LEIBNIZ-INSTITUT FÜR ATMOSPHÄREN PHYSIK
IAP

# Influence of entropically consistent turbulence parameterization on the modeling of breaking gravity waves

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## Problem

**What generates mesospheric inversion layers (MILs)?**

**How much energy is dissipated in breaking gravity waves?**

**How is dissipation computed in a numerical model?**

## dissipation = temperature * internal entropy production

In order to determine energy dissipation from model data, the numerical model has to be formulated in an energetically and entropically clean manner. First and second law of thermodynamics should hold.

- Energetically clean: **Reversible** part of the model is discretized with the help of Poisson brackets. Frictional heating is accounted for. ICON-IAP realizes this. (Gassmann, QJRMS, 2013).

- Entropically clean: **Irreversible** subgrid-scale fluxes for momentum, heat and air constituents lead to internal entropy production. ICON-IAP realizes this. (Gassmann & Herzog, QJRMS, 2014).

- The internal entropy production $\sigma$ sums the independently positive definite entropy productions by friction, heat fluxes, mixing und phase transitions

$$T\sigma = -\underline{\boldsymbol{\tau}} \cdot\cdot \nabla \boldsymbol{v} - \frac{\boldsymbol{J_s}}{T} \cdot \nabla T - \sum_i \boldsymbol{J}_i^* \cdot \nabla \mu_i|_T - \sum_i I_i \, \mu_i \geq 0$$

- Frictional dissipation is the largest where wind shear is the largest.

- Thermal dissipation is the largest where the stratification is close to unstable. Numerical modeling did not yet focus on subgrid-scale heat fluxes under the constraint of the second law of thermodynamics. All parameterizations of heat fluxes are based on a gradient approach for potential temperature or (moist) static energy. In the atmospheric boundary layer, an additional countergradient term is employed. ***In order to obtain positive internal entropy production, the heat flux has to be fomulated with a gradient ansatz for temperature. The relevant exchange coefficient has to be parameterized.*** Currently, a Prandtl number Pr=6 is chosen together with a traditional approach.

- Turbulent mixing of water vapour and dry air demands $J_{s,3} = -\rho K \frac{q_d \nabla_z p_v - q_v \nabla_z p_d}{p}$ in order to achieve positive dissipation. This does not correspond to a traditional gradient approach. The new formulation allows for a more effictive upward mixing of (lighter) water vapour.

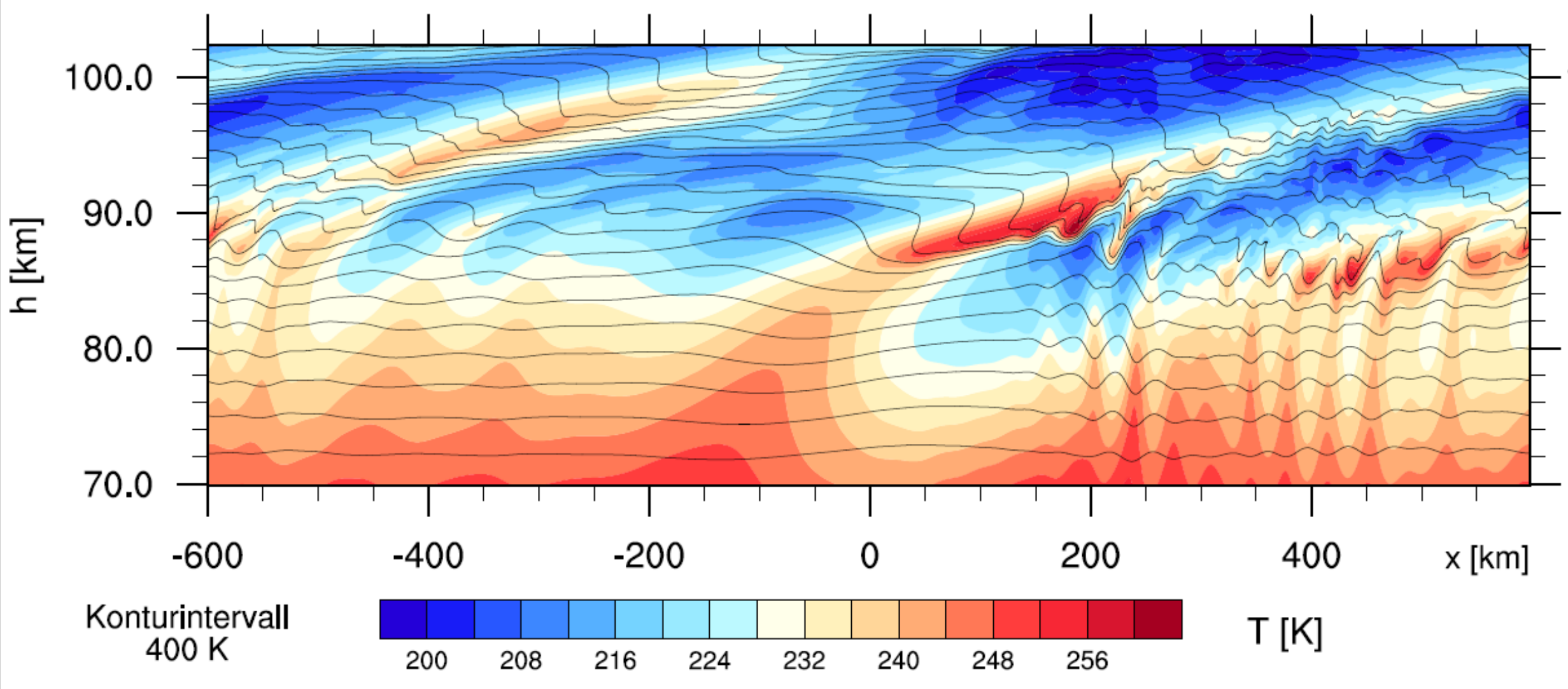
- The dissipation occurring when precipitation is falling is due to diffusive mixing of precipitation and air. The associated diffusive velocity is the sedimentation velocity.

