SWAT Soil & Water Assessment Tool 2013 International SWAT Conference, Beijing, China

Evaluation of CO_2 Treatment and the Impact on Watershed Hydrology in SWAT Using Terra MODIS GPP

27 July 2016

JUNG, Chung-Gil
Ph. D. Candidate

LEE, Ji-Wan / AHN, So-Ra
Graduate Student / Ph. D.

KIM, Seong-Joon
Professor

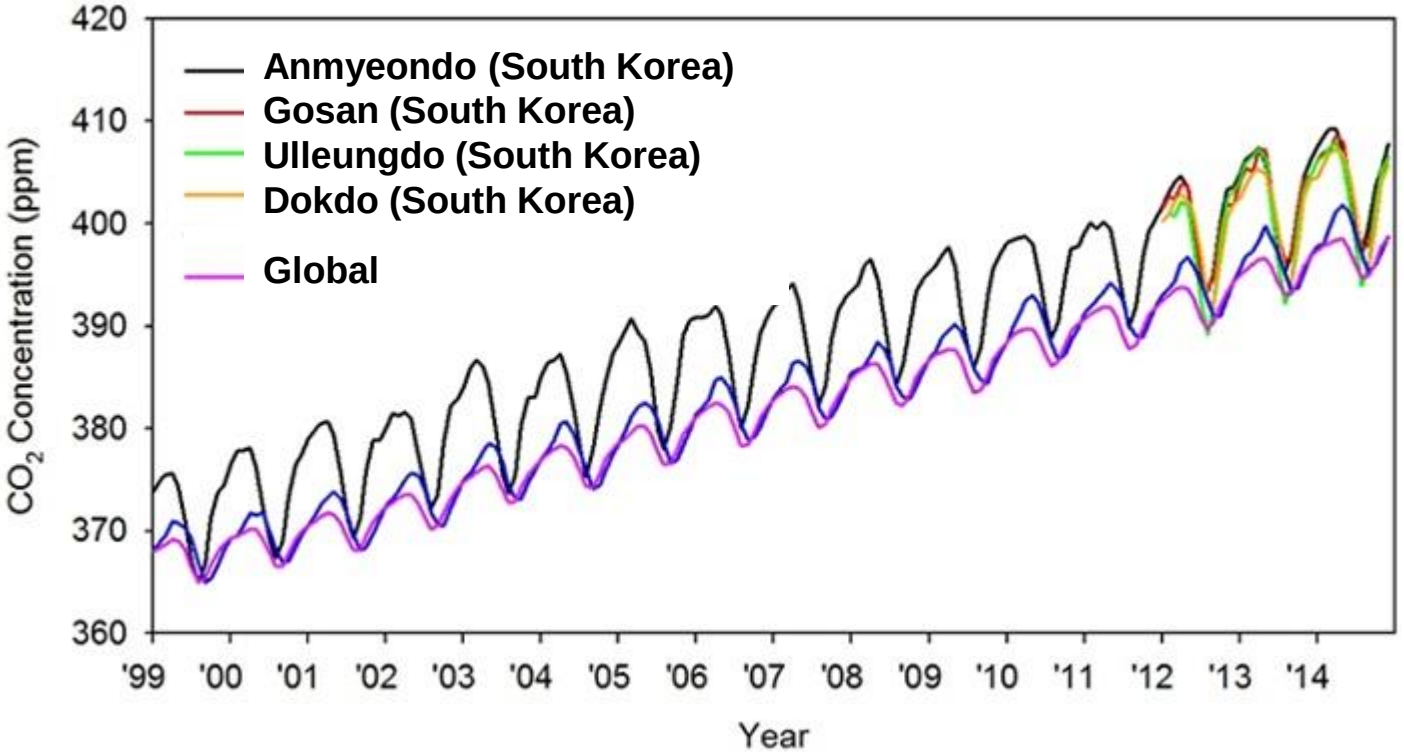
Dept. of Civil and Environmental System Eng.,
Konkuk University, Seoul, South Korea

Contents

Introduction

- ✓ Fossil fuel consumption has caused an increase in anthropogenic emissions of carbon dioxide (CO_2) and other greenhouse gases.
- ✓ Elevated atmospheric CO_2 concentration directly affects plant growth, which inherently is tied with the hydrological cycle, through lowered rates of stomatal conductance and increases in leaf area.
- ✓ Many studies based on observations and modeling have implied increased CO_2 concentrations and climate change have significant impacts on hydrological systems. However, estimation approach of the CO_2 concentration is that it is not possible to take into account the quantification of spatial CO_2 concentration within watershed.
- ✓ These potential impacts can be quantified for a specific watershed using hydrological models.
- ✓ Using Terra MODIS GPP image and Soil and Water Assessment Tool (SWAT) model, this study is to evaluate the potential CO_2 change impact on hydrologic components in a forest dominant Seolma-cheon watershed (8,48 km^2) of South Korea

