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Single-column experiments with the EFB turbulence closure

Carl Fortelius, Evgeny Kadantsev

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Outline

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The EFB turbulence closure

The starting point of the Energy- and Flux-Budget turbulence closure for stably stratified flows, *Zilitinkevich et al.,2013, BLM,146,341-373*, lies in considering the total energy of turbulence, consisting of turbulent kinetic energy and turbulent potential energy:

$$e = e_k + e_p = \frac{1}{2}\overline{u_i' u_i'} + \frac{1}{2}\frac{\beta}{\frac{\partial \Theta}{\partial z}}\overline{\theta'^2}$$

Solving a system of equations for second moments in a steady state yields diagnostic expressions for the turbulent time scale, t_T, and for the turbulent exchange coefficients of heat and momentum K_h and K_m as functions of the stability and the turbulent energies.

EFB in the AROME physics

After replacing the diagnostic formulation for $\overline{\theta'^2}$ with a prognostic one, the (two-equation) EFB closure can be implemented into the AROME physics simply by:

- setting the mixing length and dissipative length scale equal to $t_T e_k^{\frac{1}{2}}$.
  For numerical stability, the time scale was determined by relaxation towards the changing equilibrium-value computed at every time step.

- adjusting the values of several empirical constants

- deciding how to handle unstable stratification
  The solution adopted here was to simply compute the length scale as for neutral stratification

Experiments

The EFB turbulence closure was implemented into HARMONIE MUSC cy38h1, and tested in three cases:

- the stably stratified idealized GABLS1 case
- a "conventionally neutral" idealized case
- the realistic GABLS3 case

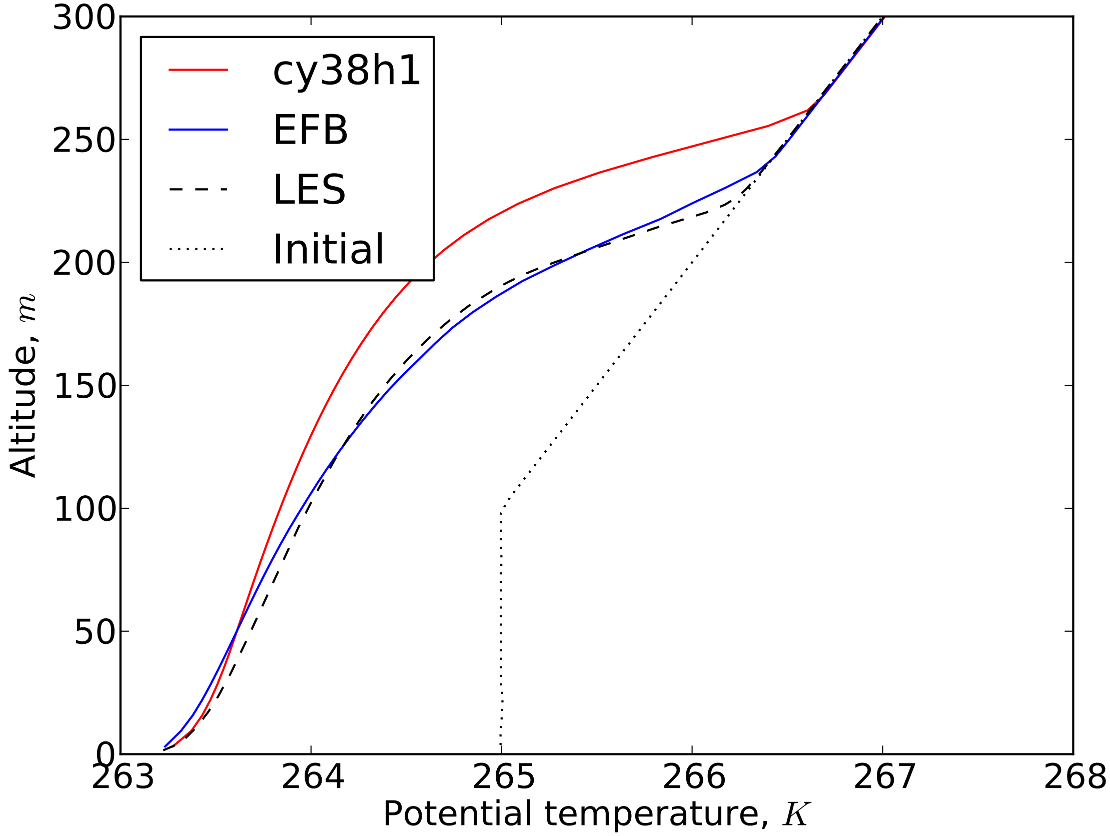
For the two idealized cases MUSC is compared to LES-results provided by Andrey Glazunov. For GABLS3 results are compared to data.

GABLS1: Setup

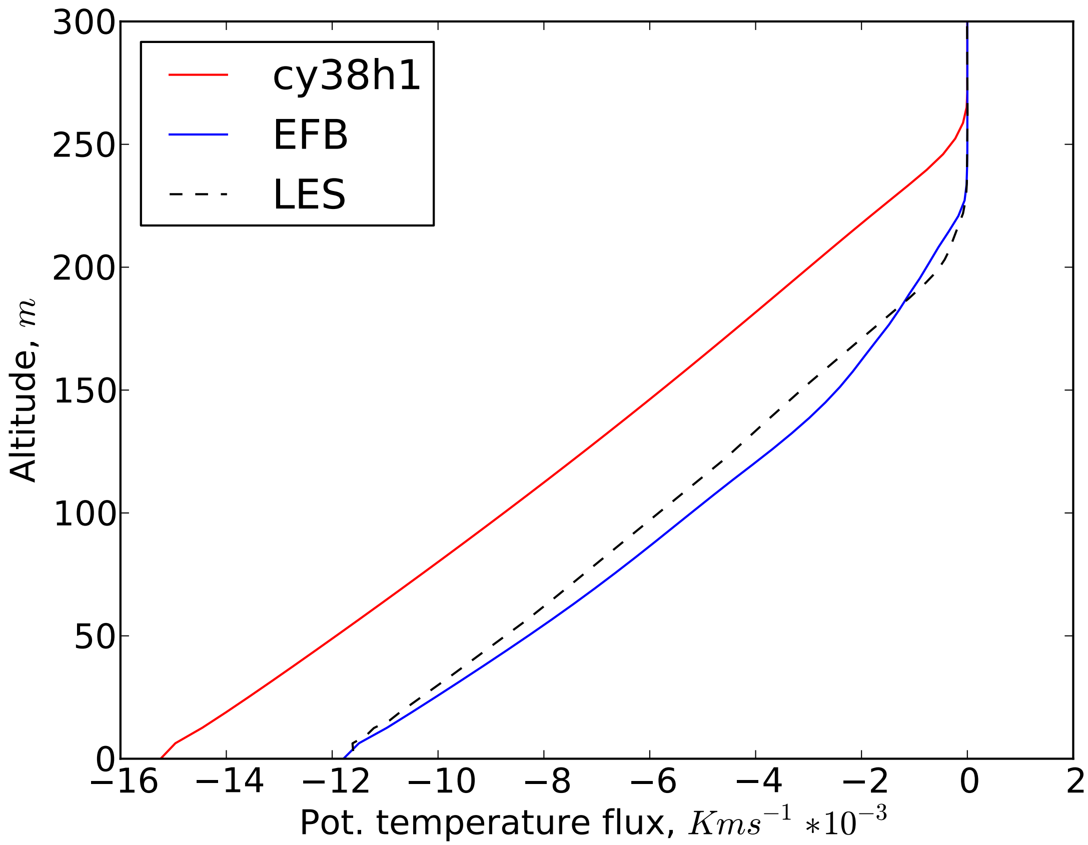
An initially 100 m deep mixed layer topped by a stably stratified atmosphere, having a uniform zonal wind in geostrophic balance is evolving in response to a constant geostrophic forcing, turbulent mixing and a surface temperature cooling at a constant rate. No parameterized processes other than turbulent mixing, surface heat flux, and surface friction are active.

