

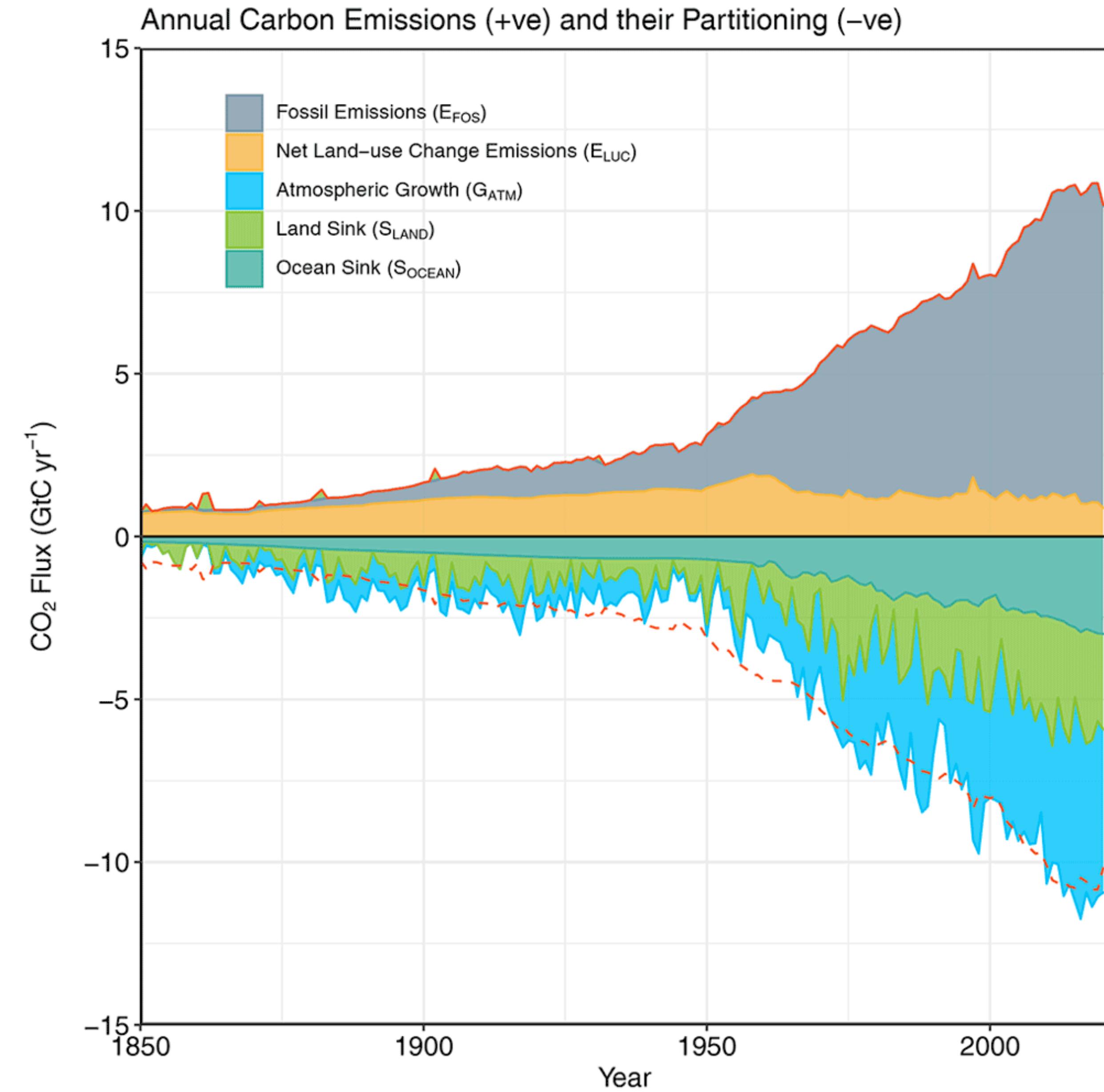
# 植物生理生态学与陆面模式

王玉杰

中国科学技术大学/地球和空间科学学院

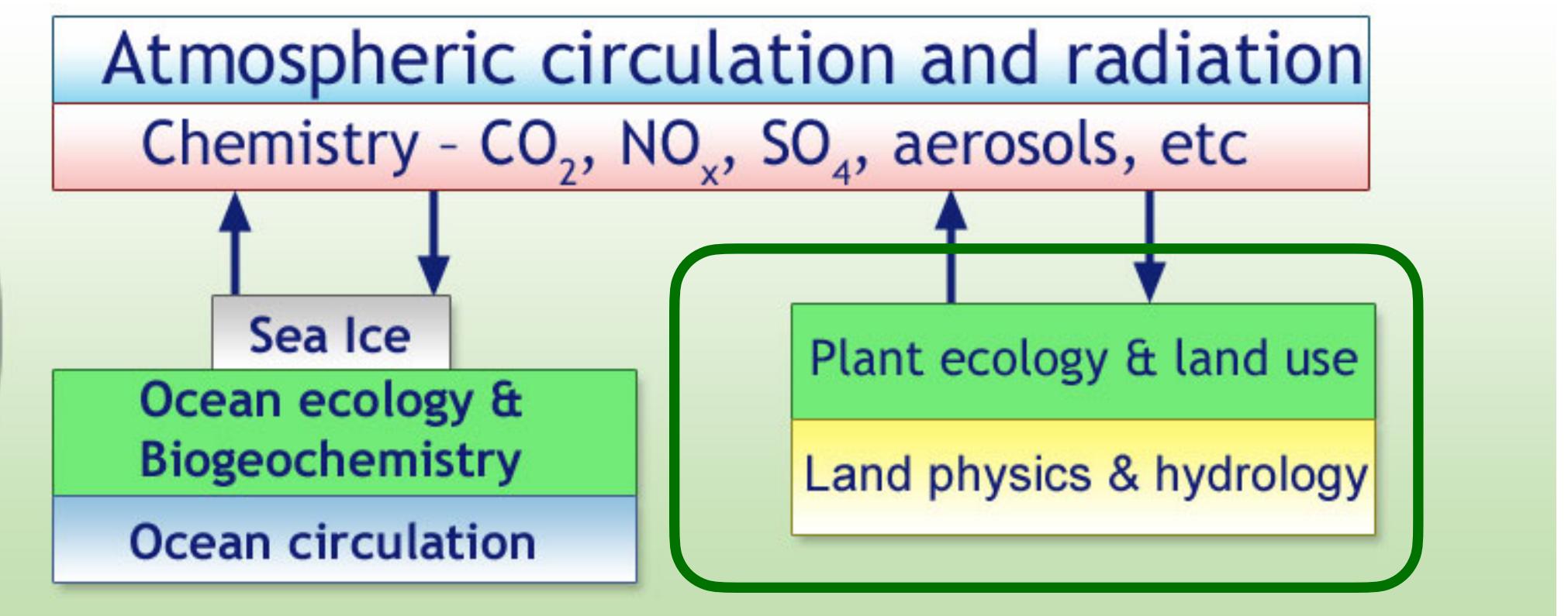


陆地吸收了25%  
的碳排放，是实  
现碳中和不可或  
缺的部分。



# 气候模式

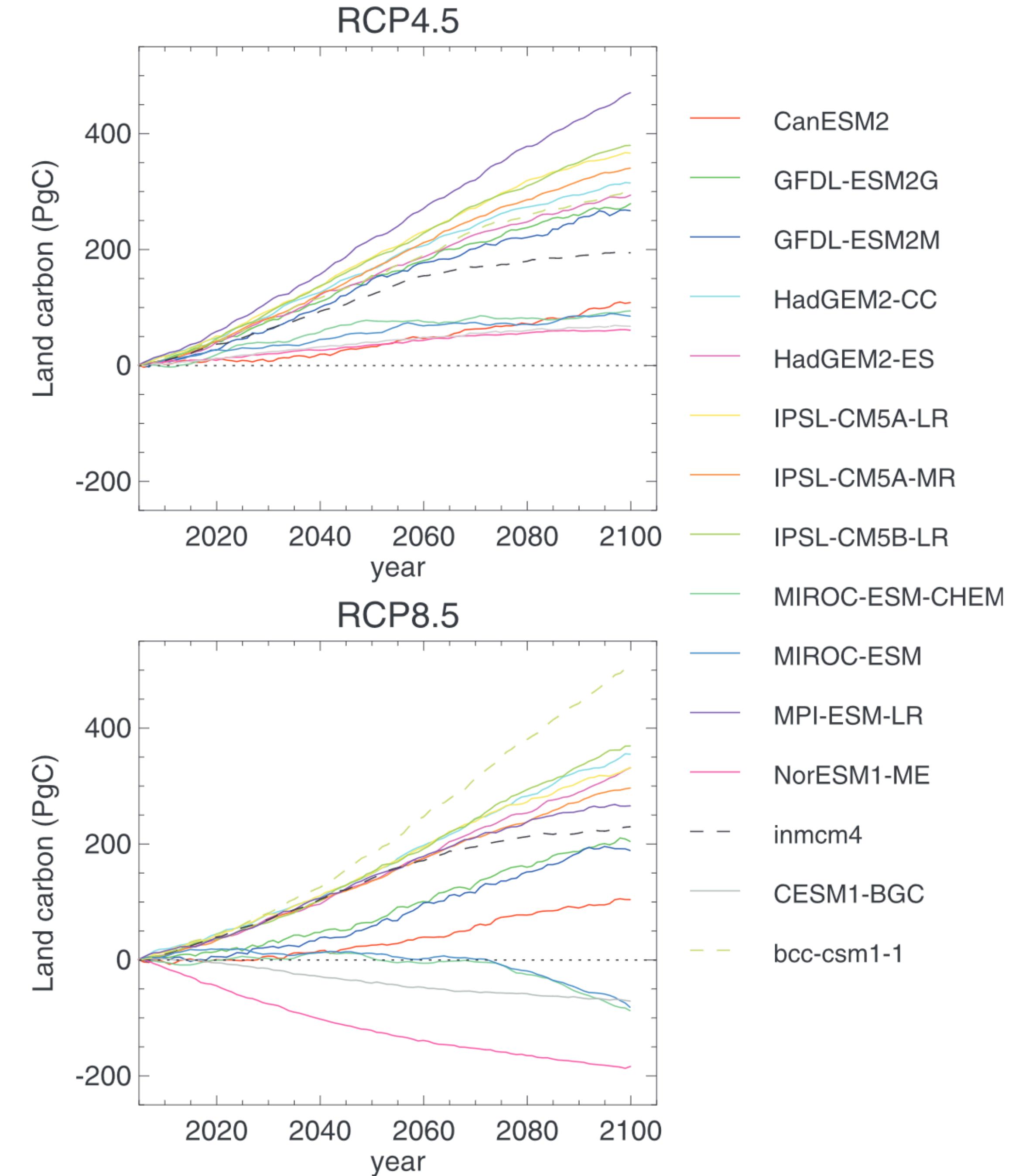
# 地球系统模式

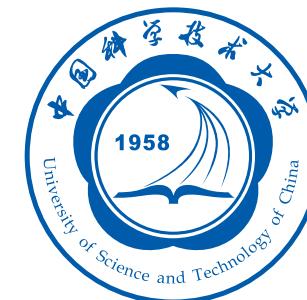


陆面模式

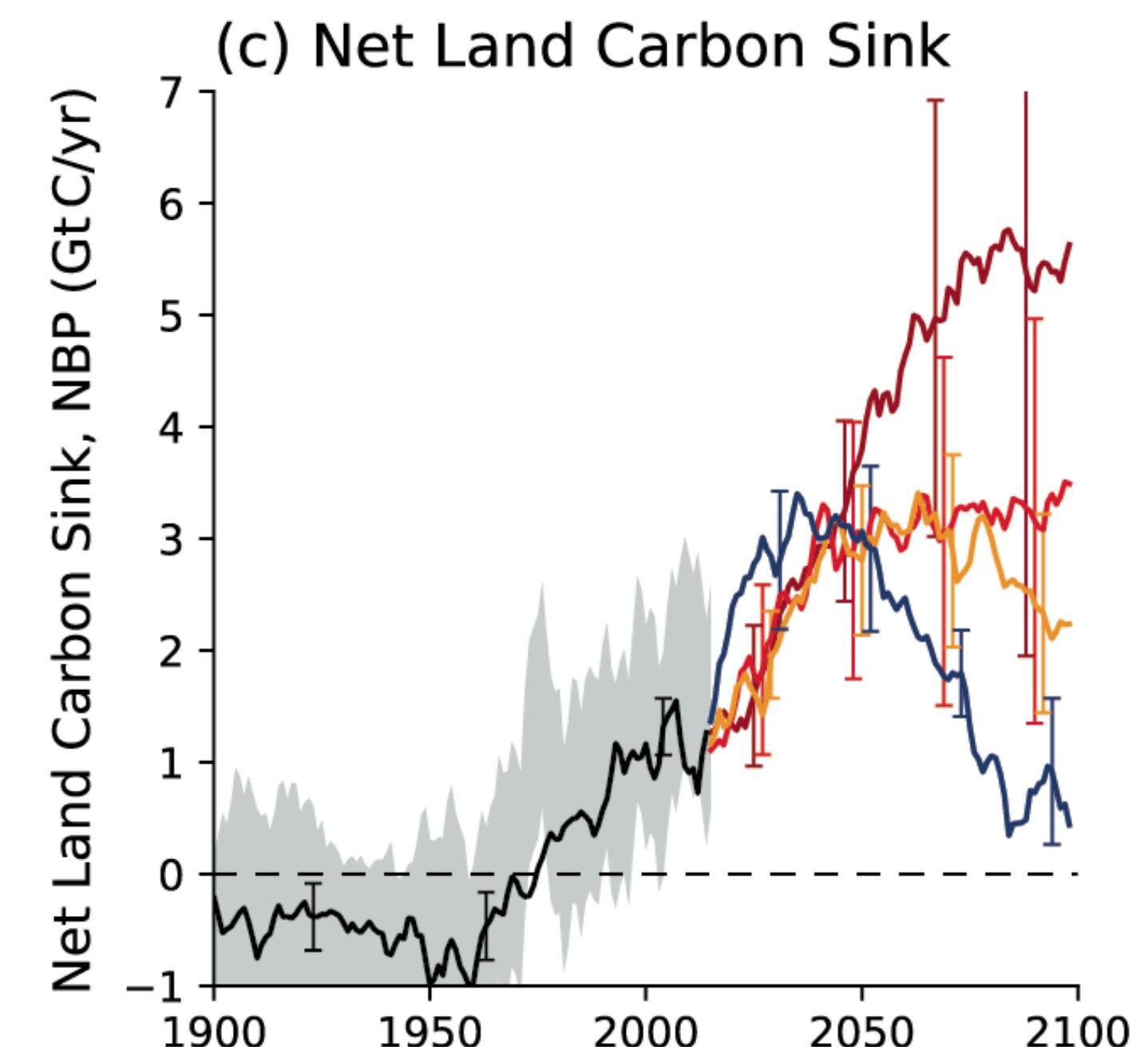
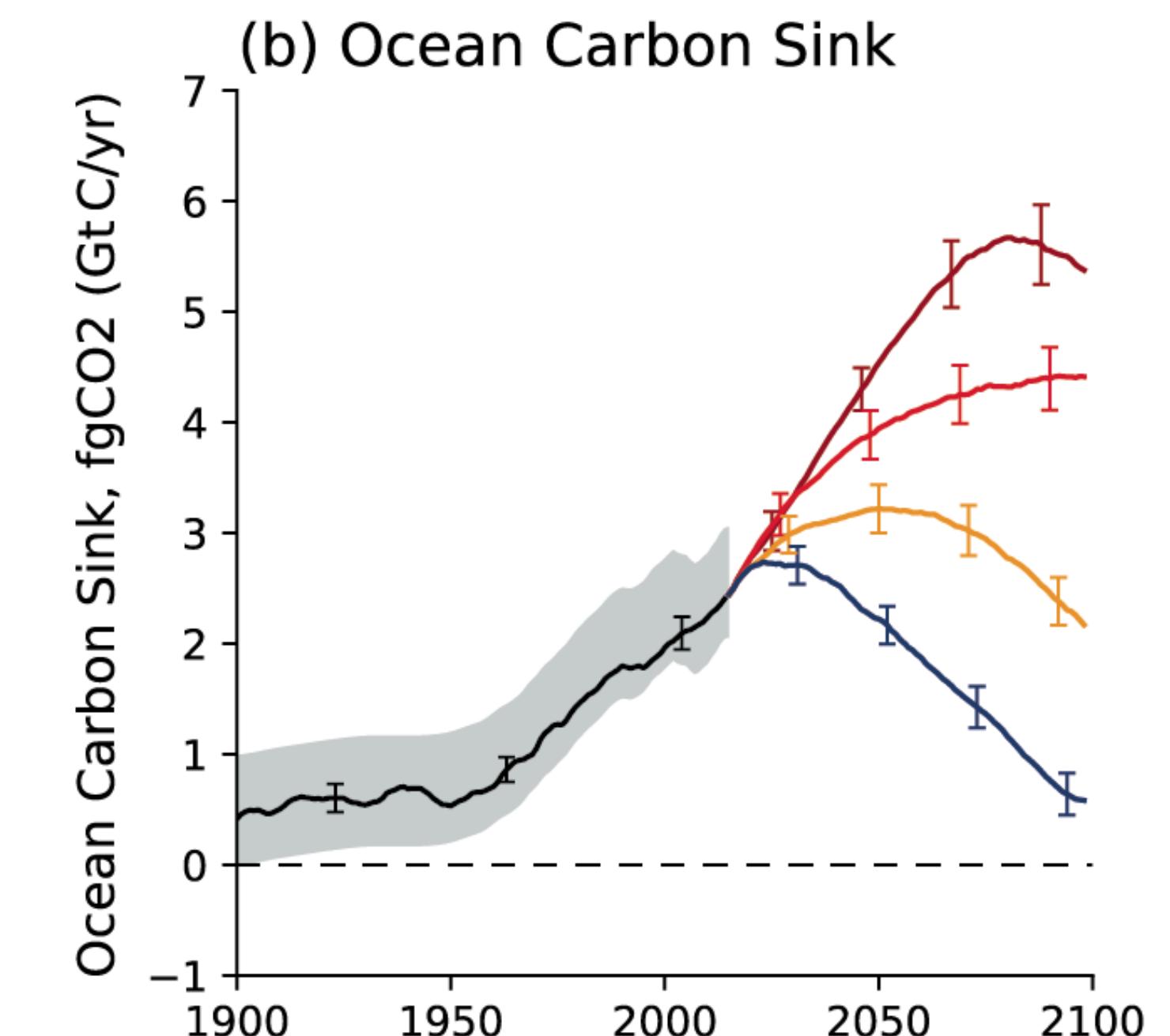


地球系统模式对  
未来碳汇的预测  
有很大**差异**，有  
些模式预测未来  
陆地会成为**碳**  
**源**。



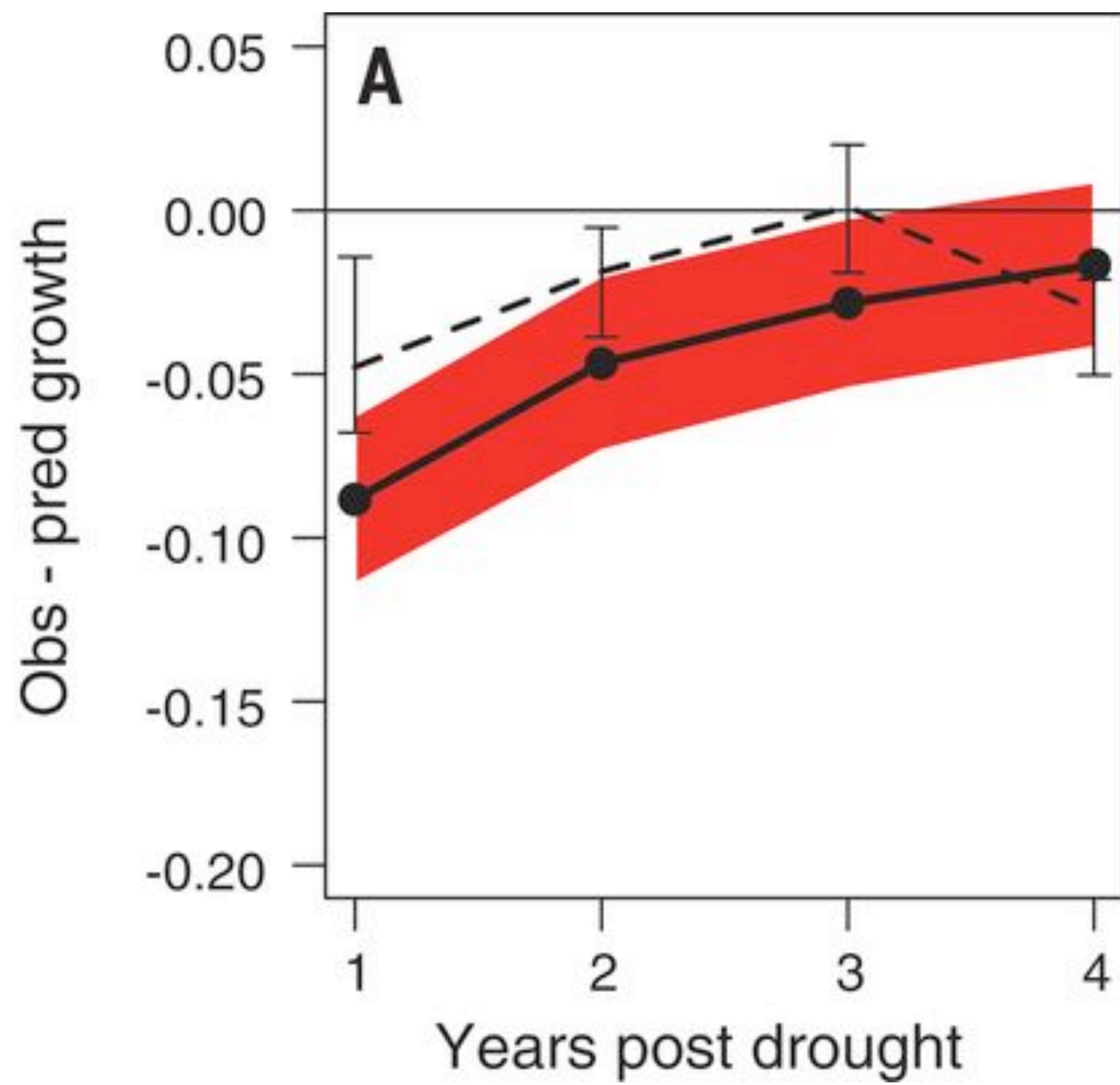
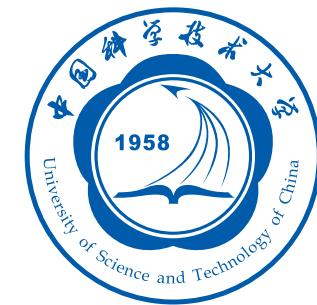


