Effect of an inversion layer on the propagation of a cold atmospheric front over a steep obstacle

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Changes in surface ozone concentration after atmospheric front propagation (372 fronts,1989-1993, Tomsk)

	Front type	Decrease %	Increase %	No change %
	Cold	70	24	6
	Warm	43	53	4
	Occlusion	35	48	17
	Surface cold	47	37	16
	Upper warm	12	56	32
	All types	49	40	11

(Belan B.D., Ozone in the troposphere., IAO SB RAS,Tomsk,2010.-488 pp.)

$$\frac{dU}{dt} + \frac{\partial P}{\partial x} = f_1(V - V_g) - f_2 W + R_u,$$

$$\frac{dV}{dt} + \frac{\partial P}{\partial y} = -f_1(U - U_g) + R_\upsilon,$$

$$\frac{dW}{dt} + \frac{\partial P}{\partial z} + \frac{gP}{C_s^2} = f_2 U + g\,\frac{G^{1/2}\bar{\rho}\theta'}{\theta} + R_\varpi$$

$$\frac{d\theta}{dt} = R_\theta,$$

$$\frac{ds}{dt} = R_s,$$

$$\frac{1}{C_s^2}\frac{\partial P}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} + \frac{\partial W}{\partial z} = \frac{\partial}{\partial t}\left(\frac{\bar{\rho}\theta'}{\theta}\right)$$

$$U = \bar{\rho}u, V = \bar{\rho}\upsilon, P = \bar{\rho}p', \; W = \bar{\rho}\omega$$

$$\delta\tau U + \frac{\partial}{\partial x} P + \frac{\partial}{\partial \xi}(G^{13}\, P) = -ADVU$$

$$\delta\tau V + \frac{\partial}{\partial y} P + \frac{\partial}{\partial \xi}(G^{13}\, P) = -ADVV$$

$$\delta\tau W + \frac{1}{G^{1/2}} \frac{\partial P^{\tau\beta}}{\partial \xi} + \frac{g P^{\tau\beta}}{Cs^2} = BUOY - ADVW$$

$$\frac{1}{Cs^2}\, \delta\tau P + \frac{\partial}{\partial x} \bar{U}^{\tau\gamma} + \frac{\partial}{\partial y} \bar{V}^{\tau\gamma} + \frac{\partial}{\partial \xi}(G^{13}\, \bar{U}^{\tau\gamma}) + \frac{\partial}{\partial \xi}(G^{13}\, \bar{V}^{\tau\gamma}) + \frac{1}{G^{1/2}} \frac{\partial \bar{W}^{\tau\beta}}{\partial \xi} = PFT$$

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$$\frac{dU}{dt} + \frac{\partial P}{\partial x} + \frac{\partial (G^{13}P)}{\partial \eta} = f_1(V - V_g) - f_2 W + R_u,$$

$$\frac{dV}{dt} + \frac{\partial P}{\partial y} + \frac{\partial (G^{23}P)}{\partial \eta} = -f_1(U - U_g) + R_v,$$

$$\frac{dW}{dt} + \frac{1}{G^{1/2}}\frac{\partial P}{\partial \eta} + \frac{gP}{C_s^2} = f_2 U + g\frac{G^{1/2}\bar{\rho}\theta'}{\bar{\theta}} + R_w,$$

