Upon scaling of near-surface TKE in the afternoon transition

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Outline:

TKE decay laws: Is it easy to interpret t^{-n} laws?

Results from observed surface TKE budgets

Results from a simple 'toy' model for TKE (near-surface and above)

Some general questions to address in this session:

Question 1:	Do we need a smooth transition regime between CBL to SBL at the surface (including an adequate scaling)
Question 2:	How does this transition affect the formation/representation of the residual layer?
Question 3:	What is the role of surface heterogeneity (different length scales of non-uniformity)?

Upon scaling of near-surface TKE in the afternoon transition

I will discuss/summarize some results from:

Part 1: *Nilsson, E., Lohou, F., Lothon, M., Pardyjak, E., Mahrt, L., and Darbieu, C.: Turbulence Kinetic Energy budget during the afternoon transition – Part 1:* ***Observed surface TKE budget*** *and Boundary layer description for 10 Intensive Observation Period days, Atmos. Chem. Phys. Discuss., 2015.*

Part 2: *Nilsson, E., Lothon, M., Lohou, F., Pardyjak, E., Hartogensis, O., and Darbieu, C.: Turbulence Kinetic Energy budget during the afternoon transition – Part 2*: ***A simple TKE model****, Atmos. Chem. Phys. Discuss., 2015.*

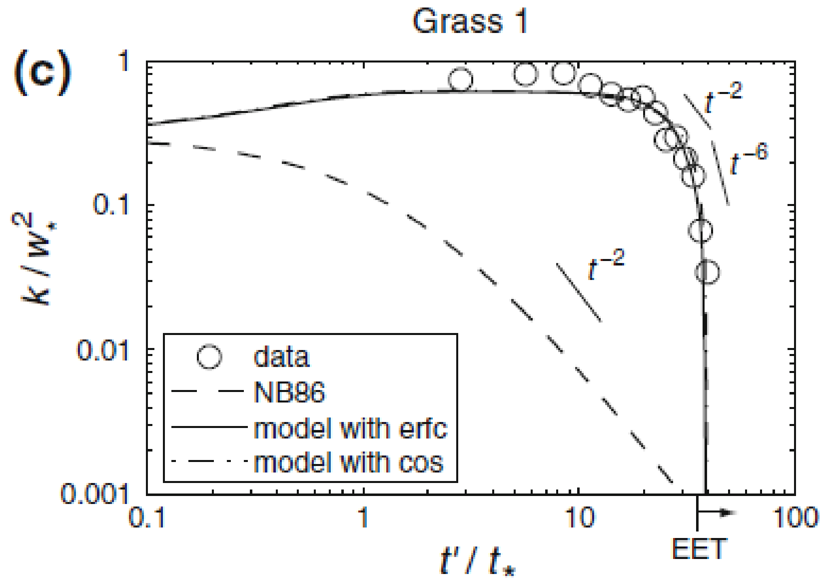
in relationship to earlier studies

TKE decay in the afternoon/evening transition

***Nieuwstadt**, F. T. M. and Brost, R. A.: The decay of convective turbulence, J. Atmos. Sci., 43, 532–546, 1986.*	LES	$t^{-1.2}$	decay
***Sorbjan**, Z.: Decay of convective turbulence revisited, Bound.-Lay. Meteorol., 82, 501–515, 1997. 3, 28, 32*	LES	t^{-n}	depends on forcing time scale
***Pino**, D., Jonker, H. J. J., Vilà de Arellano, J., and Dosio, A.: Role of shear and the inversion strength during sunset turbulence over land: characteristic length scales, Bound.-Lay. Meteorol., 121, 537–556, 2006. 3, 4*	LES	t^{-n}	shear generation decreases turbulence decay
***Nadeau**, D. F., Pardyjak, E. R., Higgins, C.W., Fernando, H. J. S., and Parlange, M. B.: A simple model for the afternoon and early evening decay of convective turbulence over different land surfaces, Bound.-Lay. Meteorol., 141, 301–324, 2011. 3, 4, 17, 24, 25*	Measurements (near-surface)	t^{-n}	continuous decay exponent -2 to -6
***Rizza**, U., Miglietta, M., Degrazia, G., Acevedo, O., and Marques, E.: Sunset decay of the convective turbulence with Large-Eddy Simulation under realistic conditions, Physica A, 392, 4481–4490, 2013.*	LES	t^{-n}	continuous decay exponents -2 to -6

TKE decay in the afternoon transition

Is a representation with both TKE and time on a logarithmic axis easy to interpret?



(from Part 2)

least −6). In the case of a linear change of TKE with time such that $\mathrm{TKE} = kt + \mathrm{TKE}_0$, we obtain $y = \ln(\mathrm{TKE}) = \ln(ke^x + \mathrm{TKE}_0)$ with $x = \ln(t)$ and the decay parameter then becomes: $\alpha = \frac{\partial y}{\partial x} = 1 - \frac{\mathrm{TKE}_0}{\mathrm{TKE}_0 + kt}$. This shows that α becomes a function of time for the simple case of a linear change of TKE with time. Furthermore, two values of observed α during a single afternoon such as −2 and −6 can occur without necessarily implying a different decay rate of TKE in terms of $m^2\,s^{-3}$ at those times. Therefore, and in the

The same decay rate in terms of $m^{-2}s^{-3}$ can have different exponant values

What governs the turbulence kinetic energy is most effectively studied by a TKE budget

TKE tendency

Shear production

Buoyancy production

$$\frac{\partial E}{\partial t} = -\left[\overline{uw}\frac{\partial U}{\partial z} + \overline{vw}\frac{\partial V}{\partial z}\right] + \frac{g}{T_0}\overline{w\theta_v}$$

Dissipation

$$-\frac{\partial \overline{wE}}{\partial z} - \frac{\partial \overline{wp/\rho_0}}{\partial z} + \epsilon,$$

Turbulent and pressure transport

Determination of TKE budget terms

(from Part 1)

TKE tendency from finite differences evaluated at 4 turb. levels $\frac{\partial E}{\partial t} = \frac{\partial\left(\overline{u'}^2+\overline{v'}^2+\overline{w'}^2\right)}{2\partial t}$

Transport is calculated as a residual for each hour from the other budget terms:

$$T = \frac{\partial E}{\partial t} - S - B - D$$

Buoyancy prod. at 4 turb. levels

$B = \frac{g}{\theta}\overline{w'\theta'_v}$

$\frac{g}{\theta}\overline{w'\theta'_v}$ 8

$\frac{g}{\theta}\overline{w'\theta'_v}$ 5

$\frac{g}{\theta}\overline{w'\theta'_v}$ 3

$\frac{g}{\theta}\overline{w'\theta'_v}$ 2

Shear production from mean wind gradient and turbulent shear stress $S = -\overline{u'w'}\frac{\partial U}{\partial z}$

