Energy, Water Flux & Carbon Cycle

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2019.11.21

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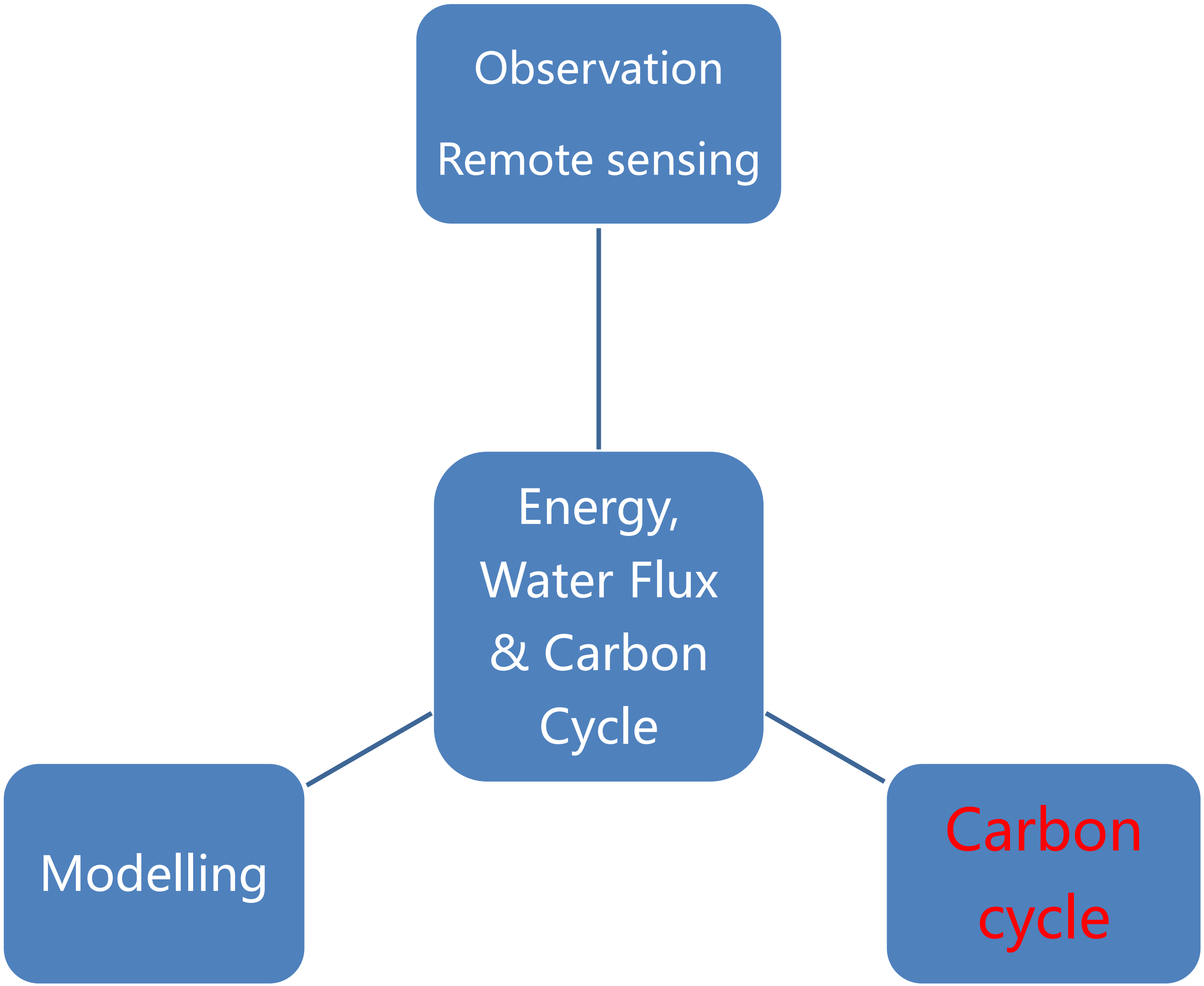

Observation
Remote sensing
Energy, Water Flux & Carbon Cycle
Modelling
Carbon cycle

OUTLINE

1. Introduction
2. Carbon Cycle Modeling
3. Case study:

✓Carbon dioxide exchange-from observations

✓The relationship between variation of terrestrial carbon cycle and ENSO

4. Related topics

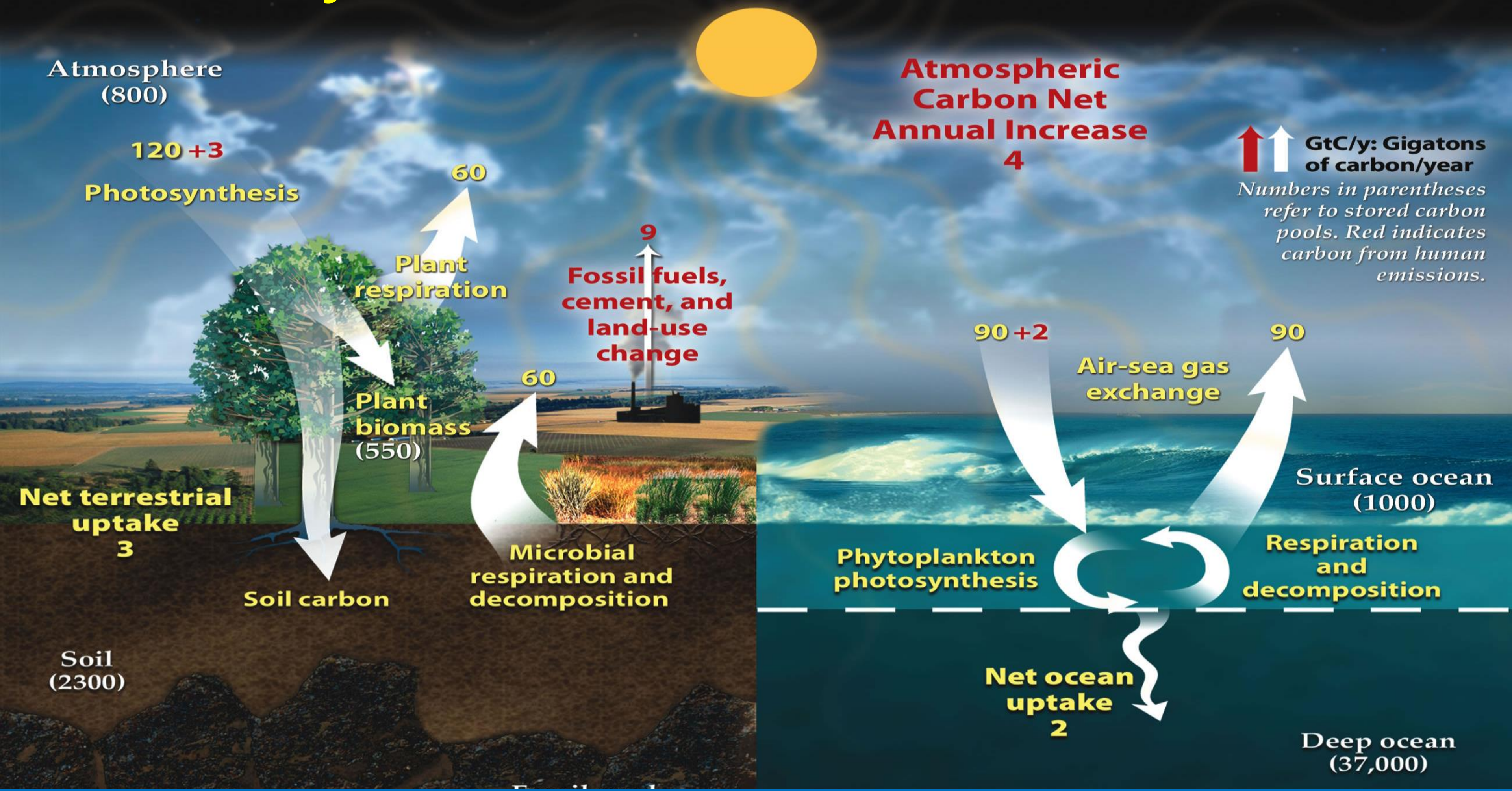
1. 背景介绍
2. 碳循环模拟
3. 个例研究:

✓CO2交换-从观测说起

✓与ENSO的关系

4. 相关信息

Carbon cycle



Fast carbon cycle shows the movement of carbon between land, atmosphere, and oceans in billions of tons per year. Yellow numbers are natural fluxes, red are human contributions, white indicate stored carbon.

- The carbon cycle is the biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth.
- Carbon exists in various forms in the atmosphere. Carbon dioxide (CO_2) and methane (CH_4) are partly responsible for the greenhouse effect and among the most important human-contributed greenhouse gases
- 碳循环是碳在生物圈，土壤圈，地圈，水圈和地球大气层之间交换的生物地球化学循环。
- 碳在大气中以各种形式存在。 二氧化碳和甲烷（CH4）是温室效应的部分原因，也是最重要的人为温室气体

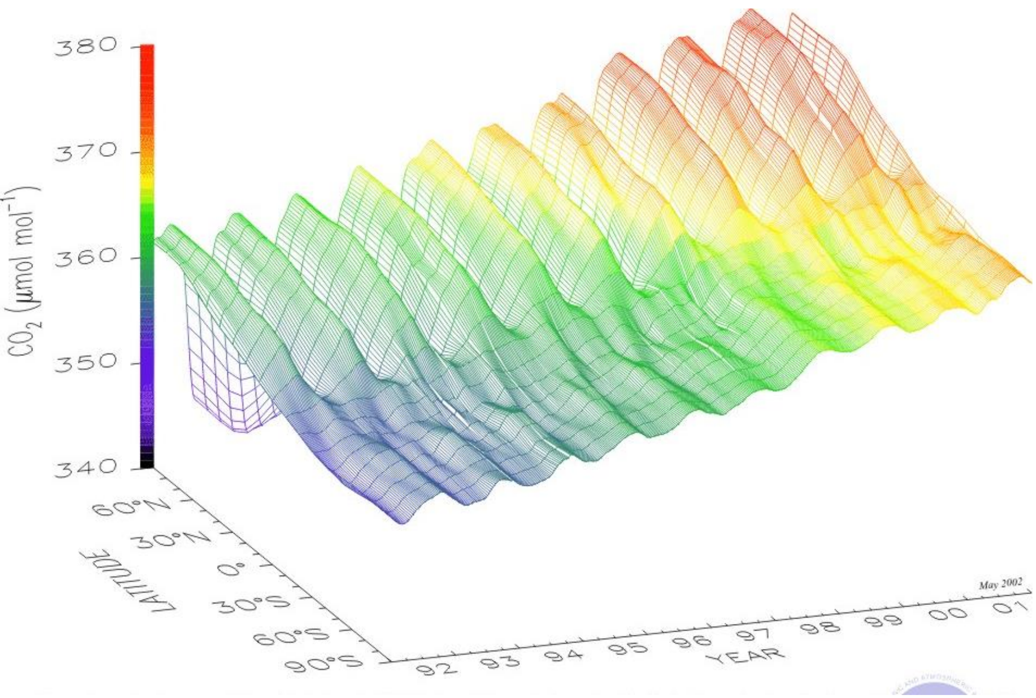
In the past two centuries, human activities have altered the global carbon cycle, most significantly in the atmosphere. Although carbon dioxide levels have changed naturally over the past several thousand years, human emissions of carbon dioxide into the atmosphere have created unnatural fluctuations. Changes in the amount of atmospheric CO2 are considerably altering weather patterns and indirectly influencing oceanic chemistry. Current carbon dioxide levels in the atmosphere exceed measurements from the last 1,000 years and levels are rising quickly, making it of critical importance to better understand how the carbon cycle works and what its effects are on the global climate.

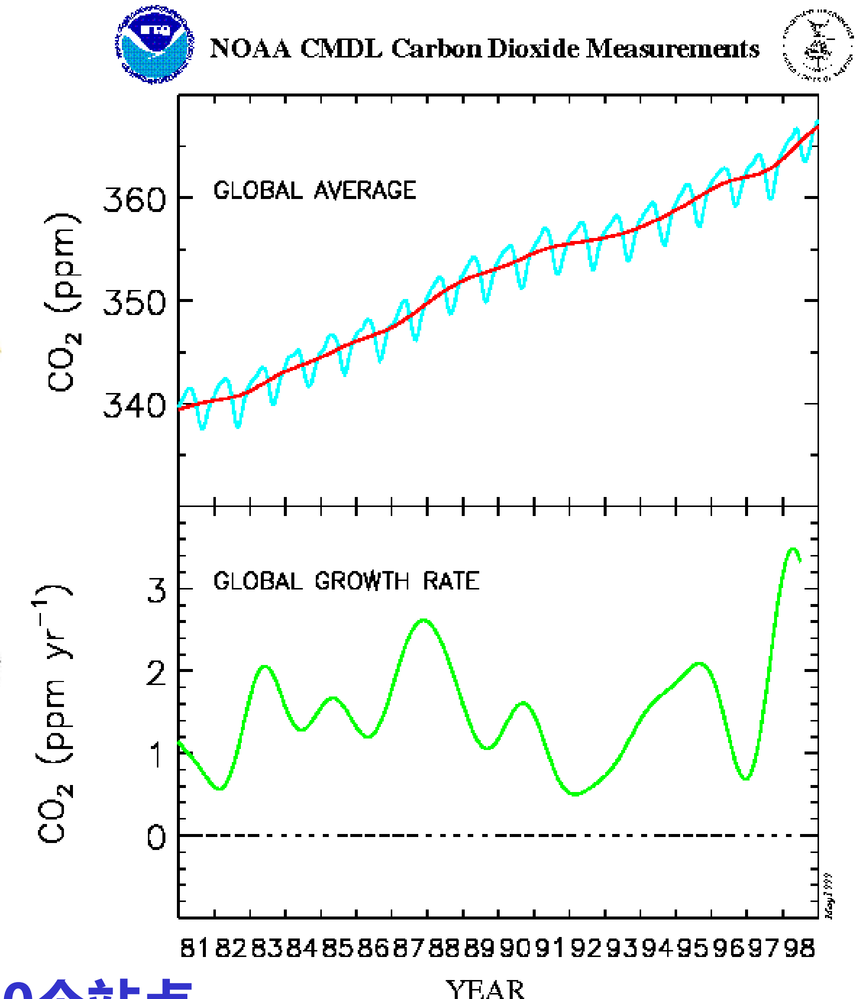
在过去的两个世纪里，人类活动改变了全球的碳循环，在大气层中最为显着。虽然过去几千年来二氧化碳水平自然发生了变化，但人类向大气排放的二氧化碳造成了不自然的波动。 大气中二氧化碳数量的变化大大改变了天气模式，并间接影响了海洋化学。 大气中的二氧化碳当前水平超过了过去1000年的测量水平，并且水平正在迅速上升，这对于更好地理解碳循环的工作原理及其对全球气候的影响至关重要。

Terrestrial Carbon Cycle：The terrestrial biosphere includes the organic carbon in all land-living organisms, both alive and dead, as well as carbon stored in soils. Most carbon in the terrestrial biosphere is organic carbon, while about a third of soil carbon is stored in inorganic forms, such as calcium carbonate ($CaCO_3$).Because carbon uptake in the terrestrial biosphere is dependent on biotic factors, it follows a diurnal and seasonal cycle.

陆地碳循环：陆地生物圈包括所有有生命和有生命的陆地生物体中的有机碳，以及土壤中储存的碳。 陆地生物圈中的大部分碳是有机碳，而大约三分之一的土壤碳以无机形式存在，例如碳酸钙。由于陆地生物圈中的碳吸收取决于生物因素，所以它遵循昼夜和季节周期。

Atm CO_2 measurements 大气中CO2观测





Top: Global average atmospheric carbon dioxide mixing ratios (blue line) determined using measurements from the NOAA CMDL cooperative air sampling network. The red line represents the long-term trend. Bottom: Global average growth rate for carbon dioxide. Principal investigator: Pieter Tans, NOAA CMDL Carbon Cycle Group, Boulder, Colorado, (303) 497-6678. ptans@cmdl.noaa.gov.

