ChinaFLUX第十四次通量观测理论与技术培训

生态系统观测中配置传感器与通量系统的考虑

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生态学博士 毕业于中国林业科学研究院

研究方向：

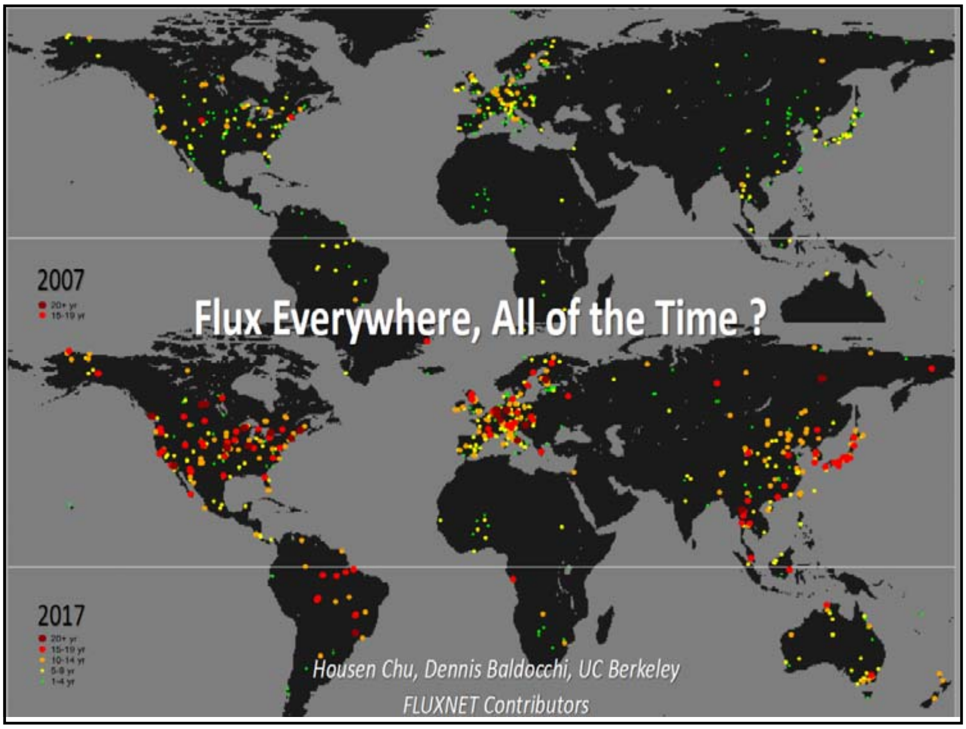
- 森林生态系统碳水通量交换
- 基于涡动相关与闪烁仪等方法和设备研究边界层气象
- 基于涡动相关与闪烁仪等研究森林生态系统热量与能量平衡
- 地表植被分布非均匀条件下，生物与环境相互作用对二氧化碳与水汽通量的影响

研究成果：主持国家自然基金1项，作为骨干成员参加科学研发专项、科技支撑、行业专项等多项课题；在国内外发表文章30余篇，获得实用新型专利2项，软件登记8项。

生态定位研究站实验设计、观测设备配置及日常管理经验

- 承担国家林业局CFERN核心站-黄河小浪底森林生态定位研究站日常管理工作，负责确定定位站野外观测实验的设计、观测设备的采购论证、观测样点的布置等关键工作；
- 直接负责通量、气象、数据传输等野外观测设备的日常维护及数据采集、处理等工作；

交流经验 共同学习 共同进步


Flux Everywhere, All of the Time ?
2007
2017
Housen Chu, Dennis Baldocchi, UC Berkeley
FLUXNET Contributors


北师大/西北院黑河观测网 阿柔站


中科院大气所 通榆站


中科院沈阳应用生态所 清原站

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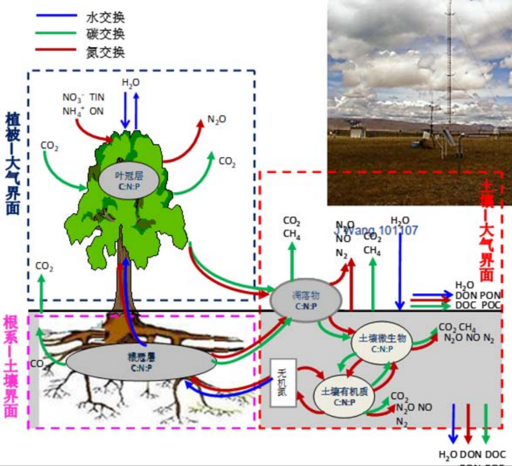
内容大纲

1、在复杂植被系统研究中通常需要测定的变量与项目

2、状态传感器与通量系统协同观测的必要性和科学意义

3、通量观测与廓线系统相结合的综合系统的主要特点、配置及应用实例

1. 在复杂植被系统研究中通常需要测定的变量与项目



- 涡动相关通量观测系统（三维风速、温度、水汽、CO_2等的快速变化→各通量）
- 微气象观测
  - 辐射各分量
  - 微气象塔（风、温、湿、CO_2浓度梯度等）
  - 土壤（各层温度、含水量、热流等）
  - 水文（降水、径流、积雪等）
- 生态系统结构与特征参数（LAI，冠层结构、光合及呼吸、土壤及根系等）
- 其它：
  - 面积平均通量观测系统（大口径闪烁仪等）
  - 大气边界层结构及地面遥感（声、光、微波遥感）