$\overline{u'w'}_8$ U_8

$\overline{u'w'}_5$ U_5

$\overline{u'w'}_3$ U_3

$\overline{u'w'}_2$ U_2

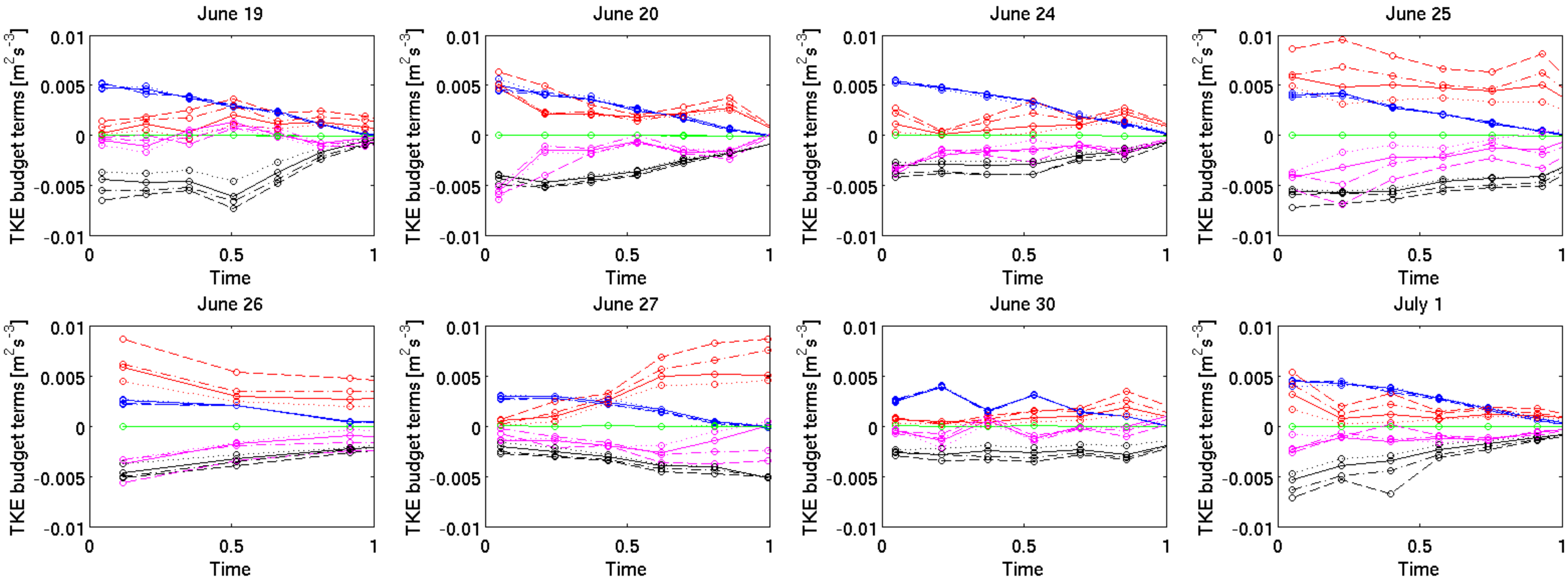
Dissipation *D* from spectral slope at four turbulence levels:

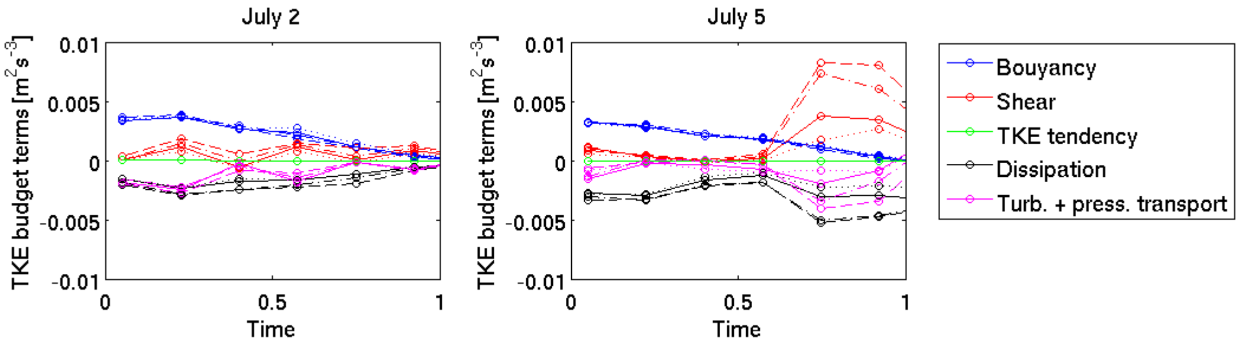
$$\epsilon = \frac{2\pi n}{U}\left[\frac{3nS_w(n)}{4\alpha_1}\right]^{3/2}$$

Here α_1 is the universal Kolmogorov constant ≈ 0.52

How does the different budget terms evolve in the afternoon? *(from Part 1)*

TKE budget from 12 UTC (t = 0) to zero buoyancy flux (t = 1)
at 2.2, 3.2, 5.3 and 8.2 m for 10 IOPs



