

Interne Schwerewellen, Leewellen und Rotoren

Andreas Dörnbrack

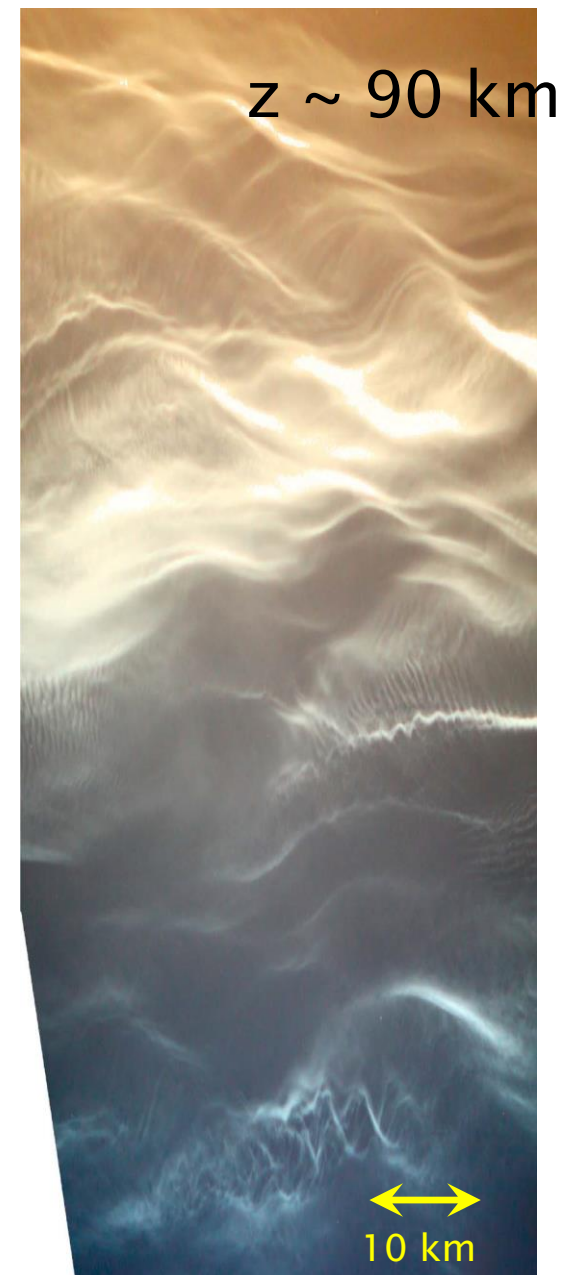
Institut für Physik der Atmosphäre

DLR Oberpfaffenhofen





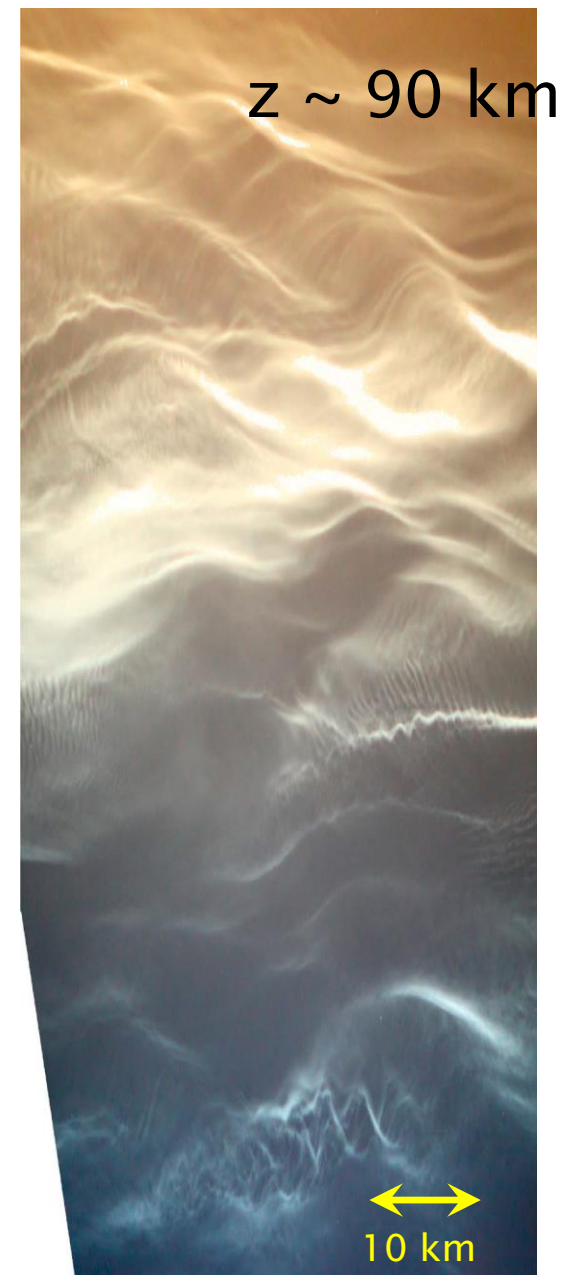
„Convective Waves“ above a single power plant, Northern Germany, 20 January 2015



Baumgarten, G., and D. C. Fritts (2014), Quantifying Kelvin-Helmholtz instability dynamics observed in noctilucent clouds: 1. Methods and observations, *J. Geophys. Res. Atmos.*, 119, 9324–9337, doi:10.1002/2014JD021832.

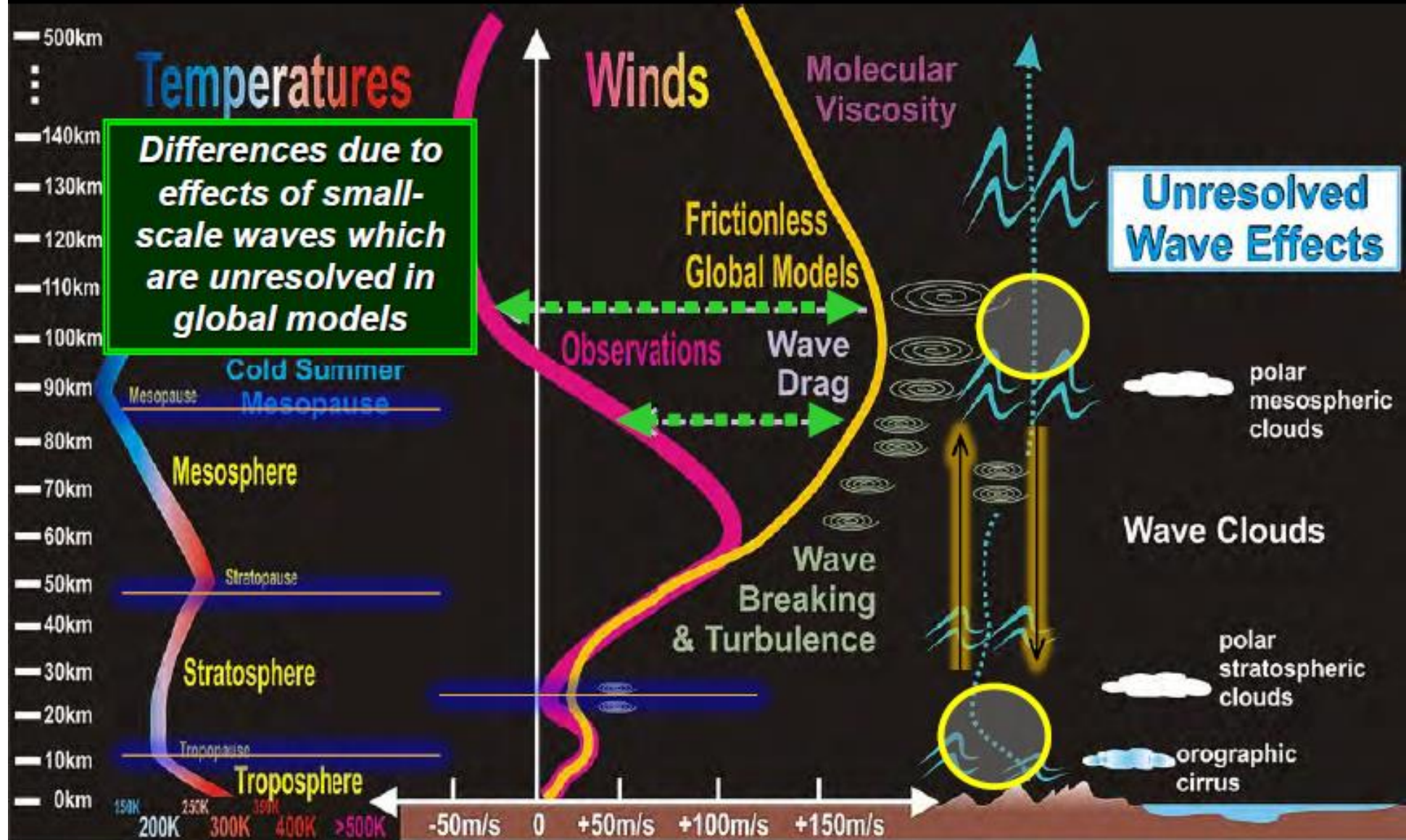


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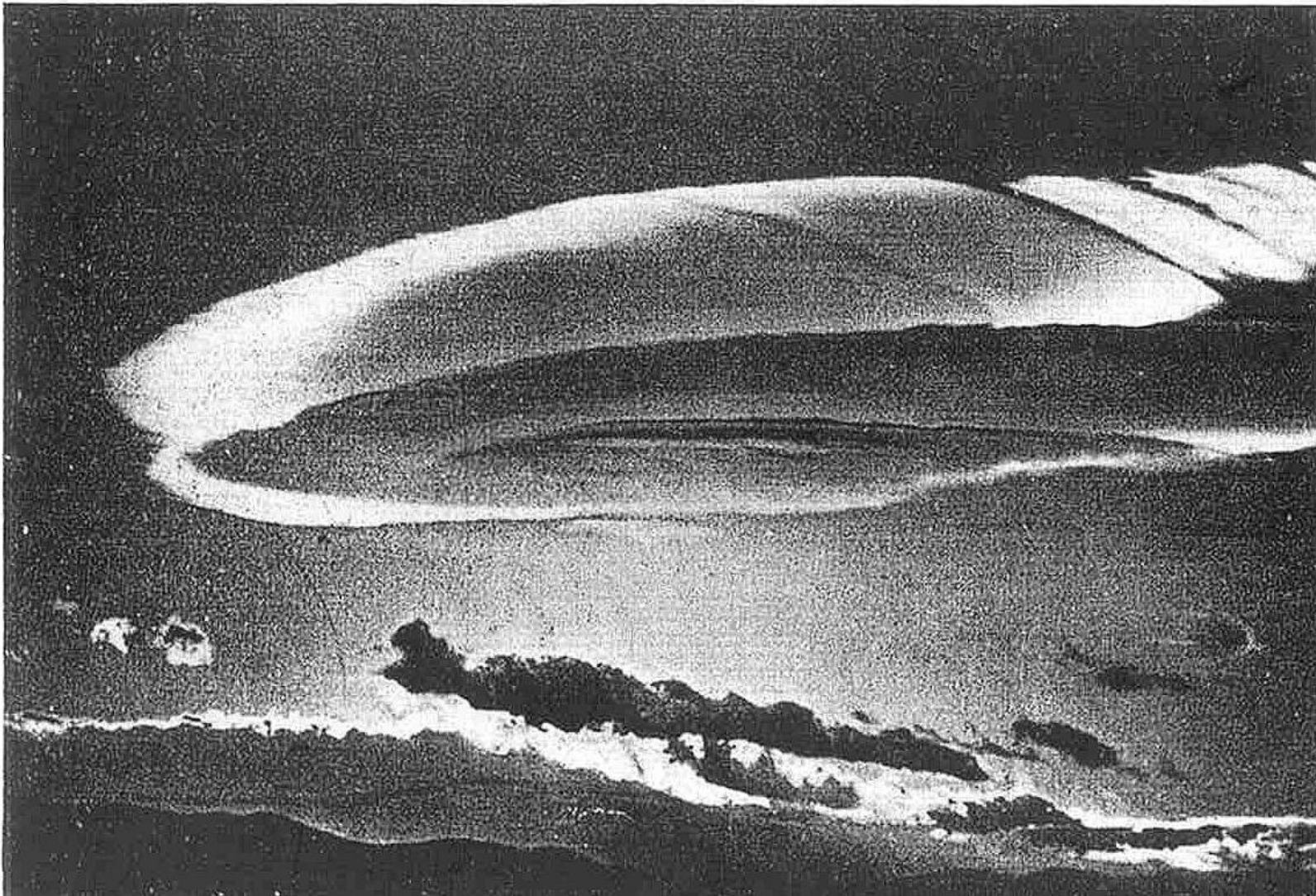
Atmospheric Gravity Waves



Die Entdeckung der Leewelle

berichtet von

Joachim Küttner 2005



Das Moazagotl des Riesengebirges, fotografiert am 11. Dezember 1936.

