On the isotopic composition of leaf water in the non-steady state

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Outline

- Introduction
- Theory
- Discussion

Introduction

- The isotopic composition of water in leaves play an important role to research environment and ecosystem sciences.

- The isotopic composition of water in a leaf is heterogeneous. And the first equation to calculate the isotopic composition was developed by Craig and Gordon for the surface of water bodies, and adapted by Dongmann et al. for leaves.

- This paper's purpose is to derive an equation for leaf water enrichment in non-steady state , the derivation is similar to that by Dogmann et al. and the equation takes into account the P éclet effect and effects of changes in leaf water content , which was missing from the treatment by Dogmann et al..

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Theory

$$\frac{d(R_L W)}{dt} = R_S J - R_E E \Longrightarrow \frac{d(W \cdot \Delta_L)}{dt} = -E\Delta_E \quad (1)$$

- R : the isotopic ratio , subscripts L,S,E stand for leaf water, source and evaporating water
- W : water content in the leaf lamina
- E : flux of leaf lamina by evaporation
- J : source water
- Δ_E : enrichment of the transpired water, $\Delta_E = R_E/R_S - 1$
- Δ_L : leaf water enrichment, $\Delta_L = R_L/R_S - 1$

Theory

$$R_E E = \frac{g\omega_i}{\alpha_k \alpha^+}(R_e - \alpha^+ R_V h) \Longrightarrow R_S E = \frac{g\omega_i}{\alpha_k \alpha^+}(R_{es} - \alpha^+ R_V h)$$

$$-E\Delta_E = -\frac{g\omega_i}{\alpha_k \alpha^+} \cdot \frac{(R_e - R_{es})}{R_S} = -\frac{g\omega_i}{\alpha_k \alpha^+}(\Delta_e - \Delta_{es}) \quad (2)$$

$$\Delta_E = \frac{\Delta_e - \Delta_{es}}{\alpha_k \alpha^+ (1-h)} \qquad \left(h = \frac{\omega_a}{\omega_i}\right) \quad (3)$$

$$\frac{d(W \cdot \Delta_L)}{dt} = -E\Delta_E \Longrightarrow \frac{d(W\Delta_L)}{dt} = -\frac{g\omega_i}{\alpha_k \alpha^+}(\Delta_e - \Delta_{es}) \quad (4)$$

$$\Delta_e = \Delta_{es} - \frac{\alpha_k \alpha^+}{g\omega_i} \frac{d(W\Delta_L)}{dt}$$

Theory

- h : the relative humidity of the ambient air, $h = \frac{\omega_a}{\omega_i}$
- g : leaf conductance
- ω_i : the mole fraction of water vapour in the intercellular spaces
- Δ_e : evaporative site water enrichment, $\Delta_e = R_e/R_S - 1$
- Δ_{es} : the steady-state values of Δ_e, $\Delta_{es} = R_{es}/R_S - 1$
- α_k : the fractionation factor for diffusion
- α^+ : the fractionation factor for the saturated vapour pressure in equilibrium with the liquid water

Theory

$$\Delta_{Ls} = \frac{\Delta_{es}\left(1 - e^{-P}\right)}{P}$$

$$\Delta_{es} = \frac{P\Delta_{Ls}}{1 - e^{-P}} \qquad (5)$$

$$\Delta_L = \Delta_{Ls} - \frac{\alpha_k \alpha^+}{g\omega_i} \cdot \frac{1 - e^{-P}}{P} \cdot \frac{d(W \cdot \Delta_L)}{dt} \qquad (6)$$

- P : Péclet number

Theory

$$\Delta_e = \Delta_{es} - \frac{\alpha_k \alpha^+}{g\omega_i} \cdot \frac{d(W \cdot \frac{1-e^{-P}}{P} \cdot \Delta_e)}{dt} \quad (7)$$

$$\Delta_L = \Delta_{Ls} + (\Delta_{L0} - \Delta_{Ls} e)^{-t/\tau} \quad (8)$$

- $\tau = \frac{W\ \alpha_K \alpha^+}{g\omega_i} = \frac{W}{E_1}$
- This equation is Dogmann model.

