An assessment of turbulence profiles in urban areas

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Turbulence

- Neutral / windy conditions
  - Strong and continuous
  - Generated by surface friction (mechanical) and wind shear
- Convective conditions
  - Buoyant overturning over a heated surface (convective)
- Stable conditions
  - Weak
  - Intermittent and patchy

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Analytical profiles

- Observational data from field experiments
  - Kansas experiment (surface layer)
  - Minnesota experiment (entire boundary layer)
- Flat uniform terrain
- Complex, urban areas?

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Urban areas

- Increased surface roughness
  - Greater mechanical turbulence
- Urban heat island
  - Affects thermally induced turbulence

Are velocity variance profiles suited to urban areas?

- Compare observational data against profiles
  - Rural area (baseline)
  - Urban area

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Observations

- Cardington
  - Flat, rural area
  - Surface instrumentation
    - » 4m, 10m and 45m
    - » Logged at 4Hz
    - » 17.5 min variances
    - » Routine measurements
  - Tethered balloon
    - » Heights up to 1.5km
    - » Logged at 4Hz
    - » Short term campaigns
- Birmingham
  - Urban site
  - Surface instrumentation
    - » 15m, 30m and 45m
    - » Logged at 4Hz
    - » Hourly variances
    - » Short term campaigns

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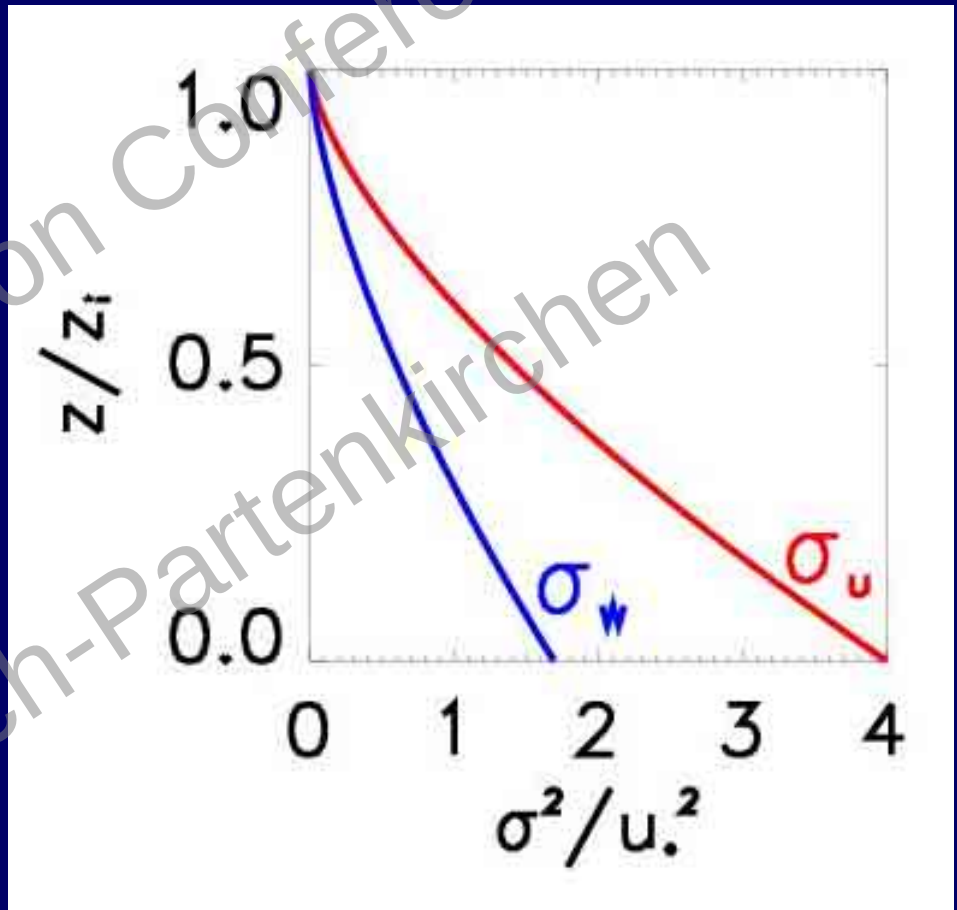
Stable profiles

