H08 Manual
User's Edition

Supplement 3: Regional Application
- Case Study of the Korean Peninsula
for H08 Version 2018

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Version information

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November 28, 2023	Manual Ver. 20231128 released. Source Code started to be available on GitHub (https://github.com/h08model/H08).

Contents

Chapter 1
Introduction

Understand what is described in this manual, and what is not.

General introduction

This manual explains how to setup H08 for a specific geographical domain. To make explanation concrete, it takes the Korean Peninsula as an example of the study domain (see the cover figure of this manual).

If you follow the instructions in this manual, you will be successfully setup the H08 model for any study domain at any spatial resolution. Please note that to avoid overlaps with the global manual ("H08 Manual User's Edition Second Edition for H08 ver 2018", Hanasaki, 2019), this manual basically includes only the procedures of running H08 without detailed explanations of rules, theories, and backgrounds. Readers are strongly recommended to complete the global manual beforehand. Additionally, the authors recommend the readers to exactly follow this manual without modifying anything for the first time. H08 is carefully designed to provide maximum freedom to the experts. Saying in different way, H08 offers minimum usability to the beginners. Even tiny errors in settings may stop or collapse the simulations. First, please make sure that all the procedures shown in this manual are reproduced on your system. Then, please change the settings one by one toward your research objective.

Installation

If you have completed the global manual or completed H08 global runs, you can skip this part.

1. Set adm/Mkinclude file
2. Change working directory to ${DIRH08} and execute install.sh to install H08.
   When you run install.sh, warnings will appear. Just ignore them and proceed to the next step.

Chapter 2
Preparing Map Data

Following the procedures, you will prepare geographical map data for H08 simulation in Korea.

2.1 Creating H08 basic spatial information

1. Change directory to ${DIRH08}/map/pre and execute prep_basmap.sh with the default (global) setting. This results in creating the base maps of global domain.
2. Execute prep_basmap.sh with the revised (regional) setting (see below). This results in creating the base map of a regional domain (i.e. Korea in this case). For example, map/dat/grd_ara_/grdara.ko5 must look like Figure 1.

   Seven parameters shown below determine the study domain of H08.The setting that were used in this manual is shown below. L is a number of total grid cells (84x132=11088 in this case). XY are numbers of horizontal and vertical grid cells. LONLAT consists of four real numbers indicating the longitude of western and eastern edge and the latitude of southern and northern edge (E124, E131, N33, N44 respectively in this case). L2X and L2Y are the files to set coordinate and generated when prep_basemap.sh is executed. SUF is the suffix of the input/output file. You can set any name, but it must be 4 characters in total, starting with a dot (.). (.ko5 stands for Korea at a spatial resolution of 5 arc-minutes). MAP is a label to identify the base map used (SNU is short for the Seoul National University who prepared the base map). You can name it freely for your domain, but you must use it consistently during simulation. Hereafter, this manual refers these settings as “the Regional Settings”. <u>Please do not change anything else unless specifically instructed.</u>

```
L=11088
XY=”84 132”
LONLAT=”124 131 33 44”
L2X=../../map/dat/l2x_l2y_/l2x.ko5.txt
L2Y=../../map/dat/l2x_l2y_/l2y.ko5.txt
SUF=.ko5
MAP=.SNU
```

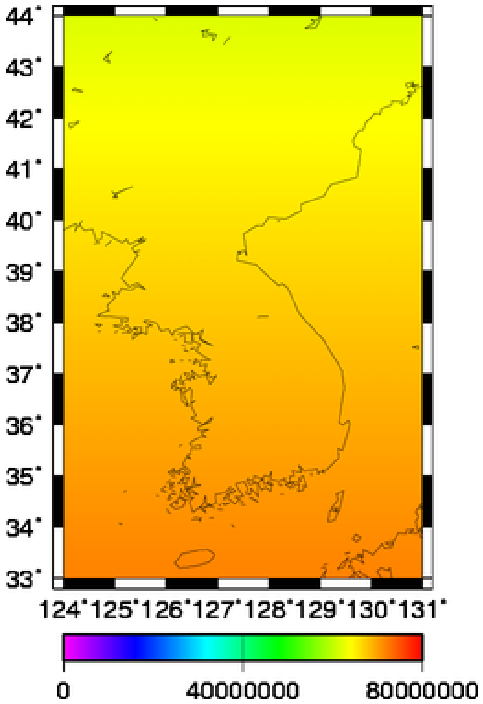

Figure 1. Grid Area (m^2)

2.2 Creating the map data required to use the land surface module

1. Download Data_Regional_2018.yyyymmdd.tar.gz from "Manuals" in the H08 website. All input data required to execute this manual is included in this file. Decompress Data_Regional_2018.yyyymmdd.tar.gz and put all data folders in the Data_Regional_2018.yyyymmdd directory (e.g. WFDEI/, AQUASTAT/, KOR/, etc) into ${DIRH08}/map/org.
2. Change working directory to ${DIRH08}/map/pre and execute prep_lnd_WFDEI.sh with the default setting. This results in creating the global land mask and land area files.
3. Check whether ${DIRH08}/map/dat/flw_dir_ exists in your system. If not, make a new empty directory.
4. Change directory to ${DIRH08}map/org/KOR. "flwdir.SNU.ko5.txt" contained in this file is basically a map of steepest slope. You can make this for your own study domain by using ArcGIS or some similar GIS software. Make sure that flwdir.txt has exactly the same number of records to "L".
5. Make sure that you are working at ${DIRH08}/map/pre. Execute prep_KOR.sh with regional settings. This results in creating the flow direction and land mask file of the study domain.

   Now the following two files are in your system.
   map/dat/lnd_msk_/lndmsk.SNU.ko5 (Figure 2)
   map/dat/flw_dir_/flwdir.SNU.ko5 (Figure 3)

7. Execute the command below (htmask). This results in creating the land area file (Figure 4).

```
%
maskko5 ../../map/dat/grd_ara_/grdara.ko5 ../../map/dat/lnd_m
sk_/lndmsk.SNU.ko5 eq 1 ../../map/dat/lnd_ara_/lndara.SNU.ko5
```

8. Change directory to map/org and make sure FAO2009_Slope/ is there. This is to prepare the slope data. These data were prepared using the slope data in the Harmonized World Soil Database v1.2 by the Food Agriculture Organization (FAO)
9. Edit and execute map/pre/prep_lnd_FAO2009_Slope_region.sh.
10. Prepare global geology data. Check that there is a folder OneGeology/ in map/org. These data were prepared using the World CGMW 1:50M Geological Units Onshore by One Geology.
11. Edit and execute map/pre/prep_lnd_OneGeology_region.sh.
12. Prepare global permafrost data. Check that there is NSIDC/ in map/org. These data were prepared using the permafrost data by the National Snow Ice Data Center.
13. Edit and execute map/pre/prep_lnd_NSIDC_mercator_region.sh
14. Prepare soil type data. Check that there is GSWP3_SoilType/ in map/org. These data were prepared using the Global Soil Wetness Project Phase 3.
15. Edit and execute map/pre/prep_lnd_GSWP3_Soiltype_region.sh. The legend of soil type ID will be added in map/dat/soi_typ_.

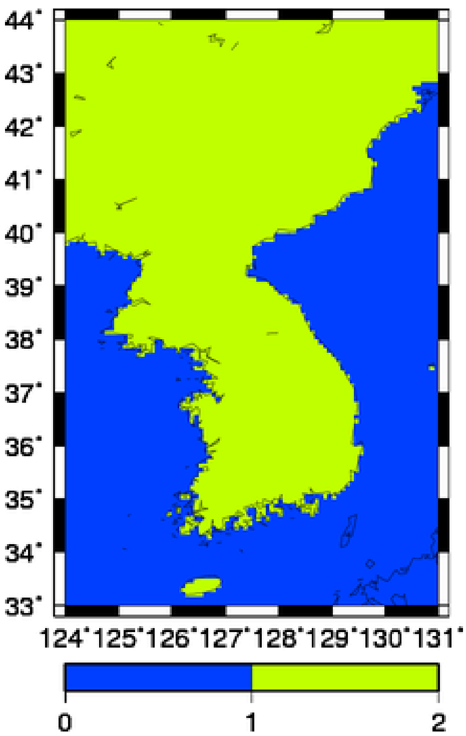

Figure 2. Land mask

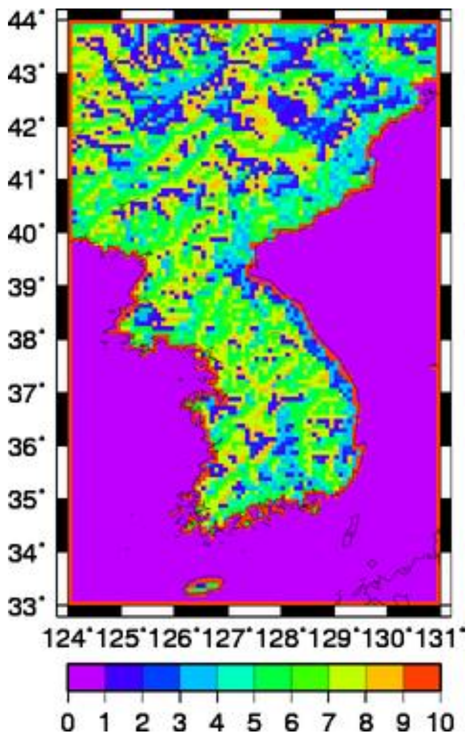

Figure 3. Flow direction

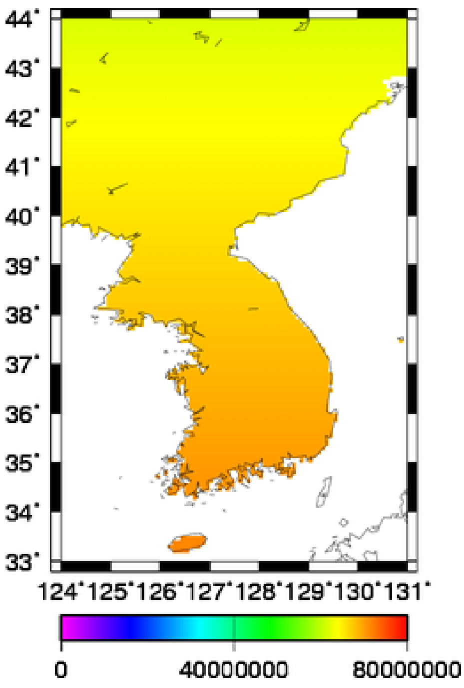

Figure 4. Land area (m^2)

2.3 Creating the map data required to use the river module

1. Change the working directory to ${DIRH08}/map/pre and execute prep_riv_WFDEI.sh with the default Setting. This results in creating global flow direction file.
2. Change the working directory to ${DIRH08}/map/bin and execute main_riv.sh with the Regional Setting. This results in creating the files including river flow sequence, L coordinate of next grid, grid distance, catchment area(Figure 5) and catchment number(Figure 6) which are indispensable in the river simulation.

