

# Implementation of the QNSE-based parameterizations in NWP models

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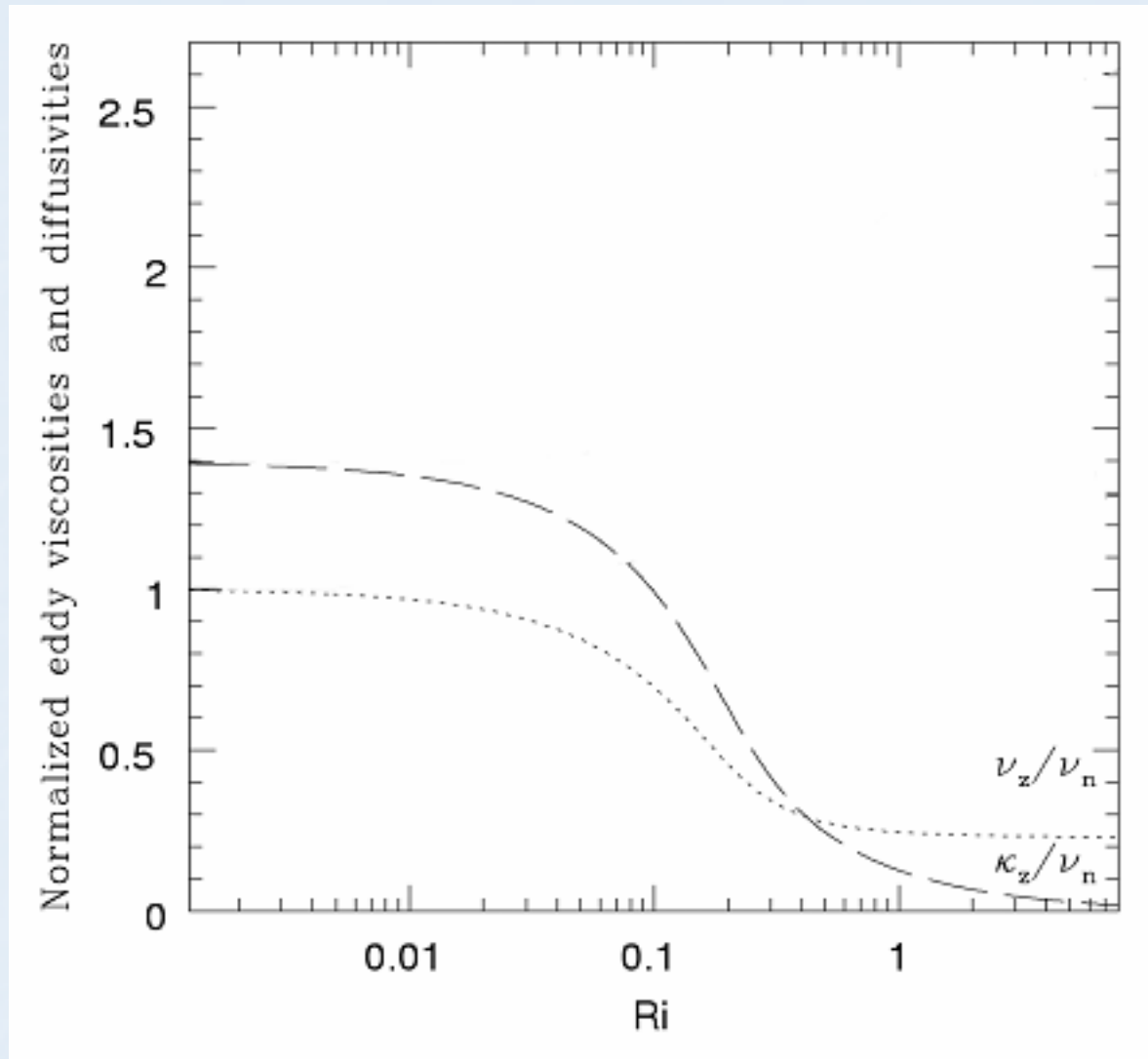
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# QNSE-based eddy viscosities and diffusivities



Source: *Phys. Fluids*, Sukoriansky et al. 2005.

