6.12 ON THE SPATIAL VARIABILITY OF BIOPHYSICAL FACTORS AND ITS INFLUENCE ON MEASURED NET ECOSYSTEM EXCHANGE OVER FOREST

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1. INTRODUCTION

All natural forest ecosystems exhibit spatial variability at some range of scales. Measured fluxes of CO_2 are thus only expected to be representative of a forest ecosystem to the extent that the biophysical forcings in the flux footprint reflect average forest conditions. Here, we examine the influence of spatial variability in biomass (as expressed by the normalized difference vegetation index, NDVI), and the amount of absorbed photosynthetically active radiation (APAR) on the estimate of net ecosystem exchange of CO_2 from eddy-covariance measurements at a height of 46 m above a forest canopy of h = 26 m at the Morgan-Monroe State Forest (MMSF, Indiana, USA) AmeriFlux site (Schmid et al., 2000).

An IKONOS satellite scene is used to determine the distribution of NDVI in the vicinity of the MMSF site. Slope angle information is obtained from a digital terrain model. Growing season average PAR is calculated for each grid-point. First incoming solar radiation is modeled across the topographical domain using the method of Moore et al. (1993). Direct and diffuse beam solar radiation are calculated based on atmospheric optical transmission, estimated from observations on the MMSF tower (including a cloudiness index). Slope and aspect effect on exposure to direct beam radiation and the sky view factor effect on receipt of diffuse beam radiation is derived using the terrain model. APAR is assumed to be related to NDVI and PAR by

$$\mathrm{APAR} \approx \alpha_P \cdot \mathrm{PAR}\left[1-\exp(-\mathrm{LAI})\right] , \qquad (1)$$

where $\alpha_P \approx 0.94$, and $\mathrm{LAI} \approx 17.35 \cdot \mathrm{NDVI} - 9.01$ (Baret and Guyot 1991; Wulder et al. 1998).

2. THE LOCATION BIAS

The footprint of a flux measurement is akin to the field of view of the sensor. It is defined as the transfer function f that relates a distribution of surface sources (Q_s) to the flux, F (e.g., Schmid, 1997):

$$F(\mathbf{x}) = \iint_{\Re} Q_s(\mathbf{x}') \cdot f(\mathbf{x}-\mathbf{x}') \cdot d\mathbf{x}' = Q_s * f \qquad (2)$$

The right hand side of (2) indicates the equivalence to a filter operation. As the source field is not generally known, Q_s in (2) needs to be replaced by a suitable flux surrogate. Here we explore the use of NDVI and APAR as indexes for the strength of CO_2 exchange with the forest fabric. For a single sensor location the equivalent of (2) for the footprint weighted NDVI_f (for example) reduces to:

$$NDVIf = NDVI(\mathbf{x}) \cdot f(\mathbf{x}) \qquad (3)$$

The distributions of NDVI and APAR, overlaid by a mask showing the footprint field-of-view for neutral stability and a wind direction of 240°, are shown in Figures 1 (NDVI) and 2 (APAR). Here, we use the simple analytical footprint model of Schmid (1997). The footprint size varies with stability (unstable: small, stable: large), its orientation is aligned with the wind direction.

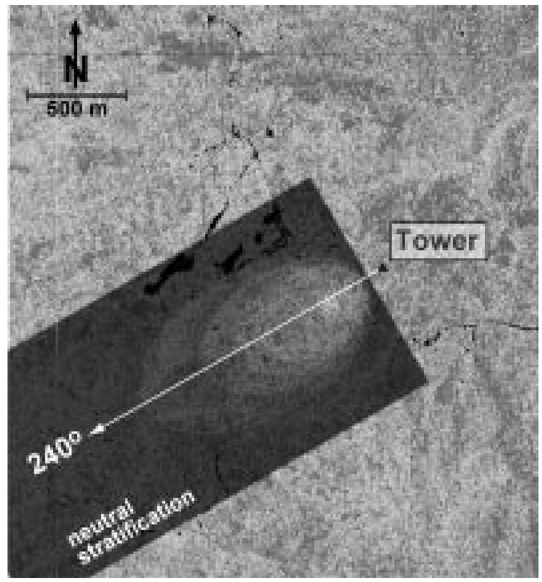

Figure 1: Satellite derived NDVI and a footprint mask. Black = no vegetation; darker grey tones = dense forest.

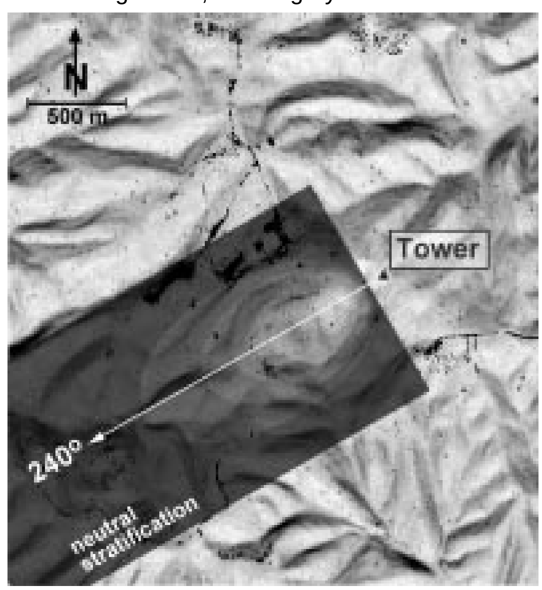

Figure 2: Same as Figure 1, for APAR. The effect of terrain is clearly evident. Bright tones = high APAR

The spatial representativeness of the footprint contents is given by the sensor location bias, Δ (Schmid, 1997):

$$\Delta = \left(\mathrm{NDVI}_f - \overline{\mathrm{NDVI}}\right)^2 \Big/ \overline{\mathrm{NDVI}}^2 \qquad (4)$$

where $\overline{\mathrm{NDVI}}$ is the "true" average over the domain.

