

**Challenged with Problems in Biometeorology:
What Would Ray Do?**



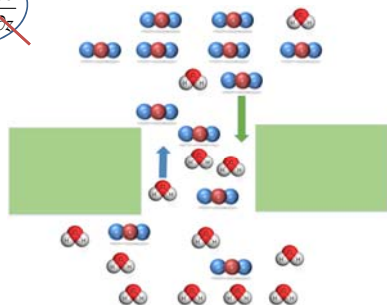
Dennis Baldocchi
University of California, Berkeley
Agricultural and Forest Meteorology Conference,
May 2014, Portland, OR

Key Contributions

- Leaves
 - Theory on Viscous and Diffusive Transport
 - Stomatal Models
 - Energy Balance and Frost
 - Ozone Deposition
- Canopies
 - Pioneering CO₂ and CH₄ Flux measurements
 - Webb-Pearman-Leuning Theory on Density Corrections
 - Treatise on Energy Balance
 - Coupled Theory on Soil-Vegetation-Atmosphere Exchange
 - Scaling Fluxes with Light and Nitrogen
- Landscapes/Regions
 - Coupling Remote Sensing and Eddy Covariance

Problem 1: Bi-Directional Diffusion of Gases Through Pores

~~$F_c = -D_c \frac{\partial c}{\partial z}$~~
Fick's Law



Plant, Cell and Environment (1983) 6, 181-194

Transport of gases into leaves

R. LEUNING CSIRO Division of Environmental Mechanics, Canberra, ACT, Australia

For Diffusion of multi-component gas mixtures through Pores you must use the Stefan Maxwell law, rather than the simpler Fick's Law

The viscous and diffusive flux densities must be added to obtain the total flux density, thus

$$N_1 = - \left[\frac{D_{12} D_{11}^k}{D_{12} + D_{12}^k} \right] \frac{p}{RT} \frac{\partial x_1}{\partial z} - \left[\frac{D_{11}^k (D_{12} + D_{22}^k) + B_k p}{D_{12} + D_{12}^k + \mu} \right] \frac{x_1}{RT} \frac{\partial p}{\partial z} \quad (12)$$

Problem 2: Modeling Stomatal Conductance

Leaf Leaf section Stomata

<http://www.meritnation.com/ask-answer/question/13-what-are-stomata-write-their-structure-and-their-function/issues/2738665>

Plant Cell and Environment 1993, 16, 359-363

THEORETICAL PAPER
A critical appraisal of a combined stomatal-photosynthesis model for C_3 plants

Modelling Stomatal Behaviour and Photosynthesis of *Eucalyptus grandis*

$$g_s = g_0 + a_t A / (C_s - \Gamma) (1 + \frac{D}{D_0})$$

Stomatal Conductance Scales with Photosynthesis (A) and Vapor Pressure Deficit (D)

Leuning vs Ball-Berry Model

mean = 9.8117
95% CI = 10.0270

g_s ($\text{mol m}^{-2} \text{s}^{-1}$)

ARH/C_i ($\text{mol m}^{-2} \text{s}^{-1}$)

Critique

- Parsimony
 - BB has one unknown, $\sim 10 \pm 0.8$; Leuning has two unknowns
- Mechanism
 - Water Moves across humidity gradients, so g_s should be a function of D (R. Leuning)
 - But $RH = (1 - D) / es(T)$ (ddb)
- Validation
 - BB works across wide range of leaf water potentials (0 to -5.0 MPa) (Ball, dissertation; Xu and ddb)
- Prediction
 - BB leads to accurate predictions of H, LE and Fc in leaf to canopy scaling models
 - Leuning will do better for global change assessments; D is a function of $es(T)$, while BB is a function of RH;
 - RH is assumed constant, or conservative, with climate change (Katul, personal communication)

Problem 3, Modeling Soil-Plant-Atmosphere Continuum

The diagram illustrates a tree with various resistances and fluxes. At the soil level, there is a resistance R_{soil} and a flux J_{soil} . The stem has a resistance R_{stem} and a flux J_{stem} . The canopy has a resistance R_{canopy} and a flux J_{canopy} . A small inset image shows a blue sky with white clouds.

Plant Cell and Environment 2010, 28, 1057-1116

A coupled model of stomatal conductance, photosynthesis and transpiration

A. W. MOSELEY, A. H. HARRISON & G. J. LEITCH

Department of Graduate Courses (ENGL 1, ENL 2, ENL 3) School of Biological Sciences, Physics and Environmental Land and Water, The University of Queensland, St. Lucia, Australia

Figure 1 shows a schematic of a plant with various resistances and fluxes. Graph (b) shows stomatal conductance g_s (MPa) over time (d) from 5 to 25. Graph (c) shows photosynthesis P_{CO_2} (mol m⁻² s⁻¹) over time (d) for day 6, day 15, and day 20, with morning and afternoon measurements.

Problem 4, How to Measure and Interpret Eddy Fluxes of CO₂ and Water?

The photograph shows an eddy flux measurement site with solar panels and a flux tower in a field.

1st Commandment of Biometeorology: 'Know Thy Site'

The photographs show different measurement sites: a flux tower in a field, a flux tower in a forest, and a flux tower in a field.

