Surface-Atmosphere Exchange over Inhomogeneous Terrain:

Seeing the Forest for the Trees

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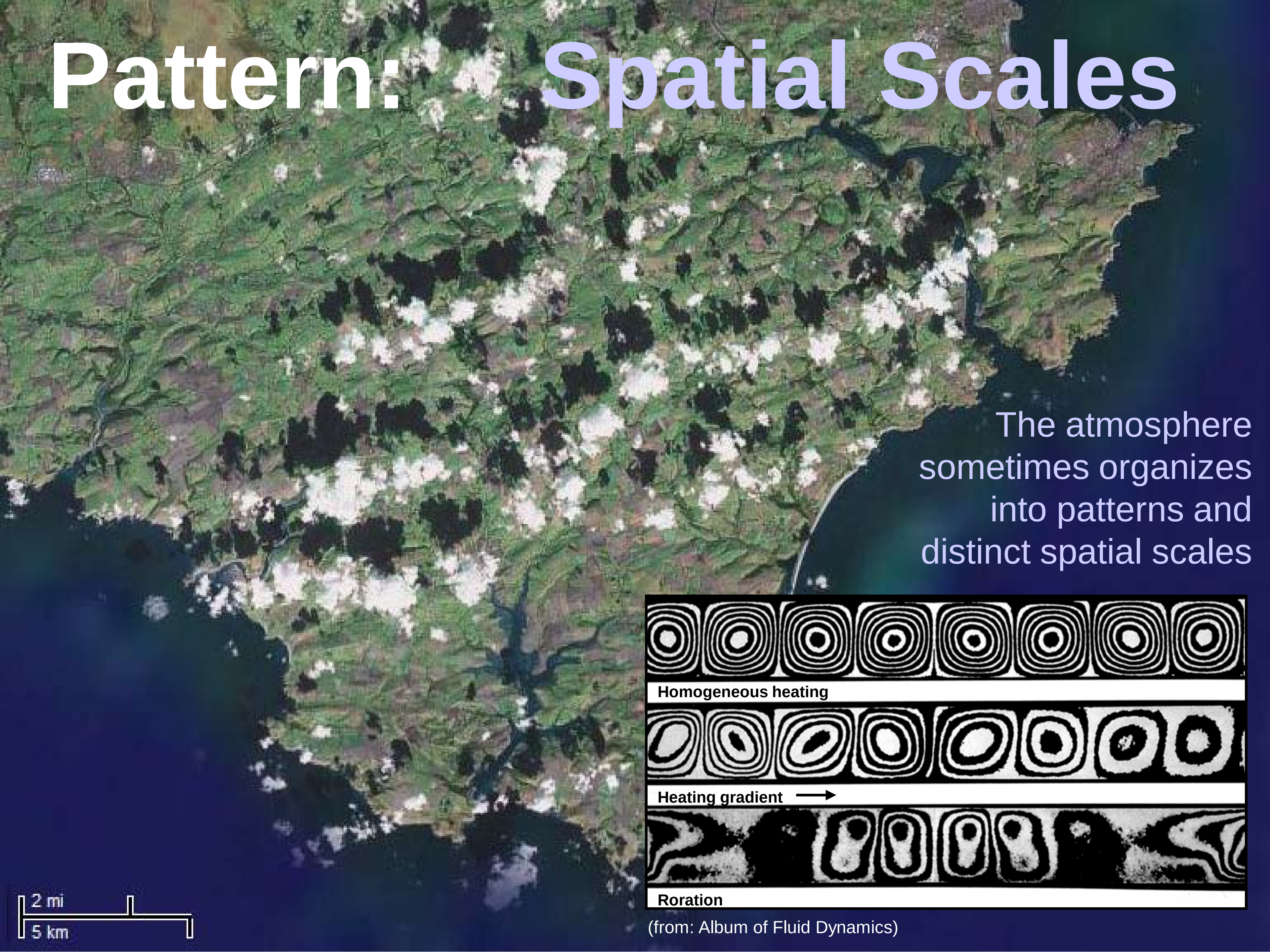
Duluth, MN, neighborhood

Morgan-Monroe State Forest, Indiana,USA

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

Pattern: Spatial Scales

The atmosphere sometimes organizes into patterns and distinct spatial scales



(from: Album of Fluid Dynamics)

Landscape:

Imposes Pattern and Scale

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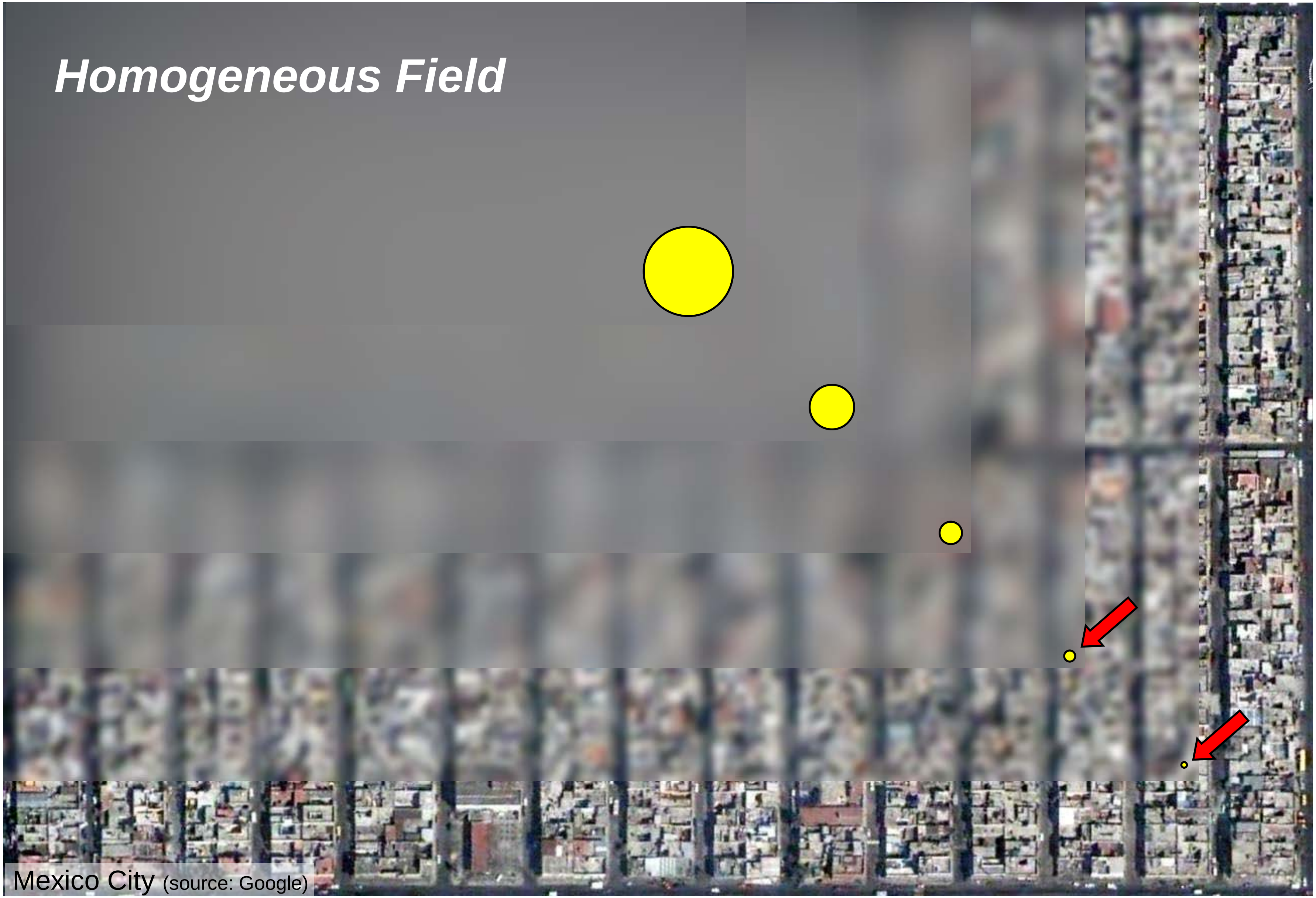
Measured Variability depends on Resolution:
the Scale of Measurement