- Phase transitions with positive dissipation are condensation at supersaturation and evaporation at subsaturation.

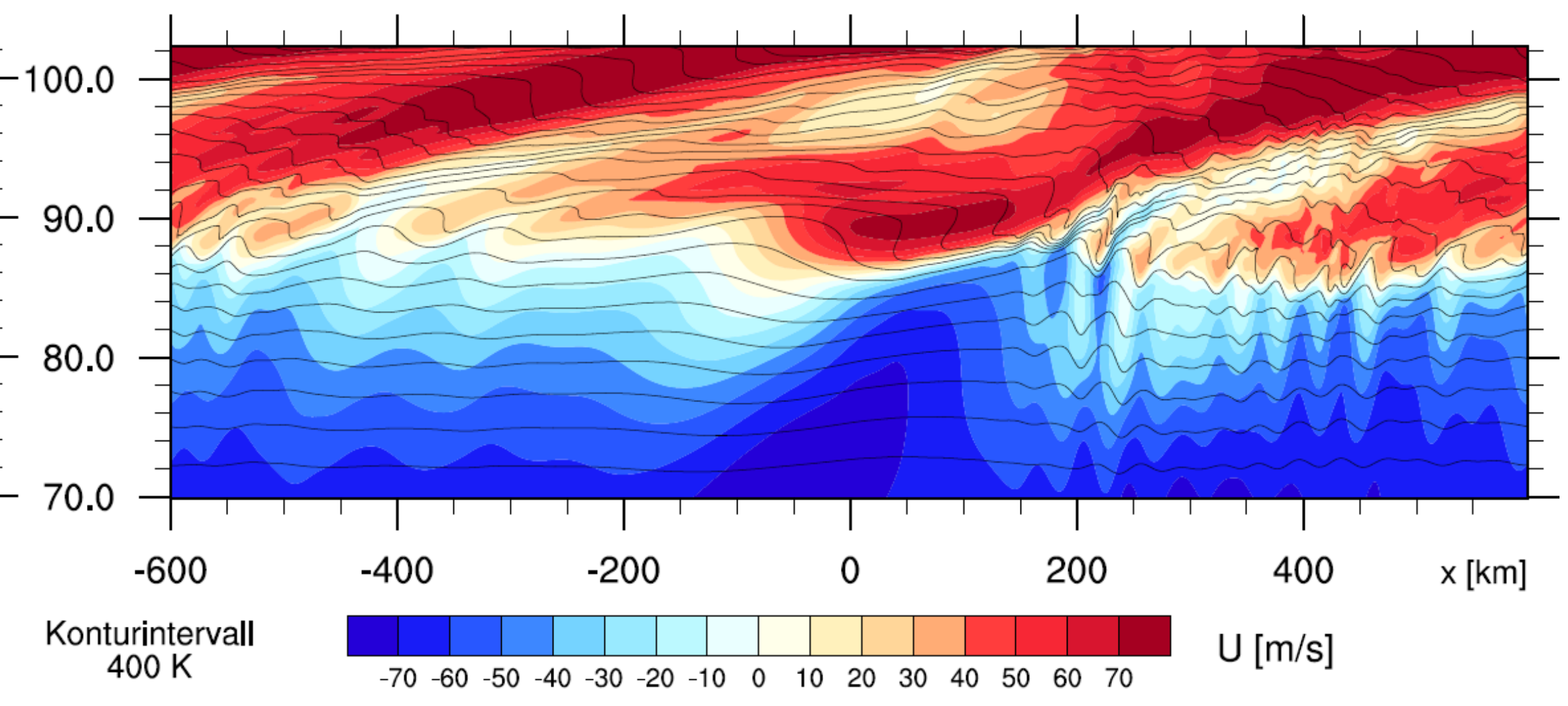
- **Numerical models of the atmosphere are not yet formulated in this rigorosity regarding the second law of thermodynamics. ICON-IAP is the first model which tries to accomplish this.**

