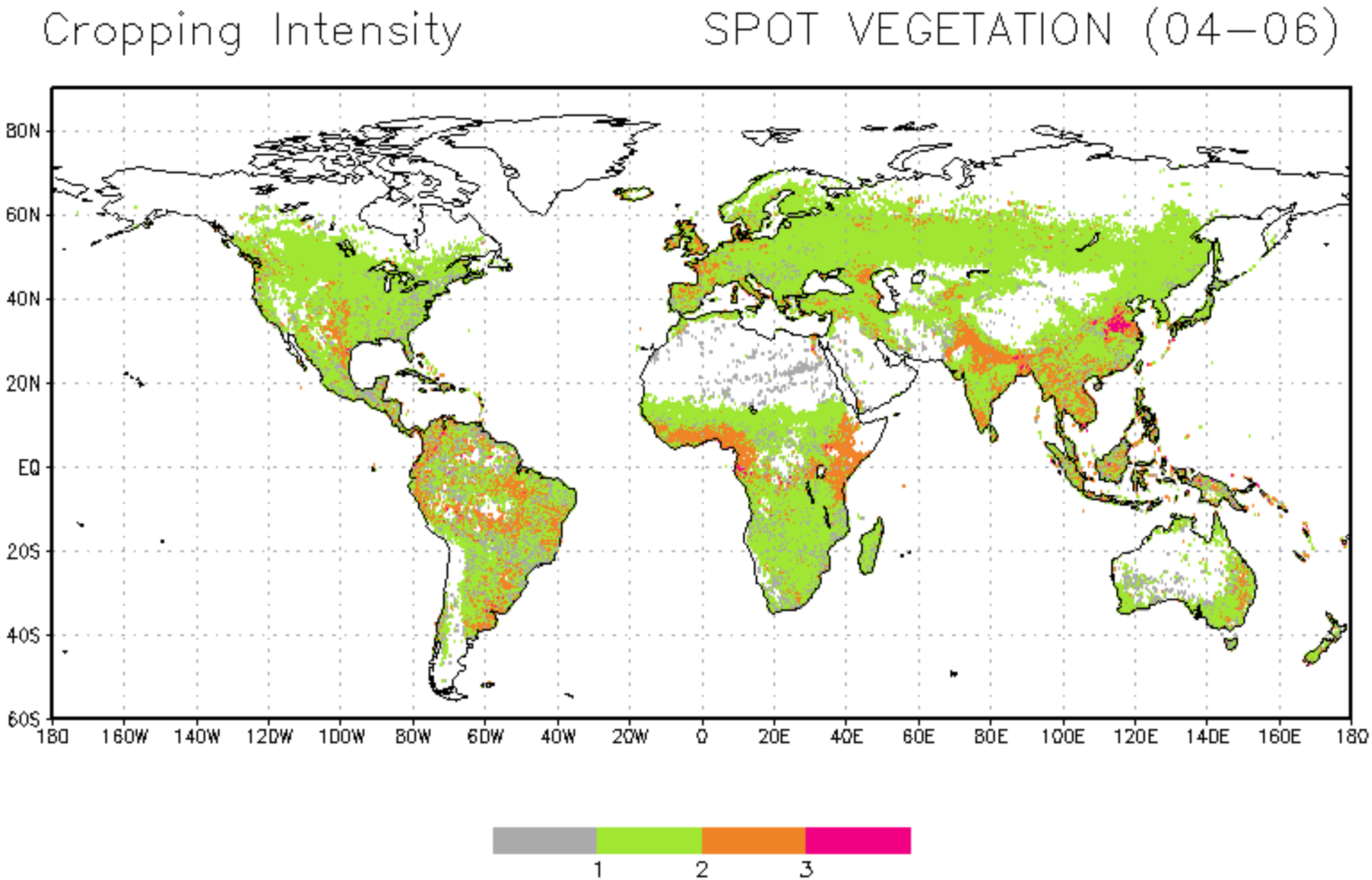
http://data-assimilation.riken.jp/opendata/sacra/sacra_des.html

Download (version 1.00; Kotsuki and Tanaka 2015, HESS)

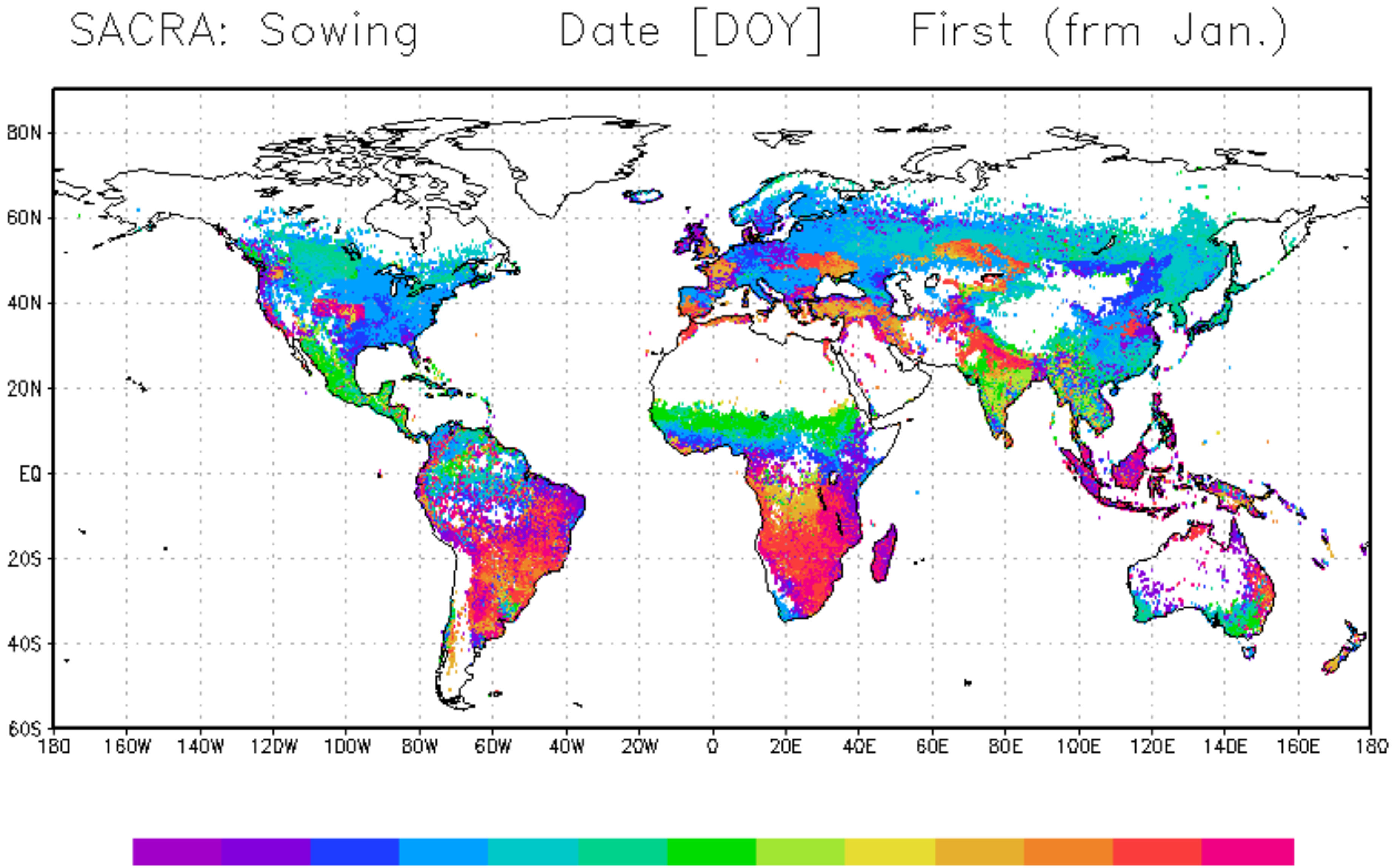
Description	Sample Image	Binary (w /GrADS ctl)
Global Map of Planting and Harvesting Dates (day of year)	click	download (33Mb)
Global Map of Cropping Intensity (yr^-1)	click	download (03Mb)
Global Map of Dominant Crop (crop species)	click	download (03Mb)
Global Map of Time Series of NDVI (10-days composite)	click	download (191Mb)
ALL	-	download (219Mb)

