





Estimating Respiratory and Photosynthetic Fluxes in a Heterogeneous Conifer Forest

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Introduction

- Terrestrial ecosystems represent a large amount of the net CO₂ uptake on the global scale (1.4 Gt C/yr, shown in Figure 1).

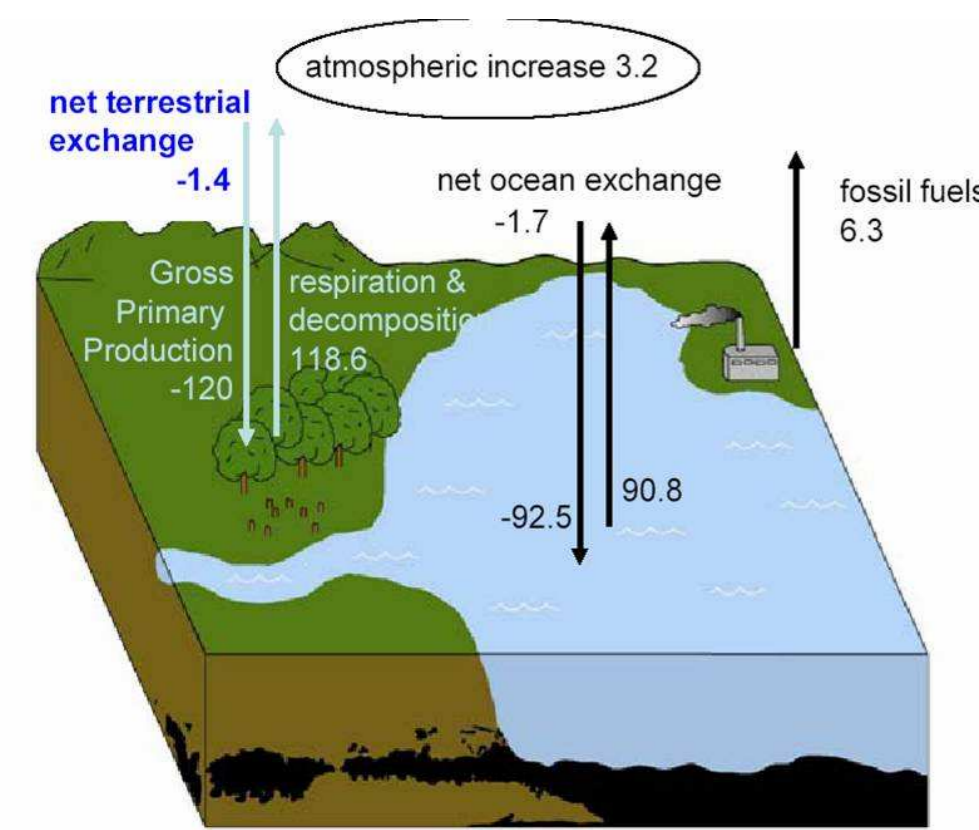


FIGURE 1: 1990s carbon cycle CO₂ fluxes from Schimel et al. (2001)

- Two challenges of carbon cycle measurements are to bridge plot scale measurements with regional estimates and to understand the influence of land cover on flux CO₂ heterogeneity.
- On an ecosystem scale, this net uptake is balanced by canopy photosynthesis (up-

take of carbon) and ecosystem respiration (release of carbon).

- With the increasing amount of CO₂ from anthropogenic sources coupled with current predictions of the increase in global temperature, the role that forests will play in a changing climate is not certain (Goulden et al., 1996; Huxman et al., 2003).
- The sum of respiratory and photosynthetic fluxes is termed **Net Ecosystem Exchange (NEE)**.
- NEE is a way to monitor the strength of CO₂ sink at a selected location. It is continuously measured at more than 260 sites in a variety of biomes through the FLUXNET network (Goulden et al., 1996; Baldocchi et al., 2001).
- The goal of this study is to estimate fluxes from photosynthesis and respiration at sub-daily time scales by measuring NEE along with CO₂ measurements.

Study Site

- Niwot Ridge is a high-elevation coniferous forest located west of Boulder, CO.
- The elevation of Niwot Ridge is approximately 3050 m (10,000 ft).
- The site is dominated by three coniferous species: lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*).
- A 21.5 m tower at Niwot Ridge is instrumented to measure NEE and CO₂ concentrations at 9 canopy heights.

