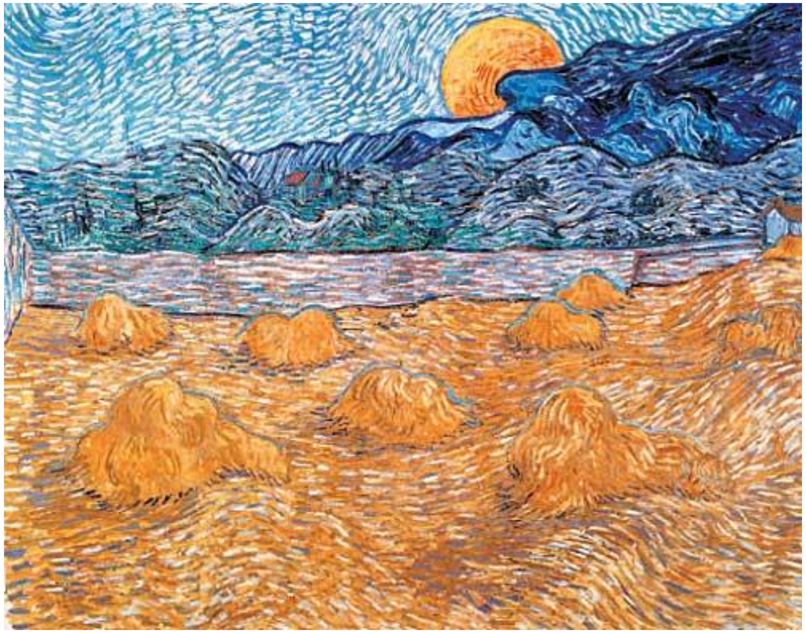
A Simple Model for the Afternoon and Early-Evening Decay of Turbulence Over Different Land Surfaces



Daniel Nadeau
ER Pardyjak, CW Higgins, HJS Fernando, MB Parlange

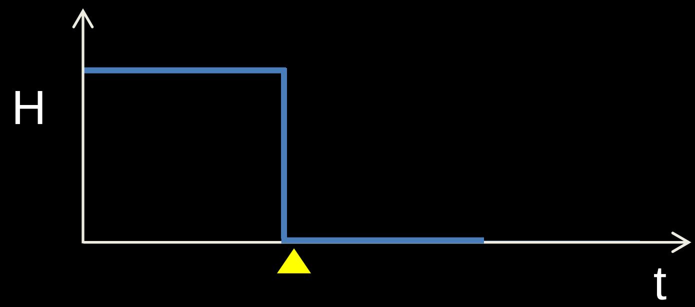
Objectives

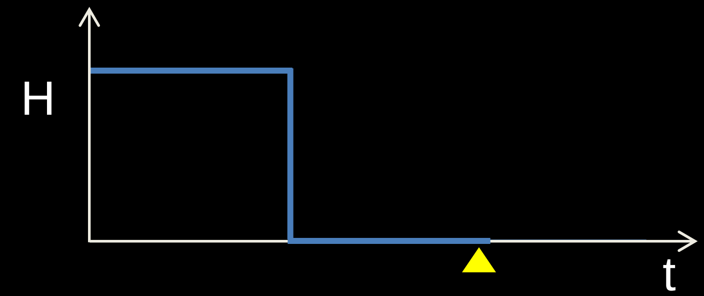
- Understand the physics of decay period better
  - phenomenologically
  - quantitatively
- Understand heterogeneous terrain decay
  - roughness
  - moisture
  - albedo
- Develop a simple turbulent kinetic energy decay model
- Develop heterogeneous sensible heat flux forcing model for Large-Eddy Simulation

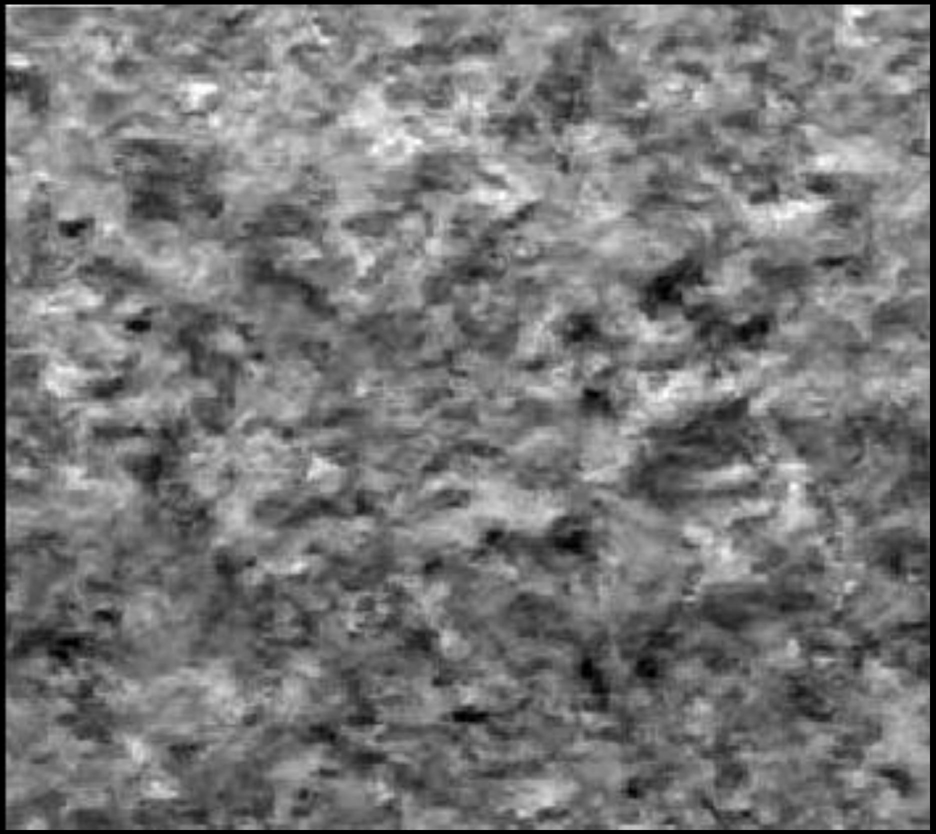
Turbulence Decay - Background

- Literature including laboratory work, field experiments and LES
- Most of the literature covers a limited forcing time scale range

