Modification of CFD code to model the non-neutral atmospheric boundary layer

Modelling atmospheric stability in EllipSys3D

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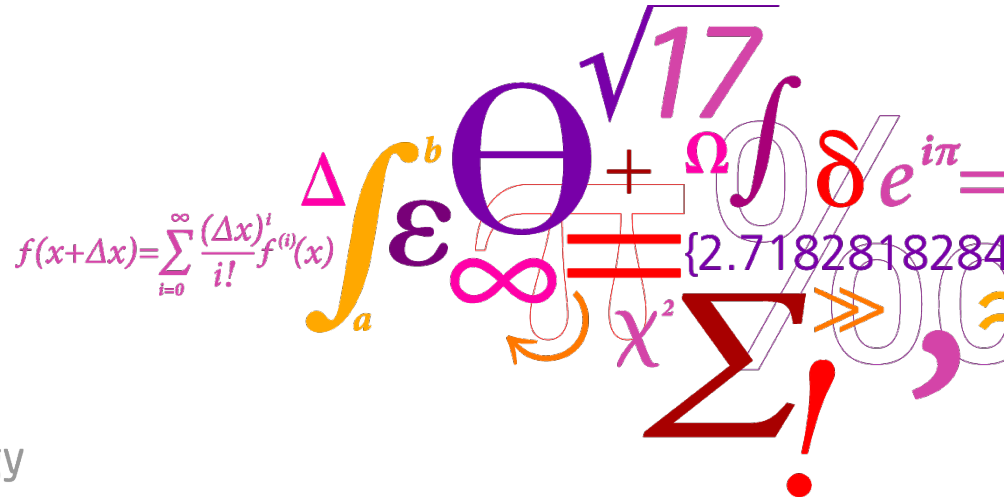


Risø DTU
National Laboratory for Sustainable Energy

Atmospheric stability

Chimney plume under stable and unstable conditions

stable

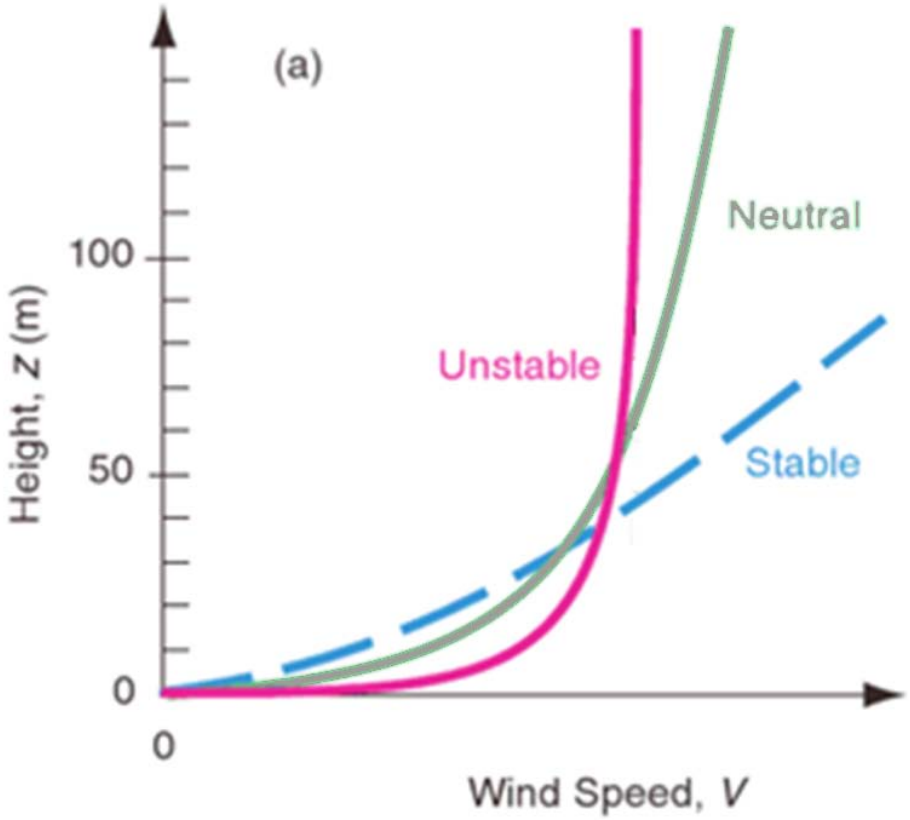
unstable

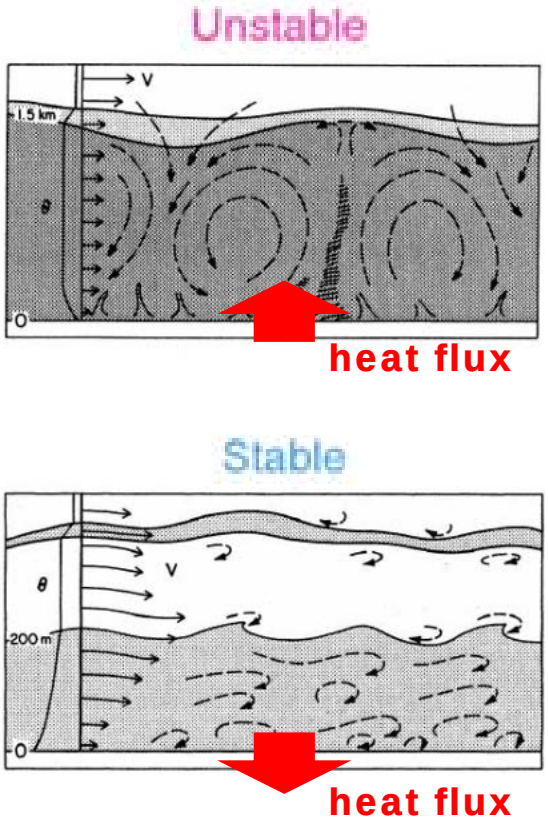
Source: *kindly been provided by Dr. Torben Mikkelsen, Risø DTU and Dr. Thomas Ellermann, National Environmental Research Institute*