Plant-Environment Interaction: CO_2

Scale of Approach

Macroscopic Approach

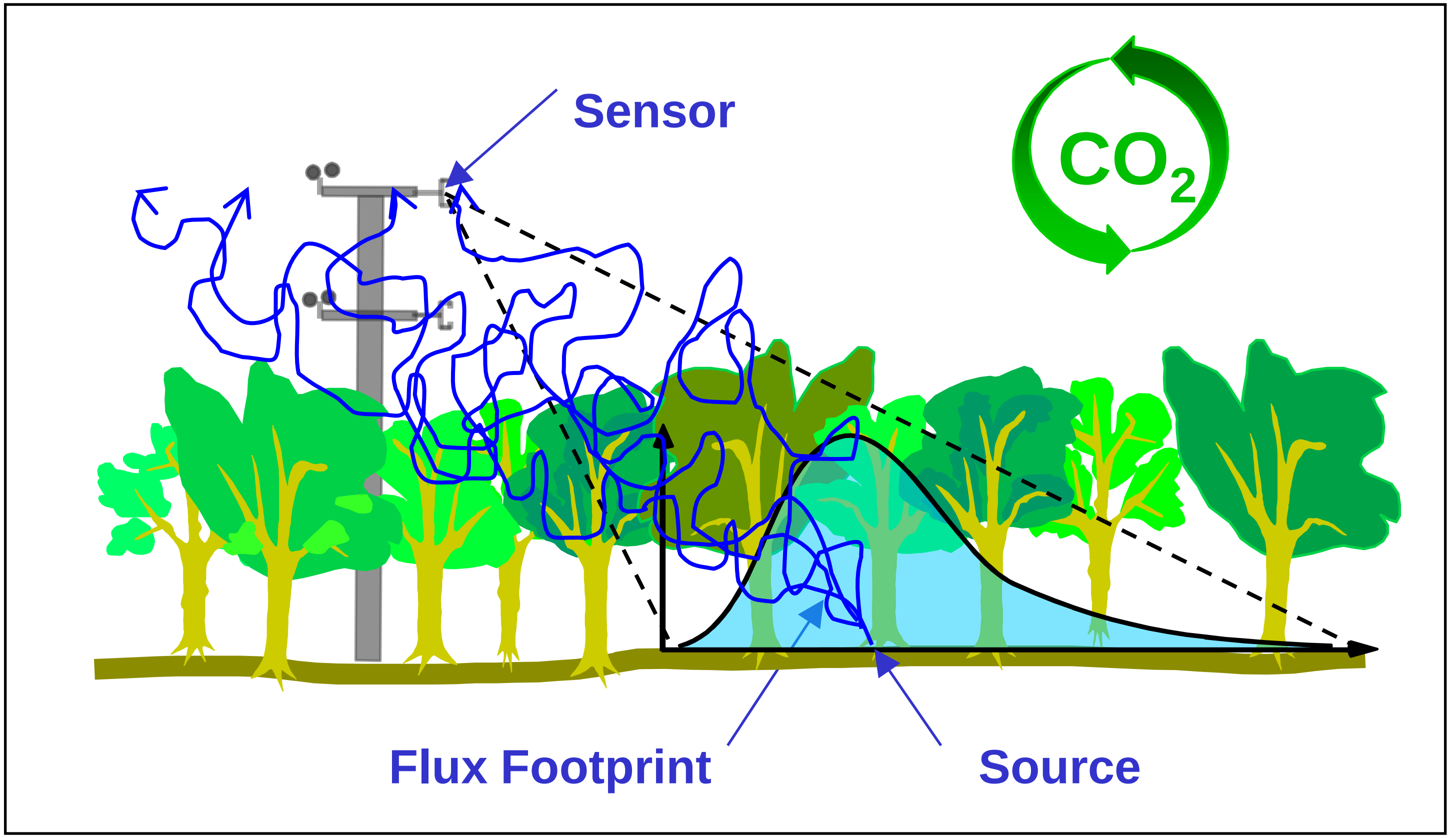
- ecosystem exchange
- transport
- 10^2 - 10^3 m
- hourly – multi-year

Microscopic Approach

- intercellular exchange
- transformation, chemical pathways
- 10^{-5} – 10^{-2} m
- seconds – hourly

← everything in between →

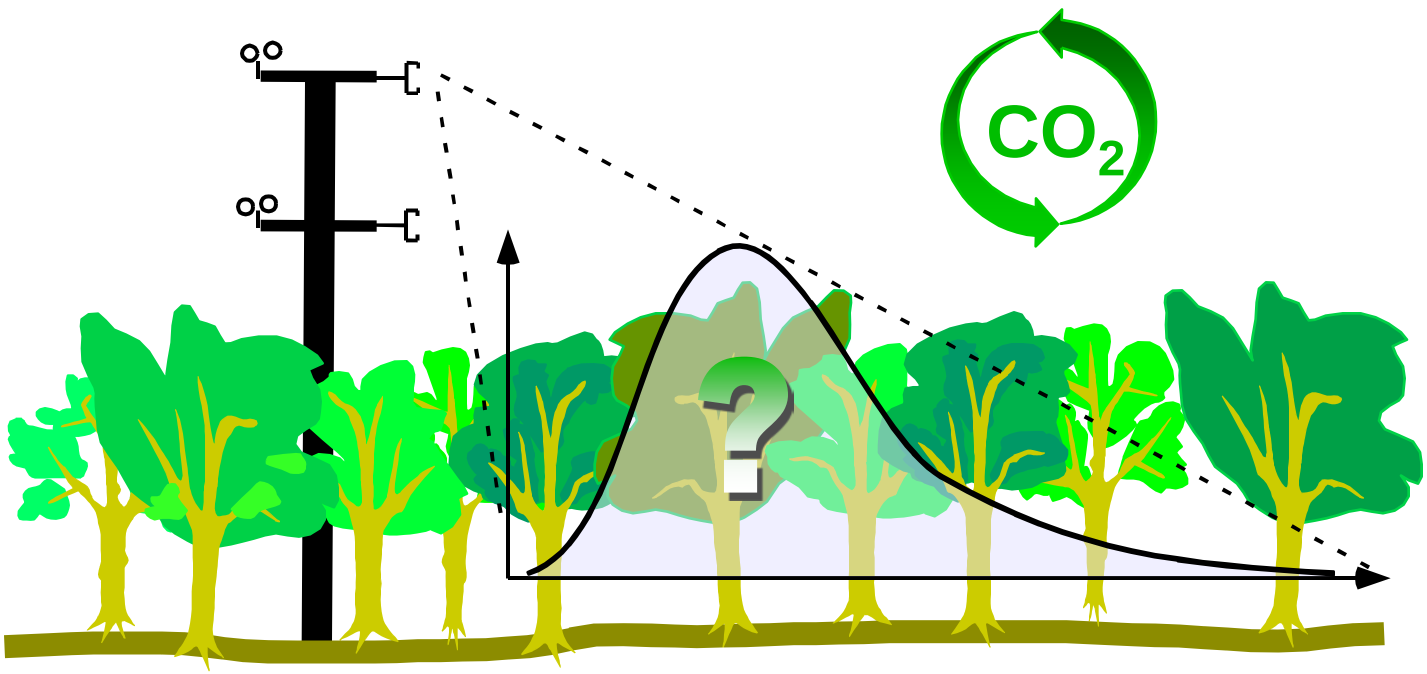
Micrometeorological Flux Measurements:
at what scale?



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)**
- **<u>If yes</u>: use data; <u>if not</u>: reject data**