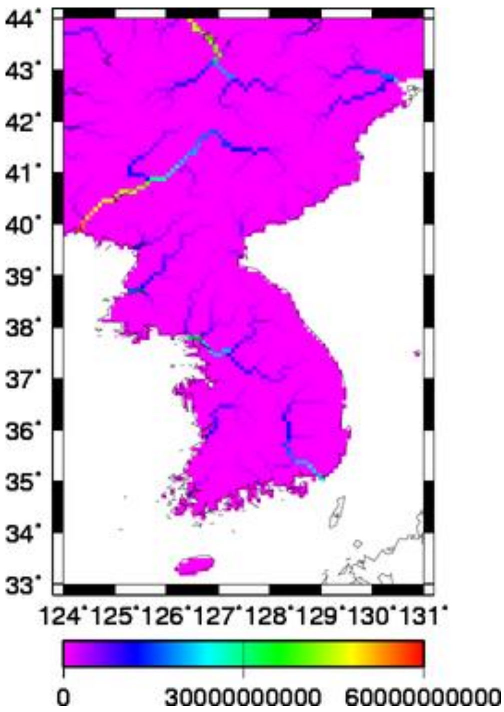

Figure 5. Catchment area (m^2)

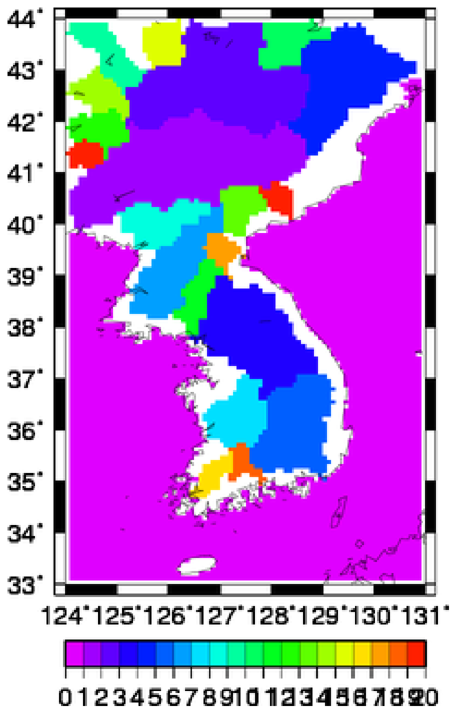

Figure 6. Catchment number (Top 20)

2.4 Creating the map data required to use the crop module

1. Check that there are C05/ and AQUASTAT/ in map/org.
2. Change the working directory to ${DIRH08}/map/pre. Execute prep_map_C05_nat.sh with the default setting. This results in creating the global national border information.
3. Execute prep_map_C05_pop.sh with the default setting. This results in creating the global population data.
4. Make sure that the directory ${DIRH08}/map/dat/nat_cod_ is in your system. If not, make a new directory, then download and locate C05_____20000000.txt there.
5. Check that there are R08/, M08/, S05/, and DS02/ in map/org.
6. Execute prep_crp_R08M08S05.sh with the default setting. This results in creating the cropland area, harvested area and irrigated area.
7. Execute prep_crp_DS02.sh with the default setting. This results in creating the irrigation area, cropping intensity and irrigation efficiency.

8. Execute prep_map_AQUASTAT.sh with changing the parameters L and SUF as shown below. This results in creating the agricultural, industrial, and domestic water withdrawal.

```
L=9331200
SUF=.gl5
```

9. Make sure whether htextract exists in ${DIRH08}/bin. H08_20130501 and earlier versions may not include htextract. If this is the case, follow the instruction shown in the "Bugs & Update" page of the H08 website (http://h08.nies.go.jp/h08/bugs_update.html).
10. Execute prep_map_region.sh with the Regional Setting. This results in creating the population, nation mask, agricultural, industrial, and domestic withdrawal and demand in Korea. Parameters "FCTIND" and "FCTDOM" in this script are the ratio of consumptive water use to industrial and domestic water withdrawal. If you know the exact numbers for your study domain, change them accordingly. If not, just keep these numbers which were taken from a global statistics.
(map/dat/pop_tot_/C05_a___20000000.ko5(Figure 7),
map/dat/nat_msk_/C05_____20000000.ko5(Figure 8),
map/dat/wit_agr_/AQUASTAT20000000.ko5(Figure 9),
map/dat/wit_ind_/AQUASTAT20000000.ko5(Figure 10),
map/dat/wit_dom_/AQUASTAT20000000.ko5(Figure 11),
map/dat/dem_ind_/AQUASTAT20000000.ko5(Figure 12),
map/dat/dem_dom_/AQUASTAT20000000.ko5(Figure 13))
11. Change directory to ${DIRH08}/map/pre and execute prep_crp_region.sh with the Regional Setting. This results in creating the crop information in Korea. Parameters "V_CRPINT" and "V_IRGEFF" in this script are the crop intensity and irrigation efficiency. The former means the number of crop harvests per year. In Asian countries, it typically exceeds 1. If you are unsure, just set to 1.0. The latter is the ratio of water applied to irrigated cropland to total irrigation withdrawal including return flow. The number is generally low for paddy-dominated Asian countries (0.3-0.5). If you are unsure, set to 0.6.
(map/dat/crp_int_/DS02____00000000.ko5, map/dat/irg_eff_/DS02____00000000.ko5,
map/dat/irg_ara_/S05_____20000000.ko5(Figure 14),
map/dat/crp_ara_/R08_____20000000.ko5(Figure 15))
12. Change directory to ${DIRH08}/map/bin and execute calc_crptyp.sh with the Regional Setting. This results in creating the crop type data (i.e. crop species or cultivar) of the first and second crop.
(map/out/crp_typ1/M08_____20000000.ko5, map/out/crp_typ2/M08_____20000000.ko5)
13. Execute ${DIRH08}/map/bin/calc_crpfrc.sh with the Regional Setting. This results in creating the areal fraction of four land use types, namely, double crop irrigated cropland, single crop irrigated cropland, rainfed cropland and other land use.
(map/out/crp_int1/S05_____0000.ko5, map/out/crp_int2/S05_____0000.ko5,
map/out/irg_arad/S05_____20000000.ko5, map/out/irg_aras/S05_____20000000.ko5,
map/out/rfd_ara_/S05_____20000000.ko5, map/out/non_ara_/S05_____20000000.ko5,
map/out/irg_frcd/S05_____20000000.ko5, map/out/irg_frcs/S05_____20000000.ko5,
map/out/rfd_frc_/S05_____20000000.ko5, map/out/non_frc_/S05_____20000000.ko5)

