CE5317QA Ecohydrology

Personal Work

-- Sensitivity Analysis of Eco-Hydrology Properties based on Tethys-Chloris (T&C) Model

- Pan Xinxin

Methodology

➢ Ecohydrological model – Tethys&Chloris (T&C)

1. In **T&C**, the simulation time chosen is **5yrs** (NN=43824 hrs; 1826 days), to ensure vegetations can adapt to new conditions.
2. Extract data from the last year (2014-01-01 to 2014-12-31), to ensure the stable feedback and this time range a full acclimation of vegetation to the new conditions.
3. Aggregate hourly data to daily or monthly data, to visualize the obvious changes.
4. The data analysis is taken **in R and Matlab**. Use functions for the Multiple or Simple Linear Regression, and give some relevant plot to analyse statistical indicators to check the regression relationship (seen in the table).

■ Statistical Indicators and Plot in R

Indicators	Interpretation
p-value	A low p-value (usually less than 0.05) suggests that the regression model is right. It indicates that the predictor variable(s) have a statistically significant relationship with the response variable.
R-square	R-square ranges from 0 to 1, where 0 indicates that the model does not explain any variance, and 1 indicates a perfect fit.
Residuals vs. Fitted	When the line y approximates to 0 and slightly fluctuates without the obvious trend, meaning residuals should be randomly scattered around zero, and the model is better fitted.
Normal Q-Q Plot	Check the normality residuals and the validity of model. If it is close to a straight line, that means the residuals are normal and the model is good.

➢ Experiment (1): Variables for soil properties, changing the content of sand and clay (soil textural classes):

① Sand = 88% *sand + 5% *clay
② Silt = 10% *sand + 5% *clay
③ Clay = 25% *sand + 50% *clay

➢ Experiment (2): Sensitivity to variation in meteorological forcing (Pr and CO_2)

① -50% Pr
② + 300 ppm CO_2

Results and Analysis

1. Experiment (1): Sensitivity to soil properties

   - components: θ, T_H, EG, ET, GPP

2. Experiment (2): Sensitivity to variation in meteorological forcing (Pr and CO_2)

   - components: ET, GPP

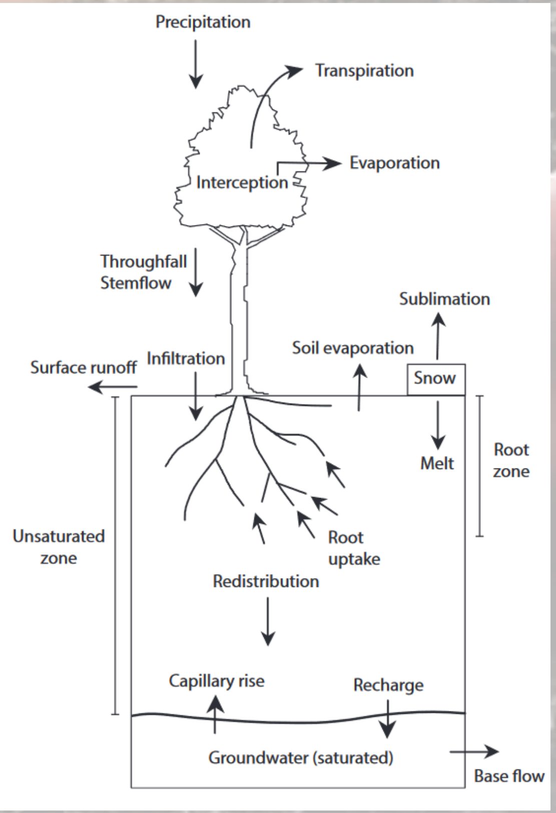
Results & Analysis

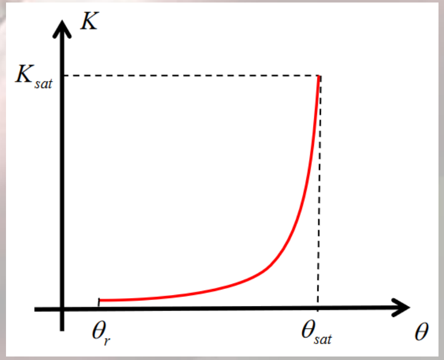
➢ 1.0 Soil texture & hydraulic parameters

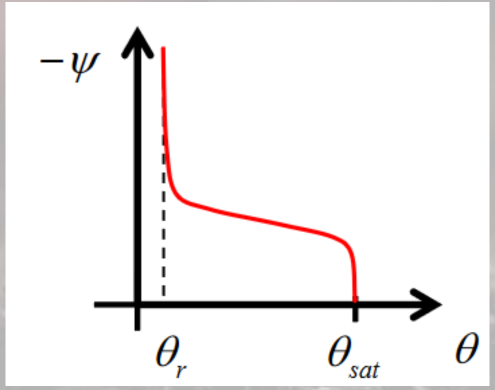
➢ Parameters & Methodology

1. The effective soil hydraulic parameters:
   ① Soil Porosity: n
   ② Water Content: θr (Residual/Hygroscopic water content), θsat (Water content at saturation)
   ③ Saturated hydraulic conductivity: Ksat
2. The hydrological processes are modeled in the unsaturated zone based on the governing equation - Richards Equation:
3. Other factors define processes:
   ① Hydraulic conductivity function: θ↓→ K↓; considering the same initial simulation settings, the initial water content in the first layer (bare surface) depends on the soil types.
   ② Moisture retention curve: relate the capacity of soil holding water to water potential and water content.
4. The data extracted from the last year (2014), because of the more stable simulation results.

NO	Parameter	UNIT	sand	slit	clay	Description
1	Ks	mm/h	**106.07**	17.65	1.01	Hydraulic conductivity at saturation – Reference Value
2	Ofc	-	0.279	0.251	**0.465**	Water content at field capacity
3	Ohy (theta_r)	-	0.0306	0.023	**0.25**	Residual/Hygroscopic water content
4	Osat (theta_sat)	-	0.45	0.456	**0.496**	Water content at saturation
5	O33	-	0.0954	0.297	**0.421**	Soil water content at -33 [kPa] of water potential







$$K = K_{sat}\left(S_e\right)^{0.5}\left[1-\left(1-S_e^{1/m}\right)^m\right]^2$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\left(\frac{\partial \psi}{\partial z}+1\right)\right]$$

Results & Analysis

➢ 1.1 Water content

➢ Result analysis: Water content (θ) profile

1. The vertical water content profile: From these 3 stacked-area plots for the first 5 soil layers (Δlayer depth=500mm), the changing trends of θ are similar, referring to slightly increases from the 1st to deeper layers until the root, and that is related to the precipitation with a little time delay.
2. The different **θ** in soils indicates: clay >> sand >silt. There are main factors:

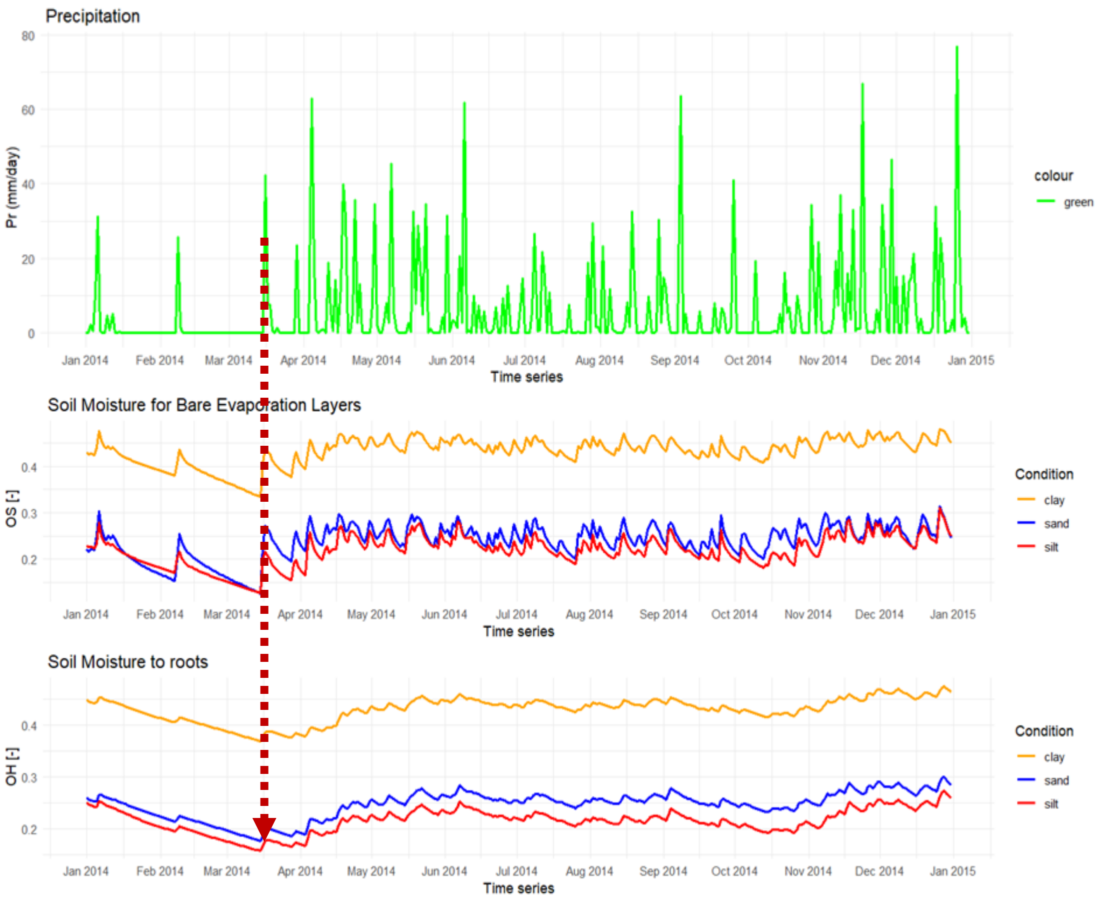
① The Effective Saturation:

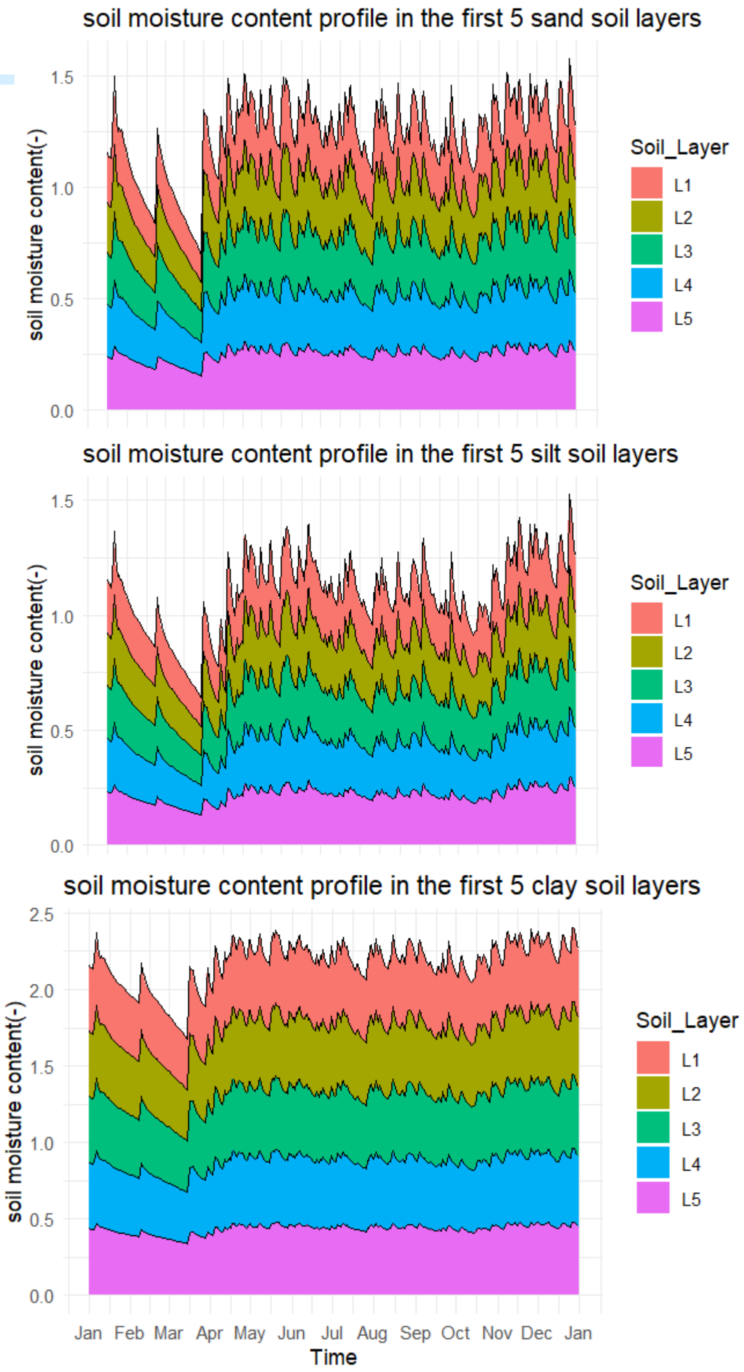
$$S_e = \frac{\theta - \theta_r}{\theta_{sat} - \theta_r}$$

② Soil Water Potential - field capacity shows the degree of holding water in soil, and the corresponding water content is θ_33 in model.

$$\psi \approx -33 \quad \text{[kPa]}$$

③ Consider the main mechanisms for water retention: the surface tension.



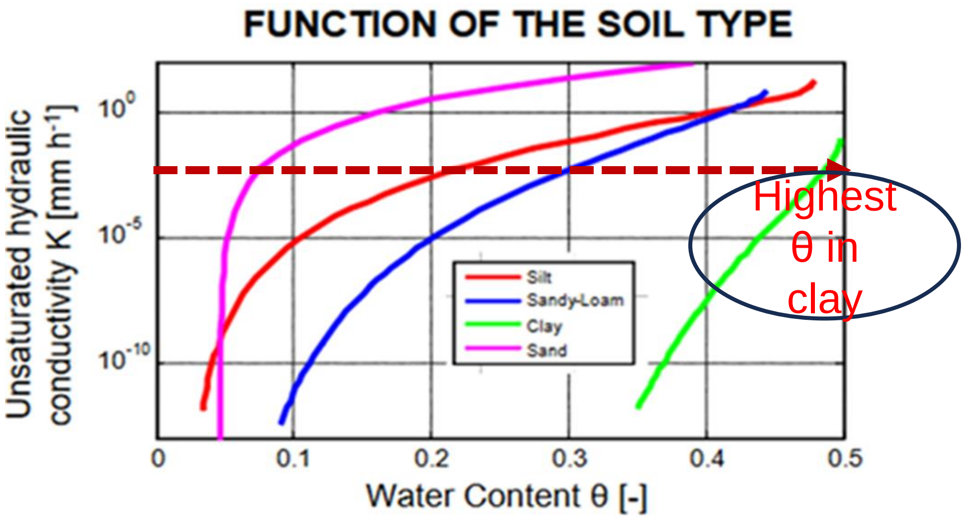


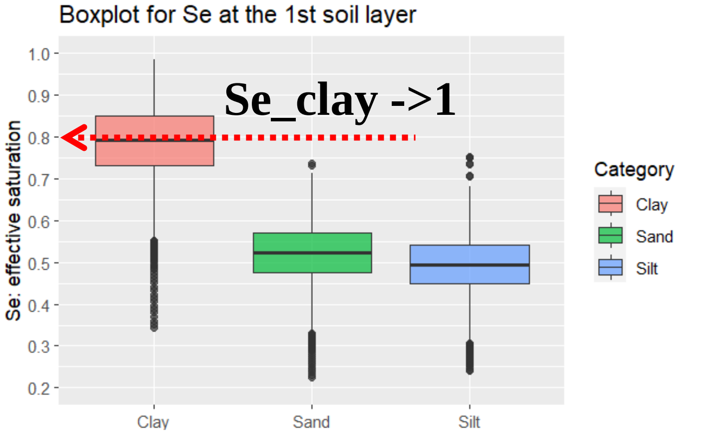
Results & Analysis

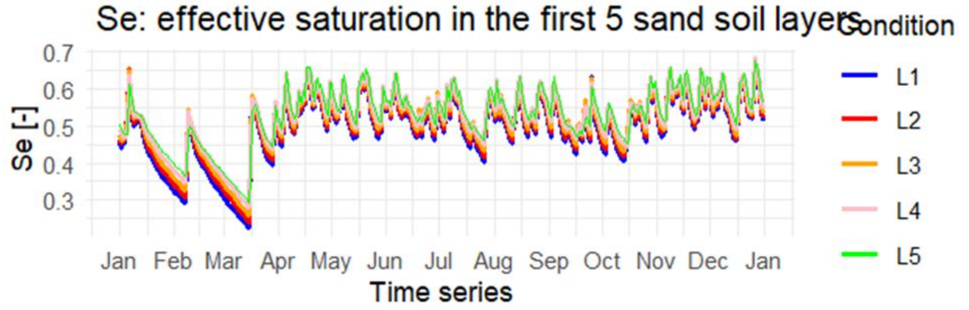
➢ 1.1 Water content

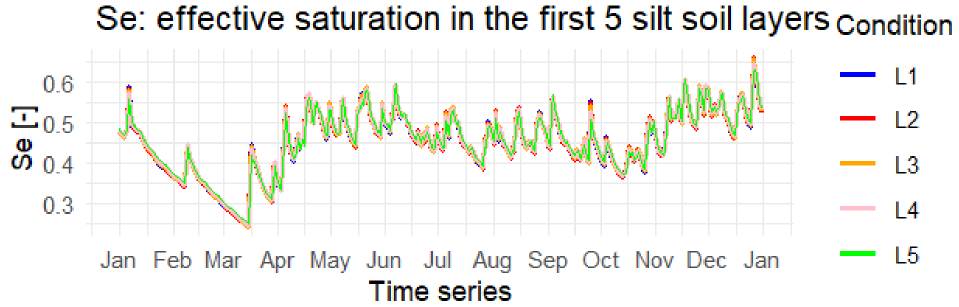
➢ Effective Saturation Se

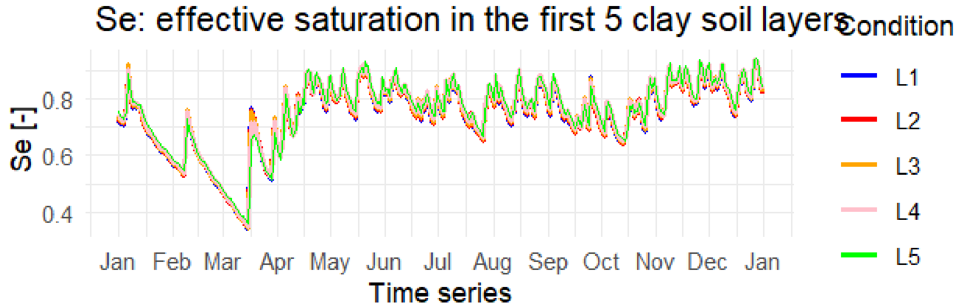
1. The boxplots and line plots show the distribution of Se:
   ① Se_clay is highest and mostly 0.8, that is closer to 1.0;
   ② Se_sand and Se_silt are close at 0.55.
2. The range of Se is [0,1], and when it is close to 1, that suggests the clay is nearly saturated with a higher water content, and the gravity dominates the flow.
3. One of the factors is related to the Se and K (seen in the following function of the soil type). In the 1st soil layer as the unsaturated zone, when the initial K is same, the corresponding θ in clay is highest.