Horizontal velocities at z/h = 0.5

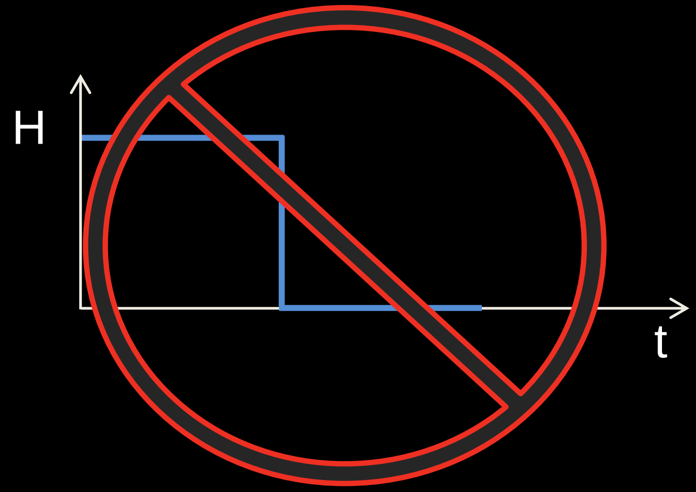


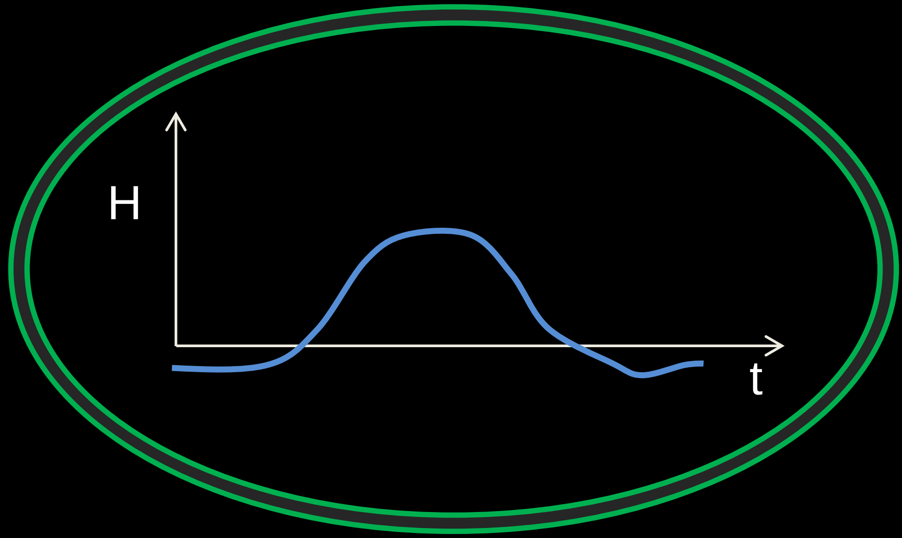




Pino et al. (BLM, 2006)

Sensible heat flux in the atmosphere

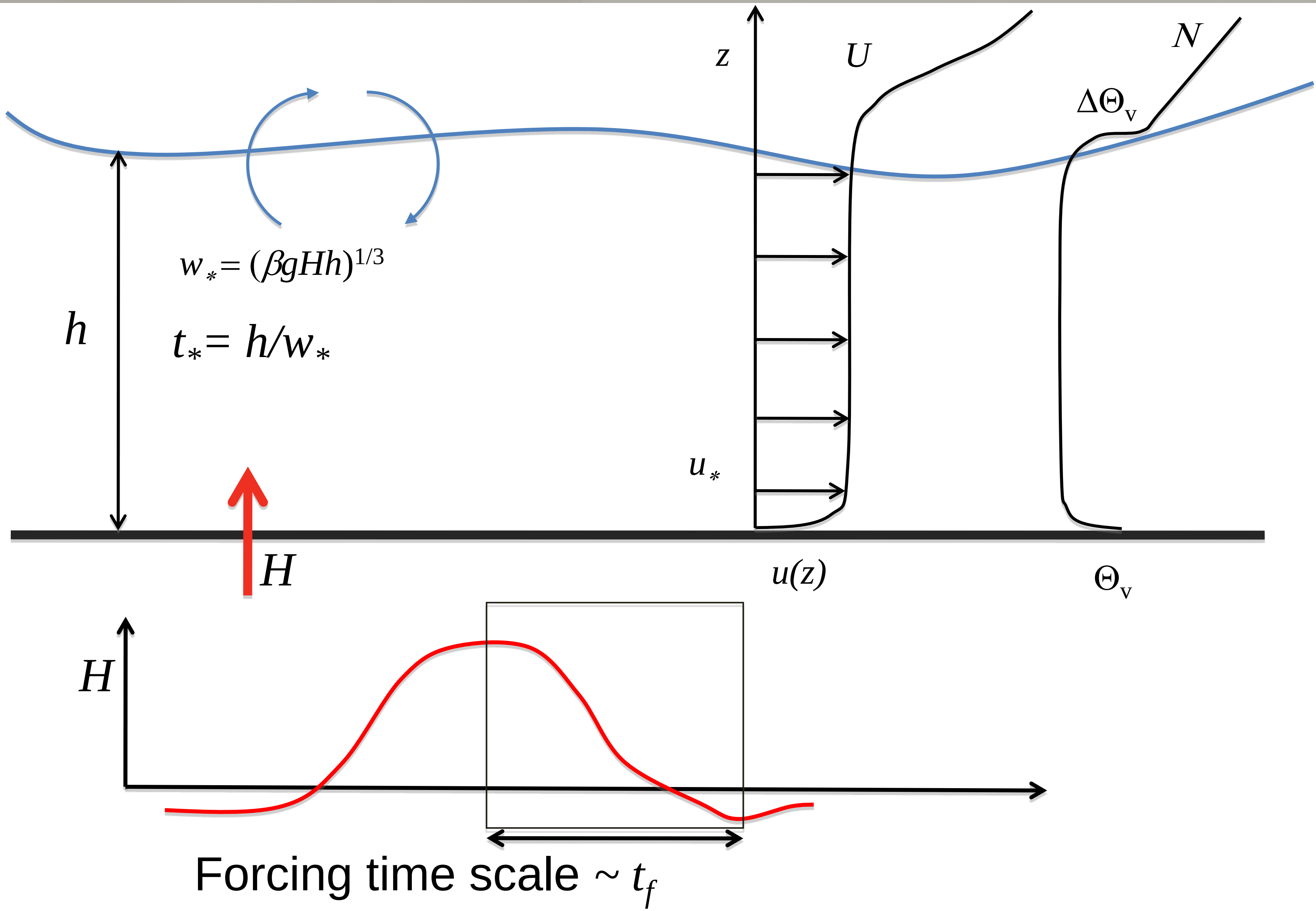




Turbulence Decay - Background

- Literature including limited laboratory, field experiments, and Large Eddy Simulation
- Most of the literature covers a limited forcing time scale range
- Important scaling from:
  - Nieuwstadt & Brost (JAS,1986)
  - Sorbjan (BLM,1997)

CBL Decay Phenomena



Some Important Decay Hypotheses

- 1 – Surface Heat Flux "Instantly Set to Zero"

  The volume integrated turbulence quantities are only a function of the initial CBL state and *t/t** (Nieuwstadt & Brost, JAS, 1986)

- 2 – Gradually Decaying Surface Heat Flux

  Turbulent decay is dependent on 2 time scales t^* and τ_f (Sorbjan, BLM, 1997)

- 3 – Limiting Cases (Sorbjan, BLM, 1997)

  $\tau_f / t^* \rightarrow 0$ Instantaneous removal of H

  $\tau_f / t^* \rightarrow \infty$ Constant H

TKE Model Development

- Nieuwstadt & Brost (JAS,1986) – Instantaneous removal of surface flux

$$\frac{\partial \bar{k}}{\partial t} = -\varepsilon \qquad \varepsilon = C_\varepsilon \frac{\bar{k}^{3/2}}{h}$$

$$\frac{k}{w_*^2} = \left(\frac{C_\varepsilon}{2} \frac{t w_*}{h} + \frac{1}{C} \right)^{-2}$$

- Modified model to account for time varying buoyancy flux

$$\frac{\partial \bar{k}}{\partial t} = \frac{g}{\overline{\theta_v}} \left(\overline{w' \theta_v{}'} \right) - \varepsilon.$$

