Aggregating fluxes and surface characterisitcs of heterogeneous surfaces

Charlotte Bay Hasager and Niels Otto Jensen

Risø National Laboratory, Wind Energy Department, Denmark

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Background

- Upscaling from point (field scale) to grid (landscape scale).

- Need for effective surface parameters in weather forecasting, climate modelling, and air pollution modelling.

- Relevant surface boundary conditions from satellite images are now available.

Objective

Calculate the effective roughness lengths for momentum and temperature in heterogenous terrain

Goal

Improve estimation of momentum and surface sensible heat fluxes in heterogeneous terrain

Motivation….for heat flux calculation

We are upscaling from point (field scale) to grid (landscape scale)

because there is a need for

effective surface roughness parameters in:

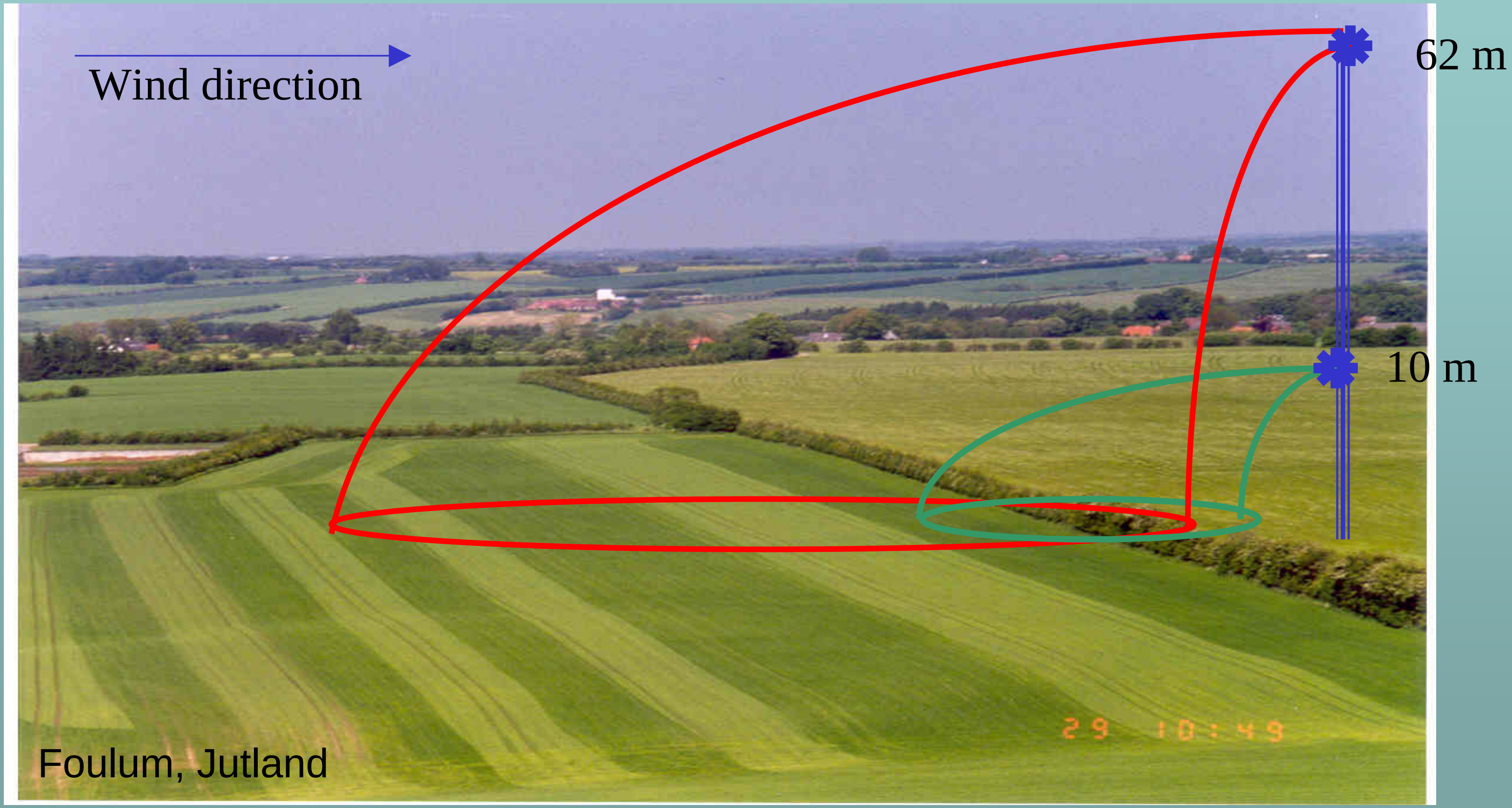
weather forecasting,

climate modelling,

crop water modelling,

air pollution modelling.