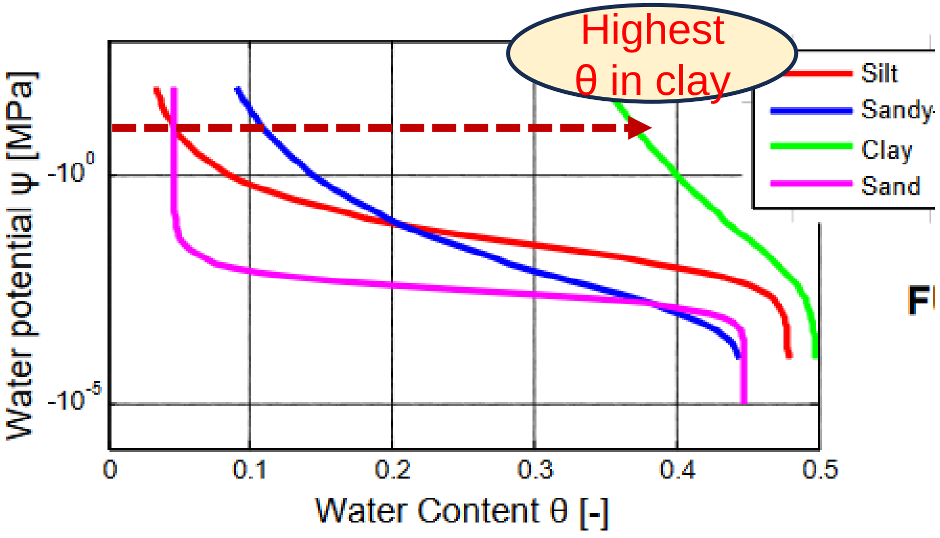


Results & Analysis

1.1 Soil moisture content profile

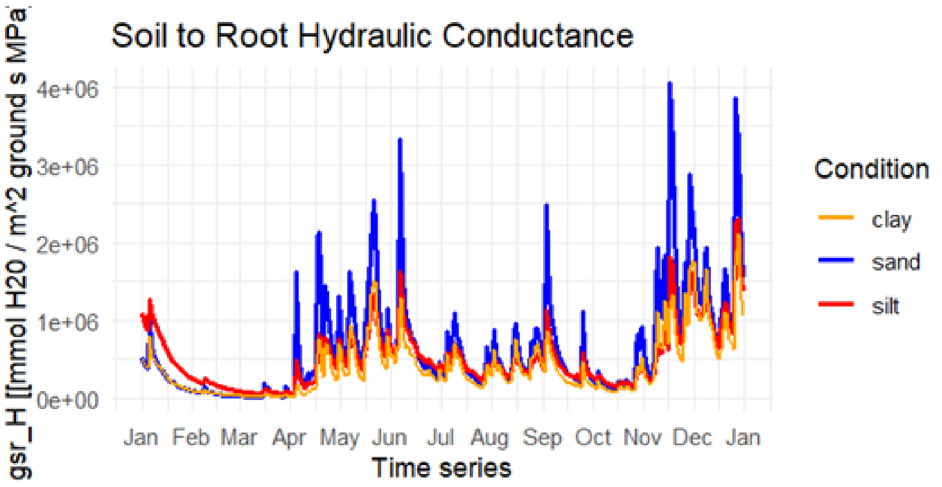
Soil Water Potential & Surface tension - capillary potential

1. The capillary potential is mainly responsible for water retention in unsaturation zone.
2. When the water potential ψ=-33kPa, that indicates the field capacity, which is the water potential holds water in the soil. In the model, O_33: clay > silt >> sand.
3. When it is rain, and the same water potential ψ occurs in the soil, the clay can hold more water and shows a higher θ.
4. At high water contents, water flow in the soil is controlled by gravity; at lower water contents capillarity is the dominant process with strong negative water potentials



Hydraulic Conductivity

1. In the sand, as a lower water content and the drier soil, the pore space filled with water becomes bigger, thus its suction increases, referring its hydraulic conductivity increases sharply.
2. The water content in sand is relatively higher in wet April than that of silt, within the increasing precipitation and infiltration, because the higher conductance and suction.



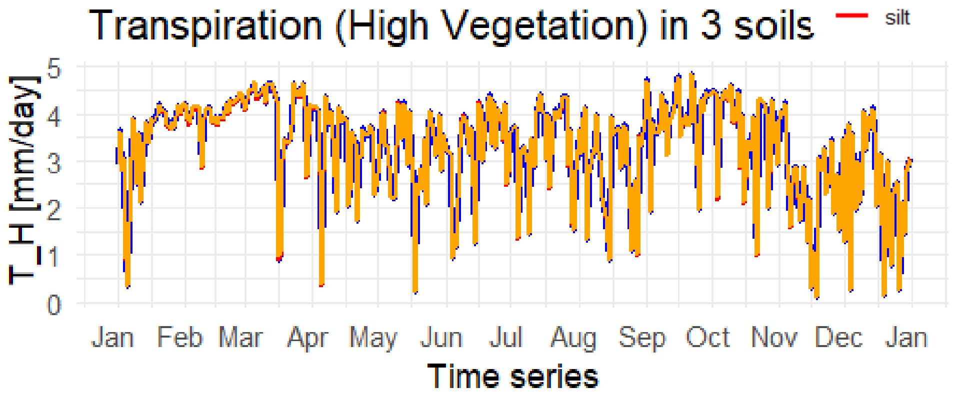
Results & Analysis

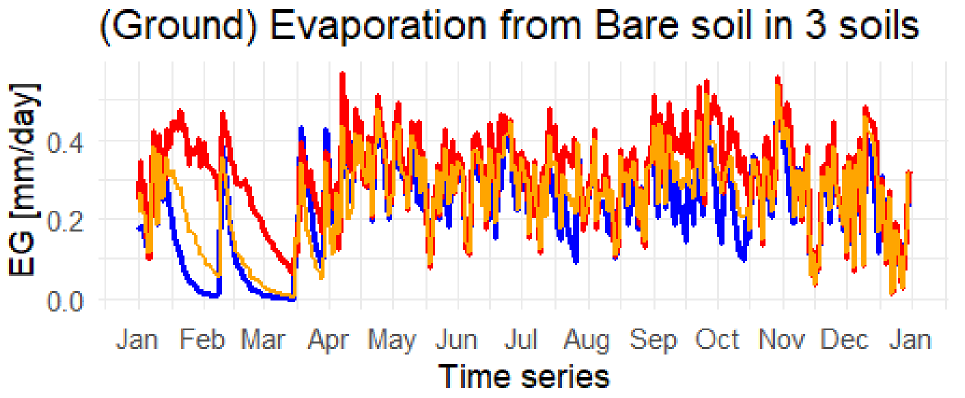
➢ 1.2 Transpiration & Ground Evaporation

➢ Results analysis:

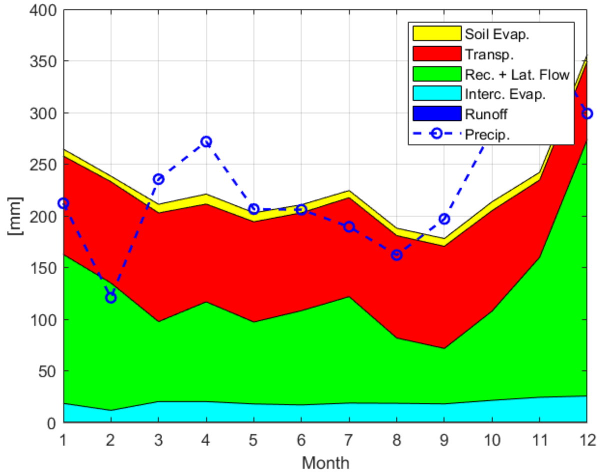
1. Transpiration (T_H, for High Vegetation):
   ① The trend and value of T is **similar** in various soils.
   ② When the total precipitation increases in Apr, Nov and Dec (wet seasons in SG), T in sand is sightly higher than another two.
   ③ When the total precipitation decreases from May to Sep (relatively dry season in SG), T is relatively lower.
2. Ground Evaporation (EG):
   ① In dry seasons, monthly EG from sand and clay is relatively lower;
   ② EG from clay is highest at all.
3. In the Richards Equation, T_H and EG act as Sink terms:

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left[K(\theta)\left(\frac{\partial\psi}{\partial z}+1\right)\right]-E_g(z)-T(z)$$

