Projection of the Impact of Climate Change on the Surface Energy and Water Balance in the Seyhan River Basin Turkey

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1. Introduction

In this study, estimation of the surface energy and water balance components and related hydrological variables of the Seyhan River basin Turkey is attempted through the off-line simulation of the land surface model forced by the product of the RCM (Regional Climate Model) for both present and future (warm-up) condition. Although the final goal of ICCAP is to assess the impact of climate change on agricultural production system including human reaction (farm management, cropping patterns, etc.), the future conditions or scenario about human reaction are not available so far. By the way, as a first step, the projection of the climate change impact on the regional hydrological cycle is attempted to start the discussion on the vulnerability of agricultural production system and to see the performance and usefulness of the product of RCM.

2. Basin Characteristics

Since planned target resolution of the hydrological model is 1km, **Gtopo30** is selected as basic topographic data. **HYDRO1k** (http://edcdaac.usgs.gov/ gtopo30/hydro/) is also utilized to characterize the location of the boundary and river channel. By analyzing the topographic data together with HYDRO1k, physical boundary of the Seyhan River Basin was defined. Once the basin boundary is defined, other basin characteristics can be extracted from the global data resources and local information.

Several kinds of landuse/landcover datasets are available from global satellite products (GLC2000, ECOCLIMAP, GLCC, etc.). Considering currently available landscape information (photo images from field survey), **GLCC-v2** (http://edcdaac.usgs.gov/glcc/), the Global Land Cover Chacteristics version 2.0, is thought to express well the condition of target basin and is selected as basic landcover data. By the way, irrigated cropland and forest areas in the original dataset (**Fig. 2(a)**) are clearly underestimated and the dataset needs to be modified (see next section).

A global digital soil map (from FAO), which has 5 minutes resolution, is utilized to run the land surface model. According to this information, three major soil categories of the Seyhan River Basin are clay loam (53.55%), light clay (42.32%), and heavy clay (4.00%).

3. Improvement of Landcover Dataset by NDVI Analysis

Satellite derived vegetation indices such as NDVI (Normarized Difference Vegetation Index), especially its time series, is very useful and powerful for describing the actual land-surface status[1)]. Here, NDVI is a common index to express the activity of vegetation. It utilizes the difference of the spectral reflectance at Red band and NIR (Near Infrared) band.

$$NDVI = (NIR - Red)/(NIR + Red)$$

Although the analysis method of global landcover dataset is effective to depict the global mapping of vegetation, it does not necessarily effective to some specfic area. Seasonal cycle of NDVI (phenology) is utilized to further improve the orig-

Table 1 : List of GCP for 5 landcover conditions

landcover	location (longitude, latitude)
forest	(35.00,37.28) (35.83,37.48) (36.14,38.06) (35.90,37.77) (35.02,37.28)
grass	(36.16,38.08) (36.18,38.17) (36.23,38.24) (36.40,38.73) (36.44,38.27)
wheat	(35.64,37.24) (35.58,37.19) (35.59,37.28) (35.17,37.06) (35.09,37.17)
1st-maize	(35.46,36.94) (35.38,36.93) (35.00,36.90) (34.98,36.89) (35.12,36.91)
2nd-maize	(35.76,37.35) (35.75,37.33) (35.72,37.31)

inal dataset. SPOT VEGETATION Products (http://free.vgt.vito.be) were utilized for analysis. This is a 10-day composite dataset which has 1km resolution. The included cloud noises were removed by BISE[2] method. Furthermore, average seasonal cycle dataset was produced from the collected 6-years period (from 1999 to 2004). Based on the field survey in March 2004 and September 2005, several GCPs (ground control points) were obtained for each landcover (forest, grass, wheat, 1st-maize, 2nd-maize). The location (longitude and latitude) of these GCPs are listed in **Table 1**. Average annual time series of NDVI at these points are shown in **Fig. 1**.

