Mapping AmeriFlux footprints: Towards knowing the flux source area across a network of towers

Olaf Menzer[1,2*], Gilberto Pastorello[1], Stefan Metzger[3,4], Cristina Poindexter[1], Deb Agarwal[1], Dario Papale[5]

*Corresponding author: omenzer@lbl.gov

Poster ID: B53A-0155

MOTIVATION

The AmeriFlux network collects long-term carbon, water and energy flux measurements obtained with the eddy covariance method. To attribute fluxes to specific areas of the land surface, flux source calculations are essential. Consequently, footprint models can support flux up-scaling exercises to larger regions, often based on remote sensing data.

However, flux footprints are not currently being routinely calculated; different approaches exist but have not been standardized. In part, this is due to varying instrumentation and data processing methods at the site level. The goal of this work is to map tower footprints for a future standardized AmeriFlux product to be generated at the network level. We are applying state of the art footprint models across a subset of six AmeriFlux sites and two ICOS sites, to evaluate the feasibility and challenges of developing standardized footprint products.

DATA I/O

A) Input Variables

Variable	Description	Units
u*	friction velocity	[m s-1]
u	horizontal wind velocity	[m s-1]
wd	wind direction	[deg]
σ_w	variance of vertical wind speed	[m s-1]
σ_v	variance of cross wind speed	[m s-1]
z_m = z - D	measurement (receptor) height z corrected for displacement height D	[m]
z_0	roughness length	[m]
L	Monin Obukhov length	[m]
h	planetary boundary layer height	[m]

Table 1: Input variables for footprint models of Kormann & Meixner (2001) and Kljun *et al.* (2004)

B) Output Variables

Variable	Description	Units
f_ci	crosswind integrated footprint function values in alongwind direction of the measurement location.	[-]
f_2D	crosswind distributed footprint function values on a regular 2D grid surrounding measurement.	[-]
x_max	alongwind distance x from the tower to the peak of the footprint function *f_ci*.	[m]
x_r{10-80}	alongwind distance x from the tower at which the integrated footprint function *f_ci* is *r* %, (i.e., where *r* % of the cumulative footprint influences the measurement). *r* = {10,20,...80}.	[m]

Table 2: Output variables generated from footprint model processing.

Cases where one of the mdels was not valid were removed from the comparison.