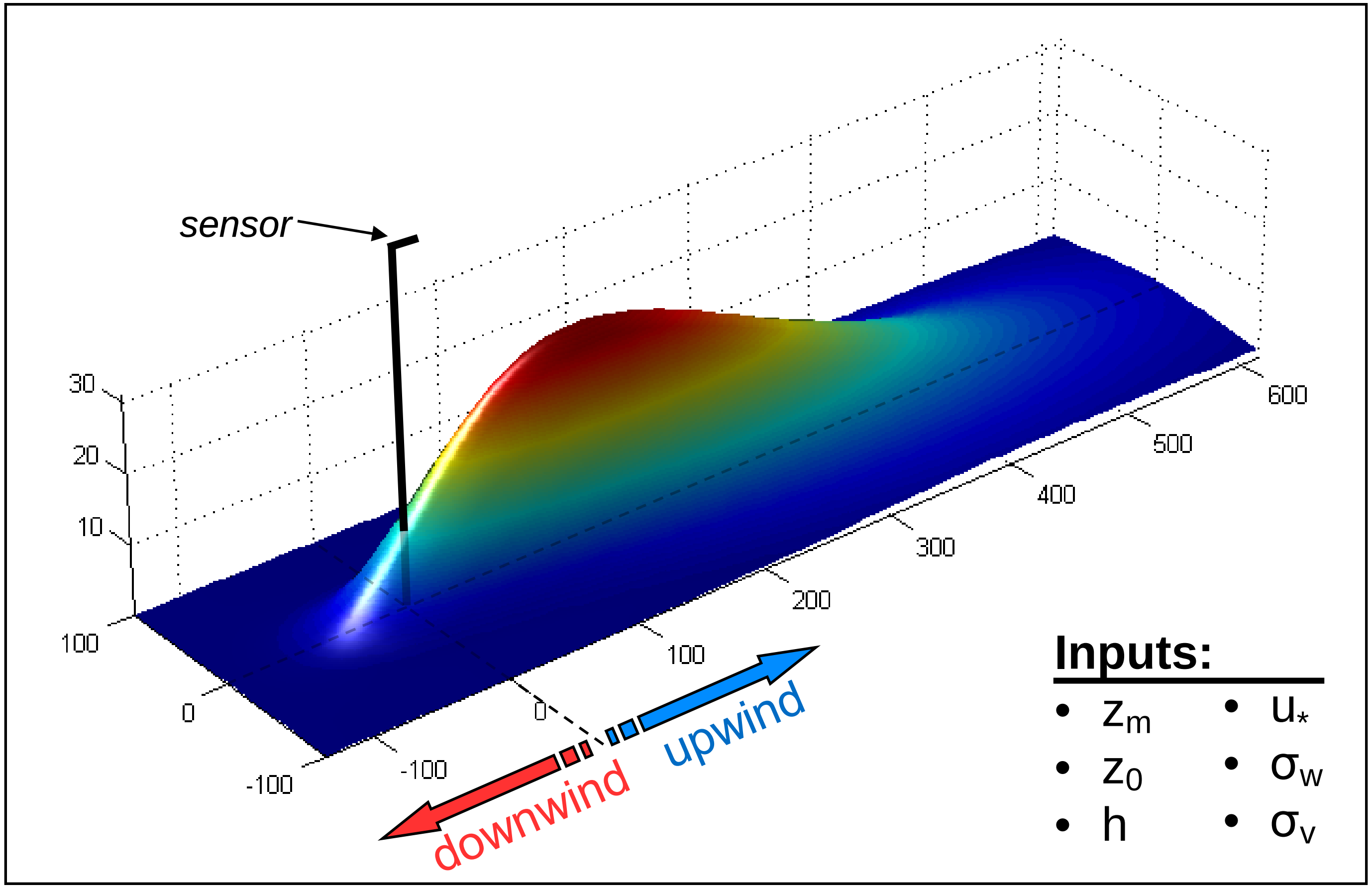


e.g.: Schmid (2002, *Ag. For. Met*., **113**, 159-184)

Flux Footprint = *spatial* ***filter***, *"field of view"*

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

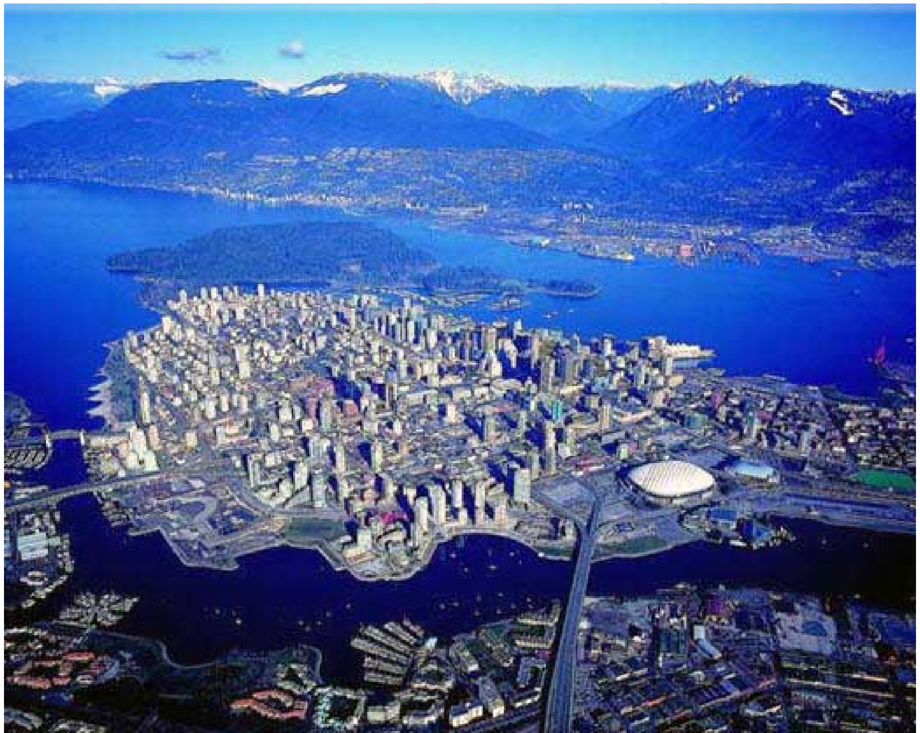
(**convolution** of the **source distribution**, ***Qs***, with the **footprint**, ***f***)

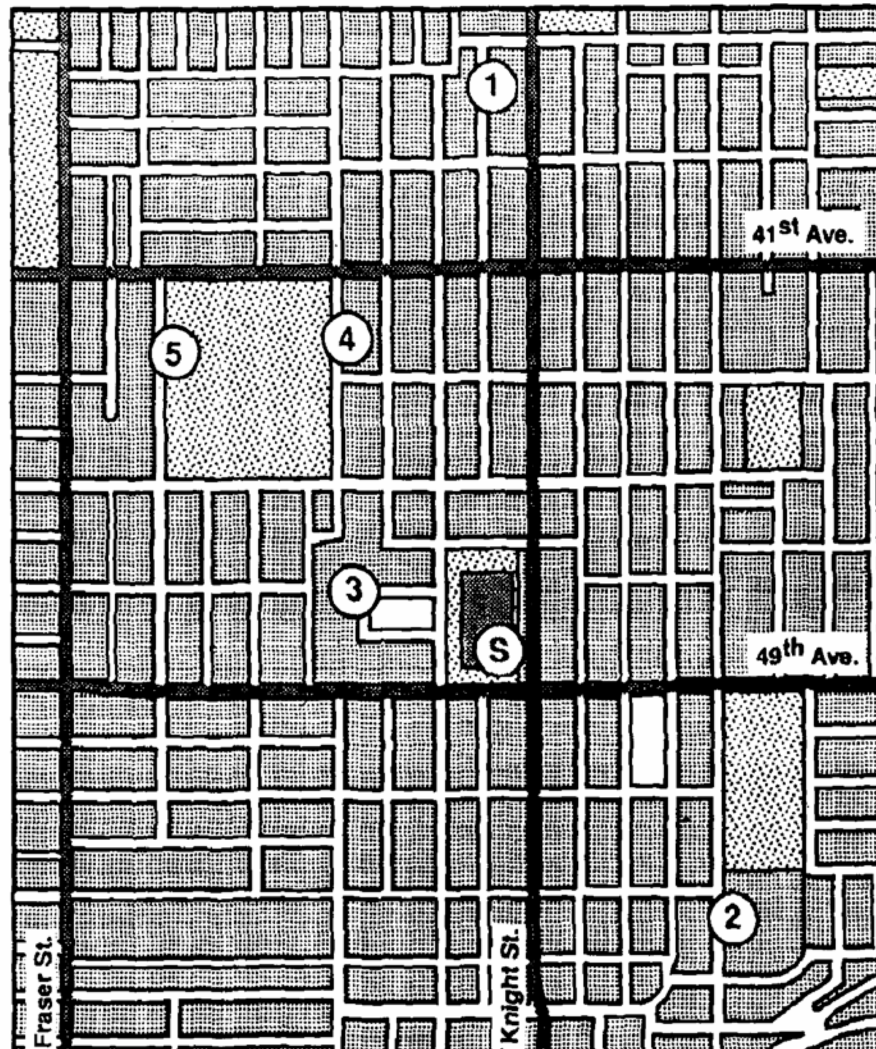


Schmid 1994 (*Boundary-Layer Meteorol.*, **67**, 293-318)

Does the Footprint Concept Actually Work?

