Surface Boundary Conditions for Temperature and Humidity (Co)Variances over Heterogeneous Surface

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Outline

- TKE-Scalar Variance turbulence scheme (Mironov & Machulskaya, 2017) and the tile approach
- The surface boundary condition for the scalar variances
- Results of a numerical experiment
- Conclusions

Mironov, D., Machulskaya, E. (2017) A Turbulence Kinetic Energy – Scalar Variance Turbulence Parameterization Scheme. COSMO Technical Report 30, available from http://www.cosmo-model.org

TKESV scheme

The main difference from the operational TKE scheme

TKESV carries transport prognostic equations not only for TKE (SGS kinetic energy), but also for scalar variances (SGS potential energy)

The scalar-variance equation

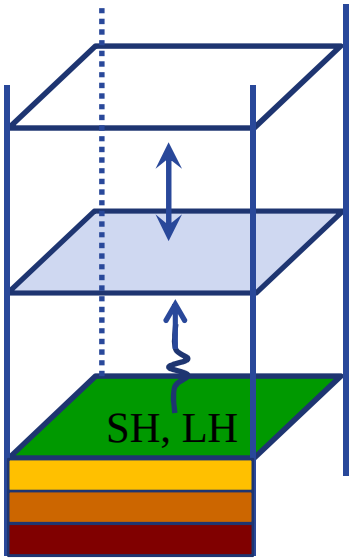
$$\frac{\partial\langle\theta'^2\rangle}{\partial t} = -2\langle w'\theta'\rangle\frac{\partial\langle\theta\rangle}{\partial z} - \frac{\partial}{\partial z}\overline{w'\theta'^2} - \varepsilon_\theta$$

The third-order moment is parameterized through the down-gradient approximation

$$\overline{w'\theta'^2} = -K_\theta\frac{\partial\overline{\theta'^2}}{\partial z}$$

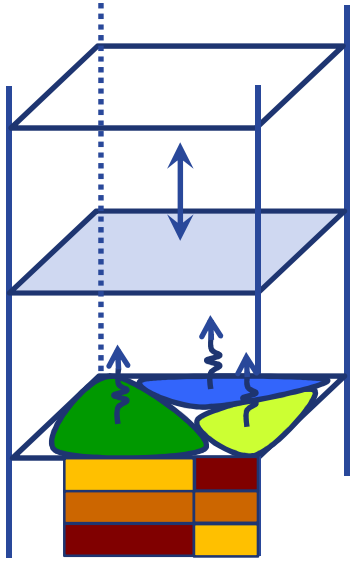
→ The equation is partially differential,
requires a boundary condition at the surface

