第9章

海洋、陆地生态系统碳循环和通量观测研究方法

第一节 背景与科学问题

第二节 全球碳的研究方法

第三节 观测方法和设备

第四节 结果

第一节、背景与科学问题

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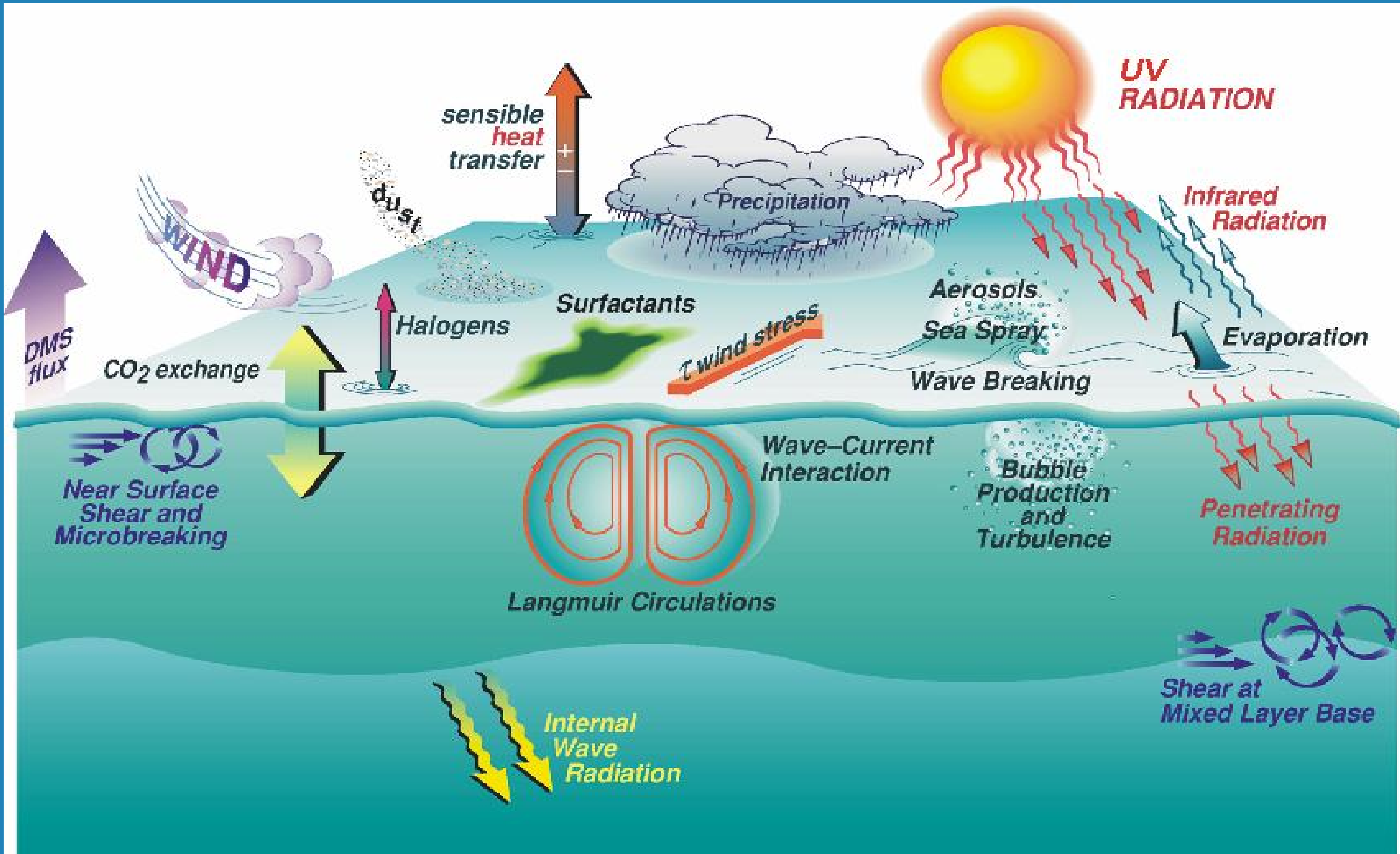
Characteristics of Surface Ocean-Low Atmosphere (SOLA)



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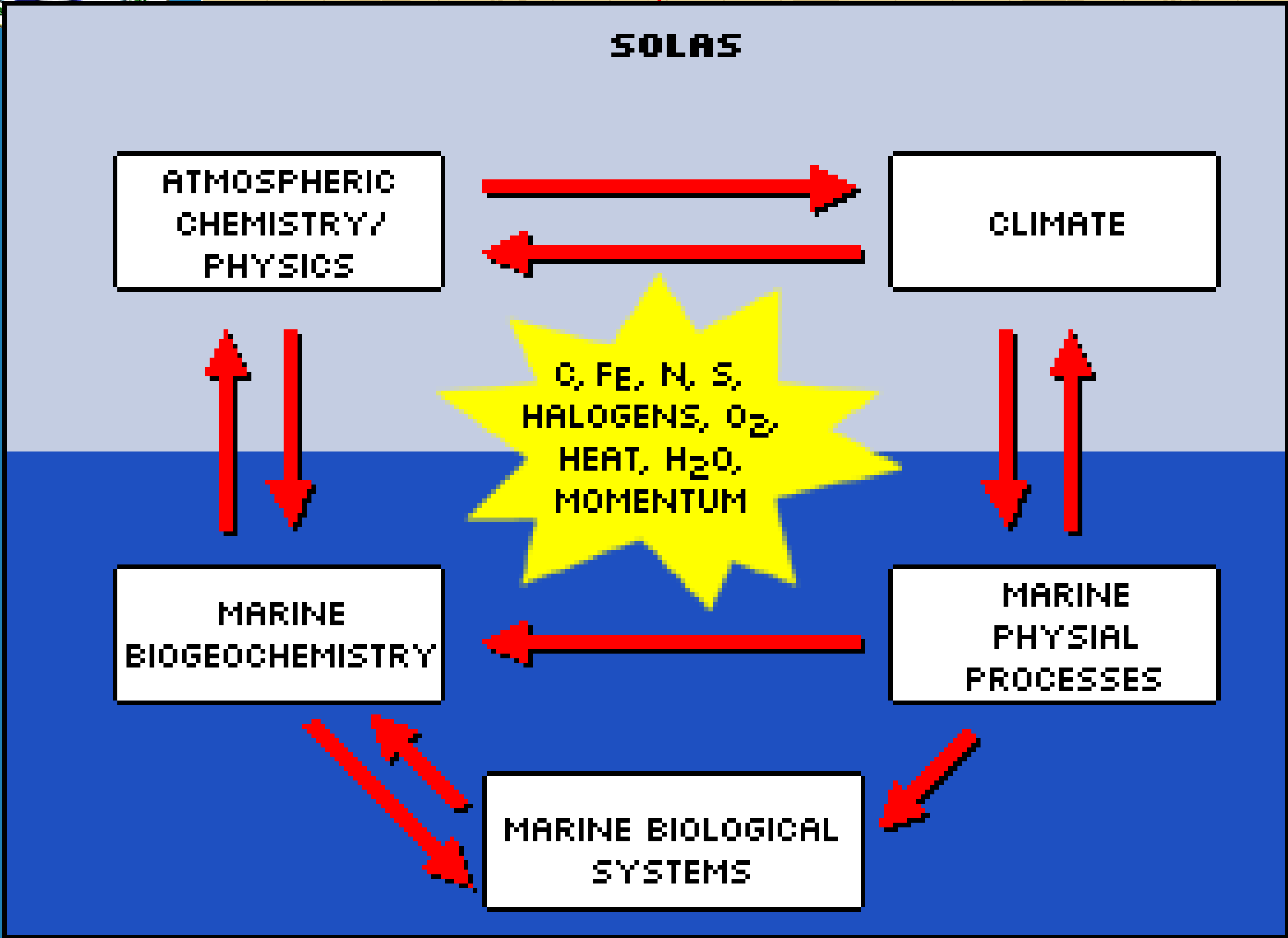
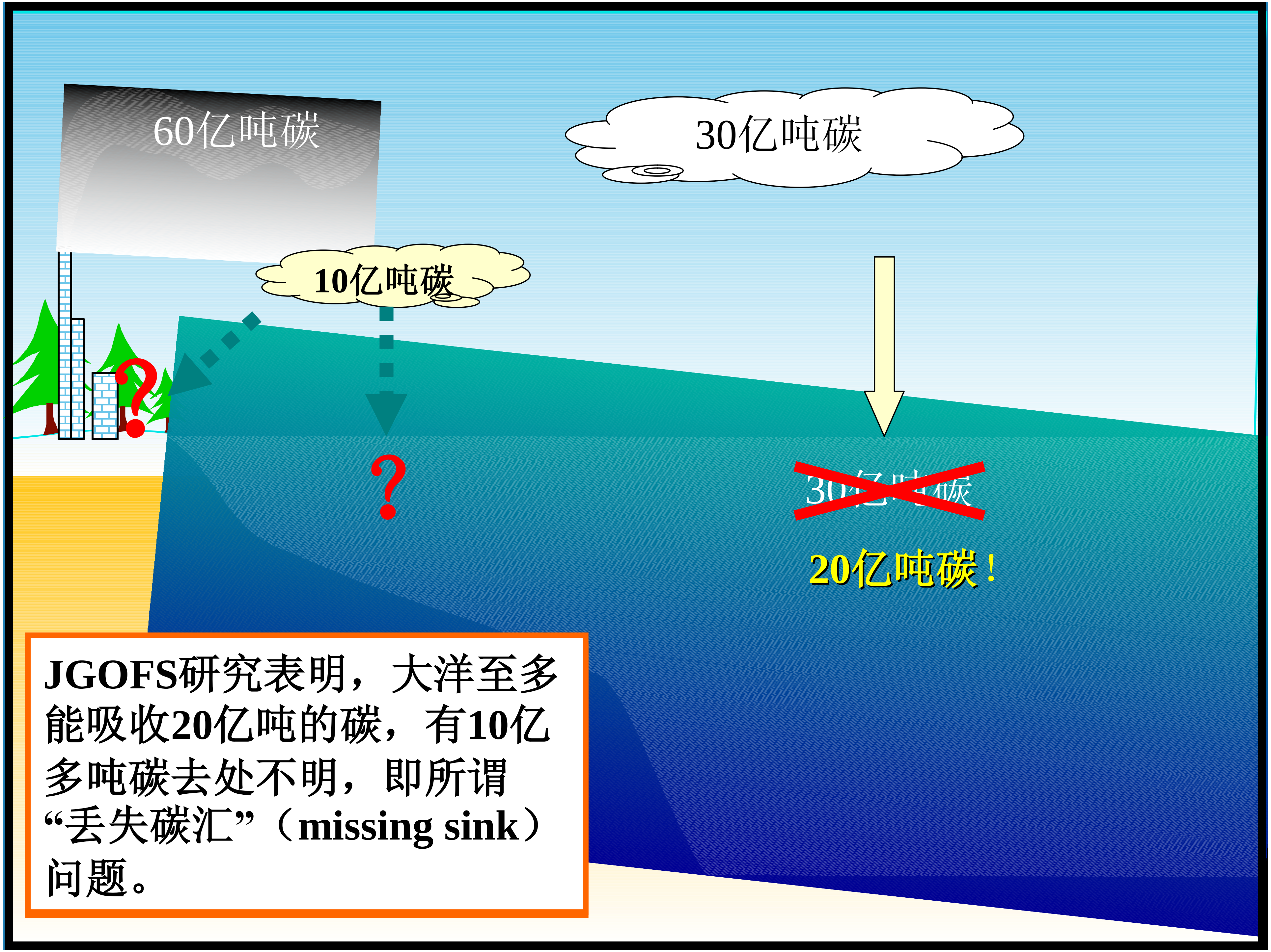
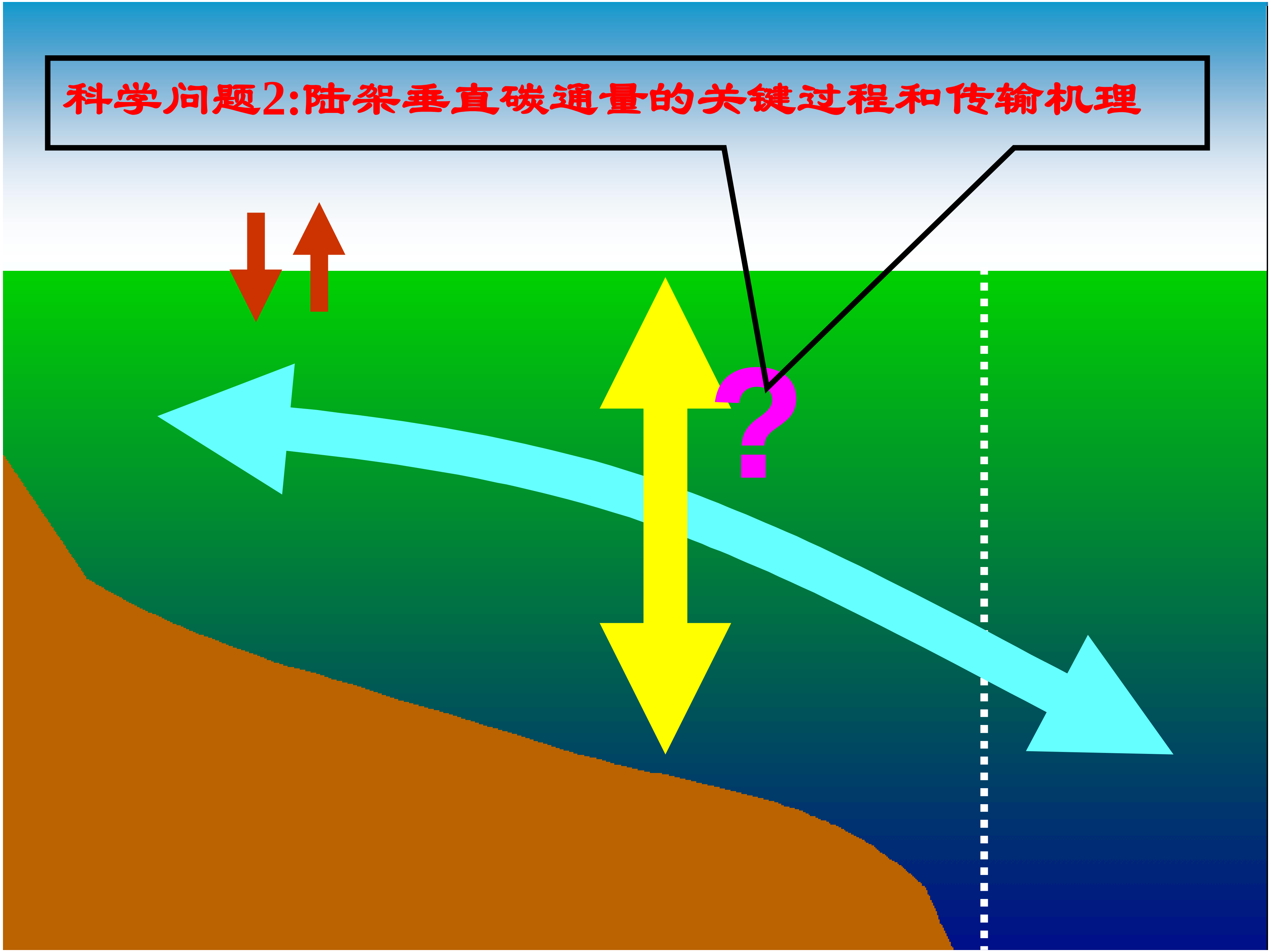
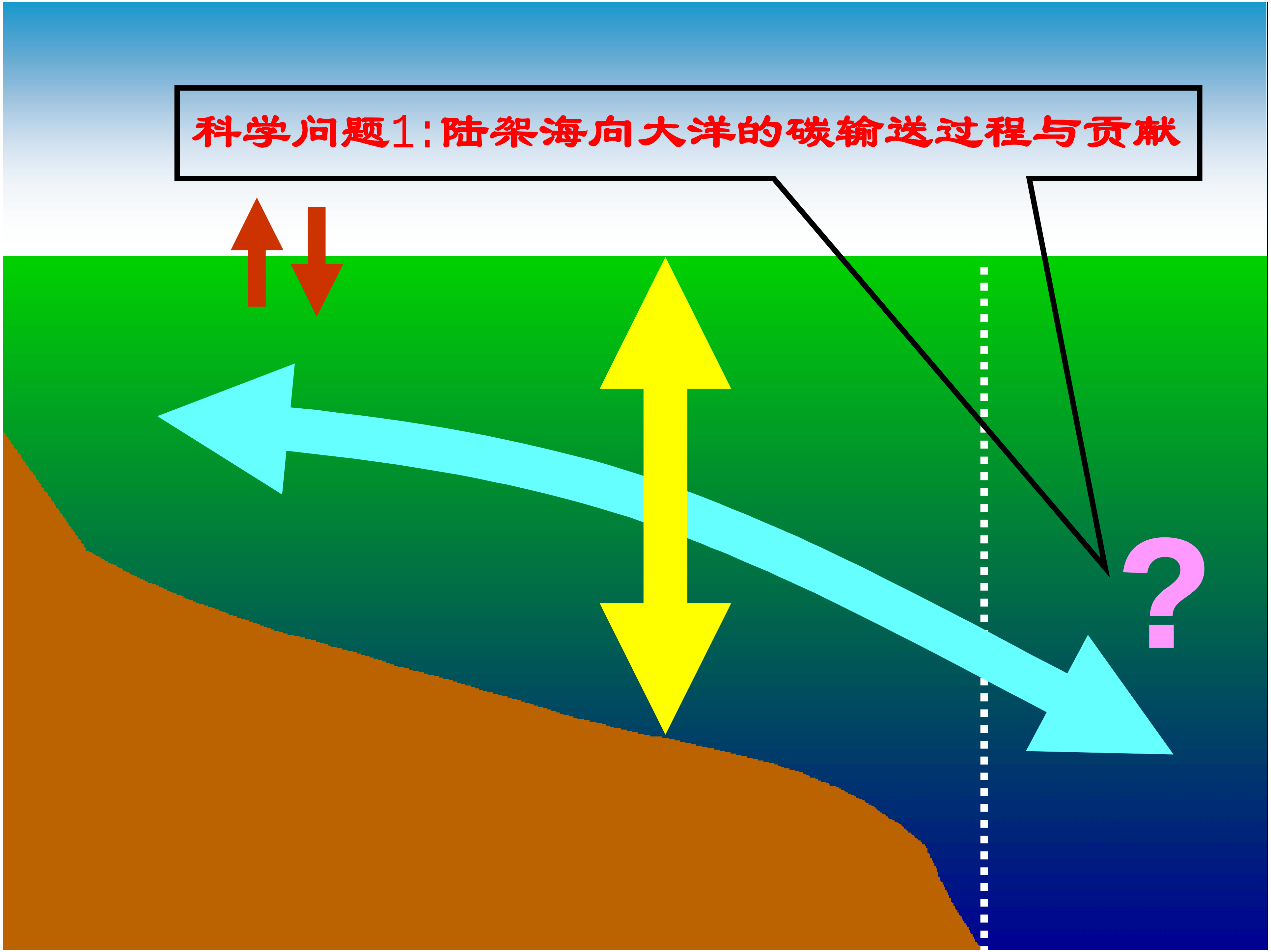




JGOFS研究表明，大洋至多能吸收20亿吨的碳，有10亿多吨碳去处不明，即所谓“丢失碳汇”（missing sink）问题。


科学问题2:陆架垂直碳通量的关键过程和传输机理
?



科学问题1:陆架海向大洋的碳输送过程与贡献
?