$$\sigma_{u,v}^2 = \left[2.0 u_* \left(1 - \frac{z}{z_i} \right)^{3/4} \right]^2$$

$$\sigma_w^2 = \left[1.3 u_* \left(1 - \frac{z}{z_i} \right)^{3/4} \right]^2$$



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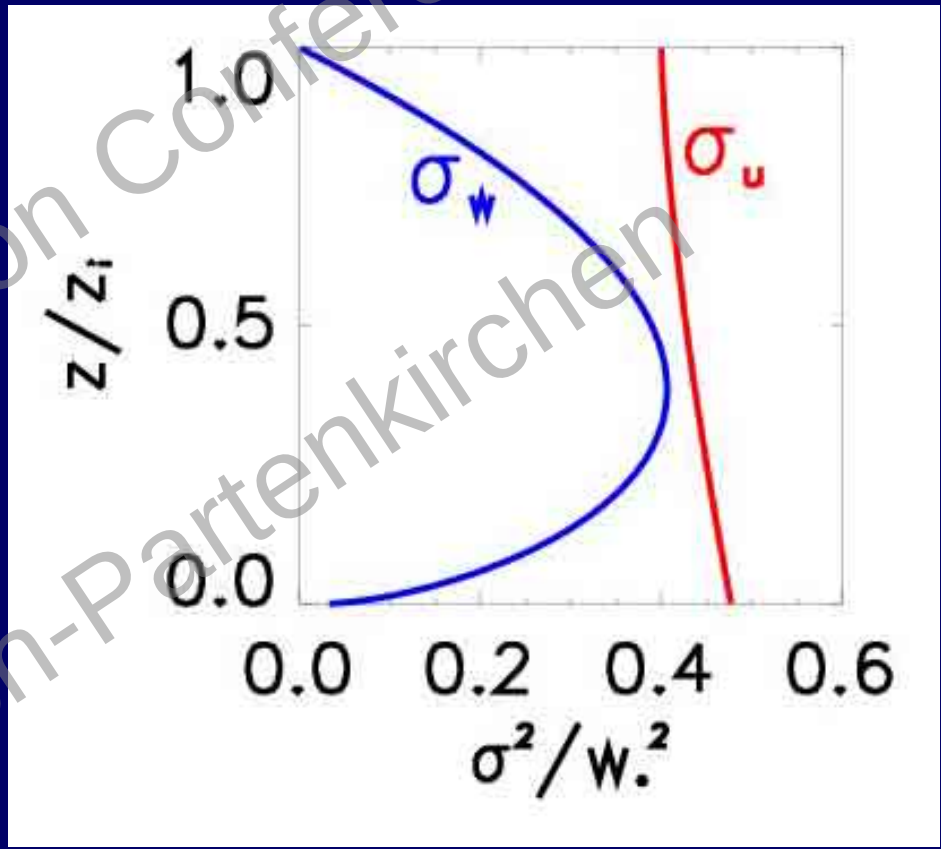
Unstable profiles

$$\sigma_{u,v}^2 = 0.4w_*^2 + 4.0u_*^2\left(1-\frac{z}{z_i}\right)^{3/2}$$

$$\sigma_w^2 = 1.2w_*^2\left(\frac{z}{z_i}\right)^{2/3}\left(1-\frac{z}{z_i}\right) + 1.69u_*^2\left(1-\frac{z}{z_i}\right)^{3/2}$$