Quart. J. R. Met. Soc. (1986), 116, pp. 87-100
351.516.3 : 551.511.61

Correction of flux measurements for density effects due to heat and water vapour transfer

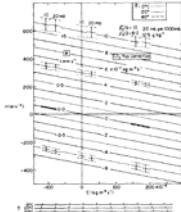
By E. K. WEBB, G. I. PEARMAN and R. LEUNING*

E. K. WEBB, G. I. PEARMAN
CSIRO Division of Atmospheric
Physics, Aspendale, Victoria
3207, Australia

R. LEUNING*
Department of Land Resource
Science, University of Guelph,
Guelph, Ontario N1G 2W1, Canada

Pearman


Cited > 1700 times




$$F = \overline{w' \rho_c'} + \mu(\overline{\rho_c} | \overline{\rho_a}) \overline{w' \rho_v'} + (1 + \mu\sigma)(\overline{\rho_c} | \overline{T}) \overline{w' T'}$$

'I wish I had a correction named after me'

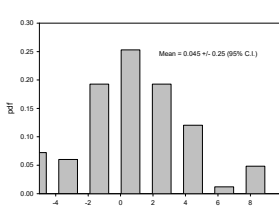
P. Jarvis, author of the Jarvis Stomatal Conductance Model



Testing Density Fluctuation Corrections at Moffatt Field

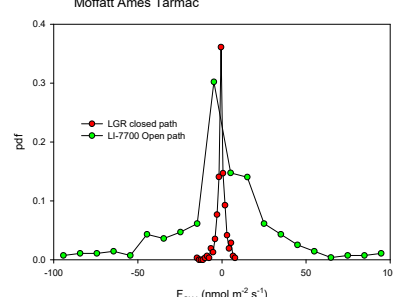


Moffatt Field, Tarmac



Mean = 0.045 ± 0.25 (95% CI)

Moffatt Ames Tarmac



pdf

F_{CH₄} (nmol m⁻² s⁻¹)

● LGR closed path
● LI-7700 Open path

While Fch4 is sensitive to H, as on Tarmac, H is relatively Small over Wet, Methane Producing Wetlands

Journal of Agricultural and Forest Meteorology 194 (2014) 10–15

Journal of Agricultural and Forest Meteorology

Reflections on the surface energy imbalance problem
 Ray Leuning^{a,*}, Eva van Gorsel^a, William J. Mansueti^a, Peter R. Keenan^a

^aClosure of the energy balance is possible at half-hourly time scales by careful attention to all sources of measurement and data processing errors in the eddy covariance system and by accurate measurement of net radiation and every energy storage term needed to calculate available energy.

Problem 5: How Do We Extrapolate Leaf-Level Information to the Canopy Scale, and Elsewhere?

Plant, Cell and Environment (2006) 9, 1183–1202

Leaf nitrogen, photosynthesis, conductance and transpiration: scaling from leaves to canopies

R. LEUNING¹, F. M. KELLNER², D. G. DE PURY¹ & E. D. SCHULZE³

Non-Linear Photosynthesis-Light Response Curve becomes Linearized; Its slope is a function of Nitrogen

Up Scaling Fluxes with Remote Sensing

Carbon and water fluxes over a temperate Eucalyptus forest and a tropical savanna across six Australian measurement and comparison with MODIS remote sensing estimates

Regional evaporation estimates from flux tower and MODIS satellite data

Ray Leuning, International Collaborator + Advisor



FLUXNET La Thuile, 1995 + 2007

Asia Flux, Korea



Fluxnet, Lake Tahoe

AsiaFlux, 2010

Thanks Ray, Job Well Done!



Agricultural and Forest Meteorology, 42 (1988) 135-150
Elsevier Science Publishers B.V., Amsterdam - Printed in The Netherlands

**LEAF TEMPERATURES DURING RADIATION FROST
PART II. A STEADY STATE THEORY**

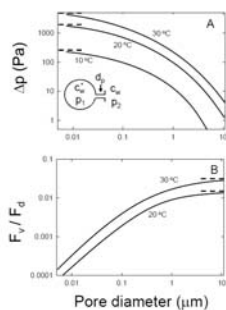
115

Agricultural Meteorology, 20(1979) 115-135
© Elsevier Scientific Publishing Company, Amsterdam - Printed in The Netherlands

OZONE UPTAKE BY CORN (ZEA MAYS L.): A GENERAL APPROACH

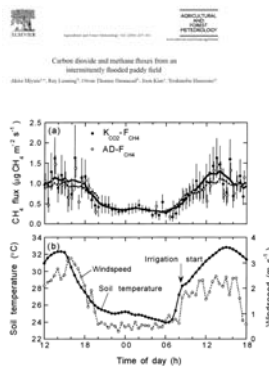
R. LEUNING¹, H. H. NEUMANN² and G. W. THURTELL¹

Viscous vs Diffusive Fluxes are a Function of Pore Diameter



Modified from Leuning, 1983

Other Trace Gas Fluxes



$$F_{\text{CH}_4} = \frac{\Delta s_{\text{CH}_4}}{\Delta s_{\text{CO}_2}} F_{\text{CO}_2}$$