Results are displayed as averages of hours 8..9 of simulated time.

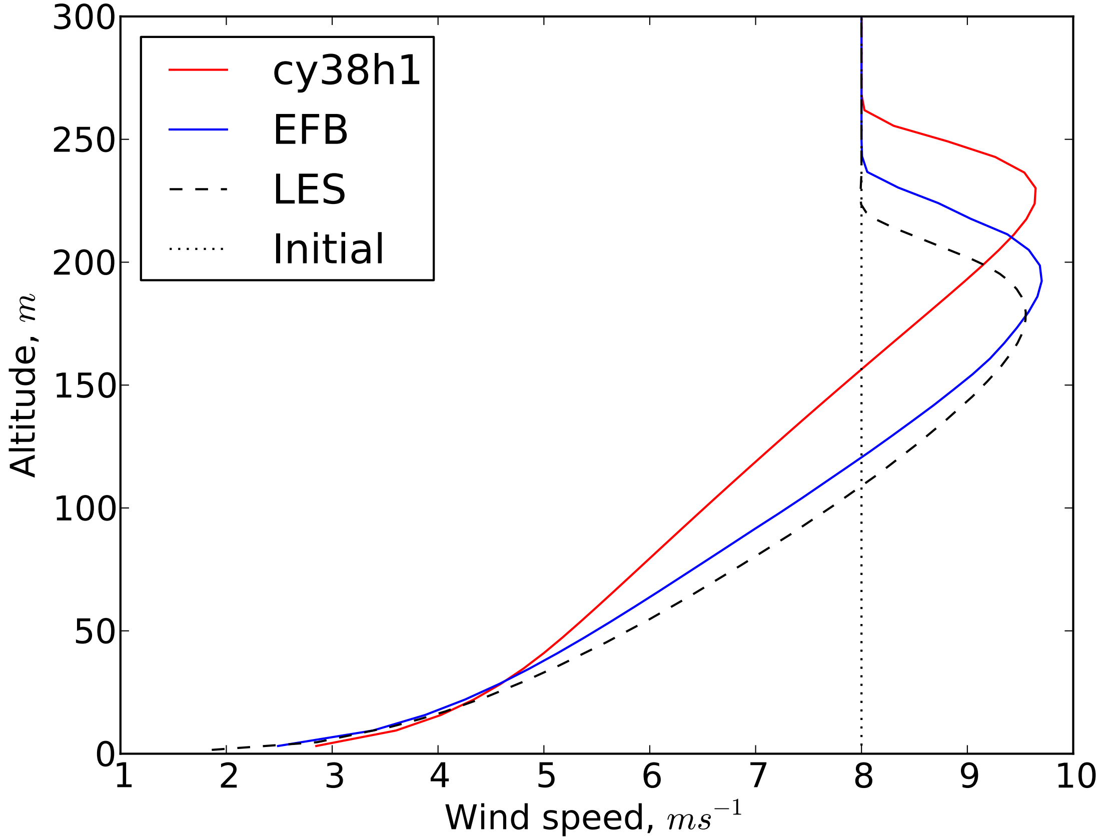
GABLS1: Potential temperature



GABLS1: Heat flux



GABLS1: Wind speed



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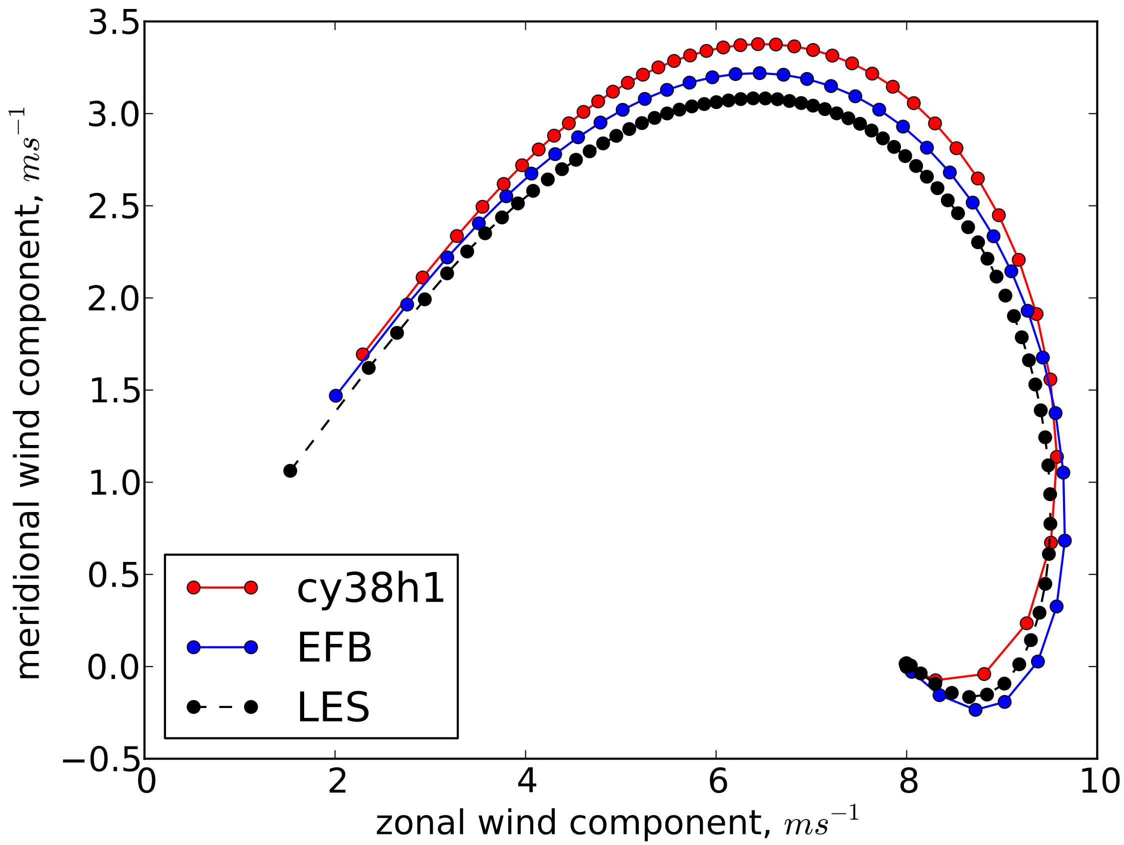
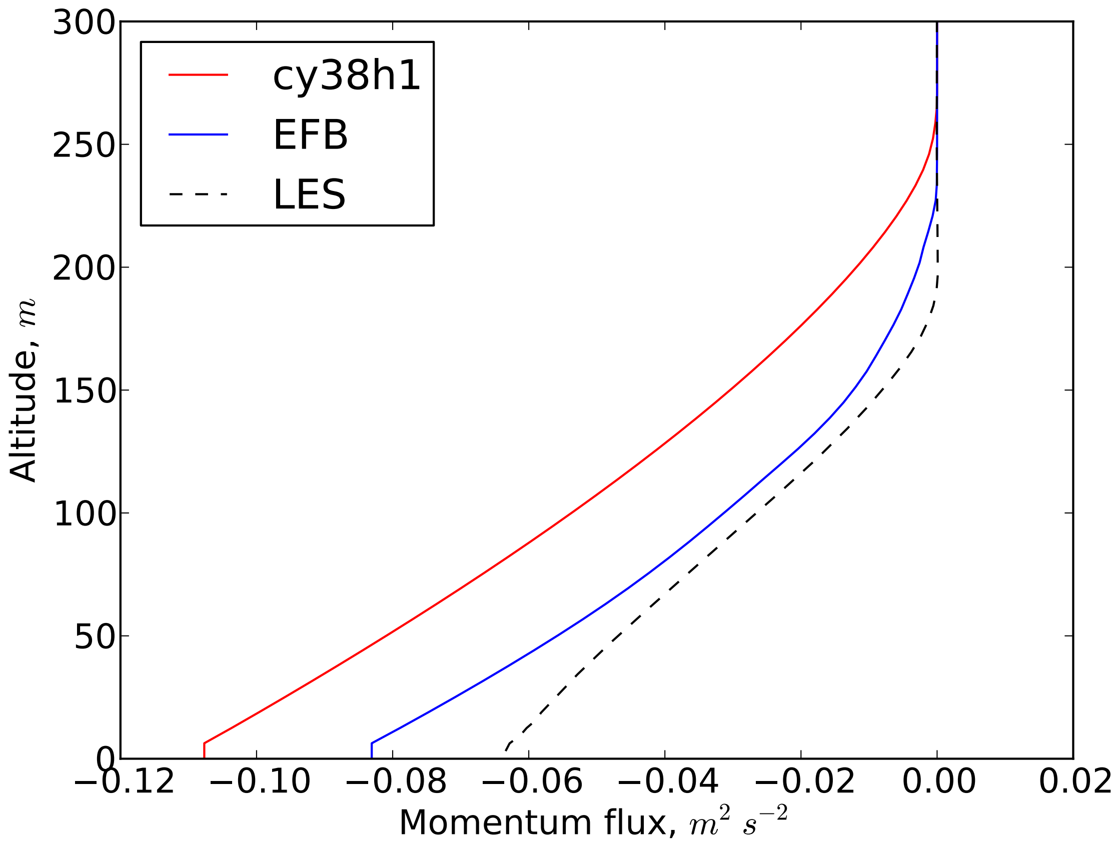
GABLS1: Hodographs



GABLS1: Momentum flux



