EGU General Assembly Vienna 2011

Orographic Drag Formation in Nonhydrostatic Pressure-Coordinate Dynamics. Spectral Drag Resonances

M. Zirk, R. Rõõm, University of Tartu, Estonia

1. INTRODUCTION

Surface pressure drag formation theory for nonhydrostatic pressure-coordinate atmospheric dynamics is developed recently. Theory provides formulae for spectral amplitude calculation of surface drag S_k (1) via omega-velocity ω (and its vertical derivative) on the surface. ω is solved numerically from nonhydrostatic wave equation [1], which forms a part of the present theory.

2. SURFACE DRAG

Surface drag force Q per unit mass is defined as:

$$Q = \sum_k |\widehat{\delta}_k|^2 S_k = \frac{1}{2\pi} \int_{-\infty}^{\infty} E_k S_k dk \ ,$$

$$E_k = \frac{2\pi}{\Delta k} \sum_{k' \in \Delta k} |\widehat{\delta}_{k'}|^2 \ ,$$

$$S_k = |k| U_s^2 \Im \left(\frac{\partial \widehat{\Omega}_k}{\partial p} \right)_s \ , \qquad (1)$$

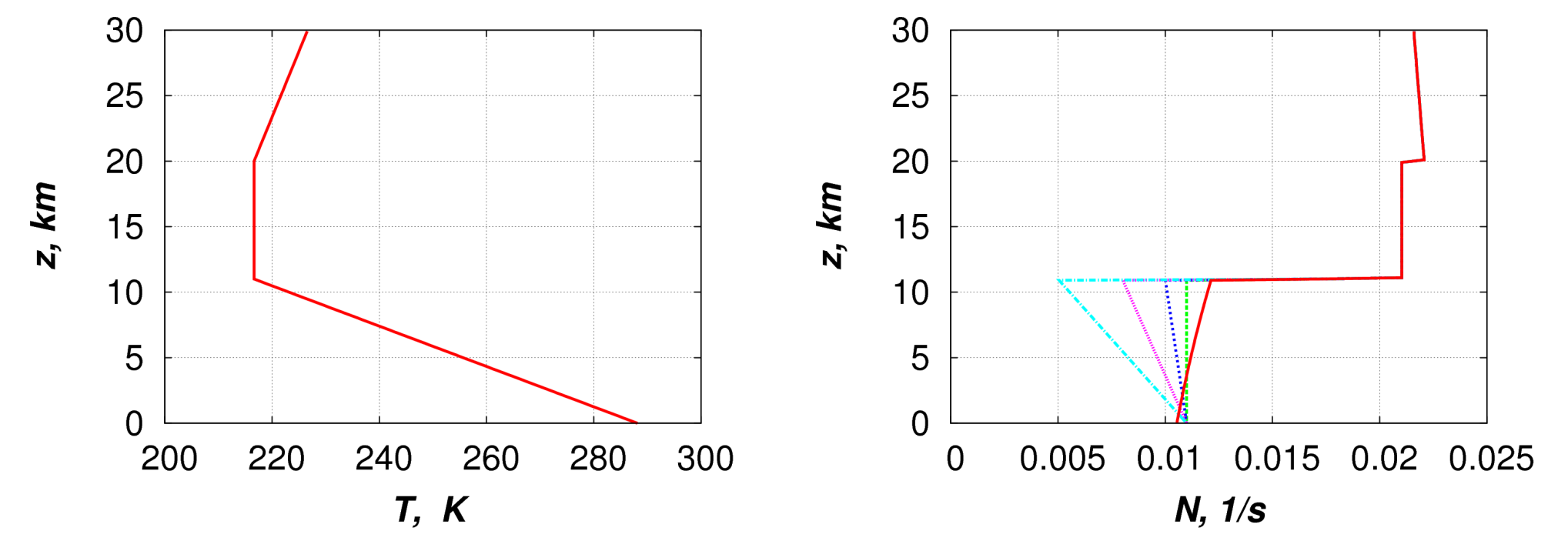
where $|\widehat{\delta}_k|^2$ is the power spectrum of relative orography, E_k is spectral intensity of orography, S_k presents the spectral amplitude of wave drag, U_s is wind on the surface and $\widehat{\Omega}_k$ is the normalized solution of wave-equation for wave-vector k. Note that S_k is independent of orography.