As for grassland, NDVI increases in April and May and decreases in July, and active period is about only two month. As for wheat, phenology is clearly earlier than grassland, and active period is about four month. As for evergreen forest, NDVI keeps high value throughout summer time (from May to October). As for green line in the forest, NDVI value drops down because of snow. For the snow-free area, NDVI value keeps high value throughout year. As for maize, there are two types. 1st-maize has NDVI increase in June and decrease in August. While the phenology of 2nd-maize is about 40-day later than 1st-maize. Of course, there are many kind of crops in the low-land irrigated area. By the way, since the size of each field is usually smaller than the pixel size (1km), it is very difficult to distinguish the difference of each crops in irrigated farmland. Important thing is that the phenology of irrigated farmland is much different from natural vegetation, and irrigated area can be detected easily. The difference between natural vegetation or rain-fed farmland and irrigated farmland is important from the view point of water management. Until the detailed crop pattern information will be provided, all the irrigated cropland is assumed to be 1st-maize or 2nd maize.

Based on these different phenological characteristics, forest, wheat, and maize (1st or 2nd) are detected and replaced in the new landcover dataset. As for the remaining pixels, original vegetation class is allocated. Denoting the NDVI value at i-th period as N_i (January 1st is N_1, December 21st is N_{36}), maximum and minimum NDVI as N_{max}, N_{min}, annual average and summertime average NDVI as N_{ave}, N_{sum}, the following conditions are used to extract the landcover.

forest (with snow)
$N_{min} < 0.2 \quad \text{and} \quad N_{sum} > 0.4$

forest
$N_{max} - N_{min} < 0.2 \quad \text{and} \quad N_{ave} > 0.4$

$N_{max} - N_{min} > 0.3 \quad \text{and}$
wheat
$N_4 < N_5 < N_6 \quad \text{and} \quad N_{13} > N_{14} > N_{15}$

1st-maize
$N_{16} < N_{17} < N_{18} \quad \text{and} \quad N_{22} > N_{23} > N_{24}$

2nd-maize
$N_{20} < N_{21} < N_{22} \quad \text{and} \quad N_{26} > N_{27} > N_{28}$

Fig. 2 shows the landcover condition for the target basin. Left-side panel is for the original dataset, and right-side panel is for the produced dataset. Comparing from original dataset, irrigated cropland area and evergreen forest area become larger in the new dataset, and the resulting spatial distribution is thought to be reasonable. According to this new information, five major landcover conditions of the Seyhan River Basin are grassland (40.06%), Crop/natural mosaic (21.27%), evergreen needleleaf forest (15.06%), dry cropland (8.72%), and irrigated cropland (6.69%).

4. Off-line Simulation Forced by RCM 8.3KM Product

4.1 SiBUC and irrigation scheme

SiBUC (Simple Biosphere including Urban Canopy)[3] land surface scheme was designed to treat the landuse condition (natural vegetation, cropland, urban area, water body) in detail. Especially irrigation scheme for the various kinds of cropland is implemented[4]. Basic concept of the irrigation scheme is to maintain the soil moisture within appropriate ranges which are defined for each growing stage of each crop type. The irrigation rules for cropland are based on at least four parameters; seeding (planting) date, harvesting date, the periods of each growing stage, and lower limit of soil wetness in each growing stage. As a default parameter, **Table 2** is prepared from agricultural manual in China. It represents the water requirement for four crops; spring wheat, winter wheat, maize, and soybean. Basically, growing stage is divided into five stages, and the period of each stage is represented by percentage of total growing period. According to the standard crop calendar information, irrigation periods for 1st-maize (from 25th May to 4th Aug) and 2nd-maize (from 4th Jul to 13th Sep) are utilized to activate the irrigation scheme.

Table 2 : Period of each growing stage and lower limit of soil wetness (unit: %)

crop	stage	1	2	3	4	5
spring wheat	period	23	14	14	14	35
	wetness	70	60	80	80	55
winter wheat	period	26	20	22	13	19
	wetness	70	70	80	80	55
maize	period	8	48	6	14	24
	wetness	75	65	70	75	65
soy bean	period	4	25	16	28	27
	wetness	75	65	65	70	65

4.2 Experimental design

The product of RCM (8.3km product) is utilized as forcing of land suface model. Seven meteorological components (precipitation, downward short-wave and long-wave radiation, wind speed, air temperature, specific humidity, pressure) are available in hourly time interval. Model domain of RCM covers the whole Seyhan River basin, and 2.75 degree × 2.75 degree area (E34.25-37.0, N36.5-N39.25) is selected as simulation domain for the land surface model. This area is divided by each 5 min (about 10km) grid boxes (33 × 33 grids). SiBUC uses mosaic approach to incorporate all kind of land-use. **Fig. 3** shows the fraction of four major landcover conditions in this region.