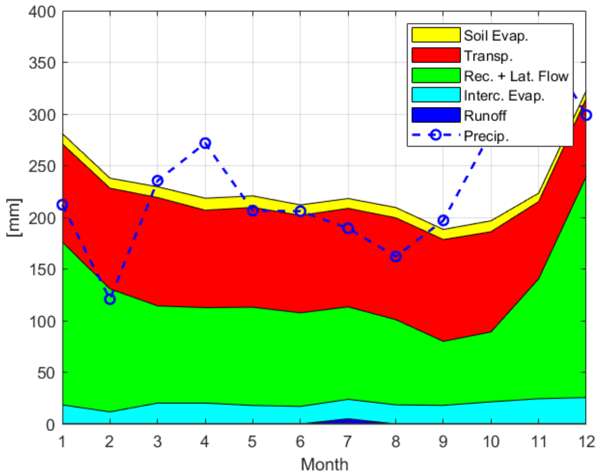




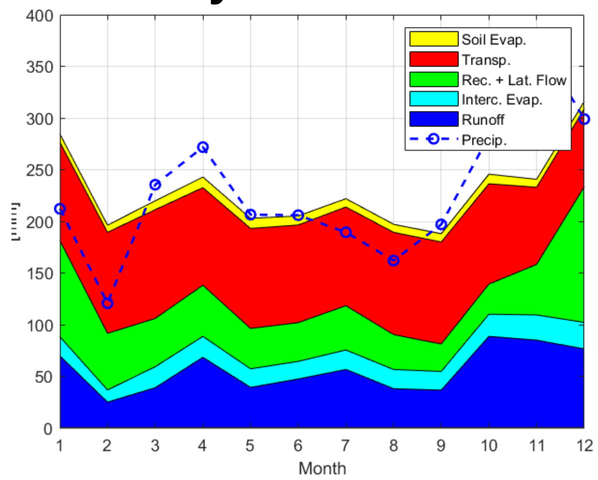
➢ Sand

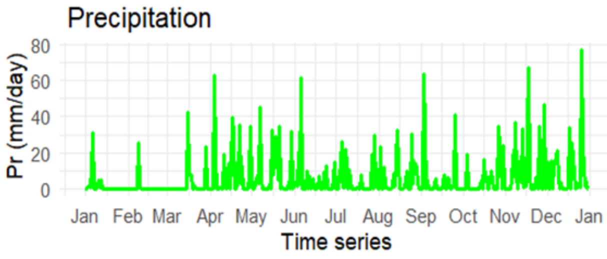


➢ Silt



➢ Clay





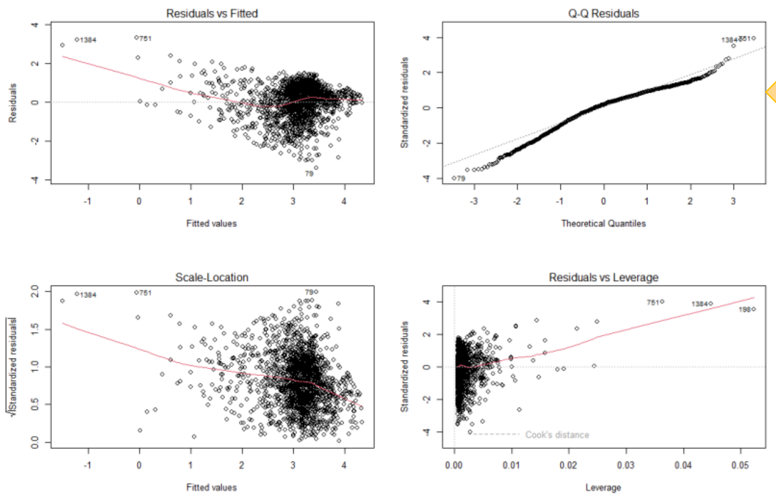
NOTE:
Dry seasons: Jan to March

Results & Analysis

➢ 1.2.1 Transpiration

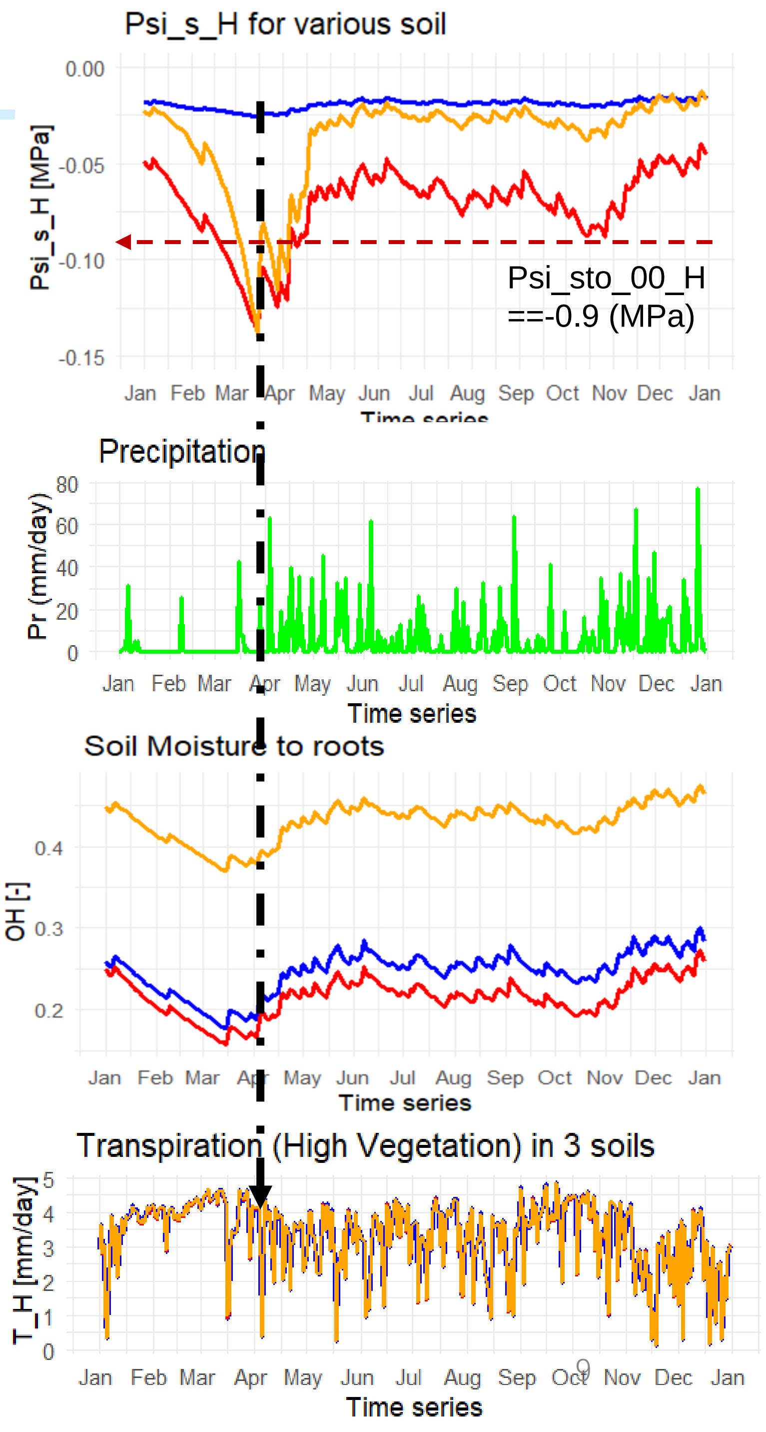
➢ Factors and Multiple Linear Regression

1. The feedback mechanism between soil moisture θ and transpiration:
   ① **Water Uptake**: Soil moisture provides the water source for plant roots. As transpiration occurs, water saved in roots moves through the plant and eventually exits through the stomata.
   ② **Stomatal Closure**: In response to low soil moisture, plants may close stomata to reduce water loss through transpiration and conserve water -> Reduced Transpiration.
   ③ Soil to Root Hydraulic Conductance.
2. In this model, the water potential at the beginning of stomatal closure is equal to -0.9MPa. From the FIG. Psi_s_H (Soil water potential felt by the roots), as Psi_s_H(clay and silt)<-0.9MPa, indicating the stomata is close in dry season.
3. Define a multiple linear function: lm(y~x): T_H ~(Pr + Psi_s_H + OH)



NOTE: Statistical analysis and plots

a) p-value< 2.20E-16, the multiple linear model is correct;
b) R-square=0.3, the proportion of variability explained by the predictors is relatively low;
c) Normal Q-Q plot: The residuals are normal and the model is good.



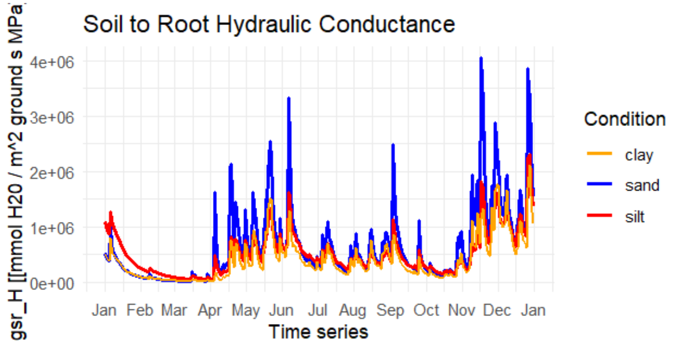
Results & Analysis

➢ 1.2.1 Transpiration

Coefficients	(Intercept)	Pr	Psi_s_H	OH
sand	-12.5	-0.025	-457.5	29.37
silt	3.8	-0.026	-8.35	-4.50
clay	11.4	-0.026	5.58	-17.98

➢ Factors and Analysis

1. The multiple linear function lm(y~x): T_H ~(Pr + Psi_s_H + OH) ->
   a) For every one-unit increase in Psi_s_H (Soil water potential felt by the roots), T in sand decreases most;
   b) For every one-unit increase in OH (Soil Moisture available to roots), T in sand increases most.
2. Consider the water transport path, from the roots to stomata in the epidermis of leaves:



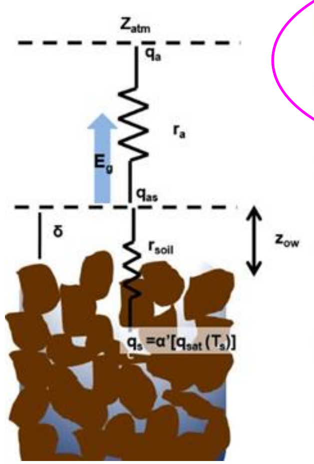
   ① The water content in the clay's root layer OH is highest, but its hydraulic conductance is lower, causing the actual water attracted into leaves to be not too high.
   ② In dry season (especially in April), with the decreasing precipitation, Psi_s_H of clay and silt reaches that of the beginning of stomatal closure, that means stomata tends to close to reduce water, causing lower transpiration rate compared to that of sand. Considering the statistical results, only T in sand and Psi_s_H present a significant degree of negative correlation, that is due to that plants in sand will not start the stomatal closure within the same amount of rainfall, causing the higher transpiration. Assume when the roots water potential in sand increasing to Psi_sto_00_H, there will be obviously decrease of T.
   ③ Combine the above explanation, although the plants in clay extract relatively more water from roots, its leaves' stomata closes, causing a lower rate of transpiration and restoring water. Thus, the total of transpiration in clay will be as similar as the other two.
3. There are not obvious differences in the T_H trends: the total transpiration is the balance of water potential in roots and hydraulic conductance, and the degree of stomatal closure.