3. EXPERIMENTS

Developed numerical scheme enables modelling of ω and S_k in arbitrary thermally stratified atmosphere with arbitrary wind shear. ω-*wave* fields are computed for Agnesi drumlin orography.

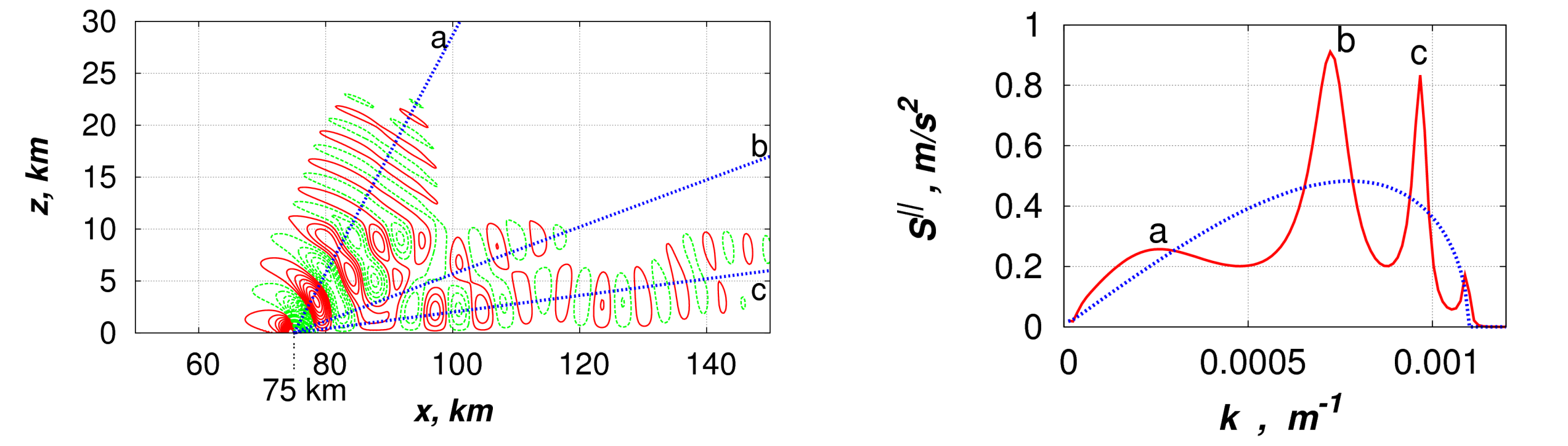
3.1. CONSTANT WIND

In Fig. 2, S_k is presented for climatological US 1976 Standard Atmosphere, which mean temperature and buoyancy frequency are presented in Fig. 1. Narrow sharp resonance peaks occur in S_k spectrum. In Fig. 3, S_k is analyzed for different tropospheric stability N conditions (colored lines in Fig. 1b). It appears that with stability decrease in upper troposphere resonances move towards longer waves in S_k spectrum.