The simulation period is from 1994 to 2003 for the present climate condition. The amount of precipitation during this period is normal. Also, future climate condition (2070's) is produced by so called 'pseud warm-up' method. In this method, boundary condition for RCM is assumed by a linear coupling of the re-analysis data (observation) and the trend component of the global warming estimated by GCM (A2 scenario). In this way, pseud warm-up utilizes the synoptic scale variability of the current condition (observation). Since the period is only ten years, the projected future climate condition does not necessarily mean the 'average' future condition. Considering that the original present condition is situated in 'normal' condition, the provided future condition is also regarded to be normal.

5. Results and Discussions

5.1 Water balance of present and warm-up condition

Annual total (10-year average) of water balance components for the present condition are shown in **Fig. 4**. As for the Seyhan delta (irrigated area), annual evaporation is about 600mm. Among them, about 200mm of irrigation water must be supplied to keep the soil wetness in the growing season in hot dry summer. The difference of annual water balance components between present and warm-up runs are shown in **Fig. 5**.

In the warm-up run, annual precipitation is projected to decrease, and evaporation decreases as well. Since the vegetation parameters (such as LAI) and farming calendar (such as irrigation period) are the same in both two simulations, irrigation water requirement is projected to increase by the higher evaporation demand in the growing season.

As a basin average, annual water balance components for present, warm-up, and differene (W-P) are summarized in **Table 3**. Precipitation is projected to decrease about 140mm, while evapotranspiration decreases about 50mm. Considering the amount of present water balance, these impacts are thought to be significantly large.

Table 3 : Basin average annual water balance components

(unit:mm)	Prec	Evap	Runoff	Irrig
Present	690.4	429.6	280.7	7.7
Warm-up	551.8	377.9	195.6	10.6
diff(W-P)	-138.6	-51.7	-85.1	+2.9

5.2 Seasonal cycle of energy and water balance at each landcover

To see the impacts of climate change on snow, model outputs are aggregated according to altitude band. **Fig. 6** shows the time series of snow water equivalent (SWE) for middle (1000-2000m) and higher (over 2000m) elevation. For both elevation bands, maximum SWE will significantly decrease and all snow will melt by the end of April in the warm-up simulation. This will bring another difficulty in the water management.

To see the typical energy and water balance components and their impacts from climate change for each landcover, model outputs within the target basin are aggregated according to the dominant landcover condition (dominant landcover is larger than 0.8). **Fig. 7** shows the time series of energy balance components and accumulated water balance components at different landcover (grassland, forest, dry cropland, irrigated crop). In this figure, lines are for present run and dots are for warm-up run.

As for energy balance, only the irrigated crop has large latent heat during summer season. Also summer-time latent heat at irrigated crop becomes much larger in the warm-up run. In the dry cropland, since the soil wetness becomes smaller (not shown), latent heat reduces (sensible heat dominates) from June to September in the warm-up run.

According to **Fig. 7 (b)**, annual total irrigation is about 400mm for present run and 500mm for warm-up run. While annual total precipitation is about 750mm for present run and 500mm for warm-up run. Comparing from precipitation (main source of natural water balance), we can see that how large the irrigation makes up in the water balance.