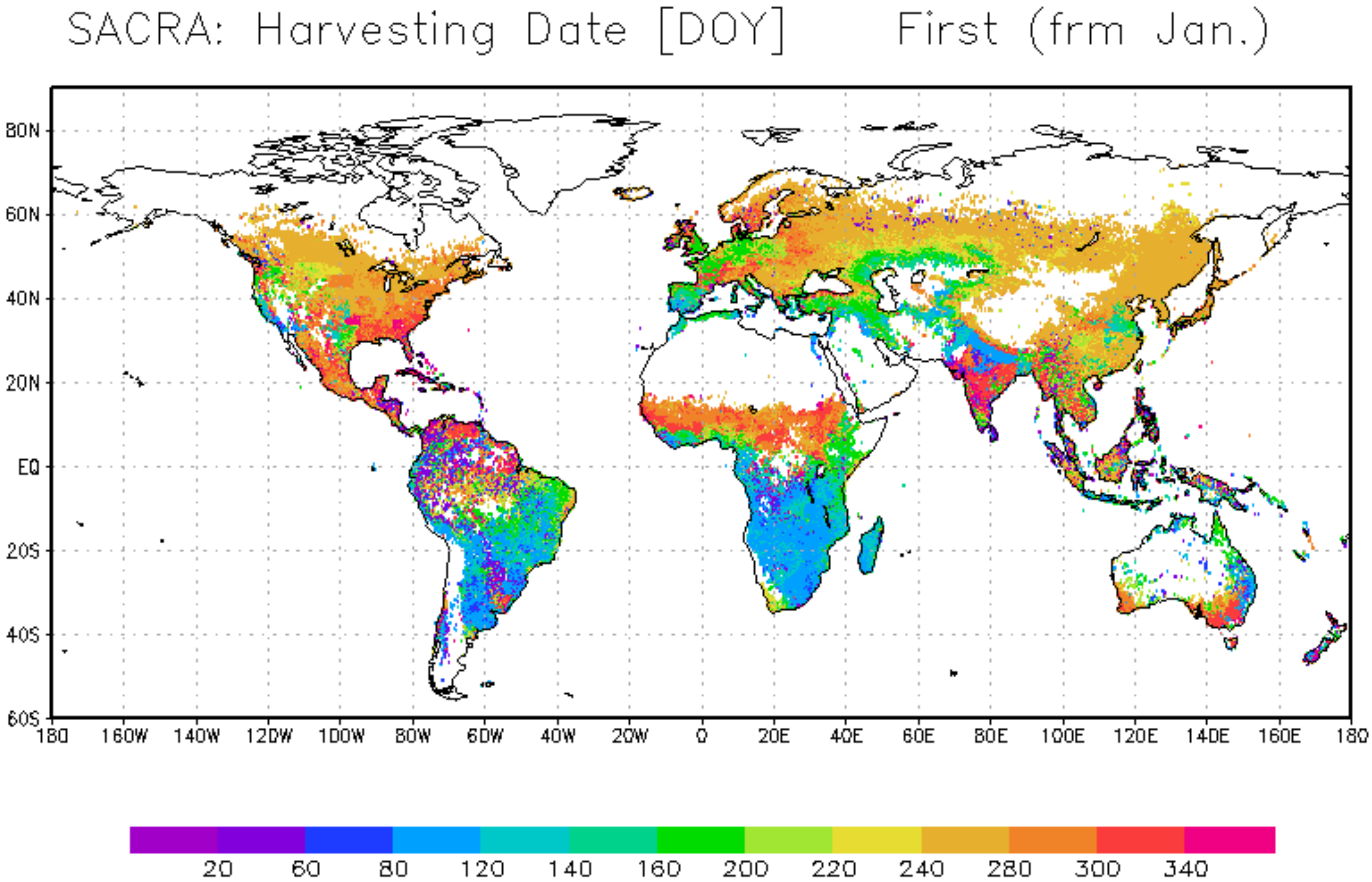
Comparison with other products



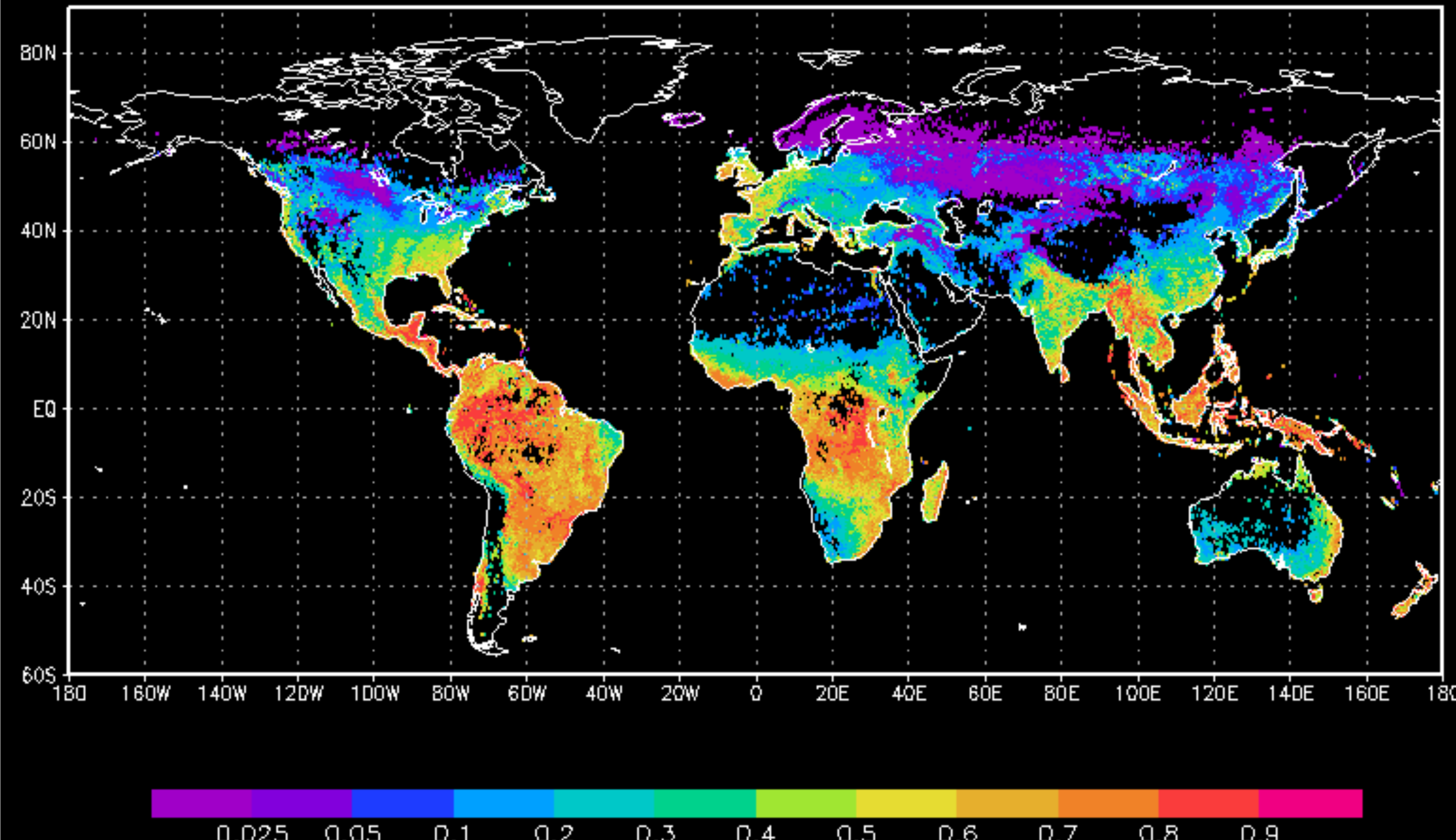


Cropping Intensity
SPOT VEGETATION (04–06)
80N
60N
40N
20N
EQ
20S
40S
60S
180
160W
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
60E
80E
100E
120E
140E
160E
180
1
2
3

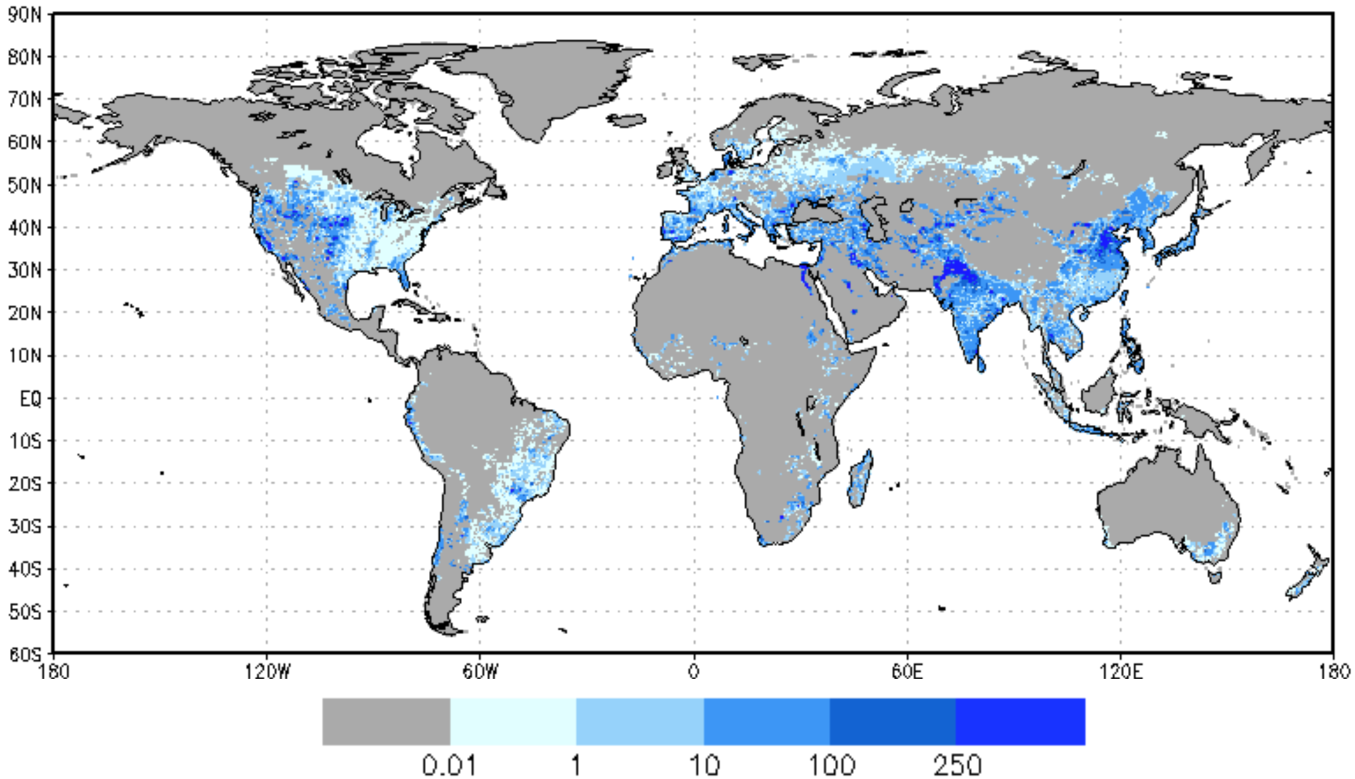

SACRA: Sowing Date [DOY] First (frm Jan.)
80N
60N
40N
20N
EQ
20S
40S
60S
180
160W
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
60E
80E
100E
120E
140E
160E
180
20
60
80
120
140
160
200
220
240
280
300
340

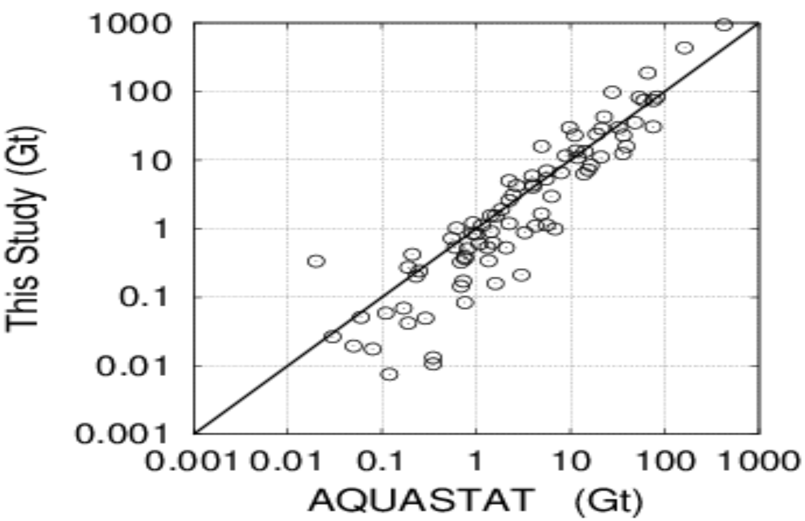

SACRA: Harvesting Date [DOY]
First (frm Jan.)
80N
60N
40N
20N
EQ
20S
40S
60S
180
160W
140W
120W
100W
80W
60W
40W
20W
0
20E
40E
60E
80E
100E
120E
140E
160E
180
20
60
80
120
140
160
200
220
240
280
300
340

NDVI−Crop (bised, doy=1)   SPOT VEGETATION (04−06)



Annual IWR (Irrigation Water Requirement) [mm/yr]



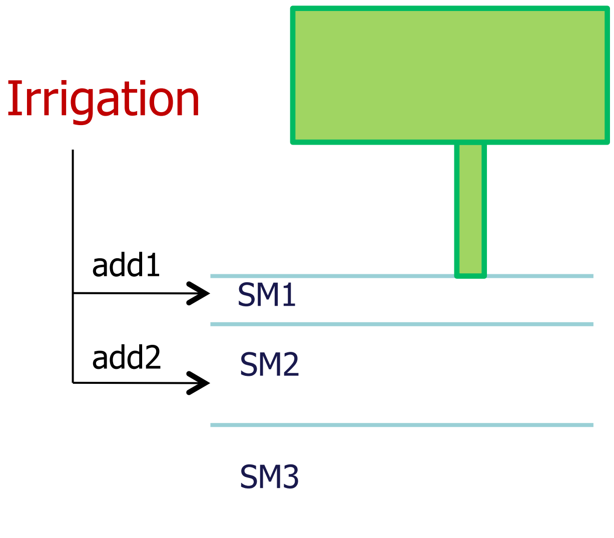


Annual IWR for each grids are aggregated into country, then compared with AQUASTAT

※ Using irrigation efficiency (Doll *et al*., 2002)

Irrigation scheme

efficient irrigation (Drip irrigation)

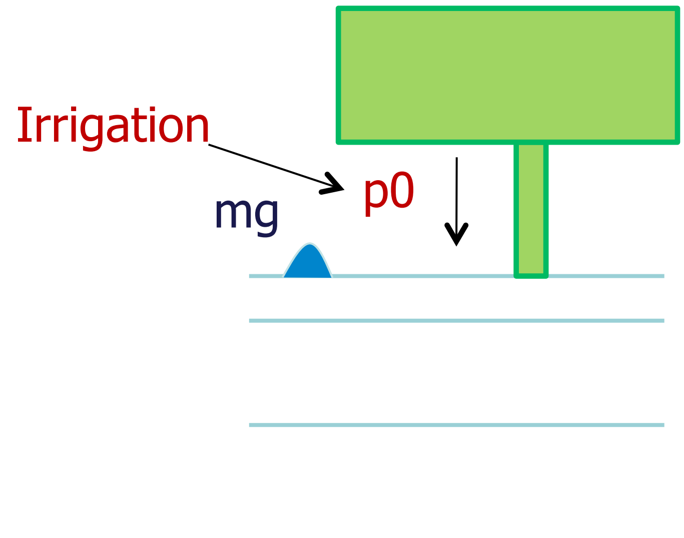


$$\Delta SM1 = waterin * \frac{d1}{d1 + d2}$$

$$\Delta SM2 = waterin * \frac{d2}{d1 + d2}$$

- Water is directly supplied to the root zone.
- Small amount of water is frequently supplied.

traditional irrigation (Furrow irrigation)

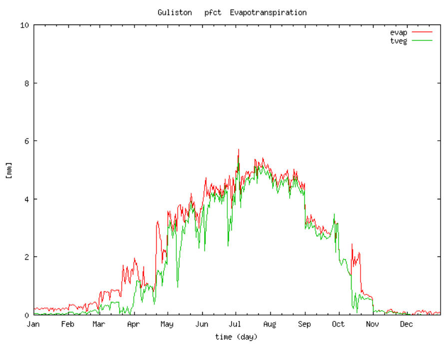


$$p0 = waterin$$

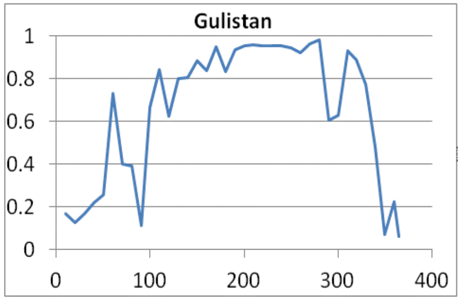
- Water is supplied on the ground.
- Huge amount of water is supplied around once a week.