- 通量系统：植被-大气界面气体通量、土壤-大气界面气体通量、土壤热通量
- 常规气象传感器
- 辐射及红外传感器
- 廓线系统

通量系统：植被-大气界面CO2/H2O/痕量气体通量

CO2/H2O

CH4/N2O

高精度大气氨本底激光开路分析仪

Atmospheric NH3 Open-path Laser Analyzer

性能参数

NH_3测量精度	0.2ppbv+0.05%读数(0.1s, 1σ)
量程范围	0~20 ppmv
大气压力范围	300~1000 Torr
环境湿度	<99% R.H，无冷凝@40℃（镜片加热）
尺寸	960mm x φ200 mm
重量	<10kg
存储方式	通过 Campell Scientific CR3000®采集器 CF 卡存储
操作方式	PC 端 UI 界面
通讯接口	RS232 串口（以太网可选）
电源	24~36VDC
功率	<100Watts

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Atmospheric Measurement Techniques

A fast and precise chemiluminescence ozone detector for eddy flux and airborne application

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Abstract. A commercially available dry chemiluminescence (CI) instrument for fast and precise measurement of ozone (O_3) is specified. The sensitivity is ~9000 counts s^{-1} per ppbv of ozone. Its precision is entirely determined by the number of photons reaching the detector (being a photomultiplier), i.e. is quantum-noise limited. The relative precision ($\Delta O_3/O_3$ in %) thus follows Poisson statistics and scales with the square root of the measurement frequency f and with the inverse O_3 mixing ratio: $\Delta O_3/O_3 \propto f^{0.5} \cdot O_3^{-0.5}$. At typical O_3 mixing ratios between 10 and 100 ppbv (and 1 bar), the precision is 0.3–1.0 % at $f = 10$ Hz. The maximum measurement frequency is 50 Hz. The mechanical and electronic setup as well as the instrument performance is described. Recommendations on the adequate inlet tube configuration (inlet tube length, sampling flow) and on the way of calibration at stationary ground-based platforms and onboard aircraft are given.

1 Introduction

Ozone (O_3) is both chemically and radiatively one of the most important trace gases in the atmosphere. It is the major precursor of the hydroxyl radical (OH), the principal detergent in the atmosphere (Levy, 1971), and it forms the stratospheric ozone layer shielding the Earth's surface from harmful UV sunlight (WMO, 2007). Tropospheric ozone is also a potent natural and anthropogenic greenhouse gas (IPCC, 2007). Ozone thus belongs to the most frequently measured atmospheric trace gases.

There are various types of in-situ ozone instruments in use which are based on electro- chemical, spectroscopic and chemiluminescence (CI) techniques (Weinheimer, 2006; Li et al., 2008; Vömel and Diaz, 2010). The largest advantage of CI techniques is their fast response time in the range of 1 to 20 Hz. One distinguishes between gas-phase CI, wet, and dry CI techniques.

Gas-phase CI instruments are more complex and are based on the reaction of ozone with either ethene or nitrogen oxide (Ridley et al., 1992; Hegglin et al., 2006; Williams et al., 2006; Baritem et al., 2010).

In wet CI instruments, first described by Ray et al. (1986) and formely sold by Unisearch Associates Inc. (Ontario, Canada), organic dyes such as eosin are solved in a liquid on the surface of which chemiluminescence reaction of O_3 with the dye generates photons that are sensed by a photomultiplier. Major advantages are their small signal drift (compared to dry CI techniques) and absence of water vapour cross-sensitivities (Takayanagi et al., 2003).

Dry CI techniques are quite simple and also use organic dyes (such as luminol, rhodamine-B, eosin-Y, or coumarin adsorbed on solid surfaces/discs) whose reactions with ozone yields to the emission of photons (usually in the visible wavelength range) that are detected with a photomultiplier. The first instrument was described by Regener (1960). For an excellent review, especially of the early work in the 1960s to 1980s (see Weinheimer, 2006; Muller et al., 2010, and references therein).

Important to note is the fact that dry CI techniques are not absolute, i.e. they need frequent calibration in periods of 1 to 60 min, depending on the scientific requirements, the sensor disc that is used, and ambient conditions (e.g. water mixing ratio). See Sect. 6 for more discussion.

To our knowledge, four types of dry CI ozone instruments have been used during the last ~20 years: (1) a commercial, battery-powered instrument (Drummond et al., 1991)