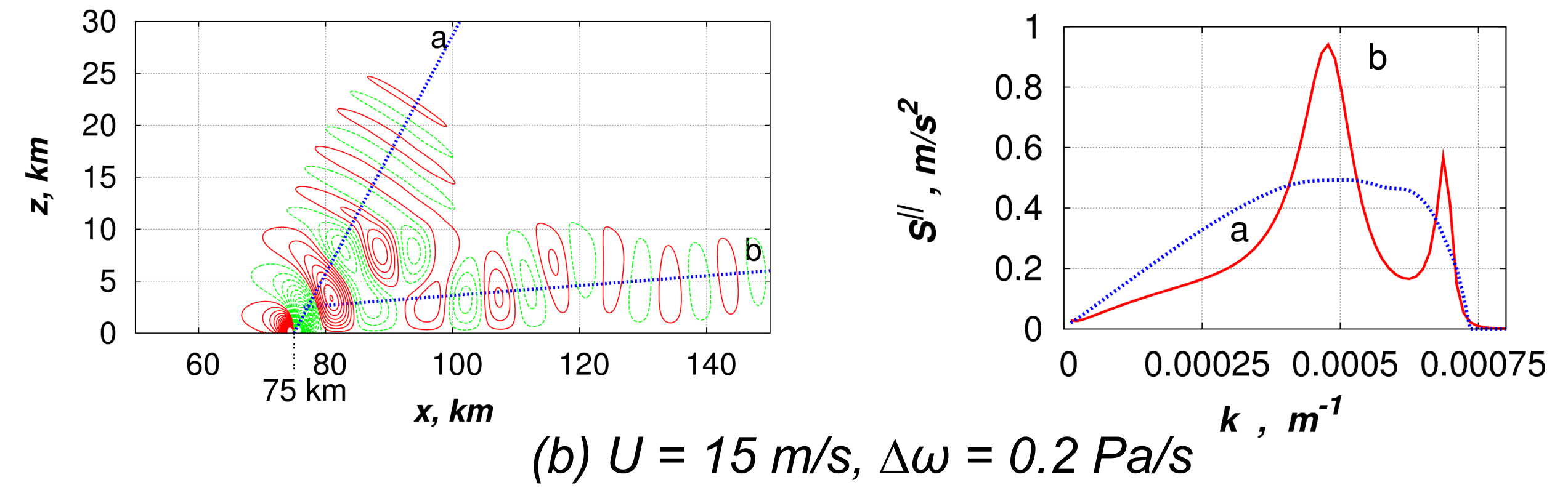


(a) Temperature *(b) N vertical profiles*

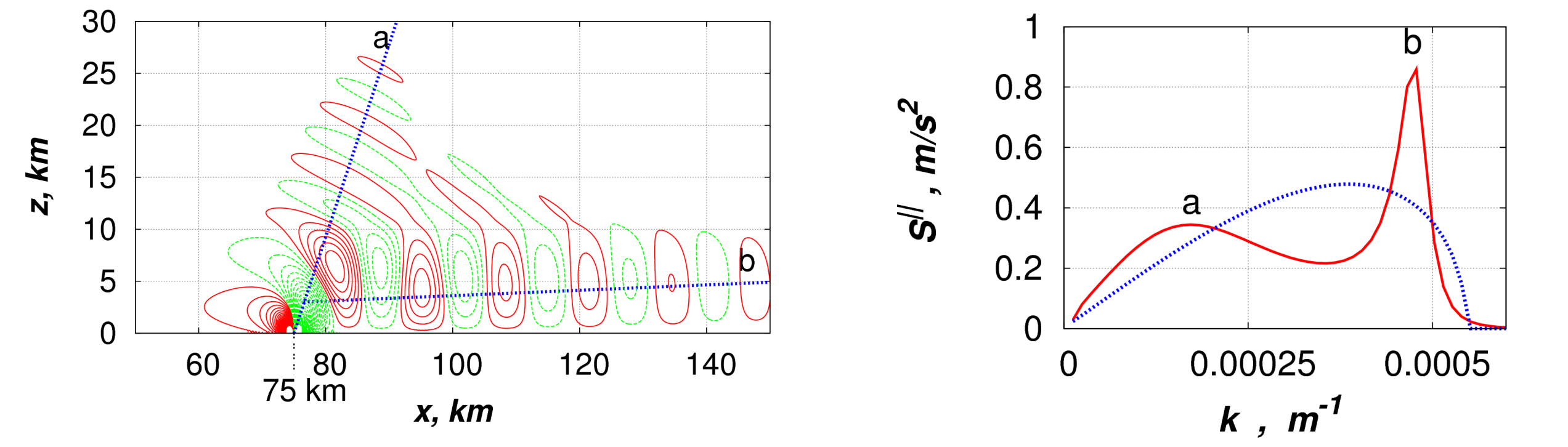
Figure 1. (a) The US 1976 temperature T; (b) the consequent buoyancy frequency N, with red lines. Other colors present various N models of different static stability of the upper troposphere.