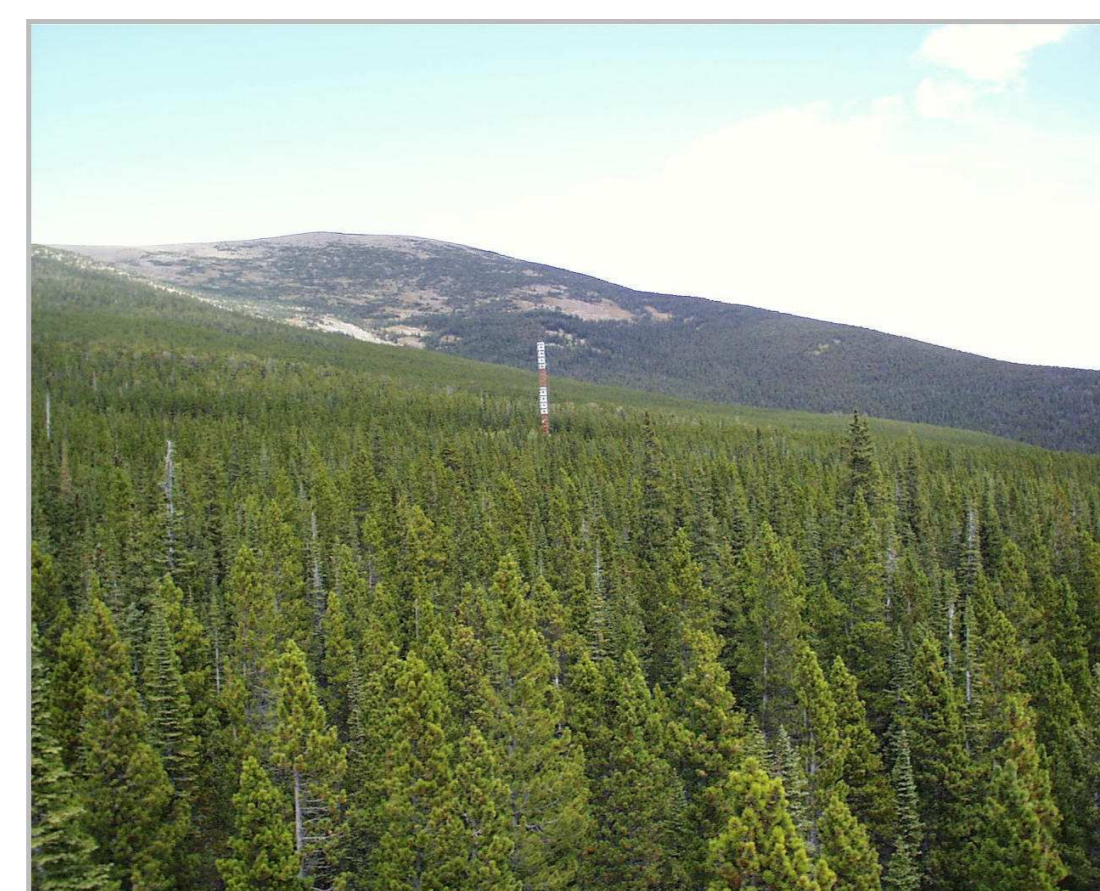


FIGURE 2: Aerial view of Niwot Ridge.

Stable Carbon Isotopes

- ¹³C is a stable isotope of carbon that is 1.11% abundant in the world, compared to ¹²C, which is 98.89% abundant.
- Stable isotopes of carbon have a wide use in ecosystem ecology (Dawson et al., 2002).
- One application is to determine an ecosystem scale photosynthetic and respiratory flux by measuring ¹³CO₂ concentrations. This is possible since a ¹³CO₂ molecule is heavier by mass, ¹²CO₂ will preferentially diffuse through the leaf stomata.
- Furthermore, during photosynthesis ¹²CO₂ is biochemically preferred (Farquhar et al., 1982).
- Because of this "discrimination" against ¹³CO₂, measuring stable isotopes of carbon may help to elucidate the photosynthetic and respiratory fluxes.