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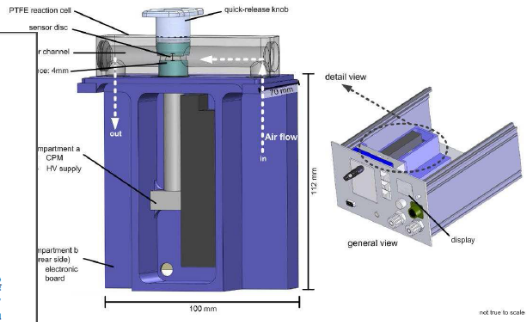
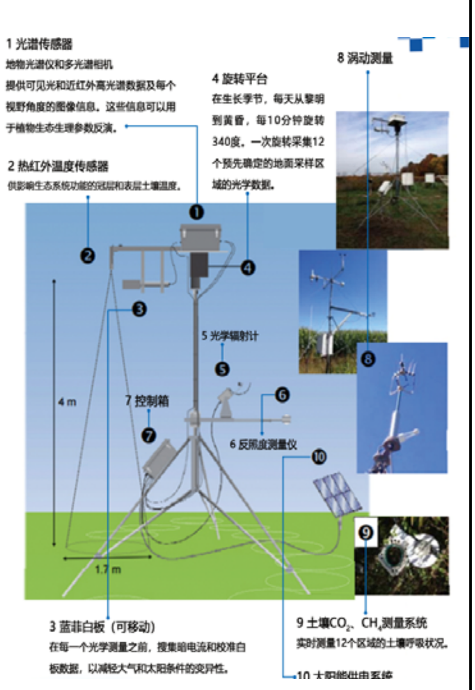




通量系统：土壤-大气界面CO2/H2O/痕量气体通量

总初级生产力（Gross primary productivity，GPP）是指单位时间内生物（主要是绿色植物）通过光合作用所固定的有机碳量，又称总第一性生产。

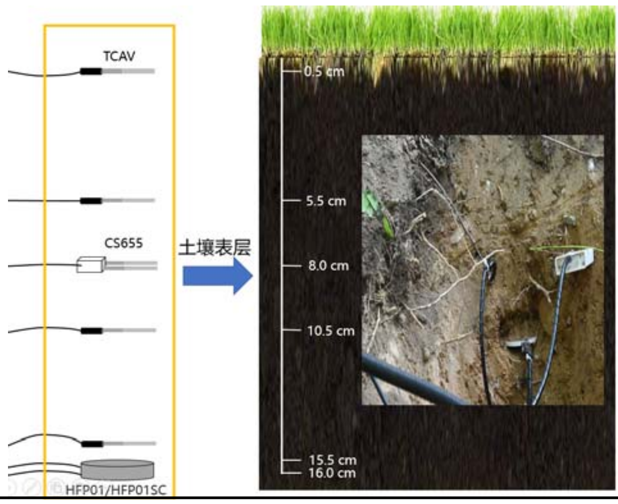
净初级生产力（Net primary productivity, NPP）表示植被所固定的有机碳中扣除本身呼吸消耗的部分，也称净第一性生产力。NPP反映了植物固定和转化光合产物的效率，也决定了可供异养生物（包括各种动物和人）利用的物质和能量。

净生态系统生产力（Net ecosystem productivity, NEP）指净初级生产力中减去异养生物呼吸消耗（土壤呼吸）光合产物之后的部分。NEP表示较大尺度上碳的净贮存，其数值可以为正也可以为负。当NEP大于0时表示该生态系统为CO2之汇，反之则为源。

通量系统：土壤热通量

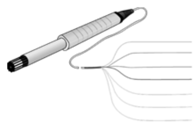
$$G = G_{Deapth} + \Delta_{storage}$$

$$\Delta_{storage} = \frac{\left[c_s\rho_s(T_{soil,f} - T_{soil,i}) + c_w p_w(T_{soil,f}q_{v,f} - T_{soil,i}q_{v,i})\right]D}{\Delta t}$$



常规气象传感器：空气温湿度、降水量等

OR



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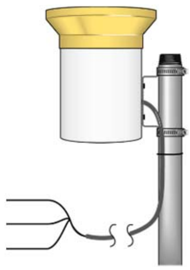


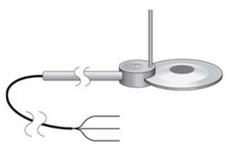
翻斗式	称重式
测量液态降水，不能承接固态降水	测量固态降水，可以监控冬季固态和固液混合性降水以及春夏对流冰雹所产生的降水量
有异物堵塞或翻斗不灵活	只需要防止电磁干扰
大雨时由于翻斗的惯性使得翻斗来不及翻转将一部分雨量流失	在发生降水时降水器口缘及内壁容易黏附引起滞后，通常固态降水越强会使误差越大
虽然翻斗的分辨率很高，翻转一次误差很小，但一次降水过程中因翻转次数多而累积起来的误差也很大。	外部无网膜隔离，内壁也无过滤网，会使得掉落的杂物也计入降水量而产生偏差或野值，且其口缘较高不容易被发现和清理

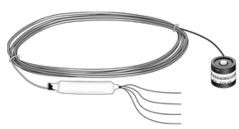
融雪型雨雪量计是利用加热、不冻液等方式将固态降水（雪、雨夹雪）融化为液态后，进行雨雪量自动测量的仪器。融雪型雨雪量计由融雪装置、雨量传感器、记录器三部分组成。