Surface fluxes in heterogeneous terrain



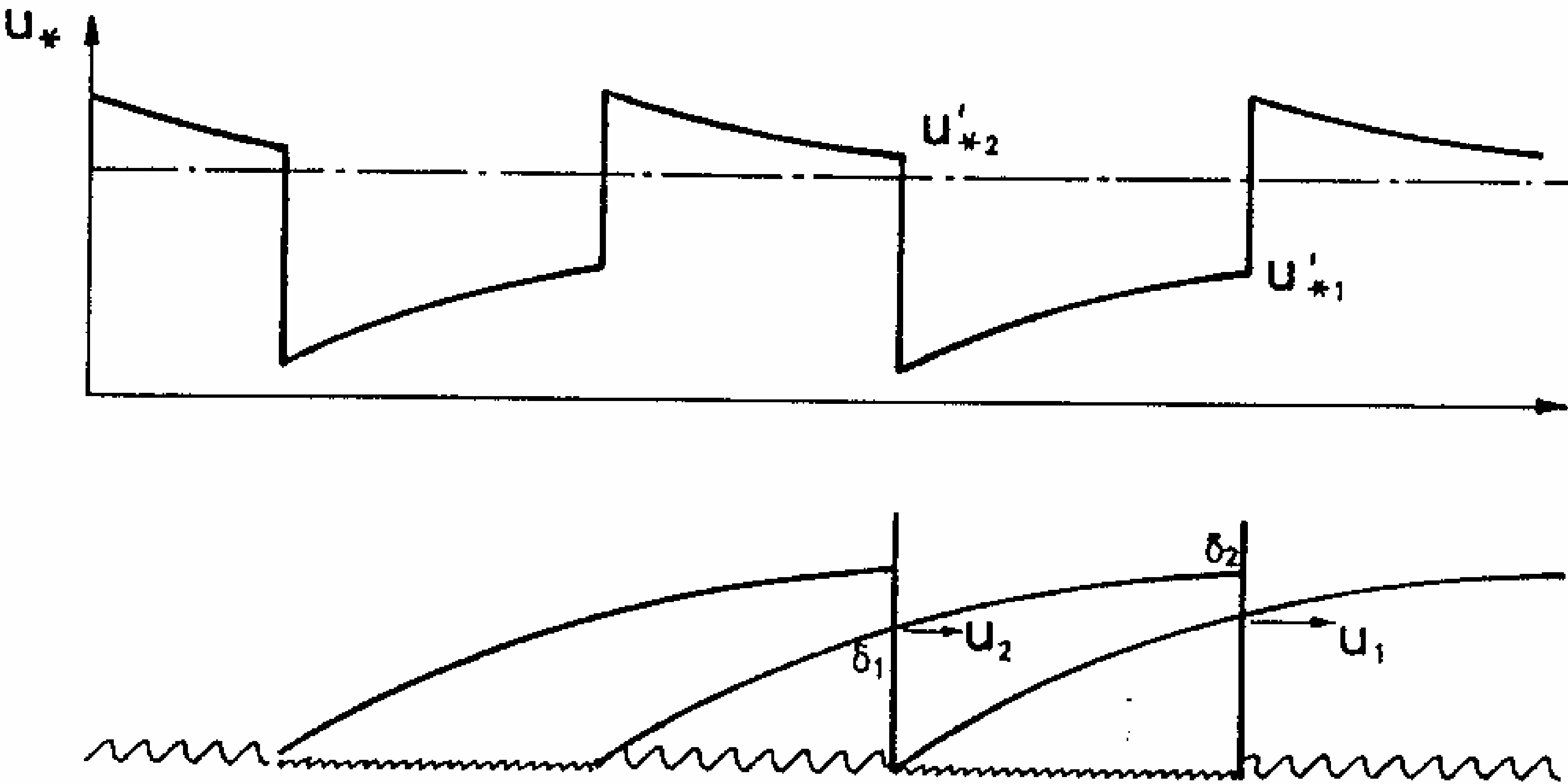
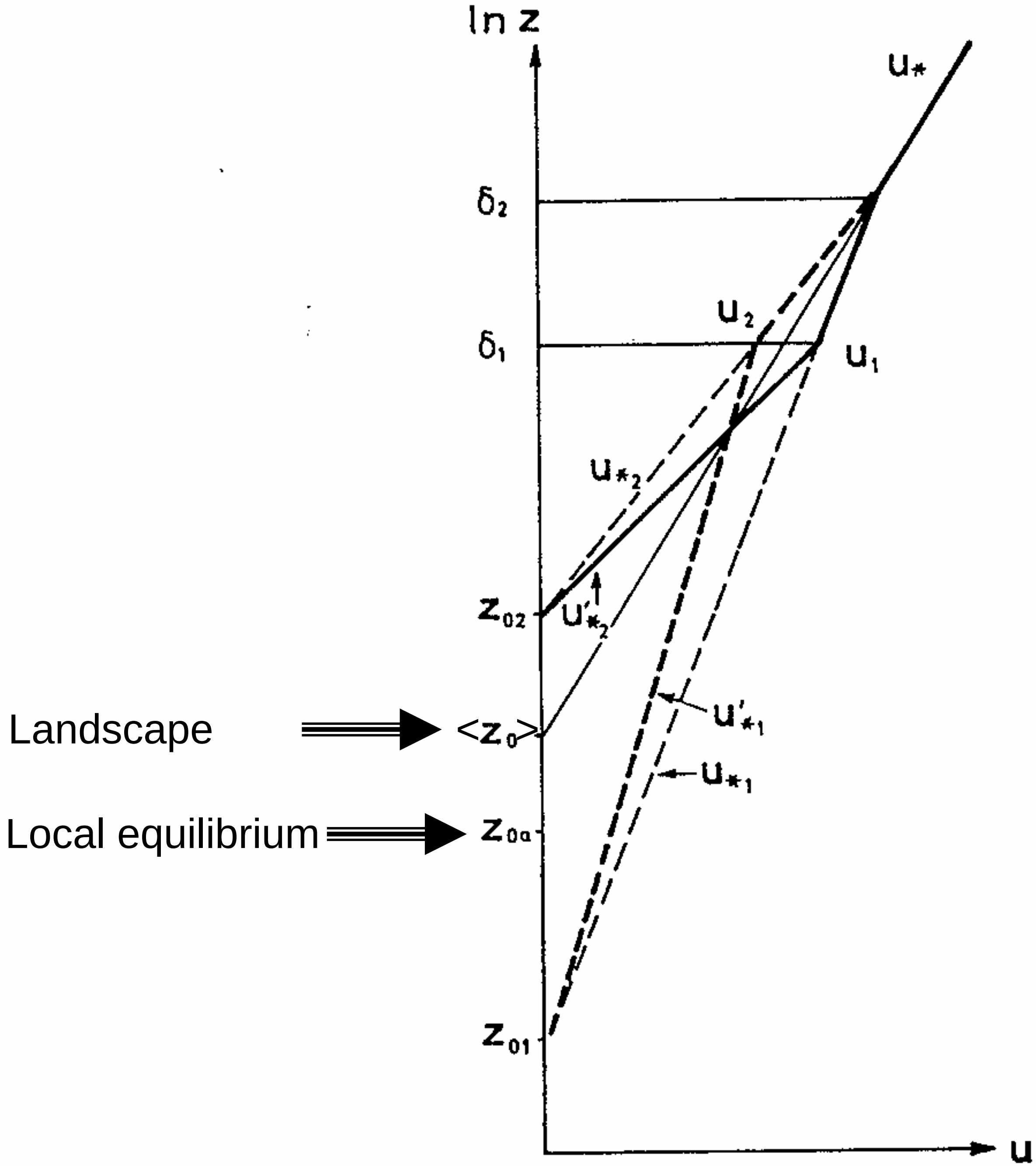