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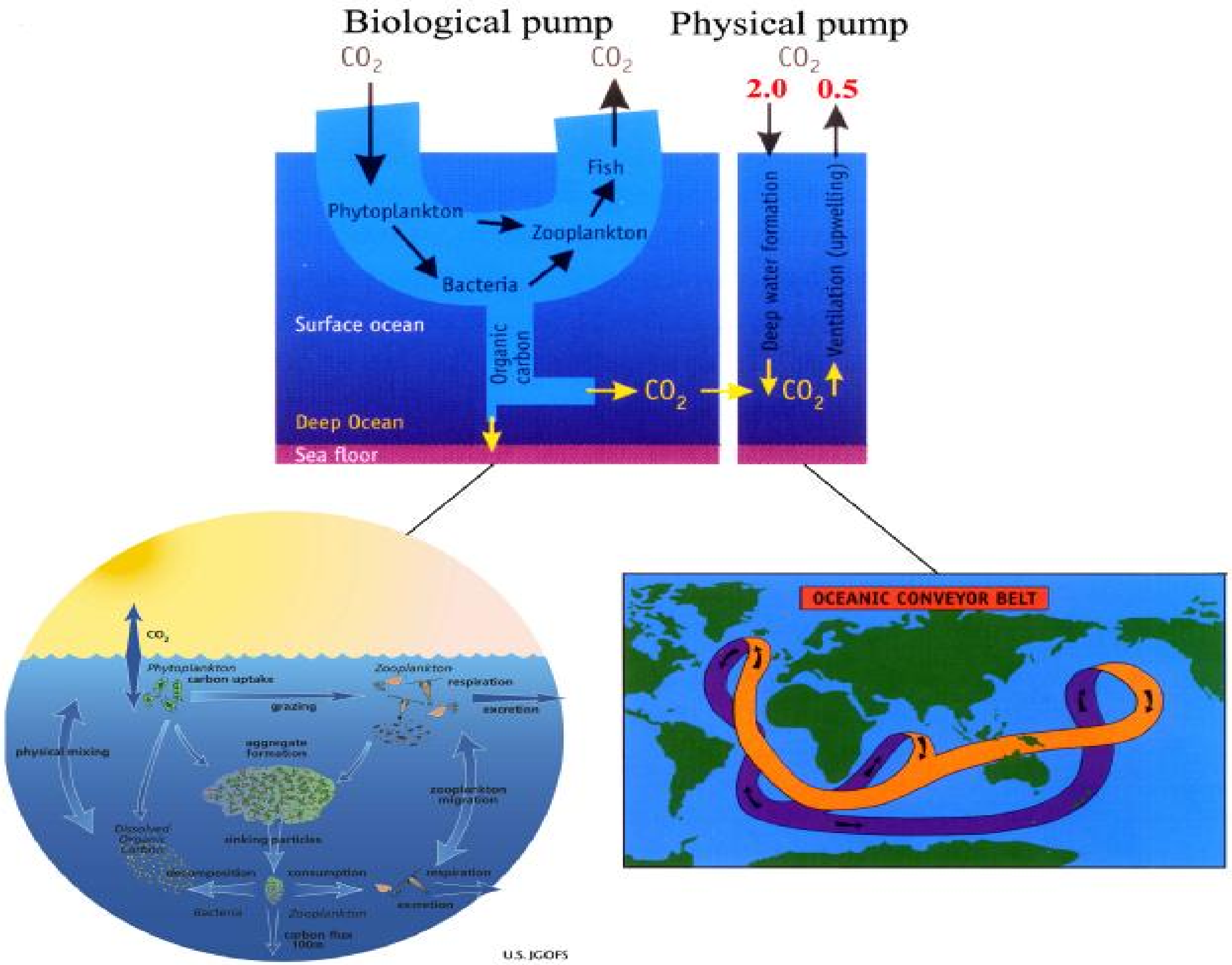
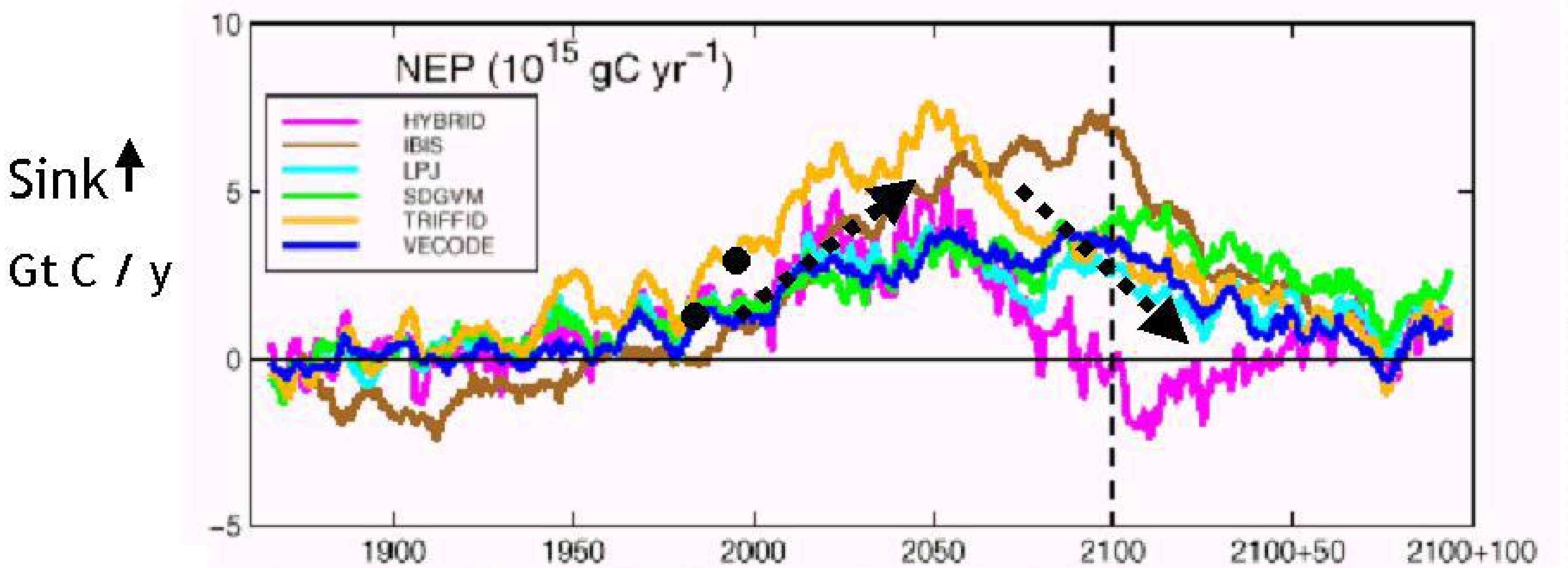
The Role of the Ocean in the Global Carbon Cycle



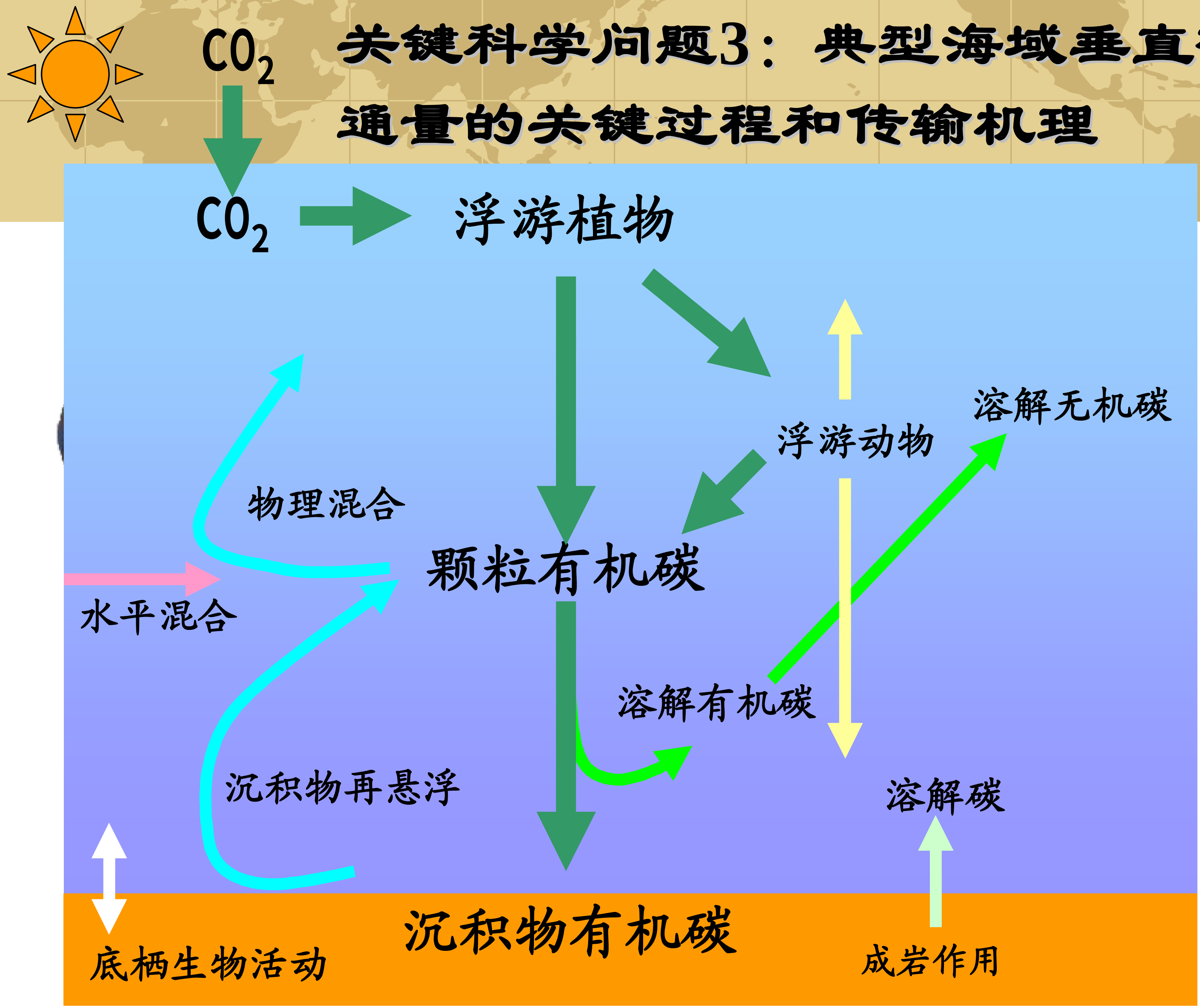
IGBP model comparison

(The role of terrestrial ecosystem in carbon cycle)

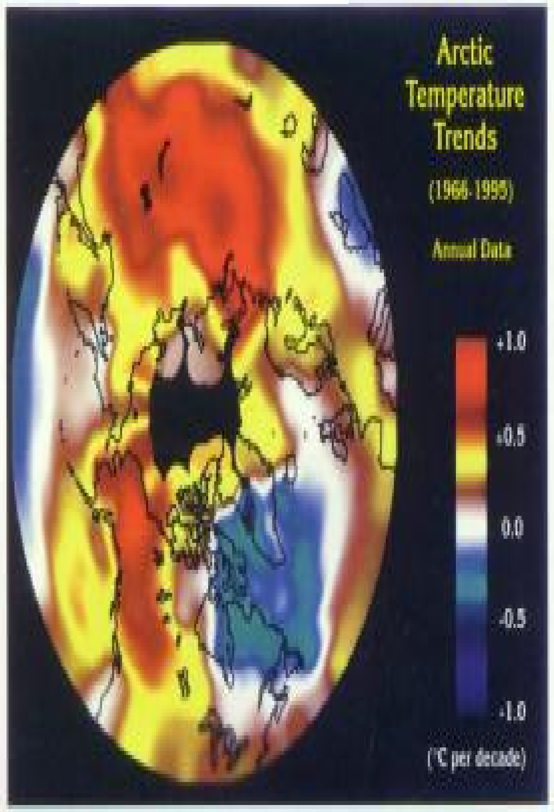


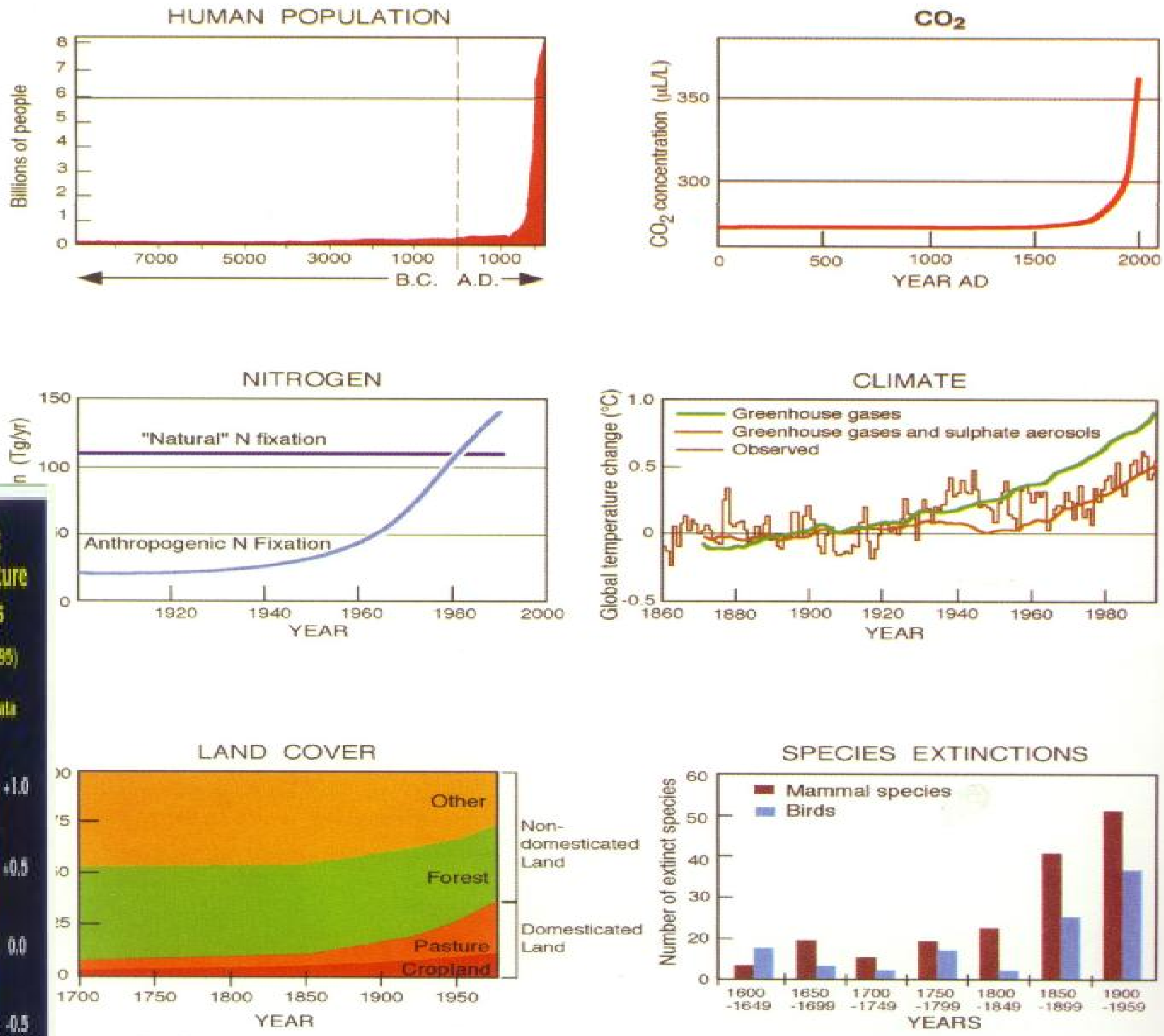
Times series of simulated Net Ecosystem Productivity (NEP, 10-year running average) for six (Table 1), with atmospheric CO_2 and climate change forcing [Copyright Global Change Biolog

关键科学问题3：典型海域垂直碳通量的关键过程和传输机理



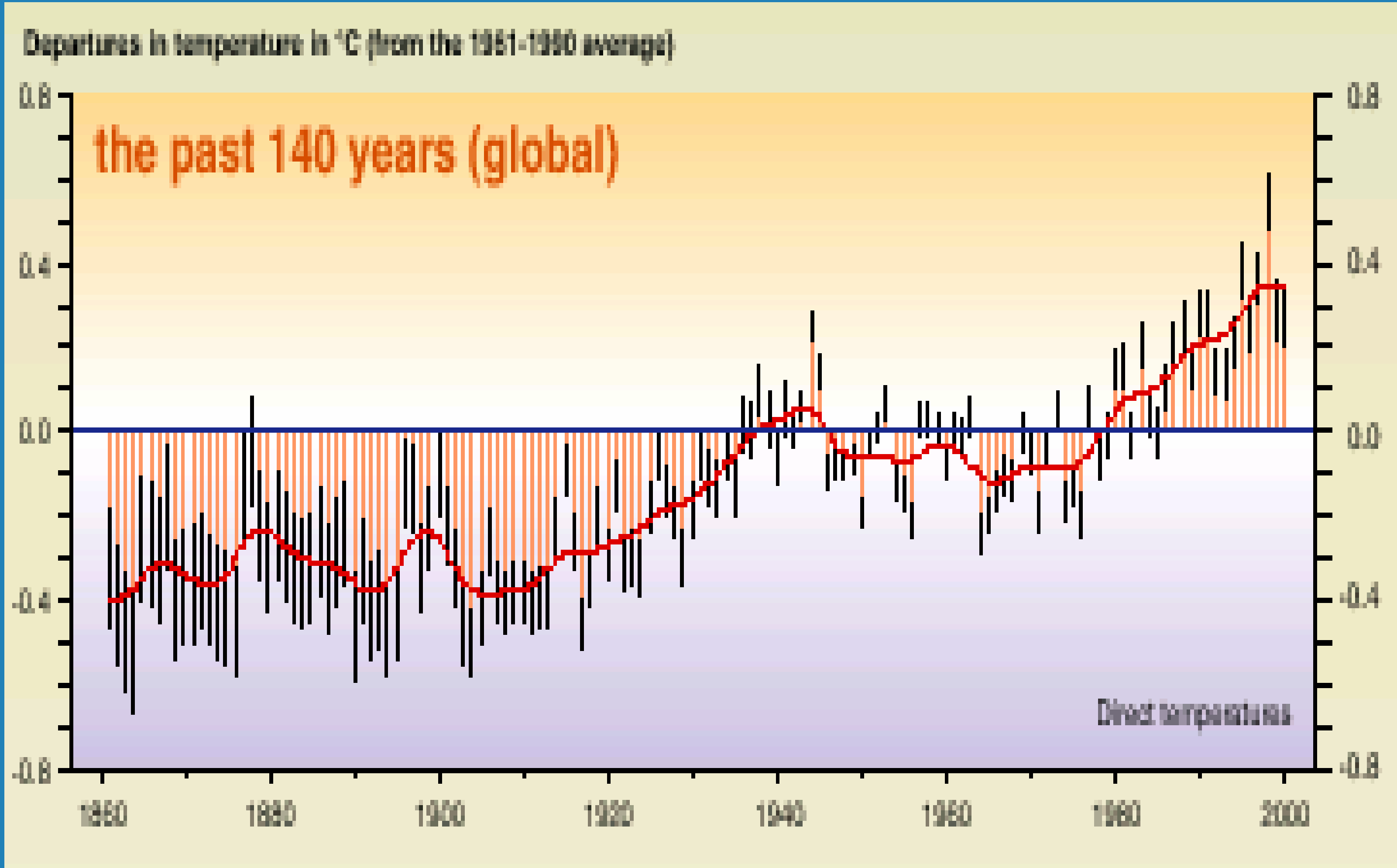
温度升高





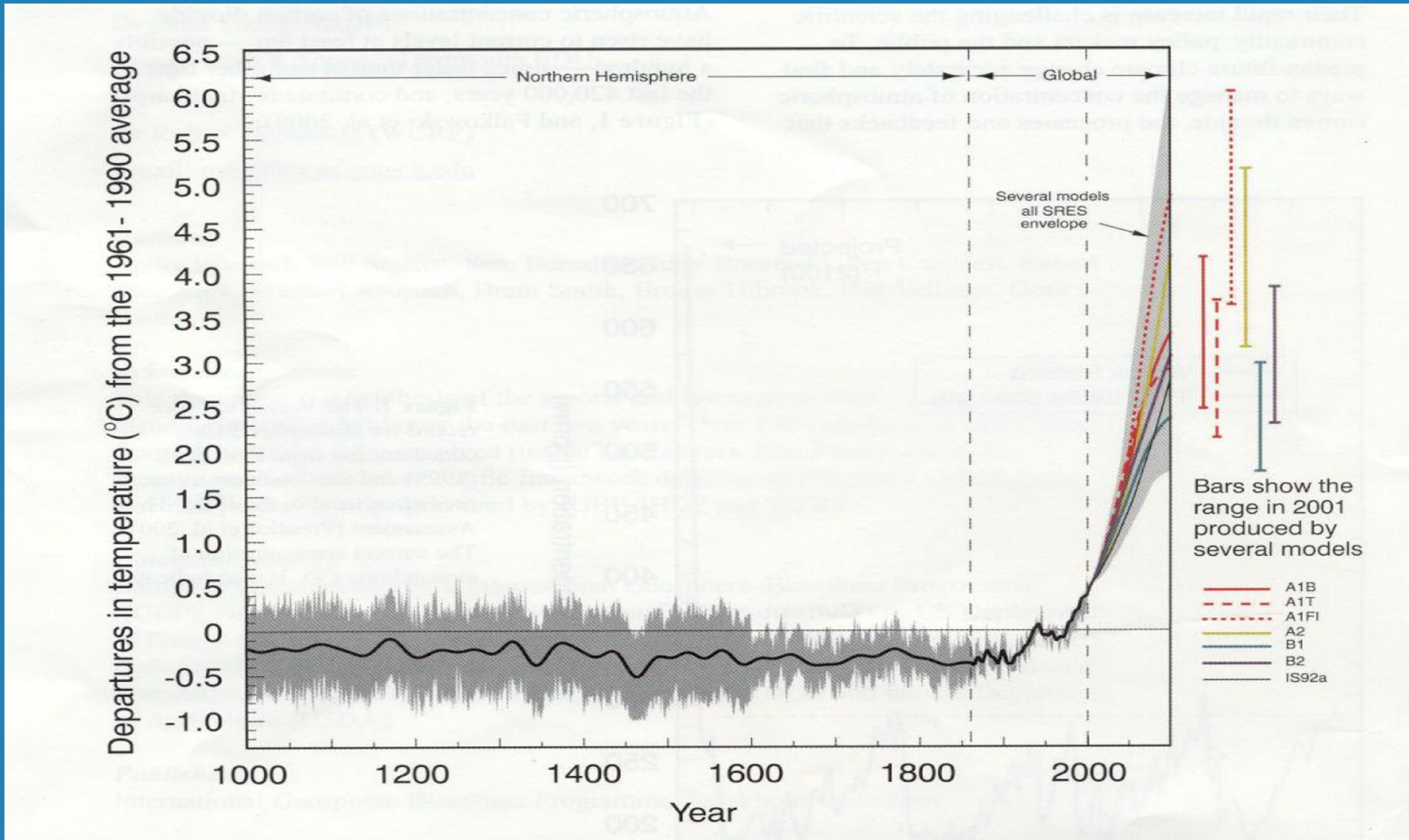
re 13. This figure shows some components of global change: (a) increase in human population; (b) increase in ›spheric CO_2 concentration; (c) anthropogenic alteration of the nitrogen cycle; (d) modeled and observed change in ıl mean temperature; (e) change in global land cover; and (f) increase in extinction of birds and mammals. From usek (1994); Houghten et al. (1995); Klein Goldewijk and Battjes (1995); and Reid and Miller (1989). Used permission from the International Geosphere-Biosphere Programme (IGBP); © IGBP.