GABLS1: Summary

- MUSC (cy38h1) overestimates the downward transport of heat and momentum. The mixed layer is too deep, the wind maximum occurs too high, and the profile of wind speed has a spurious point of inflexion.

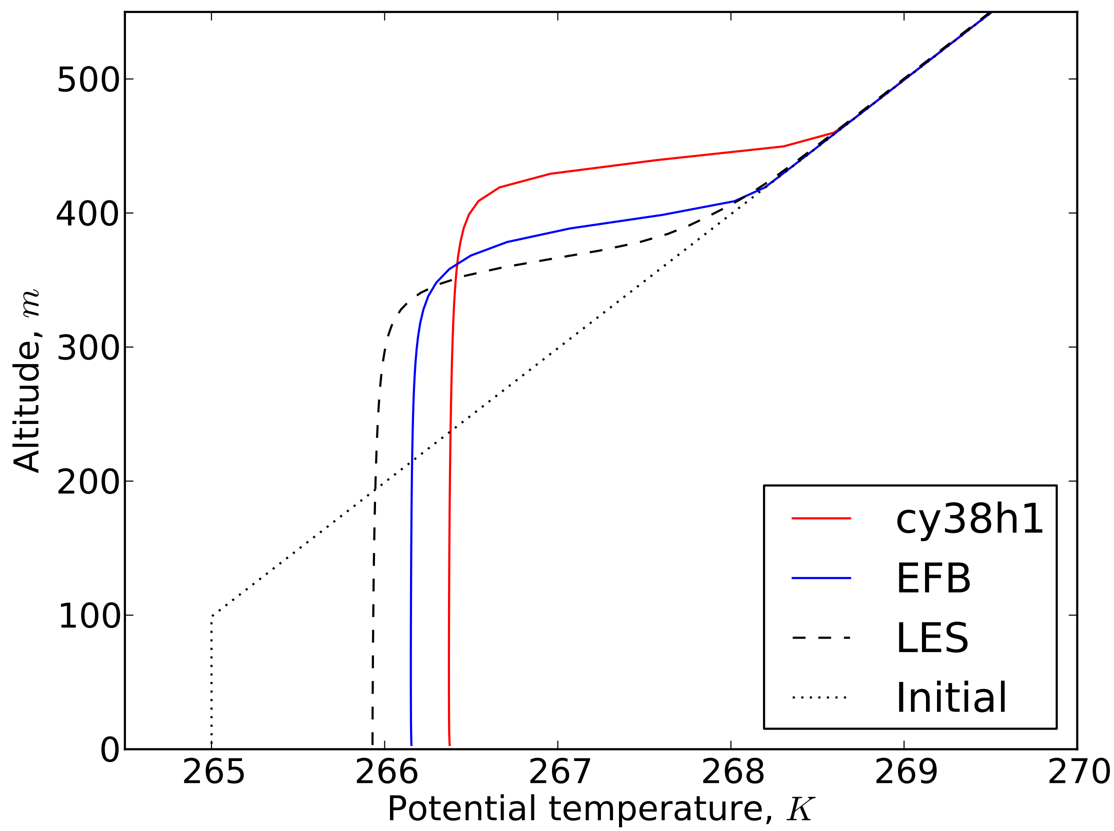
- Introducing the EFB-turbulence closure improves all these features, as well as the shape of the hodograph.