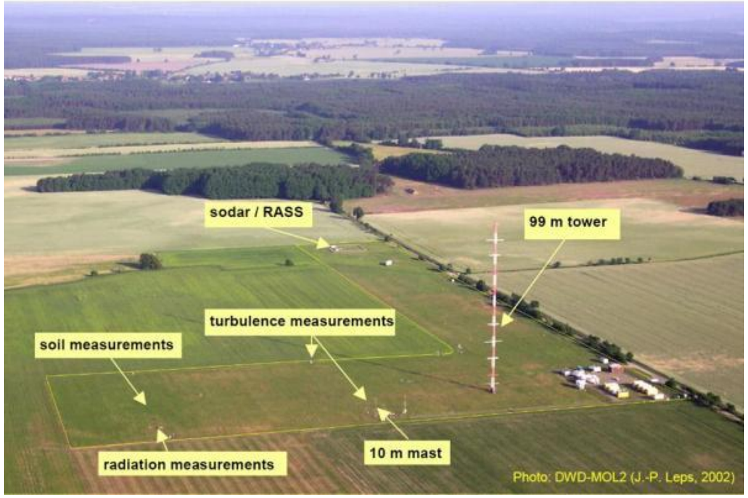
function of time

Approach: Simple empirical to model approach that uses relatively easy to obtain meteorological data.

Field Experiments

LITFASS – 2003

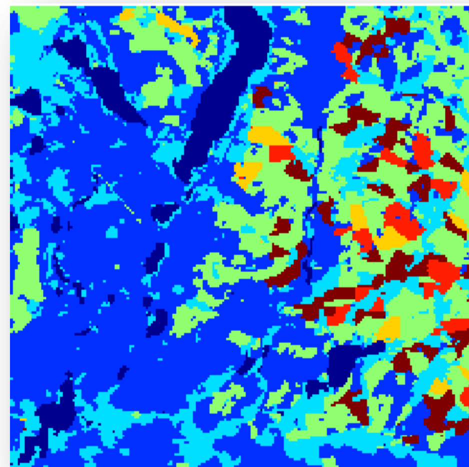
- Strong heterogeneities over flat terrain
- 20 x 20 km area
- Energy balance weather stations over different surface types
- Regular radiosonde launches



Beyrich and Mengelkamp (BLM, 2006)

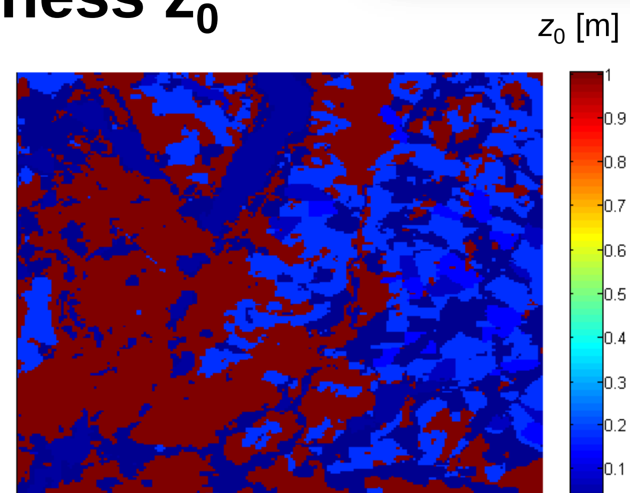
Field Experiments – LITFASS-2003

Surface types



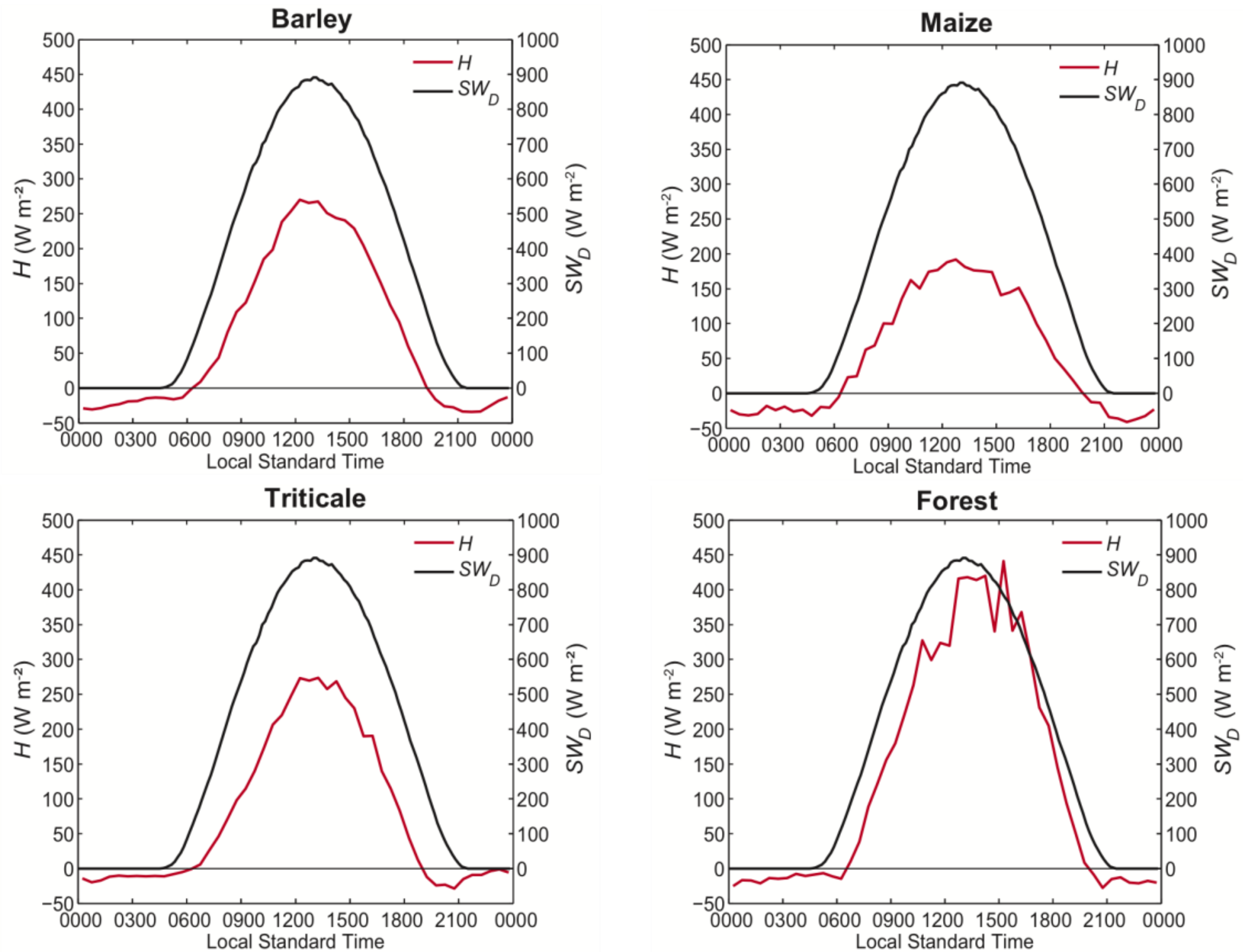
- maize
- triticale
- barley
- rye
- grass
- forest
- water

