Detection of surface heterogeneity in eddy covariance data

R. Deckert ¹,² and T. Hauf ¹

¹ Institute for Meteorology and Climatology, Leibniz University Hannover, Germany
² now at: German Aerospace Centre, Institute of Atmospheric Physics, Oberpfaffenhofen, Germany

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Introduction

Eddy covariance method

- Fast sampling of $w$ and transported quantity $c$
- Vertical turbulent flux via covariance: $\overline{w'c'}$
- Usually half-hour interval
- Here: $\overline{w'\rho'}$ and $\overline{w'T'}$
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Interpretation in terms of surface exchange

- Quality issues (ecosystem research: Mahrt 2010; Vickers et al. 2010; Vesala et al. 2008; Foken et al. 2005; ...)
- Here: focus on stationarity
Introduction

Instationarity

1. Atmospheric trends / variability
Introduction

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2. Surface heterogeneity + wind-direction fluctuations
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1. Atmospheric trends / variability
2. Surface heterogeneity + wind-direction fluctuations
   (water resources, agriculture, roads, ...)

![Diagram of instationarity concept]
Introduction

Instationarity

1. Atmospheric trends / variability
2. Surface heterogeneity + wind-direction fluctuations

Presenting a data-based detection scheme
Method

Fetch ~ location of source area
Method

- Association of $w$ and $c$ with fetch
Method

- Association of $w$ and $c$ with fetch
- Median fetch defines two bins
Method

- Association of $w$ and $c$ with fetch
- Median fetch defines two bins
- Separate calculation: $\bar{w}'c'$ and $\bar{w}'c'$
Method

Statistical inference: $w'c' - w''c''$
Method

Statistical inference: \( \frac{\mathbf{w'}}{c'} - \frac{\mathbf{w'}}{c'} \)

- Autocorrelation → keep individual blocks together
- Repeat a lot of times:
  1. Random permutation of "color"
  2. Binning and flux calculation
Campaign

Airport in northern Germany
Campaign

Airport in northern Germany

➢ Acceptance sector → 40 half-hour data sets
➢ Spring, daytime, dry conditions
Results

Hypothesis test

- $H_0$: $w'c' = w'c'$
- $H_1$: two sided

<table>
<thead>
<tr>
<th>p</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 0.01$</td>
<td>◊</td>
</tr>
<tr>
<td>$0.01 &lt; p \leq 0.05$</td>
<td>□</td>
</tr>
<tr>
<td>$p &gt; 0.05$</td>
<td>○</td>
</tr>
</tbody>
</table>
Results

Hypothesis test
➢ $H_0$: $\bar{w}' \bar{c}' = \bar{w}' \bar{c}'$
➢ $H_1$: two sided

Pooled inference
➢ Weighted least squares (generalized) / weighted bootstrap
➢ Assumptions ok

![Graphs showing the relationship between $w' \rho'$ and $w' \bar{T}'$.]
Results

- $w' \rho' \; [10^{-4} \text{ kg/m}^2/\text{s}]$
  - $p = 0.005 - 0.00004$

- $w' T' \; [10^{-1} \text{ Km/s}]$
  - $p = 0.1$
Results

Low test power?

$p = 0.005 - 0.00004$

$p = 0.1$
Results

Low test power?

No physical effect?

$p = 0.005 - 0.00004$

$p = 0.1$
Results

→ Decomposition: $w'c' = \sigma_w \cdot \sigma_c \cdot C_{w,c}$

Low test power?

No physical effect?

$p=0.005-0.00004$

$p=0.1$
Results

\[ w' \rho' = \sigma_w \cdot \sigma_\rho \cdot C_{w,\rho} \]

Roughness contrast → physically plausible

Evapo-transpiration contrast → physically plausible

\( \sigma_w \ [\text{m/s}] \)

\( \sigma_\rho \ [10^{-4} \text{ kg/m}^3] \)

\( p < 0.00001 \)

\( p < 0.00001 \)
Results

\[ \langle w' \rho' \rangle = \sigma_w \cdot \sigma_\rho \cdot C_{w,\rho} \]

Equal sign

Roughness contrast
→ physically plausible

Evapo-transpiration contrast
→ physically plausible

\[ \sigma_w \quad [\text{m/s}] \]

\[ \sigma_\rho \quad [10^{-4} \text{ kg/m}^3] \]

\[ p << 0.00001 \]

\[ p < 0.00001 \]
Results

\[ w' \rho' = \sigma_w \cdot \sigma_\rho \cdot C_{w,\rho} \]

But: scatter from correlation coefficient

Roughness contrast \( \rightarrow \) physically plausible

\( \sigma_w [m/s] \)

\( p<<0.00001 \)

\( C_{w,\rho} \)

\( p=0.008 \)

\( p<0.00001 \)
Results

\[
\bar{w}'T' = \sigma_w \cdot \sigma_T \cdot C_{w,T}
\]

Roughness contrast → physically plausible

Temperature contrast → physically plausible

\begin{align*}
\sigma_w & [\text{m/s}] \\
\sigma_T & [\text{K}] \\
p & << 0.00001 \\
p & < 0.0001
\end{align*}
Results

\[ \overline{w'T'} = \sigma_w \cdot \sigma_T \cdot C_{w,T} \]

Opposite sign

Roughness contrast → physically plausible

Temperature contrast → physically plausible

\( p \ll 0.00001 \)

\( p < 0.0001 \)
Results

\[ \overline{w'T'} = \sigma_w \cdot \sigma_T \cdot C_{w,T} \]

In addition: scatter from correlation coefficient

\[ p<<0.00001 \]
\[ p<0.0001 \]
\[ p=0.0002 \]
Summary

Eddy covariance method

➢ Quality issue instationarity
➢ Here: surface heterogeneity + wind-direction fluctuations

Detection scheme

➢ Fetch-based binning
➢ Statistical inference
  - Uses random permutation
  - Accounts for auto-correlation

Test: paved surface ↔ grassland

➢ Results agree with physical setting
➢ Individual / pooled tests match
➢ But: correlation coefficients