Results & Analysis

➢ 1.2.2 Ground Evaporation

➢ **Factors and Analysis:**

1. Ground evaporation occurs from the soil close to the surface, and it is strongly controlled by:
   ① Soil resistance (r_soil): sand >> clay ≥ silt;
   ② water content θ in surface soil (OS).
2. Although EG from clay is highest at all, the main difference of EG occurs in Feb, when it is the minimum precipitation, and the soil resistance of sand increases sharply.
3. Consider the Empirical Methods general equation for EG:



Empirical Methods general equation

$$E_g = \frac{\rho_a \beta\left[\alpha(\alpha' q_{sat}(T_s)) - q_a\right]}{r_a}$$

Empirical method (α)

$$\alpha = \frac{q_{as}}{\alpha' q_{sat}(T_s)} = f(\theta, Soil) \qquad \beta = 1$$

Empirical method (β)

$$\beta = \frac{E_g}{E_{g,POT}} = f(\theta, Soil) \qquad \alpha = 1$$

And combine the statistical analysis in the next slide
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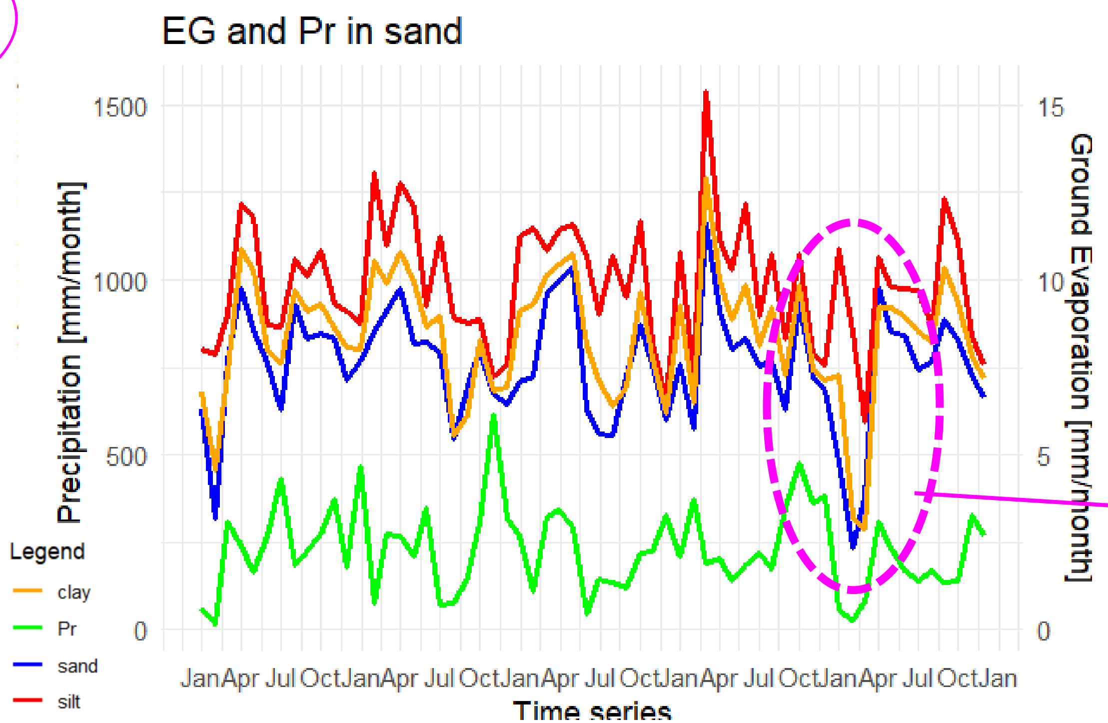
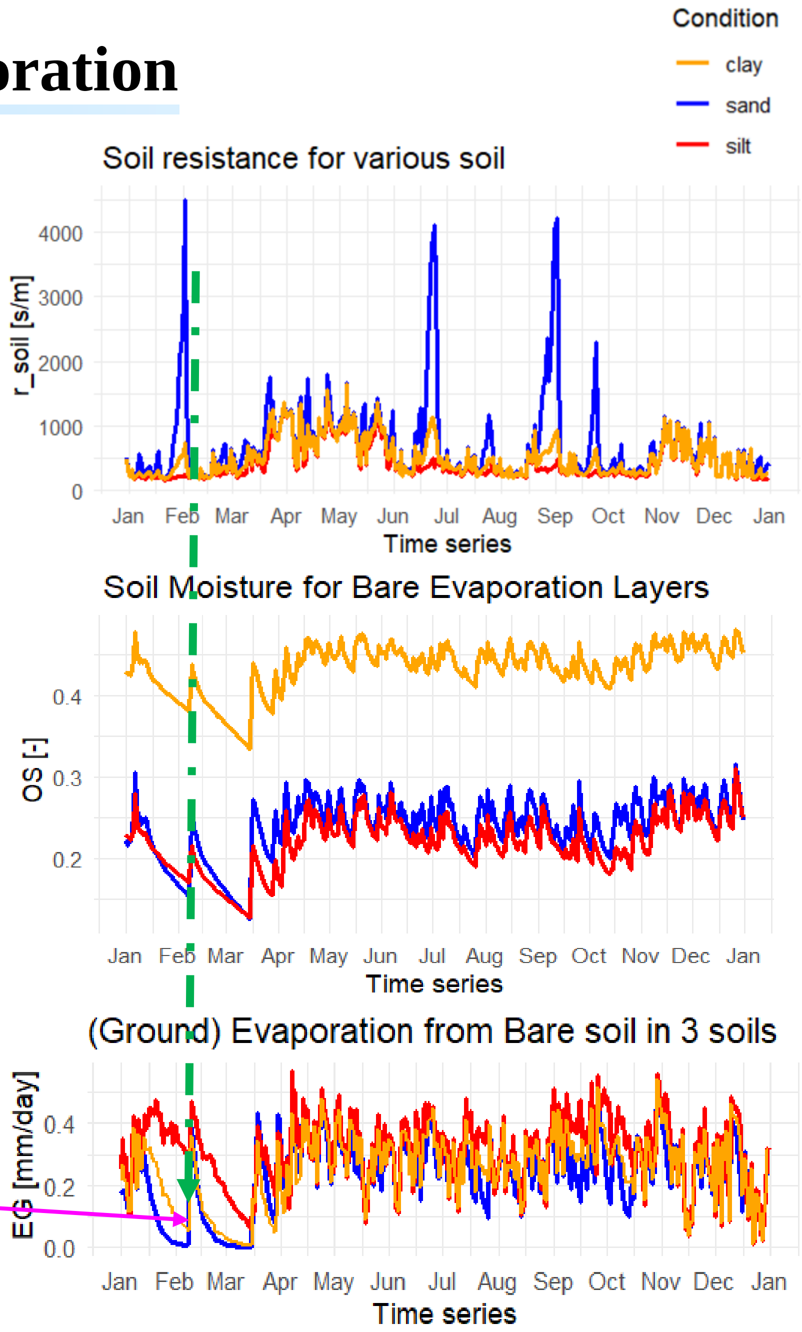




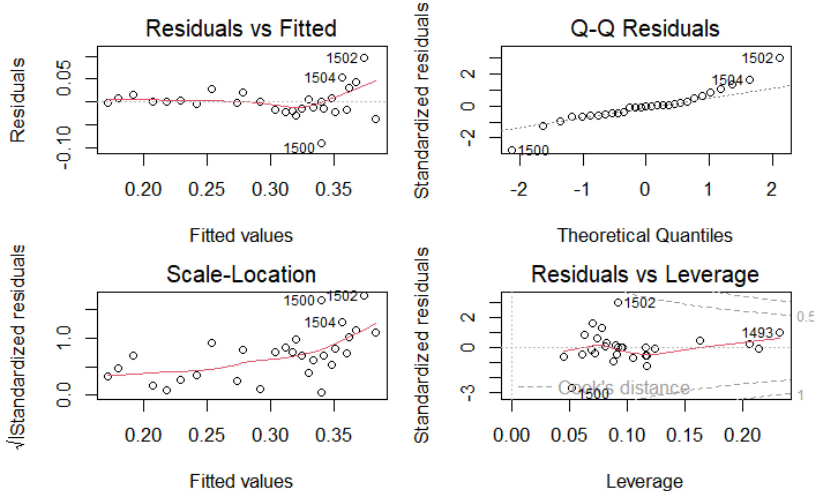
Results & Analysis

➢ 1.2.2 Ground Evaporation

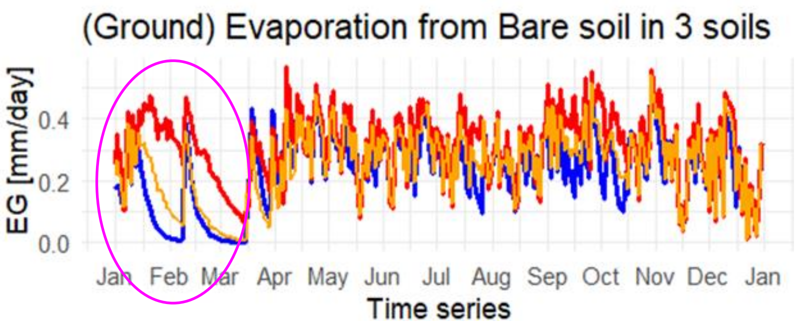
➢ Empirical Methods general equation for EG and Regression:

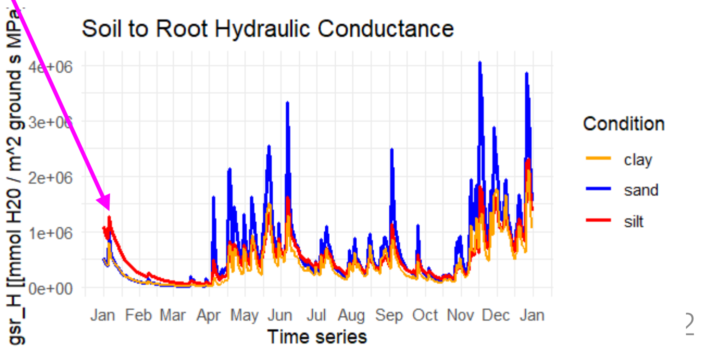
1. In the driest season, Feb, the soil resistance (r_soil) dominates ground evaporation (negative correlation): $E_g = \frac{\rho_a(\alpha' q_{sat}(T_s) - q_{as})}{r_{soil}}$
2. Some of soil resistance (r_soil) accounts for the resistance for vapor transport from the surface to the atmosphere just above the pore. When it is dry, there is less water in the pore, and the resistance in the pore will define EG. It is also related to the hydraulic conductance. In Feb, sand shows a lower conductance and a higher resistance, that causes it is hard to transport surface vapor water into the atmosphere, meaning a lower EG.
3. From the regression relationship, the p-value is less than 0.05, and R-square shows the model is correct, indicating most changes of EG can be explained by r_soil and OS in Feb.
4. Considering the sharp increasing of sand's r_soil, it can be seen that r_soil(sand) can decrease EG significantly.