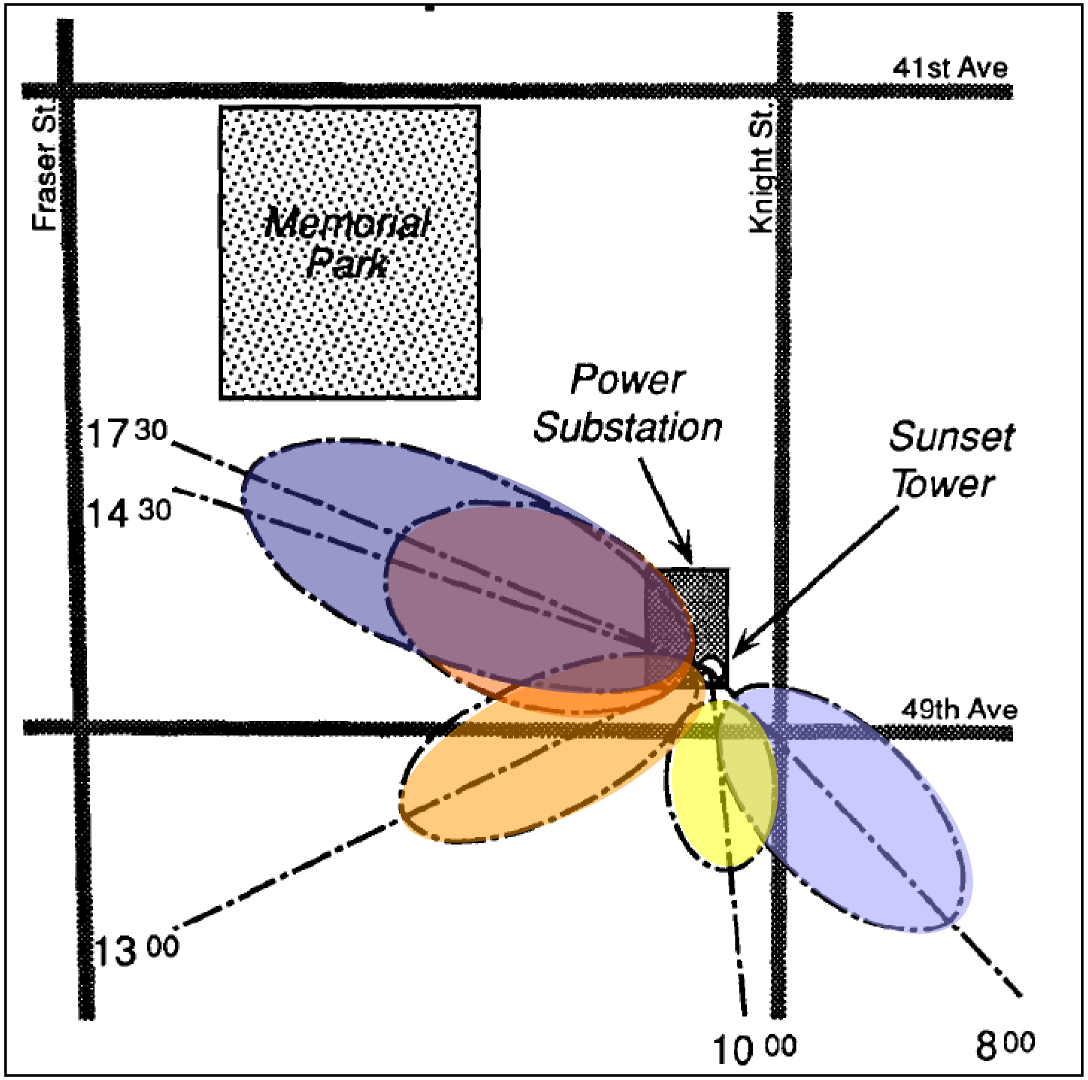
Vancouver, B.C., Canada: Summer 1986





Schmid *et al.*, BLM 1991

"Field of View" / Footprint Varies with Time



(after Schmid et al. 1991)

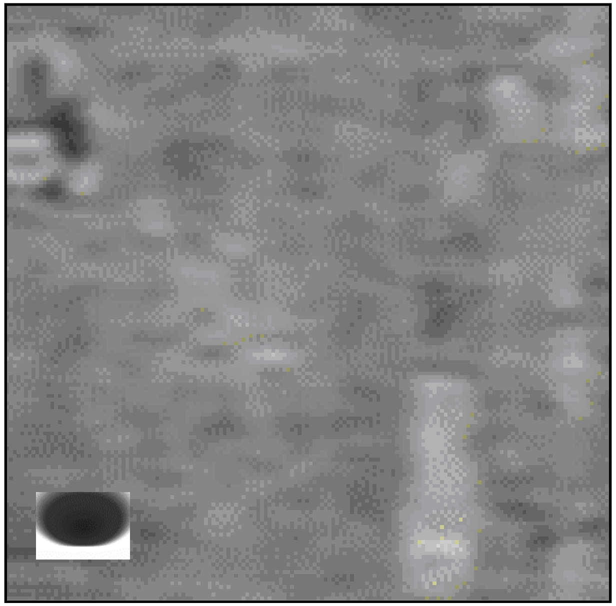
- Turns with wind direction
- Small in unstable conditions
- Larger in neutral/stable conditions

Is the Vancouver Suburban Study Area Homogeneous?

(regarding a turbulent flux sensor at 30 m)

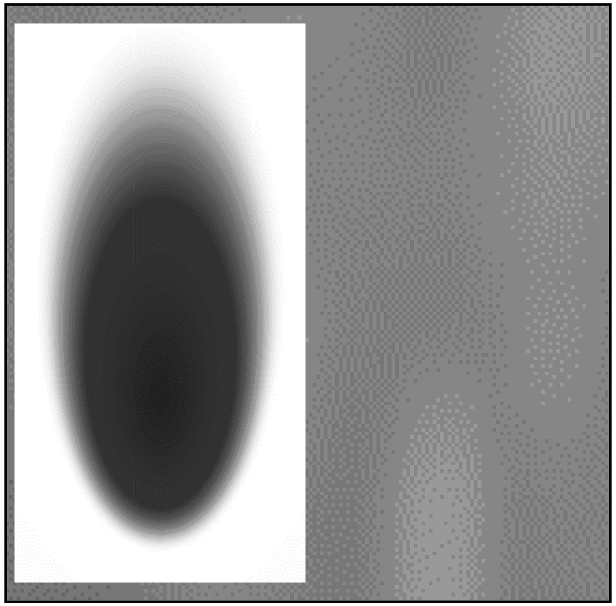
Vancouver Temperature Distribution
at full resolution (from airborne IR scanner)