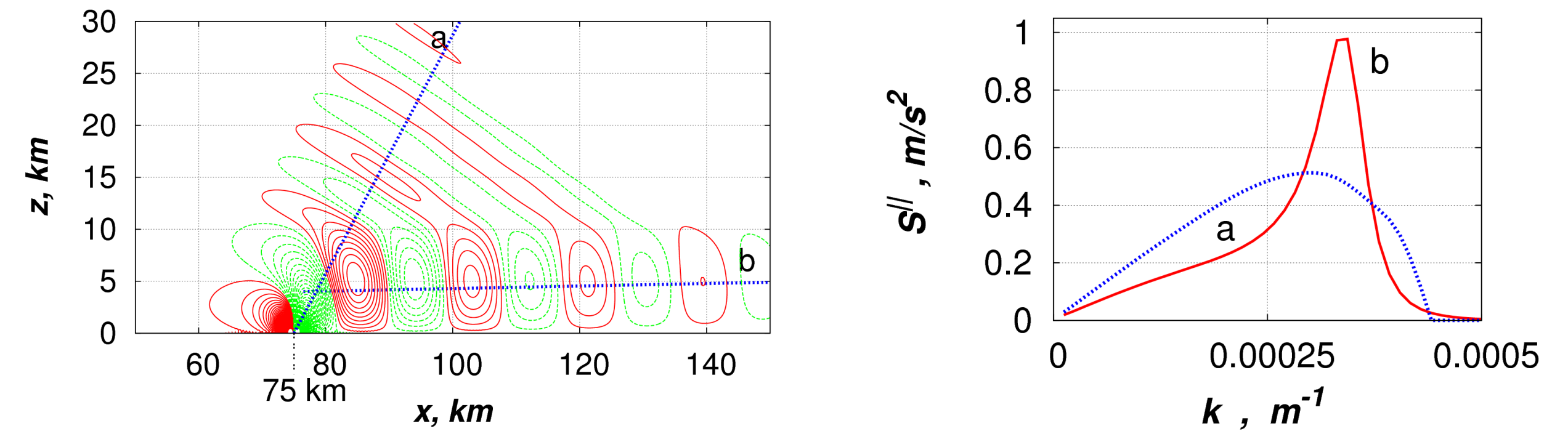
(a) U = 10 m/s, Δω = 0.25 Pa/s



(b) U = 15 m/s, Δω = 0.2 Pa/s

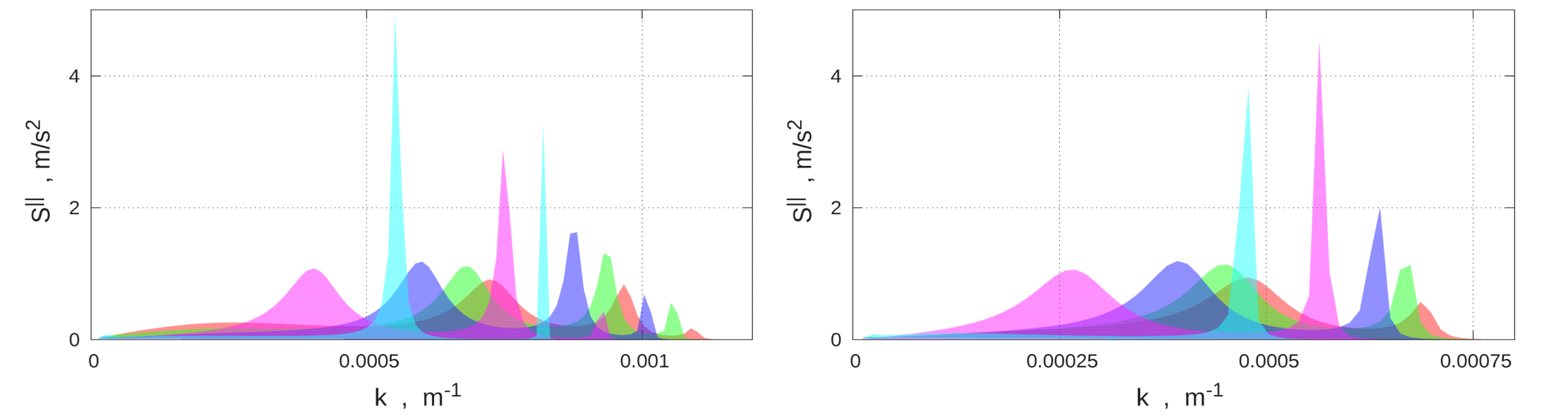


(c) U = 20 m/s, Δω = 0.15 Pa/s

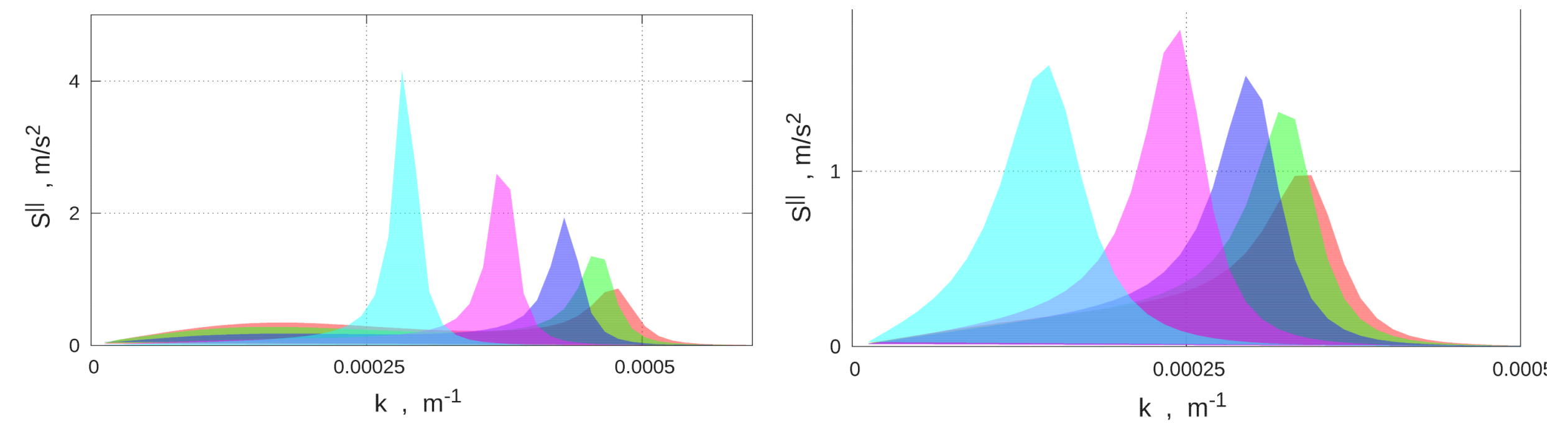


(d) U = 25 m/s, Δω = 0.1 Pa/s

Figure 2. Left: ω-velocity waves. Right: spectral drag S_k for climatological T and N, shown with red lines, blue spectrum corresponds to quasi-homogeneous atmosphere with N = 0.011 m/s.