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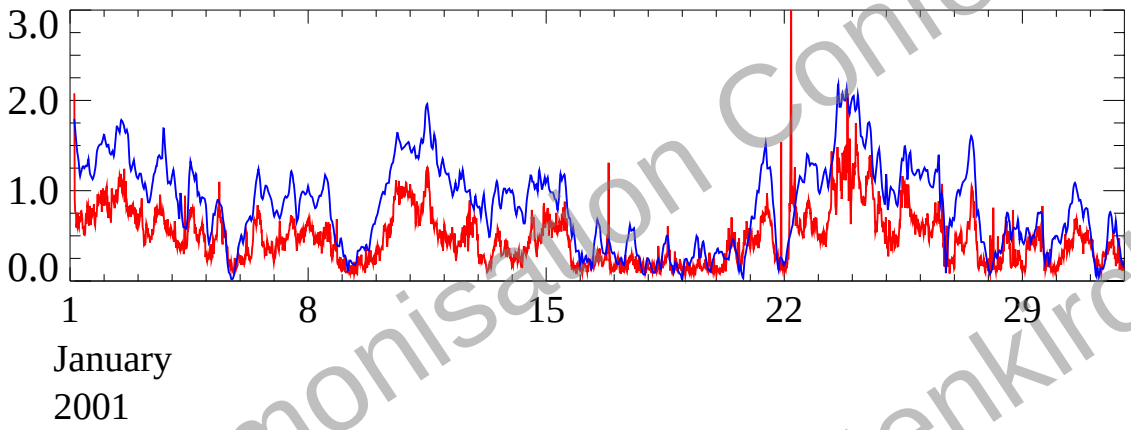
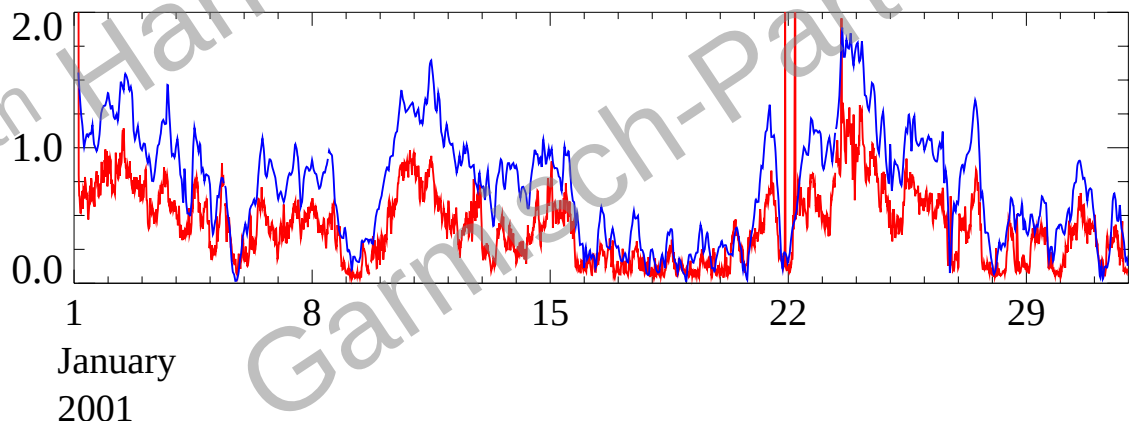
Cardington – surface (10m) using NWP met

$\sigma_{u,v}$



σ_{w}



Observations (red)

Profiles (blue)