Blick von Grunau nach Süden der Strömung entgegen.

Die mehrfache Schichtung und die laminare Wellenstruktur der *Lenticularis* Wolke sind erkennbar; darunter die Föhnmauer und die in der Wirbelwalze durch starke Turbulenz zerrissenen *Cumuli fracti* (aus: KÜTTNER, 1938).



Wolfgang Hirth - German gliding pioneer and sailplane designer
1931 Grunau, Selesia

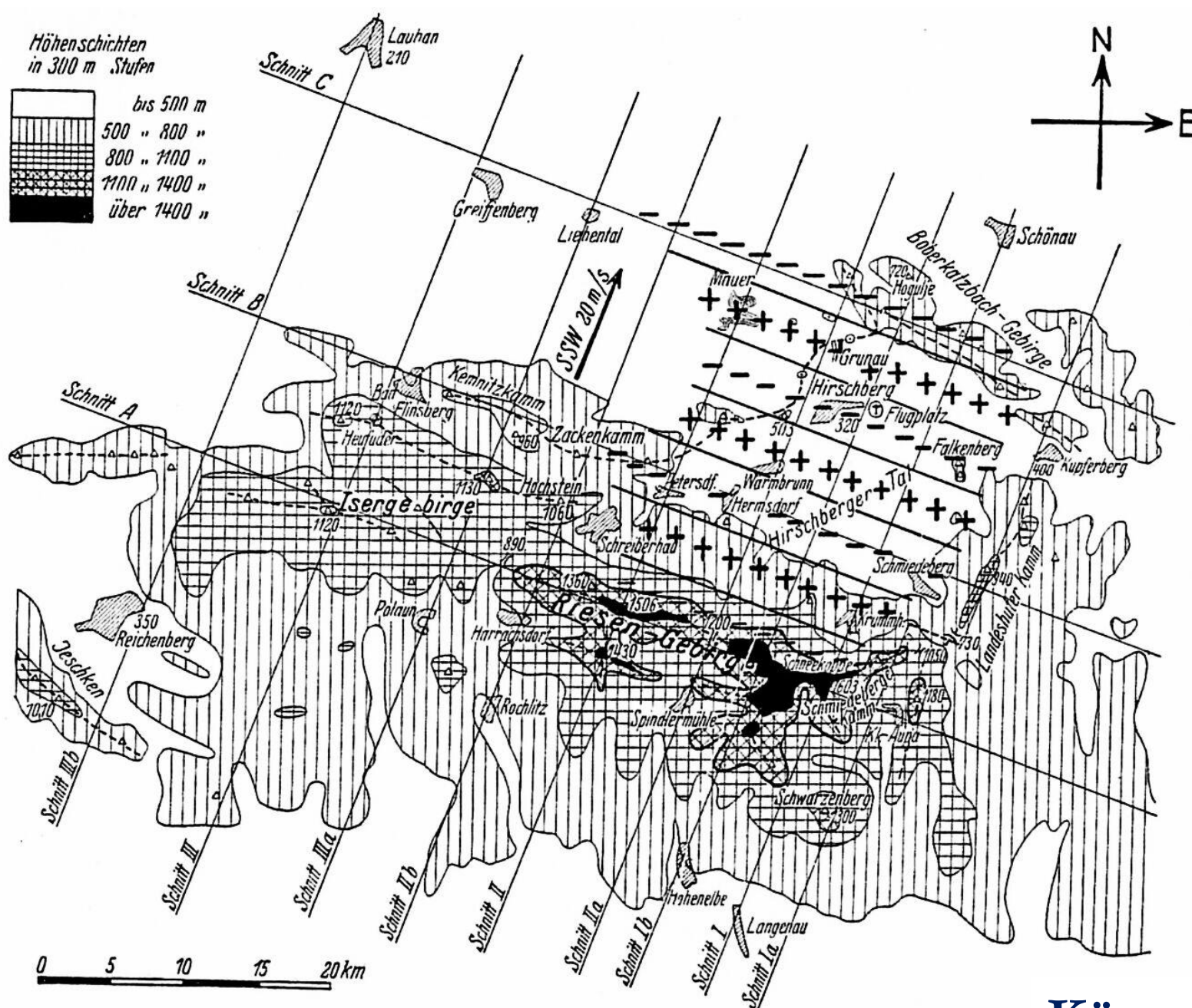
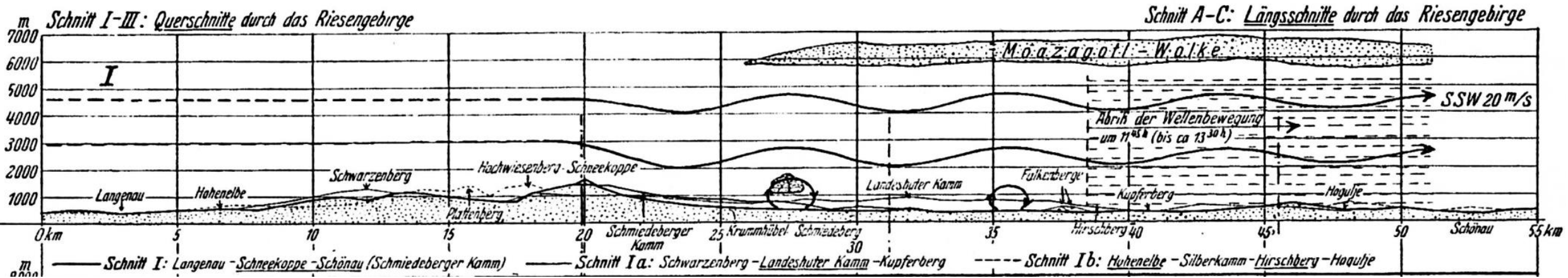


Fig. 32. Grundriß zu Fig. 31, 21. Mai 1937, vormittags.

Pluszeichen: Gebiete aufsteigender Luftbewegung. Minuszeichen: Gebiete absteigender Luftbewegung.

Küttner, 1938



Küttner, 1938

Trapped Lee Waves

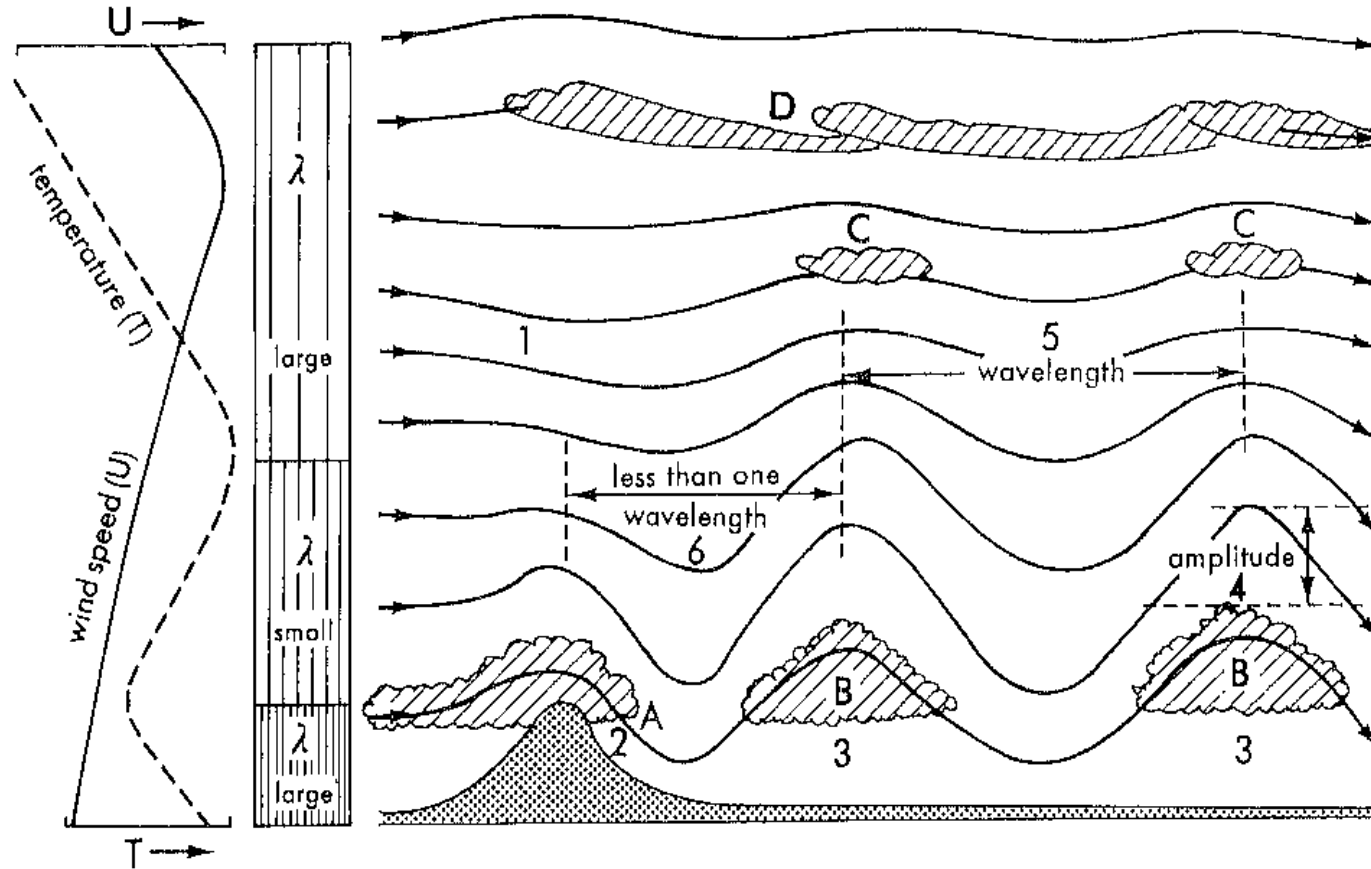


FIG. 18. Features of airflow across a long mountain range: (1) downdraught may occur at some levels to windward of ridge; (2) strong surface wind down lee slope; (3) variable surface wind; (4) maximum amplitude in stable layer; (5) order of wavelength, 5–30 km; (6) first wave crest usually less than one wavelength downstream of ridge. (A) Foehnwall; (B) roll cloud; (C) altocumulus lenticularis; (D) cirrus. λ denotes the natural wavelength determined by the airstream wind and temperature conditions. (After Wallington, 1960.)