Atmospheric stability

Why: Influence on the wind field

Flat terrain



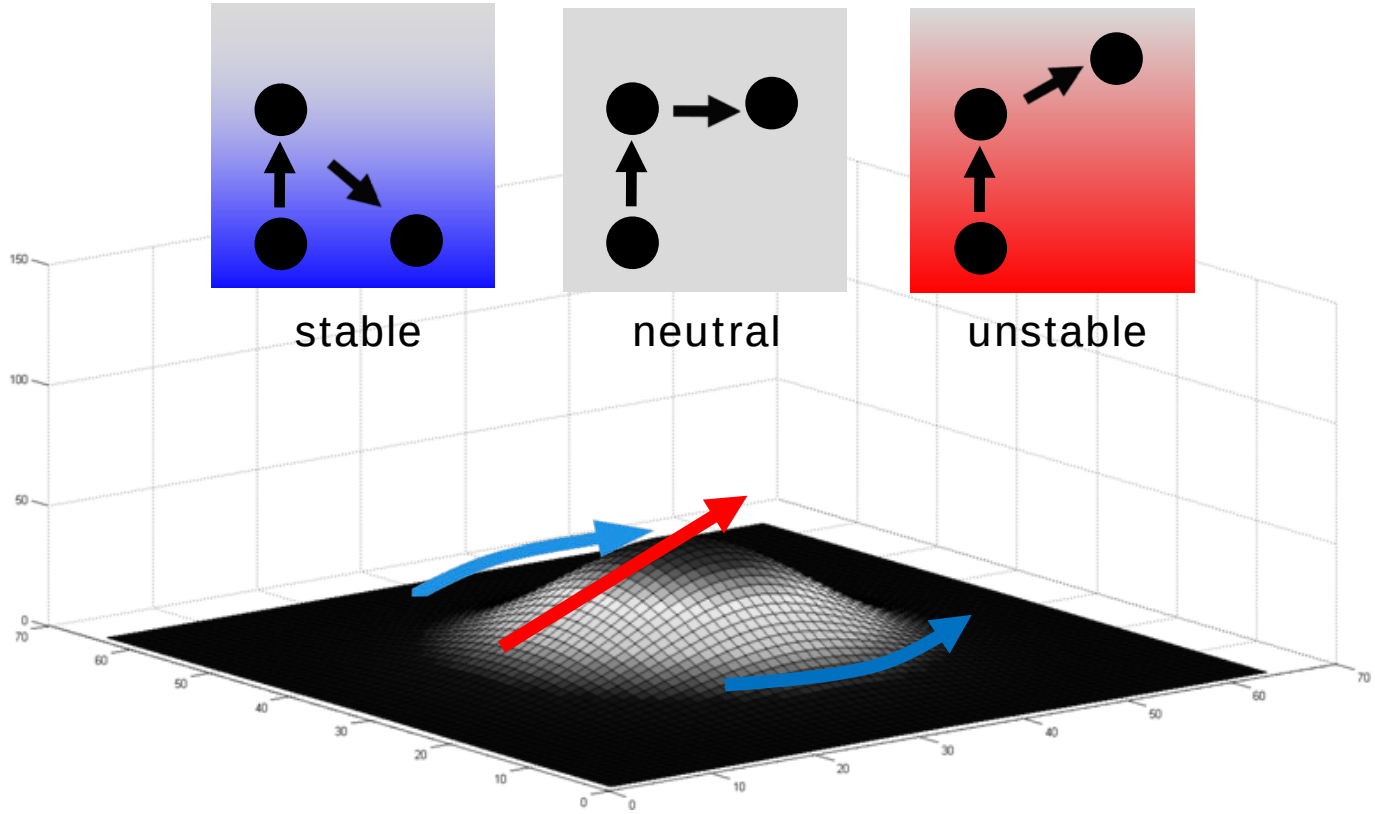


Source: *Kaimal and Finnigan 1994, Wallace and Hobbs 2006*

Atmospheric stability

Why: Influence on the wind field

Complex terrain



Contents

Atmosperic stability

- **Why** Influence on the wind profile ✓
- **How** Momentum, Temperature, Turbulence equations
- **Results** Diurnal cycle I
  Diurnal cycle II
  Gaussian hill

Atmospheric stability

How: Implementation into Ellipsys3D

Governing equations:

- Momentum $$\frac{\delta}{\delta t}(\rho U_i) + \frac{\delta}{\delta x_k}(\rho U_k U_i) = -\frac{\delta}{\delta x_i}p + \frac{\delta}{\delta x_j}\left[\mu_{eff}\left(\frac{\delta U_i}{\delta x_j} + \frac{U_j}{\delta x_i}\right)\right]$$
  - Coriolis forcing $F_{C,i} = f_c u_j m$, $f_c = 2\Omega sin\lambda$
- Temperature $$\boxed{\frac{\delta}{\delta t}(\rho\theta) + \frac{\delta}{\delta x_j}(\rho U_j \theta) = \frac{\delta}{\delta x_j}\left[\left(\frac{\lambda}{C_p} + \frac{\mu_T}{\sigma_\theta}\right)\frac{\delta\theta}{\delta x_j}\right]}$$