WATER BALANCE IN IRRIGATED FARM

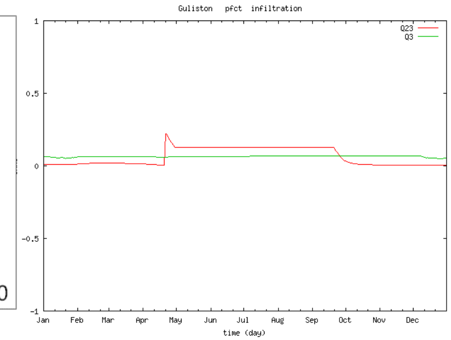
Drip irrigation



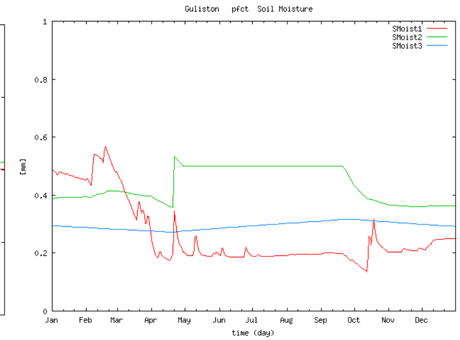
Evapotranspiration



Evaporation/ Evapotranspiration

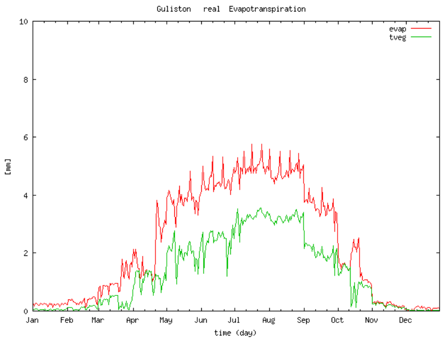


Infiltration to deeper layer

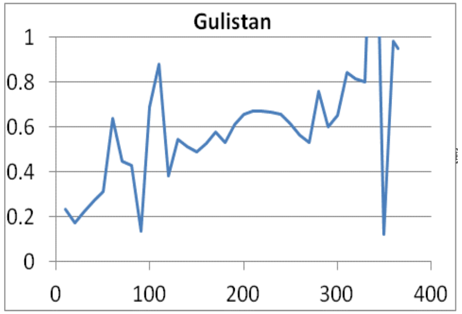


Soil moisture

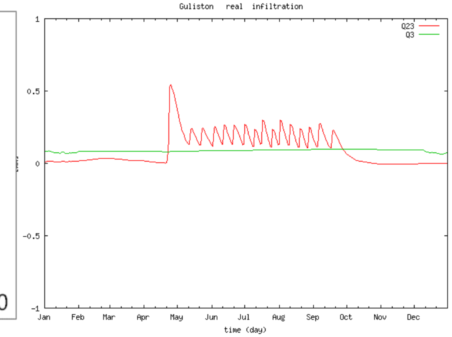
Furrow irrigation



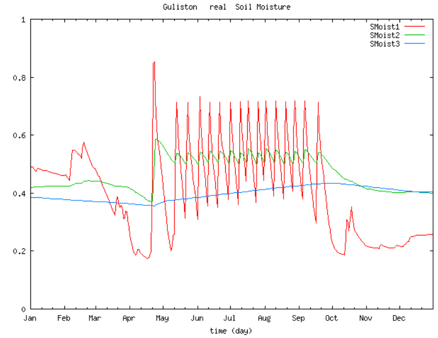
Evapotranspiration



Evaporation/ Evapotranspiration

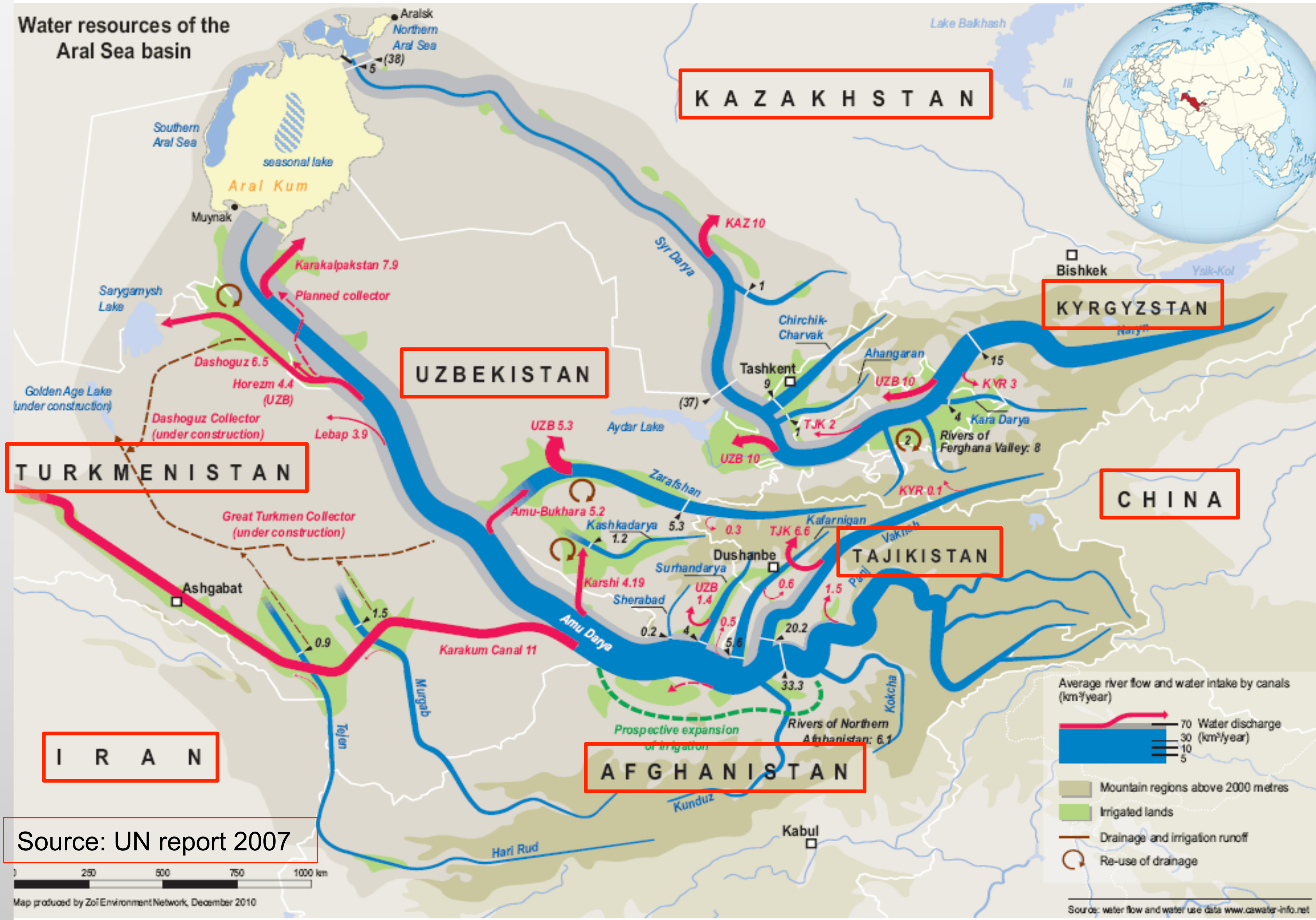


Infiltration to deeper layer



Soil moisture

Aral Sea Basin (Central Asia)



Source: UN report 2007

OBSERVATION SYSTEM IN UZBEKISTAN

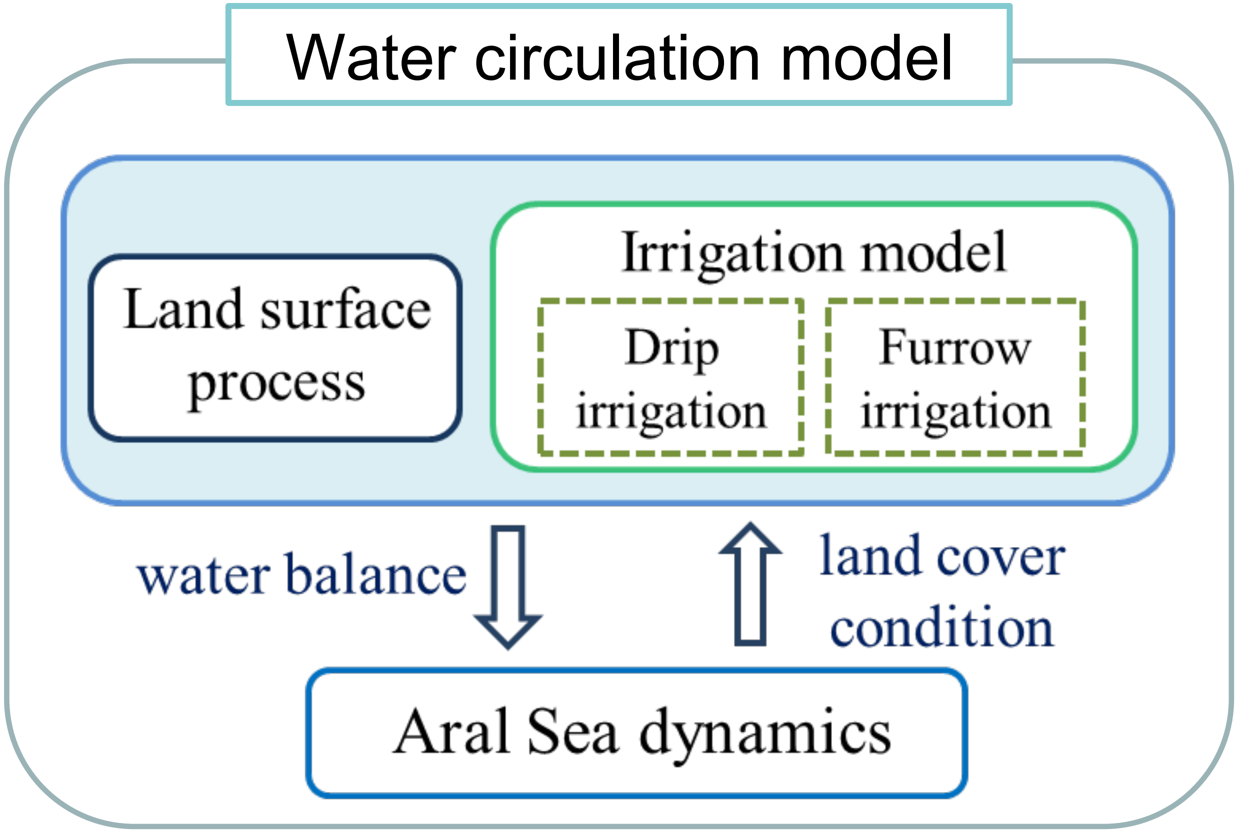
New equipment in Sorghum farm

Cotton

Precipitation gauge

About Water Circulation Model

Aral Sea shrinking is dynamically analyzed in the model.



Model can be applied for global scale,

But Basin scale water balance is analyzed considering regional features.