地球系统模式对  
未来碳汇的预测  
有很大**差异**，有  
些模式预测未来  
陆地会成为**碳  
源**。

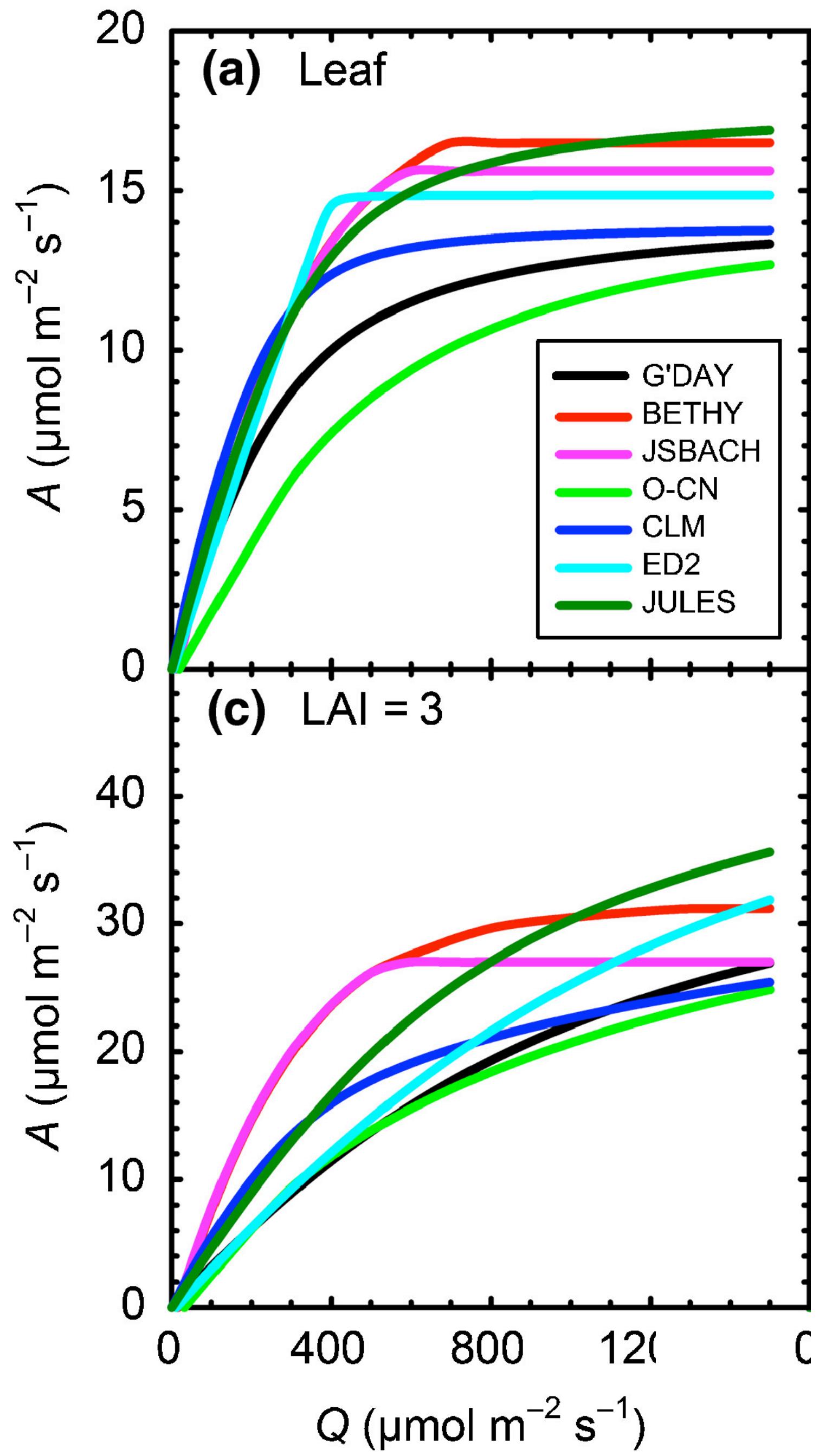


# 重要原因

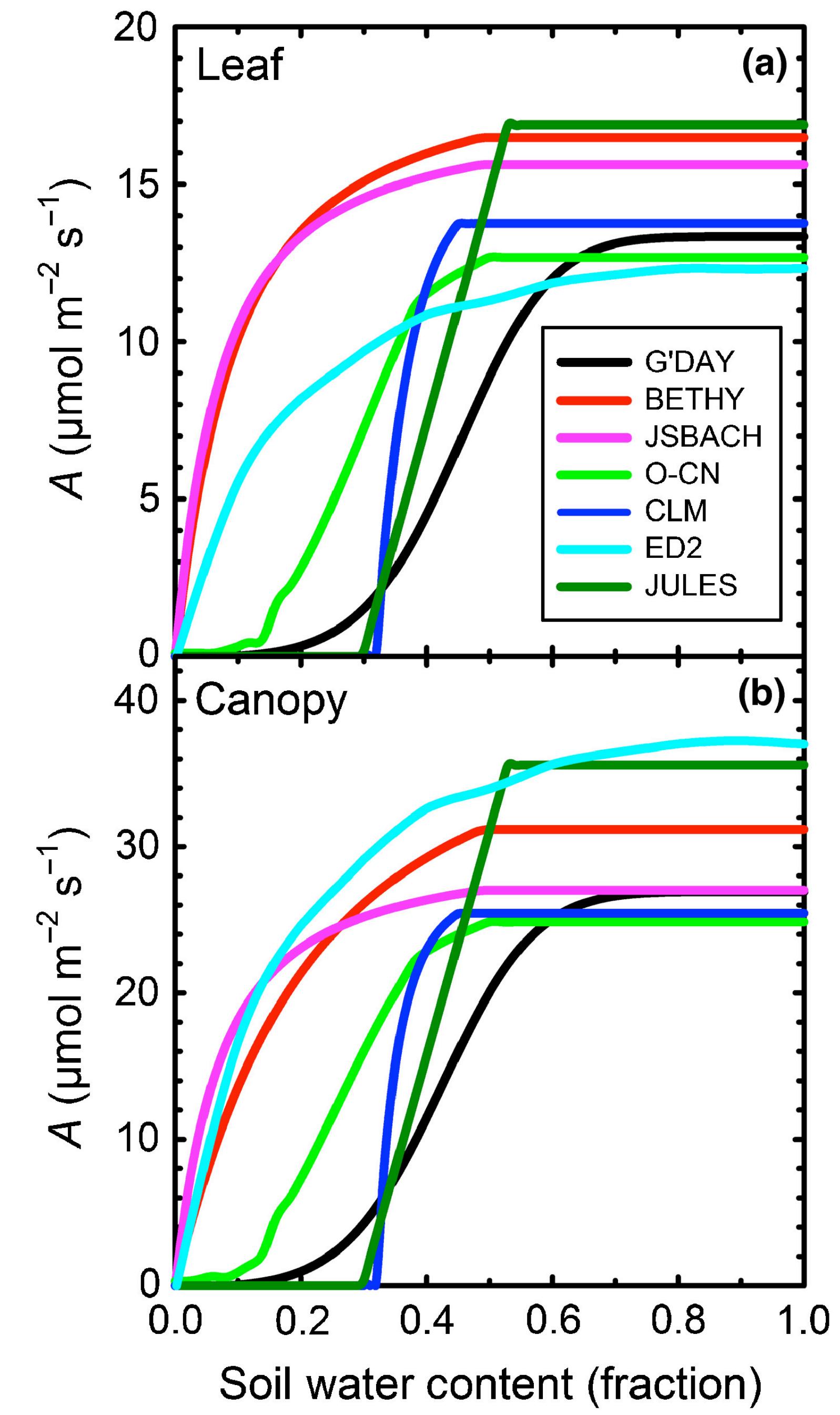
1. 现有陆面模式中生理  
过程过于简单

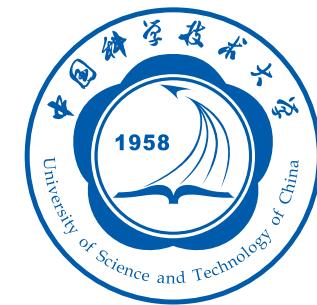


## 2. 模式的参数化差异很大

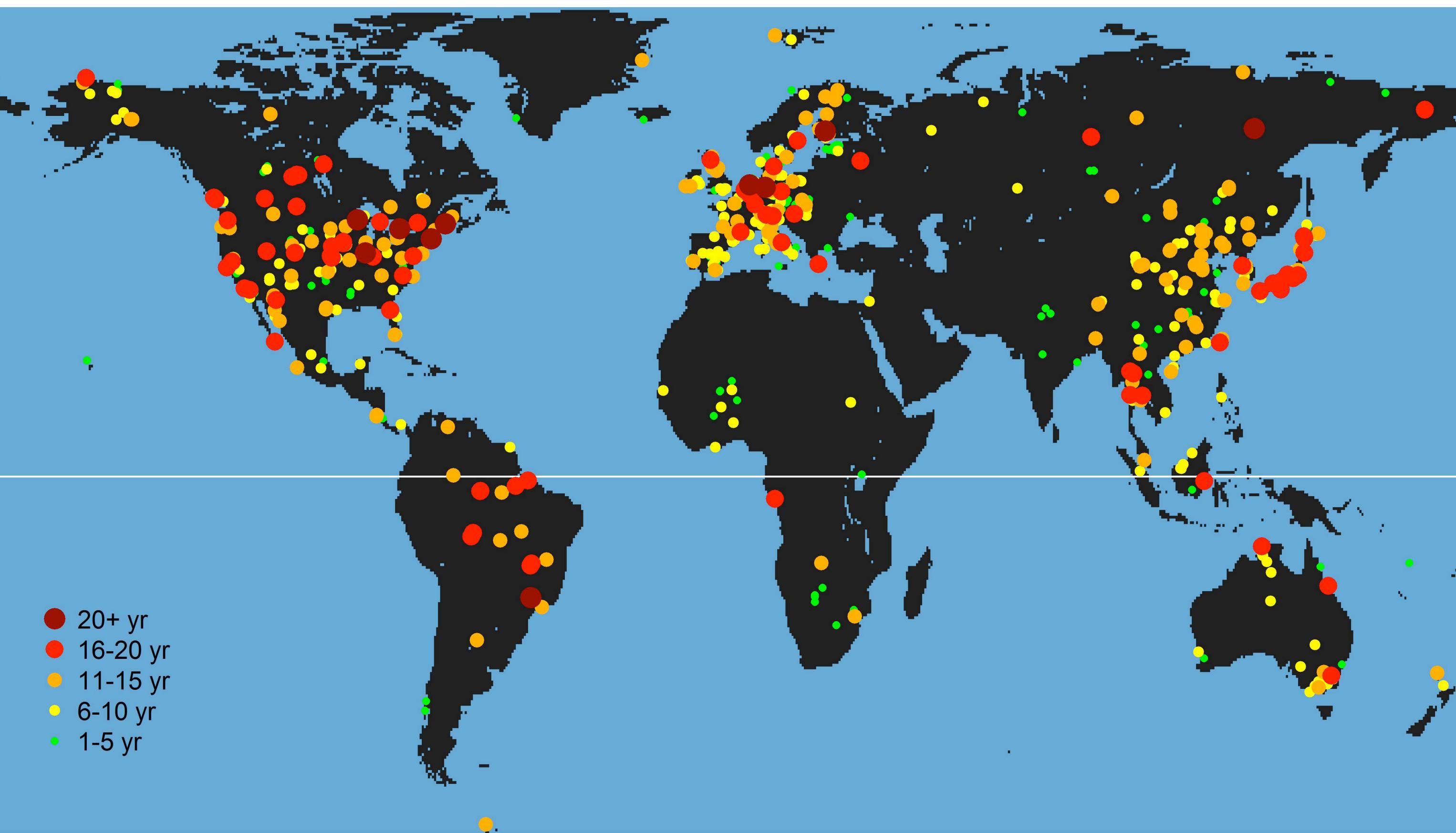


## 2. 模式的参数化差异很大





### 3. 能用于模式矫正的数据很少

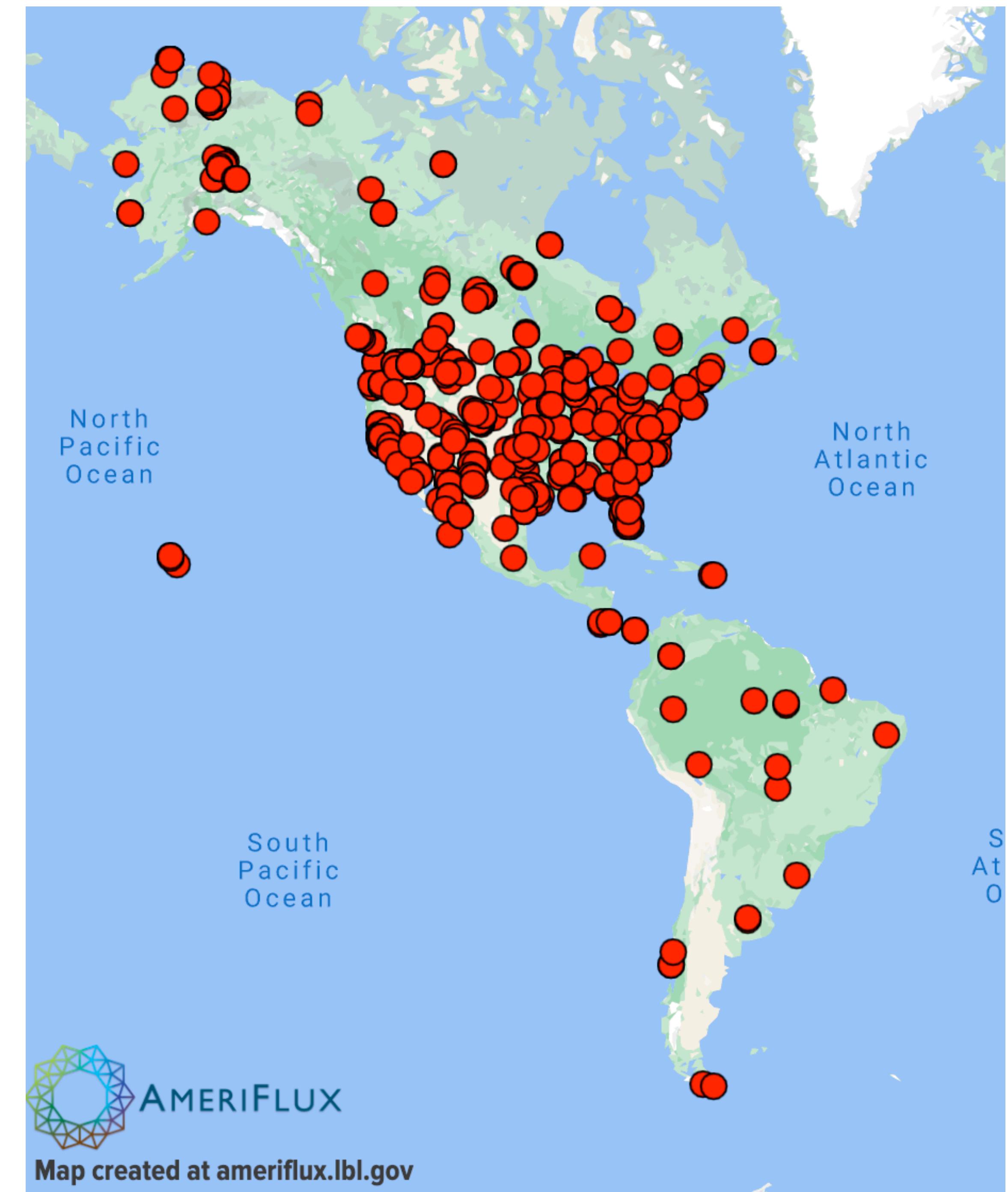




### 3. 能用于模式矫正的数据很少



### 3. 能用于模式矫正的数据很少





	Site ID	Policy <small>i</small>	Data Product <small>i</small> (Variables) <small>i</small>	1990	1995	2000	2005	2010	2015	2020
	BR-CST	C	AmeriFlux BASE (32) AmeriFlux FLUXNET						✓ ✓	✓ ✓
	BR-Sa1	C	AmeriFlux BASE (17)				✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓			
	BR-Sa3	L	AmeriFlux BASE (26)				✓ ✓ ✓ ✓ ✓			
	CA-Ca1	C	AmeriFlux BASE (33)			✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓				
	CA-Ca2	C	AmeriFlux BASE (28)			✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓				
	CA-Ca3	C	AmeriFlux BASE (39)			✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓				

# 面临的挑战



## 1. 模式开发

改进土壤-植物-  
大气连续体模  
型，加入更多的  
生理机制

## 2. 模式设置

使用更合理的模  
型设置与组合，  
降低对经验模式  
的依赖

## 3. 参数矫正

使用更多、更系  
统的多来源数据  
进行模型参数的  
矫正

# 新一代 陆面模式

CLiMA Land





## 新一代模式

新一代模式应该  
包含哪些元素？

### 从数据中学习

- 学习什么？
- 怎么学习？
- 向谁学习？

### 模式框架

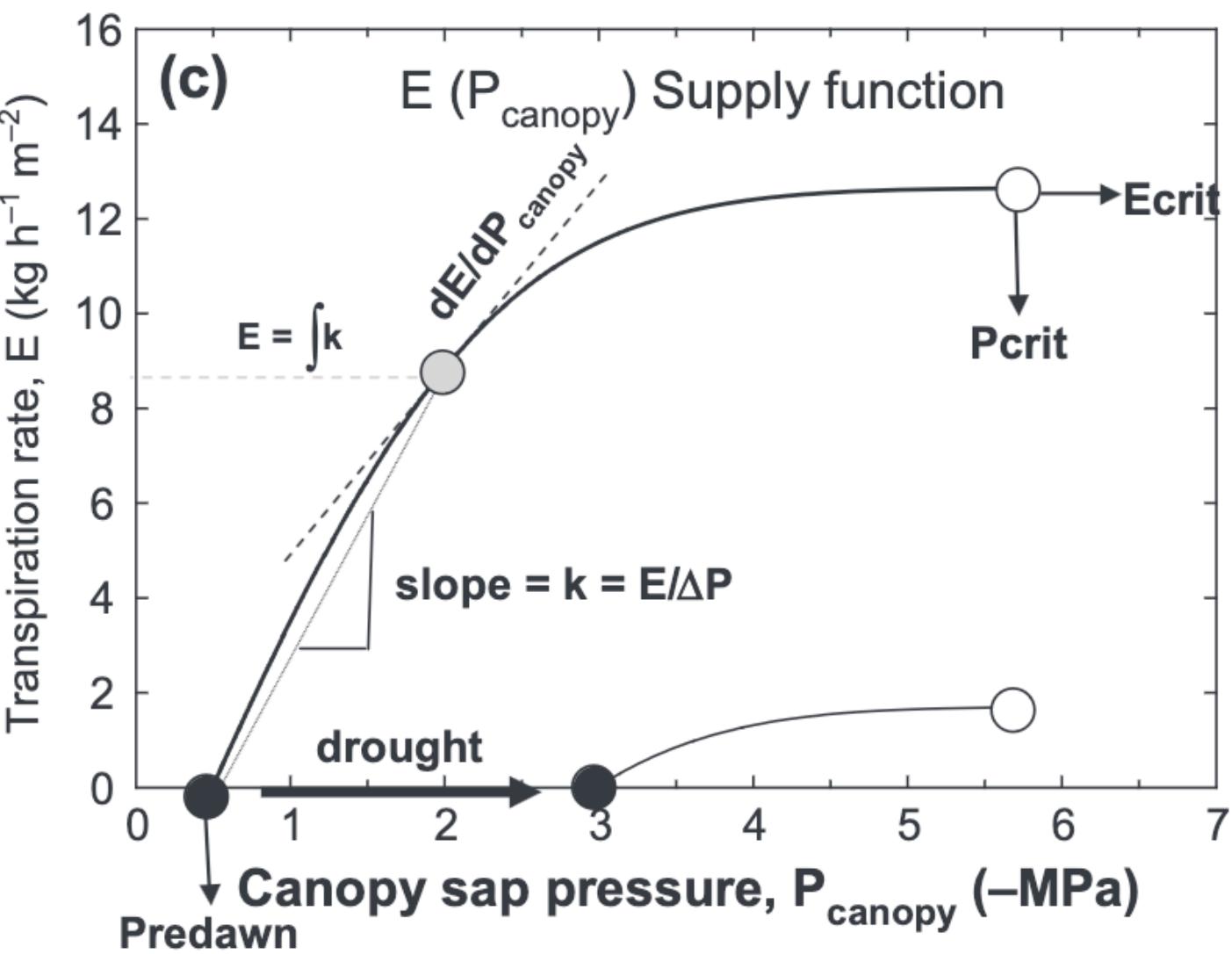
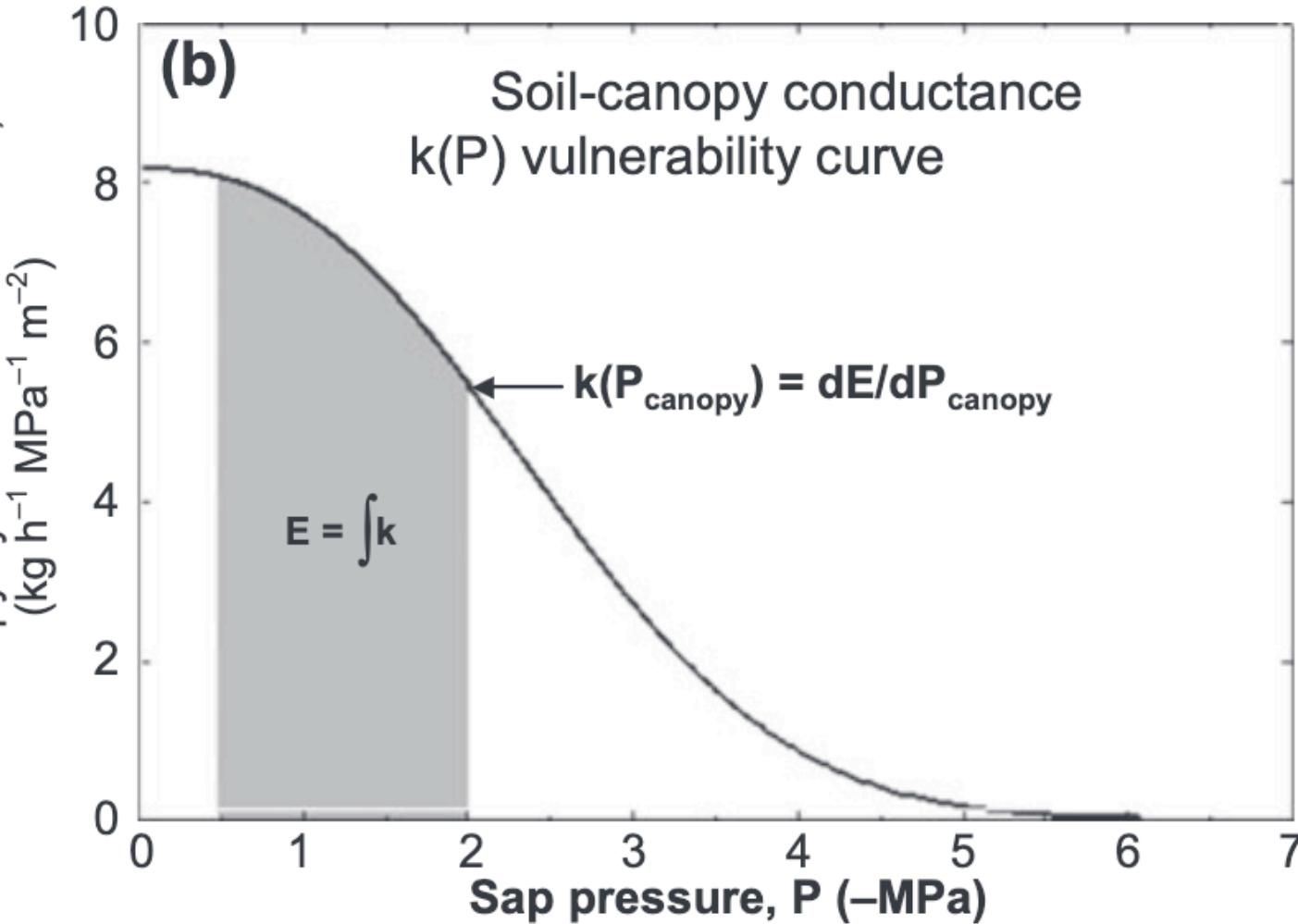
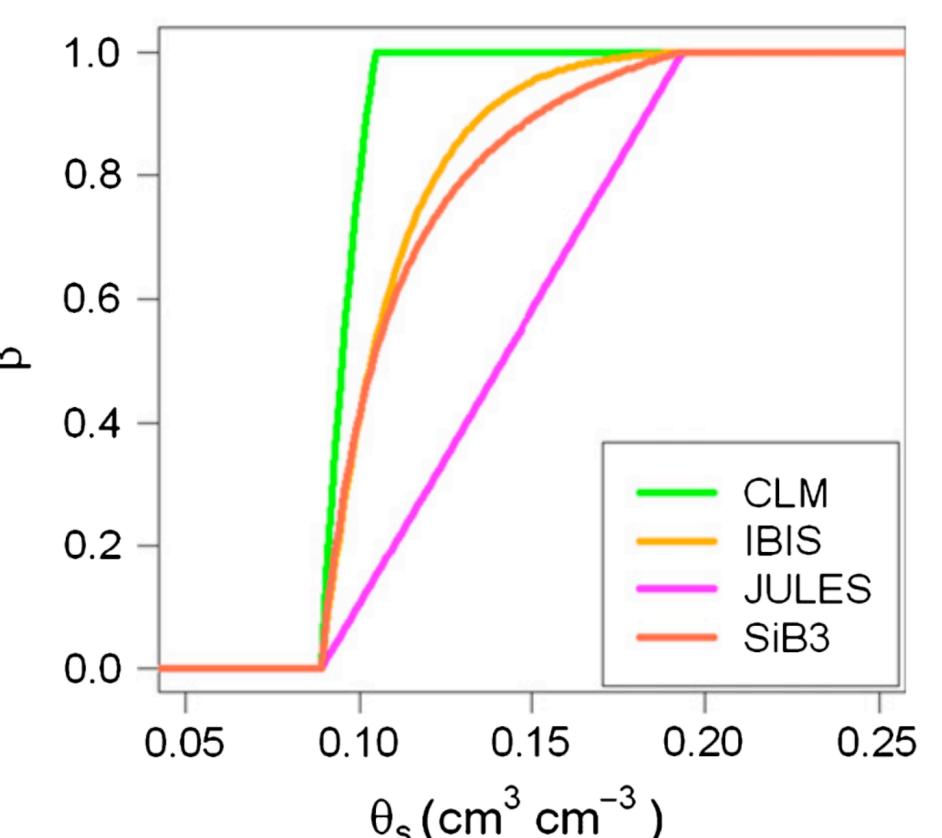
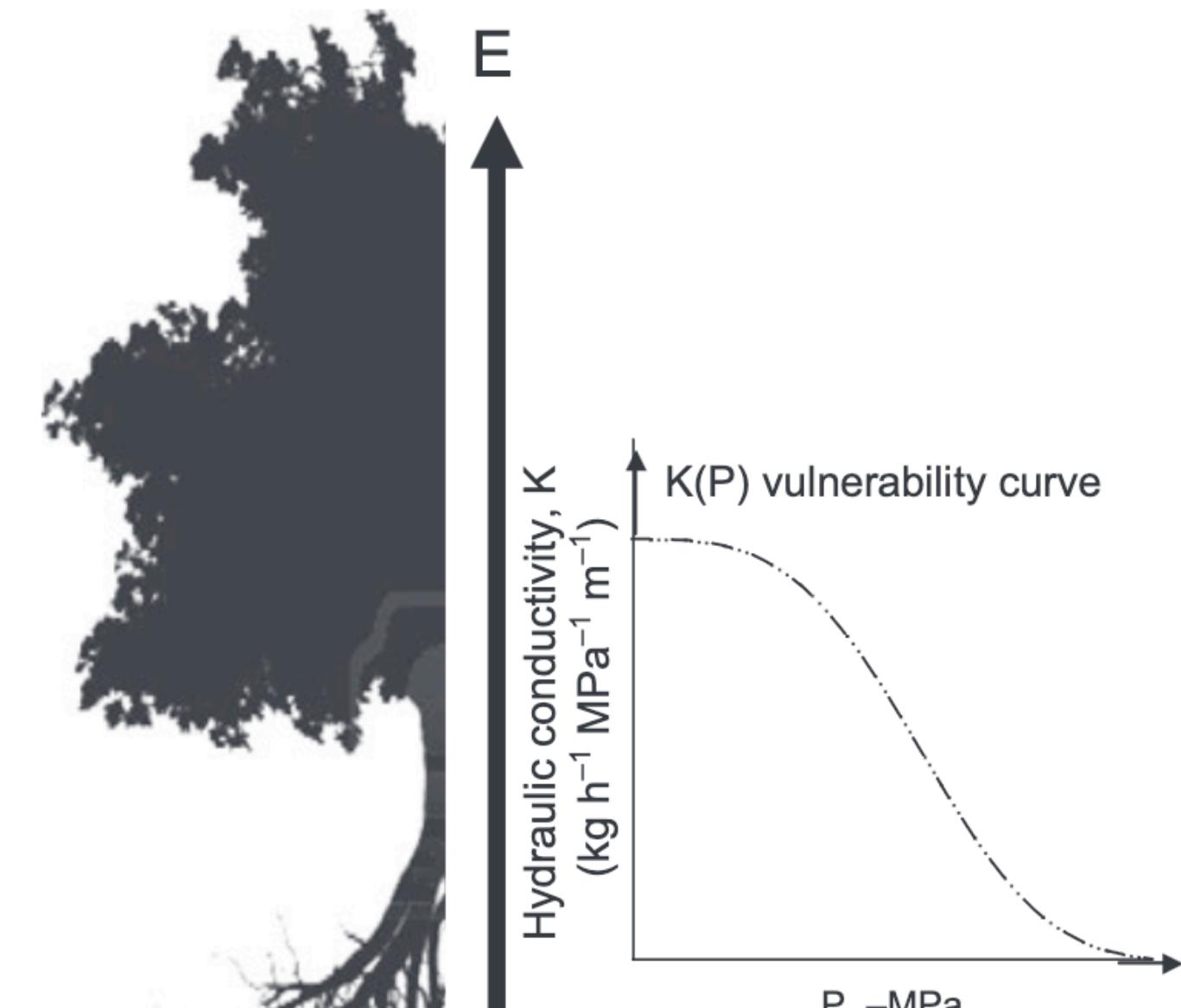
- 模块化
- 伸缩性
- 体系结构
- 对用户更友好



## 1. 模式开发

改进陆面模式中  
土壤-植物-大气  
连续体，加入更  
多的生理机制

(a) Single element continuum with one conductivity  $K(P)$  vulnerability curve

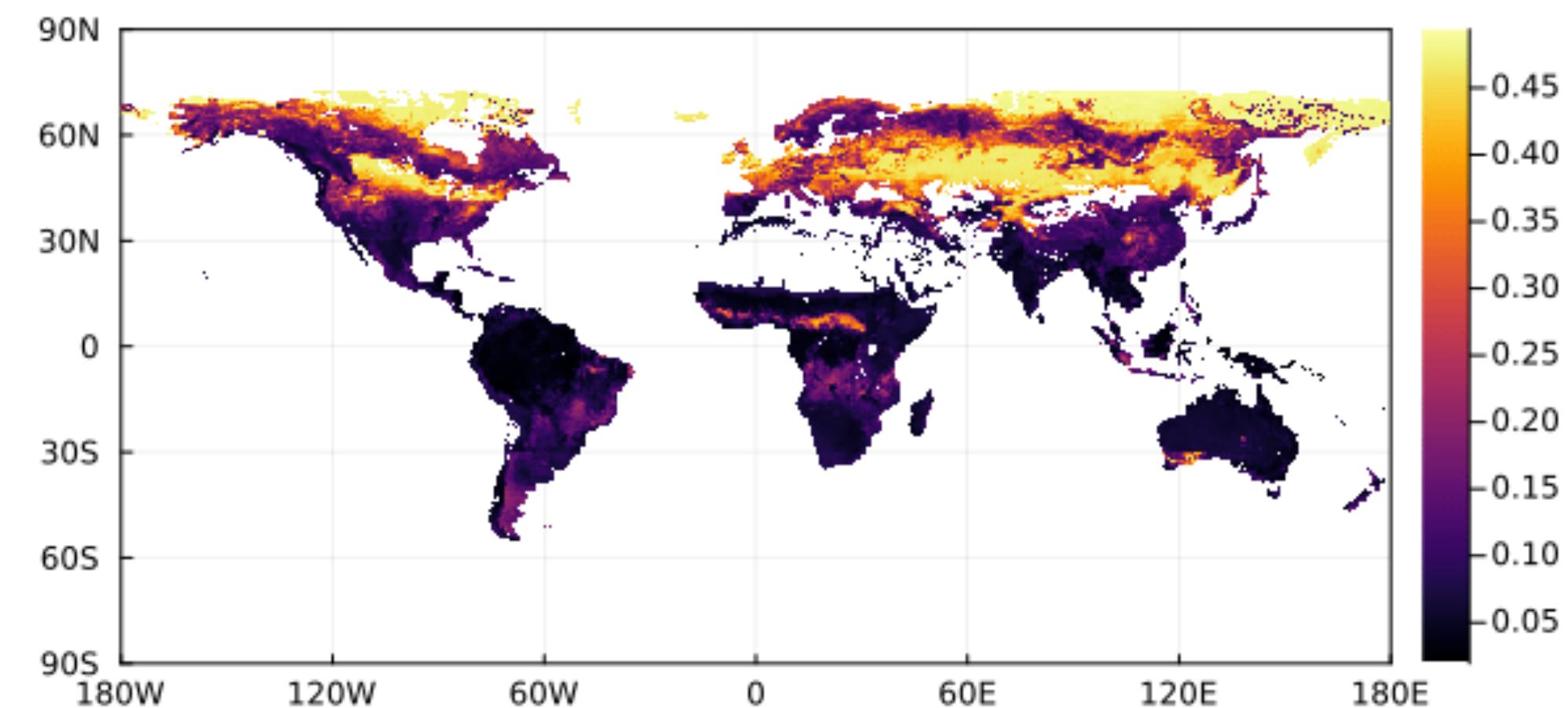




## 2. 模式设置

使用更合理的模式设置与组合，降低对经验模式的依赖

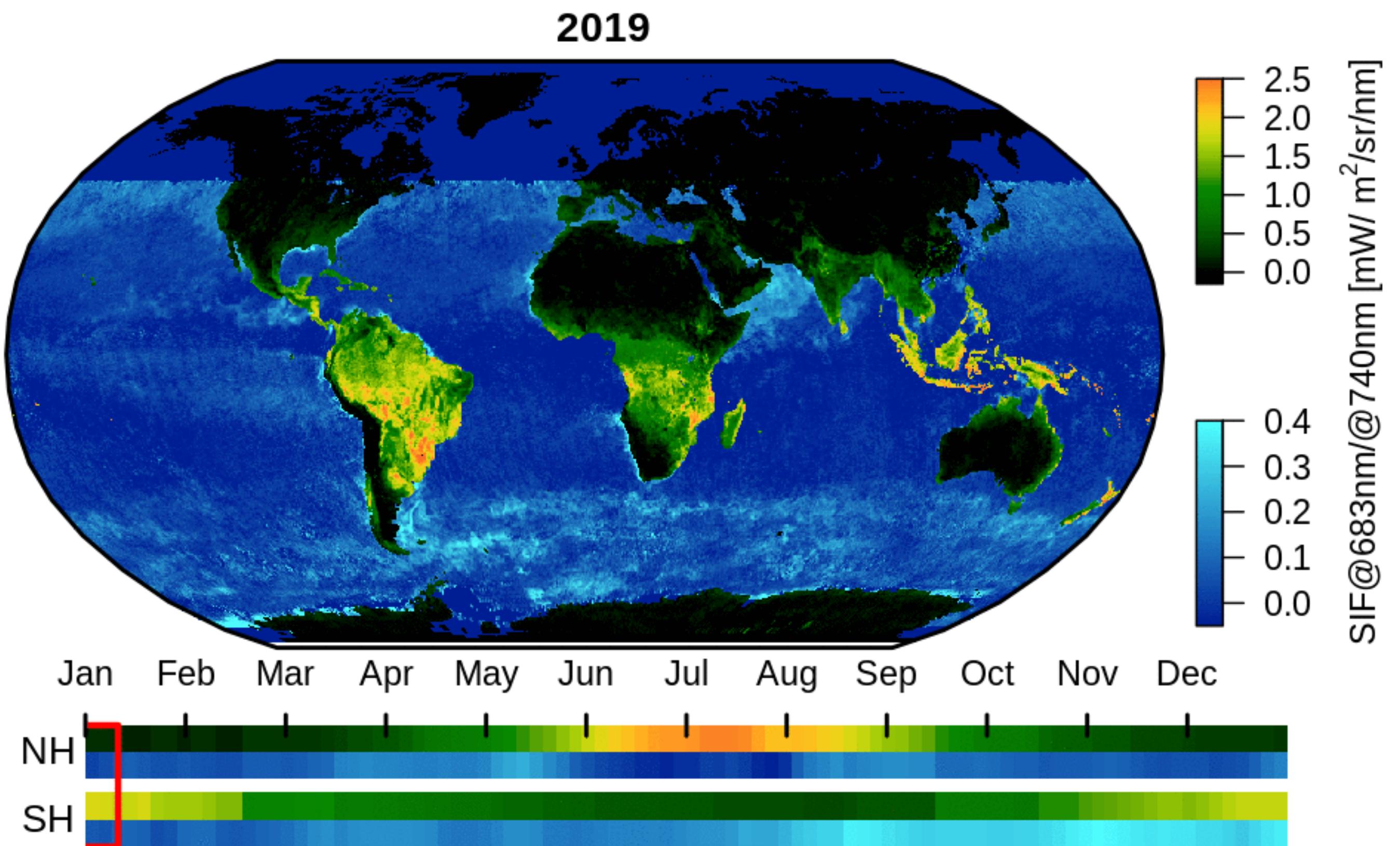
Plant Functional Type	$\chi_L$	$\alpha_{vis}^{leaf}$	$\alpha_{nir}^{leaf}$	$\alpha_{vis}^{stem}$	$\alpha_{nir}^{stem}$	$\tau_{vis}^{leaf}$	$\tau_{nir}^{leaf}$
NET Temperate	0.01	0.07	0.35	0.16	0.39	0.05	0.10
NET Boreal	0.01	0.07	0.35	0.16	0.39	0.05	0.10
NDT Boreal	0.01	0.07	0.35	0.16	0.39	0.05	0.10
BET Tropical	0.10	0.10	0.45	0.16	0.39	0.05	0.25
BET temperate	0.10	0.10	0.45	0.16	0.39	0.05	0.25
BDT tropical	0.01	0.10	0.45	0.16	0.39	0.05	0.25
BDT temperate	0.25	0.10	0.45	0.16	0.39	0.05	0.25
BDT boreal	0.25	0.10	0.45	0.16	0.39	0.05	0.25