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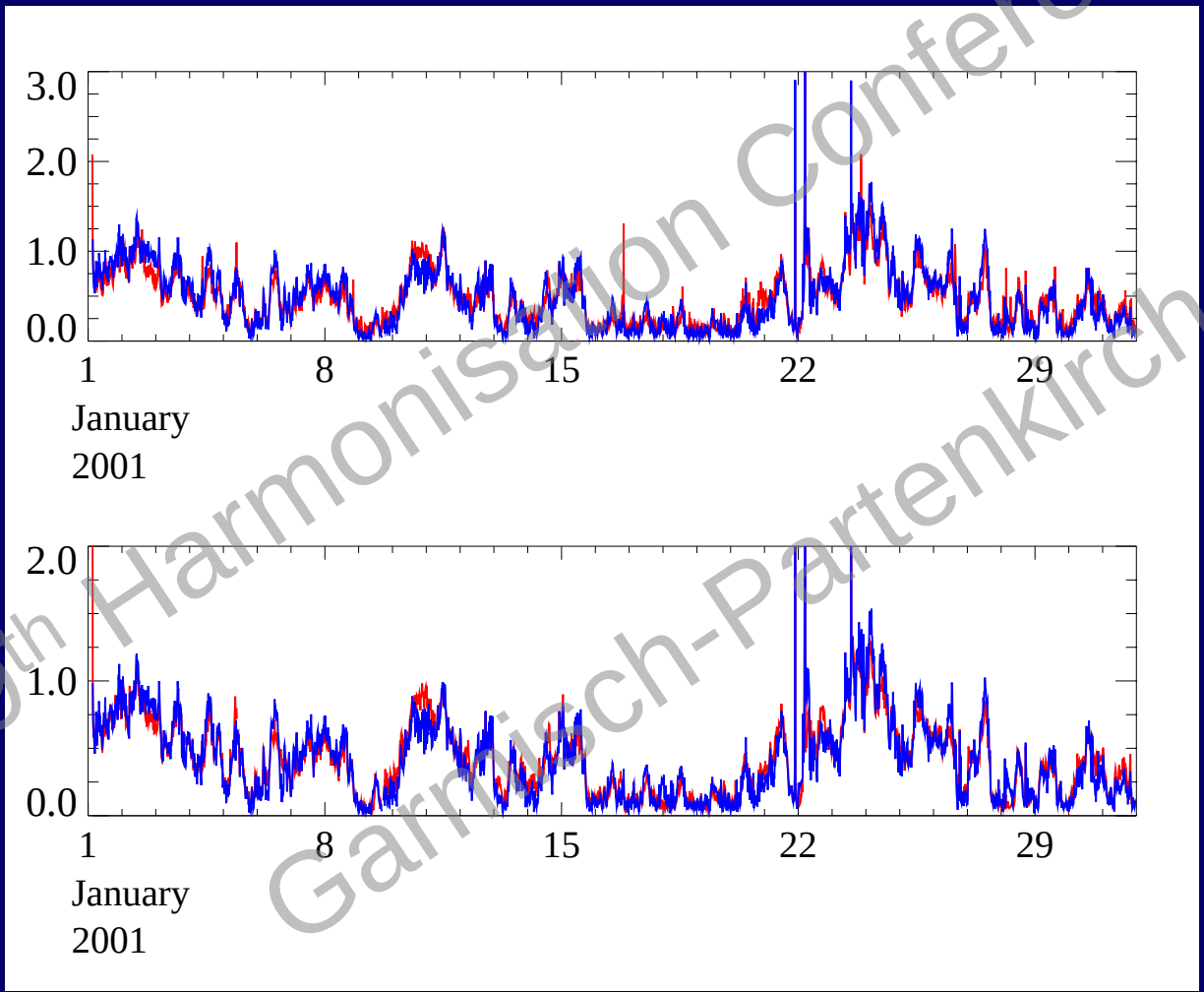
Cardington – surface (10m) using observed u_*

$\sigma_{u,v}$

σ_w



Observations (red)

Profiles (blue)