as "seen" by a flux sensor at 30 m in unstable conditions



variability reduced to 18%

as "seen" by a flux sensor at 30 m in near-neutral conditions



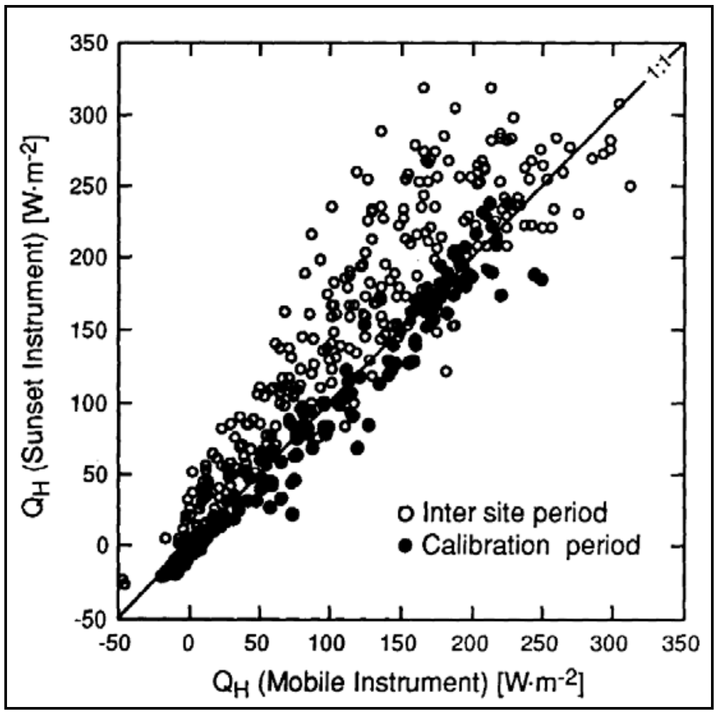
variability reduced to 4%

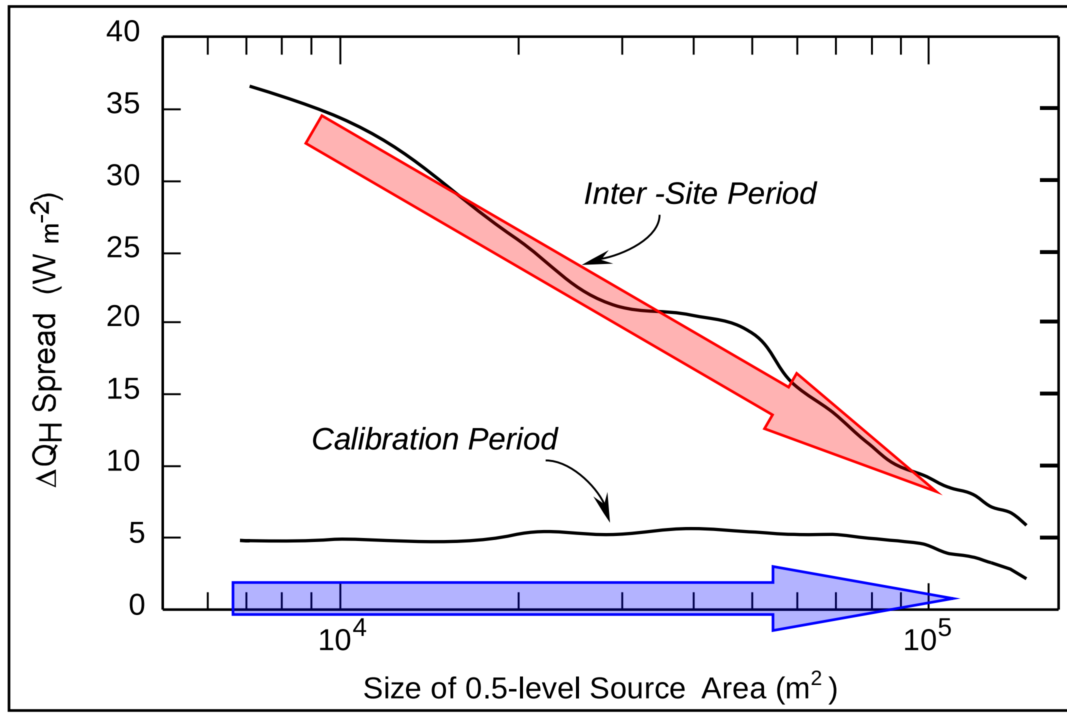
- **in unstable conditions: expect spatial variability**
- **in near-neutral/stable conditions: expect homogeneity**

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)





spatial representativeness

Schmid, 1988; Schmid *et al.*, BLM 1991; Schmid, AgForMet 1997

Morgan-Monroe State Forest (Indiana)

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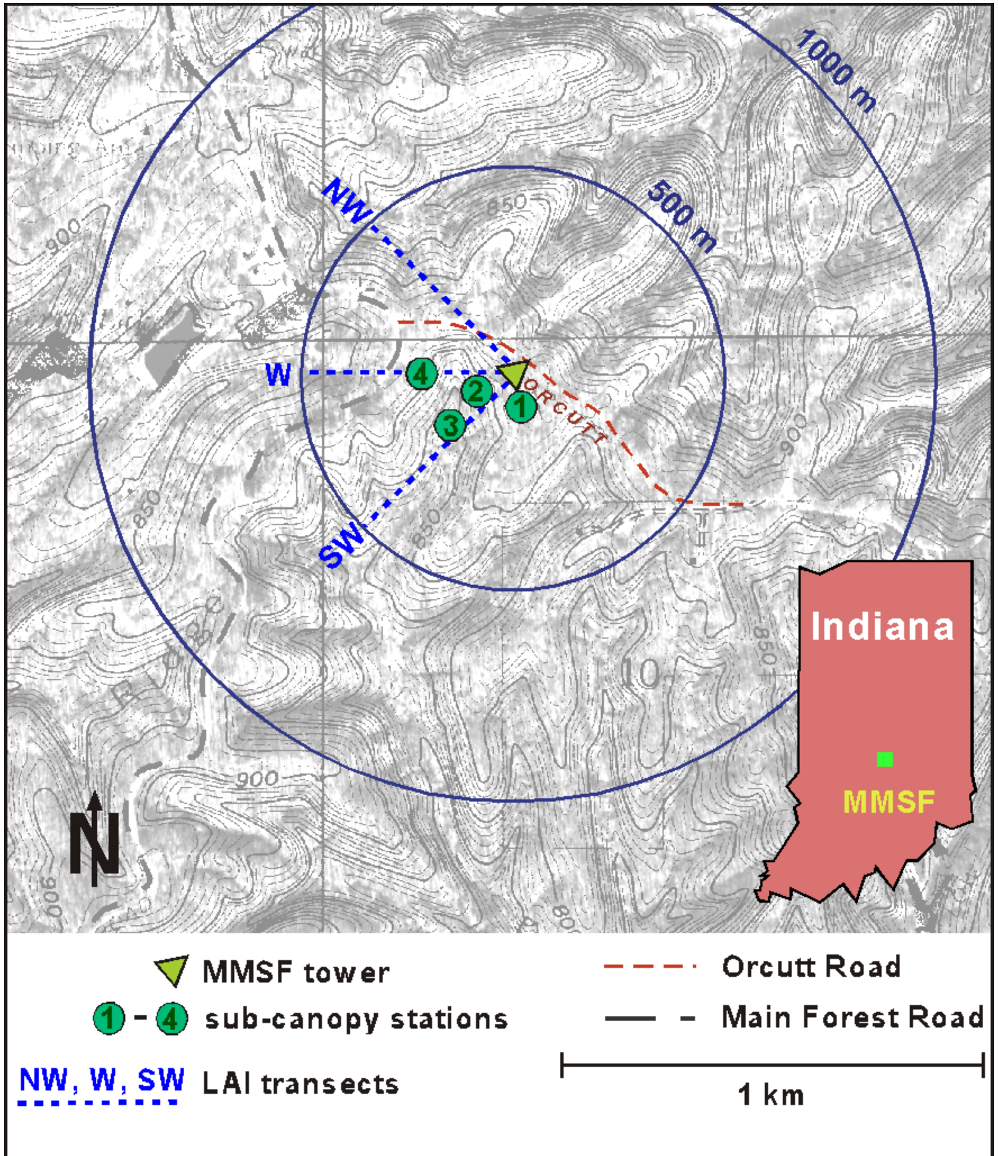
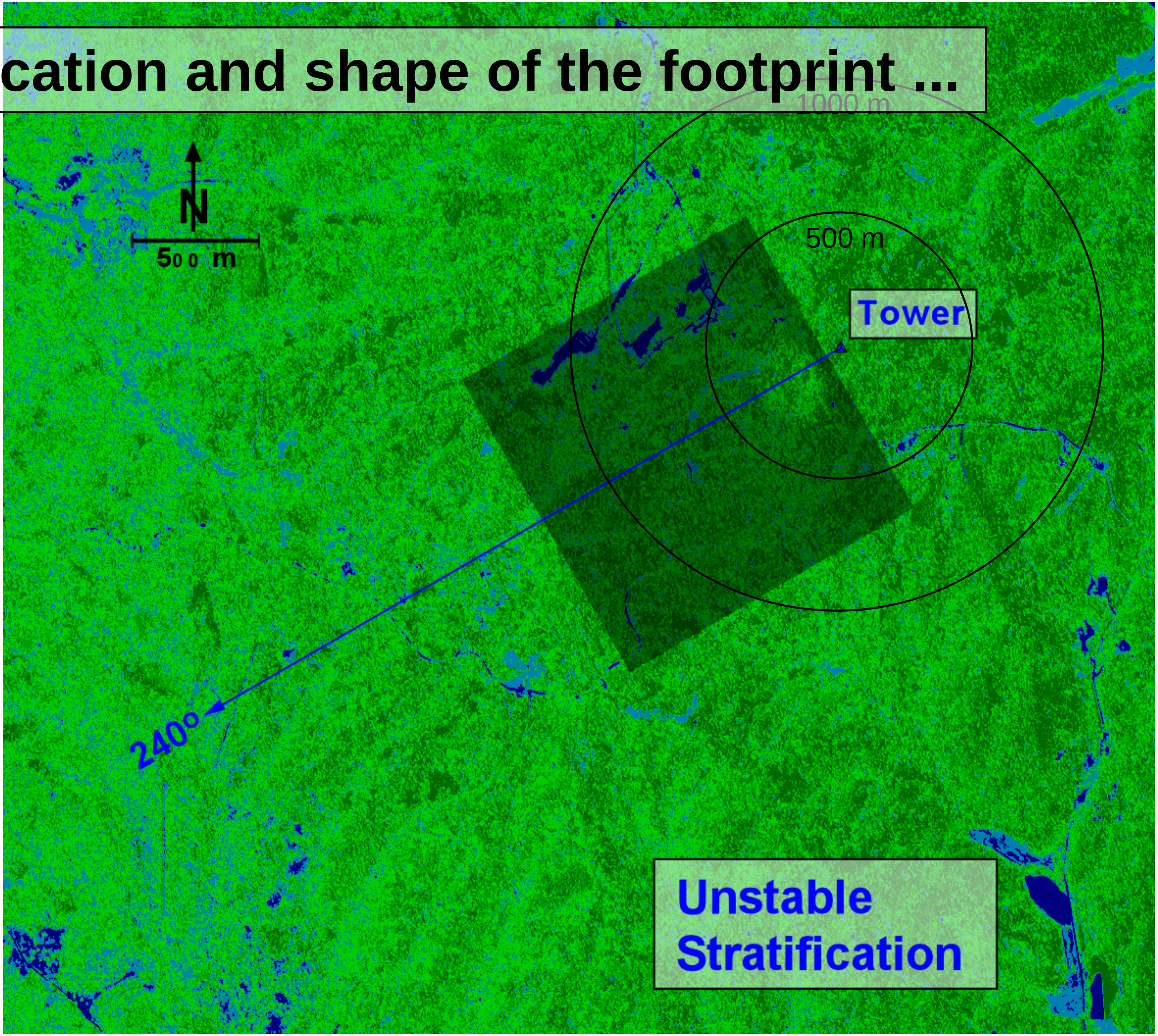
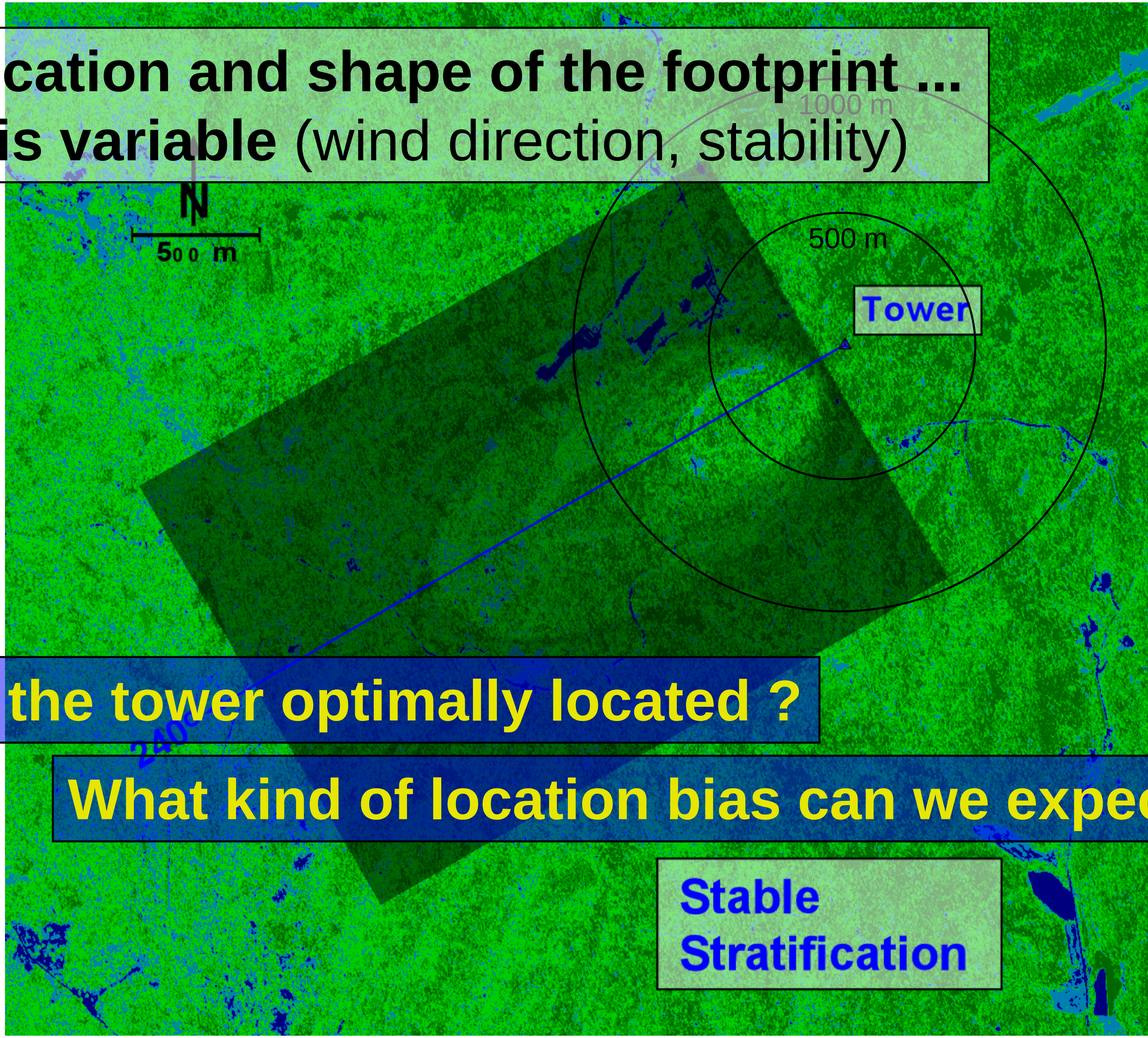