aus: Kuettner, 1959

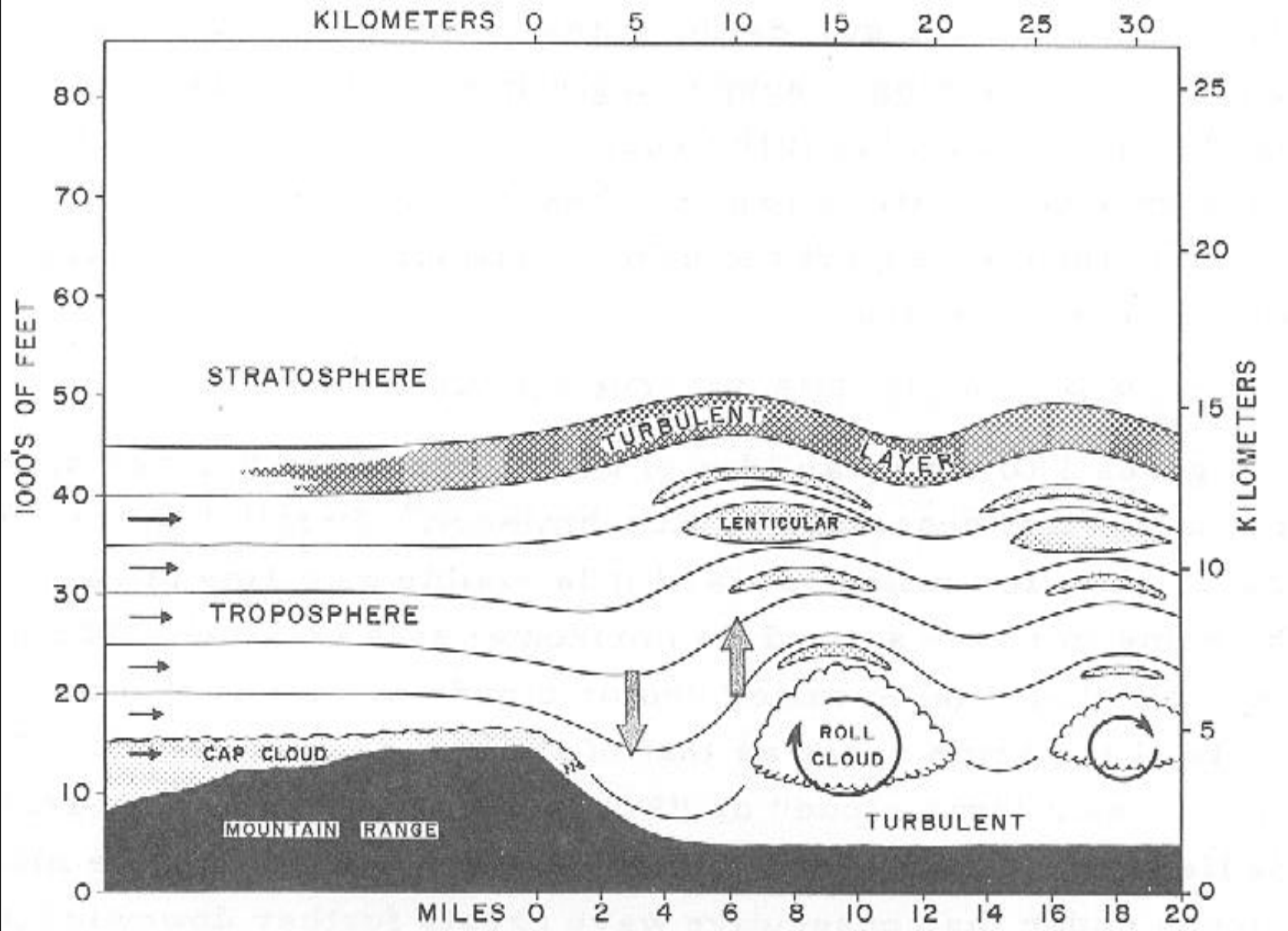


FIG. 2. Schematic diagram of flow pattern over mountain range with roll cloud.

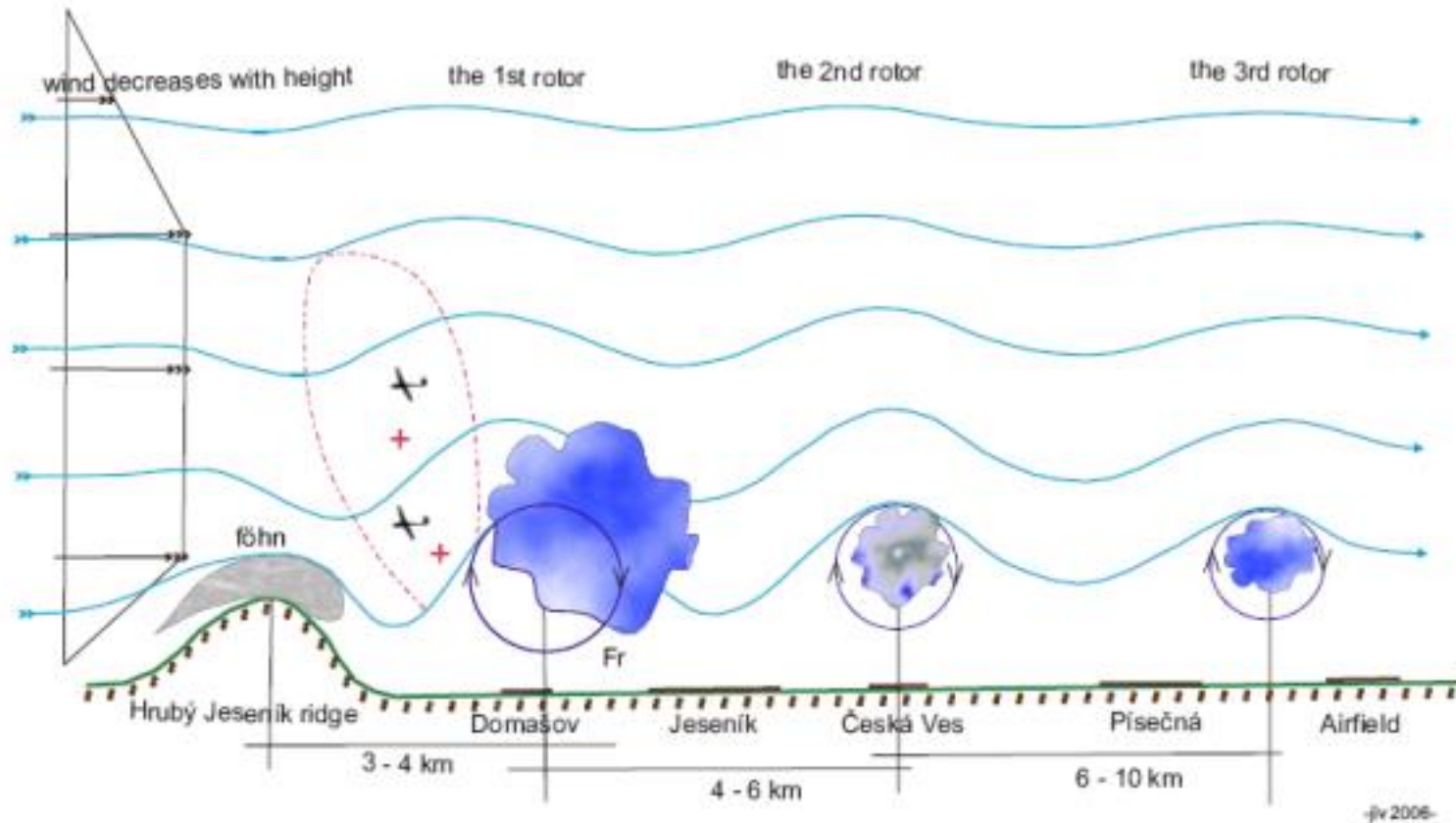


Fig. 1.3: Schematic of the lee waves in the area of the Hrubý ridge near Jeseník, Czech Republic. The height of the mountain ridge is about 1000 m above the surrounding terrain.

Source: Aeroclub Jeseník

Flow over sinusoidal ridges: Small-amplitude gravity waves

Linearized equations of motion

$$\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial z^2} + \frac{N^2}{U_0^2} w = 0 \quad N^2 = \frac{g}{\Theta_0} \frac{d\Theta}{dz}$$

$$\text{RB : } w(x, 0) = U_0 \frac{\partial z_s}{\partial x} = -U_0 k h_m \sin kx$$

$$z_s(x) = h_m \cos kx$$

$$w(x, z \rightarrow \infty) = 0$$

$$k = 2\pi / \lambda_x$$

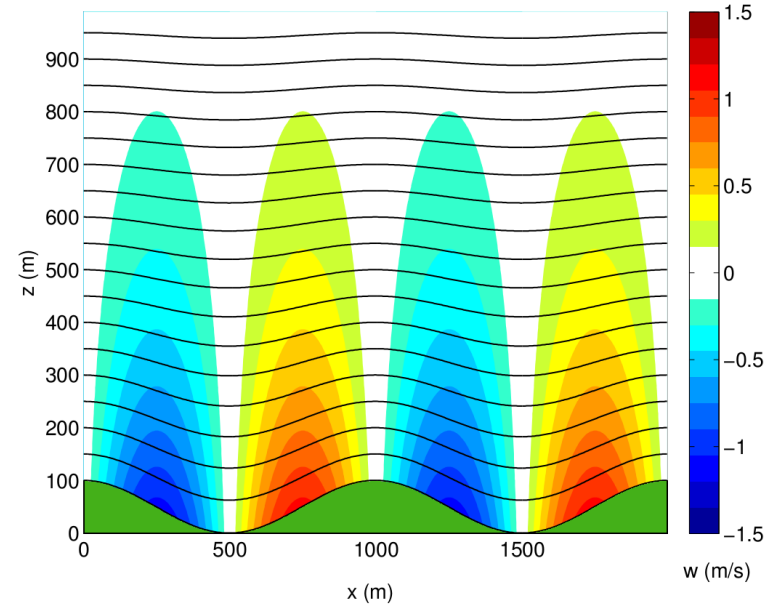
Uniform flow over periodic ridges

Evanescent waves

$$w(x, z) = -U_0 h_m k e^{-\mu z} \sin(kx)$$

$$\mu = \left(k^2 - N^2 / U_0^2 \right)^{1/2}$$

$$U_0 k > N$$



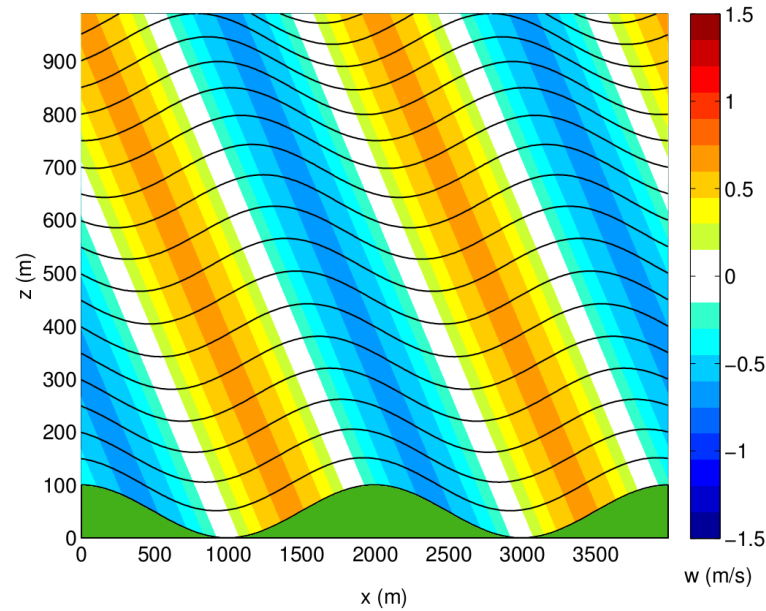
$$\frac{U_0 2\pi}{N} > \lambda_x$$

Propagating waves

$$w(x, z) = -U_0 h_m k \sin(kx - mz)$$

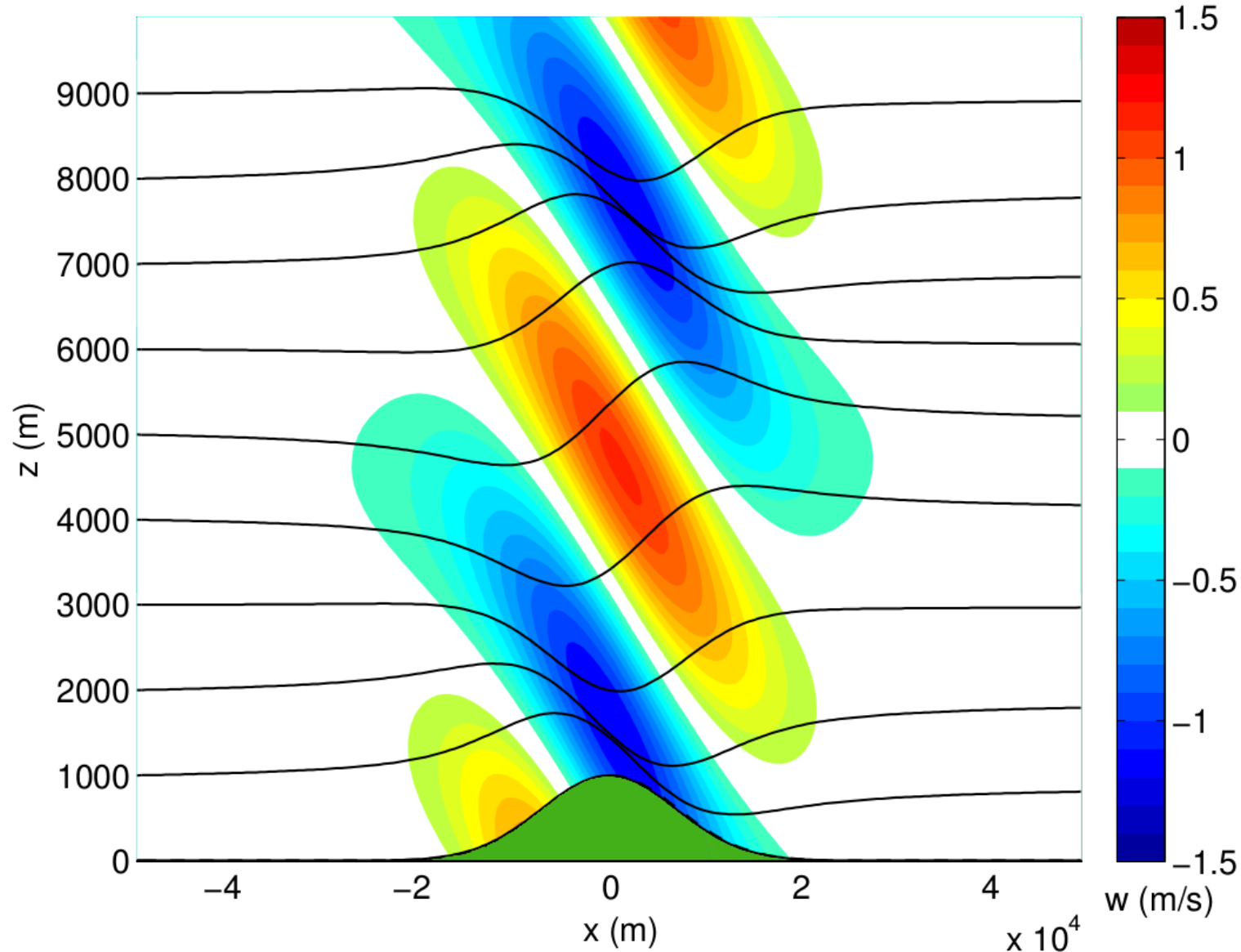
$$m = \left(N^2 / U_0^2 - k^2 \right)^{1/2}$$