Conventionally neutral case: Setup

As in GABLS1, but surface heat flux is disabled: An initially 100 m deep mixed layer topped by a stably stratified atmosphere, having a uniform zonal wind in geostrophic balance is evolving in response to a constant geostrophic forcing and turbulent mixing. No parameterized processes other than turbulent mixing and surface friction are active.

Results are displayed as averages of hours 19..20 of simulated time.

Conventionally neutral: Pot. t.



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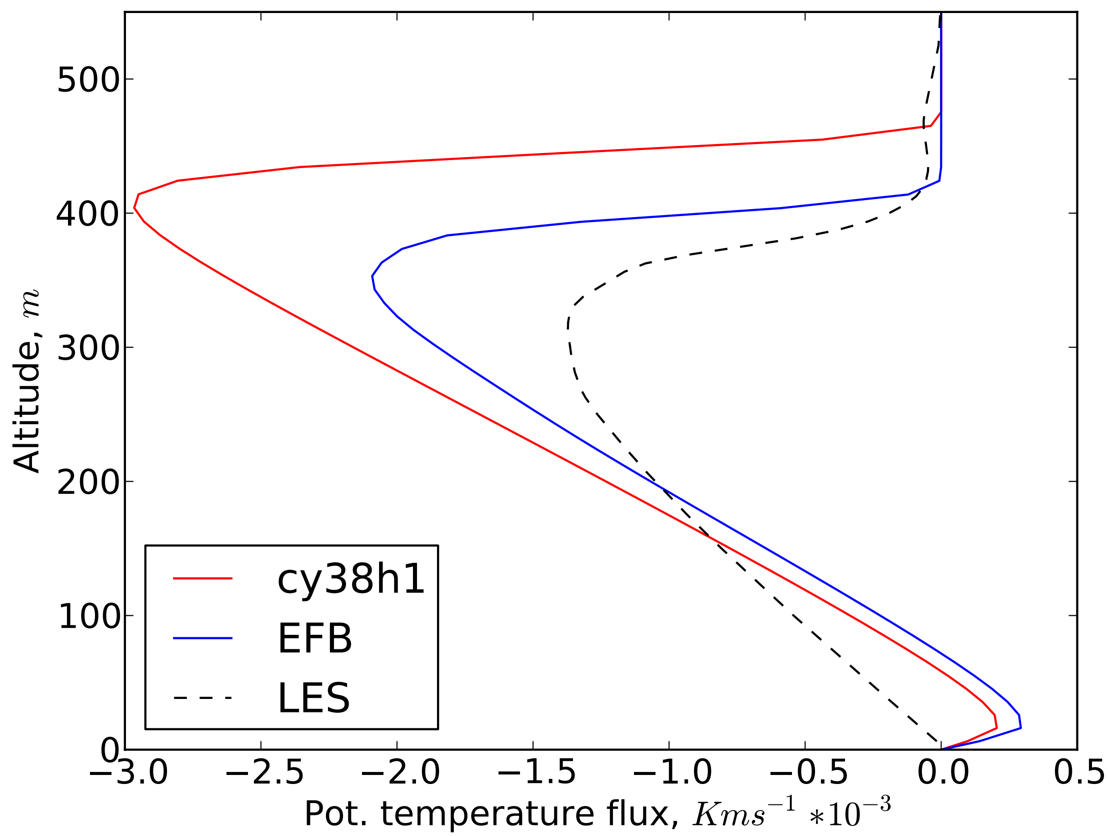
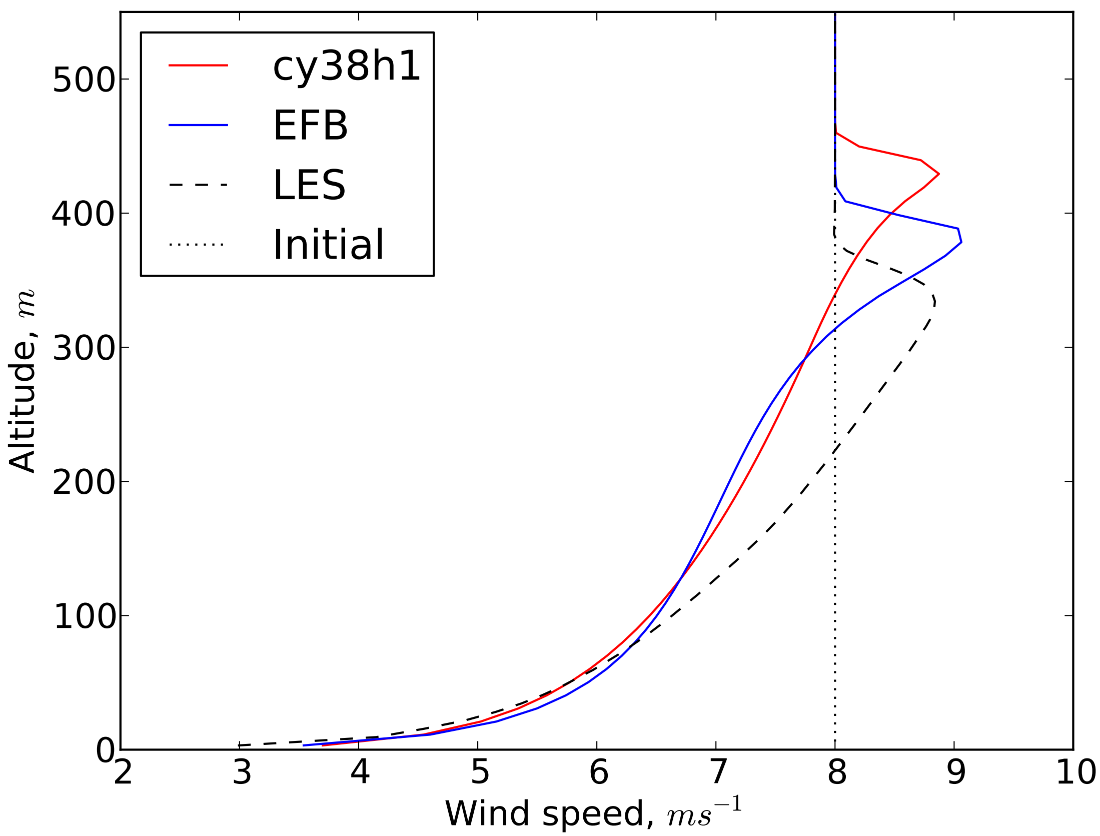
Conventionally neutral: Heat flux