$$\frac{d\theta}{dt} = R_\theta,$$

$$\frac{ds}{dt} = R_s,$$

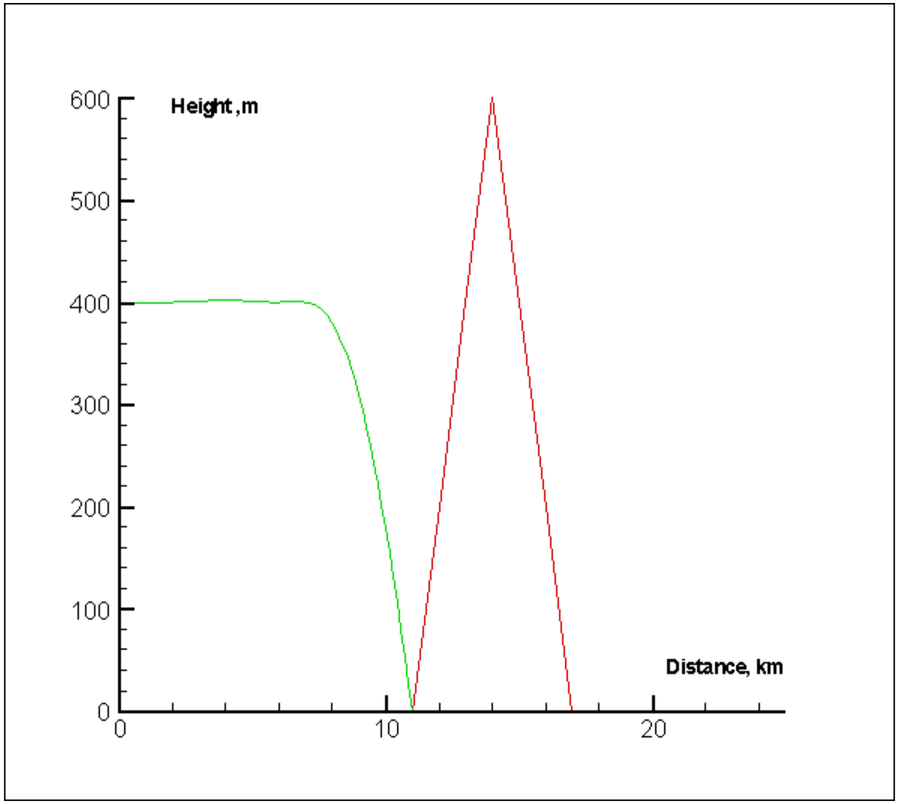
$$\frac{1}{C_s^2}\frac{\partial P}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} + \frac{\partial}{\partial \eta}\left(G^{13}U + G^{23}V + \frac{1}{G^{1/2}}W\right) = \frac{\partial}{\partial t}\left(\frac{G^{1/2}\bar{\rho}\theta'}{\bar{\theta}}\right).$$

$\bar{\rho}G^{1/2}u$, $V = \bar{\rho}G^{1/2}v$, $W = \bar{\rho}G^{1/2}w$, $P = G^{1/2}p'$, where p', θ' are deviations from the state pressure $\bar{p}$ and potential temperature $\bar{\theta}$, s is specific humidity, C_s is the sound speed, u_g, v_g are the components of geostrophic wind representing the synoptic part of ressure, η is a terrain-following coordinate transformation:

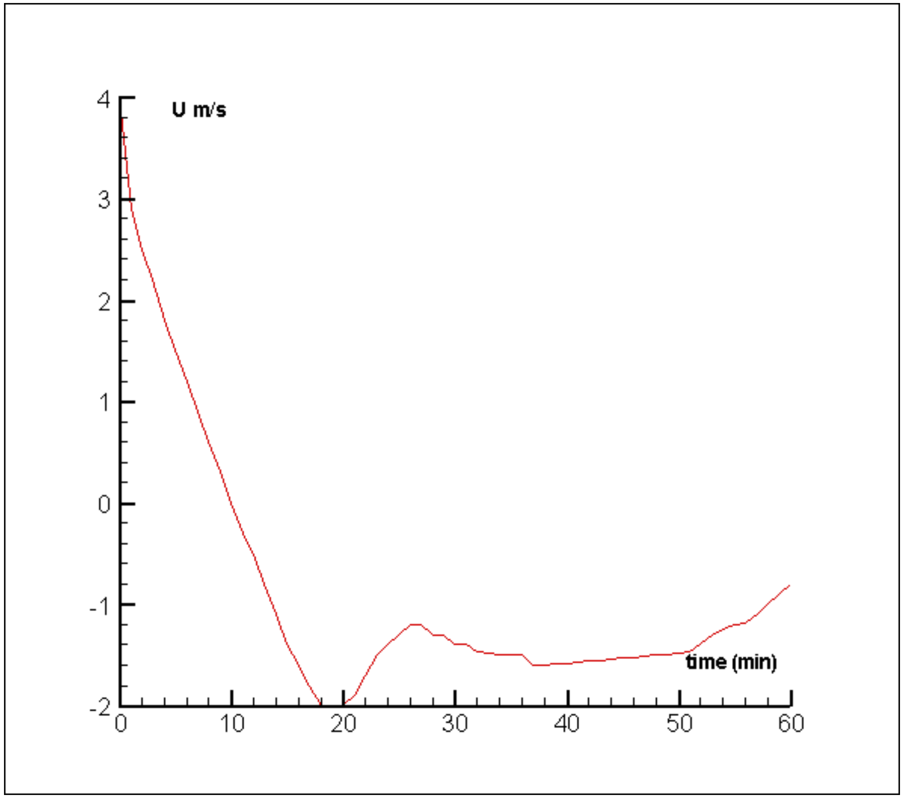
$$\eta = \frac{H(z - z_s)}{(H - z_s)},$$