过去140年间全球温度的距平变化
(按1961-1990年的平均)

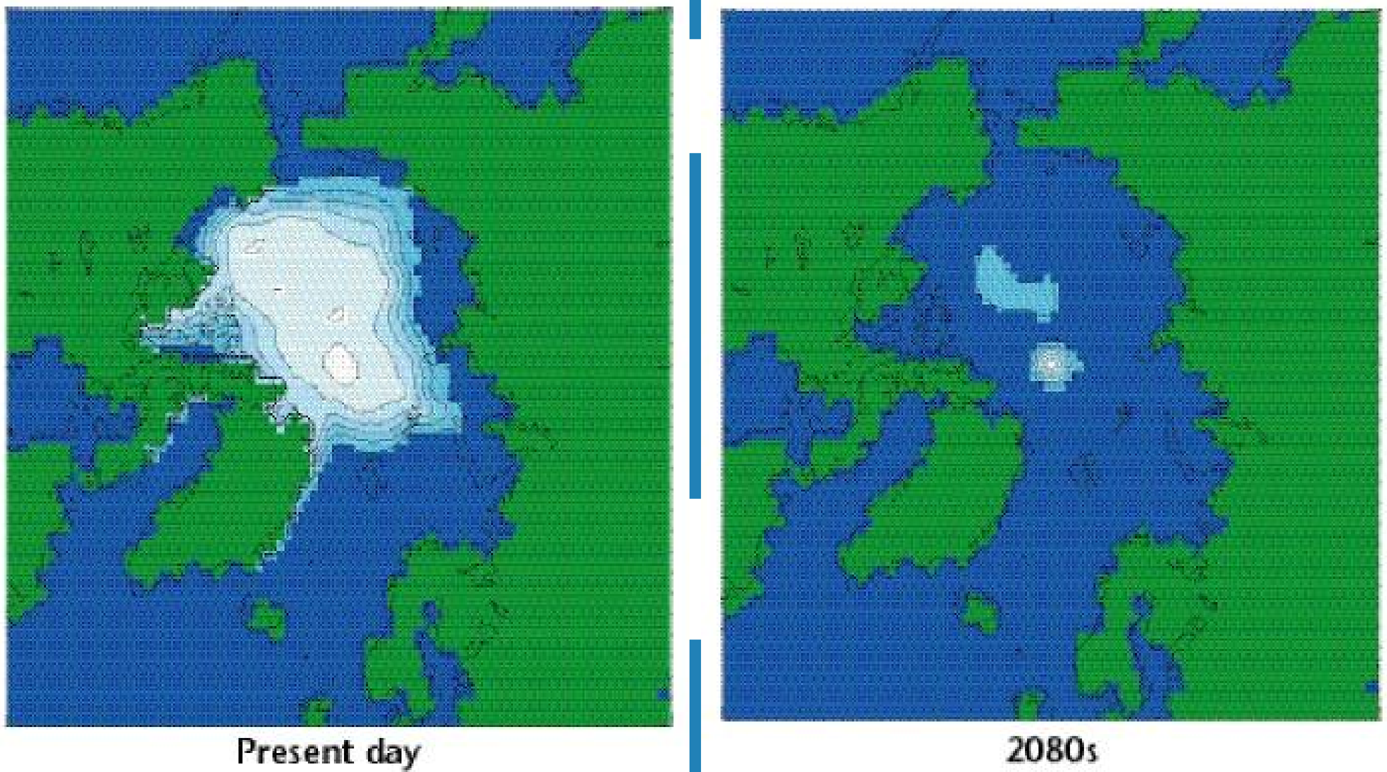


Departures in temperature in ºC from the 1961-1990 average

各种模型对未来气温变化的预测



Arctic Sea Ice will disappear by 2080



Hadley Centre for Climate Change November 2000

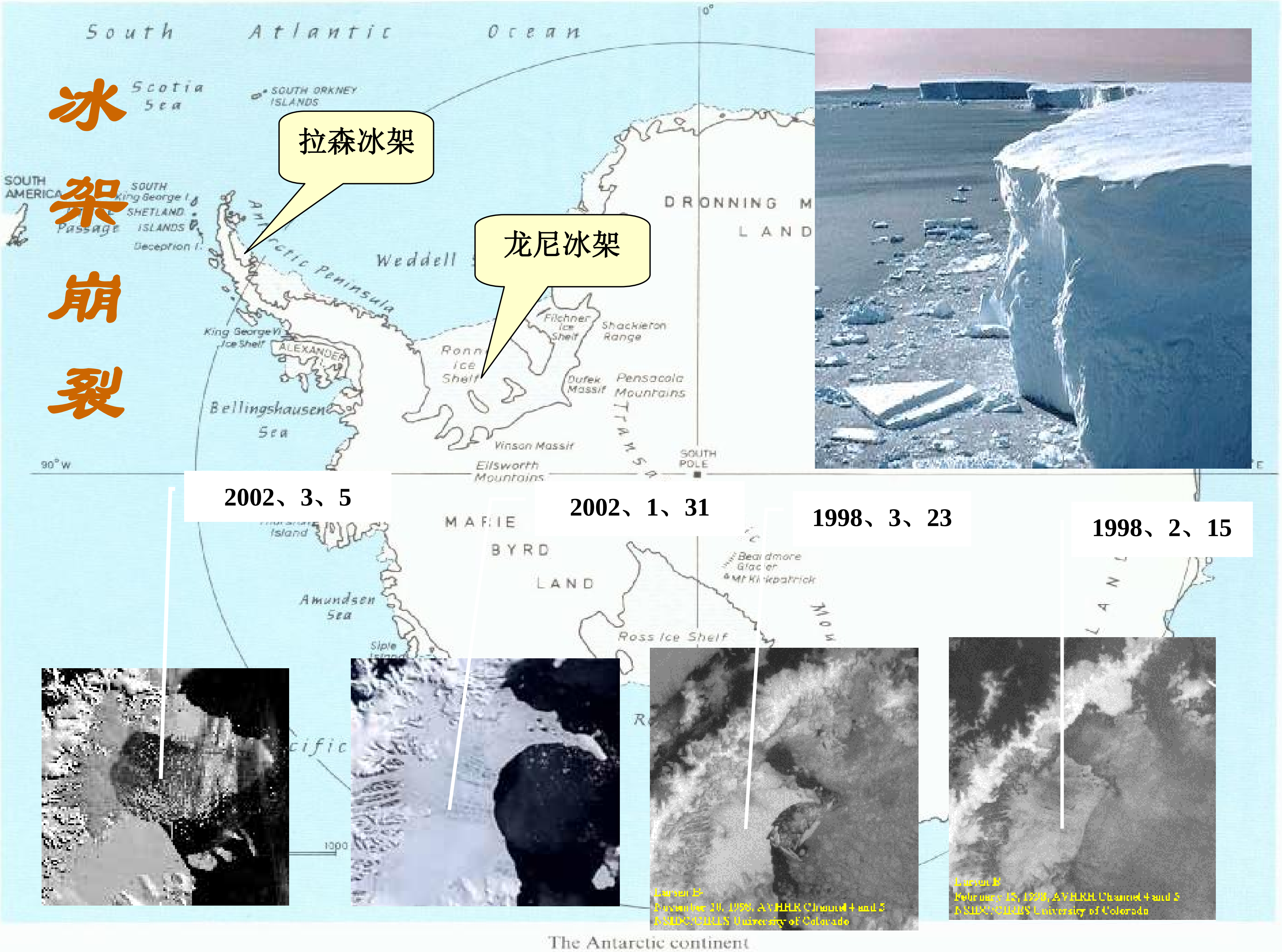
Climate model estimates of September Northern hemisphere sea-ice coverage (fractional) at present day and at the end of the 21st century for A1FI emissions scenario. The cluring of ice around the North Pole in the future prediction may be an artifact of the model.

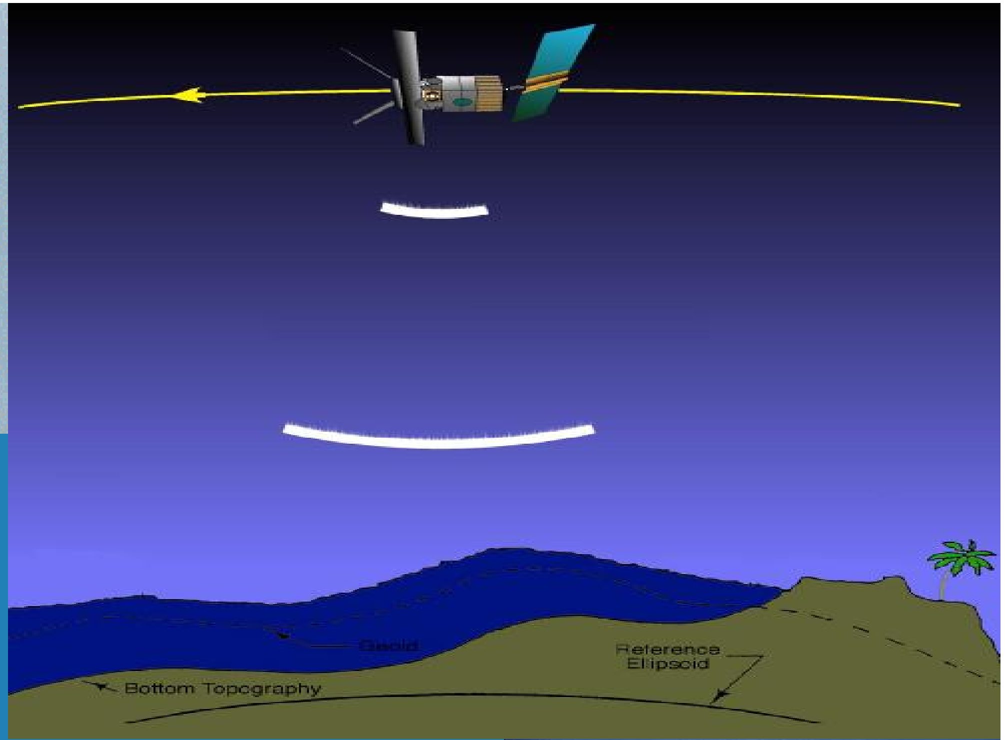
Snow cover and ice extent have decreased.

- Northern Hemisphere spring and summer sea-ice extent h decreased by about 10 to 15% since the 1950s. It is likely that there has been about a 40% decline in Arctic sea-ice thickness during late summer to early autumn in recent decades and a considerably slower decline in winter sea-i thickness.

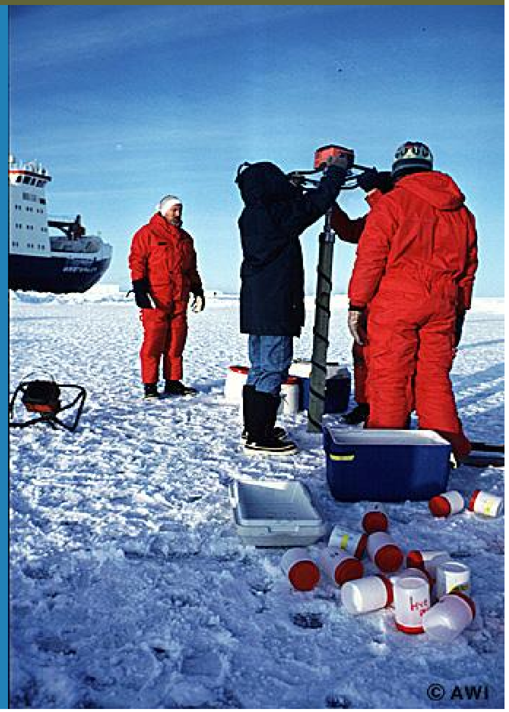
The Met.Office

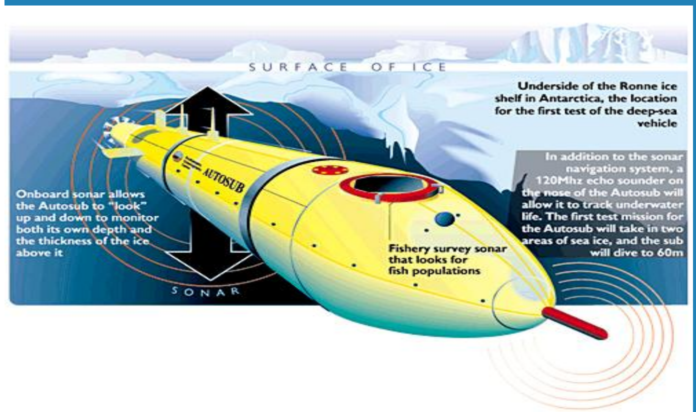
冰架崩裂

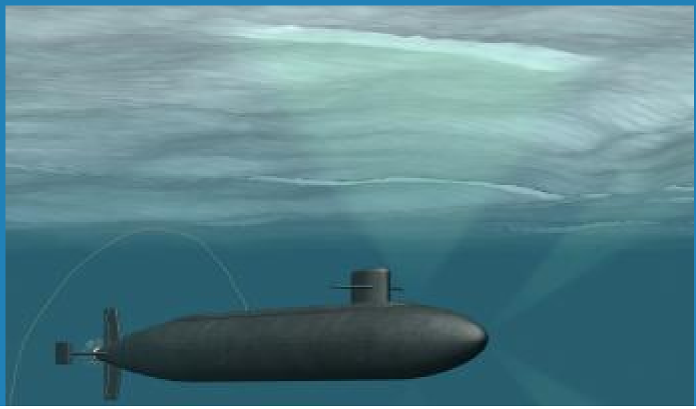

拉森冰架
龙尼冰架
2002、3、5
2002、1、31
1998、3、23
1998、2、15
South Atlantic Ocean
Scotia Sea
SOUTH ORKNEY ISLANDS
SOUTH AMERICA
SOUTH SHETLAND ISLANDS
King George I.
Deception I.
Antarctic Peninsula
Weddell Sea
DRONNING MAUD LAND
King George VI Ice Shelf
ALEXANDER
Ronne Ice Shelf
Filchner Ice Shelf
Shackleton Range
Dufek Massif
Pensacola Mountains
Bellingshausen Sea
Vinson Massif
Ellsworth Mountains
SOUTH POLE
90° W
0°
MARIE BYRD LAND
Beardmore Glacier
Mt Kirkpatrick
Amundsen Sea
Siple Island
Ross Ice Shelf
The Antarctic continent



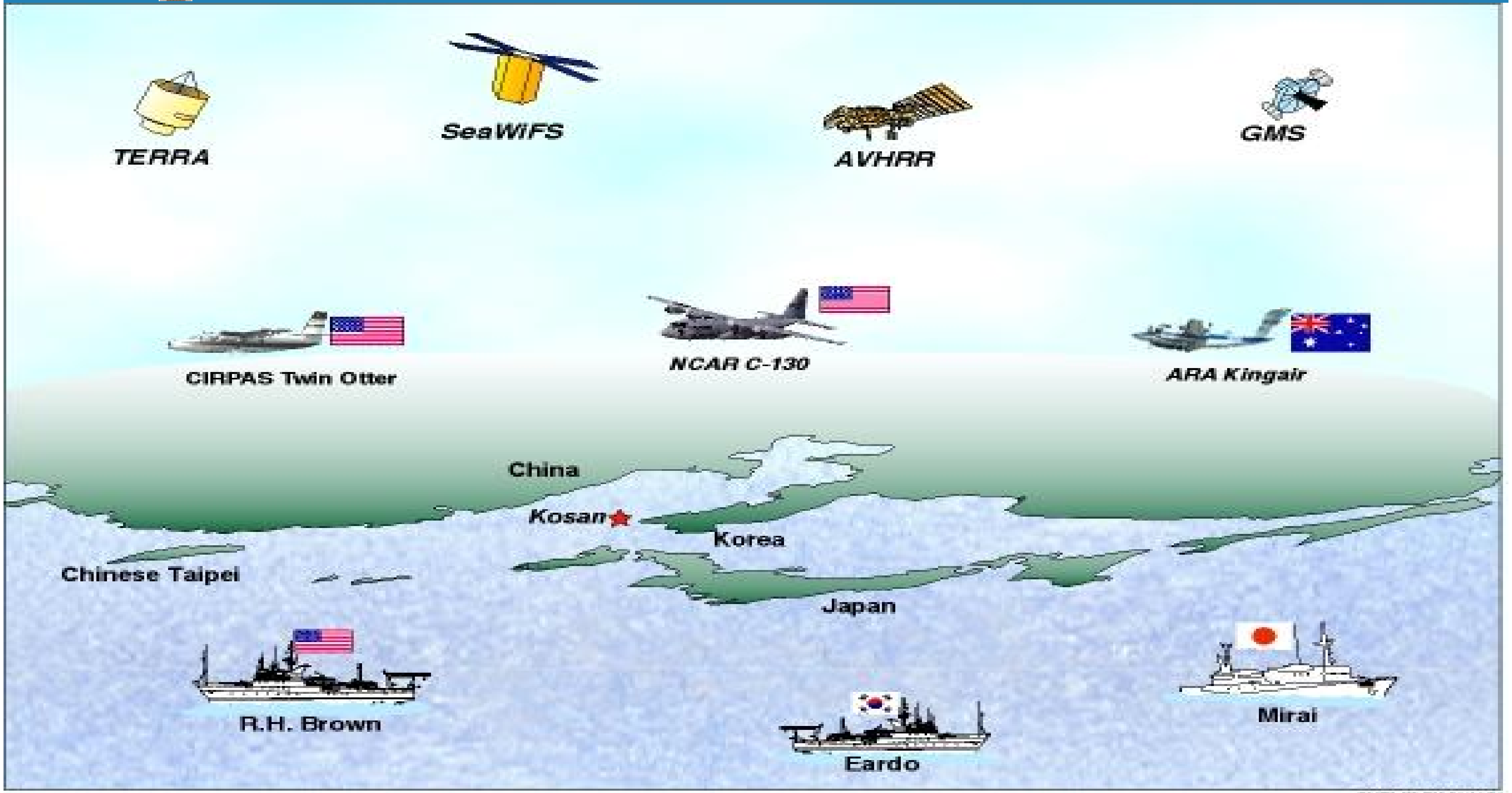
各种设备探测
冰层厚度变化



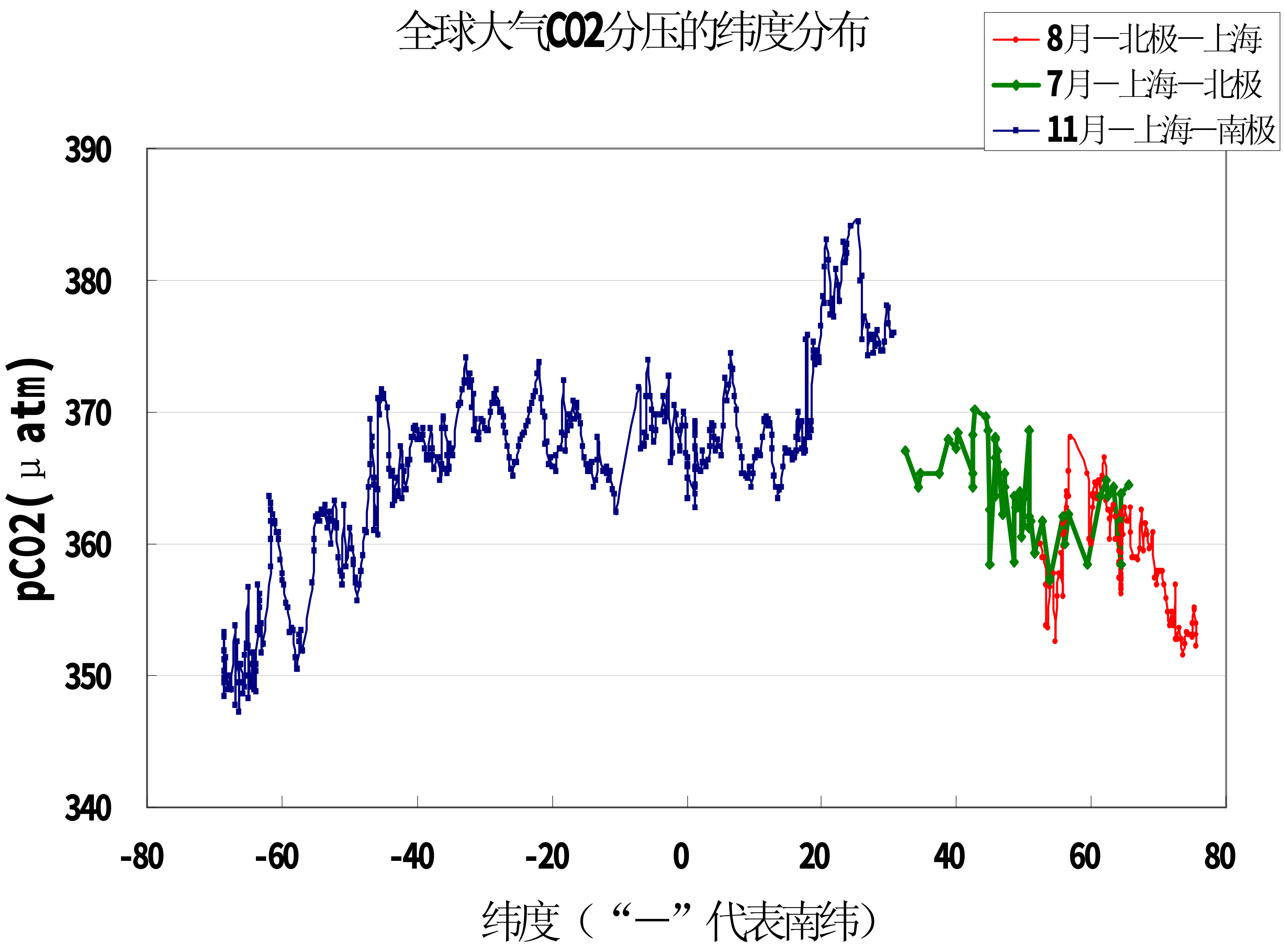




Chinese Ecosystem Research Network



采用各种设备探测冰层厚度和CO_2浓度变化，扑捉气侯变化证据


全球大气CO2分压的纬度分布
8月—北极—上海
7月—上海—北极
11月—上海—南极
390
380
370
360
350
340
pCO2(μatm)
-80
-60
-40
-20
0
20
40
60
80
纬度（“—”代表南纬）

减少温室效应的科学设想

1、在平流层中释放反射粒子；

2、向太空释放太阳光反射装置；

3、采取措施增加海洋对大气层中碳的吸收。

- 《联合国气候变化框架公约，UNFCCC 》于1992年签署生效。
- 《京都议定书（1997）》拟订了各国的碳排放指标，可以通过“造林、再造林、森林和农田管理”等措施增加的碳吸收量，来抵消本国的碳排放指标。
- 发达国家都在加大陆地碳有效储存时间和增汇技术的研究力度，评价各种植被和土壤的固碳能力以及土地管理措施的成本效益。

国家	京都议定书 COP3	波恩协议 COP6
日本	-6	-2.1
EU各国	-8	-7.6
罗马尼亚	-8	-6.5
美国	-7	-5.3
加拿大	-6	+1.2
新西兰	0	+1
俄罗斯	0	+2.1
挪威	+1	+3.8
澳大利亚	+8	+8

朱镕基宣布中国核准《京都议定书》

本报约翰内斯堡 9 月 3 日电（人民日报9月4日第三版）

中国国务院总理朱镕基9月 3 日在约翰内斯堡可持续发展世界首脑会议上讲话时宣布，中国已核准《〈联合国气候变化框架公约〉京都议定书》。朱镕基指出，这显示了中国参与国际环境合作，促进世界可持续发展的积极姿态。