加热型	不冻液
典型融雪装置中的加热元件为管状或板状，分两组安装在传感器桶身内侧和底座上。	一般采用装有不冻液（专配）的融雪器（可与雨量传感器桶身合为一体）承接并融化降雪。融雪器内有一溢流装置，装人的不冻液平时维持在某一溢流高度，而当有固态降水进人融雪器后，不冻液的溉冰点特性可使降雪自行融化，由此引起液面升高并产生溢流，溢流出的液体进人传感器计量发信。
除了加热元件外，融雪装置中还需设置温控器。温控器一般为电接式，一旦达到设定温度时（用于检测固态降水），就接通主加热元件进行加热，以提供集水漏斗内固态降水融化所需的热量。另外，温控保险开关也是必需的，当加热温度达到上限温度时，能切断加热器电源。	不冻液的冰点应在-40℃以下，密度为0.92~0.96g/cm3，具有良好的融雪性能。为了减少挥发量，在不冻液表面一般均注有低温性能优良的防蒸发油。
桶身内有隔热保温材料衬垫，以防从桶身部散热。	由于不冻液易受环境因素（如温度、挥发等）的影响，在长期（特别是精度要求较高的情况下）使用时，其测量精度不够稳定，所以往往要采取一些补偿措施。例如，设置补液桶、温度补偿装置等。

辐射及红外传感器：辐射各分量及净辐射、总辐射、光合有效辐射及冠层温度





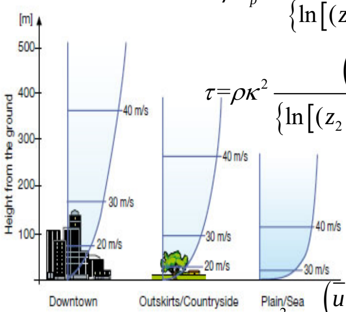



CNF4加热/通风罩

加热/强制通风罩可以防止凝露在辐射表窗口上，提高测量精度和可靠性。

可以通过程序控制加热器电源。当辐射值低于20W/m^{2}时打开加热；者如果可以计算露点温度的话，当仪器温度接近到露点时，打开加热器。

廓线系统：CO2/H2O/痕量气体廓线系统/空气温度/湿度廓线、土壤温度/水分廓线



$$H=\rho c_p \kappa^2 \frac{(\bar{u}_2-\bar{u}_1)(\bar{\theta}_2-\bar{\theta}_1)}{\{\ln[(z_2-d)/(z_1-d)]\}^2}$$

$$\tau=\rho \kappa^2 \frac{(\bar{u}_2-\bar{u}_1)^2}{\{\ln[(z_2-d)/(z_1-d)]\}^2}$$

$$E=\rho \kappa^2 \frac{(\bar{u}_2-\bar{u}_1)(\bar{q}_2-\bar{q}_1)}{\{\ln[(z_2-d)/(z_1-d)]\}^2}$$

$$\lambda E=\rho \lambda \kappa^2 \frac{(\bar{u}_2-\bar{u}_1)(\bar{q}_2-\bar{q}_1)}{\{\ln[(z_2-d)/(z_1-d)]\}^2}$$

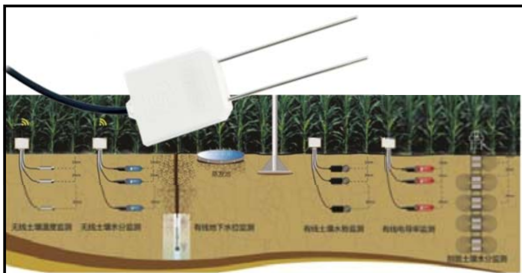
$$F_c=\rho \kappa^2 \frac{(\bar{u}_2-\bar{u}_1)(\bar{c}_2-\bar{c}_1)}{\{\ln[(z_2-d)/(z_1-d)]\}^2}$$

作为一个网络测量，在冠层之上个某个任意高度做的单次测量的价值有限。假设风速廓线呈对数，那么可以通过分析冠层界面上开展的多个观测风速廓线的测量确定阻尼系数、粗糙长度的零平面位移。

储存项可以通过在所有高度同等吸入空气的良好混合的进气口总管的持续测量来量化，并且浓度廓线的形状和变化经常包含重要的生态信息。在冠层顶部以下的测量水平层对于拟合廓线和正确估算储存项至关重要。