Atmospheric stability

How: Implementation into Ellipsys3D

- Turbulence (k-ε)

$$\frac{\delta}{\delta t}(\rho k) + \frac{\delta}{\delta x_j}(\rho U_j k) = \frac{\delta}{\delta x_j}\left[\left(\mu + \frac{\mu_T}{\sigma_k}\right)\frac{\delta k}{\delta x_j}\right] + P - \rho\varepsilon \boxed{+G}$$

$$\frac{\delta}{\delta t}(\rho \varepsilon) + \frac{\delta}{\delta x_j}(\rho U_j \varepsilon) = \frac{\delta}{\delta x_j}\left[\left(\mu + \frac{\mu_T}{\sigma_s}\right)\frac{\delta \varepsilon}{\delta x_j}\right] + C_{\varepsilon 1}\frac{\varepsilon}{k}P - C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k} \boxed{+C_{\varepsilon 3}\frac{\varepsilon}{k}G}$$

$$\boxed{G = -\frac{\mu_{eff}}{\sigma_H}\frac{g}{\theta_h}\frac{\delta\theta}{\delta z}}$$

- coefficient $C_{\varepsilon 3}$
  Sogachev (2009)

$$C_{\varepsilon 3} = C_{\varepsilon 1} - C_{\varepsilon 2}$$

- length-scale limiter
  Apsley & Castro (1997)

$$C^*_{\varepsilon 1} = \left[C_{\epsilon 1} + (C_{\epsilon 2} - C_{\epsilon 1})\frac{l}{l_{max}}\right]$$

- ambient turbulence values
  Spalart & Rumsey (2007)

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Diurnal Cycle I

Transient simulation of diurnal cycle in the ABL

Numerics

- boundary conditions :

  bottom: rough wall, T(t)

  top: symmetry

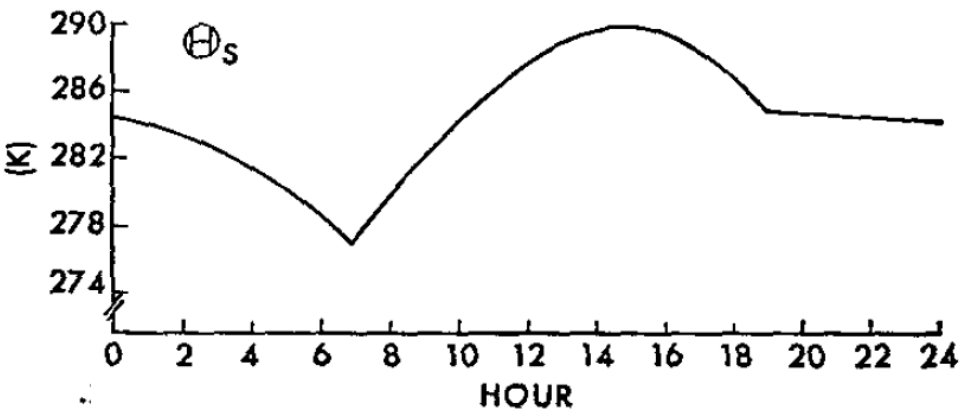
  vertical: cyclic

- computational domain:

  12 x 12 x 3 km

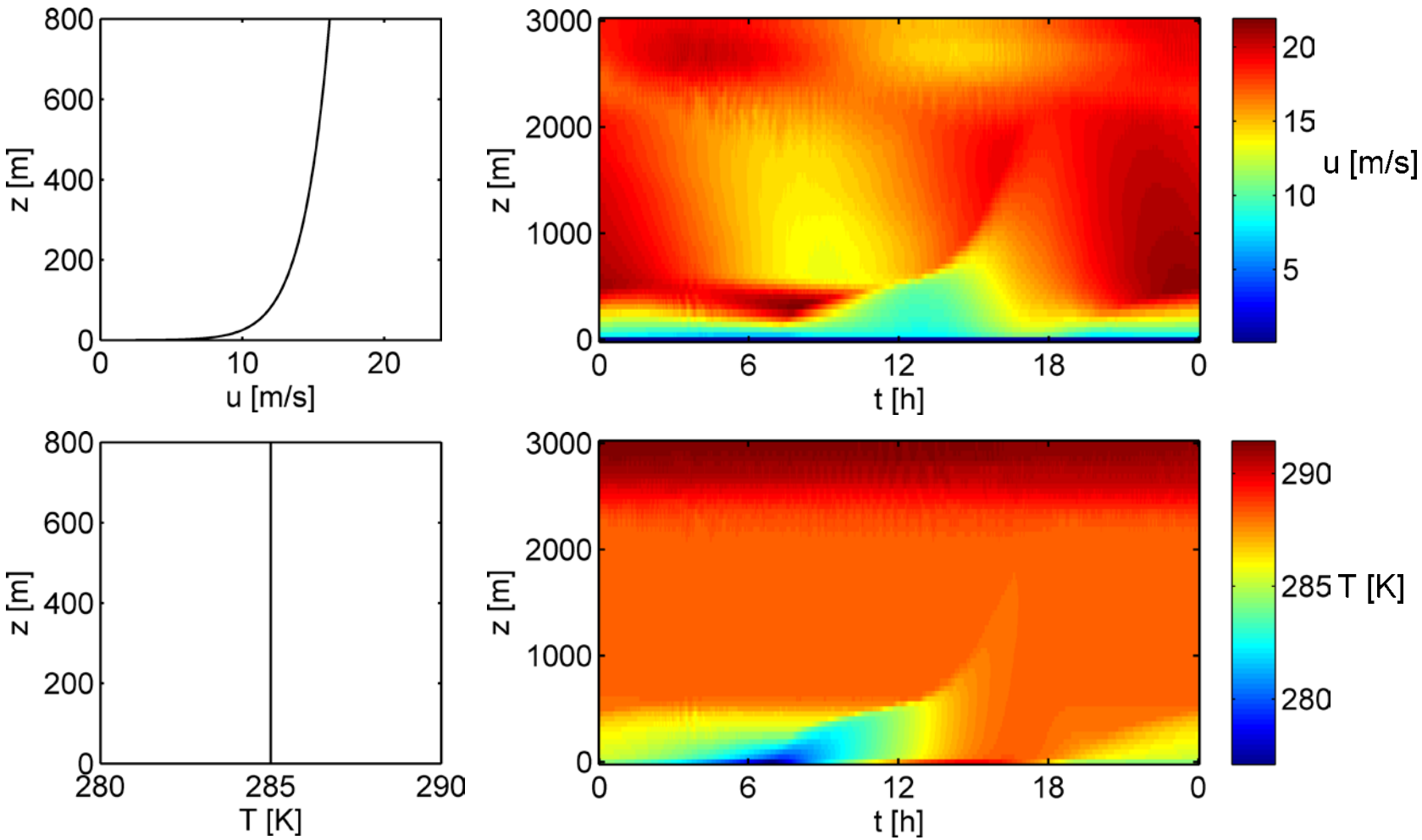
  32 x 32 x 128 grid points

Mellor & Yamada (1974)



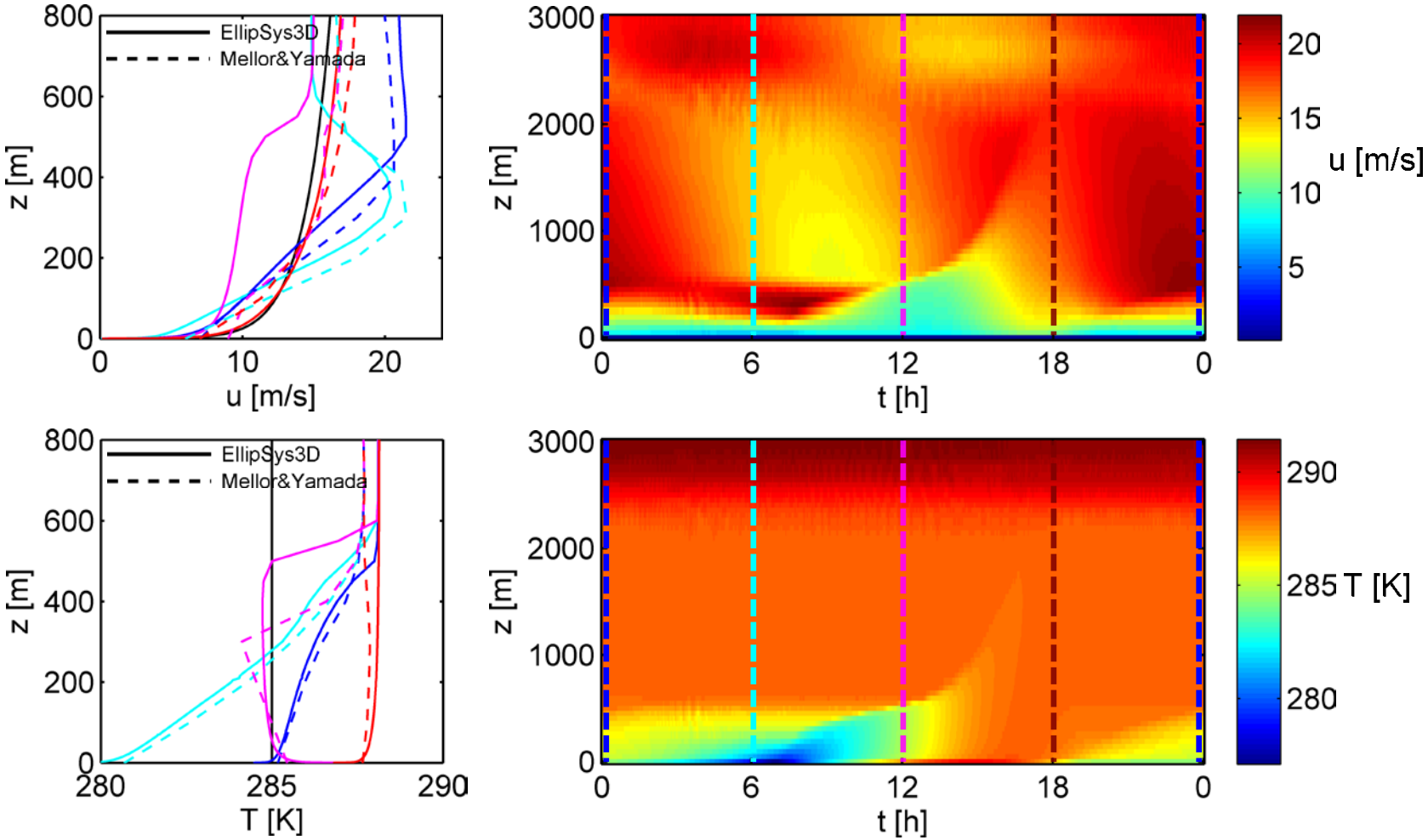
Diurnal Cycle I

Transient simulation of diurnal cycle in the ABL



Diurnal Cycle I

Transient simulation of diurnal cycle in the ABL



Diurnal Cycle II

GABLS II experiment

Numerics

- boundary conditions :

  bottom: rough wall, T(t)