全球碳循环研究中的三大科学问题（IGBP、IHDP和WCRP）

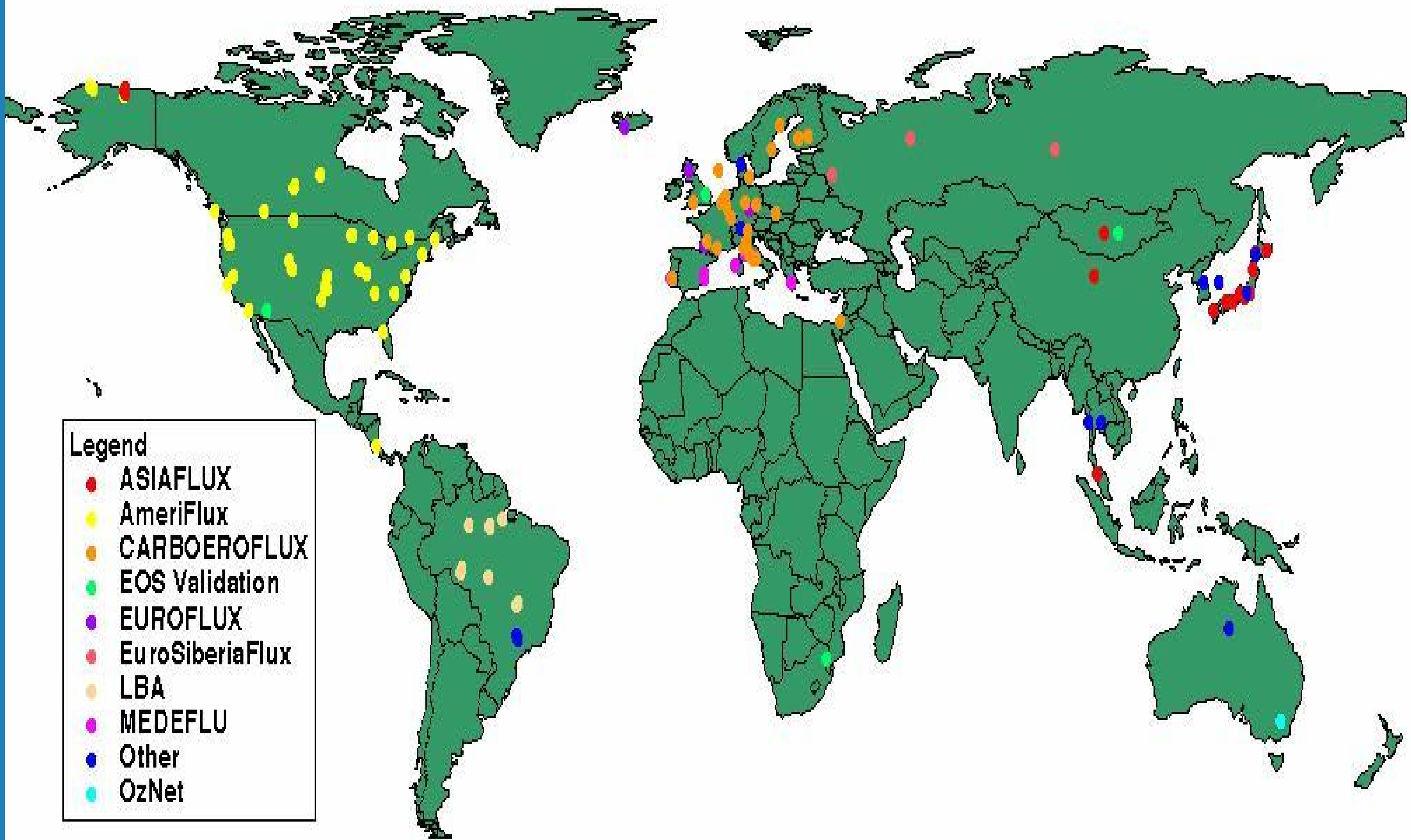
（1）目前碳源/碳汇的时空格局；

（2）碳循环过程的控制因素（人类和自然）与相互作用机理；

（3）未来碳循环的动力学过程及趋势。

第二节、全球碳的研究方法

FLUXNET的观测系统

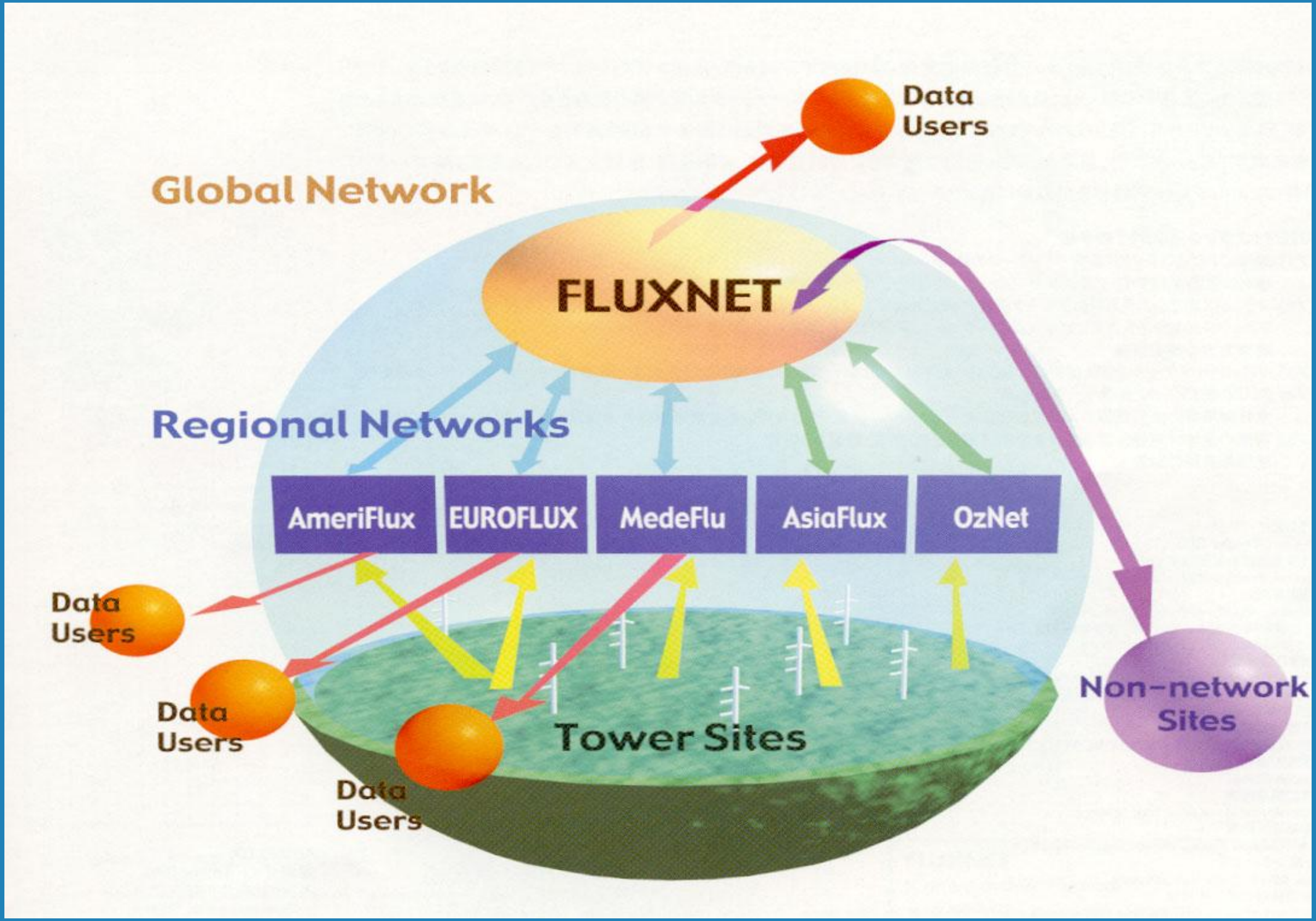


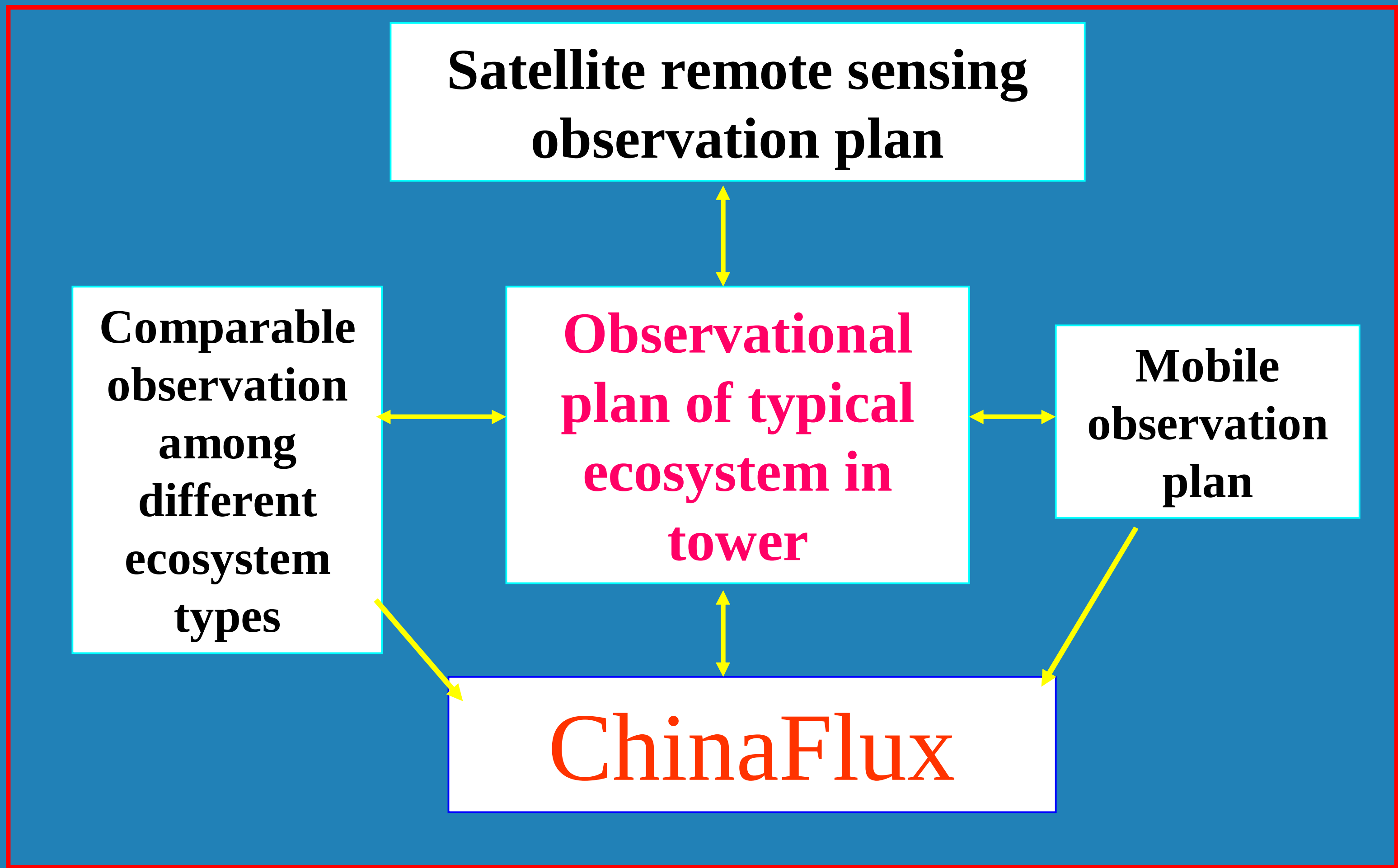
日本的FLUXNET观测系统

ASIAFLUX
観測サイト　Tower Site

1 釧路湿原温根内低層湿原
Onnenai, Kushiro Mire, Hokkaido, Japan
2 釧路湿原赤沼
Akanuma, Kushiro Mire, Hokkaido, Japan
3 羊ケ丘実験林(5林班へとち小班) 常緑針葉樹人工林
The Hitsujigaoka Experimental Forest
4 札幌羊ケ丘実験林
Sapporo Forest Meteorology Research Site
5 IGBPタワーサイト（北海道大学苫小牧演習林）
IGBP Tower Site, Hokkaido
6 安比森林気象試験地
APPI FOREST METEOROLOGY RESEARCH SITE
7 岩手大学御明神演習林
Omyojin Forest
8 果樹試験場圃場
National Institute of Fruit Tree Science
9 気象研究所鉄塔
Meteorological Tower, Meteorological Research Institute
10 霞ヶ浦沿岸ハス田
Lotus field on Lake Kasumigaura
11 農業環境技術研究所草地
Glassland at National Instituteof Agro-Environmental Sciences, Tsukuba Japan
12 筑波大学水理実験センター熱収支・水収支観測圃場
Heat balance and water balanceExperiment field, Environmental Research Center, University of Tsukuba
13 谷和原水田
Rice paddy at Yawara,Ibaraki Prefecture, Japan
14 川越
Kawagoe Forest
15 富士吉田
Fujiyoshida forest meteorology research site
16 高山（岐阜県高山市）
Takayama
17 京都大学桐生水文試験地
Kiryu
18 桐生水文試験地ヒノキ林
Kiryu
19 山城
Yamashiro
20 潮岬風力実験所
Shionomisaki Laboratory
21 岡山大学資源生物科学研究所圃場
Research Institute for Bioresources, Okayama University
22 八浜観測所(大滝プロジェクト)
Hachihama Observatory (Ohtaki project)
23 八浜観測所(米谷プロジェクト)
Hachihama Observatory (Maitani project)
24 鹿北流域試験地
Kahoku experimaental watershed
25 九州農業試験場
Kyushu National Agricultural Experiment Station

FLUXNET的组织系统





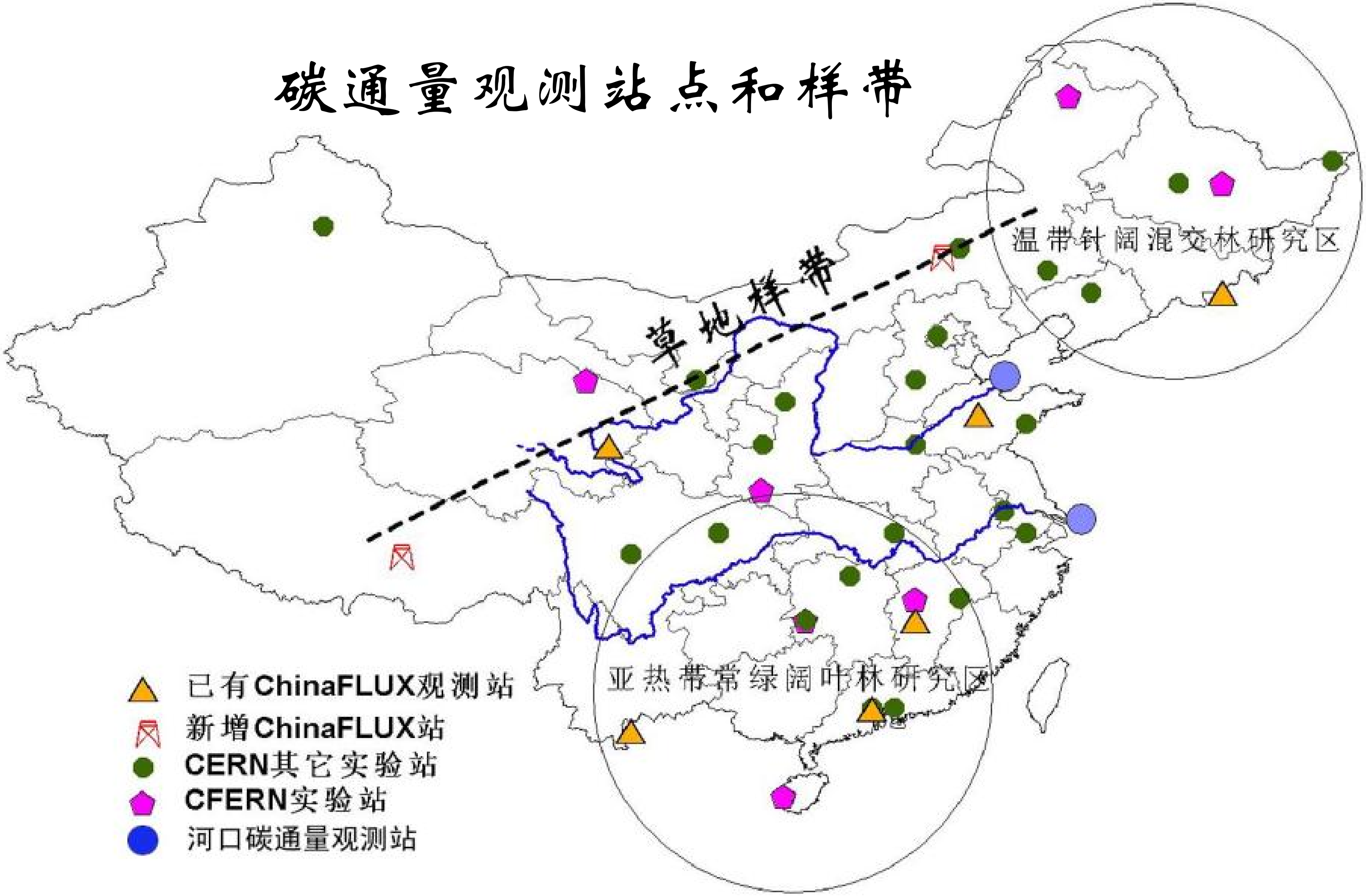
Observational Plans of The ChinaFLUX

Chinese Ecosystem Research Network

Position of the ChinaFlux Sites

Chinese Ecosystem Research Network

碳通量观测站点和样带



微气象学的直接测定法

- 空气动力学法
- 热平衡法
- 涡度相关法

在群落上部，测定风速和CO_2浓度，直接计算群落－大气间的CO_2通量。

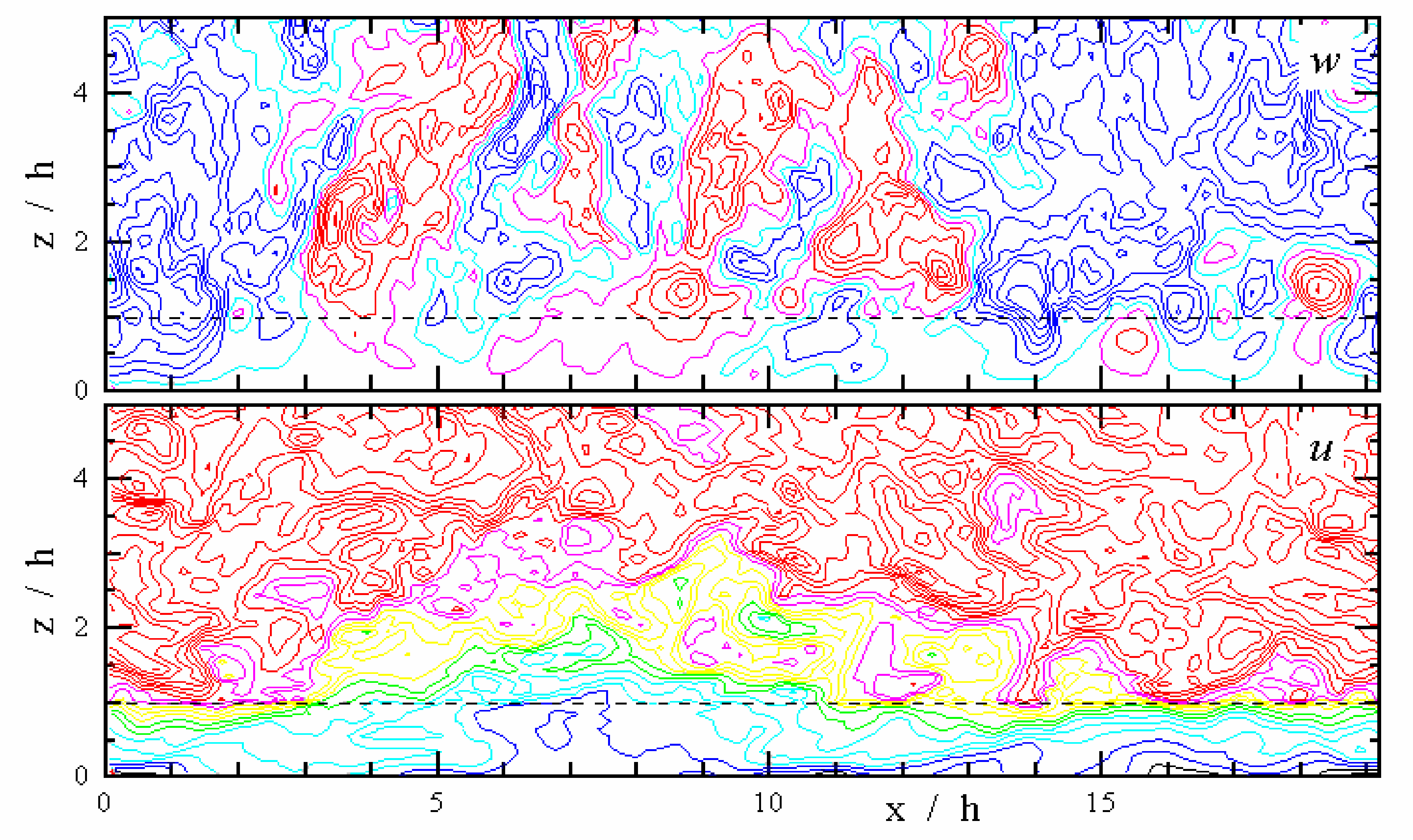
这种方法是能够直接测定大气与群落CO_2交换量的唯一方法，已经成为检验各种模型估算精度的最为权威的方法，也是验证以上各方法精度的标准方法。

涡度相关法原理

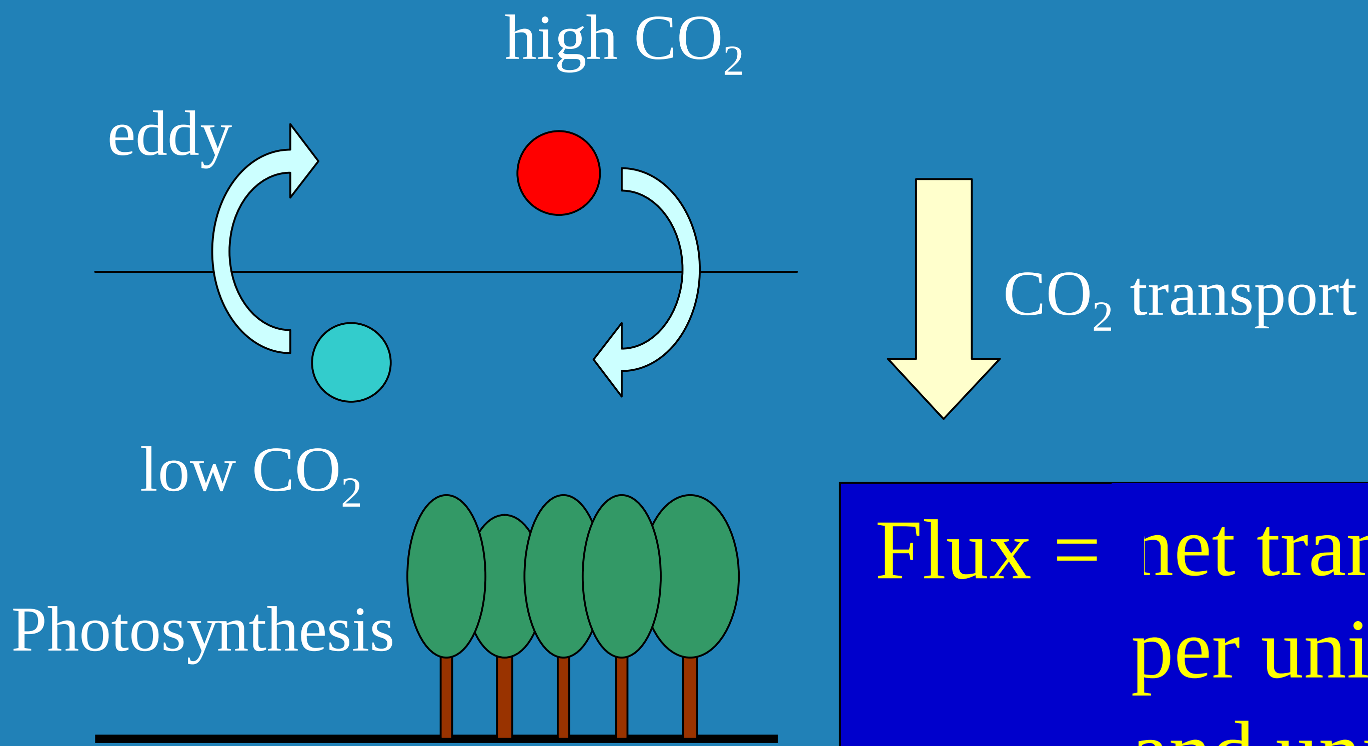
鉛直(x − z)断面乱流运动

鉛直風速　赤：正　　水平風速　赤：強
（上図）青：負　　（下図）青：弱

LAI=2



Flux and wind eddy



Flux = net transport rate
per unit area
and unit time

Equations of Eddy Correlation Method

Sensible Heat Flux:

$$H = r \quad Cp \quad \overline{w' \quad q \quad '}$$

Latent Heat Flux:

$$E = r \quad Lv \quad \overline{w'q'}$$

CO_2 Heat Flux:

$$F = r \overline{w'c'}$$

式中:

$$w' = w - \overline{w} \qquad \overline{w} = \frac{1}{T}\int_{o}^{T} w\,dt \approx \frac{1}{N}\sum_{i=1}^{N} w_i$$

$$q' = q - \overline{q} \qquad \overline{q} = \frac{1}{T}\int_{0}^{T} q\,dt \approx \frac{1}{N}\sum_{i=1}^{N} q_i$$

$$q' = q - \overline{q} \qquad \overline{q} = \frac{1}{T}\int_{0}^{T} q\,dt \approx \frac{1}{N}\sum_{i=1}^{N} q_i$$

$$c' = c - \overline{c} \qquad \overline{c} = \frac{1}{T}\int_{0}^{T} c\,dt \approx \frac{1}{N}\sum_{i=1}^{N} c_i$$

Bowen Ratio/Energy Balance Method

The definition of the Bowen ratio was made with respect to fluxes as follows (Bowen 1926):

$$b = H / E \tag{1}$$

The theoretical base of Bowen ratio method is surface energy balance. If A presents the sum of H and E, then

$$A = H + E = R_n - G - S \tag{2}$$

From (1) and (2), we can get

$$\begin{cases} H = \dfrac{b}{b+1} A \\ E = \dfrac{1}{b+1} A \end{cases} \tag{3}$$

Bowen Ratio/Energy Balance Method

The Bowen ratio can be expressed after approximating the fluxes by gradients in the following manner

$$b = \frac{H}{E} = \frac{Cp\Delta q}{l\Delta q} \qquad (4)$$

With equation (4), the Bowen ratio can be calculated using profile data. Then introduces β into equation (3), and so H and E are calculated.