Tile approach



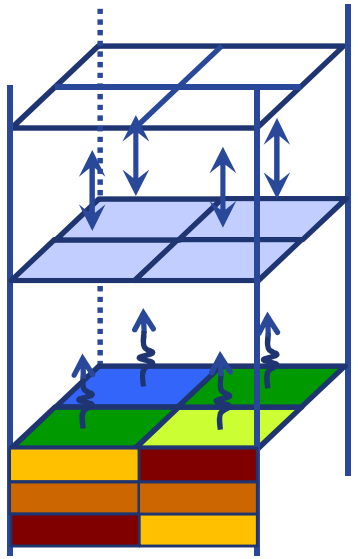
Standard model resolution

resolution of atmosphere: low
surface & soil: low



Tile approach

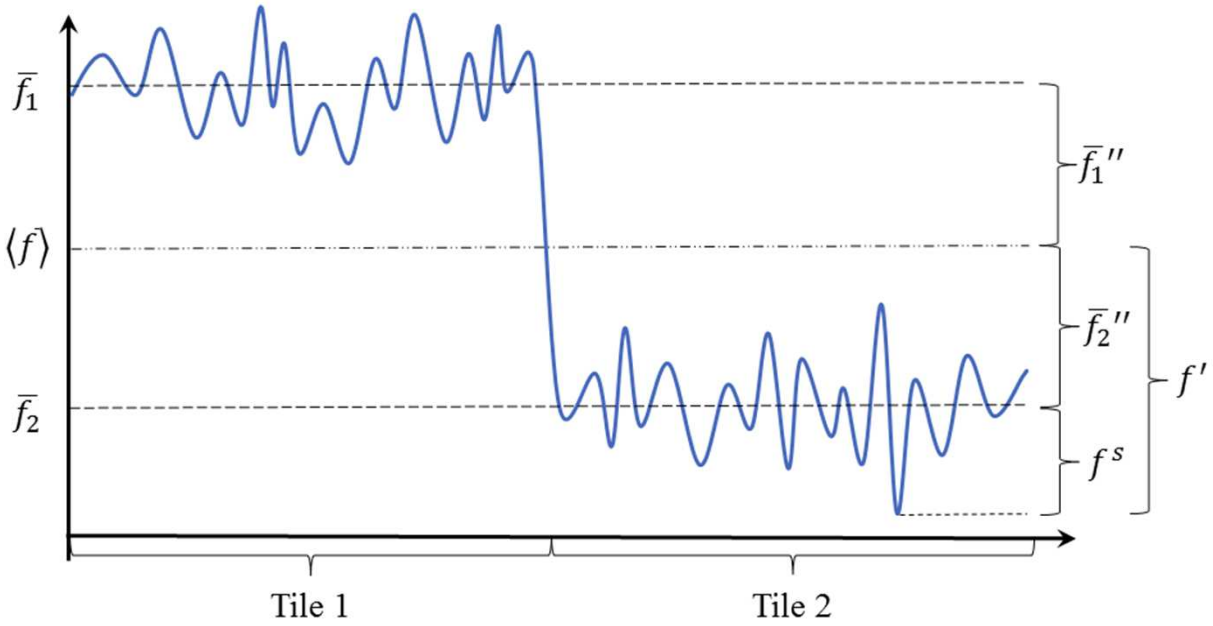
resolution of atmosphere: low
surface & soil: high



High model resolution

resolution of atmosphere: high
surface & soil: high

Another view… Triple decomposition



$$f = \langle \bar{f} \rangle + \bar{f}'' + f^s$$

grid-box mean

inter-tile fluctuation

intra-tile fluctuation

Second-order moment (scalar flux) as boundary condition for mean scalar

$$\langle w' f' \rangle = \left\langle \overline{(\bar{w}'' + w^s)(\bar{f}'' + f^s)} \right\rangle = \langle \bar{w}'' \bar{f}'' \rangle + \langle \overline{w^s f^s} \rangle = \langle \overline{w^s f^s} \rangle$$

$\langle \bar{w}'' \bar{f}'' \rangle = 0$ ($\bar{w} = 0$ at the surface)

grid-box mean flux

sum of the tile-specific fluxes

Surface boundary condition

Similarly: the third-order moment (scalar-variance flux) as boundary condition for the second-order moment (scalar variance)

$$\langle w'\theta'^2\rangle = \underbrace{\langle \bar{w}''\bar{\theta}''^2\rangle}_{=0} + \underbrace{\langle \bar{w}''\overline{\theta^{s2}}''\rangle}_{=0} + 2\langle \bar{\theta}''\overline{w^s\theta^{s}}''\rangle + \langle \overline{w^s\theta^{s2}}\rangle$$