### 3. 参数矫正

使用更多、更系统的多来源数据  
进行模式参数的  
矫正



# 基于植物生理过程的日间气孔导度的模型



## 1. 模式开发

改进土壤-植物-  
大气连续体模  
型，加入更多的  
生理机制

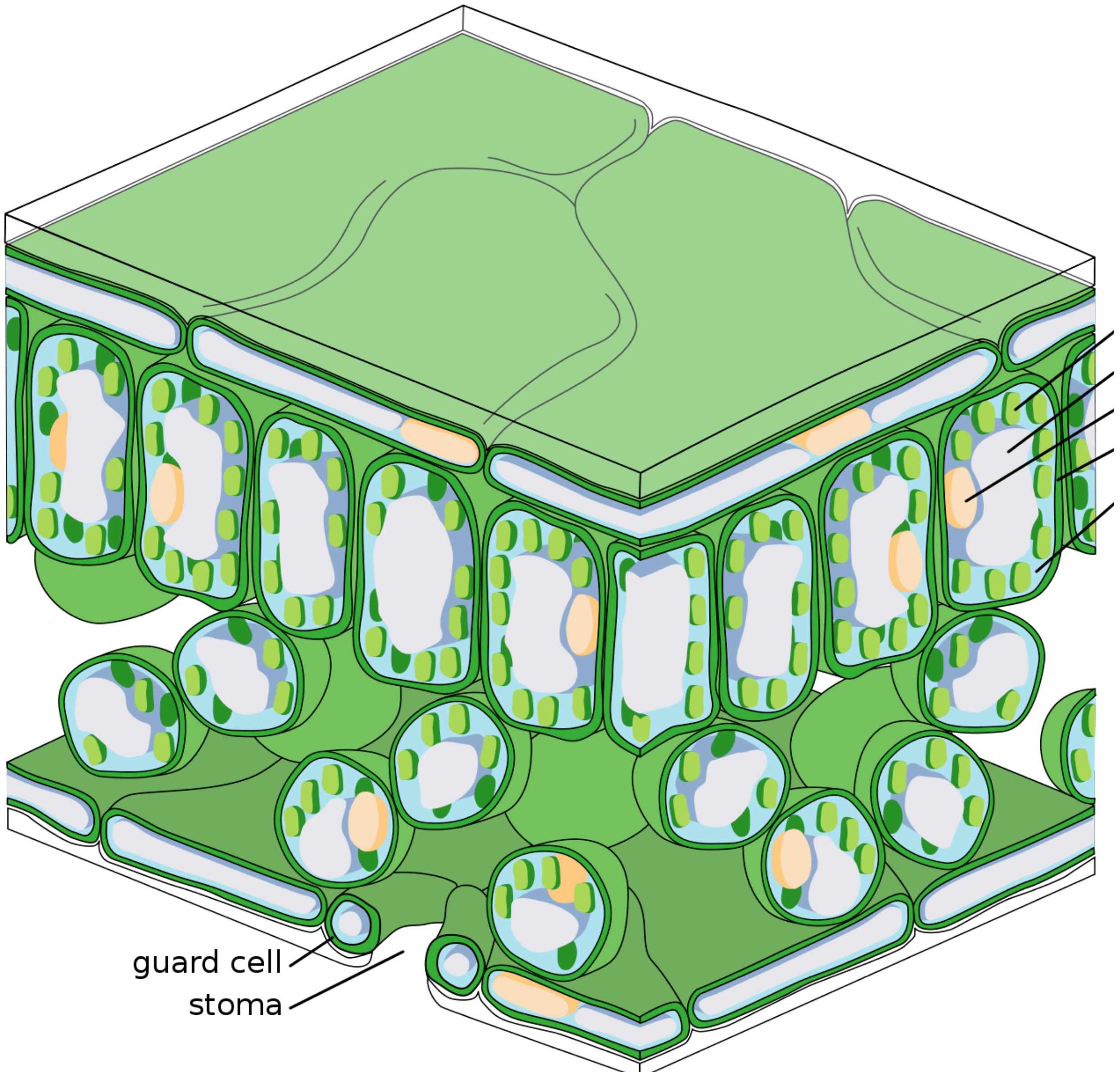
## 2. 模式设置

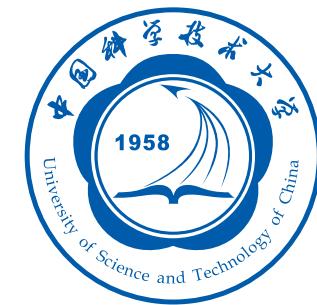
## 3. 参数矫正



通过气孔的蒸腾将  
~40%的降水返还到  
大气

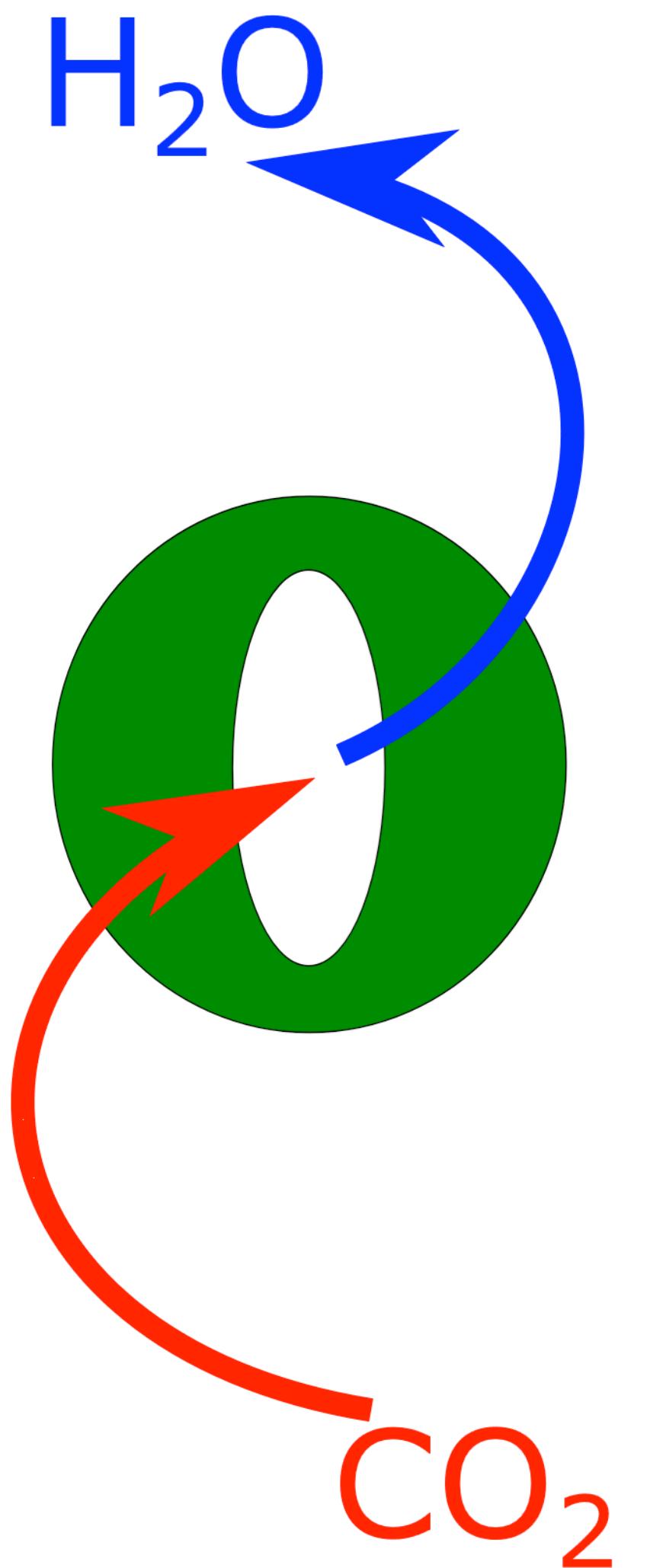
通过气孔的光合作用  
固定 >99% 的 CO<sub>2</sub>





## 植物生理

- 脱落酸
- 细胞膨压
- 水力导度
- 光合能力
- 叶肉导度
- ...

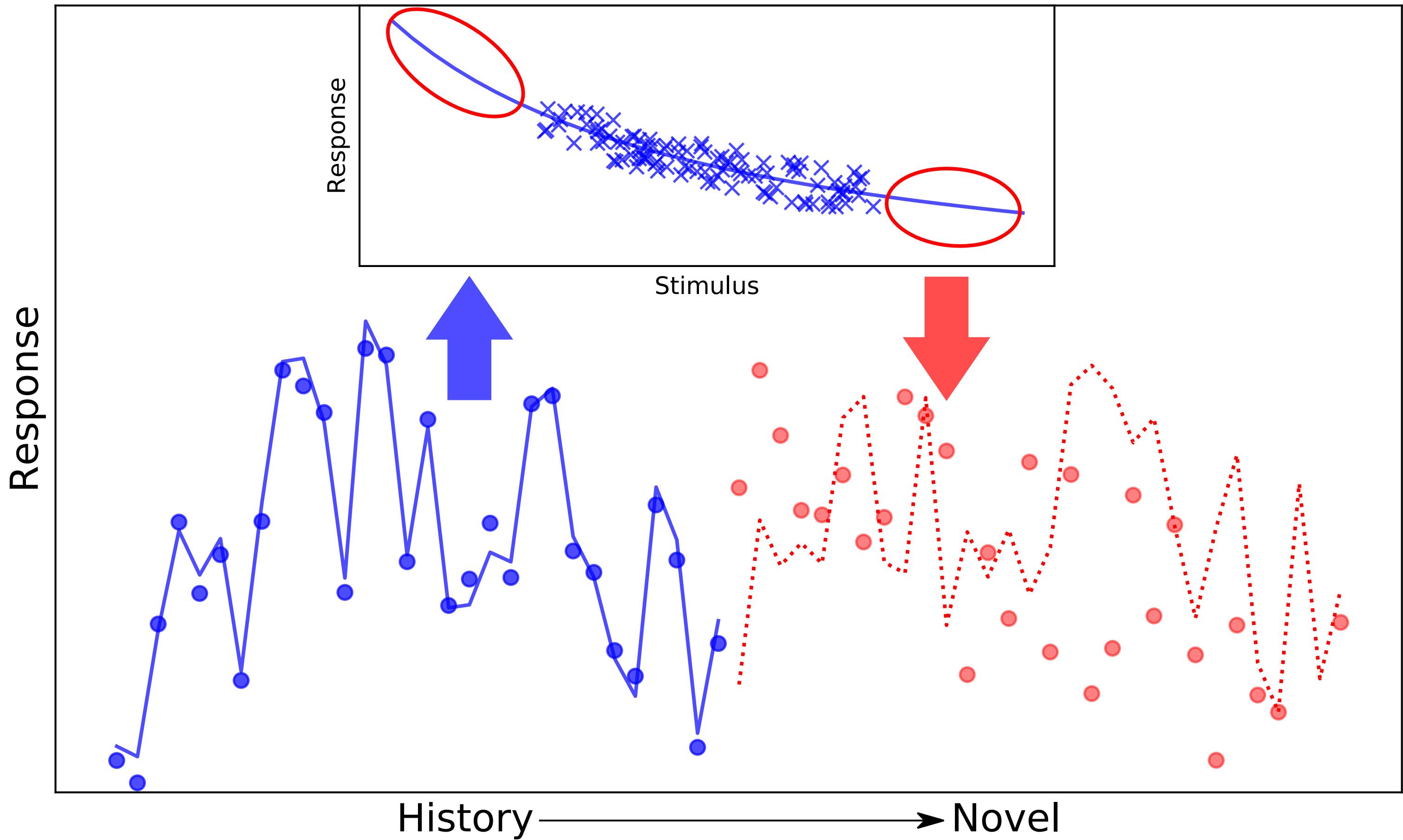


## 环境因素

- 大气CO<sub>2</sub>浓度
- 空气湿度
- 空气温度
- 光照条件
- 风速
- 土壤湿度
- ...