空气动力学方法

空气动力学方法是根据近地面层空气动力学特征，计算能量和物质通量的输送过程。风速、温度、湿度、二氧化碳或氧化亚氮输送的梯度表达式为:

$$\frac{\partial \bar{u}}{\partial z} = \frac{u_*}{k(z-d)}\varphi_m \qquad (5)$$

$$\frac{\partial \bar{\theta}}{\partial z} = \frac{-H}{\rho C_p k u_*(z-d)}\varphi_h \qquad (6)$$

$$\frac{\partial \bar{q}}{\partial z} = \frac{-LE}{\rho L_V k u_*(z-d)}\varphi_w \qquad (7)$$

$$\frac{\partial \overline{C_{N_2O,CO_2}}}{\partial z} = \frac{-F_{N_2O,CO_2}}{k u_*(z-d)} \qquad (8)$$

由（5）—（8）可得

$$\tau = \rho k^2 (z-d)^2 \left(\frac{\partial \bar{u}}{\partial z} \right)^2 \varphi_m^{2} \qquad (9)$$

$$H = -\rho C_P k^2 (z-d)^2 \frac{\partial \bar{u}}{\partial z} \frac{\partial \bar{q}}{\partial z} (\varphi_m \varphi_h)^{-1} \qquad (10)$$

$$LE = -\rho L_V k^2 (z-d)^2 \frac{\partial \bar{u}}{\partial z} \frac{\partial \bar{q}}{\partial z} (\varphi_m \varphi_w)^{-1} \qquad (11)$$

$$F_{N_2O,CO_2} = -\rho k^2 (z-d)^2 \frac{\partial \bar{u}}{\partial z} \frac{\partial \bar{C}_{N_2O,CO_2}}{\partial z} (\varphi_m \varphi_{N_2O,CO_2})^{-1} \qquad (12)$$

式中k为Karman常数；g为湿度表常数，$\gamma = \frac{C_P P}{\varepsilon L_v} = 0.67 hPa\,^0C^{-1}$;d为位移长度(d=0.63h,h为植被高度）；φ_m，φ_h，φ_w，φ_{N_2O,CO_2} 分别为风速、温度、湿度和二氧化碳及氧化亚氮的稳定度通用函数，它们的表达式为

$$\varphi_m\left(\frac{z}{L}\right) = 1 + \beta_m \frac{z}{L}, \text{当} \frac{z}{L} \geq 0 \qquad (13)$$

$$\varphi_m\left(\frac{z}{L}\right) = \left(1 - \gamma_m \frac{z}{L}\right)^{-\frac{1}{4}}, \text{当} \frac{z}{L} \leq 0 \qquad (14)$$

$$\varphi_h\left(\frac{z}{L}\right) = \varphi_w\left(\frac{z}{L}\right) = \varphi_{N_2O,CO_2}\left(\frac{z}{L}\right) = 1 + \beta_h \frac{z}{L}, \text{当} \frac{z}{L} \geq 0 \qquad (15)$$

$$\varphi_h\left(\frac{z}{L}\right) = \varphi_w\left(\frac{z}{L}\right) = \varphi_{N_2O,CO_2}\left(\frac{z}{L}\right) = \left(1 - \gamma_h \frac{z}{L}\right)^{-\frac{1}{2}}, \text{当} \frac{z}{L} \leq 0 \qquad (16)$$

系数 β_m, γ_m 和 β_h, γ_h 见下表.

表6.5 风、温、湿稳定度函数表达式系数

来源	b_m	g_m	b_h	ɑ γ	k
Businger(1971)	4.7	15.0	6.4	9.0	0.35
Panison(1970)	7.0	16.0	7.0	16.0	---
Weeb(1970)	5.2	18.0	5.2	9.0	0.41
Dyer and Hicks(1970)	---	16.0	---	16.0	0.40

$\frac{z}{L}$ 的计算：

$$\frac{z}{L}=\begin{cases} R_i, R_i \le 0 \\ \frac{R_i}{1-5R_i}, R_i \ge 0 \end{cases}$$

R_i为Richardson数；L为Moni-Obukhov 长度

$$R_i=\frac{g}{\bar{q}}\frac{\frac{\partial \bar{q}}{\partial z}}{\left(\frac{\partial \bar{u}}{\partial z}\right)^2}; L=-\frac{r C_p \bar{q} u_*^3}{kgH}$$

热量平衡方法

这是一种以能量守衡定律为基础的计算方法。实际上是一种余项法。在环境生态研究中如有辐射平衡观测资料时，使用此法较好。地表面热量平衡方程为

$$R_n = H + LE + G$$

或 (6.48)

$$R_n = -\rho C_P K \frac{\partial \bar{\theta}}{\partial z} - \rho L_V K \frac{\partial \bar{q}}{\partial z} + G$$

其中Rn为辐射平衡，其余符号都是已知量。如果以差分代替微分，并从中解出K，可得

$$K = \frac{(R_n - G)\Delta z}{\rho C_P \Delta\bar{\theta} + \rho L_V \Delta\bar{q}}$$

将 $\frac{\partial \overline{q}}{\partial z}$ 和 $\frac{\partial \overline{q}}{\partial z}$ 写成差分形式 $\frac{\Delta \overline{q}}{\Delta z}$ 和 $\frac{\Delta \overline{q}}{\Delta z}$ 则

$$\left(R_n - G\right) = -rC_pK\frac{\Delta \overline{q}}{\Delta z} - rL_vK\frac{\Delta \overline{q}}{\Delta z}$$

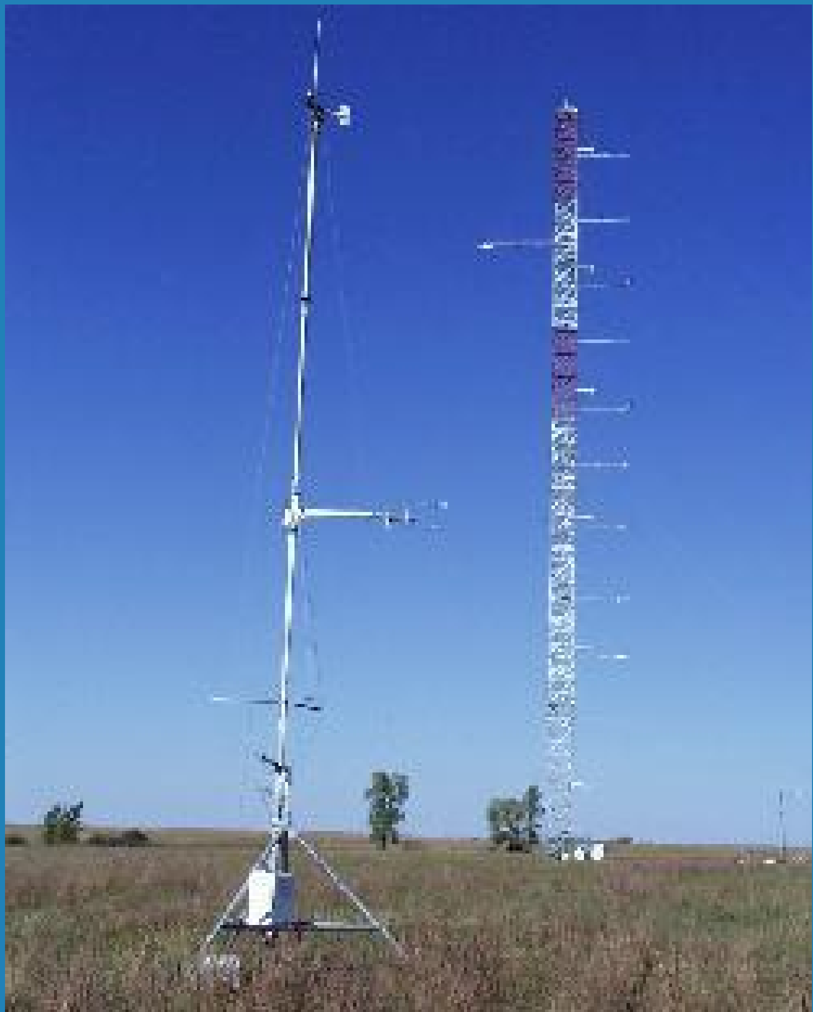
或直接求出湍流热通量和蒸发耗热项，则有

$$H = -rC_PK\frac{\P \overline{q}}{\P z} = rC_P\frac{\left(R_n - G\right)\Delta z}{rC_p\Delta \overline{q} + rL_v\Delta \overline{q}}\frac{\Delta \overline{q}}{\Delta z} = \frac{R_n - G}{1 + \frac{L_v}{C_p}\frac{\Delta \overline{q}}{\Delta \overline{q}}}$$

$$LE = -rL_VK\frac{\P \overline{q}}{\P z} = rL_v\frac{\left(R_n - G\right)\Delta z}{rC_p\Delta \overline{q} - rL_v\Delta \overline{q}}\frac{\Delta \overline{q}}{\Delta z} = \frac{R_n - G}{\frac{C_P}{L_V}\frac{\Delta \overline{q}}{\Delta \overline{q}} + 1}$$

第三节、观测方法和设备

EBEX2000试验场地



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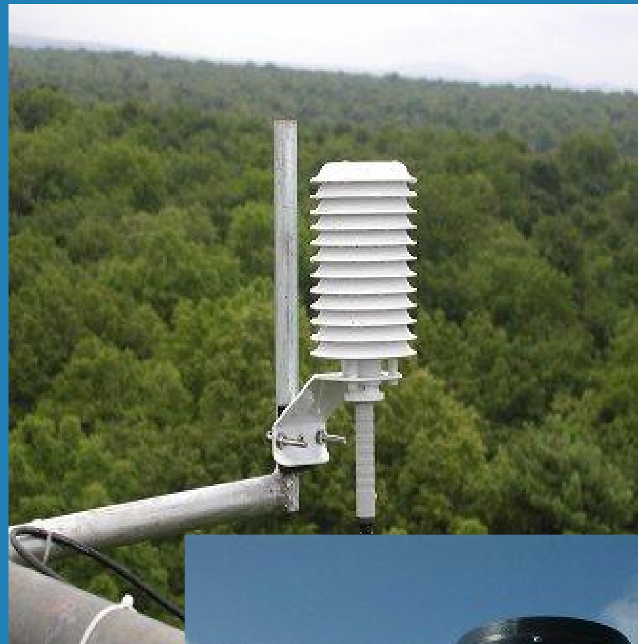
Above Canopy Sonic Anemometers /Thermometers and CO_2/H_2O Analyzer

Below Canopy Sonic Anemometers /Thermometers and CO_2/H_2O Analyzer

Eddy Correlation Method Analyzing system

7-Level CO_2 Profile Sampling and Analyzing system

Chinese Ecosystem Research Network

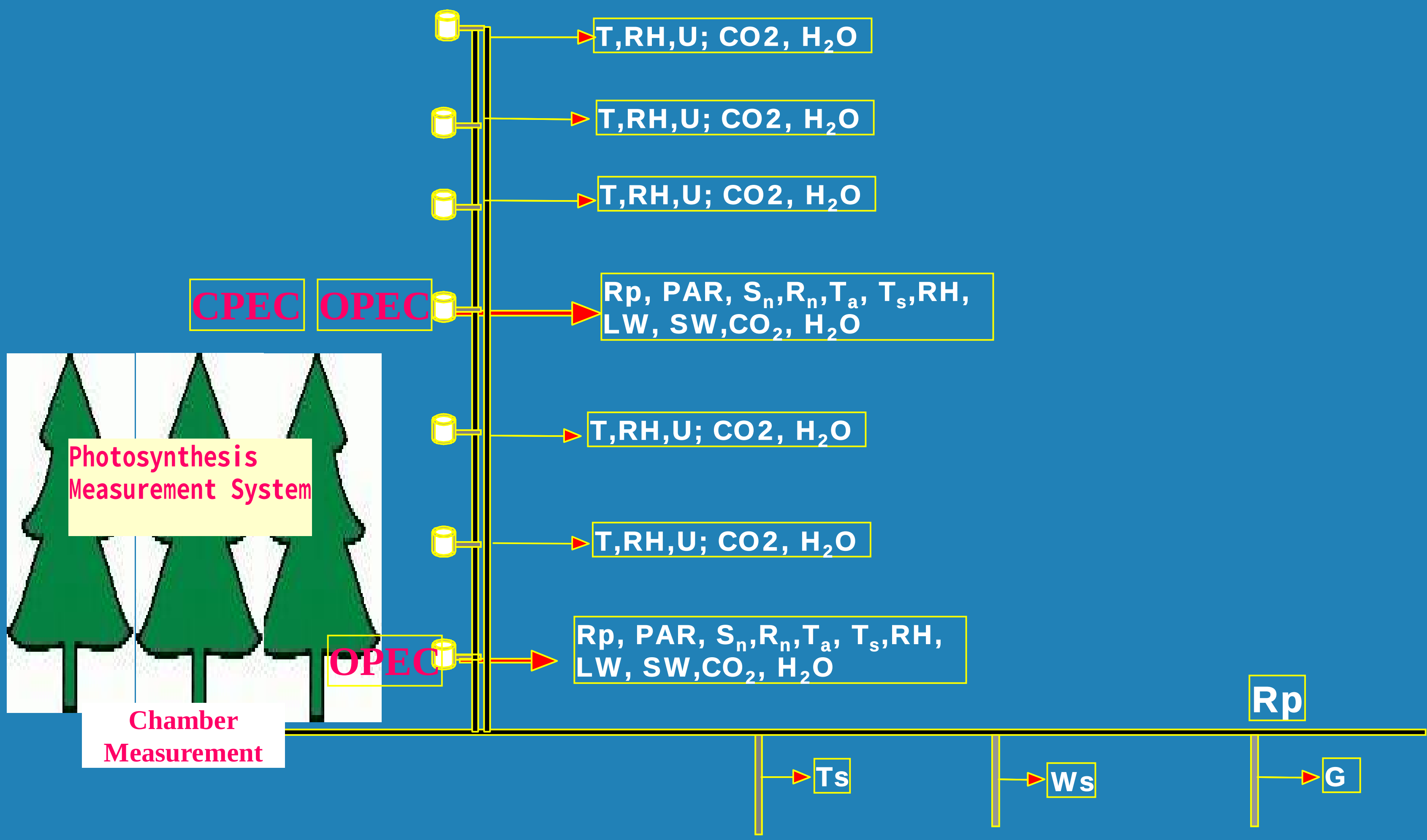


Sensors of Routine Meteorological Factors

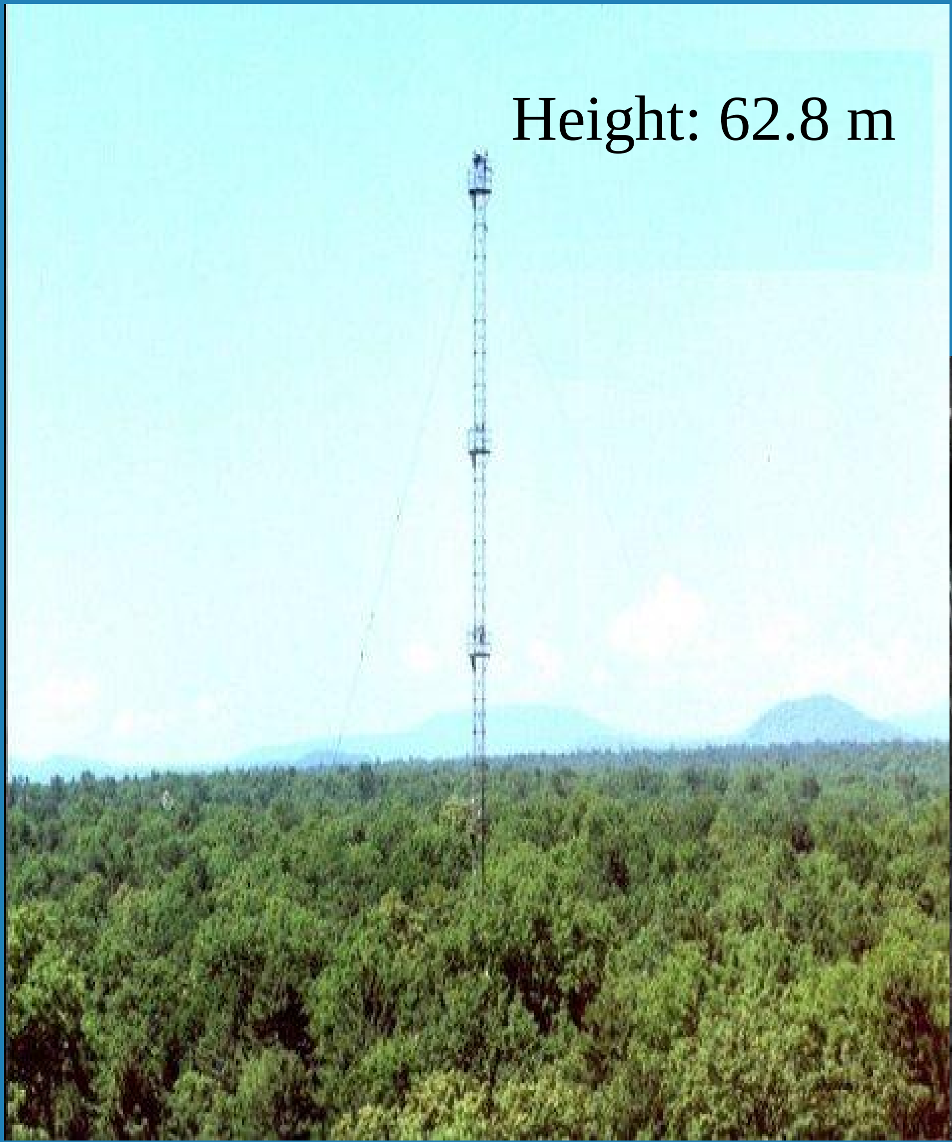
Pyranometer

Net Radiation

F1 Site: Diagram of Changbai Mountain Forest Site



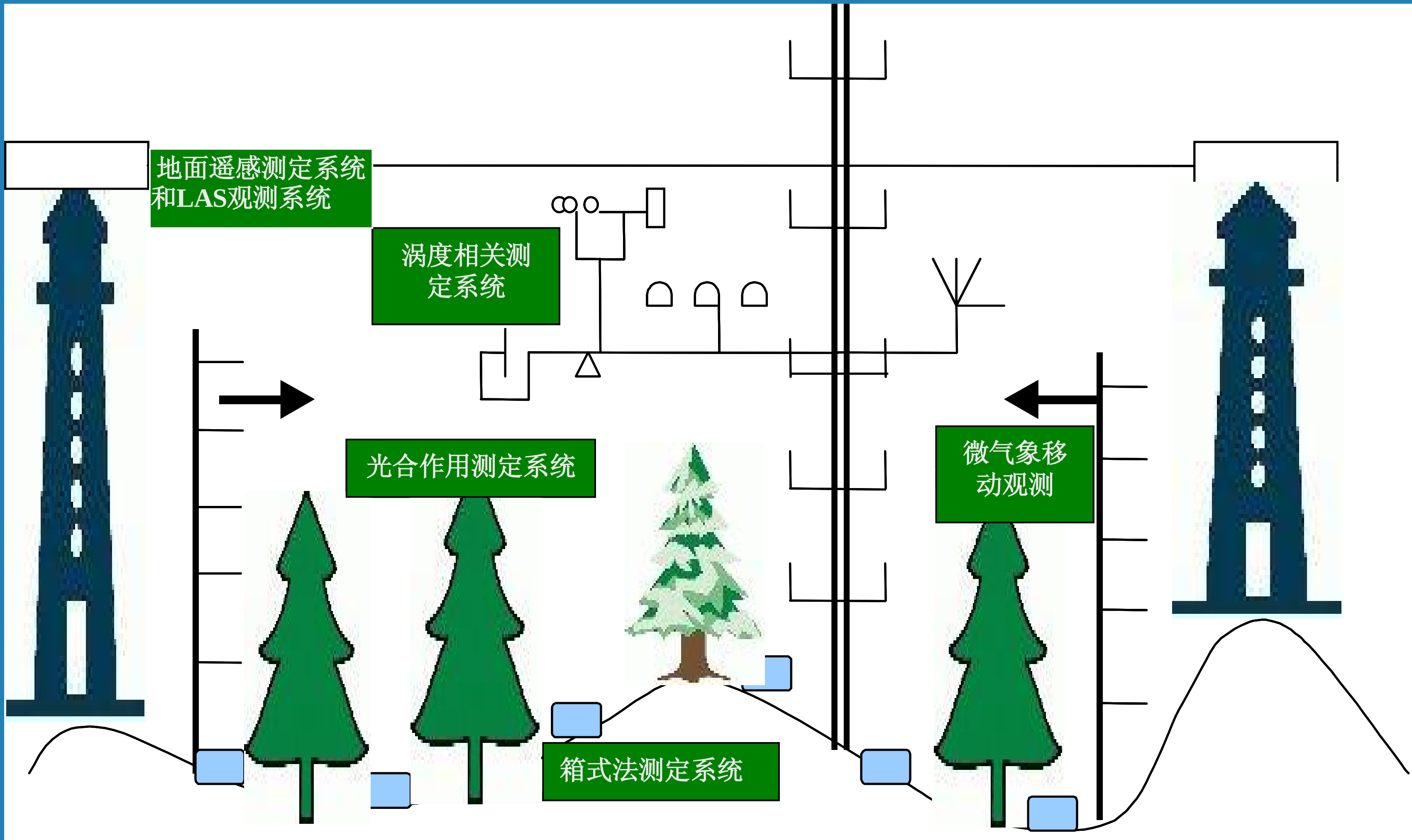
Chinese Ecosystem Research Network



Broadleaved Korean Forest

In Changbai Mountain

F2 Site: Diagram of Qianyanzhou Forest Site



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Observation Tower in QianYanZhou