Correlation of the inter-tile fluctuations of temperature and temperature flux

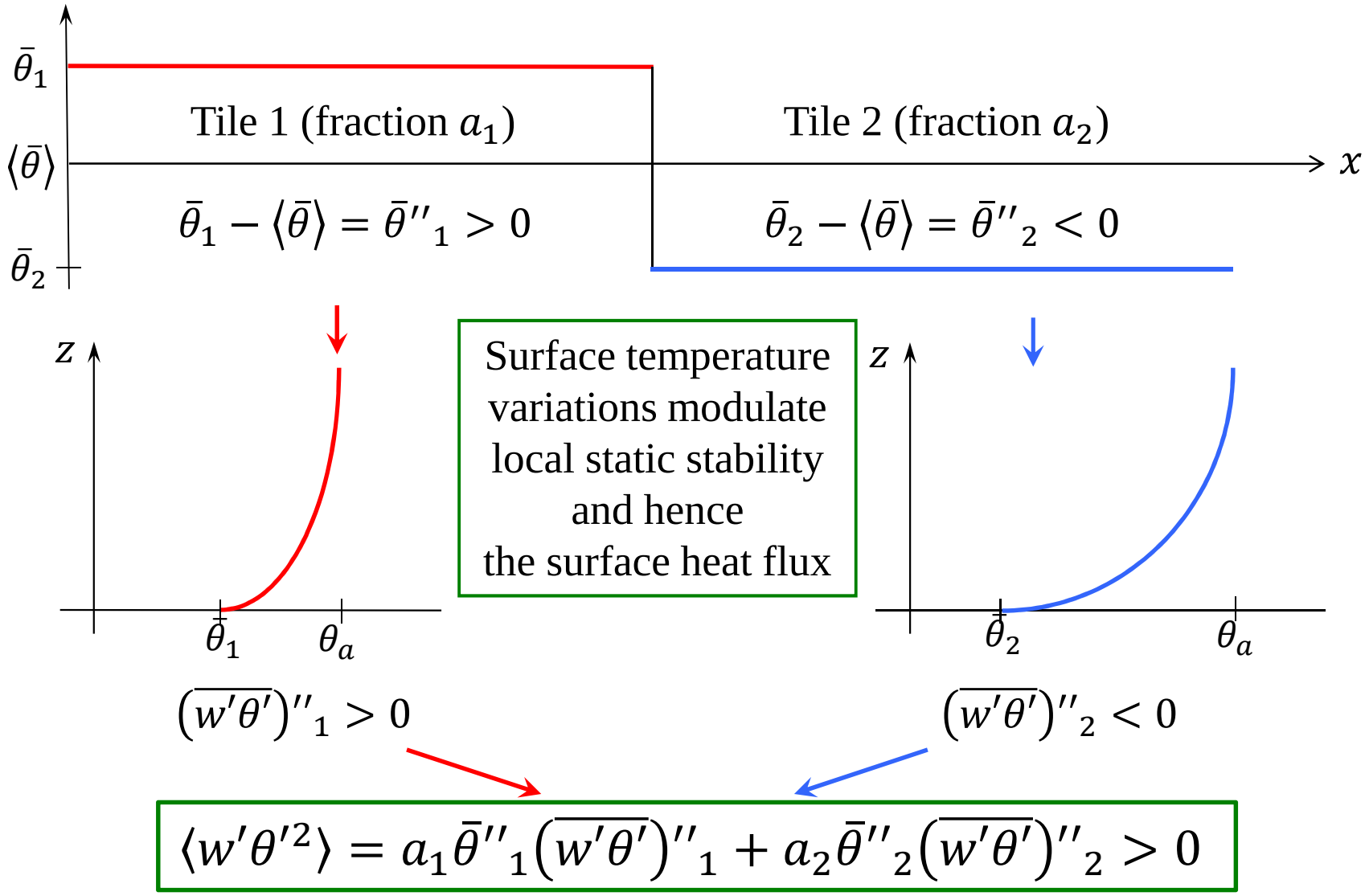
unknown

$$\langle w'\theta'^2\rangle = -K_\theta \frac{\partial \overline{\theta'^2}}{\partial z} = 2\langle \bar{\theta}''\overline{w^s\theta^{s}}''\rangle$$

