Surface-Atmosphere Exchange over Inhomogeneous Terrain:
Seeing the Forest for the Trees

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Gibbs Roundsavall: "suburban sprawl" (detail)
19" x 24", enamel on aluminium, 2005

Duluth, MN, neighborhood

Morgan-Monroe State Forest, Indiana, USA
The atmosphere sometimes organizes into patterns and distinct spatial scales.
Landscape: Imposes Pattern and Scale
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Measured Variability depends on Resolution: the Scale of Measurement

Homogeneous Field
Plant-Environment Interaction: \( \text{CO}_2 \)

**Scale of Approach**

**Macroscopic Approach**
- ecosystem exchange
- transport
- \( 10^2 - 10^3 \) m
- hourly – multi-year

**Microscopic Approach**
- intercellular exchange
- transformation, chemical pathways
- \( 10^{-5} – 10^{-2} \) m
- seconds – hourly

everything in between
Micrometeorological Flux Measurements: at what scale?

Schmid 2002 (Agric. For. Meteorol. 113, 159-184)
The Flux Footprint:

- What Part of the Ecosystem does the Flux Sensor ‘see’?
- Is that Part Representative of the Ecosystem? (answer varies over time)
- If yes: use data; if not: reject data

e.g.: Schmid (2002, Ag. For. Met., 113, 159-184)
**Flux Footprint** = spatial filter, "field of view"

\[ F(x) = \int \int_{\mathbb{R}} Q_s(x') \cdot f(x - x') \cdot dx' = Q_s \ast f \]

(\textit{convolution} of the source distribution, \(Q_s\), with the footprint, \(f\))

\[ \left( \begin{array}{l} \text{Inputs:} \\
\bullet \ z_m \\
\bullet \ u_* \\
\bullet \ z_0 \\
\bullet \ \sigma_w \\
\bullet \ h \\
\bullet \ \sigma_v \\
\end{array} \right) \]

Schmid 1994 (\textit{Boundary-Layer Meteorol.}, 67, 293-318)
Does the Footprint Concept Actually Work?

Vancouver, B.C., Canada: Summer 1986

Schmid et al., BLM 1991
"Field of View" / Footprint Varies with Time

• Turns with wind direction
• Small in unstable conditions
• Larger in neutral/stable conditions

(after Schmid et al. 1991)
Is the Vancouver Suburban Study Area Homogeneous? (regarding a turbulent flux sensor at 30 m)

Vancouver Temperature Distribution at full resolution (from airborne IR scanner) as "seen" by a flux sensor at 30 m in unstable conditions as "seen" by a flux sensor at 30 m in near-neutral conditions

- variability reduced to 18%
- variability reduced to 4%

- in unstable conditions: expect spatial variability
- in near-neutral/stable conditions: expect homogeneity
Measured Spatial Variability of Sensible Heat Flux ($Q_H$) in Residential Vancouver Area (1986)

- $Q_H$ variations within ~ 1 km
- instrument uncertainty

$Q_H$ variations decrease with increasing source area (= effective spatial averaging)

Schmid, 1988; Schmid et al., BLM 1991; Schmid, AgForMet 1997
Morgan-Monroe State Forest (Indiana)
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- 39º 53’ N, 86º 25’ W
  South central Indiana – 275 m
- Red Oak, White Oak, Tulip Poplar, Sugar Maple
- 60 – 80 year stand age
- 25 – 30 m canopy height
- 4.9 maximum Leaf Area Index
- 18.52 kg m⁻² mean above-ground biomass
- 236 ~ 261 g C m⁻² y⁻¹ NEP (1998/99)
Location and shape of the footprint...
Location and shape of the footprint ... 
... is variable (wind direction, stability)

Is the tower optimally located?

What kind of location bias can we expect?

Stable Stratification
• Original NDVI:

NDVI Variance: 0.053
(= 100 %)
• **Original NDVI:**
  NDVI Variance: 0.053 (= 100 %)

• **Filtered NDVI:**
  Unstable FSAM filter
  Remaining Variance: 28 %

FSAM Filter Size:
• **Original NDVI:**
  NDVI Variance: 0.053 (= 100 %)

• **Filtered NDVI:**
  Unstable FSAM filter
  Remaining Variance: 28 %

• **Histogram Comparison:**
Hourly Footprints 2001: YD 217-YD 225
Aug 5 – Aug 13
8-Day Flux Footprint Composite

Hourly Footprints 2001: YD 217-YD 225

Aug 5 – Aug 13
Conclusions

• Surface patterns impose atmospheric scales

• Averaging over at least a pattern-unit provides a "scale of homogeneity"

• Measurements at scales of homogeneity are basis for generalisation and linking with models (e.g., at the micro-, stand-, or ecosystem-scale)
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