NOAA-CMDL

- ~ 100 sites at remote marine locations
- Long-term increase
- Seasonal cycle

- 在偏远海域有100个站点
- 长期增加
- 季节性周期

Climate - Carbon Cycle Links

Carbon is present in natural reservoirs (atmosphere, ocean, biosphere)

碳存在于自然界（大气，海洋，生物圈）

The growth of carbon in the atmospheric reservoir is the major contributor to climate change

大气层中碳的增长是气候变化的主要原因

Climate change will affect the cycling of carbon through natural reservoirs

气候变化将影响通过自然界的碳循环

Understanding carbon cycle feedbacks is crucial to predicting future climate

了解碳循环反馈对预测未来气候至关重要

Global Carbon Cycle

Key Messages

- Human activities (combustion of fossil fuels and land-use changes) have and are continuing to perturb the carbon cycle -- increasing the atmospheric concentration of carbon dioxide
- The terrestrial biosphere has historically been a source of carbon to the atmosphere - it is currently a net sink
- The current terrestrial carbon sink is caused by land management practices, higher carbon dioxide and possibly recent changes in climate
- 人类活动（化石燃料燃烧和土地利用变化）已经并正在继续干扰碳循环 - 增加大气中的二氧化碳浓度
- 陆地生物圈一直是大气中碳的来源 - 目前它是一个净汇
- 目前的陆地碳汇是由土地利用，更高的二氧化碳以及最近可能出现的气候变化造成的

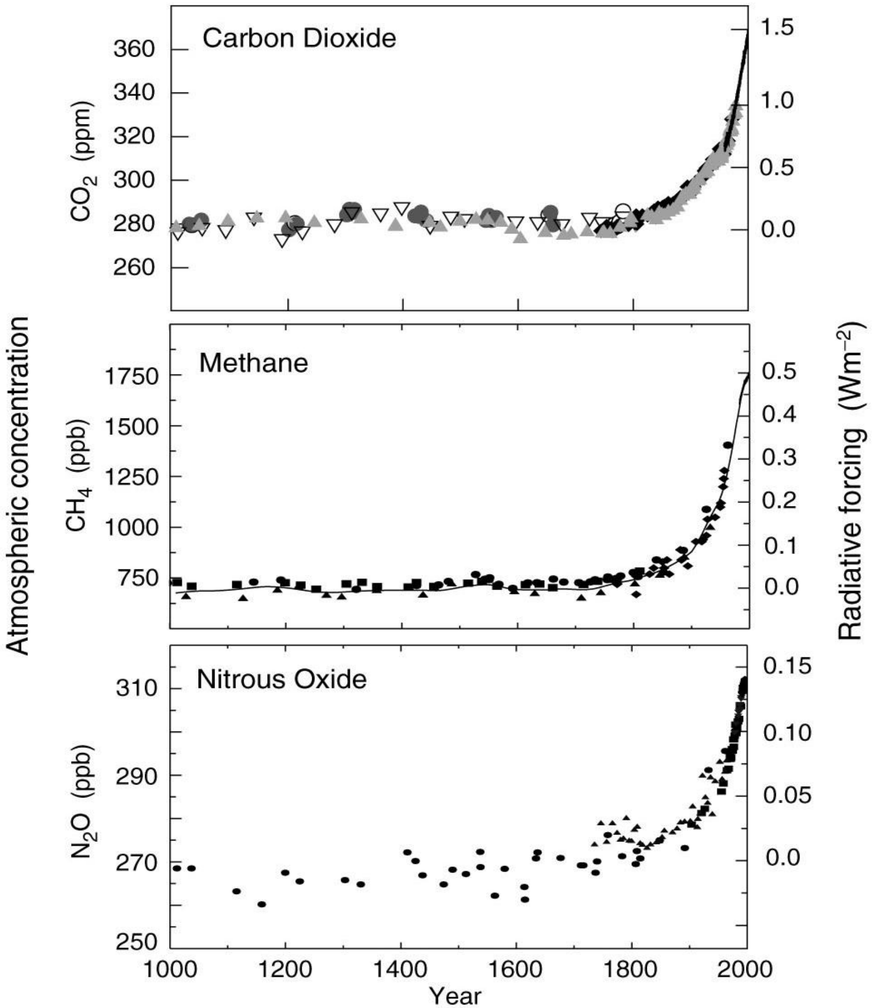
Global Carbon Cycle

- Key Messages
  - This uptake by the terrestrial biosphere will not continue indefinitely. The question is when will this slow down, stop or even become a source?
  - some of the LULC sequestered carbon could be released back to the atmosphere due to changes in climate
  - slowing deforestation has multiple environmental and social benefits
  - monitoring systems can be put in place to monitor carbon
  - 陆地生物圈的这种吸收不会无限期地持续下去。 问题是什么时候会放慢速度，停止甚至成为源?
  - 由于气候的变化，一些LULC隔离的碳可以释放回大气
  - 放缓森林砍伐具有多重环境和社会效益
  - 可以建立监测系统来监测

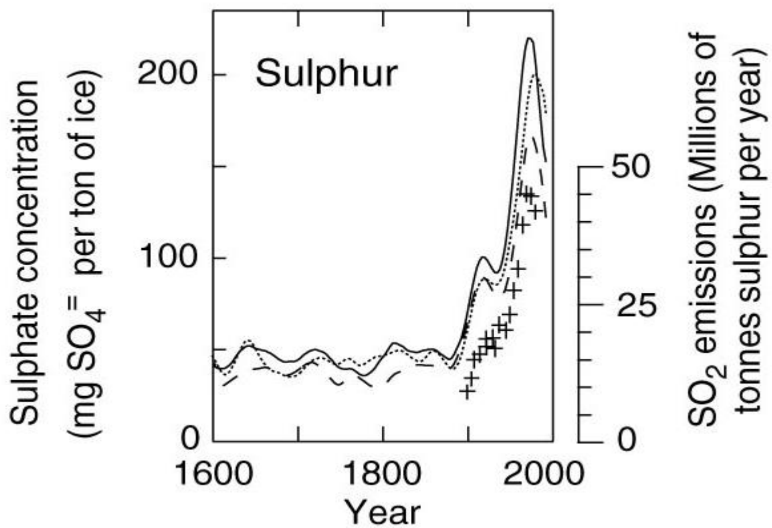
Indicators of the Human Influence on the Atmosphere during the Industrial Era

工业时代的人类影响力指标

(a) Global atmospheric concentrations of three well mixed greenhouse gases



(b) Sulphate aerosols deposited in Greenland ice



Carbon Cycle Modeling

Terrestrial Ecosystem Models

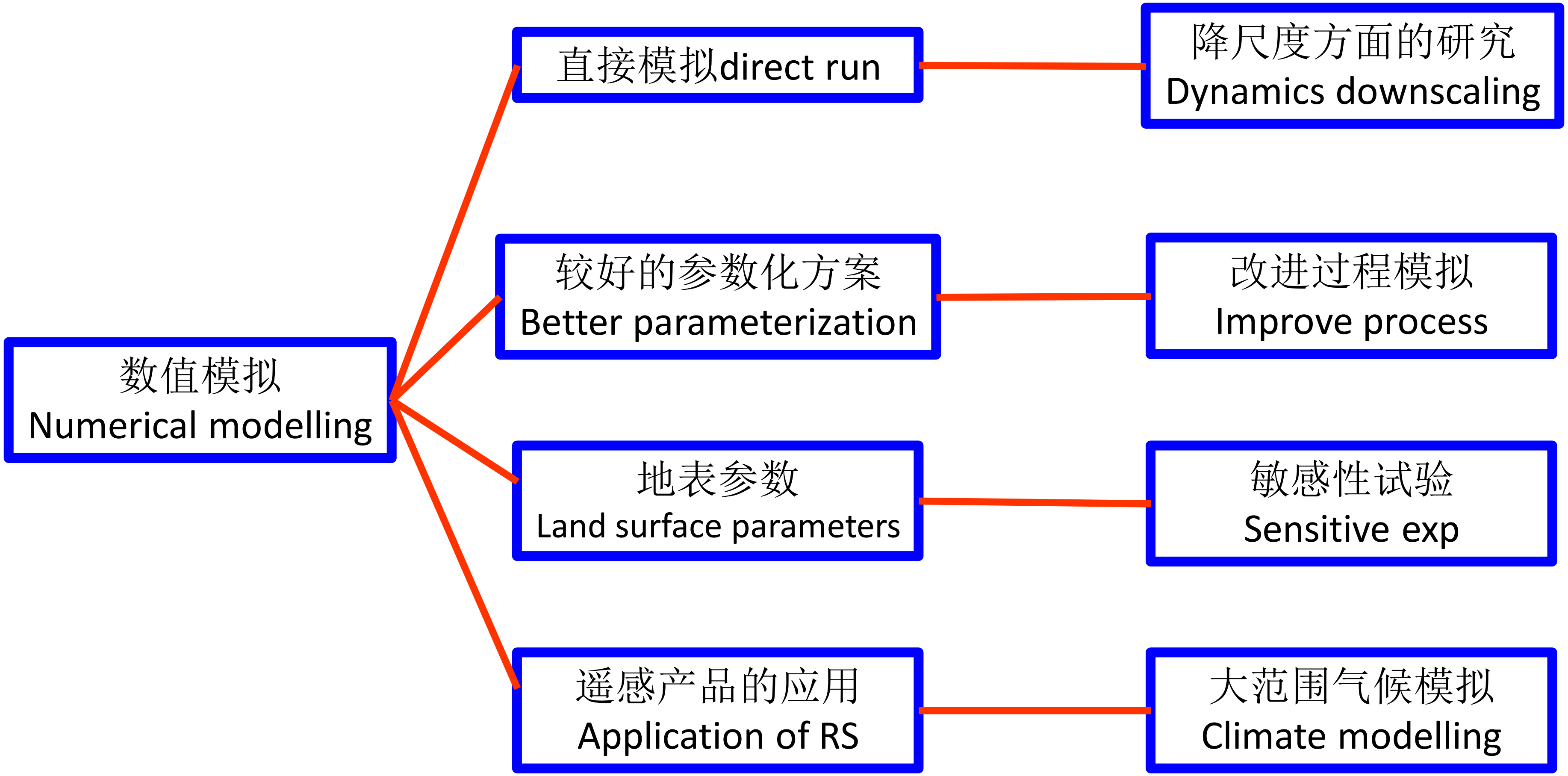
W.M. Post, ORNL

Atmospheric Measurements and Models

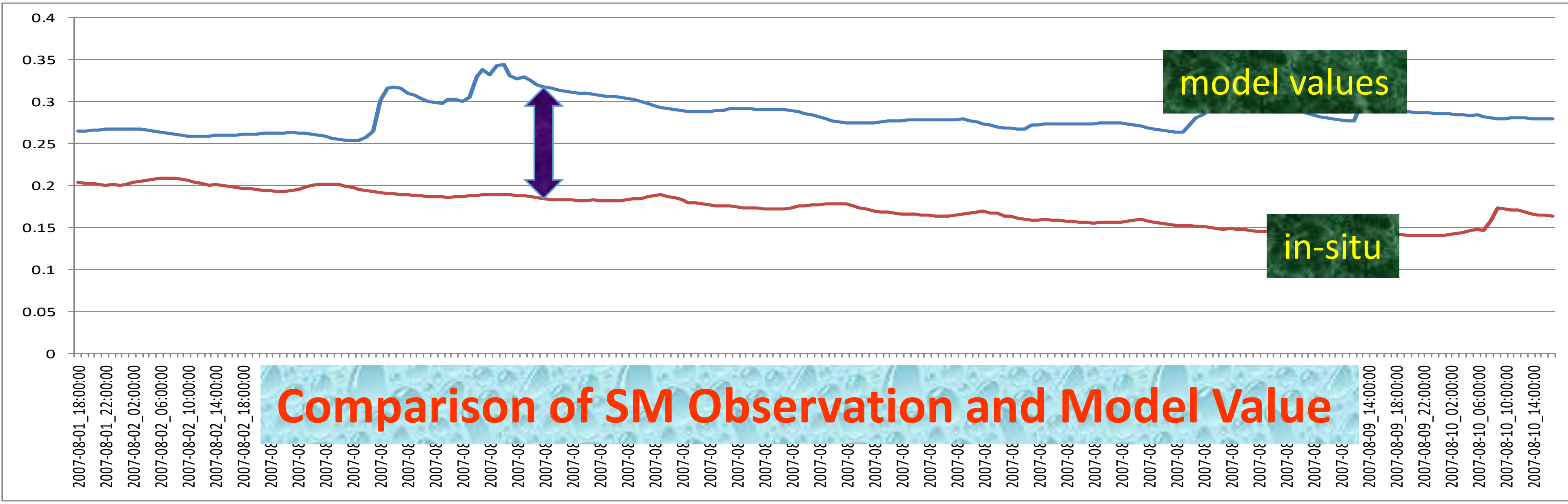
S. Denning, CSU

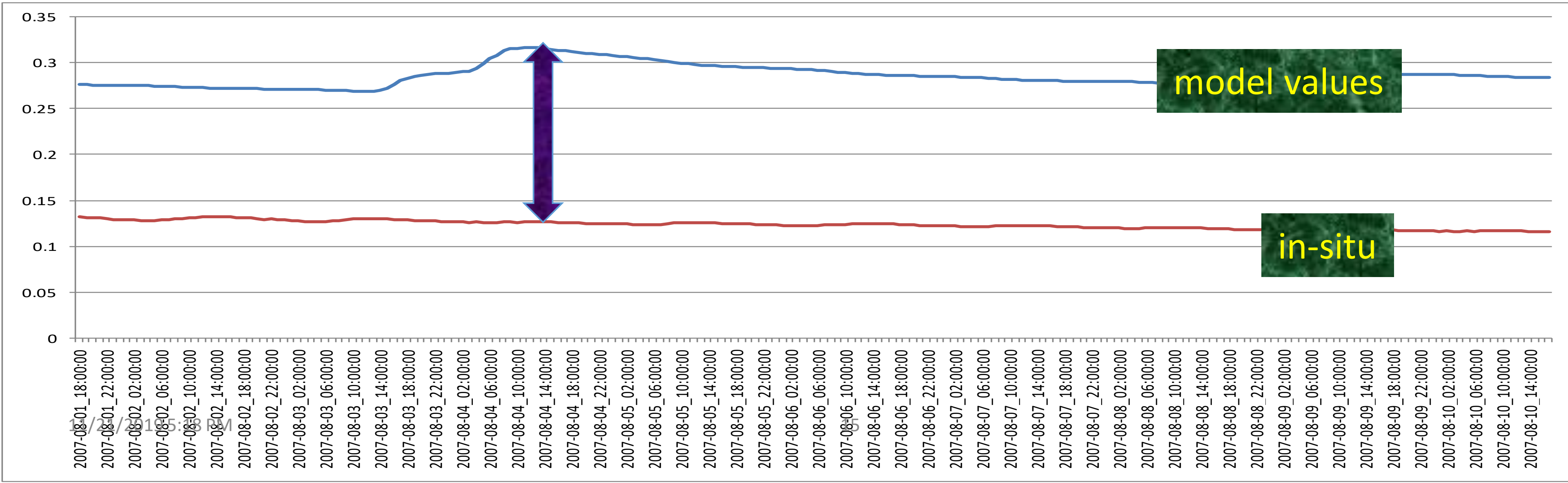
Global and Regional Inferences from Monitoring

C.D. Keeling, SIO


数值模拟
Numerical modelling
直接模拟direct run
降尺度方面的研究
Dynamics downscaling
较好的参数化方案
Better parameterization
改进过程模拟
Improve process
地表参数
Land surface parameters
敏感性试验
Sensitive exp
遥感产品的应用
Application of RS
大范围气候模拟
Climate modelling

Comparison of SM Observation and Model Value





Terrestrial Modeling

- Objectives
- Progress
- New Directions
- Future Challenges

Terrestrial Modeling - Objectives

- Quantify CO_2 exchanges with the atmosphere
- Project how terrestrial CO_2 exchanges will change in the future
- Provide estimates of trace gas sources and sinks for use with atmospheric models or in Earth System Models

- 量化二氧化碳与大气的交换
- 将如何改变陆地CO2交换
- 提供与大气模型或地球系统模型一起使用的示踪气体源和汇的估计值

Terrestrial Modeling - Progress

- Photosynthesis, evapotranspiration - detailed characterization,
  - Biochemical models
  - Light-use efficiency models
- Soil organic matter decomposition – model/data comparisons at different temporal scales

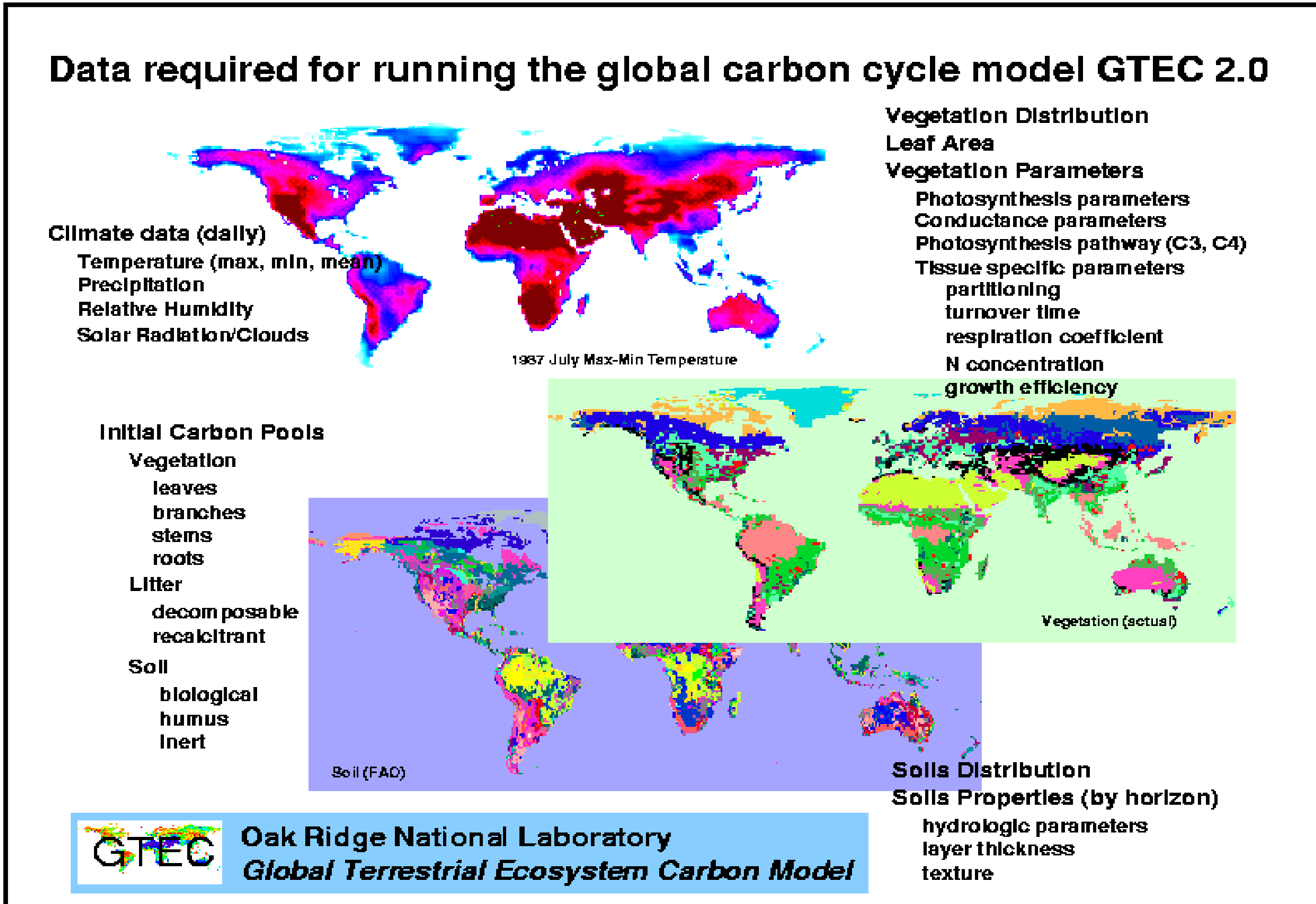
- 光合作用，蒸散作用 – 详细的表征，
  - ✓生化模型
  - ✓光使用效率模型
- 土壤有机质分解 – 模型/数据比较在不同的时间尺度

Terrestrial Models - Progress (cont.)