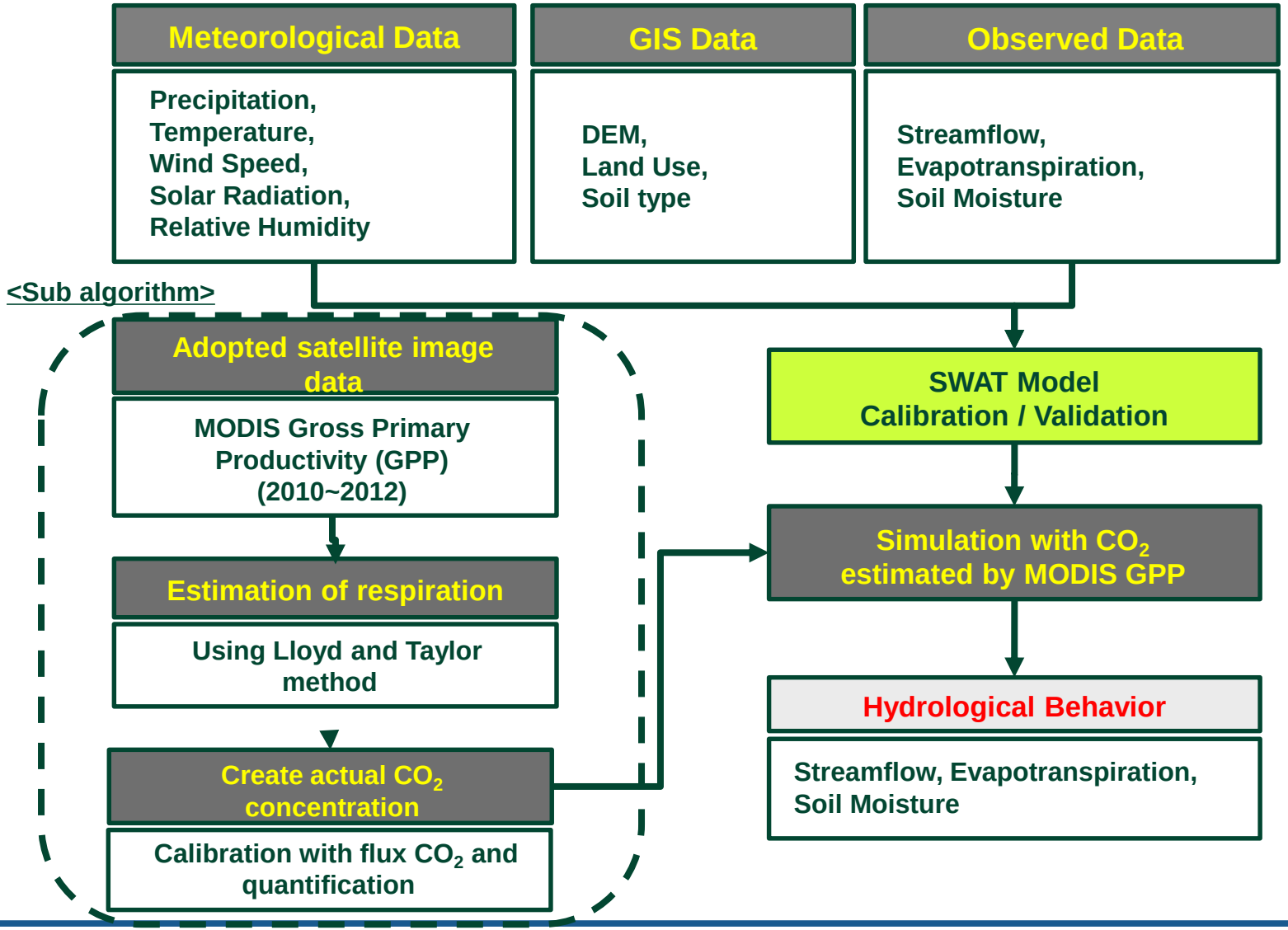
Current Status



Measure CO_2 at
4 stations by Korea
Global Atmosphere
Center in South Korea

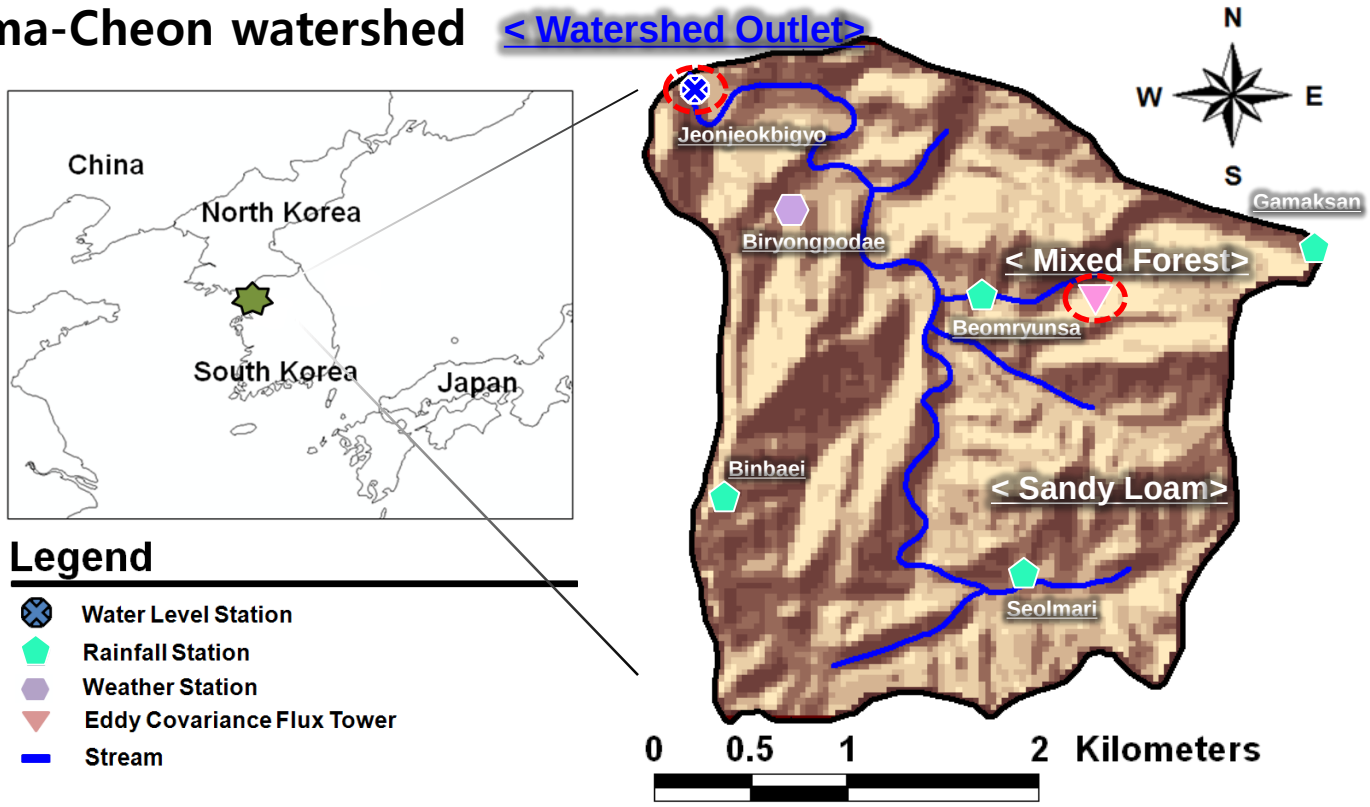
Data Type	Global	Anmyeondo (South Korea)
2015. 03	400.83 PPM	411.03 PPM
2014	397.16 PPM	404.84 PPM
Increase ratio (2012 ~ 2014)	2.25 PPM	2.42 PPM