$$U_0 k < N$$



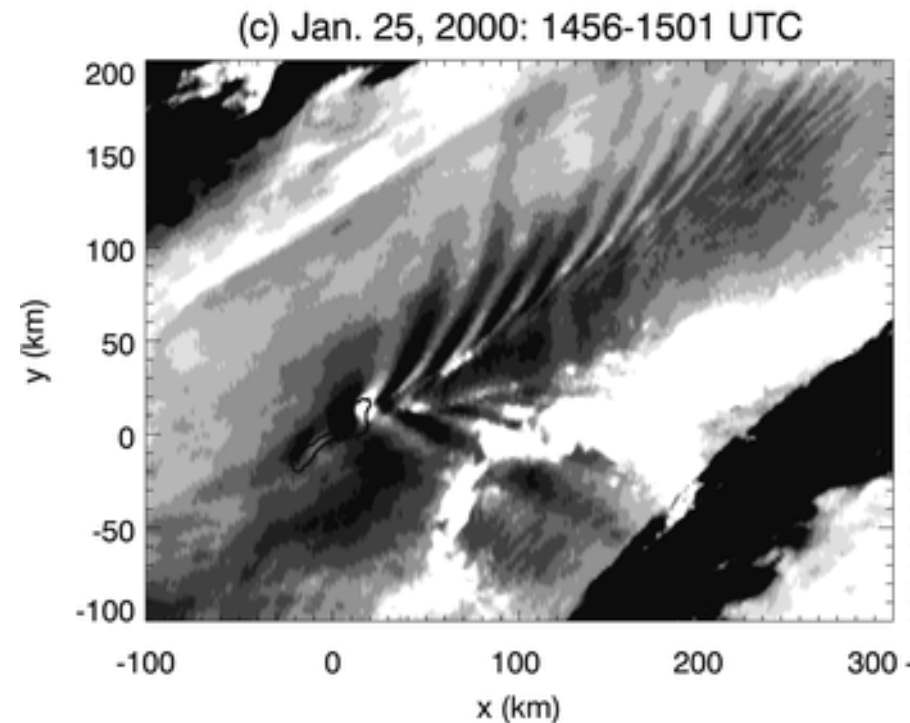
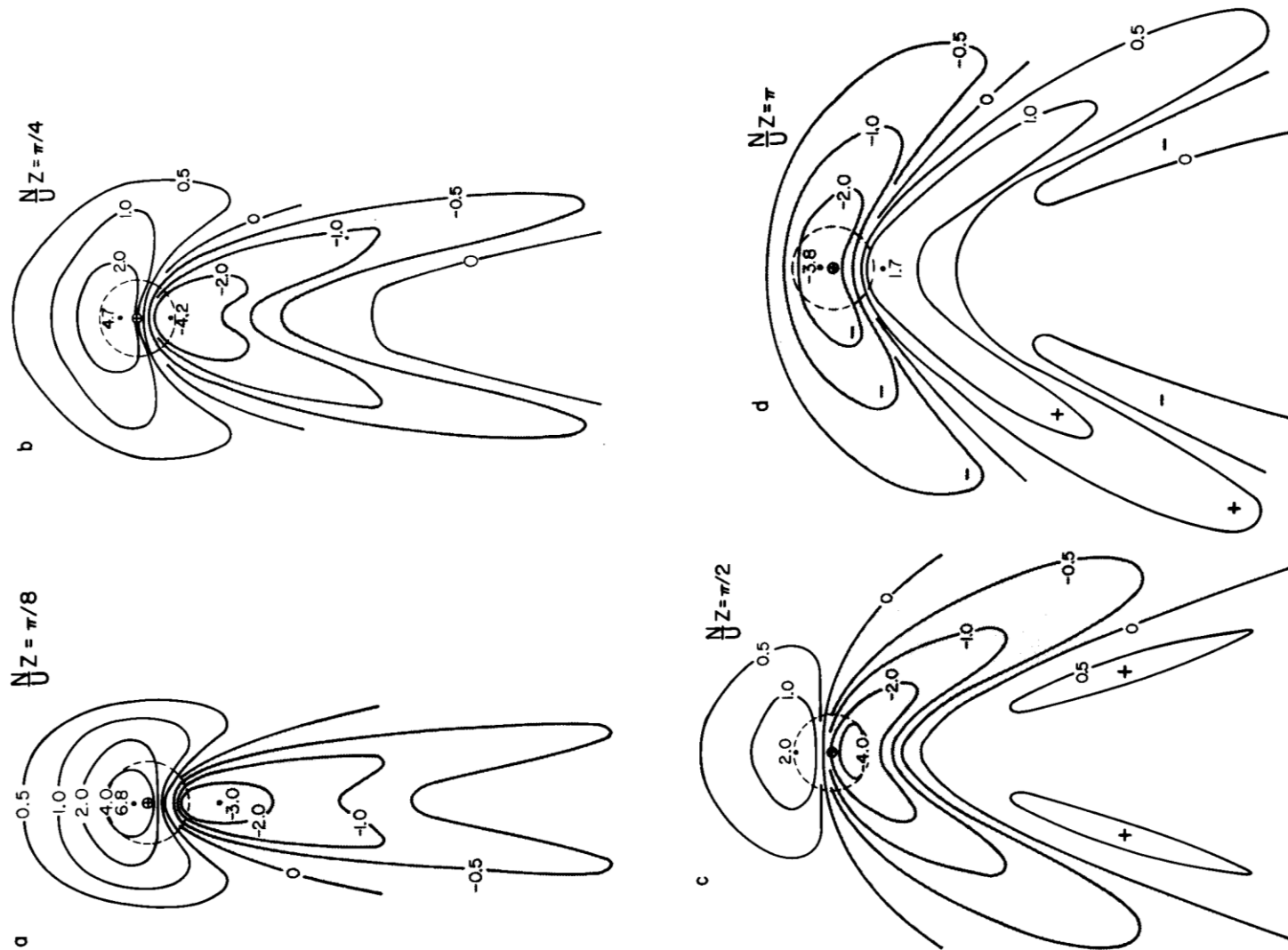
$$\frac{U_0 2\pi}{N} < \lambda_x$$

Uniform flow over single mountain



$$U_0 k < N$$
$$U_0 \frac{2\pi}{\lambda_x} < N$$
$$\frac{U_0 2\pi}{N} < \lambda_x$$

Geometrical Spreading vs. Ship Waves



Eckermann, S. D., D. Broutman, J. Ma, and J. Lindeman, 2006: Fourier-Ray Modeling of Short-Wavelength Trapped Lee Waves Observed in Infrared Satellite Imagery near Jan Mayen. *Mon. Wea. Rev.*, **134**, 2830–2848

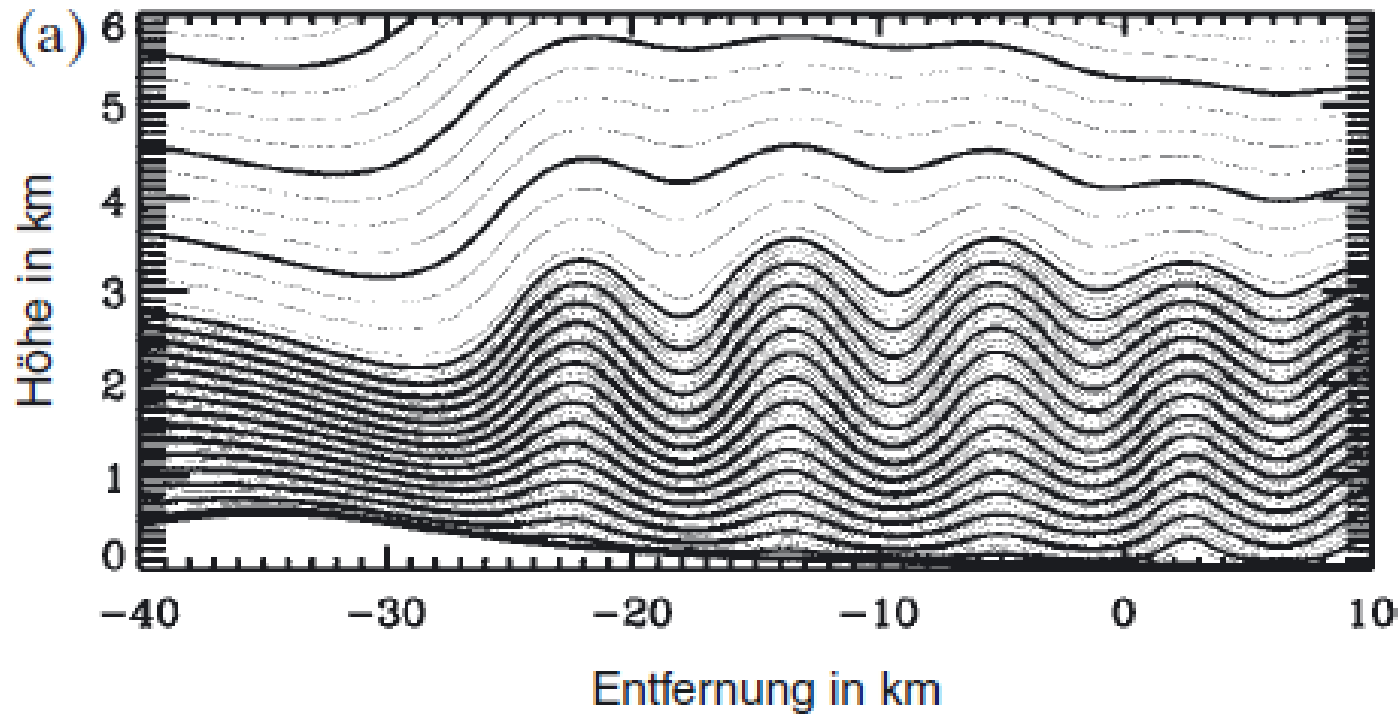
Ronald B. Smith (1980) Linear theory of stratified hydrostatic flow past an isolated mountain, *Tellus*, 32:4, 348-364, DOI: 10.3402/tellusa.v32i4.10590

