Specification of the Turbulent Length Scale for the COSMO Model Boundary Layer Scheme

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Outline

- Specification method of the length scale on the base of Bougeault and Lacarrere approach (BL89)

- Use of the method in SCM and LM COSMO models. Preliminary results.

- Definition of the new stability functions on the base of spectral theory of turbulence

- Summary

First-order schemes

$$K_m = l_m^2 \frac{\partial U}{\partial z} f_m,$$

$$K_h = l_m l_h \frac{\partial U}{\partial z} f_h,$$

$$\frac{1}{l_m} = \frac{1}{\kappa z} + \frac{1}{\lambda_0}$$

Higher-order schemes

$$K_m = c_m \sqrt{e}\, l_m f_m,$$

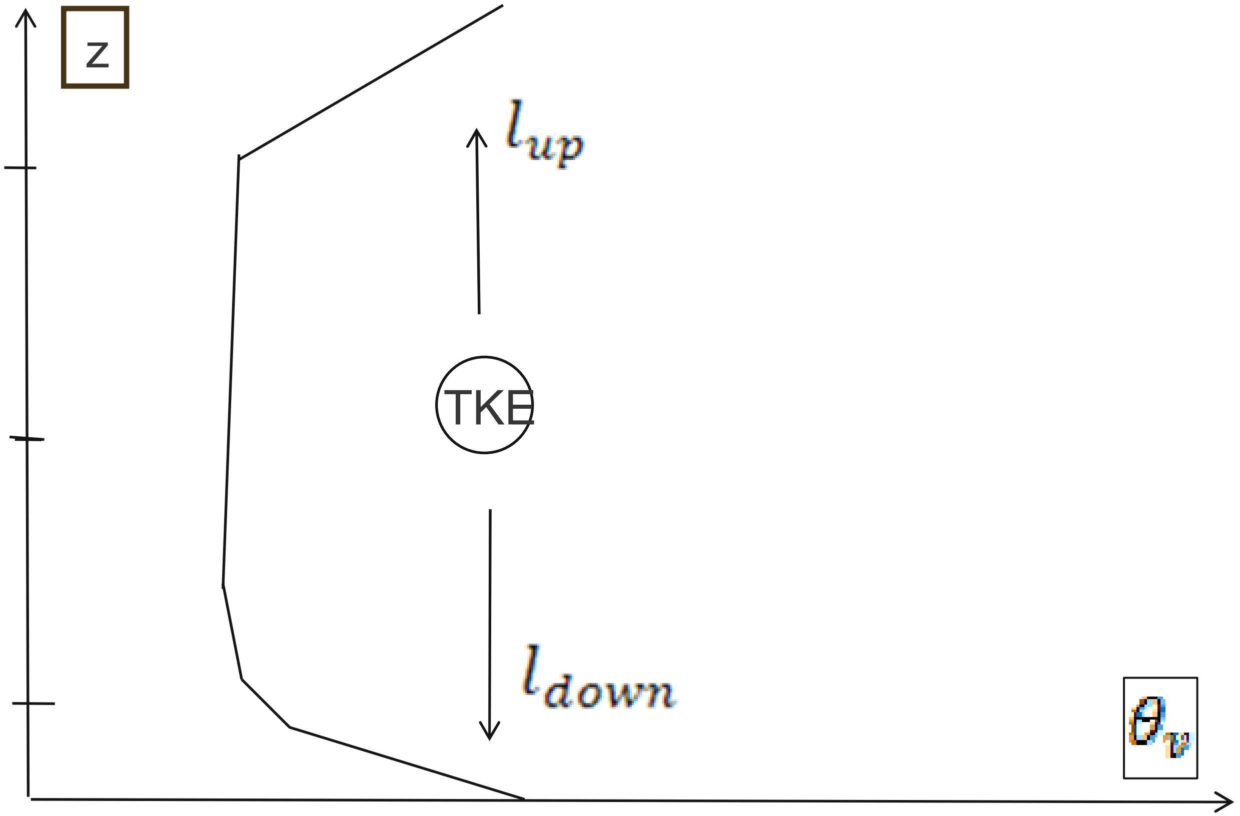
$$K_h = c_h \sqrt{e}\, l_h f_h,$$

$$\frac{\partial e}{\partial t} = -\overline{u'w'}\frac{\partial u}{\partial z} - \overline{v'w'}\frac{\partial v}{\partial z} + \frac{g}{\theta_{ref}}\overline{w'\theta'} - \frac{\partial \overline{w'e}}{\partial z} - c_\epsilon \frac{e^{\frac{3}{2}}}{l_\epsilon},$$

The e–ϵ models

$$\frac{\partial \epsilon}{\partial t} = c_{\epsilon 1}\frac{\epsilon}{e}P(e) - \frac{\partial \overline{w'\epsilon}}{\partial z} - c_{\epsilon 2}\frac{\epsilon^2}{e},$$

$$K_m = c_m \left(\frac{e^2}{\epsilon}\right) f_m, \qquad K_h = c_h \left(\frac{e^2}{\epsilon}\right) f_h.$$



- Schematic view of BL(89) length scale
  - for a convective boundary layer

- BL(89) seems physically well founded
- The length scale of the largest eddies at a given level is determined as a function of the stability profile of the adjacent levels
- The algorithm relies on the computation of the maximum vertical displacement allowed for a parcel of air having the mean kinetic energy of the level as initial kinetic energy
- The maximum upward and downward displacement are computed by assuming that the parcel will stop when the cumulated buoyancy acceleration equal the initial kinetic energy (Fig)
- The method allows the length scale at any level to be affected not only by the stability at this level, but by the effect of remote levels ("non-local" length)

Turbulence Length Scale

$$\int_{z}^{z+l_{up}} \frac{g}{\theta_{vref}}\left[\theta_v(z') - \theta_v(z)\right] dz' = E(z)$$

$$\int_{z-l_{down}}^{z} \frac{g}{\theta_{vref}}\left[\theta_v(z) - \theta_v(z')\right] dz' = E(z)$$

then $L = \left(l_{up} \cdot l_{down}\right)^{1/2}$, $\frac{1}{l} = \frac{1}{kz} + \frac{1}{L}$

Blackadar formula, local l

$$\frac{1}{l} = \frac{1}{\kappa z} + \frac{1}{l_\infty} + \frac{N}{C_N e^{1/2}}, \quad \kappa = 0.40, \quad C_N = 0.76, \quad l_\infty = 200\text{m}.$$

TABLE III

Some characteristics of the turbulence schemes.

Model	K_m ($m^2 s^{-1}$)	K_h ($m^2 s^{-1}$)	Lengths (m)	Stab. functions (adim)
ECMWF	$l_m^2 \frac{\partial U}{\partial z} f_m$	$K_m \frac{l_m l_h}{l_m^2} \frac{f_h}{f_m}$	$l_{m,h}^{-1} = (kz)^{-1} + \lambda_0^{-1}$,	$f_m^{-1} = 1 + 10Ri(1 + 5Ri)^{-0.5}$
(and ECMWF-MO)			$\lambda_0 = 150$ m	$f_h^{-1} = 1 + 15Ri(1 + 5Ri)^{0.5}$
NOAA-NCEP	$\frac{u_* \kappa z}{f_m}(1 - z/h)^2$	$K_m/1.32$		$f_m = \min(1 + 0.5h/L, 5.)$
MeteoFrance	as ECMWF	$K_m \frac{l_h}{l_m} \frac{f_h}{f_m}$	l_m, l_h	$f_m^{-1} = 1 + 10Ri(1 + 5Ri)^{-0.5}$
			as ECMWF with mods.	$f_h^{-1} = 1 + 15Ri(1 + 5Ri)^{0.5}$
JMA	as ECMWF	as ECMWF	$l_m = l_h$, $\lambda_0 = 50$m	LE (Yamada, 1975)
MetOffice	as ECMWF	as ECMWF	as ECMWF, $\lambda_0 = \max(40., 0.15h)$	$f_m = f_h = (1 + 10Ri)^{-1}$
MetOffice-res	$K_m(z, h, u_*, L)$	$K_h(z, h, u_*, L)$	$l_{m,h}^{-1} = \frac{A}{z} + B\frac{N}{\sigma_w} + C\frac{S}{\sigma_w}$	implicit in K_m, K_h
WageningenU	as ECMWF	as ECMWF	$l_{m,h} = kz$	$f_m(\frac{z}{\Lambda})$, $f_h(\frac{z}{\Lambda})$ (Duynkerke, 1991)
SandiaLabs	ND	ND	ND	ND
MSC	$0.516\sqrt{e}l_m$	$K_m/0.85$	$l_m = \min(kz, 200) f_m$	$f_m = (1 + 12Ri)^{-1}$
KNMI-RACMO	$\sqrt{e}l_m$	$\sqrt{e}l_h$	$l_m(Ri, e, N)$, $l_h(e, N)$	
UIB-UPC	$0.067\sqrt{e}l_m$	$0.167\sqrt{e}l_h f_h$	Bougeault and Lacarrère (1989) $l_\epsilon = l_m = l_h$	$f_h = (1 + Cl_m^2 N^2/e)^{-1}$
NASA	$0.1\sqrt{e}l_m$	$K_m \min(3, F(l_m))$	$l_m = 0.76\sqrt{e/N^2}$	
WVU	$C_1\sqrt{e}l_m f_m$	$C_2\sqrt{e}l_h f_h$	$l_m = l_h = \min(h/4, 0.65z, \sqrt{e/2N^2})$	$f_m(Ri)$, $f_h(Ri)$
YorkU	$0.55\sqrt{e}l_m$	$K_m/0.85$	$l_m, l_\epsilon = F(z, L, \lambda_0)$	
LouvainU-L	$0.5\sqrt{e}l_m$	$1.3K_m$	$l_m = l_h, l_\epsilon$ (Therry and Lacarrère, 1983)	
LouvainU-eps	$C_1 e^2/\epsilon$	$K_h = K_m$	ND	
SwedishMS	$C_1(Re)e^2/\epsilon$	$K_h = K_m$	ND	
StockholmU	LE	LE	$l_m = l_h = l_\epsilon$	f_m, f_h (Andrén, 1990)
StockholmU-sim	LE	LE	$l_\epsilon^{-1} = (\kappa z)^{-1} + \frac{N}{3.04\sqrt{e}} + \frac{S}{1.52\sqrt{e}}$	

L is the Obukhov length, N is the Brunt-Väisälä frequency, S is the wind shear and Λ is the local Obukhov length; LE stands for 'long expressions' and ND for 'not defined'. Further specifications can be found in the references listed in Table II.