测量层数的要求

安装位置的要求



当前测量方法所面临的挑战

通过开挖土壤并在不同深度下从侧面横向插入安装多个传感器被认为是获取土壤剖面水分的最佳方式。然而，该方法却存在多个明显的局限性：

•首先，安装费时费力；

•可能需要动用大型机械；

•将破坏土壤原状。

土壤剖面传感器通过集成多个传感器，可以实现不同深度下的土壤剖面测量。但是，此类传感器往往具有以下重大缺陷：

•传感器可能与土壤接触不佳，从而引入测量误差；

•水流将沿传感器外侧更快地入渗到深层土壤中(土壤优势流)，这也将影响测量结果。

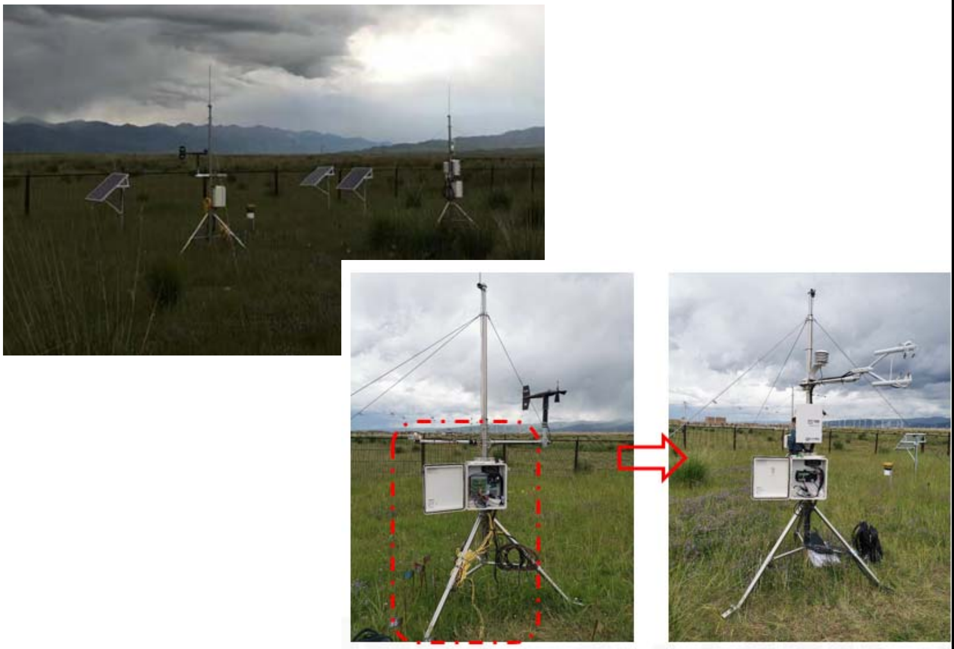
传感器结构设计

SoilVUE ™ 10 通过结构设计解决了扰动土壤、土壤接触和优势流这三大问题。与其它土壤剖面传感器类似，安装SoilVUE ™ 10 时只需预先钻孔即可，从而尽可能地避免对土壤原状的干扰。与其它传感器不同的是，SoilVUE ™ 10 采用了独特的螺纹设计。安装时，螺纹将嵌入到安装孔中，这样做的好处是：

•测量的探针复合在螺纹中，充分保证与土壤间的紧密接触；

•减慢甚至消除土壤优势流。

2. 状态传感器与通量系统**协同观测**的必要性和科学意义

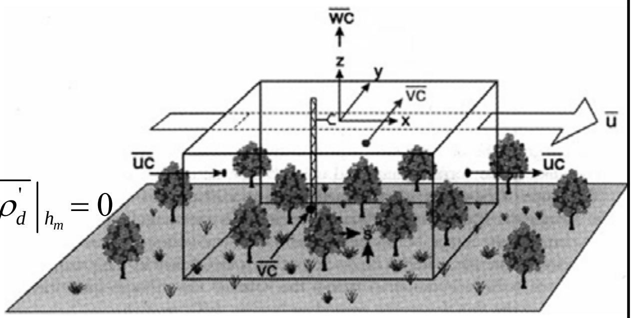


- 参与通量系统计算能量平衡、净生态系统生产力（NEE）；校正/插补通量观测结果；
- 可以获得更加全面的生态学和气象学观测结果；
- 监控通量系统运行状态，参与控制关键运行过程

NEE计算方程

干空气收支方程

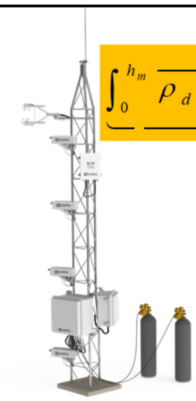
$$\int_0^{h_m}\frac{\partial\overline{\rho_d}}{\partial t}dz+\overline{w}\,\overline{\rho_d}\Big|_{h_m}+\overline{w'\rho_d'}\Big|_{h_m}=0$$



在均匀地势中的一个控制容积上的综合示意图 Finnigan et al. 2003

标量收支方程（广义涡度协方差方法）

$$\frac{1}{4L^2}\int_{-L}^{L}\int_{-L}^{L}\int_0^{h_m}\left[\underbrace{\overline{\rho_d}\frac{\partial\overline{\chi_s}}{\partial t}}_{I}+\underbrace{\overline{\rho_d}\,\overline{u}\frac{\partial\overline{\chi_s}}{\partial x}+\overline{\rho_d}\,\overline{v}\frac{\partial\overline{\chi_s}}{\partial y}+\overline{\rho_d}\,\overline{w}\frac{\partial\overline{\chi_s}}{\partial z}}_{II}+\underbrace{\frac{\partial\overline{\rho_d u'\chi_s'}}{\partial x}+\frac{\partial\overline{\rho_d v'\chi_s'}}{\partial y}}_{III}+\underbrace{\frac{\partial\overline{\rho_d w'\chi_s'}}{\partial z}}_{IV}\right]dzdxdy=\frac{1}{4L^2}\int_{-L}^{L}\int_{-L}^{L}\underbrace{\int_0^{h_m}\overline{S_s}dzdxdy}_{V}$$



$$\underbrace{\int_0^{h_m}\overline{\rho_d}\,\overline{w}\frac{\partial\overline{\chi_s}}{\partial z}dz}_{I}+\underbrace{\overline{\rho_d w'\chi_s'}\Big|_{h_m}}_{II}=\underbrace{F_s}_{V}$$