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$$\frac{d(W \cdot \Delta_L)}{dt} = -E\Delta_E \qquad \Delta_L = \Delta_{Ls} - \frac{\alpha_k \alpha^+}{g\omega_i} \cdot \frac{1 - e^{-P}}{P} \cdot \frac{d(W \cdot \Delta_L)}{dt}$$

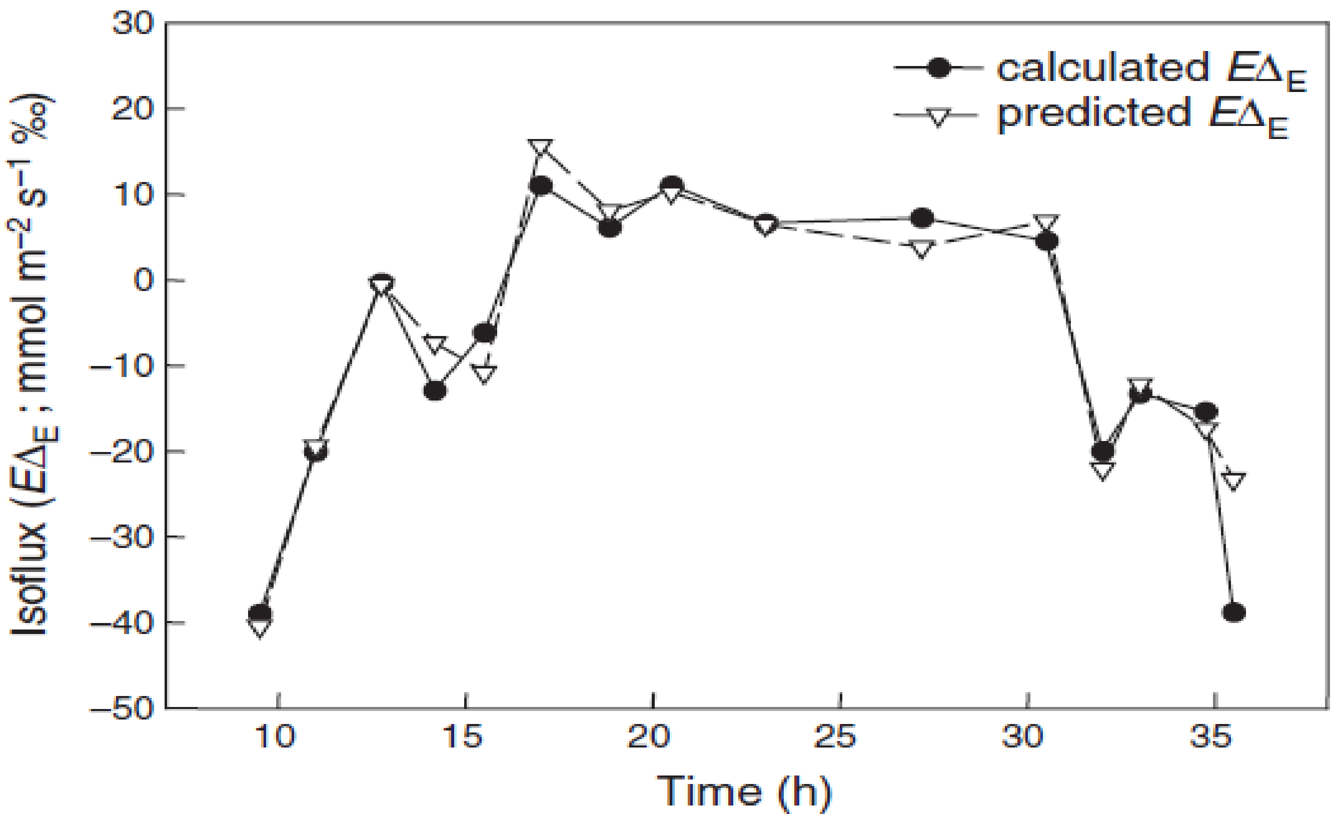

Fig.1 Time-course of variation in the calculated and predicted leaf water isoflux.