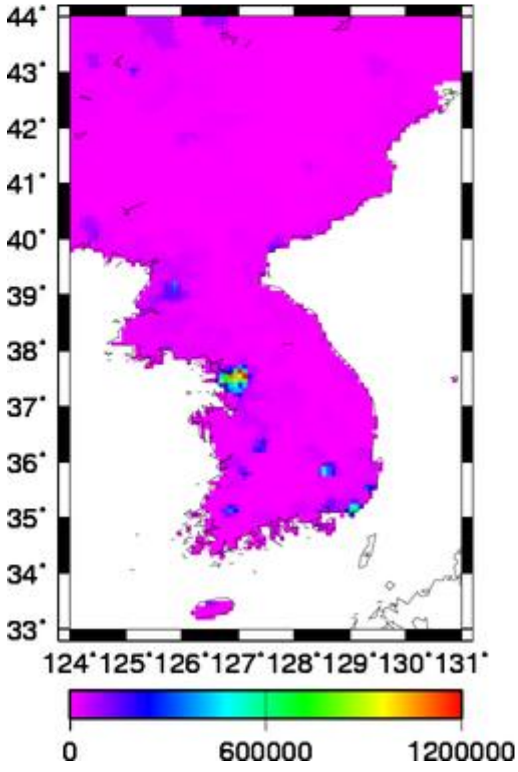

Figure 7. Population

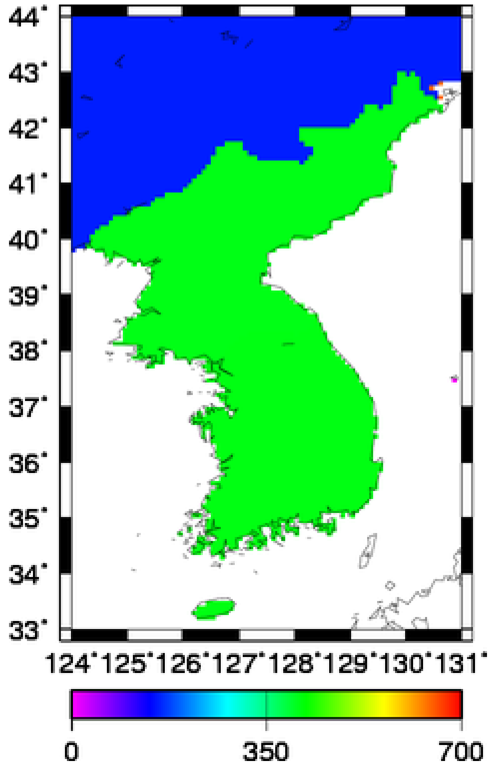

Figure 8. Nation mask

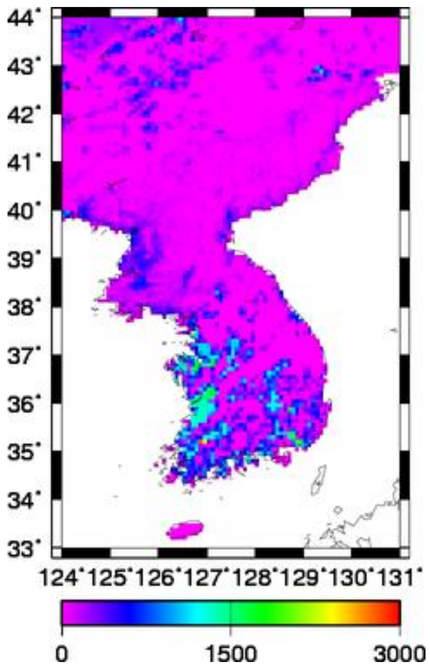

Fig 9. Agricultural water withdrawal

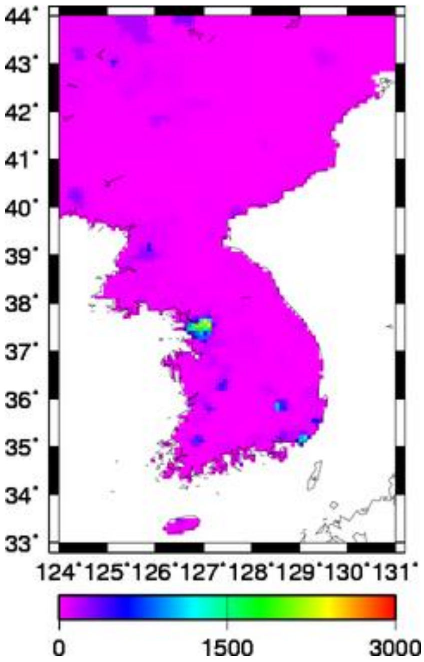

Fig 10. Industrial water withdrawal

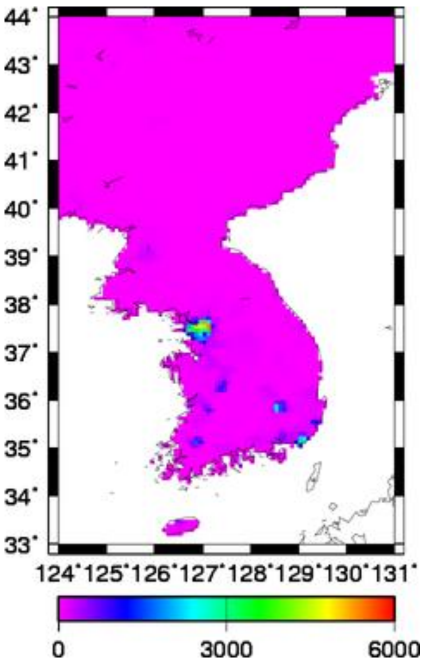

Fig 11. Domestic water withdrawal

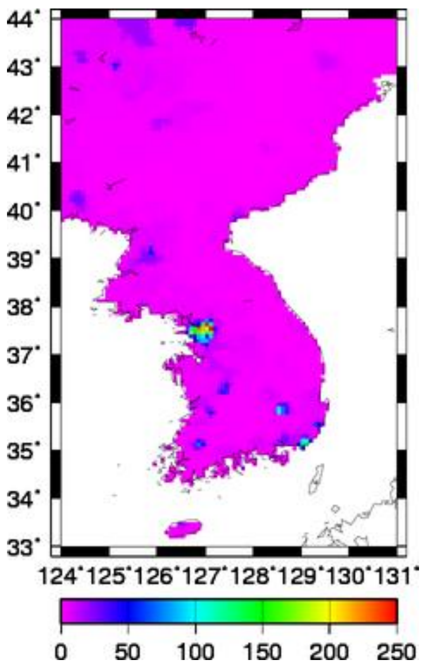

Figure 12. Industrial water demand

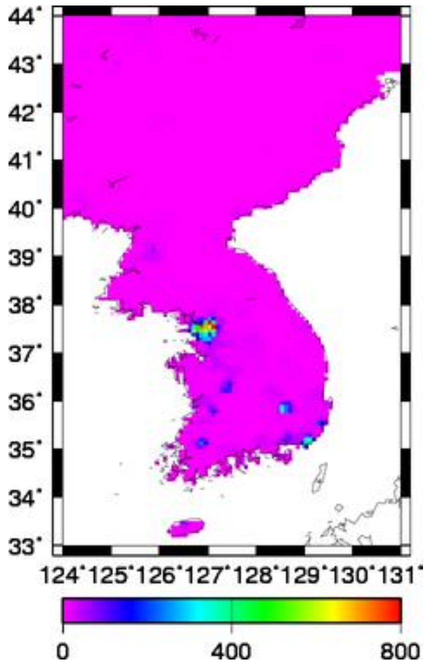

Figure 13. Domestic water demand

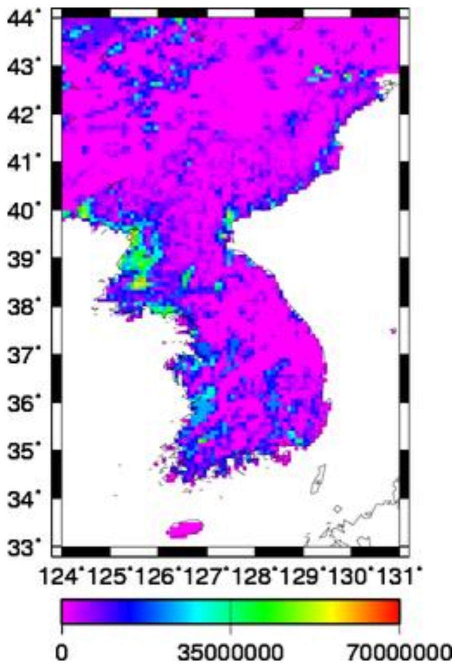

Figure 14. Irrigation area

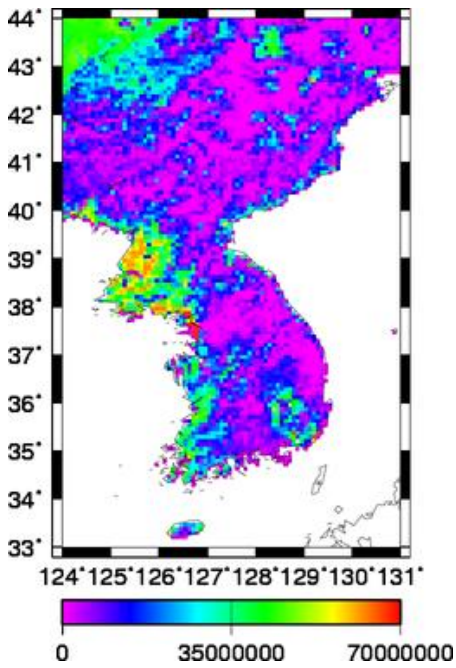

Figure 15. Cropping area

2.5 Creating the map data required to use the reservoir module

1. Check that there is SNU-GRanD/ in map/org.
2. Change directory to ${DIRH08}/map/pre. Execute prep_dam_GRanD.sh with the Regional Setting. This results in converting the dam list file into H08 2D format.

   Calculate average river discharge (Chapter 4) first, then proceed to 3.

3. Change directory to ${DIRH08}/map/bin. Execute main_dam.sh with the Regional Setting. Additionally, change the parameter for DAMDBG as shown below. This results in creating some files including auxiliary information on dams.
   (map/out/dam_d2s_/GRanD_L_00005943.ko5, 5946.ko5, 5949.ko5,
   map/out/dam_d2d_/GRanD_L_00005943.ko5, 5946.ko5, 5949.ko5,
   map/out/dam_up__/GRanD_L_.ko5, map/out/dam_upc_/GRanD_L_.ko5,
   map/out/dam_alc_/WFDELR__00005943.ko5, 5946.ko5, 5949.ko5,
   map/out/dam_dom_/WFDELR__.ko5)

   To set the mean monthly discharge, edit and execute riv/pst/calc_mean.sh with the regional settings. This calculates the mean discharge between ${YEARMIN} and ${YEARMAX}.

```
DAMDBG=5949
```

2.6 Creating the map data required to use the water withdrawal module

1. Change directory to ${DIRH08}/map/pre. Open prog_map_K14.f with a text editor and modify the setting of n0l in order to make the number consistent with that of L

```
parameter         (n0l=11088)
```

2. Open prog_map_cstlin.f with a text editor and modify the settings of n0l, x0l, y0l as same as prog_map_K14.f.

```
parameter         (n0l=11088)
parameter         (n0x=84)
parameter         (n0y=132)
```

3. Recompile these programs.

```
% make all
```

4. Check that there is GMIA5/ in map/org.
5. Edit and execute prep_map_GMIA5_region.sh with the regional settings. This creates water source-specific irrigated area information.
6. Edit and execute prep_map_GMIA5_aux_region.sh with the regional settings. This creates

auxiliary information on water source-specific irrigated area.

7. Check that there is IGRAC/ in map/org.
8. Execute prep_map_IGRAC.sh. This creates sector-specific groundwater abstraction information.
9. Edit and execute prep_map_frcgw_doll_region.sh with the regional settings. This creates the fraction of groundwater to total water demand.
10. Check that there is K14/ in map/org.
11. Edit and execute prep_map_lcan_region.sh with the regional settings. This creates global information on aqueducts, generating a global "implicit" aqueduct network.
12. Edit and execute prep_map_K14_region.sh with the regional settings. This creates a global map of "explicit" aqueducts.
13. Check that there is IIASA_SSP/ in map/org.
14. Edit and execute prep_map_IIASA_SSP_region.sh with regional settings. The GDP data of Shared Socioeconomic Pathways will be generated.
15. Check that there is MISC_Maps/ in map/org.
16. Edit and execute prep_map_cstlin_region.sh with the regional settings. This creates the global coast line data.
17. Finish section 5.1 before moving on to the next step.
18. Edit and execute prep_map_despot.sh with the regional setting. This results in generating utilizing seawater desalination.

2.7 Preparing meteorological data

1. Make sure the directory ${DIRH08}/met/org exists in your system. If not, make an empty directory.
2. Put the WFDEI global meteorological data into met/org (See the global manual for details).
3. Check that there is GSWP2_Albedo/ in map/org. The global monthly mean albedo data for 1986-1995 are in this file.
4. Move to map/pre. Edit and execute prep_lnd_GSWP2_Albedo.sh with the default setting.
5. Execute prep_iplmet_Albedo.sh with the regional setting.
   This results in interpolating the global 1 x 1 degree Albedo data into regional 5 x 5min.(map/dat/Albedo__/GSW2____00000100.ko5~00001200.ko5)
6. Execute prep_iplmet.sh. This results in interpolating the original global 0.5 x 0.5 degree meteorological data into regional 5 x 5min.
   (met/dat/LWdown__/wfde____19860000.ko5~19951231.ko5,
   met/dat/PSurf__/wfde____YYYYMMDD.ko5, met/dat/Qair____/wfde____
   YYYYMMDD.ko5, met/dat/Rainf__/wfde____ YYYYMMDD.ko5,
   met/dat/SWdown__/wfde____ YYYYMMDD.ko5, met/dat/Snowf___/wfde____
   YYYYMMDD.ko5, met/dat/Tair____/wfde____ YYYYMMDD.ko5,
   met/dat/Wind____/wfde____ YYYYMMDD.ko5)
7. Execute prep_mean.sh with the regional setting to calculate the mean meteorological variables between YEARMIN and YEARMAX.
8. Execute prep_Prcp.sh with the regional setting. This calculates the total precipitation (Prcp) by adding up rainfall (Rainf) and snowfall (Snowf).
9. Change to directory met/pst.

10. Execute calc_koppen.sh with regional setting. This outputs the Köppen-Geiger Climatic Zones into met/out/Koppen__.

Chapter 3
Land Surface Process Module

Following the procedures, you will be able to simulate the land surface process in Korea.

1. Change directory to ${DIRH08}/lnd/pre and execute prep.sh with the Regional Setting. This results in creating the files including land surface parameters and initial values of state variables.
2. Edit and execute prep_gamtau.sh with the Regional Settings. This results in generating the files for the runoff shape parameter γ (lnd/dat/gamma__) and the time constant τ (lnd/dat/tau_____), which reflect the Köppen-Geiger climatic zones (see Hanasaki et al. 2008a).
3. Edit and execute prep_gwr.sh with the Regional Settings. This results in generating the groundwater recharge parameters fr, ft, fa, fg,fp , and rgmax (lnd/dat/gwr_____; see Hanasaki et al. 2018)
4. Change directory to ${DIRH08}/lnd/bin. Open main.f with text editor, and modify the setting of n0l in order to make the number consistent with that of L.

```
parameter    (n0l=11088)
```

5. Compile the main program.

```
% make main
```

   This is just to change the setting of n0l and recompile main.f in lnd/bin instead of recompiling everything by “install.sh”. (Same for riv/bin, crp/bin, and cpl/bin)
6. Execute main.sh with the Regional Setting. The main program on the land surface process will be started.
7. When the simulation completed, change directory to ${DIRH08}/cpl/pst. Execute list_watbal.sh with the Regional Setting. This results in creating a summary of water balance of the simulation named ${DIRH08}/tab/wat_bal_/WFDELR__0000000.yyyy.txt. Check the “Water balance of land” section, and make sure that water balance is closed. For Example, Table 1 shows the imbalance is as small as 0.00km^3 yr^{-1}.