Flow Chart


Meteorological Data
Precipitation,
Temperature,
Wind Speed,
Solar Radiation,
Relative Humidity
GIS Data
DEM,
Land Use,
Soil type
Observed Data
Streamflow,
Evapotranspiration,
Soil Moisture
<Sub algorithm>
Adopted satellite image data
MODIS Gross Primary Productivity (GPP) (2010~2012)
Estimation of respiration
Using Lloyd and Taylor method
Create actual CO_2 concentration
Calibration with flux CO_2 and quantification
SWAT Model Calibration / Validation
Simulation with CO_2 estimated by MODIS GPP
Hydrological Behavior
Streamflow, Evapotranspiration, Soil Moisture

Study Watershed

- **Seolma-Cheon watershed** < Watershed Outlet>



- ✓ Watershed area : 8.54 km^2
- ✓ Annual average precipitation : 1,210 mm (for 5 years)
- ✓ Annual average temperature : 10.3 ℃
- ✓ Forest area : 96.2 % (8.22 km^2)
- ✓ Soil texture : Sandy loam, Loam

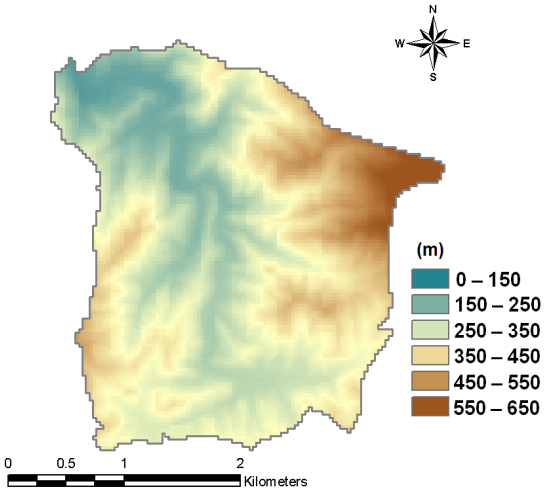
Input and Measured Data

Data set for SWAT model

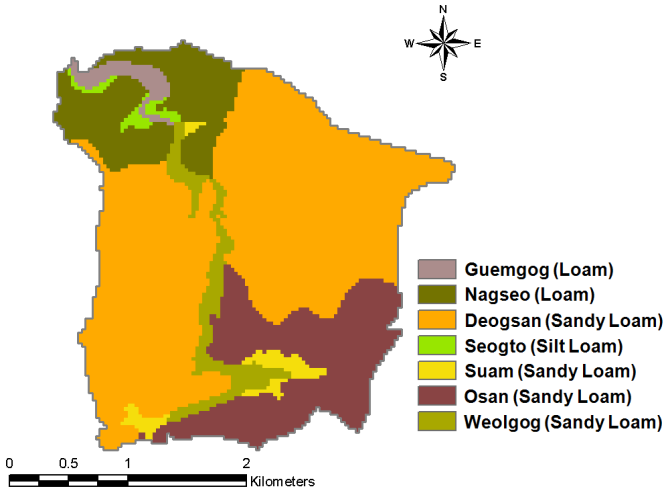
Data Type	Source	Scale / Periods	Data Description / Properties
Terrain	Korea National Geography Institute	30 m	Digital Elevation Model (DEM)
Soil	Korea Rural Development Administration	1/25,000	Soil classification and physical properties viz. texture, porosity, field capacity, wilting point, saturated conductivity, and soil depth
Land use	2004 Landsat TM Satellite Image	1/25,000	Landsat land use classification (8 classes)
Weather	Korea Institute of Construction Technology / WAter Management Information System	1971-2009	Daily precipitation, minimum and maximum temperature, mean wind speed and relative humidity data
Streamflow	Korea Institute of Construction Technology	2003-2012	Daily streamflow data at watershed outlet
Evapo-transpiration	Korea Institute of Construction Technology / Yonsei Univ.	2008-2012	Daily evapotranspiration data at mixed forest area

GIS Input Data

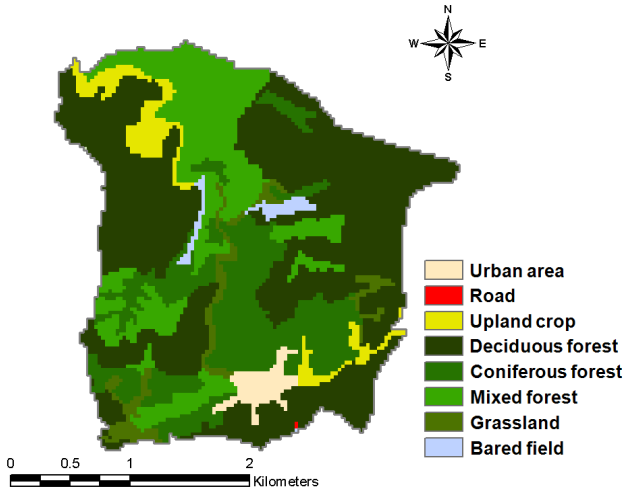
- **SWAT Input data**



(a) DEM



(b) Soil



(c) Landuse

SWAT Model theory

Peman-Monteith evapotranspiration equation

- ✓ The Evapotranspiration (ET) as simulated by SWAT is based on canopy resistance equation related to CO_2 concentration.
- ✓ The relationship between stomatal resistance and canopy resistance has direct ratio.
- ✓ This ET method has inverse relationship with r_c

$$r_c = r_l \cdot [(0.5 \cdot LAI) \cdot (1.4 - 0.4 \cdot \frac{CO_2}{330})]^{-1}$$