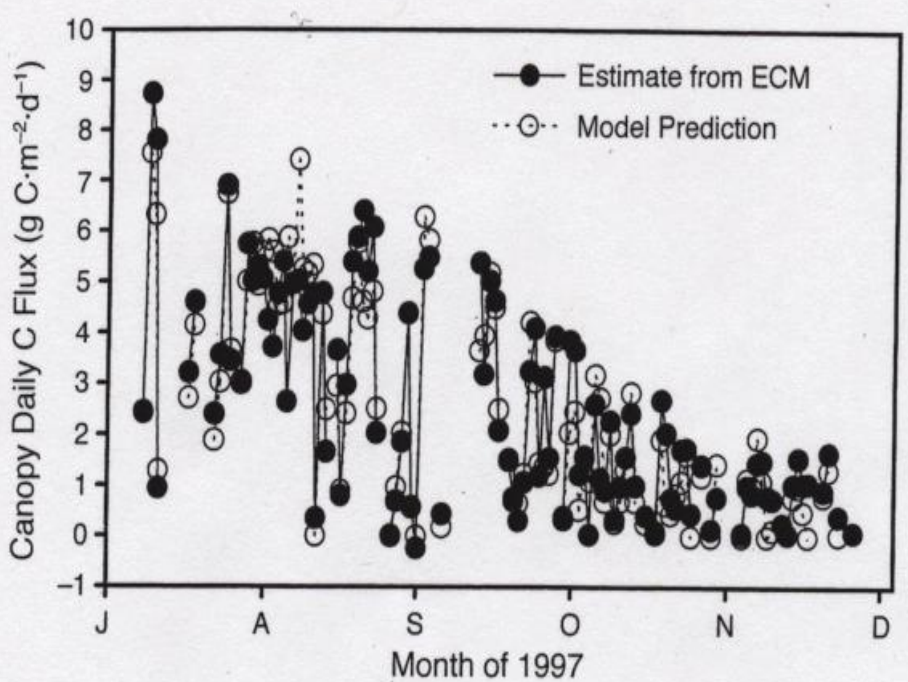
- Model intercomparison projects
  - CMEAL, VEMAP, CCMLP
- Model - data comparison projects
  - Individual experimental and monitoring sites
  - AmeriFlux modeling activity
  - Ecosystem Model-Data Intercomparison

- 模型比对项目
  - ✓ CMEAL, VEMAP, CCMLP
- 模型 – 数据比较项目
  - ✓ 试验和监测网站
  - ✓ AmeriFlux建模活动
  - ✓ 生态系统模型 – 数据比较（EMDI）

Global Biogeochemical Simulations



MAESTRA Simulations vs. Eddy Covariance Measurements – Duke FACE (Luo et al. 2001)



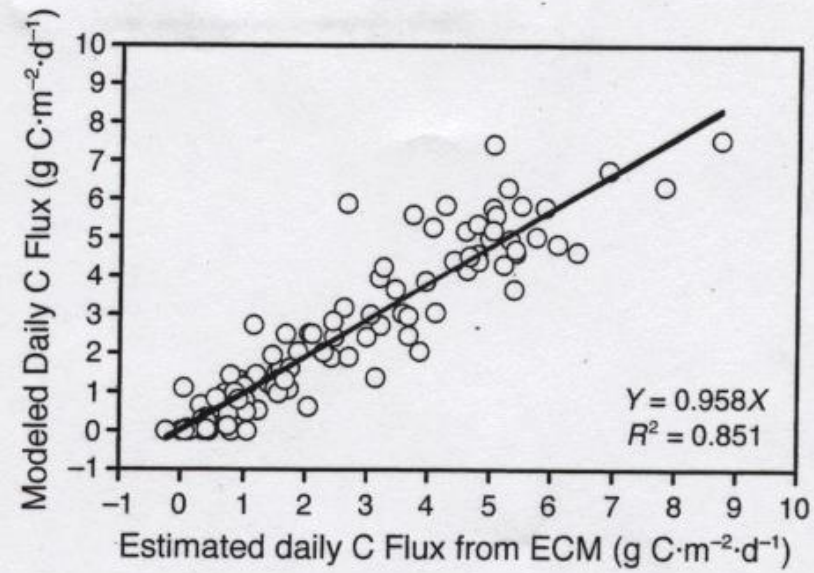
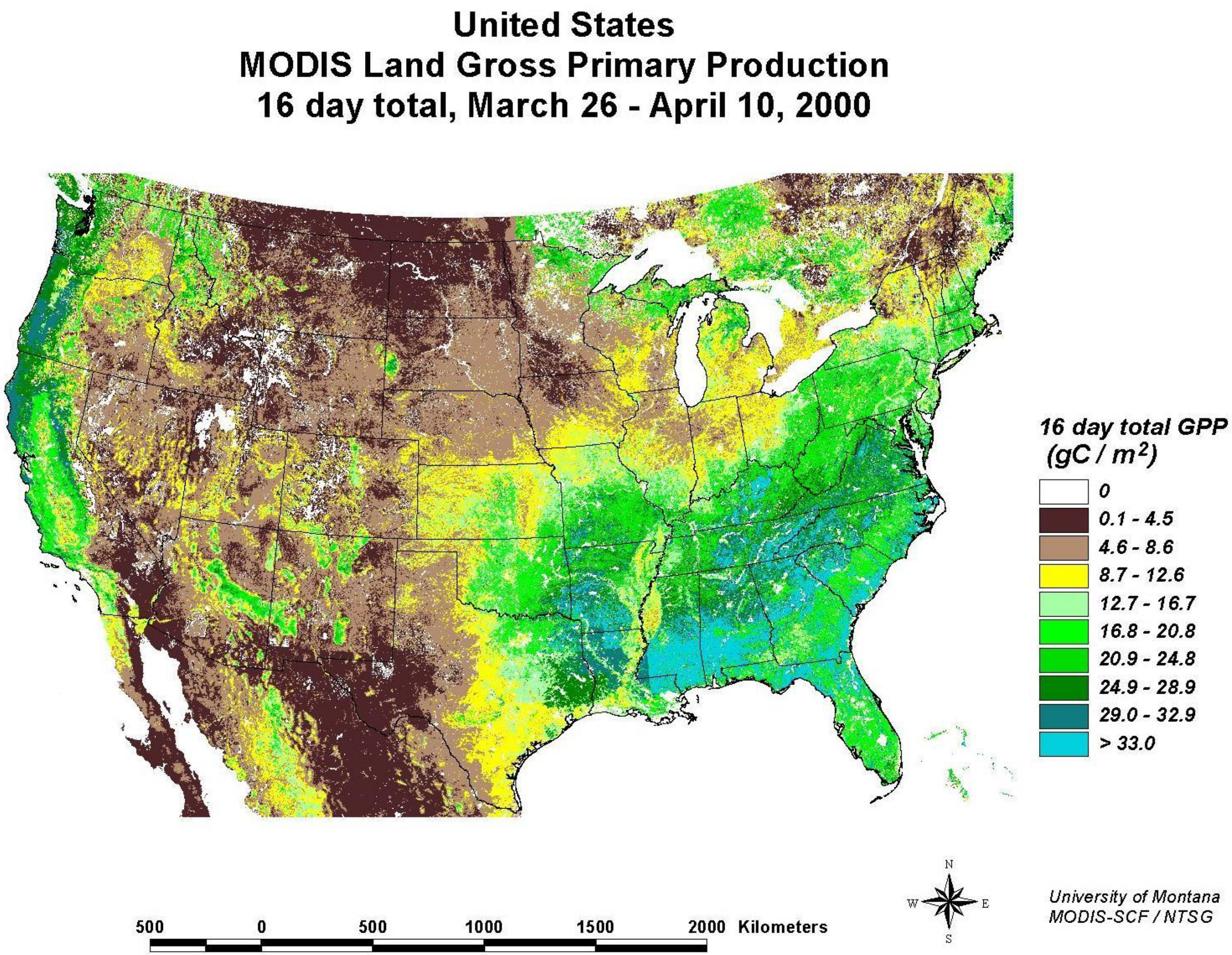


FIG. 8. Comparison of modeled with measured daily values of canopy C fluxes. The solid line is the regression indicating model-predicted daily C fluxes: $y = 0.958x$, where x = measured daily C fluxes with $R^2 = 0.851$.

Regional Light-Use Efficiency Model Calculations



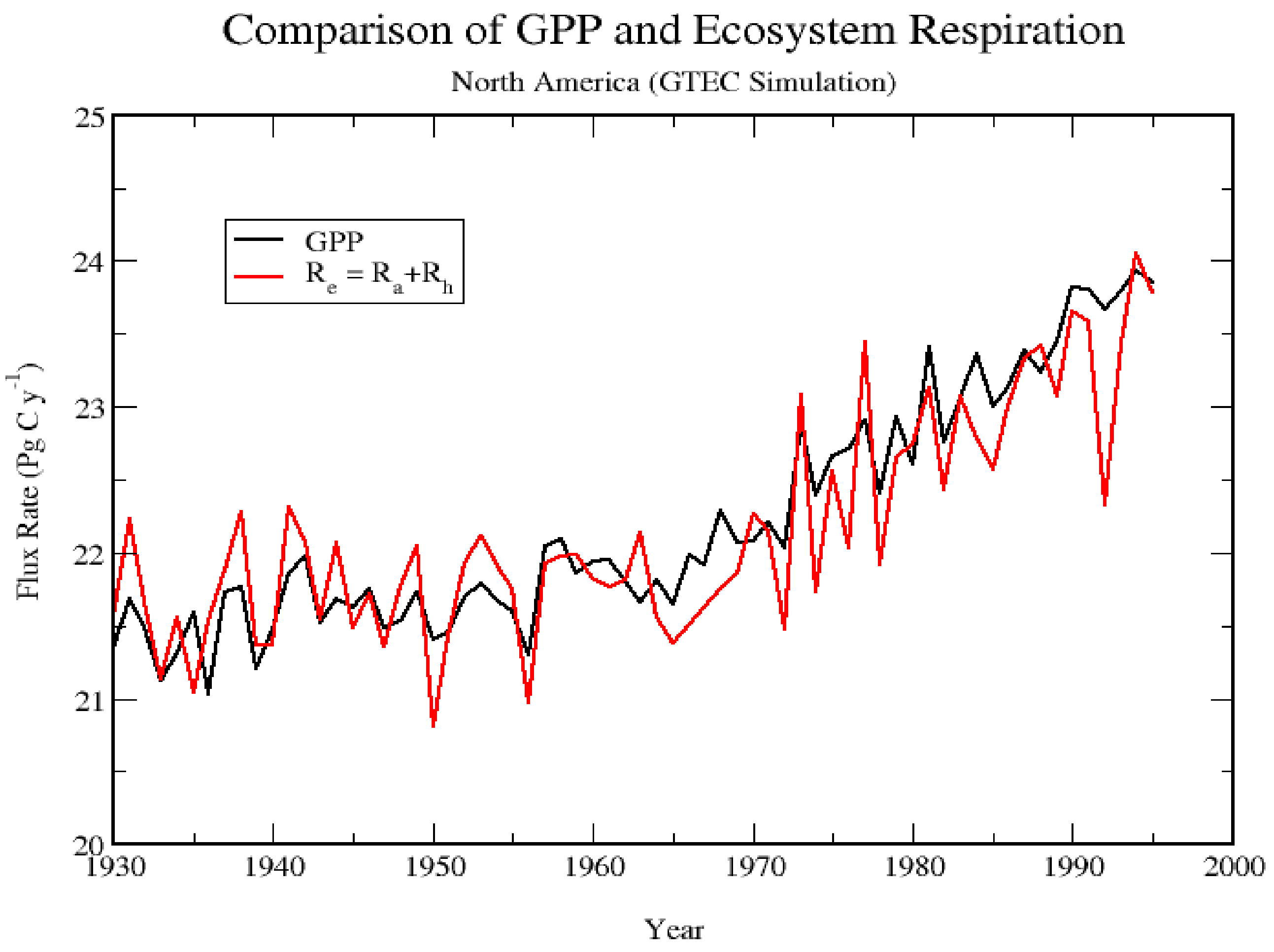
总初级生产力GPP.单位时间内生物通过光合作用途径所固定的光合产物量或有机碳总量

Model-Experimental Observations Interaction

- Detailed process level description allows:
  - Incorporation of new experimental findings
  - Model comparison to experimental and field measurements
  - Identify measurements and processes that suggest additional hypotheses

- 详细描述：
  - ✓新的实验结果
  - ✓模型比较实验和野外观测
  - ✓结果和流程，提出更多的假设

North America Historical Simulation



Role of clouds, aerosols in global carbon cycle
云，气溶胶在全球碳循环中的作用

- Diffuse radiation results in higher light use efficiencies by plant canopies
- Diffuse radiation has a much less tendency to cause canopy photosynthetic saturation
- Under a turbid atmospheric environment caused by natural events such as volcanic eruptions, canopy photosynthesis can be enhanced if part of the reduction in direct solar radiation is converted into diffuse radiation
- 漫射辐射导致植物冠层更高的光利用效率
- 漫射辐射具有较少的引起冠层光合饱和的倾向
- 在由火山爆发等自然事件引起的混浊大气环境下，如果直接太阳辐射的减少部分转化为漫射辐射，则可以增强冠层光合作用

Terrestrial Modeling - New Directions

- Additional processes
  - Phenology
  - Allocation
- Biogeography shifts
- Land-use change
  - Inventories and surveys
  - Remote sensing

- 其他进程
  - ✓物候
  - ✓分配
- 生物地理学转变
- 土地利用变化
  - ✓清单和调查
  - ✓遥感

Terrestrial Modeling - Challenges

- Continue to increase spatial and temporal resolution
  - improves process representation of regional and global spatial variation
  - allows use of wider range of observations for tests of consistency/validation
- Data assimilation
  - Parameter estimation
  - Initial condition or state estimation

- 继续增加时分辨率
  - ✓ 改进区域和全球空间变化的过程表示
  - ✓ 允许使用更广泛的观察来进行一致性/验证
- 数据同化
  - ✓ 参数估计
  - ✓ 初始条件或状态估计

Initial Condition Strategy

- Model spin-up with conditions "typical" of pre-simulation period
- Adjust initial conditions with simulation using available historical observations (land-use statistics, remote sensing)
- Use numerical weather prediction like data assimilation techniques to continually adjust model states to be consistent with "real time" monitoring information (Ameriflux, Globalview, MODIS, FIA, etc.)
- 模型在预模拟期间"典型"条件下模式spin-up
- 利用现有的历史数据（土地利用统计，遥感），利用模拟调整初始条件
- 使用数据天气预报（如数据同化技术）不断调整模型状态以与"实时"监测信息（Ameriflux，Globalview，MODIS，FIA等）保持一致

Terrestrial Modeling - Summary

- Biogeochemical process understanding results in:
  - Improving generality of terrestrial models
  - Improving representation of interactions and feedbacks between CO_2, radiation, climate, nutrient cycles
- Terrestrial models are increasing in spatial and temporal resolution
- Integration with atmospheric models will be critical for identifying terrestrial C sources and sinks
- 生物地球化学过程的理解结果在：
- ✓ 改善地面模型的适用性
- ✓ 改善二氧化碳，辐射，气候，养分循环之间相互作用和反馈的表达
- ✓ 地球模型的空间和时间分辨率正在增加
- 与大气模型的整合对于识别陆地碳源和汇是至关重要的

The relationship between variation of terrestrial carbon cycle and ENSO

1. **Background of Carbon Cycle**
2. **What we concern about**
3. **Model and Data**
4. **Results and discussion**
5. **Conclusion**
6. **Future plan**

What we know and don't make sure

- Bacastow (1976) firstly noticed the relation between CO2 and ENSO.
- Ocean-atmosphere flux variation is relative modest (Feely 1987;Winguth et al.1994; Francy et al. 1995; Bousquet et al. 2000; Roedenbeck et al. 2003; Zeng et al. 2005)
- Inverse modeling (Schimel et al. 2001; Gurney et al.,2002; Houghton 2003) long term sink and source & regional uncertainties.
- Potter et al. did statistical analysis of ENSO with modeled land_atmosphere flux.
- Hashimoto et al. (2004) proposed that NPP is related to ENSO. Cao et al. (2005) modeled year to year variation of NEP up to 2.5 PgC/yr, in which 1.4 PgC/yr can be attributed to ENSO cycle
- Generally, on regional scale, there are still many uncertainties in mechanisms of climate controlling terrestrial carbon cycle.
- Bacastow（1976）首先注意到CO2和ENSO之间的关系。
- 海洋 - 大气通量变化相对较小（Feely 1987; Winguth et al.1994; Francy et al.1995; Bousquet et al.2000; Roedenbeck et al.2003; Zeng et al.2005）
- 反演模型（Schimel et al。2001; Gurney et al。， 2002; Houghton 2003）长期下沉和源区域不确定性。
- Potter等人 对ENSO进行了陆面大气通量模拟的统计分析。
- Hashimoto et al。 （2004）提出，NPP与ENSO有关。 曹等人 （2005）将NEP的逐年变化模型高达2.5 PgC /年，其中每年1.4 PgC /年归因于ENSO循环
- 一般来说，在区域尺度上，气候控制的陆地碳循环机制还有很多不确定性。

The questions we concern:

- What's kind of terrestrial carbon cycle in response to ENSO cycle.
- What are their common features during ENSO cycle?
- How do the climate factors control carbon exchange between land and atmosphere?
- 什么样的陆地碳循环响应ENSO循环。
- ENSO循环期间它们的共同特征是什么?
- 气候因素如何控制土地与大气之间的碳交换?