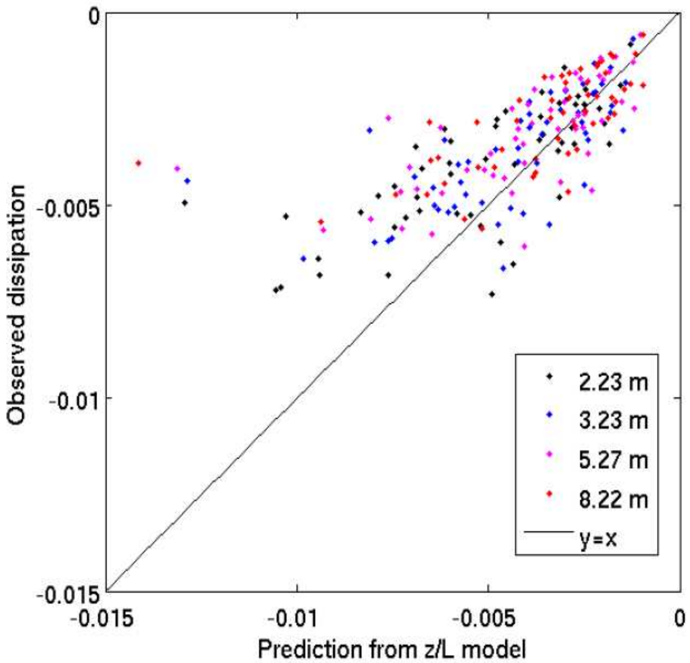


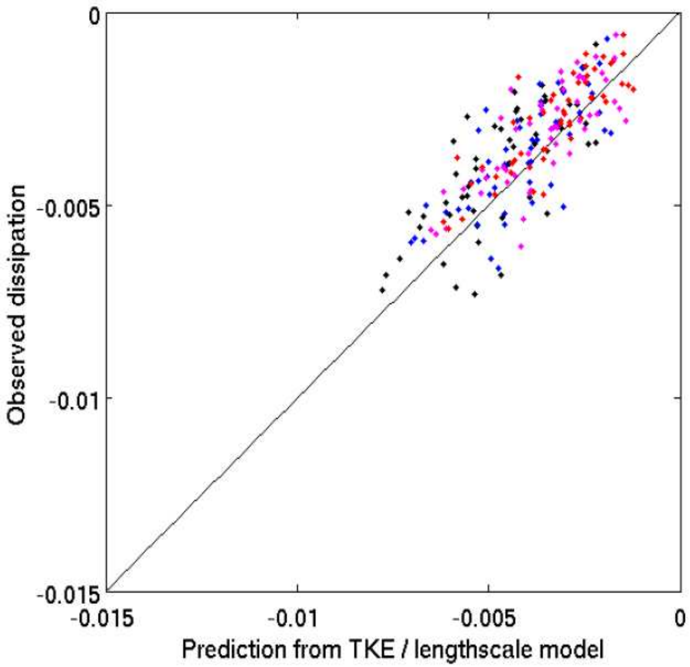
TKE tendency in green is much smaller than other budget terms

We consider this a ’quasi-stationary’ evolution of TKE

Evaluation of two dissipation models

(from Part 1)





$$D = -\frac{u_*^3}{kz}\left(0.45(1-1.2z/L)\right)$$

$$D = -\frac{E^{3/2}}{l_\epsilon} = -E^{3/2}\left(\frac{2.2}{z_i} + \frac{0.006}{z}\right)$$

Error statistics:		
Bias:	$-9.3*10^{-4}$ m^2s^{-3}	$-4.9*10^{-4}$ m^2s^{-3}
CRMS difference:	$1.8*10^{-3}$ m^2s^{-3}	$0.93*10^{-3}$ m^2s^{-3}
Correlation:	0.70	0.80

Non-local influences are important!

Summary of some results used in a simple TKE 'toy' model:

• **TKE tendency is always small** = A 'quasi-stationary' evolution of TKE

Motivate us to use quasi-steady idealized vertical profiles for our CBL description

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• Even very **near surface dissipation** rates were found to be **influenced by mixed layer** dynamics and z_i

Motivates use of length-scale parameterization:

$$D = -\frac{E^{3/2}}{l_\epsilon} = -E^{3/2}\left(\frac{2.2}{z_i} + \frac{0.006}{z}\right)$$

• As a crude approximation: **about 60% of production of turbulence is locally dissipated and 40% is transported**

(from Part 1 and Part 2)

A 'simple' TKE toy model

(Part 2)

- 1-Dimensional model (only vertical direction)
- TKE budget for each vertical level used to calculate TKE tendency dE/dt
  dE/dt = S + B + T + D

  and thereby update E = TKE

$$\frac{\partial E}{\partial t} = -\left[\overline{uw}\frac{\partial U}{\partial z} + \overline{vw}\frac{\partial V}{\partial z}\right] + \frac{g}{T_0}\overline{w\theta_v} - \frac{\partial \overline{wE}}{\partial z} - \frac{\partial \overline{wp/\rho_0}}{\partial z} + \epsilon, \quad (3.1)$$

T

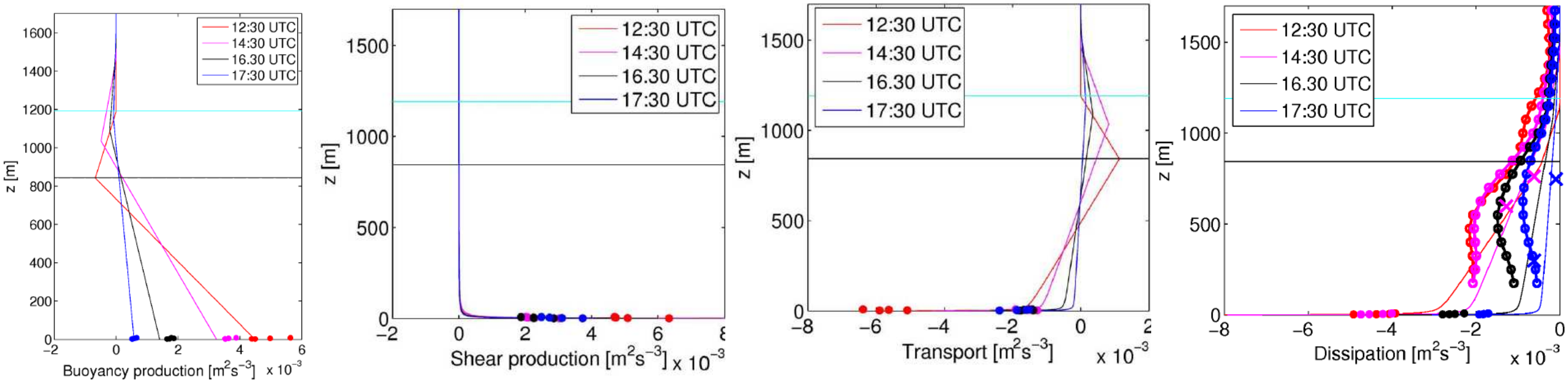
- 1 m vertical resolution
- 1 s time step

Some assumptions regarding the height variation of budget terms:

(Part 2)

- Assumes vertical profiles for **TKE budget terms with shape of idealized simplified quasi-steady profiles** (inspired by profiles for a barotropic CBL, Wyngaard 2010 and overall similar to Lenschow 1974)

-linearly decaying surface fluxes with height (momentum, bouyancy)



- **Dissipation calculated with TKE/length scale model:**

$$D = -\frac{E^{3/2}}{l_\epsilon} = -E^{3/2}\left(\frac{2.2}{z_i} + \frac{0.006}{z}\right)$$

(Part 2)

