Implementation of the QNSE-based parameterizations in NWP models

Evgeny Atlaskin, Semion Sukoriansky and Boris Galperin

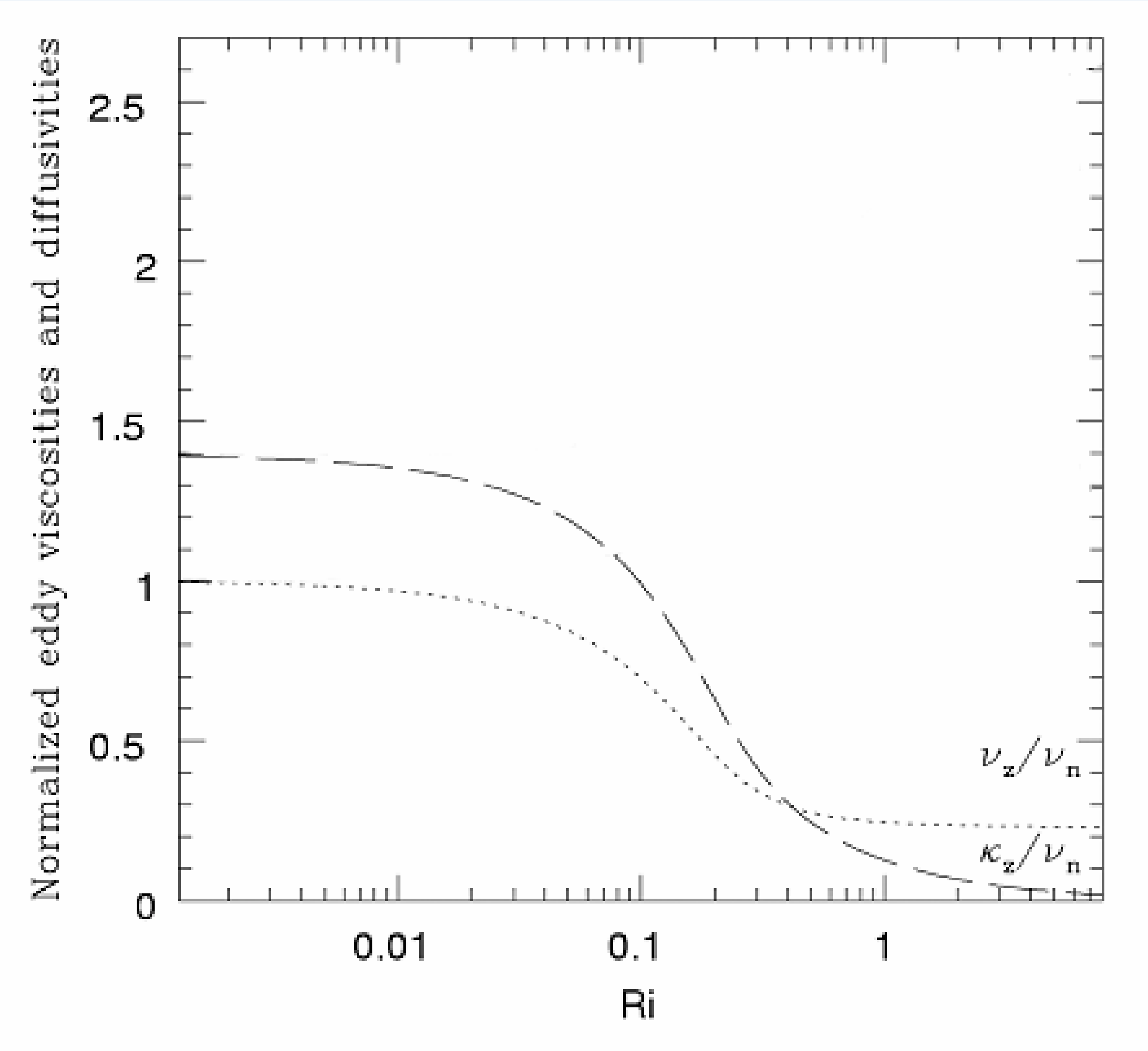
Russian State Hydrometeorological University

Ben-Gurion University of the Negev, Beer-Sheva, Israel

University of South Florida, St. Petersburg, Florida

18th Symposium on Boundary Layers and Turbulence
9-13 June 2008, Stockholm, Sweden