Table 1. The results of water balance of land (1979) [km ^{3} y $^{-1}$]

Item		Value
Precipitation	+	387.30
Evapotranspiration	-	235.98
Total runoff	-	150.93
Δ Soil moisture	-	0.00
Δ Snow water equivalent	-	0.00
Δ Ground water	-	0.39
Water balance of land surface	-	0.00

Chapter 4
River Module

In this chapter, you can calculate river discharge and river storage in Korea.

1. Change directory to ${DIRH08}/riv/pre and execute prep.sh with the Regional Setting. This results in creating the files including parameter and initial states.
2. Change directory to ${DIRH08}/riv/bin. Open main.f with text editor and modify the setting of n0l in order to make the number consistent with that of L.

```
n0l=11088
```

3. Compile the main program.

```
% make main
```

4. Make sure that your working directory is ${DIRH08}/riv/bin. Execute main.sh with the Regional Setting. The main program on the river routing process will be started. This results in creating the river discharge (Figure 16) and river storage (Figure 17) data.
5. When the simulation is completed, change directory to ${DIRH08}/cpl/pst. Execute list_watbal.sh with the Regional Setting. This results in creating ${DIRH08}/tab/wat_bal_/WFDELR__0000000.yyyy.txt. Check the "Water balance of river" section, and make sure that water balance is closed. For , Table 2 shows the imbalance is as small as 0.00km^3 yr^{-1}.
6. Return to section 2.5 and execute main_dam.sh

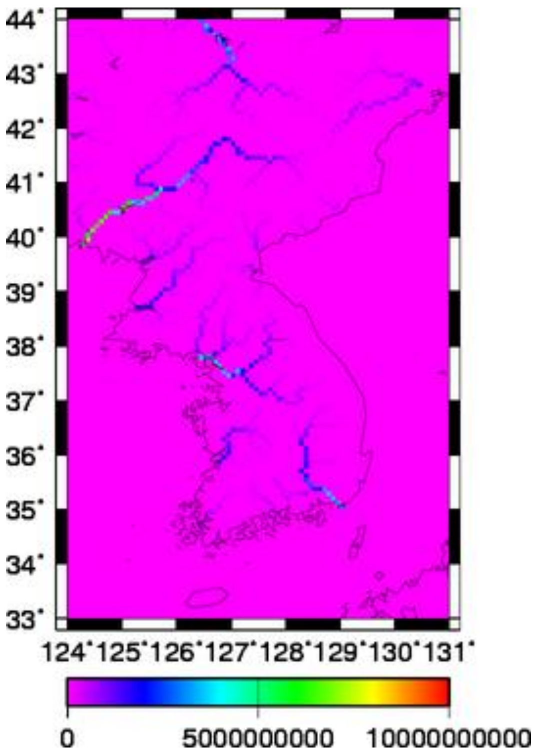

Figure 16. River storage (kg)

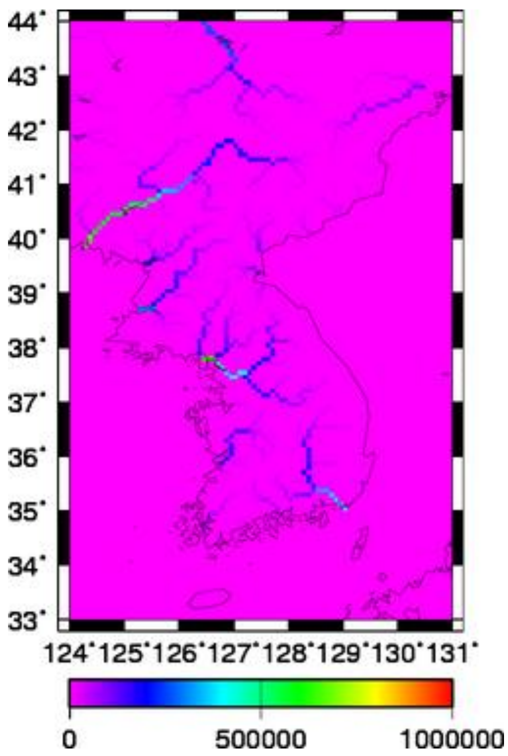

Figure 17. River discharge (kg s^{-1})

Table 2. The results of water balance of river (1979) [km ^{3} y $^{-1}$]

Item		Value
Total runoff	+	150.93
River discharge	-	150.93
Δ River storage	-	0.00
Water balance of river		0.00

Chapter 5
Crop Growth Module

Following the instructions, you will be able to simulate cropping calendar of your study domain.

1. Change directory to ${DIRH08}/crp/pre and edit prep.sh. This results in creating the initial value files (e.g. ${DIRH08}/crp/ini/uniform.0.0.ko5)
2. Go back to section 2.6 and execute prep_map_despot.sh
3. Make sure the directory ${DIRH08}/crp/org exists in your system. If not, make a new empty directory.
4. Move map/org/SWIM to ${DIRH08}/crp/org.
5. Change directory to ${DIRH08}/crp/bin and open main.f with text editor and modify the setting of n0l in order to make the number consistent with that of L.

```
n0lall=84*132
n0llnd=5793
```

6. Compile the main program.

```
% make main
```

7. Execute main.sh with the Regional Setting. The main program on the crop growth will be started. This results in simulating the cropping calendars for individual crops.
8. Change directory to ${DIRH08}/crp/pst and execute calc_crpcal.sh with the Regional Setting. This results in determining the cropping calendar of first crop.
9. Change directory to ${DIRH08}/crp/bin and execute main.sh with the Regional Setting. The main program on the crop growth will be started for seeking the possibility of the second crop. This results in creating the cropping calendar of second crop.

```
JOBS=2nd
```

10. Change directory to ${DIRH08}/crp/pst and execute draw_crpyld_map.sh with the Regional Setting. This results in drawing the figures of cropping calendar and estimated maximum potential crop yield in ${DIRH08}/crp/fig.
11. Look at the figures in ${DIRH08}/crp/fig and consider whether the results are feasible.
(${DIRH08}/crp/fig/yld_mai_/WFDE__C_00000000.png (Figure 18),
${DIRH08}/crp/fig/yld_whe_/WFDE__C_00000000.png (Figure 19),
${DIRH08}/crp/fig/yld_ric_/WFDE__C_00000000.png (Figure 20))

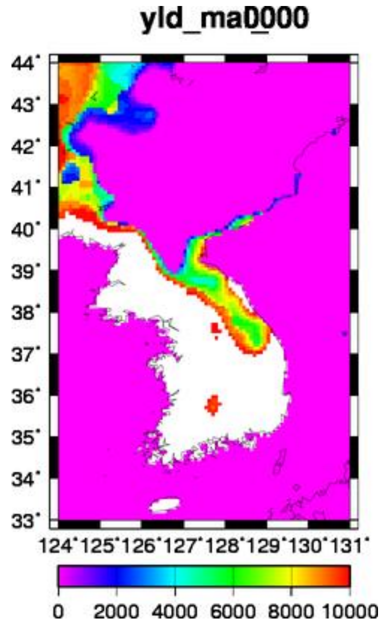

Figure 18. Yield of maize (kg ha^{-1})

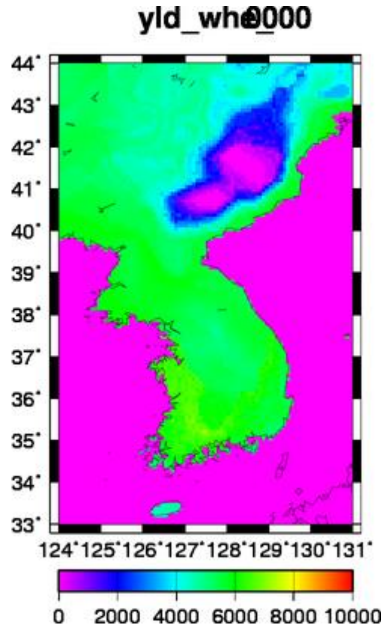

Figure 19. Yield of wheat (kg ha^{-1})

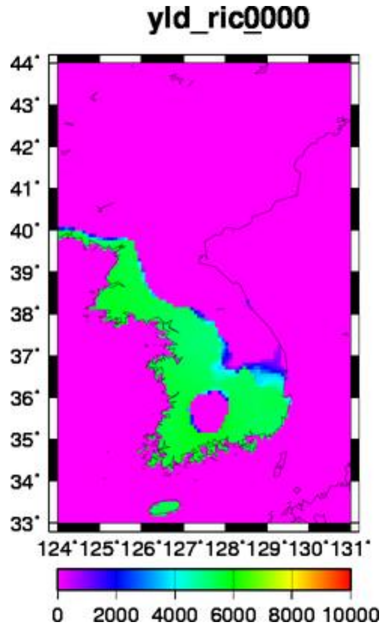

Figure 20. Yield of rice (kg ha^{-1})

Chapter 6
Reservoir Module

Following the procedures below, you will be able to setup the files for reservoir operation module.

1. Change directory to ${DIRH08}/riv/pst and execute calc_mean.sh with the Regional Setting. This results in calculating the monthly and annual mean river discharge.
2. Change directory to ${DIRH08}/riv/pst and execute calc_flddro.sh with the Regional Setting. This results in identifying the reservoir operating year which is another indispensable information for the reservoir operation module.

Chapter 7
Environmental Flow Module

Following the procedures below, you will be able to simulate the environmental flow requirement in Korea.

1. Change directory to ${DIRH08}/riv/pst and execute calc_envout.sh with the Regional Setting. This results in calculating the environmental flow.

2. Change directory to ${DIRH08}/cpl/pst and execute list_watbal.sh with the Regional Setting. Then check the "Environmental (flow)" section. Table 3 shows the estimation of environmental flow.

Table 3. The results of estimation of environmental flow (1979) [$km^3\ y^{-1}$]

Item	Value
Environmental flow	53.64

Chapter 8
Coupled Module

Following the procedures below, you will be able to run the coupled model in Korea. First, you will run the N_C_ experiment. This estimates agricultural water demand which is an important input of the H08. Then, you will run the N_C_ and LECD experiments. These estimate water availability and scarcity of the study domain.

8.1 N_C_ experiment

1. Change directory to ${DIRH08}/cpl/pre and execute prep.sh with the Regional Setting. This results in creating the reservoir storage information.
2. Change directory to ${DIRH08}/cpl/bin. Open main.f with text editor and modify the setting of n0l in order to make the number consistent with that of L.

```
n0l=11088
```

3. Compile the main program.

```
% make main
```

4. Change directory to ${DIRH08}/cpl/bin and execute main.sh with the Regional Setting. Make sure that the parameters are set as shown below. This results in calculating the potential agricultural water demand.

```
RUN=N_C_
LDBG=1 # any integer number not larger than n0l

DAMID_=NO
DAMPRP=NO
DAMCAP=NO
DAMMON1ST=NO
DAMALC=NO
DAMRIVOUTFIX=NO
DAMDEMAGRFIX=NO
MSRCAP=NO
MSEAFC=NO

OPTNNB=YES
```

Before execute Section 8.2 LECD experiment, please execute Section 2.5.