Trapped Lee Waves

2D inviscid airflow over an isolated bell-shaped mountain (Witch of Agnesi)

$$z_s(x) = h_m / (1 + x^2/L^2)$$

with two layers of different Brunt-Väisälä frequencies N_U and N_L



$$N_U = 0.010 \text{ s}^{-1}$$

← $H = 3000 \text{ m}$

$$N_L = 0.025 \text{ s}^{-1}$$

$$\ell_L^2 - \ell_U^2 > \frac{\pi^2}{4H^2} \quad \ell^2 = \frac{N^2}{U_0^2}$$

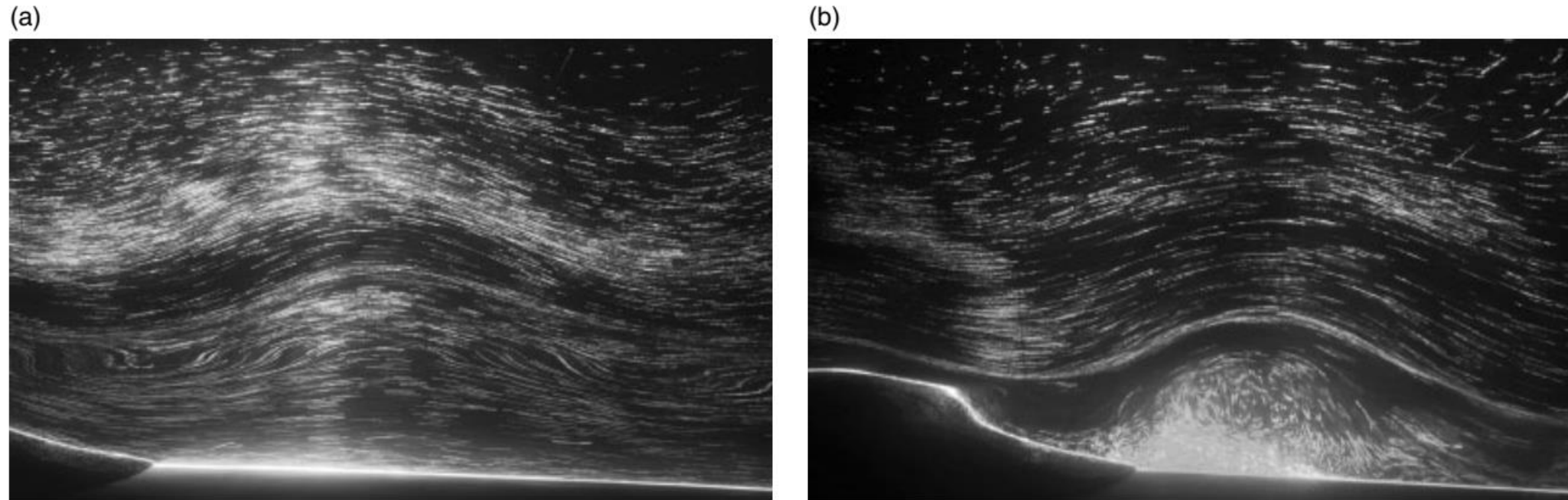


Figure 4. Streaklines of the flow behind the downstream side of the obstacle. (a) lee-wave case: $H/z_i = 0.46$, $F_i = 0.64$, $Re = 20800$, $Fr = 1.23$, (b) rotor case: $H/z_i = 1.1$, $F_i = 0.90$, $Re = 23400$, $Fr = 1.38$.

Knigge C, Etling D, Paci A, Eiff O. 2010. Laboratory experiments on mountain-induced rotors. *Q. J. R. Meteorol. Soc.* **136**: 442–450. DOI:10.1002/qj.564

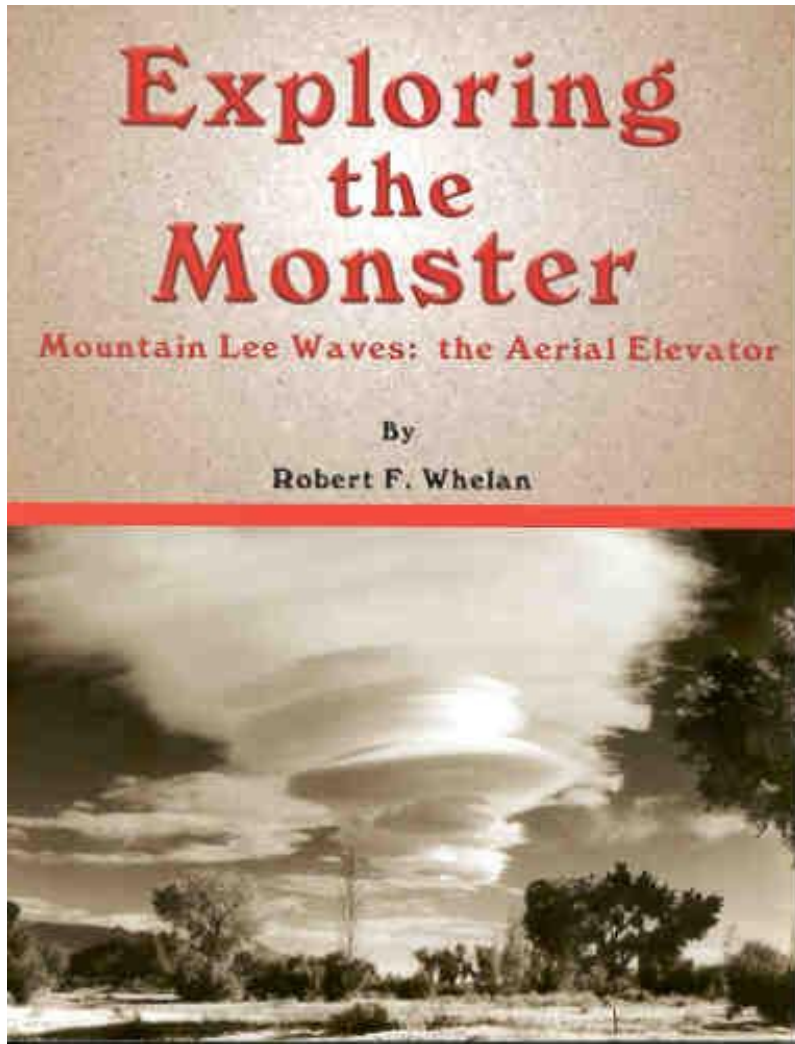


Owens Valley in the lee of the Sierra Nevada Range, illustrating common rotor characteristics such as rotor and lenticular clouds and blowing dust.

Sierra Wave Project 1951/52 1955



FIG. 3. The Sierra Wave Project scientists on the field location in Owens Valley during a visit on 3 Feb 1952. From left to right: Paul Queney (University of Paris), Jacob Bjercknes (UCLA), Joachim Kuettner (USAF Cambridge Research Center), and Jørgen Holmboe (UCLA). (From Harold Klieforth's private collection.)



Sierra Wave Project 1951/52 1955



FIG. 3. The Sierra Wave Project scientists on the field location in Owens Valley during a visit on 3 Feb 1952. From left to right: Paul Queney (University of Paris), Jacob Bjercknes (UCLA), Joachim Kuettner (USAF Cambridge Research Center), and Jørgen Holmboe (UCLA). (From Harold Klieforth's private collection.)

20070119 02 Rotorwind Wasserauen

Aus Schweizer Sturmarchiv

Diese Seite befindet sich im Aufbau!

Appenzell / Wasserauen: Infolge des heftigen Sturmes entgleiste am Freitagvormittag 19. Januar 2007 eine dreiteilige Zugkomposition der Appenzeller Bahnen zwischen Schwende und Wasserauen.

Die um 10:20 Uhr aus dem Bahnhof Wasserauen ausfahrende Zugkomposition wurde wegen dem Sturm Kyrill etwa nach 200 Meter Fahrt aus den Schienen geworfen. Dabei kippte der Steuerwagen ABt 133 auf die Hauptstrasse Schwende-Wasserauen. Der mittlere Wagen geriet in Schiefelage und der schwere Triebwagen BDe 4/4 33 "Gonten" blieb standfest auf den Schienen.

Zum Zeitpunkt des Ereignisses befanden sich ausser dem Lokführer keine Personen im Zug. Verletzt wurde niemand. Es entstand Sachschaden von mehreren hunderttausend Franken.

Quelle: bahnonline.ch

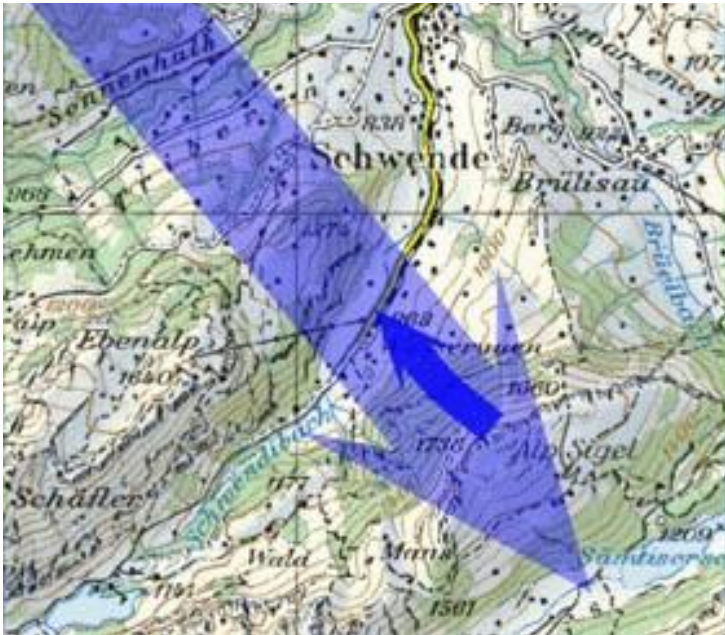


Kyrill: Wind-Kreisel muss mit über 200 km/h gewütet haben

Es waren kreisende Winde, die mit gigantischer Wucht einen Zug von den Schienen fegten. Jörg Kachelmann will künftig vor dem lokalen Wetterphänomen warnen.

Der Steuerwagen, den Sturm Kyrill am Freitag in Wasserauen aus den Schienen geworfen hat, steht jetzt beim Depot der Appenzeller Bahnen (AB) in Gais. Gestern haben Versicherungsspezialisten den Schaden untersucht. «Wir schätzen ihn auf eine halbe Million Franken», sagt Roger Wenk, Leiter Rollmaterial der AB. Wie der Steuerwagen von den Schienen geblasen werden konnte, ist für die Verantwortlichen schwer nachvollziehbar.

Zum Zeitpunkt des Unglücks wurden Winde von über 100 km/h gemessen. «Das reicht nie, um 20 Tonnen aus den Schienen zu werfen», sagt AB-Mediensprecher Hanspeter Müller. Deshalb wurde der Meteorologe Jörg Kachelmann eingeschaltet. Kachelmann kennt die speziellen Verhältnisse in Wasserauen. «Hier gibt es das seltene Phänomen von sehr starken Rotoren», so Kachelmann.



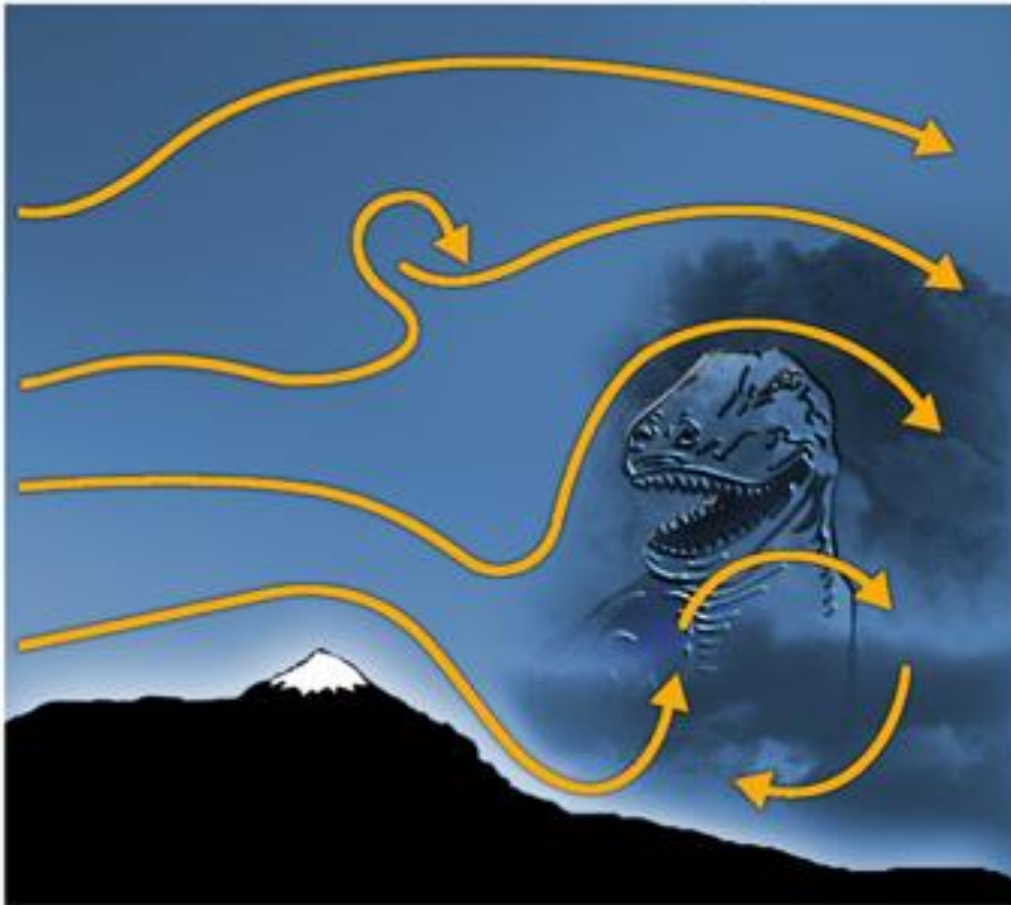
Terrain-Induced Rotor Experiment

March/April 2006

(T-REX)