r_c = *canopy resistance (s/m)*

r_l = *minimum effective stomatal resistance of a single leaf (s/m)*

LAI = *leaf area index of the canopy*

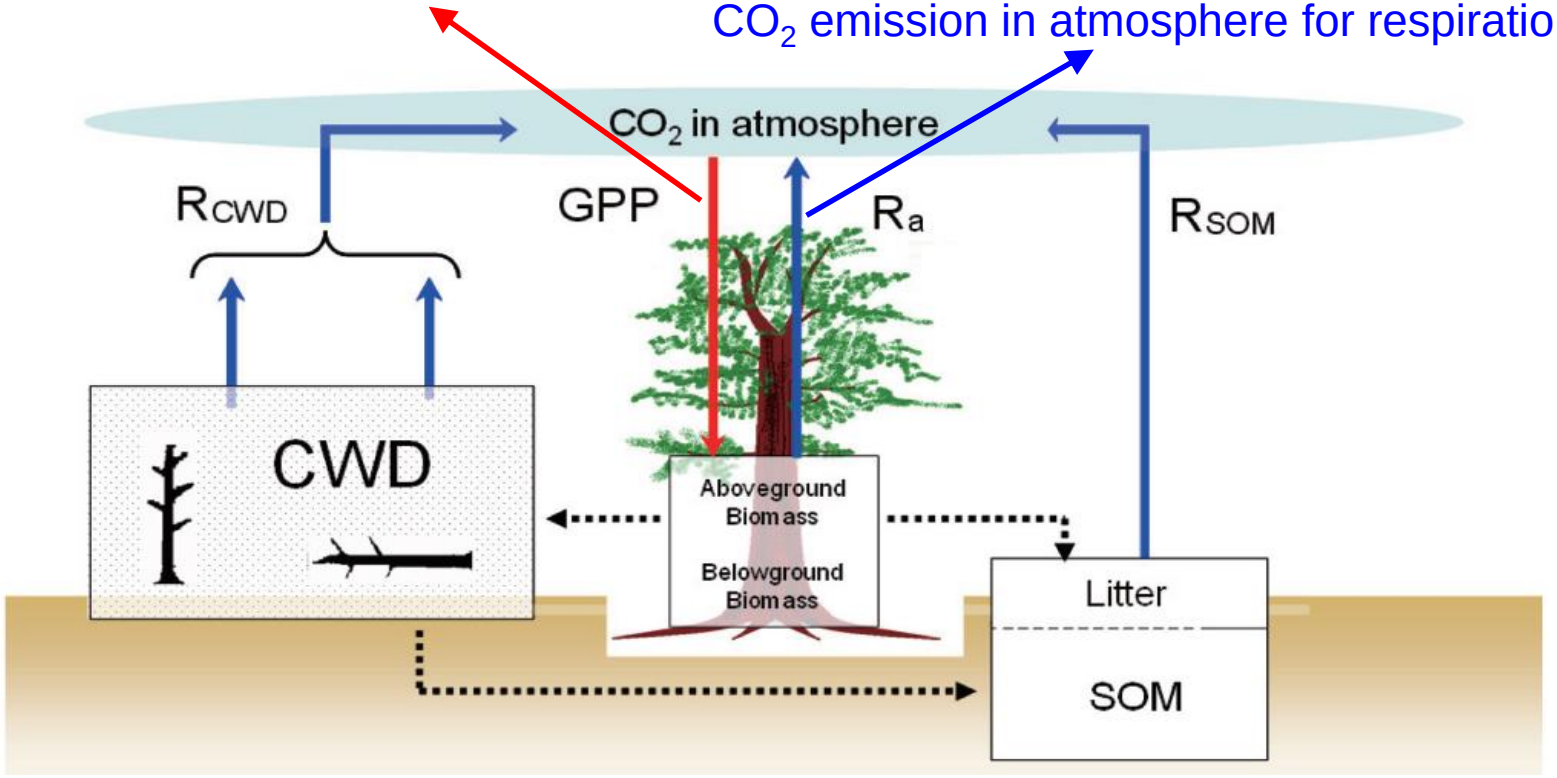
CO_2 = *concentration of carbon dixide in the atmosphere (ppmv)*

CO_2 Estimation

- **CO_2 flux theory**

CO_2 absorption in atmosphere for photosynthesis

CO_2 emission in atmosphere for respiration



CO_2 Estimation

CO_2 flux theory

- ✓ Gross Primary Production (GPP) is absorbed amount by photosynthesis from animals and plants
- ✓ Re is total respiration from animals and plants
- ✓ Net Echo-system Exchange (NEE) means total CO_2 flux on soil, and NPP (Net Primary Production) is practically absorption CO_2 by a plant community
- ✓ Also, NEE is net CO_2 flux for a day (day and night)
- ✓ NEE is calculated by GPP and Re from following equation:

GPP (MODIS GPP) – Re (Lloyd and Taylor method) = NEE (CO_2 concentration)

Re (ecosystem respiration) Estimation

Lloyd and Taylor method (1994)

- ✓ We use Lloyd and Taylor equation for estimation of ecosystem respiration.
- ✓ The ecosystem respiration equation is shown as following equation. Especially, the R_{ref} *and* E_0 are empirical coefficients using regression analysis with air temperature.
- ✓ We could analyze regression analysis about the coefficients. So, R_{ref} *and* E_0 resulted in 0.054 mg/m·s and 204.8 K respectively.

$$Re = R_{ref} \cdot exp(E_0 \cdot \left[\frac{1}{T_{ref} - T_0} - \frac{1}{T_a - T_0}\right])$$

Re = ecosystem respiration (mm)

R_{ref} *= the normalized ecosystem respiration at reference temperature* (T_{ref} *= 10℃)*