TEMPORAL CYCLES OF FOOTPRINTS

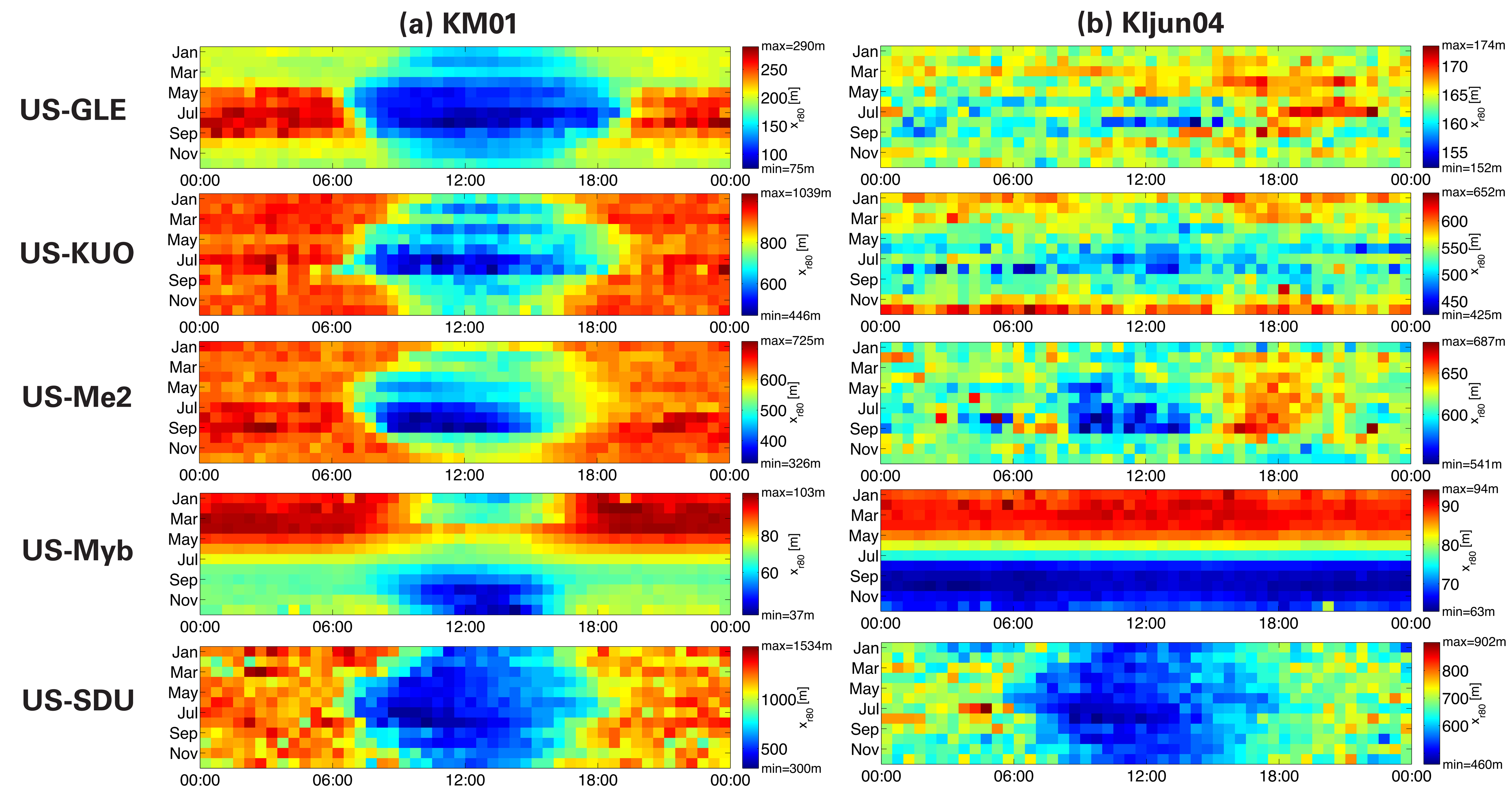

Fig. 2: Mean diurnal cycles of *x_r80* [m] by month for five example sites. (a) Footprints calculated with the model of Kormann & Meixner (2001), (b) footprints calculated following Kljun *et al.* (2004). Color ranges have been scaled to the indicated maximum and minimum *x_r80* to ensure comparability of temporal variation. Time of day shown below graphs.

METHODS & STUDY SITES

Footprints were computed with the model of Kormann & Meixner (2001), referred to as "KM01", and the model of Kljun *et al.* (2004), referred to as "Kljun04". The KM01 model calculates an *analytical* solution of the advection-diffusion equation in the surface layer. It uses an exponential mean wind profile, an eddy diffusivity, and Monin Obukhov similarity theory. The Kljun04 model is a simple parameterisation of model calculations from a three-dimensional Lagrangian particle dispersion over a range of atmospheric stratifications from convective to stable. Both models can estimate crosswind-integrated (1D) and crosswind-distributed (2D) representations (cf. Table 2) of the theoretical footprint functions (Fig. 1).

Site	Year	Type	Climate	Z [m]
US-GLE	2013	Evergreen needleleaf forest	Subarctic	23
US-KFS	2013	Grasslands	Subtropical	3
US-KUO	2007	Urban and Built-up lands	Continental	40
US-Me2	2012	Evergreen needleleaf forest	Mediterranean	34
US-Myb	2013	Permanent wetlands	Mediterranean	3
US-SDU	2013	Urban and Built-up lands	Continental	60
IT-CA1	2013	Croplands	Mediterranean	7
IT-CA3	2013	Croplands	Mediterranean	6

Table 3: Study site information. *Z* is the measurement (receptor) height in [m].

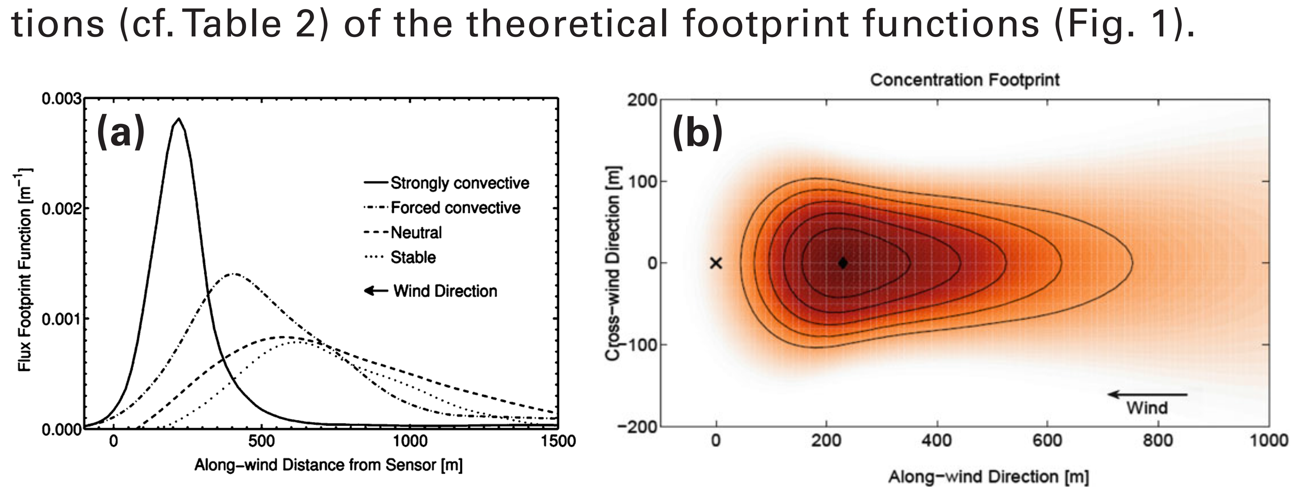

Fig. 1: (a) *f_ci* for four different cases of stability obtained by Lagrangian simulation according to Kljun *et al.* (2002). **(b)** f_2D example plot (Rannik *et al.*, 2012)).