8.2 LECD experiment

1. Make sure that you have completed all the procedures shown in Section 2.5 (Creating the Map Data Required to Use the Reservoir Module). Change directory to ${DIRH08}/cpl/pst and execute calc_mean.sh with the Regional Setting. This results in calculating the annual mean value of agricultural demand.
(lnd/out/DemAgr__/WFDEN_C_00000000.ko5)
2. Change directory to ${DIRH08}/cpl/bin and execute main.sh with the Regional Setting. Additionally, set the parameters as shown below.

```
RUN=LECD
LDBG=1 # any integer number not larger than n0l

DAMID_=../../map/dat/dam_id__/GRanD_L_20000000${SUF}
DAMPRP=../../map/dat/dam_prp_/GRanD_L_20000000${SUF}
DAMCAP=../../map/dat/dam_cap_/GRanD_L_20000000${SUF}
DAMMON1ST=../../riv/out/fld2dro_/${PRJLR__}${RUNLR__}0000000
      0${SUF}
DAMALC=../../map/out/dam_alc_/${PRJLR__}${RUNLR__}${SUF}ID
DAMRIVOUTFIX=../../riv/out/riv_out_/${PRJLR__}${RUNLR__}0000
      0000${SUF}
DAMDEMAGRFIX=../../lnd/out/DemAgr__/${PRJN_C_}${RUNN_C_}0000
      0000${SUF}FX
MSRCAP=../../map/dat/dam_cap_/GRanD_L_20000000${SUF}
MSRAFC=../../map/dat/dam_cap_/GRanD_L_20000000${SUF}

OPTNNB=NO
```

3. Change directory to ${DIRH08}/cpl/pst and execute list_watbal.sh with the Regional Setting. This results in creating the water balance list named ${DIRH08}/tab/wat_bal_/WFDELR__0000000.yyyy.txt. Check the "Water balance of the coupled system" section, and make sure that water balance is closed. Table 4 shows that the water imbalance is as small as -0.00 km^3 yr^{-1}.

Table 4. Water balance of the coupled system[km^3 y^{-1}]

Item		Value
Precipitation	+	387.30
Evapotranspiration	-	235.98
River discharge	-	150.93
Δ Soil moisture	-	0
Δ Snow water equivalent	-	0
Δ Ground water	-	0.39
Δ River storage	-	0
Water balance of coupled module		0

Chapter 9
Climate Change Simulation

Following the procedures below, you will be able to analyze the impacts of climate change in Korea. Basically, you will re-run all the processes conducted so far with the future climatic conditions.

9.1 Data preparation

1. Open a web browser and visit the H08 Global Meteorological Data Server. http://h08.nies.go.jp/ddc (user: cmip5 password: CMIP5)
2. Click “Data Downloader” then click ”ISIMIP-FT”.
3. Set parameters as shown below and click “Download”. The historical and the future climate data will be prepared on the server.

Options	Settings
Dataset	MIROC-ESM-CHEM
Scenarios	Historical and rcp8.5
Temporal resolution	Daily
Variables	rlds, rsds, wind, ps, prsn, pr, rh, tas
Year	1979-1979 for historical, 2079-2079 for rcp8.5
Spatial domain	124, 131, 33, 44
Spatial resolution	User defined resolution (84, 132, Surface)
Meridional sequence	North to South
File type	Plain binary (little endian) with short name
Suffix	.ko5
Compress	Yes

4. When all of the requested data are shown on the screen, proceed to “Your Personal Site”. Do NOT download the files manually.
5. Change directory to ${DIRH08}/met/pre and edit prep_ISIMIPFT_mean.sh. Set $YEARMIN=1979, $YEARMAX=1979, $PID1, $PID2, $SUF before executing. . This script includes automatic download of the files you requested. Note that URL is that of “Your Personal Site”. PID is short for Process ID, which is a number appear at the individual files (e.g. ****tas2071.tar.gz)
6. Prepare the future climate data in the same way.
7. Execute prep_Rainf.sh with the Regional Settingand prepare rainfall data for 1979 and 2079. Parameters are shown below..

```
PRJ=mesc
RUN=hs1_ # for 1979
RUN=851_ # for 2079
```

9.2 Land surface process module

1. Change directory to ${DIRH08}/lnd/bin and execute main.sh with the Regional Setting and the parameters shown below. The main process of the land surface module will be started.

```
PRJ=mesc
RUN=LR__

PRJMET=mesc
RUNMET=hs1_  #for the past(1979)
RUNMET=851_ #for the future(2079)

QAIR=NO
RH=../../met/dat/RH______/${PRJMET}${RUNMET}_${SUF}DY
```

2. Change directory to ${DIRH08}/cpl/pst and execute list_watbal.sh with the Regional Setting and the parameters shown below. Check the "Water balance of land" section, and make sure that water balance is closed. Table 5 shows the water balance of land under the climate change conditions.

```
PRJ=mesc
RUN=LR__
PRJMET=mesc
RUNMET=hs1_  #for the past(1979)
RUNMET=851_  #for the future(2079)
```

Table 5. Results of water balance of land under the climate change conditions(1979)[km ^{3} y $^{-1}$]

Item		Value
Precipitation	+	375.63
Evapotranspiration	-	230.57
Total runoff	-	144.58
Δ Soil moisture	-	0.00
Δ Snow water equivalent	-	0.00
Δ Ground water	-	0.49
Water balance of land surface	-	0.01

9.3 River module

1. Change directory to ${DIRH08}/riv/bin and execute main.sh with the Regional Setting and the parameters shown below. The main process of the river module will be started. This results in creating the river discharge (Figure 21) and river storage (Figure 22) data.

```
PRJ=mesc
RUN=LR__
YEARMIN=1979
YEARMAX=1979
```

2. Change directory to ${DIRH08}/cpl/pst and execute list_watbal.sh with the Regional Setting. Check the "Water balance of river" section, and make sure that water balance is closed. Table 6 shows the water balance of river under the climate change conditions.

Table 6. Results of water balance of river under the climate change conditions(1979)[km ^{3} y $^{-1}$]

Item		Value
Total runoff	+	144.58
River discharge	-	144.58
Δ River storage	-	0.00
Water balance of river		0.00

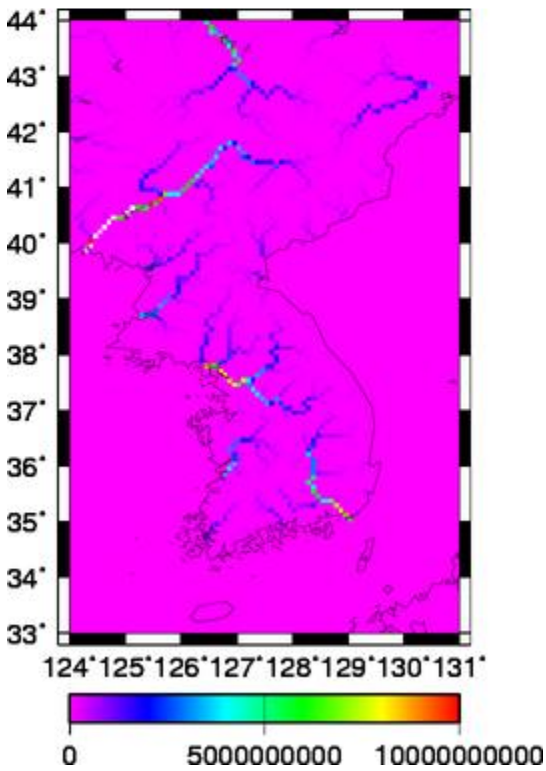

Figure 21. River storage (kg)

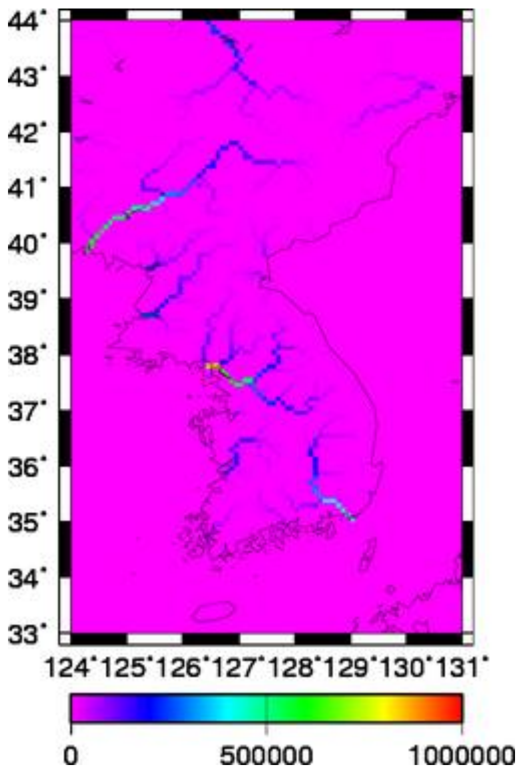

Figure 22. River discharge (kg s^{-1})

9.4 Crop growth module

1. Change directory to ${DIRH08}/crp/pre and execute prep.sh with the parameters below. This results in creating the initial parameter sets.

```
PRJSIM=mesc
RUNSIM=LR__
PRJMET=mesc
RUNMET=hs1_  #for the past(1979)
RUNMET=851_  #for the future(2079)
YEARMIN=1979
YEARMAX=1979
```

2. Change directory to ${DIRH08}/crp/bin and execute main.sh with the Regional Setting and the parameters below. This results in calculating the cropping calendars for individual crops under the climate change conditions.

```
JOBS=”1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19”
PRJ=mesc
RUN=__C_

POTEVAP=../../lnd/out/PotEvap_/mescLR__${SUF}DY
EVAP=../../lnd/out/Evap____/mescLR__${SUF}DY
```

3. Change directory to ${DIRH08}/crp/pst and execute calc_crpcal.sh with the Regional Setting and the parameters shown below. This results in creating the cropping calendar of first crop.

```
PRJ=mesc
RUN=__C_
YEAR=0000
MON=00
DAY=00
```

4. Change directory to ${DIRH08}/crp/bin and execute main.sh with the Regional Setting and the parameters shown below. This results in creating the cropping calendar of second crop.

```
JOBS=”2nd”
```

5. Change directory to ${DIRH08}/crp/pst and execute draw_crpyld_map.sh with the Regional Setting. This results in creating the figure of cropping calendar and yield in crp/fig.