QNSE-based eddy viscosities and diffusivities



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

Curve fitting functions

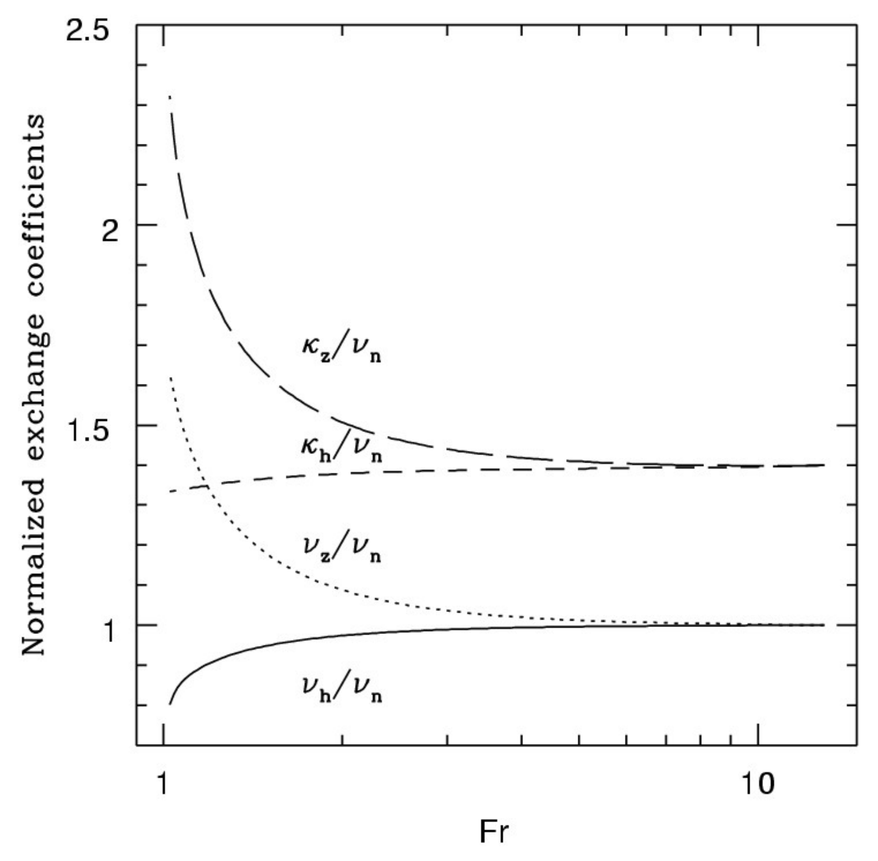
For implementation in PBL schemes, the theoretically derived stability functions, $\alpha_M = K_M/K_0$ and $\alpha_H = K_H/K_0$, were approximated by a fraction-polynomial fit (K_0 is the eddy viscosity at Ri=0):

$$\alpha_M = \frac{1 + 8\,Ri^2}{1 + 2.3\,Ri + 35\,Ri^2}$$

$$\alpha_H = \frac{1.4 - 0.01\,Ri + 1.29\,Ri^2}{1 + 2.344\,Ri + 19.8\,Ri^2}$$

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-l model

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

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

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

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

****

$$K_m = l\, E^{1/2}, \qquad K_h = \varphi l_h\, E^{1/2}$$

QNSE-based K-l model

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

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

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

* * *

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

QNSE-based surface layer parameterization

Using theoretically derived stability functions α_M, α_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:

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

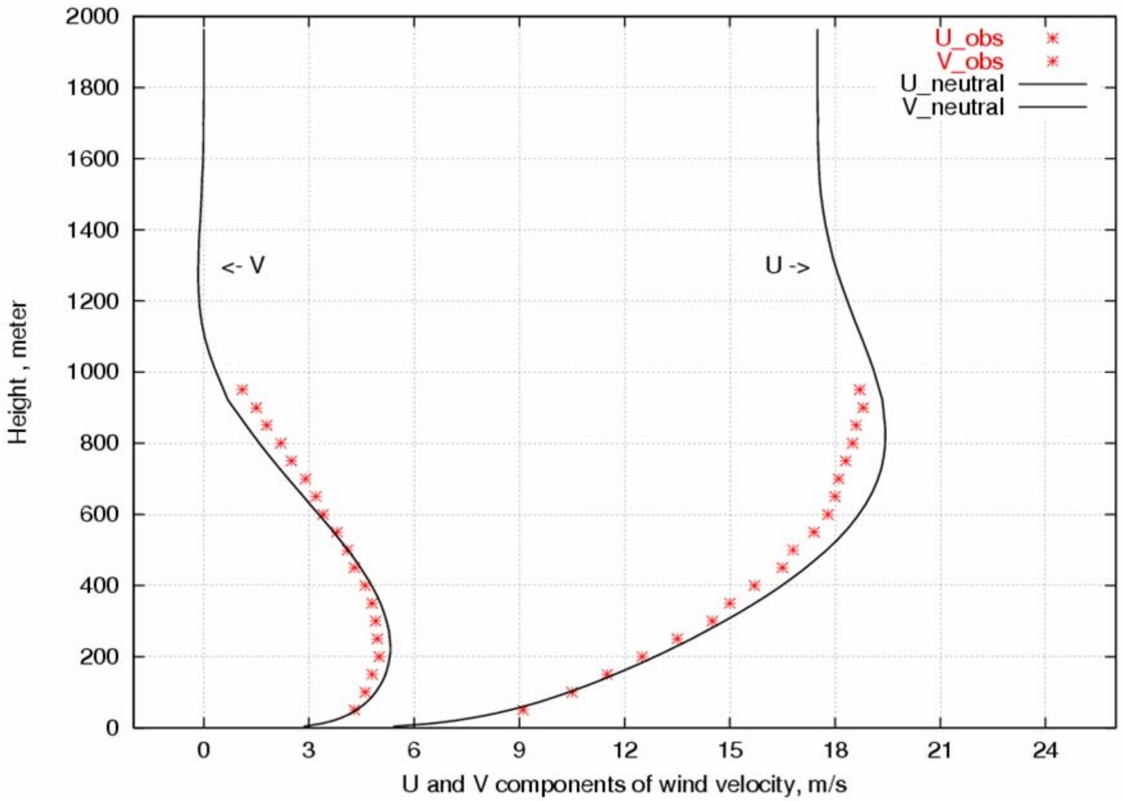
$$C_H = \frac{\kappa^2}{\left(\ln\frac{z}{z_{0T}} + \psi_M(\zeta) - \psi_M(\zeta_{0T})\right)\left(\mathrm{Pr}_0 \ln\frac{z}{z_{0T}} + \psi_H(\zeta) - \psi_H(\zeta_{0T})\right)}$$