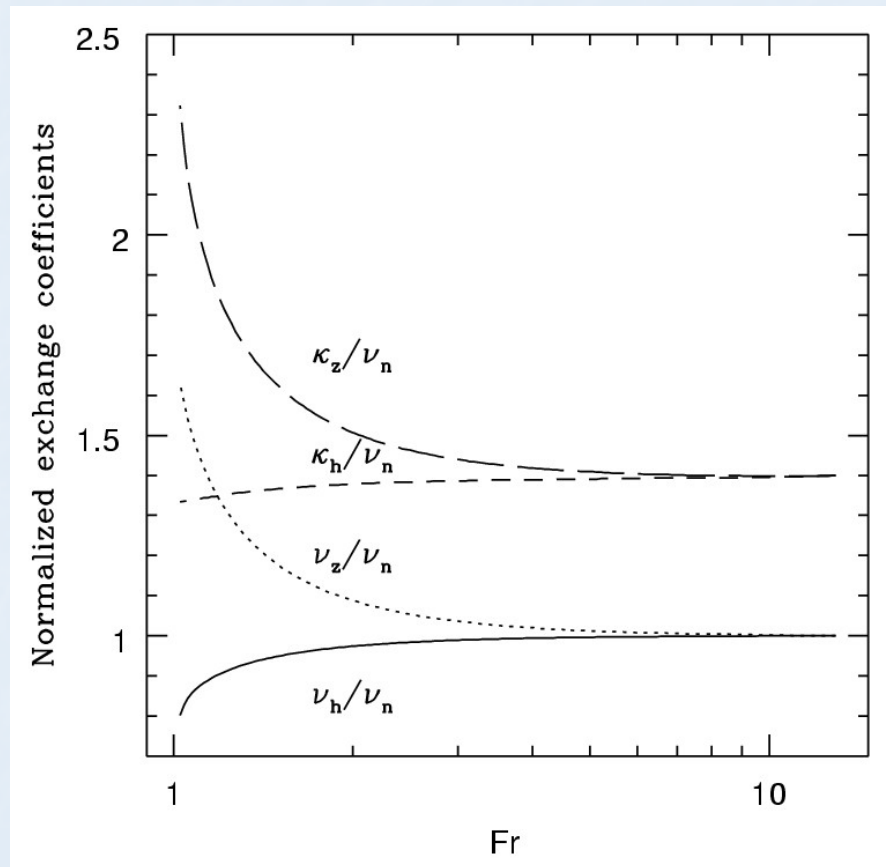
# Curve fitting functions

For implementation in PBL schemes, the theoretically derived stability functions,  $\alpha_M = K_M/K_0$  and  $\alpha_H = K_H/K_0$ , were approximated by a fraction-polynomial fit ( $K_0$  is the eddy viscosity at  $Ri=0$ ):

$$\alpha_M = \frac{1 + 8 Ri^2}{1 + 2.3 Ri + 35 Ri^2}$$
$$\alpha_H = \frac{1.4 - 0.01 Ri + 1.29 Ri^2}{1 + 2.344 Ri + 19.8 Ri^2}$$

The fitting functions are valid for  $Ri < 1.5$ . For larger values, flux Richardson number  $R_f$  approaches limiting value  $< 0.5$

# Unstable stratification (Convection)



# CBR-based K-I model

$$\frac{\partial E}{\partial t} = K_M \left[ \left( \frac{\partial U}{\partial z} \right)^2 + \left( \frac{\partial V}{\partial z} \right)^2 \right] - \frac{g}{\Theta_0} K_H \frac{\partial \theta}{\partial z} - \varepsilon + \frac{\partial}{\partial z} \left( K_q \frac{\partial E}{\partial z} \right)$$

$$\varepsilon = c_\varepsilon \frac{E^{3/2}}{l}; \quad \frac{1}{l} = \frac{1}{l_{up}} + \frac{1}{l_{dw}}, \quad l_{up} = \int_{z_{bottom}}^z F(Ri), \quad l_{dw} = \int_z^{z_{top}} F(Ri)$$

$$l_N = c_N \frac{E^{1/2}}{N}; \quad c_N = 0.75$$

$$\frac{1}{l_{m,h}} = \frac{1}{\max(l_{int}, l_{min})} + \frac{1}{l_N}; \quad c_\varepsilon = 0.1$$

\*\*\*\*\*

$$K_m = l E^{1/2}, \quad K_h = \phi_h E^{1/2}$$

## QNSE-based K-I model

$$\frac{\partial E}{\partial t} = K_M \left[ \left( \frac{\partial U}{\partial z} \right)^2 + \left( \frac{\partial V}{\partial z} \right)^2 \right] - \frac{g}{\Theta_0} K_H \frac{\partial \theta}{\partial z} - \varepsilon + \frac{\partial}{\partial z} \left( K_q \frac{\partial E}{\partial z} \right)$$

$$\varepsilon = c_\varepsilon \frac{E^{3/2}}{l}; \quad l_B = \frac{kz}{1 + \frac{kz}{\lambda}}, \quad l_N = c_N \frac{E^{1/2}}{N}; \quad c_N = 0.75$$

$$\frac{1}{l} = \frac{1}{l_B} + \frac{1}{l_N}; \quad c_\varepsilon = c_0^3, \quad c_0 = 0.55, \quad \lambda = Bu_* / f$$

\*\*\*\*\*

$$K_M = \alpha_M K_0, \quad K_H = \alpha_H K_0, \quad K_0 = c_0 l E^{1/2}$$

# QNSE-based surface layer parameterization

Using theoretically derived stability functions  $\alpha_M$ ,  $\alpha_H$  and approximations of constant flux layer, there were derived the drag coefficients for momentum and heat,  $C_D$ ,  $C_H$ , that replace the Louis formulation. The corresponding expressions are:

$$C_D = \frac{\kappa^2}{\left( \ln \frac{z}{z_0} + \psi_M(\zeta) - \psi_M(\zeta_0) \right)^2}, \quad \zeta = z/L, \quad \zeta_0 = z_0/L$$