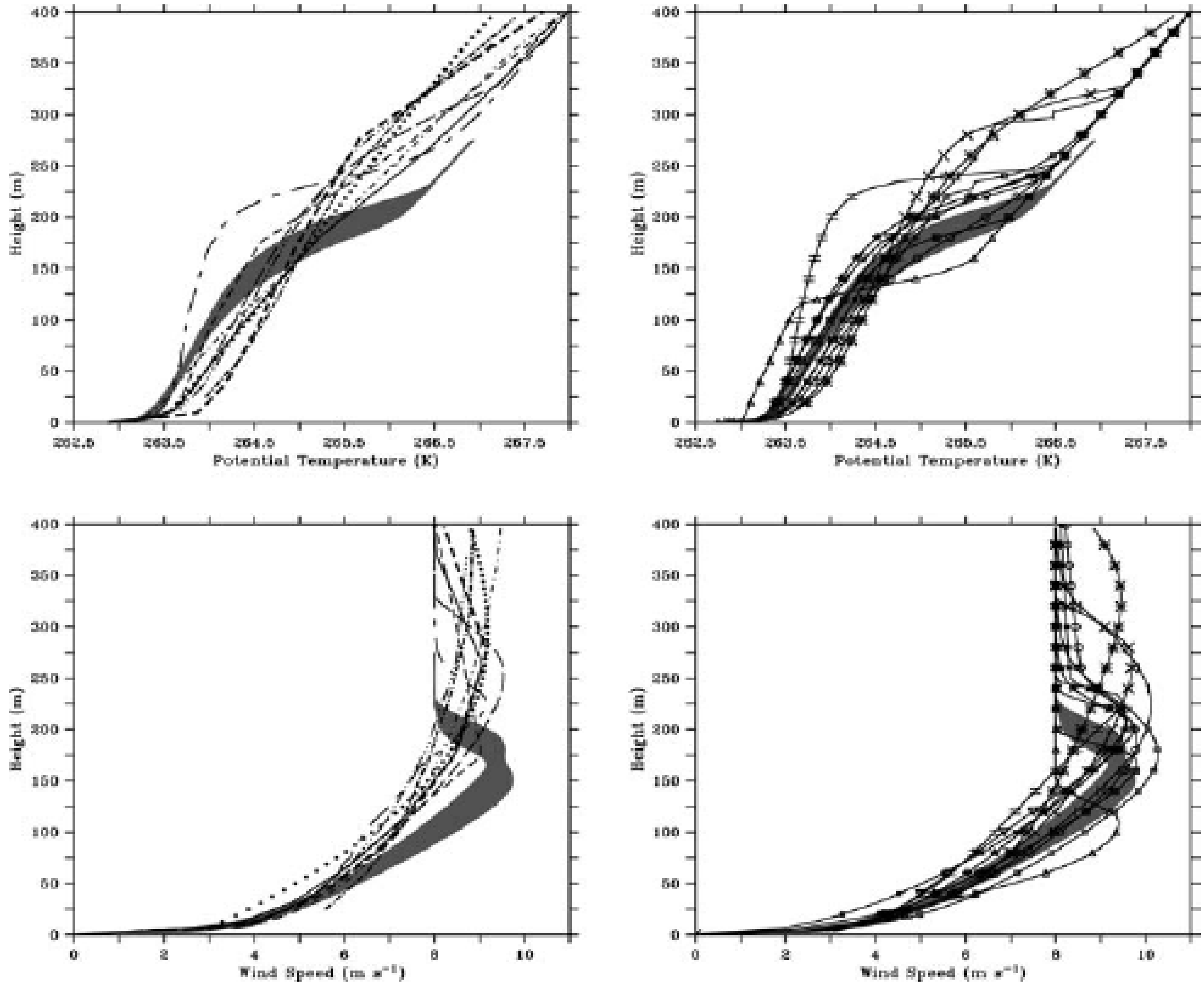


Figure 3. Potential temperature (top) and wind speed (bottom) averaged profiles for the ninth hour. Left column: first-order schemes + ODT; right column: higher-order schemes.

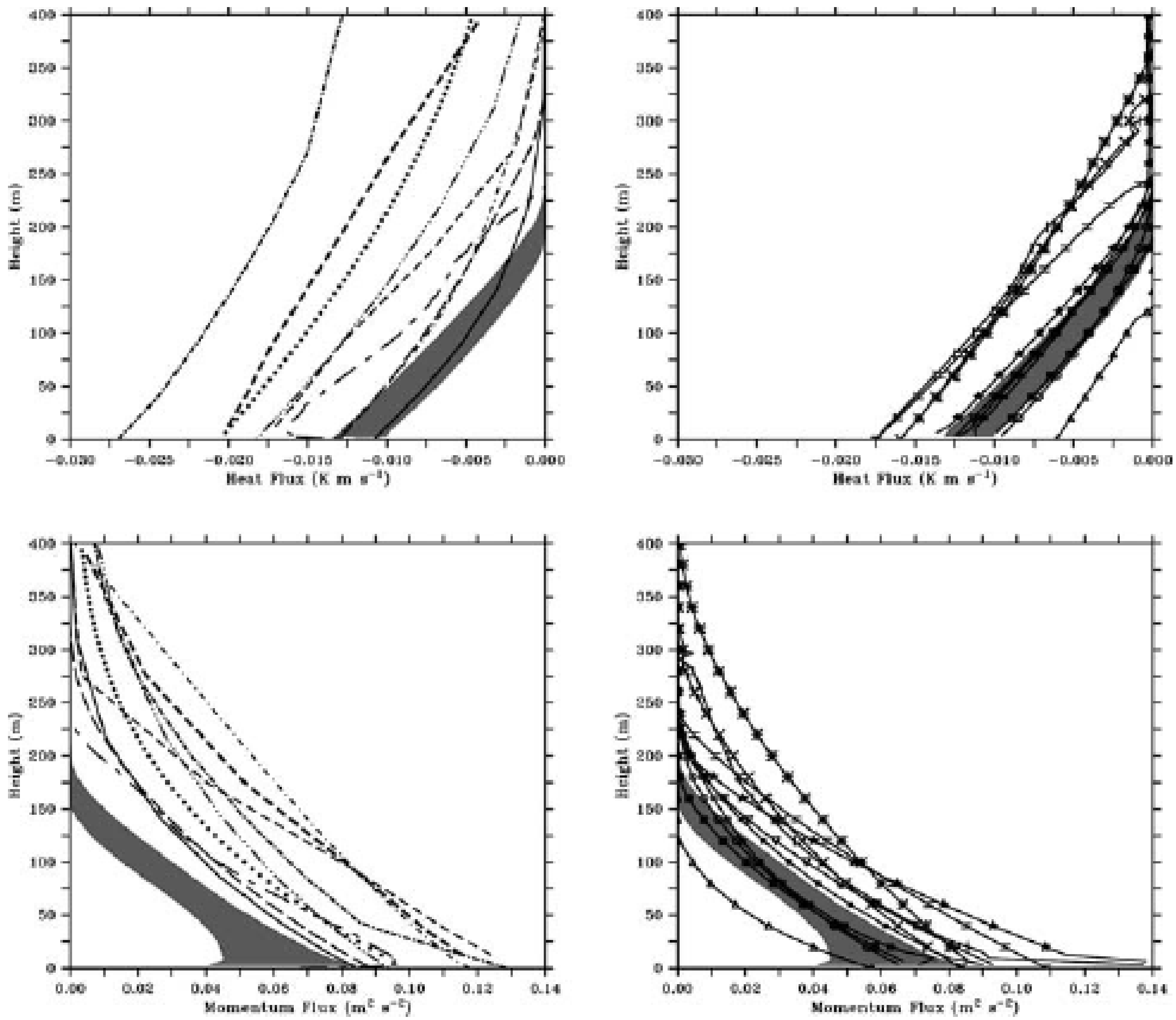
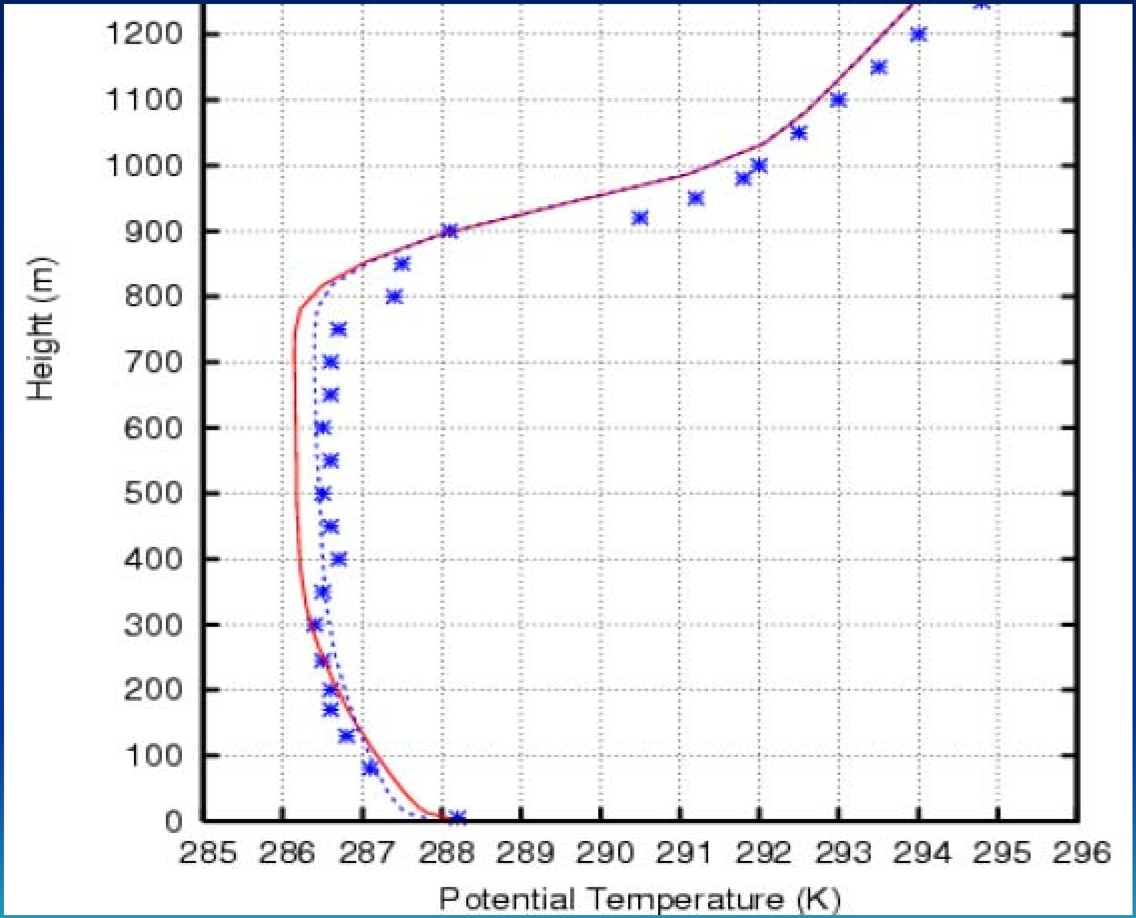
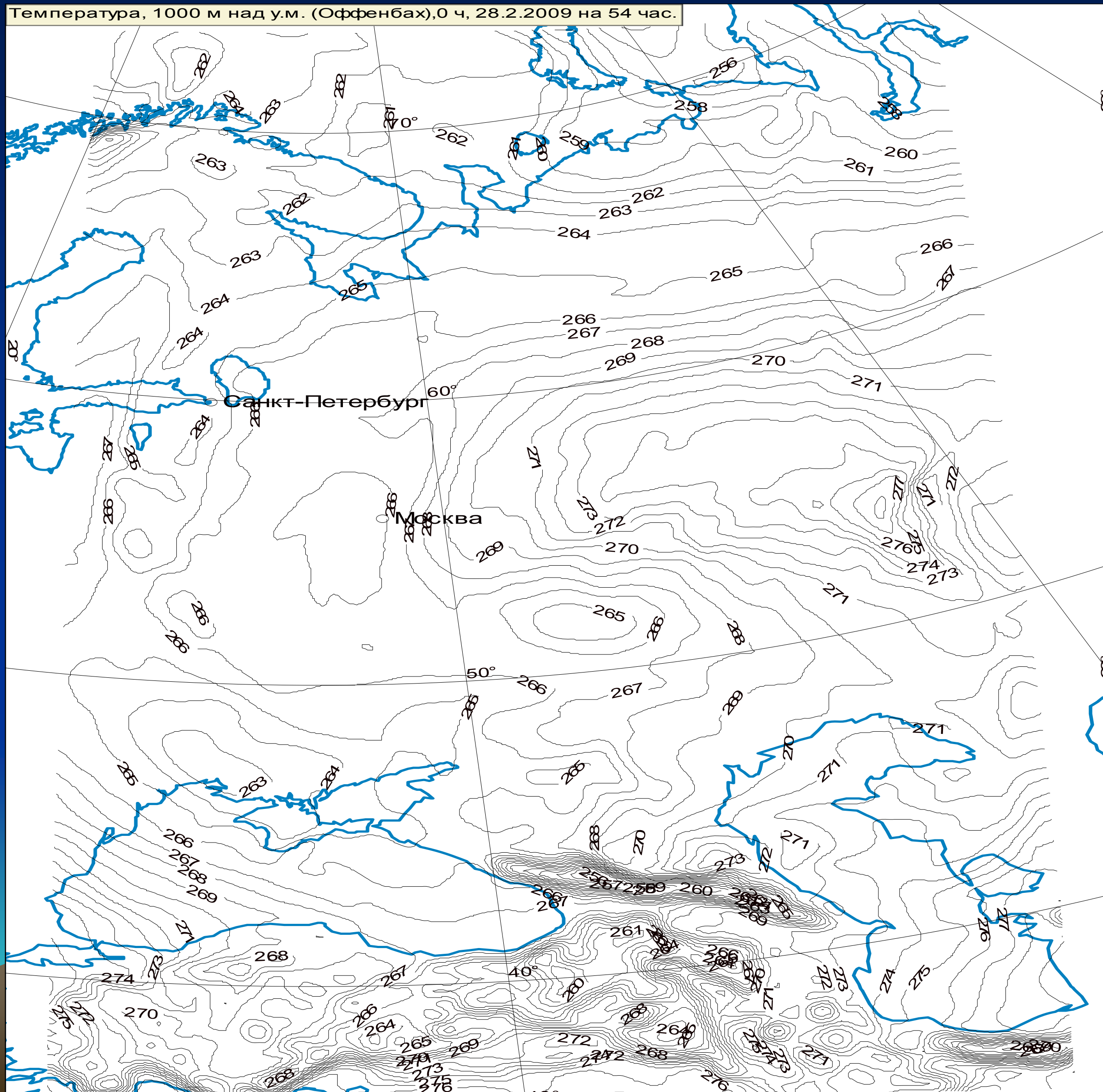