Conventionally neutral: Wind speed



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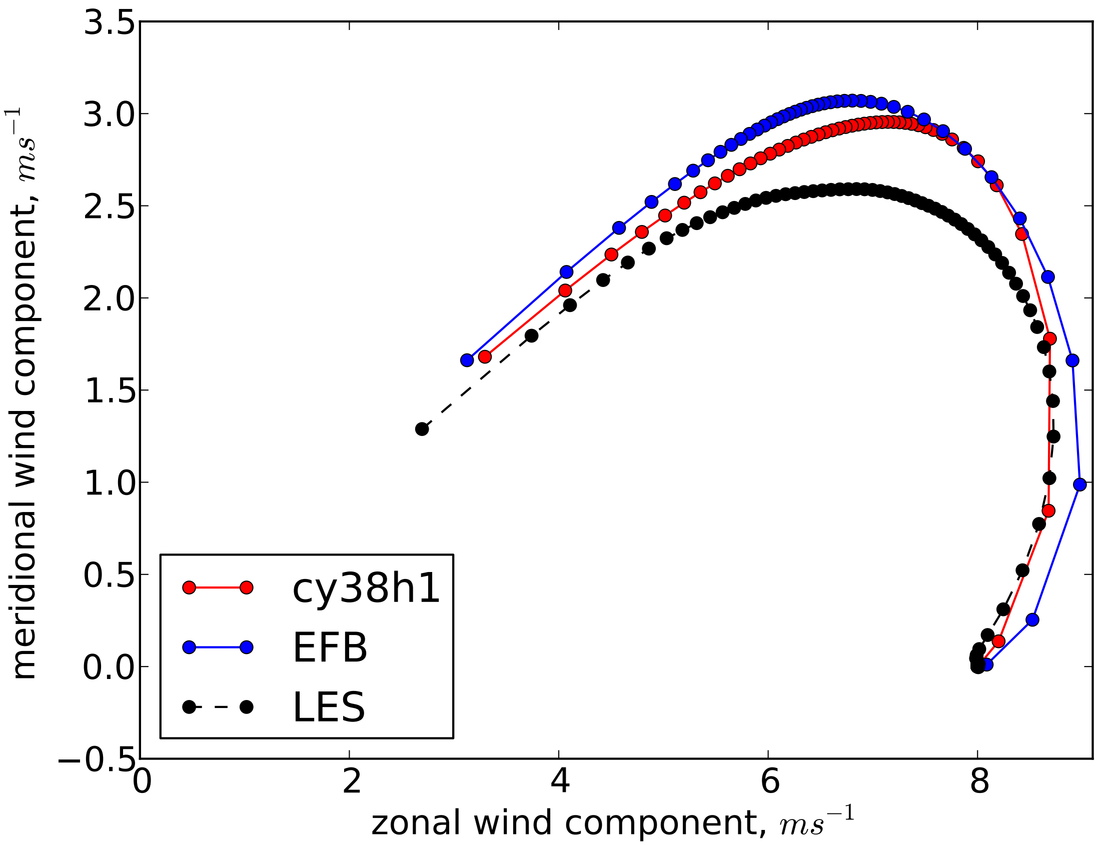
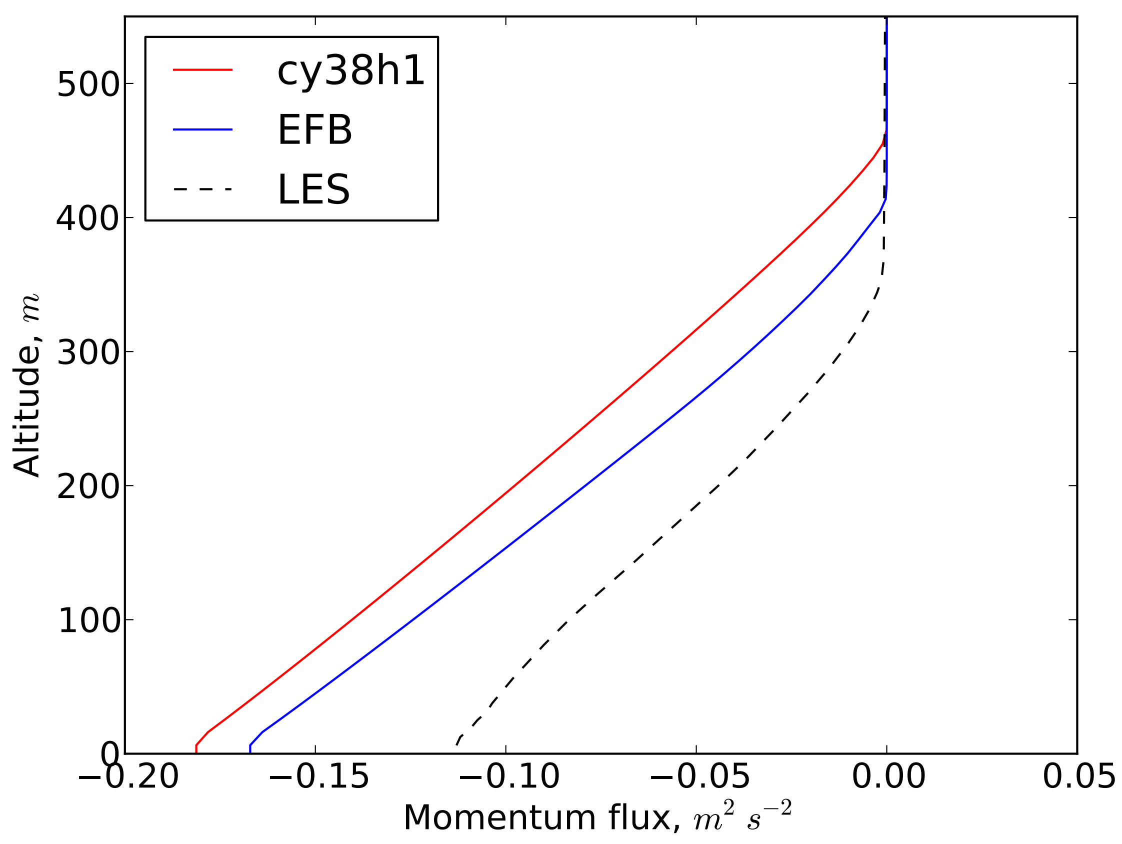
Conventionally neutral: Hodographs