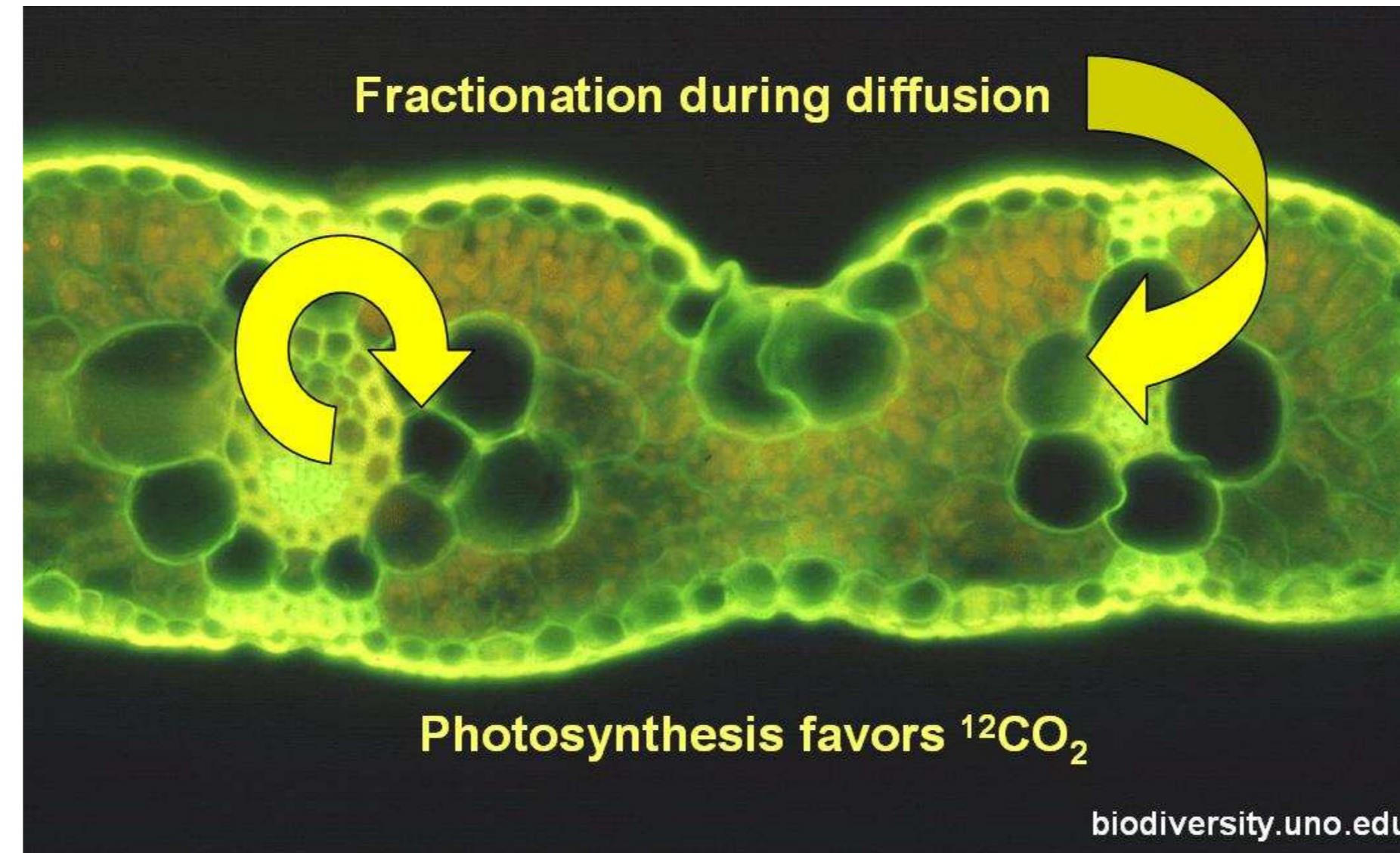


FIGURE 3: Cross-section of a leaf stomata. Because ¹³CO₂ is a heavier molecule, it will diffuse more slowly to the site of photosynthesis. ¹²CO₂ is biochemically preferred during photosynthesis, further making fixed carbon more enriched in ¹²C.