(${DIRH08}/crp/fig/yld_mai_/mesc__C_19790000.png (Figure 23), ${DIRH08}/crp/fig/yld_whe_/mesc__C_19790000.png (Figure 24), ${DIRH08}/crp/fig/yld_ric_/mesc__C_19790000.png (Figure 25))

```
PRJ=mesc
RUN=__C_
YEAR=0000
MON=00
DAY=00
```

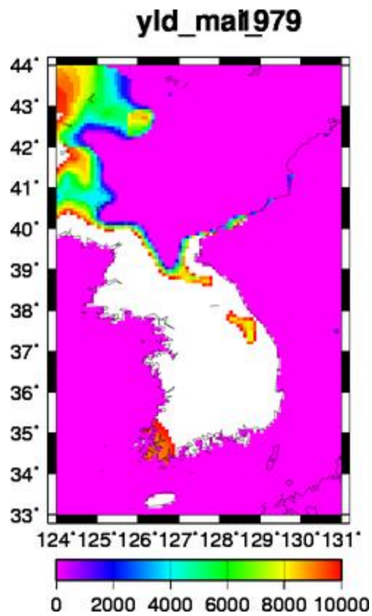

Figure 23. Yield of maize (kg ha^{-1})

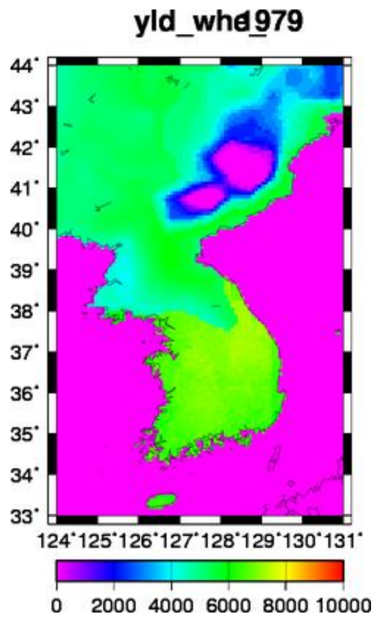

Figure 24. Yield of wheat (kg ha^{-1})

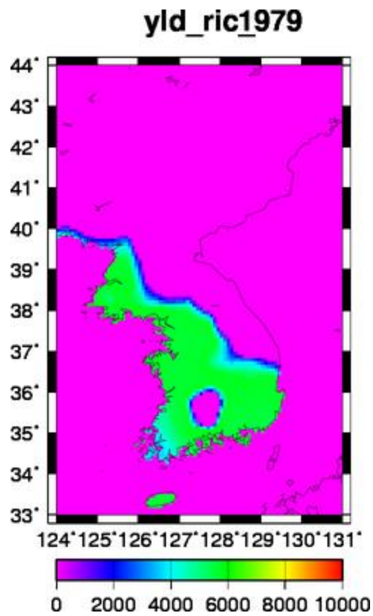

Figure 25. Yield of rice (kg ha^{-1})

9.5 Inputs for the reservoir module

1. Change directory to ${DIRH08}/riv/pst and execute calc_mean.sh with the Regional Setting and the parameters below. This results in creating the monthly and annual mean river discharge.

```
PRJ=mesc
RUN=LR__
YEAROUT=0000
```

2. Execute calc_flddro.sh with the Regional Setting and the parameters below. This results in creating the storage and release periods information.

```
PRJ=mesc
RUN=LR__
```

```
YEARMIN=0000
YEARMAX=0000
```

9.6 Environmental flow module

1. Execute calc_envout.sh with the Regional Setting and the parameters shown below. This results in calculating the environmental flow.

```
PRJ=mesc
RUN=LR__
```

2. Execute cpl/pst/list_watbal.sh with the Regional Setting and the parameters shown below. Then check the "Environmental" section of the output file. Table 7 shows the environmental flow under the climate change condition.

```
PRJENV=mesc
RUNENV=LR__
```

Table 7. Results of environmental flow under the climate change condition[$km^3 y^{-1}$]

ENVFLW
44.05

9.7 Coupled module(N_C_ experiment)

1. Change directory to ${DIRH08}/cpl/bin and execute main.sh with the Regional Setting and the parameters shown below.

```
PRJ=mesc
RUN=N_C_
LDBG=1

PRJMET=mesc
RUNMET=hs1_ #for the past(1979)
RUNMET=851_ #for the future(2079)
PRJLR__=mesc
RUNLR__=LR__
PRJ__C_=mesc
RUN__C_=__C_
PRJN_C_=mesc
RUNN_C_=N_C_

QAIR=NO
RH=../../met/dat/RH______/${PRJMET}${RUNMET}${SUF}DY

DAMID =NO
DAMPRP=NO
DAMMON1ST=NO
DAMCAP=NO
DAMSRF=NO
DAMALC=NO
DAMRIVOUTFIX=NO
DAMDEMAGRFIX=NO

OPTNNB=yes
```

9.8 Coupled module(LECD experiment)

1. Change directory to ${DIRH08}/cpl/pst and execute calc_mean.sh with the Regional Setting and the parameter shown below.

```
PRJ=mesc
RUN=LECD
YEAROUT=0000
```

2. Change directory to ${DIRH08}/map/bin and execute main_dam.sh with the Regional Setting and the parameter shown below.

```
PRJDIS=mesc
```

3. Change directory to ${DIRH08}/cpl/bin and execute main.sh with the Regional Setting and the parameters shown below.

```
PRJ=mesc
RUN=LECD
LDBG=1

DAMID_= ../../map/dat/dam_id__/GRanD_L_20000000${SUF}
DAMPRP= ../../map/dat/dam_prp_/GRanD_L_20000000${SUF}
DAMCAP= ../../map/dat/dam_cap_/GRanD_L_20000000${SUF}
DAMSRF=NO
DAMMON1ST= ../../riv/out/fld2dro_/${PRJLR__}${RUNLR__}0000000
0${SUF}
DAMALC= ../../map/out/dam_alc_/${PRJLR__}${RUNLR__}${SUF}ID
DAMRIVOUTFIX= ../../riv/out/riv_out_/${PRJLR__}${RUNLR__}0000
0000${SUF}
DAMDEMAGRFIX= ../../lnd/out/DemAgr__/${PRJN_C_}${RUNN_C_}0000
0000${SUF}FX
MSRCAP=../../map/dat/dam_cap/GRanD_L_20000000${SUF}
MSRAFC=../../map/dat/dam_afc_/GRanD_L_20000000${SUF}

OPTNNB=no
```

4. Change directory to ${DIRH08}/cpl/pst and execute list_watbal.sh with the Regional Setting and the parameters shown below. Please check the “Water balance of the coupled system” section. Table 8 shows the water balance of the coupled system under the climate change condition.

```
PRJ=mesc
```

```
RUN=LECD
PRJMET=mesc
RUNMET=hs1_
PRJDEM=mesc
RUNDEM=N_C_
PRJENV=mesc
RUNENV=LR__
```

Table 8. Results of water balance of the coupled system under the climate change condition[km ^{3} y $^{-1}$]

Item		Value
Precipitation	+	375.63
Evapotranspiration	-	230.57
River discharge	-	114.58
Δ Soil moisture	-	0
Δ Snow water equivalent	-	0
Δ River storage	-	0.49
Water balance of coupled module		0.01

Chapter 10
Calibration and Validation

This chapter describes how to calibrate the parameters of the land surface module and validate the H08 simulation results with observed river discharge.

There are four parameters that should be calibrated in the land surface model, namely soil depth (SD), CD (the drag coefficient), γ, and τ(the shape parameters of sub surface flow). To find the optimal combination of parameters, we are applying the concept of Monte Carlo Method. We are going to test three parameter values for each, and conduct altogether 81 simulation runs (3 x 3 x 3 x 3) and find the parameter set that maximize the score. More details are described in Hanasaki et al. (2014) and Masood et al. (2015). For this chapter, you need to prepare meteorological data from 1986 – 1995.

10.1 Preparing data and additional programs/scripts

Table 9 shows the information of all station.

Table 9. stnlst.SNU.txt

ID	Name	RIV	LON(OBS)	LAT(OBS)	AREA(OBS)	LON(H08)	LAT(H08)	AREA(H08)
1	Gongju	Geum_River	127.14	36.46	7.15E+03	127.13	36.46	7.18E+03
2	Goryeong	Nakdong_River	128.39	35.75	1.40E+04	128.38	35.79	1.46E+04
3	Gyuam	Geum_River	126.89	36.28	8.25E+03	126.88	36.29	7.94E+03
4	Jeokpo	Nakdong_River	128.36	35.53	1.64E+04	128.38	35.54	1.67E+04
5	Moonmak	Seom_River	127.81	37.31	1.34E+03	127.88	37.38	1.57E+03
6	Naju	Yeongsan_River	126.73	35.04	2.06E+03	126.79	35.13	2.10E+03
7	Samrangjin	Nakdong_River	128.83	35.38	2.29E+04	128.79	35.29	2.21E+04
8	Songjeong	Seomjin_River	127.54	35.19	4.27E+03	127.54	35.2	2.24E+03
9	Waegwan	Nakdong_River	128.39	36	1.11E+04	128.38	35.96	1.13E+04
10	Yeoju	Han_River	127.65	37.31	1.11E+04	127.71	37.2	8.67E+03

10.2 Calibration

1. Change directory to ${DIRH08}/lnd/pre and execute prep_genpar.sh with the Regional Setting. This results in creating parameter files for the Monte Carlo simulation. (lnd/dat/uniform.*.*.ko5)
2. Edit and execute lnd/set/setfile_WFDEI.sh, riv/set/setfile_riv with the regional setting. The simulation parameters other than SD, CD, γ, and τ are commonly used in the Monte Carlo simulations.

```
YEARMIN=1986
YEARMAX=1990
```

3. Edit and execute ${DIRH08}/lnd/pre/chparam.sh. This results in creating 81 simulation setting files for the land surface mod-ule with different combinations of SD, CD, γ, and τ. (lnd/set/${PRJ}AAAA${DATE}.set～CCCC${DATE}.set)
4. Change directory to ${DIRH08}/lnd/bin. Edit and execute loop_region.sh. This shell script manages 81 simulations of the land surface module.
5. Change directory to ${DIRH08}/riv/pre and execute chparam.sh. This results in creating 81 simulation setting files for the river module. (riv/set/${PRJ}AAAA${DATE}.set～CCCC${DATE}.set)
6. Change directory to ${DIRH08}/riv/bin. Edit and execute loop.sh. This shell script manages 81 simulations of the river module.
7. Make sure whether htmettxt and htstatlst exist in ${DIRH08}/bin. H08_20130501 and earlier versions may not include htmettxt and htstatlst. If this is the case, follow the instruction shown in the “Bugs & Update” page of the H08 website (http://h08.nies.go.jp/h08/bugs_update.html).
8. Change directory to ${DIRH08}/riv/pst and execute calc_evldis.sh. This shell script evaluates the score of 81 individual simulations for each river gauging station. This results in determining the best combination of parameters (SD, CD, CAMMA, TAU) and calculating the score (i.e. NSE (Table 10)). (Results are written to riv/out/par_cmb_/WFDE.txt, riv/out/riv_dis_/WFDEAAAA00000001～CCC00000010.txt)

Table 10. Value range and evaluation of the Nash-Sutcliffe Efficiency (NSE)