the surface height, H is the height of the top of the model domain. Here $H = \text{const}$,

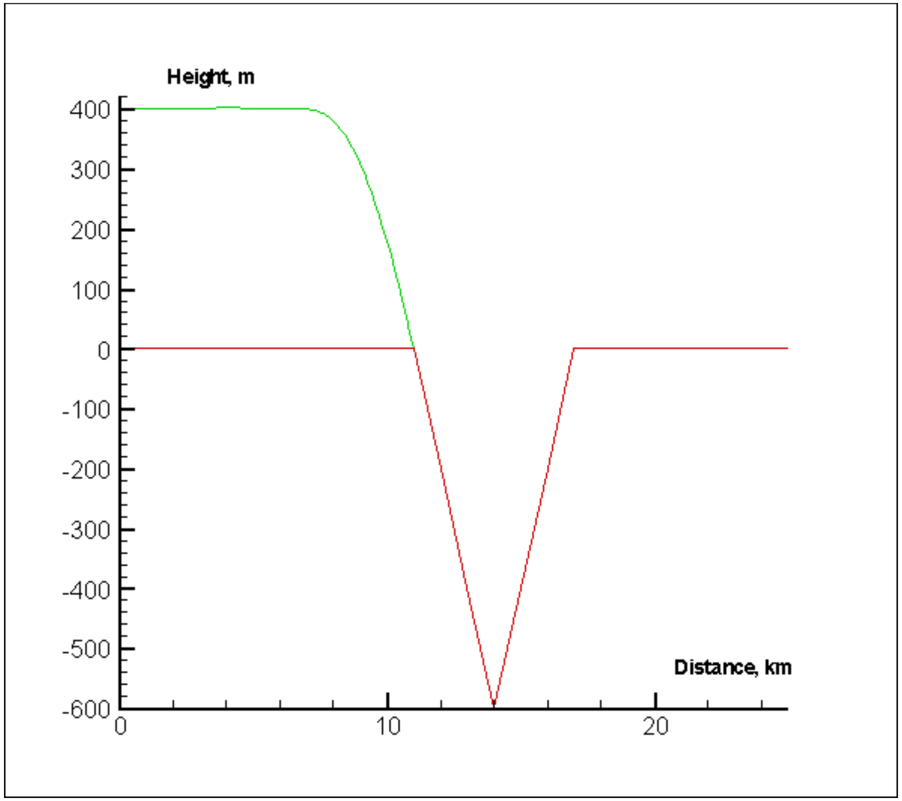
$$G^{1/2} = 1 - \frac{z_s}{H}, \quad G^{13} = \frac{1}{G^{1/2}}\left(\frac{\eta}{H} - 1\right)\frac{\partial z_s}{\partial x}, \quad G^{23} = \frac{1}{G^{1/2}}\left(\frac{\eta}{H} - 1\right)\frac{\partial z_s}{\partial y}.$$