Owens Valley, CA

Terrain-Induced Rotor Experiment



Vanda Grubišić
Joachim Kuettnner
Robert Banta
James Doyle
Stephen Mobbs
Greg Poulos
Ronald Smith
David Whiteman
Martin Weissmann
Andreas Dörnbrack

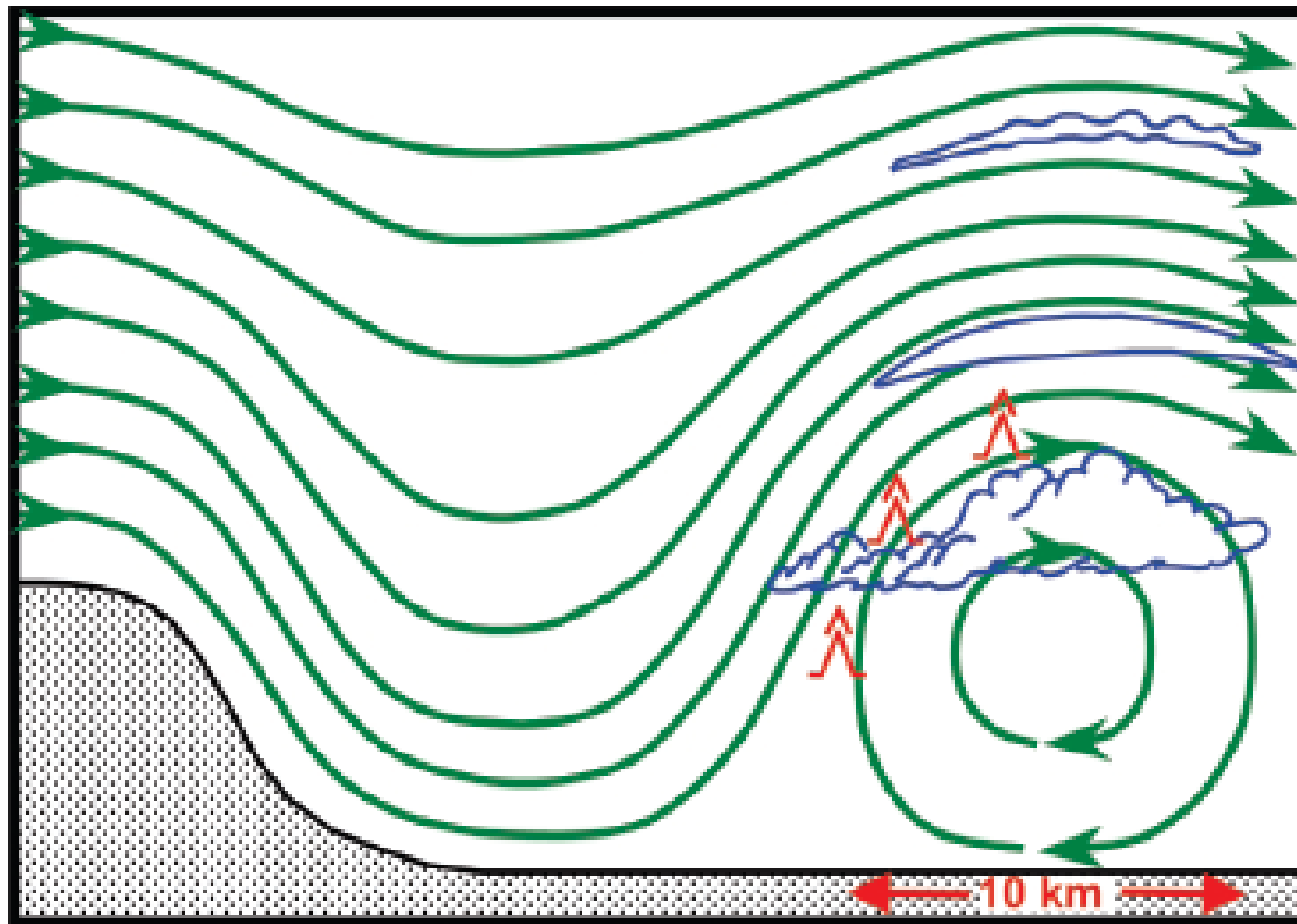
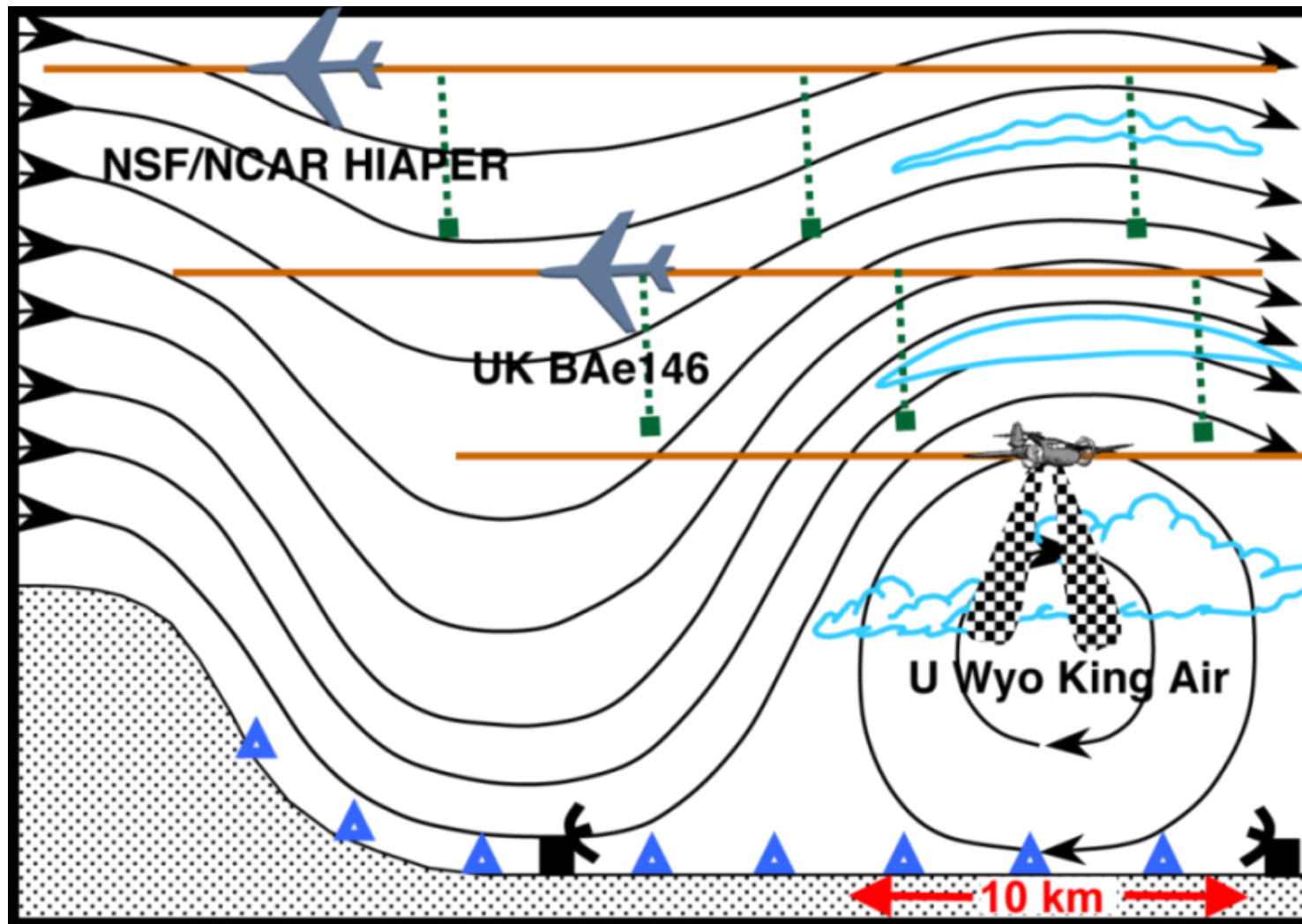







FIG. 2. Schematic streamlines illustrating a rotor circulation and attendant cloud features (adapted from Ludlam and Scorer 1957). Regions of clear-air turbulence associated with the rotor circulation are denoted by the red symbols.



 ground-based lidars
 surface stations
 dropsondes

 jet aircraft
 turbo-prop aircraft with cloud radar

Terrain-Induced Rotor Experiment

IPA Participation: 14 March - 24 April 2006

March/April 2006 (T-REX) Owens Valley, CA



2- μm Doppler wind lidar

nearly continuous measurements for 6 weeks

- backscatter from atmospheric aerosols
- Doppler shift \rightarrow radial velocity