Value range	Evaluation
NSE < 0	Poor
0 ≤ NSE < 0.5	Moderate
0.5 ≤ NSE	Good

9. Change directory to ${DIRH08}/lnd/pre and execute prep_optpar_region.sh. This script generates the geographical maps of the optimized parameters. Check if your results are identical to Figure 26-29. Now you are ready to run H08 with calibrated parameters. (lnd/dat/WFDE.sd.ko5(Figure 26), lnd/dat/WFDE.cd.ko5(Figure 27),

lnd/dat/WFDE.gamma.ko5(Figure 28), lnd/dat/WFDE.tau.ko5(Figure 29),
map/out/sub_bsn_/________00000001.ko5～00000010.ko5)

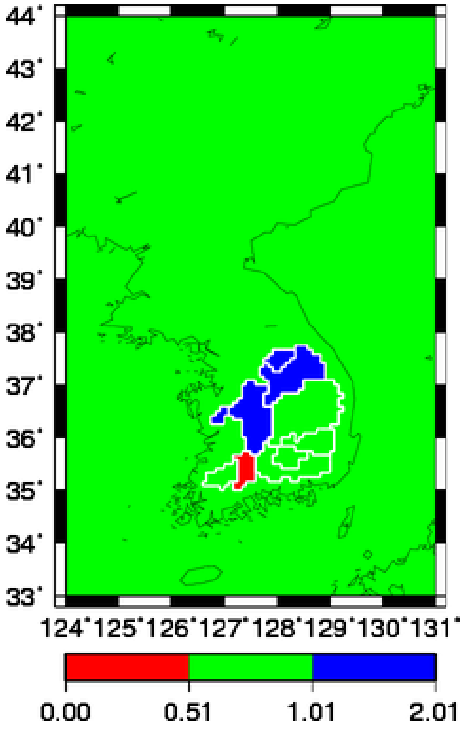

Figure 26. SoilDepth

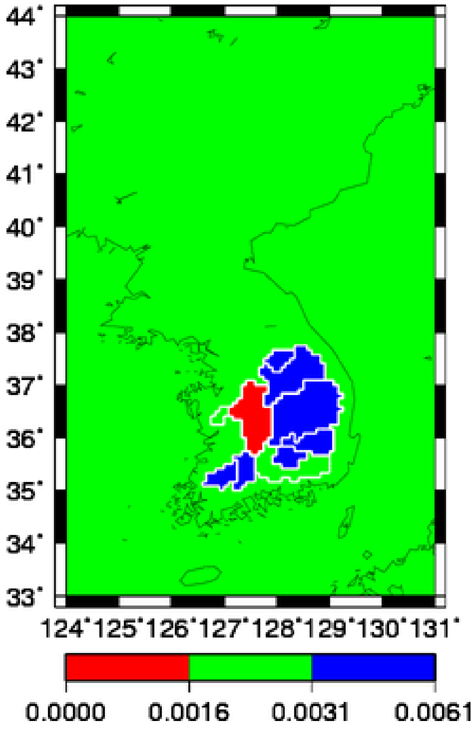

Figure 27. CD

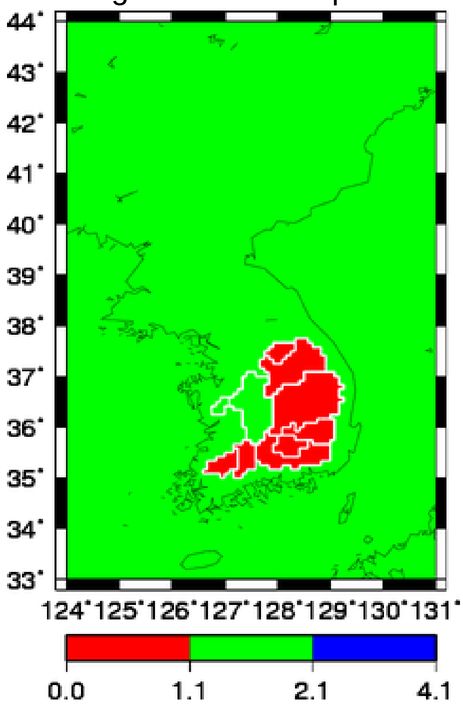

Figure 28. GAMMA

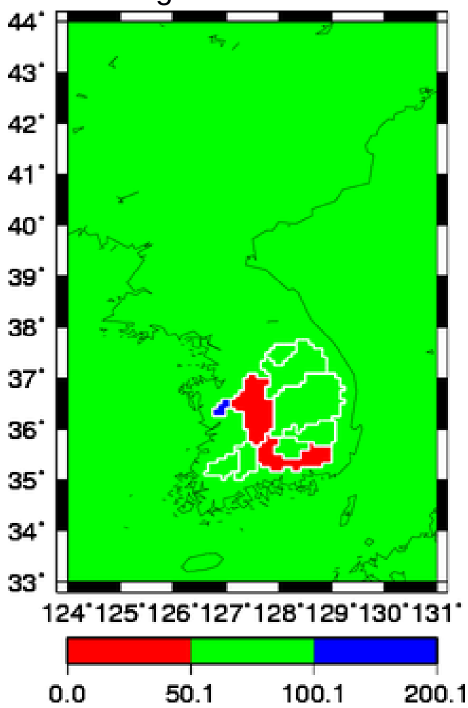

Figure 29. TAU

• Column 1

NSE

NSE（Nash-Sutcliffe Efficiency）is a widely used index to evaluate the performance of hydrological simulations. It is defined as follows (Nash and Sutcliffe, 1970).

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(Q_i - Q_i')^2}{\sum_{i=1}^{n}(Q_i - \bar{Q})^2}$$

Here, Q_i is observed discharge at time i, Q_i' is simulated discharge at time i, $\bar{Q}$ is the mean observed discharge. NSE ranges from -∞ to 1. Simulations are considered 'good' when NSE exceeds 0.5 (Moriasi et al., 2007). NSE takes 0 when $Q_i' = \bar{Q}$ or the timeseries of simulation are identical to the mean observed discharge. Simulations are considered 'poor' when NSE falls below 0 or when they perform worse than the constant mean observed discharge.

To better understand this index, the NSE values are calculated for the following function y and shown in Figure 30.

$$y = a \times \sin\left(\frac{x+b}{6}\right)\pi + c$$

Here, x is month, and y is the discharge. We assume that a=1, b=0, and c=1.5 are the time series of observed discharge. Figure 30 (a) shows an example of the simulation when a=1, b=0, c=1.5 (i.e. the simulation perfectly matches with observation). In this case, NSE takes 1. Figure 30 (b) shows the case a=1, b=1, and c=1.5 (i.e. the phase delays by one month). For this case, NSE takes 0.73. Figure 30 (c) shows the case a=1.5, b=0, and c=1.5 (i.e. the amplitude is 1.5 times of the observation). For this case, NSE takes 0.75. Figure 30 (d) shows the case a=1.5, b=1, and c=1.5 (i.e. the amplitude is 1.5 times of the observation and the phase delays by one month). For this case, NSE takes 0.35.

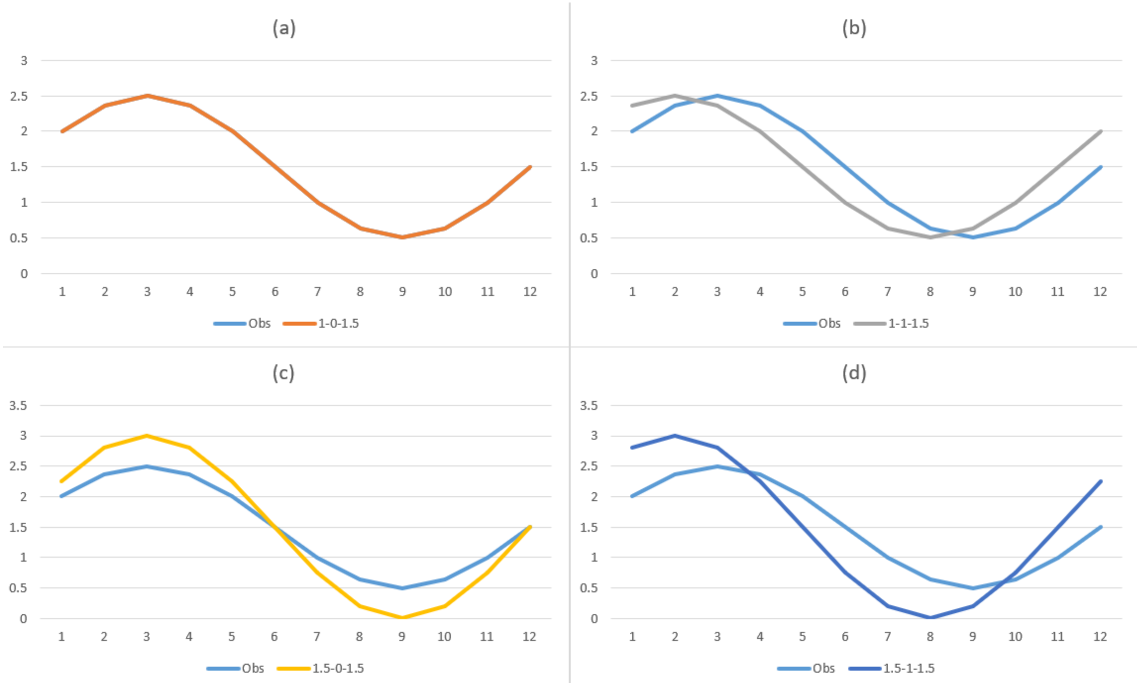

Figure 30 (a) Simulation (a=1, b=0, c=1.5) perfectly agree with observation. (b) The phase differs by one month (a=1, b=1, c=1.5). (c) The magnitude of amplitude differs by 1.5 times (a=1.5, b=0, c=1.5). (d) The phase and the magnitude of amplitude differs by one month and 1.5 times, respectively (a=1.5, b=1, c=1.5).

10.3 Validation

1. Change directory to ${DIRH08}/lnd/bin and execute main.sh with the Regional Setting and the parameters shown below. The land surface module with the optimal parameter set will be executed. Note that the validation period is set to 1991-1995, which is different from the calibration period.

```
PRJ=WFDE
RUN=VALI
YEARMIN=1991
YEARMAX=1995
SOILDEPTH=../../lnd/dat/WFDE.sd.ko5
CD=../../lnd/dat/WFDE.cd.ko5
GAMMA=../../lnd/dat/WFDE.gamma.ko5
TAU=../../lnd/dat/WFDE.tau.ko5

Qair=../../met/dat/Qair____/${PRJMET}${RUNMET}${SUF}DY
RH=NO

TCOR=NO
PCOR=NO
LCOR=NO

TAIROUT=NO
RAINFOUT=NO
SNOWFOUT=NO
LWDOWNOUT=NO
```

2. Change directory to ${DIRH08}/riv/bin and execute main.sh with the Regional Setting and the parameters shown below. The river module with the optimal parameter set will be executed.
(riv/out/riv_out_/GSW2VALIYYYYMMDD.ko5,
riv/out/riv_sto_/GSW2VALIYYYYMMDD.ko5)

```
PRJ=WFDE
RUN=VALI
YEARMIN=1991
YEARMAX=1995
```

3. River discharge simulation is outputted to ${DIRH08}/riv/out. Compare output data (riv_out_/) with observed river discharge data. Note that observed data is located as shown in Table 11.