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

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

$\mathrm{Pr}_0 = 0.71$ – turbulentPrandtl 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

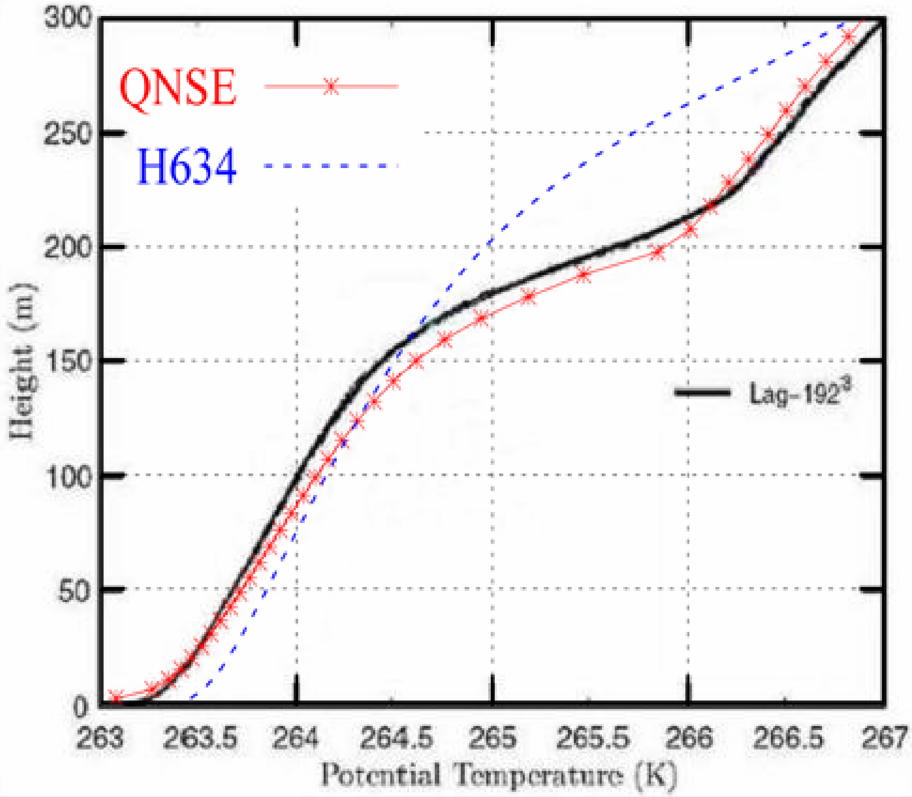
Initial state: $\Theta = 265K$ ≤ 100 metres
$d\Theta/dz = -0.01K/m$ > 100 metres

$U_g = 8$ m/s
$V_g = 0$ m/s

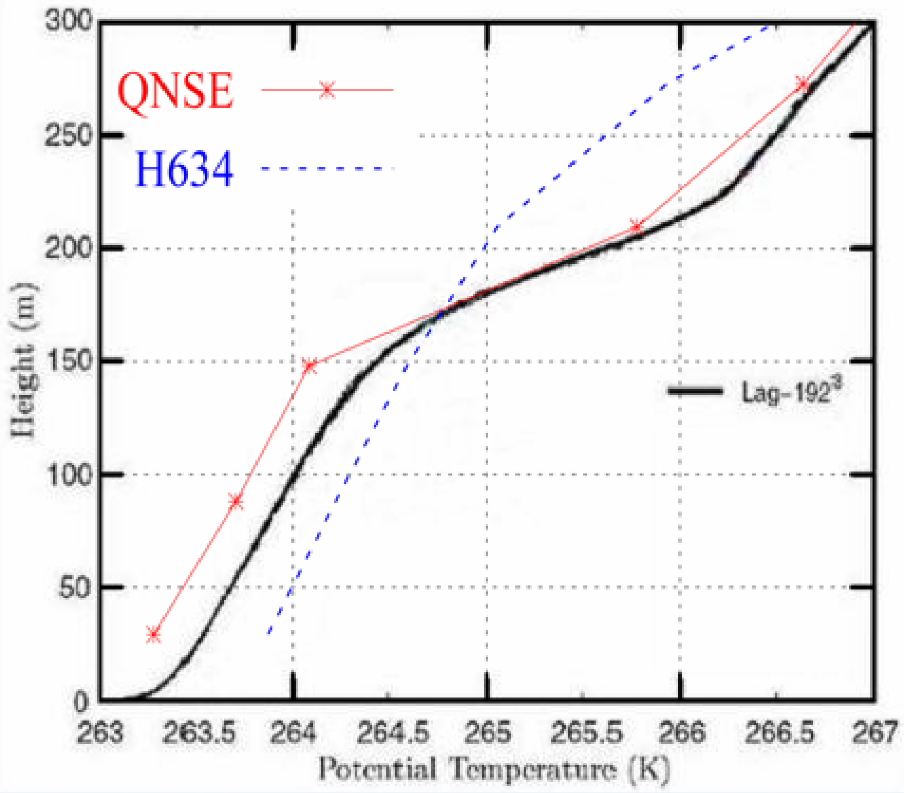
9 hours run: $d\Theta_s/dz = -0.25/h$
$z_0 = 0.1$ m