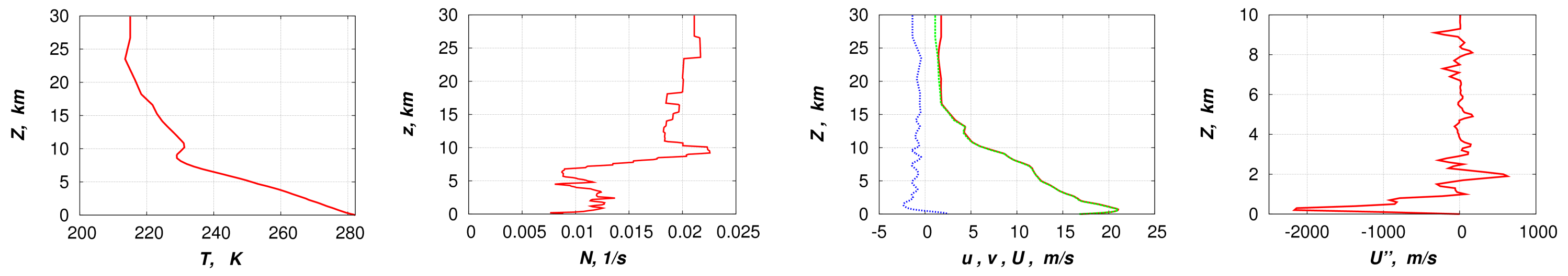


(a) U = 10 m/s *(b) U = 15 m/s*

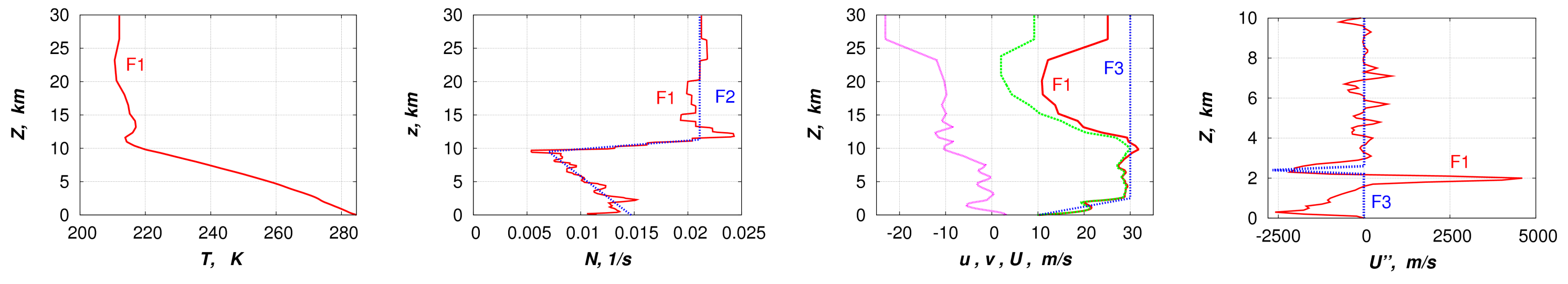


(c) U = 20 m/s *(d) U = 25 m/s*

Figure 3. S_k for different U and tropospheric stability conditions. See Fig 1b for N vertical distribution details.