Table 11 Paths of the observed river discharge data

Item	Paths
Daily river discharge	${DIRH08}/riv/dat/riv_disD/SNU_v1__00000001.txt~00000010.txt
Monthly river discharge	${DIRH08}/riv/dat/riv_disM/SNU_v2__00000001.txt~00000010.txt

Figures 31-37 show the simulated and observed river discharge at ten stations. NSE for the calibration and validation periods are also shown. NSE exceeds 0.5 except Moonmak in the Seom River (Figure 35), and Naju in the Yeongsan River (Figure 36) in the calibration period. Particularly, the simulation at Moonmak in the Seom River is considerably different from observation which requires further investigation that are behind the observation. For most cases, simulations in the calibration period outperformed those in the validation.

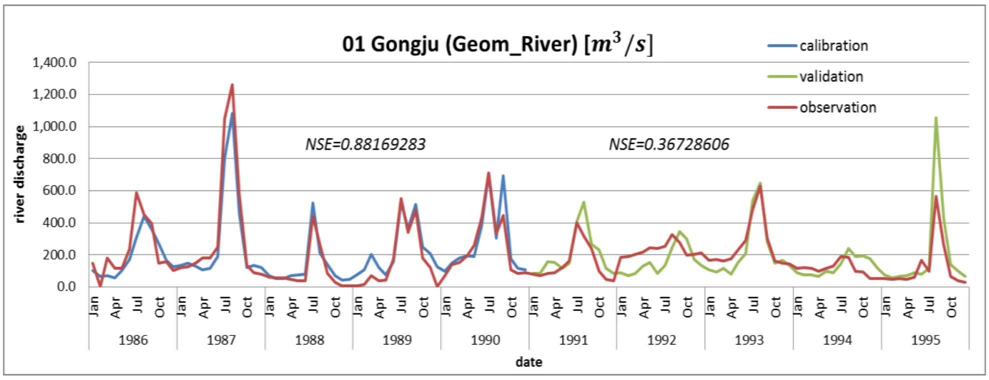

Figure 31. River discharge of Gongju in the Geom River

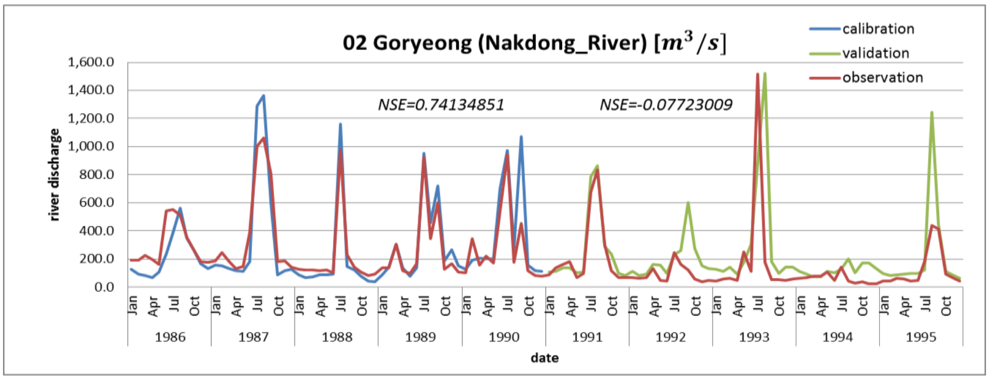

Figure 32. River discharge of Goryeong in the Nakdong River

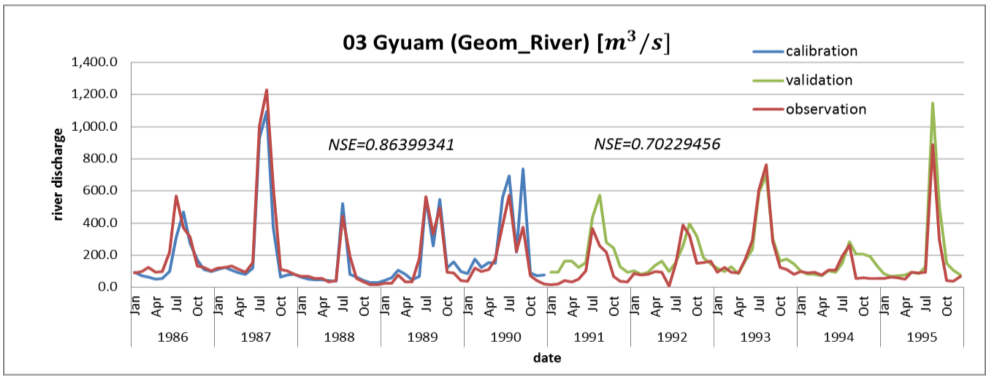

Figure 33. River discharge of Gyuam in the Geom River

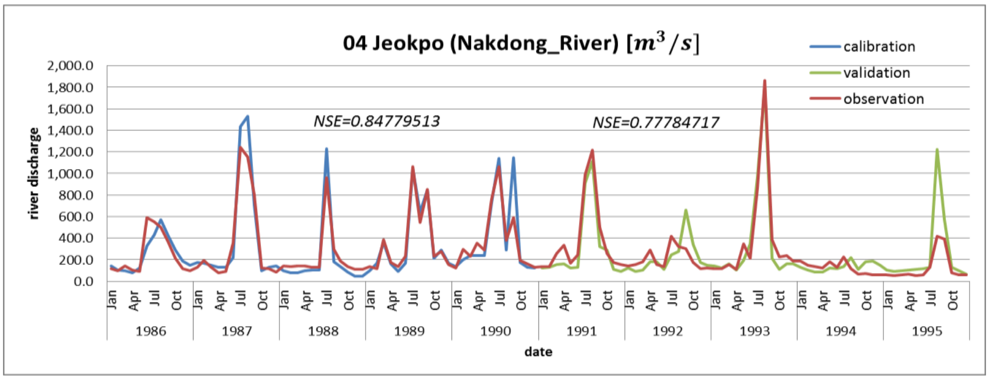

Figure 34. River discharge of Jeokpo in the Nakdong River

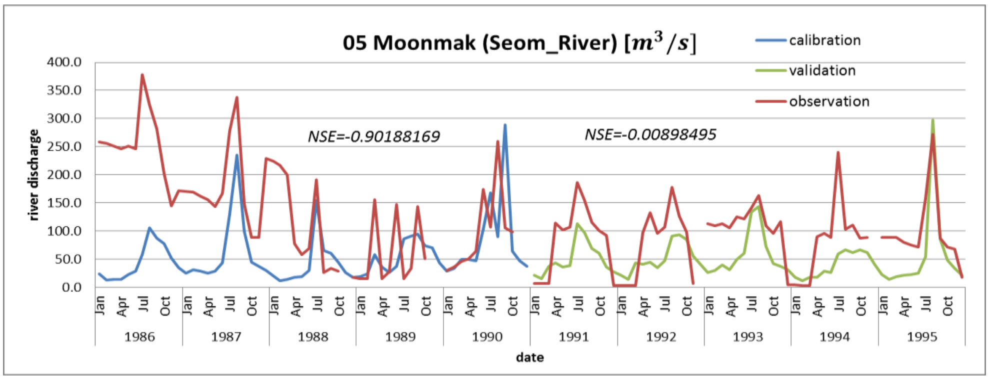

Figure 35. River discharge of Moonmak in the Seom River

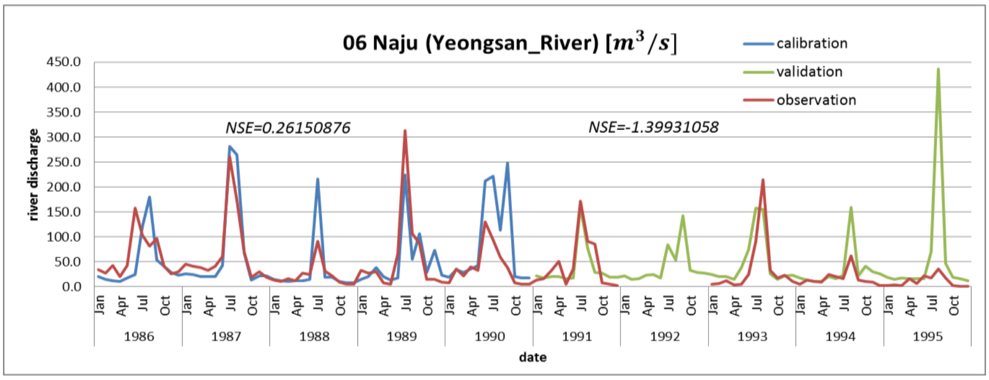

Figure 36. River discharge of Naju in the Yeongsan River

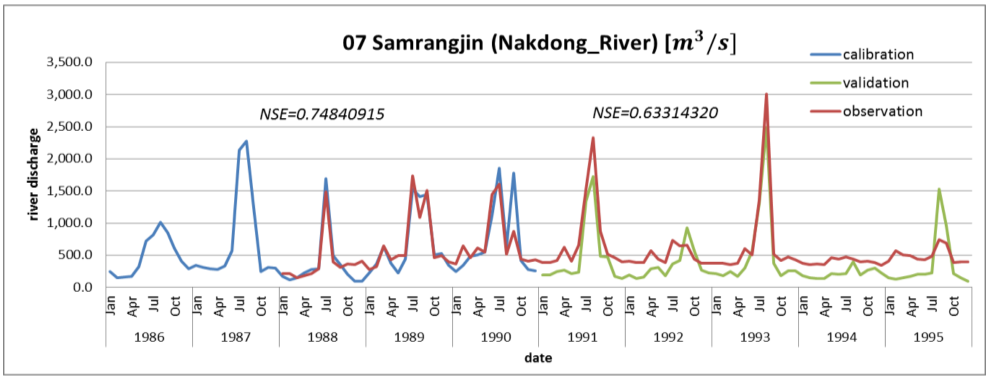

Figure 37. River discharge of Samrangjin in the Nakdong River

References

Hanasaki, N., S. Kanae, T. Oki, K. Masuda, K. Motoya, N. Shirakawa, Y. Shen, and K. Tanaka (2008), An integrated model for the assessment of global water resources - Part 1: Model description and input meteorological forcing, Hydrol. Earth Syst. Sci., 12(4), 1007-1025.

Hanasaki, N., S. Kanae, T. Oki, K. Masuda, K. Motoya, N. Shirakawa, Y. Shen, and K. Tanaka (2008), An integrated model for the assessment of global water resources - Part 2: Applications and assessments, Hydrol. Earth Syst. Sci., 12(4), 1027-1037.

Hanasaki, N., Y. Saito, C. Chaiyasaen, A. Champathong, C. Ekkawatpanit, S. Saphaokham, T. Sukhapunnaphan, S. Sumdin, and J. Thongduang (2014), A quasi-real-time hydrological simulation of the Chao Phraya River using meteorological data from the Thai Meteorological Department Automatic Weather Stations, Hydrological Research Letters, 8(1), 9-14.

Masood, M., P. J. F. Yeh, N. Hanasaki, and K. Takeuchi (2015), Model study of the impacts of future climate change on the hydrology of Ganges–Brahmaputra–Meghna basin, Hydrol. Earth Syst. Sci., 19(2), 747-770.