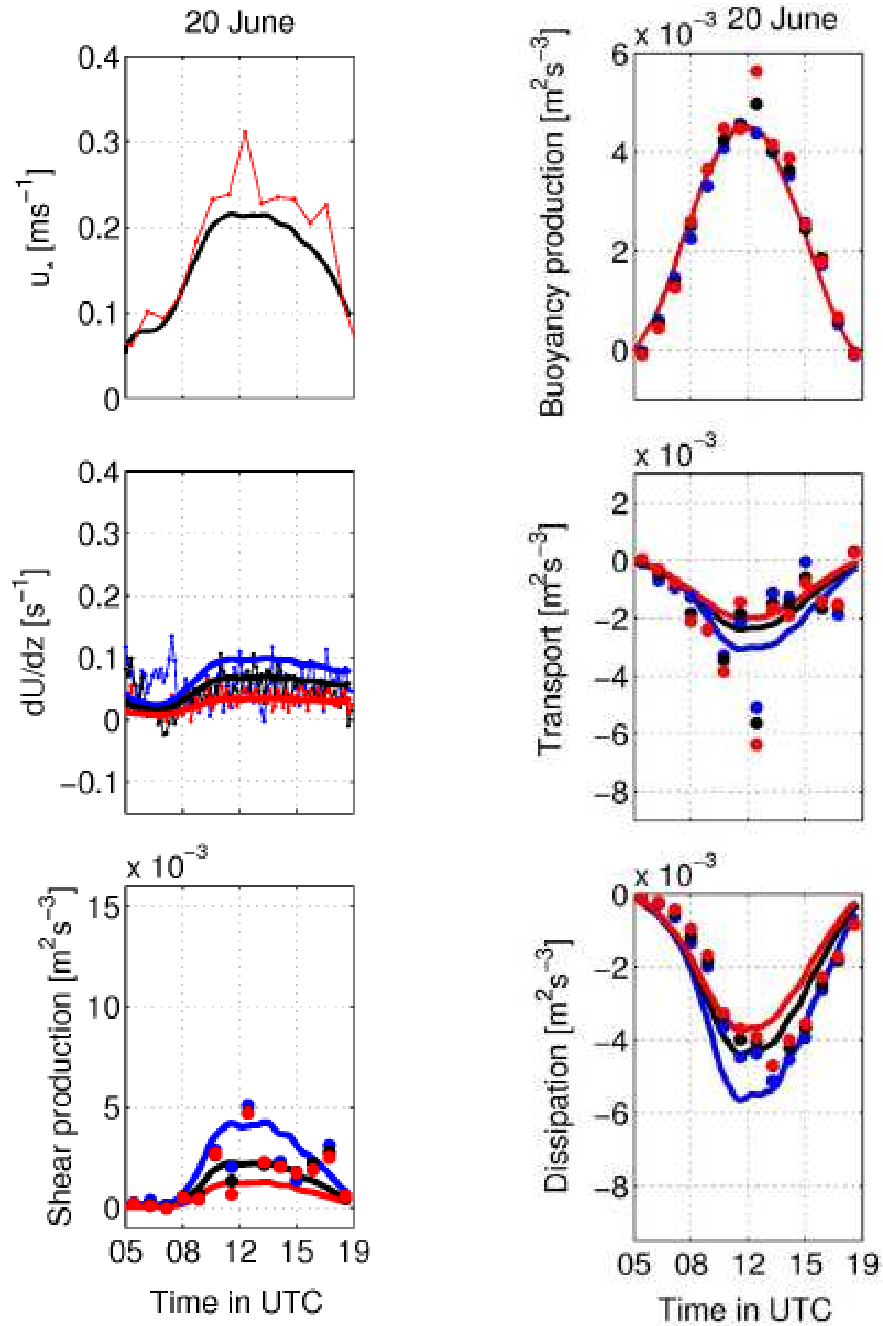
Inputs for the model:

It is based on an idealized mixed-layer approximation and a simplified near-surface TKE budget. In this model, the TKE is dependent on four budget terms (turbulent dissipation rate, buoyancy production, shear production and vertical transport of TKE) and only requires measurements of three input available (near-surface buoyancy flux, boundary layer depth and wind speed at one height in the surface layer).

The model also has a z_0 value (and displacement height d)

(from Part 2)

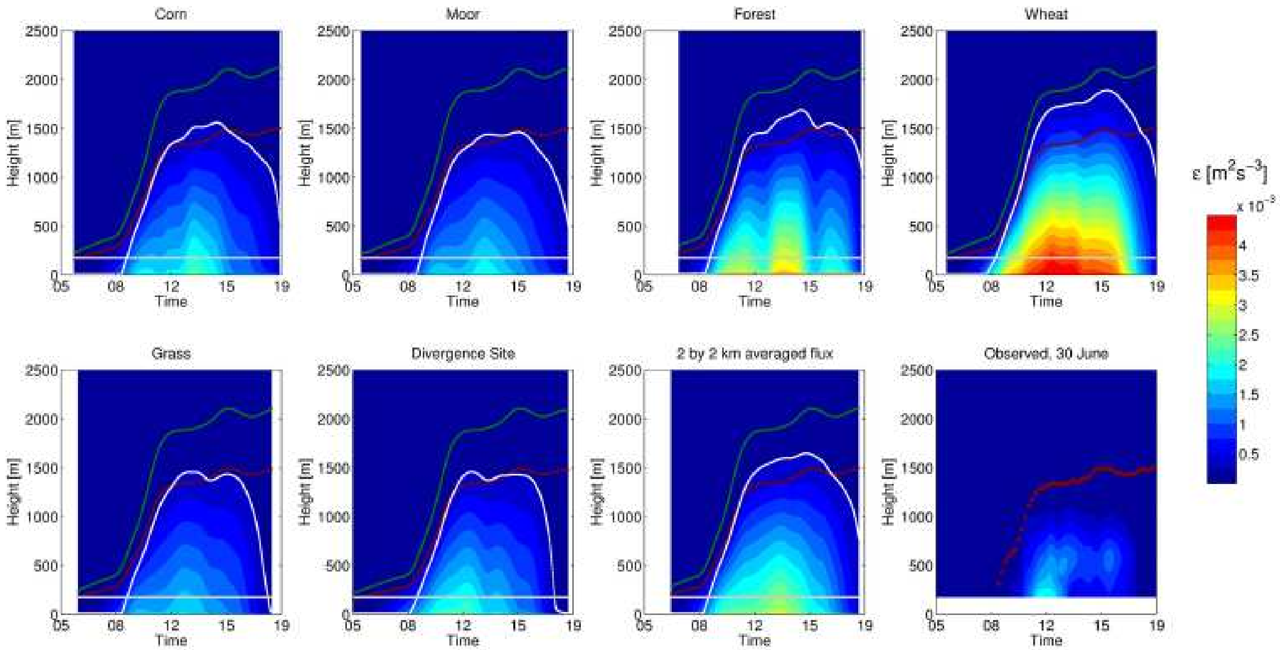
We evaluate how the different modeled budget terms evolve in comparison to measurements for 9 IOPs