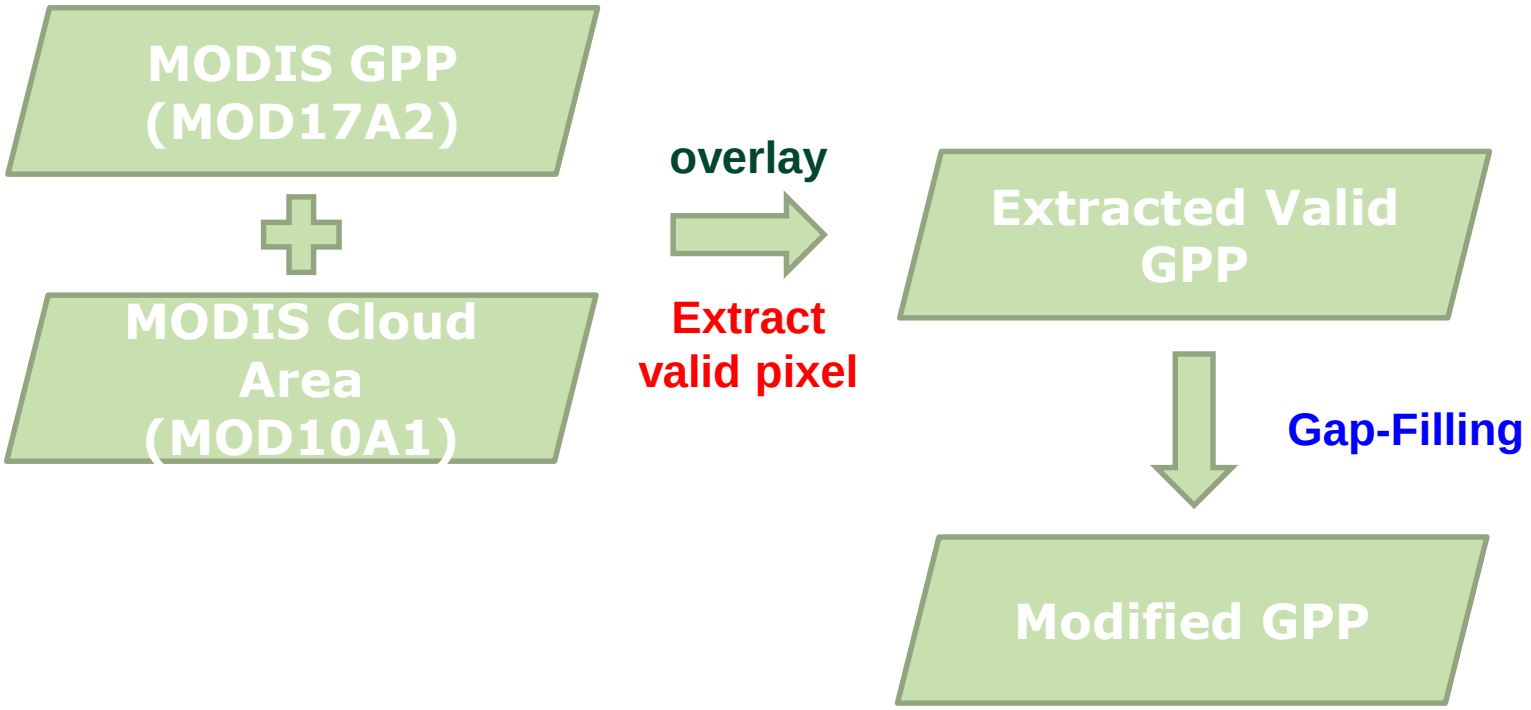
E_0 *= activation energy which is a fitted site-specific parameter (J/mol)*