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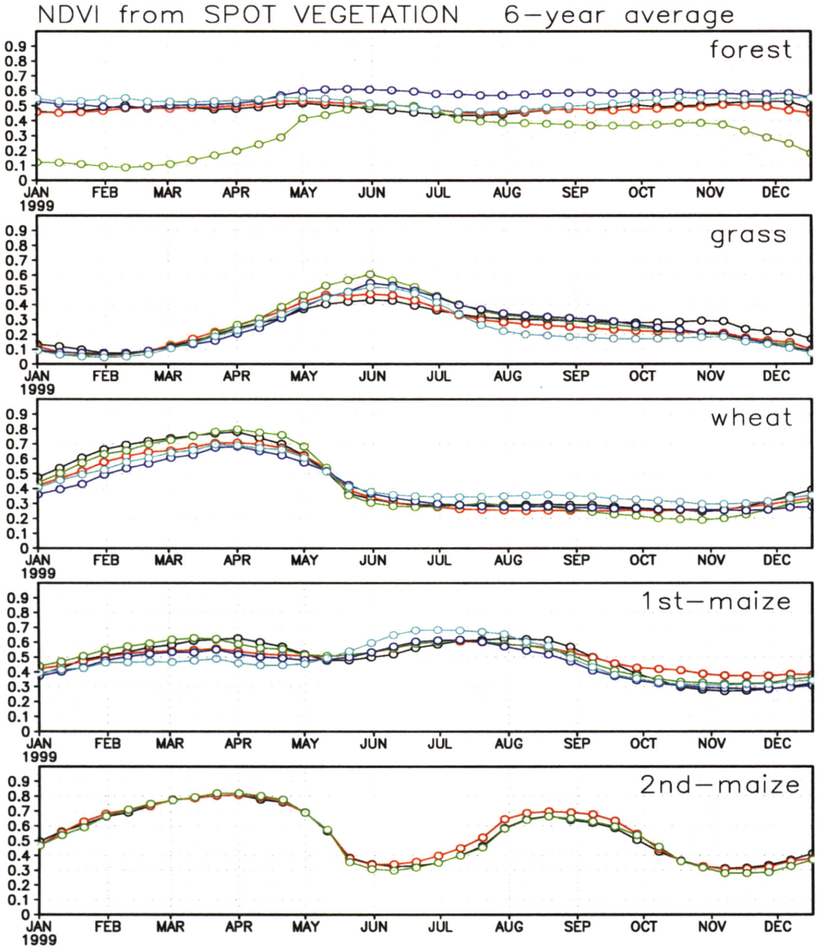
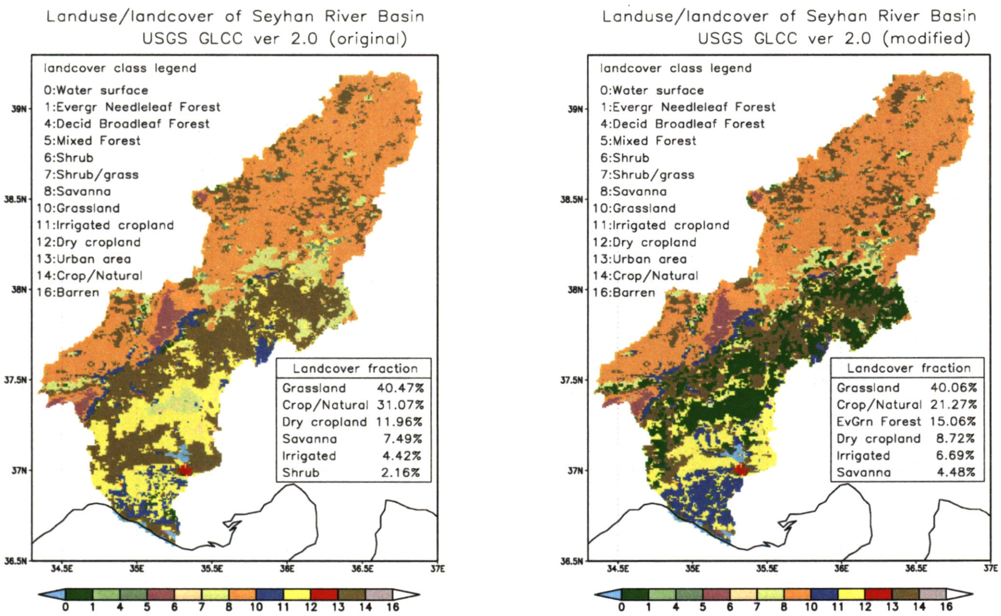