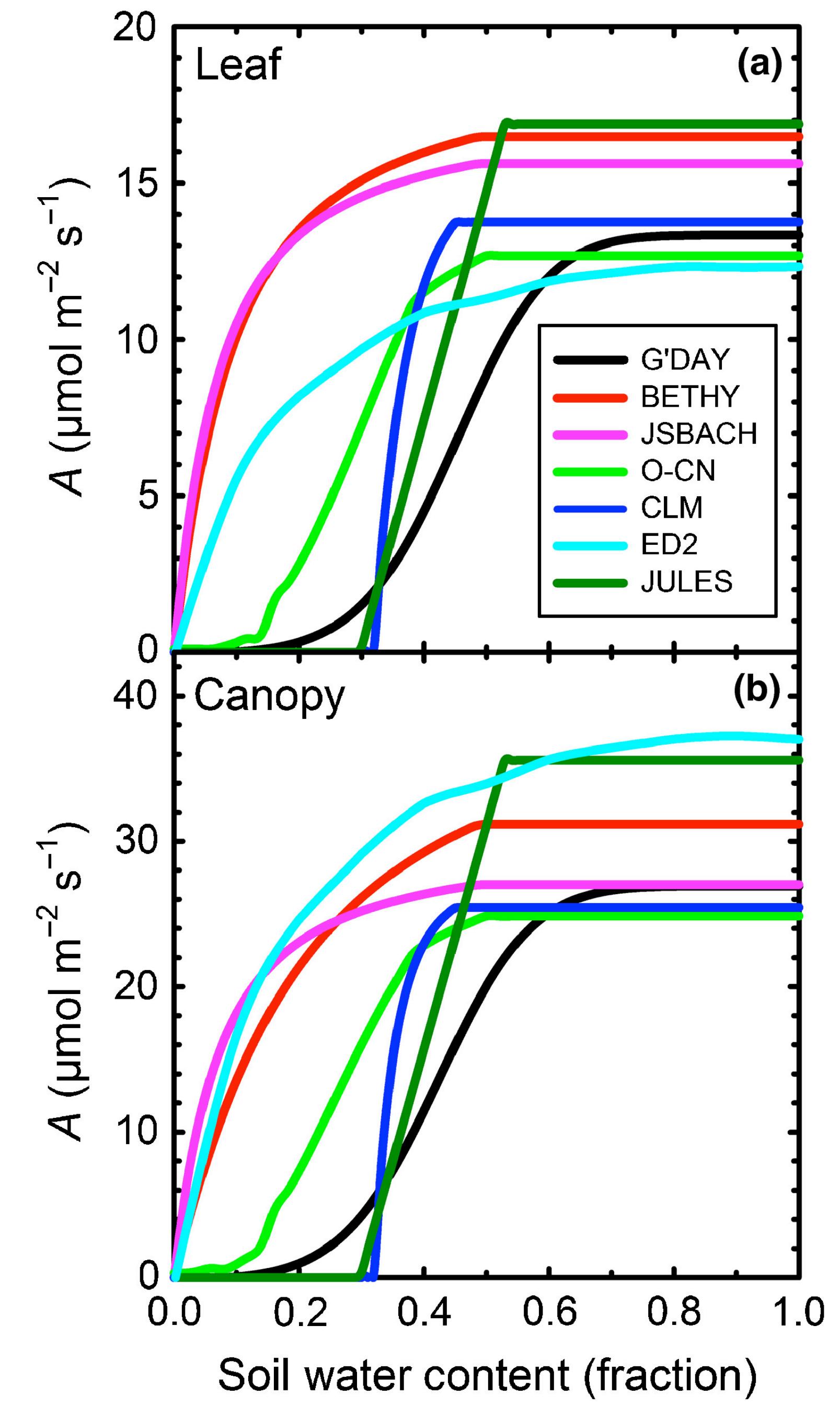


传统的经验模型运行效率高，但不能很好地预测植物对新环境的响应。



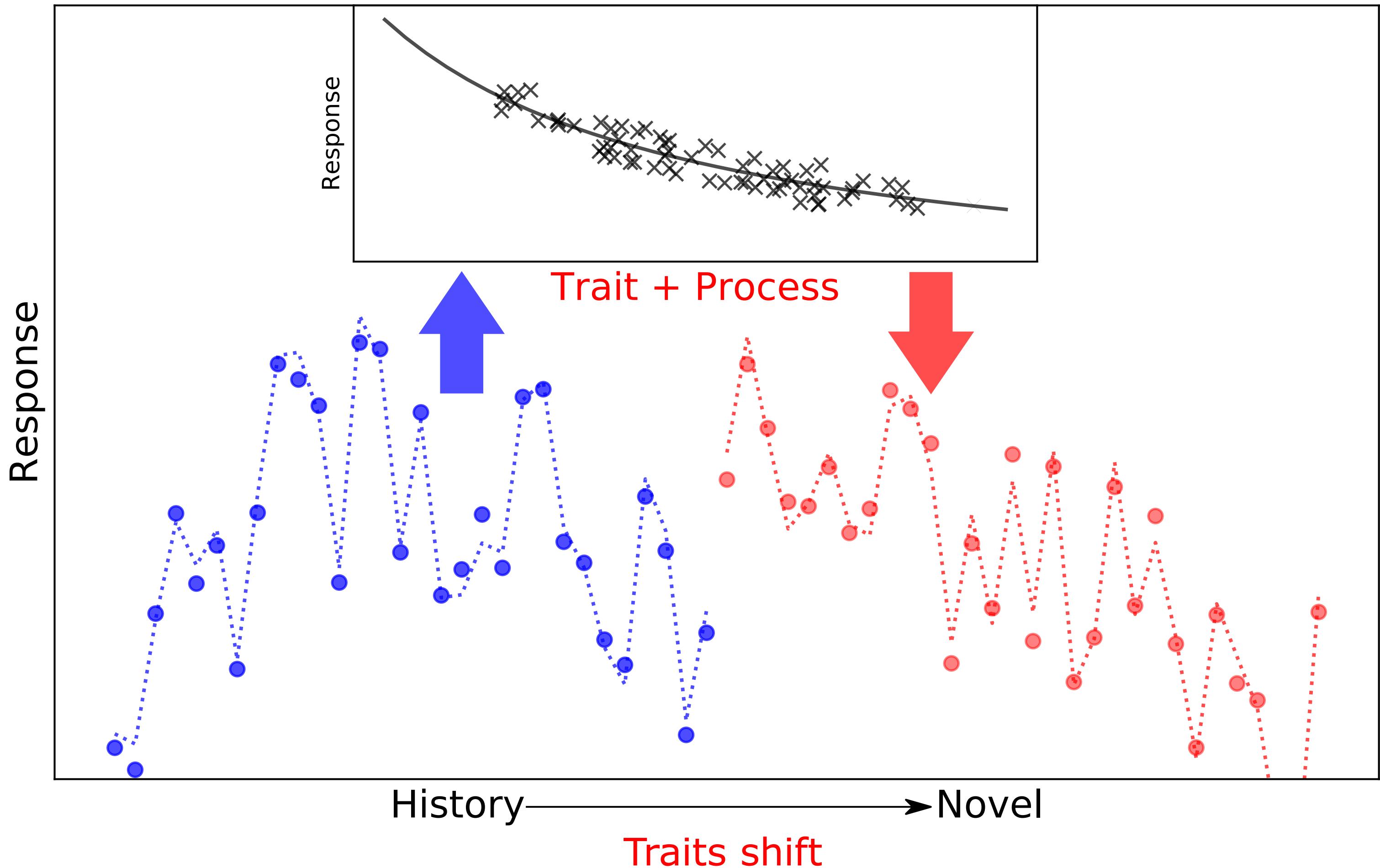


传统的经验模型运行效率高，但不能很好地预测植物对新环境的响应。





机理模型运行速度更慢，  
但能够更好地表征植物在  
新环境下的响应。生理与  
性状的使用更使得模型能  
够模拟植物对环境的适  
应。



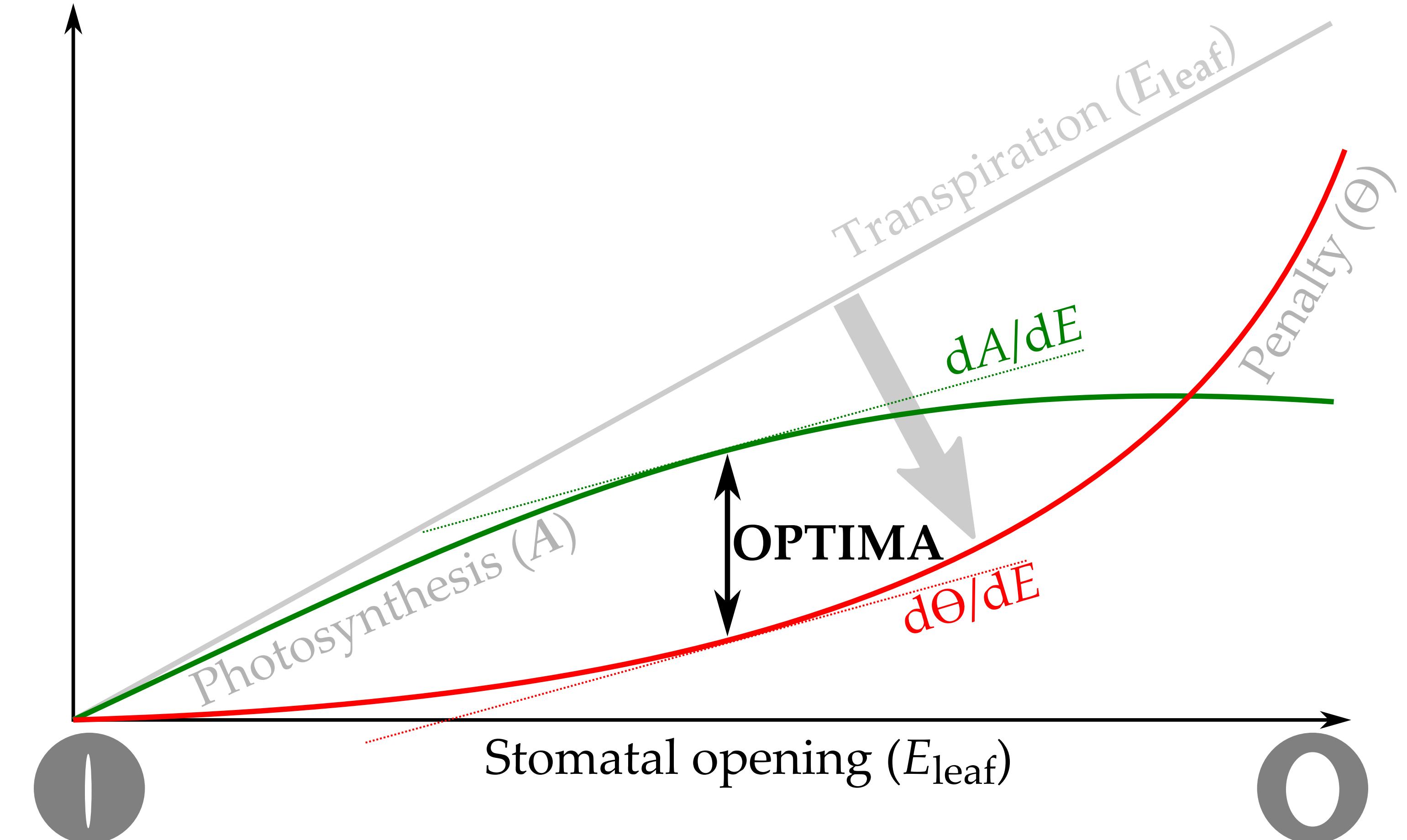


## 最优化理论

生物会进化出为了适应环境的行为模式。

我们需要去找：

- 收益
- 损耗

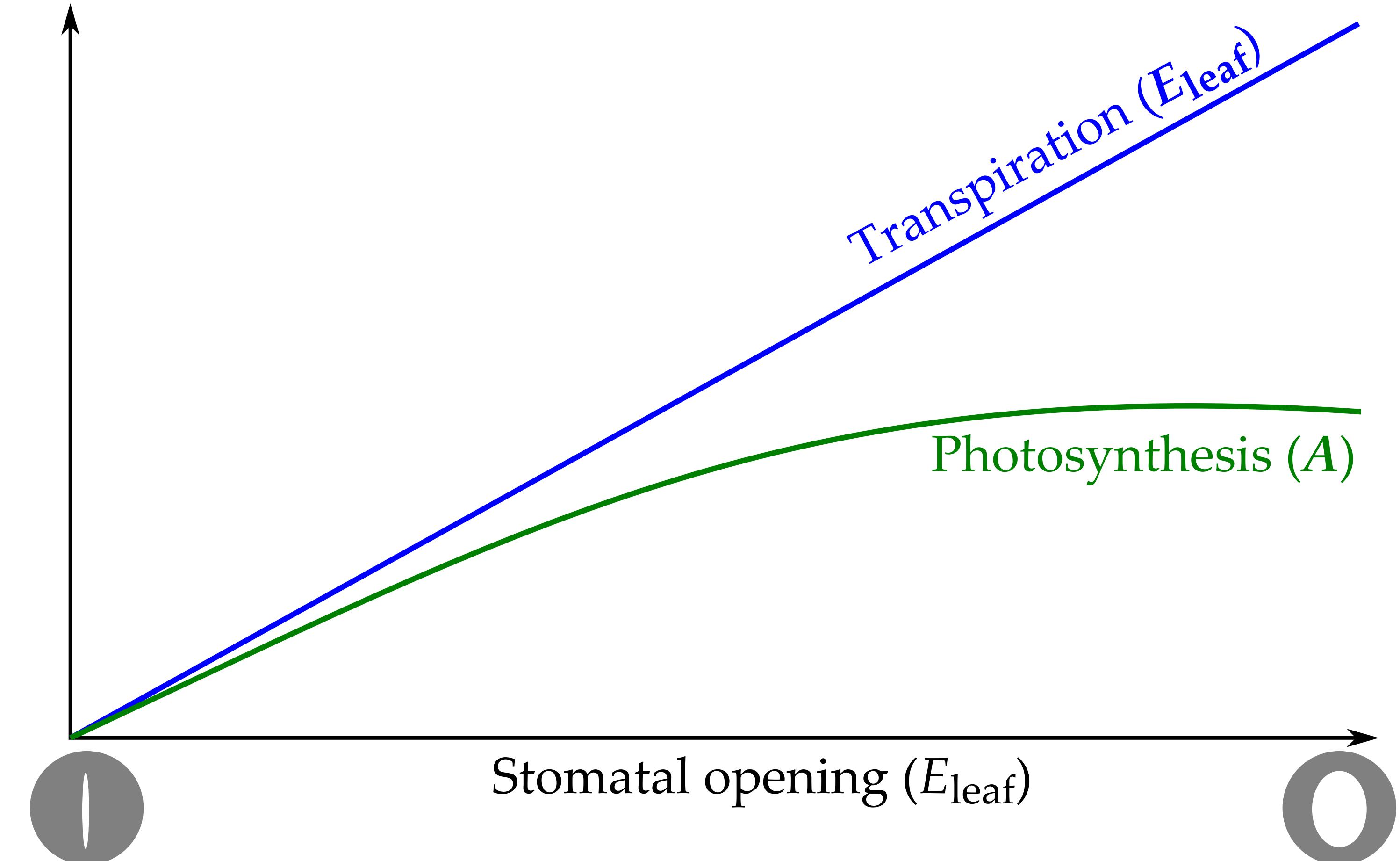




## 最优化理论

最大化收益与损  
耗之间的差异

收益:  $A(E_{leaf})$

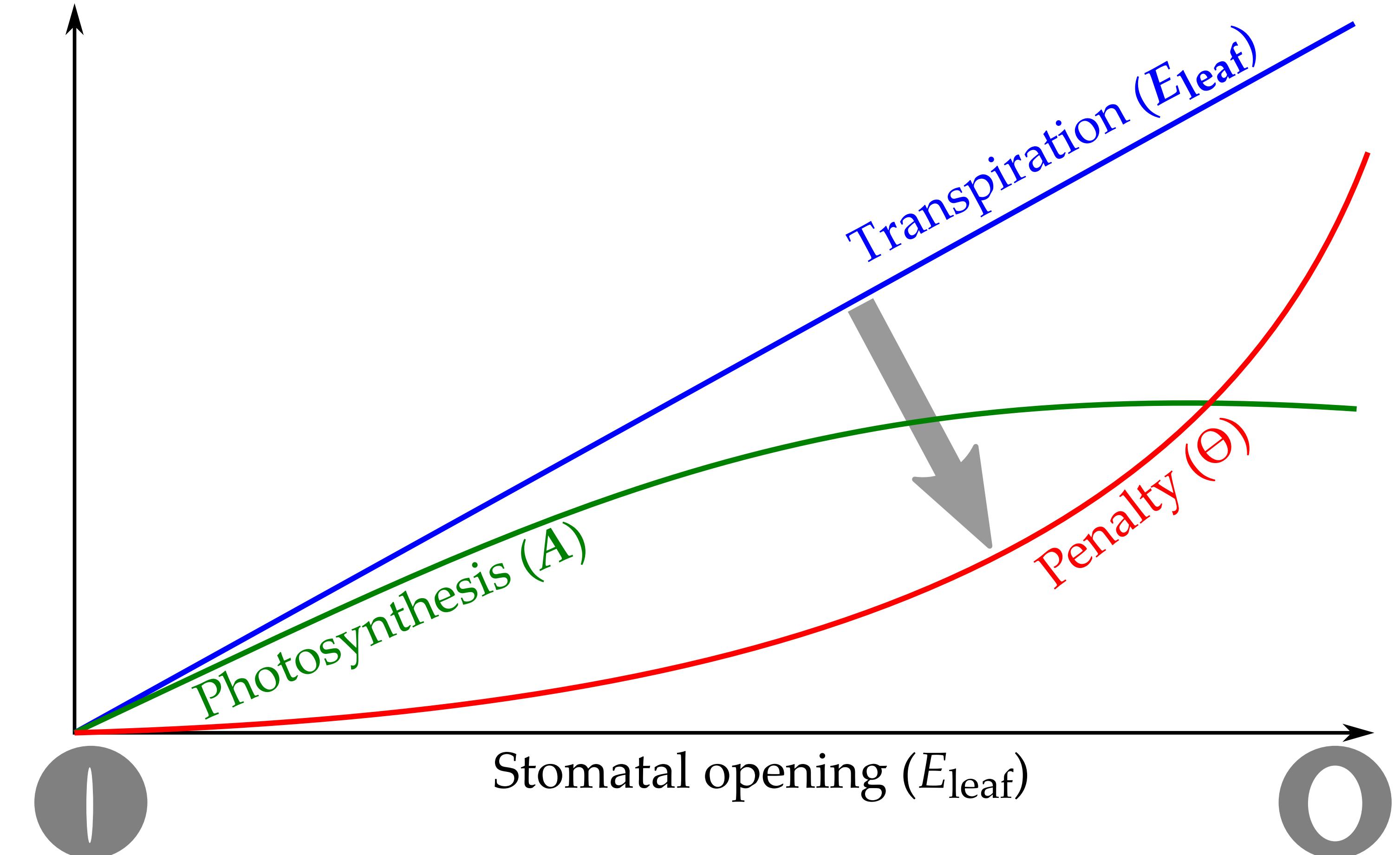




## 最优化理论

最大化收益与损  
耗之间的差异

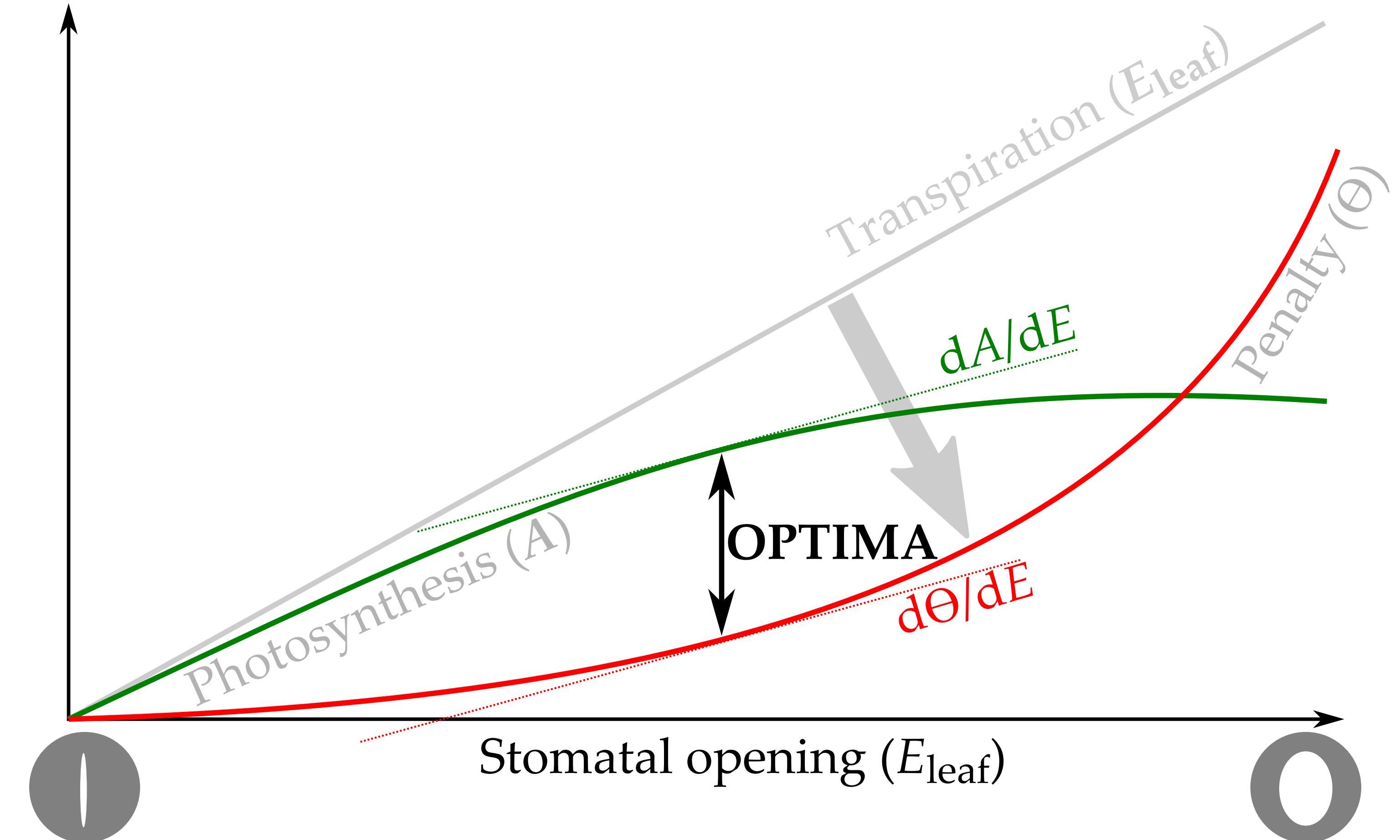
损耗:  $\Theta(E_{leaf})$

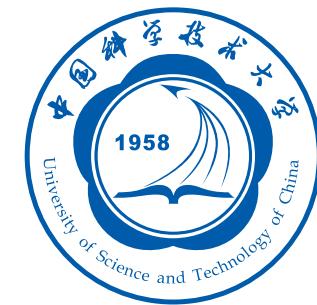




最优化理论  
满足以下条件

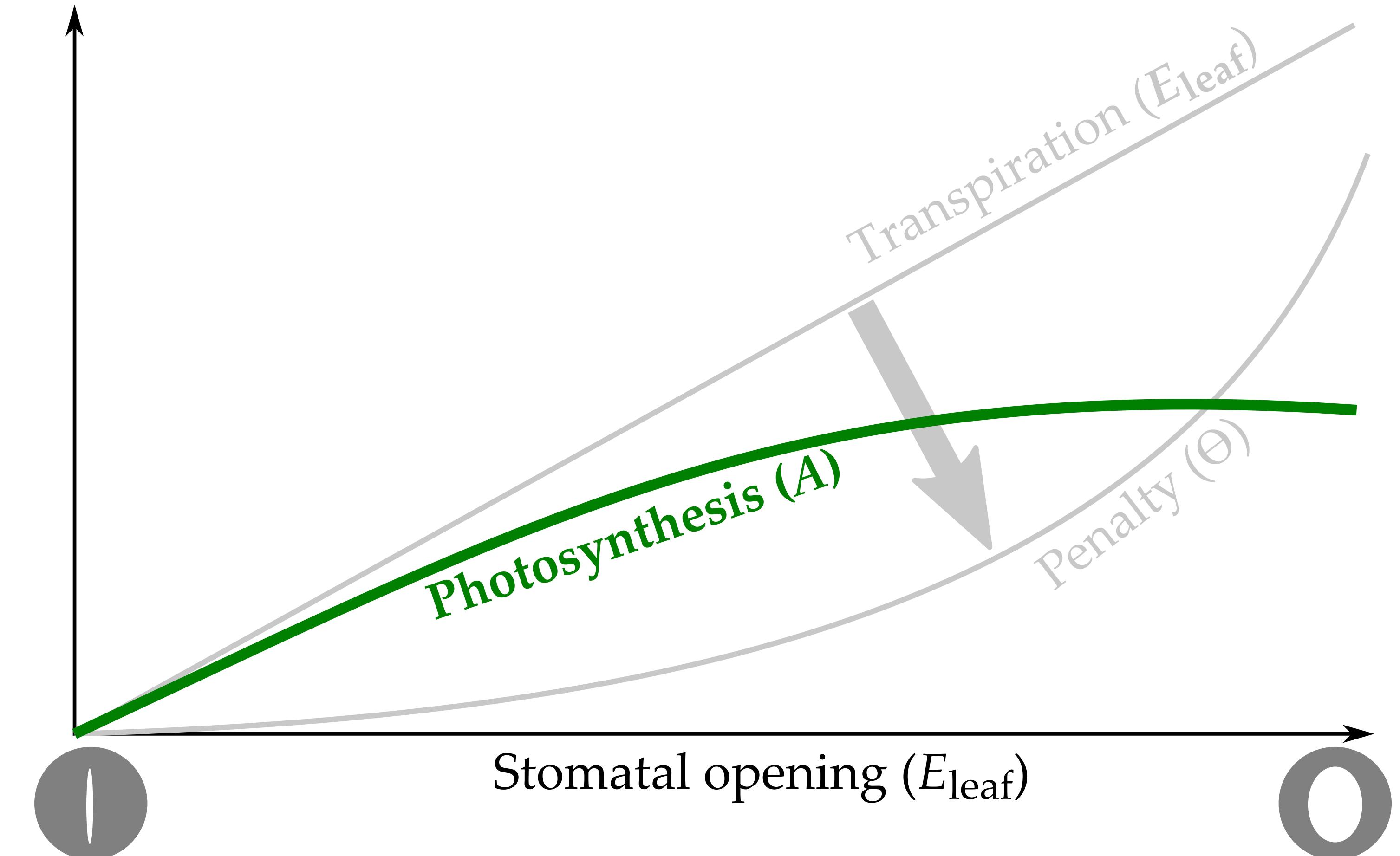
$$\frac{dA}{dE_{leaf}} = \frac{d\Theta}{dE_{leaf}}$$

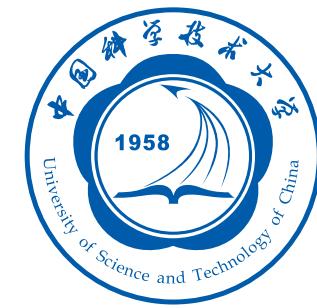




收益方程

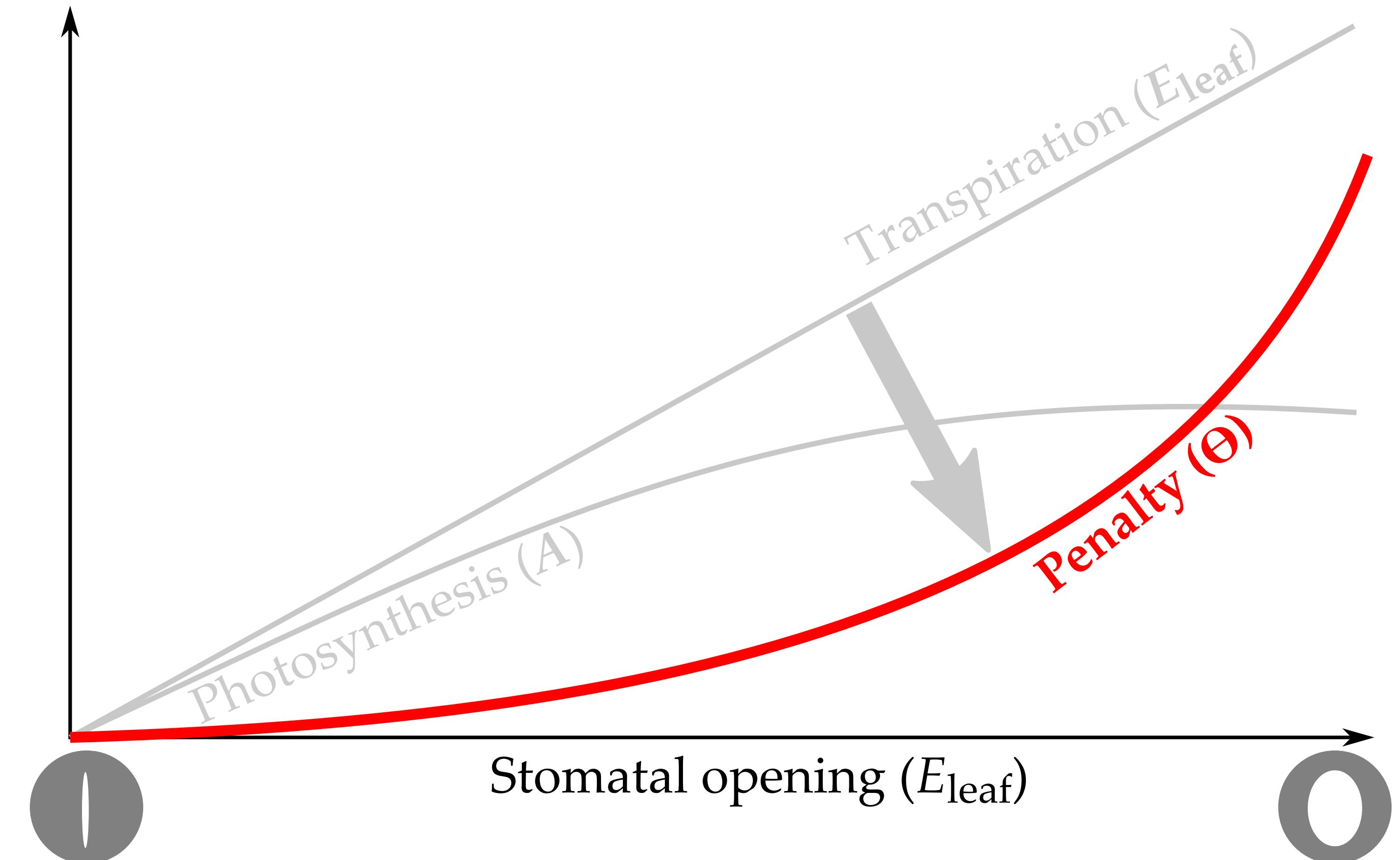
瞬时的光合作用

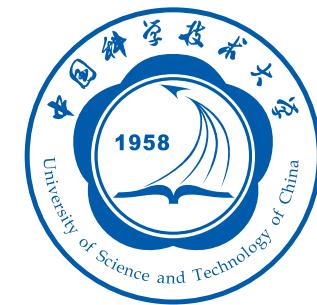




## 损耗方程

？？？



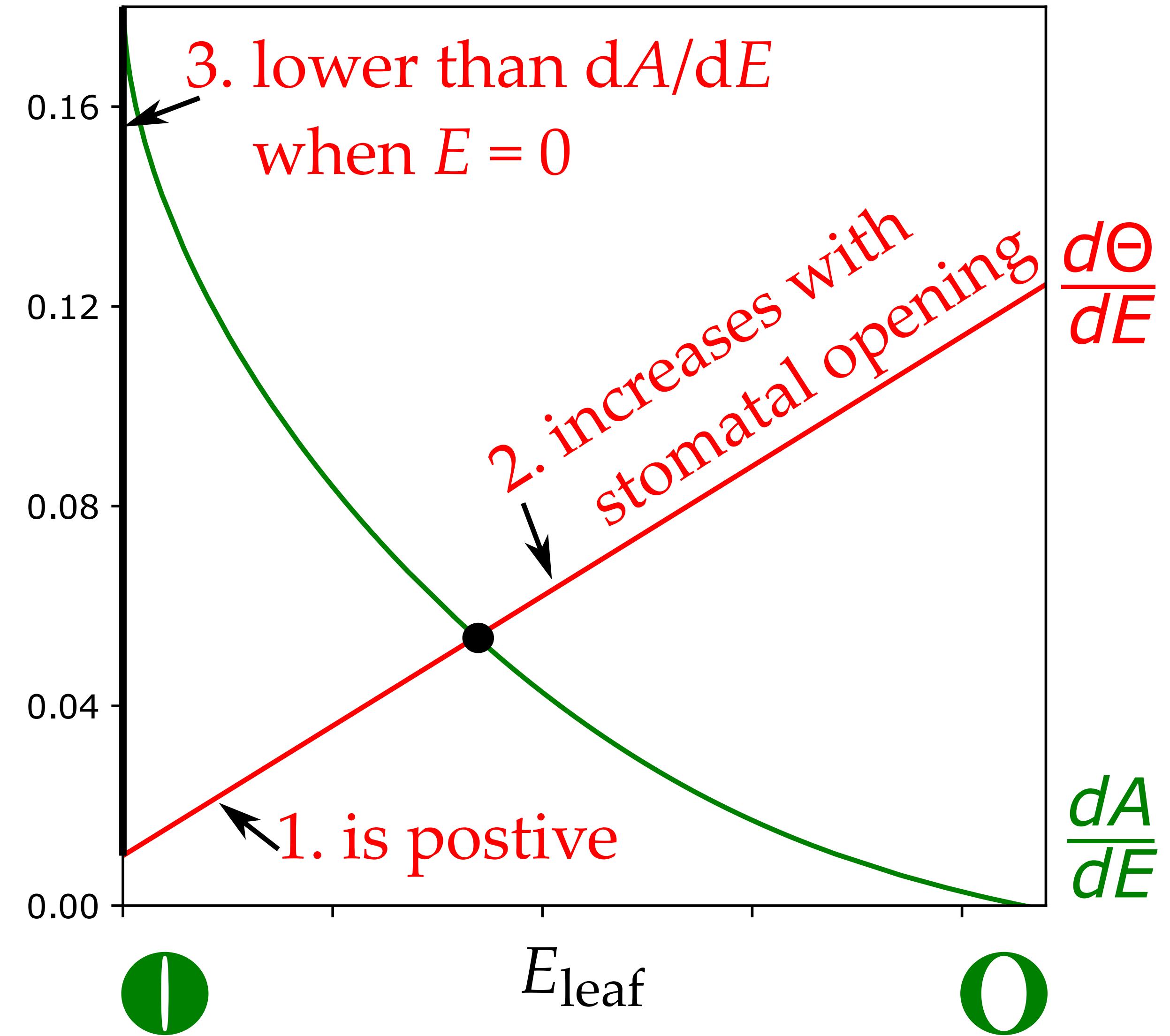


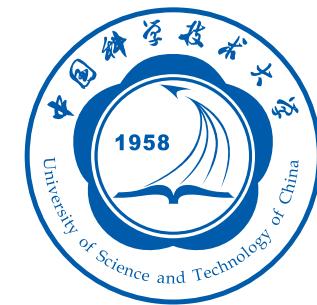
## Criteria

1. Positive

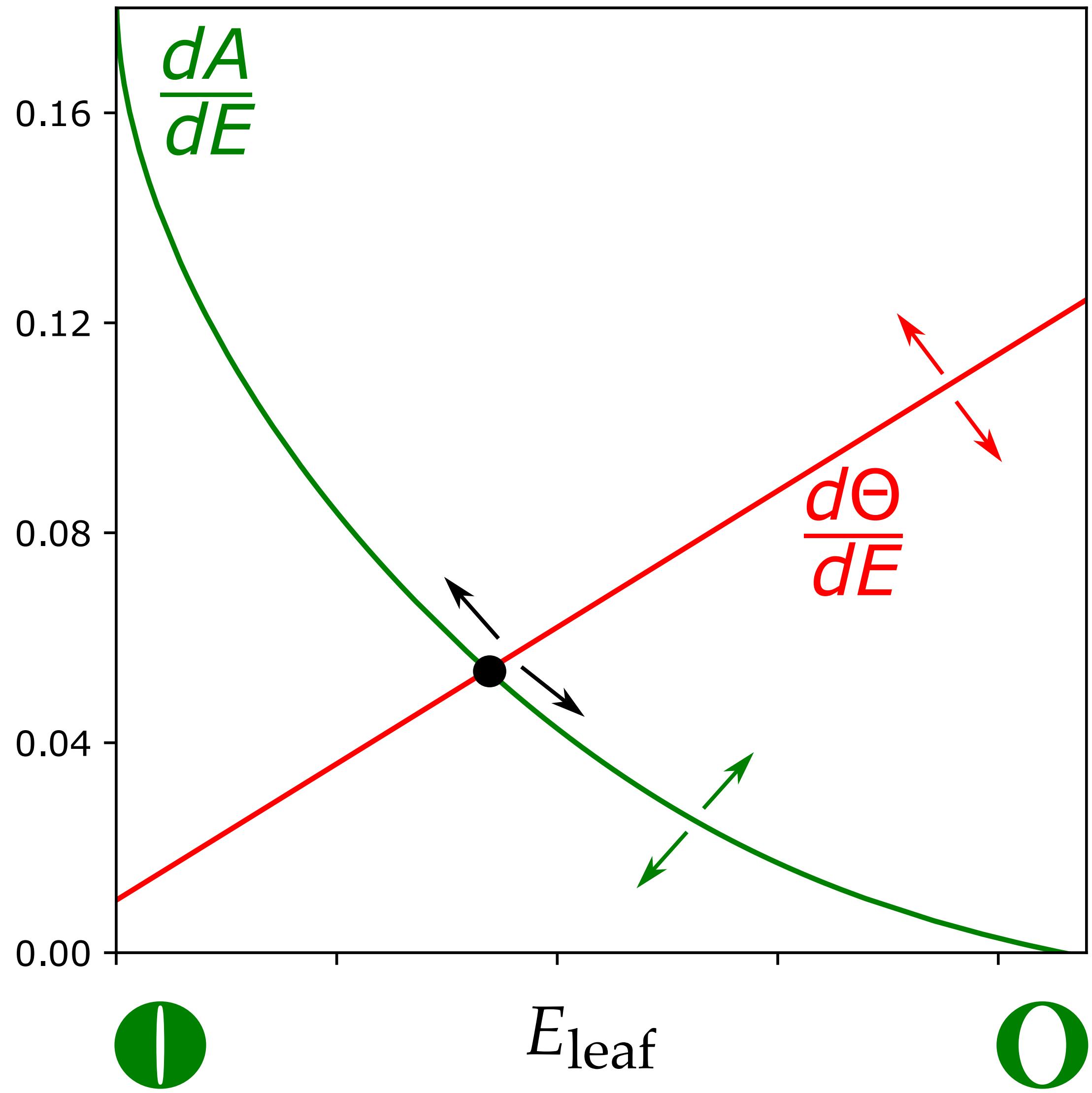
2. Increase with E

3. Lower than gain  
when  $E = 0$





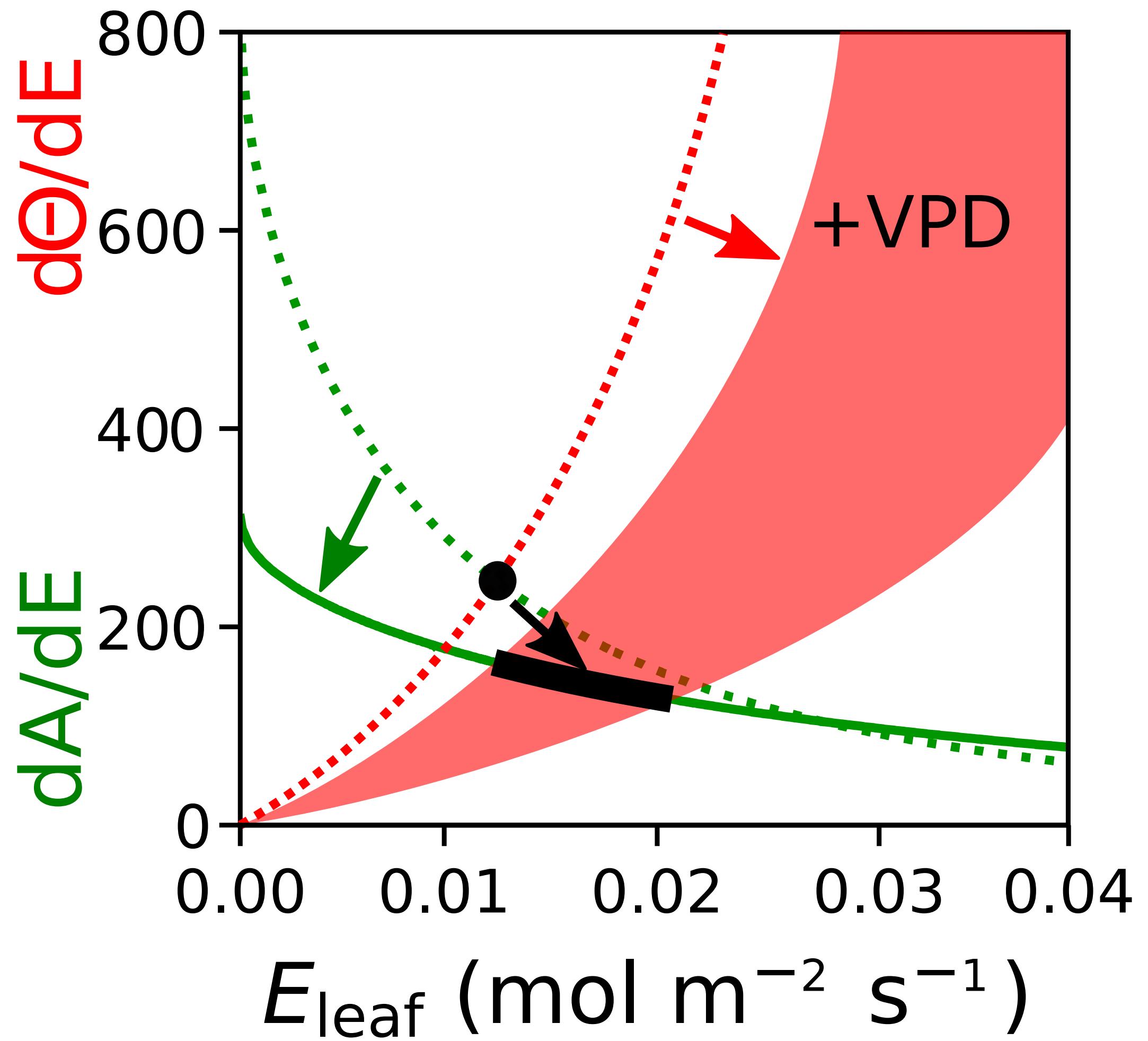
## Criteria

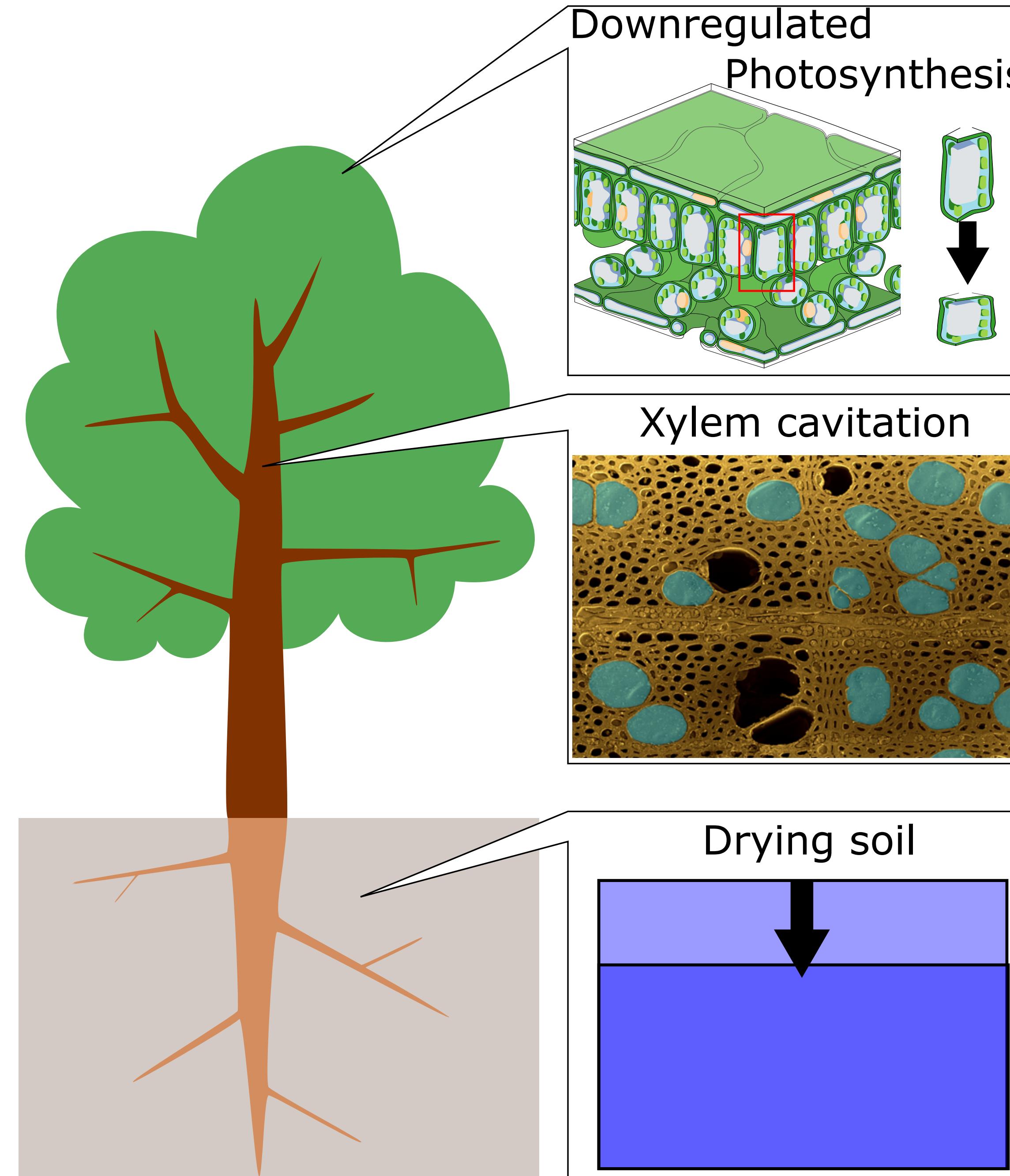




## Criteria

4. Decrease with VPD
5. Increase with CO<sub>2</sub>
6. Increase with drought
7. Increase with drought history





Holtta *et al.* (2017)

Dewar *et al.* (2018)

Huang *et al.* (2018)

... ...