hemispherical scanner

vertical slice scan: 30 - 90 s; conical scan: 60 - 120 s

up to \sim 3000 scans per day



25 March 2006
18:22 UTC; 10:22 am LT

Case A



25 March 2006
17:40 UTC; 9:40 am LT

Case B



26 March 2006
~00:46 UTC; 4:46 pm LT

Case A



25 March 2006
17:40 UTC; 9:40 am LT

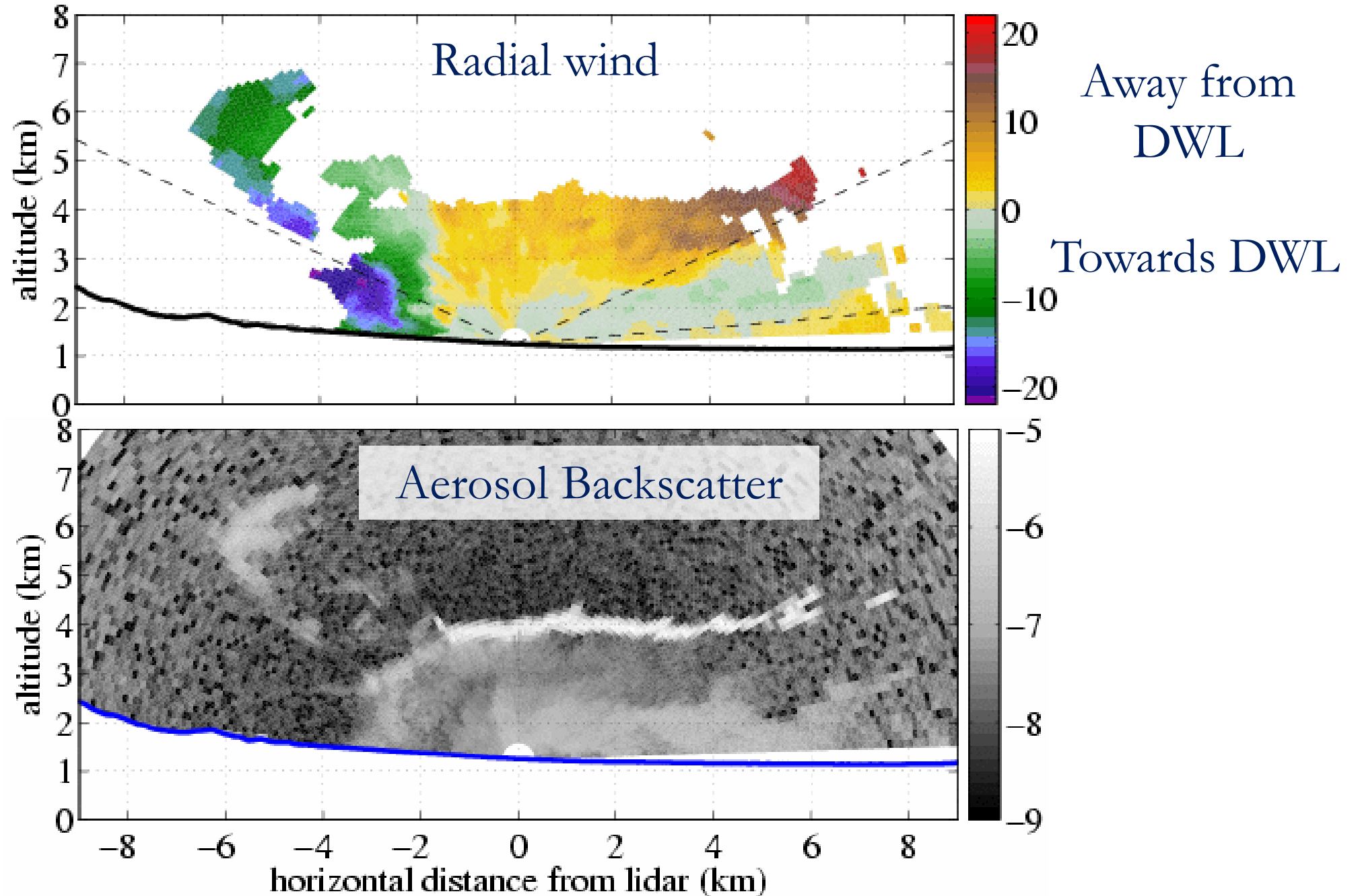
Case B



26 March 2006
~02...04 UTC; 6...8 pm LT

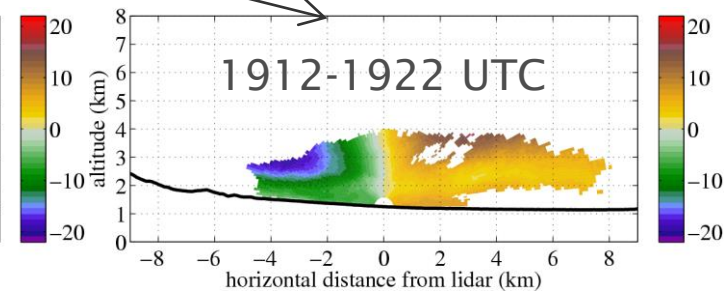
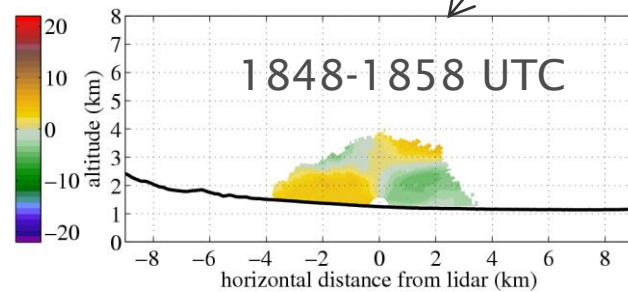
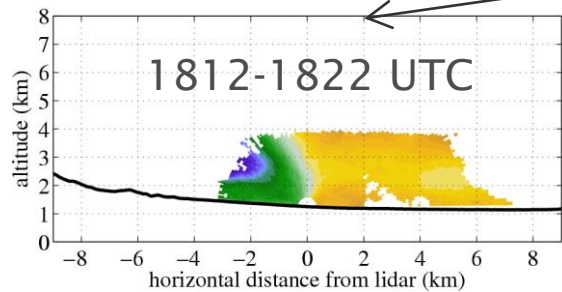
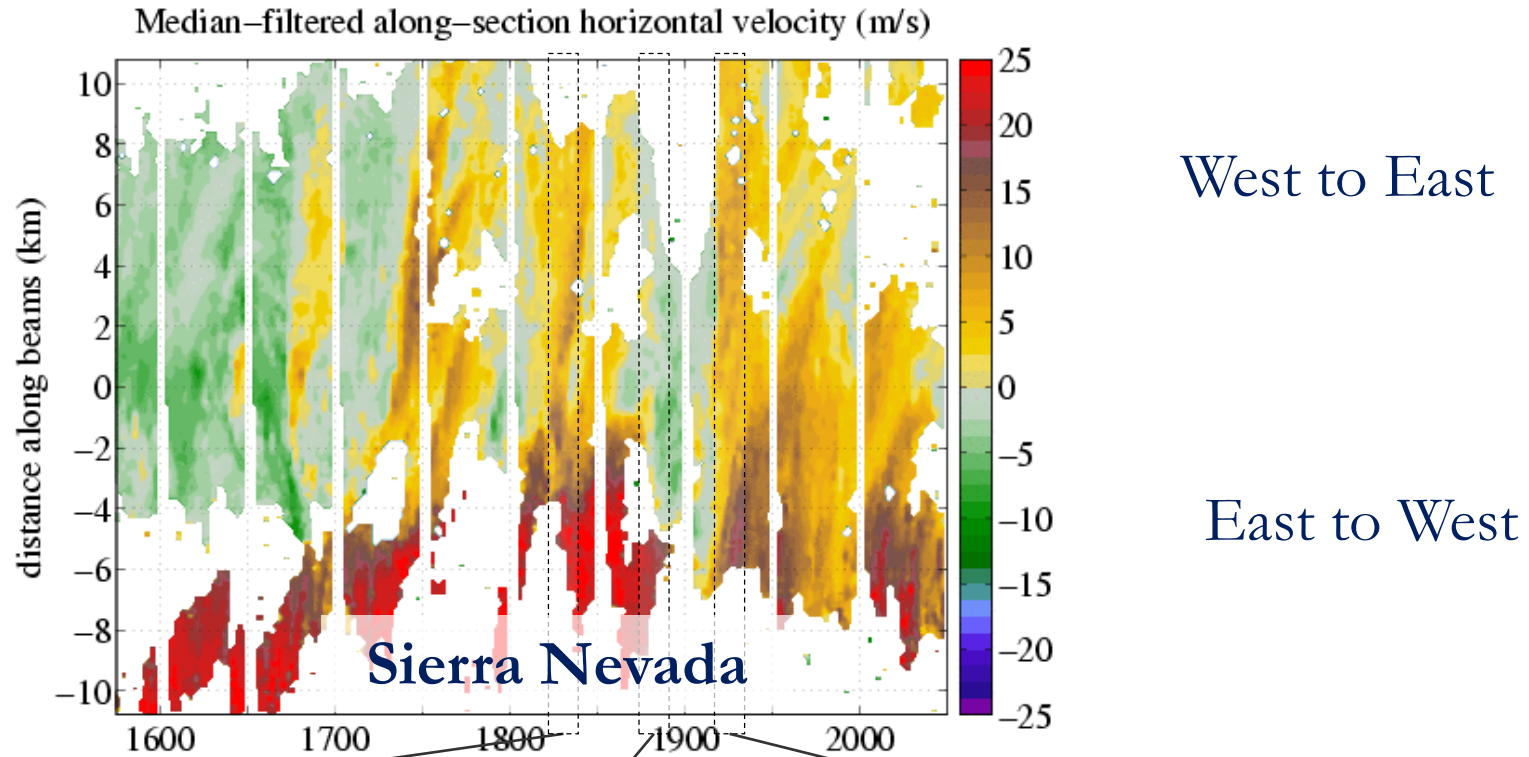
Case A