Calculation of Water Balance

Water balance of each mesh

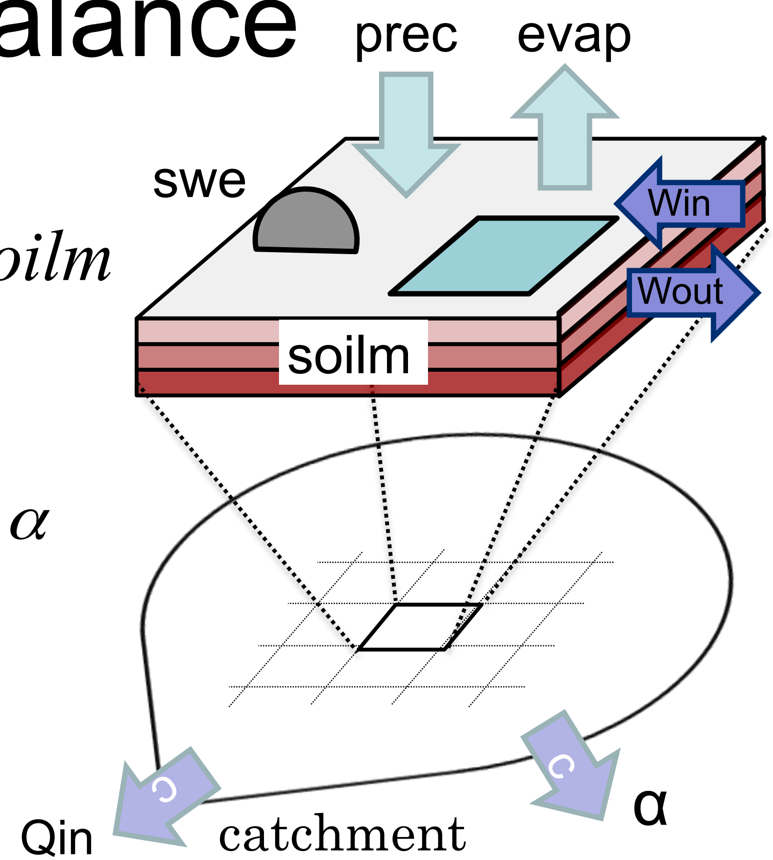
$$Runoff = prec - evap - \Delta swe - \Delta soilm$$

Water balance of the catchment

$$Qin = \sum Runoff - \sum \frac{Win}{\gamma} + \sum Wout - \alpha$$

Water balance of the Aral Sea

$$\Delta S = Qin + (P - E)_{aral}$$



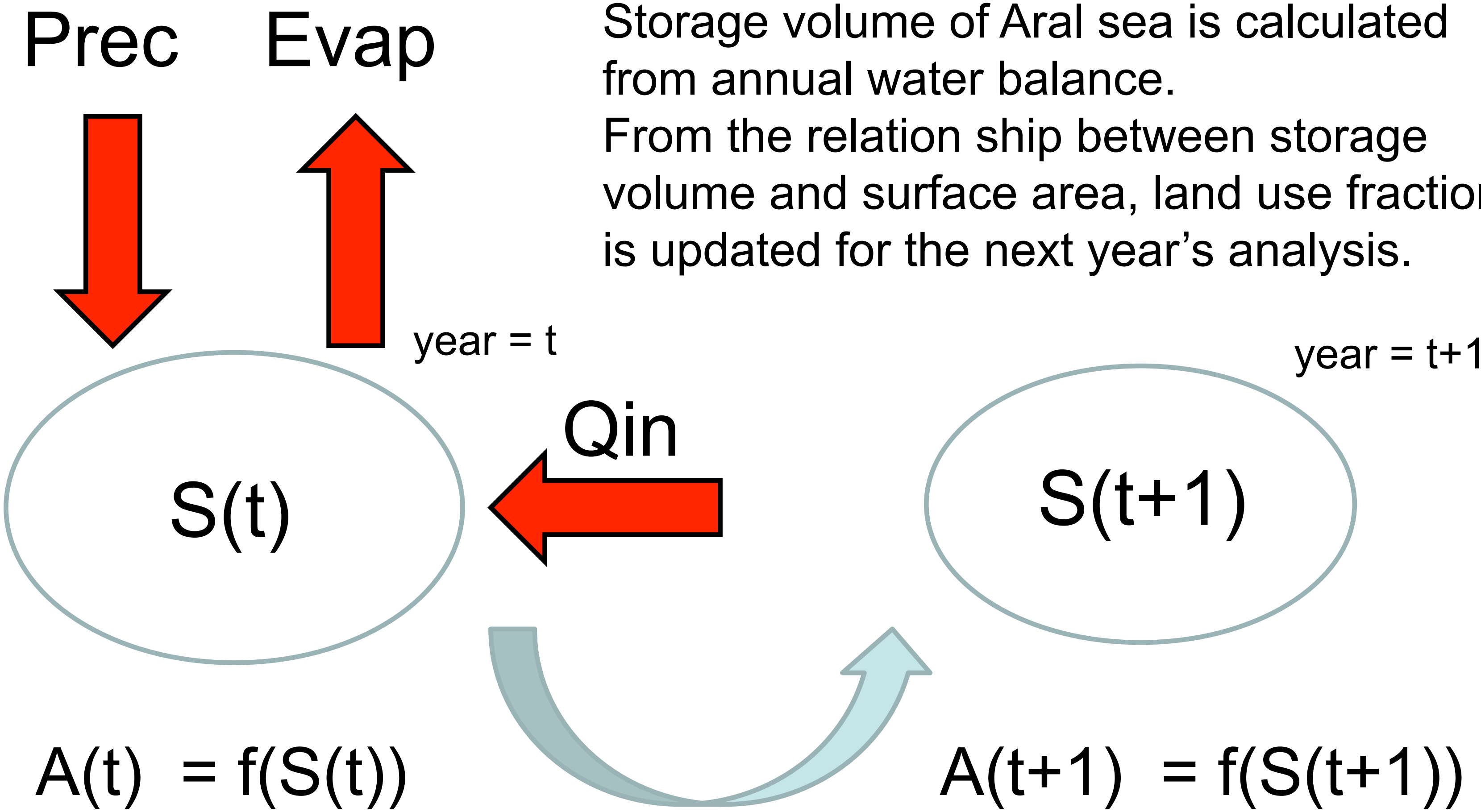
Runoff	Water resource	Gt
prec	Precipitation	Gt
evap	Evapotranspiration	Gt
Win	Irrigation water requirement	Gt
Wout	Drainage water	Gt

γ	Water conveyance efficiency (=**0.4**)	
Qin	Inflow to the Aral	Gt
soilm	Soil moisture	Gt
swe	Snow water equivalent	Gt

α : Water requirement outside of the basin

Annual water balance of the Aral Sea

Storage volume of Aral sea is calculated from annual water balance.
From the relation ship between storage volume and surface area, land use fraction is updated for the next year's analysis.

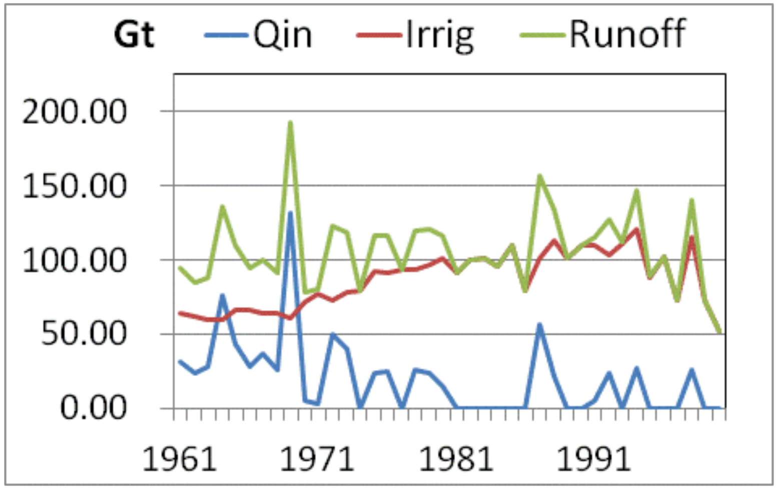


$A(t) = f(S(t))$

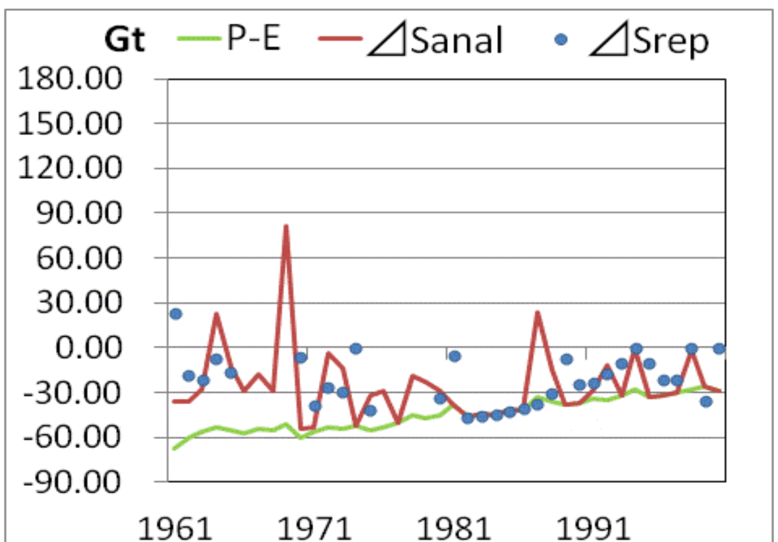
$A(t+1) = f(S(t+1))$

$$S(t+1) = S(t) + Qin + (Prec-Evap)$$

WATER BALANCE OF THE BASIN



Historical change of water balance



Water balance of the Aral Sea

Comparing with reported value

Average of water resource

Analysis 137Gt Report 133Gt

Irrigation water demand

1990 Analysis 124Gt Report 126Gt

1995 Analysis 106Gt Report 111Gt

(Report : Micklin, 2000)

Historical water balance is clearly analyzed.

Q in	Water inflow into the Aral Sea
Irrig	Irrigation water requrement
Runoff	Water resource
P−E	Precipitation − Evaporation in the Aral Sea
⊿Sanal	Analyzed storage change
⊿Srep	Reported storage change

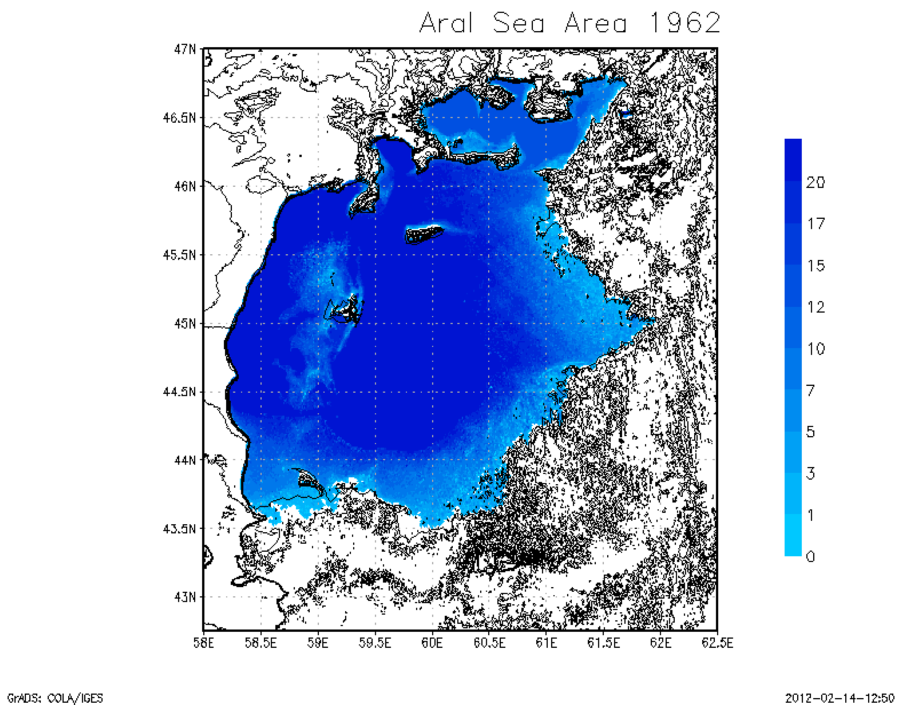
Reproducing of the Aral Sea Shrinking

Annual water balance in the basin

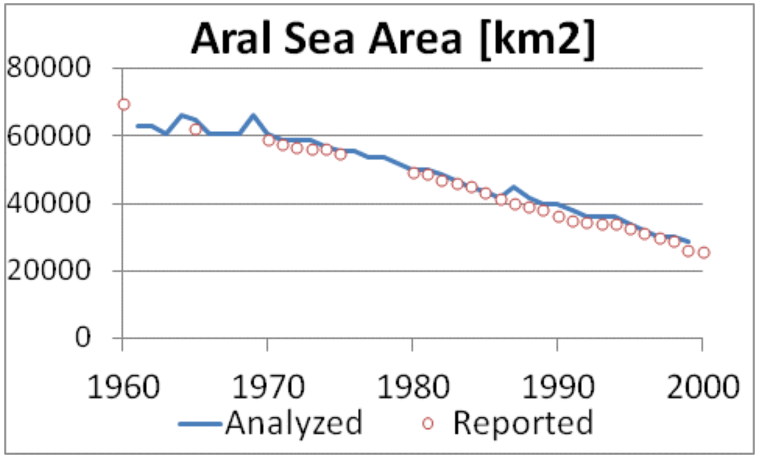
(Inflow to the Aral Sea)