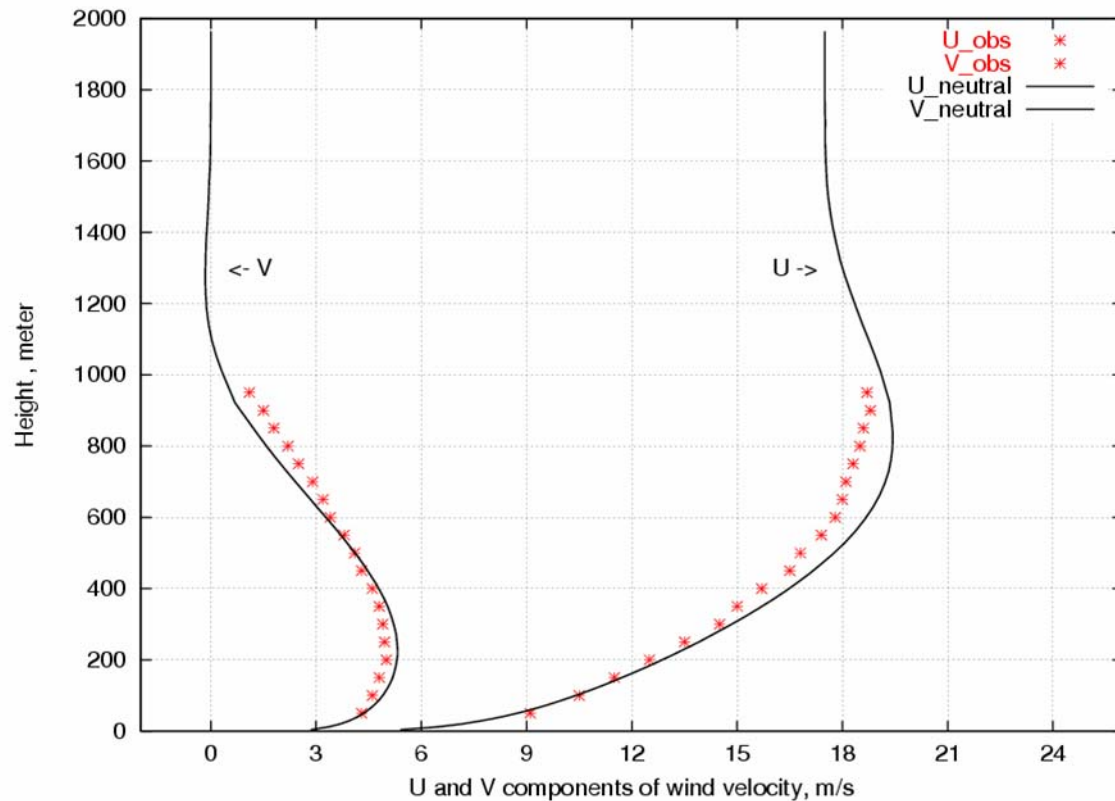
$$C_H = \frac{\kappa^2}{\left( \ln \frac{z}{z_{0T}} + \psi_M(\zeta) - \psi_M(\zeta_{0T}) \right) \left( \text{Pr}_0 \ln \frac{z}{z_{0T}} + \psi_H(\zeta) - \psi_H(\zeta_{0T}) \right)}$$

$$\psi_M(\zeta) = 2.25\zeta - 0.2\zeta^2$$

$$\psi_H(\zeta) = 2\text{Pr}_0 \zeta + 0.1 \left( (\zeta - 0.5)^5 - 0.5^5 \right),$$

$\text{Pr}_0 = 0.71$  – turbulent Prandtl number for neutral flow

# Testing of the model - neutral ABL



Comparison with Leipzig wind profile



# Testing of the HIRLAM – BASE

## Case description

Vertical domain = 400m

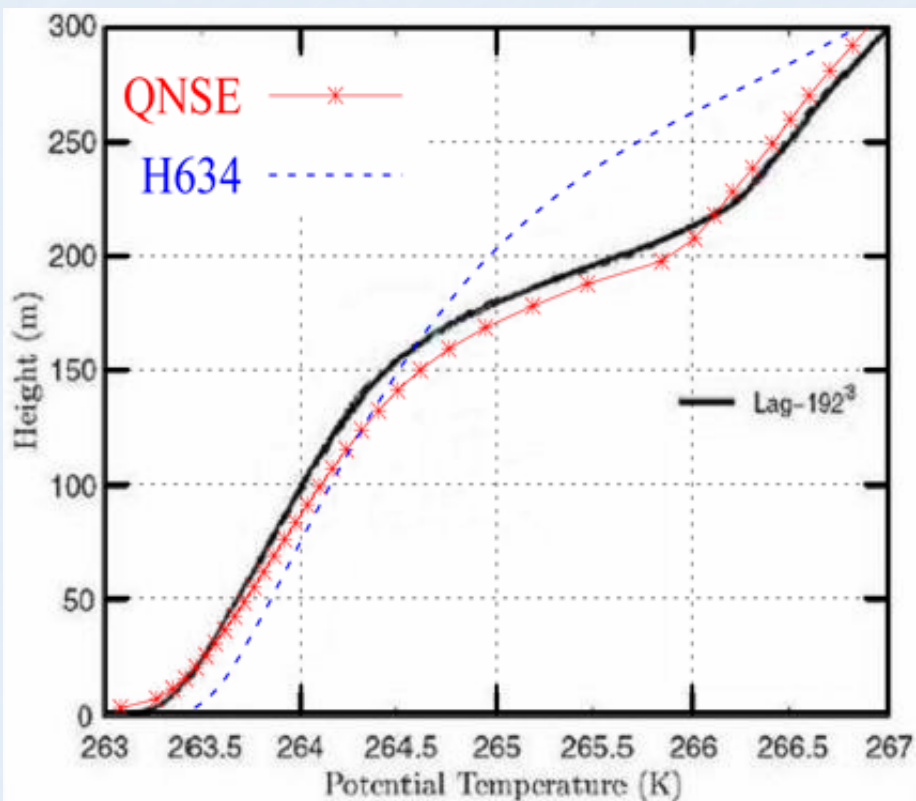
Initial state:  $\Theta = 265\text{K}$   $\leq 100$  metres  
 $d\Theta/dz = -0.01\text{K/m}$   $> 100$  metres