  top: symmetry

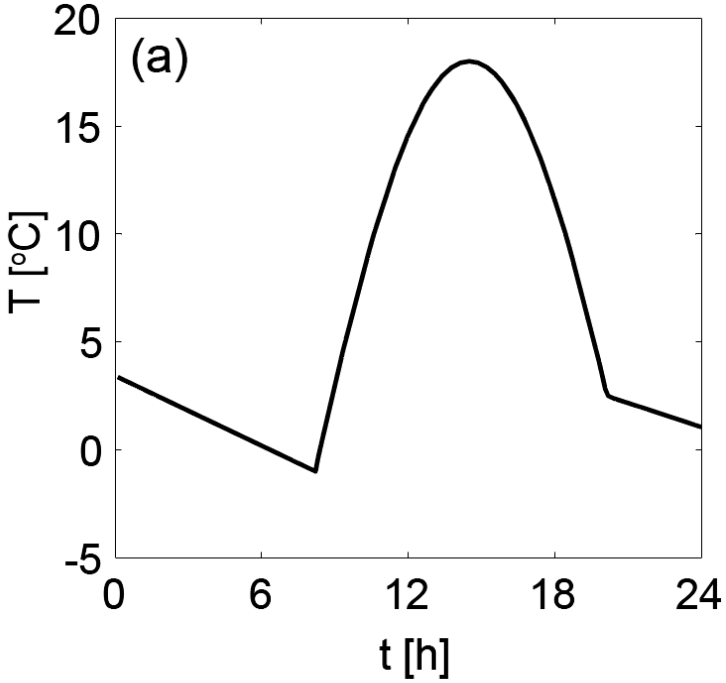
  vertical: cyclic

- computational domain:

  12 x 12 x 6 km

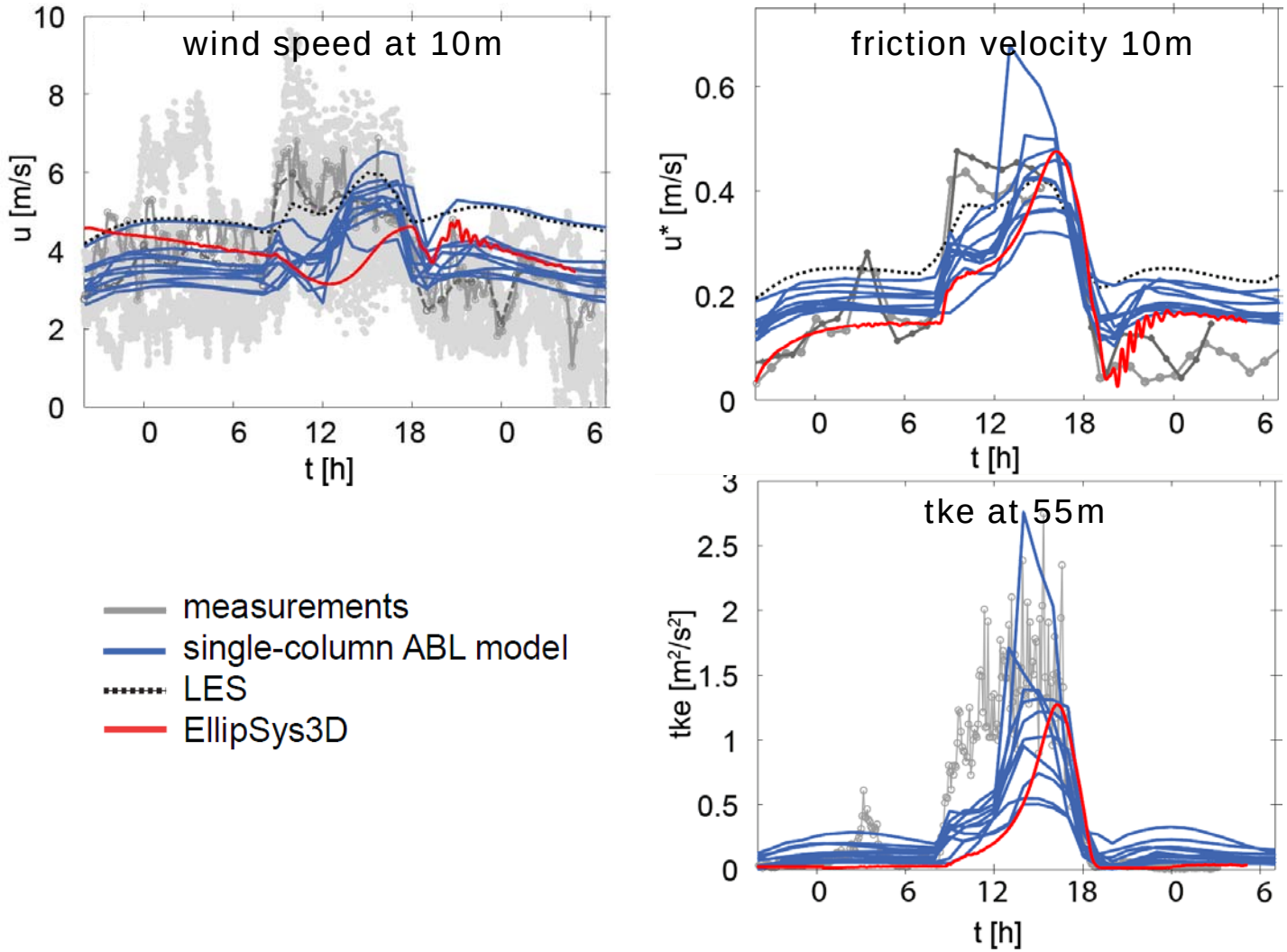
  32 x 32 x 256 grid points

Svensson et al. (2011)