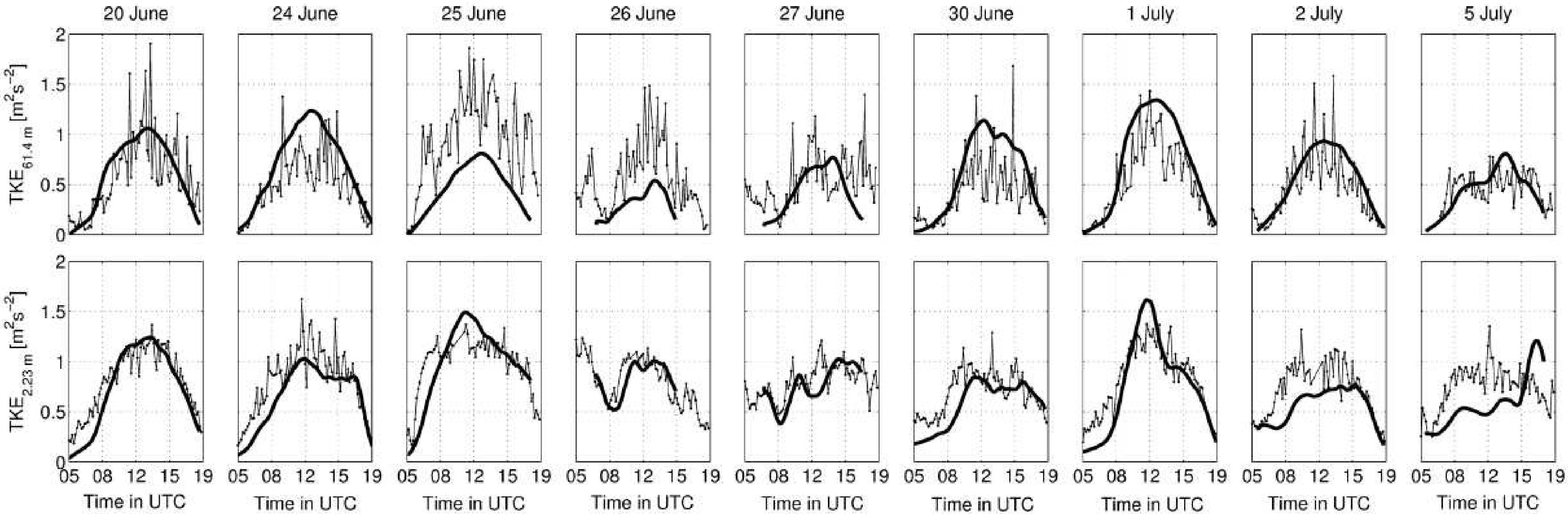


The model's errors result from the exclusion of processes such as elevated shear production and horizontal advection. The model also produces an overly rapid decay of shear production with height. However, the most influential budget terms governing

(from Part 2)

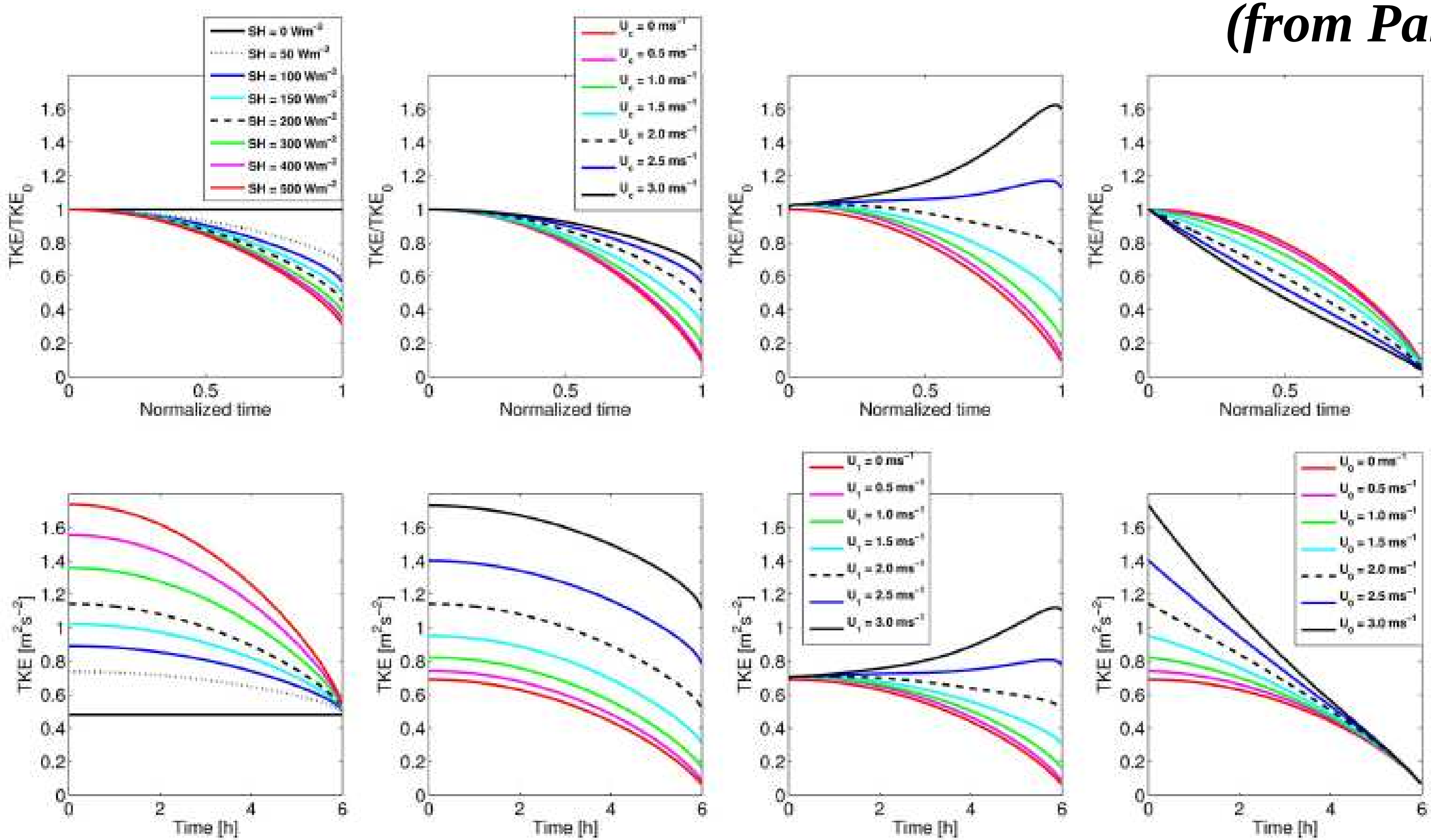
We evaluate how the modeled TKE evolve in comparison to measurements for 9 IOPs and explored sensitivity using forcing from different surfaces