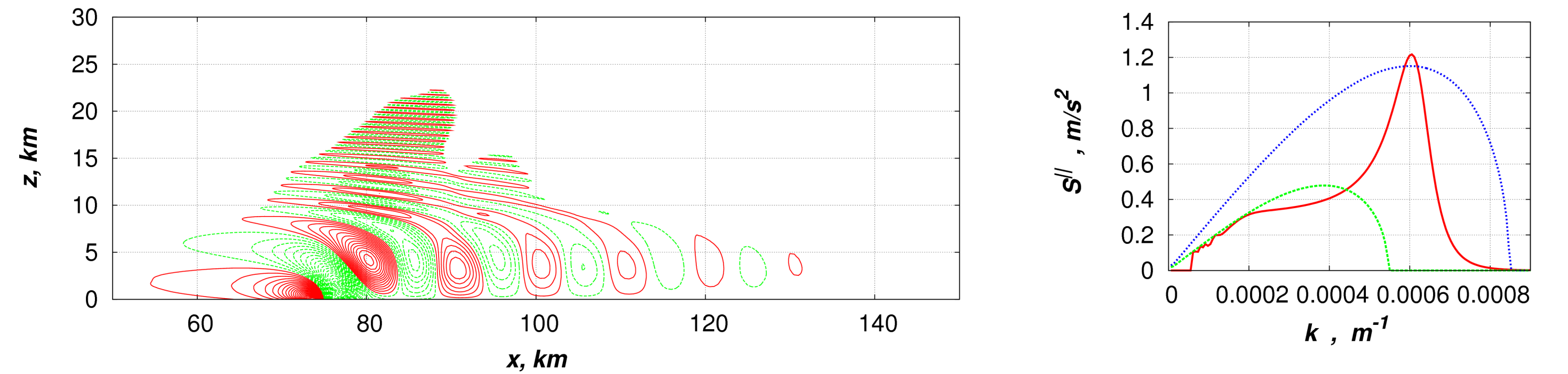


(a) cyclone

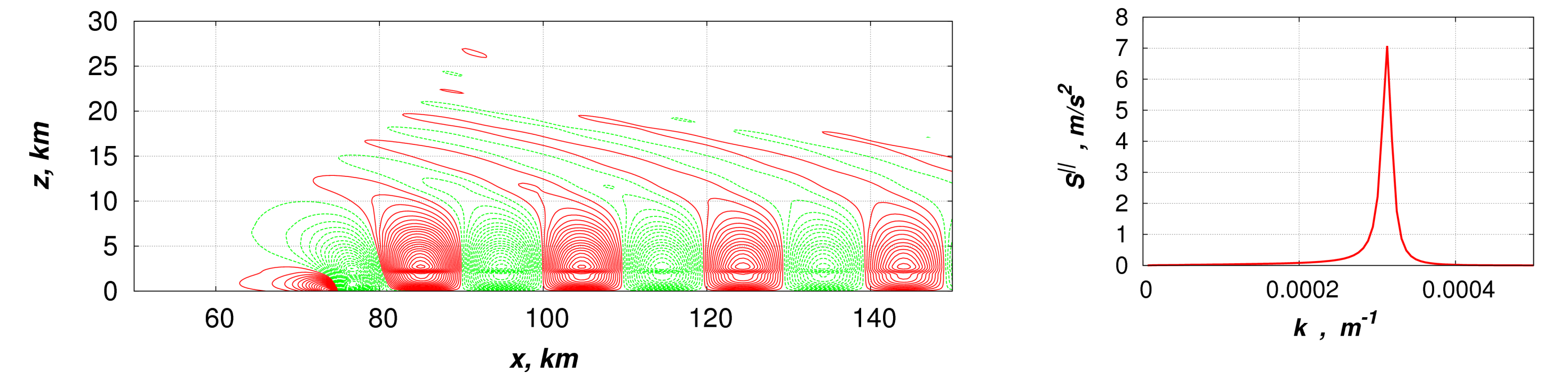


(b) front

Figure 4. Temperature T, buoyant frequency N, wind components and absolute wind vertical curvature U'' in (a) cyclone; (b) front.



(a) cyclone



(b) front

Figure 5. Left: ω-velocity waves (Δω = 0.25 Pa/s) over isolated drumlin in (a) cyclone; (b) front. Right: S_k for vertical distribution of T, N, U and U'', shown in Fig. 4.

In Fig. 6, S_k is besides the original front (F1) modelled for modified stratification parameters, as described in Table 1. Main drag resonance amplifier is small stability N in the upper troposphere. The second booster is large U'' at PBL top.