## Simulation with ICON-IAP as two-dimensional slice model in the x-z-plane

Gravity waves are generated in the troposphere and propagate upward through a typical summer atmosphere. They break at about 80 km height. Mesospheric inversion layers (MILs) develop during this process. MILs are not necessarily stationary, but quite frequent.



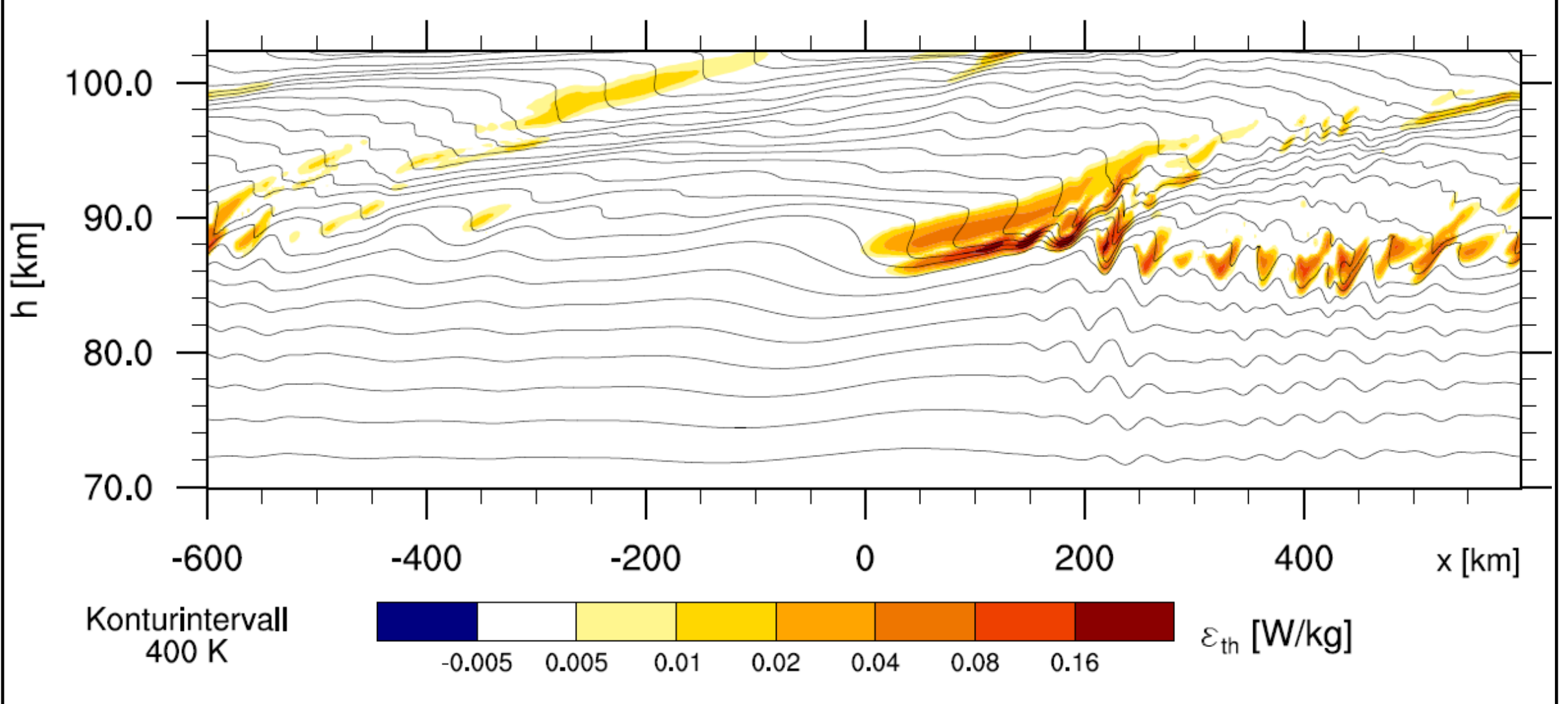
***temperature (colors)*** and ***potential temperature (lines)***