$$U_g = 8 \text{ m/s}$$
$$V_g = 0 \text{ m/s}$$

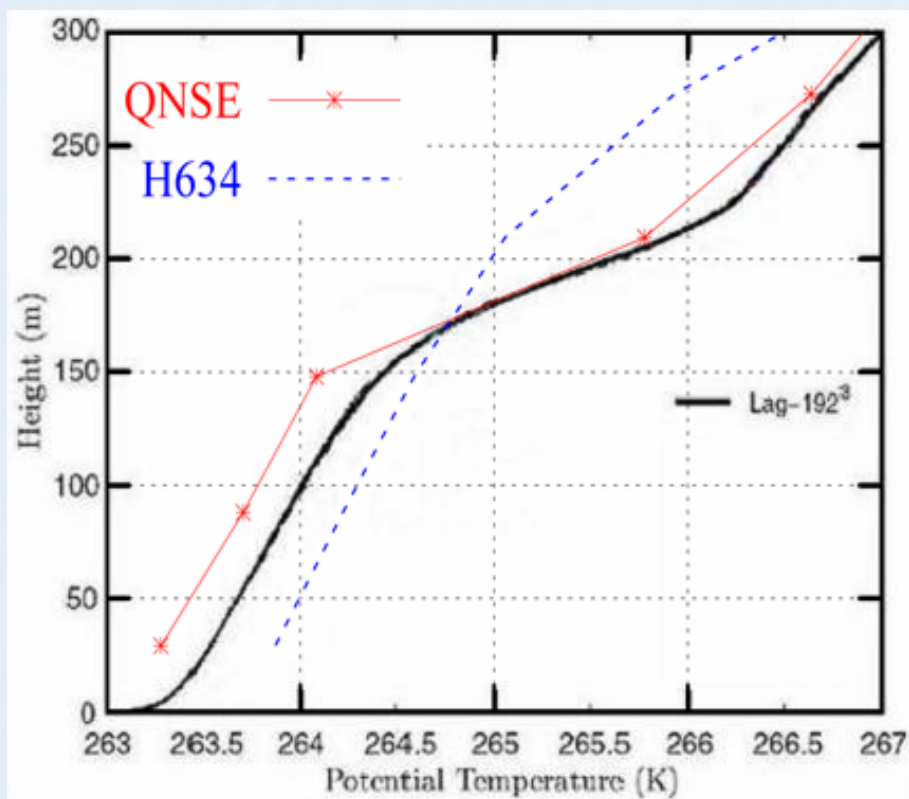
9 hours run:  $d\Theta_s/dz = -0.25/h$   
 $z_0 = 0.1 \text{ m}$