Figure 3:


ln z
u*
δ2
u2
δ1
u1
u*2
z02
u'*2
Landscape
<z0>
u'*1
u*1
Local equilibrium
z0a
z01
u

The heterogenieties are

variations in surface boundary conditions

Roughness (z_0)

Surface temperature (T_s)

Leaf area index (LAI)

Surface humidity

The spatial scale is important

How to model the non-linear effects?

Use a two-dimensional atmospheric model in the horizontal domain

Describe the non-linear response at each boundary condition step change

Remember the influence from one grid cell to the next

Apply Monin-Obukhov similarity theory and phsi-function for stability correction

Calculate the local surface fluxes and roughness

Basic flow equation

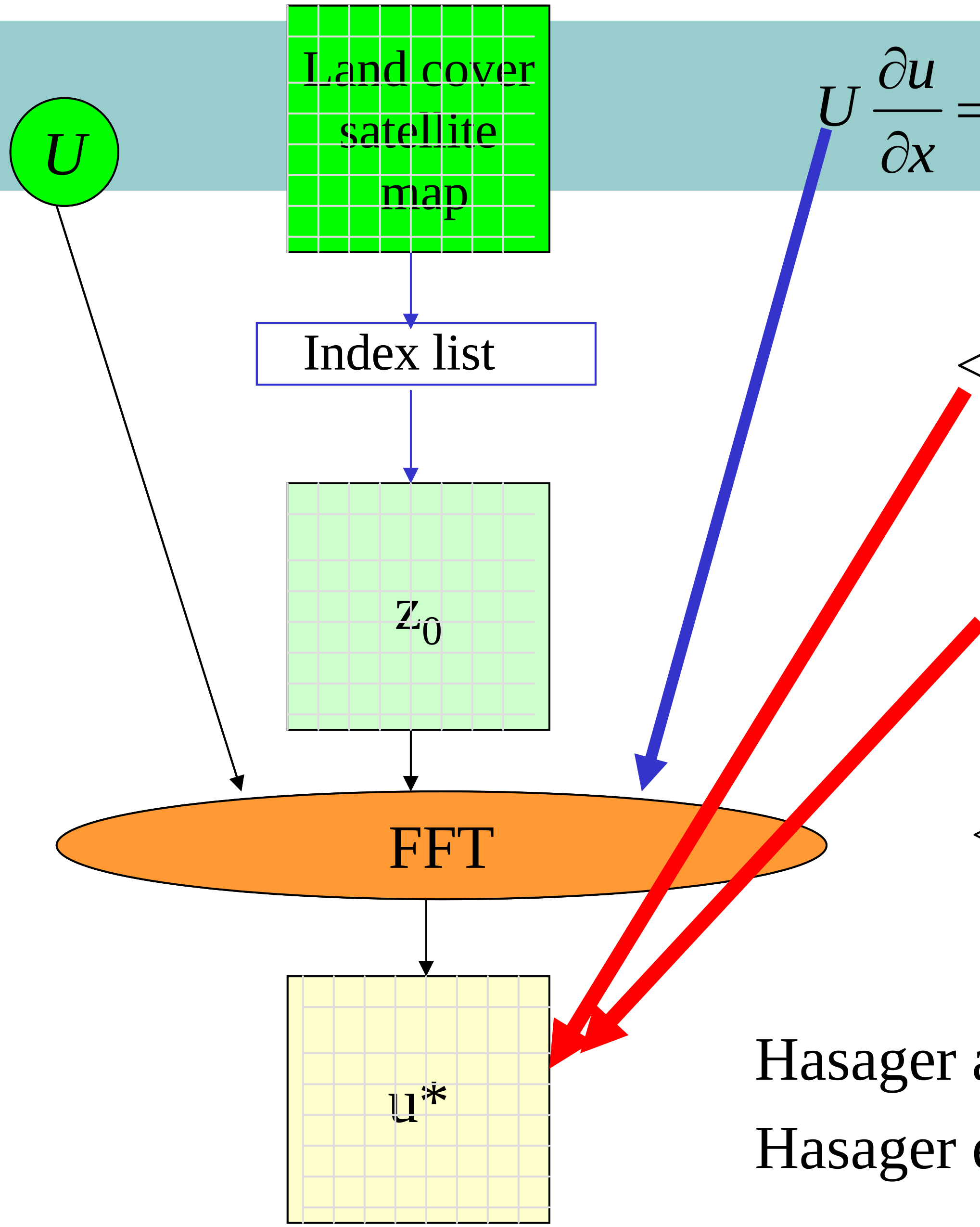
$$U_0 \frac{\partial u}{\partial x} = K \frac{\partial^2 u}{\partial z^2}$$