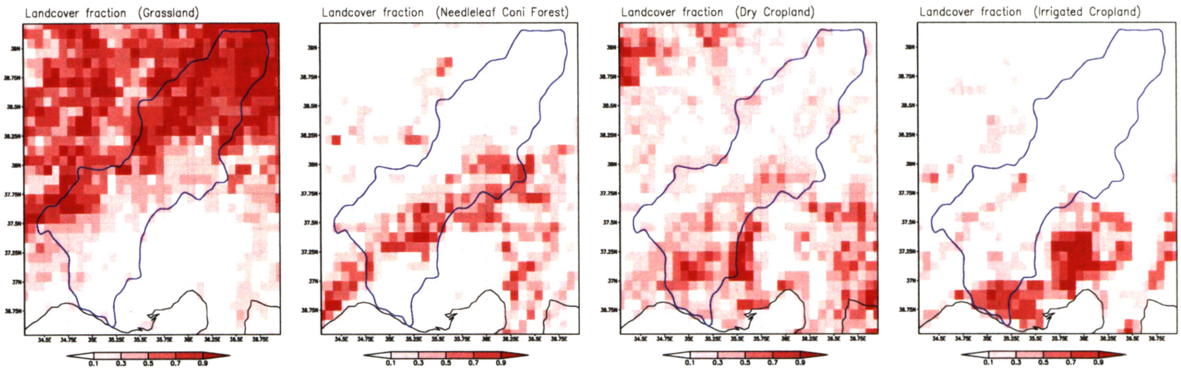
Fig. 1 : Average annual time series of NDVI at different landcover conditions. Several lines in one panel correspond to each GCP in Table1.