Biological Formulation of the Problem

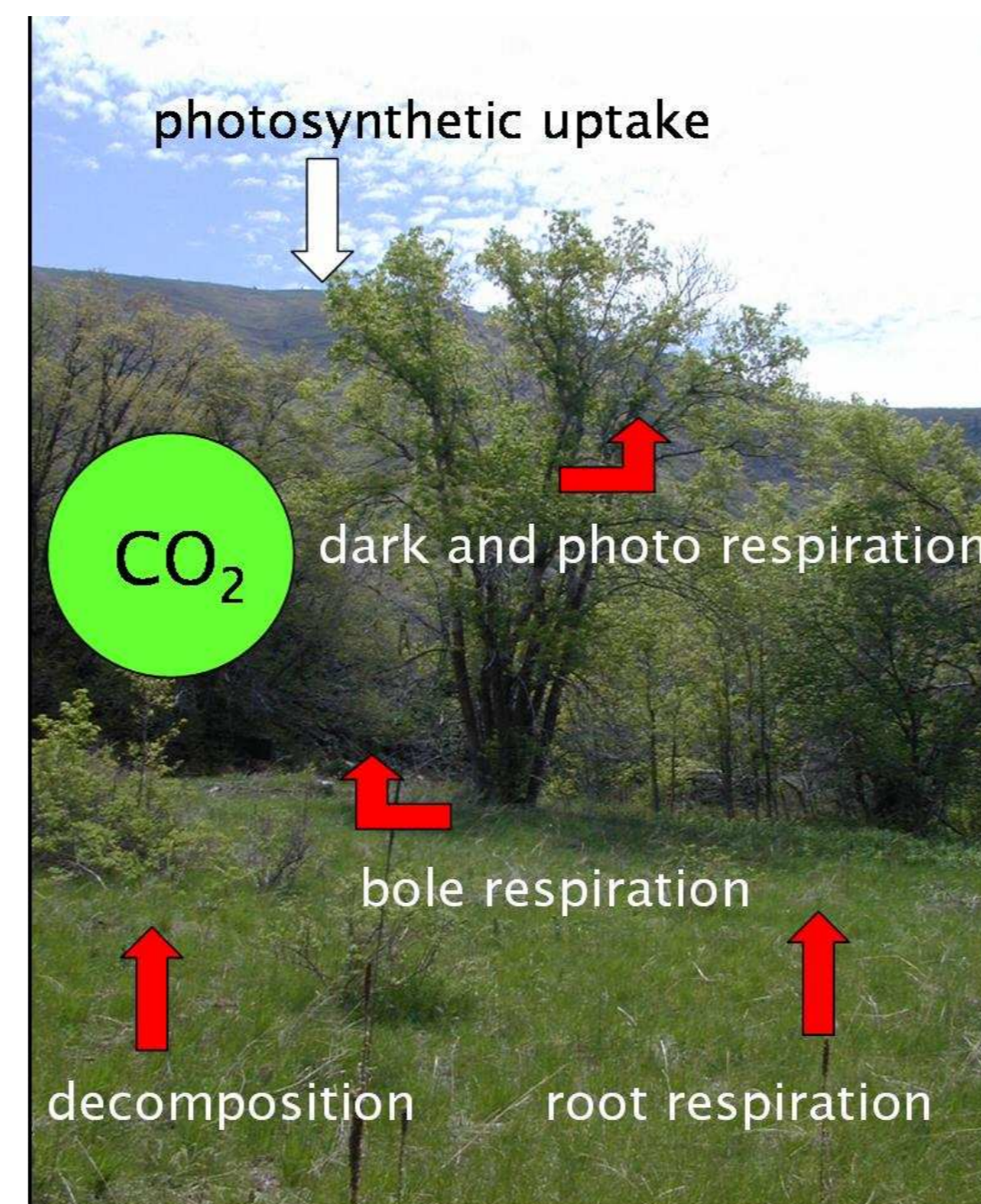


FIGURE 4: An ecosystem's CO₂ budget

- An ecosystem's CO₂ budget, shown in Figure 4, is comprised of respiratory CO₂ from leaves, stems, and soil. CO₂ is taken up through photosynthesis. The total amount of CO₂ present in an ecosystem is dynamically influenced by temperature,

moisture, and other variables.

- Conservation of CO₂ requires that NEE be equal to the sum of fluxes due photosynthesis (F_A) and respiration (F_R).

$$NEE = F_A + F_R \quad (1)$$

- It is also possible to define an equation for conservation of ¹³CO₂. Because we have two independent equations, it should be mathematically possible to determine the two unknowns F_A and F_R .
- Previous studies have been able to determine F_A and F_R using stable isotopes (Yakir and Wang, 1996; Bowling et al., 2001). However measurement uncertainty and inherent spatial and temporal heterogeneity at Niwot Ridge affect our ability to do a successful partitioning at sub-daily timescales.
- Recent studies stress the need for a more careful formulation of the mathematical uncertainties and error propagation when determining photosynthetic and respiratory fluxes (Ogée et al., 2004; Zobitz et al., 2005).

Mathematical Formulation & Preliminary Results

- Determining a photosynthetic and respiratory flux from measured data is an example of an *inverse problem*.
- Inverse problems define a relationship between estimated parameters (m) and measured data (d_{obs}):

$$g(m) = d_{obs} \quad (2)$$

- Using a Bayesian statistical approach, it is possible to find the best parameters m that produce d_{obs} by minimizing the following functional (Tarantola, 2005):

$$S(m) = \|m - m_{prior}\|^2 + \|d_{obs} - g(m)\|^2 + \|Dm\|^2, \quad (3)$$

where:

- m_{prior} : Prior estimates on parameters m .
- Dm : A difference operator to account for smoothness between time steps.
- Using the formulations described above, it is possible to determine F_A and F_R at sub-daily time scales as shown in Figure 5. Since photosynthesis is light dependent, there is no photosynthetic flux during the night.