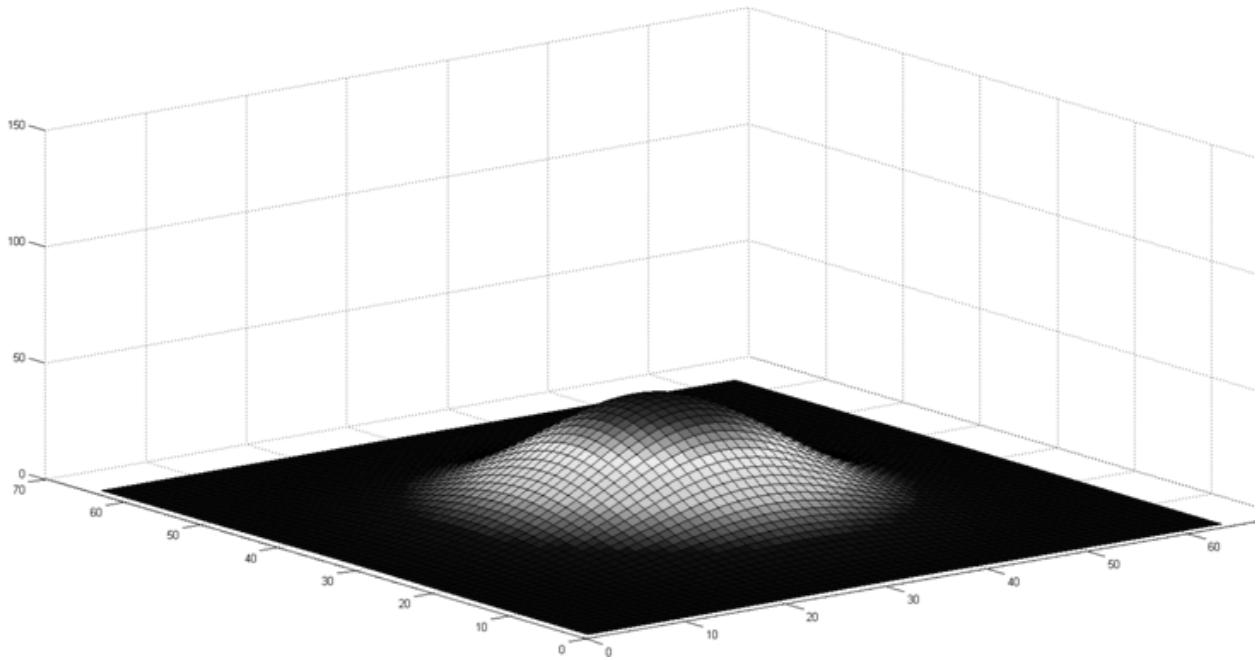
Diurnal Cycle II

GABLS II experiment



Gaussian Hill

Diurnal cycle over hill



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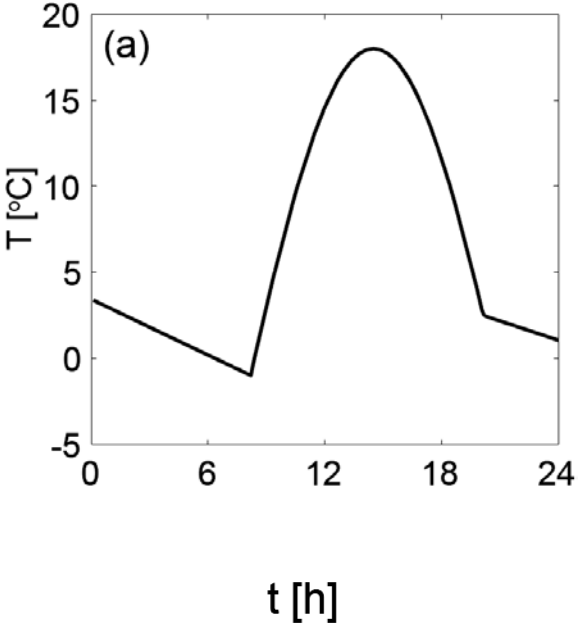
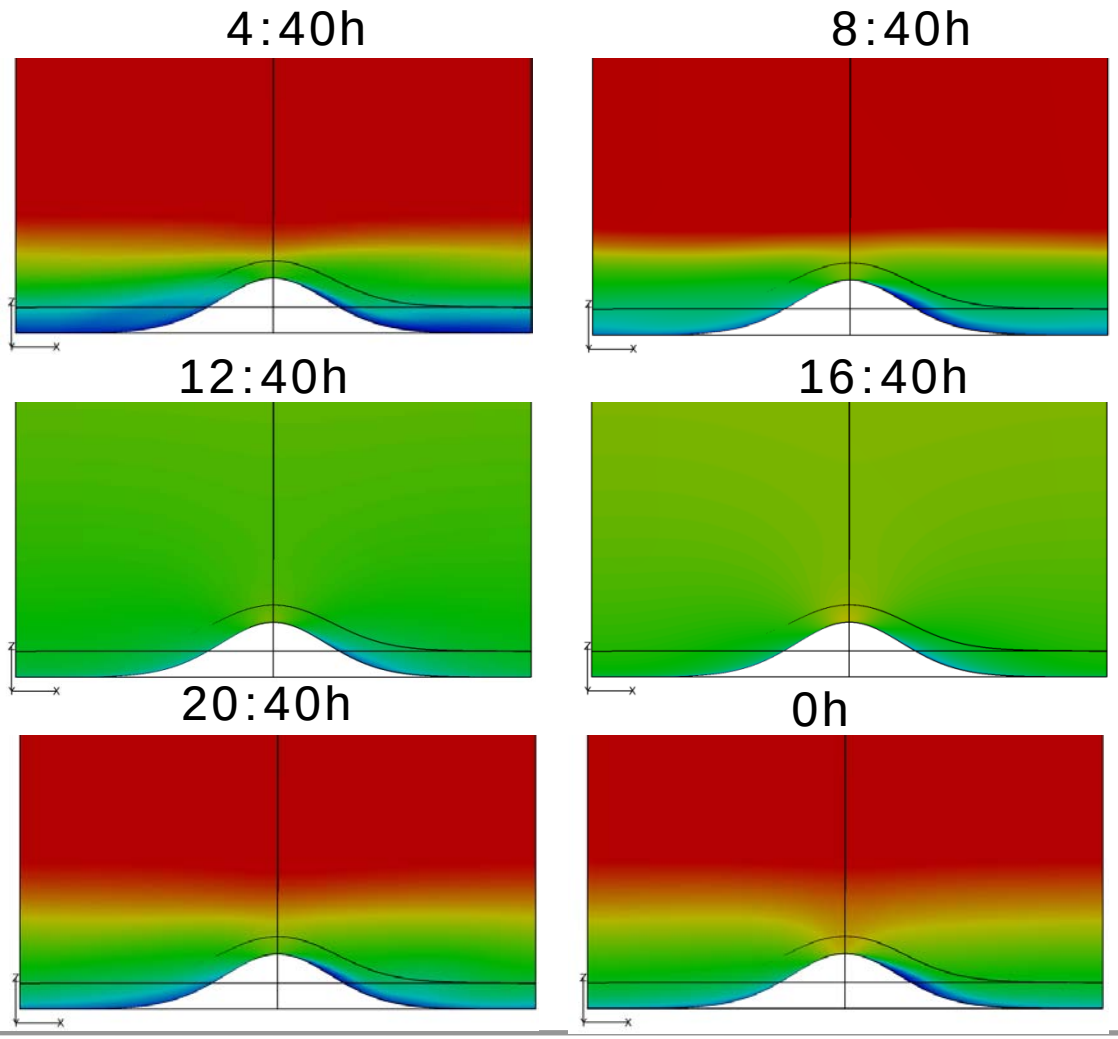
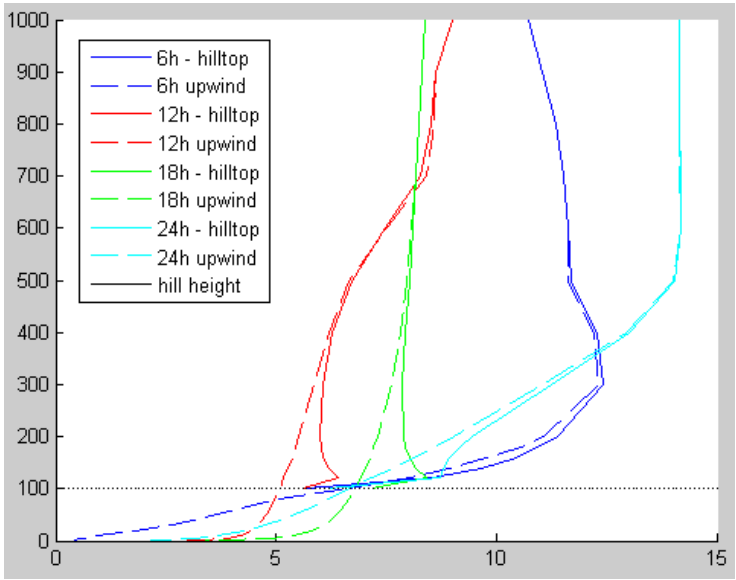