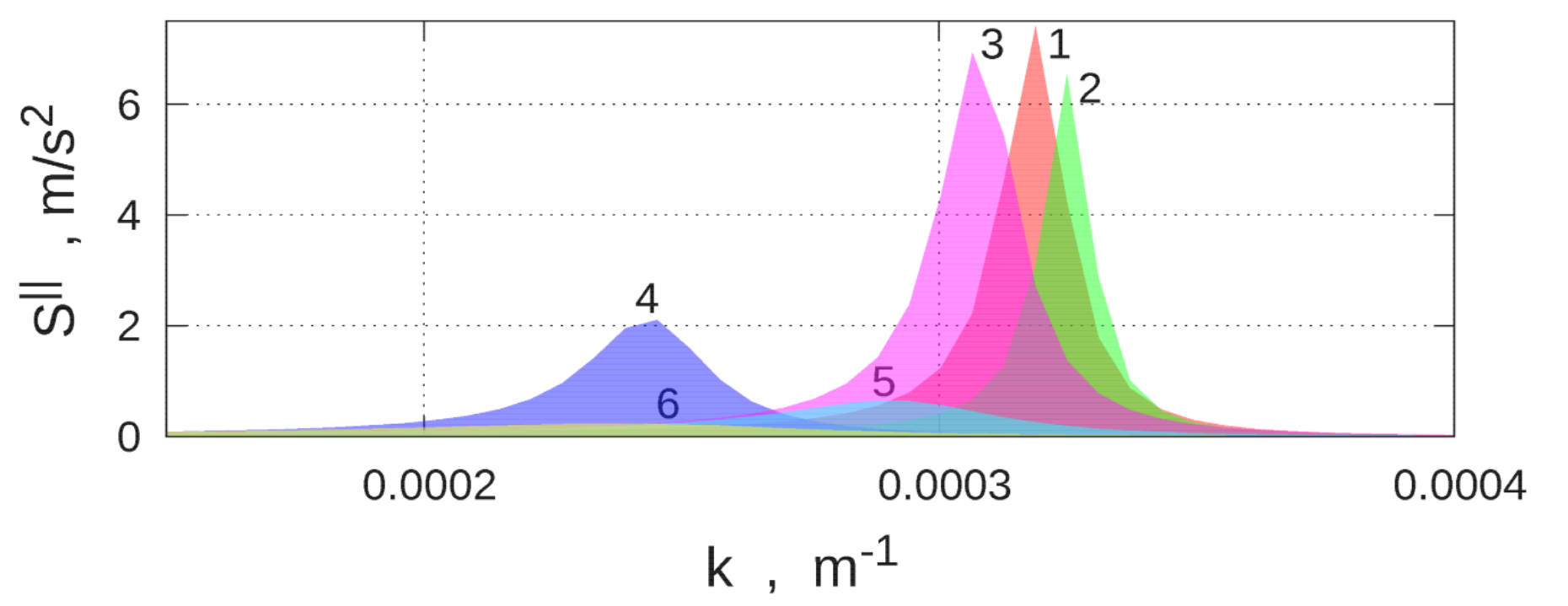


Figure 6. S_k in front F1 (red polygone), and for different model fronts.

3.2. VARIABLE WIND

In the real atmosphere wind also varies with height, which brings along further changes in the S_k and its location. In Fig. 4, vertical stratification characteristics are presented for typical cyclone and front. Miscellaneous smoothed models of N, U and U'' (labelled as F2 and F3) are introduced in frontal case (Fig. 4b).

S_k and corresponding wave field in cyclone and front are presented in Fig 5. Wave field in cyclone (Fig 5a) has a downstram scattered trapped wave-train (corresponding to resonance wave-number) and an intensive upward radiated beam. It appears that small flutter in vertical T, N and U'' distributions have little influence on the S_k and their removal does not produce substantial changes.

Wave field in front is characterized by large PBL wind shear and U'' values. These wind features cause specific drag behavior, different from cyclone. Waves are almost completely trapped in the troposphere with weak refraction of wave-tops into stratosphere.

Table 1. Front models used in Fig. 6.

Graph	T	N	U	U''
1, Red	F1	F1	F1	F1
2, Green	F1	F1	F3	F3
3, Lilac	F1	F2	F1	F1
4, Blue	F1	F1	F3	$U'' \equiv 0$
5, Cyan	US'76	US'76	F3	F3
6, Yellow	US'76	US'76	F3	$U'' \equiv 0$

4. CONCLUSIONS

- Jump of N on tropopause is responsible for wave reflection, trapped wave-train origin and spectral pressure-drag resonance formation.
- N decrease in upper troposphere causes resonance strenghtening and mono-wave arrival in trapped wave spectrum.
- Large negative wind curvature is the second mayor spectral drag and wave-field moderator.

ACKNOWLEDGEMENTS

This presentation was supported by Estonian Science Foundation (Grant 7478) and Estonian Research Council (Targeted Financing Project SF0180038s08).

REFERENCES

[1] Rõõm R., Zirk M., 2007. An Efficient Solution Method for Buoyancy-Wave Equation at Variable Wind and Temperature. *Mon. Weather Rev.*, **135**, 3633 - 3641.