Model and Data

➢ The VEgetation-Global Atmosphere-Soil Model (VEGAS) (Zeng 2003) and Land surface model(S_Land)(Zeng 2000) 2.5x2.5

Climate forcing:

1. Observed precipitation and Temperature (CRU, GISS, CMAP);
2. Seasonal climatology of radiation, humidity, wind speed;
3. Atmospheric co2 is kept constant at preindustrial level;

➢ Manua Loa atmospheric co2 (http://www.cmdl.noaa.gov)

➢ Roedenbeck inverse data (Max-Planck-Institut für Biogeochemie)

➢ NDVI data (http://islscp2.sesda.com/)

➢VEGAS和陆面模型，气候强迫：
➢1.观测降水量和温度（CRU，GISS，CMAP）；
➢2.辐射季节气候，湿度，风速；
➢3.大气二氧化碳在工业化前保持不变。
➢大气二氧化碳（http://www.cmdl.noaa.gov）
➢反演数据（Max-Planck-InstitutfürBiogeochemie）
➢NDVI数据（http://islscp2.sesda.com/）

Conclusion and discussion

- Interannual variability of atmospheric co2 growth rate at Mauna Loa is strongly correlated with ENSO signals with about 6 months lags
- VEGAS and inverse simulation generally agree well. Tropics plays the dominant role. In the extrotropics, the situation is more complicate due to weaker response to ENSO and regional cancellation.
- 大气二氧化碳生长速率的年际变化与ENSO信号强烈相关，约6个月的滞后VEGAS和反演模拟结果一致。
- 热带地区起主导作用。 在外向型的情况下，由于对ENSO和区域性取消的反应较弱，情况更为复杂。

Carbon dioxide exchange between an alpine steppe ecosystem and the atmosphere on the Tibetan Plateau

青藏高原不同草地下垫面CO_2通量的分布研究

outline

1. 绪论 Introduction

2. 研究区域与研究方法Research area and methods

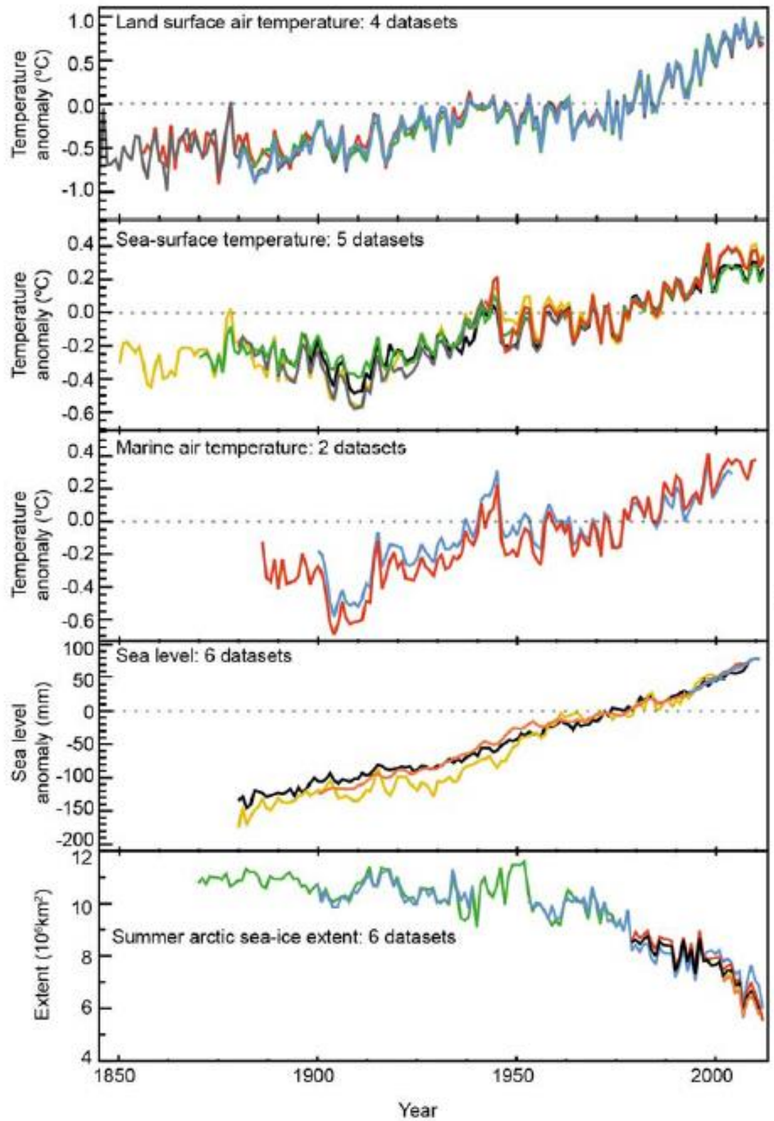
3. 青藏高原草地生态系统CO_2通量变化特征分析
Analysis of the CO2 flux change of grassland ecosystem in Tibetan Plateau(TP)

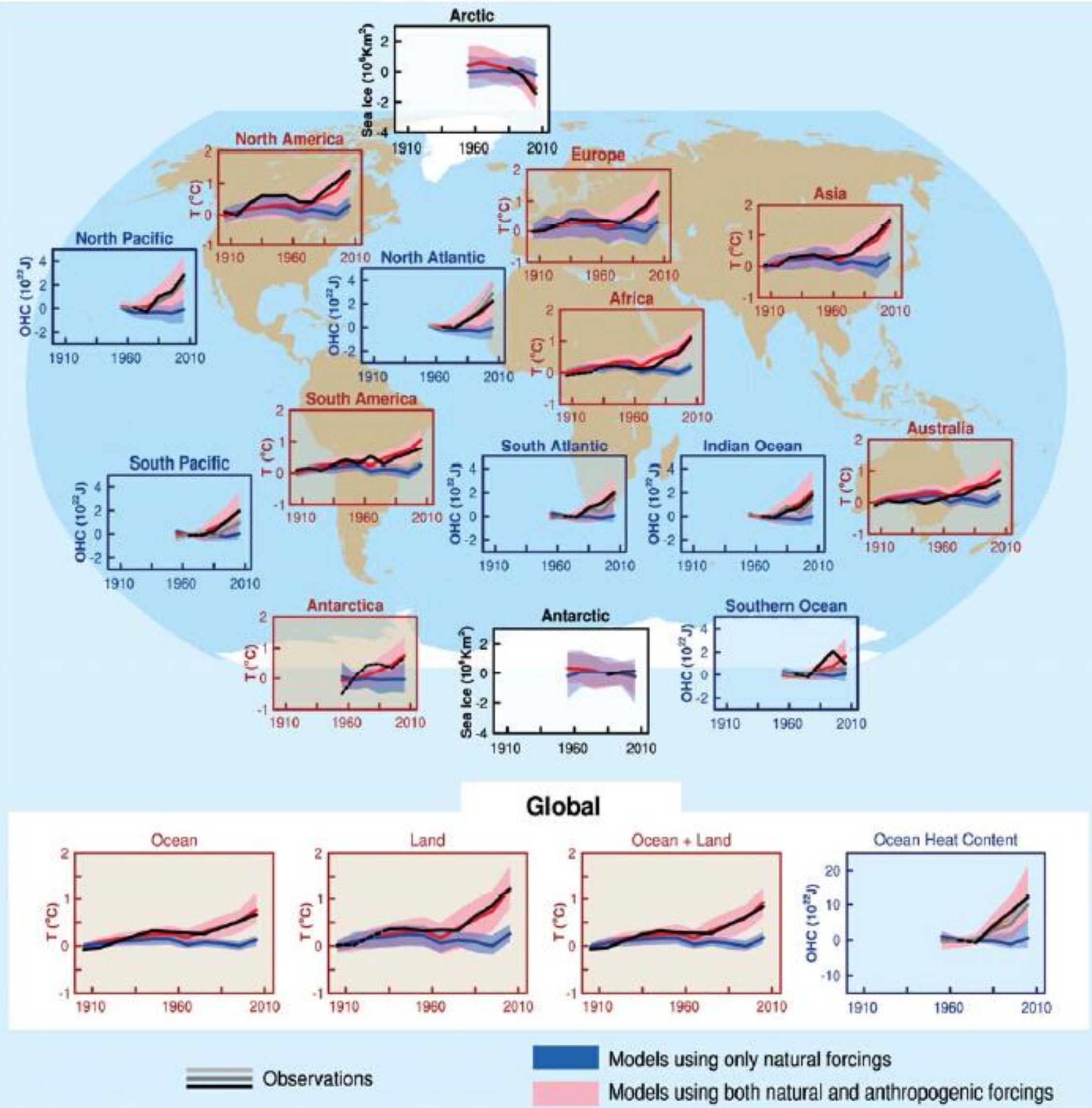
4. 青藏高原草地生态系统CO2通量与环境因子关系
The relationship between CO2 flux and environmental factors of grassland ecosystem in TP

5. 青藏高原CO_2通量空间分布的初步研究
Preliminary study on the distribution of CO2 fluxes in TP

6. 结论与展望 Conclusion and future plan

研究背景Background





全球变暖 **Global warming（*IPCC AR5*）**

Human activity is an important factor in the increase of greenhouse gas concentrations in the atmosphere. About 44 percent of the CO2 released into the air remains in the atmosphere, and the rest is absorbed by the ocean and land ecosystems.

人类活动是大气中温室气体浓度增加的重要原因，排放到大气中的CO_2大约有44%存留在大气中，其余被海洋和陆地生态系统吸收。

Many studies have shown that land ecosystems is a huge carbon sinks, the land ecosystem carbon storage and carbon flux response is sensitive to global warming, the rise of temperature is a positive feedback, but this response have seasonal and regional differences.

很多研究已经表明，陆地生态系统是地球表层巨大的碳库，而陆地生态系统碳存储和碳通量对于全球变暖的响应比较敏感，与温度的升高是正反馈效应，但是这种响应存在季节和区域差异。

The strong mutual feedback between ecosystem and climate system makes the terrestrial ecosystem's response and adaptation to climate change and human activity become a hot issue in today's global change research.

生态系统与气候系统之间强烈的相互反馈作用使得陆地生态系统对气候变化和人类活动的响应和适应成为当今全球变化研究的热点问题。

Limited by double driving mechanism of natural changes and human activities on the carbon cycle, and the complexity of carbon exchange and atmospheric transmission in the regional system , the scientific understanding of human activities and natural factors on carbon source still have limitations, estimation and forecast regional and global land ecosystem carbon source still have uncertainty.

限于自然变化和人为活动对碳循环的双重驱动机制，以及地区系统碳交换和大气传输的复杂性，人类活动和自然因素对碳源汇影响的科学认识还存在局限性，区域和全球陆地生态系统碳源汇估算和预测存在着很大的不确定性

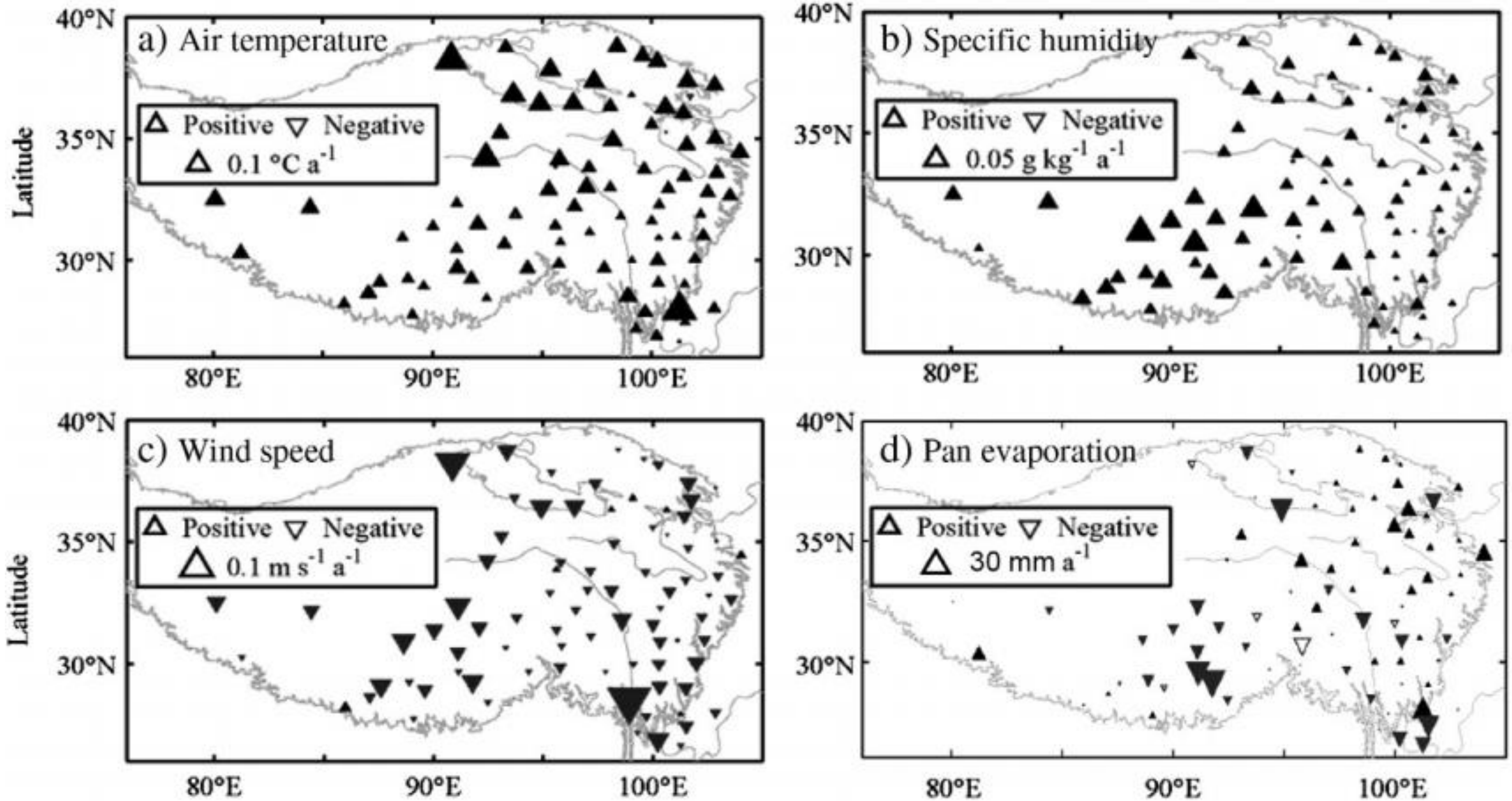
Studies have shown that forest ecosystems are important carbon sinks. The grassland is the most widely distributed type of vegetation in the world, accounting for about 20% of the world's land area, and its carbon balance plays an important role in global carbon accounting.

已有研究表明森林生态系统是重要的碳汇。而草地是世界上分布最广的植被类型，约占全球陆地面积的20%，它的碳收支状况对全球碳核算也起着重要的作用

The grassland area in China covers 41% of the land, most of them is distributed in the temperate continental climate zone in the north and northwest and the high elevation of the Tibetan Plateau.

我国草地面积约覆盖了国土面积的41%，大部分分布在北方和西北的温带大陆性气候区以及海拔较高的青藏高原地区

青藏高原气候变化Climate change on the Tibetan plateau



1984~2006年中国气象局观测站的数据

Yang et al., *Global and Planetary Chang*, 2014

Why？

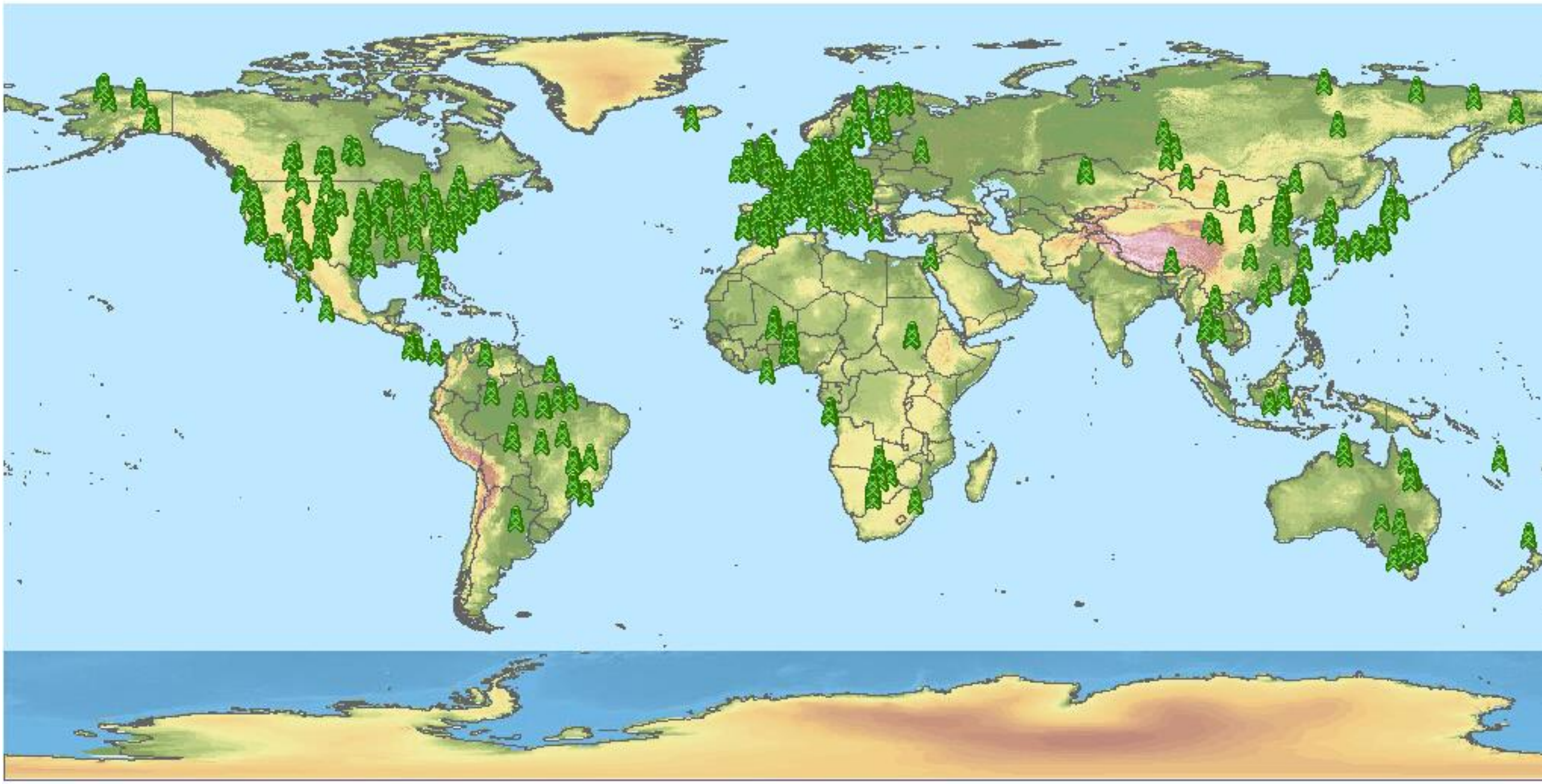
Over the past decade, research in the Tibetan Plateau grassland ecosystem carbon balance and its impact factor deepened the understanding of alpine grassland ecosystem carbon cycle process and provided important data of evaluation carbon balance in land ecosystem of the northern hemisphere. However, the study of grassland is concentrated in the eastern plateau, and the study in the center and the west of the plateau is still deficient.

…这些研究加深了对高寒草地生态系统碳循环过程的理解和认识，同时也为评价北半球陆地生态系统的碳平衡提供了重要的数据。但是研究的草地多集中在高原东部，对高原腹地及西部的草地碳通量的研究仍然较少。

Therefore, it is important to research on the dynamic balance of CO2 flux and the carbon budget and its influencing factors on the different grassland in Tibetan Plateau which is an important part of carbon budget of China's grassland ecosystem, it will help predict alpine grassland ecosystem response to climate change in the future.

因此，开展对青藏高原不同草地下垫面CO_2通量动态和碳收支状况及其影响因子的研究，是中国草地生态系统碳收支研究的重要组成部分。有助于预测高寒草地生态系统对未来气候变化的响应。

观测生态系统与大气碳交换——FLUXNET



http://www.daac.ornl.gov/

全球超过650个站点 More than 650 sites around the world.