Wolf *et al.* (2016)

Sperry *et al.* (2017)

Anderegg *et al.* (2018)

Eller *et al.* (2019)

... ...

Cowan & Farquhar (1977)

... ...

Manzoni *et al.* (2013)

Prentice *et al.* (2014)

Lu *et al.* (2016)

... ...



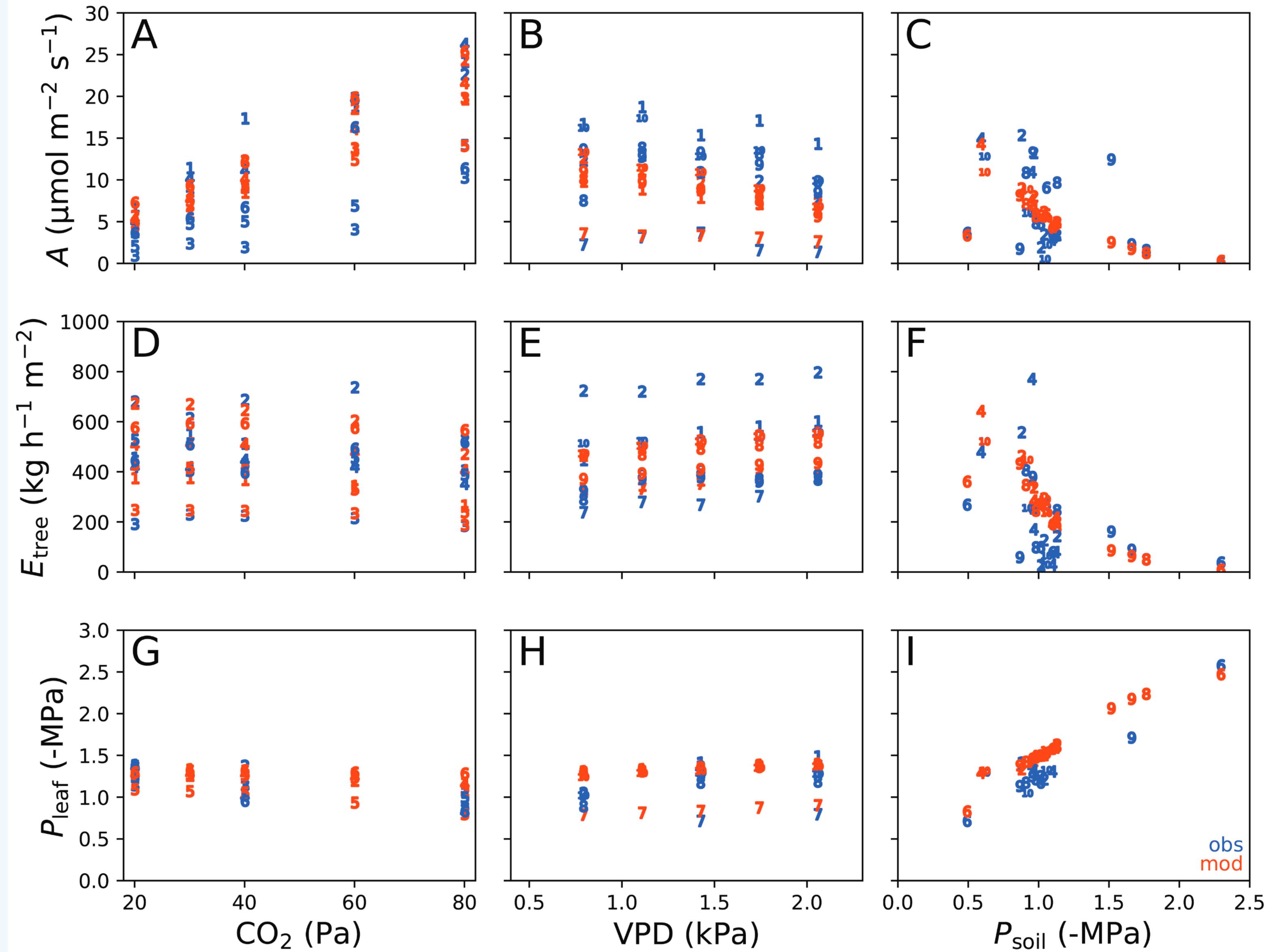
Model	Reference	Water Penalty ( $\Theta$ or $\Theta'$ )	Marginal Penalty ( $d\Theta/dE$ or $d\Theta'/dE$ )	Response Criteria	
				I–III	IV–VII DCPK
Cowan-Farquhar	(Cowan and Farquhar, 1977)	$\Theta = \frac{E_{leaf}}{\lambda}$	$\frac{d\Theta}{dE} = \frac{1}{\lambda}$	YNN	NNNN
Manzoni	(Manzoni et al., 2013)	$\Theta = \frac{E_{leaf}}{\Lambda}$	$\frac{d\Theta}{dE} = \frac{1}{\Lambda}$	YNN	NNNN
Prentice	(Prentice et al., 2014)	$\Theta = A \cdot \left(1 - \frac{1}{c_E E_{leaf} + c_V V_{cmax}}\right)$	$\frac{d\Theta}{dE} = \frac{A}{E_{leaf} + \frac{c_V}{c_E} V_{cmax}}$	YNY	YYNN
Lu	(Lu et al., 2016)	$\Theta = \frac{E_{leaf}}{\lambda}$	$\frac{d\Theta}{dE} = \frac{1}{\lambda}$	YNN	NNNN
Wolf-Anderegg	(Wolf et al., 2016) (Anderegg et al., 2018)	$\Theta = aP^2 + bP + c$	$\frac{d\Theta}{dE} = \frac{2aP + b}{K}$	YYN	NNYY
Sperry	(Sperry et al., 2017)	$\Theta = A_{max} \cdot \left(1 - \frac{K}{K_{max}}\right)$	$\frac{d\Theta}{dE} = -\frac{dK}{dE} \cdot \frac{A_{max}}{K_{max}}$	YYY	YYYY
Eller	(Eller et al., 2018)	$\Theta = A \cdot \left(1 - \frac{K}{K_{max,0}}\right)$	$\frac{d\Theta}{dE} = -\frac{dK}{dE} \cdot \frac{A}{K}$	YYY	YYYN
New Model		$\Theta = A \cdot \frac{E_{leaf}}{E_{crit}}$	$\frac{d\Theta}{dE} = \frac{A}{E_{crit} - E_{leaf}}$	YYY	YYYY
Hölttä	(Hölttä et al., 2017)	$\Theta' = A_{ww} \cdot \frac{SC}{SC_{max}}$	$\frac{d\Theta'}{dE} = \frac{A}{SC_{max} - SC} \cdot \frac{dSC}{dE}$	YYY	YYYY
Dewar CAP	(Dewar et al., 2018)	$\Theta' = A_{ww} \cdot \frac{P}{P_{crit}}$	$\frac{d\Theta'}{dE} = \frac{A}{K \cdot (P_{crit} - P)}$	YYY	YYYY



## 测试数据1

### 生长室实验

- 大气CO<sub>2</sub>
- 空气湿度
- 土壤湿度

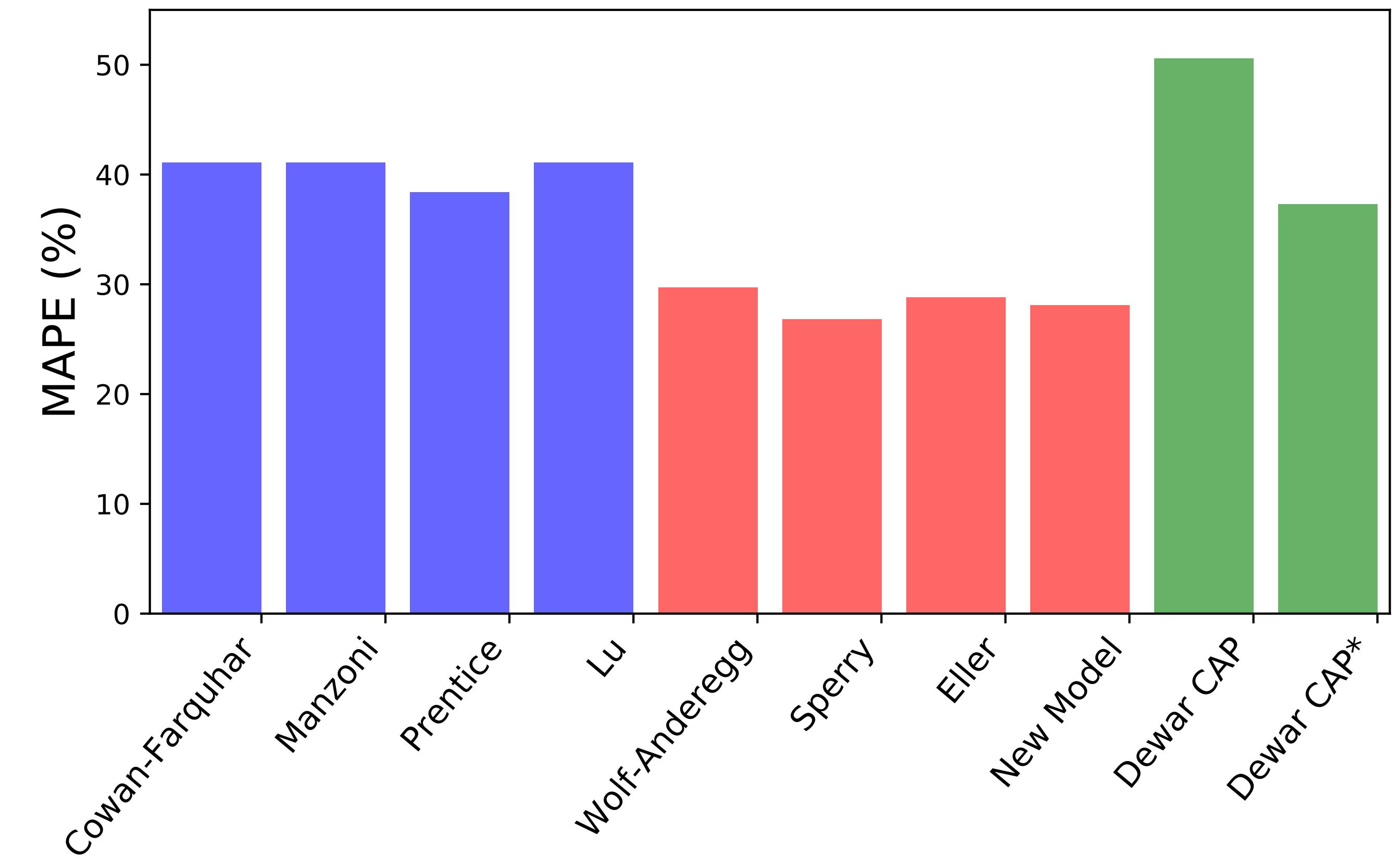




## 测试数据1

### 生长室实验

- 大气CO<sub>2</sub>
- 空气湿度
- 土壤湿度

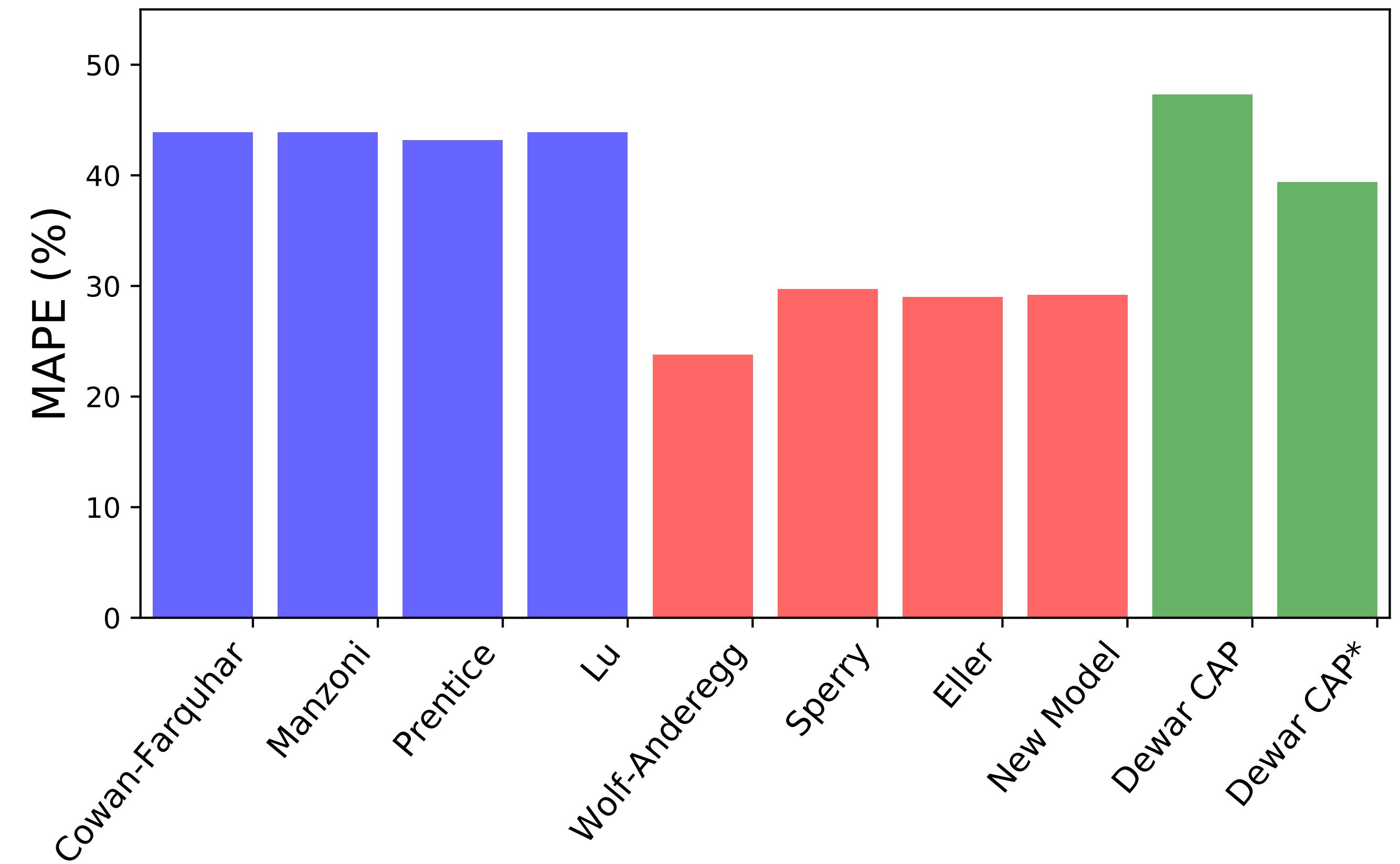




## 测试数据2

### 人工站点

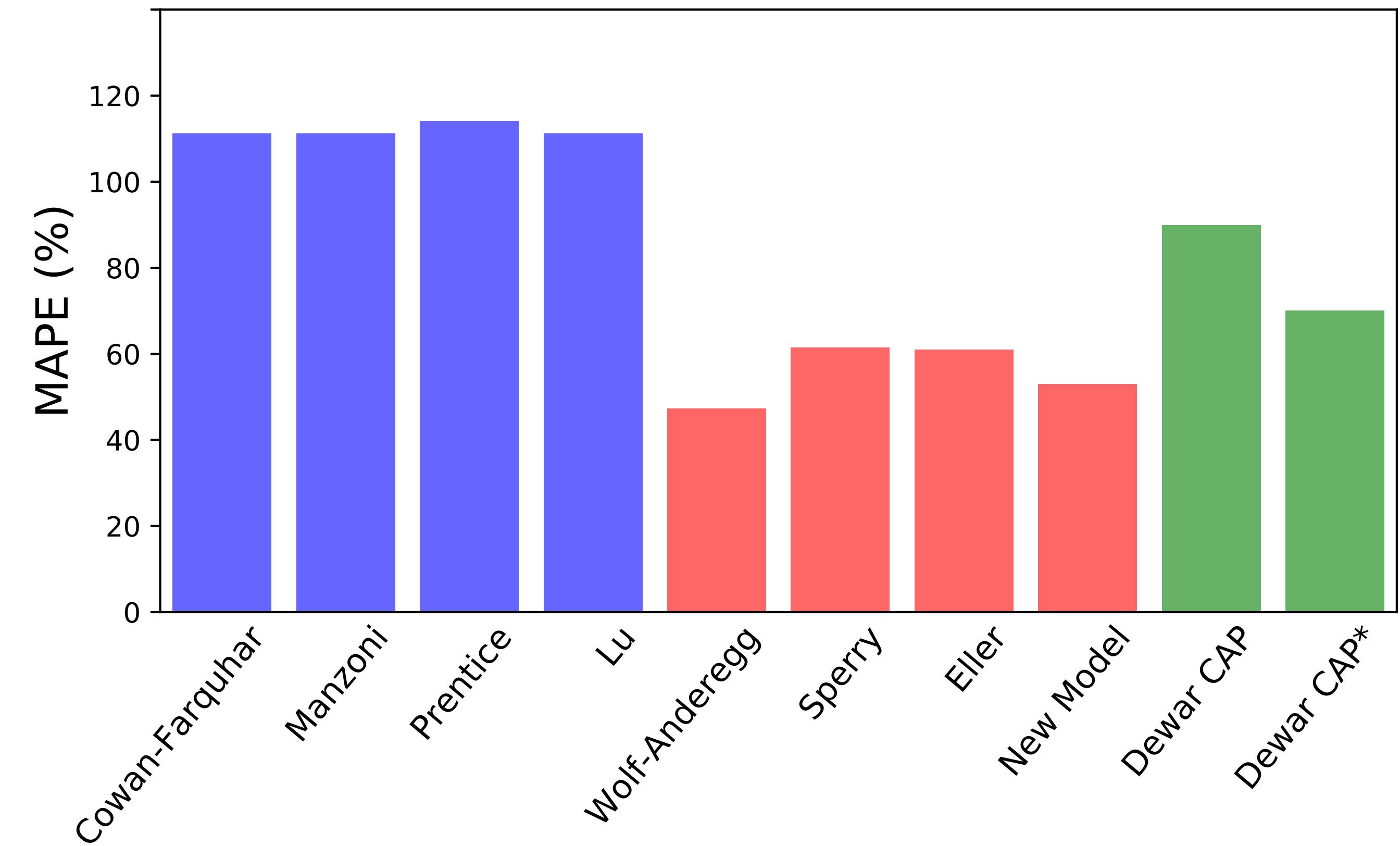
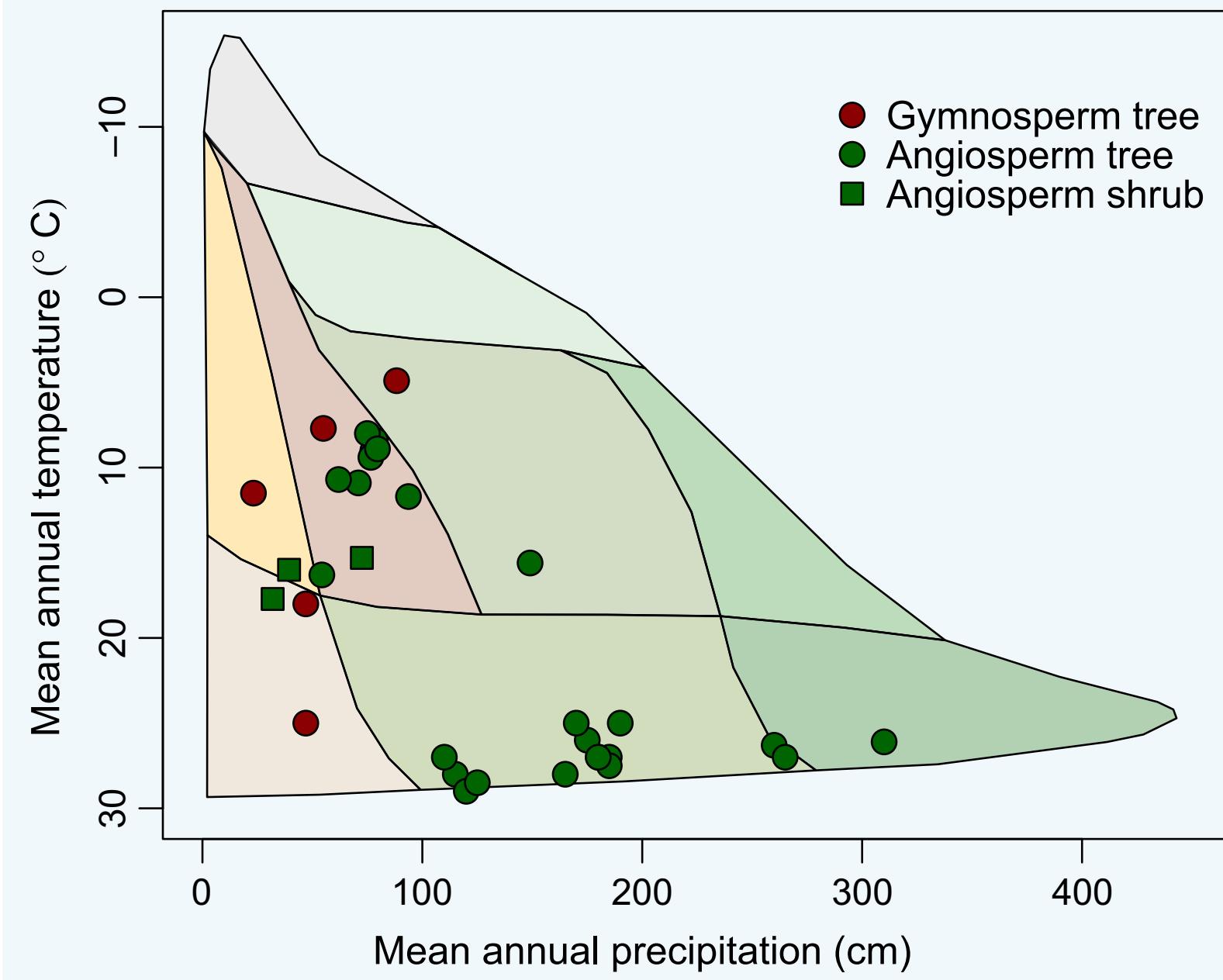
- 土壤湿度
- 空气湿度\*



## 测试数据3

### 野外站点

- 土壤湿度\*
- 空气湿度\*





Model	Reference	Water Penalty ( $\Theta$ or $\Theta'$ )	Marginal Penalty ( $d\Theta/dE$ or $d\Theta'/dE$ )	Response Criteria	
				I–III	IV–VII DCPK
Cowan-Farquhar	(Cowan and Farquhar, 1977)	$\Theta = \frac{E_{leaf}}{\lambda}$	$\frac{d\Theta}{dE} = \frac{1}{\lambda}$	YNN	NNNN
Manzoni	(Manzoni et al., 2013)	$\Theta = \frac{E_{leaf}}{\Lambda}$	$\frac{d\Theta}{dE} = \frac{1}{\Lambda}$	YNN	NNNN
Prentice	(Prentice et al., 2014)	$\Theta = A \cdot \left(1 - \frac{1}{c_E E_{leaf} + c_V V_{cmax}}\right)$	$\frac{d\Theta}{dE} = \frac{A}{E_{leaf} + \frac{c_V}{c_E} V_{cmax}}$	YNY	YYNN
Lu	(Lu et al., 2016)	$\Theta = \frac{E_{leaf}}{\lambda}$	$\frac{d\Theta}{dE} = \frac{1}{\lambda}$	YNN	NNNN
Wolf-Anderegg	(Wolf et al., 2016) (Anderegg et al., 2018)	$\Theta = aP^2 + bP + c$	$\frac{d\Theta}{dE} = \frac{2aP + b}{K}$	YYN	NNYY
Sperry	(Sperry et al., 2017)	$\Theta = A_{max} \cdot \left(1 - \frac{K}{K_{max}}\right)$	$\frac{d\Theta}{dE} = -\frac{dK}{dE} \cdot \frac{A_{max}}{K_{max}}$	YYY	YYYY
Eller	(Eller et al., 2018)	$\Theta = A \cdot \left(1 - \frac{K}{K_{max,0}}\right)$	$\frac{d\Theta}{dE} = -\frac{dK}{dE} \cdot \frac{A}{K}$	YYY	YYYY
New Model		$\Theta = A \cdot \frac{E_{leaf}}{E_{crit}}$	$\frac{d\Theta}{dE} = \frac{A}{E_{crit} - E_{leaf}}$	YYY	YYYY
Hölttä	(Hölttä et al., 2017)	$\Theta' = A_{ww} \cdot \frac{SC}{SC_{max}}$	$\frac{d\Theta'}{dE} = \frac{A}{SC_{max} - SC} \cdot \frac{dSC}{dE}$	YYY	YYYY
Dewar CAP	(Dewar et al., 2018)	$\Theta' = A_{ww} \cdot \frac{P}{P_{crit}}$	$\frac{d\Theta'}{dE} = \frac{A}{K \cdot (P_{crit} - P)}$	YYY	YYYY

# 基于植物生理过程的夜间气孔导度的模型



## 1. 模式开发

改进土壤-植物-  
大气连续体模  
型，加入更多的  
生理机制

## 2. 模式设置

## 3. 参数矫正

# 植物会在夜间开放气孔吗？

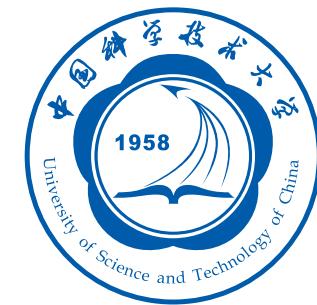
Yes?

- 气孔泄漏
- 营养运输
- 氧气吸收
- 竞争
- 蒸腾散热
- 昼夜循环
- ...

No?