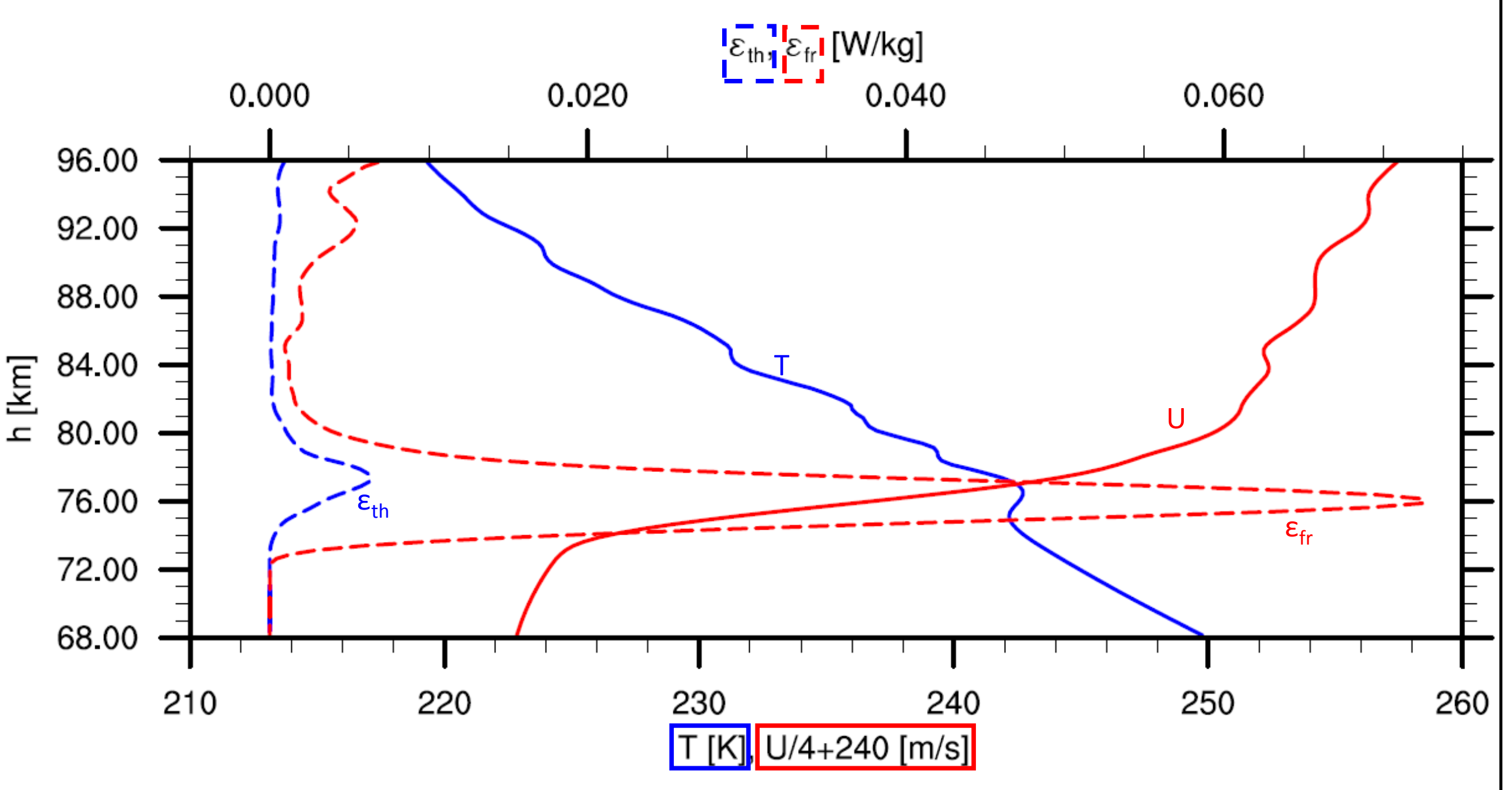
***horizontal wind (colors)*** and ***potential temperature (lines)***