# Testing in HIRLAM - BASE

280 levels

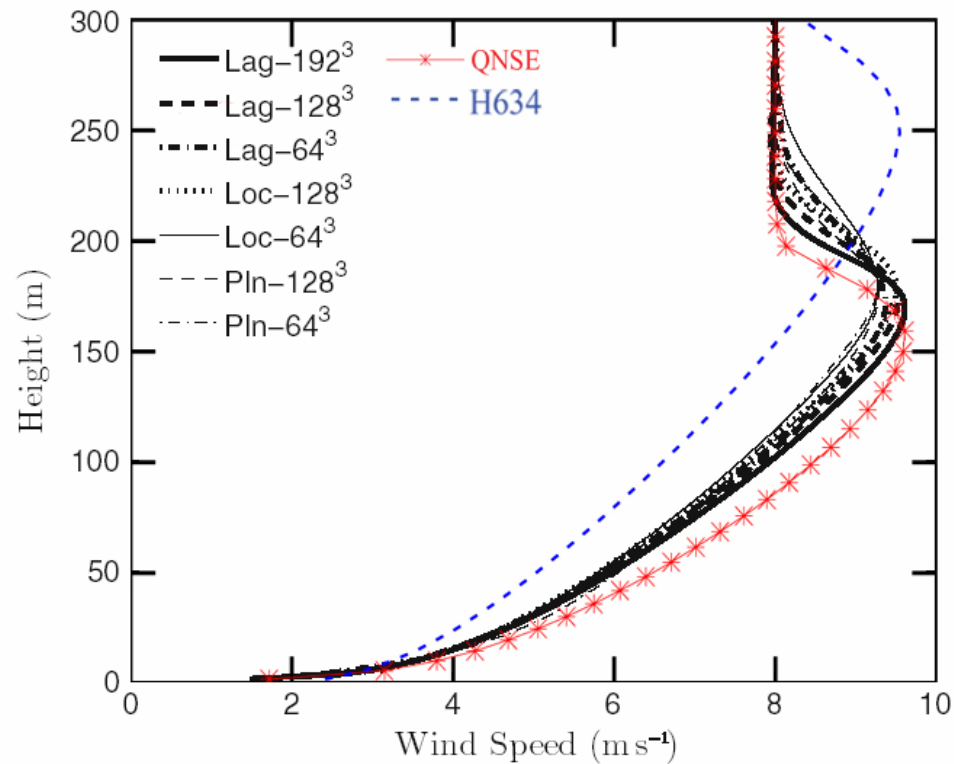


60 levels

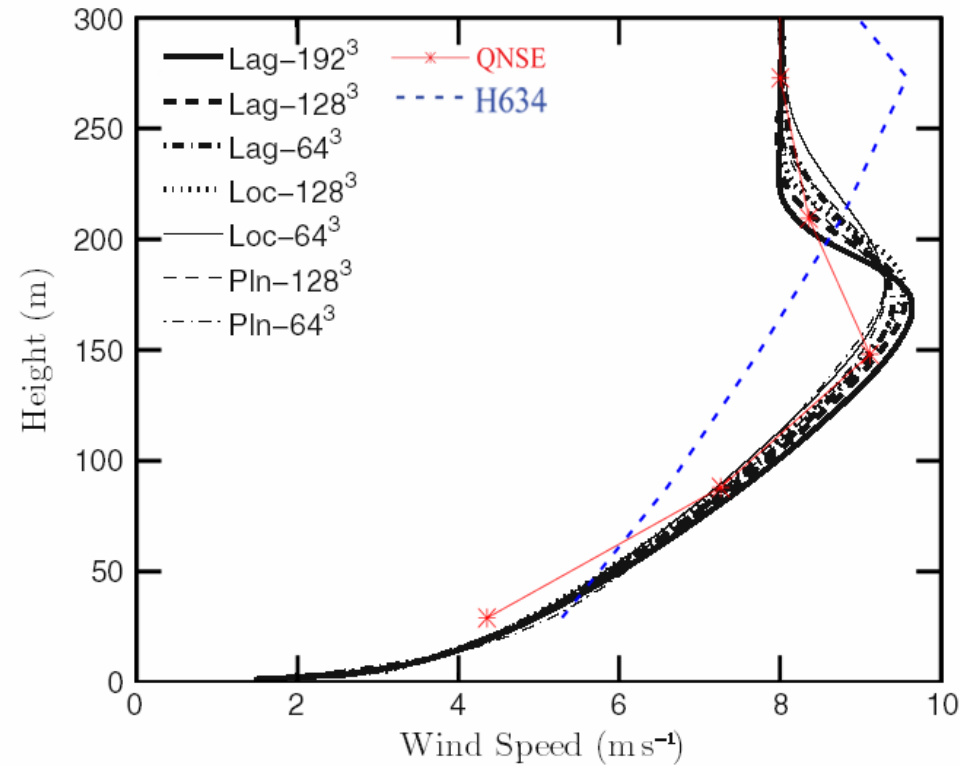


# Testing in HIRLAM - BASE

280 levels

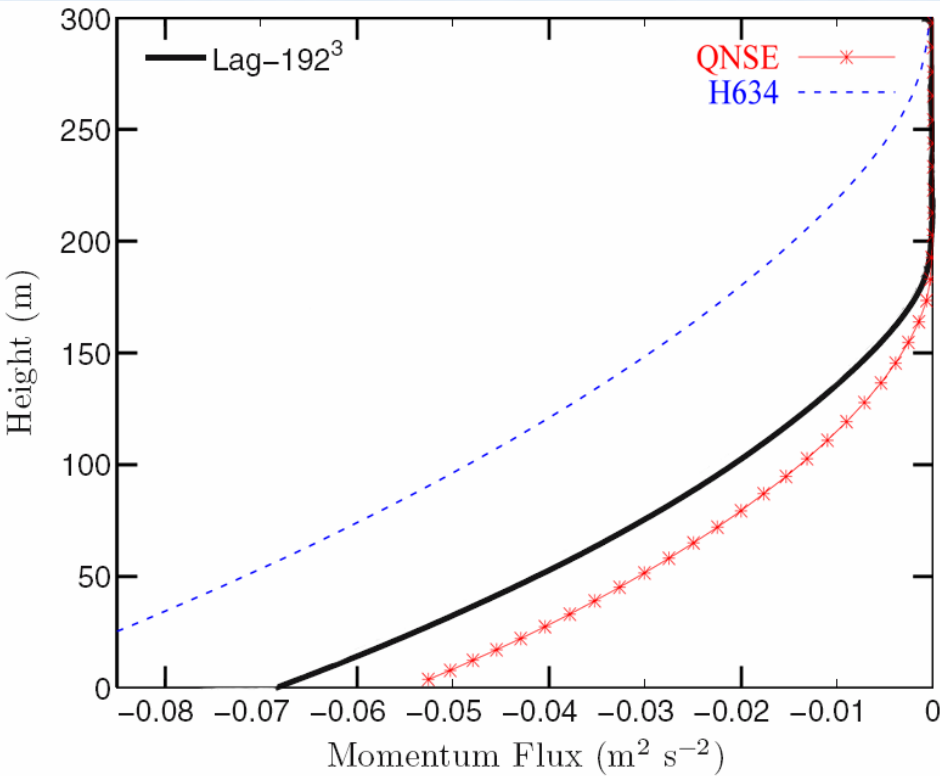


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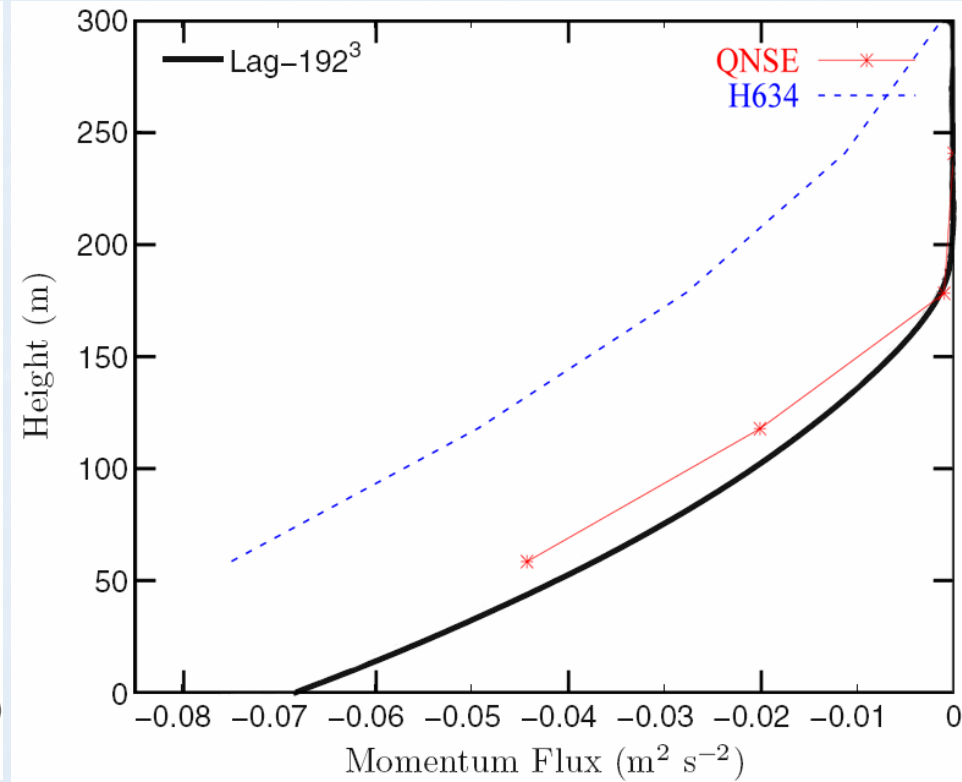