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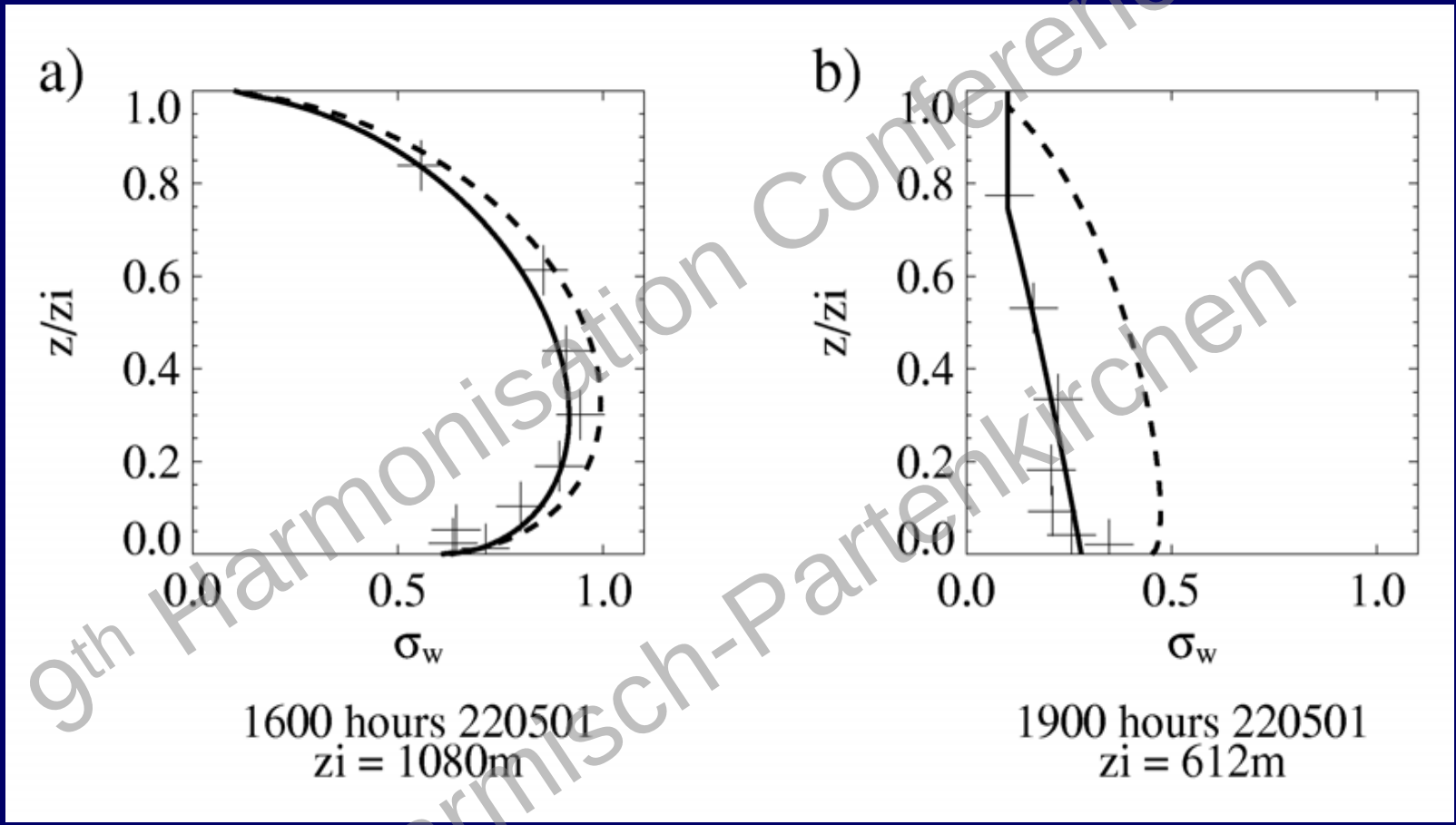