T_0 *= -46.02℃*

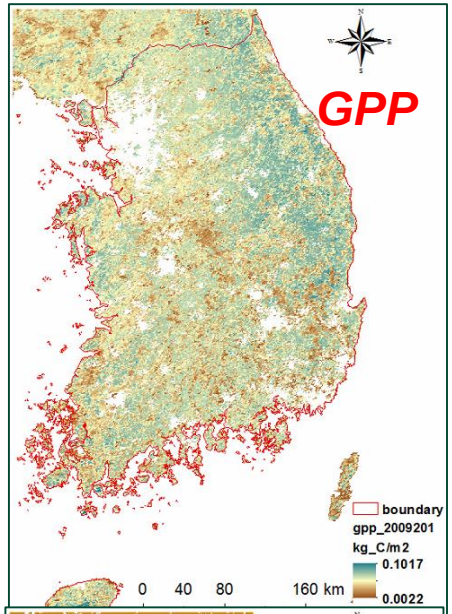
T_a *= Air temperature (mm)*

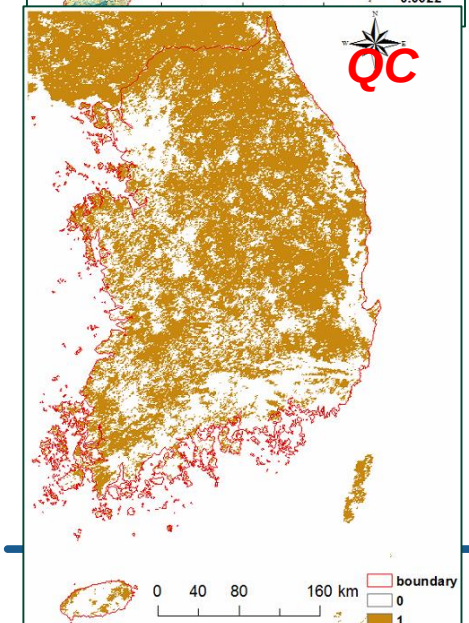
GPP Estimation

- MODIS GPP QC and Gap-filling process



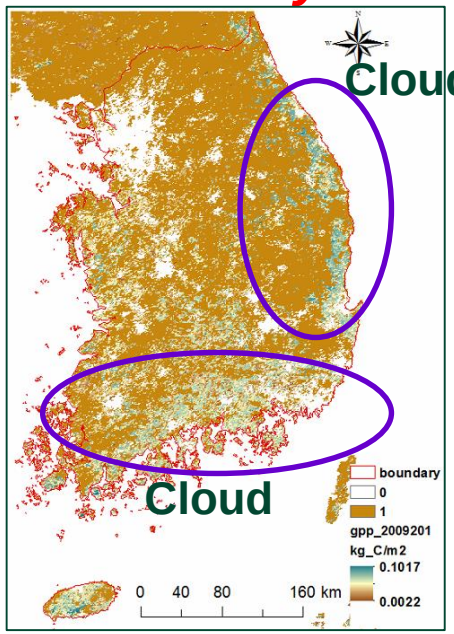
GPP Estimation



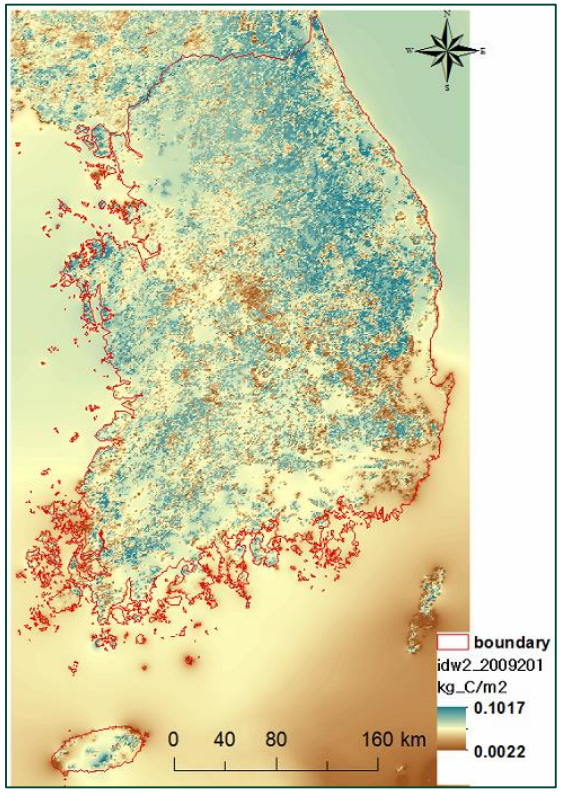


◆ Gap-filling process

Overlay

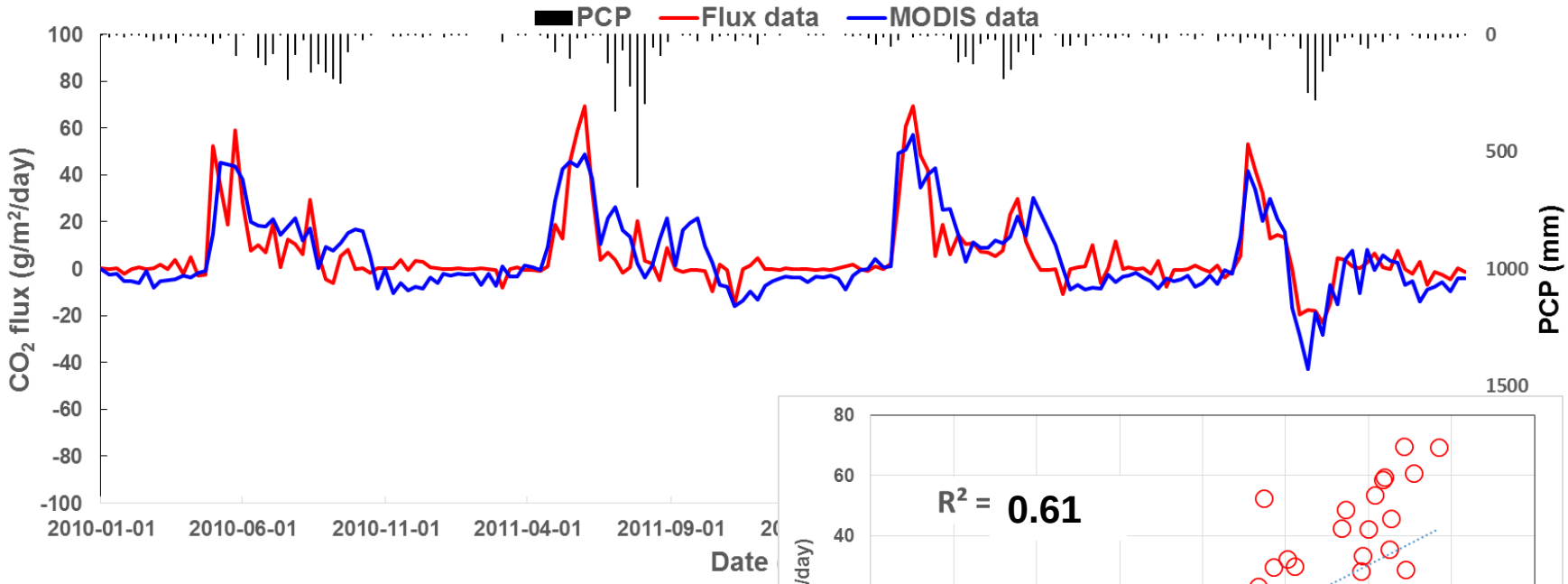


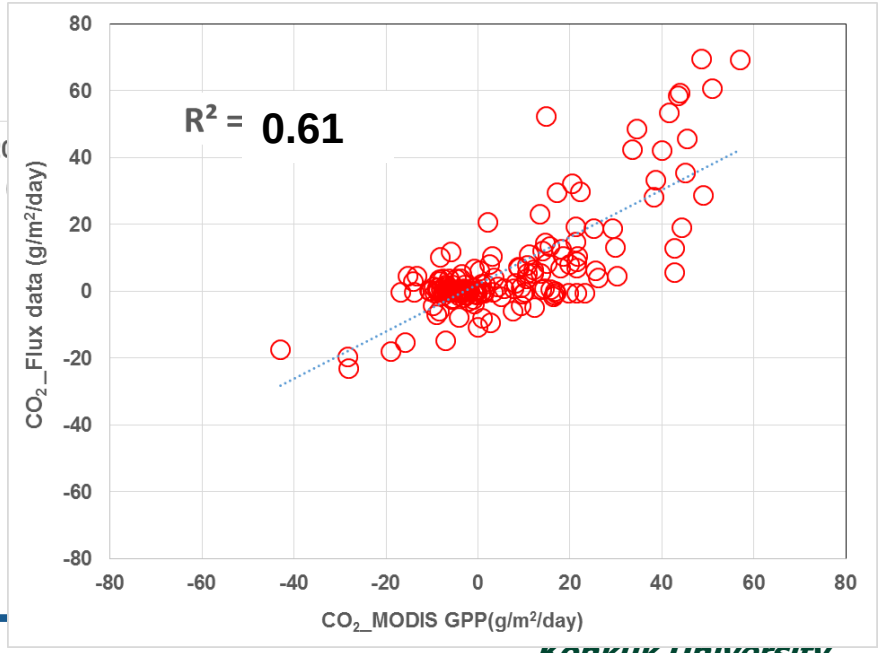
Gap-Filling



CO_2 Estimation

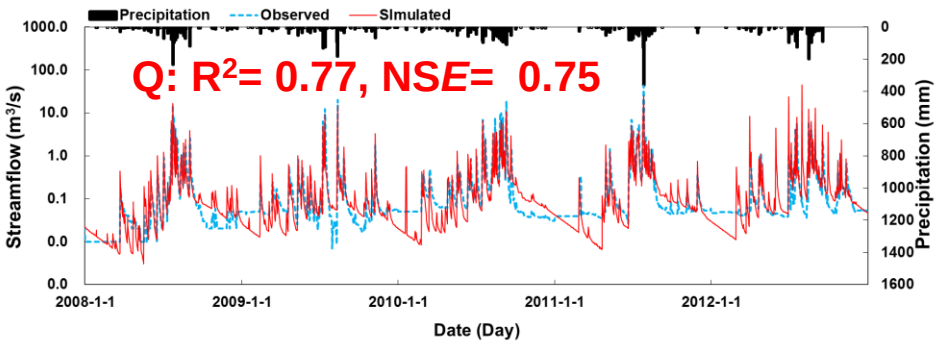
- GPP, Re, and CO_2 flux

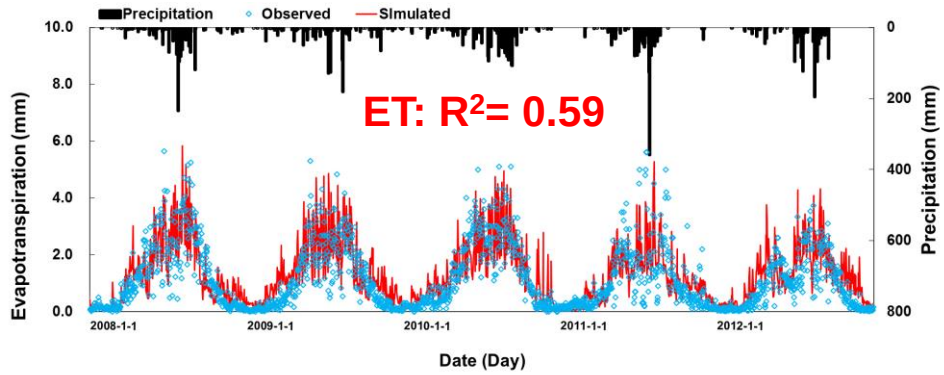