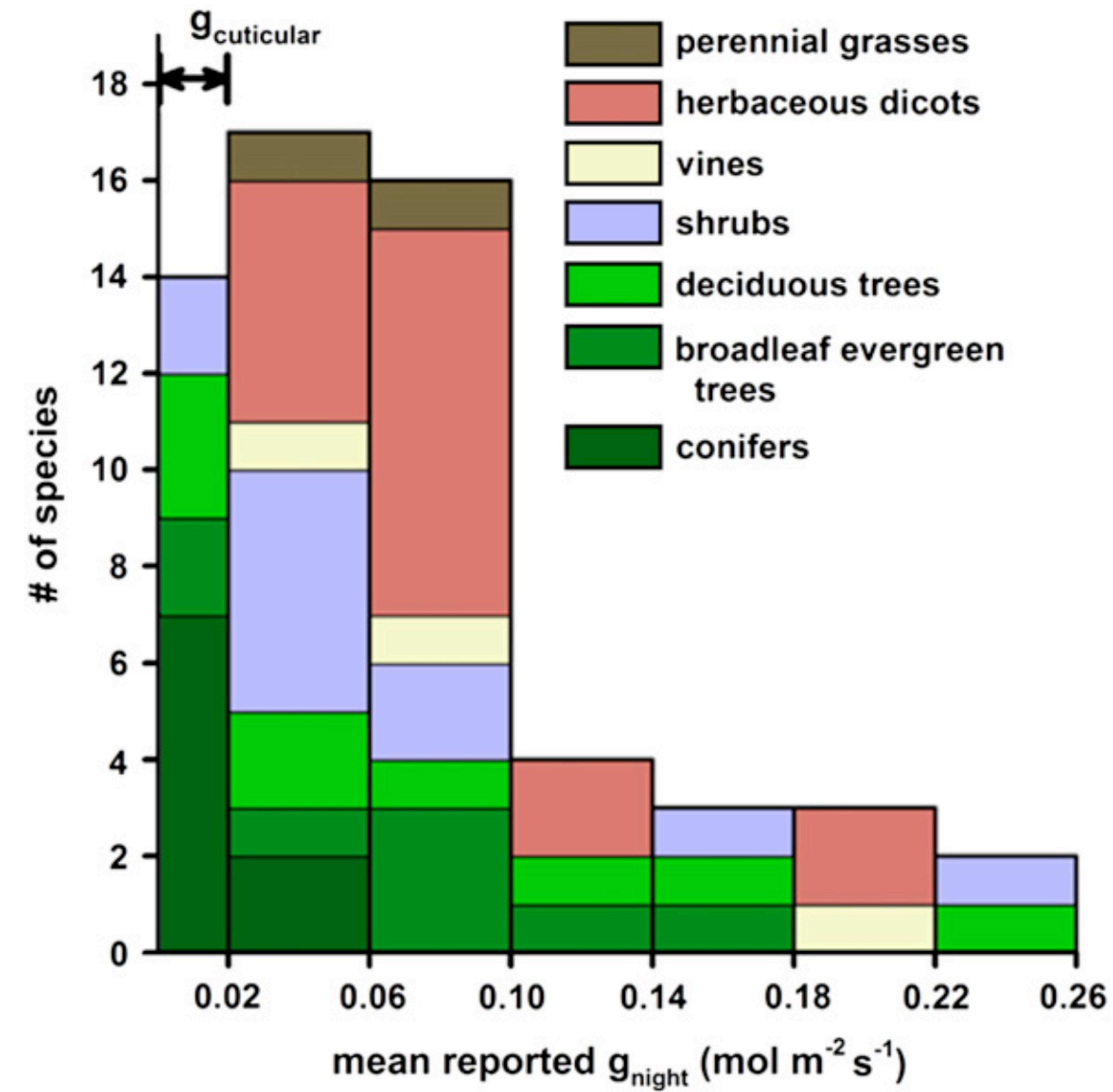
- 水可以在日间使用，促进光合作用
- 维持细胞膨压用来生长
- ...





夜间蒸腾

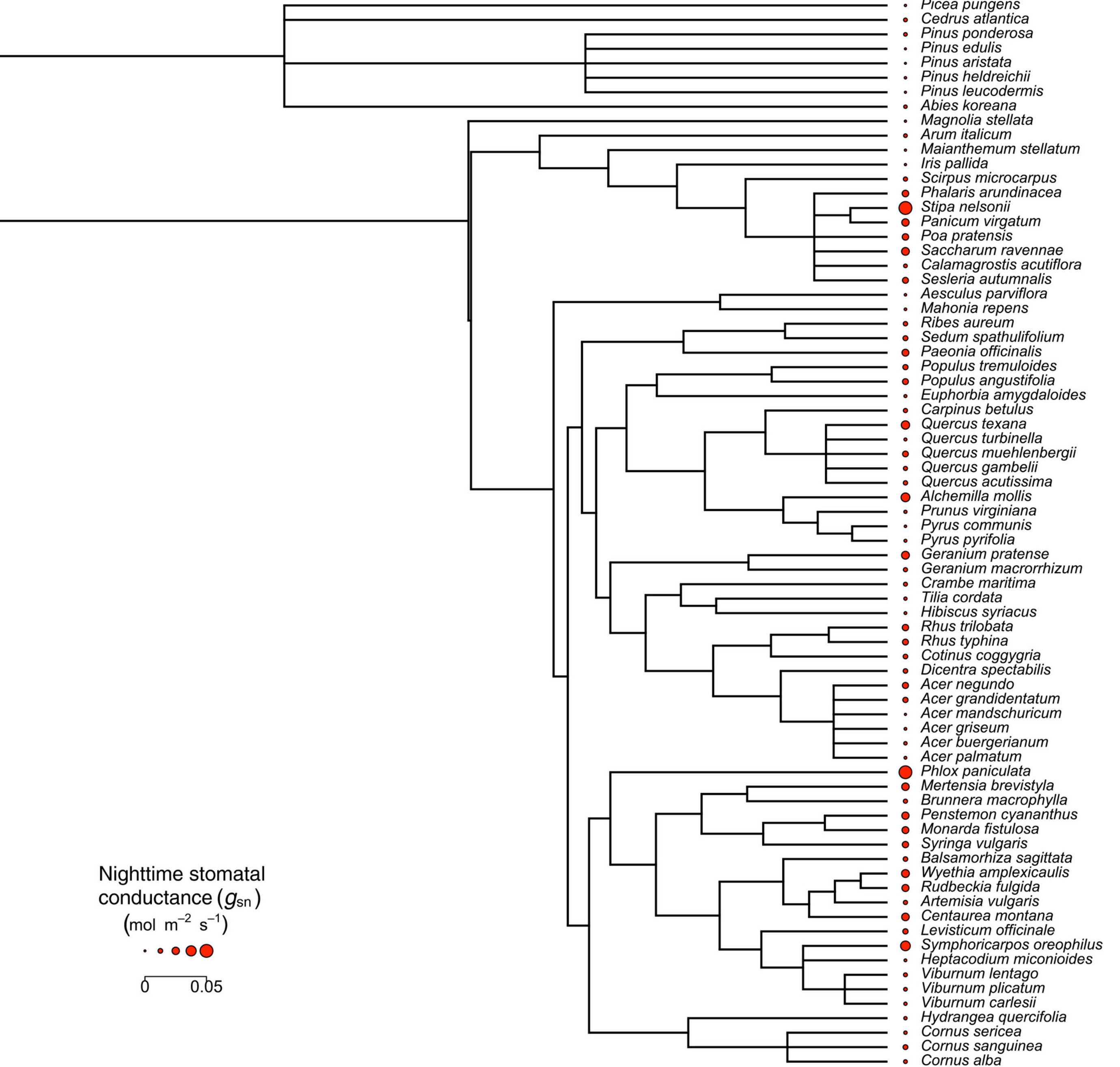
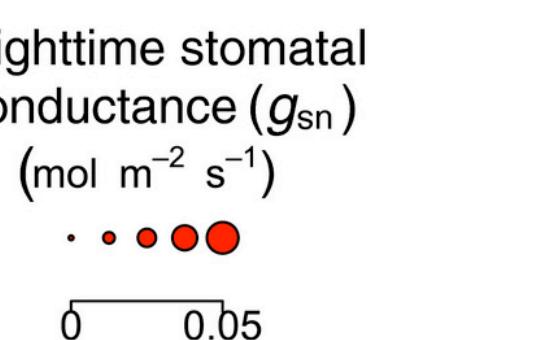
平均占比日间蒸  
腾的10%到15%





## 夜间蒸腾

广泛存在于不同物种和植被类型之间



# 夜间蒸腾对生理与环境的响应：

## 主要原因?

- 气孔泄漏
- 营养运输
- 氧气吸收
- 竞争
- 蒸腾散热
- 昼夜循环
- ...



- 空气湿度
- 大气CO<sub>2</sub>浓度
- 土壤湿度
- 叶片温度
- 叶片呼吸



## 最优化理论

最大化收益与损  
耗之间的差异

### 收益

- 夜间可能的收益

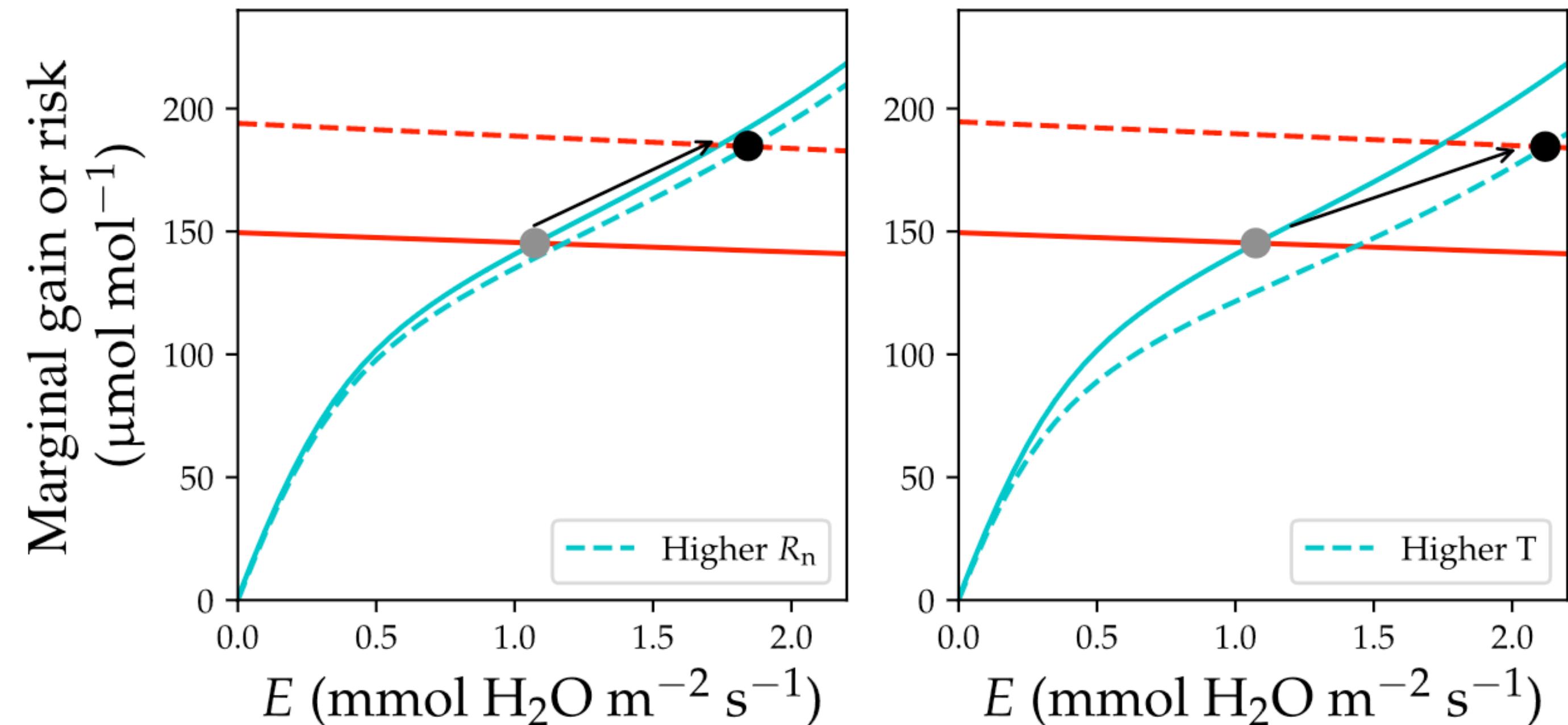
### 损耗

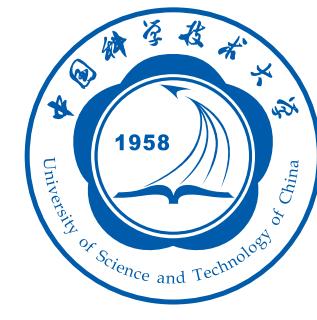
- 日间的光合作用

$$-\frac{\partial R_{\text{leaf}}}{\partial E_n} - f_f \cdot \frac{A_d(E_n)}{E_{\text{crit}} - E_n} = 0$$

## 最优化理论

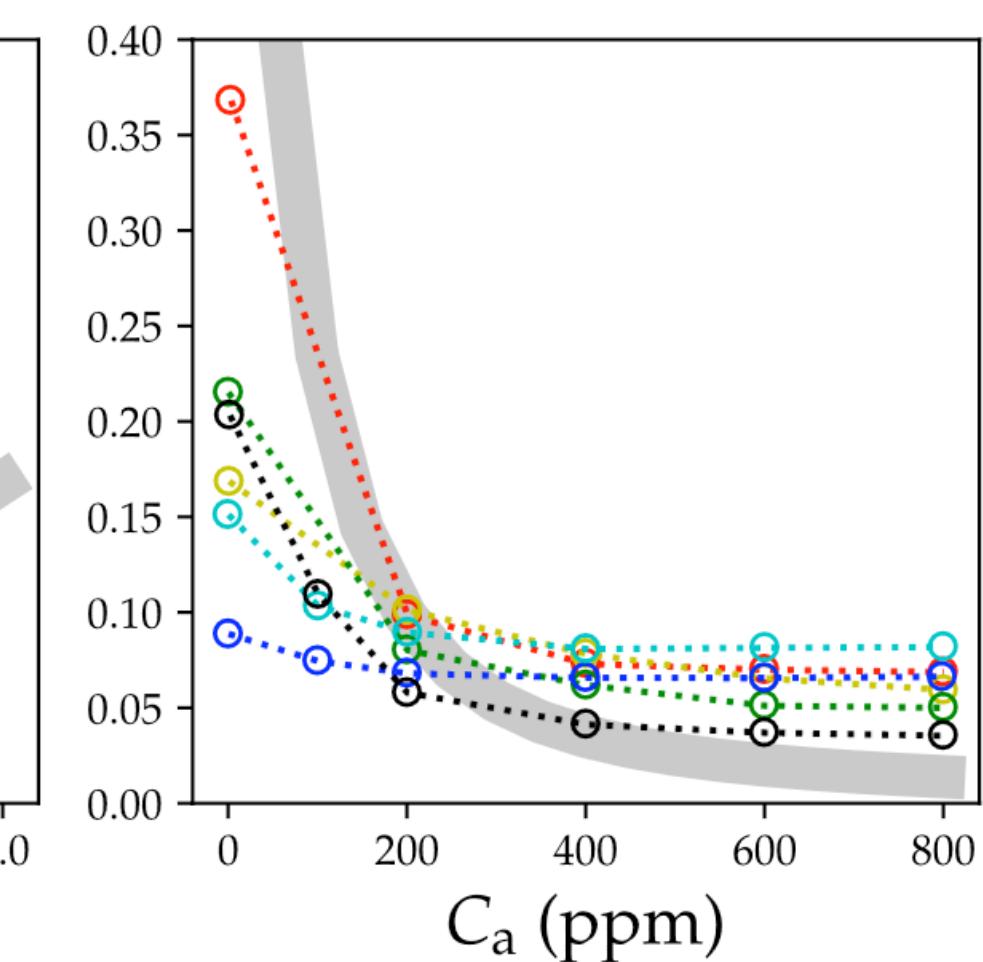
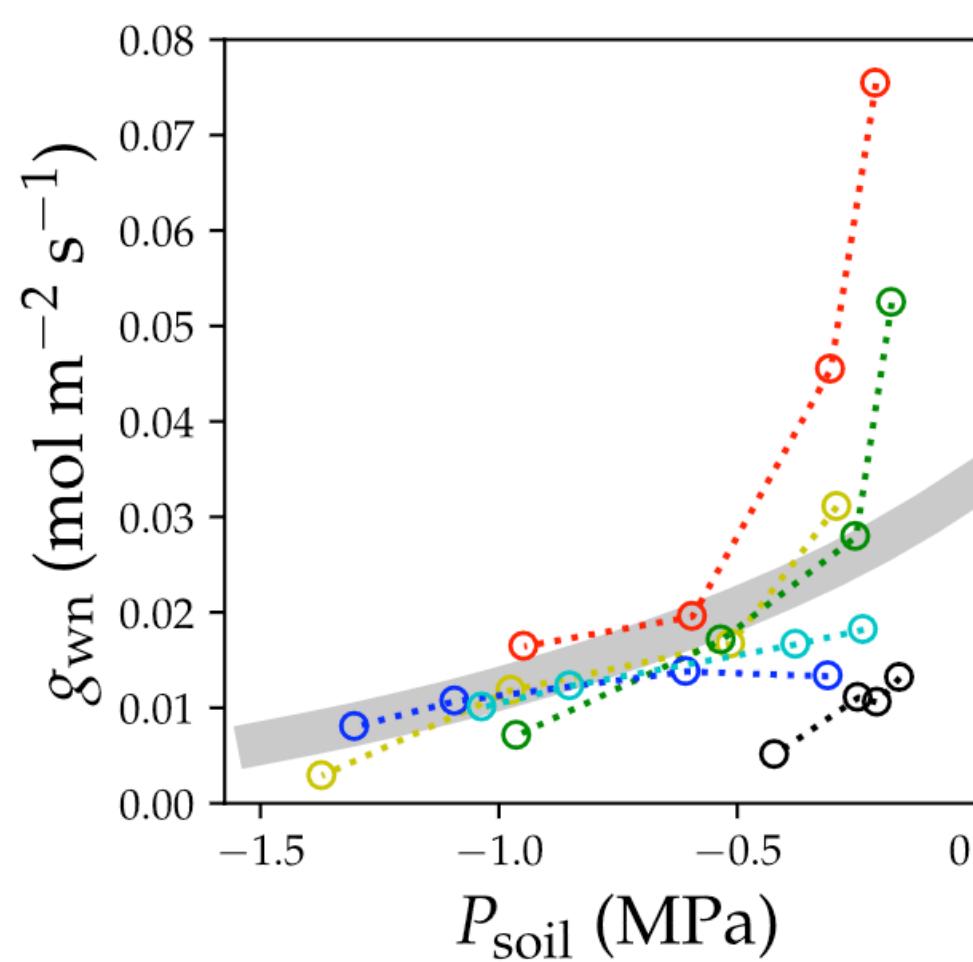
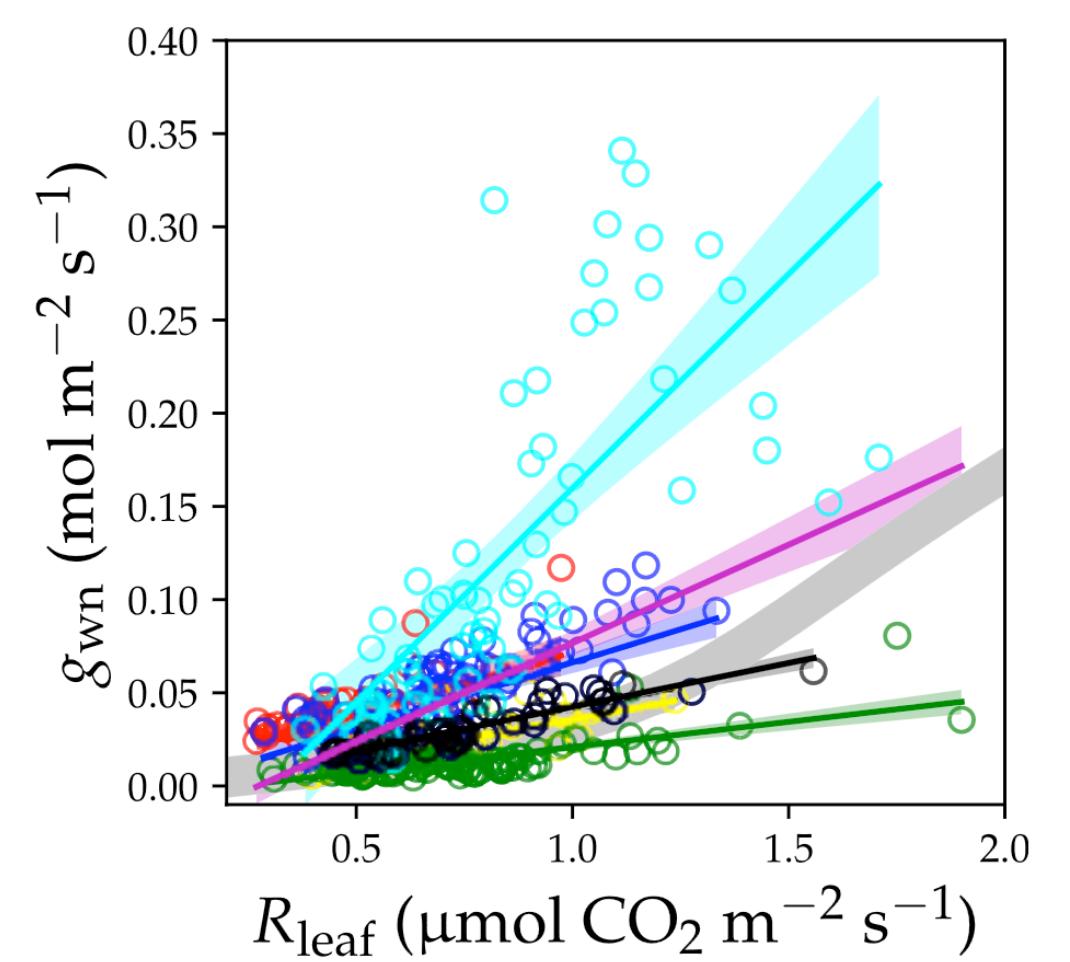
最大化收益与损  
耗之间的差异

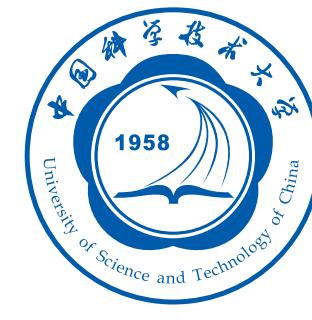




## 最优化理论

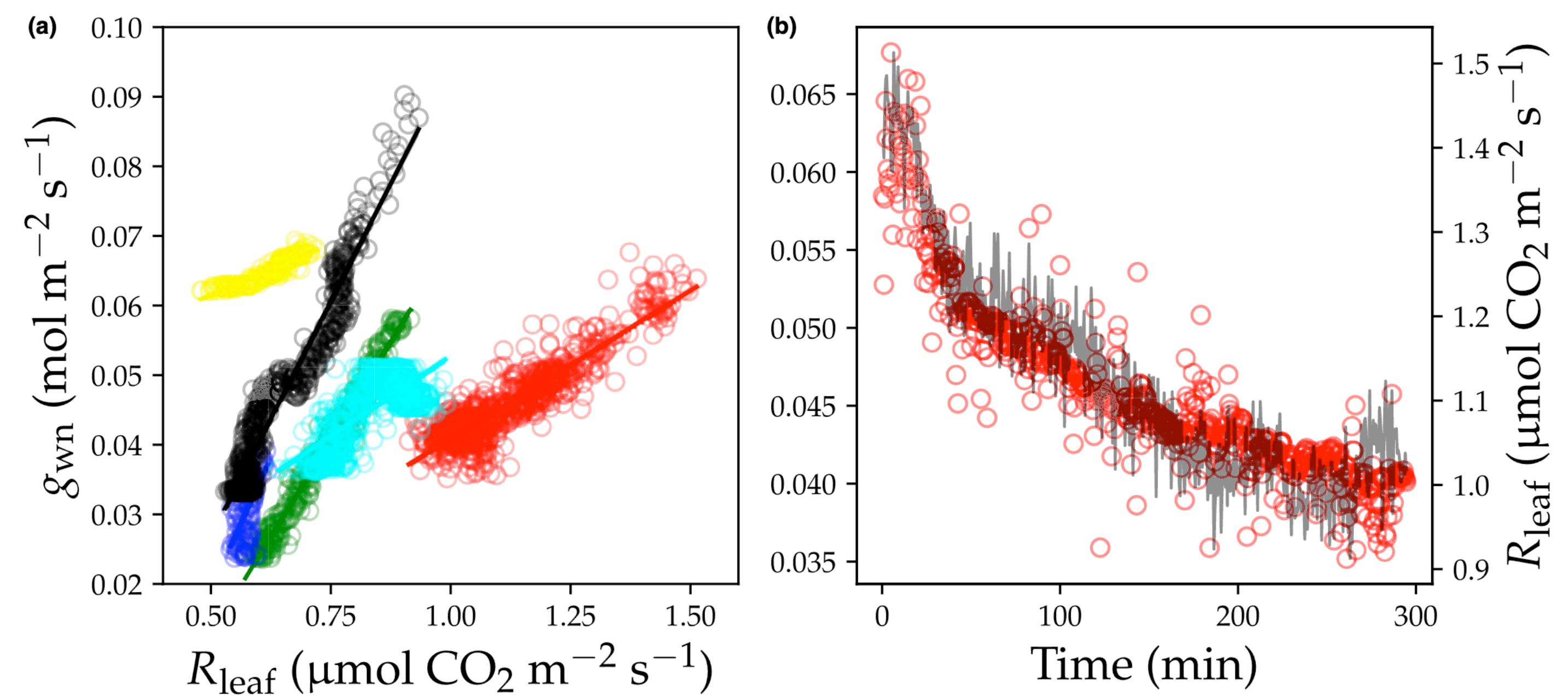
最大化收益与损  
耗之间的差异





## 最优化理论

最大化收益与损  
耗之间的差异



# 新一代高度模块化的陆面模式—CliMA Land

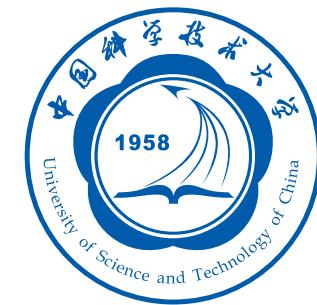


## 1. 模式开发

## 2. 模式设置

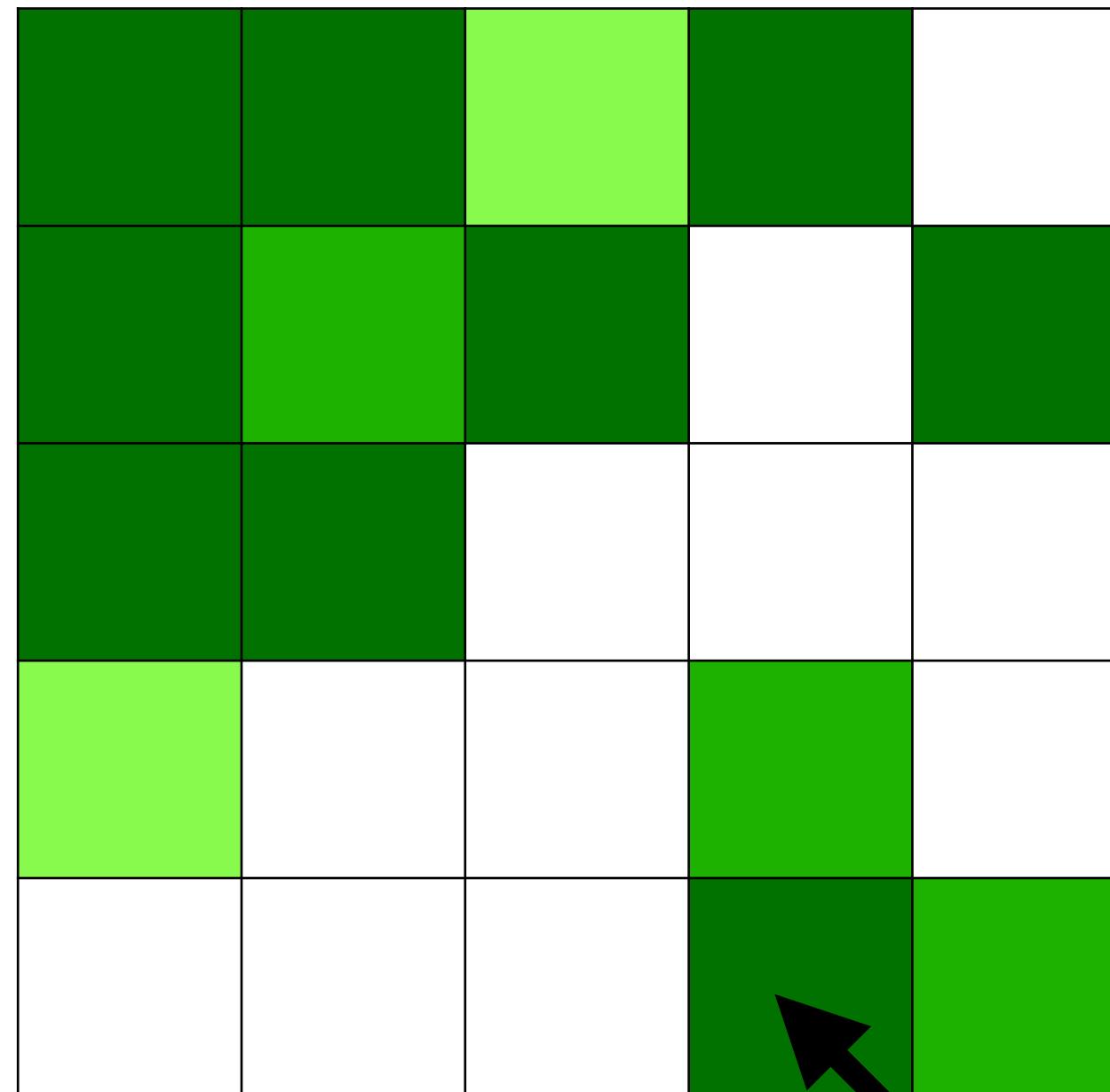
使用更合理的模式设置与组合，降低对经验模式的依赖

## 3. 参数矫正



## 利弊权衡

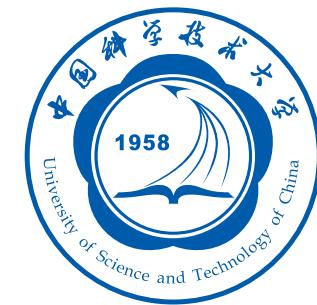
- 复杂度
- 精确度
- 可读性
- 开发速度
- 运行速度
- 学习框架



最小元素

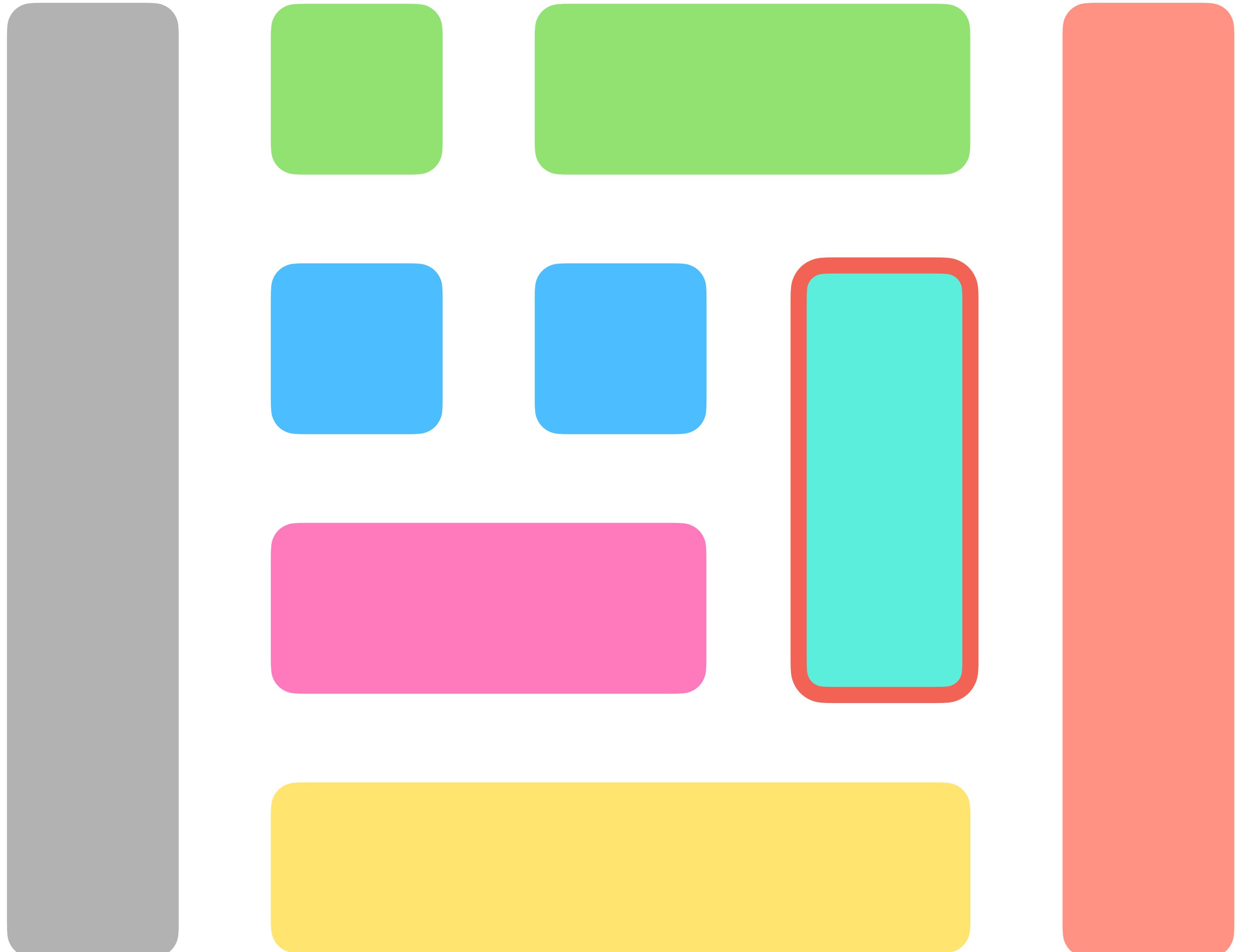
土壤-植被-大气连续体





## 1. 模块化

每个模块均可以  
作为一个独立的  
应用存在



## 1. 模块化

每个模块均可以  
作为一个独立的  
应用存在

```
config = EmeraldLand.Namespace.SPACConfiguration{FT}();
bio = EmeraldLand.Namespace.LeafBio(config);
EmeraldLand.LeafOptics.leaf_spectra!(config, bio, FT(5));
```