After evaluation we also performed some idealized simulations for different buoyancy- shear effects in situations with constant and time-varying wind

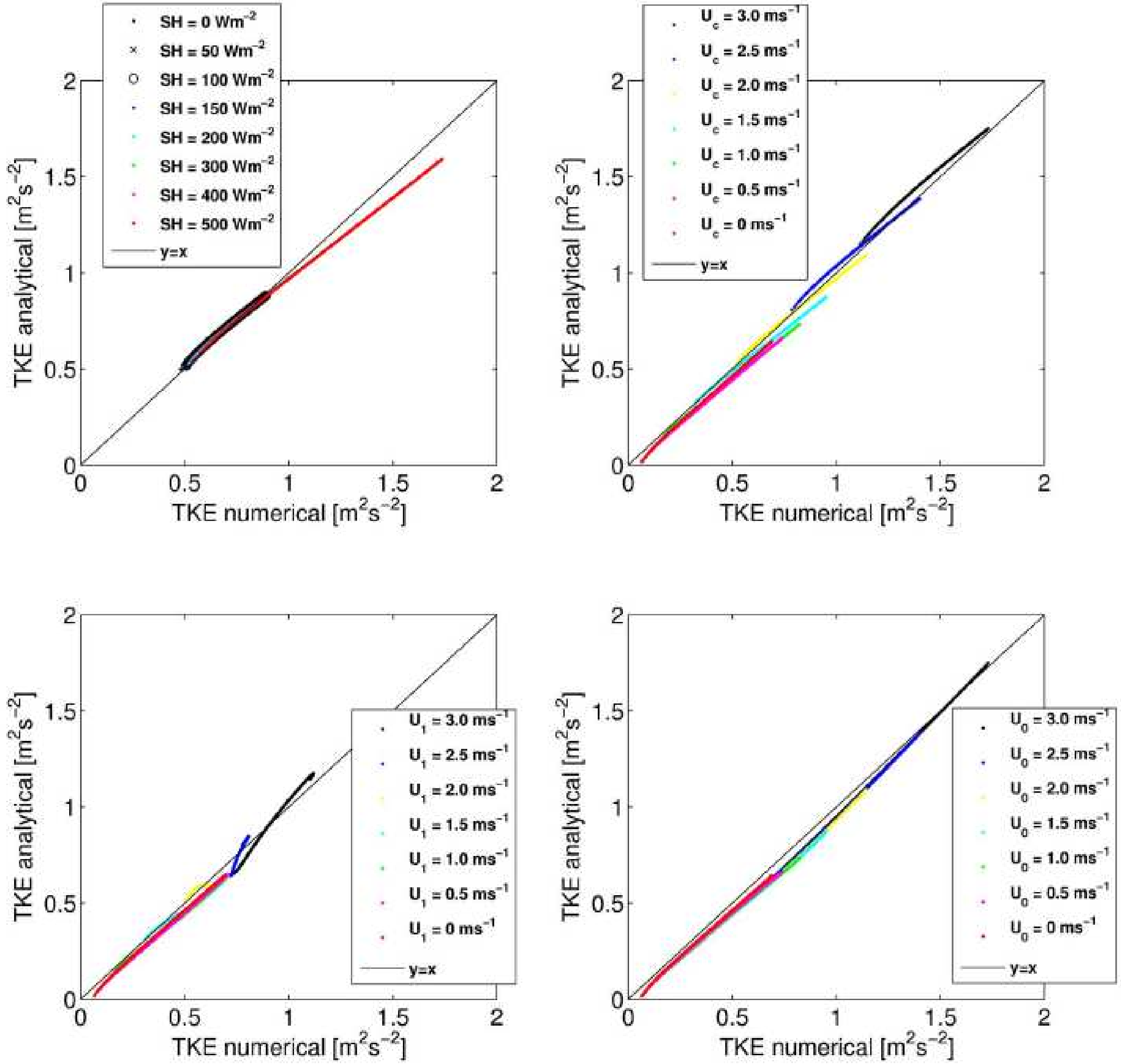
(from Part 2)



time-varying winds during the afternoon transition. From this, we conclude that many different TKE decay rates are possible under time-varying winds and that generalizing the decay with simple scaling laws for near-surface TKE of the form t^{α} may be questionable.

(from Part 2)

We simplify the numerical model for very **near-surface TKE** (here at 2 m) to an analytical expression by assuming among other things quasi-stationarity



$$E^{3/2} = \frac{0.6 l_\epsilon u_*^3}{kz}\left(1 + 3.6k^{2/3}\left(\frac{z}{z_i}\right)^{2/3}\left(\frac{w_*}{u_*}\right)^2\right)^{-1/2} + \frac{0.6 l_\epsilon w_*^3}{z_i}$$

TKE in the afternoon transition above the surface layer

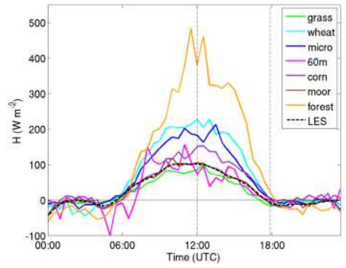
Darbieu et al. (2015)

Considered a case study, June 20:

1.Observed sensible and **latent heat flux**
2.Correct forcing time scales
3.Initialized **with observed wind** and

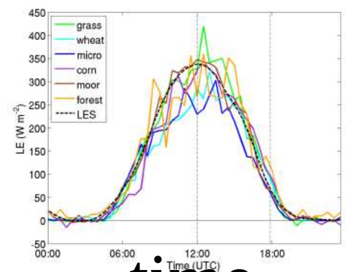
Described the decay of TKE at different levels of the boundary layer from LES and compared to observations