中国科学院中国生态系统研究网络生态站分布图

Chinese Ecosystem Research Network

http://www.chinaflux.org

1.3 青藏高原草地生态系统CO_2通量的观测与研究

早期均采用箱式法对高寒草地的CO_2排放进行了观测研究。

箱式法可以用来测定土壤及低矮植被的CO_2通量及CH_4、N_2O等痕量气体的通量，主要原理是根据箱内目标气体的浓度变化，以及气压、温度、箱体高度等，计算箱子所覆盖的植被类型的气体通量。这种方法成本较低，移动方便，但会影响箱内的自然状况，会对痕量气体的交换过程产生影响。

Observation and study of CO2 flux of grassland ecosystem in Tibetan plateau.
In the early stage,
the CO2 emission of alpine grassland was studied
by box method.

1.4 研究目标和内容

本研究目标为利用涡动相关技术观测青藏高原典型草地生态系统与大气间的CO2通量，通过对数据进行严格质量控制和评价，探明CO2通量日变化、季节变化和年变化特征；通过分析CO2通量与环境因子的关系，了解CO2通量对环境影响因子的响应机制；应用陆面过程模式，初步探讨整个青藏高原CO2通量的空间分布。

The aim of this study is using eddy-covariance technology to observe CO2 flux between typical grassland ecosystem in Tibetan Plateau and atmospheric, through control and evaluation of data to acquire the seasonal variation and the annual variation characteristics of CO2 flux. By analyzing the relationship between CO2 flux and environmental factors to understand the response mechanism of them. The spatial distribution of CO2 fluxes in the whole Tibetan plateau is preliminarily discussed by LSMs.

The main research contents of this study include:

- Analyzes the CO_2 fluxes diurnal, seasonal and annual change characteristics of the alpine meadow, alpine grassland, desert grassland ecosystem in the Tibetan plateau and evaluates its carbon budget.
- Analyzes the relationship between CO_2 flux and environmental factors such as temperature, photosynthetic effective radiation, saturated vapor pressure in these ecosystems during the growing season.
- using numerical model to simulate spatial distribution of CO_2 flux in Tibetan plateau.

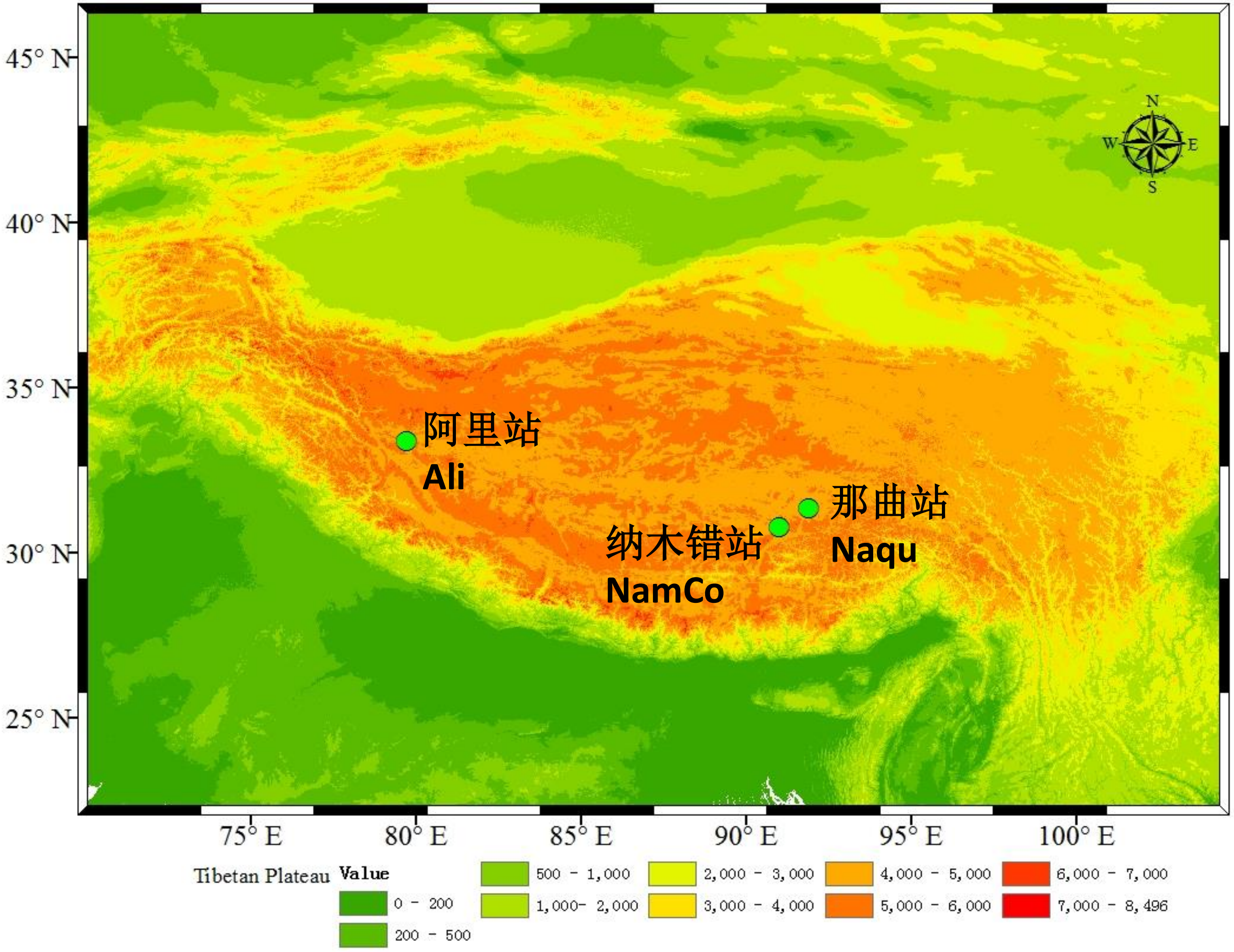
主要研究内容包括：

(1) 分析青藏高原高寒草甸、高寒草原、荒漠草原生态系统与大气间CO_2通量的日变化特征、季节变化及年变化特征，评估其碳收支状态；

(2) 分析上述三种草地生态系统生长季CO_2通量对温度、光合有效辐射、饱和水汽压差等环境因子的相关关系；

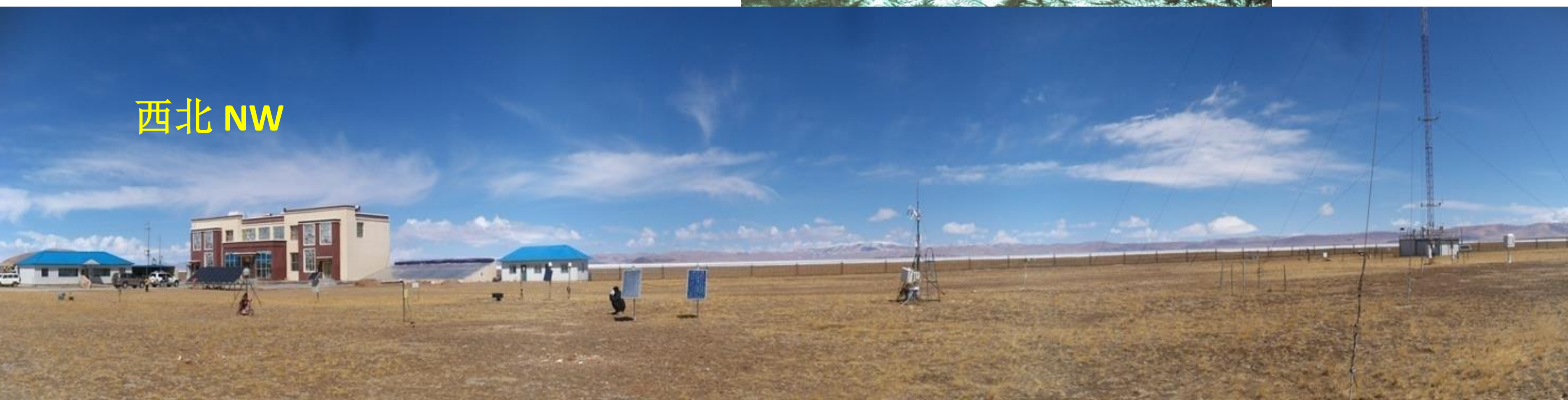
(3) 利用数值模式模拟青藏高原CO_2通量的空间分布状况。

2. 研究区域-青藏高原 Research area - Tibetan Plateau



观测站情况 Stations condition

NAMORS
Nam-co



那曲高寒草甸

- 那曲站位于那曲河谷高寒草原，处在高原亚寒带半湿润气候区，海拔高度为4509m。站区及其所在那曲河流域的地带性植被为高寒小嵩草草甸，河流滩地等低洼地分布有藏嵩草草甸，具有典型的区域代表性。土壤高山草甸土，呈黑褐色，表层紧实而有弹性，耐牲畜践踏，保护土壤免受侵蚀。

The alpine meadow of Naqu station. The semi-humid climate of the plateau subfrigid zone.

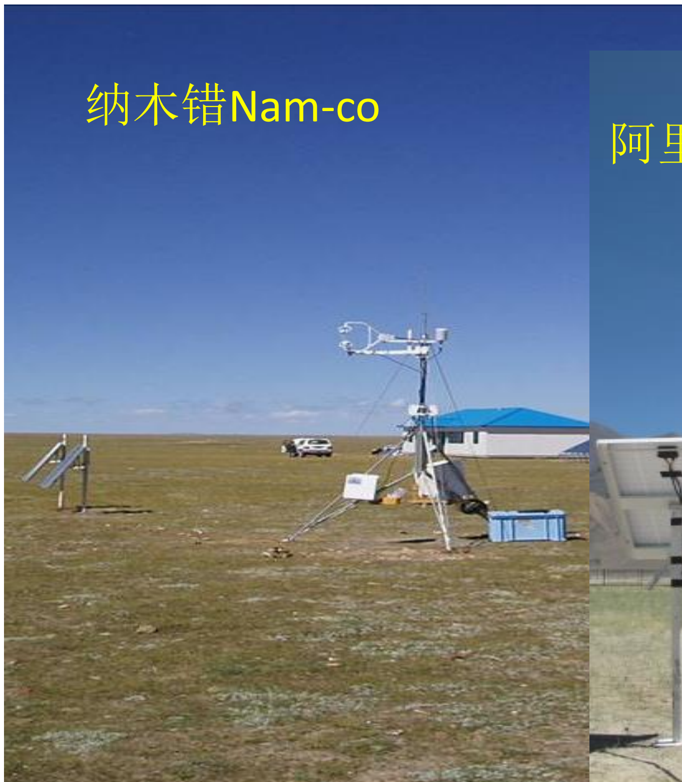
阿里荒漠草原

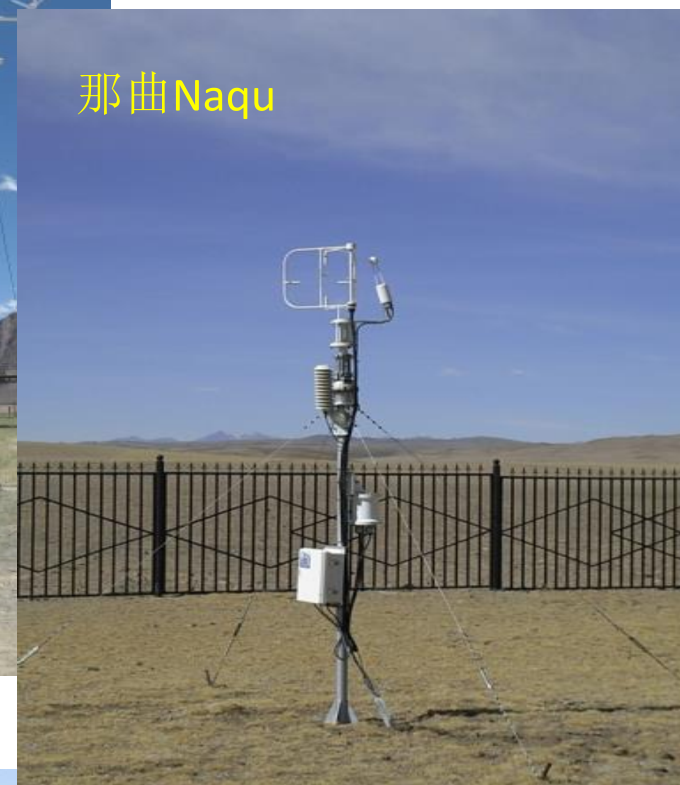
阿里站位于西藏自治区阿里地区日土县境内，在县城以西3km，距离班公错南岸10km左右。海拔4271m。

阿里站草地属于寒冷干旱山地荒漠草地类，土壤为亚高山荒漠土和高山草原化荒漠土。植被组成较为单一，以沙生针茅为建群种的荒漠草原地作为植被基带，其中伴生着少数几种强旱生植物，分布稀疏而不均匀，覆盖度3-15%

The desert grassland of Ali station. Grassland belongs to the cold arid hilly desert grassland, the soil is subalpine desert soil and alpine grassland desert soil.

观测仪器-Eddy covariance system





观测仪器及项目

	经纬度 Latitude And longitude	海拔 altitude	PBL观测项目 PBL observation projects	涡动相关系统主要传感器及观测项目 Eddy covariance system
高寒草原 （纳木错站） Alpine grassland （Nam-co）	30°46'N 90°59'E	4730	气温、风速和风向、相对湿度(Vaisala，1.5,2,4,10,20m),土壤温湿度(10, 20, 40, 80, 160cm), 土壤热通量（10, 20cm），气压和降水， 辐射四分量(Kipp&Zonen)， 采样频率10min	CSAT3， 三维超声风速仪，测算风速三维分量； LI-7500，红外气体分析仪，测算空气中CO_2和水汽密度； CR5000，数据采集器，在线处理并存储数据，采样频率10Hz
荒漠草原 （阿里站） Desert grassland (Ali)	33°23'N 79°42'E	4271	气温和相对湿度(1.5, 2.8m), 土壤温湿度(0, 20, 50, 100, 200cm)，气压和降水，辐射四分量(Kipp&Zonen)， 采样频率30min	
高寒草甸 （那曲站） Alpine meadow (Naqu)	31°22'N 91°54'E	4509	气温(1, 8.4 m)、风速(1, 5, 10.3 m)和风向(10.3 m)、相对湿度(1, 8.4m),土壤温度(0, 4, 10, 20, 40cm), 土壤湿度(4, 20 cm), 土壤热通量（10, 20cm），气压和降水，辐射四分量(Kipp&Zonen)， 采样频率10min	DAT600/ CSAT3， 三维超声风速仪测算风速三维分量； LI-7500，红外气体分析仪，测算空气中CO_2和水汽密度； CR5000，数据采集器，在线处理并存储数据，采样频率10Hz

高寒草原和高寒草甸土壤参数(Chen et al., 2012)
Soil parameters of alpine grassland and meadow

站点 Site	深度 Depth (cm)	有机质 m_{soc} (%)	砂粒 %sand	粘粒 %clay	容重 Bulk density (g cm^{-3})
纳木错 Nam-co	0-10	2.46	91.88	0.40	1.12
	10-20	1.61	95.00	0.00	1.47
	20-30	1.54	93.07	0.29	1.70
那曲 Naqu	0-10	2.1	87.3	0.71	1.41
	10-20	1.3	94.18	0.01	1.71
	20-30	1.1	92.32	0.34	1.52
	30-40	1.5	84.05	1.34	1.56

10Hz的资料*u, v, w, T, C, q…*

↓

野点剔除 Outliers are removed

↓

通量计算及必要校正
Flux calculation and necessary calibration
平面拟合（PF）
频率响应校正
密度（WPL）校正

↓

各通量（H、LE、 F_{CO2}）

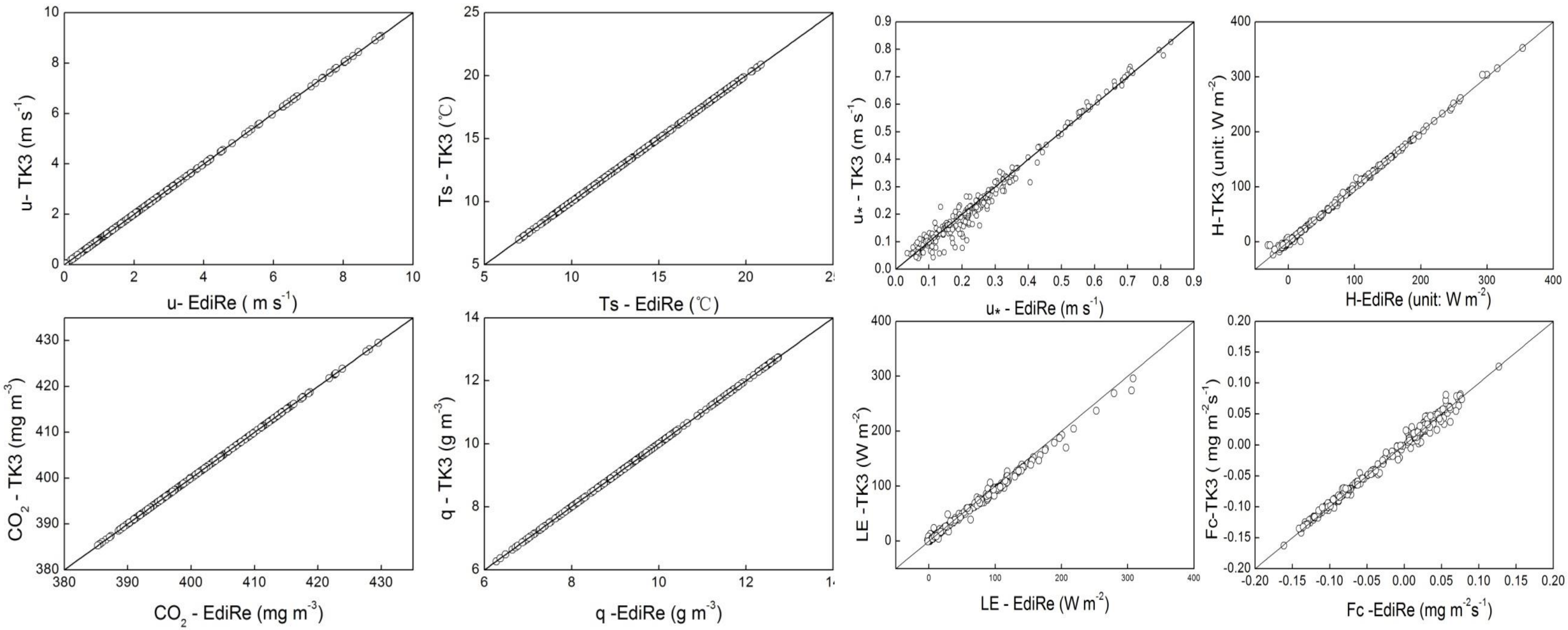
↓

质量控制/评价
Quality control/evaluation
平稳性、相似性（湍流特征）检验与通量质量评级

采用德国Bayreuth大学微气象学系Matthias 和Foken等人开发的TK3软件进行计算和校正。
calculations and corrections by TK3