Figure 4. Heat flux (top) and momentum flux (bottom) as for Figure 3.

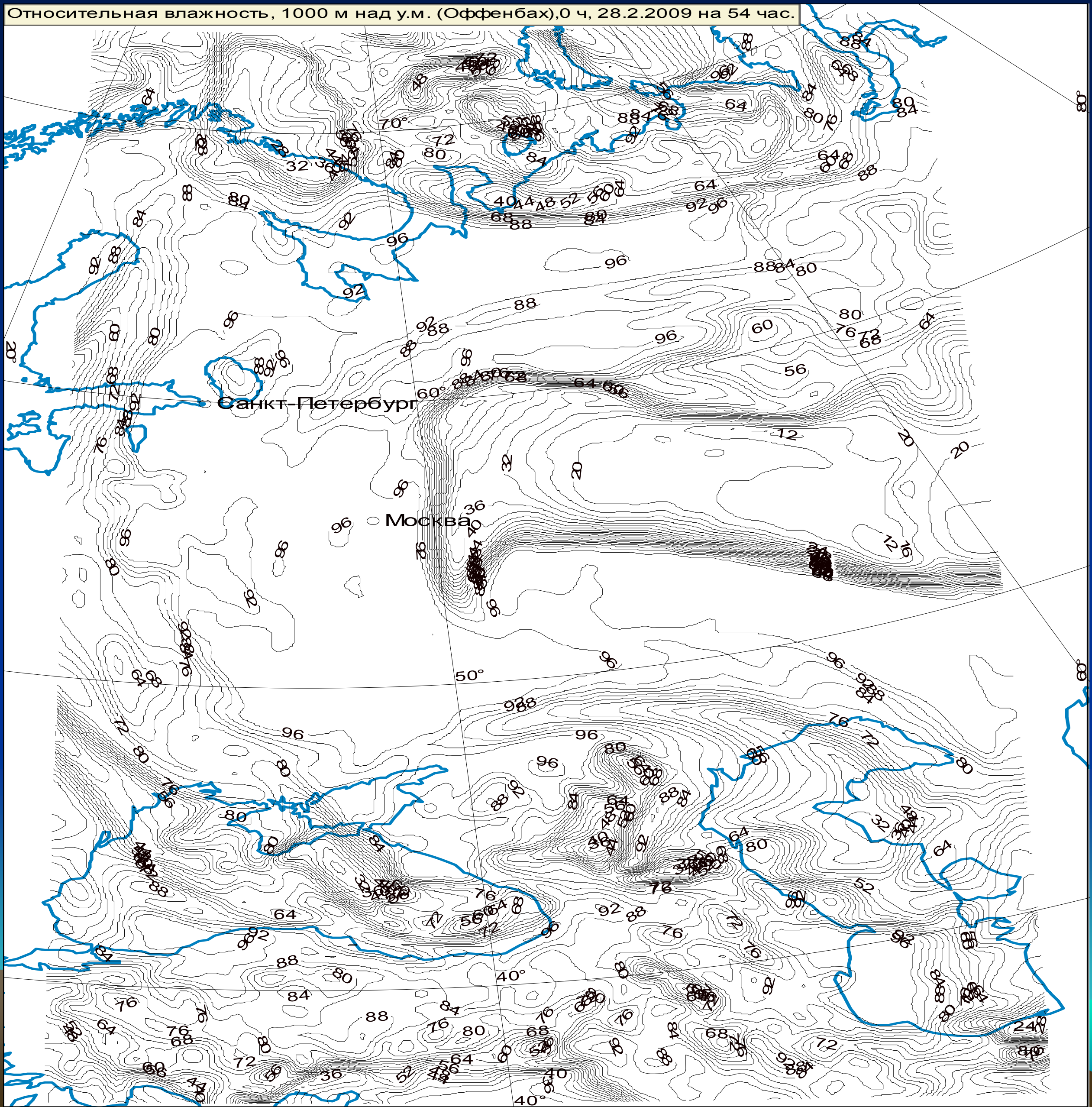
Comparison with GABLS2



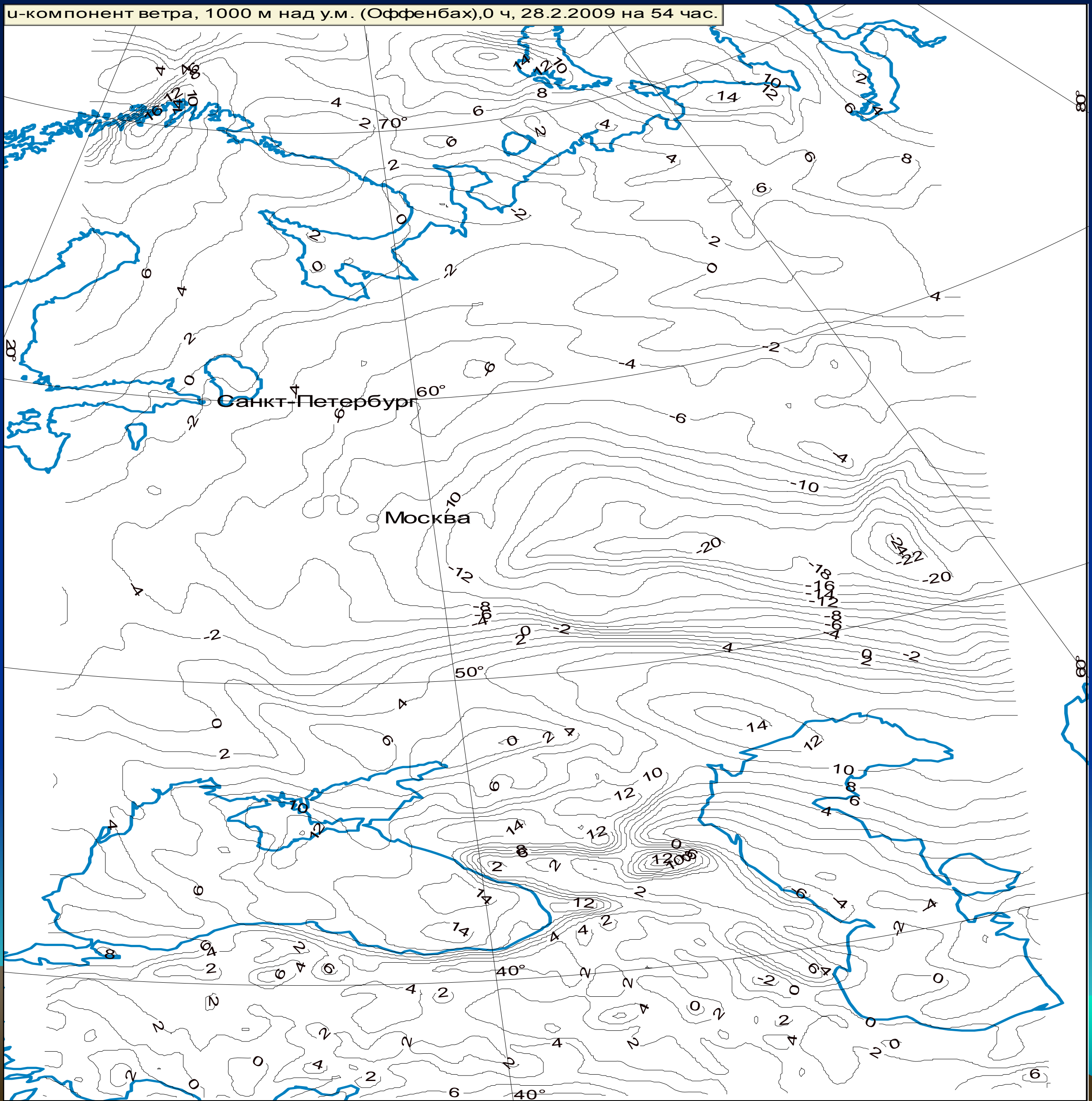
Temperature at 1000m over sea level, 0h, 28.2.2009, 54 h forecast