Testing in HIRLAM - BASE

280 levels

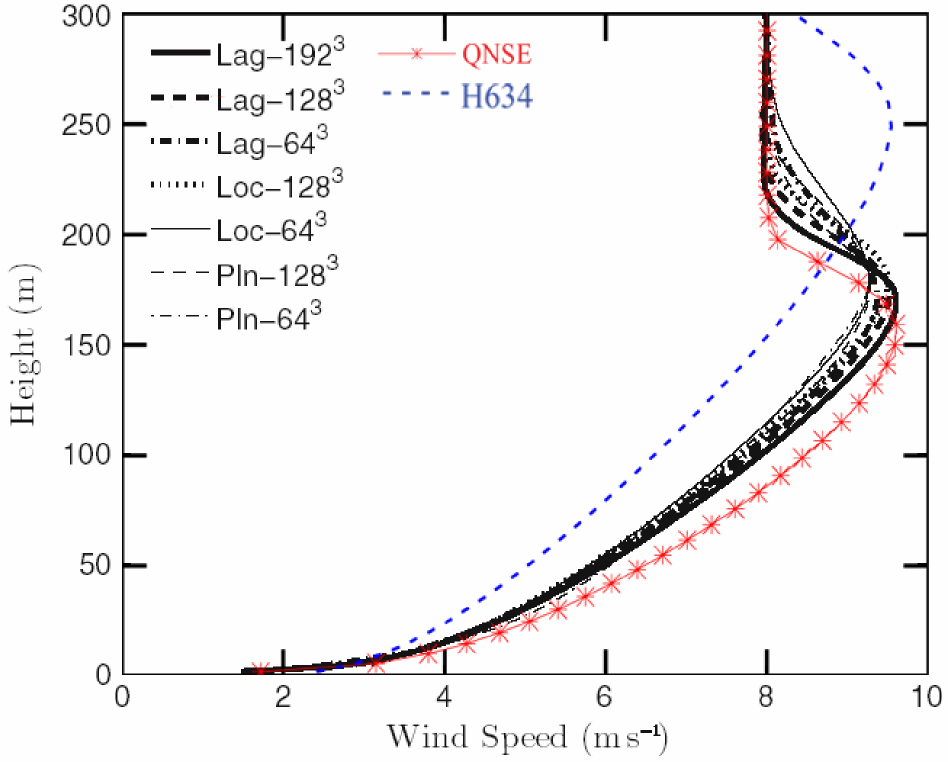


60 levels

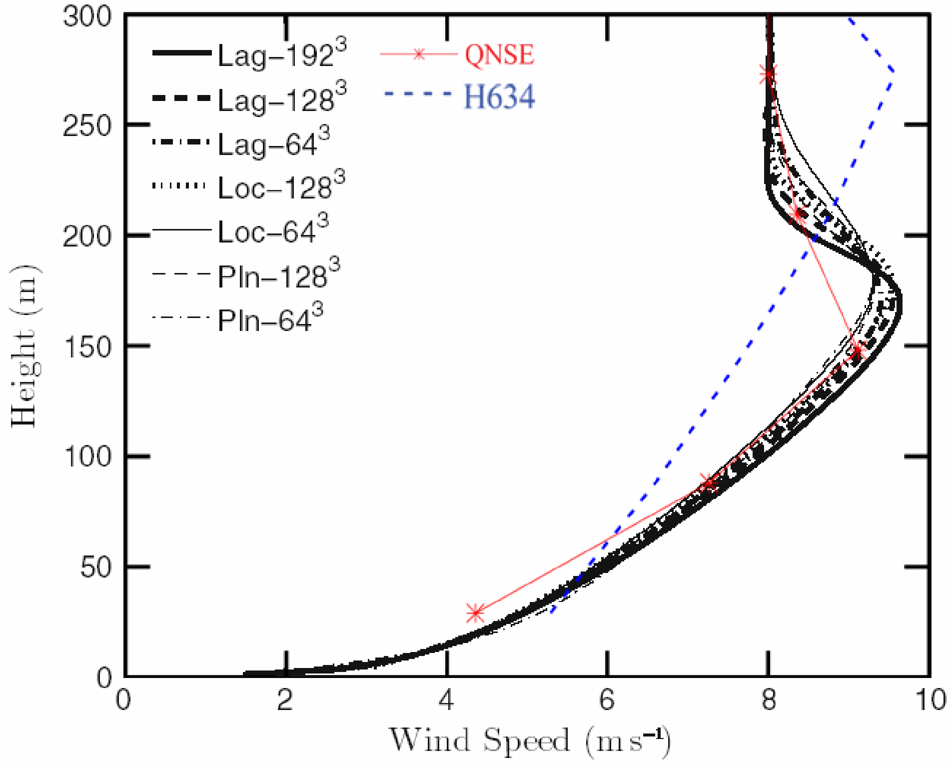


Testing in HIRLAM - BASE

280 levels