Discussion

$$\Delta_e = \Delta_{es} - \frac{\alpha_k \alpha^+}{g\omega_i} \frac{d(W\Delta_L)}{dt}$$

$$\Delta_e = \Delta_{es} - \frac{\alpha_k \alpha^+}{g\omega_i} \cdot \frac{d(W \cdot \frac{1-e^{-P}}{P} \cdot \Delta_e)}{dt}$$

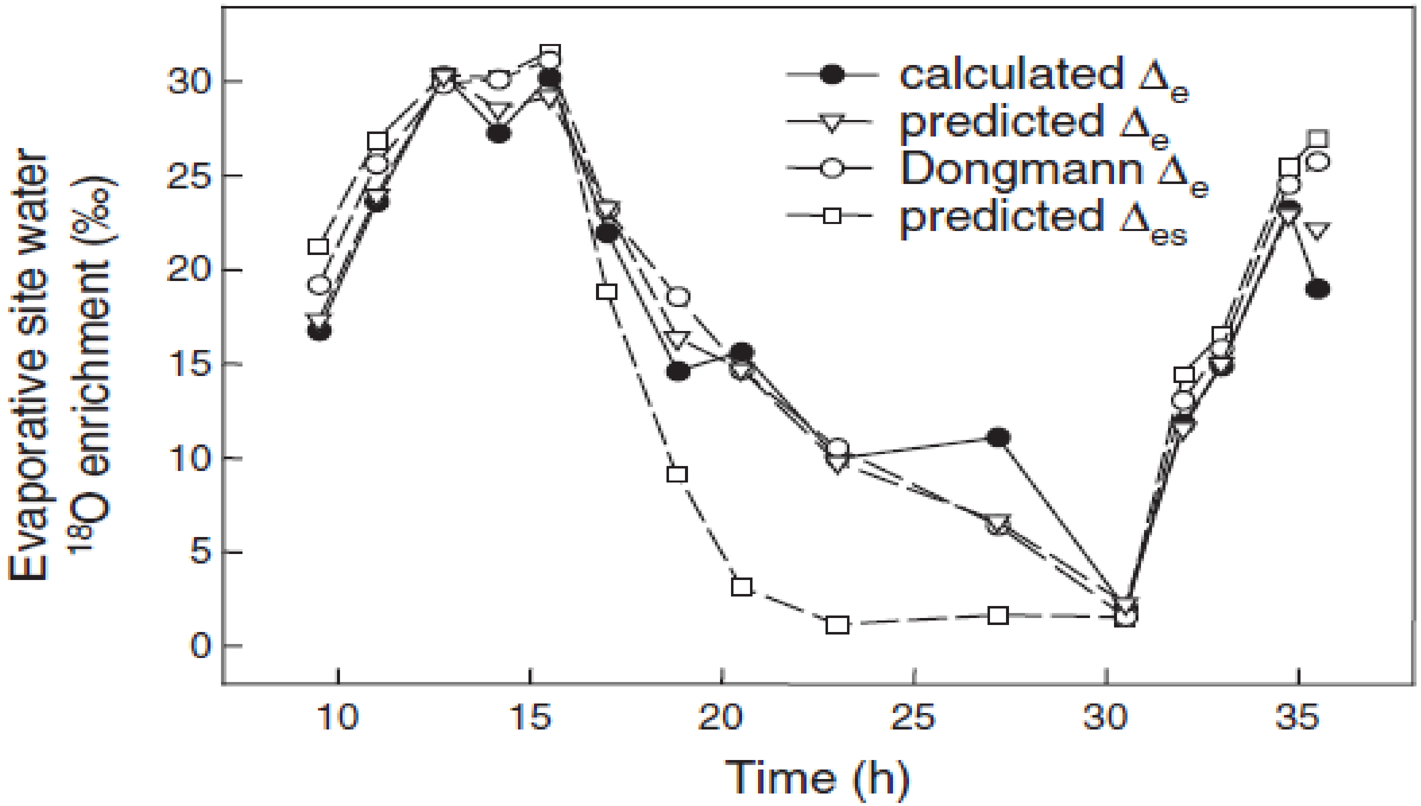

Fig.2 A comparison of the time-course of variation in calculated and predicted evaporative site water enrichment.