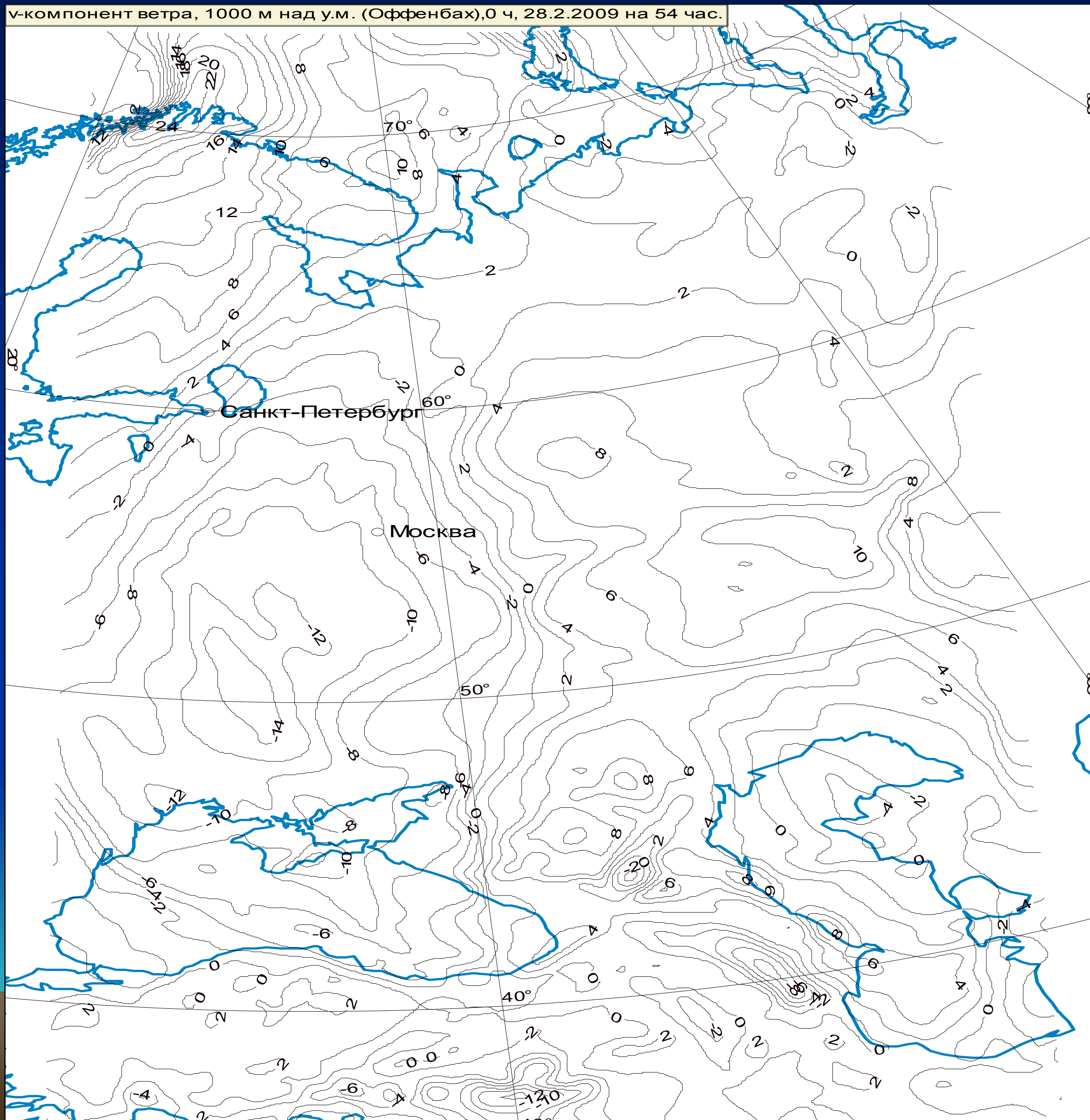
Relative humidity at 1000m over sea level, 0h, 28.2.2009, 54 h forecast



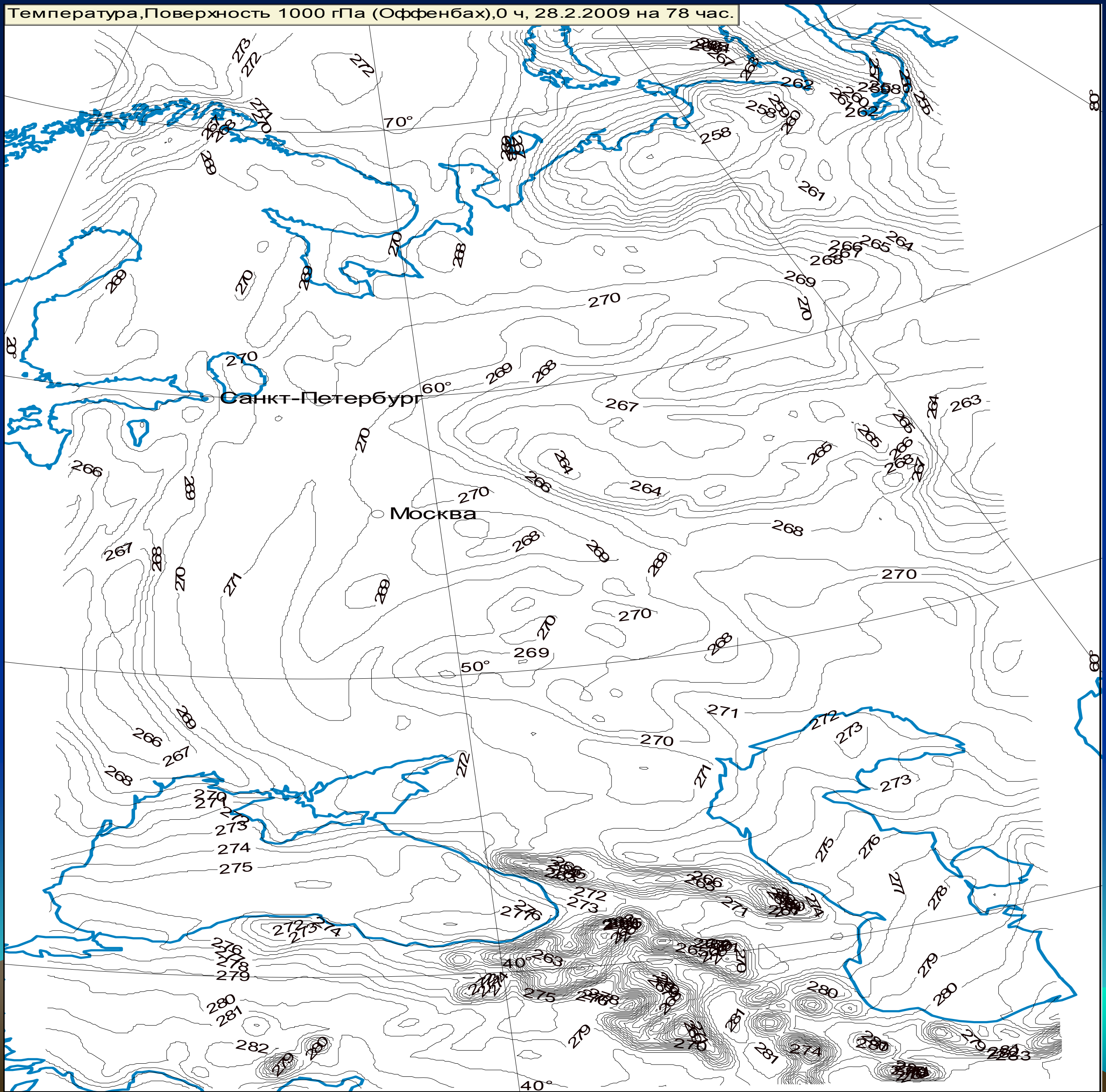
U wind at 1000m over sea level, 0h, 28.2.2009, 54h forecast