U_0 is the mean wind

u is the perturbation wind

RISØ

$$U\frac{\partial u}{\partial x} = K_x \frac{\partial^2 u}{\partial z^2}$$



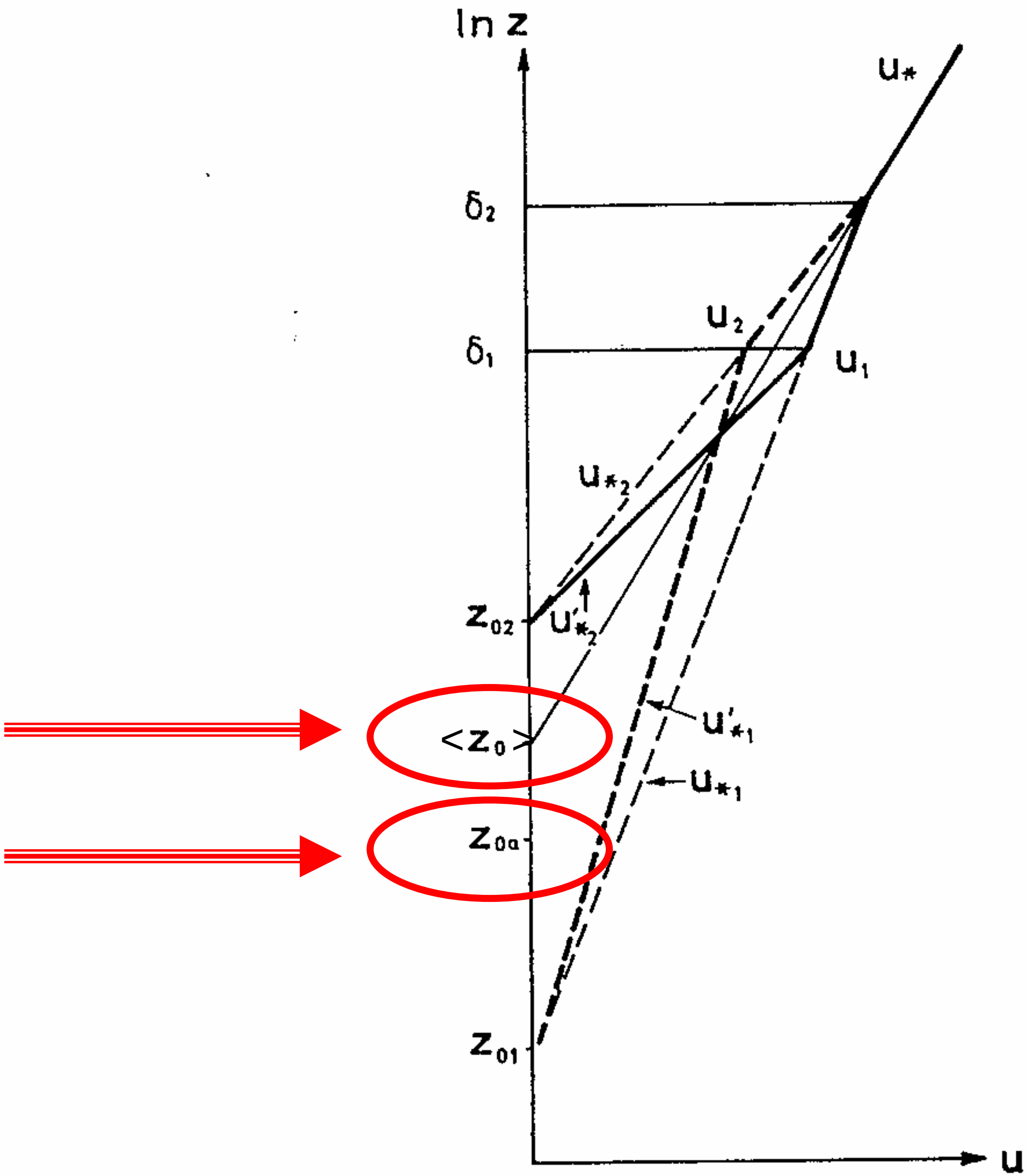
$$< u_* > = \sqrt{\frac{1}{n_1 n_2} \sum_{x=1}^{n_1} \sum_{y=1}^{n_2} u_*^2(x,y)}$$