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Measured wind directions and stabilties over 1999 are used to derive a footprint climatology in three stability categories. The distribution of the root bias, $\sqrt{\Delta}$, over wind direction is shown in Figure 3, as the fraction of the total bias (root bias fraction, RBS) using NDVI (upper panel) and APAR (lower panel) as the flux index.

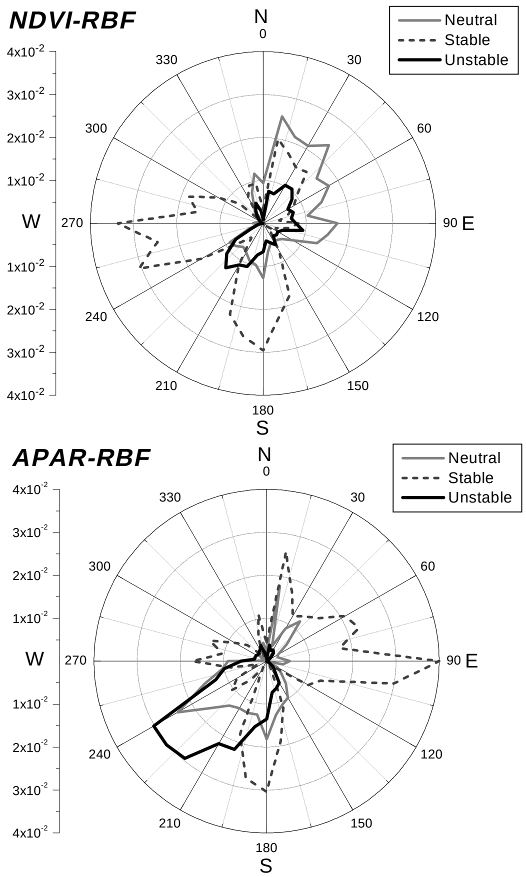

Figure 3: Distribution of the root bias fraction (RBF) over wind direction for 1999, using NDVI (top) and APAR (bottom) as flux indices. The modulation of APAR by topography (Figure 2) causes the distribution of the APAR-RBF to differ strongly from NDVI-RBF.

Large biases are not significant, if their occurence is associated with times when the magnitude of turbulent exchange is small (e.g. nighttime stable conditions). To examine this notion, $\sqrt{\Delta}$ is weighted by the measured CO_2 flux, F_{CO2}, to form the absolute weighted root bias fraction (AWRBF, Figure 4):

$$\mathrm{AWRBF} = \left| F_{CO_2} \cdot \sqrt{\Delta} \right| \Big/ \sum_{yr} \left(F_{CO_2} \cdot \sqrt{\Delta} \right). \qquad (5)$$

Recognizing that biases associated with positive and negative fluxes cancel in the evaluation of the cumulative annual net ecosystem exchange (NEE), the annual location bias (ALB) is determined as:

$$\mathrm{ALB} = \frac{\sum_{yr} \left(F_{CO_2} \cdot \sqrt{\Delta} \right)}{\sum_{yr} \left(F_{CO_2} \right)} \cdot 100\% = 1.8\% (1999). \qquad (6)$$

For 1999 the annual location bias amounted to 1.8 % of the cumulative NEE. This value can be interpreted as the degree to which the measured NEE is not representative of the spatial average, due to the location of the flux tower. Compared with uncertainties and systematic biases from other sources, the annual location bias for NEE at MMSF is negligible.

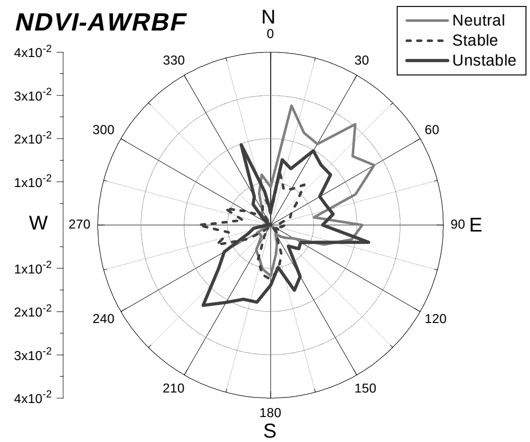

Figure 4: The NDVI based root bias fraction, weighted by the magnitude of the exchange process (eq. 5). Although the RBF for unstable conditions is relatively small, it becomes dominant here, because unstable conditions are associated with efficient turbulent exchange.

3. DISCUSSION

The analysis presented here shows that estimates of location bias and spatial representativeness are strongly affected by the choice of flux index used as a surrogate for the source/sink strenght distribution in (2). Ideally, the flux index should represent the dominant biophysical forcing for the exchange process at hand. While APAR is likely an adequate surrogate for carbon assimilation, NDVI can be interpreted to represent biomass and thus may serve as an index for ecosystem respiration processes. This notion will be explored in future work.

ACKNOWLEDGEMENTS

This research is supported in part by a grant from NIGEC/US-DoE.

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