# Testing in HIRLAM - BASE

280 levels

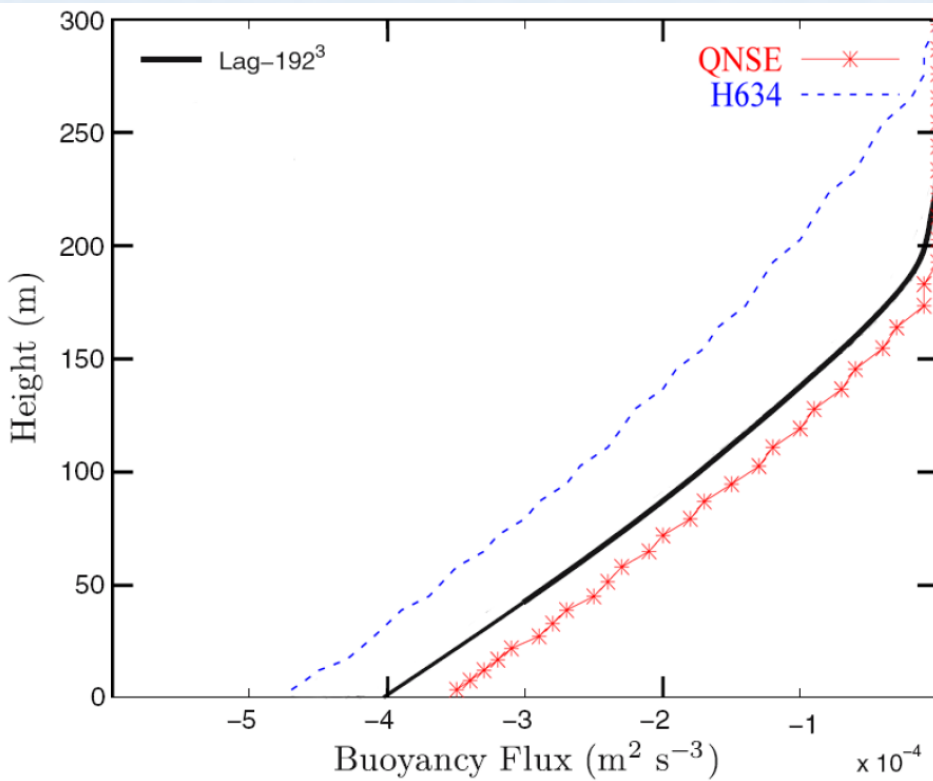


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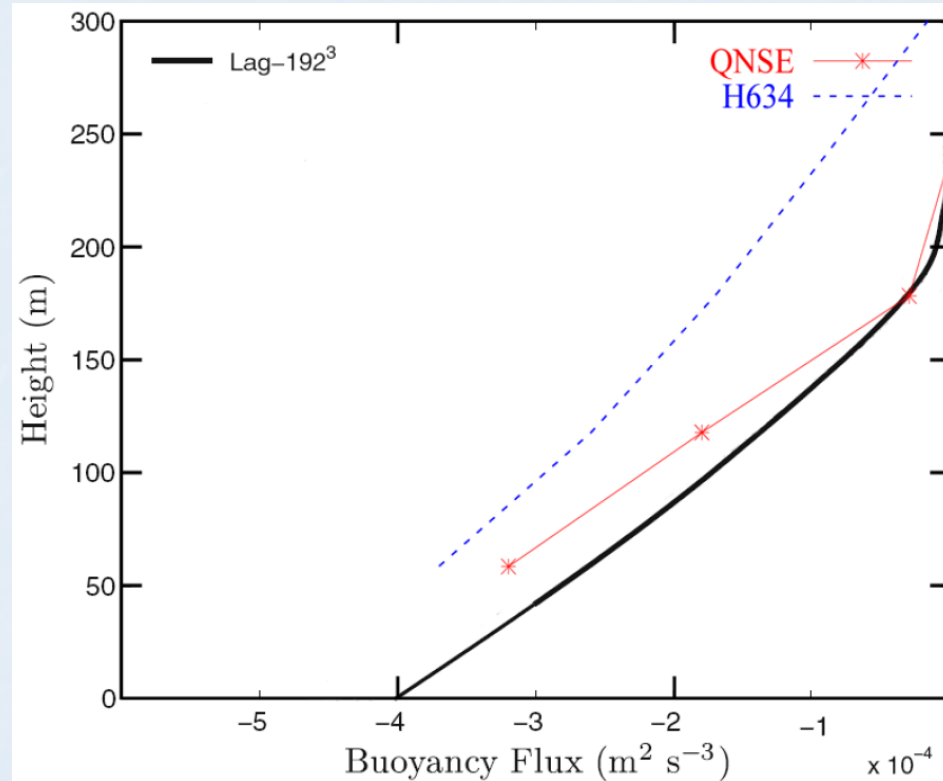