(EG ~ r_soil + OS) in Feb - dry season					
Coefficients	(Intercept)	r_soil	OS	p-value	R-square
sand	-1.0	-2.30E-06	5.42	1.56E-05	0.57
silt	-4.3	-7.27E-05	4.11	1.77E-09	0.77
clay	-8.0	-9.70E-06	2.38	2.40E-04	0.47



➢ Dry season (in Feb)





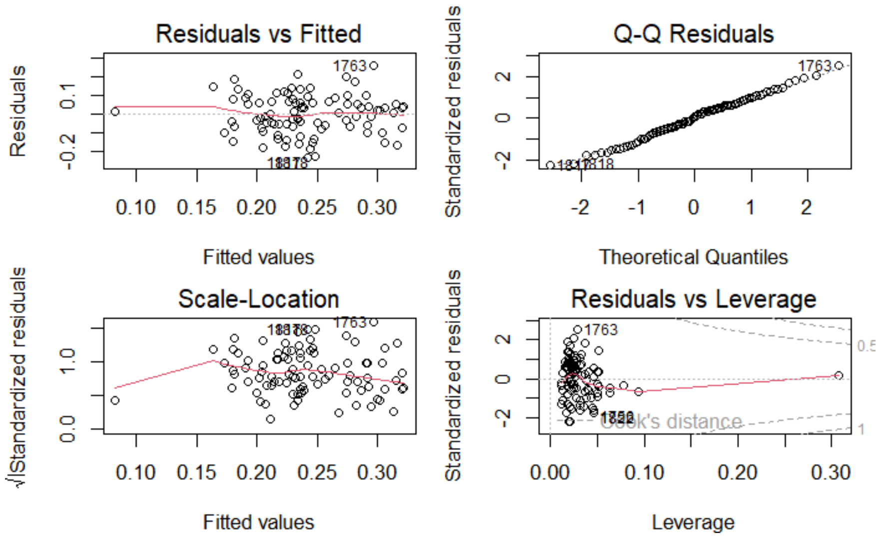
Results & Analysis

➢ 1.2.2 Ground Evaporation

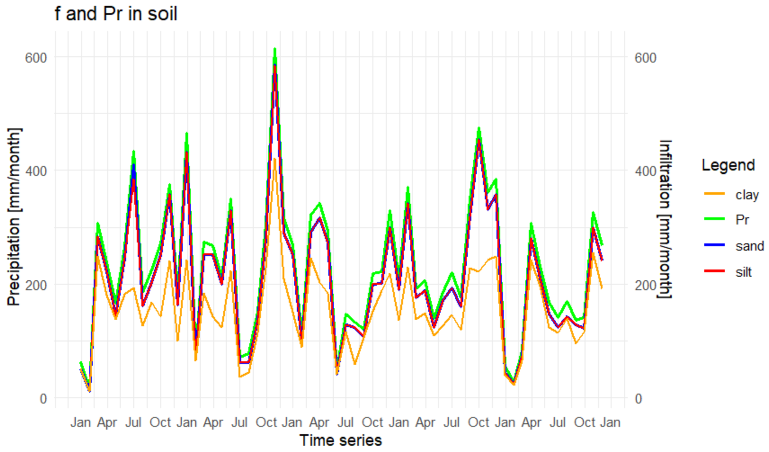
➢ Empirical Methods general equation for EG and Regression

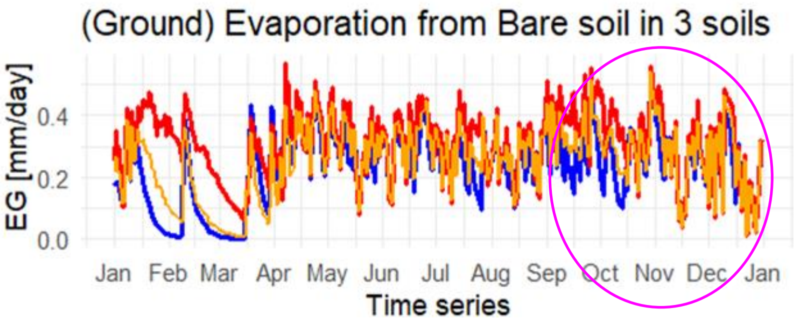
5. In wet seasons, from Oct to Dec, there is no obvious difference of EG. One of factors is the similar r_soil, that causes the same EG.
6. In wet seasons, the regression shows an incorrect effect (too low R-square value), that means it is not fitted by this scenario.
7. Considering the infiltration(f) = Pr - EG, that is one order of magnitude larger than the EG amount. That of clay is lowest, and that of sand and silt are same with a relatively higher value. But the most water will be hold in clay as its highest O_33, the finial EG of these 3 soil is similar.
8. Due to sufficient moisture, the 3 soil may be able to provide sufficient water supply during the rainy season, also can reduce the evaporation differences between them.

(EG ~ r_soil + OS) in Feb – wet seasons					
Coefficients	(Intercept)	r_soil	OS	p-value	R-square
sand	0.84	-7.55E-05	-2.06	7.50E-04	0.15
silt	0.81	2.01E-06	-2.29	2.10E-04	0.17
clay	1.77	-3.01E-05	-2.01	1.60E-02	0.09



➢ Wet season (Oct to Dec)



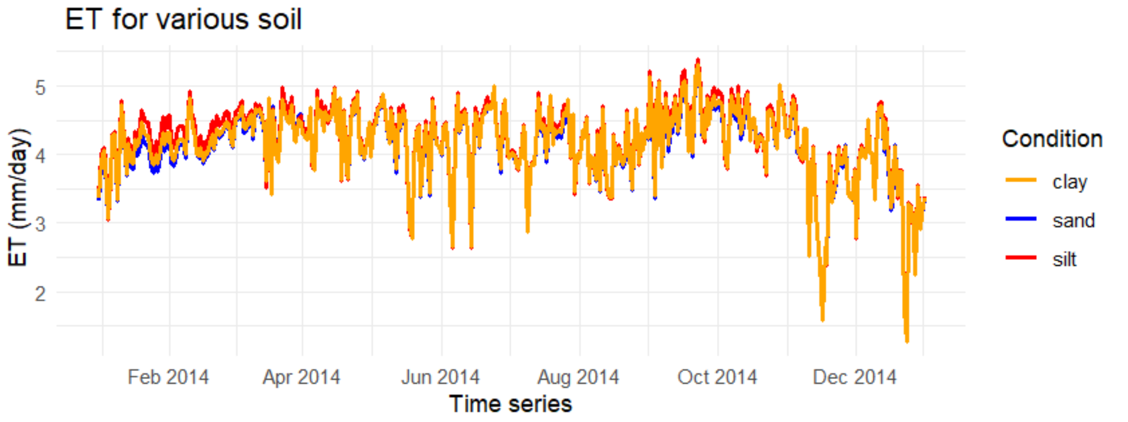


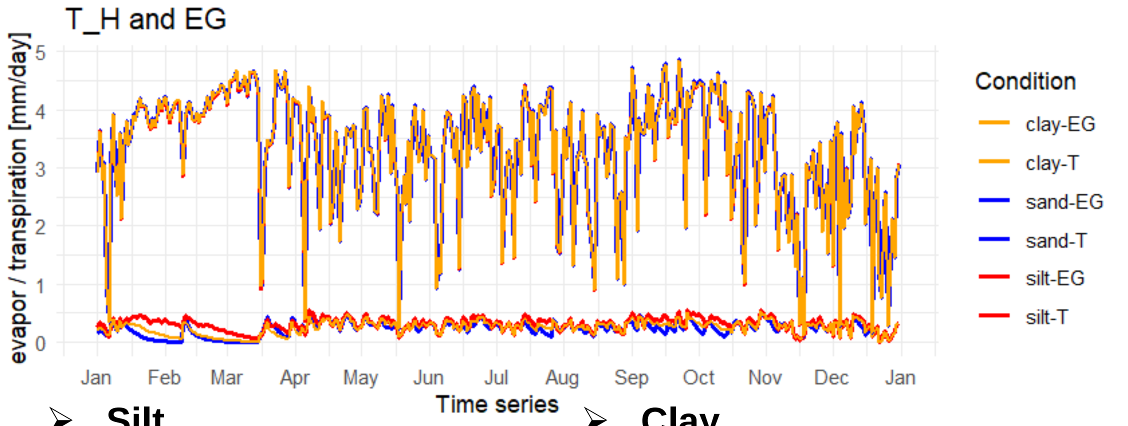
Results & Analysis

➢ 1.3 ET: total evapotranspiration

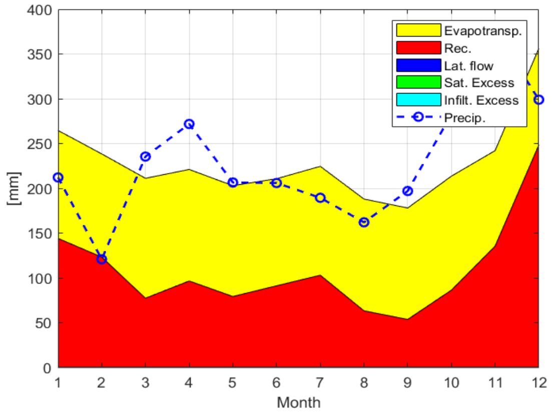
➢ Result analysis

1. Consider the main components, ET = T_H + EG. As the magnitude of T_H is one order larger than the EG amount, and there are not obvious differences in the T_H trends, the significant trends depends on the changes of EG.
2. In driest season, Feb, there is an obvious difference in ET: silt>clay>sand, that is related to the significant difference in EG, meanwhile T_H is similar in 3 soils.
3. In other months, as the sufficient water moisture, that can reduce the evaporation, the EG in 3 kinds of soil is similar, the total ET is similar.