⇩

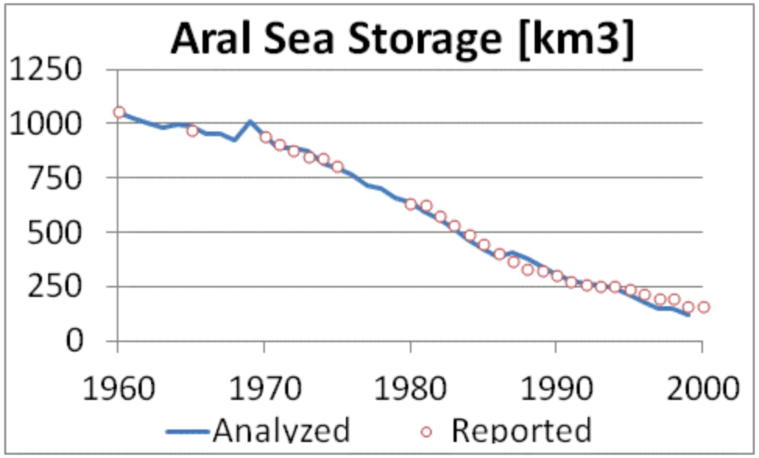
The Aral Sea area



Historical change of the Aral Sea area



Annual change of the Aral Sea area

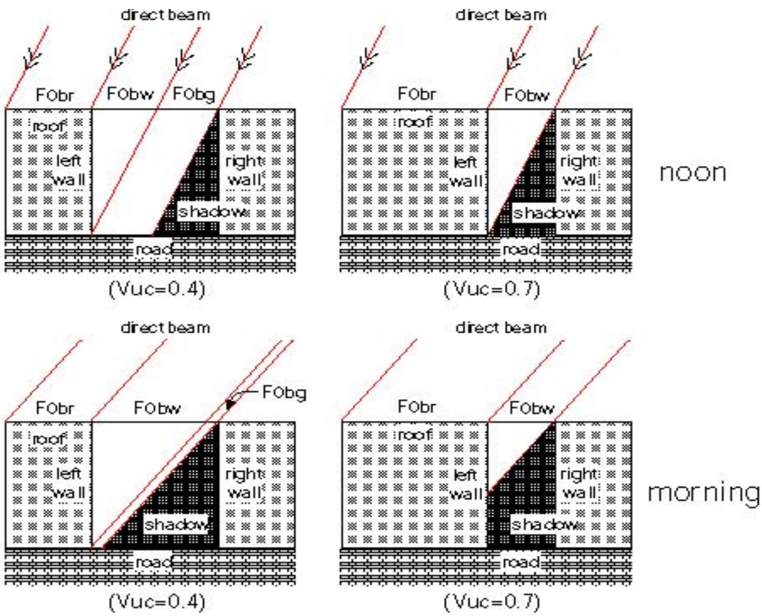


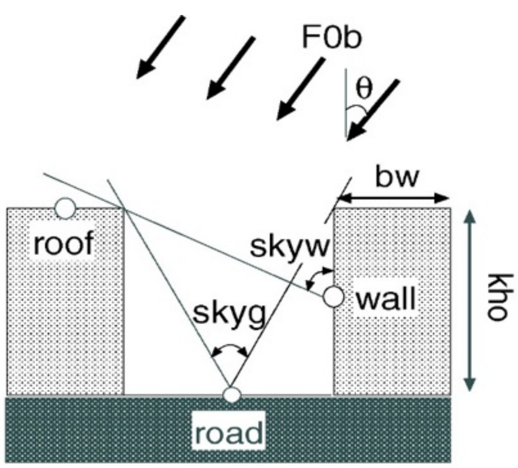
Annual change of the Aral Sea storage

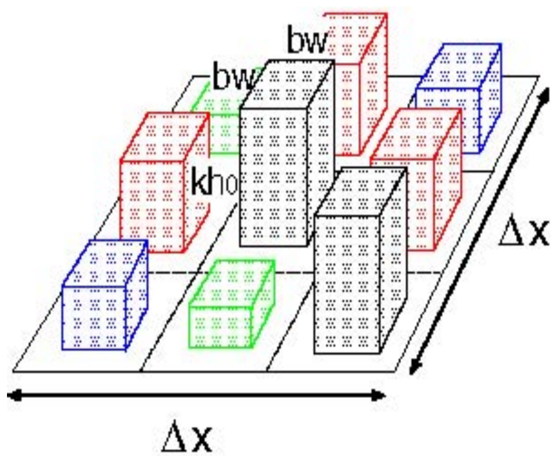
Aral Sea shrinking is clearly analyzed.

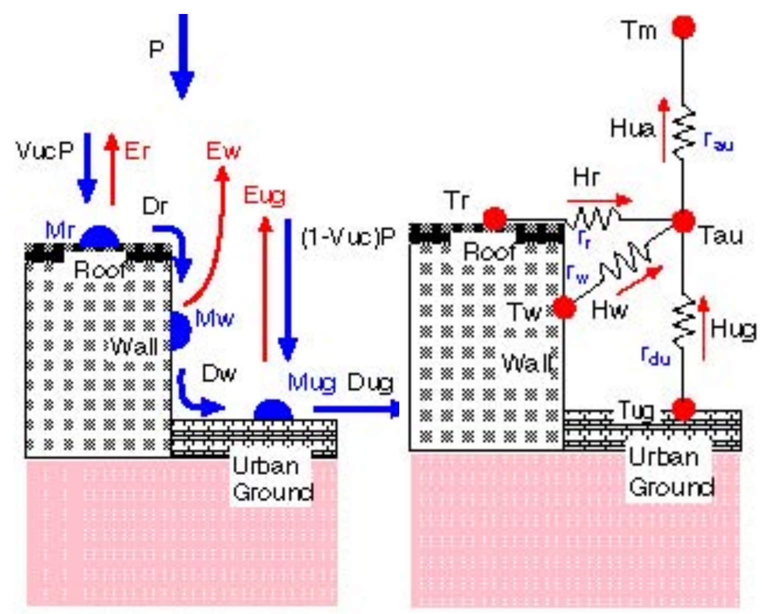
Urban Canopy model

- Urban canyon concept
  sky-view factor (road: skyg   wall: skyw)
- Prognostic variables
  temperature (roof, wall, road, deep soil)
  interception water (roof, wall, road)
- Roughness elements
  (same width but different roof height)
- Spatial distribution of roof height and anthropogenic heat