Gaussian Hill

Windspeeds during diurnal cycle



wind speed upstream vs. hilltop



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Conclusions / Future Work

Conclusions

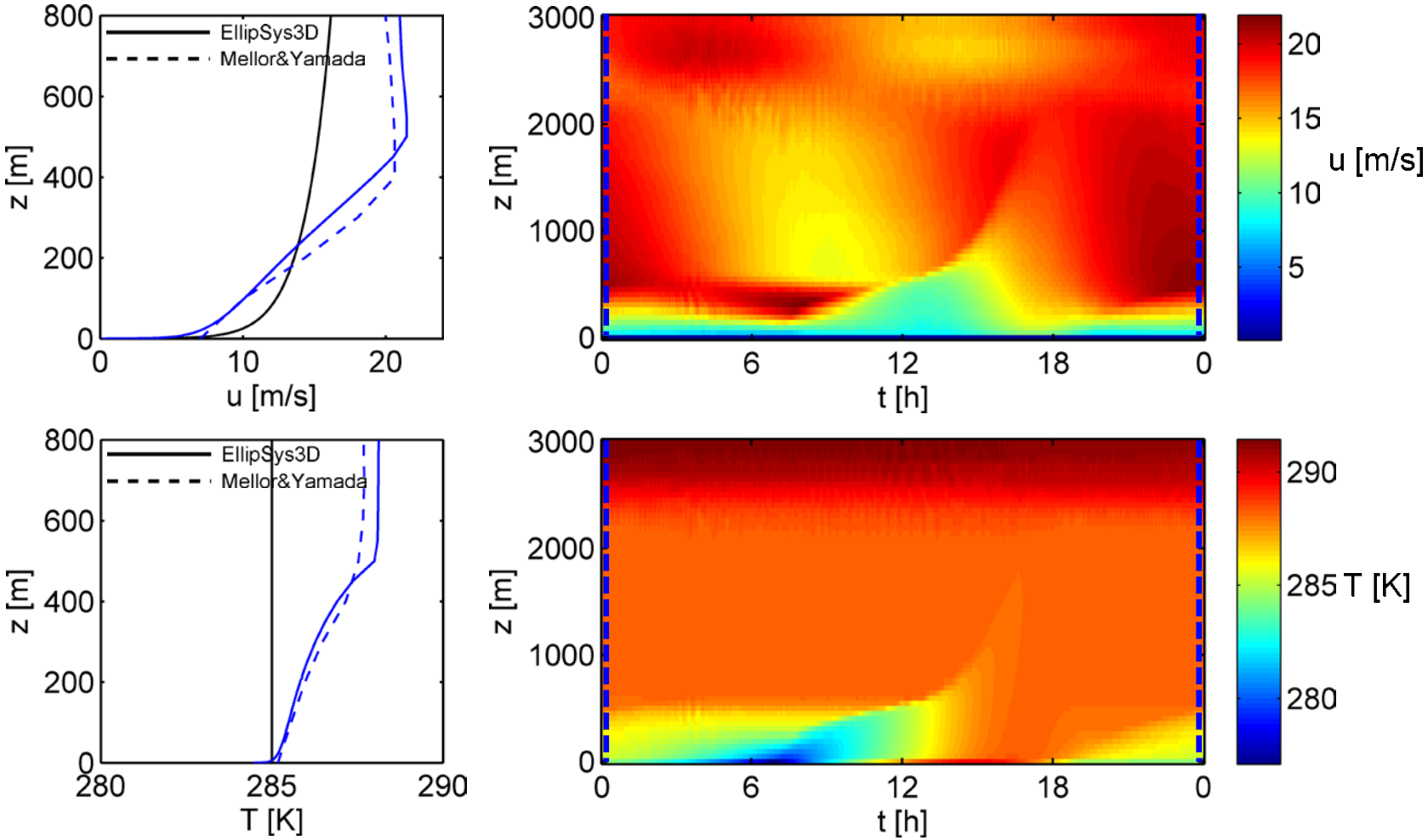
- diurnal flow pattern reproduced
- best agreement from late afternoon throughout the night
- biggest deviations after the morning transition:
  - growth of the convective ABL and the turbulence level are too weak
  - underestimated low-level wind speed