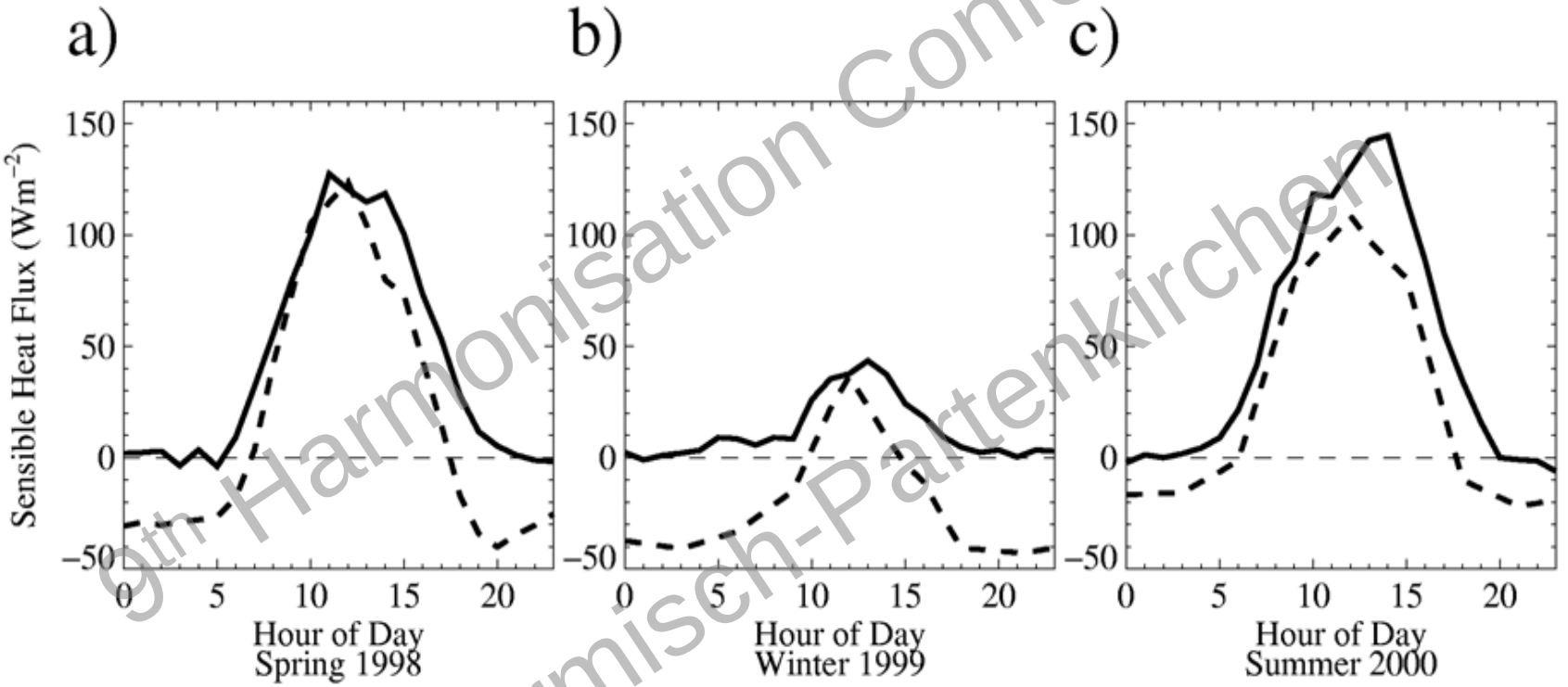
Cardington - balloon