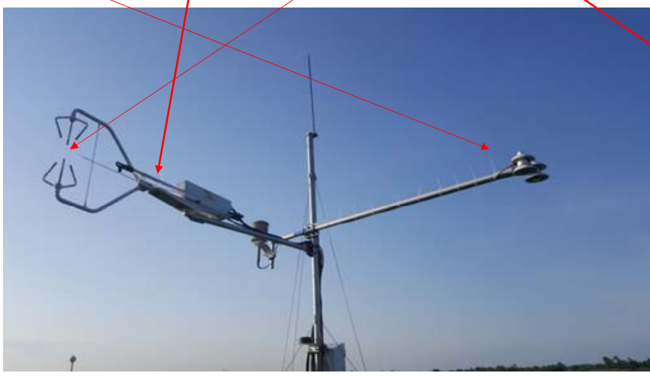
这个方程式广义涡度协方差的基础，它明确指出，一个由生态系统交换的标量通量能够被估算在高度垂直涡度协方差以及土壤与这个高度之间的标量存储量的变化的总和。

由上述方程可知，准确测算观测对象生态系统水、碳通量应该由**涡动协方差设备**和**廓线设备**共同观测得到，并且观测及计算处理要保证时间同步性。

能量平衡计算方程

Rn = LE + H + G (W m^{-2} s^{-1})

净辐射通量　潜热通量　感热通量　地表热通量



配置的空气温湿度传感器用于监测通量系统的工作状态

$$e_s = \begin{cases} 0.61121\exp\left(\frac{17.368T}{T+238.88}\right) f_w(T,P) & T \ge 0 \\ 0.61121\exp\left(\frac{17.966T}{T+247.15}\right) f_w(T,P) & T < 0 \end{cases}$$

$$f_w(T,P) = 1.00041 + P\left[3.48\times10^{-5} + 7.4\times10^{-9}\left(T + 30.6 - 0.38P\right)^2\right]$$

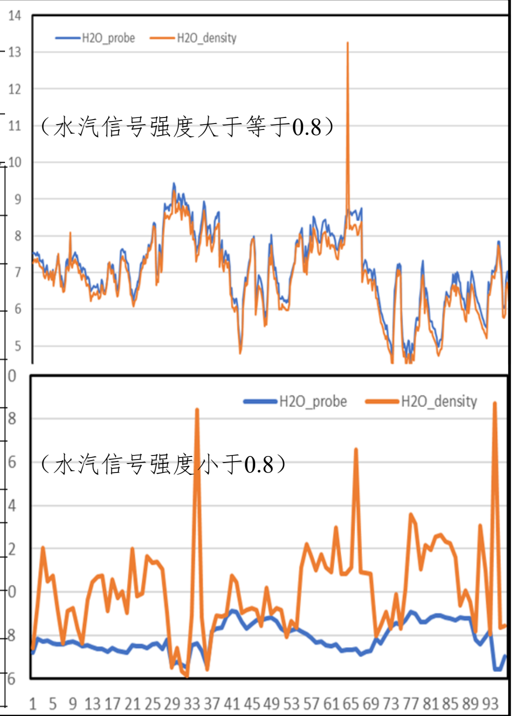
$$e = e_s\frac{RH}{100}$$

Buck, A. L.: 1981, “New equations for computing vapor pressure and enhancement factor”, J. Applied Meteorol., 20:1527-1532.

$$H_2O = \frac{e}{(T+273.15)*Rv}$$

Rv为水汽的气体常数，R/18.016
page 467 in Wallace AND Hobbs (2006)

TA_1_1_1	deg C	Average ambient temperature from EC100 temperature probe
RH_1_1_1	deg C	Relative humidity calculated from TA_1_1_1 (EC100 temperature probe), water vapor density, and pressure.
T_DP_1_1_1	deg C	Average dewpoint temperature calculated using temperature from the EC100 temperature probe
amb_e	kPa	Average water vapor pressure calculated using temperature from the EC100 temperature probe
amb_e_sat	kPa	Average saturated water vapor pressure calculated using temperature from the EC100 temperature probe
TA_2_1_1	deg C	Average ambient temperature calculated from sonic temperature, water vapor density, and pressure
RH_2_1_1	deg C	Average dewpoint temperature calculated using sonic temperature, water vapor density, and pressure
T_DP_2_1_1	deg C	Average dewpoint temperature calculated using sonic temperature, water vapor density, and pressure
e	kPa	Average water vapor pressure calculated from sonic temperature
e_sat	kPa	Average saturated water vapor pressure calculated from sonic temperature
TA_3_1_1	deg C	Average air temperature from temp/RH probe
RH_3_1_1	%	Average relative humidity from temp/RH probe
T_DP_3_1_1	deg C	Average dewpoint temperature from temp/RH probe
e_probe	kPa	Average saturation vapor pressure derived from gas analyzer measurements
e_sat_probe	kPa	Average vapor pressure derived from gas analyzer measurements
H2O_probe		Average water vapor density derived from temp/RH probe measurements