Conventionally neutral: Momentum flux



Conventionally neutral: Summary

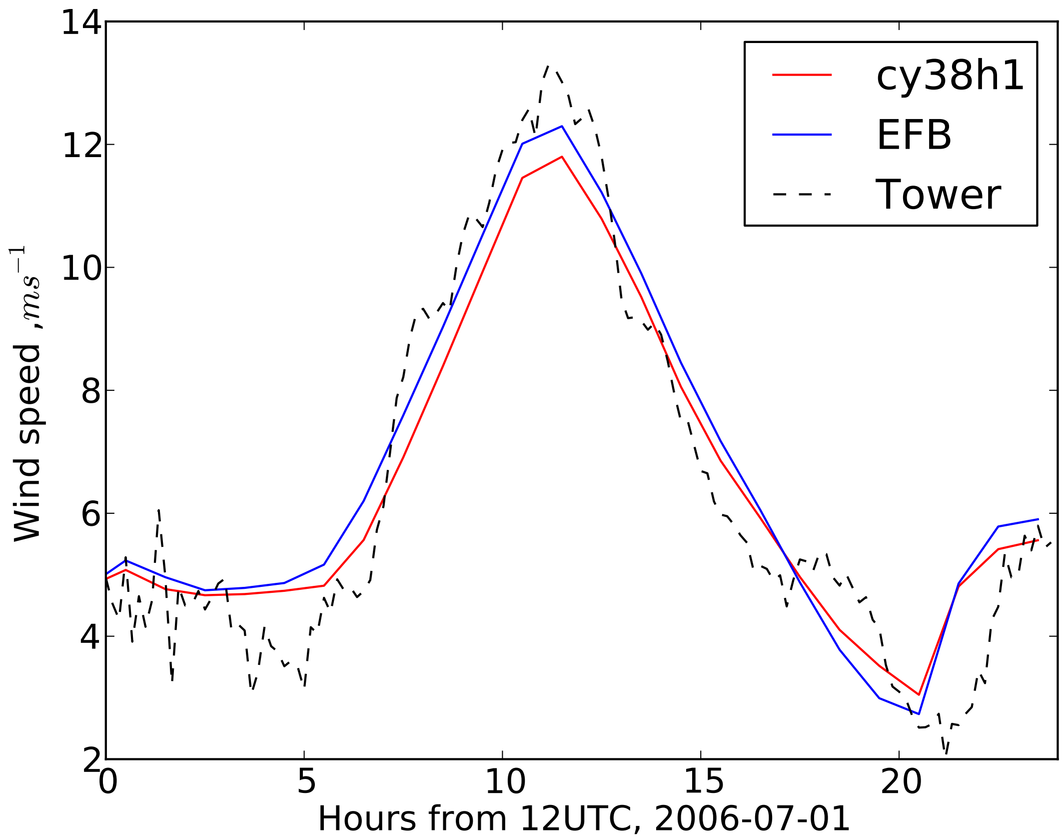
- MUSC (cy38h1) overestimates the downward transport of heat by a factor of 3 at the top of the mixed layer, which becomes consequently too deep and too warm. Introducing EFB reduces the flux, but it remains too strong.

- MUSC (cy38h1) overestimates the momentum flux by a factor 2. The wind-maximum occurs too high, and the shape of the wind profile is wrong, having a pronounced spurious point of inflection. Introducing EFB reduces the momentum flux, but does not improve the shape of the wind-profile.

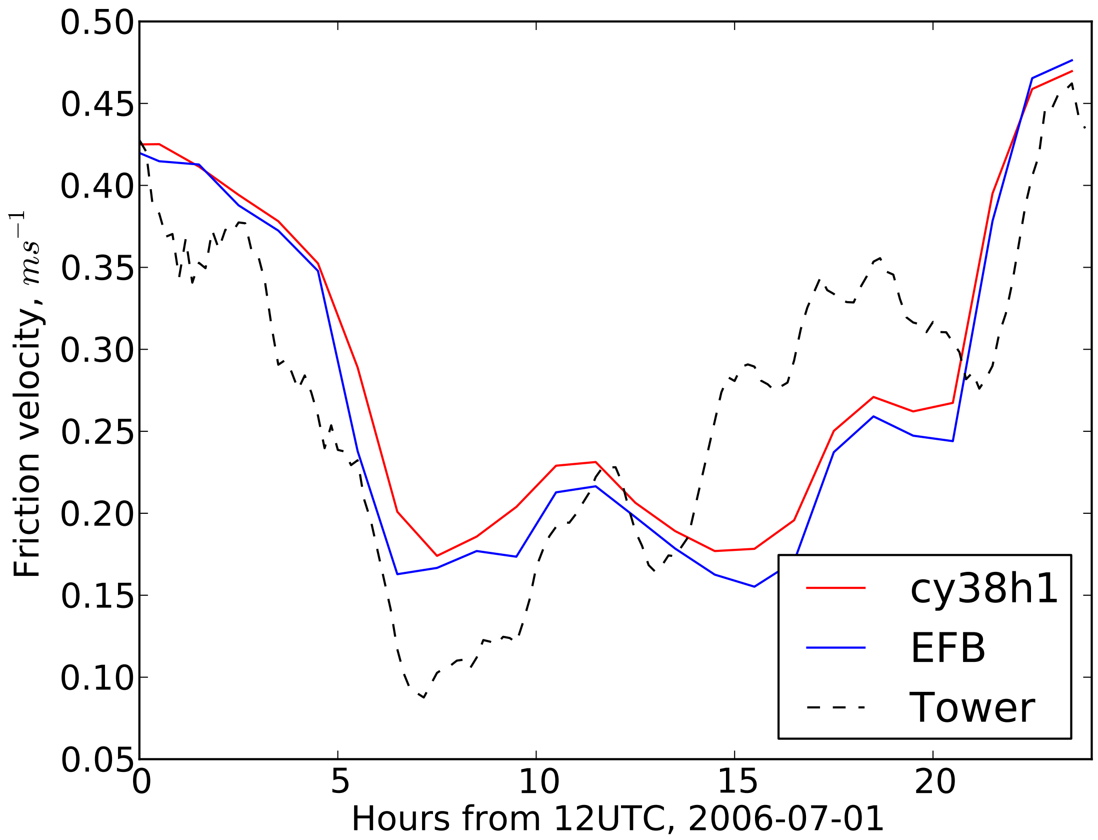
GABLS3: Setup

A clear-sky mid-latitude summertime diurnal cycle at Cabauw in the Netherlands, starting from a convective bl at 12 UTC, close to mid day LST, on the 1st of July 2006. Initial conditions and time-dependent geostrophic/advective forcing specified based on local observations, radio sounding at De Bilt, and 3-D modelling. The full (AROME) physics is active in MUSC.