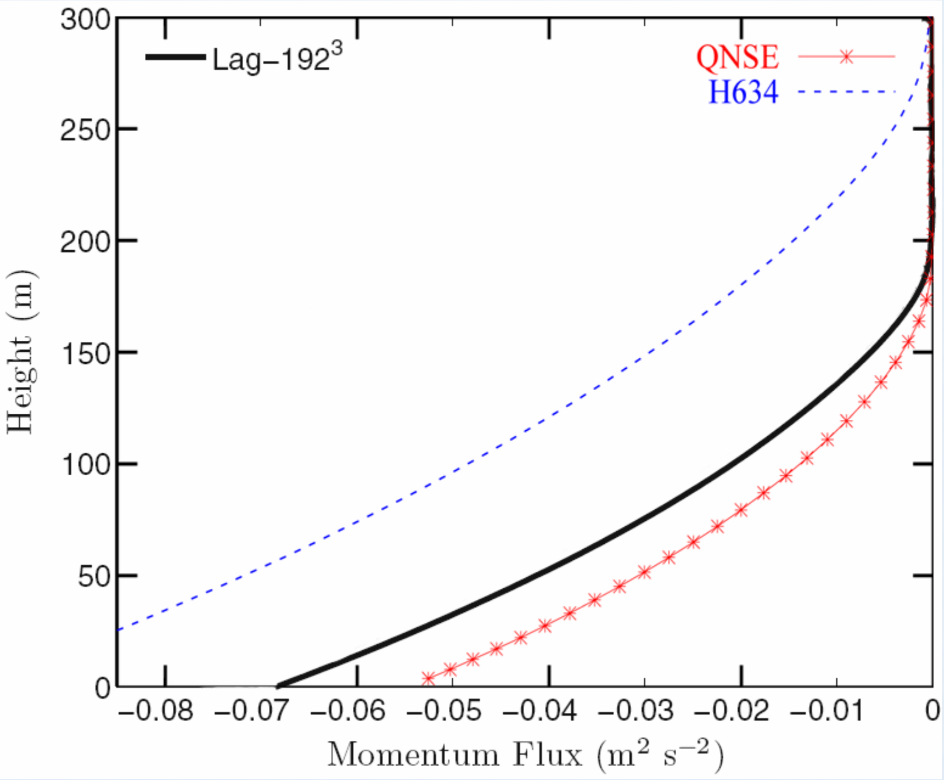


60 levels

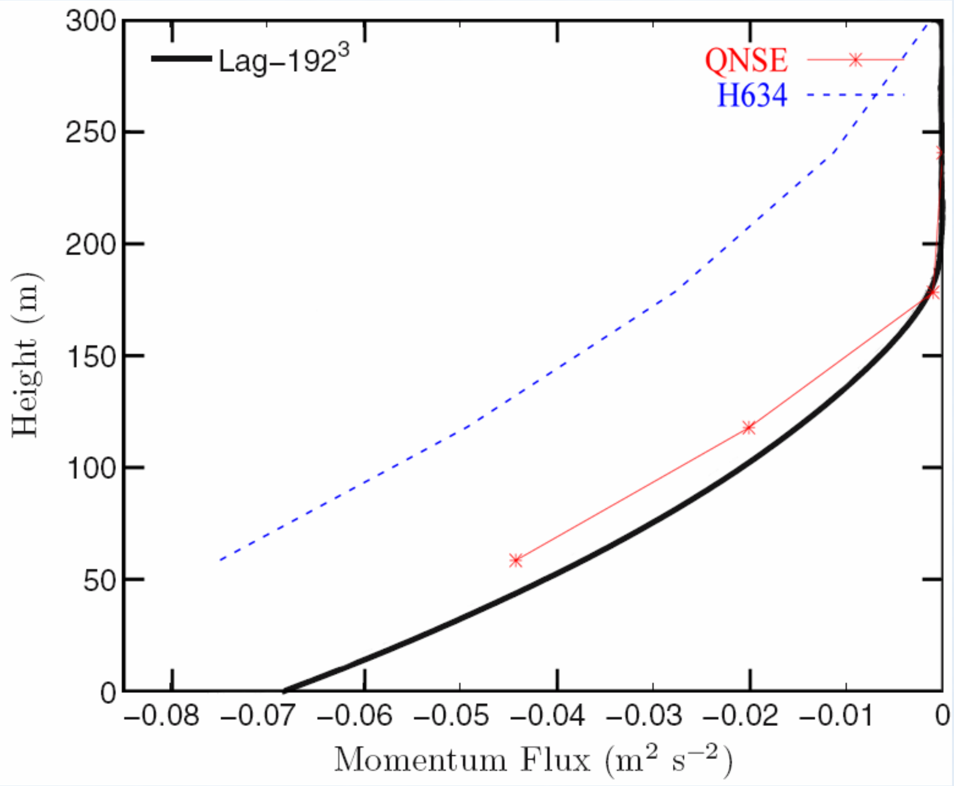


Testing in HIRLAM - BASE

280 levels

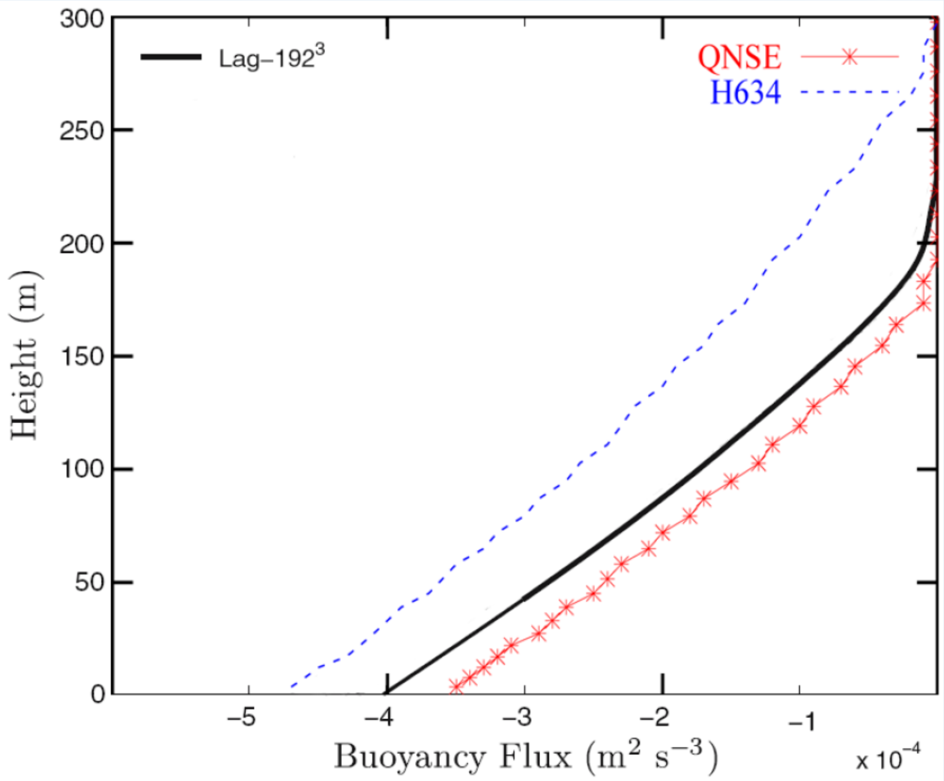


60 levels

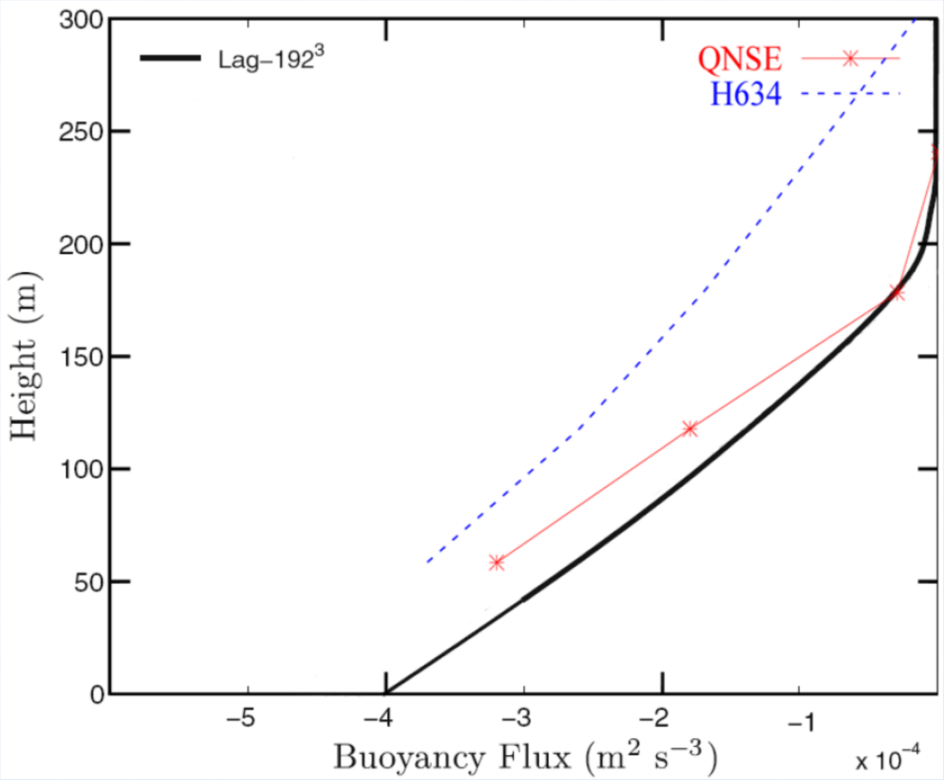