### Run with mit subgrid-scale temperature (heat) flux

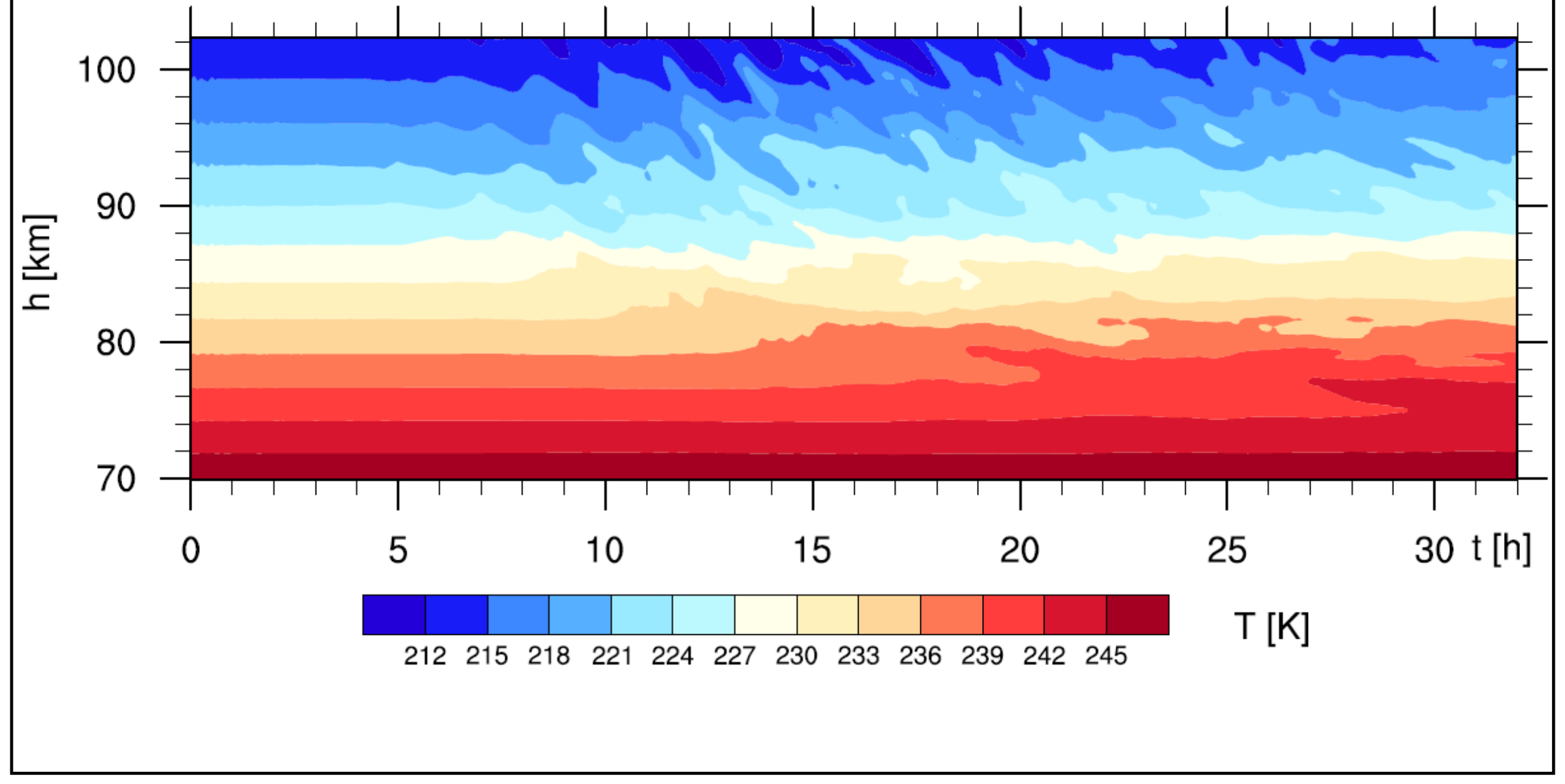
The ***thermal dissipation rate*** at a certain time is always positive definite and large where the statification is near to neutral or within the inversion zone. This is physically sensible.↓