MAP VISUALIZATION

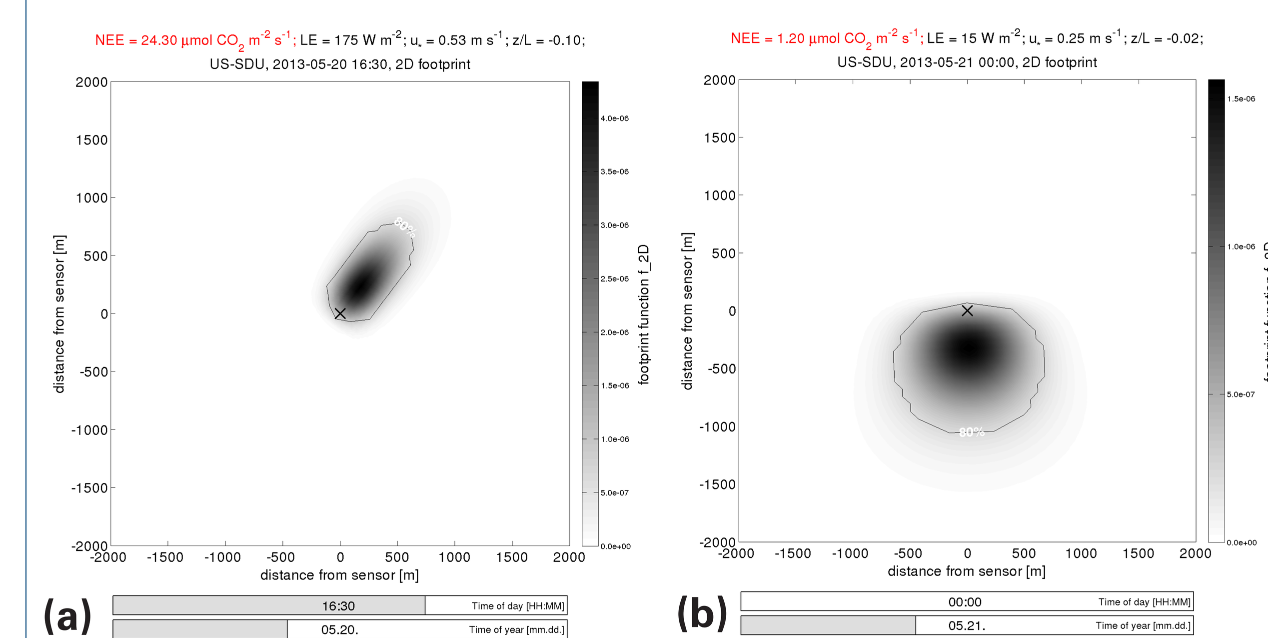

Fig. 3: Crosswind distributed footprint function *f_2D* caclulated with Kljun04 for examples of daytime (a) and nighttime (b) atmospheric conditions (as shown above the graphs along with the fluxes) at site US-SDU.

CONCLUSIONS & OUTLOOK

(1) Temporal signatures indicate diurnal and seasonal footprint variability, with KM01 estimates following more distinct cycles.

(2) Overall, agreement between the two methods is reasonable for daytime conditions ($r = 0.14^{***} - 0.68^{***}$), but there are larger differences during nighttime conditions when the atmosphere is more stable.

(3) Footprint results can be used as additional information within the AmeriFlux database to support data interpretation.

(4) This work gives a practical perspective on where footprint model adaptations may be needed.

- Update of the Kljun04 footprint model (Kljun, in prep.) could impact diurnal and seasonal variability and accuracy.
- Future work aims at verification of footprints with experimental data where available, and validation of footprints using the spatiotemporal signature of the fluxes.

References

Kljun, N. et al. (2002), *Boundary-Layer Meteorology*, 1**03,** 205-226.
Kljun, N. et al. (2004), *Boundary-Layer Meteorology*, 1**12,** 503-523.
Kormann, R. & Meixner, F. (2001), *Boundary-Layer Meteorology*, **99**. 207-224.
Rannik, U. et al. (2012), *Footprint Analysis*, **Chapter 8** in: Eddy Covariance, A practical guide to measurement and data analysis.

Acknowledgements

We acknowledge the site PIs, W. Massman, N. Brunsell, J. McFadden, B. Law, D. Baldocchi, D. Anderson, S. Sabbatini et al. for sharing their data. We also thank N. Kljun, L.Golston and C. Sturtevant for valuable discussion of the results.
Funding for the AmeriFlux Management Project was provided by the U.S. Department of Energy's Office of Science under Contract No. DE-AC02-05CH11231

Affiliations: [1]Lawrence Berkeley National Laboratory, Data Science and Technology, Berkeley, California, USA; [2]University of California, Santa Barbara, Department of Geography, Santa Barbara, California, USA; [3]National Ecological Observatory Network, Fundamental Instrument Unit, Boulder, Colorado, USA; [4]University of Colorado, Institute for Arctic and Alpine Research, Boulder, Colorado, USA; [5]Tuscia University, Department for Innovation in Biological, Agro-food and Forest systems (DIBAF), Viterbo, Italy