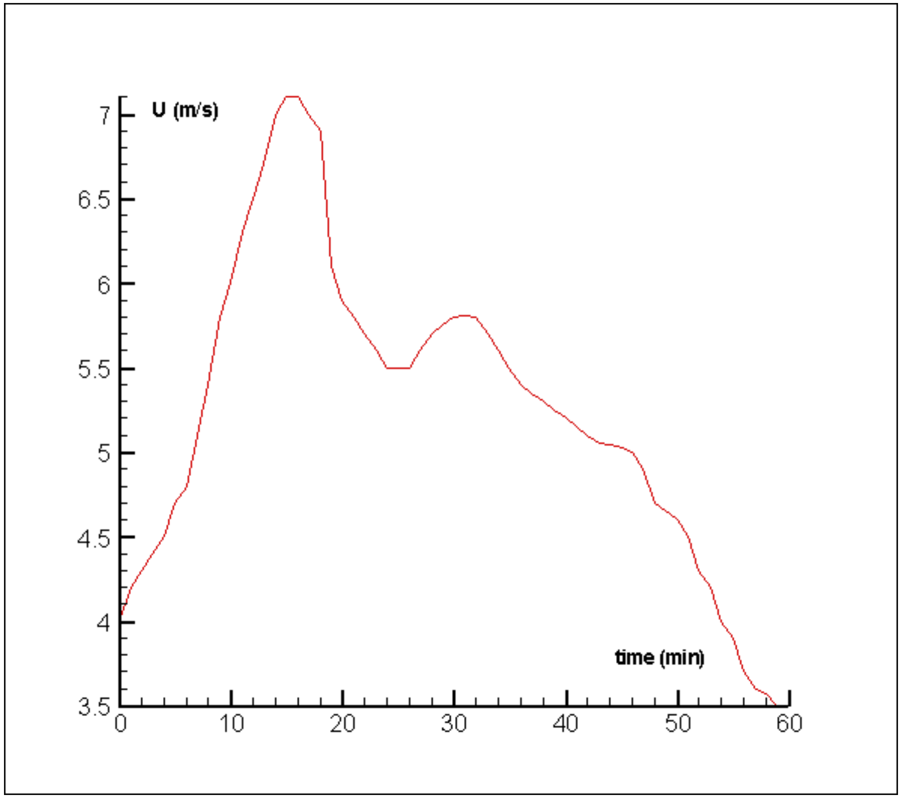
Location of the front as it meets with the obstacle : hill
Neutral stratification



Normal to the front velocity component: hill
Neutral stratification.