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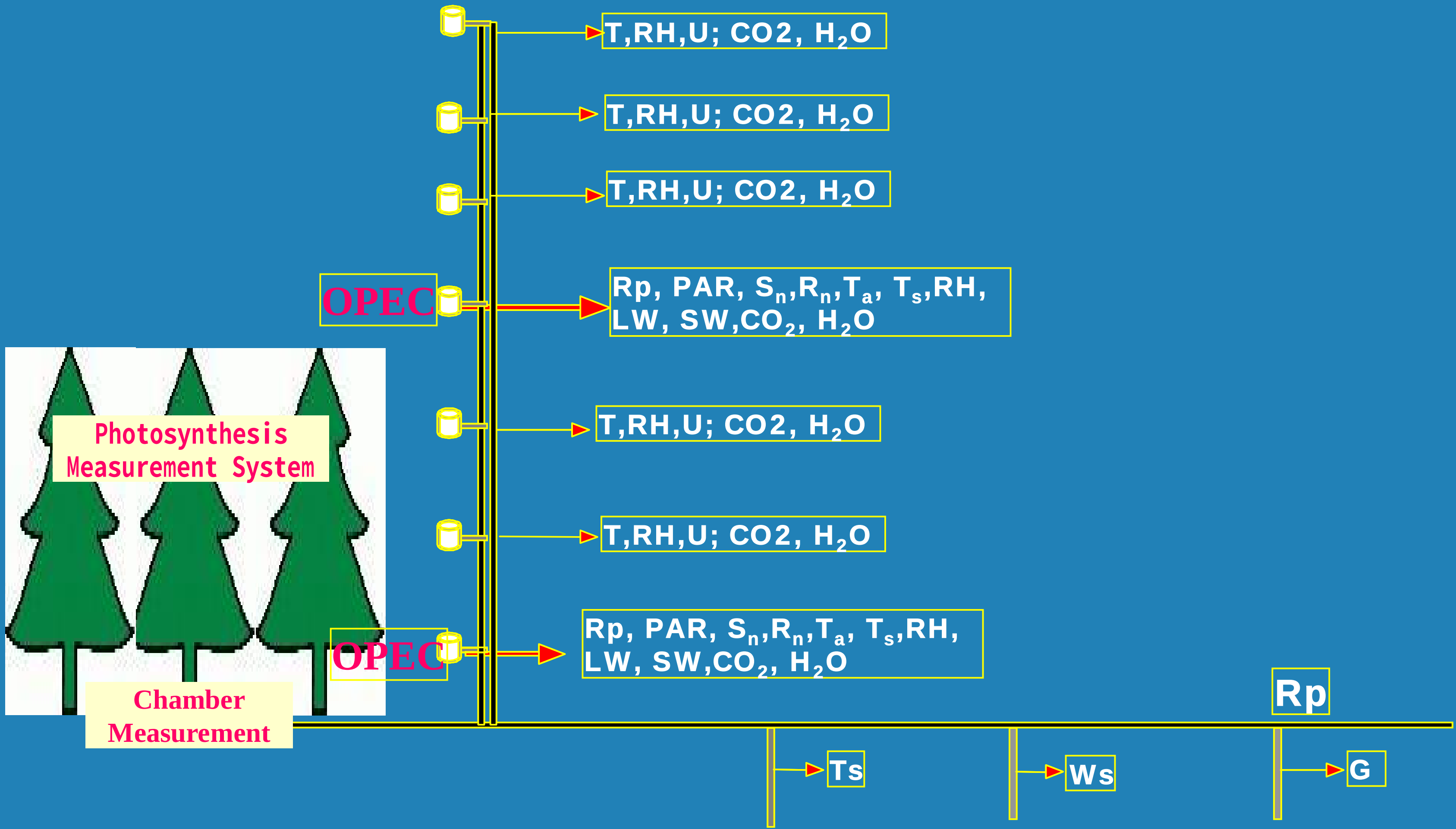
Measurement over forest (Karuizawa, Nagano, July 2001, courtesy Central Research Institute of Electric Power Industry).

F3 and F4 Site: Diagram of Dinghu Mountain and Xishuangbanna Forest Site



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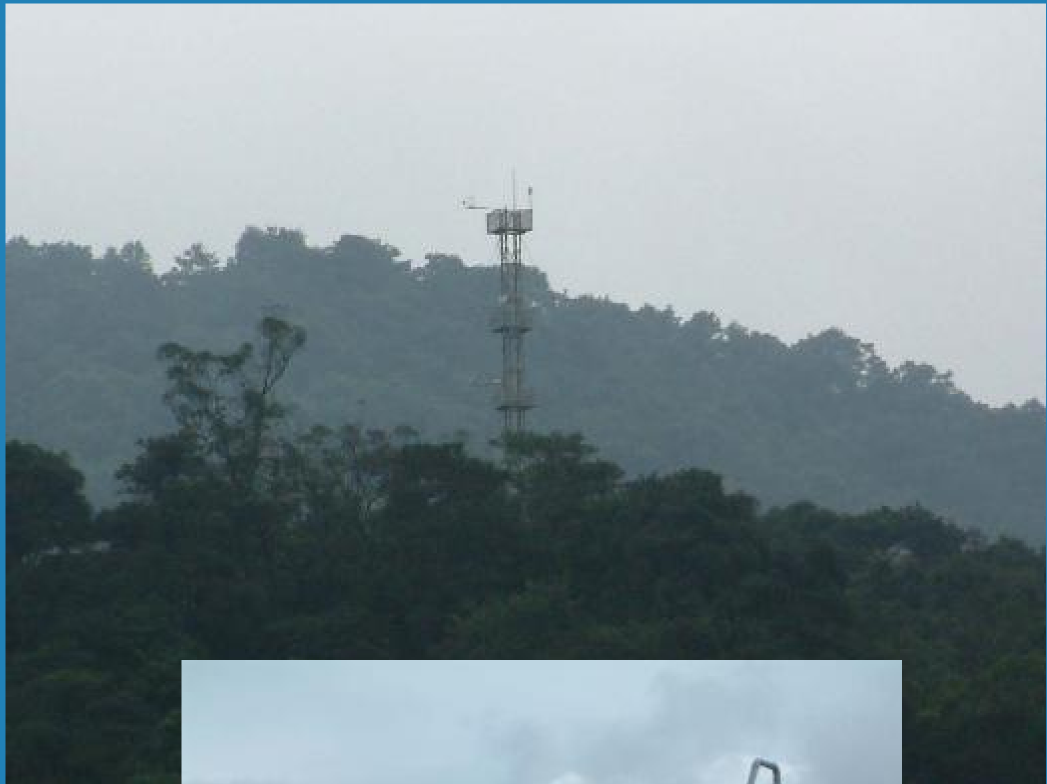
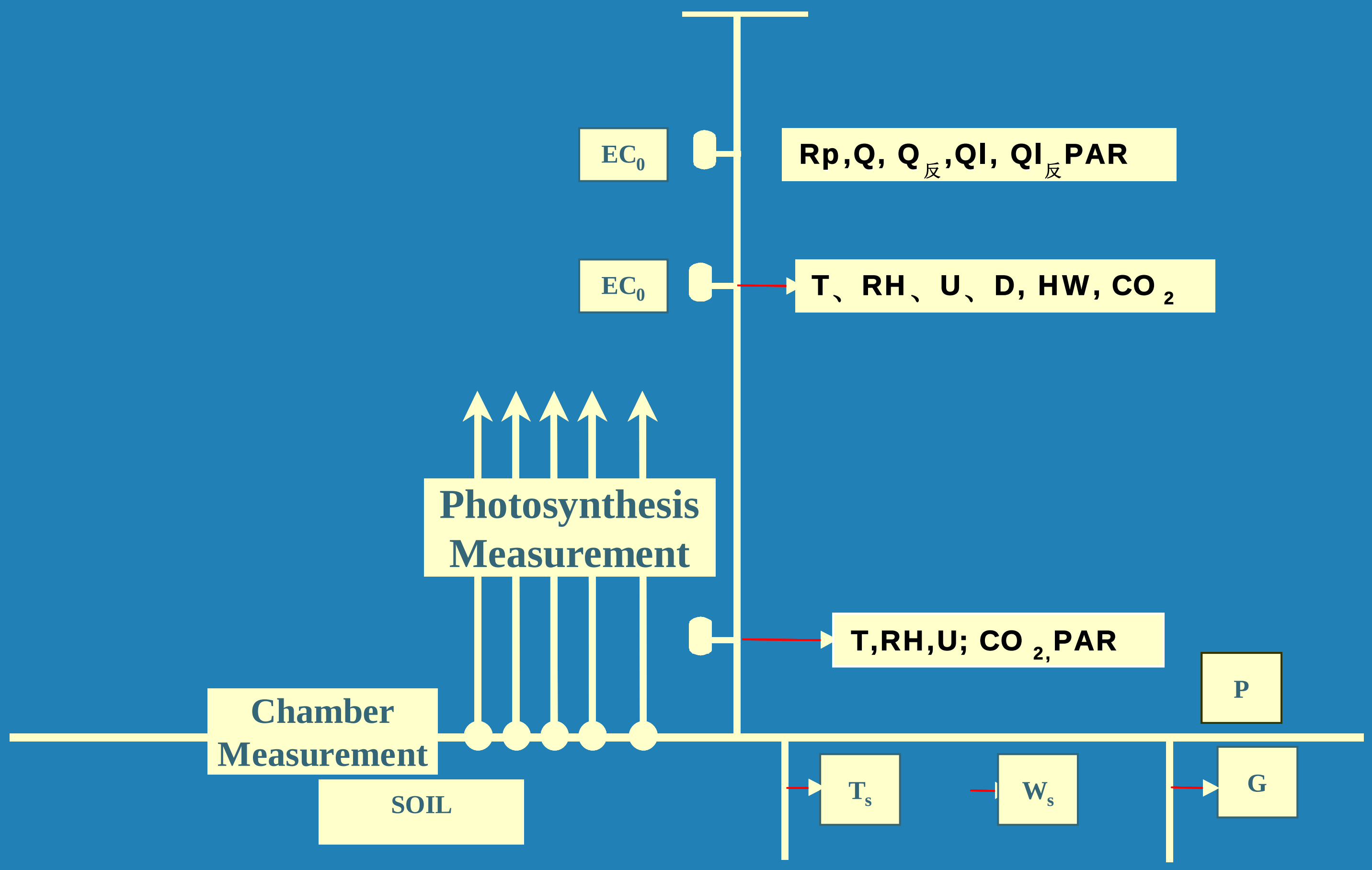


C1 and C2 Site: Diagram of Yucheng Farmland and Haibei Grassland Site



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Experiment in Yucheng Farmland Station

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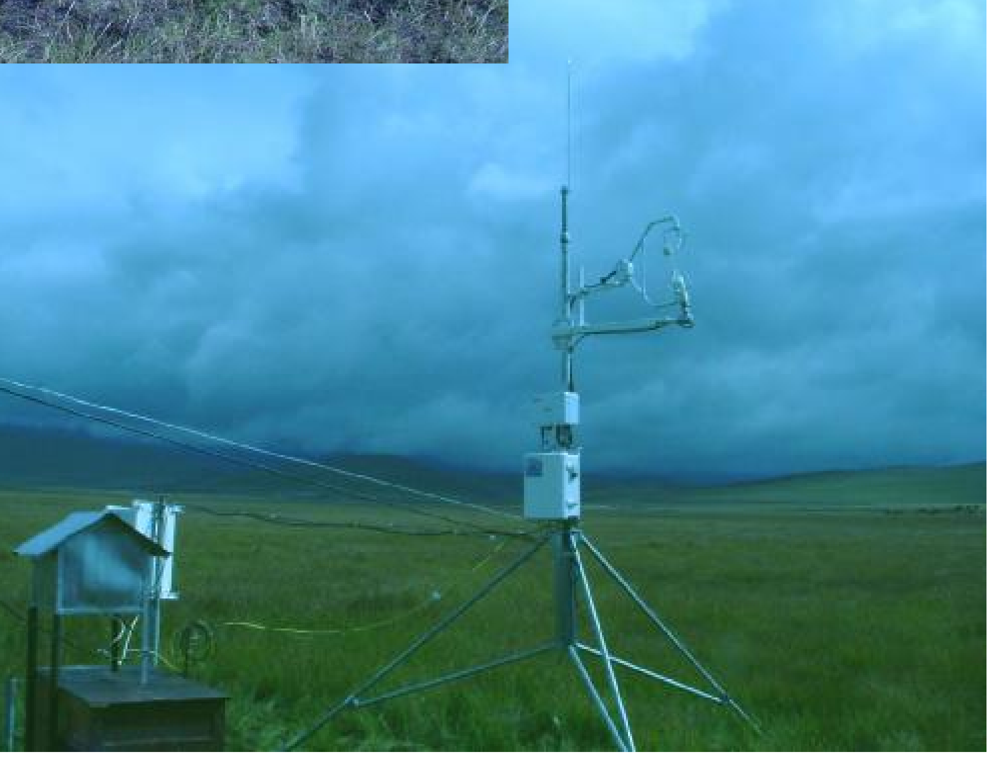
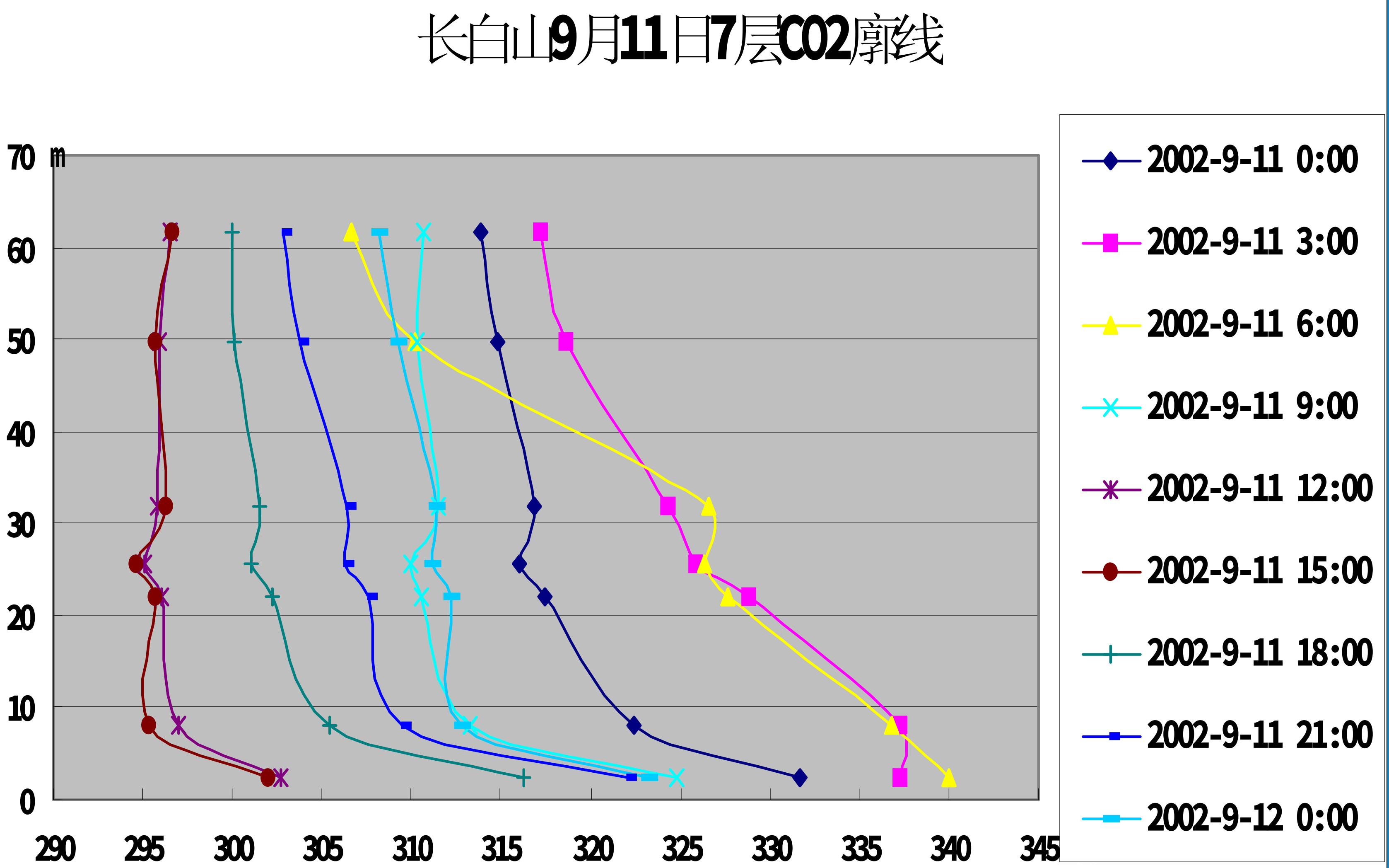
Haibei Grassland Station



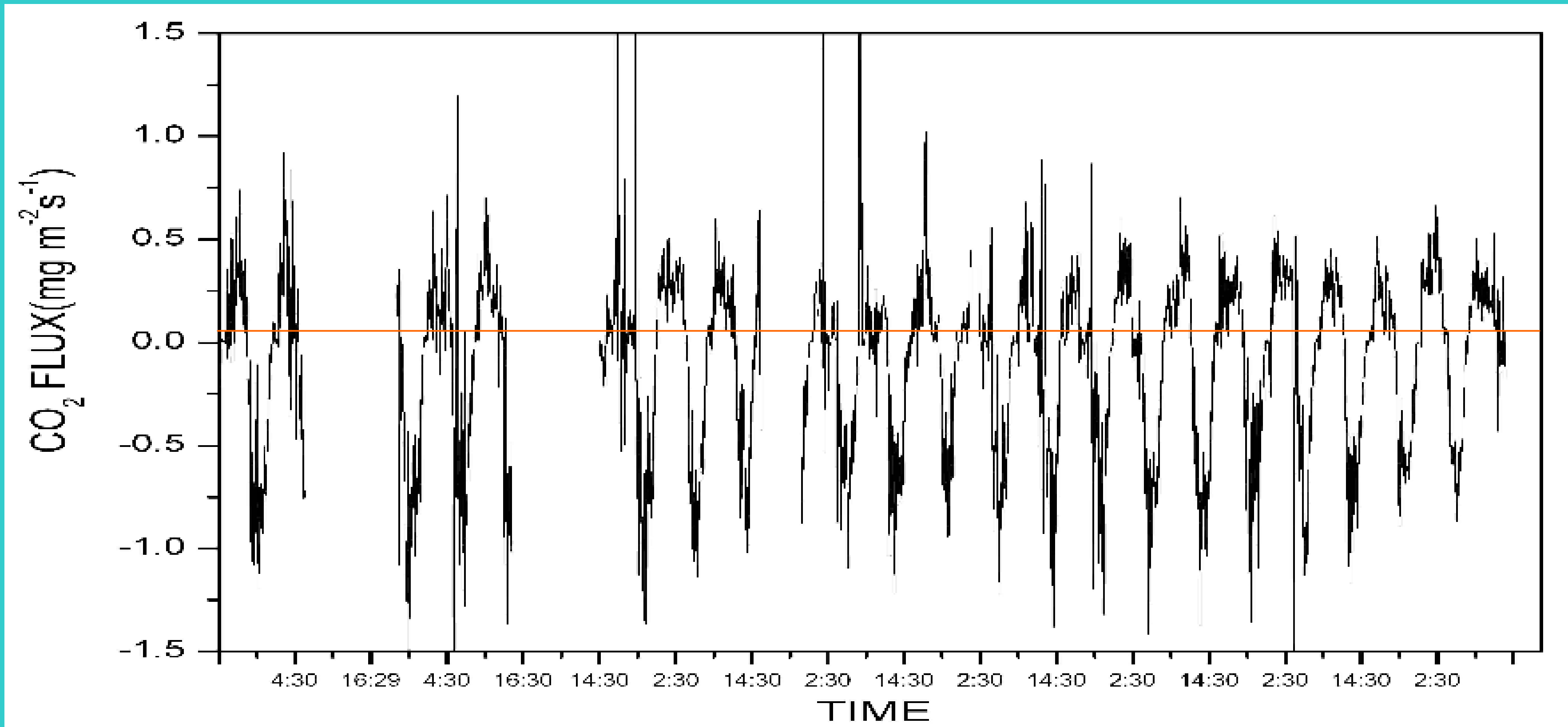
第四节、结果

长白山的观测结果: CO2浓度梯度



长白山数据: 冠/气碳通量(2002/08/25-2002/09/18)

冠/气碳通量　　　(2002/08/25-2002/09/18)