Observations (crosses)
profiles - NWP met (dashed line)
profiles – observed met (solid line)

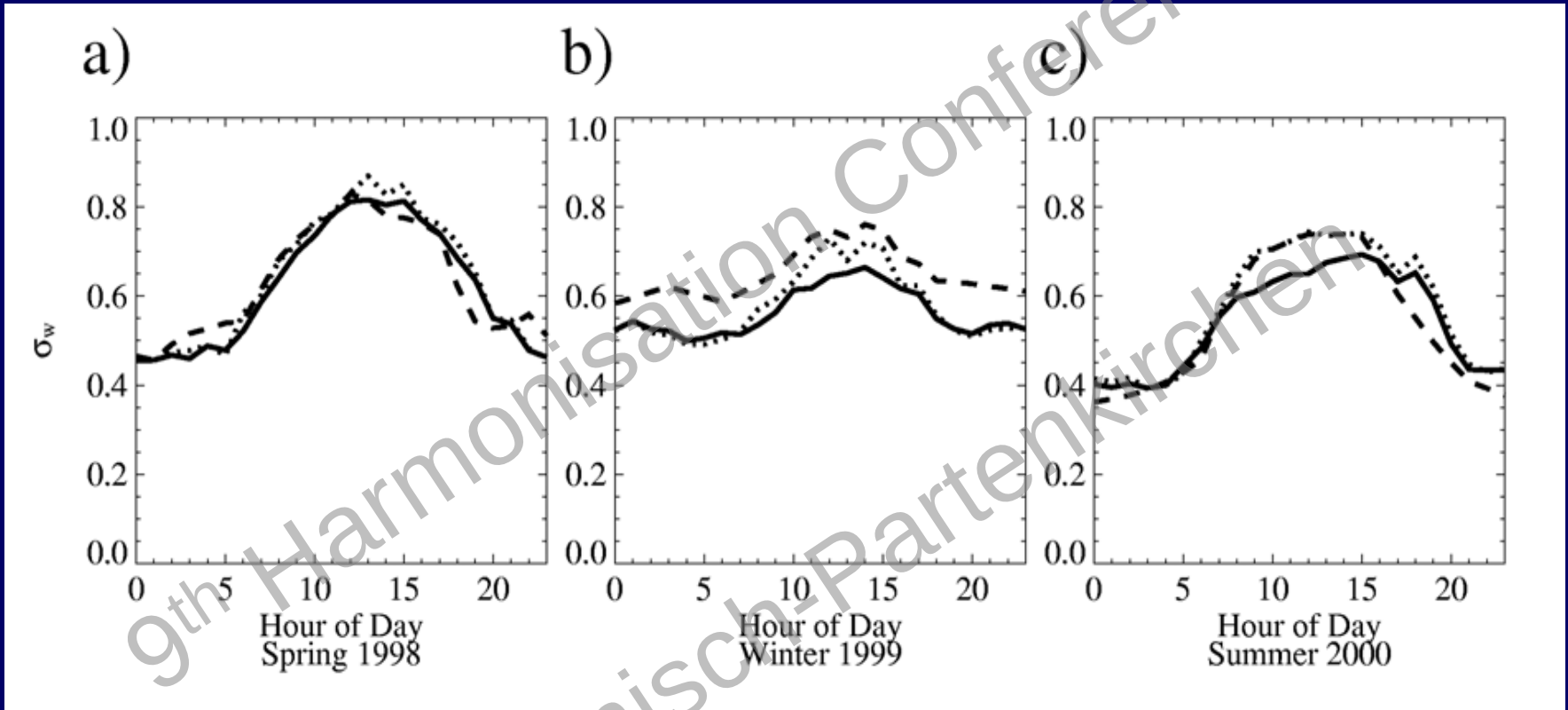
Urban sensible heat flux



Observations (solid line)

NWP (dashed line)

Birmingham – surface (15m)



Observations (solid line)
Profiles – NWP met (dashed line)
Profiles – observed met (dotted line)