$$< z_0 > = z\left[\exp\left(\frac{\kappa U}{< u_* >}\right)\right]^{-1}$$

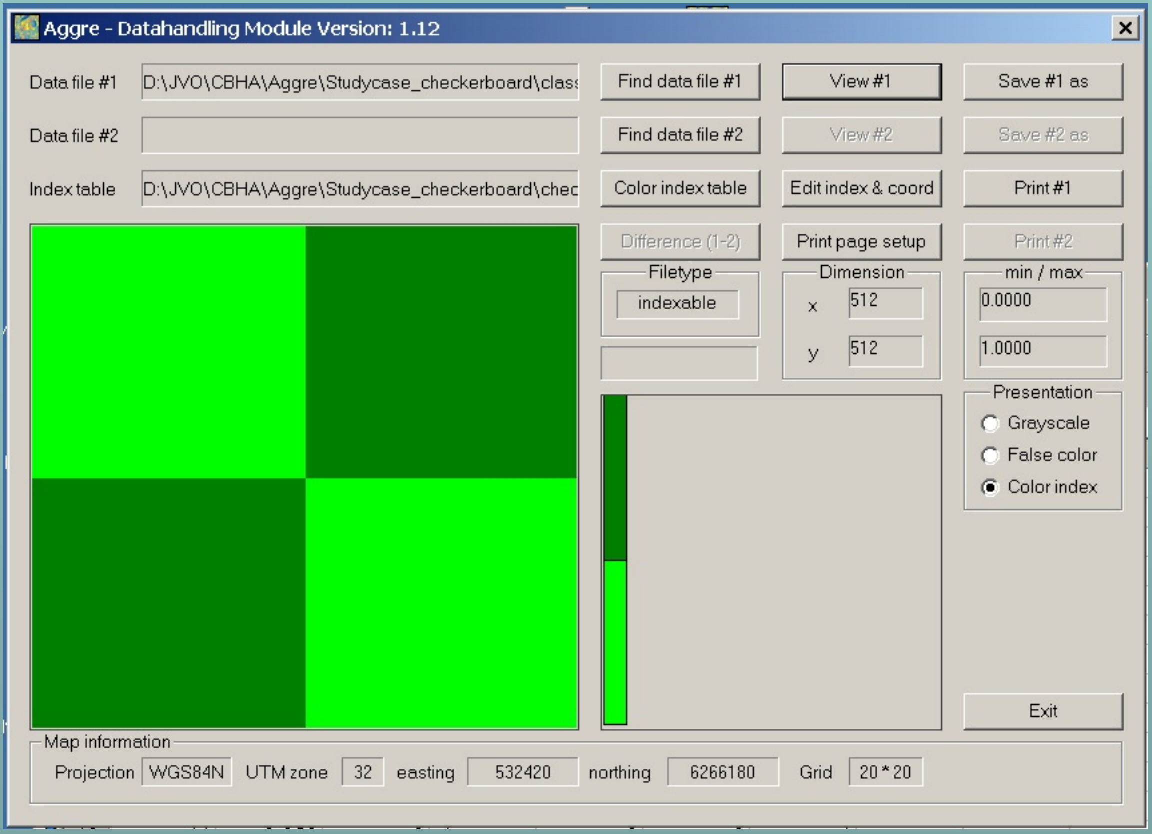
$<z_0>$ larger than z_{0a}

Hasager and Jensen 1999 *QJRMS*

Hasager et al. 2003 *BLM*


ln z
u*
δ2
u2
δ1
u1
u*2
z02
u'*2
<z0>
u'*1
u*1
z0a
z01
u

Checkerboard case (synthetic data)



$\langle z_0 \rangle / z_{0a}$

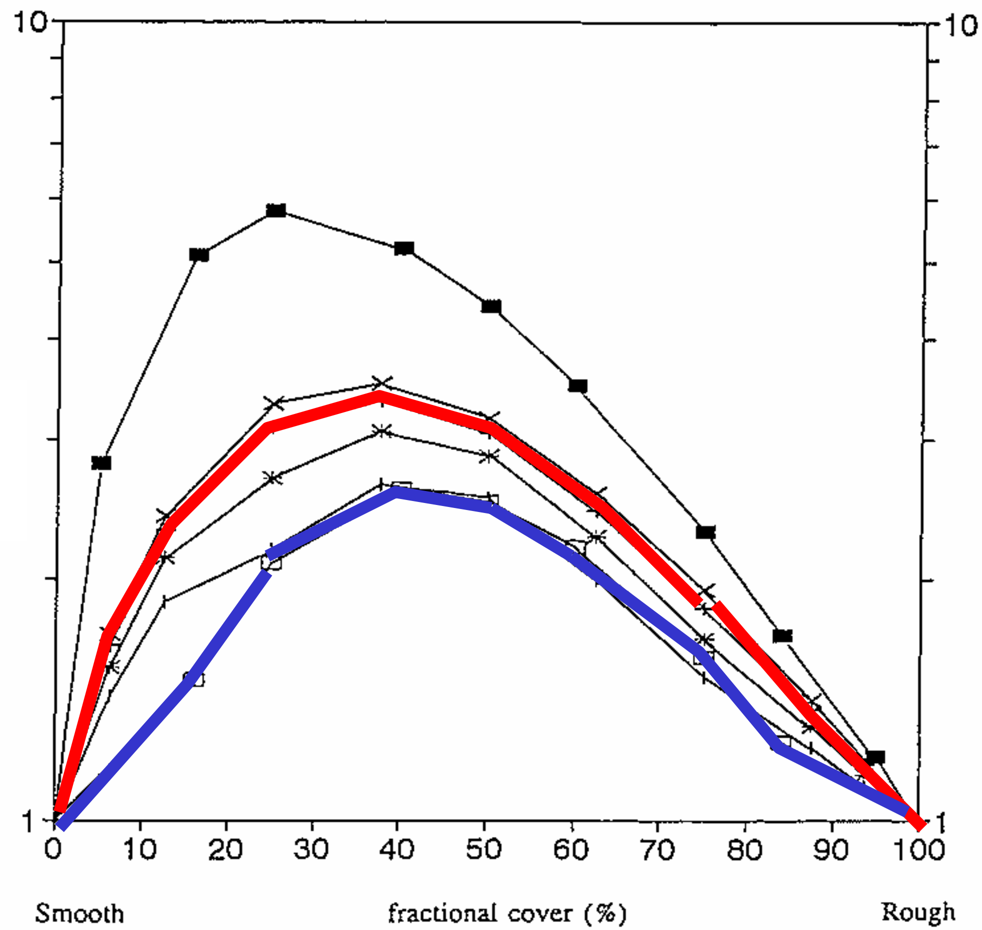


Figure 5. Microscale aggregation results of the effective roughness compared with the logarithmic average as a function of fractional areal coverages. The results are calculated for (z_{01}, z_{02}, M) (see text) of (0.1 m, 0.001 m, ±4.8) for variable patch sizes: ×, 12.5 m; +, 50 m; ∗, 200 m; |, 800 m. Results from Schmid and Bünzli (1995) for: ■, mixing-length model for 50 m patches and □, $K-\varepsilon$ model for 50 m patches are shown.