# Testing in HIRLAM - BASE

280 levels

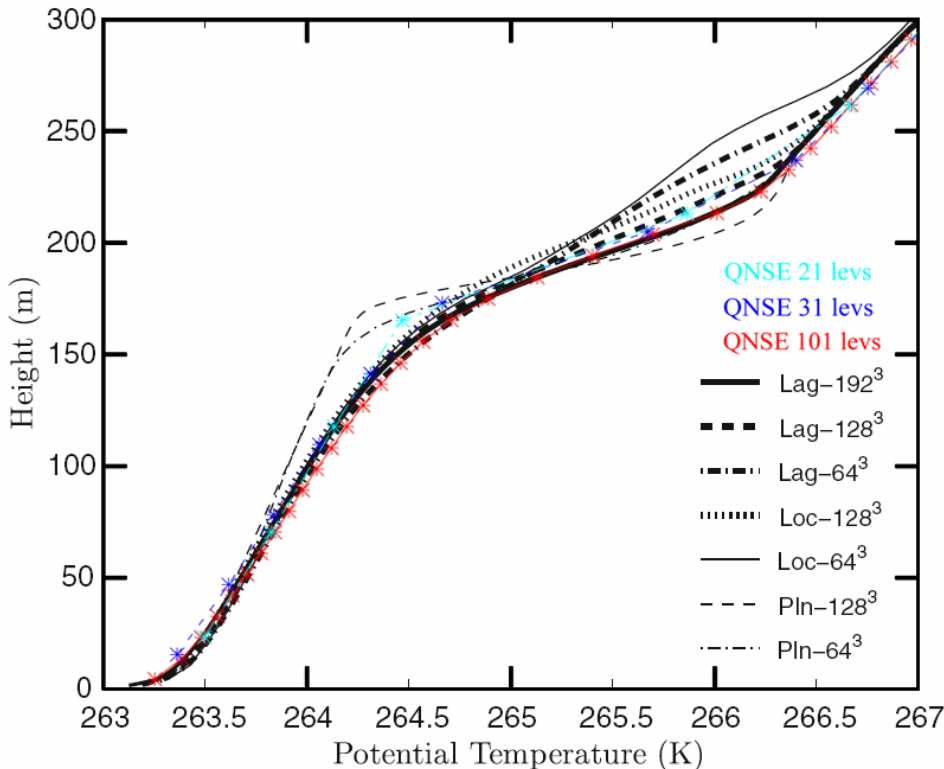


60 levels

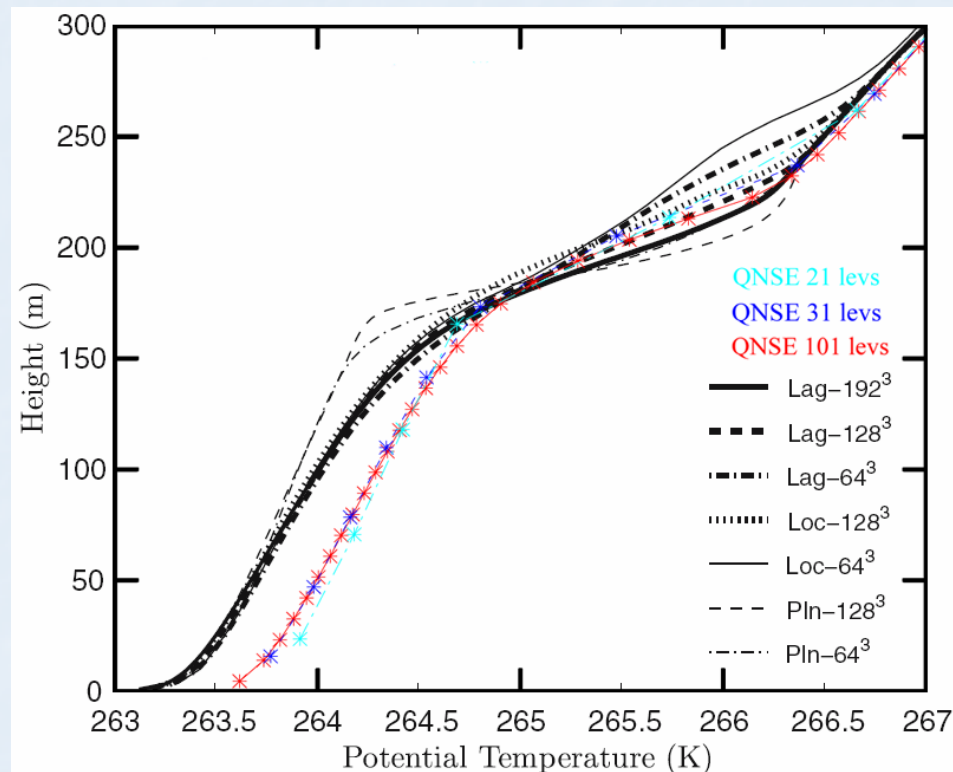


# Testing in WRF - BASE

Full QNSE-based parameterization



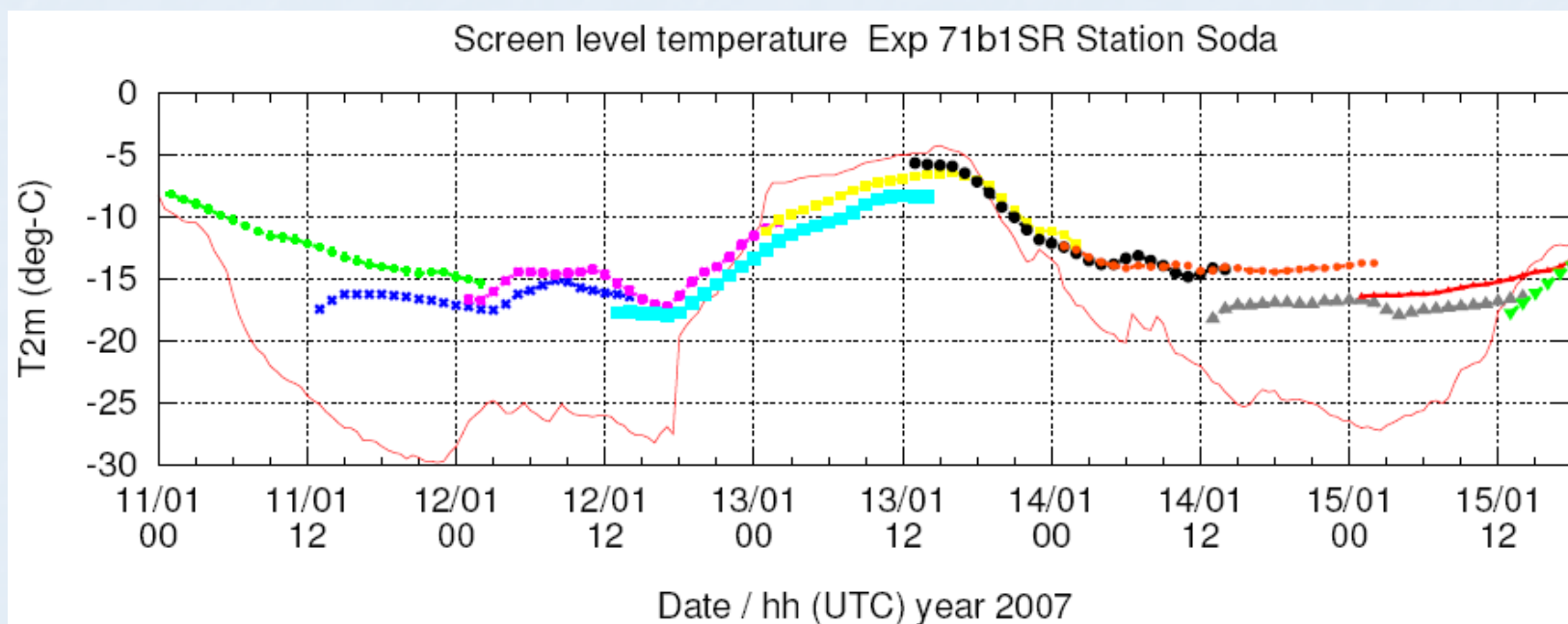
QNSE with YMJ surface scheme



QNSE surface scheme eliminates warm temperature bias in BASE case. With other schemes in WRF, increase in resolution may improve the bias but does not eliminate it.

# QNSE-based surface layer parameterization in numerical weather prediction - the Nordic Temperature Problem

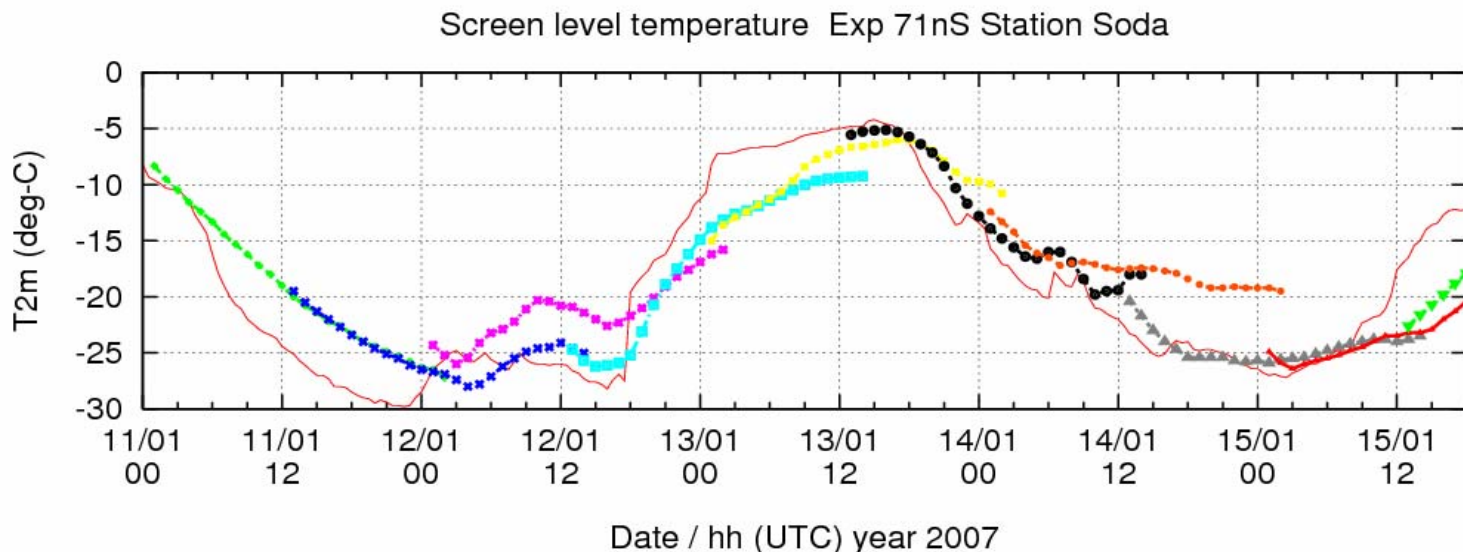
Conventional models suffer from the warm bias when used to predict 2m temperature at Sodankylä station in Finland and in other Nordic regions. Large warm bias occurs for very low near-surface temperatures ( $-25^{\circ}\text{C}$  and lower). This problem has been notoriously well-known as the Nordic Temperature Problem.



Predictions of the 2-m temperature at Sodankylä station by a reference HIRLAM model. Red line is the data; color symbols and color lines show various 24-hour predictions.

# NTP solution in HIRLAM

- **Advanced parameterization in the Surface Biosphere Atmosphere Interaction (ISBA) scheme**
  - Improved treatment of the snow/ice and the forest
  - Tiling + heat diffusion in the soil
  - Samuelson et al., 2006. The land surface scheme of the Rossby Centre regional atmospheric climate model (RCA3). SMHI, Meteorologi 122
- **Implementation of QNSE-based drag coefficients in ISBA scheme (and in the turbulence K-l scheme in future)**





# Conclusions

- The quasi-normal scale elimination model has been implemented in HIRLAM TKE-I and advanced ISBA scheme schemes, as well as in WRF turbulence closure schemes
- Single column experiments reveal good agreement between model's results, LES and observations for different resolutions
- QNSE model was used to derive the universal stability functions in the Monin-Obukhov theory which were implemented in the new surface layer parameterization that replaced the Louise scheme
- New QNSE-based drag coefficients have been implemented in 3D "newsnow" surface atmosphere biosphere interaction scheme of HIRLAM
- Preliminary comparisons of 3D HIRLAM with Sodankyla Mast measurements have shown much improvement of T2m forecasts with QNSE-based modifications and advanced "newsnow" scheme
- QNSE turbulence models are a viable alternative to Reynolds stress closure schemes

# References

Sukoriansky, S., B. Galperin and I. Staroselsky, A quasi-normal scale elimination model of turbulent flows with stable stratification. *Physics of Fluids*, **17**, 085107–1–28, 2005.

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