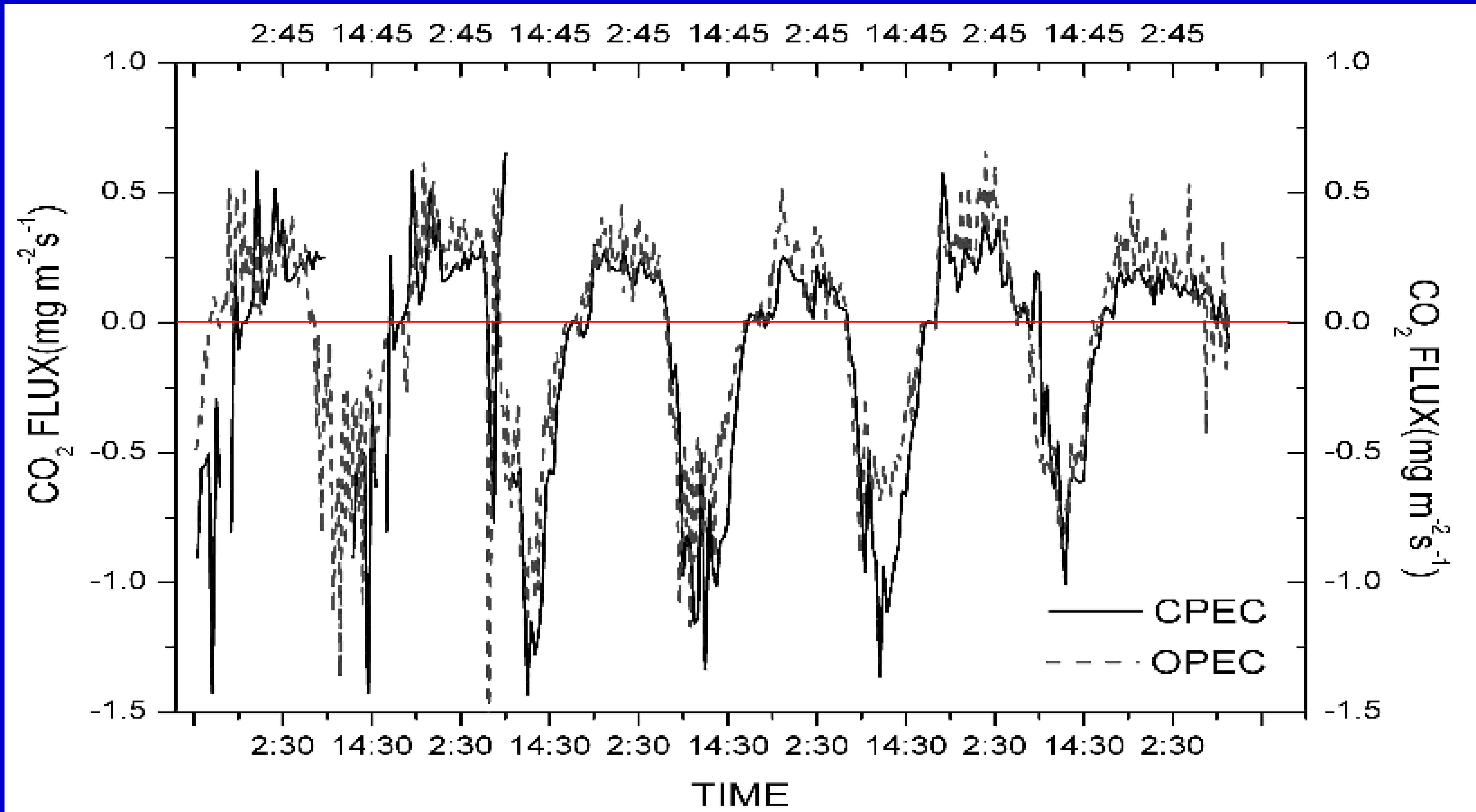


显著的日动态，白天冠层为碳汇，夜间为碳源，平均而言为碳汇。

交换强度在$-1.5mgm^{-2}s^{-1}$~$0.9mgm^{-2}s^{-1}$之间。

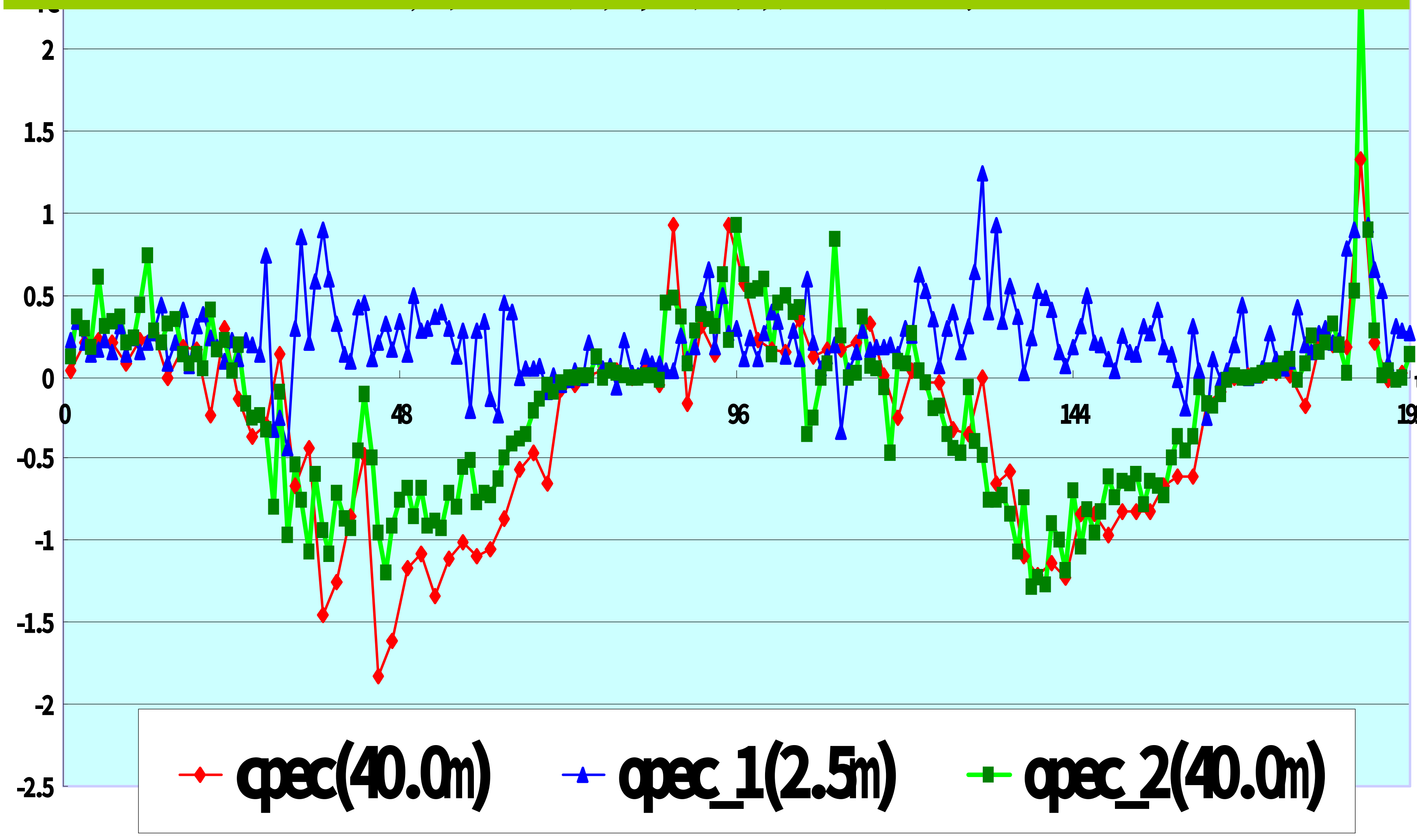
长白山数据：涡度相关技术的比对

OPEC与CPEC结果比较(2002/08/25-2002/09/18)



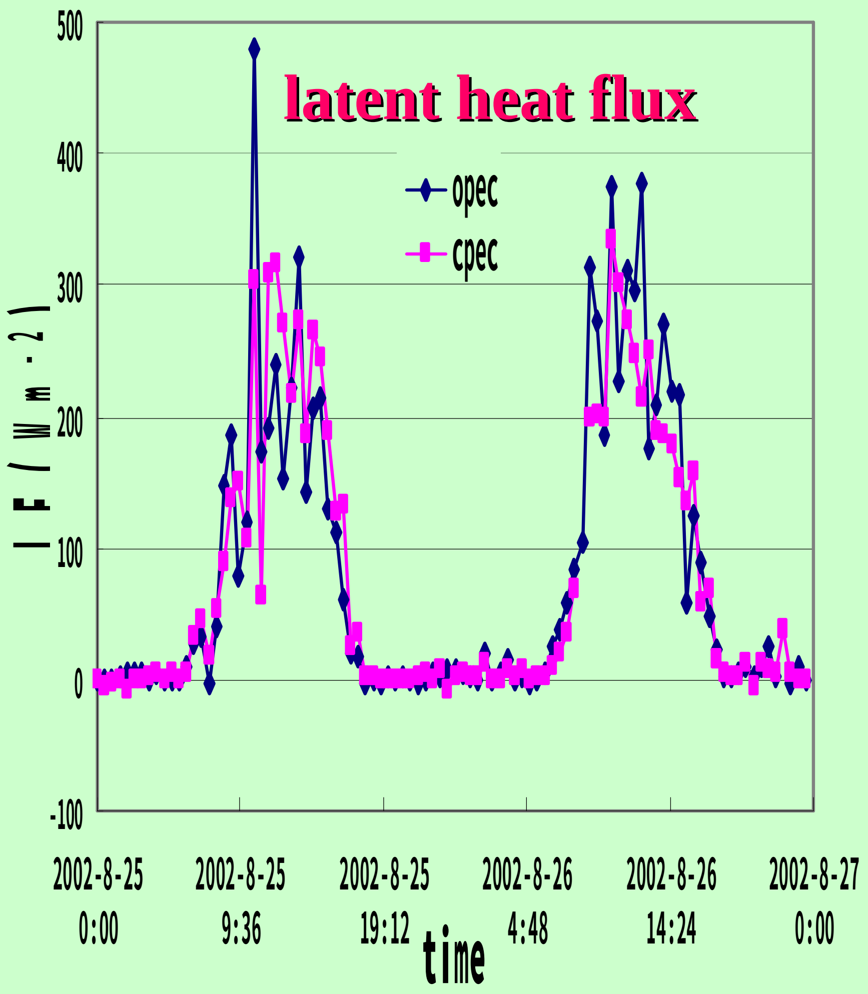
从数据动态（图4）上看OPEC与CPEC结果吻合的很好

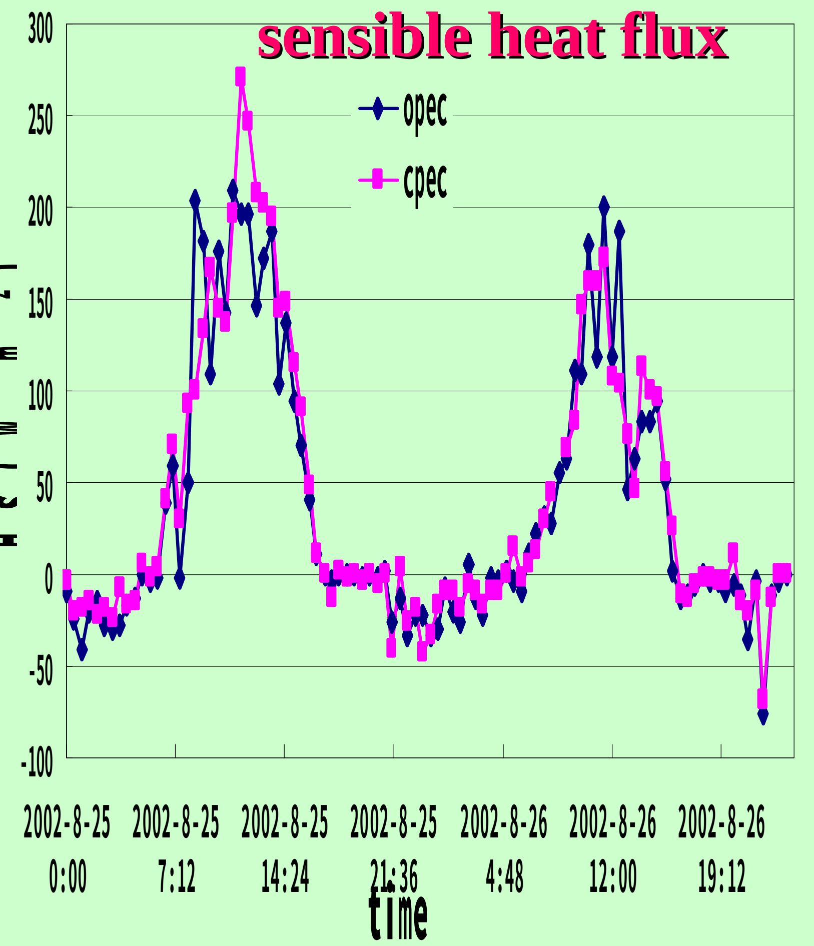
3个涡相关系统的比较
(8月25日—8月27日)



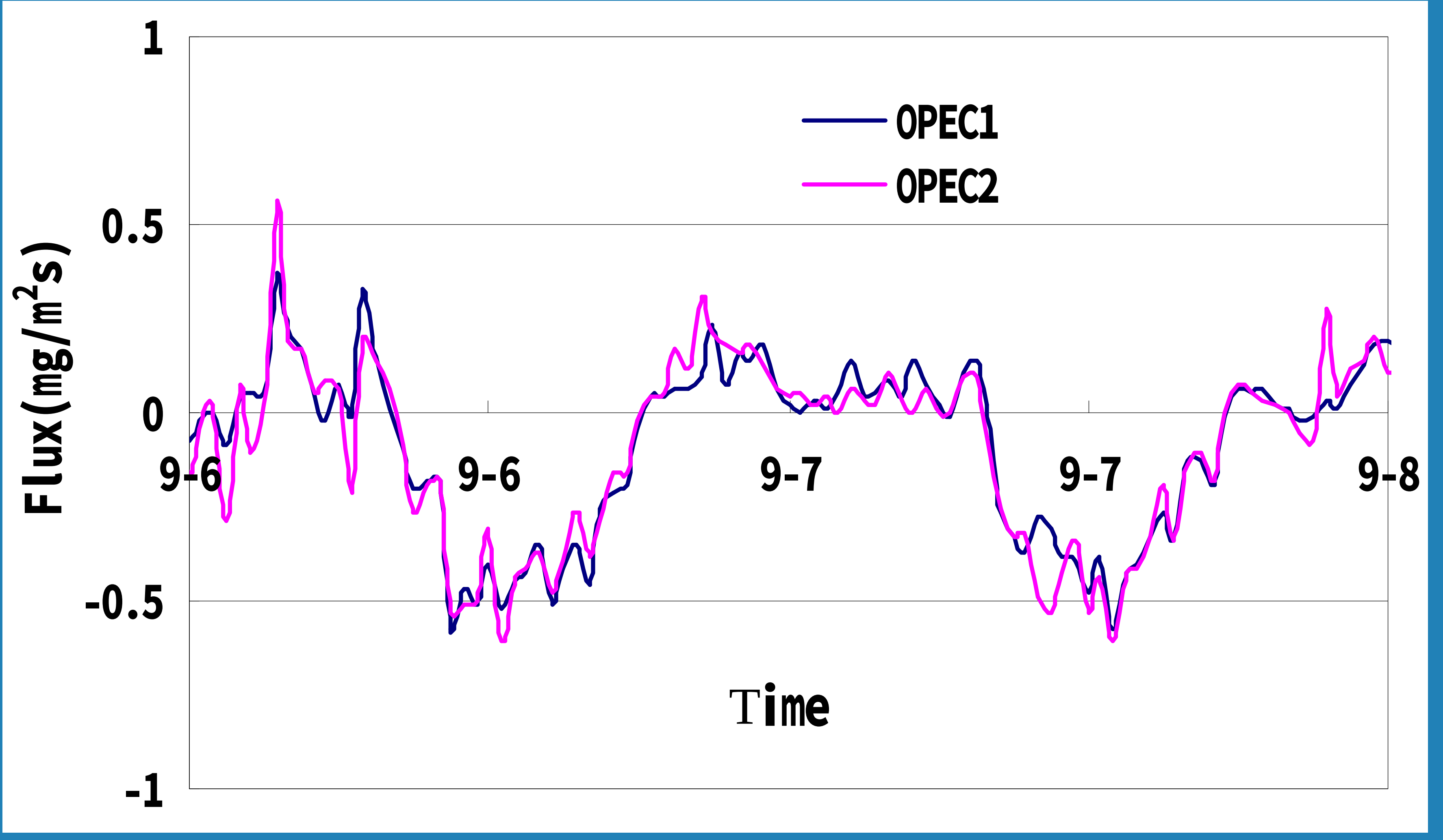
长白山的观测结果: 显热和潜热通量

(OPEC与CPEC结果比较)



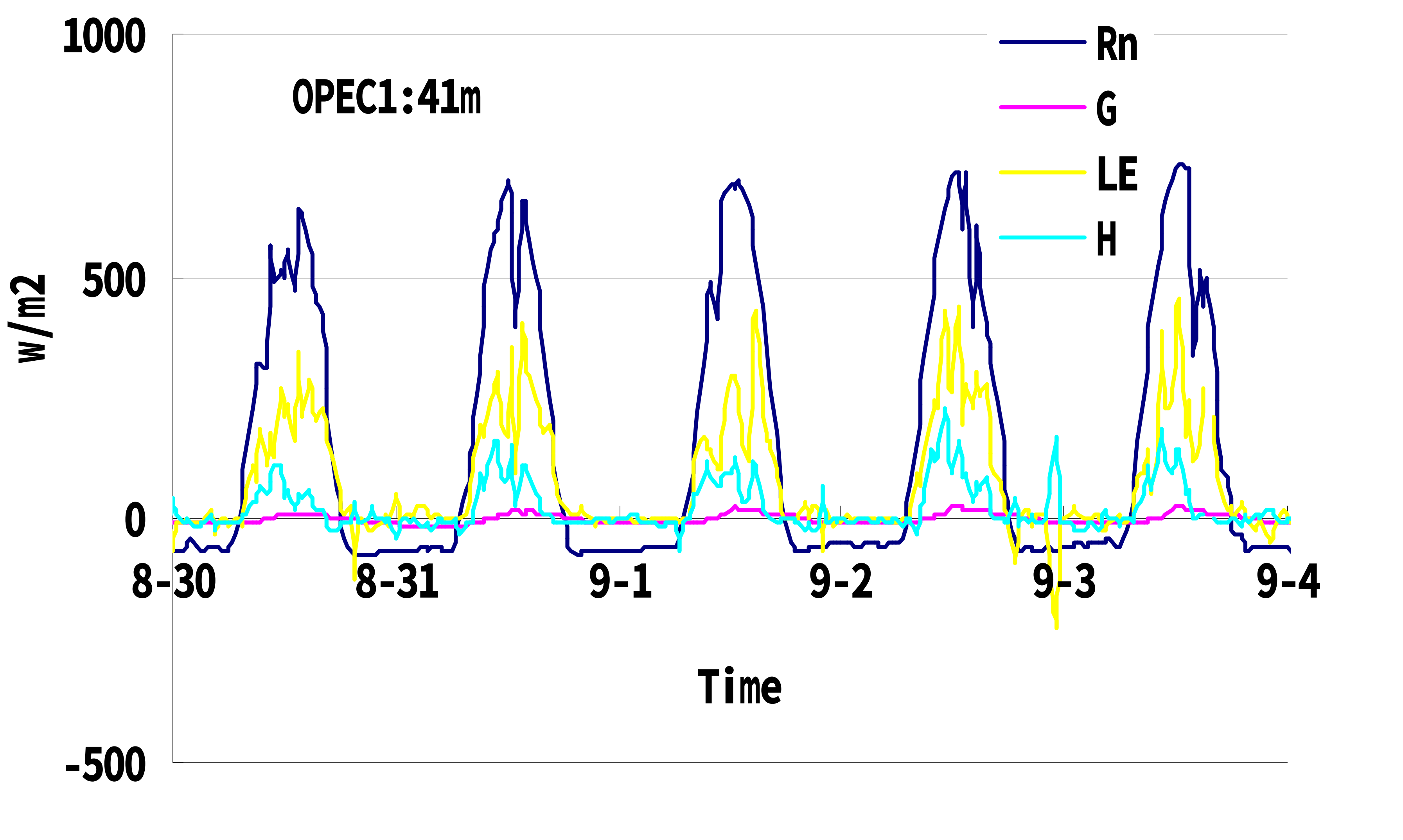


千烟洲数据: 不同观测高度的碳通量

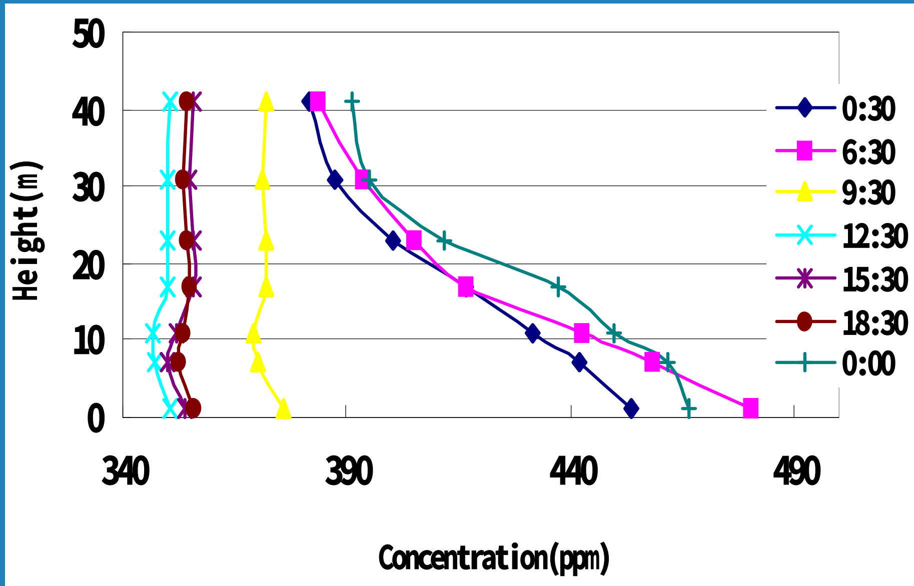


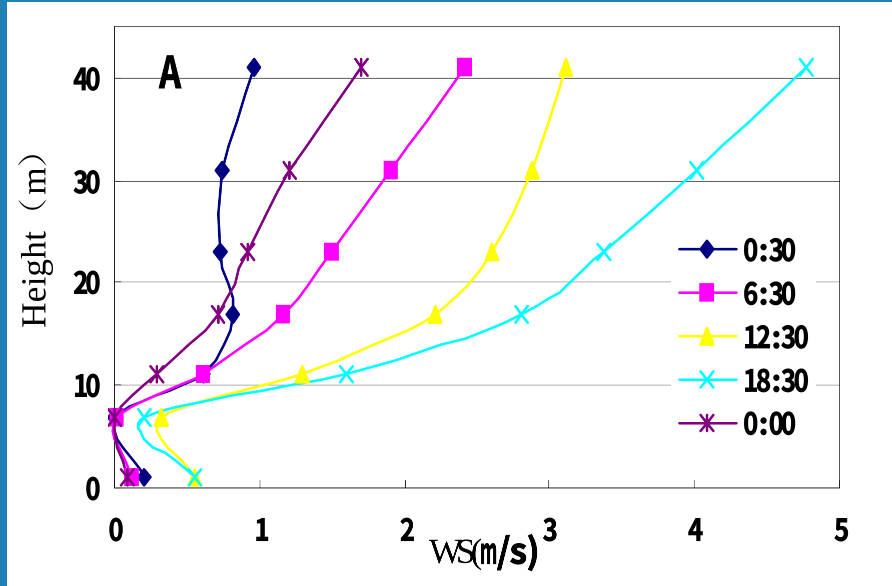
Measurement results of of the CO2 flux with OPEC system in Qianyanzhou site(All datum are collected in 2002)