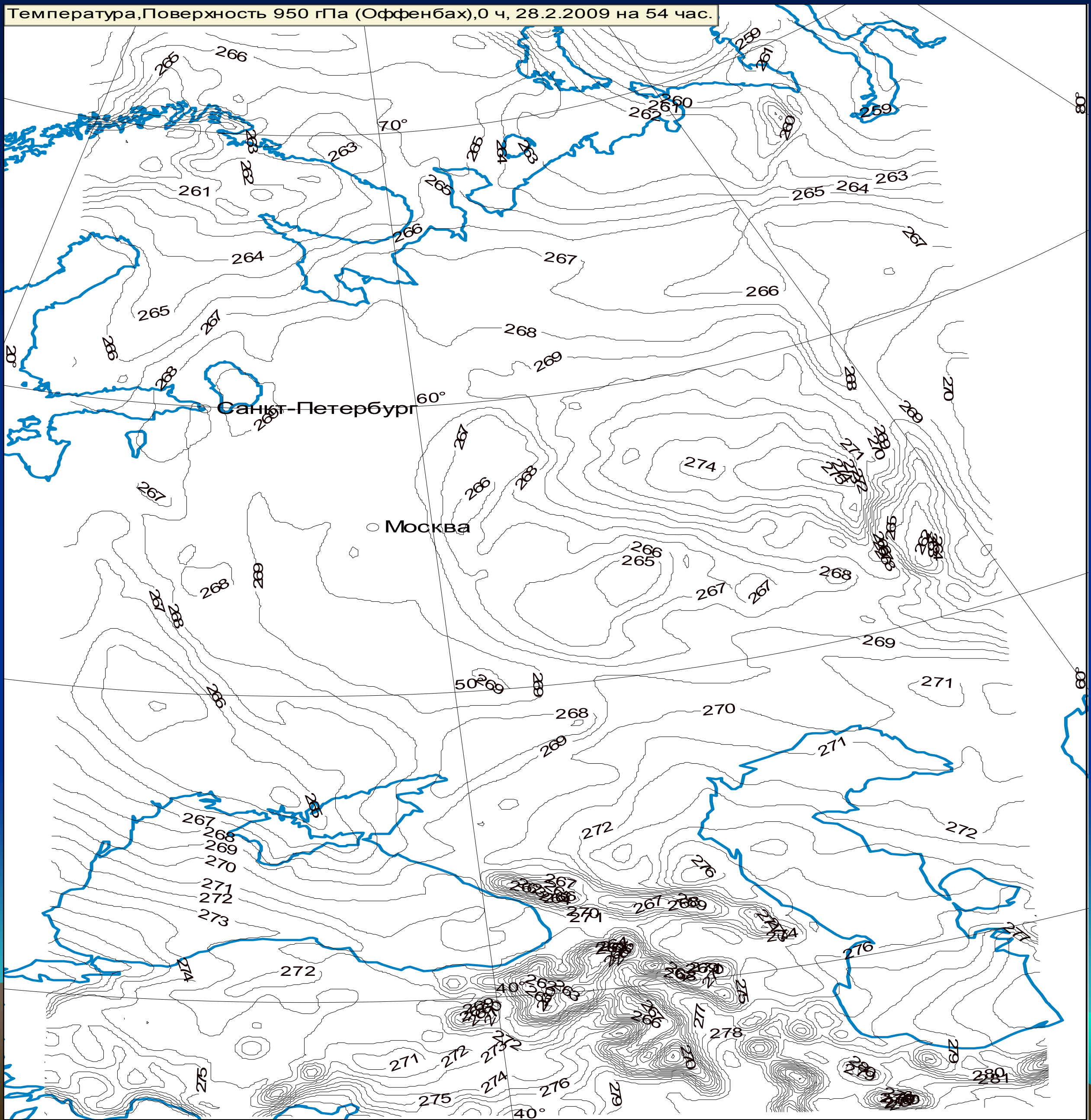
V – wind at 1000m over sea level, 0h, 28.2.2009, 54h forecast



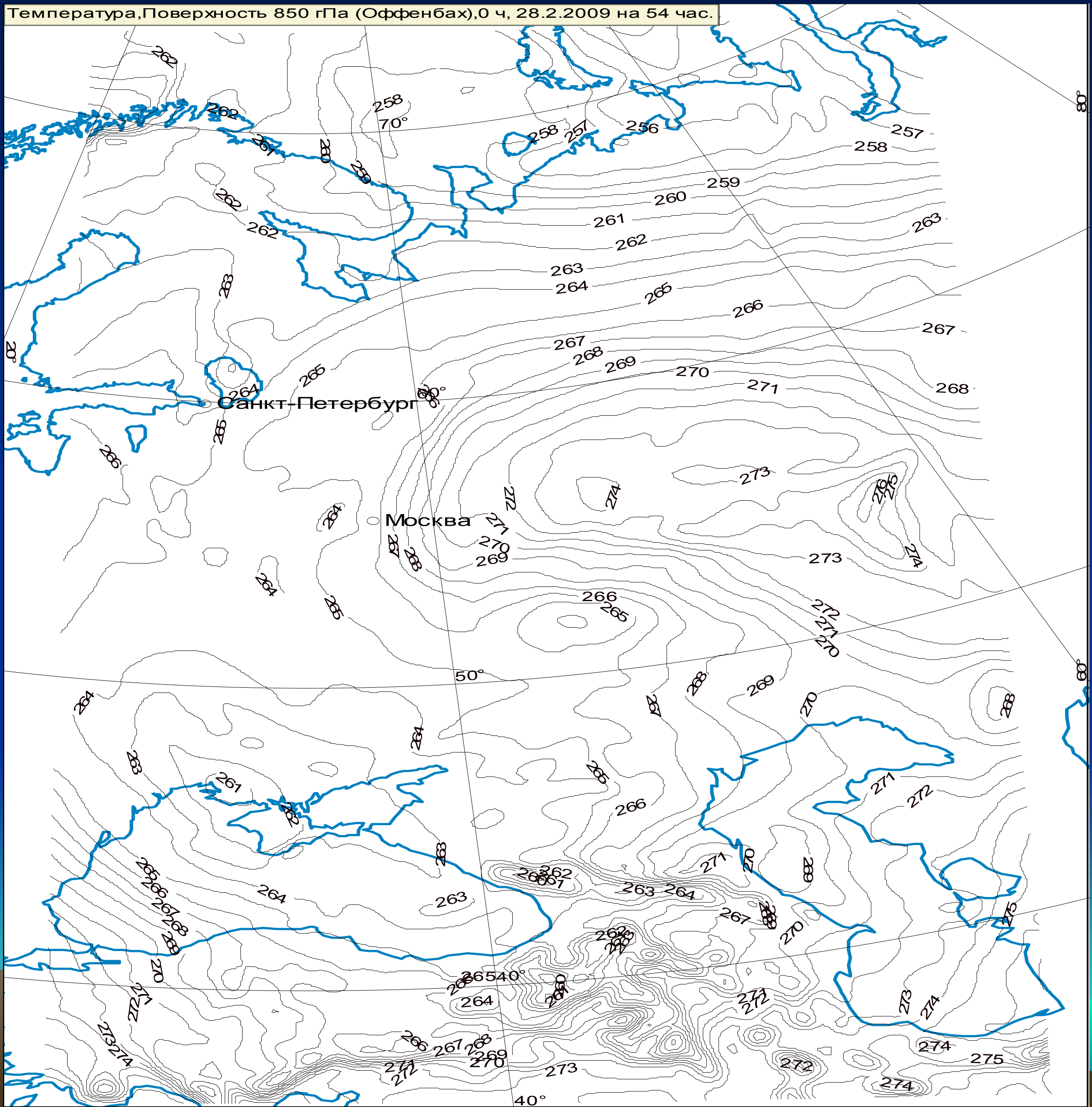
Temperature 1000 gPa, 0h, 28.02.2009, 78h forecast