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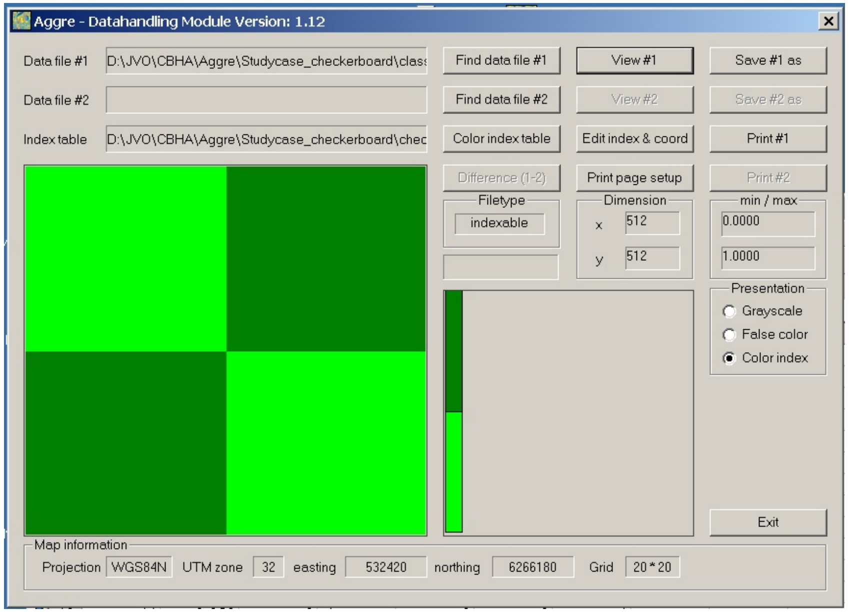
TABLE 5. SENSIBLE-HEAT FLUX RESULTS (Wm^{-2}) FOR CHECKERBOARD TERRAIN WITH WARM, ROUGH AND COOL, SMOOTH PATCHES (CASE A) AND REVERSED (CASE B) FOR VARIABLE AIR TEMPERATURES AT 5 M HEIGHT AND WIND SPEED 5 M S^{-1}

			Temperature (°C)									
			14	15	16	17	18	19	20	21	22	23
(1)	QH_{eq}	A	407	337	267	198	131	65	0	−62	−122	−179
		B	411	340	270	201	133	66	0	−64	−125	−184
(2)	$\langle QH \rangle$	A	591	500	409	321	233	147	64	−18	−98	−176
		B	453	364	276	189	104	21	−60	−138	−215	−288

(1) Equilibrium. (2) Nonlinear aggregation.



Cases

A: Warm rough and cool smooth

B: Cool rough and warm smooth

Equations for vegetation, non-vegetation and water

Vegetated land **(include grass, grains, decidouos and conifer forest)**

$$z_{ot} = \frac{z_o}{\exp(\frac{5.85}{LAI^{2/3}} u_*^{1/3})}$$

Bare land **(include bare soil, ice, snow and urban areas)**

$$z_{0t} = \frac{z_0}{\exp(23.1\sqrt{u_*})}$$ **for $z_0 < 0.05$ m**

$$z_{0t} = \frac{z_0}{\exp(103.3\sqrt{z_0 u_*})}$$ **for $z_0 \geq 0.05$ m**

For smooth water, ie for $u_* < 0.1$

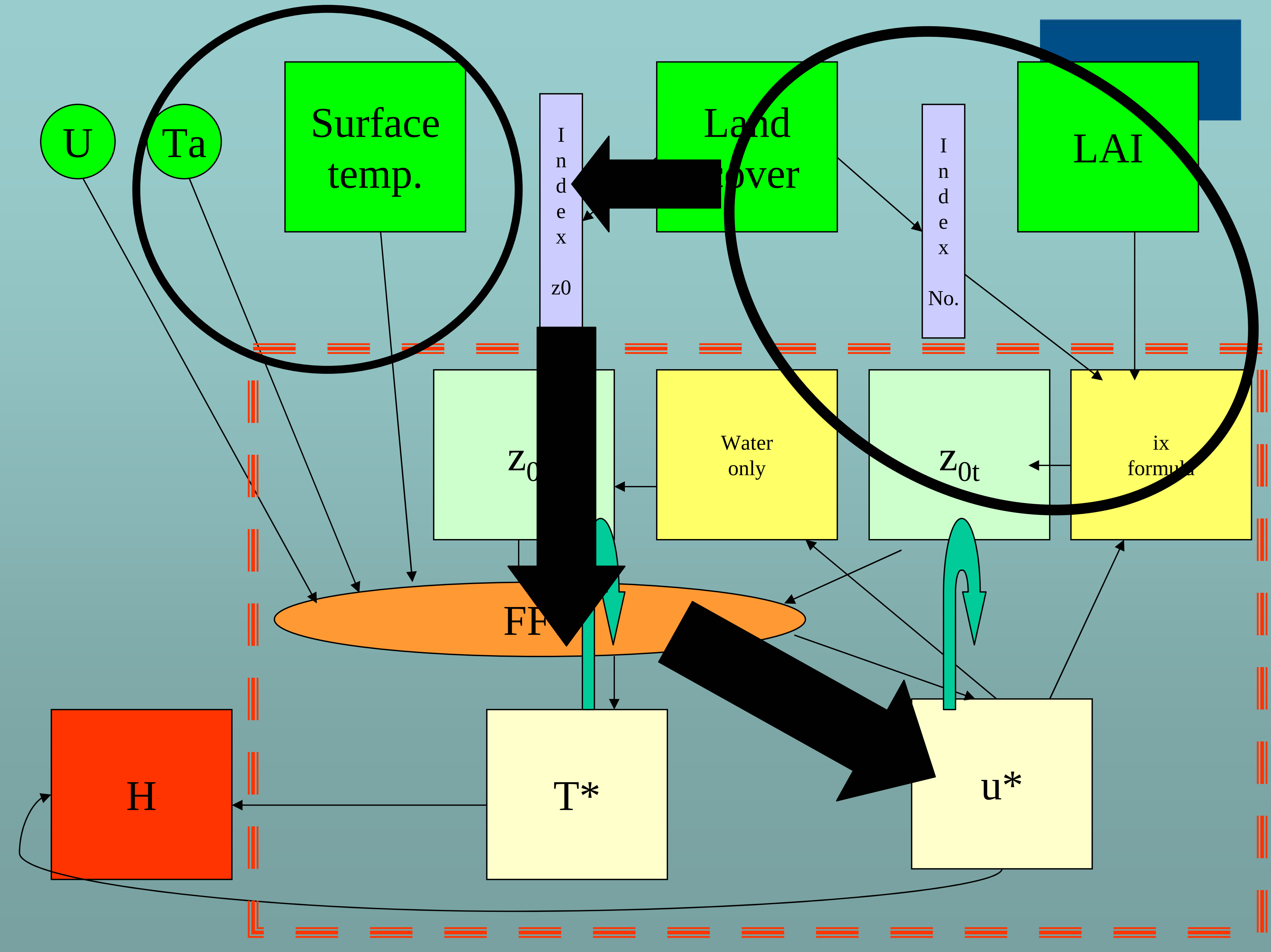
$$z_0 = 0.1\ \nu / u_*$$

$$z_{ot} = z_o$$

For rough water, ie for $u_* > 0.1$

$$z_0 = 0.015 \frac{u_*^2}{g}$$

$$z_{ot} = \frac{z_o}{\exp(100\,(z_0\, u_*)^{1/2})}$$


U
Ta
Surface temp.
Index z0
Land cover
Index No.
LAI
z0
Water only
z0t
ix formula
FF
H
T*
u*