Surface roughness z_0

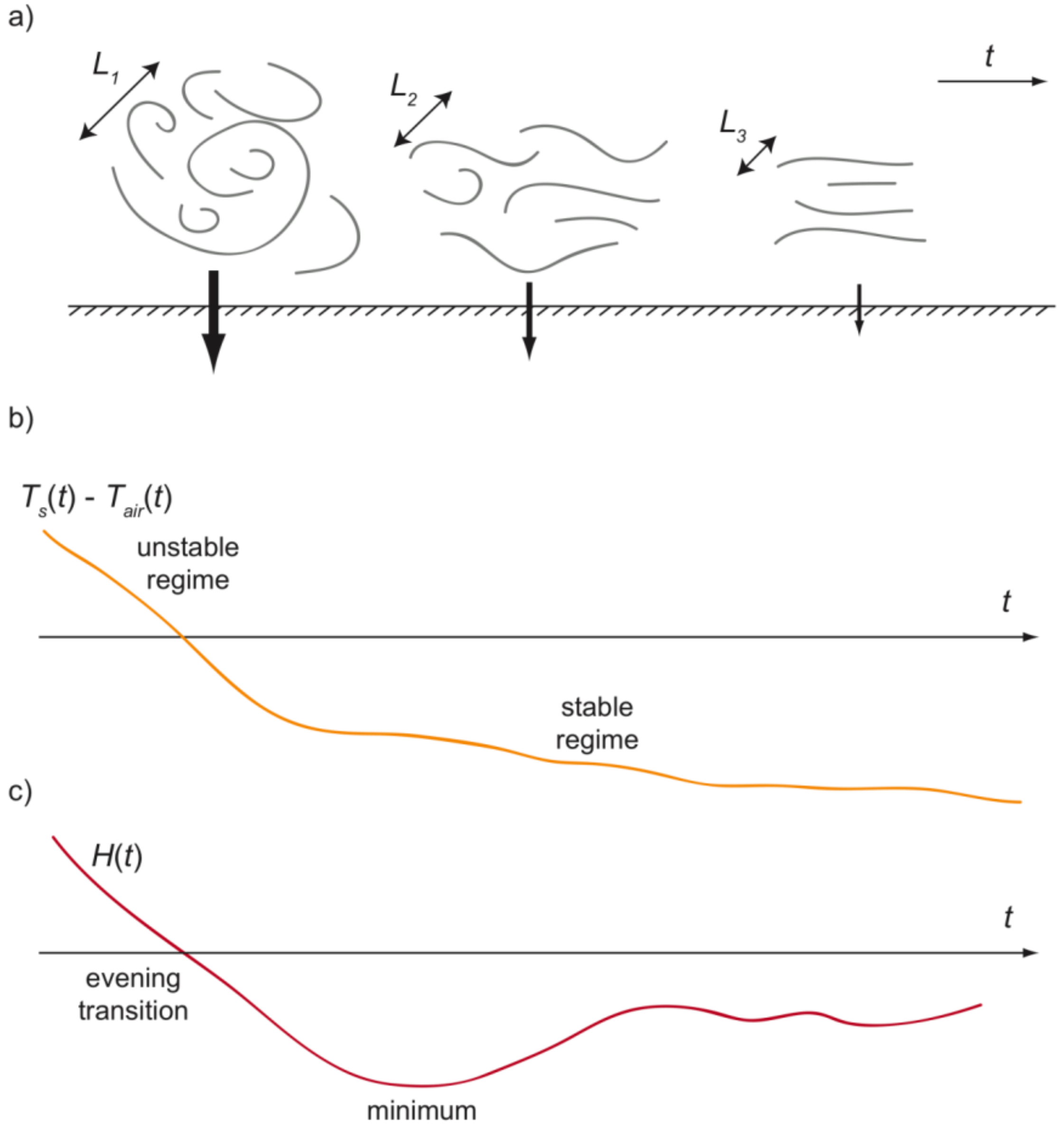


- Range of roughness
- Range of Bowen ratios (0.75 - 8)

Solar radiation – LITFASS-2003
Sensible Heat Flux



Collapse of Turbulence

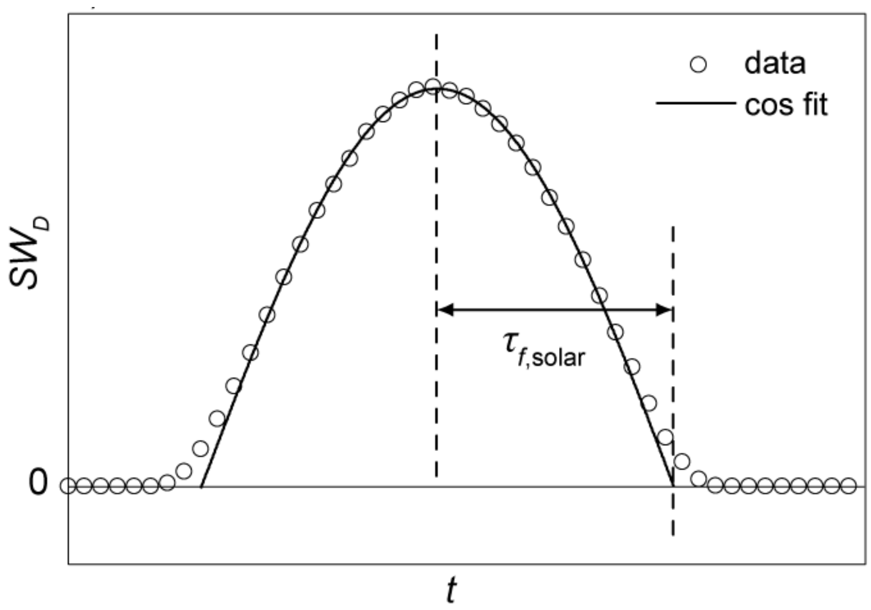


Modeling the Heat Flux

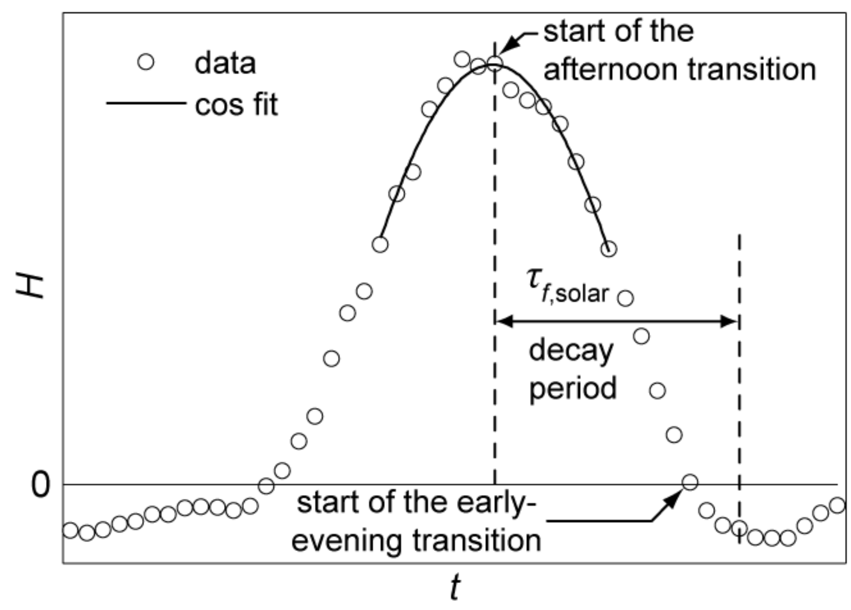
$$H_{\cos}(t) = H_{\max}\cos\left(\frac{\pi t}{2\tau_{\cos}}\right)$$

$$H_{\text{erfc}}(t) = \frac{(H_{\max} - H_{\min})}{2}\left[\text{erfc}\left(\frac{t}{\tau_{\text{erfc}}\sqrt{2}} - \frac{3}{\sqrt{2}}\right)\right] + H_{\min}$$