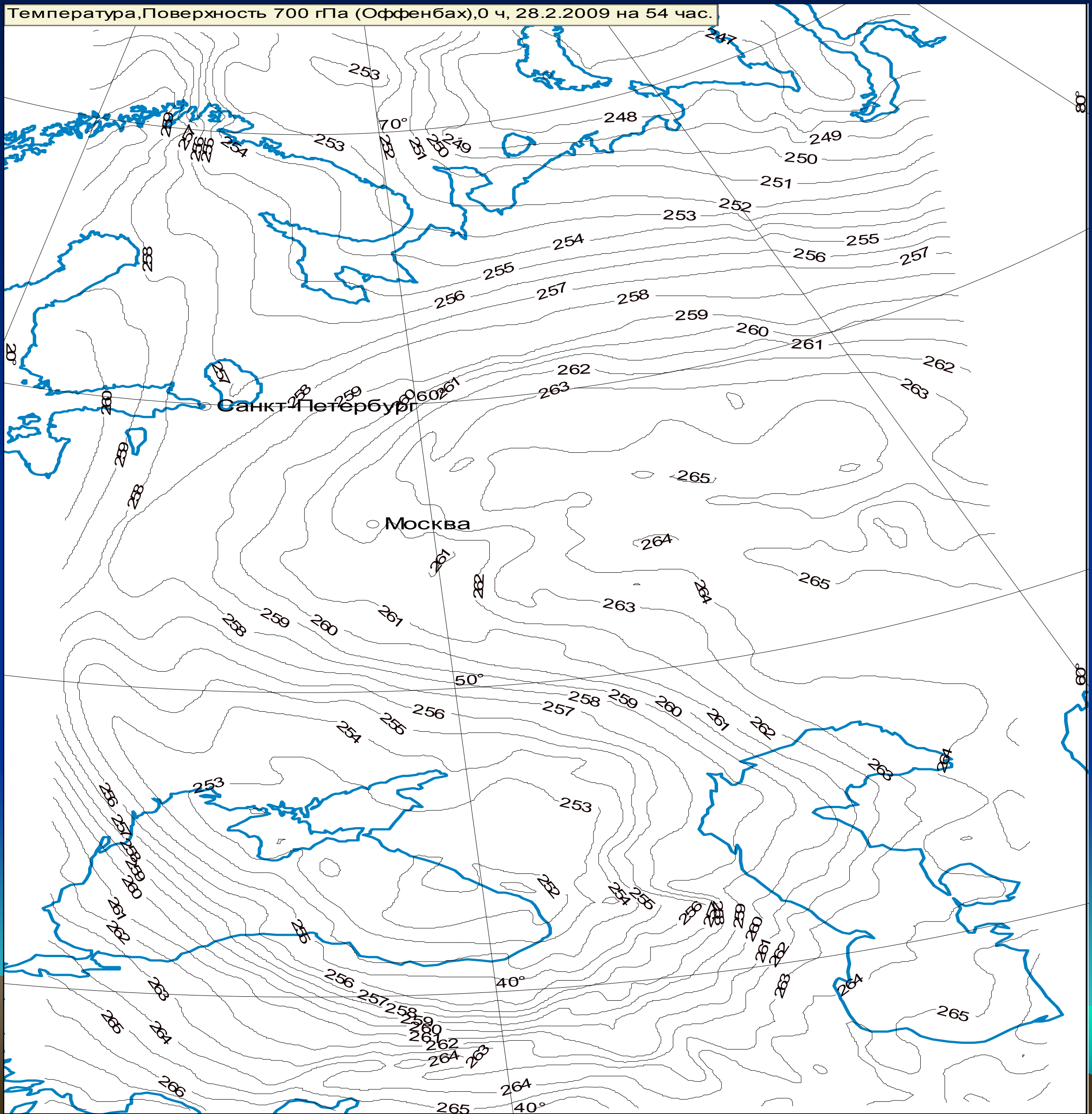
Temperature at 950 gPa, 0h, 28.2.2009, 54 h forecast



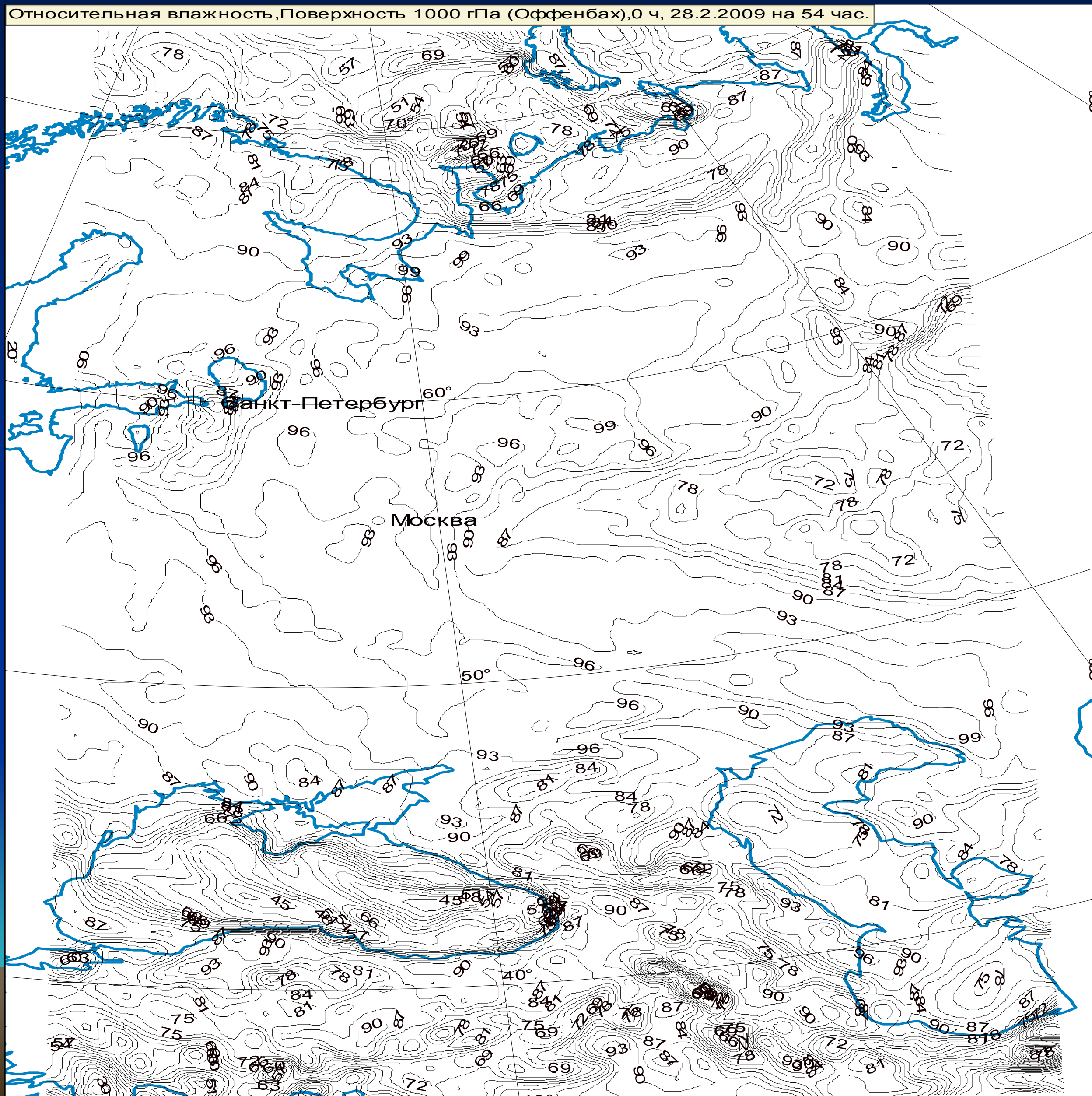
Temperature at 850 gPa, 0h 28.2.2009, 54h forecast



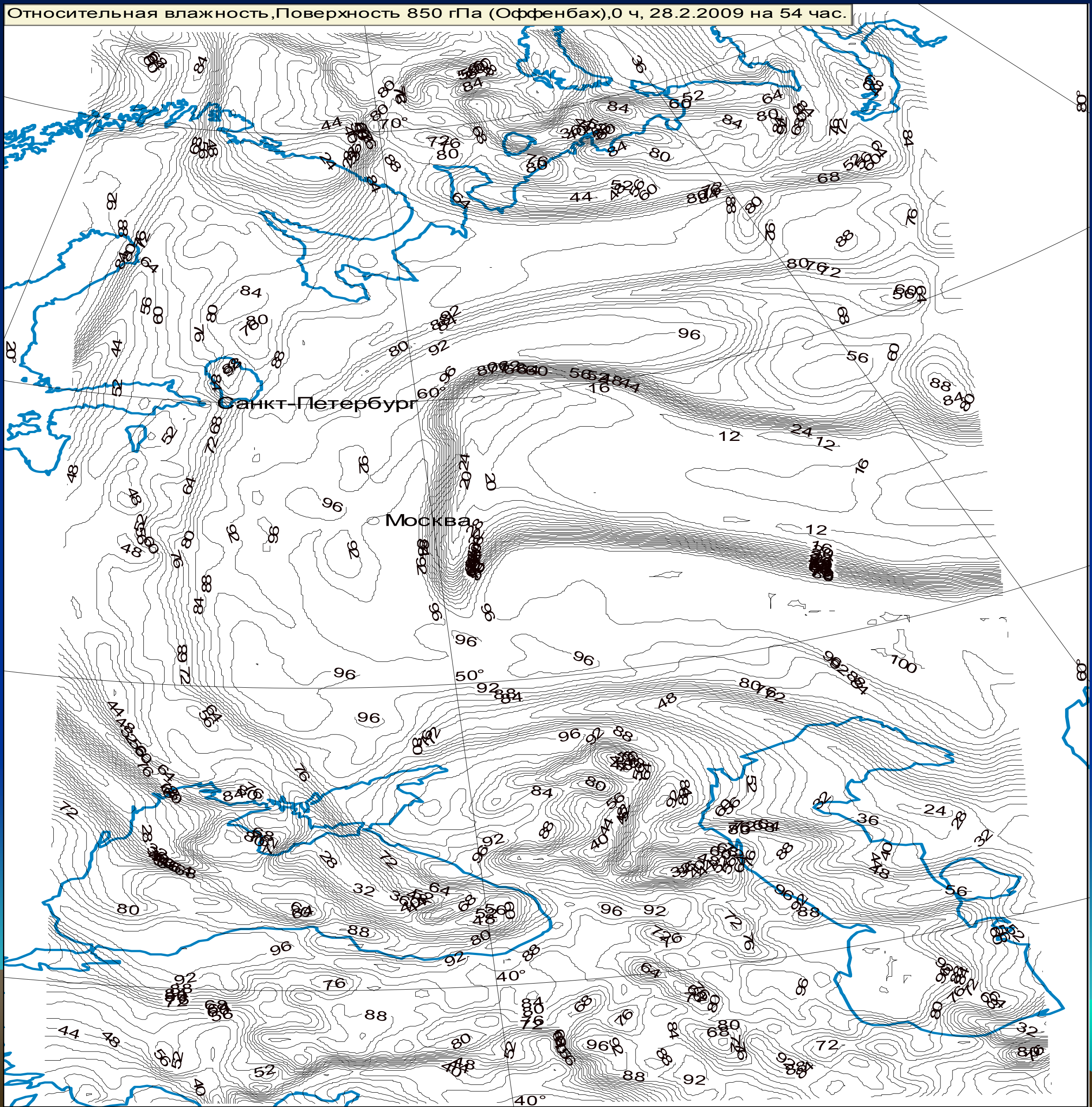
Temperature at 700 gPa, 0h, 28.2.2009, 54h