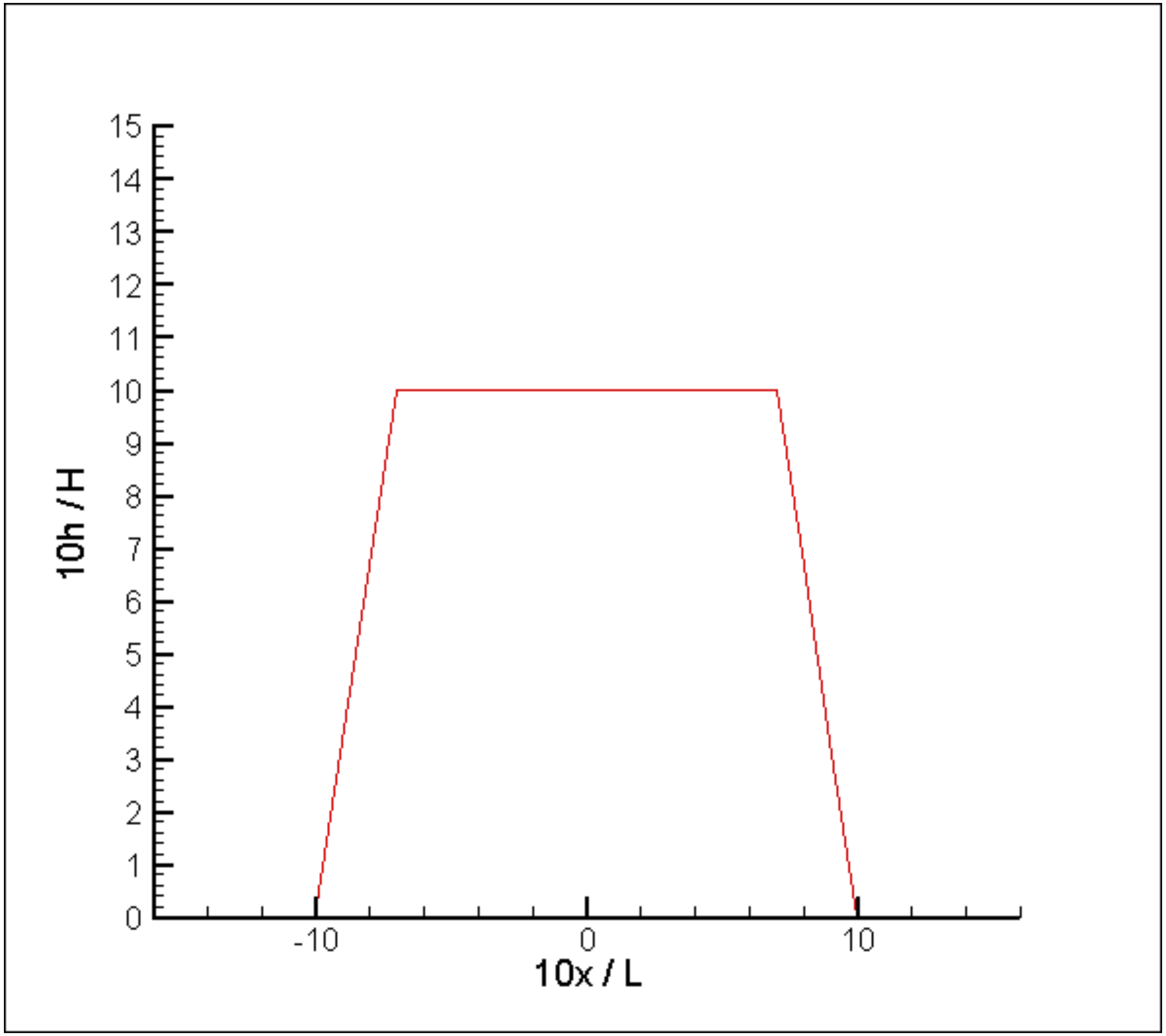


Location of the front as it meets with the obstacle: valley
Neutral stratification