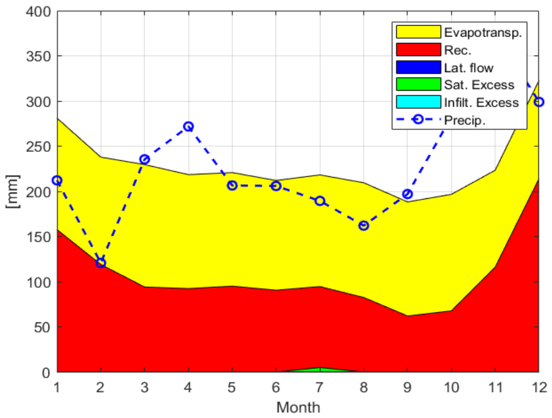




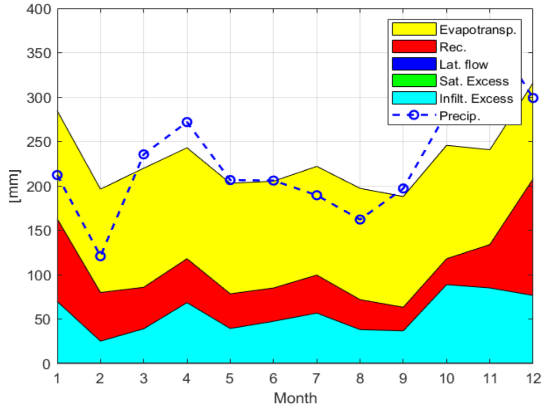
➢ **Sand**



➢ **Silt**



➢ **Clay**

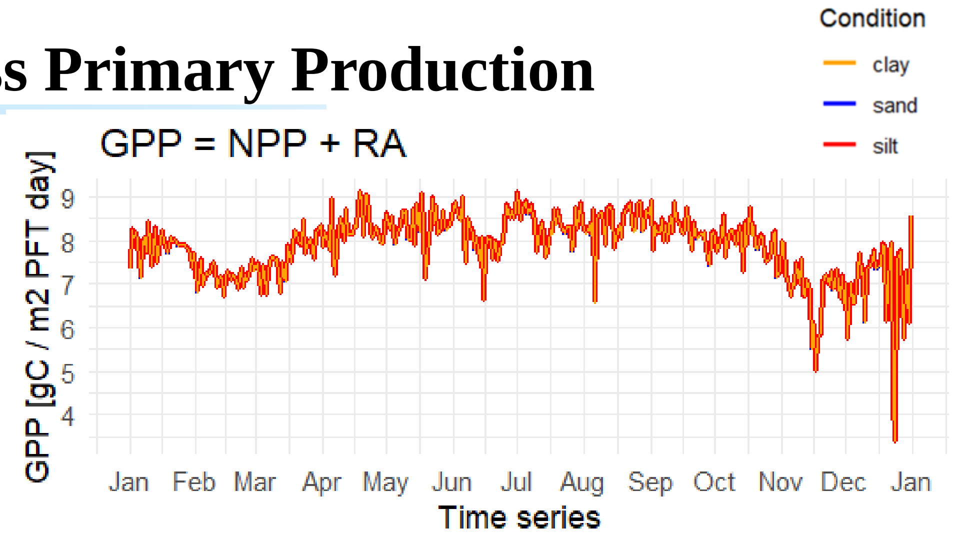


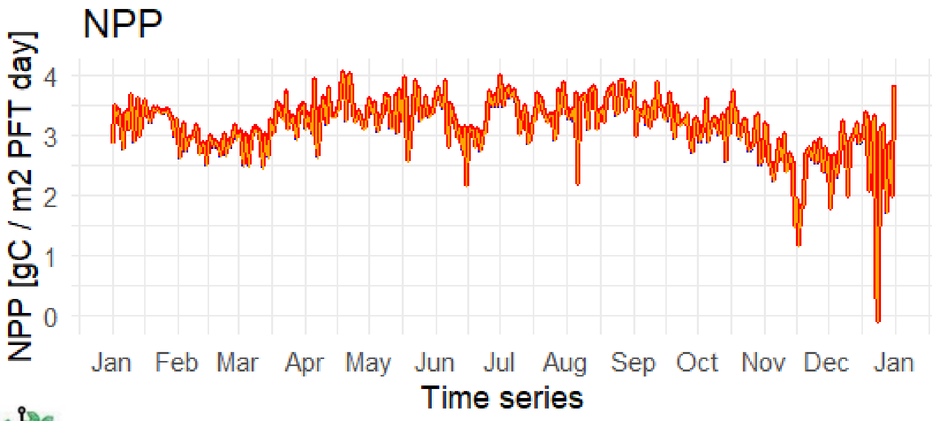
Results & Analysis

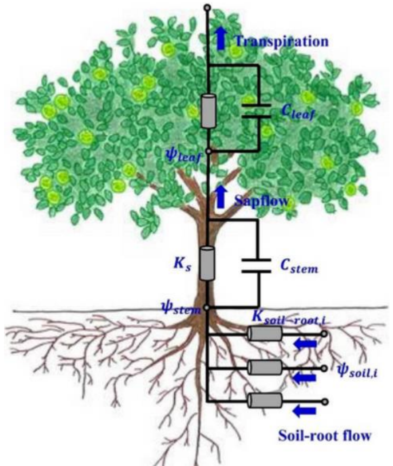
➢ 1.4 GPP: Gross Primary Production

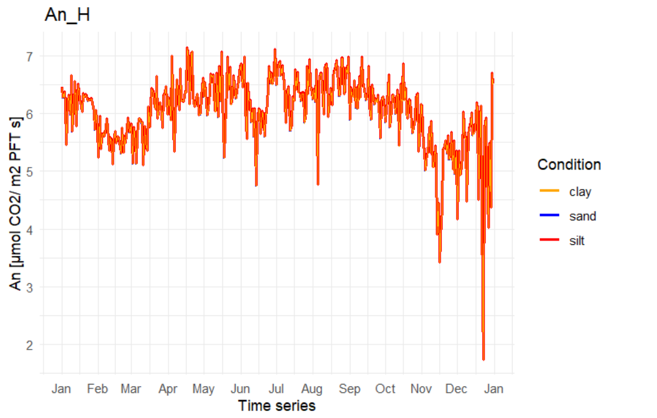
➢ Result analysis

1. **GPP = NPP+RA_H**
2. There are not obvious differences in GPP, including the components NPP (Net Primary Production) and RA (Autotrophic Respiration High Vegetation).
3. Consider the carbon cycle: $A_g = A_n + R_d$ ➡ $GPP = \kappa \overline{A_g}$
   Where the gross carbon assimilation Ag is same in 3 kinds of soil.
4. The atmospheric conditions dominate the Gross or Net Primary Production, instead of the soil properties, as even that in different soil, the nutrient availability or gross carbon assimilation will not change.
5. Also, as the different water content and potential only affect the water transportation, CUE in leaves (NPP/GPP Carbon Use Efficiency) or carbon cycle will not change as the water in roots.