SURFACE HEAT FLUX

$$\frac{H}{\rho c_p} = w'\theta' = -u_*\theta_*$$

$$u(z) = \frac{u_*}{\kappa}\ln(\frac{z}{z_0}) \qquad \theta(z) - \theta_0 = \frac{\theta_*}{\kappa}\ln(\frac{z}{z_{0t}})$$

$$z_{ot} = \frac{z_o}{\exp(\frac{5.85}{LAI^{2/3}}\mathrm{u}_*^{1/3})}$$

Parameters from remote sensing

Input-output

You will need

1. Land cover type map
2. Roughness map (or look-up table)
3. Leaf area index (LAI) map
4. Surface temperature map
5. Air temperature (e.g at 10 or 50 m)
6. Wind vector (e.g at 10 or 50 m)

You will achieve

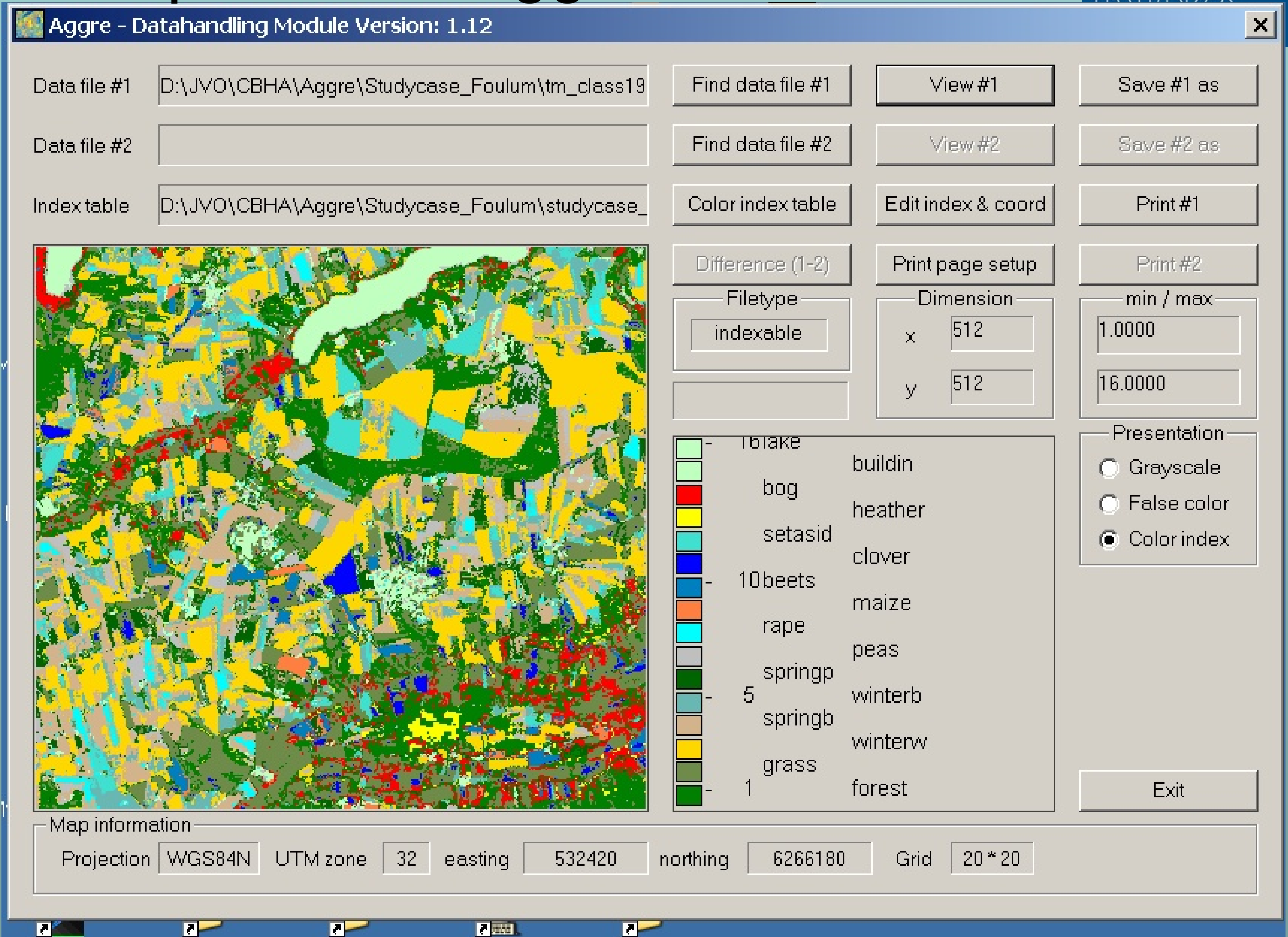
1. The effective roughness for momentum $\langle z_0 \rangle$
2. The effective roughness for temperature $\langle z_{0t} \rangle$
3. A friction velocity map
4. A surface sensible heat flux map