湍流数据处理流程
Turbulence data processing

EdiRe和TK3计算结果 calculation results



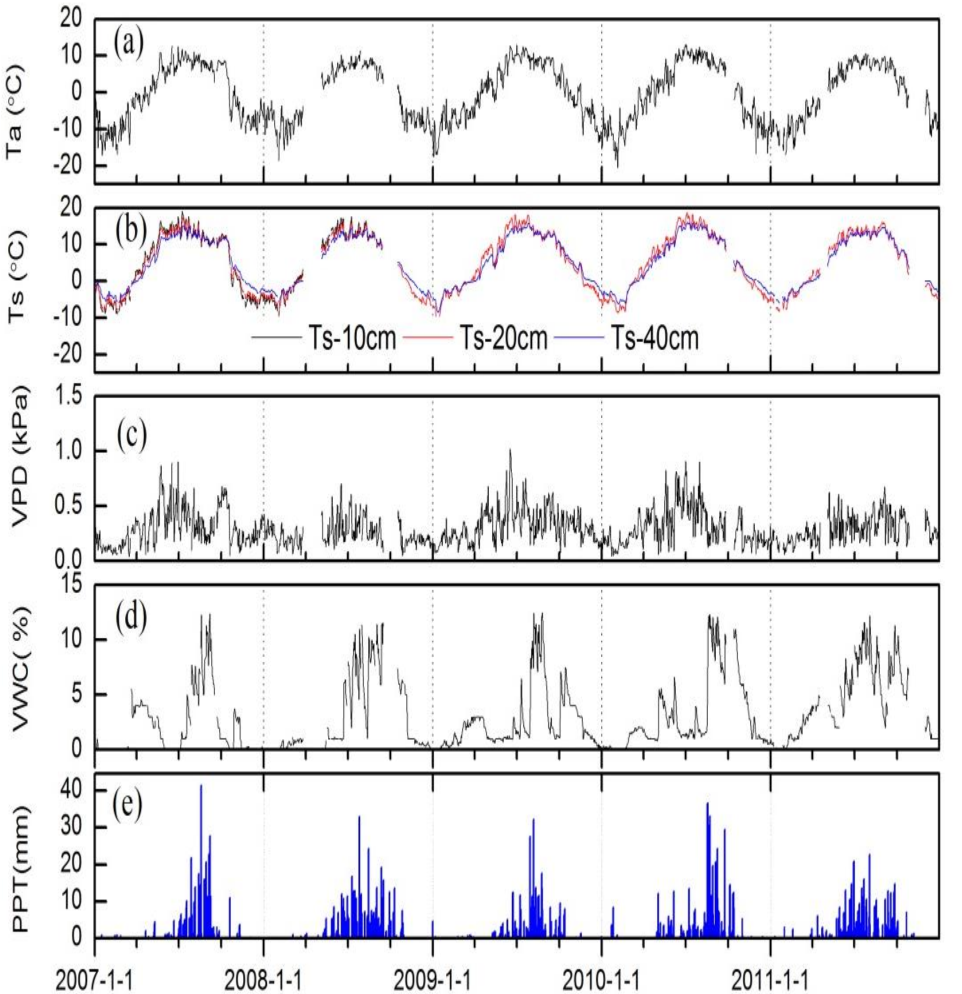
站点 sites	拟合参数	风速 u (m/s)	湿度 q (g/m³)	CO_2浓度 (mg/m³)	温度Ts (℃)	摩擦风速 u_*(m/s)	感热Hs (W/m²)	潜热LE (W/m²)	CO_2通量 Fc(mg/m²/s)
纳木错 Nam-co	a	1	1	1	1	0.982	0.996	0.936	0.954
	R^2	0.999	1	1	1	0.991	0.999	0.997	0.917

3.青藏高原草地生态系统CO_2通量变化特征分析

Analysis of the CO2 flux change of grassland ecosystem in Tibetan Plateau

高寒草原气象要素变化特征

Changing characteristics of meteorological elements in alpine grassland



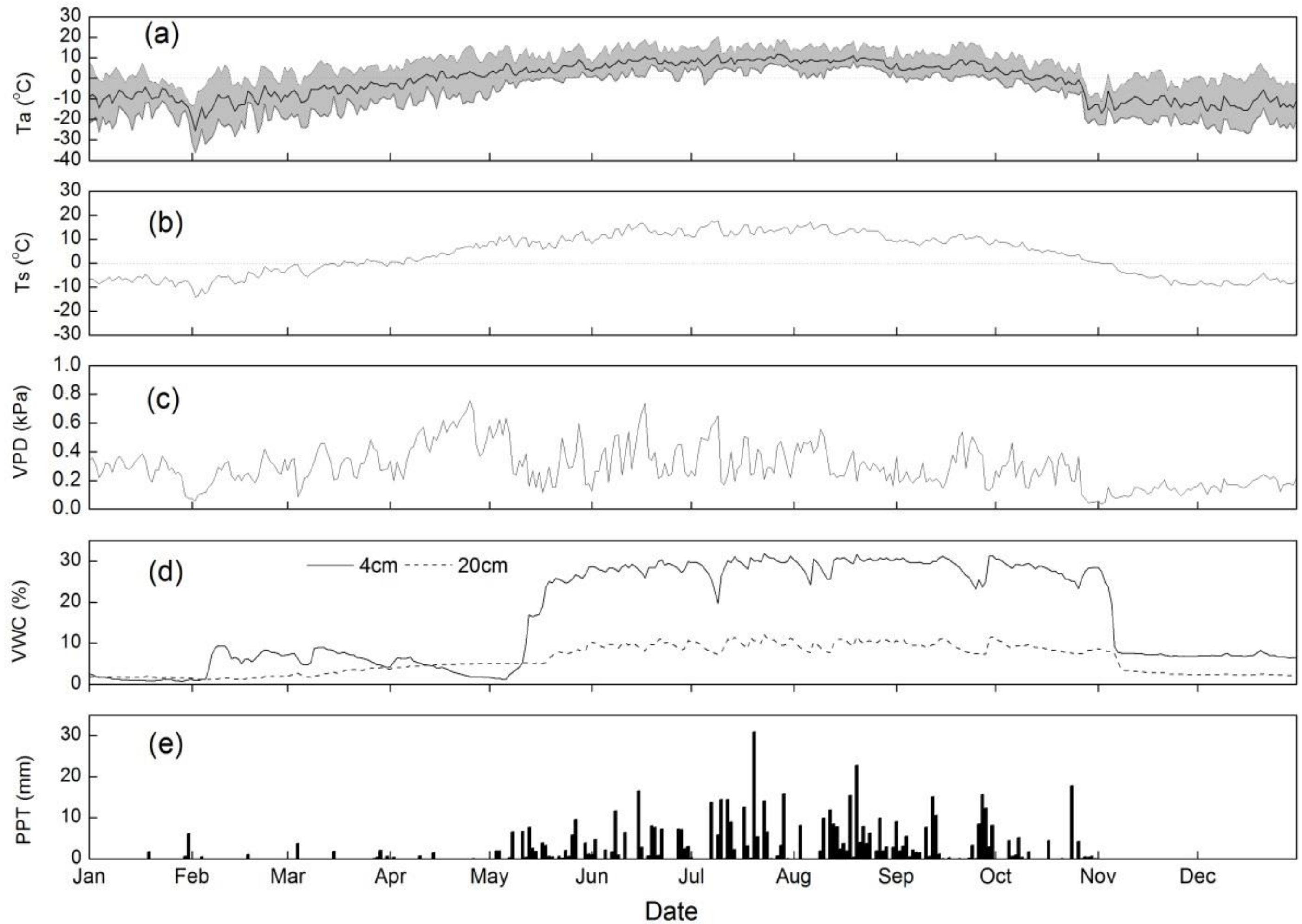
气温	2007	2008	2009	2010	2011
1月	-10.0	-7.2	-10.4	-11.2	-10.8
2月	-11.6	-10.3	-8.0	-11.3	-10.6
3月	-6.0	-7.0	-5.5	-4.9	-6.4
4月	-1.8	-	-0.3	-0.1	-
5月	4.7	3.8	2.7	3.3	3.5
6月	6.9	6.5	8.7	8.7	6.6
7月	9.2	8.4	10.3	10.5	8.7
8月	8.5	7.8	8.4	9.3	7.9
9月	7.0	-	6.9	7.2	7.0
10月	2.8	-	1.6	-	1.4
11月	-6.1	-7.0	-3.4	-6.3	-
12月	-7.1	-8.2	-8.2	-9.6	-6.5

纳木错站降水 precipitation of Nam-co

降水	2007	2008	2009	2010	2011
1月	0.9	0.2	5.1	12.0	3.7
2月	2.6	0	0.6	1.0	2.5
3月	0.3	3.0	4.9	0	3.7
4月	3.3	2.8	0.3	2.1	12.1
5月	11.1	27.3	18.3	37.8	26.0
6月	10.8	87	34.1	29	90.2
7月	91.2	147	76.6	47.3	118.4
8月	155.8	115.7	166.1	250.3	71.6
9月	104.9	116.1	31.9	127	95.6
10月	11.0	48.9	33.8	55.3	19.0
11月	6.7	0	1.9	6.5	3.9
12月	0.6	0	0.7	0.5	0
合计	399.2	548.0	374.3	568.8	446.7

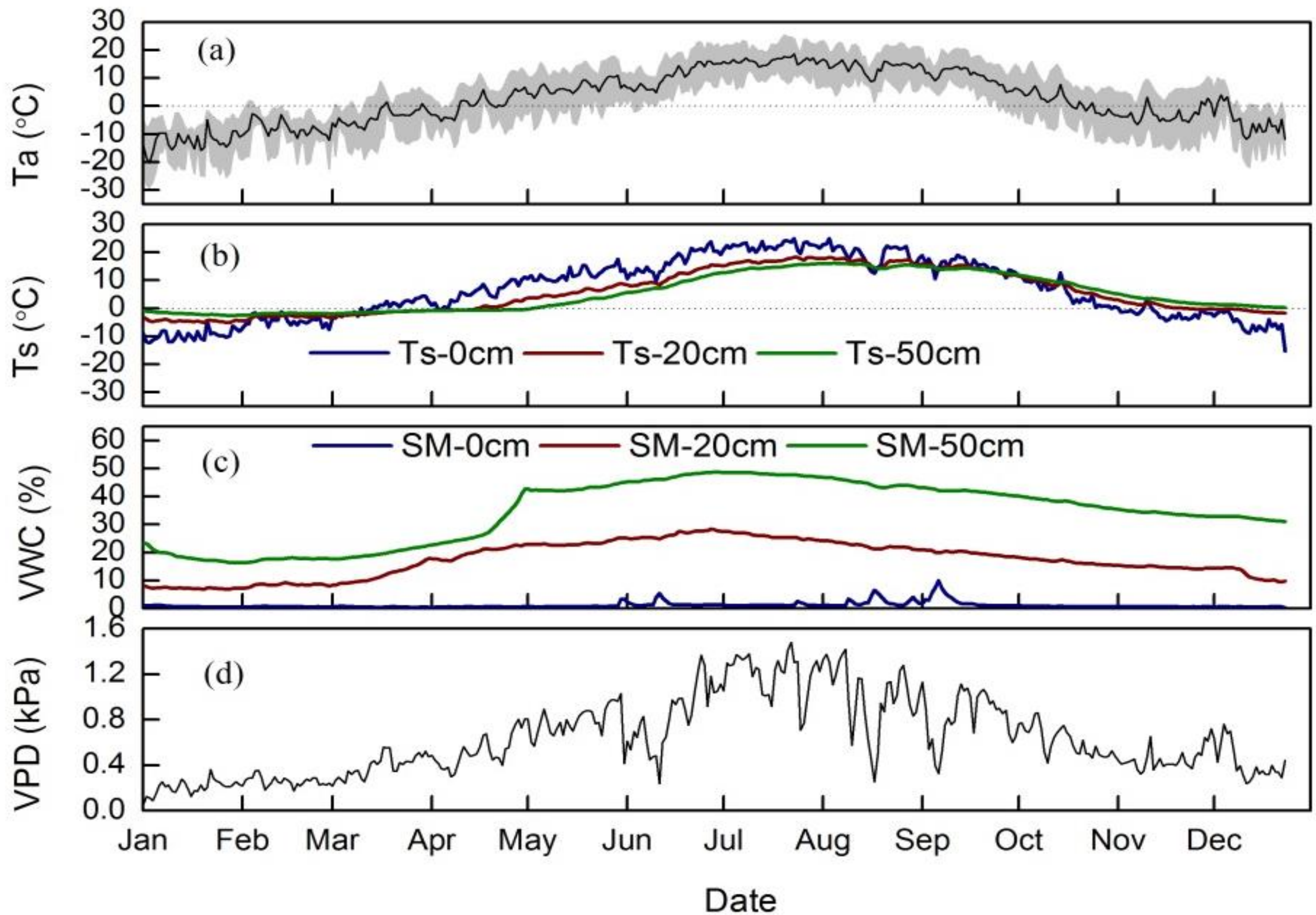
高寒草甸生态系统气象要素季节变化

Seasonal variation of meteorological elements in alpine meadow ecosystem

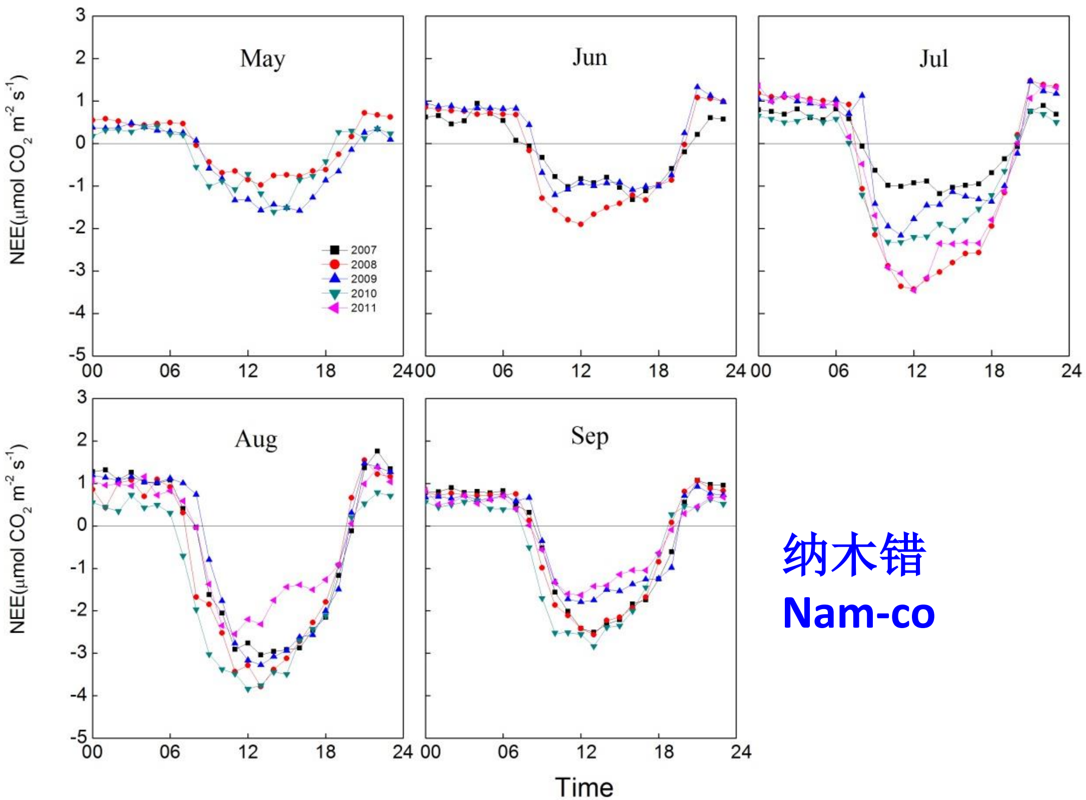


高寒荒漠草地气象要素季节变化

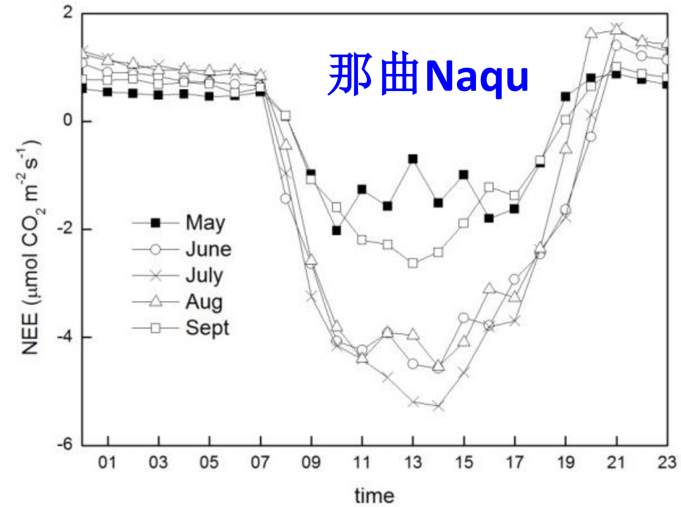
Seasonal variation of meteorological elements in alpine desert grassland