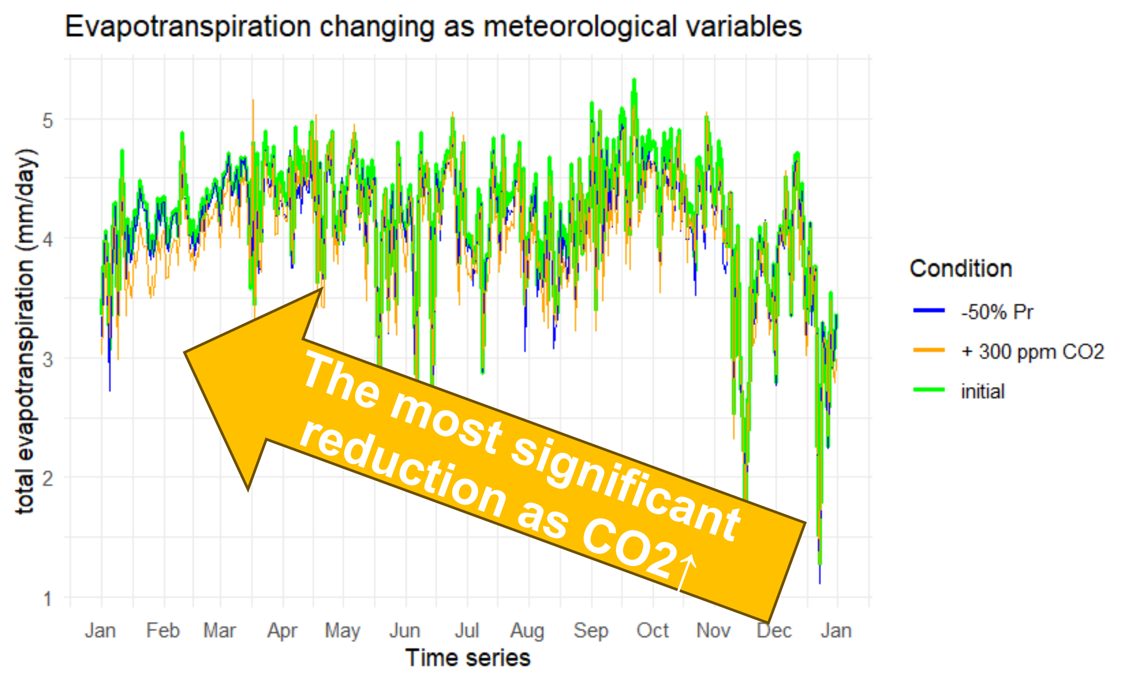
Results & Analysis

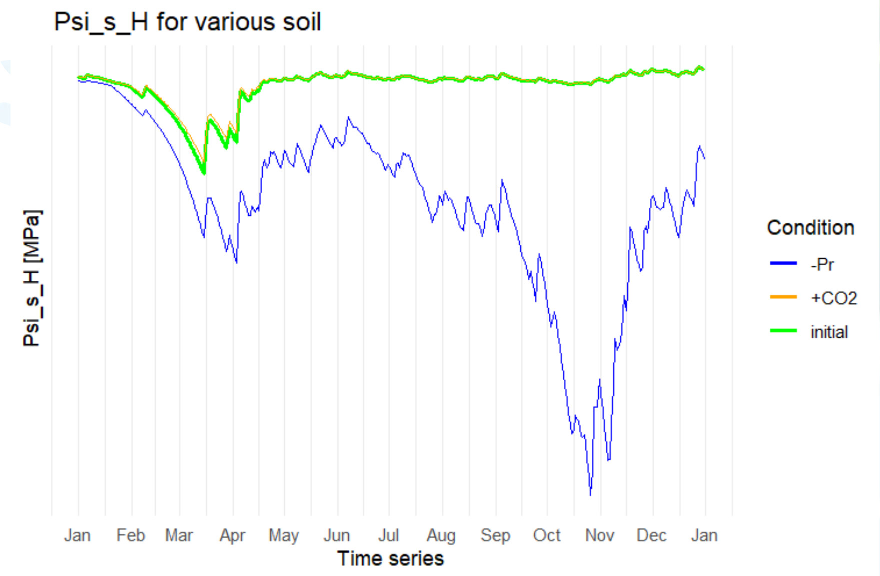
➢ 2.1 ET: Total Evapotranspiration

➢ Result analysis

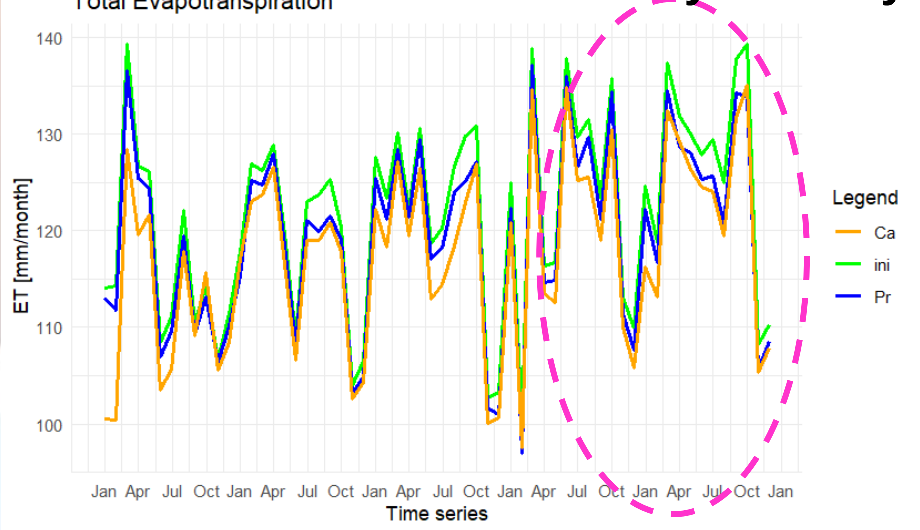
1. There are tiny difference in ET:
   ① When **Pr** decreases by half (-50% Pr), ET will decrease;
   ② When **Ca** (CO_2 atmospheric concentration) increases (+300 ppm), ET will be lower than that reduction of Pr. Especially in driest Feb, ET will sharply decrease.
2. The difference caused by Pr is related to the water content in soil. Use the soil water potential felt by the roots (Psi_s_H) as the soil hydraulic indicator, it can be seen that since the reduction of Pr, the corresponding water content is lower, and then the stomata closes, leading the lower transpiration in leaves and the total evapotranspiration.

- Daily ET in 2014





- Monthly ET in 5yr

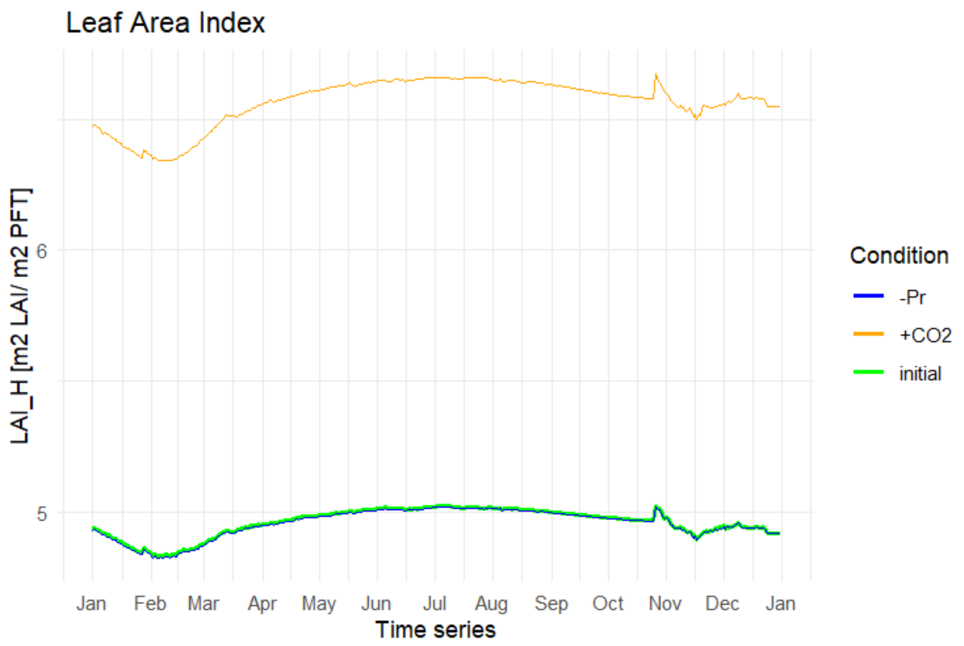


Results & Analysis

➢ 2.1 ET: Total Evapotranspiration

➢ Result analysis

3. The difference caused by CO2 is as the plant growth, and LAI is used to show the growth of canopy structure. From the fig, the LAI of increasing CO2 is significantly higher, indicating the more extensive and denser canopies as the more carbon as its nutrition.

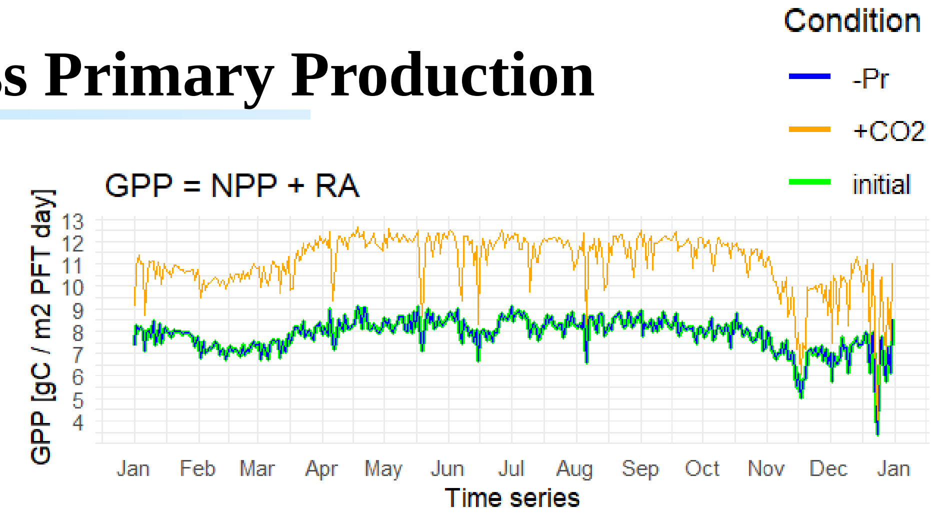


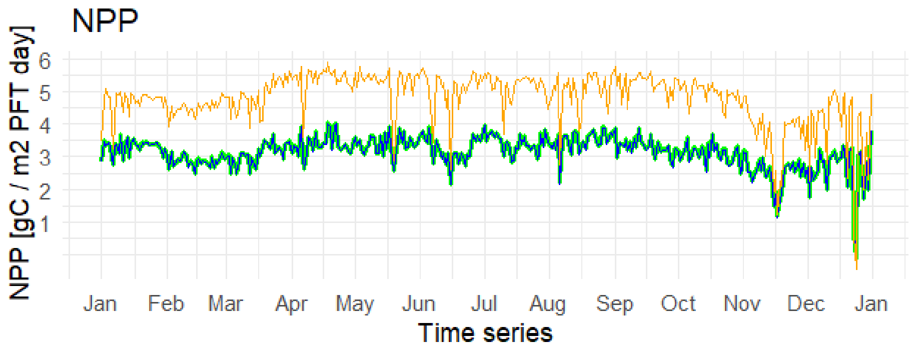
Results & Analysis

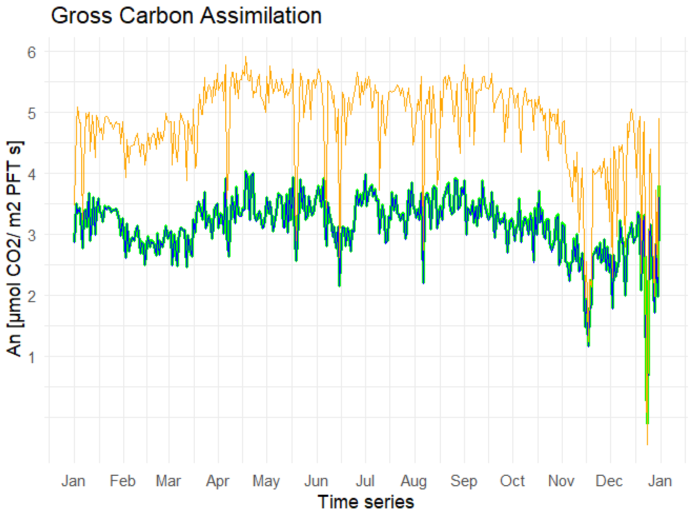
➢ 2.2 GPP: Gross Primary Production

➢ Result analysis

1. There are tiny difference in GPP:
   ① The precipitation related to water content in soil will not affect carbon cycle (i.e. GPP or NPP);
   ② When **Ca** (CO2 atmospheric concentration) increases (+300 ppm), the corresponding GPP is higher. It can be quantified as the gross carbon assimilation (An) indicator.
2. A plant uses the carbon gained during photosynthesis for maintenance and survival. When CO2 increases, the more carbon can be gained for plants and leaves, referring to higher carbon assimilation, thus the GPP increases.







$$A_g = A_n + R_d \quad \Rightarrow \quad GPP = \kappa \overline{A_g}$$

GPP **=** Gross Primary Production [gC m^{-2} day^{-1}]
A_g **=** gross carbon assimilation [μmol CO_2 m^{-2} s^{-1}]
A_n **=** net carbon assimilation [μmol CO_2 m^{-2} s^{-1}]
R_d **=** leaf mitochondrial respiration [μmol CO_2 m^{-2} s^{-1}]
κ = 1.0368 unit conversion factor [gC s μmol CO_2^{-1} day^{-1}]

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