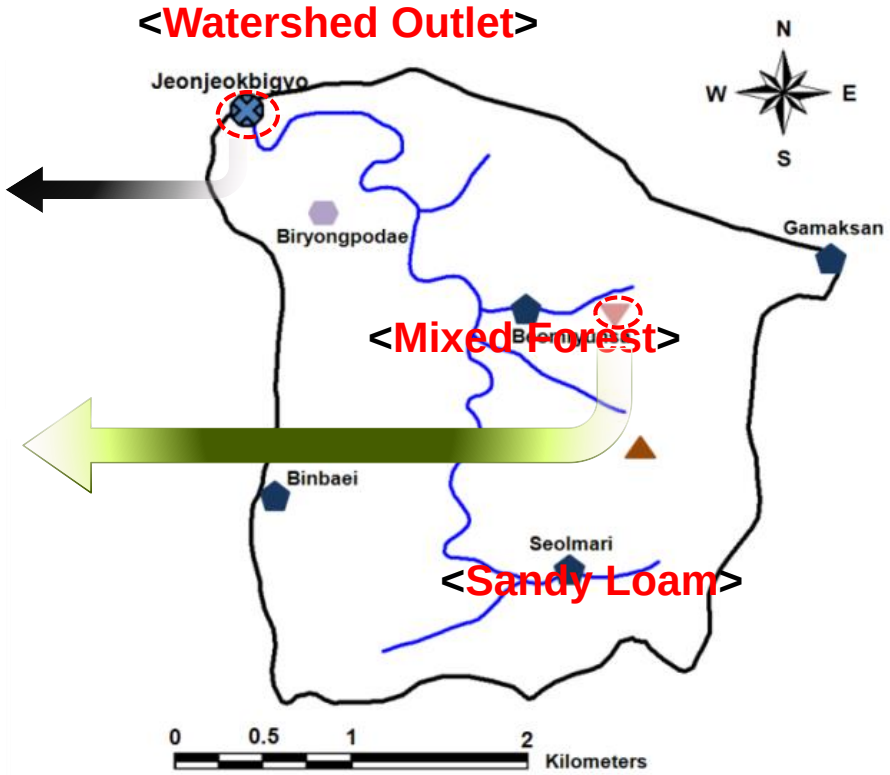


Calibration and Validation

- Streamflow, Evapotranspiration







Impact on hydrologic components

Quantification of actual estimated CO_2 concentration

- ✓ CO_2 flux is the incoming and returning movement of atmosphere CO_2.
- ✓ So, we defined that atmosphere CO_2 concentration is sum of annual CO_2 flux.
- ✓ The unit of the estimated CO_2 flux is converted as PPM unit.

Year	Actual estimated CO_2 concentration (PPM)
SWAT default	330.0
2010	351.7
2011	375.2
2012	404.9