Testing in HIRLAM - BASE

280 levels

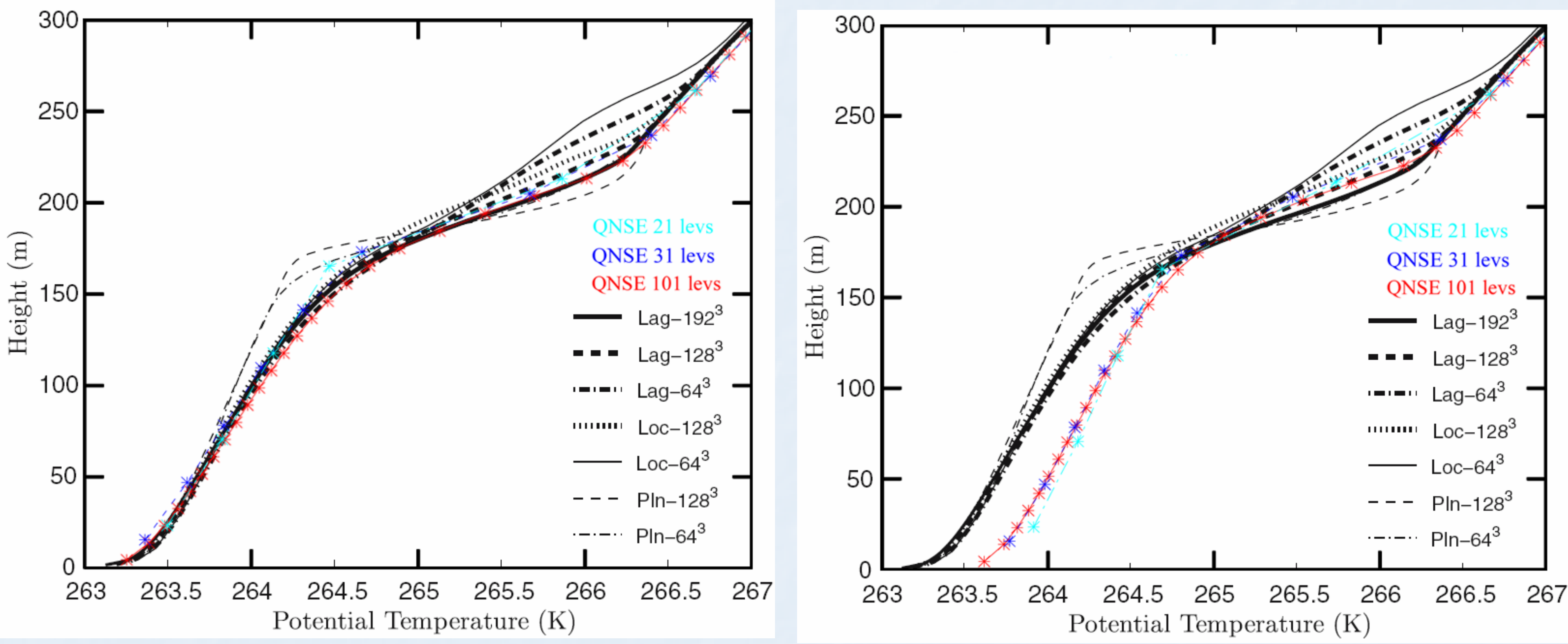


60 levels



Testing in WRF - BASE

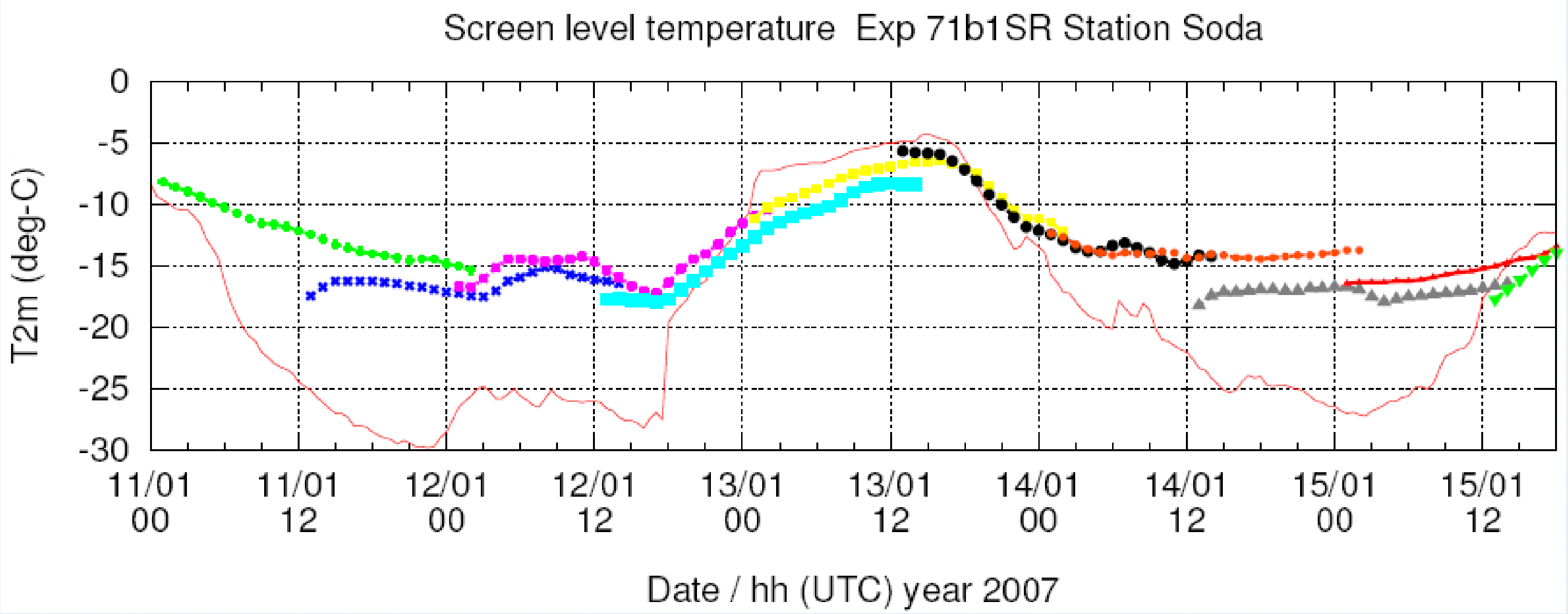
Full QNSE-based parameterization	QNSE with YMJ surface scheme



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°C and lower). This problem has been notoriously well-known as the Nordic Temperature Problem.