Future work

- validation against flat terrain field data (e.g. Høvsøre)
- non-neutral flow over complex terrain
- validation against complex terrain field experiments
  (e.g. Benekanahalli hill, India)

Results

Transient simulation of diurnal cycle in the ABL



Results

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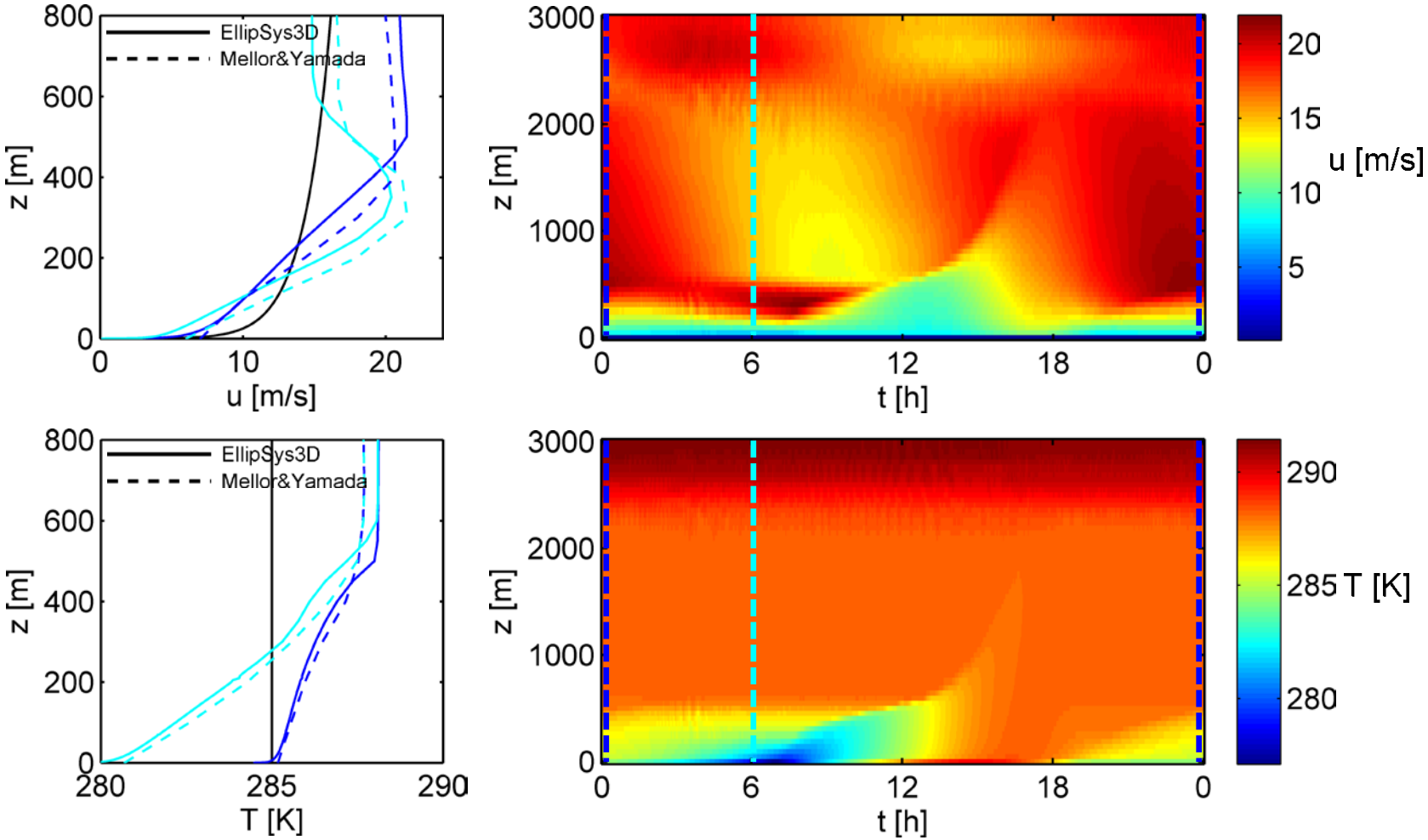

Results

Transient simulation of diurnal cycle in the ABL