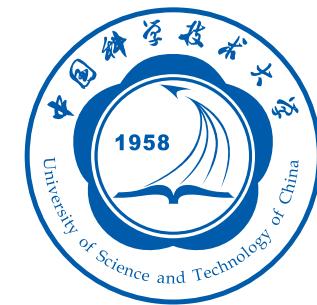


## 2. 用户体验

方便快捷的使用  
方式

```
config = EmeraldLand.Namespace.SPACConfiguration{FT}();
spac = EmeraldLand.Namespace.BulkSPAC(config);
EmeraldLand.SPAC.initialize!(config, spac);
EmeraldLand.SPAC.spac!(config, spac, FT(1));
```





### 3. 自由度

许多不同的模型  
供用户选择、自  
由组合

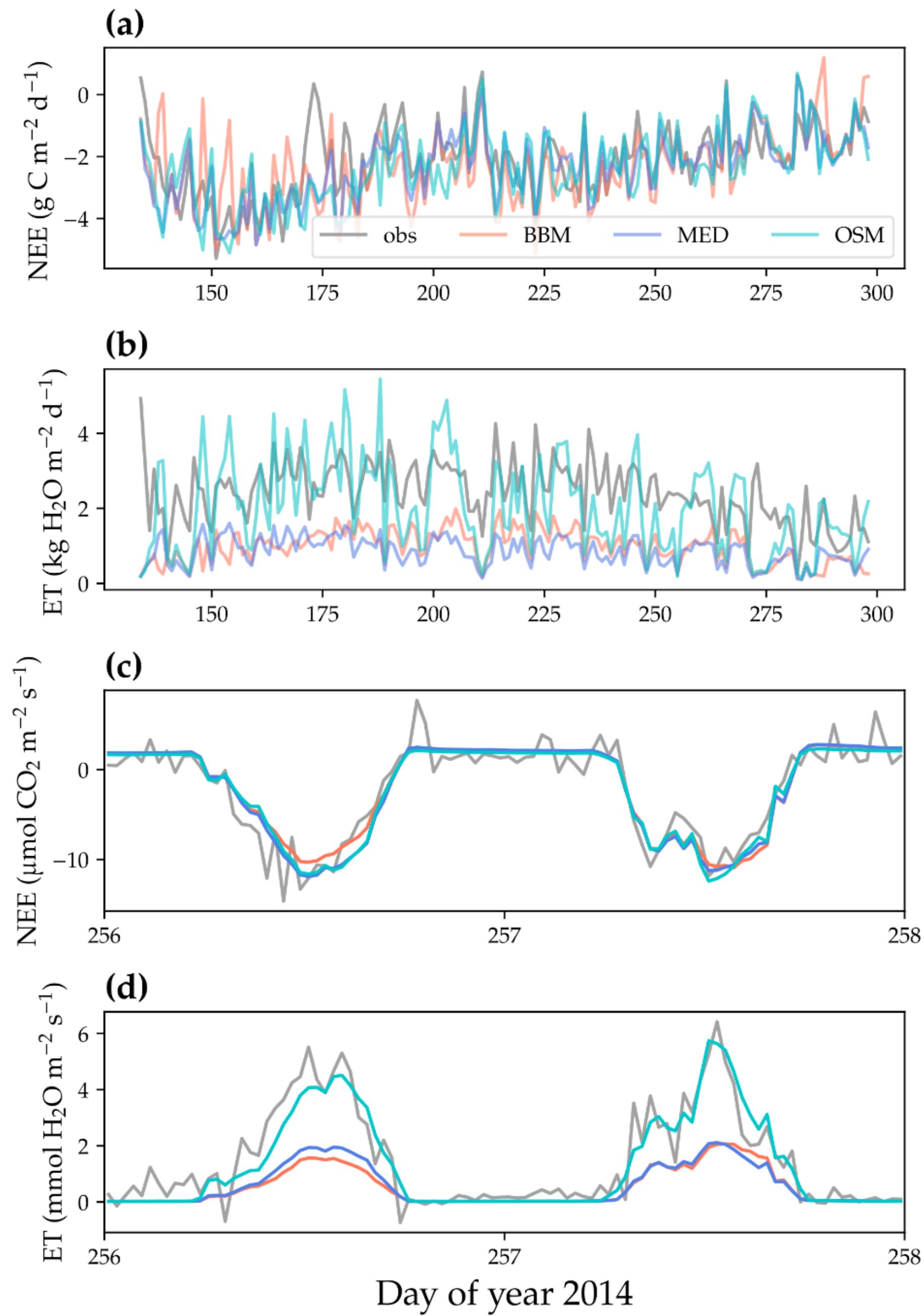




### 3. 自由度

示例1：

不同气孔模型的  
比较

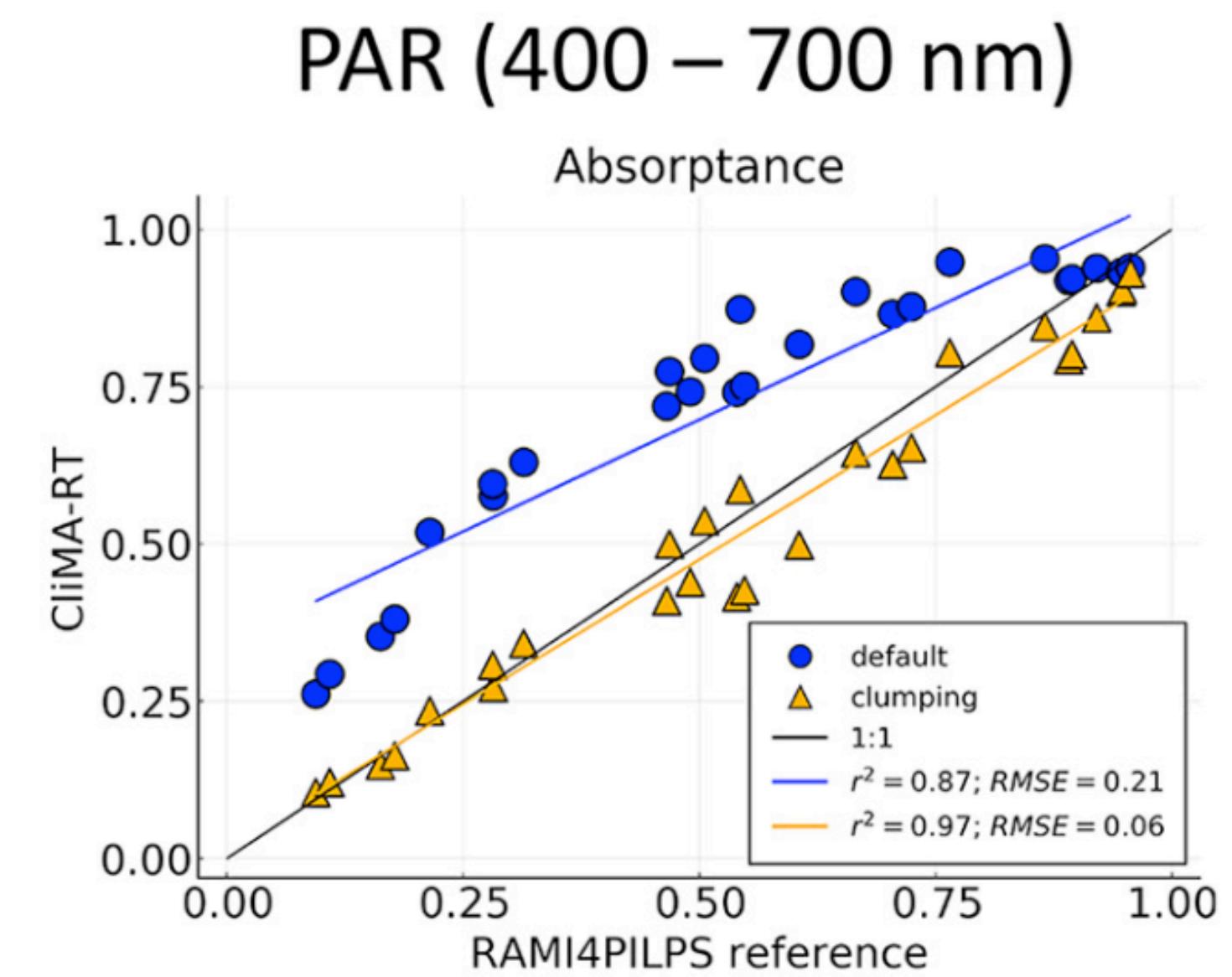
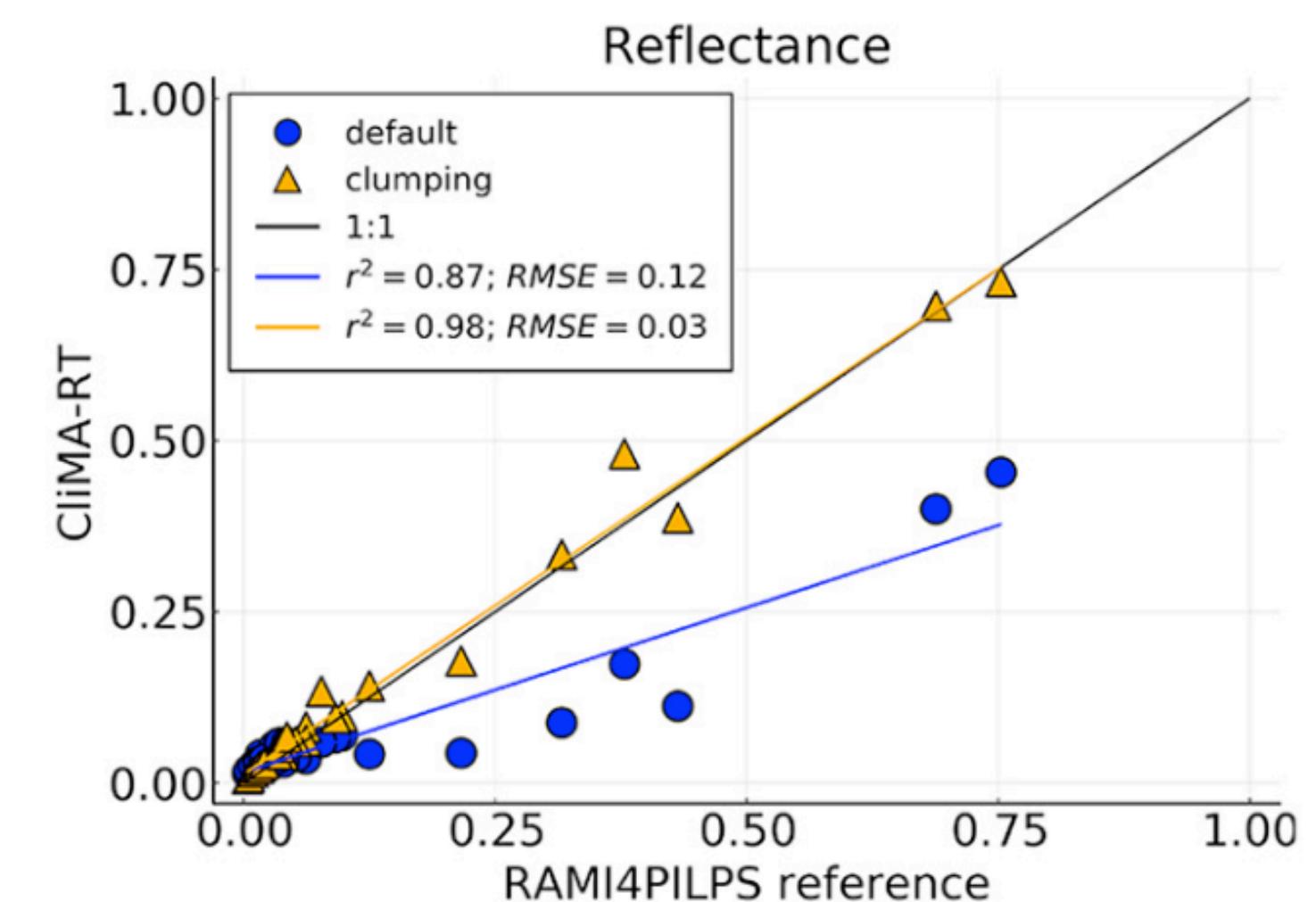




### 3. 自由度

示例2：

打开/关闭植被的  
聚集指数功能

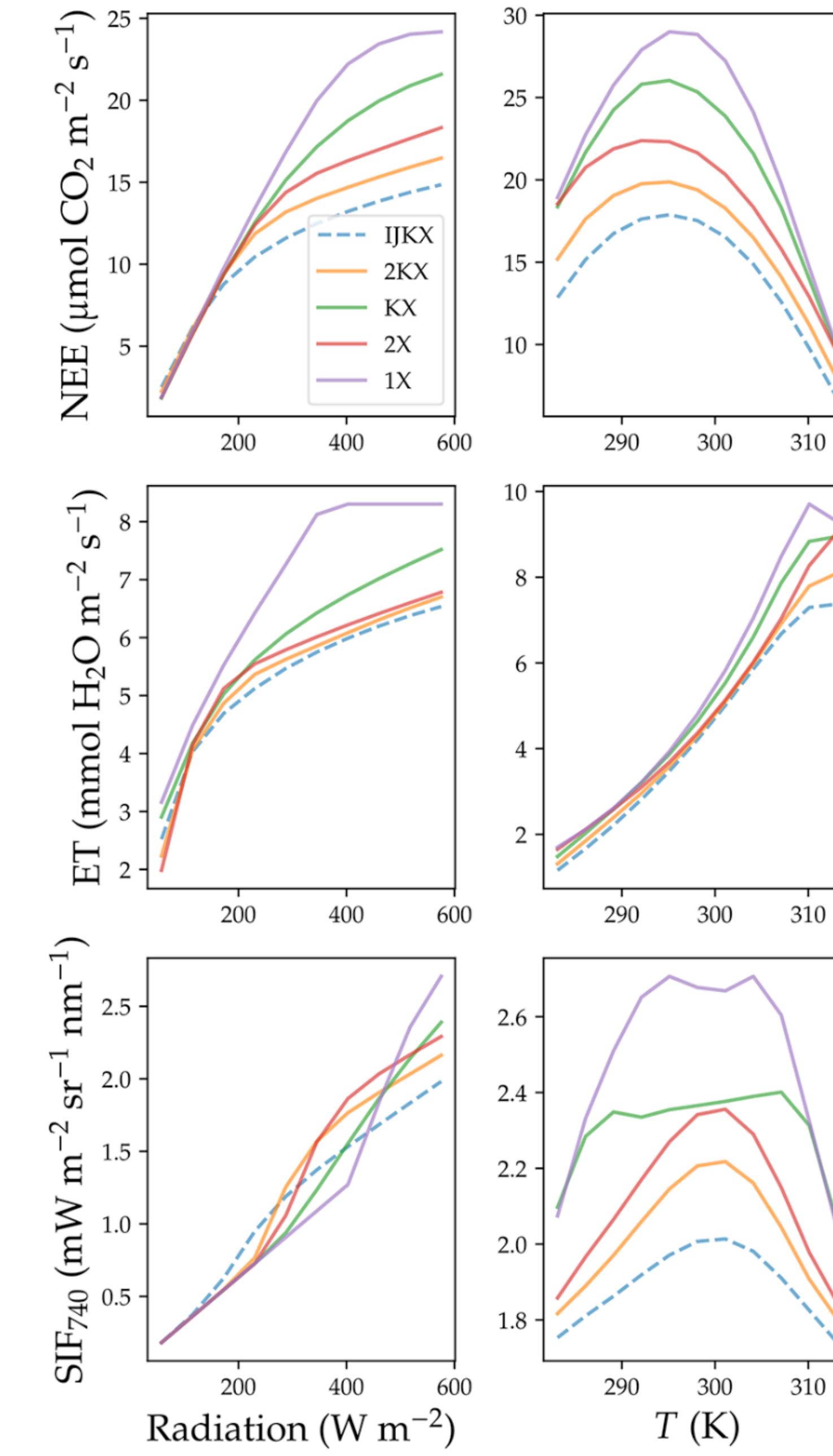
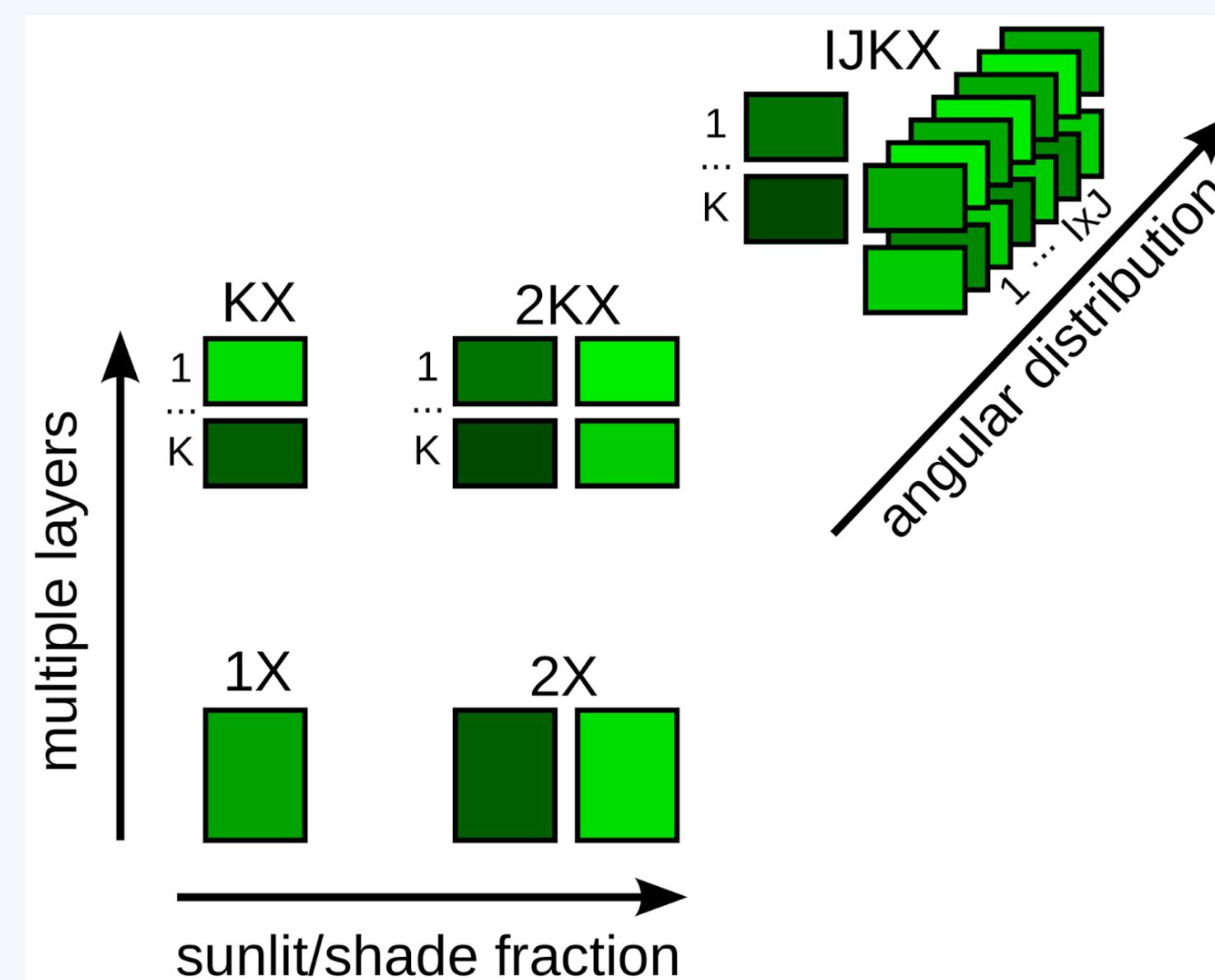




### 3. 自由度

示例3：

冠层结构的复杂程度可自由调节



# GriddingMachine：新的全球尺度数据库软件



1. 模型构建

2. 模型设置

3. 参数矫正

使用更多、更系统  
的多来源数据  
进行模型参数的  
矫正

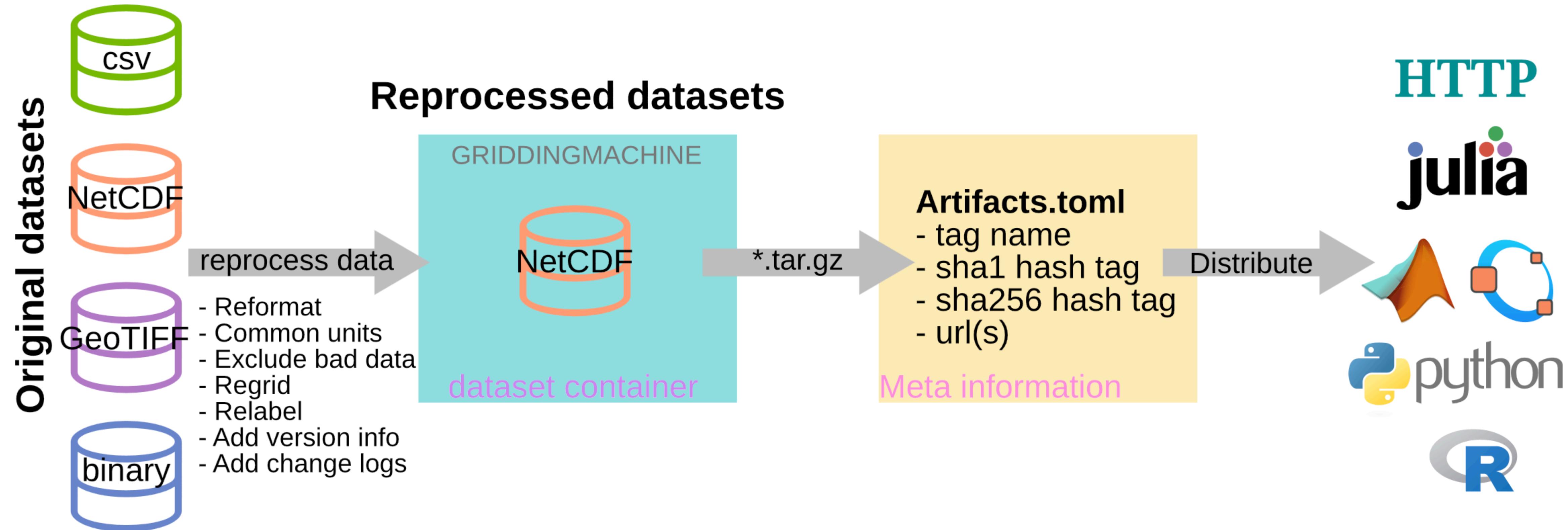


## 副产品

ClIMA Land需要  
全球数据作为输入

## 挑战

- 数据存放网站
- 数据格式
- 不能直接使用
- 地图方向
- 地图覆盖面积
- 地图映射
- 数据单位
- ... ...
- 用户忘记把数据存哪了





## GriddingMachine

### Testing modules

- **Blender**
- **Fetcher**
- **Partitioner**

## GriddingMachine.jl

### Collector.jl

Tool to manage our collection of datasets locally

### GriddedCollection

Data struct that contains information of the collection, such as supported data versions

### query\_collection

Function to locate the local dataset; if file does not exist, download it automatically

### clean\_collection!

Function to clean up the collection, such as out-of-dated collections

### read\_LUT

Function to read the data full or in part data from local files

### Indexer.jl

Tool to read the datasets locally

### Requestor.jl

Tool to request data for a given latitude and longitude from the server

### request\_LUT

Function to request data in part from a server, rather than from locally downloaded file



用户只需要知道  
数据的标签

## API

```
using GriddingMachine.Collector: query_collection;
file_path = query_collection("VCMAX_2X_1Y_V1");

using GriddingMachine.Requestor: request_LUT;
dat,std = request_LUT("LAI_MODIS_20x_1M_2020_V1", 31.82, 117.23);
```

Dataset type	LABEL	EXTRALABEL	IX	JT	YEAR	VK	Reference	Change logs
Gross primary productivity	GPP	MPI_RS	2X	1M, 8D	2001-2019	V1	Tramontana et al. (2016)	4,9
	GPP	VPM	5X, 12X	8D	2000-2019	V2	Zhang et al. (2017)	1,4
Leaf area index	LAI	MODIS	2X, 10X, 20X	1M, 8D	2000-2020	V1	Yuan et al. (2011)	1,4,9
Latent heat flux	LE	MPI_RS	2X	1M, 8D	2001-2015	V1	Jung et al. (2019)	4,9
Solar induced chlorophyll	SIF	TROPOMI_683, TROPOMI_683DC	1X, 2X, 4X,	1M, 8D	2018-2020	V2	Köhler et al. (2020)	1,8

# API

## 快速获取多边形 的数据

- **Partitioner**

```
# new feature under testing
using GriddingMachine.Partitioner: query_data;
data = query_data("TROPOMI.json", polygon, 2020; months=[1,2]);
```