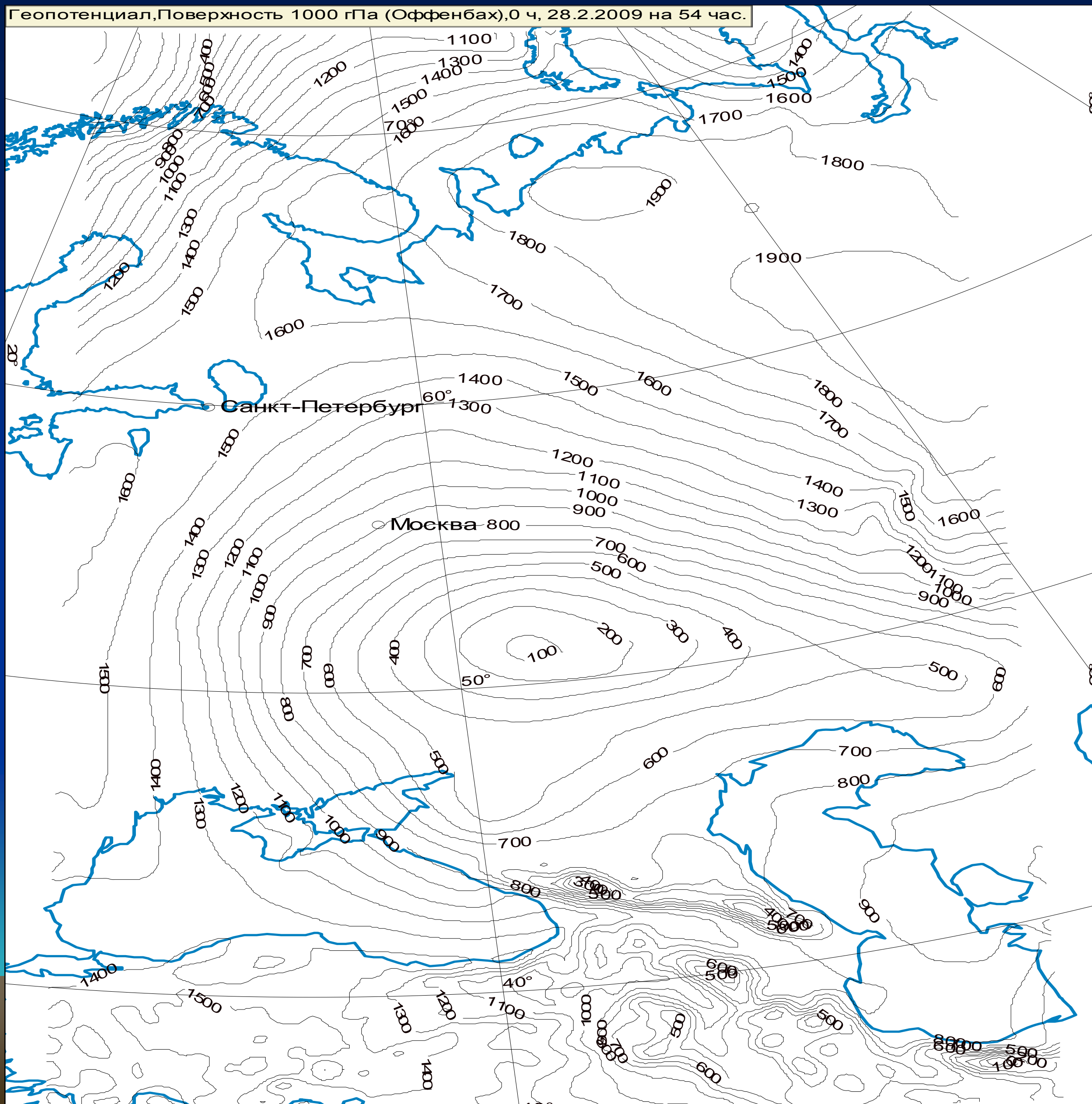
Relative humidity at 1000 gPa, 0h, 28.2.2009, 54h



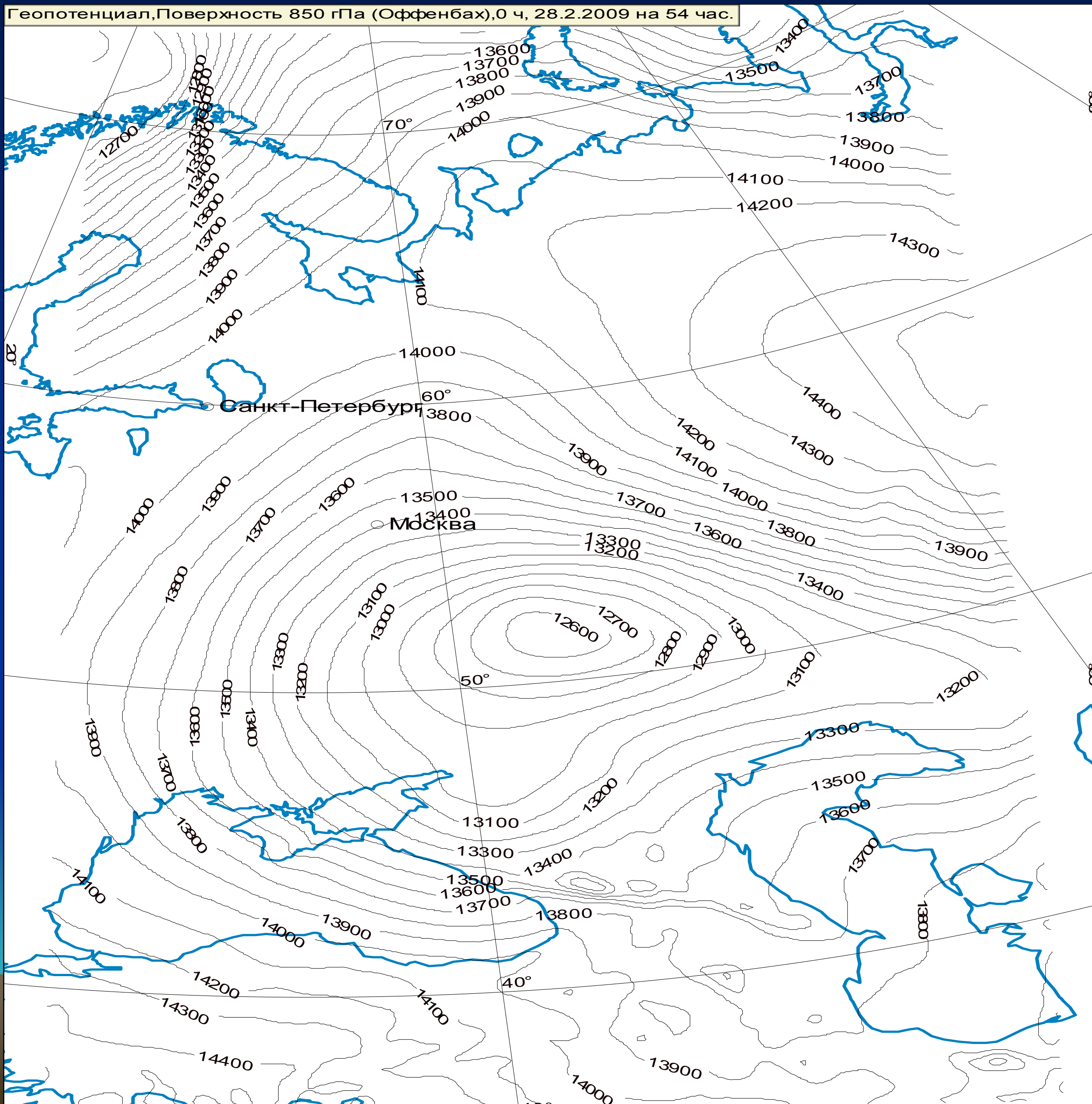
Relative humidity at 850 gPa, 0h, 28.2.2009, 54h



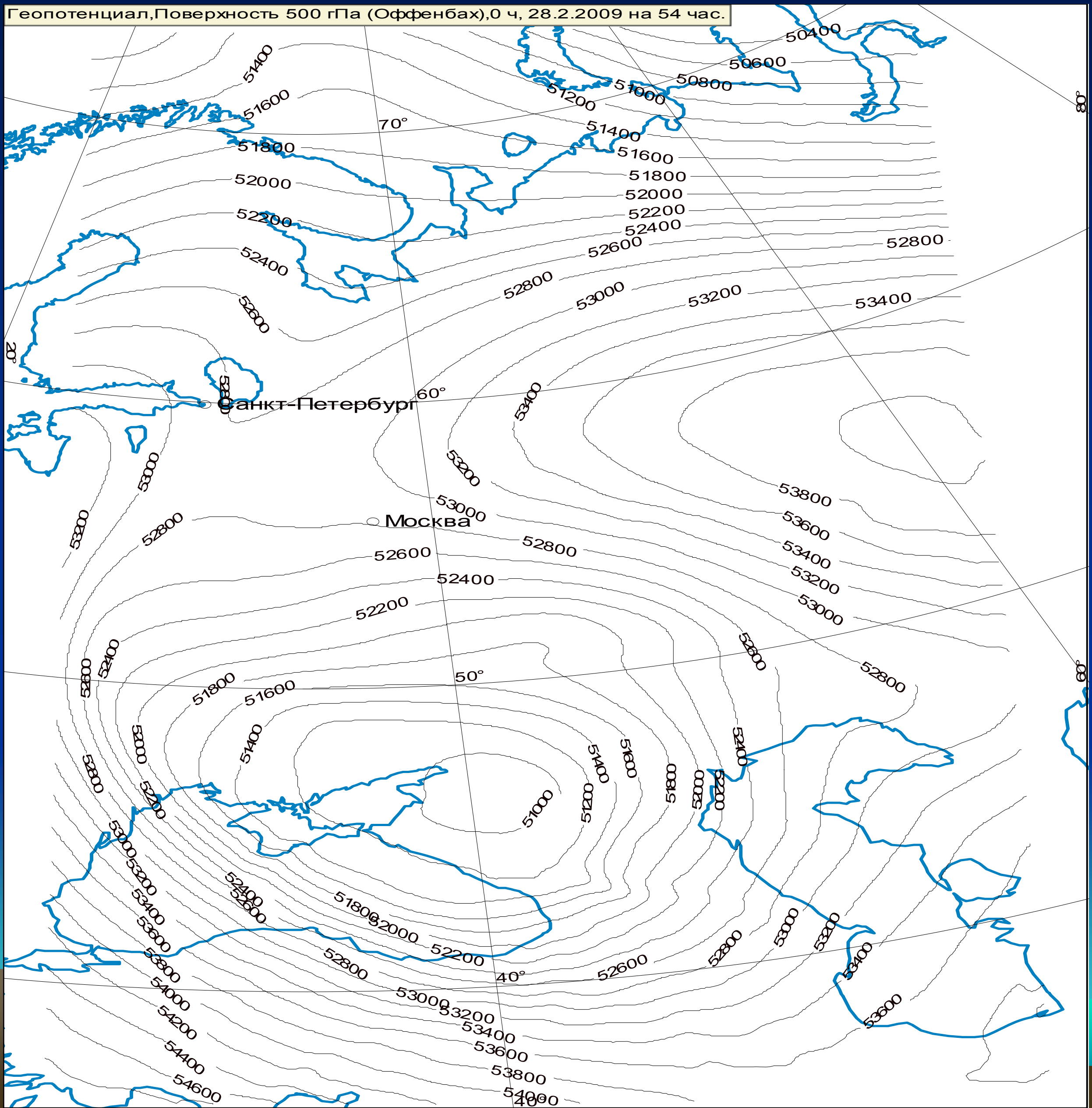
Geopotential, surface 1000 gPa, 0h, 28.2.2009, 54h