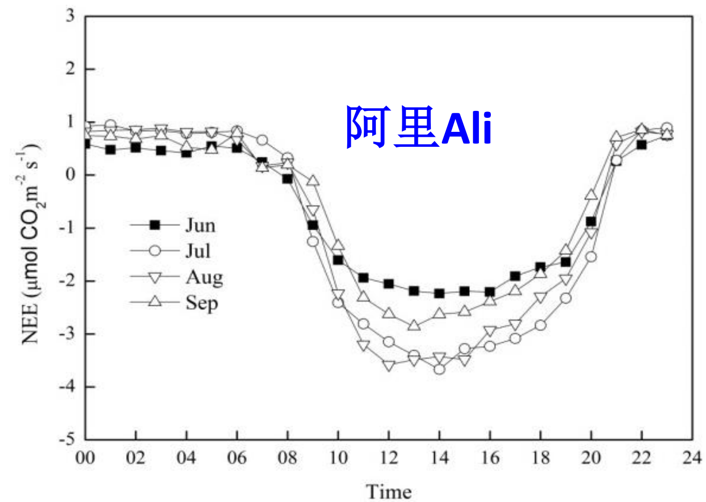


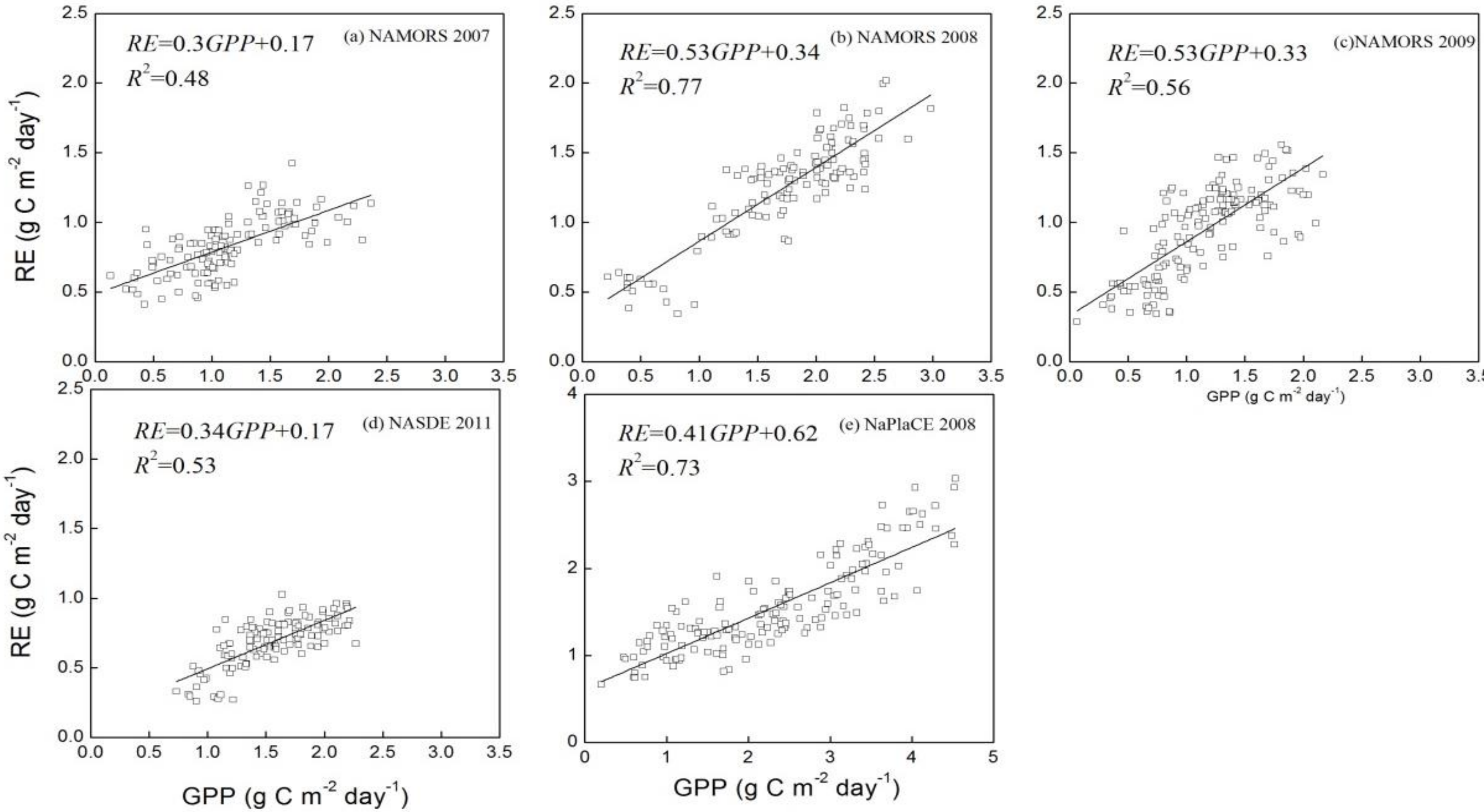
NEE的日变化特征 diurnal variation



纳木错
Nam-co







从Re呼吸率与GPP的日累积量来看，两者有着非常好的相关关系，这三种草地生长季，GPP可以解释50%以上的RE的变化。在降水较为充沛的2008年，高寒草原和草甸生长季的光合作用明显主导着呼吸作用（R^2>0.73）。GPP影响RE的方式，是通过根系渗出物提供了自养呼吸和异养呼吸所需要的底物（substrate），而光合作用影响这种底物的利用效率，从而控制呼吸作用(Davidson et al., 2006b)。

RE（respiration rate） and GPP's daily cumulative volume have a very good correlation.

小结

- 纳木错高寒草原和那曲高寒草甸生态系统年平均气温都在0℃以下，而阿里荒漠草原在0℃以上。全年86%以上降水主要发生在生长季5~9月份，但降水量的季节分配及年际变化较大。
- 纳木错站、那曲站和阿里站草地存在相似的日变化、季节变化特征。生长季节6~9月，CO2通量呈现单谷的吸收模式，平均的CO_2日最大吸收速率仅为-3.9 、-5.3、-3.7μmol m^{-2} s^{-1}，高寒草甸明显要高于其他两种草地类型。这三种草地生态系统在生长季表现为明显的碳汇，在生长季6~9月份，这三种草原碳吸收量由高到低分别为高寒草甸（123.34 g C m^{-2}）>荒漠草原（105.66 g C m^{-2}）>高寒草原（58.54 g C m^{-2}）。但是从全年来看，纳木错地区高寒草原为弱小的碳源，2008和2009年碳排放量分别为23.2和38.3 g C m^{-2}；而高寒草甸生态系统为明显的碳汇，年吸收量为41.3 g C m^{-2}，但碳汇强度明显弱于高原东部海拔相对较低的草地和纬度相近的平原地区的草地生态系统。

  Grassland have similar diurnal and seasonal variation characteristics. The alpine grassland is a weak carbon source, The alpine meadow is an obvious carbon sink.

- 从RE与GPP的日累积量来看，两者有着非常好的相关关系，这三种草地生长季，GPP可以解释50%以上的RE的变化。在降水较为充沛的年份，生长季的光合作用明显主导着呼吸作用（R^2>0.73）。全年RE占GPP的比重较高，这表明生态系统通过光合作用固定的碳，大部分通过呼吸作用消耗掉。

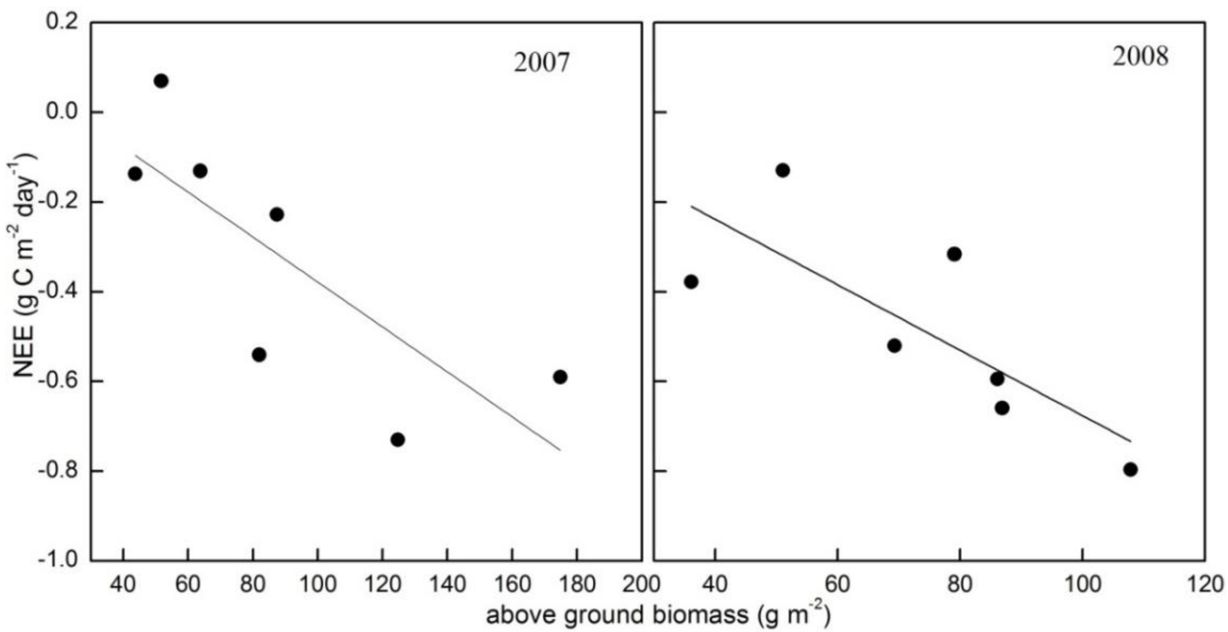
  RE and GPP's daily cumulative volume have a very good correlation.

- 对高寒草原来说，雨季来的较早且降水比较丰沛的年份，生长季吸收碳要明显高于其他年份。降水的季节分配和年际变化对草地生态系统的碳收支状况有着重要的影响。

  The seasonal distribution and annual change of precipitation have important influence on the carbon balance of grassland ecosystem.

NEE与地上生物量的关系

The relationship between NEE and aboveground biomass



2007年生长季NEE = (-0.005±0.0018) ×AGB + (0.1230 ± 0.1752), R^2=0.54。

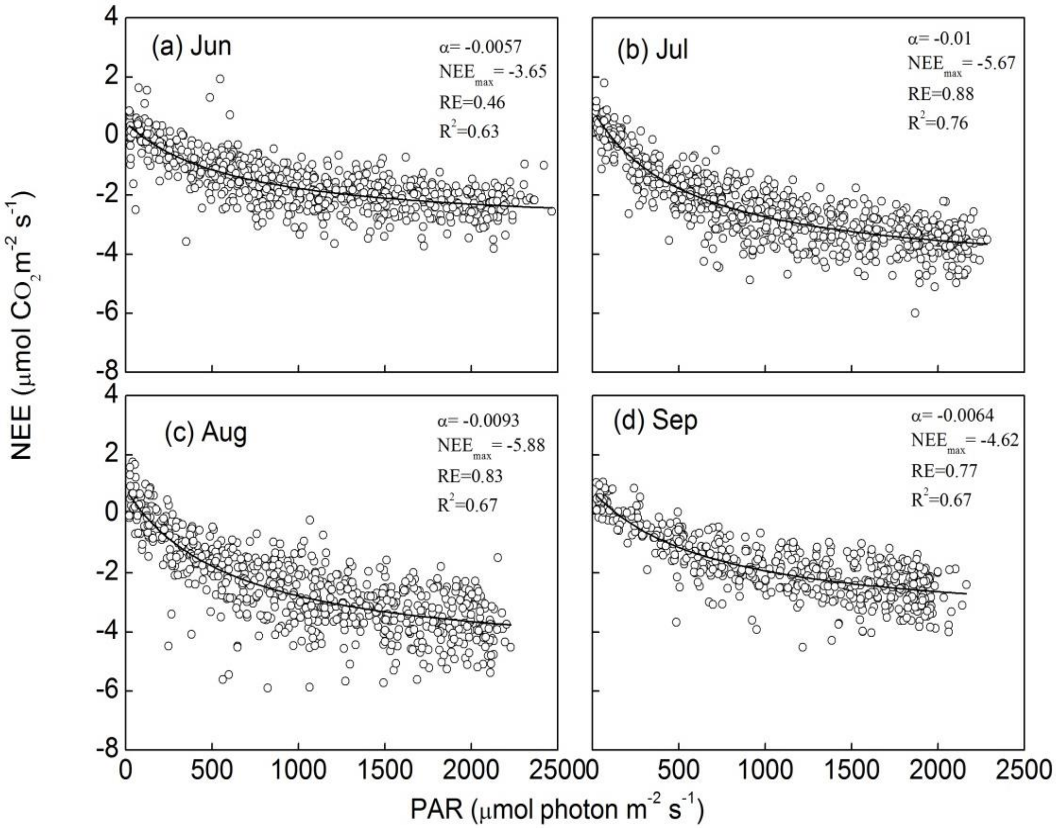
2008年生长季NEE = (-0.0073 ± 0.0027) ×AGB + (0.0533 ± 0.2049), R^2=0.52。

超过50%的NEE日累积量的变化可以由地上生物量的变化来解释，其余的可能是由其他环境要素引起的，例如温度、水分、光照等。

More than 50% of the change in the amount of the NEE's day can be explained by changes in the biomass of the ground, and the rest may be caused by other environmental factors, such as temperature, water and light.

NEE对光合有效辐射的响应

NEE's response to photosynthetic effective radiation



阿里荒漠草原生长季白天NEE对PAR的响应

The response of NEE to PAR during the growing season of Ali desert grassland

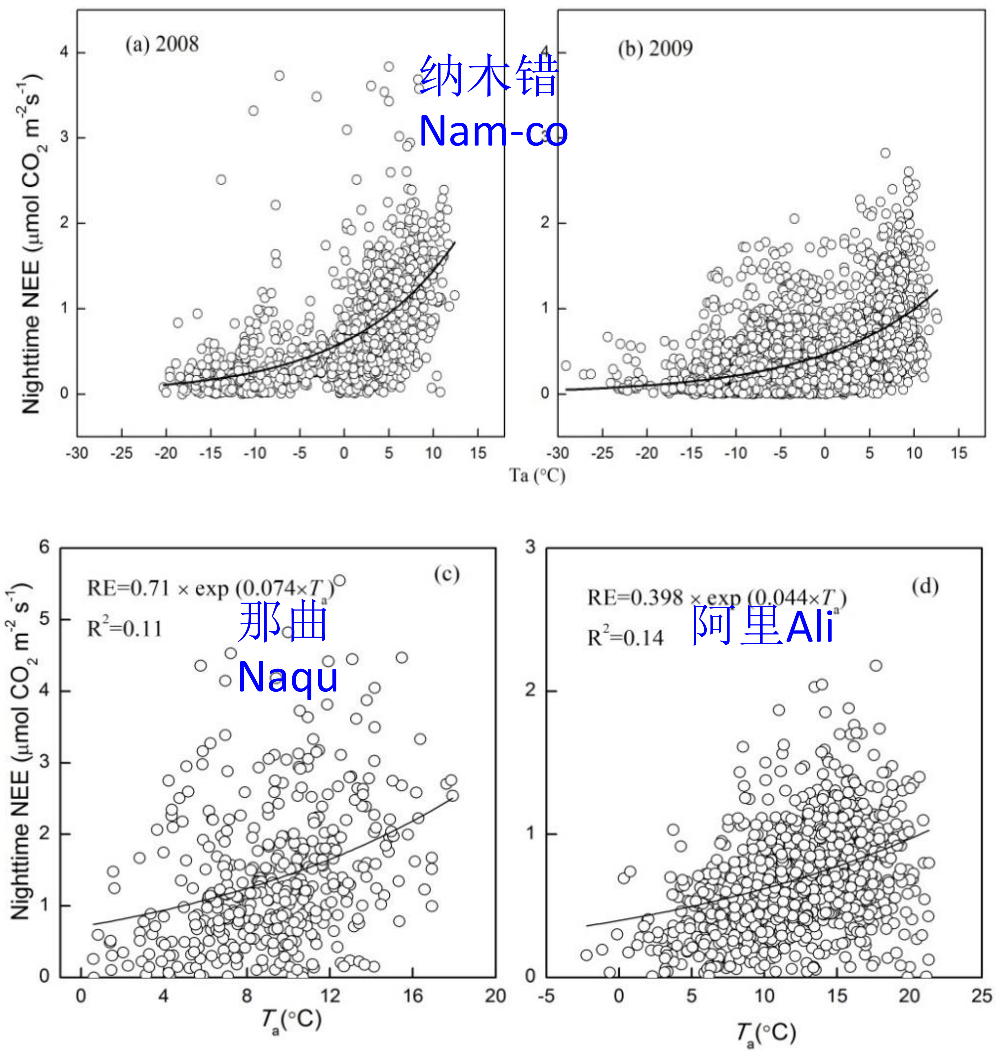
$$NEE = \frac{\alpha \times PAR \times NEE_{max}}{\alpha \times PAR + NEE_{max}} - RE_{day}$$

可以看到Michalis-Menten光响应方程很好的描述了白天NEE随PAR的变化，R^2均在0.63以上。这表明阿里站草地生长季NEE的变化主要受光合有效辐射的控制

The change of the NEE in the growth season of Ali station is mainly controlled by the photosynthetic effective radiation

生态系统呼吸作用与温度的关系

The relationship between respiration and temperature of ecosystem



小结

- 纳木错高寒草原生态系统日累积NEE与地上生物量有着明显的线性关系，2007年生长季这种线性关系为NEE = (-0.005±0.0018) ×AGB + (0.1230 ± 0.1752), R^2=0.54； 2008年生长季NEE = (-0.0073 ± 0.0027) × AGB + (0.0533 ± 0.2049), R^2=0.52。超过50%的NEE日累积量的变化可以由地上生物量的变化来解释。

  There is an obvious linear relationship between the daily accumulation NEE and the aboveground biomass of Nam-co.

- 利用Michalis-Menten光响应方程，拟合得到高寒草原、高寒草甸、荒漠草原三种草地的生长旺盛期的α值分别为-0.0370、-0.0255、-0.010 □mol CO_2· mol^{-1} photons。阿里荒漠草原在生长季各月，NEE主要受到PAR控制（生长季各月R^2在0.63以上）。高寒草原NEE则受到在土壤水分和PAR的共同影响，在土壤水分适宜时，NEE和光合有效辐射（PAR）有较好的直角双曲线关系，表观光量子效率α可以达到0.0370 mol CO_2· mol^{-1} photons。当土壤含水量较低时，α绝对值也明显减小，且NEE和光合有效辐射的关系也变得不显著。散射辐射对生态系统碳吸收增加的影响并不明显，这是因为观测到的NEE不仅受到PAR的影响，还受到温度的影响

  Michalis - Menten light response equation shows the α in alpine grassland, alpine meadow, desert grassland are respectively -0.0370, -0.0255, -0.010 during growth period.

- 生态系统的呼吸作用同时受到温度和土壤水分的影响。高寒草原和高寒草甸的温度敏感性Q10值均高于2.0，表明高寒草地生态系统对未来气候变暖的敏感性。高寒草原的Q10值随着土壤水分的降低而减小，表明土壤水分调节高寒草原CO_2排放过程，旱季不利于其排放，并降低温度敏感性。

  The respiration of the ecosystem is affected by both temperature and soil moisture.

- 那曲高寒草甸生长季昼夜温差与NEE呈负相关关系，NEE = -0.16 ±⍰ 0.04 (Tmax-Tmin) -2.62 ± 0.49, R^2=0.14, P< 0.001，这表明昼夜温差大有利于该草地生态系统的碳累积；而其他两个站草地昼夜温差和碳累积没有明显的关系。

  The diurnal temperature difference in the growth season of alpine meadow was negatively correlated with NEE in Naqu.