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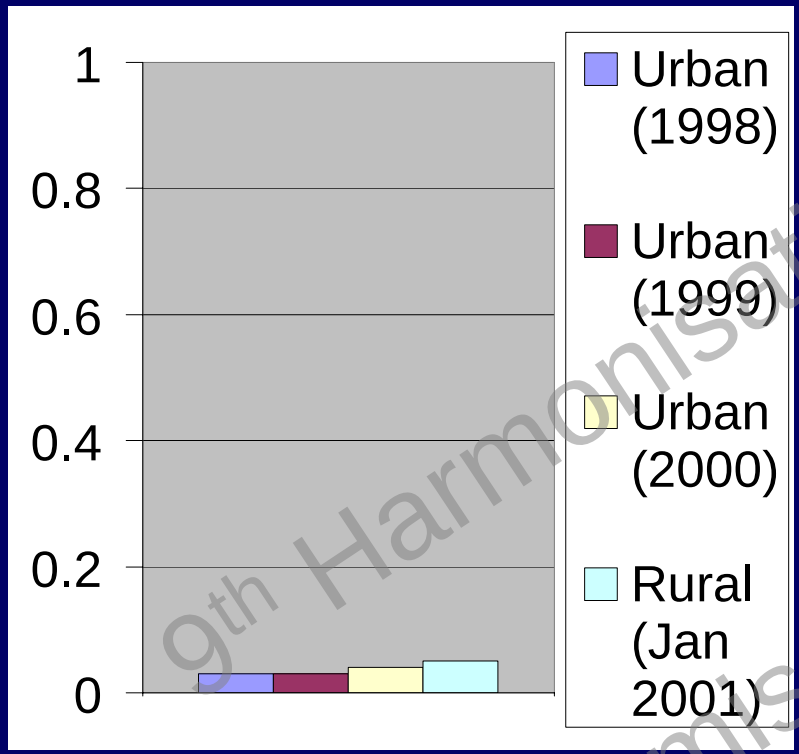
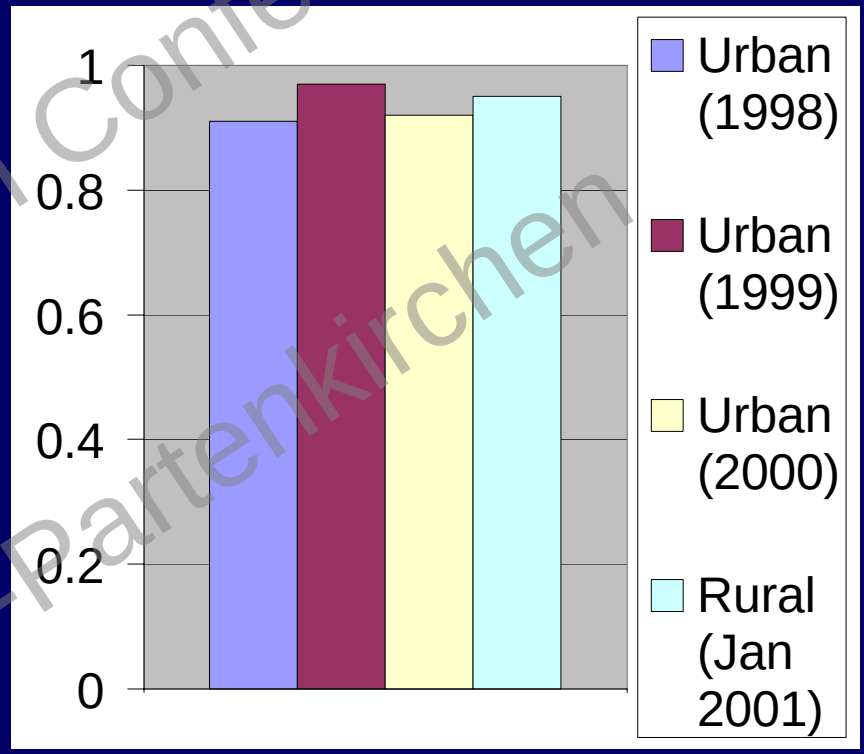
Urban v Rural - surface



Normalised mean square error



Correlation

Summary

- Turbulence profiles compared against a range of surface-based and balloon data in both rural and urban areas
- Main features are captured
- A tendency to over-predict particularly during stable conditions
- Good agreement when met observations appropriate to the local environment are used
- Profiles equally suitable for use in urban as well as rural areas

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Summary

- Highlights the importance of good meteorological input data for turbulence modelling
- Highlights the limitations of NWP data and the effect this has on dispersion modelling
- More study in modelling urban meteorology is needed

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