Discussion

$$\Delta_L = \Delta_{Ls} - \frac{\alpha_k \alpha^+}{g\omega_i} \cdot \frac{1 - e^{-P}}{P} \cdot \frac{d(W \cdot \Delta_L)}{dt}$$

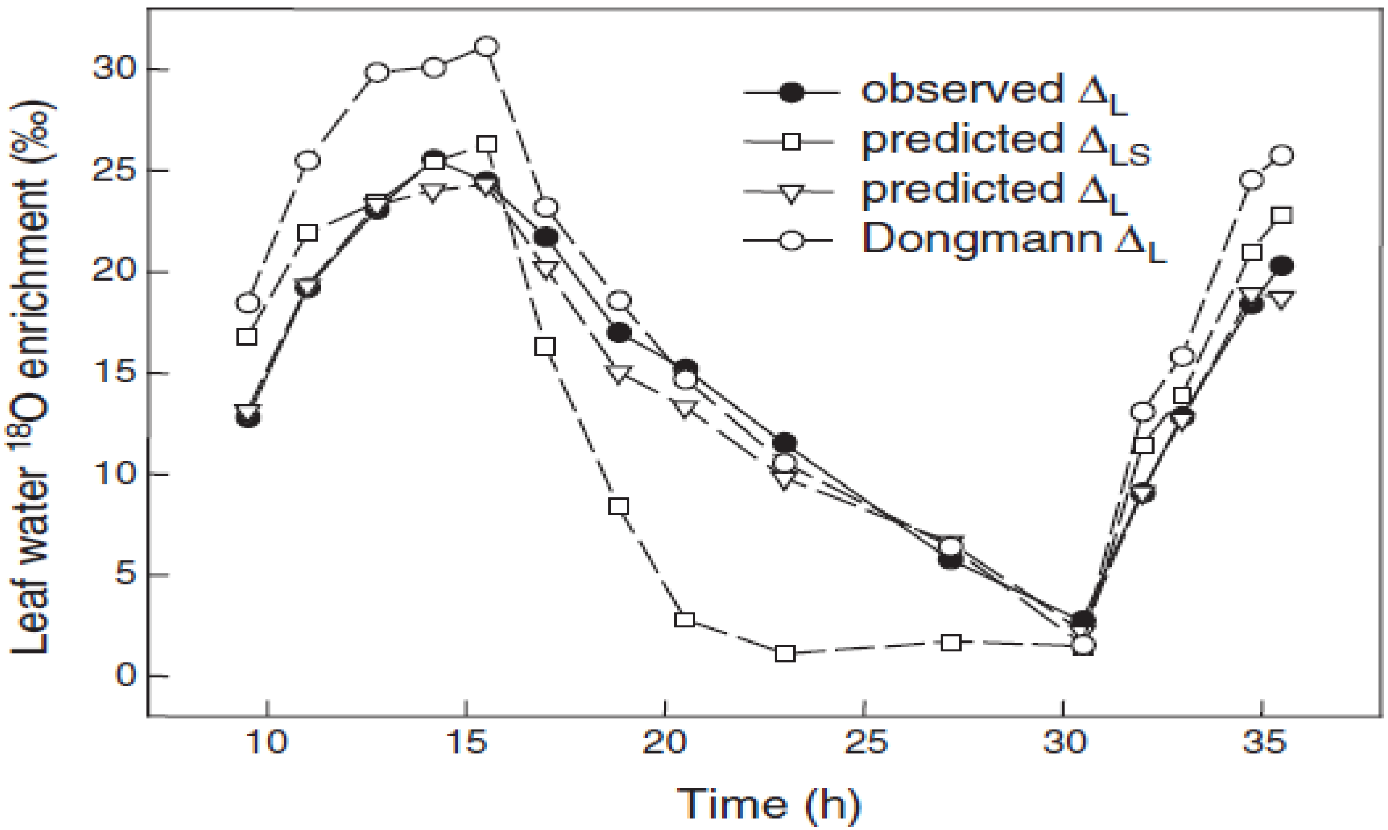

Fig.3 Time-course of variation in predicted steady state and non-steady state leaf water enrichment.