Geopotential, surface 850 gPa, 0h, 28.2.2009, 54h



Geopotential, surface 500 gPa, 0h, 28.2.2009, 54h



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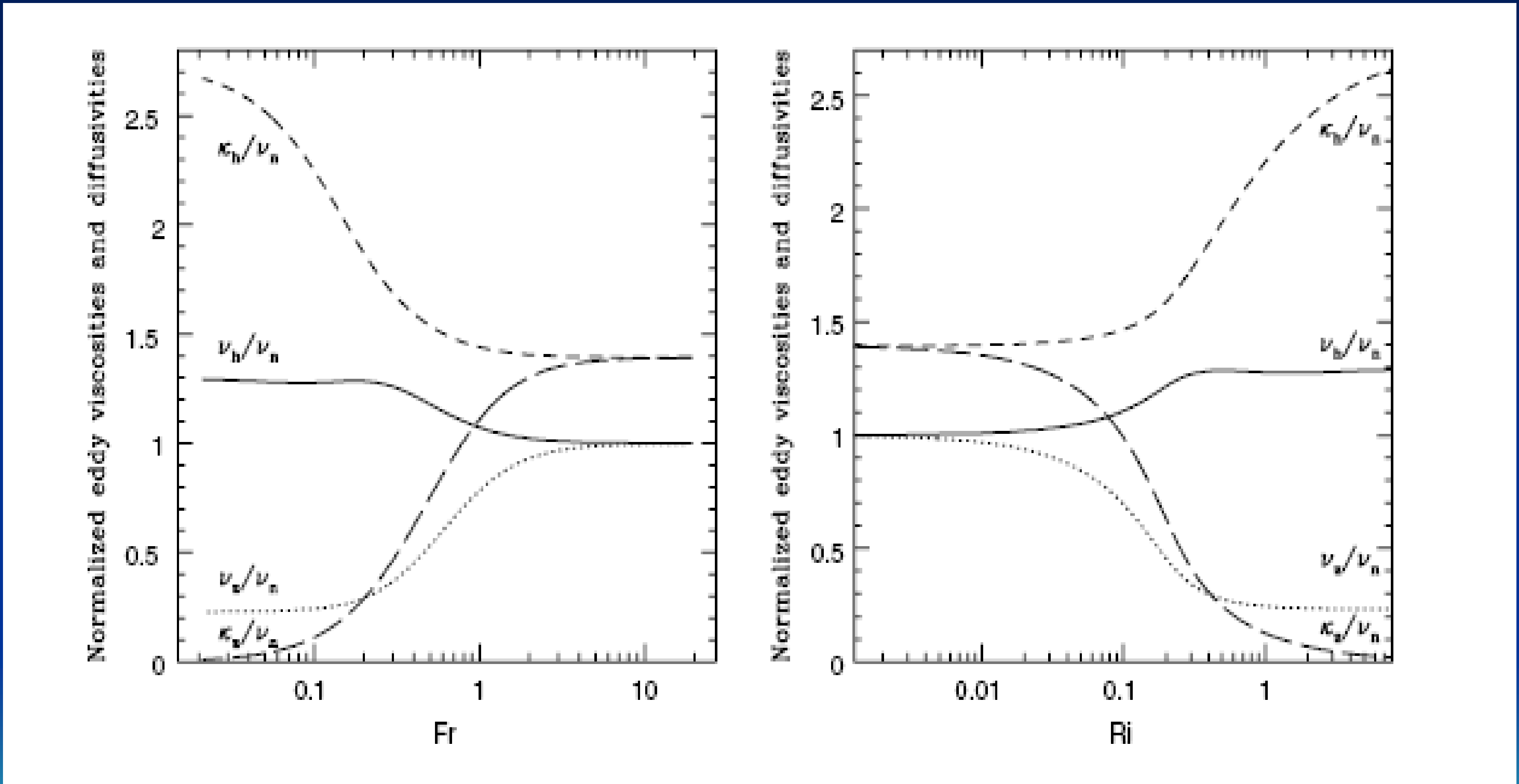
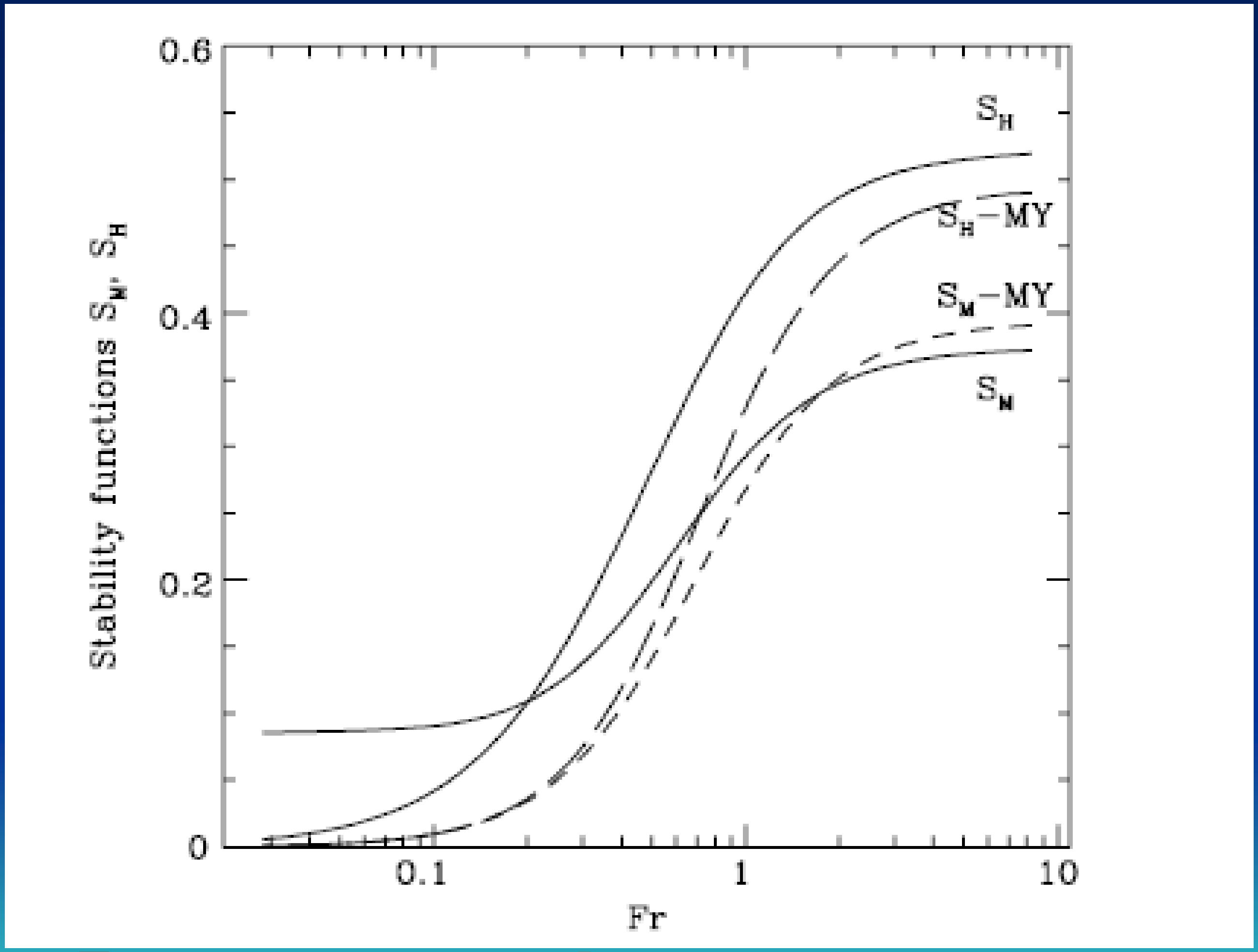
New stability functions on base of the spectral theory of turbulence



$Fr = \varepsilon / NK$

$Ri = N^2 / S^2$

Comparison of stability functions calculated from Mellor-Yamada model and from the spectral theory



Summary

- The method for specification of the non-local turbulent length scale base on BL(89) has been implemented in the *COSMO* model

- The results of 54h and 78h forecasts show realistic fields of T, RH,U,V, P for low and middle atmosphere

- The tests for different stratification and different types of clouds will be run in the nearest months

- Finally, the new stability functions based on the spectral theory of turbulence have been discussed

Thank you for your attention