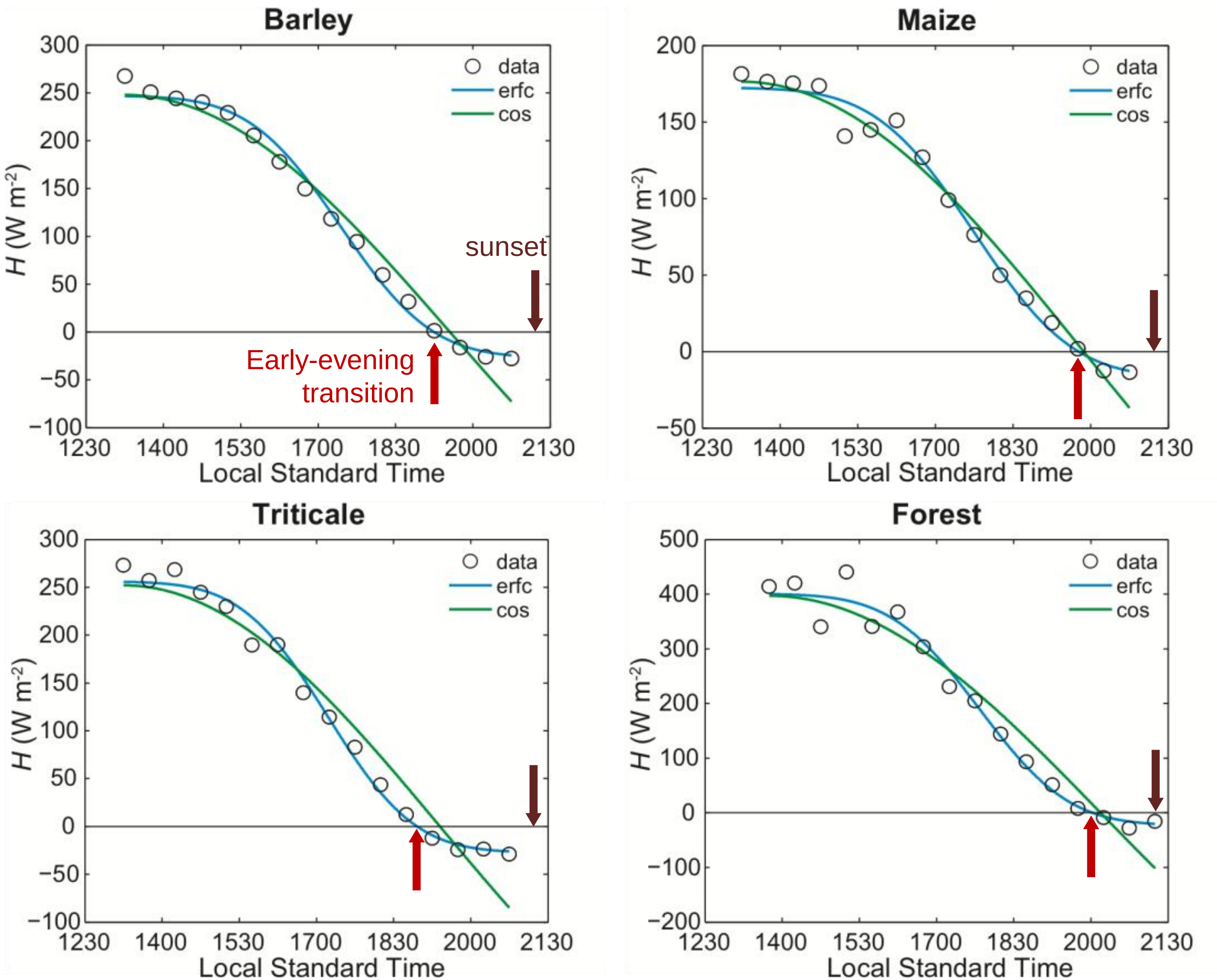
Incoming Solar Radiation



Sensible Heat Flux

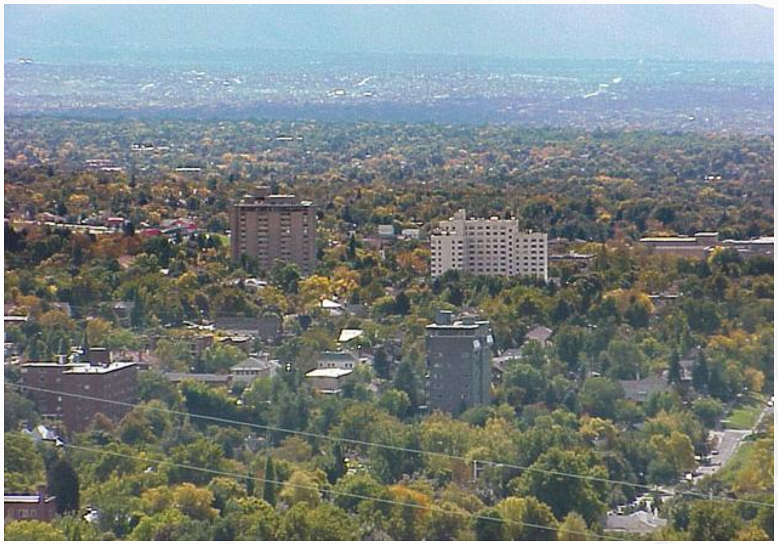


Sensible Heat Flux Model Performance

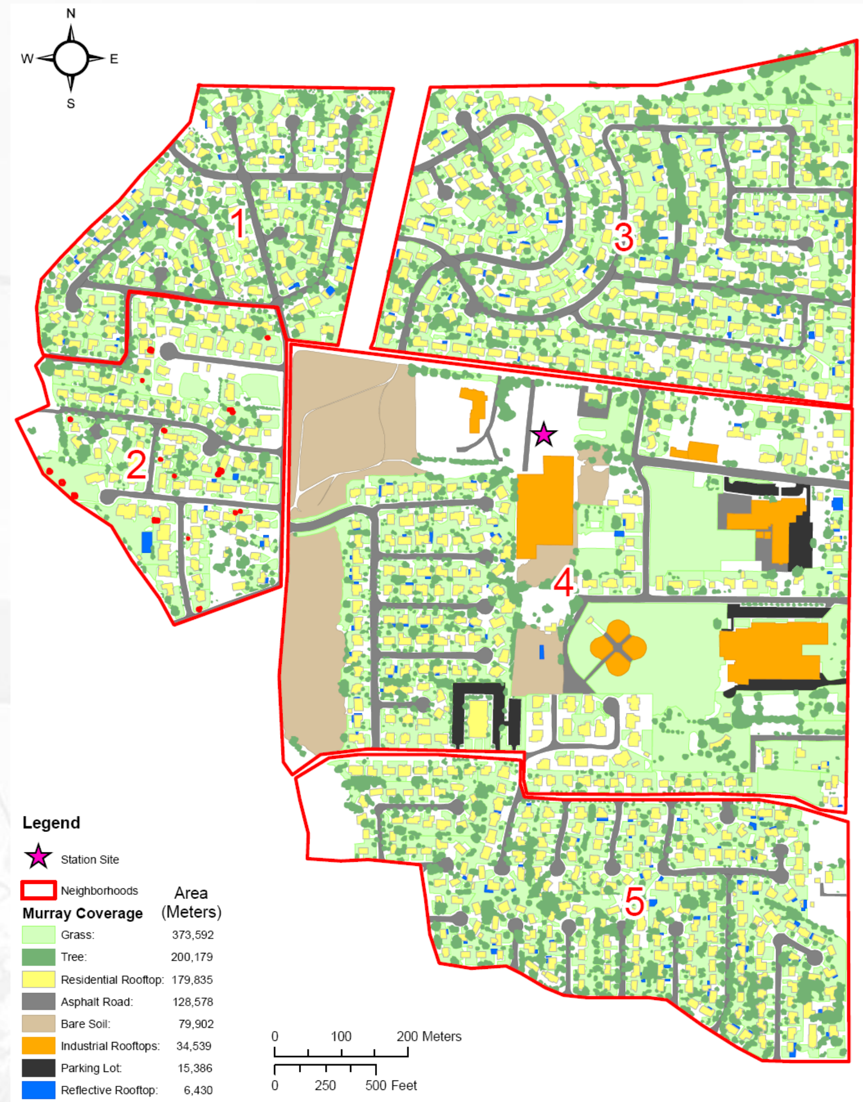


Testing the Model

Field Experiments – Suburban Salt Lake City, USA