- 生长季末期的降水会提高生态系统的呼吸作用，消耗固定的碳，对生态系统碳收支有重要影响。

  The precipitation at the end of the growth season will improve the respiration of the ecosystem and consume the fixed carbon, which will have an important impact on the carbon balance of the ecosystem.

5. 青藏高原CO_2通量空间分布的初步研究
Preliminary study on the distribution of CO2 fluxes in TP

评价区域生态系统碳收支的模型研究
To evaluate the carbon budget model of regional ecosystem

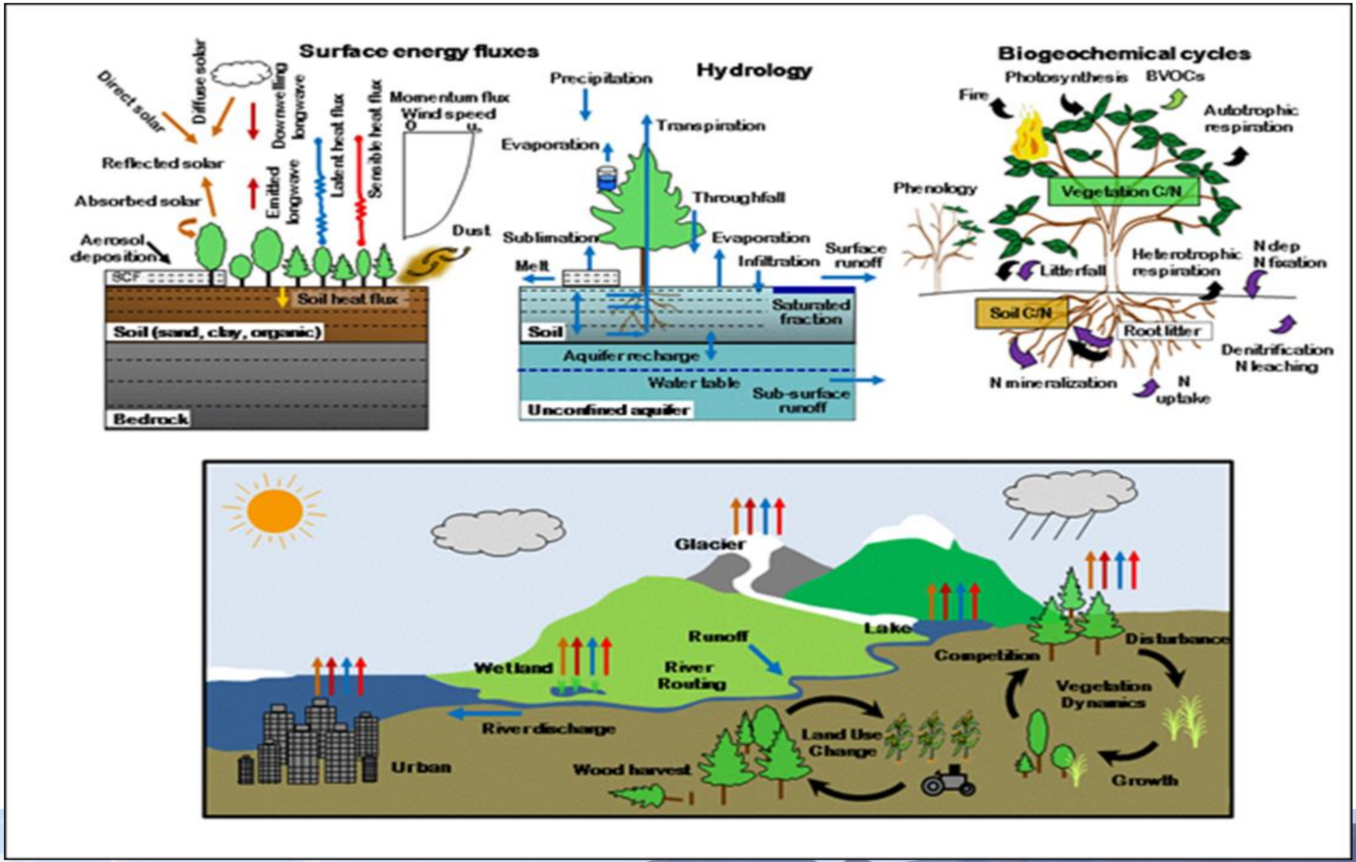
- 涡动相关技术被认为是可以直接测定大气与群落CO_2交换通量的标准方法，但仍是一种中小尺度的观测方法，其观测结果难以直接向大尺度外推。

  Eddy covariance technology is considered to be directly related standard method for determination of atmospheric CO2 exchange flux, but it is a kind of small and medium scale observation method, the observation result is difficult to make large scale extrapolation.

- 陆地生态系统碳循环模型模拟是研究区域尺度生态系统碳收支有效方法之一，能够模拟生态系统碳循环的空间格局。目前，应用较为广泛的模型主要分为两大类：基于遥感信息的模型和基于生态系统过程的模型

  The carbon cycle model simulation of land ecosystem is one of the effective methods to study the carbon balance of the regional scale ecosystem, and can simulate the spatial pattern of the carbon cycle of the ecosystem. At present, the widely used models are divided into two main categories: the model based on the remote sensing information and the model based on the process of the ecosystem

- 通用陆面过程模式（Community Land Model）-CLM由美国国家大气研究中心（National Center for Atmospheric Research, NCAR）的Community Climate System Model-CCSM通用地球系统模式中的陆面模式工作组（LMWG）发展并维护，是CCSM中的陆面模块 (Dickinson et al., 2006)。CLM主要包括了生物地球物理过程、水文过程。CLM4.0改进了土壤水文过程和雪盖的参数化方案，引入了土壤有机质，更新了植被功能型的分布，并增加了碳氮循环的生物地球化学模块Biome-BGC (Thornton et al., 2005; Lawrence et al., 2011)



- 驱动数据：中国区域高时空分辨率地面气象要素数据集 ITP-forcing（何杰，2010）；温、压、湿、风是融合了普林斯顿气象驱动数据集和CMA 740站的观测资料而来，在降水数据中还使用了TRMM 3B42 (Huffman et al., 2007)和GLDAS (Rodell et al., 2004) 降水数据产品。数据空间分辨率是0.25度，覆盖整个中国大陆地区。

  Forcing data set of ground meteorological elements in high spatial and temporal resolution in China- ITP-forcing and the Princeton meteorological driven dataset and CMA 740 data.

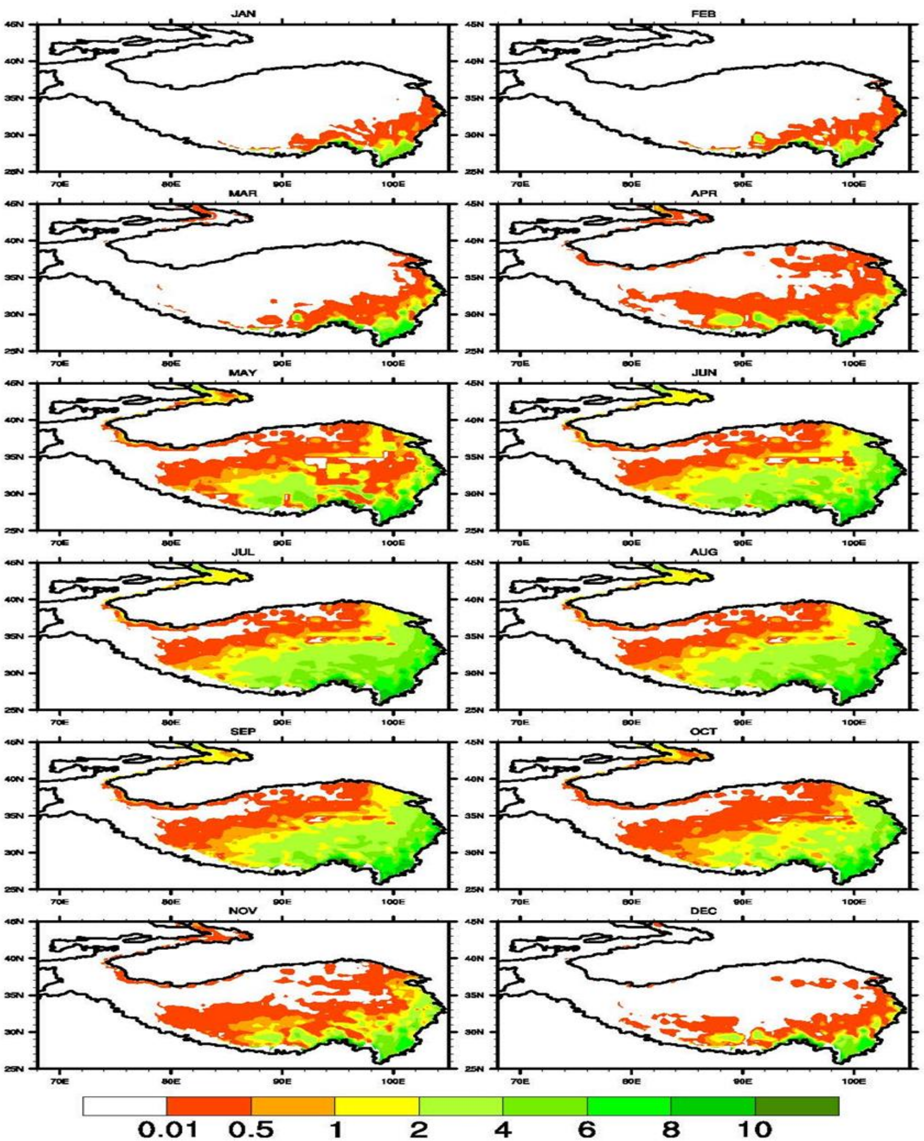
- 由于CLM4.0种提供的默认有机质数据在高原上偏大许多，我们使用北京师范大学戴永久教授课题组制作的“中国土壤数据集”（Wei et al., 2012）中的有机质数据来代替，使得对高原土壤成分描述更为准确地表的，其他物理属性，如月平均的叶面积指数等用CLM4.0模式的默认值。

  Organic matter data from “Chinese soil data set”

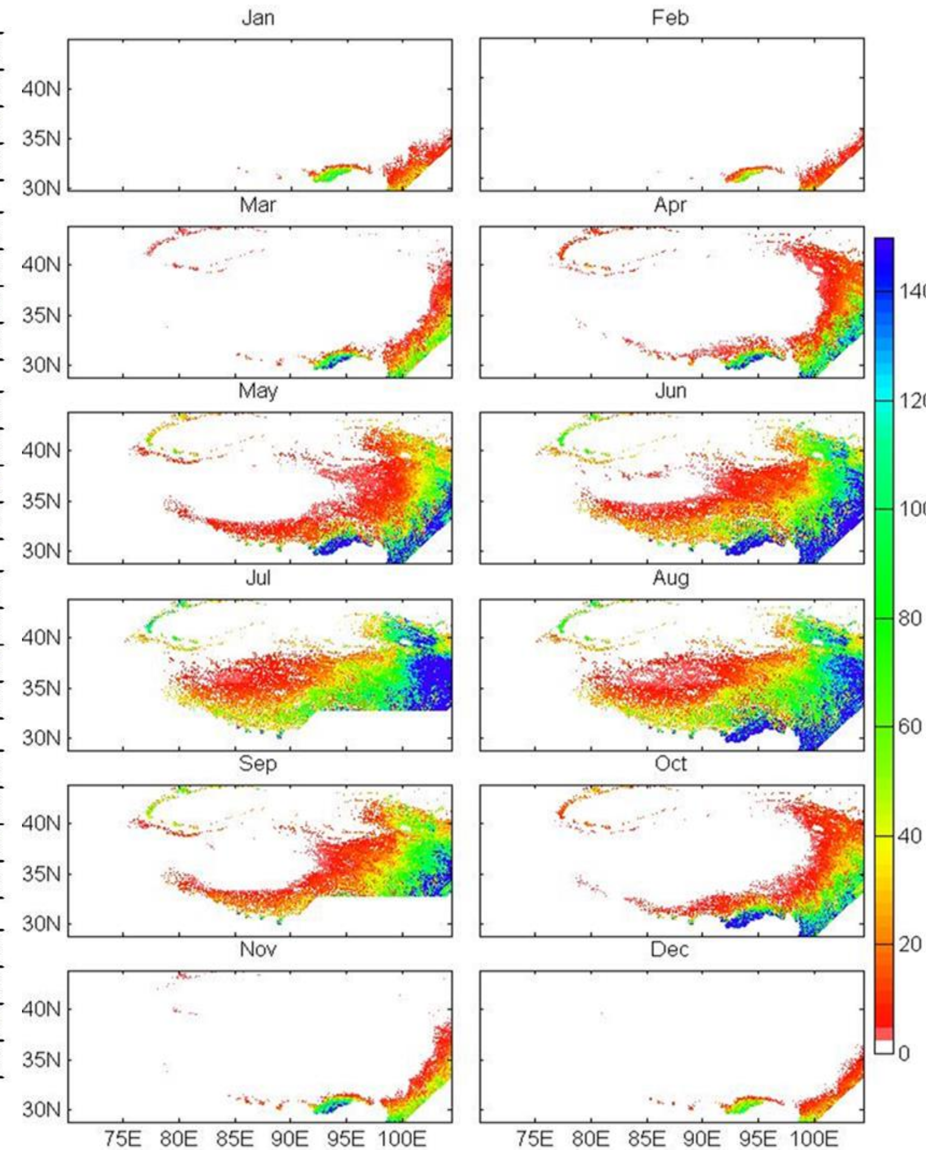
青藏高原区域GPP的时空分布 （ 2008年）

Spatial and temporal distribution of GPP in Tibetan plateau region (2008)

GPP-CLM4



GPP-MODIS



6. 结论与展望 Conclusion and prospect

结论与展望-1. CO_2通量的季节和年变化特征

The seasonal and annual variations of CO2 flux

- 在日尺度上，RE和GPP两者有着非常好的相关关系，这三种草地生长季，GPP可以解释50%以上的RE的变化。在降水较为充沛的年份，生长季的光合作用明显主导着呼吸作用（R^2>0.73）。全年RE占GPP的比重较高，这表明生态系统通过光合作用固定的碳，大部分通过呼吸作用消耗掉。

  On a daily scale, RE and GPP have a very good correlation.

- 从季节尺度上，高寒草原、高寒草甸和高寒荒漠这三种草地生态系统在生长季表现为明显的碳汇，在6~9月份，这三种草原碳吸收量由高到低分别为高寒草甸（123.34 g C m^{-2}）>荒漠草原（105.66 g C m^{-2}）>高寒草原（58.54 g C m^{-2}）。

  On the seasonal scale, the three grassland ecosystems of alpine grassland, meadow and desert are obvious carbon sinks in the growth season. Carbon uptake in summer is alpine meadow> desert grassland >alpine grassland

- 从全年来看，纳木错高寒草原为弱小的碳源，2008和2009年碳排放量分别为23.2和38.3 g C m^{-2}。而高寒草甸生态系统为的碳汇，年吸收量为41.3 g C m^{-2}，但碳汇强度明显弱于高原东部海拔相对较低的草地和纬度相近的平原地区的草地生态系统

  For the whole year, Nam-co alpine grassland is the weak carbon source, alpine meadow ecosystem is carbon sink.

问题与展望 Problems and prospects

In the field observation, eddy-covariance is still restricted by heterogeneous surface and non-ideal meteorological conditions. It need more comprehensive, long-term and effective positioning observations, combine with other observational methods.

涡动相关技术测定CO_2通量的方法虽然已经得到微气象学家和生态学家的认可，并在全球范围内不同生态系统广泛应用，但在实地观测中，仍受到非均一下垫面和非理想气象条件等因素的制约，严冬极端低温对通量观测的影响，还需要进一步研究。为了更为准确的理解青藏高原典型草地生态系统的土壤-植被-大气间的相互作用，需要更为全面的、长期有效的定位观测，并同时将涡动相关技术与其他观测方法，如箱式法、同位素示踪技术等相结合，开展综合观测。

The eddy-covariance technology is only a small scale observation method, and the observation results are difficult to push directly to the larger scale. The next step is to improve the model performance of CLM in the plateau region by combining the data of the flux observation site with the satellite remote sensing data and the carbon cycle mechanism model of the ecosystem.

涡动相关技术只是一种小尺度的观测方法，观测结果很难直接向更大尺度外推。目前，应用生态过程模型和遥感模型等手段研究的区域生态系统碳汇，已经取得的了很多的成果。然而不同方法计算的结果，仍存在着较大的差异。本文利用CLM4.0模拟的GPP与MODIS的GPP产品之间也存在较大差别。下一步工作重点，就是将通量观测站点数据与卫星遥感数据和生态系统碳循环机理模型有机的结合，改善CLM在高原地区的模型性能。

Agricultural and Forest Meteorology 203 (2015) 169–179

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Carbon dioxide exchange between an alpine steppe ecosystem and the atmosphere on the Nam Co area of the Tibetan Plateau

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ARTICLE INFO

Article history:
Received 22 April 2013
Received in revised form
27 December 2014
Accepted 29 December 2014
Available online 24 January 2015

Keywords:
Alpine steppe
Net ecosystem CO_2 exchange
Nam Co area
Tibetan Plateau

ABSTRACT

The net ecosystem carbon dioxide (CO_2) exchange (NEE) between the atmosphere and an alpine steppe ecosystem was measured by the Eddy covariance (EC) method on the Nam Co area of the Tibetan Plateau during the growing season in 2008 and 2009. The diurnal amplitude of NEE varied substantially during the growing seasons. The maximum CO_2 uptake rates were 3.74 and 3.44 μmol CO_2 m^{-2} s^{-1} in August 2008 and 2009, respectively. The peak daily CO_2 uptake was observed on 16 July (DOY 198, 1.19 g C m^{-2} day^{-1}) 2008, which occurred one month earlier than that in 2009 (DOY 228, 1.12 g C m^{-2} day^{-1}). This indicated that the alpine steppe had lower carbon sequestration potential comparing with other grasslands. The daily NEE responded to AGB in a linear manner (NEE = (−0.0073 ± 0.0027) × AGB) + (0.0533 ± 0.2049), R^2 = 0.52). Fifty-two percent of the NEE variance could be explained by the variance of AGB. The amount and pattern of precipitation was significantly different between the two growing seasons. In 2008, the steppe received 493 mm from May to September. In contrast, the value was 327 mm in 2009 and more than 50% of this precipitation was received in August. The alpine steppe ecosystem became a weak