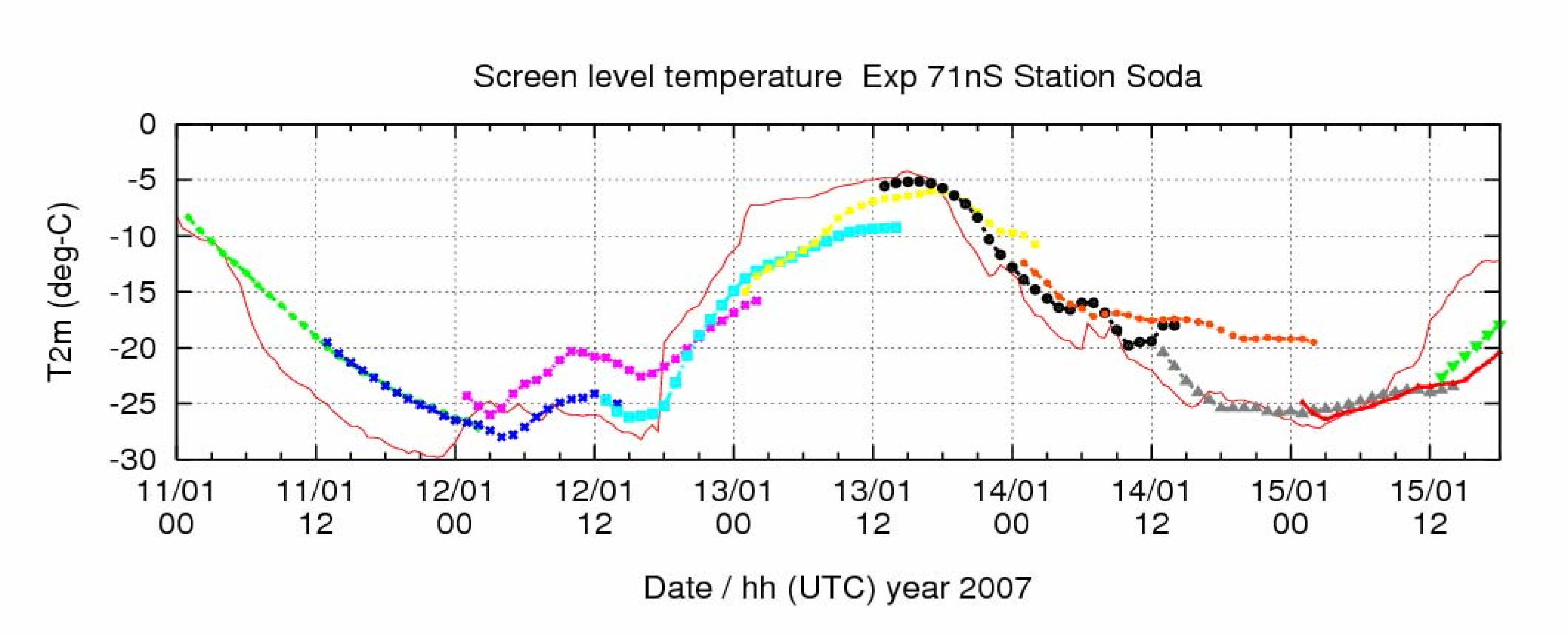


Predictions of the 2-m temperature at Sodankylä station by a reference HIRLAM model. Red line is the data; color symbols and color lines show various 24-hour predictions.

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-l 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.

Sukoriansky, S., B. Galperin, and V. Perov, Application of a new spectral theory of stably stratified turbulence to atmospheric boundary layers over sea ice. *Boundary-Layer Meteorology*, **117**, 231–257, 2005.

Sukoriansky, S., B. Galperin, and V. Perov, A quasi-normal scale elimination model of turbulence and its application to stably stratified flows. *Nonlinear Processes in Geophysics,* **13***,* 9–22, 2006.

B. Galperin, S. Sukoriansky, and P. S. Anderson, "On the critical Richardson number in stably stratified turbulence", *Atmospheric Science Letters*, **8**: 65–69 (2007), DOI: 10.1002/asl.153.

Acknowledgments

This research has been supported by NetFAM, the US Army Research Office, Office of Naval Research and Israel Science Foundation

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.

Sukoriansky, S., B. Galperin, and V. Perov, Application of a new spectral theory of stably stratified turbulence to atmospheric boundary layers over sea ice. *Boundary-Layer Meteorology*, **117**, 231–257, 2005.

Sukoriansky, S., B. Galperin, and V. Perov, A quasi-normal scale elimination model of turbulence and its application to stably stratified flows. *Nonlinear Processes in Geophysics,* **13**, 9–22, 2006.

B. Galperin, S. Sukoriansky, and P. S. Anderson, “On the critical Richardson number in stably stratified turbulence”, *Atmospheric Science Letters*, **8**: 65–69 (2007), DOI: 10.1002/asl.153.