- 39º 53' N, 86º 25' W
  South central Indiana – 275 m
- Red Oak, White Oak, Tulip Poplar, Sugar Maple
- 60 – 80 year stand age
- 25 – 30 m canopy height
- 4.9 maximum Leaf Area Index
- 18.52 kg m^{-2} mean above-ground biomass
- 236 ~ 261 g C m^{-2} y^{-1} NEP (1998/99)

Location and shape of the footprint ...

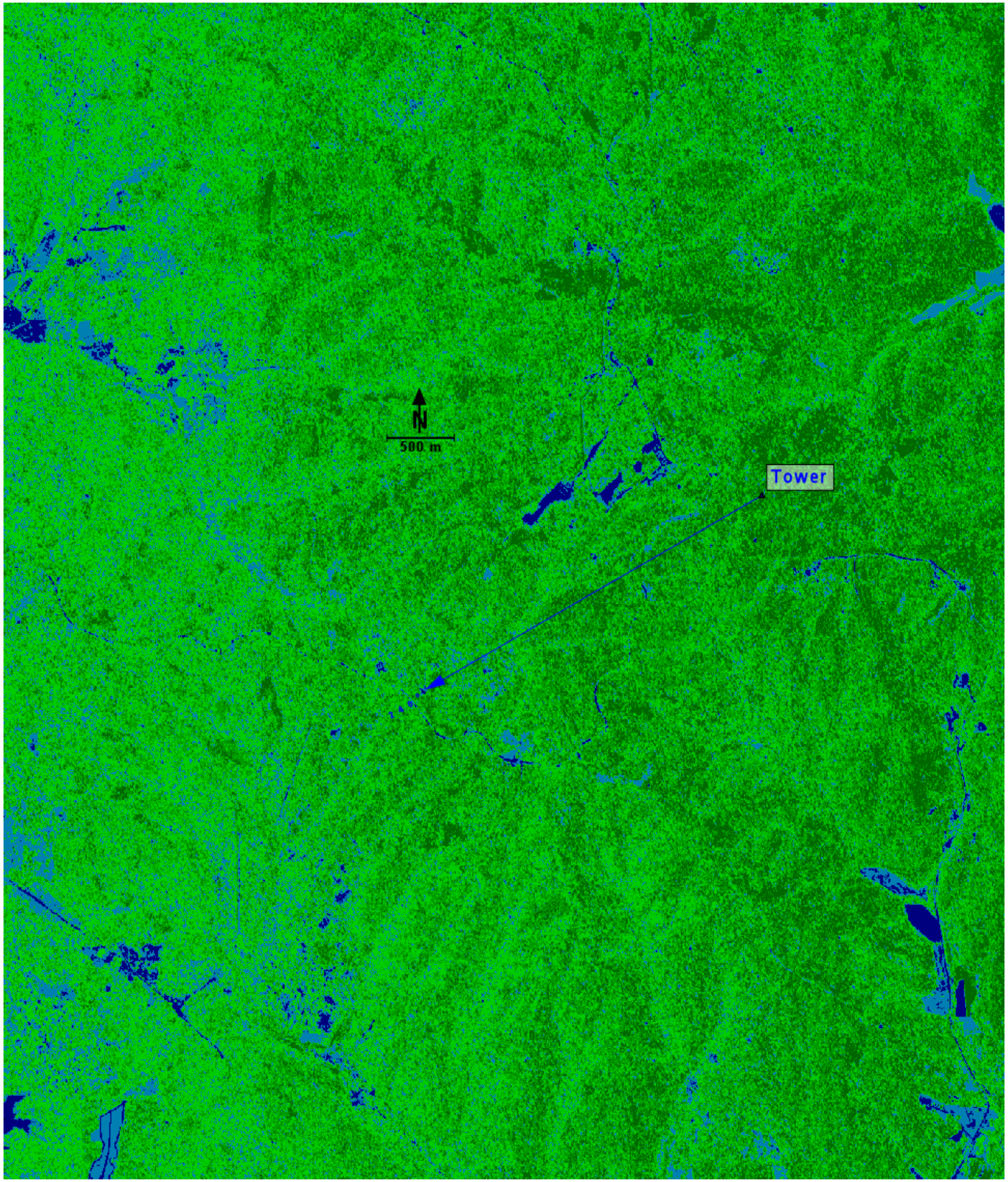


Location and shape of the footprint ...
... is variable (wind direction, stability)