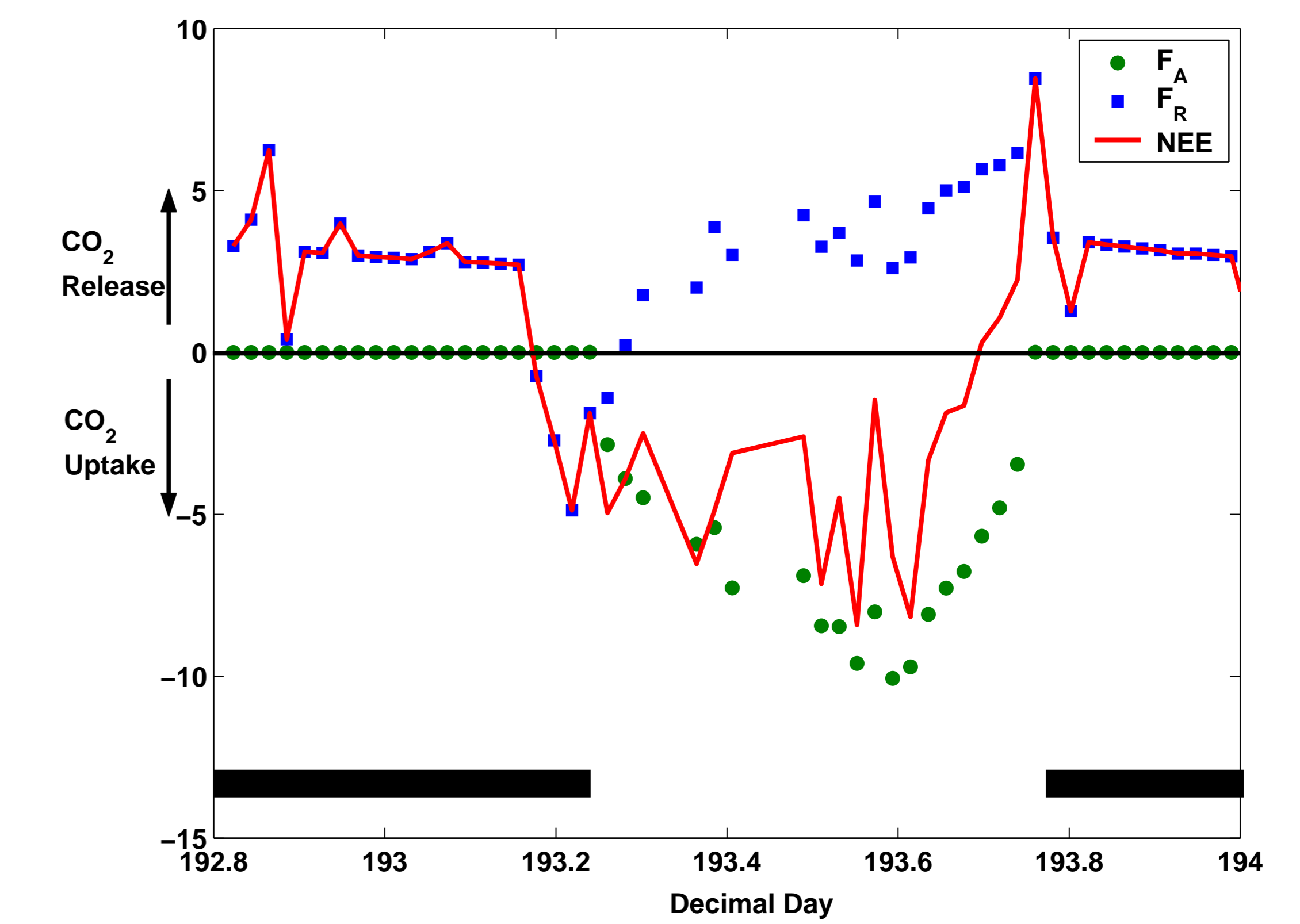


FIGURE 5: Partitioning of NEE into a photosynthetic (F_A) and respiratory flux (F_R). Note that positive fluxes are fluxes of CO₂ out of the ecosystem, and negative fluxes are fluxes of CO₂ into the ecosystem. Dark bars indicate night.

- These results show the promise of the method. Additional work includes a more careful characterization of the function g , comparing this method to others that estimate respiratory and photosynthetic fluxes (Griffis et al., 2003; Goulden et al., 1996; Yi et al., 2004), and characterizing the uncertainty in the partitioned fluxes.

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