# ClIMA Land的全球模拟结果：植被过程与遥感



1. 模式开发

2. 模式设置

3. 参数矫正

使用更多、更系统  
的多来源数据  
进行模型参数的  
矫正



## CliMA Land全球模拟

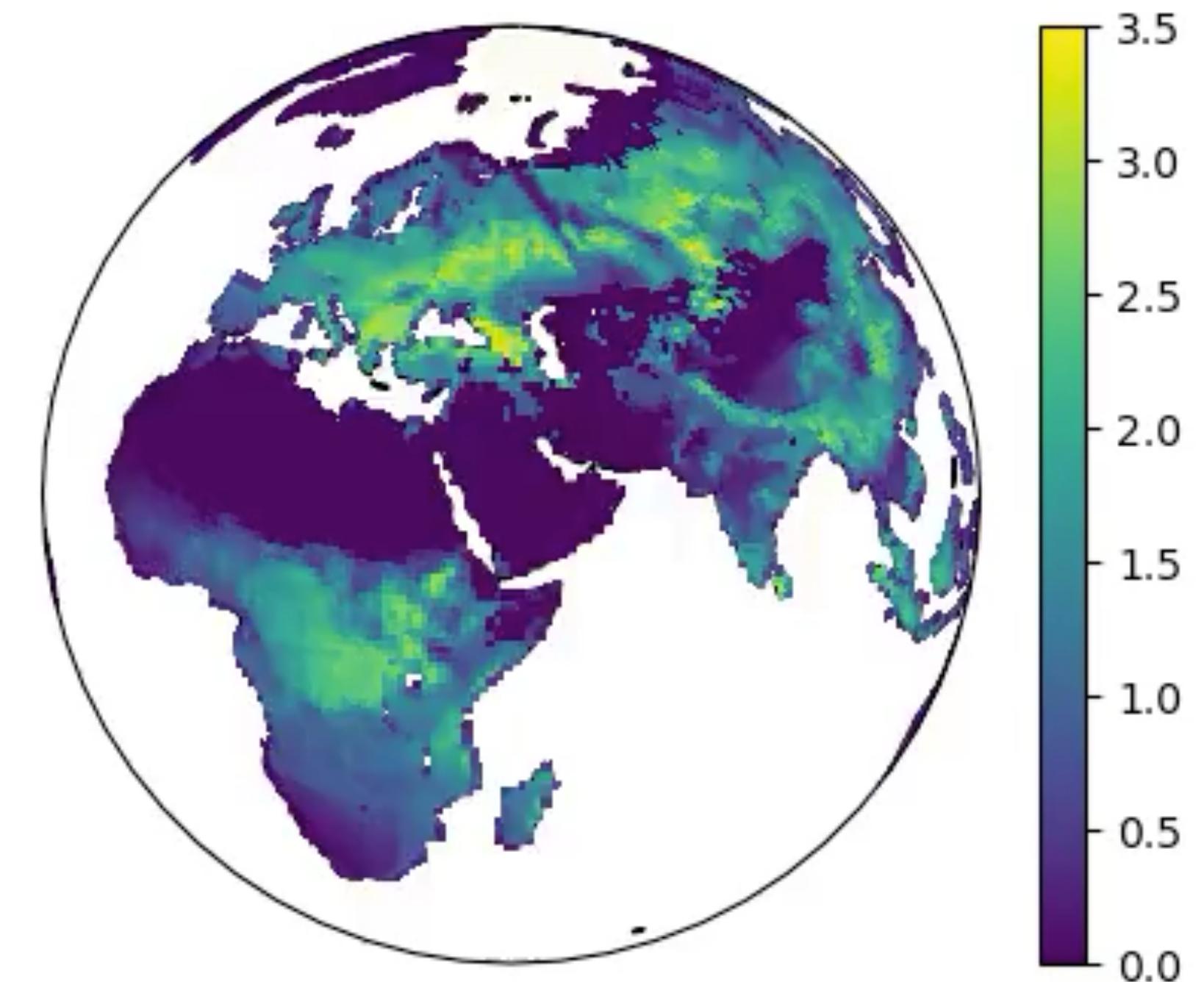
### 模式设置

- 高光谱的辐射模型（400–2500 nm）
- 经验气孔模型
- ERA5气候数据
- GriddingMachine输入
- ....
- 小时尺度的模拟

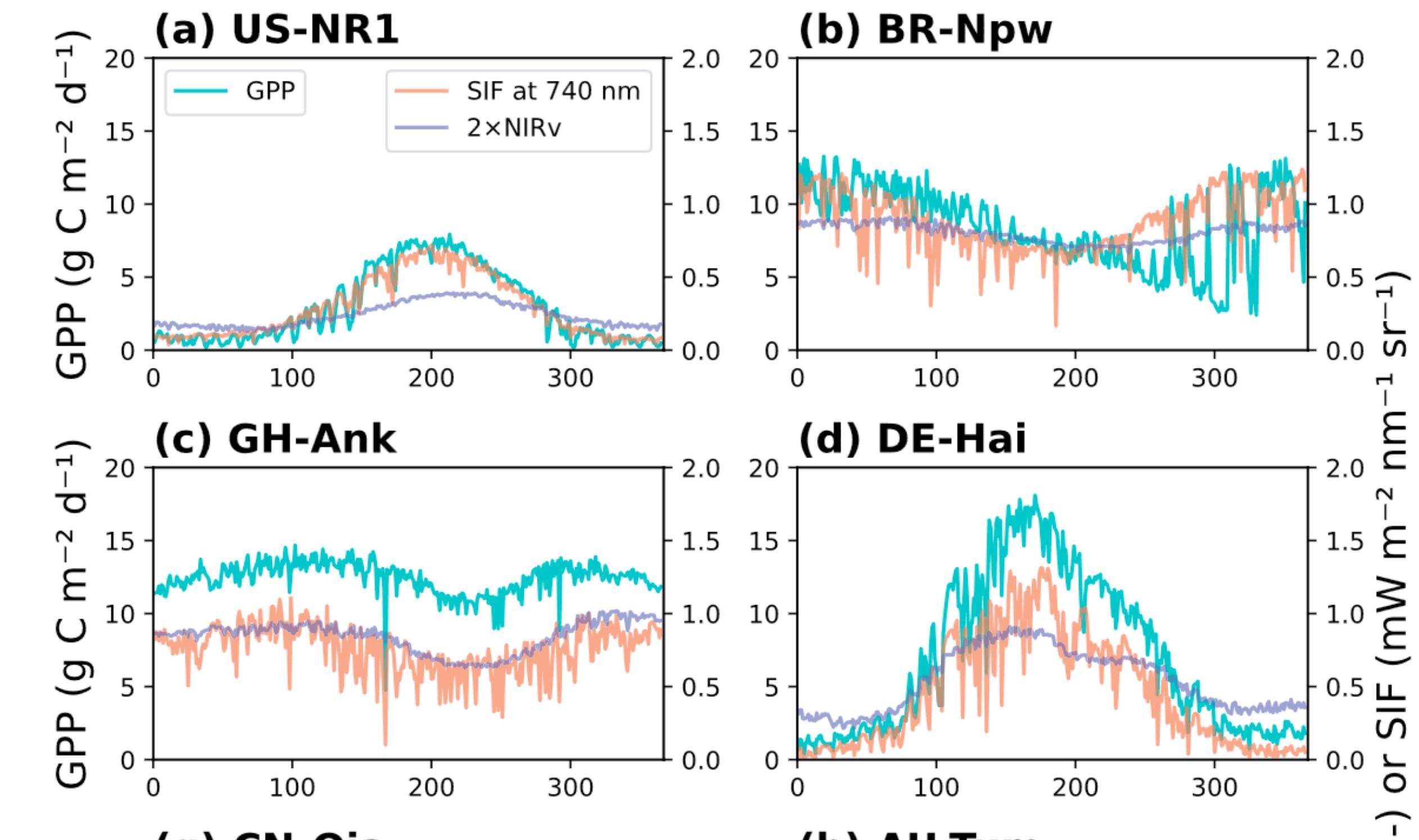
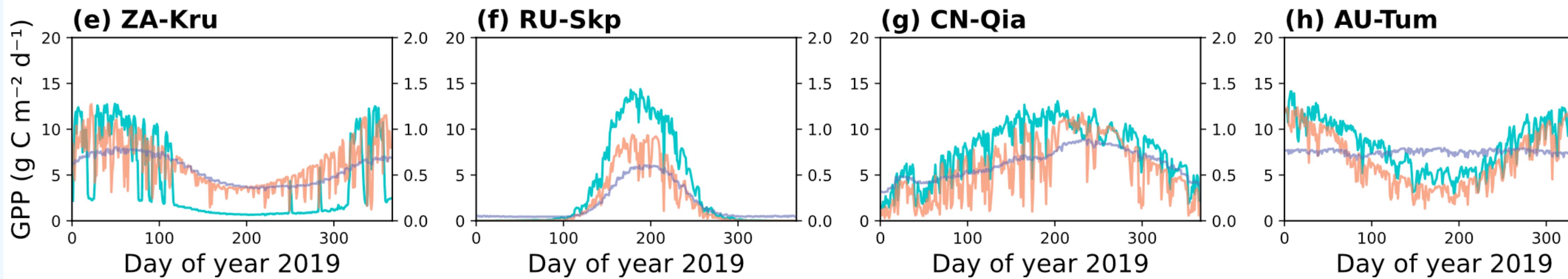
~2小时/年/160核

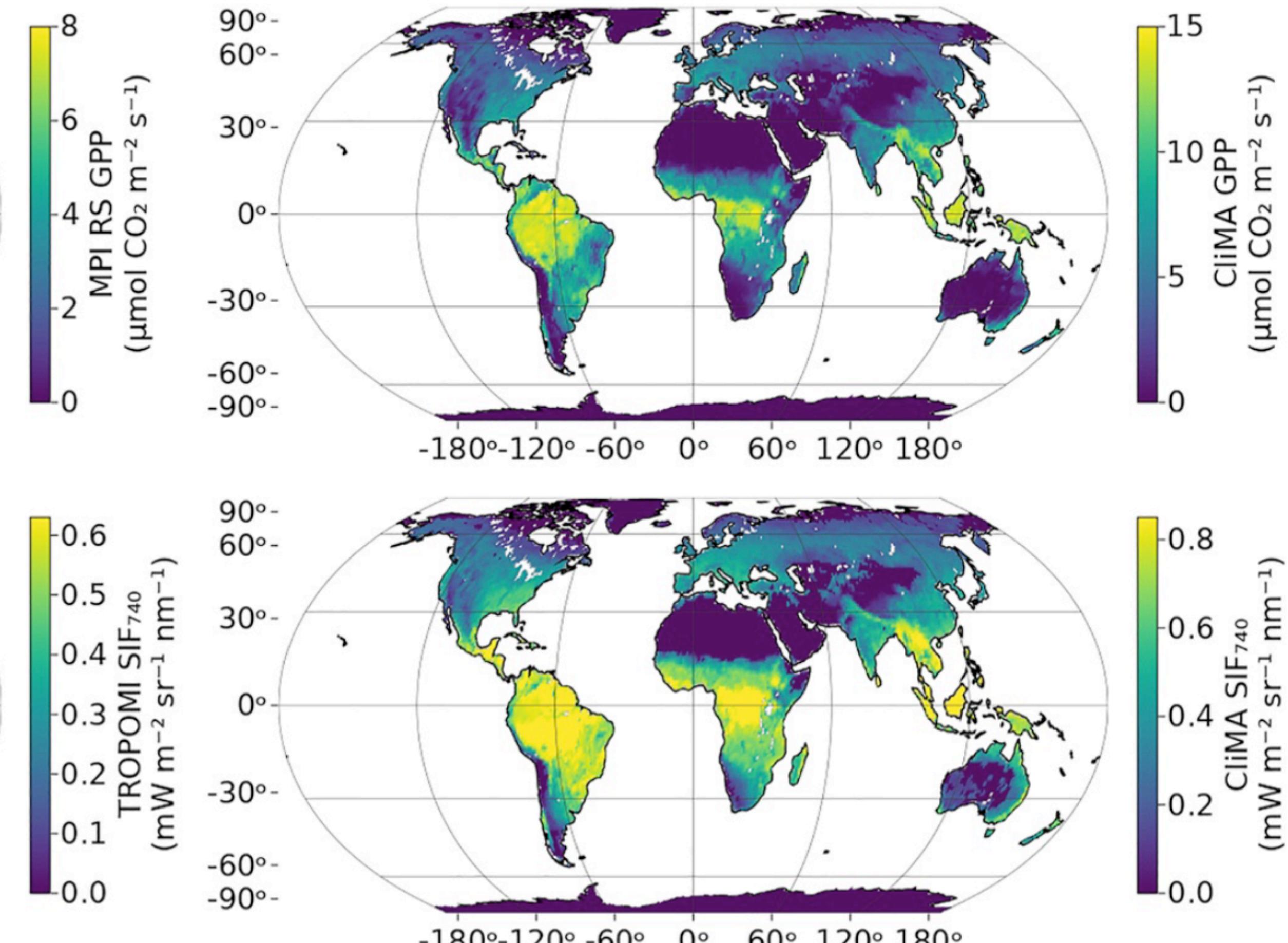
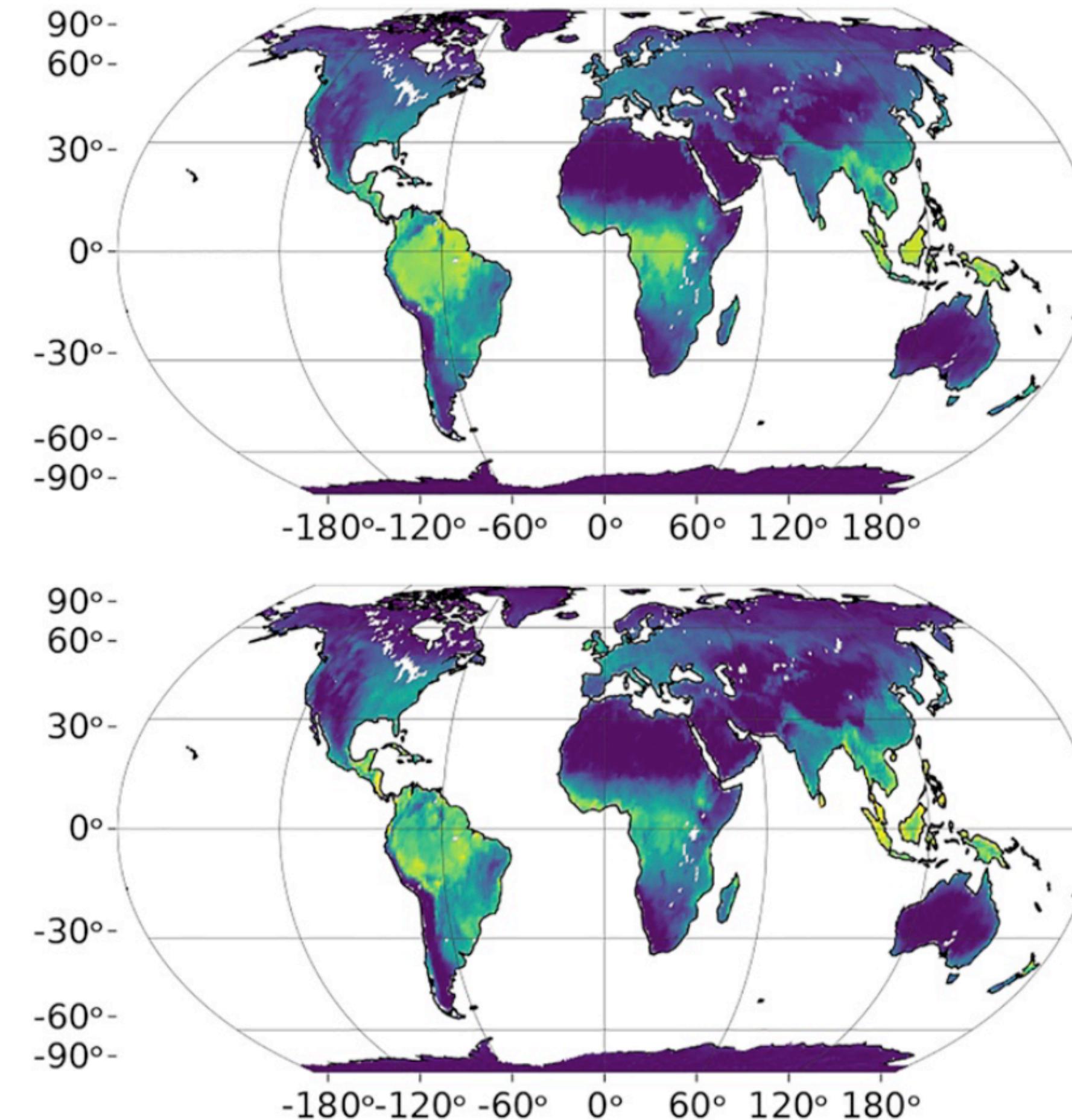


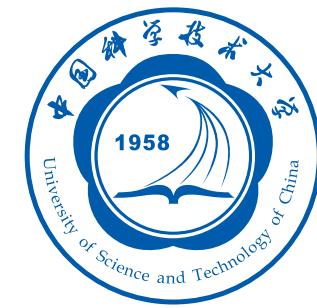
除了碳、水的通量模  
拟，还包含了冠层光学  
特征



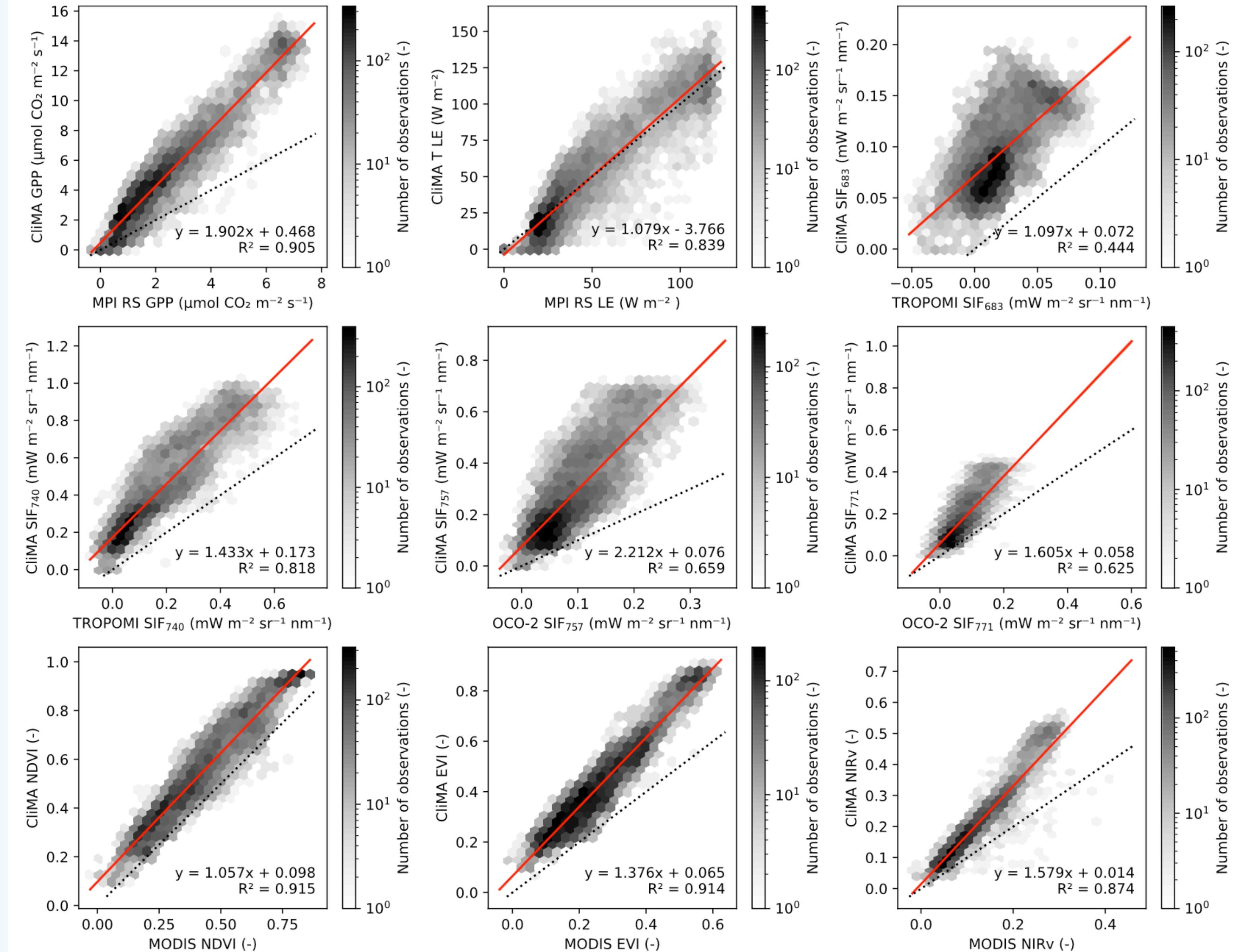
CLiMA Land SIF @ 740 nm







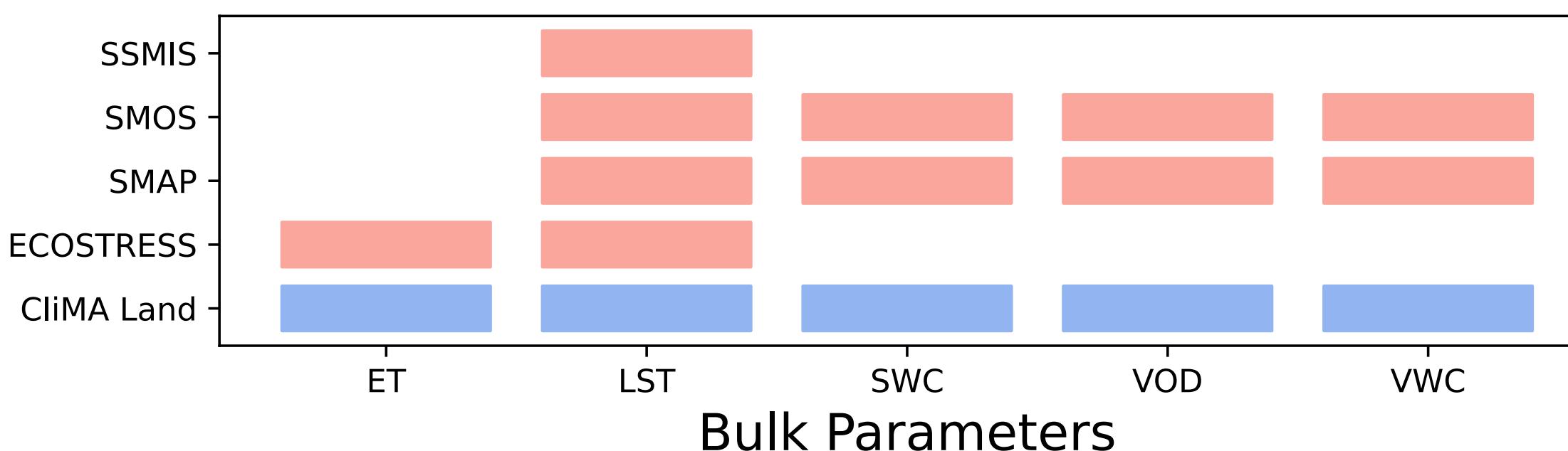
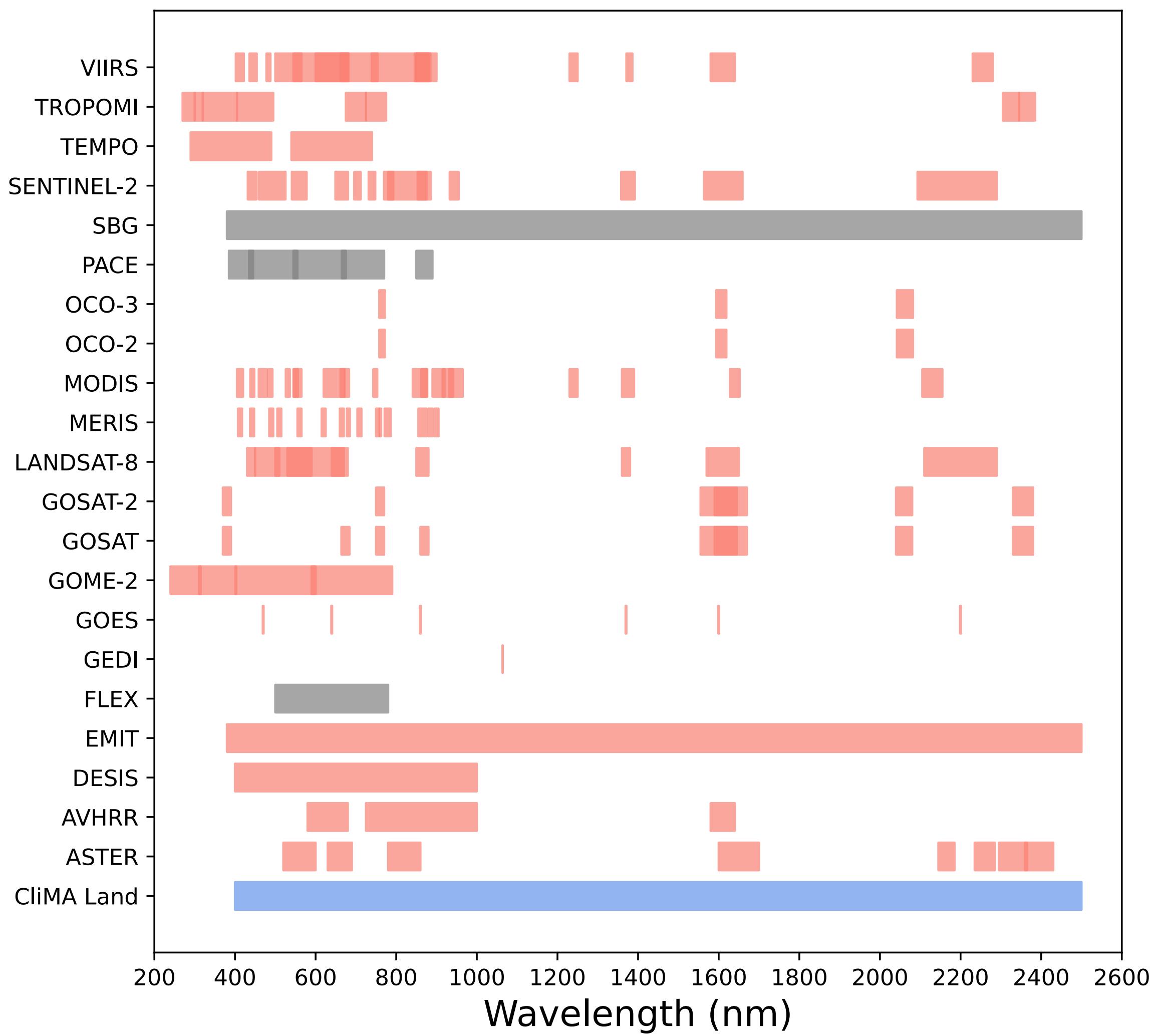
# CLiMA Land还需要进一步的参数矫正





## 遥感数据

ClIMA Land能进行高光谱的辐射模拟，因此可以直接使用大多数卫星的L1、L2数据进行参数矫正



# 未来研究方向



## 1. 模式开发

改进土壤-植物-  
大气连续体模  
型，加入更多的  
生理机制

- 引入更多机制模型
- 基于最优化理论的植被生长、繁殖、竞争、演替
- 拓展高光谱以覆盖UV、IR
- 考虑更加复杂的生态系统结构
- ....

# Beyond the visible: Accounting for ultraviolet and far-red radiation in vegetation productivity and surface energy budgets



Yujie Wang<sup>1</sup>  | Renato K. Braghieri<sup>1,2</sup>  | Yi Yin<sup>1,3</sup>  | Yitong Yao<sup>1</sup>  | Dalei Hao<sup>4</sup>  | Christian Frankenberg<sup>1,2</sup> 

<sup>1</sup>Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California, USA

<sup>2</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

<sup>3</sup>Department of Environmental Studies, New York University, New York, New York, USA

<sup>4</sup>Atmospheric, Climate, and Earth Sciences

## Abstract

Photosynthetically active radiation (PAR) is typically defined as light with a wavelength within 400–700 nm. However, ultra-violet (UV) radiation within 280–400 nm and far-red (FR) radiation within 700–750 nm can also excite photosystems, though not as efficiently as PAR. Vegetation and land surface models (LSMs) typically do not explicitly account for UV's contribution to energy budgets or photosynthesis, nor FR's contribution to photosynthesis. However, whether neglecting UV and FR

# 未来研究方向



## 2. 模式设置

使用更合理的模式设置与组合，降低对经验模式的依赖

- 将陆面模式和大气、海洋模式耦合
- 测试更多的模型组合
- 添加更多的应用，如农业、林业
- 更多的模型示例，方便教学
- ....

# 未来研究方向



## 3. 参数矫正

使用更多、更系统的多来源数据  
进行模型参数的  
矫正

- 为GriddingMachine引入更多功能
- 进行CliMA Land的参数矫正
  - 叶面积指数 (进行中)
  - 叶绿素含量 (进行中)
  - 冠层结构 (进行中)
- 探索基于自然的应对气候变化的策略

# 致谢

## Caltech:

Christian Frankenberg, Philipp Köhler, Yi Yin, Russell Doughty, Rupesh Jeyaram, Vincent Humphrey,  
Liyin He, Rui Cheng, Newton Nguyen, Ke Liu, Yitong Yao, Alexandre Renchon, Yinon Bar-On, Nora  
Oshima

## CliMA:

Tapio Schneider, Charles Kawczynski, Zhaoyi Shen, Eviatar Bach, Leilani Rivera-Dotson

## JPL:

Anthony Bloom, Renato Braghieri, Marcos Longo, Alexander Norton, Shuang Ma

## University of Missouri:

Jeffrey Wood

## University of Utah:

John Sperry, William Anderegg, David Bowling, Jame Ehleringer, Fred Adler, Tom Kursar, David Love,  
Martin Venturas, Kailiang Yu, Anna Trugman, Xiaonan Tai

## Special Thanks:

Melvin Tyree