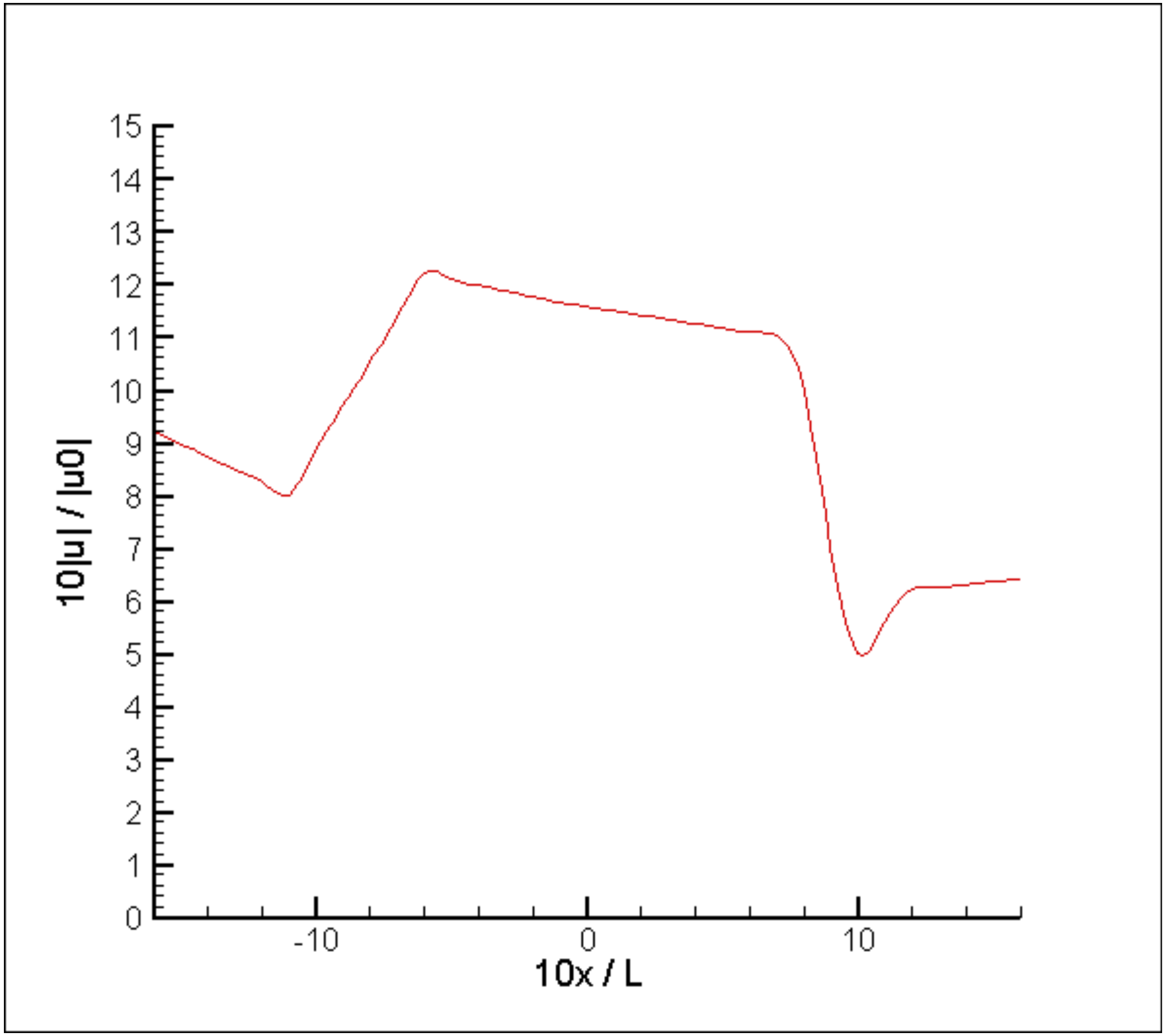


Normal to the front velocity component: valley

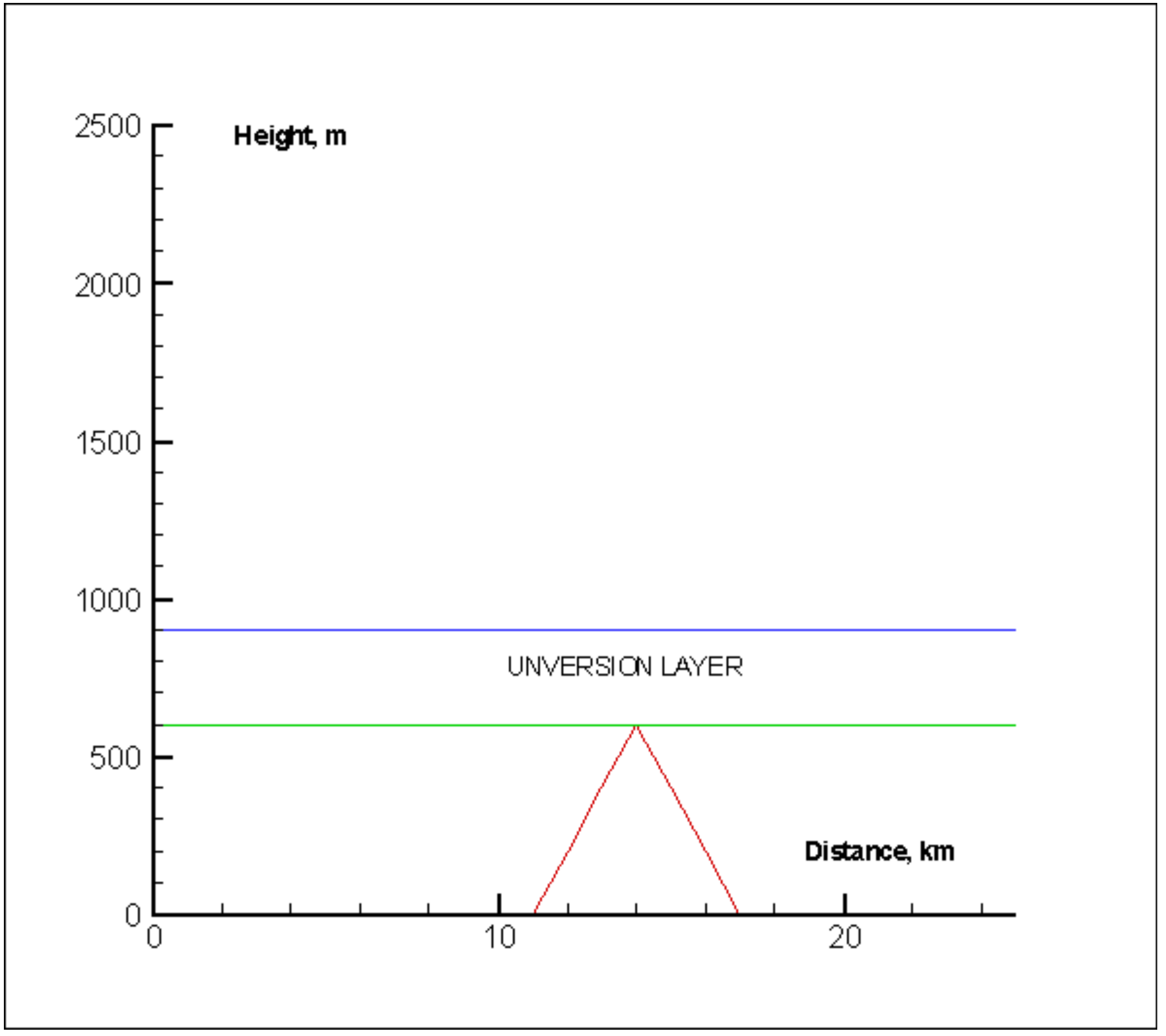
Neutral stratification.



Trapezoidal obstacle: topography
Neutral stratification



Trapezoidal obstacle: wind speed
Neutral stratification



An inversion layer over an isolated orographic obstacle.
Stable stratification.

Cold front propagation over orographic obstacles of various shapes and stratifications