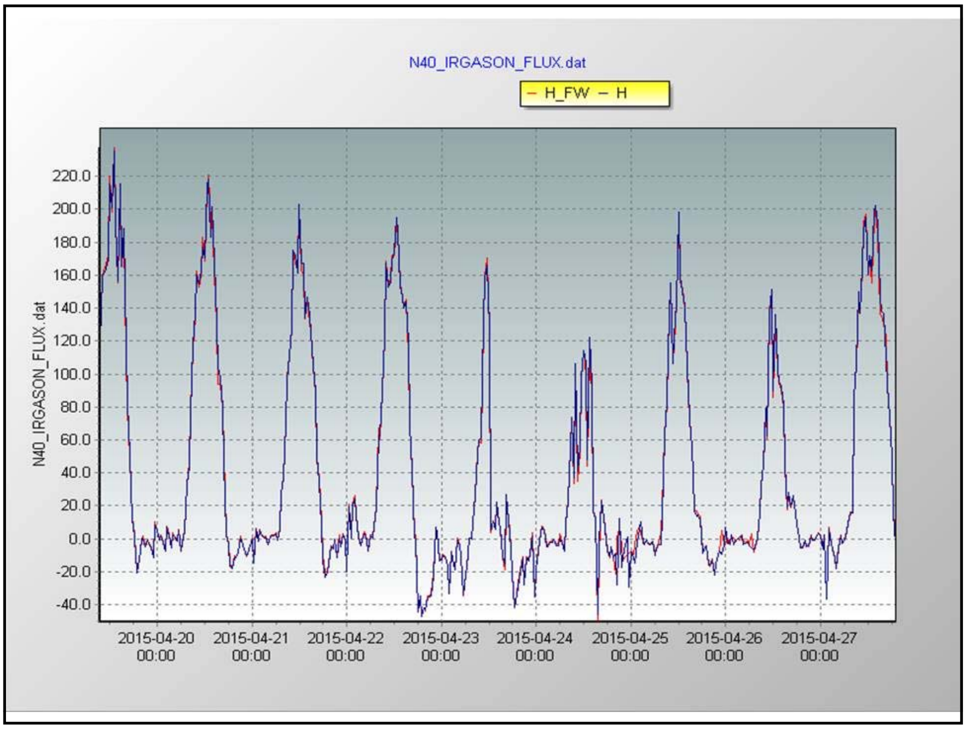
配置的FW3直接测得感热通量以监测系统的工作状态

$$H = -\rho c_p \overline{w'T'}$$

$$T_s = T(1 + 0.51q)$$

$$q = \frac{\rho_w}{\rho_d + \rho_w}$$

$$T_s = T(1 + 0.51\frac{\rho_w}{\rho_d + \rho_w})$$



TimeStamp	RECORD RN	Message	Current	Previous
		Smp	Smp	Smp
2019-03-25 10:04:33	0	"CPEC started."	"Starting"	"Sleeping"
2019-03-25 10:05:36	1	"Previous EC100 config recorded."	"Recording"	"Starting"
2019-03-25 10:05:36	2	"EC100 w/ required configuration."	"Configuring"	"Recording"
2019-03-25 10:06:06	3	"Warmup finished: To mode recorded."	"FLD_MEA"	"
2019-03-25 10:06:06	4	"To FLD_MEA through equilibration."	"FLD_MEA"	"
2019-03-25 10:06:36	5	"Equilib finished to FLD_MEA."	"FLD_MEA"	"
2019-03-26 00:32:00	6	"TO AUTO_ZS cycle;"	"AUTO_ZS"	"
2019-03-26 00:32:01	7	"Zero/Span: Transition."	"fld smp"	"
2019-03-26 00:32:16	8	"Zero/Span: Press offset."	"offst P"	"
2019-03-26 00:33:36	9	"Zero checked."	"chk zro"	"
2019-03-26 00:33:37	10	"Zero performed."	"set zro"	"
2019-03-26 00:34:16	11	"Equilib finished to FLD_MEA."	"FLD_MEA"	"
2019-03-29 00:32:00	12	"TO AUTO_ZS cycle;"	"AUTO_ZS"	"
2019-03-29 00:32:01	13	"Zero/Span: Transition."	"fld smp"	"
2019-03-29 00:32:16	14	"Zero/Span: Press offset."	"offst P"	"
2019-03-29 00:33:36	15	"Zero checked."	"chk zro"	"
2019-03-29 00:33:37	16	"Zero performed."	"set zro"	"
2019-03-29 00:34:16	17	"Equilib finished to FLD_MEA."	"FLD_MEA"	"
2019-04-01 00:32:00	18	"Zero/span not started; Raining."	"AUTO_ZS"	"
2019-04-04 00:32:00	19	"Zero/span not started; Raining."	"AUTO_ZS"	"
2019-04-07 00:32:00	20	"Zero/span not started; Raining."	"AUTO_ZS"	"