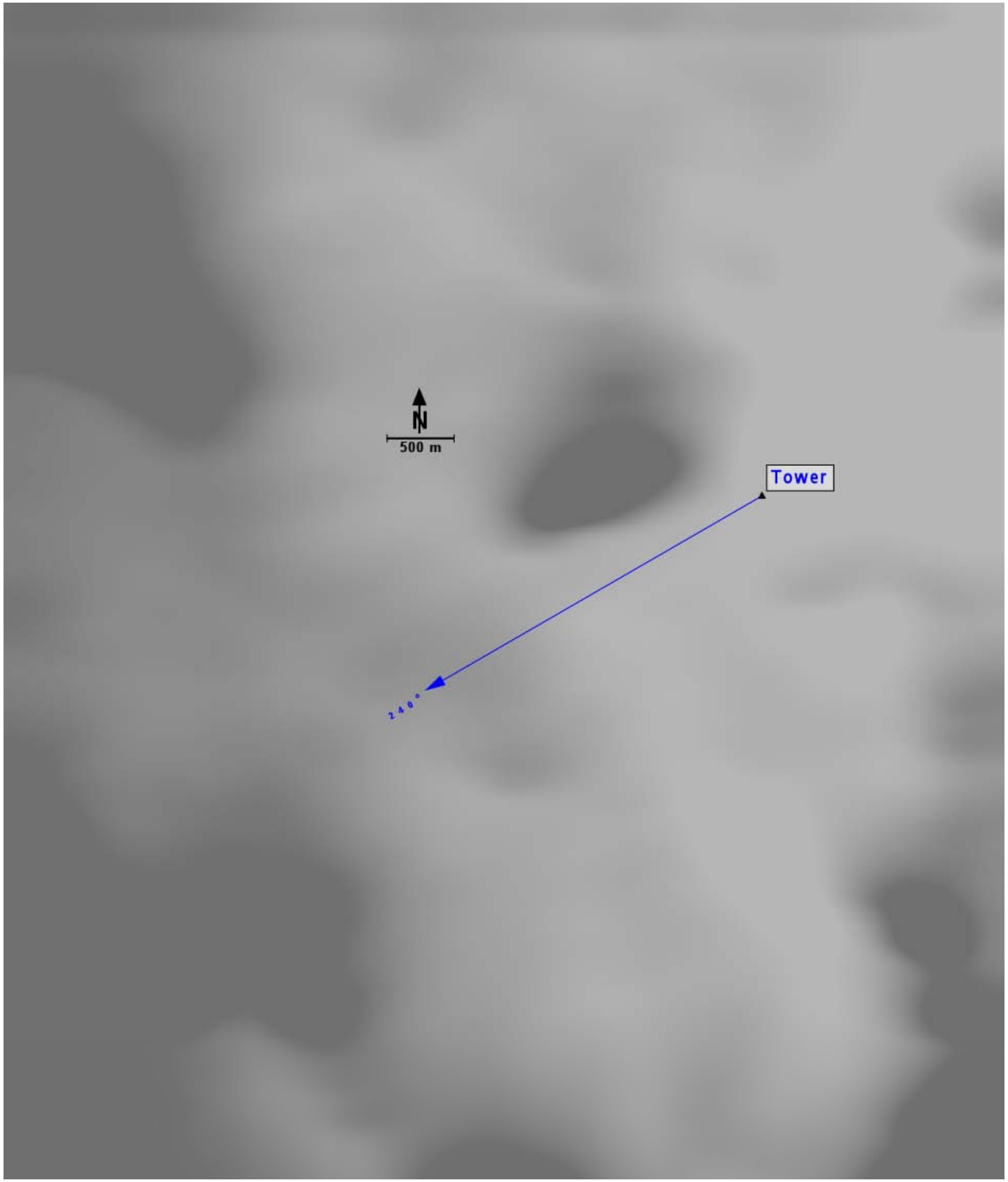
Is the tower optimally located ?

What kind of location bias can we expect ?



- **Original NDVI:**

NDVI Variance: 0.053
(= 100 %)



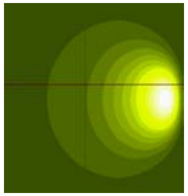
- **Original NDVI:**

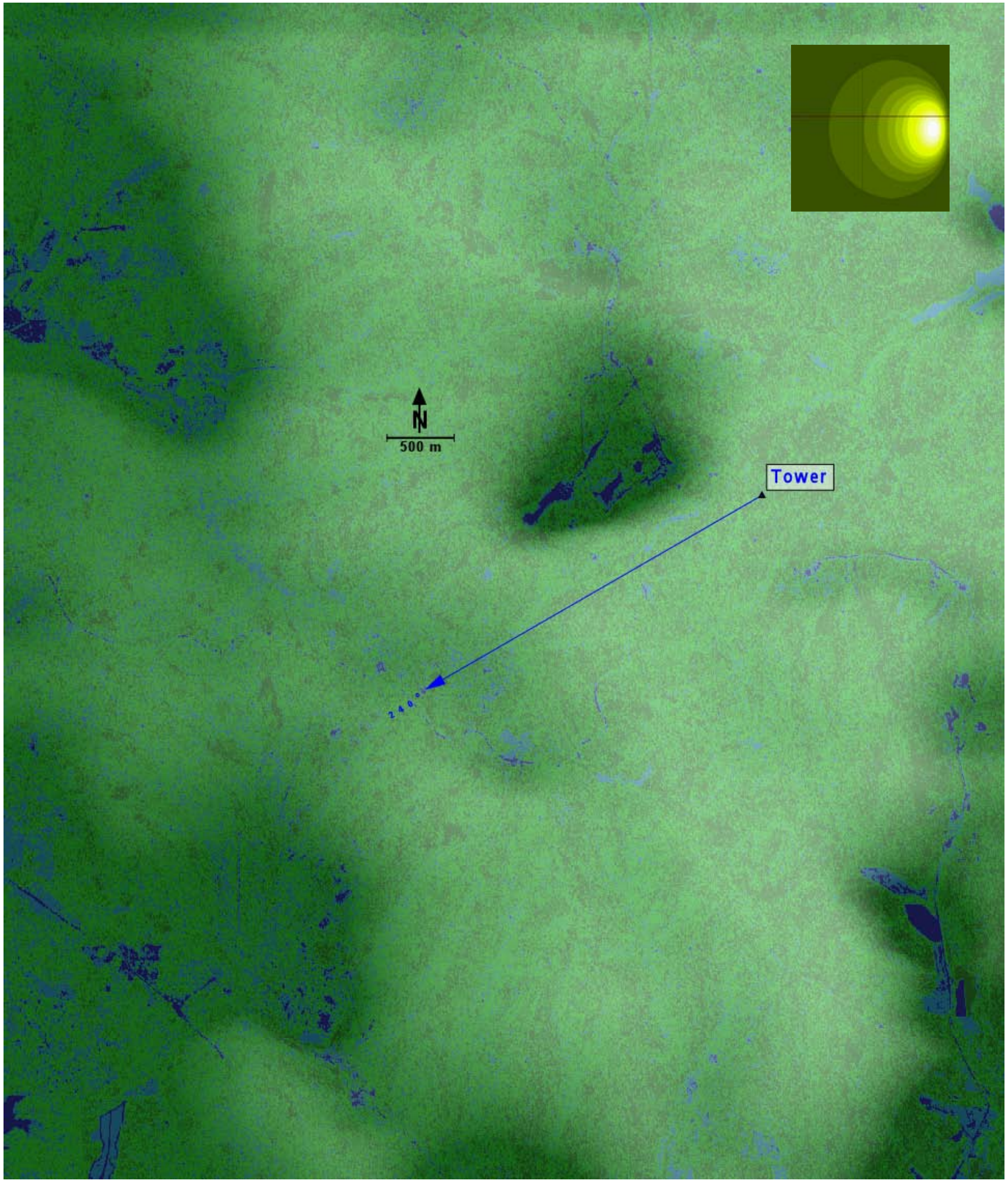
  NDVI Variance: 0.053
  (= 100 %)

- **Filtered NDVI:**

  Unstable FSAM filter
  Remaining Variance:
  28 %

  FSAM Filter Size:





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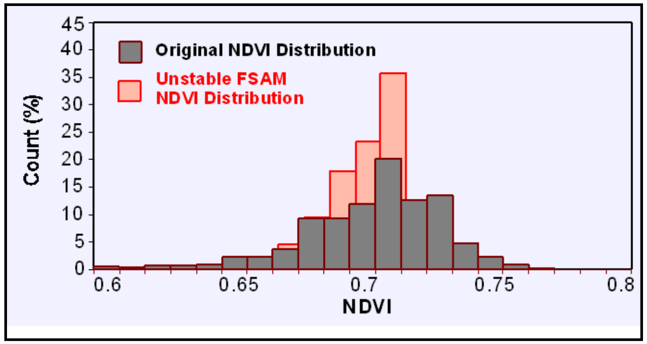
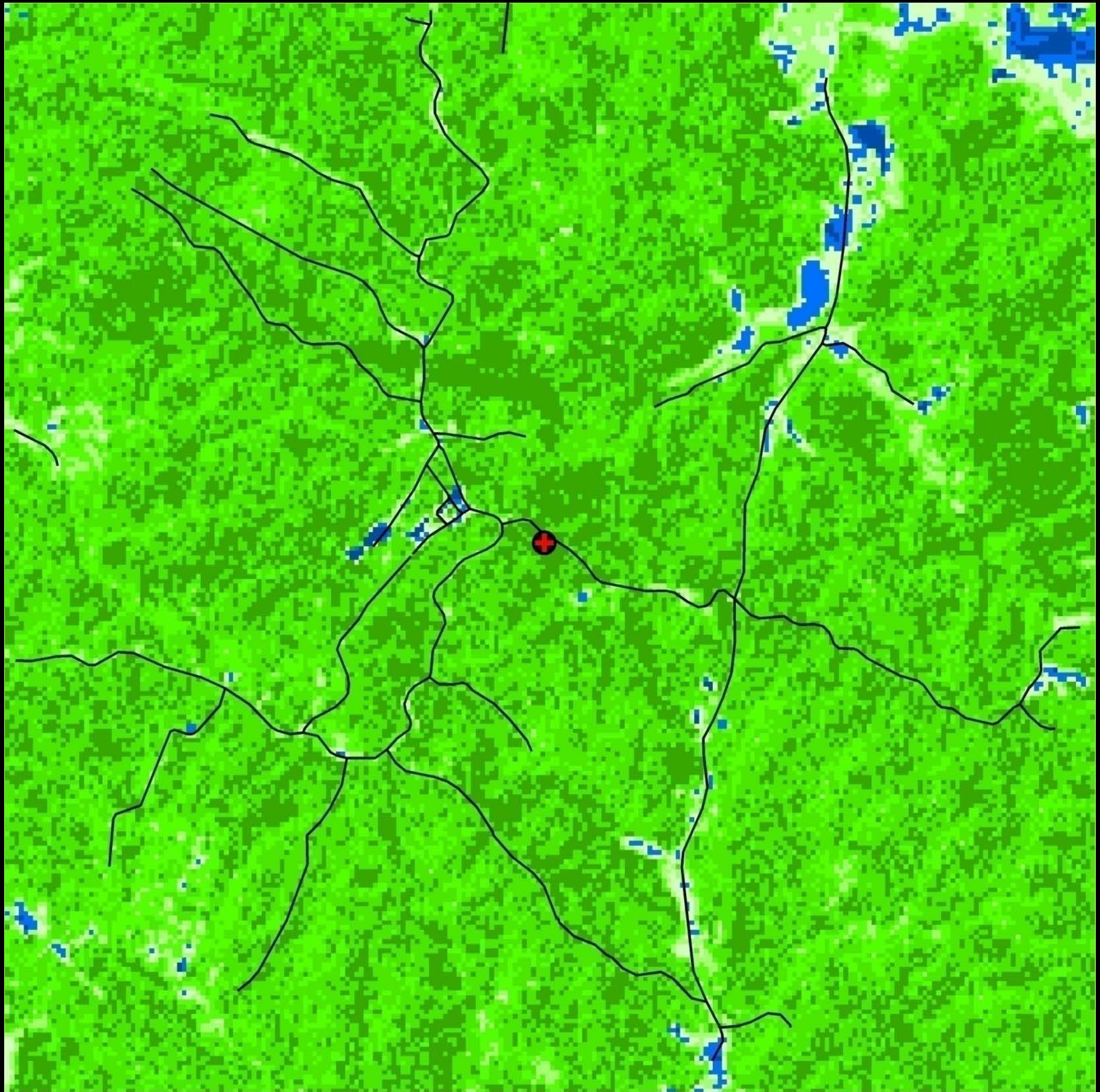
- Histogram Comparison:

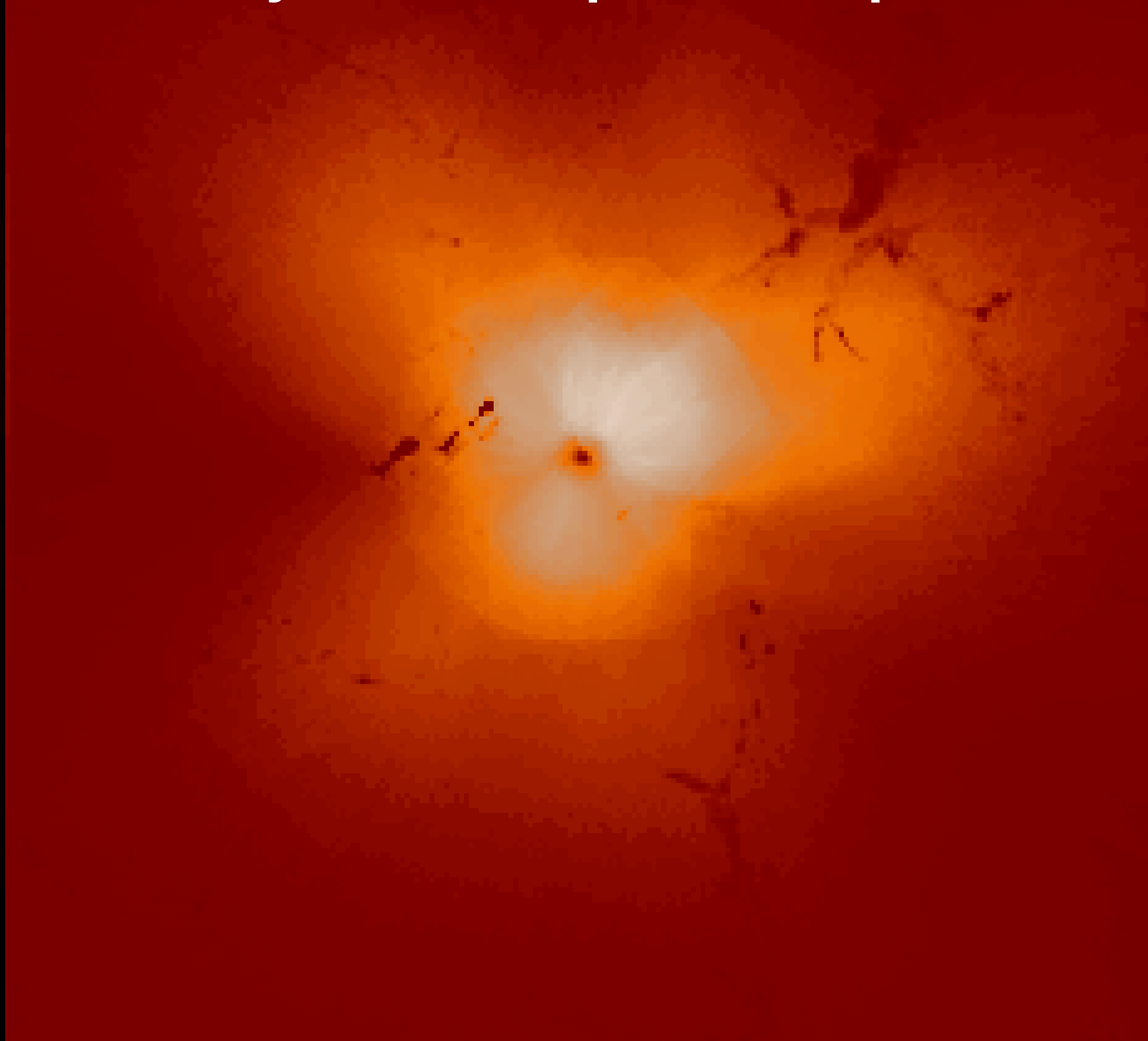




Hourly Footprints 2001: YD 217- YD 225

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

Lynn Basa: "Sprawl", acrylic on canvas, 12" x 12", 2007

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