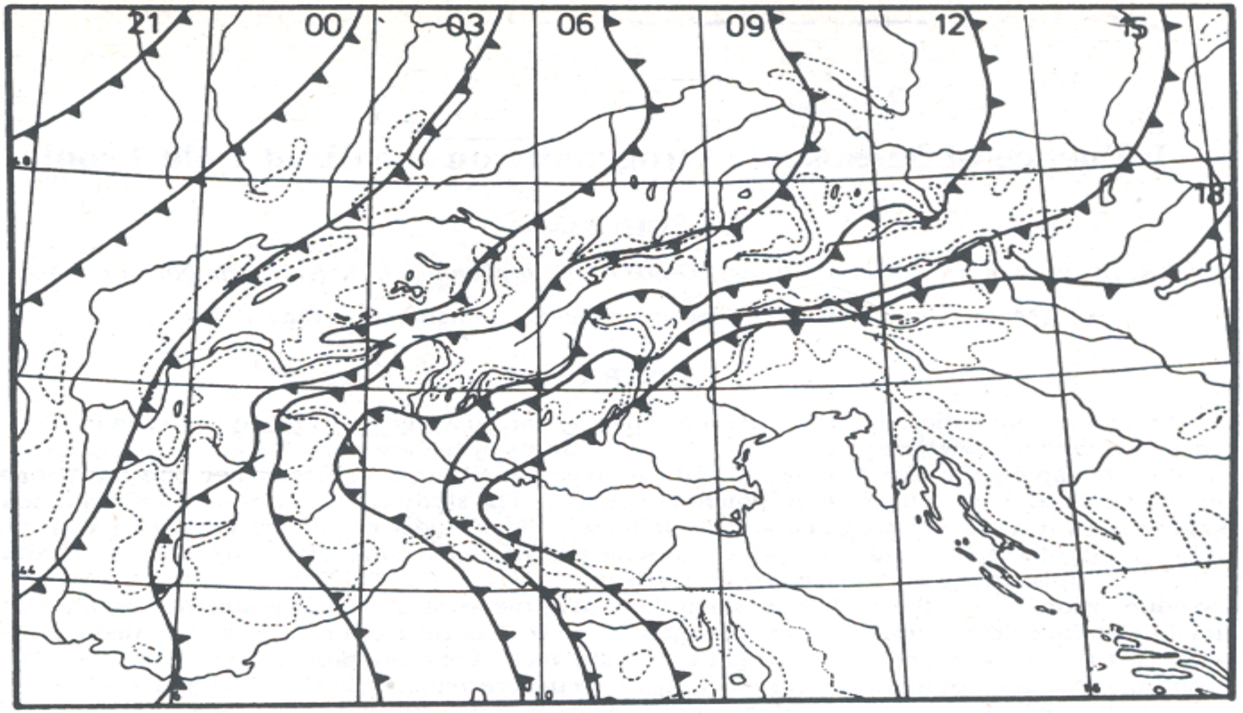
OBSTACLE HEIGHT (m)	INITIAL FRONT HEIGHT (м)	STRATIFICATION (K / 100m)	WINDWARD SPEED (m /sec)	LEEWARD SPEED (m /sec)
0	400	0.0	4.5	4.5
0	400	0.35	5.1	5.1
600	400	0.0	4.4	3.7
600	400	0.35	4.9	2.7
600	100	0.35	3.0	0.0
600	700	0.35	7.5	4.5
- 600	400	0.0	4.5	3.9

Calculated windward and leeward speeds of cold front propagation over a hill
Stable stratification

OBSTACLE HEIGHT (m)	INITIAL FRONT HEIGHT (м)	STRATIFICATION (K / 100m)	WINDWARD SPEED (m /sec)	LEEWARD SPEED (m /sec)
600	400	0.35 no inversion	4.9	2.7
600	400	0.35 inversion	4.4	2.2

Calculated windward and leeward speeds of cold front propagation over a plain
Stable stratification

OBSTACLE HEIGHT (m)	INITIAL FRONT HEIGHT (м)	STRATIFICATION (K / 100m)	WINDWARD SPEED (m /sec)	LEEWARD SPEED (m /sec)
0	400	0.35 no inversion	5.1	5.1
0	400	0.35 inversion	4.6	5.6



COLD FRONT PROPAGATION AROUND AND OVER THE ALPS
MARCH 1-2, 1982
(Schumann,1987)

PHYSICAL PARAMETERS

• Hm	2.5	2.5	km
• L	200.0	200.0	km
• Hf	4.5	9.0	km
• DeltaT	6.0	7.0	K
• U	12.0	10.0	m/sec
• V	40.0	15.0	m/sec
• C	30.0	45.8	m/sec
• R	300.0	458.0	km

CONCLUSIONS

The above results have been obtained with a 2D finite-element model based on triangular elements .The model was used to simulate the effects of cold front propagation over an idealized trapezoidal obstacle under neutral stratification and in a stably stratified atmosphere with an inversion layer over an isolated hill.

The results of the calculations were compared with measurements taken in a wind tunnel at neutral thermal stratification. A reasonable front propagation behavior is obtained, as compared with the results of wind tunnel measurements .

The influence of an inversion layer introduced above an obstacle in the atmosphere on the propagation of gravity currents such as a well formed cold atmospheric front was investigated as well .The study was performed at stable stratification in and beyond the inversion layer. It has been shown that the introduction of the inversion later produces a significant decrease in the front speed both for the currents over the obstacle and those over flat orography.

Although the present study is of limited scope, the above simulation results show that the numerical studies performed in this paper can be used for the numerical simulation of gravity flows in the atmosphere over steep terrain.