(a) Original

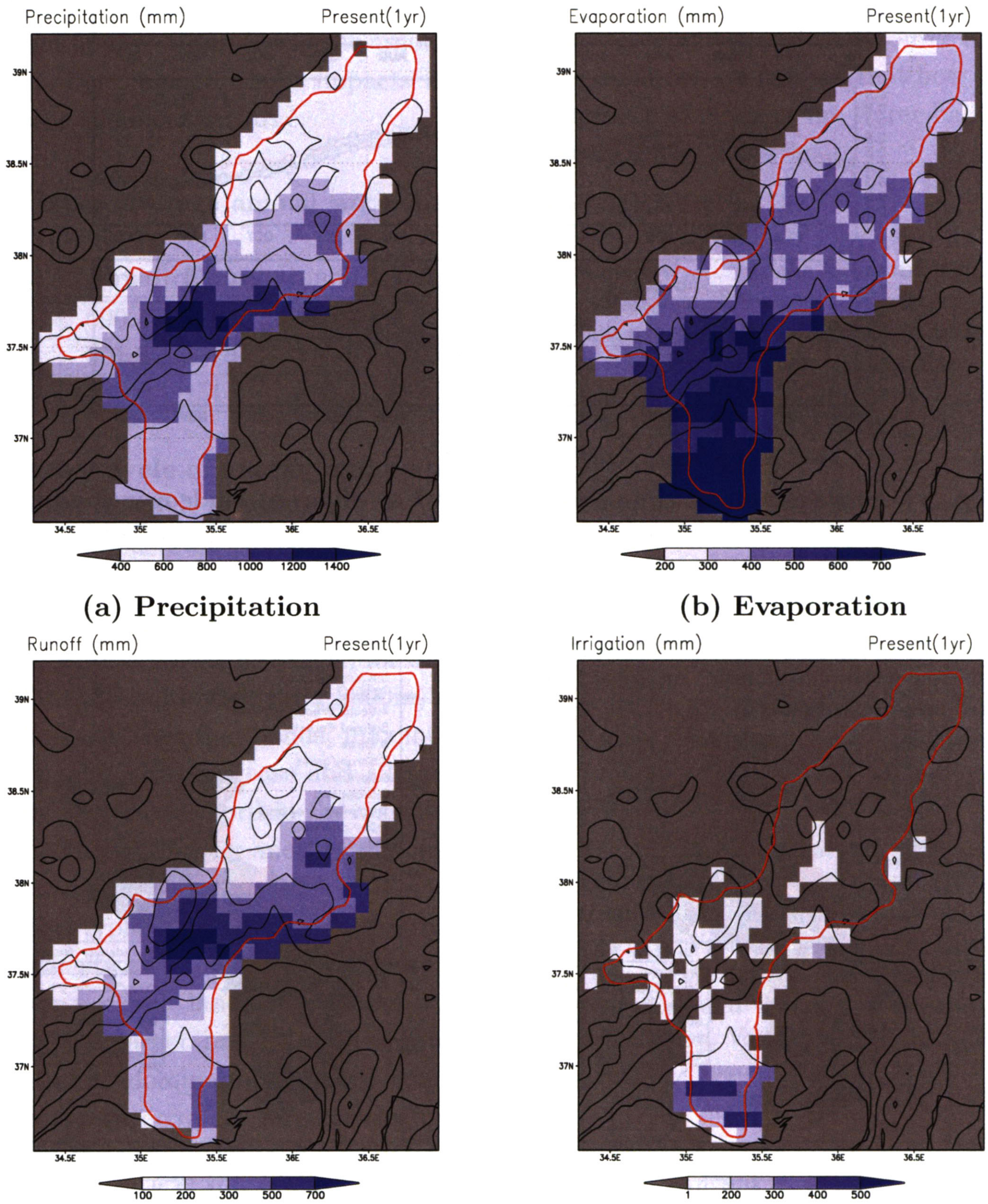
(b) Modified

Fig. 2 : Original and modified landcover information of the Seyhan River Basin



(a) Grassland (b) Evergreen forest (c) Dry cropland (d) Irrigated cropland

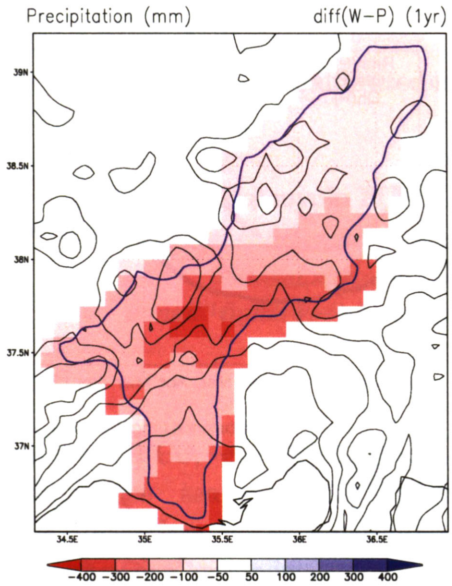
Fig. 3 : Landcover fraction of each grid (5 min resolution)



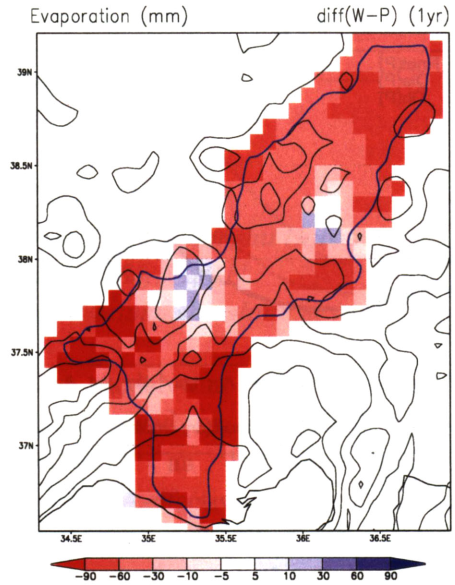
(a) Precipitation (b) Evaporation

(c) Runoff (d) Irrigation

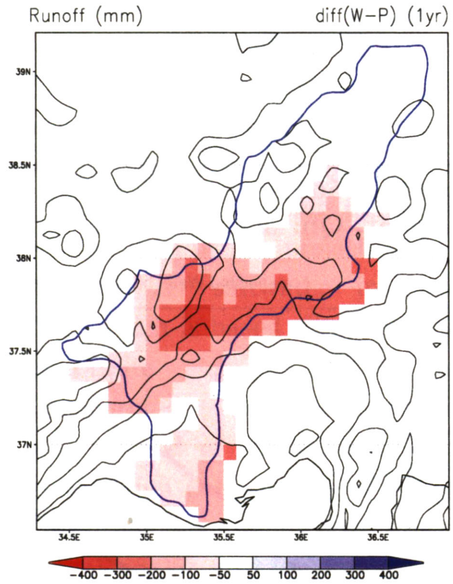
Fig. 4 : Annual water balance components of the present run