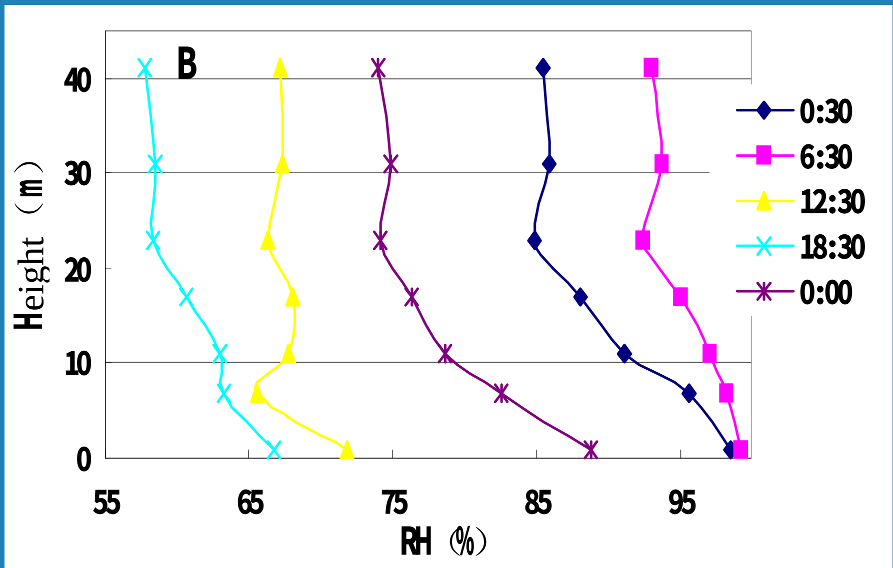
千烟洲数据：开路系统测定的能量平衡

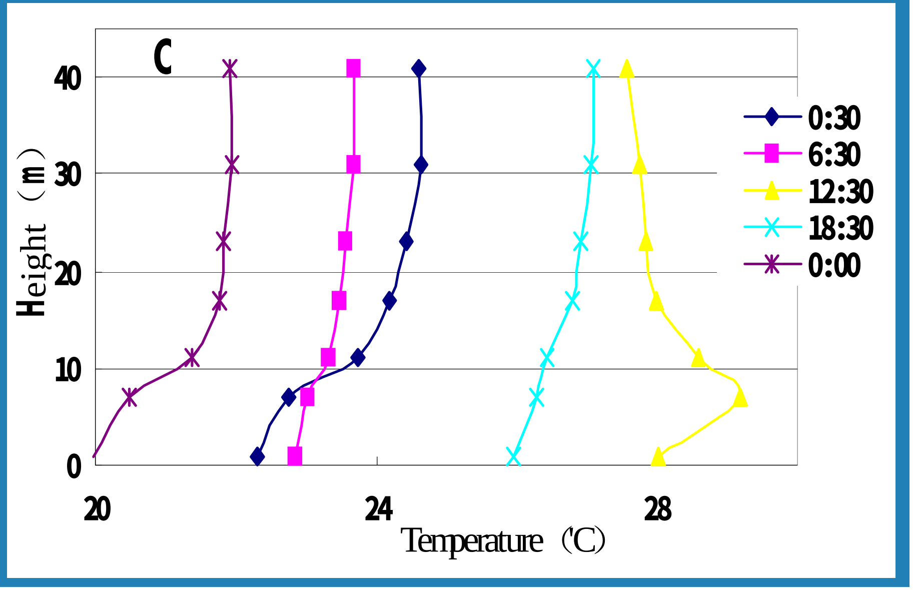


千烟洲数据: CO_2,,风速等垂直廓线

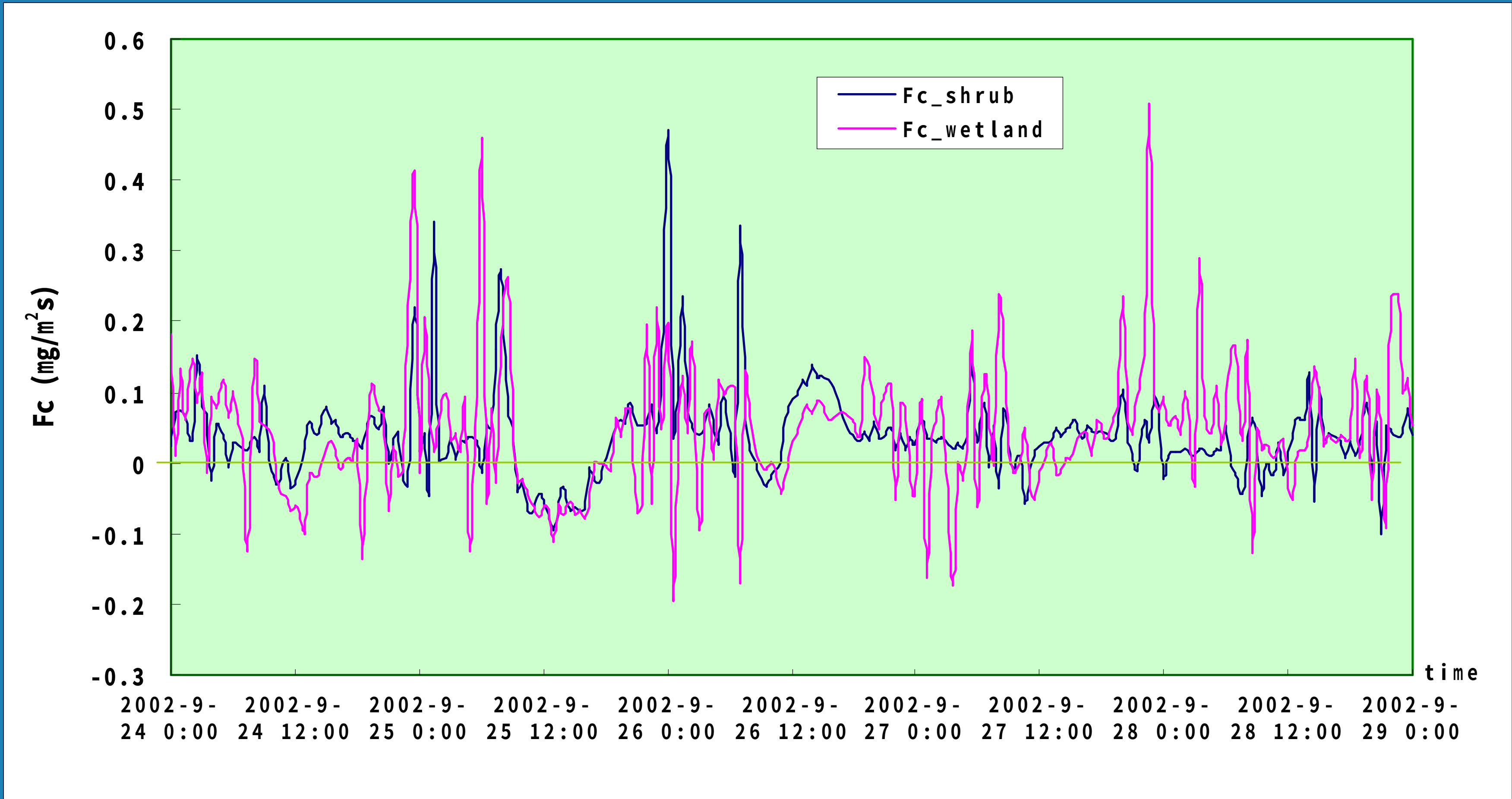






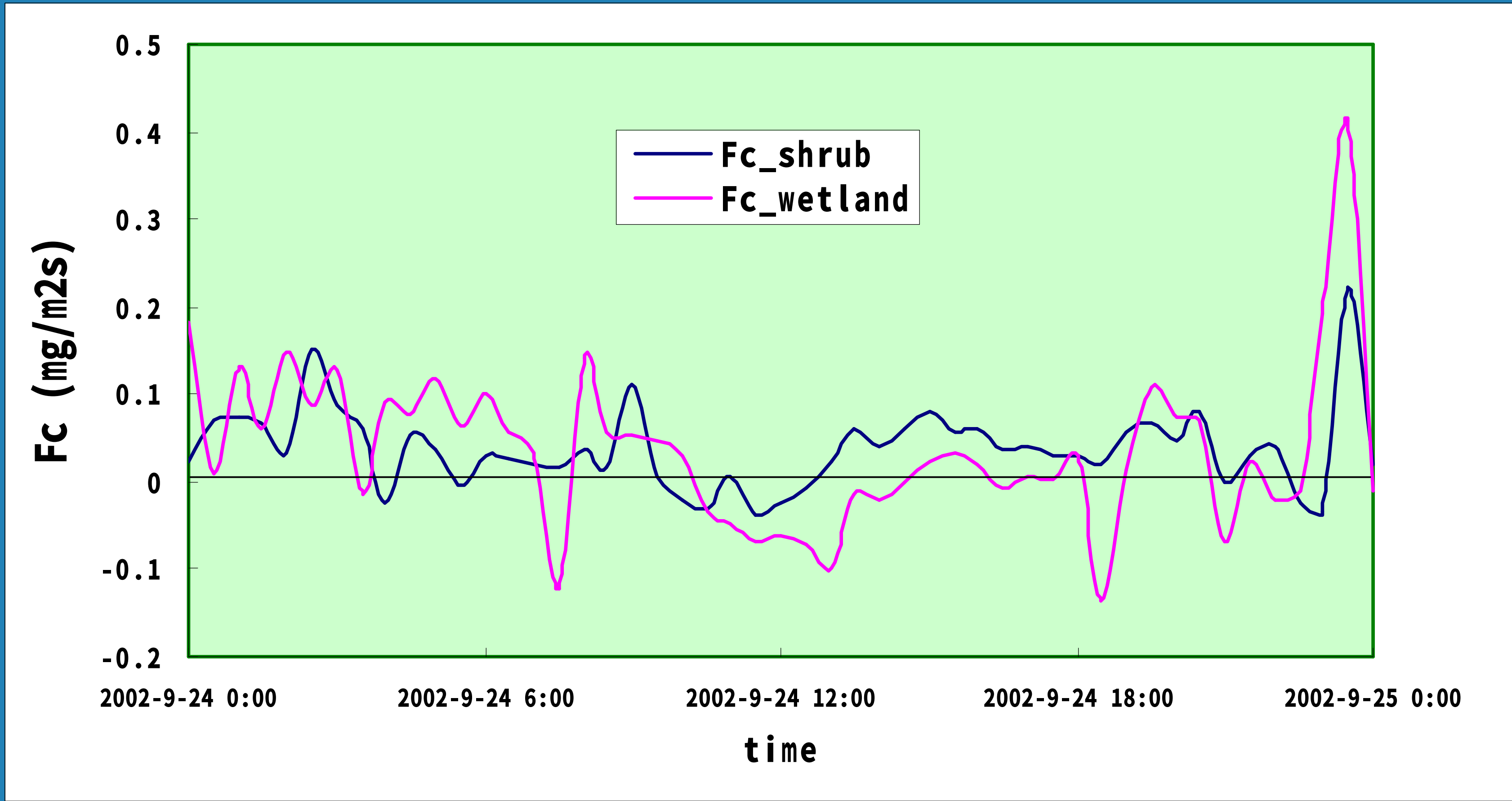


海北数据:　　CO_2 *flux* 观测结果



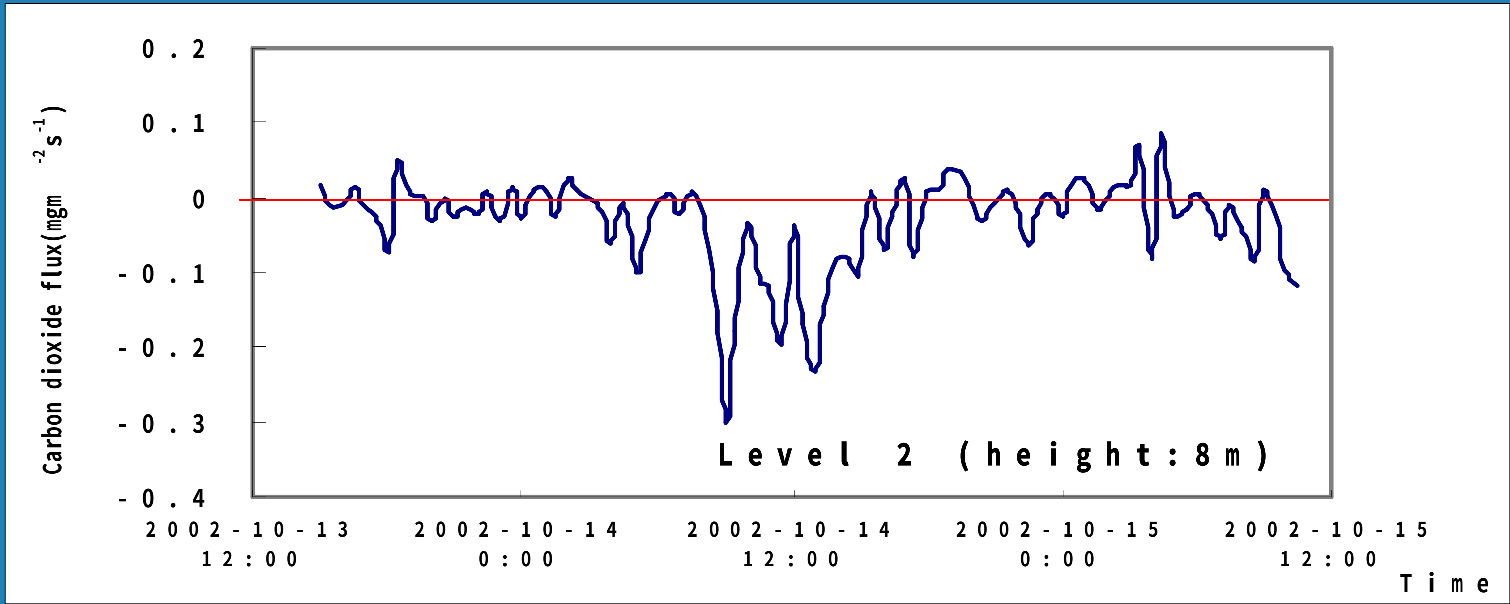
Comparison of *CO2 flux* between shrub and wetland, obtained at Haibei station during Sep. 24-29th, 2002 (1)

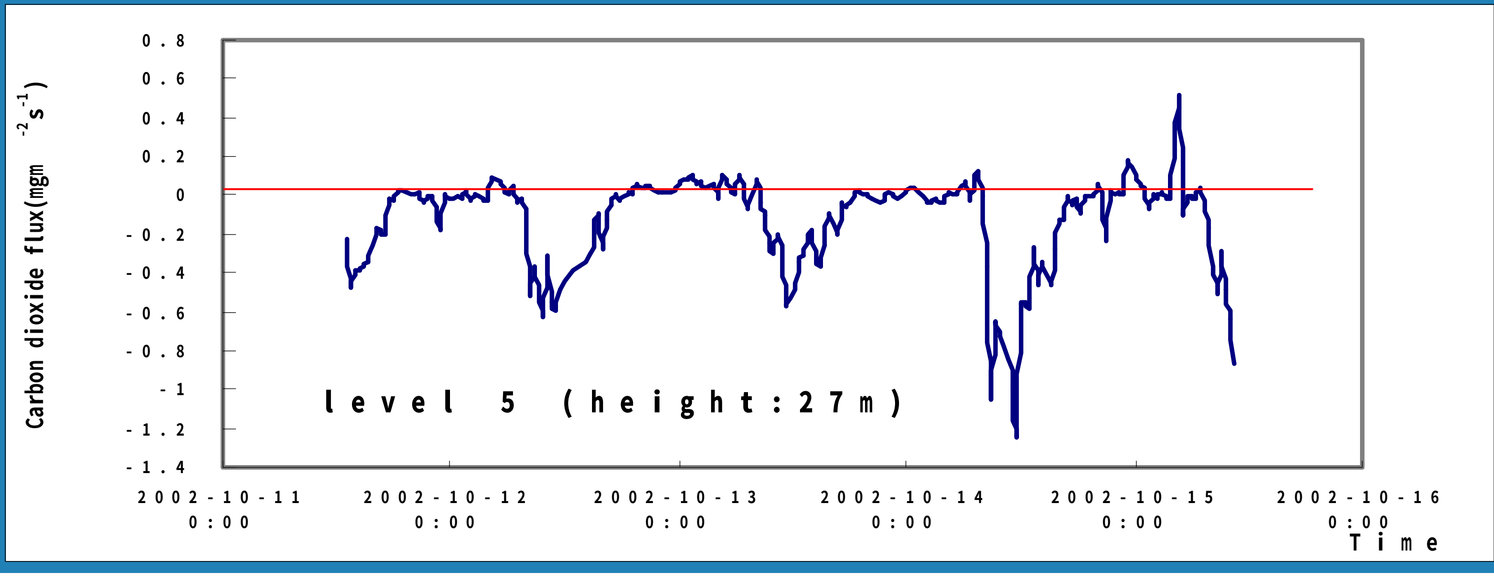
海北数据: CO_2 *flux* 观测结果



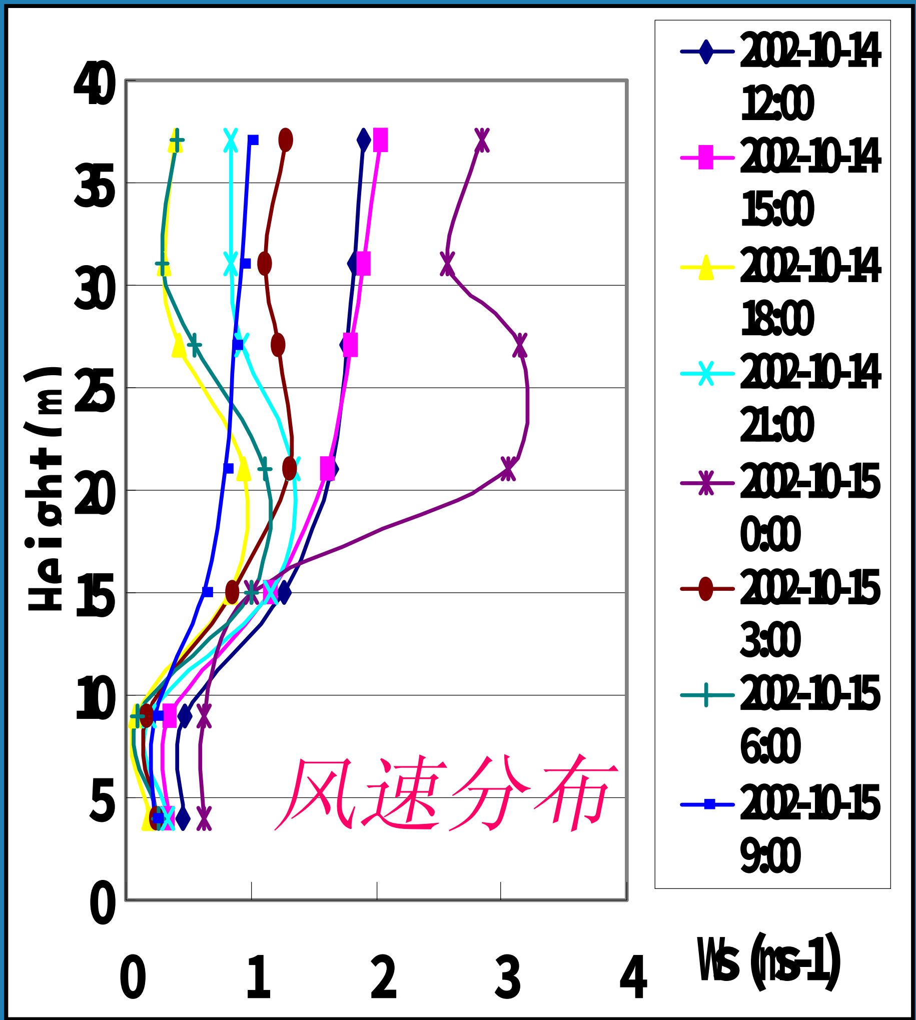
Comparison of CO_2 *flux* between shrub and wetland ecosystem, obtained at Haibei station during Sep. 24-25th 2002(2)

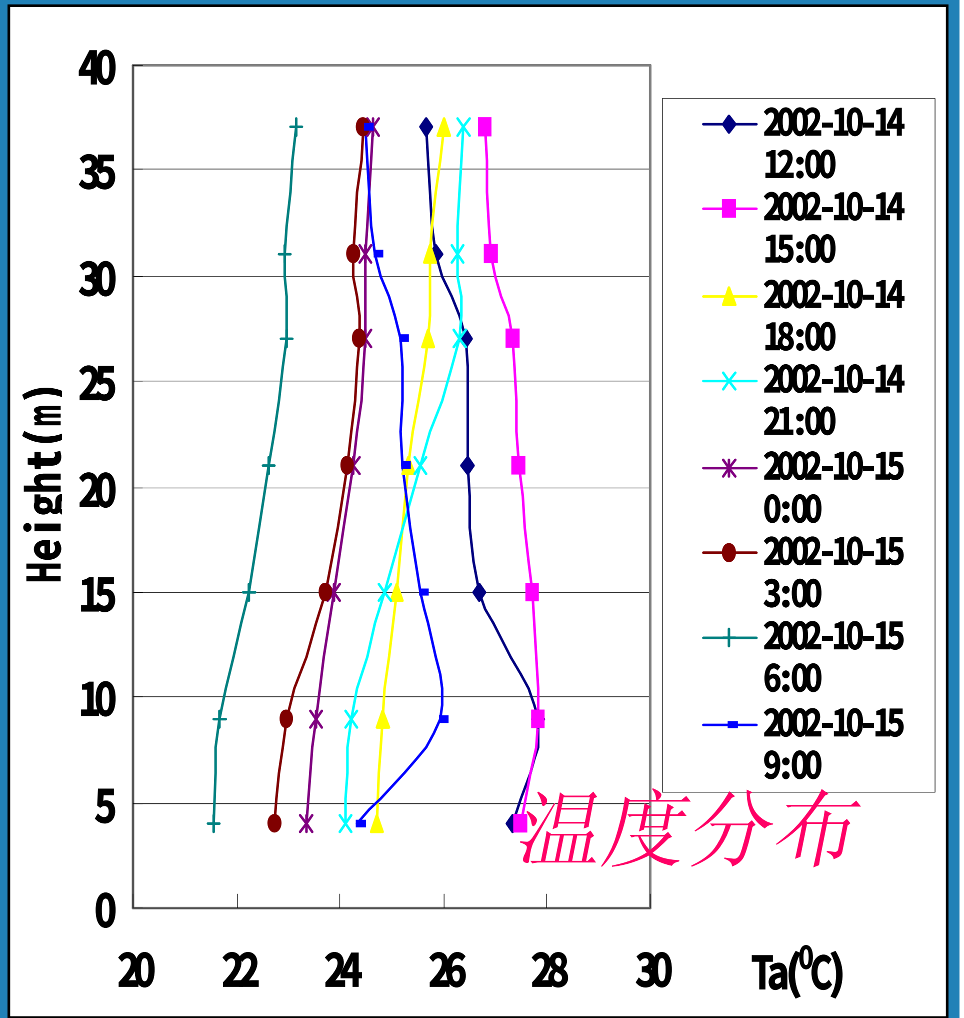
鼎湖山 CO2通量的观测结果





鼎湖山　不同高度的风速和问土温度分布





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