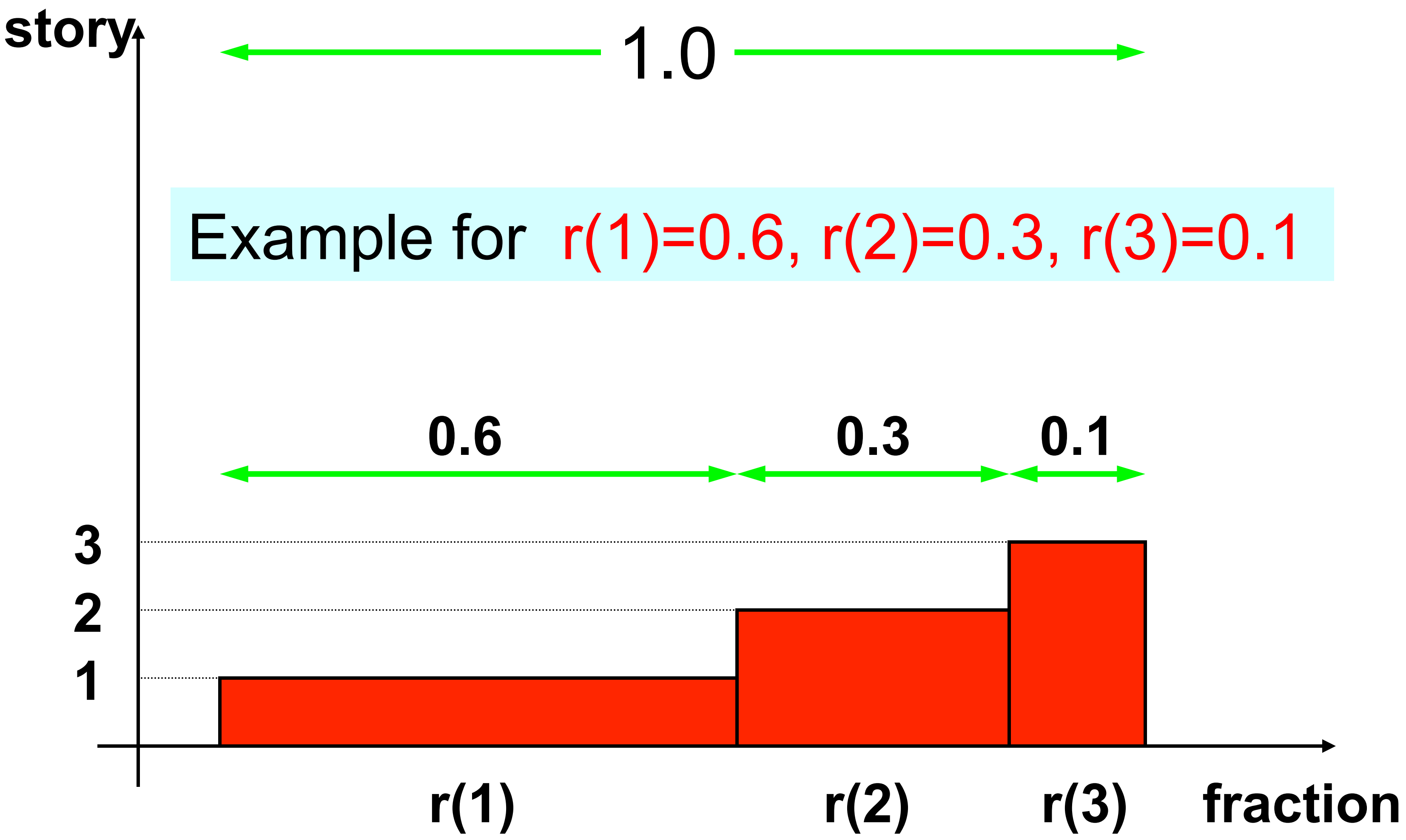






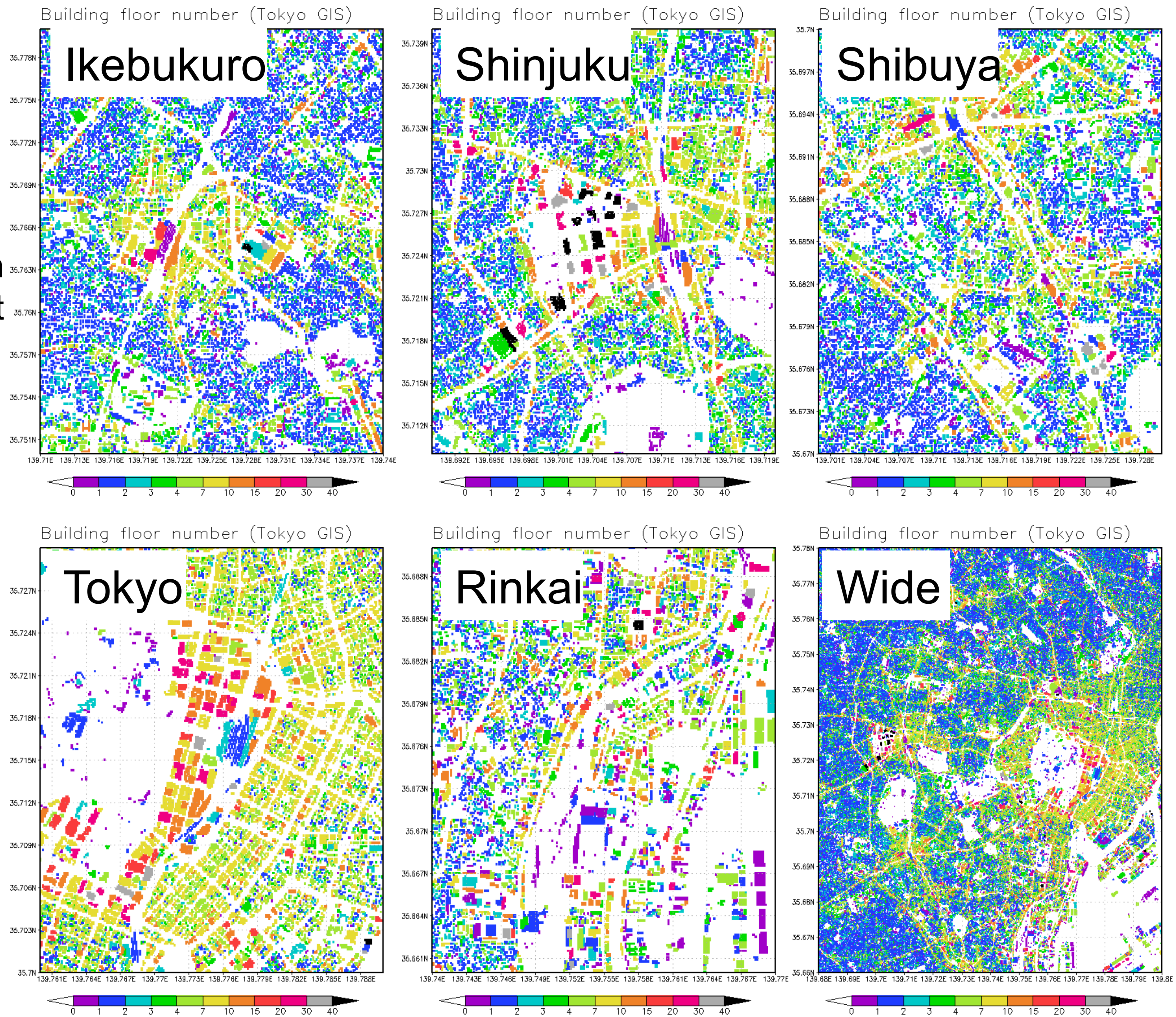


Building floor number distribution

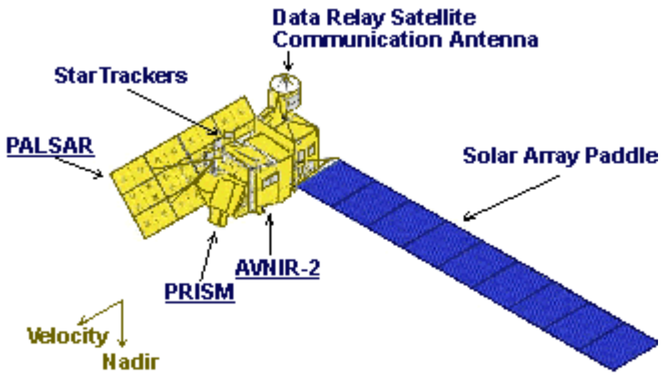


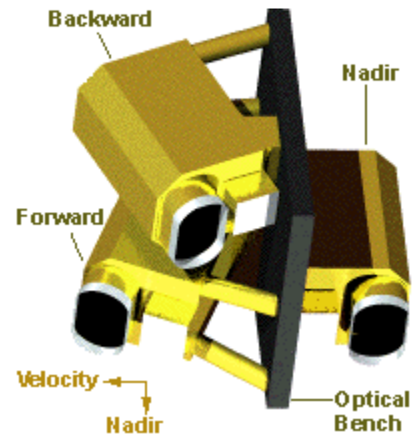
GIS

Tokyo Metropolitan Government

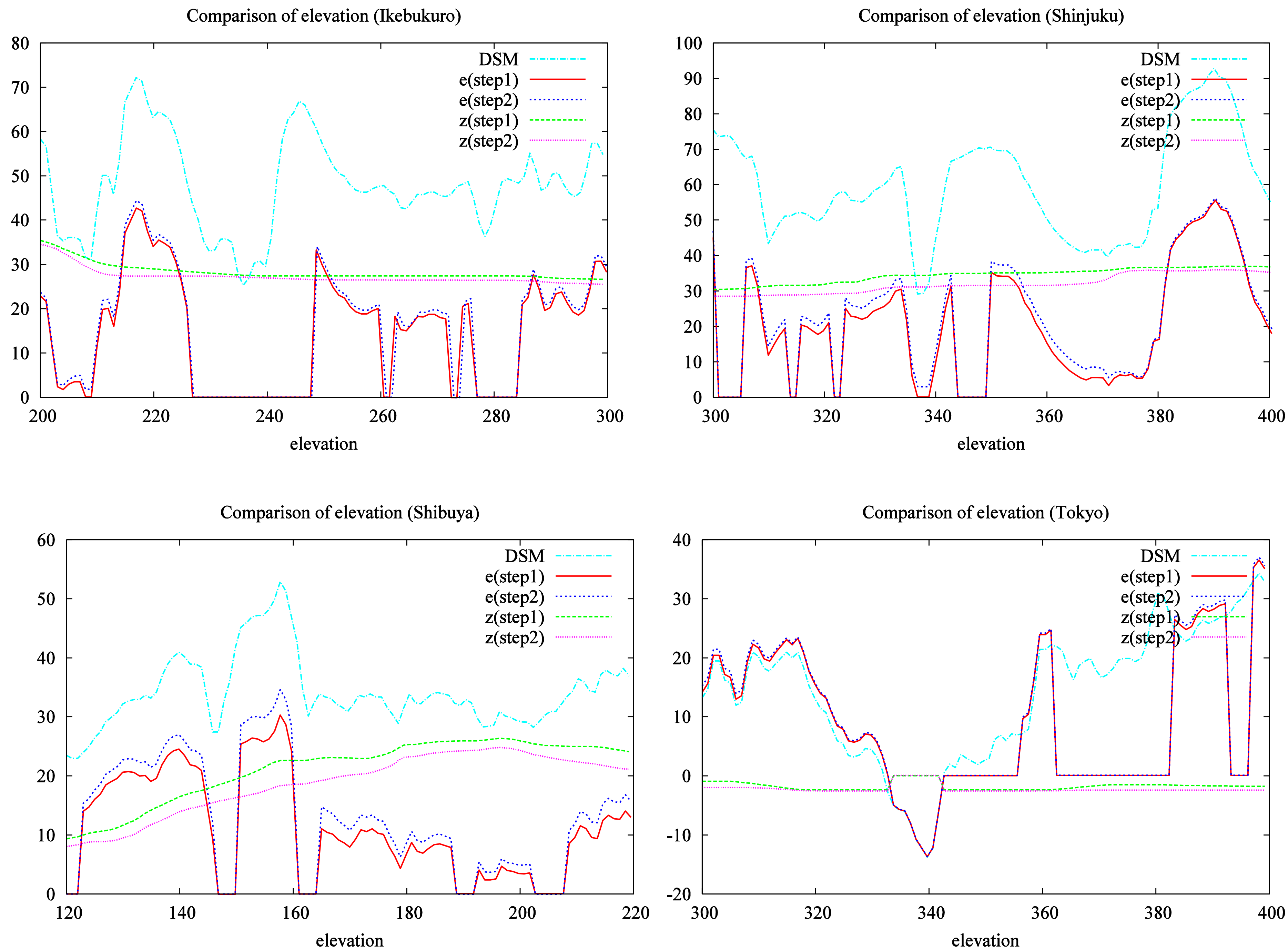


How to estimate urban parameter where GIS information is not available?

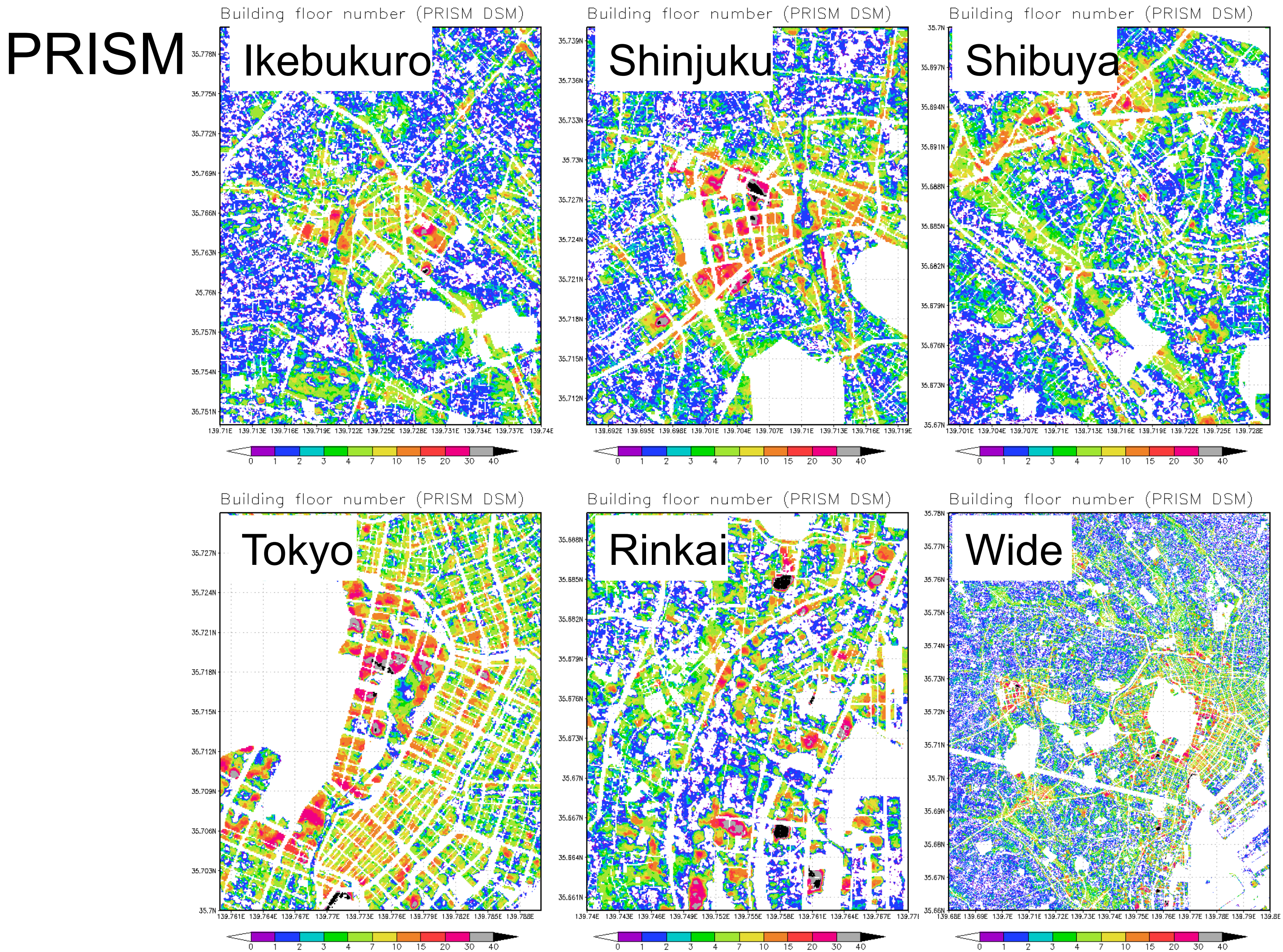




Digital Surface Model from satellite（ALOS PRISM）



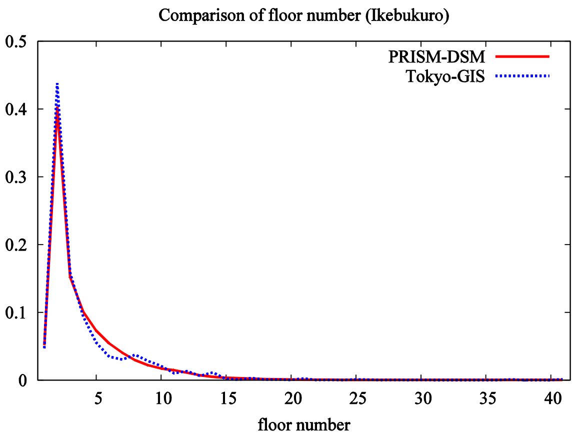
Comparison of elevation (Ikebukuro)
DSM
e(step1)
e(step2)
z(step1)
z(step2)
elevation
Comparison of elevation (Shinjuku)
DSM
e(step1)
e(step2)
z(step1)
z(step2)
elevation
Comparison of elevation (Shibuya)
DSM
e(step1)
e(step2)
z(step1)
z(step2)
elevation
Comparison of elevation (Tokyo)
DSM
e(step1)
e(step2)
z(step1)
z(step2)
elevation