Discussion

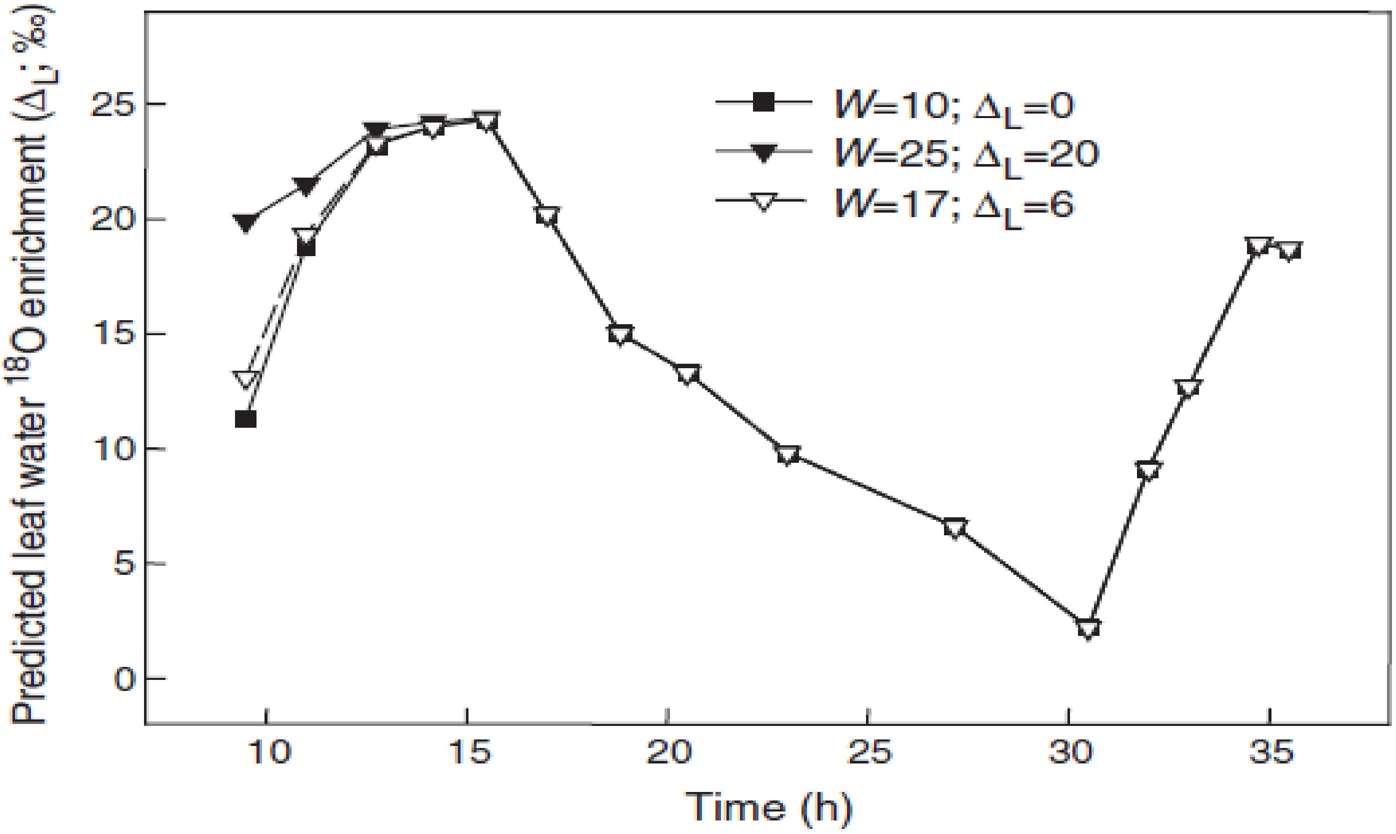

Fig.4 A comparison of the affect of changing the boundary condition on subsequent predictions of Δ_L.