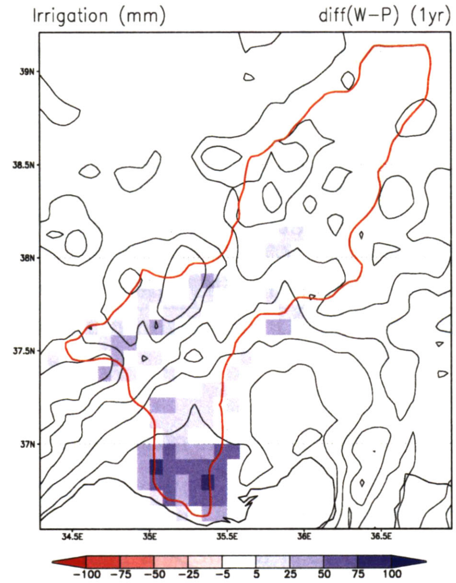
(a) Precipitation



(b) Evaporation

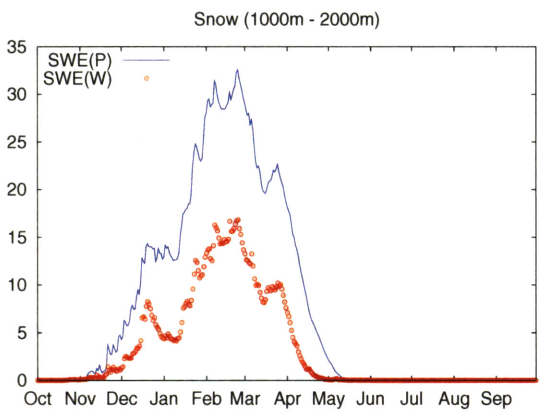


(c) Runoff

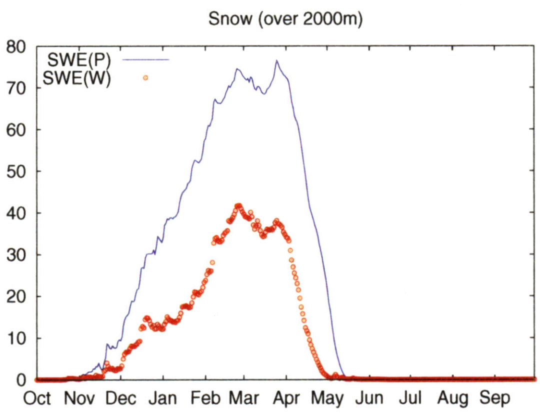


(d) Irrigation

Fig. 5 : Difference (Future - Present) of annual water balance components

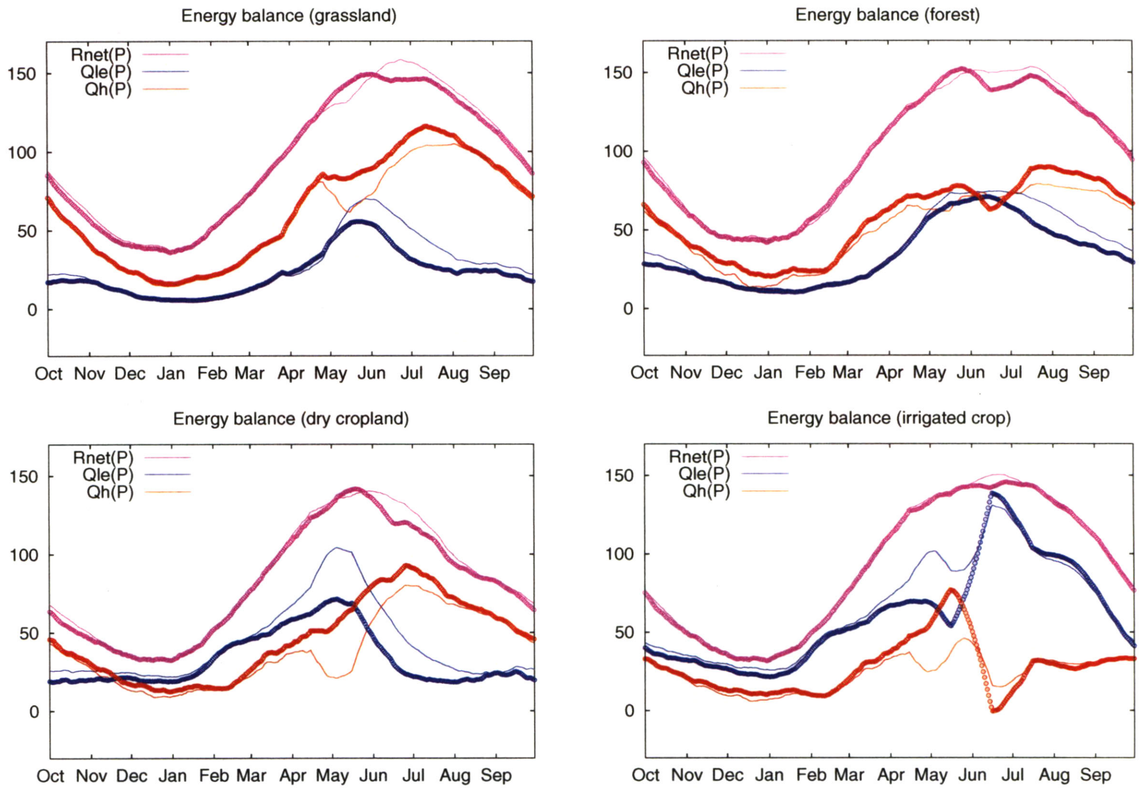


(a) 1000m - 2000m

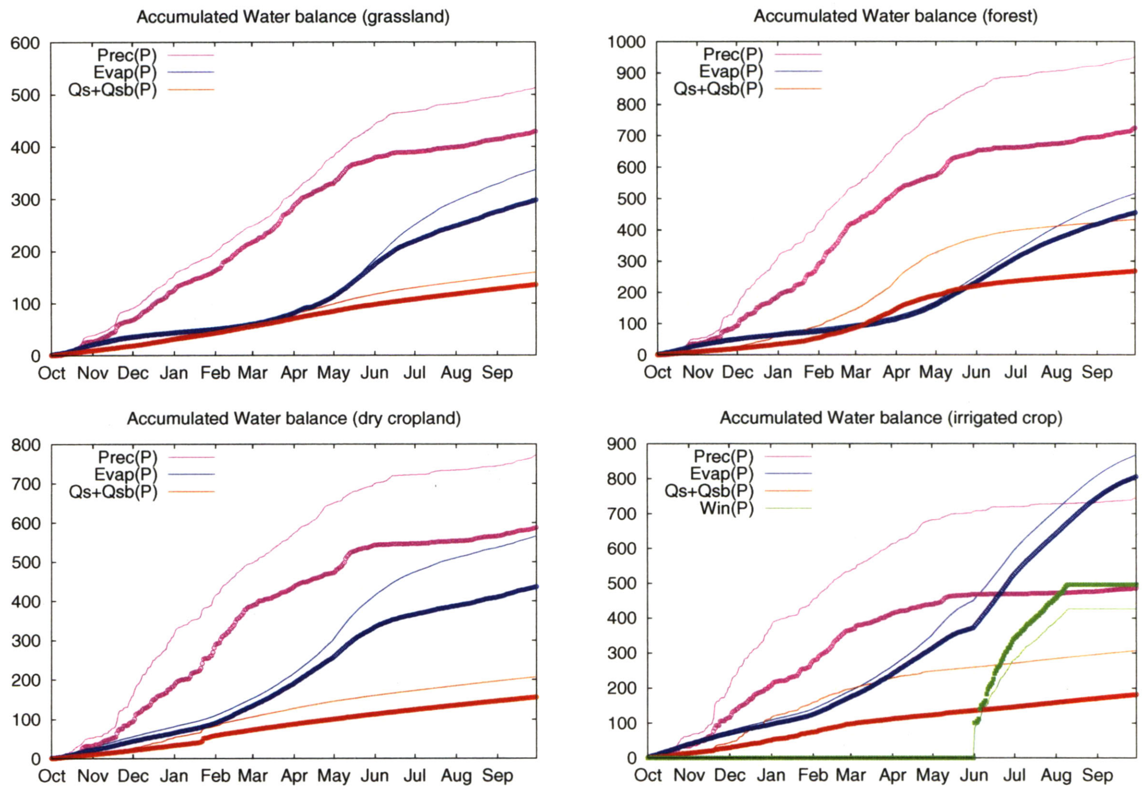


(b) over 2000m

Fig. 6 : Snow water equivalent (daily)



(a) Surface energy balance components (15days running mean)
Rnet: net radiation, Qle: latent heat, Qh: sensible heat



(b) Accumulated water balance components (daily)
Prec: precipitation, Evap: evaporation, Qs+Qsb: runoff, Win: irrigation

Fig. 7 : Comparison of the present and warm-up run at four different landcover condition (lines: present run, dots: warm-up run)