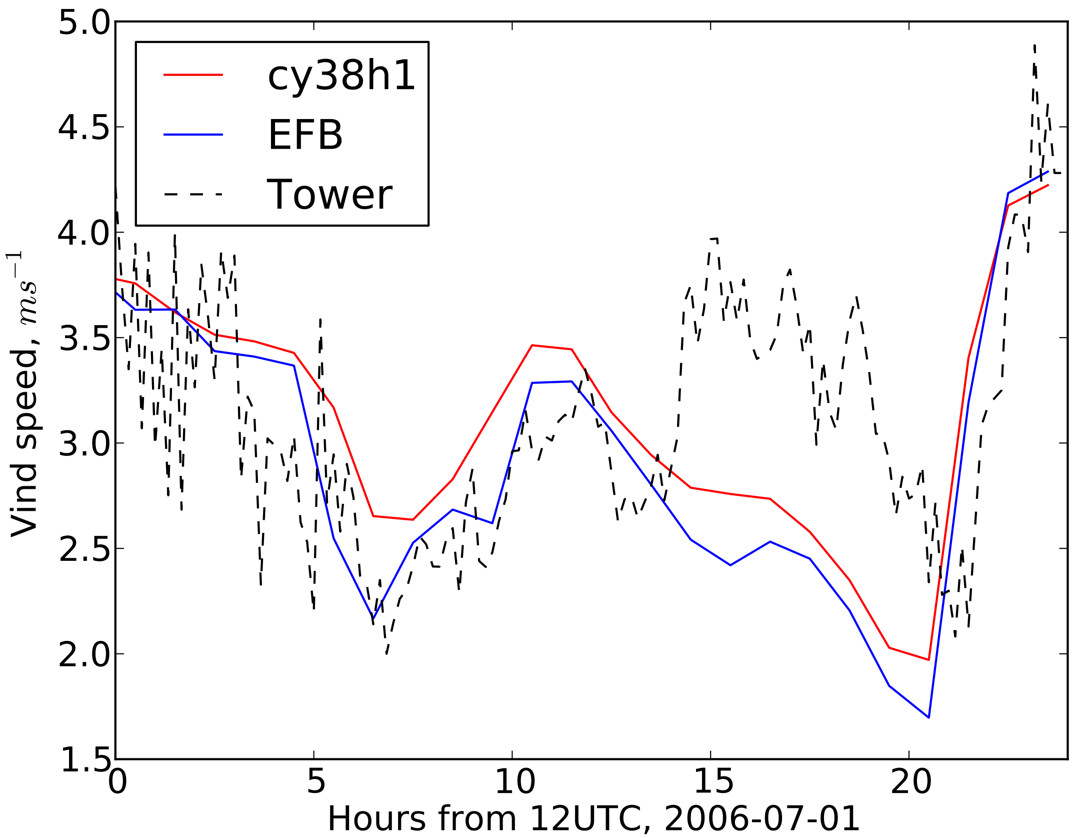
GABLS3: Wind speed at 200 m a.g.