Discussion

$$\Delta_e = \Delta_{es} - \frac{\alpha_k \alpha^+}{g\omega_i} \cdot \frac{d(W \cdot \frac{1-e^{-P}}{P} \cdot \Delta_e)}{dt}$$

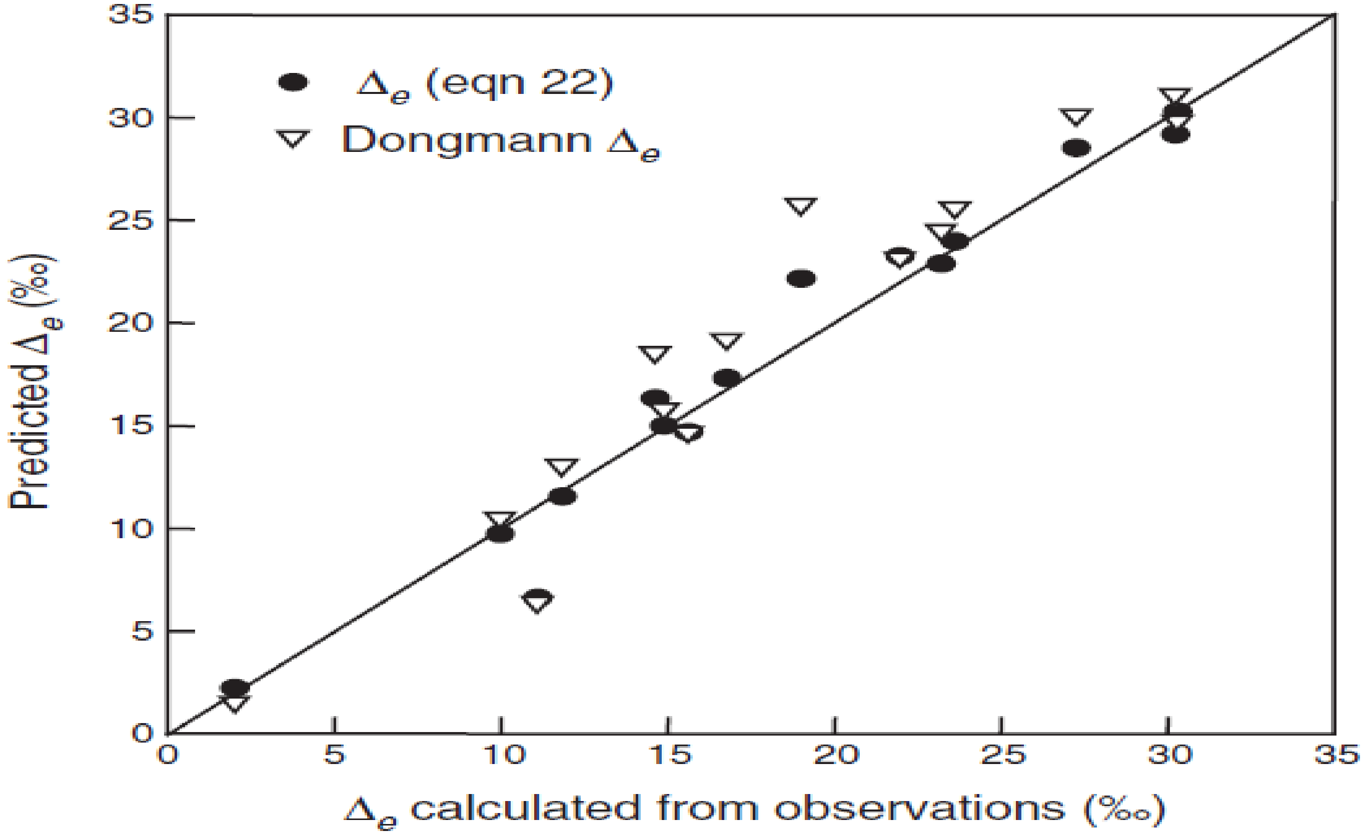

Fig.5 A comparison of Δ_e calculated from observations and predicted values for Δ_e .