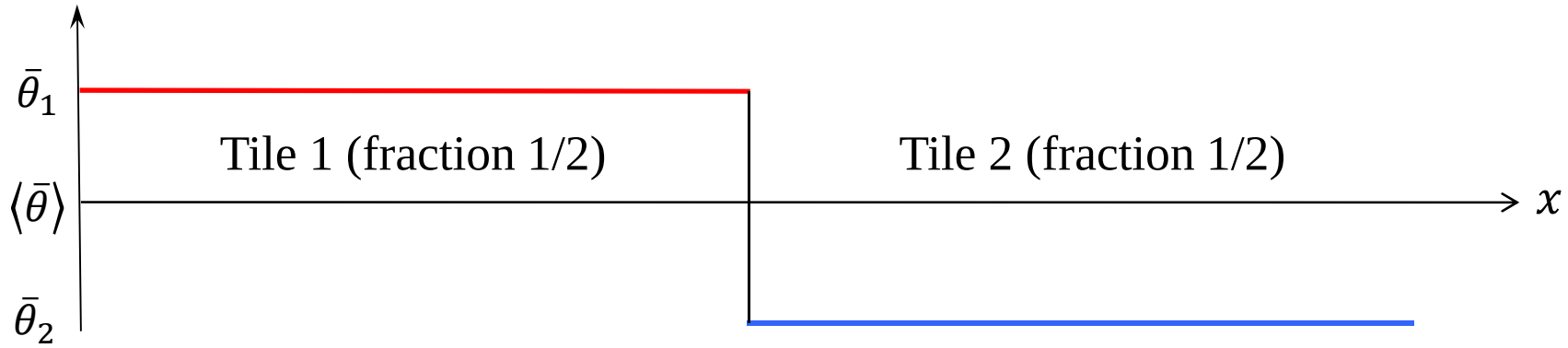
Neumann-type boundary condition for $\langle \theta'^2\rangle$

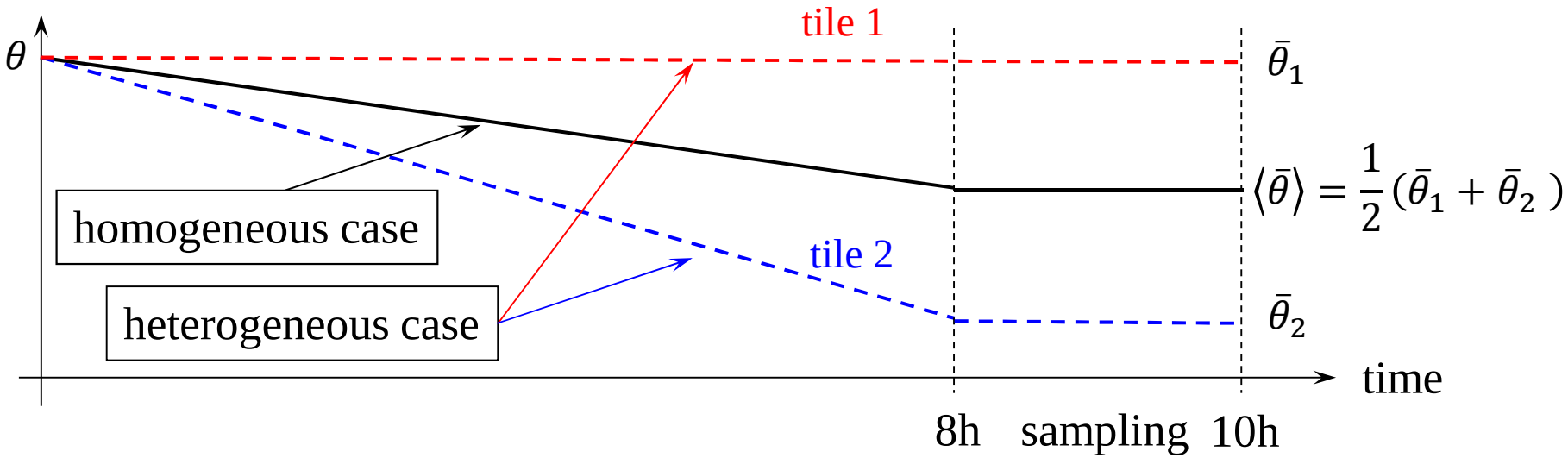
The use of the same type of information provided by the tile approach for the boundary condition for the second-order moments makes the entire model more physically consistent