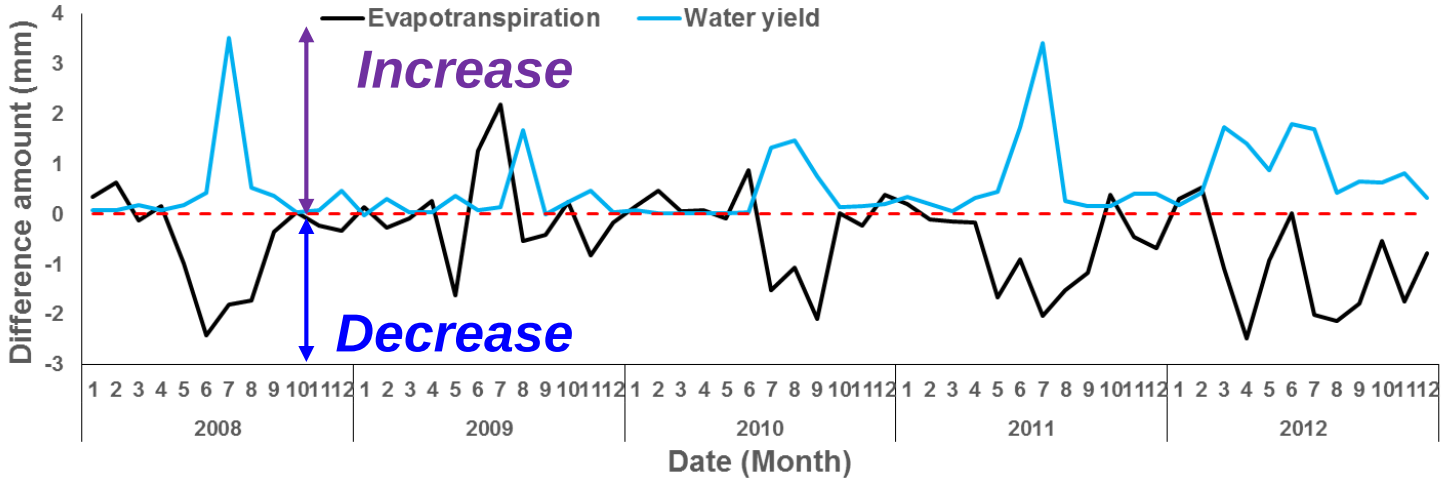
Impact on hydrologic components

Application of estimated CO_2 concentration

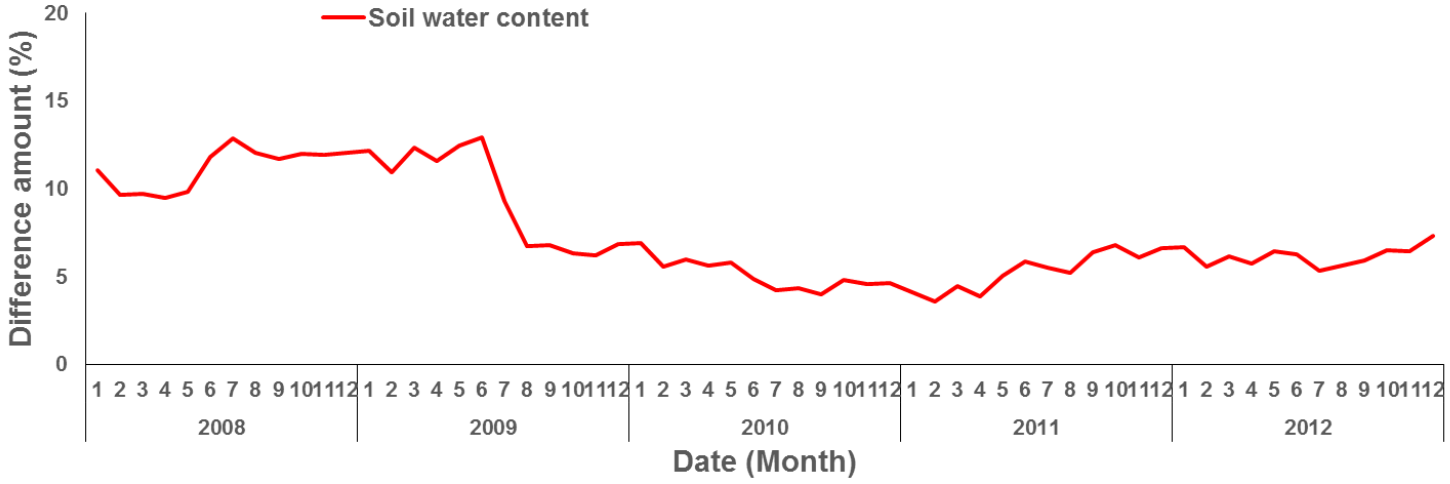
- ✓ The result of ET applied estimated CO_2 concentration (351.7, 375.2, 404.9) has difference from -2.47mm/month to 2.18mm/month (ET applied estimated CO_2 – default (330ppm) ET).
- ✓ The result of water yield (WY) applied estimated CO_2 concentration (351.7, 375.2, 404.9) has difference from -0.02 mm/month to 3.52 mm/month (WY applied estimated CO_2 – default (330ppm) WY).
- ✓ The result of soil water content (SW) applied estimated CO_2 concentration (351.7, 375.2, 404.9) has difference from 3.5 % to 12.9 % (SW applied estimated CO_2 – default (330ppm) SW).
- ✓ Because this study area is very small, the change amount of hydrological components didn't be shown definitely. So, we illustrate the differences between SWAT result applied estimated CO_2 and default SWAT result.

Impact on hydrologic components

- Application of actual estimated CO_2 concentration



The R^2 of ET are improved from 0.59 to 0.60 under the actual estimated CO_2



After applied actual estimated CO_2 , ET decreased by average 2 % compared default CO_2 PPM (330 PPM).

After applied estimated CO_2 WY increased by average 1.5 % compared default O_2 PPM (330 PPM)

After applied estimated CO_2 SW increased by average 6.0 % compared default O_2 PPM (330 PPM)

As ET, WY are amount (mm) per unit area (km^2), loss volume by ET mistakenly simulated as 51,753.8 ton/year under default CO_2 condition (330 ppm).

Summary and Conclusion

- ✓ The hydrological model SWAT was applied to investigate hydrological effects of rising CO_2 concentrations in watershed.

  - For estimation of CO_2 flux using MODIS GPP, the MODIS GPP product, 8-day composite at 1-km spatial resolution was adopted for the spatial CO_2 flux generation. The MODIS GPP data were corrected by Quality Control (QC) flag. The MODIS CO_2 flux was estimated as the sum of GPP and Re (ecosystem respiration) by Lloyd and Taylor method (1994).

  - The Evapotranspiration could annually decrease about average 2 % in contrast water yield, soil water content could annually increase about 1.5, 6 % respectively, under actual estimated CO_2 concentration.

  - As ET, WY are amount (mm) per unit area (km^2), loss volume (ton) by ET decrease as 51,753.8 ton/year under actual CO_2 concentration.

  - Our analyses of sensitivity of hydrological components to actual estimated CO_2 on the direction, magnitude, and spatial distribution of hydrological responses provide needed input for consideration towards watershed management and policies for water resource management.

" Thank You "

For further information, please contact:

JUNG, Chung-Gil
Doctoral candidate, Dept. of Civil & Environmental System Engineering, Konkuk University
wjd0823@konkuk.ac.kr

Dept. of Civil and Environmental System Eng.,
Konkuk University, Seoul, South Korea