Discussion

$$\Delta_L = \Delta_{Ls} - \frac{\alpha_k \alpha^+}{g\omega_i} \cdot \frac{1 - e^{-P}}{P} \cdot \frac{d(W \cdot \Delta_L)}{dt}$$

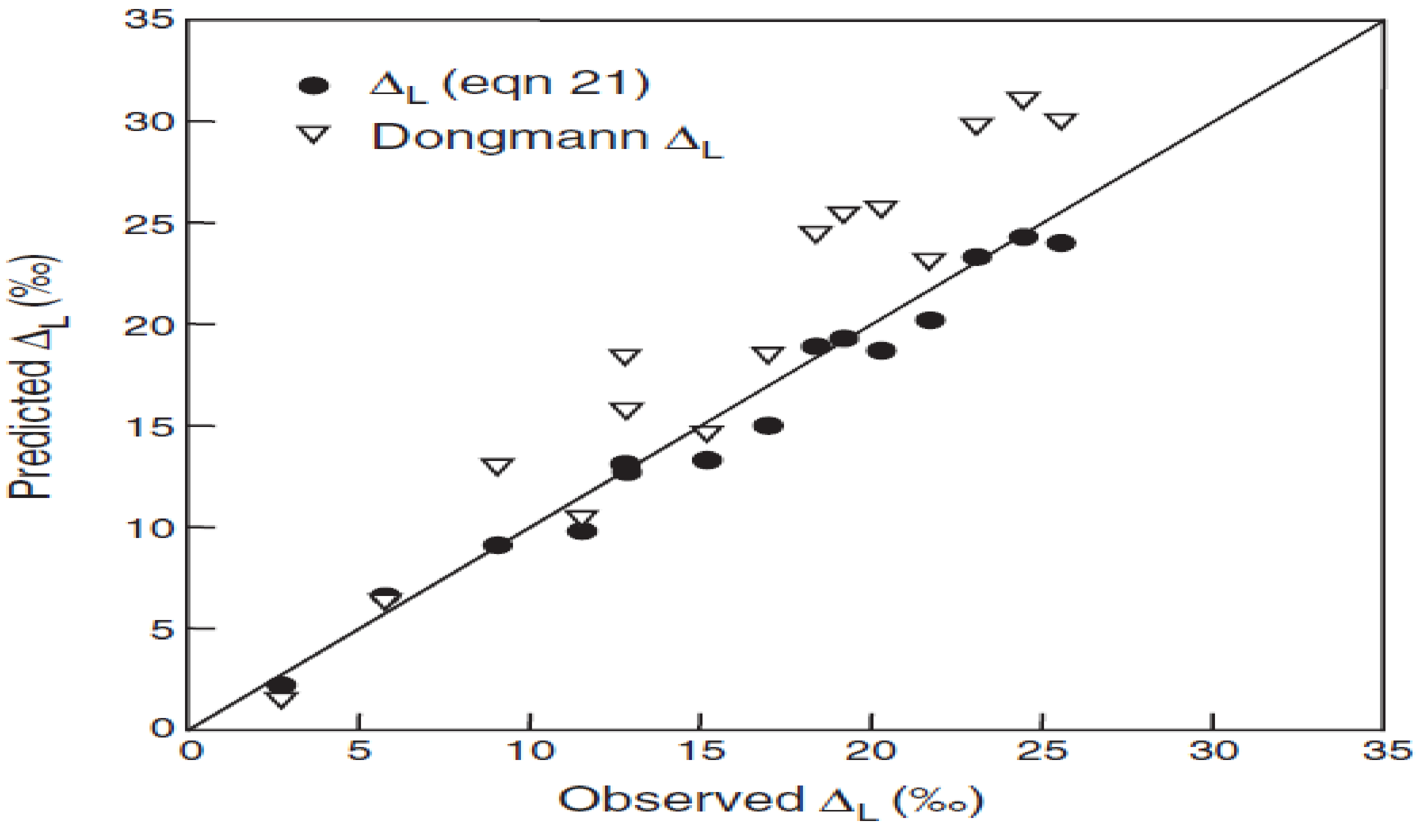

Fig.6 A comparison of observed and predicted Δ_L .

Discussion

- Taking into account the ability to model the enrichment of transpired water, the enrichment at the sites of evaporation as well as leaf water enrichment, both day and night, the new non-steady-state model is an improvement on what was previously available.

- The effects on Δ_L of changing W is small.

- At night ,the Péclet effect is small , and in the daytime, P is not negligible.

Thank You