B. C.: why not zero?

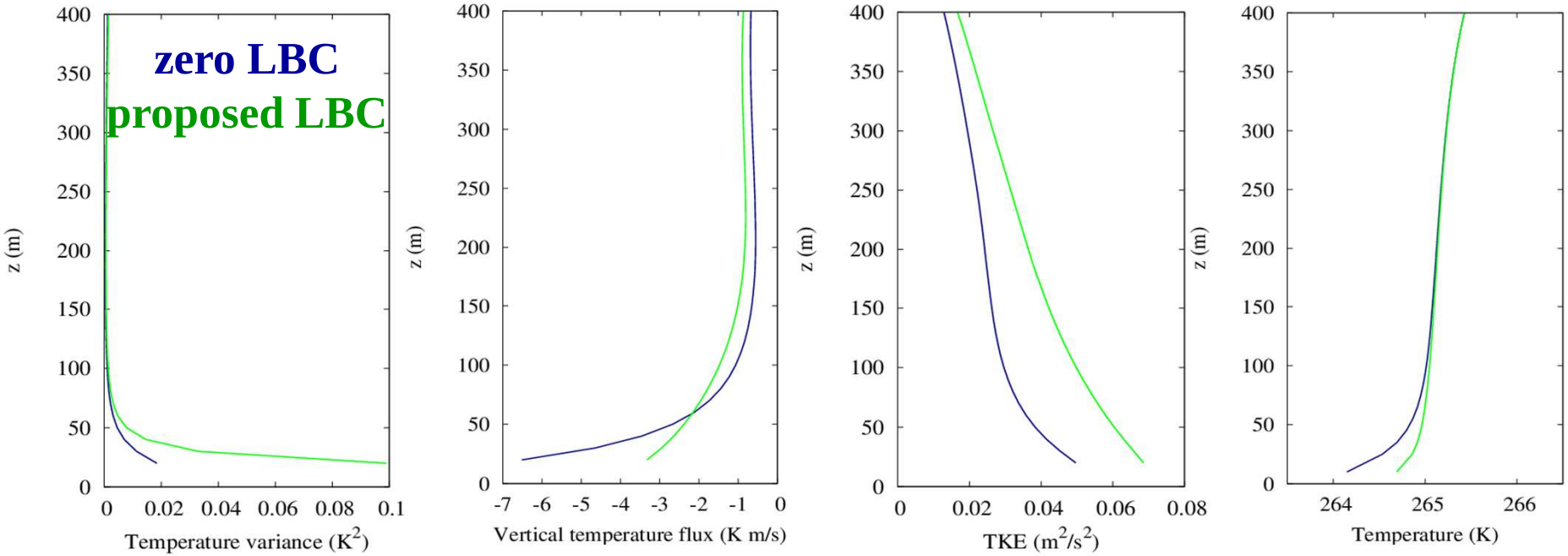


Numerical experiment: setup





Numerical experiment: results



increased $\langle\theta'^2\rangle$ near the surface → reduced magnitude of downward heat flux → less work against the gravity → increased TKE → stronger mixing

$$\langle w'\theta'\rangle = \underbrace{-K_H \frac{\partial\langle\theta\rangle}{\partial z}}_{\text{downward}} + \underbrace{F_H\langle\theta'^2\rangle}_{\text{upward}}$$

Conclusions

- The boundary conditions for the scalar variances over heterogeneous surfaces are proposed that are consistent with the tile approach
- In the weakly-to-moderately stable PBL, the proposed boundary conditions enhance the mixing in the PBL
- The use of the proposed boundary conditions makes the entire atmospheric model more physically consistent
- The associated computational costs are negligible
- The proposed boundary conditions are implemented into the test version of COSMO with TKESV

Thank you for your attention!