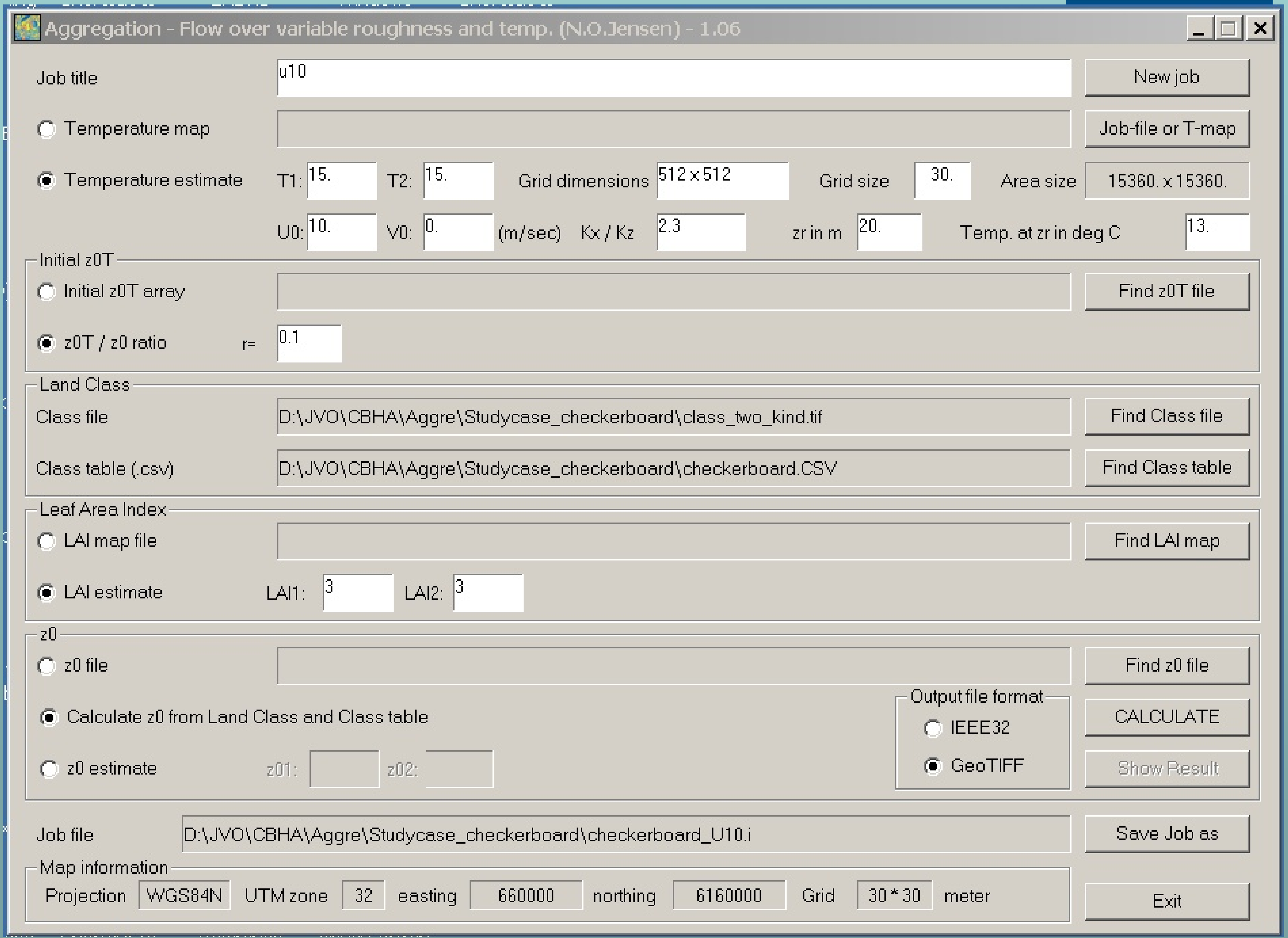
Summary

Major characteristics of the model:

- It is a microscale model valid for local to regional scale from 20 m to 15 km
- It is two-dimensional in the horizontal domain
- It calculates the effective roughness values for momentum and heat
- It calculates the surface momentum flux and sensible heat flux
- It is fast as it is a spectral model (linearized equations solved with FFT)

Example of the AggreData interface




Aggregation - Flow over variable roughness and temp. (N.O.Jensen) - 1.06
Job title
u10
New job
Temperature map
Job-file or T-map
Temperature estimate
T1: 15.
T2: 15.
Grid dimensions 512 x 512
Grid size 30.
Area size 15360. x 15360.
U0: 10.
V0: 0.
(m/sec)
Kx / Kz 2.3
zr in m 20.
Temp. at zr in deg C 13.
Initial z0T
Initial z0T array
Find z0T file
z0T / z0 ratio
r= 0.1
Land Class
Class file
D:\JVO\CBHA\Aggre\Studycase_checkerboard\class_two_kind.tif
Find Class file
Class table (.csv)
D:\JVO\CBHA\Aggre\Studycase_checkerboard\checkerboard.CSV
Find Class table
Leaf Area Index
LAI map file
Find LAI map
LAI estimate
LAI1: 3
LAI2: 3
z0
z0 file
Find z0 file
Calculate z0 from Land Class and Class table
z0 estimate
z01:
z02:
Output file format
IEEE32
GeoTIFF
CALCULATE
Show Result
Job file
D:\JVO\CBHA\Aggre\Studycase_checkerboard\checkerboard_U10.i
Save Job as
Map information
Projection WGS84N
UTM zone 32
easting 660000
northing 6160000
Grid 30 * 30
meter
Exit

References:

Hasager C.B. and N.O.Jensen, 1999, Surface flux aggregation in heterogeneous terrain, *Quart. J. Royal. Meteorol. Soc.* **125**, 2075-2102

Hasager, C.B. Nielsen, N.W., Jensen, N.O., Boegh, E., Christensen, J.H, Dellwik, E. and Soegaard, H., 2002 Effective roughness calculated from satellite-derived land cover maps and hedge information used in a weather forecasting model. *Boundary-Layer Meteorology* 109, 227-254