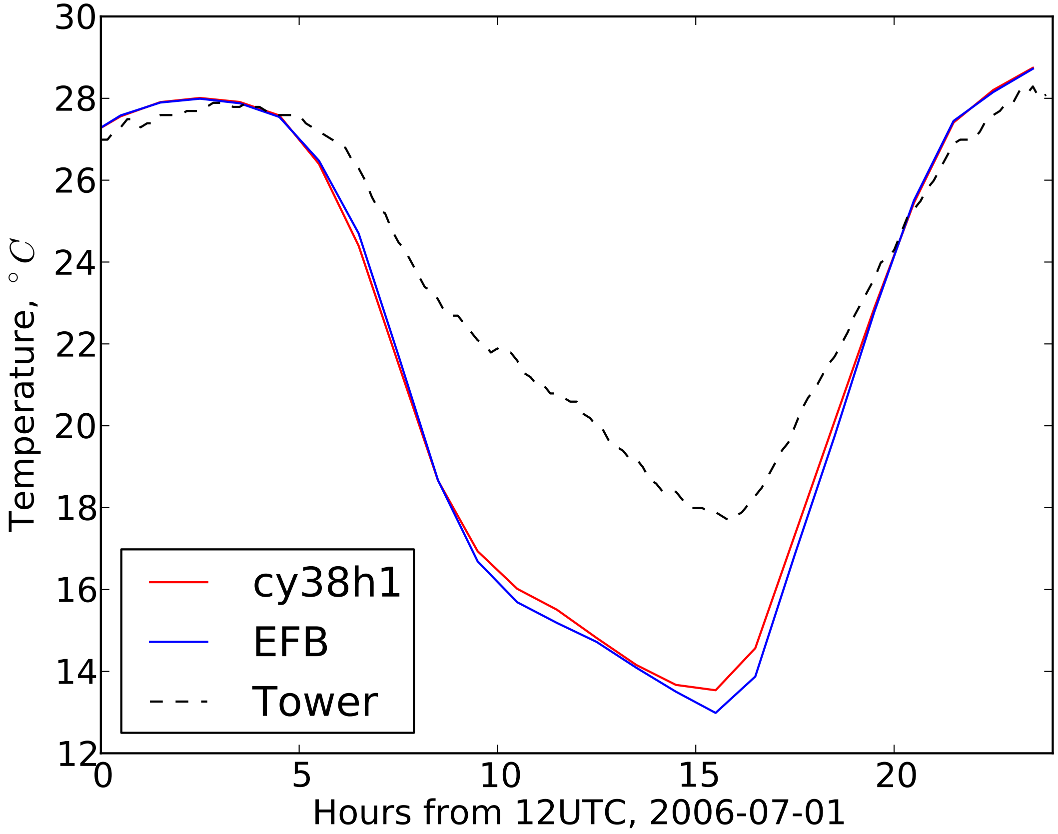
GABLS3: Friction velocity



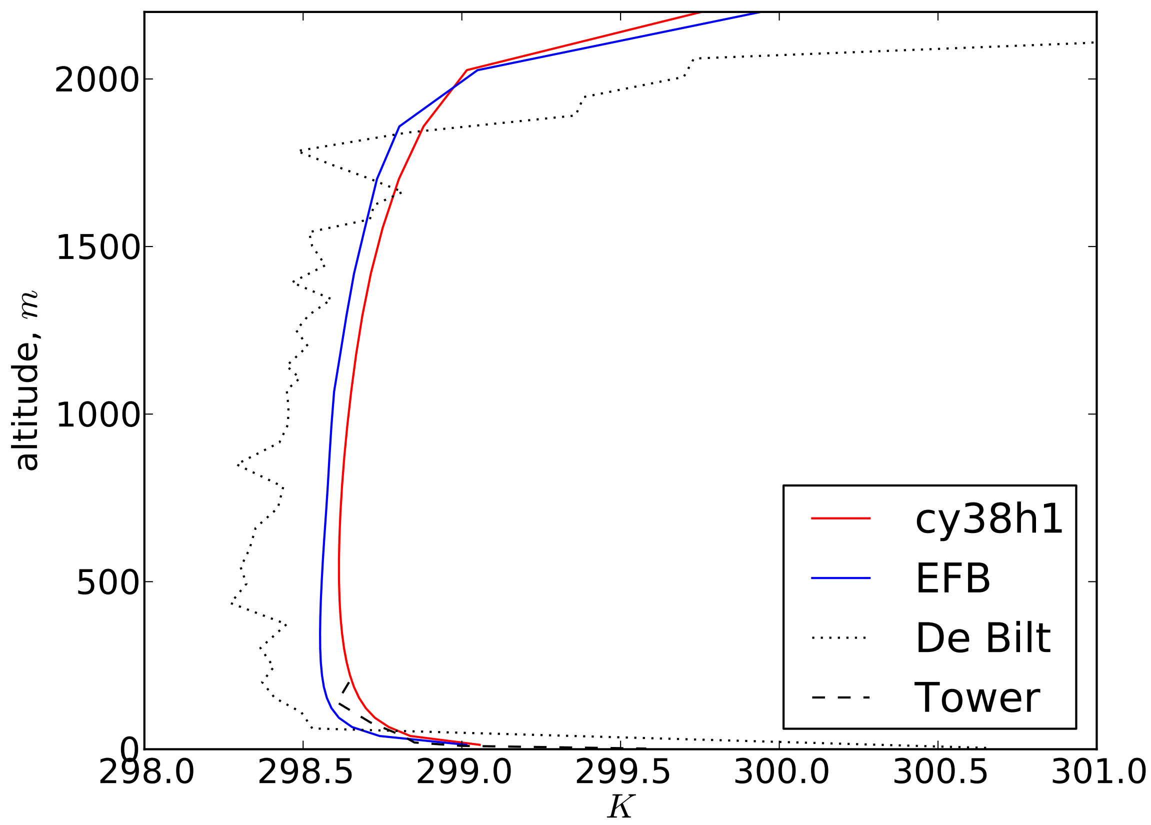
GABLS3: Wind speed at 10 m a.g.



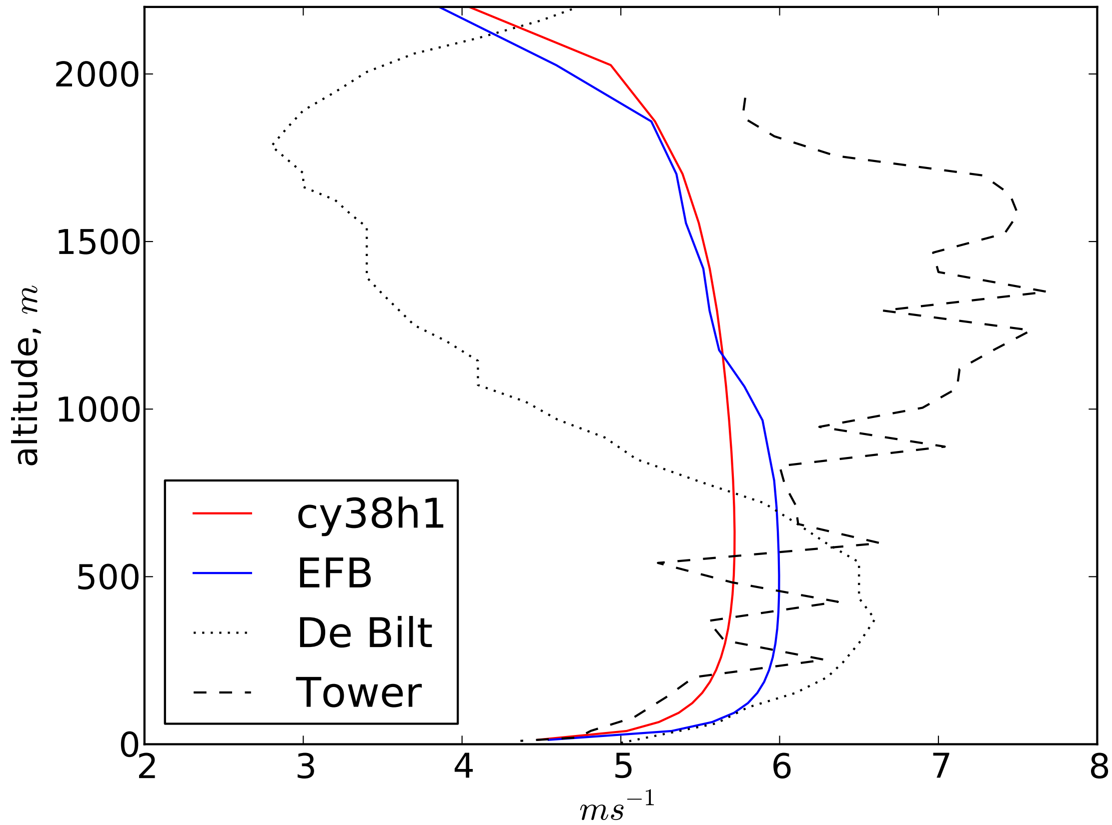
GABLS3: Screen temperature



GABLS3: P. temperature, h+24



GABLS3: Wind speed, h+24



GABLS3: Summary

- The interaction of processes, as well as the imposed advective/geostrophic forcing are important.
- Night-time screen temperature is too cool in both versions of MUSC. EFB closure gives no improvement.
- In MUSC (cy38h1) the strength of the nocturnal jet is underestimated, and the onset is delayed compared with observations. Introducing the EFB closure yields moderately improved strength and timing.

Conclusions and outlook

- Application of the EFB turbulence closure shows potential for improving the simulation of stably stratified flows, and can be implemented in MUSC/AROME without obvious adverse effects for neutral or unstable stratification.

- Issues requiring further attention:
  - ⋆ Determination of the turbulent length scale, and related issues of numerical stability
  - ⋆ A length scale for unstable stratification
  - ⋆ Relinquishing the prognostic turbulent potential energy (or $\overline{\theta'^2}$)

Acknowledgements

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