H



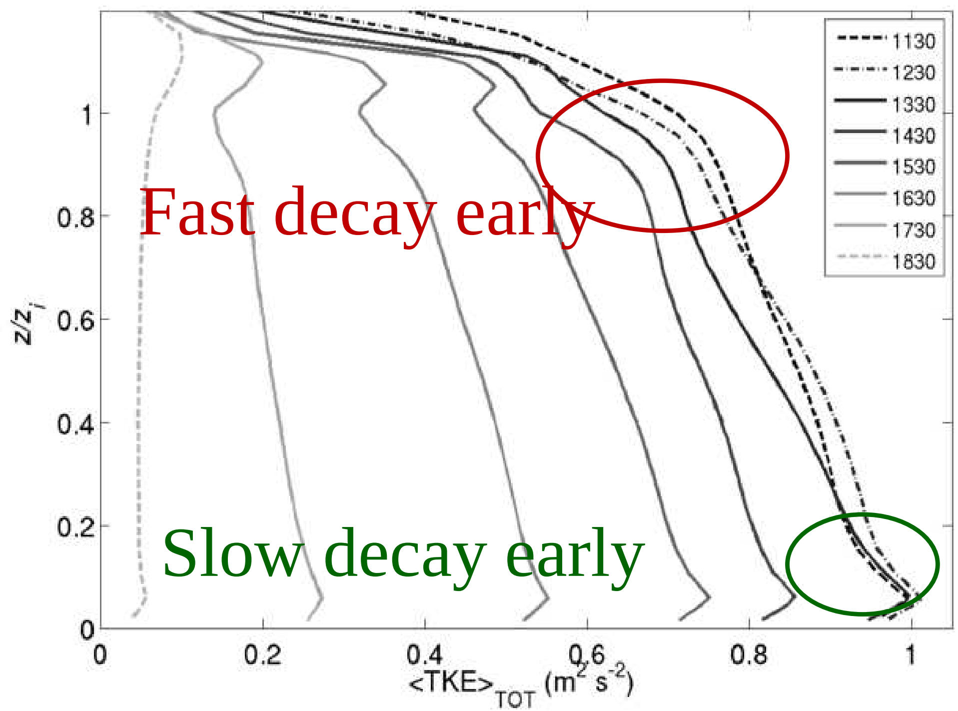
(b)

L



time

about 6 h long afternoon

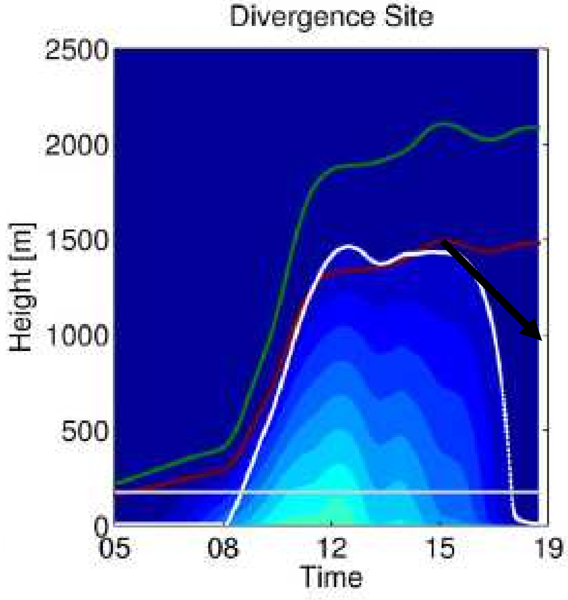


TKE in the afternoon transition above the surface layer

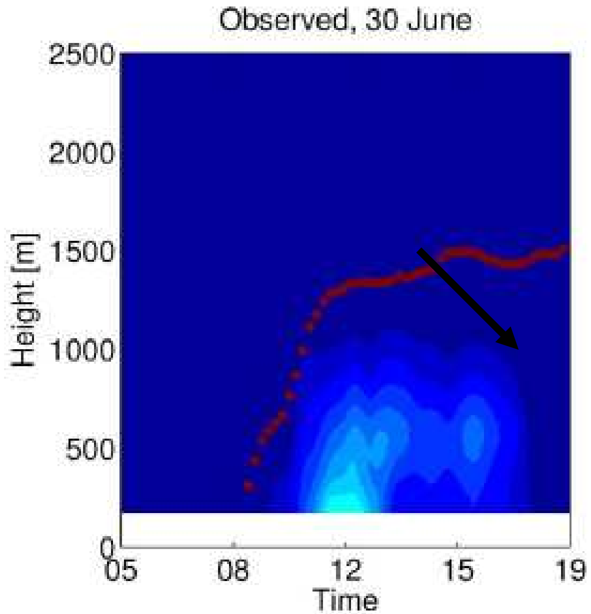
(From Part 2)

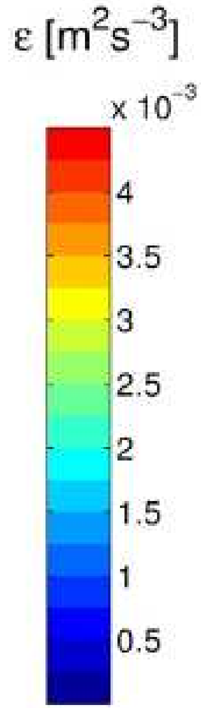
We use the simple 1D TKE model to discuss the reduced weak levels of TKE and dissipation rate obtained in the upper boundary layer during still unstable conditions