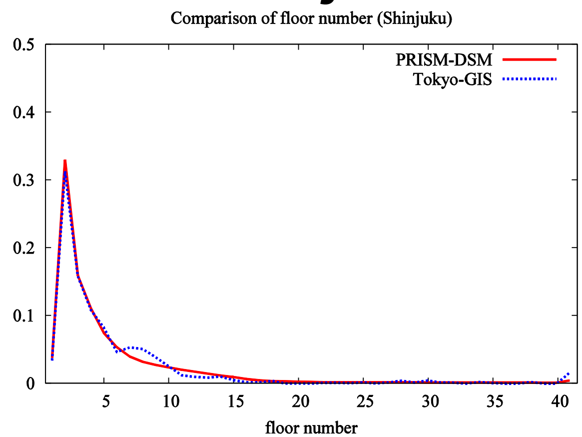
PRISM
Building floor number (PRISM DSM)
Ikebukuro
Building floor number (PRISM DSM)
Shinjuku
Building floor number (PRISM DSM)
Shibuya
Building floor number (PRISM DSM)
Tokyo
Building floor number (PRISM DSM)
Rinkai
Building floor number (PRISM DSM)
Wide
0 1 2 3 4 7 10 15 20 30 40

Building Floor number distribution

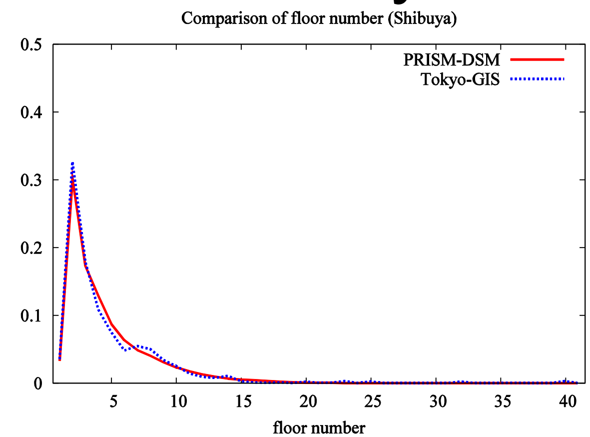
Ikebukuro



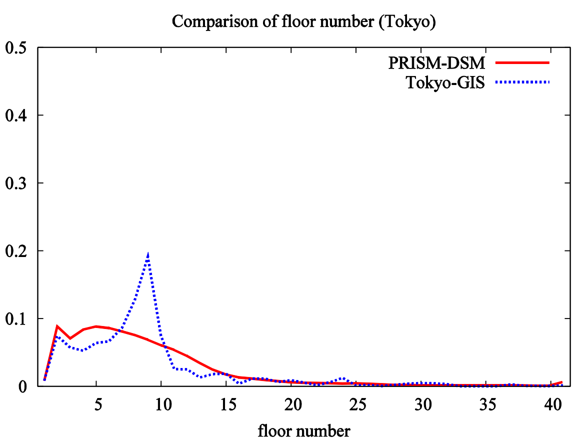
Shinjuku



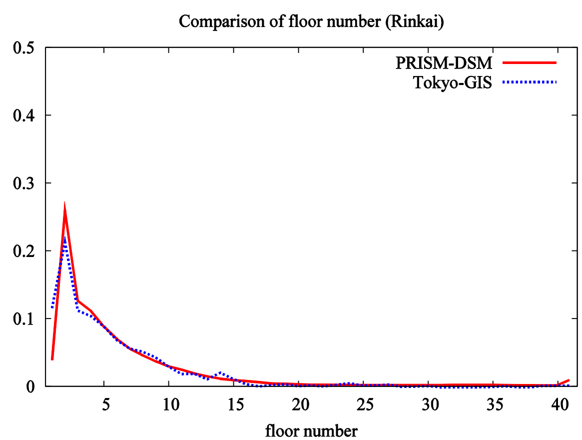
Shibuya



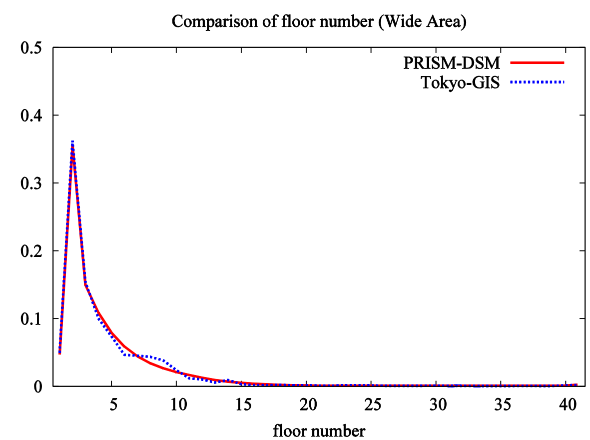
Tokyo



Rinkai



Wide Area

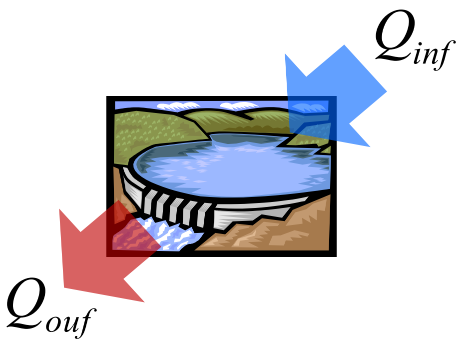


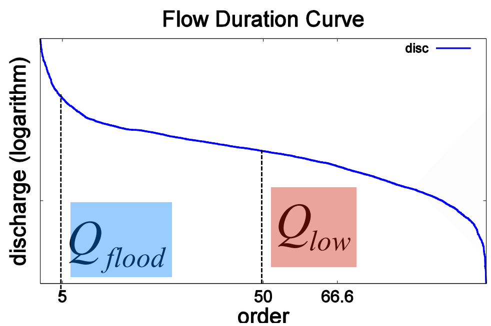
New building?

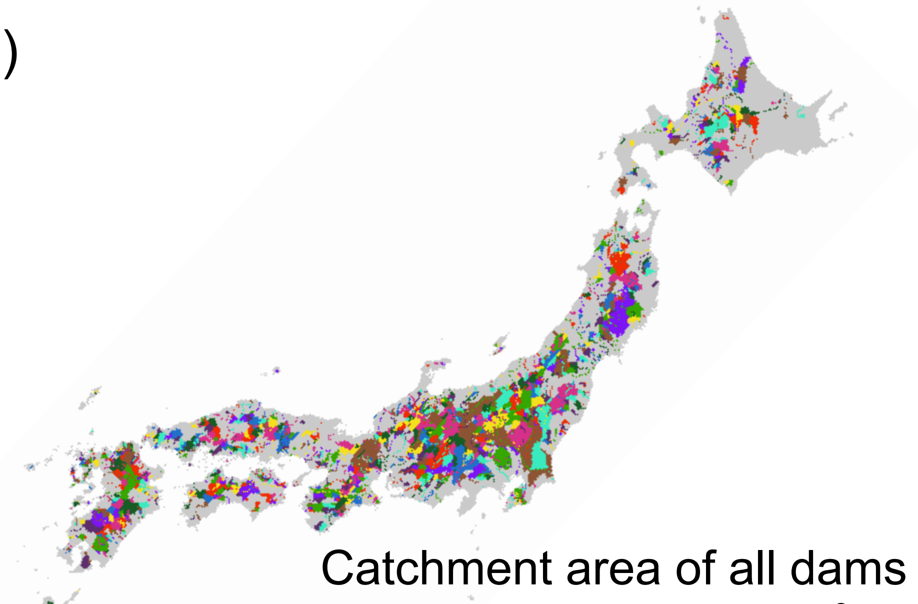
MAPCUBEで要検証

Dam Operation Modeling

- 1231 dams (more than one million m^3)
  - Flood protection dam (f)
  - Water utilization dam (u)
  - Multi purpose dam (m)







Catchment area of all dams more than one million m^3

1. Flood protection operation

$$Q_{base} = \begin{Bmatrix} Q_{flood} \\ Q_{norm} \end{Bmatrix} when \begin{Bmatrix} Q_{inf} > Q_{flood} \\ Q_{inf} \le Q_{flood} \end{Bmatrix}$$

$$Q_{norm,f} = \min\{Q_{flood}, Q_{inf}\}$$

2. Water utilization operation

$$Q_{ouf} = \max\{Q_{base}, \beta \cdot Q_{req}\}$$

$$Q_{norm,u} = \begin{cases} Q_{low} & for\ rainy\ season \\ Q_{dry} & for\ dry\ season \end{cases}$$

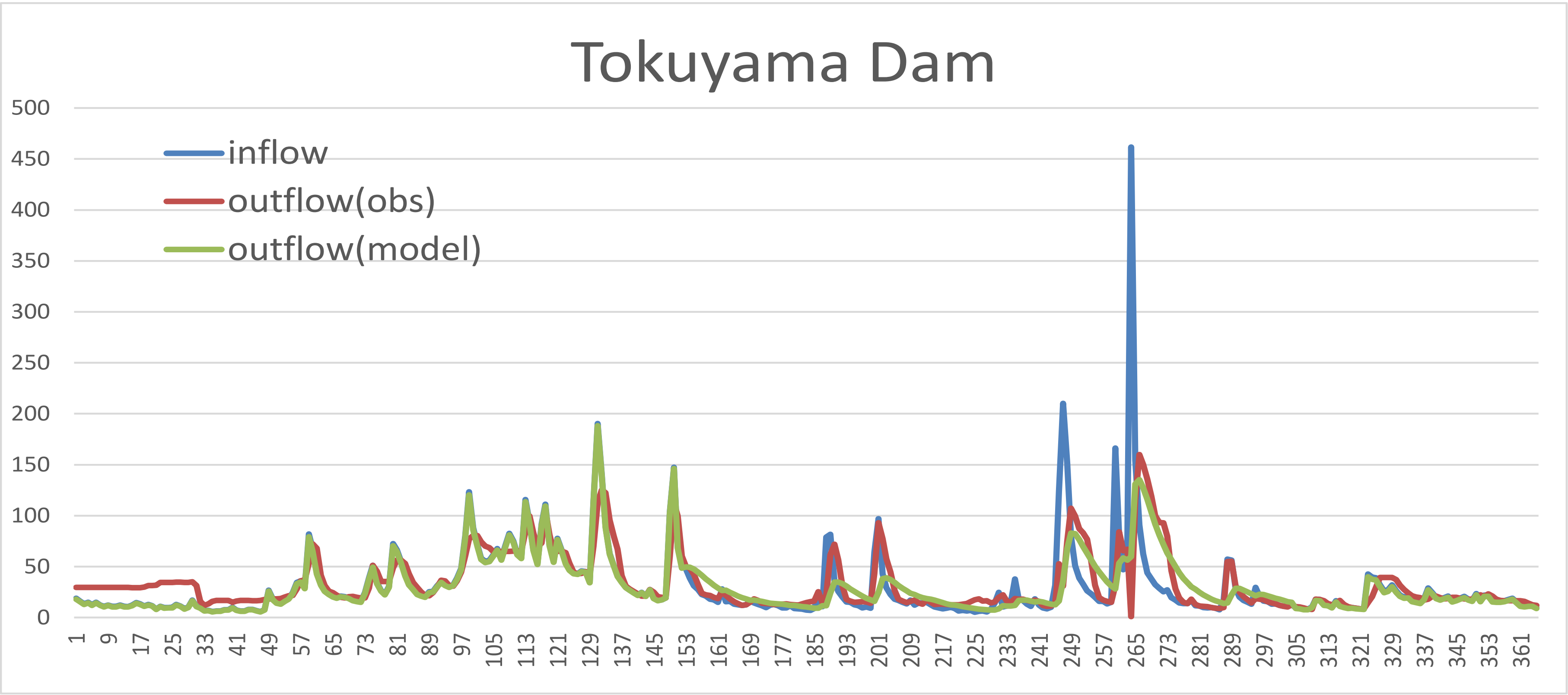
$$Q_{norm,m} = \begin{cases} Q_{norm,f} & for\ St > V_u \\ Q_{norm,u} & for\ St \le V_u \end{cases}$$

Qreq: water demand

$$Q_{dry} = \frac{St}{\text{dry period}}$$

St: storage, Vu: water use capacity

Based on the historical data, model parameters can be optimized.



Now we are trying to find out the relationship between optimized parameters and dam specification to estimate the parameter of the dam where no historical data are available.