● UTES monitoring station

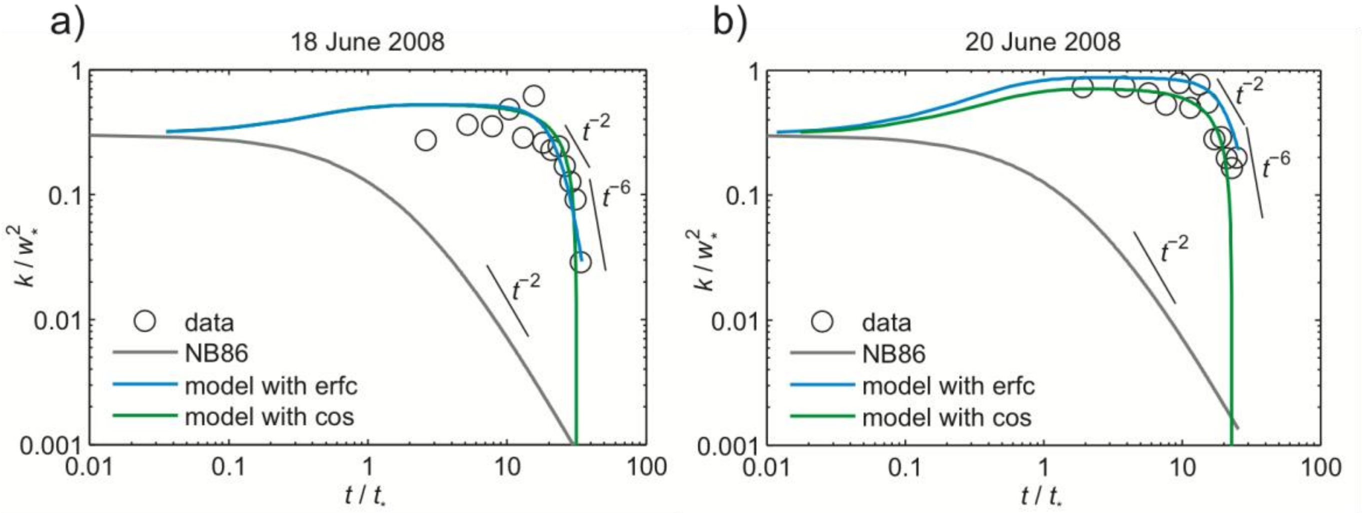


Field Experiments – Desert Salt Flats, USA

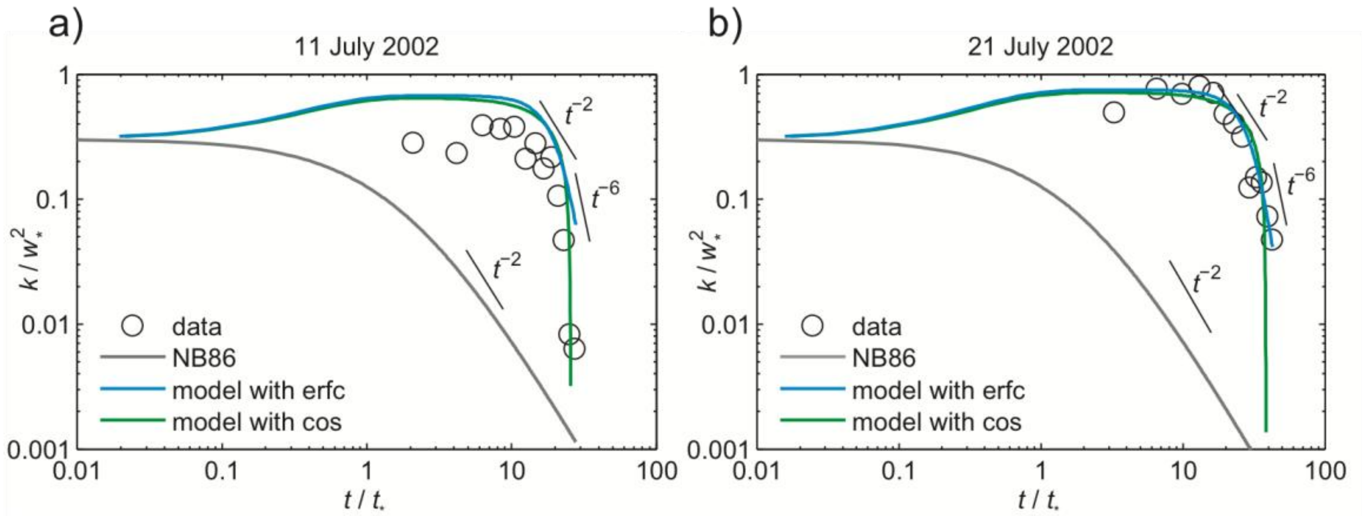
- Very large sensible heat flux
- Very large mid-day BL depth (3 - 4.5 km)
- Very smooth