The maximal ***thermal dissipation (blue dashed lines)*** is displaced *upward* in the mean (1200 km, last 6 hours) compared to the maximal ***mechanical dissipation (red dashed lines)***.↓

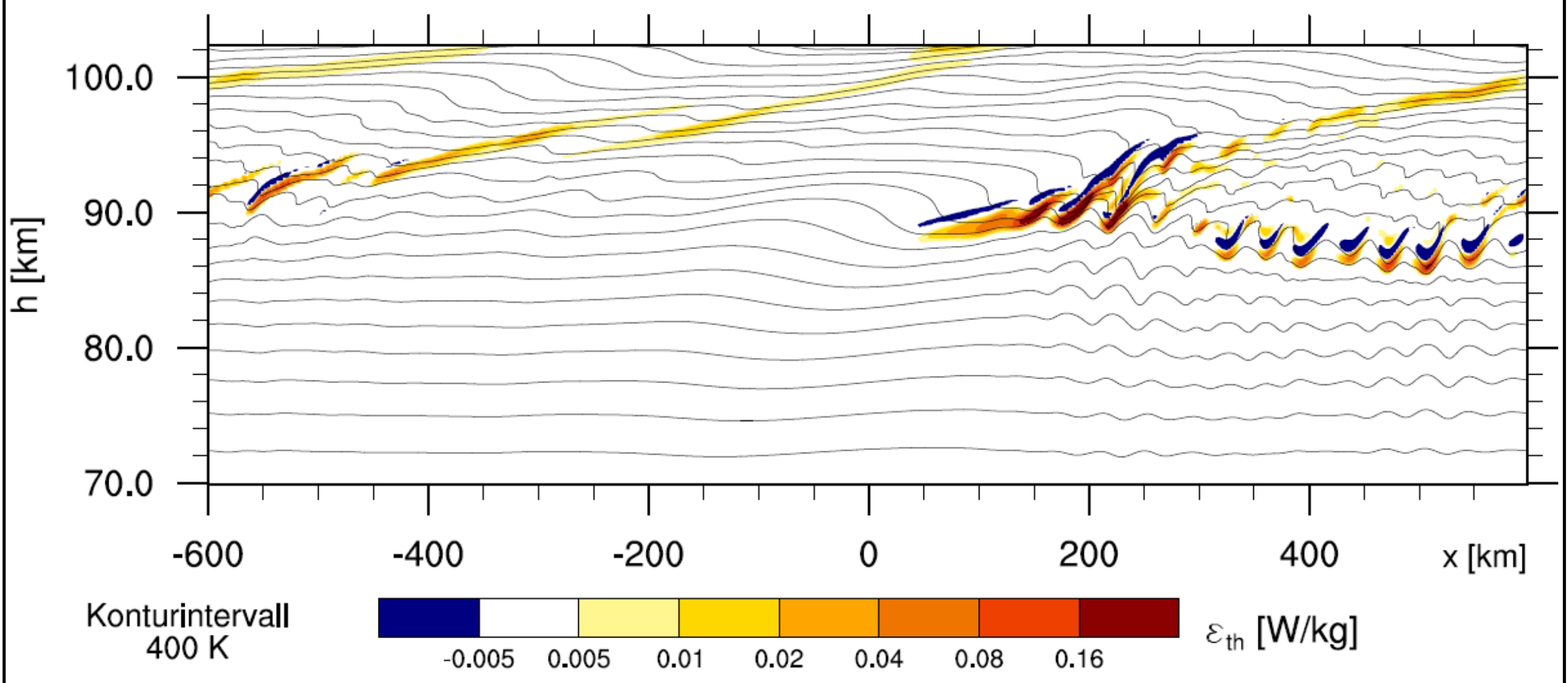


The ***temperature*** in the breaking layer is rising slightly, presumably because a part of the energy deposition is occurring as a warming. The inversion layer is intermittently present.↓