Modelled

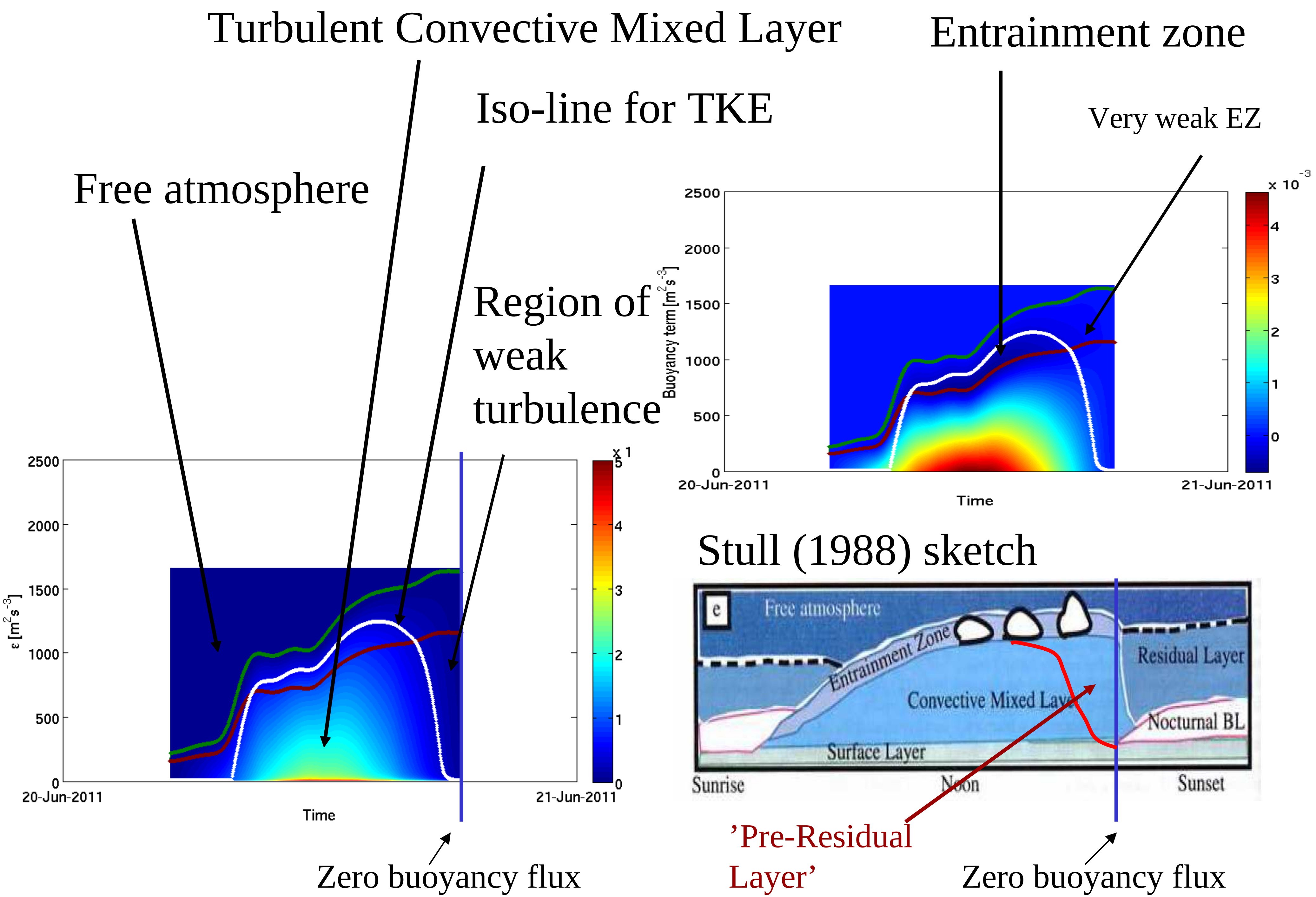


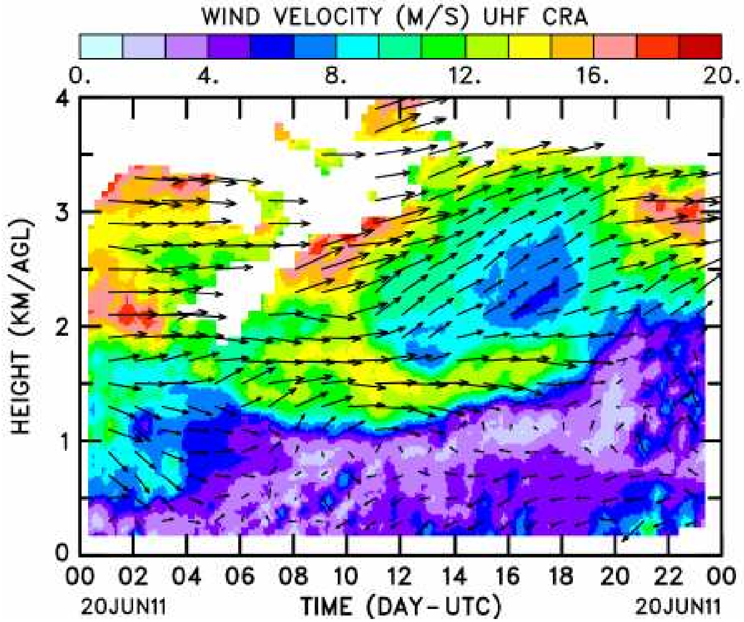
Observed from UHF

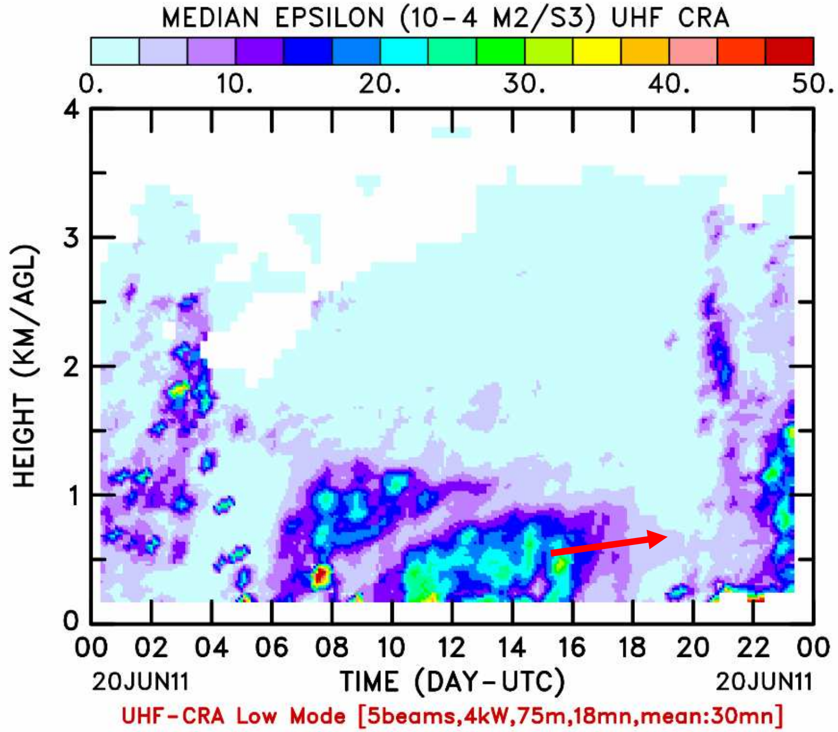




TKE in the afternoon transition







Effects to be studied further:

Elevated shear production and directional wind shear related to meso-scale effects and mountain-plain circulation

A batchelor student Robin Isaksson in Uppsala will focus on this for June 20 using WRF and observations.

Signatures of residual layer turbulence remaining at elevated levels also in the evening

A Phd student Nina Svensson in Uppsala is studying coastal and evening transitions with horizontal roll structures generated over land that survives in stable stratification when advected out over the Baltic Sea.

General questions to address in this session:

Question 1: **Do we need a smooth transition regime between CBL to SBL at the surface (including an adequate scaling)**

Answer 1: Yes perhaps, but time scales? and more processes? to increase realism
A simple ‘smooth’ transition sketch may however be useful as a starting point for discussion of our conceptual understanding of the situation

Question 2: **How does this transition affect the formation/representation of the residual layer?**

Answer 2: We introduced the ‘pre-residual layer’ for the unstable afternoon transition which may help in discussions of low turbulence onset conditions for the actual residual layer. This is not complete! Elevated wind shear effects and horizontal advection is for instance lacking in our simple model/sketch

Question 3: **What is the role of surface heterogeneity (different length scales of non-uniformity)?**

Answer 3: We only explored a little bit what different surface forcings may imply for dissipation rate and TKE. More work needed, including studies of what blending heights are for different parameters