Application of the TKE Decay Model

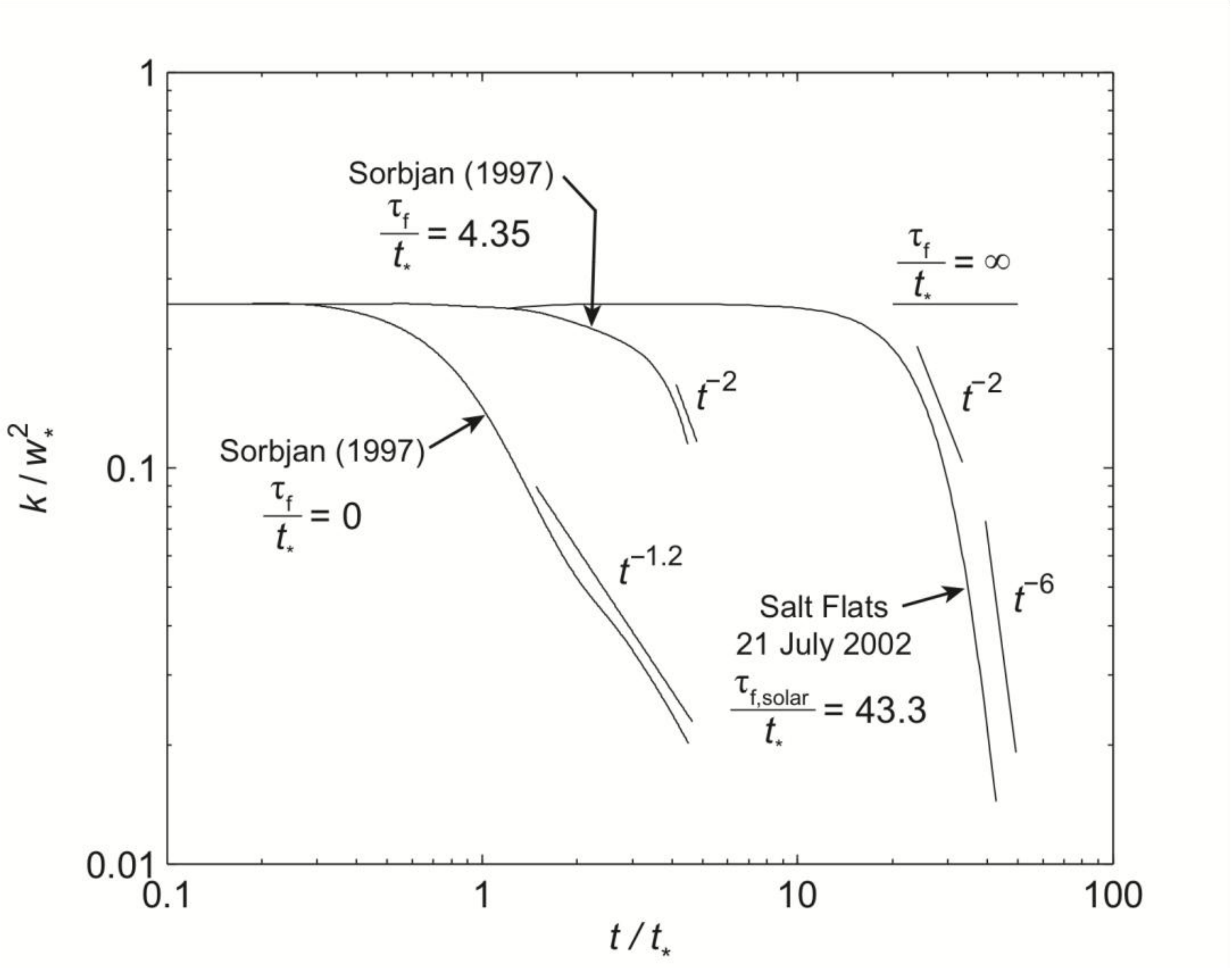
Suburban – Salt Lake City, USA



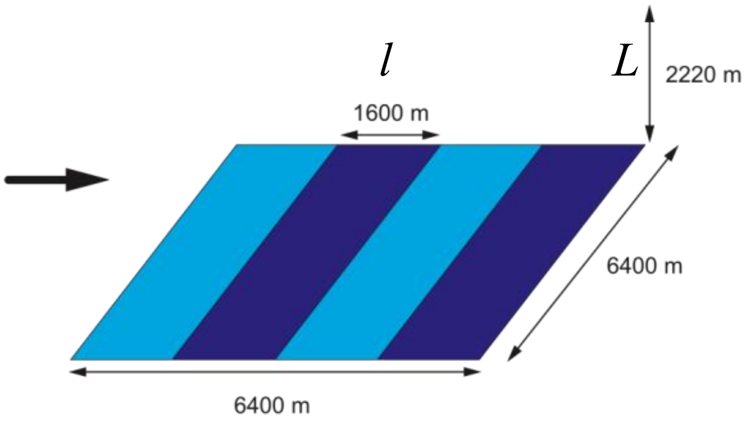
Desert – Salt Flats, USA

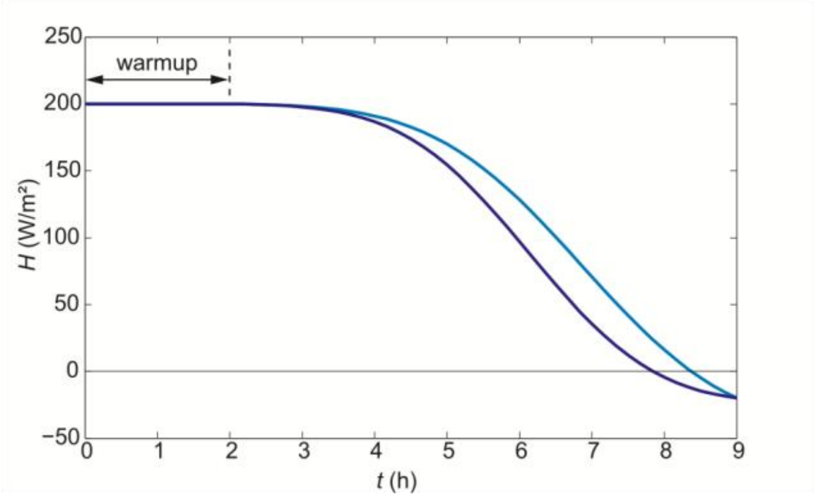


Expanded Decay Picture



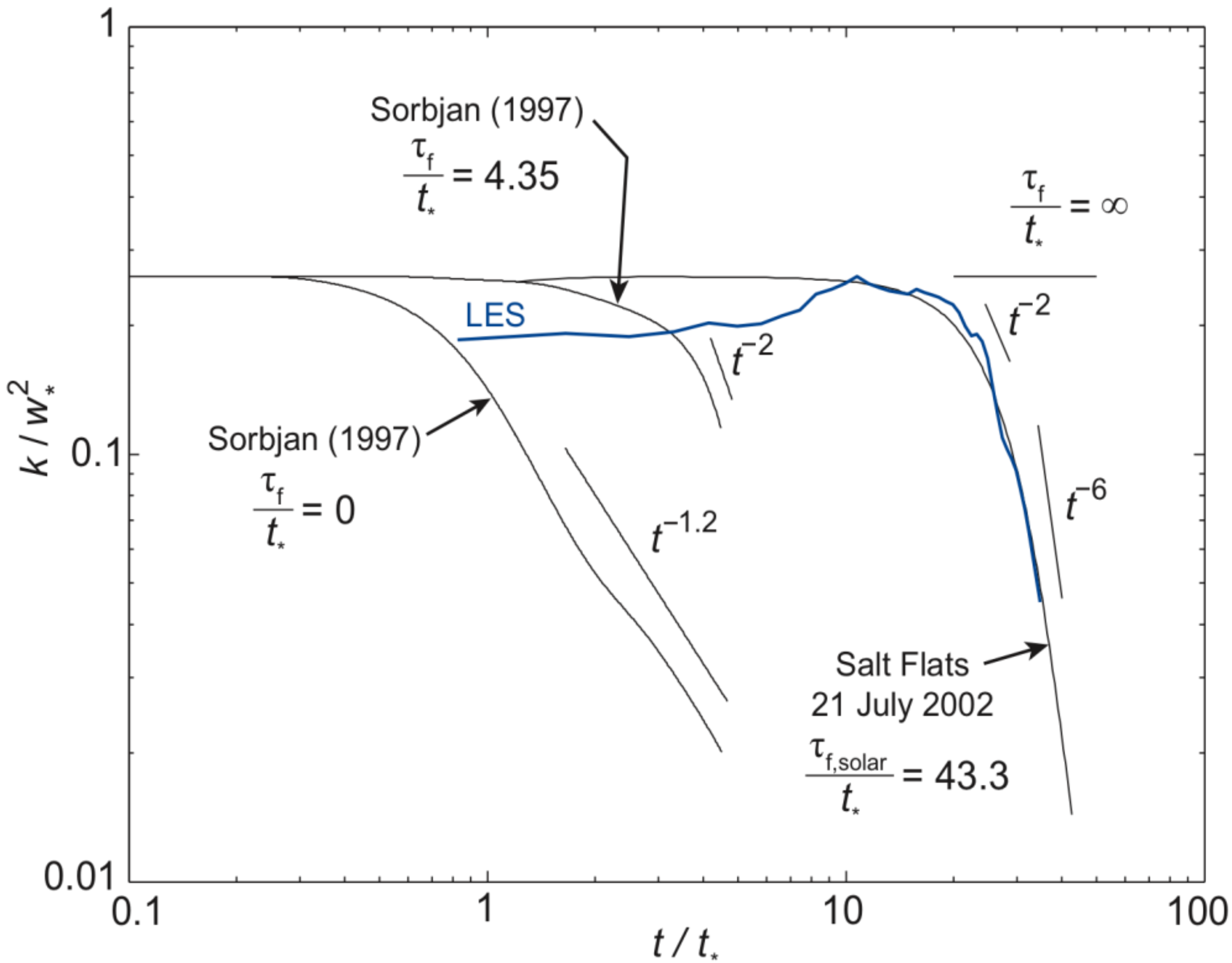
LES – Decay over Heterogeneous Terrain





- Setup SH5 from Pino et al. (BLM, 2006)
- 128 x 128 x 128
- Patches with *l*/*L* ~ *0.72*
- Lagrangian scale-dependent dynamic model for subgrid scales (Bou-Zeid et al., PF, 2005)

Expanded Decay Picture - with LES

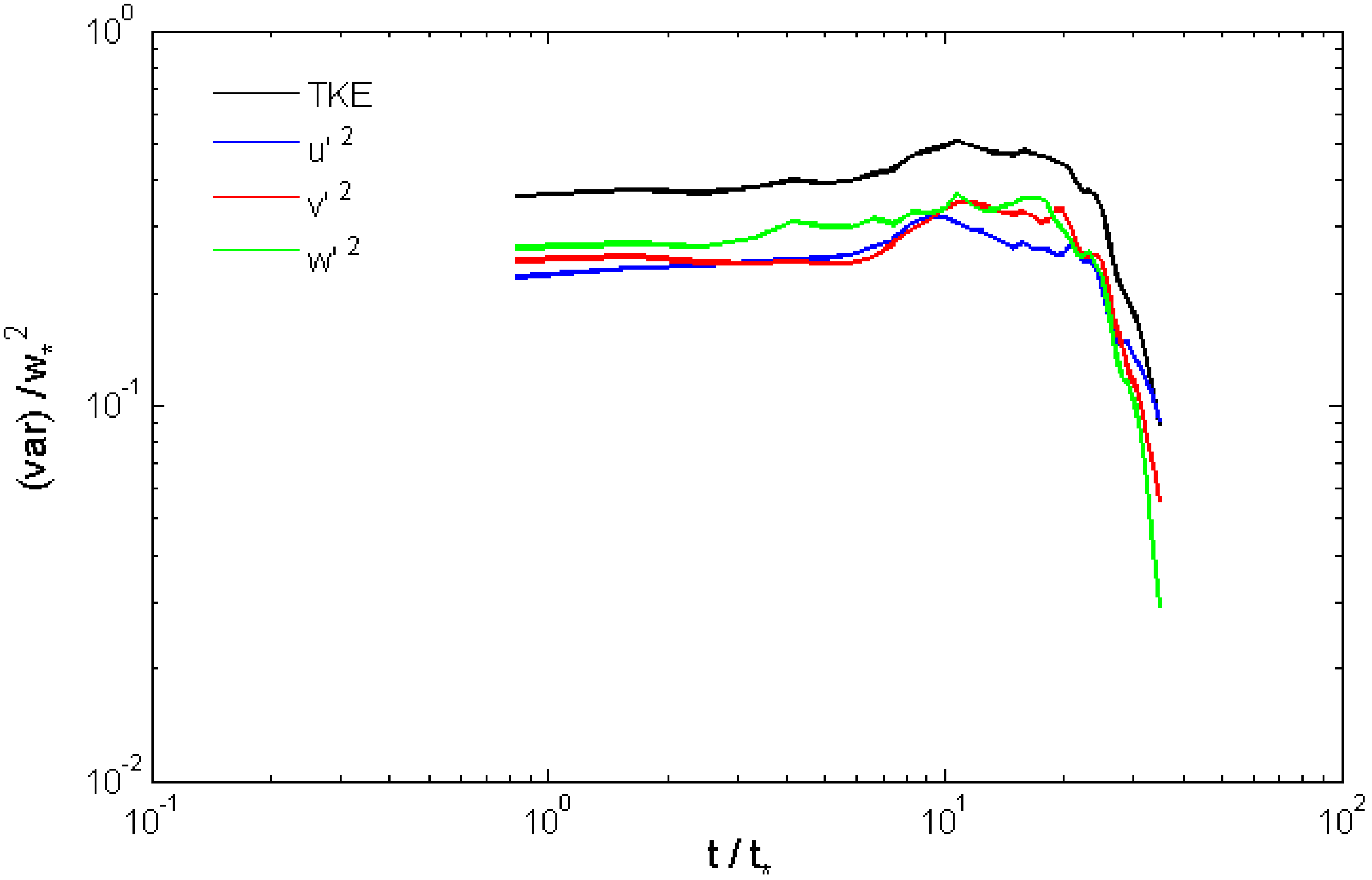


Comments

- Tremendous variability in the forcing sensible heat flux – even over relatively flat terrain
- Need to consider realistic forcing time scales
- The *erfc* function does a good job of modeling the surface sensible heat flux
- Two apparent decay regimes – LES confirms
  - afternoon transition: from max heat flux to zero (slow decay)
  - early evening transition: just after the sensible heat flux changes sign (rapid decay and collapse of turbulence)

- BLAST experiment will investigate these issues in 2011

The End – Any Questions?



TKE
u' 2
v' 2
w' 2
(var) /w* 2
t / t*
10^0
10^-1
10^-2
10^-1
10^0
10^1
10^2