Data source for future water demand estimation

	dataset	unit	year	purpose
Domestic water	AQUASTAT (FAO)	country	1960-2010 (every 5 year)	Determination of parameter and variable
Industrial water	AQUASTAT (FAO)	country	1960-2010 (every 5 year)	Determination of parameter and variable
Population (nation)	United Nations	country	1950-2100 (every year)	Future projection of domestic water
Power generation	United Nations	region	Historical data (every year)	Future projection of industrial water
GDP	EPOC (Environment Policy Committee)	country	2050, 2100 (each SSP)	power generation (region → country)
Population (gridded)	GPW (GriddedPopulation of the world)	2.5 min mesh	2010	Country -> 2.5min Grid

Prognostic equation for domestic and industrial water demand

AIM (MoE, Japan)

$$D = POP \times \left(i_{dom,t0} + s_{dom} \times (t - t_0) \right) \times 0.365$$

$$I = ELC \times \left(i_{ind,t0} + s_{ind} \times (t - t_0) \right)$$

[day year^{-1}m^3 L^{-1}] unit conversion factor

Disaggregate the regional future estimation by AIM using power generation ∝ GDP

D[m^{3}year^{-1}]: domestic water demand

POP[person]: population

I [m^{3}year^{-1}]: industrial water demand

ELC[MWh]: power generation

$i_{dom,to}$[L day^{-1}person^{-1}]: domestic water per capita at t0

t_o[yr]: reference year

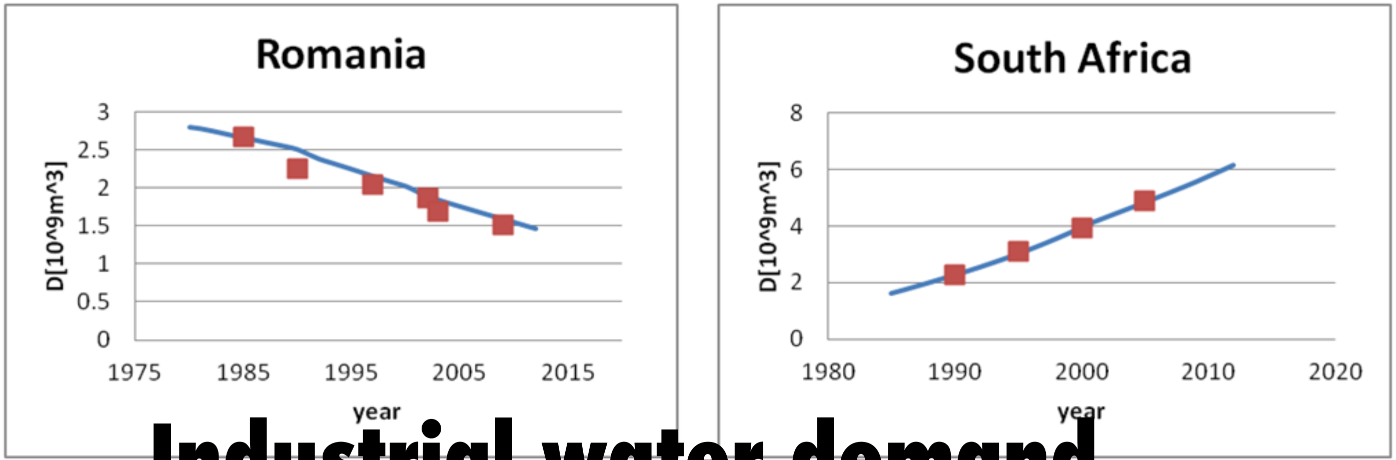
$i_{ind,to}$[m^3 yr^{-1}MWh^{-1}]: industrial water per power generation at t0

t[yr]: target year

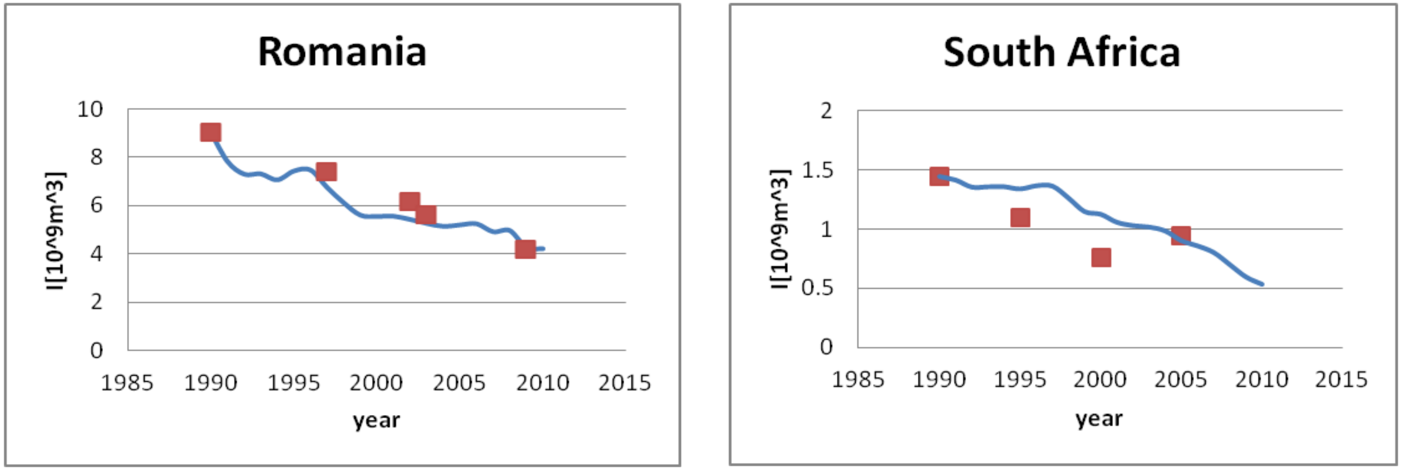
s_{dom}[L day^{-1}person^{-1}yr^{-1}]: change rate of domestic water per capita

s_{ind}[m^3 $^{-1}$person^{-1}yr^{-2}]: change rate of industrial water per power generation

Domestic water demand reproduction



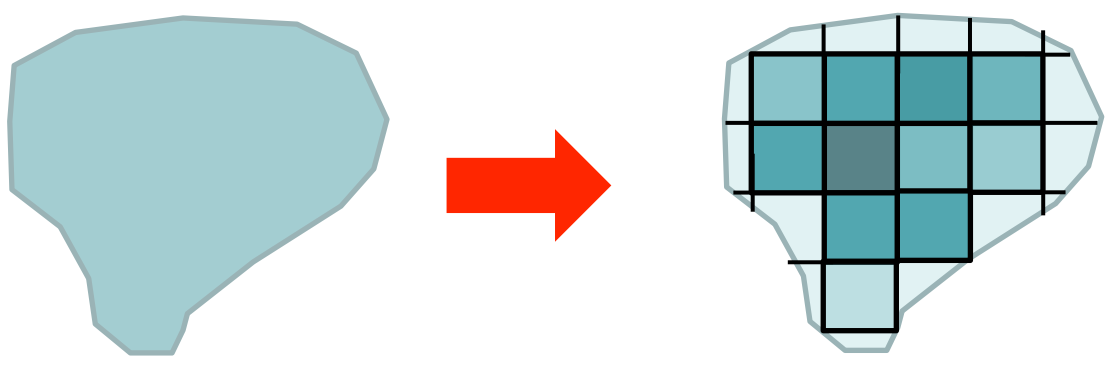
Industrial water demand reproduction



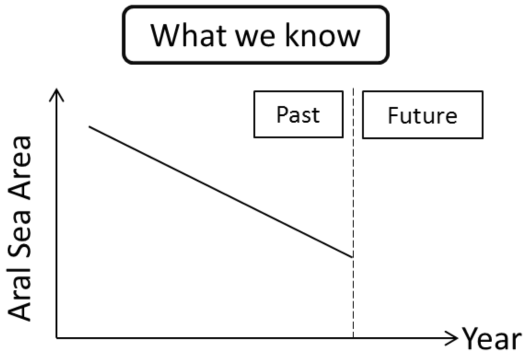
Disaggregation to each grid

$$\text{Water demand for each mesh} = \text{Water demand for each country} \times \frac{\text{Population for each mesh}}{\text{Population for country}}$$

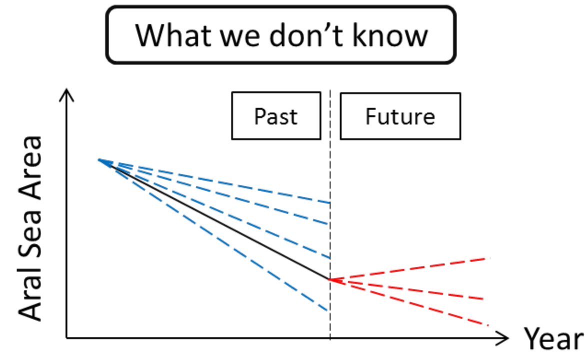
GPW
(Gridded Population of the World)



Scenario Analysis



Only **real situation** in the **past**



Virtual situation or future projection

For decision making, impact of plans must be assumed. ⇨ Virtual situation is difficult to be estimated...

In this study

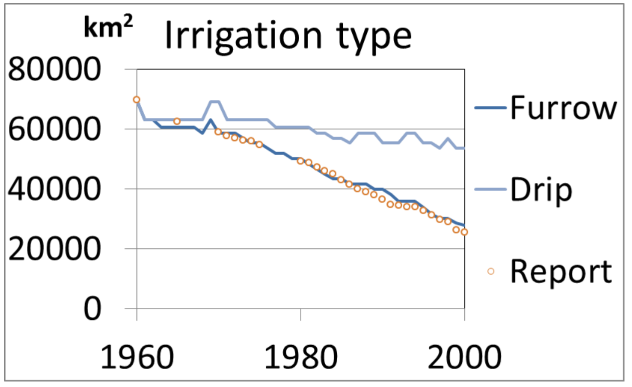
Virtual water balance in each scenario is quantitatively estimated by physical approach.

Scenario

Irrigation type	Drip irrigation			Furrow irrigation	
Water conveyance efficiency	40%	45%	50%	55%	60%
Irrigated area	0%	25%	50%	75%	100%

SCENARIO ANALYSIS

Irrigation type

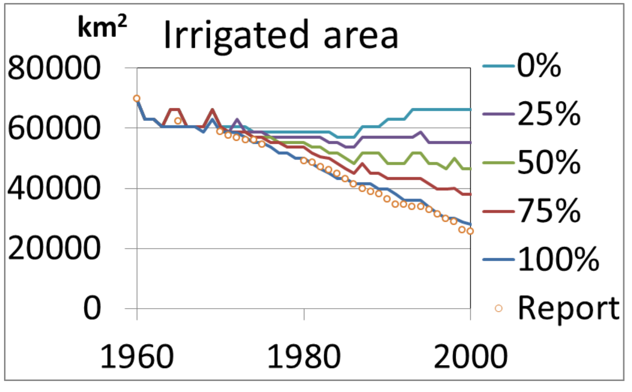


Drip irrigation scenario

⇒ 16Gt can be annually saved

Aral Sea would be 1976's level

Irrigated area



0% ⇒ 23Gt water can be annually saved
Aral Sea would be 1960's level.

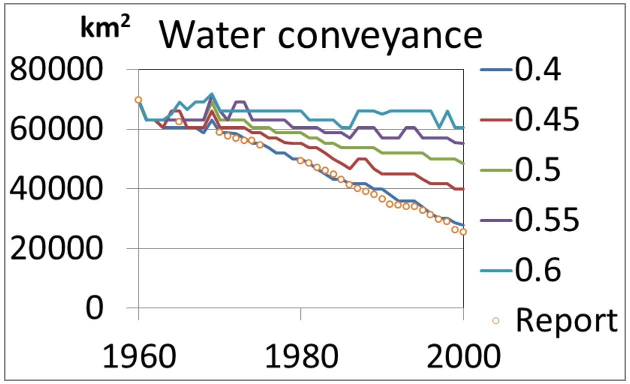
25% ⇒ 17Gt water can be annually saved
Aral Sea would be 1974's level.

50% ⇒ 10Gt water can be annually saved
Aral Sea would be 1982's level.

75% ⇒ 4Gt water can be annually saved
Aral Sea would be 1991's level.

Scenario Analysis

Water conveyance efficiency



0.45 (5% improvement)
⇒ 6Gt water can be annually saved
Aral Sea would be 1986's level.

0.50 (10% improvement)
⇒ 12Gt water can be annually saved
Aral Sea would be 1980's level.

0.55 (15% improvement)
⇒ 18Gt water can be annually saved.
Aral Sea would be 1974's level.

0.60 (20% improvement)
⇒ 22Gt water can be annually saved
Aral Sea would be 1967's level.

- Quantitative scenario analysis was enabled by physical model.
- To Make a plan for sustainable development, these information will be important.