3.通量观测与廓线系统相结合的综合系统的主要特点、配置及应用实例

综合系统在复杂植被系统研究中观测的优势及实现；

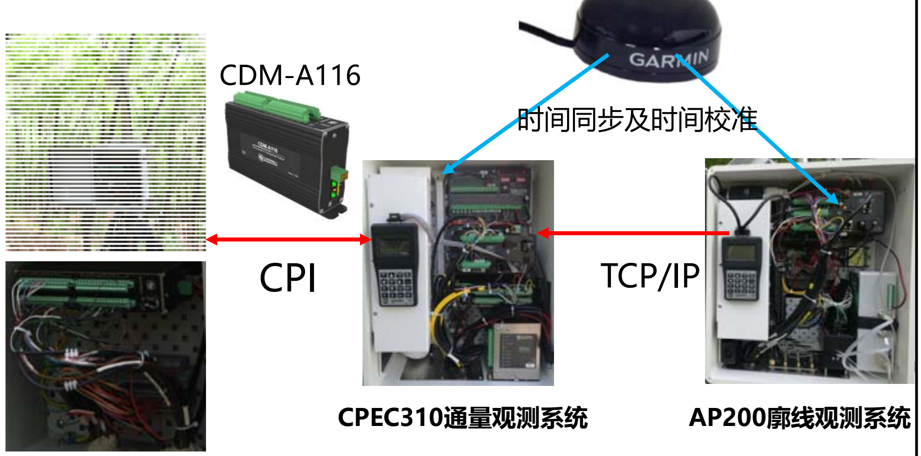
综合系统在时间上的统一方法；

综合系统的各个分析系统的通讯和变量交换；

应用实例介绍

简要介绍

各分析统的通讯，变量交换及时间统一

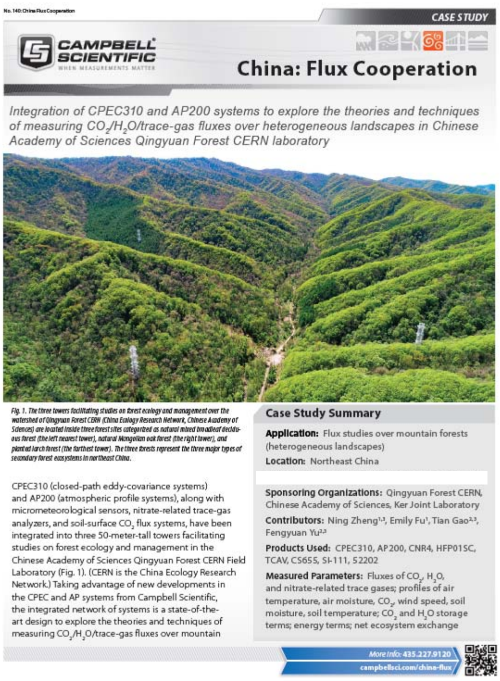


土壤观测系统测算单元

控制土壤廓线\土壤热通量\附近观测设备。

控制土壤廓线CO2\H2O廓线、风速廓线等系统的测算及数据处理。

从CPEC310系统获取相关通量、气象土壤数据，统一整合计算NEE数据。



No. 140: China Flux Cooperation

CASE STUDY

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

China: Flux Cooperation

Integration of CPEC310 and AP200 systems to explore the theories and techniques of measuring CO_2/H_2O/trace-gas fluxes over heterogeneous landscapes in Chinese Academy of Sciences Qingyuan Forest CERN laboratory

Fig. 1. The three towers facilitating studies on forest ecology and management over the watershed of Qingyuan Forest CERN (China Ecology Research Network, Chinese Academy of Sciences) are located inside three forest sites categorized as natural mixed broadleaf deciduous forest (the left nearest tower), natural Mongolian oak forest (the right tower), and planted larch forest (the farthest tower). The three forests represent the three major types of secondary forest ecosystems in northeast China.

CPEC310 (closed-path eddy-covariance systems) and AP200 (atmospheric profile systems), along with micrometeorological sensors, nitrate-related trace-gas analyzers, and soil-surface CO_2 flux systems, have been integrated into three 50-meter-tall towers facilitating studies on forest ecology and management in the Chinese Academy of Sciences Qingyuan Forest CERN Field Laboratory (Fig. 1). (CERN is the China Ecology Research Network.) Taking advantage of new developments in the CPEC and AP systems from Campbell Scientific, the integrated network of systems is a state-of-the-art design to explore the theories and techniques of measuring CO_2/H_2O/trace-gas fluxes over mountain

Case Study Summary

Application: Flux studies over mountain forests (heterogeneous landscapes)

Location: Northeast China

Sponsoring Organizations: Qingyuan Forest CERN, Chinese Academy of Sciences, Ker Joint Laboratory

Contributors: Ning Zheng[1,3], Emily Fu[1], Tian Gao[2,3], Fengyuan Yu[2,3]

Products Used: CPEC310, AP200, CNR4, HFP01SC, TCAV, CS655, SI-111, 52202

Measured Parameters: Fluxes of CO_2, H_2O, and nitrate-related trace gases; profiles of air temperature, air moisture, CO_2, wind speed, soil moisture, soil temperature; CO_2 and H_2O storage terms; energy terms; net ecosystem exchange

More Info: 435.227.9120
campbellsci.com/china-flux

基于中科院沈阳应用生态所清原站的应用实例及示范系统2和系统3介绍综合系统的构建与应用

小结

高质量的观测和高质量的数据是解决科学问题，完成科研工作的重要基础。

高质量的数据不仅仅是后期的数据处理和插补，这是一个系统的工作和团队的协作的结果：
初期：
站点位置的选择和观测方案的确定。
通量观测设备和相关传感器类型配置的确定。

中期:
了解设备的基本观测原理和监控设备的运行状态。
做好站点及设备的运维工作，保证设备的长期运行稳定。

后期：
数据处理和深入分析，多种数据深度融合，发掘更多的科学信息。

谢谢！