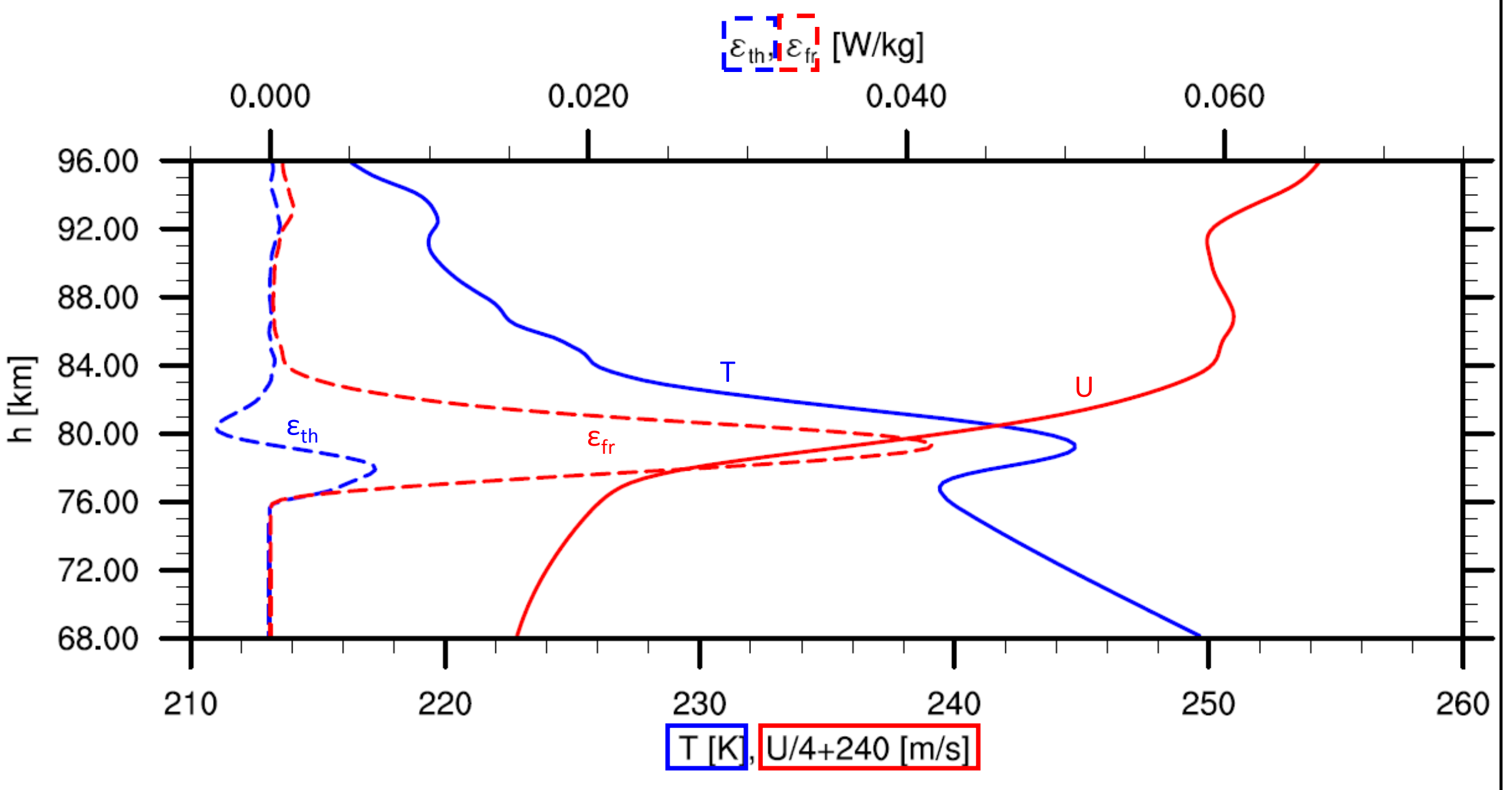


### Run with tradtional subgrid-scale potential temperature (buoyancy) flux

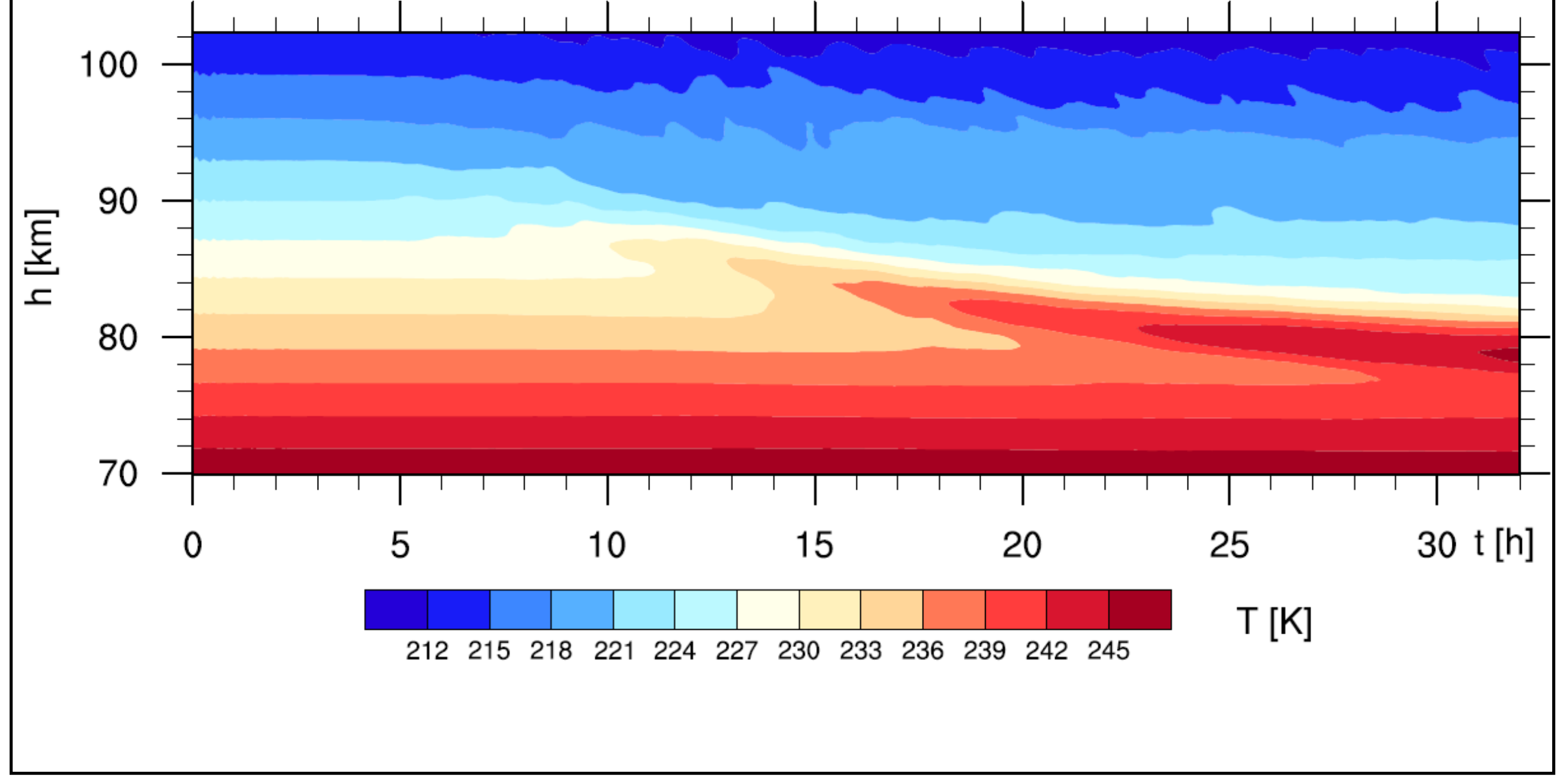
The ***thermal dissipation rate*** at a certain time is at maximum at very stable stratification, where wind shear is high. Within the neutral to unstable layer one finds negative thermal dissipation rates. This contradicts to the second law of thermodynamics.↓



The maximal ***thermal dissipation (blue dashed lines)*** is displaced *downward* in the mean (1200 km, last 6 hours) compared to the maximal ***mechanical dissipation (red dashed lines)***. ↓



The ***temperature*** in the breaking layer decreases in the upper part and raises in the lower part. Especially the decrease in the upper part is similar to a spurious decrease of the temperature in the convective boundary layer, if a countergradient term is not added in the parameterization.



## Publications

Gassmann, A. and Herzog, H-J., 2014: How is local material entropy production represented in a numerical model? Q.J.R.Meteorol. Soc. DOI: 10.1002/qj.2404
Gassmann, A. 2013: A global hexagonal non-hydrostatic dynamical core (ICON-IAP) designed for energetic consistency. Q.J.R.Meteorol. Soc. 139: 152–175, DOI: 10.1002/qj.1960