RHI sweep: Date:03/25/2006 Time:18:07:37 AZ:80.0



Case A

Radial wind

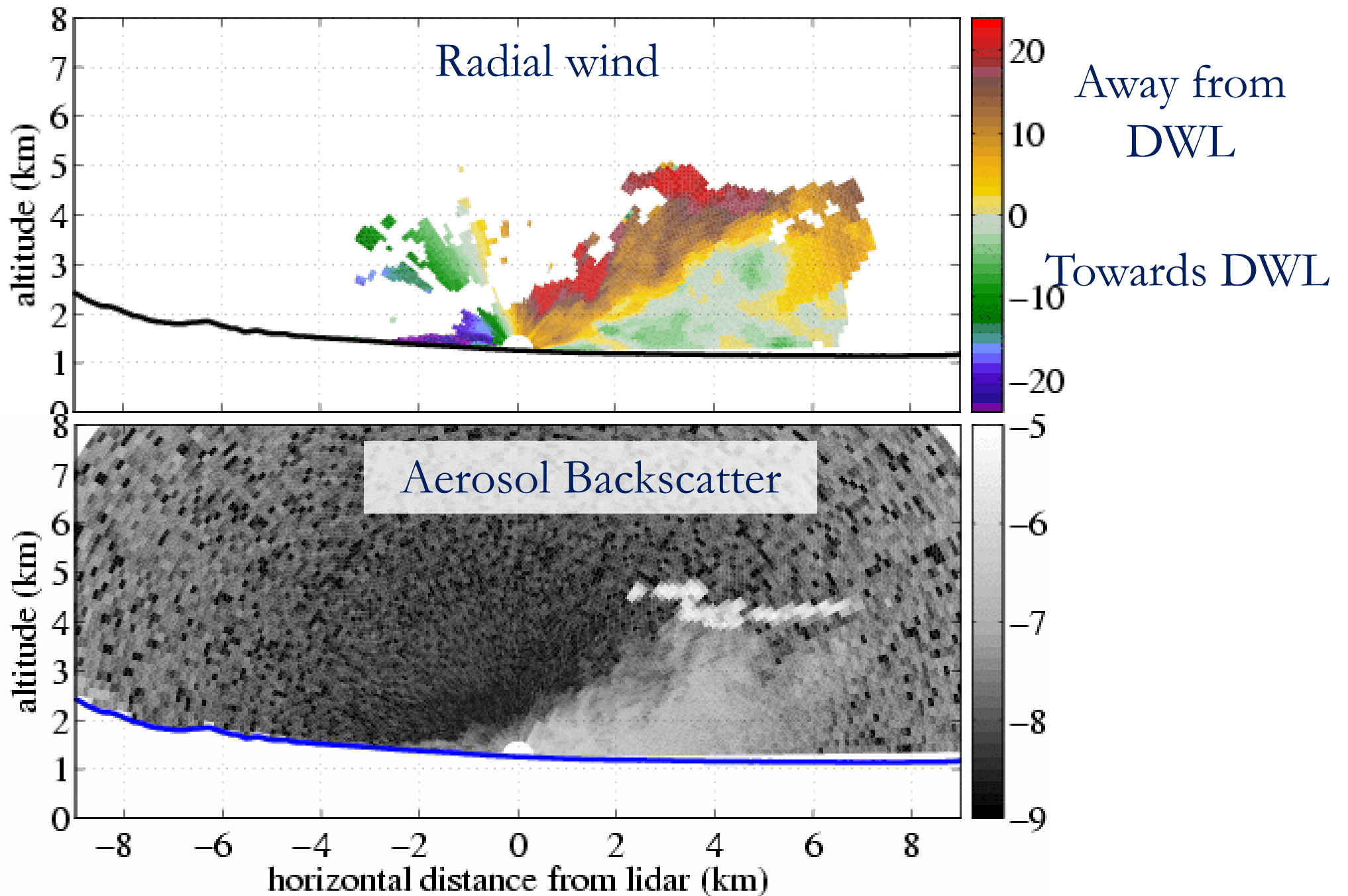


Away from DWL

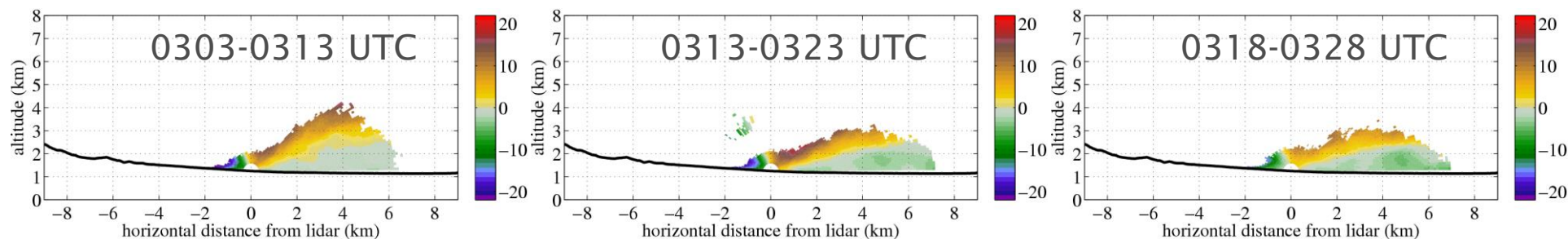
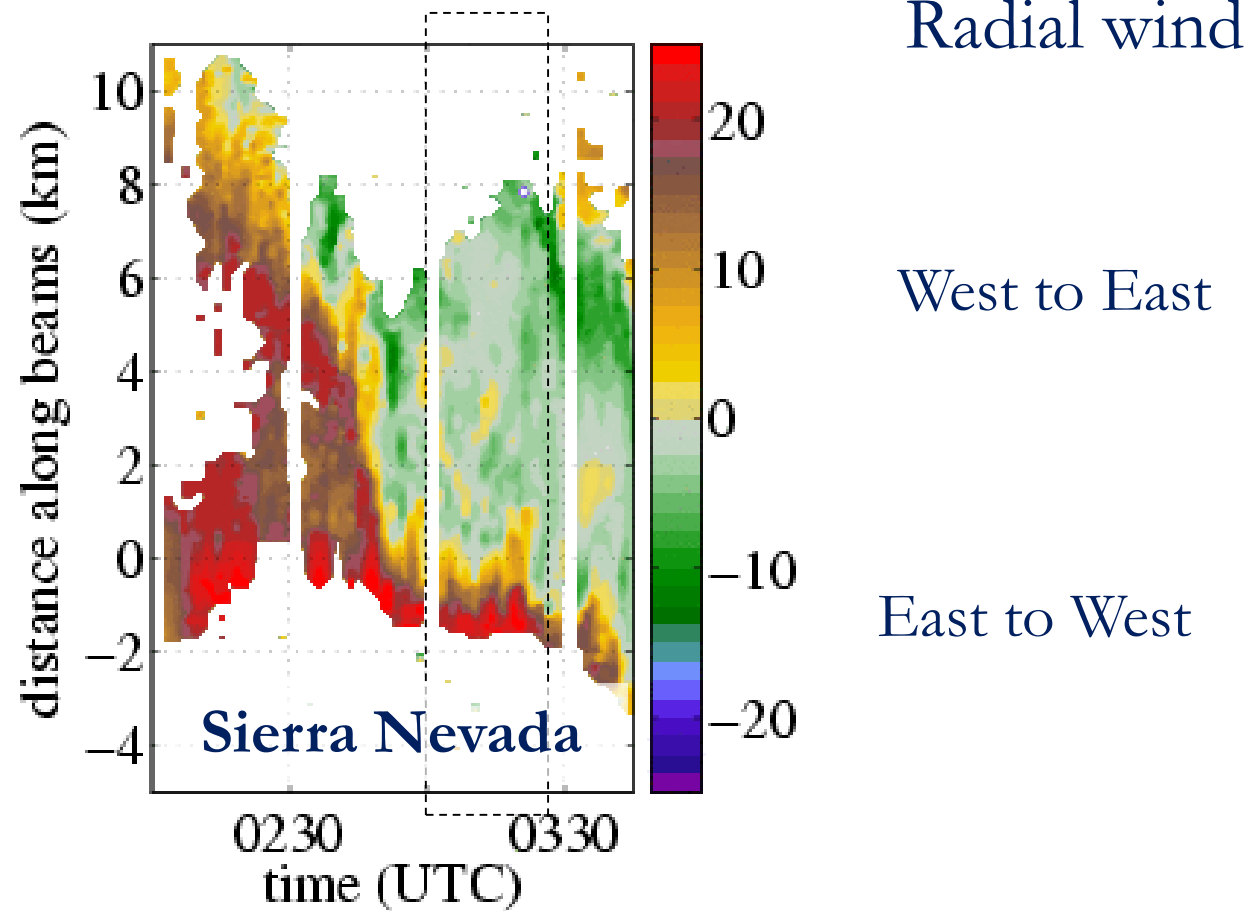
Towards DWL

Case B

RHI sweep: Date:03/26/2006 Time:03:04:05 AZ:80.0



Case B



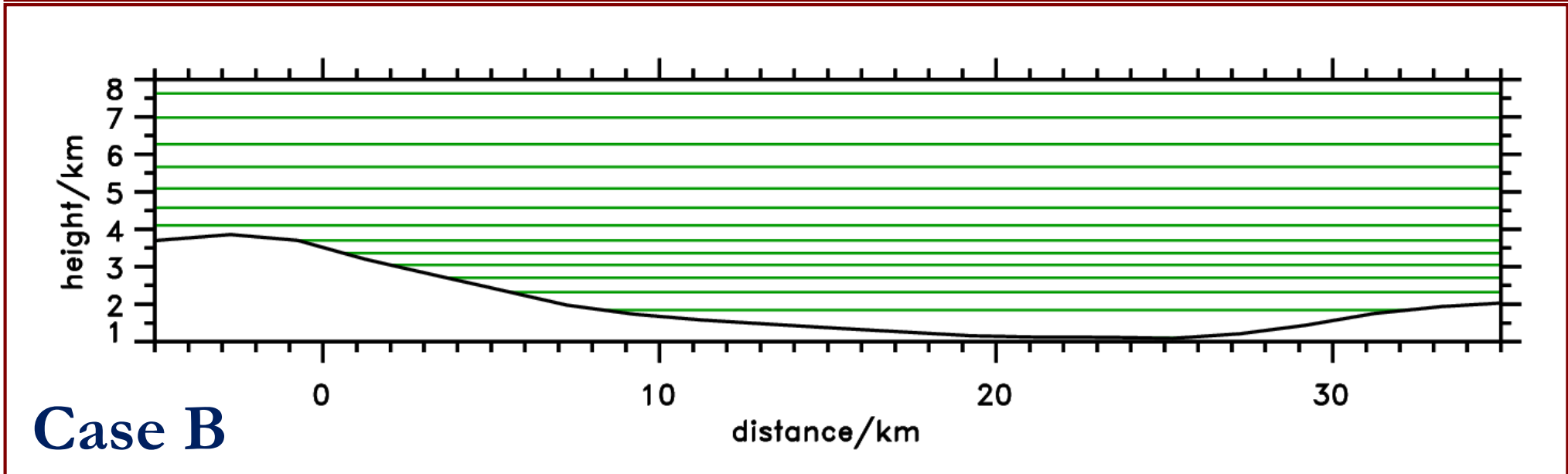
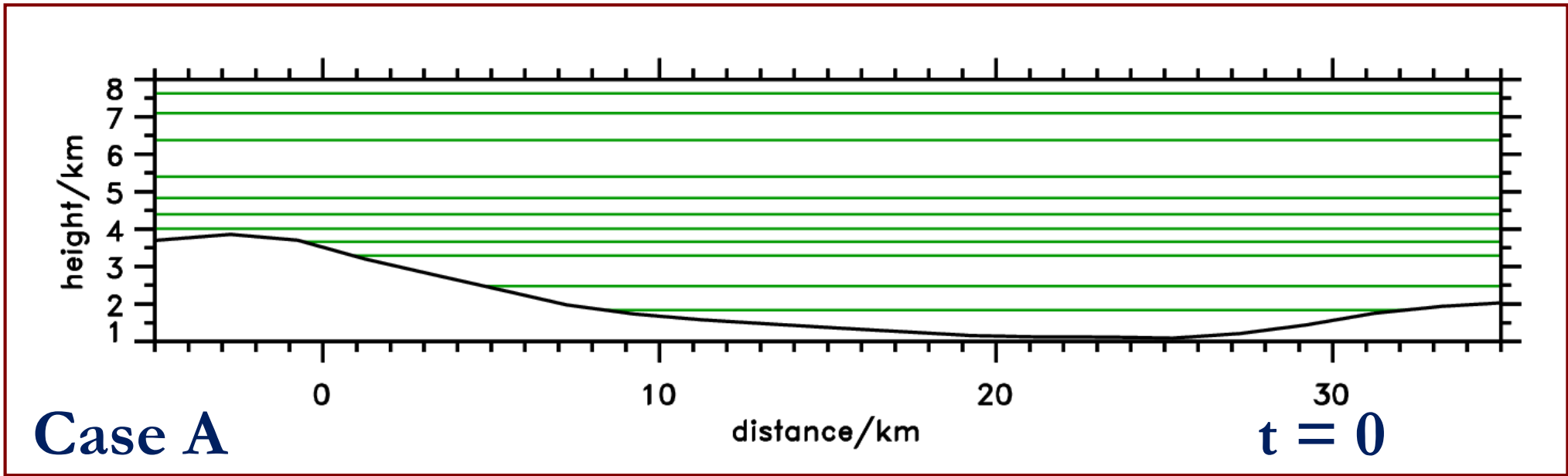
Away from DWL

Towards DWL

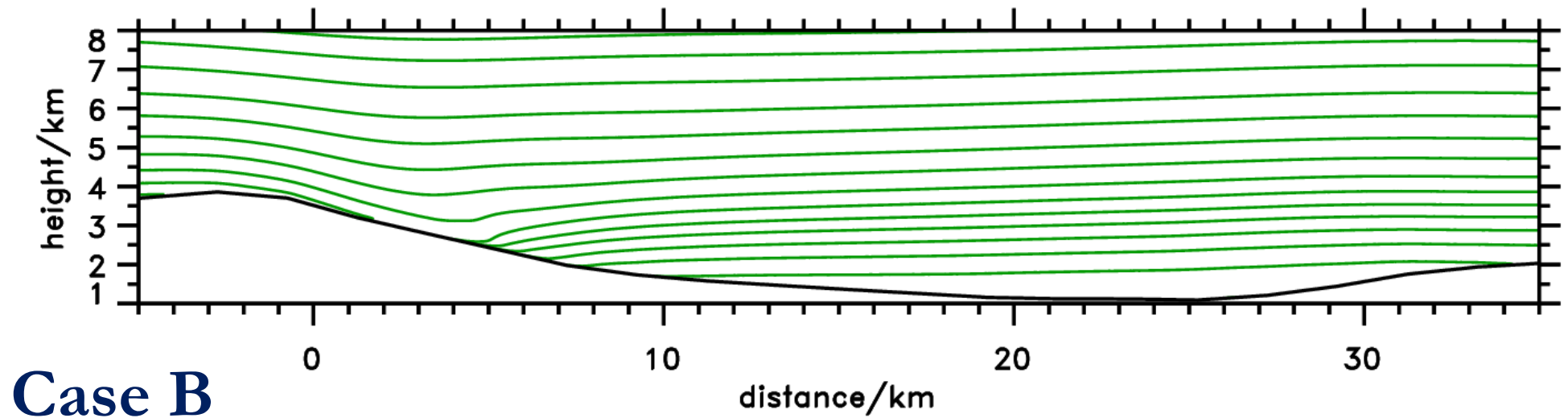
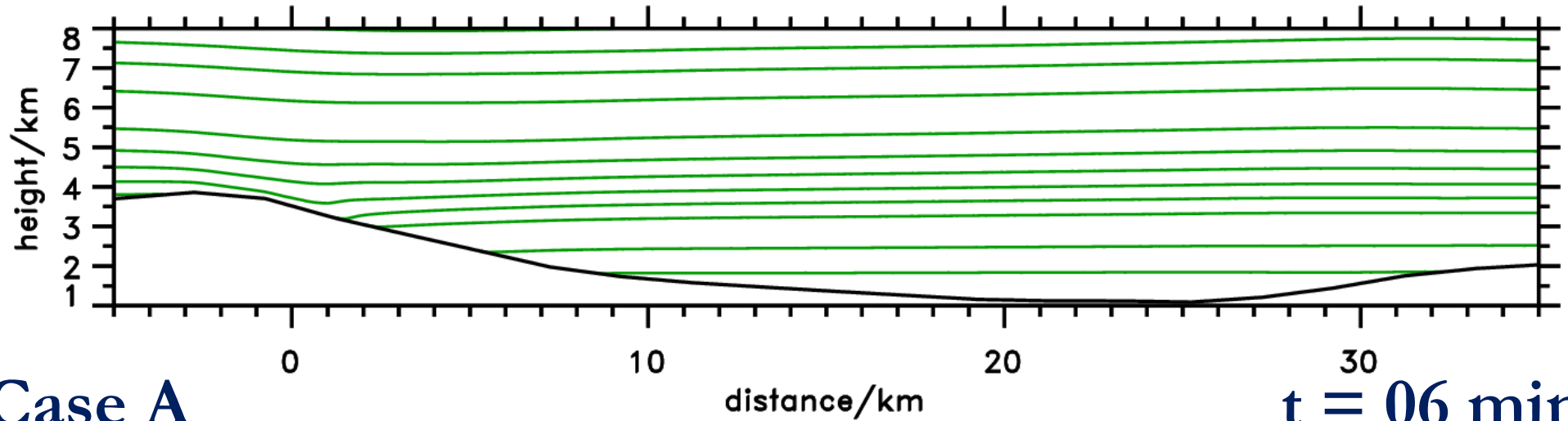
2-D numerical simulations

- a. EULAG - non-hydrostatic, anelastic model by Smolarkiewicz et al.
- b. $\Delta x=100$ m, $\Delta z=20$ m, $\Delta t=0.25$ s
- c. $n_x=4096$, $n_z=1251$, $n_t \sim 16000$
- d. TKE-closure
- e. "realistic" orography of the Owens valley with $dx=2$ km
- f. no-slip boundary condition at the surface
- g. initial conditions: ECMWF upstream profiles

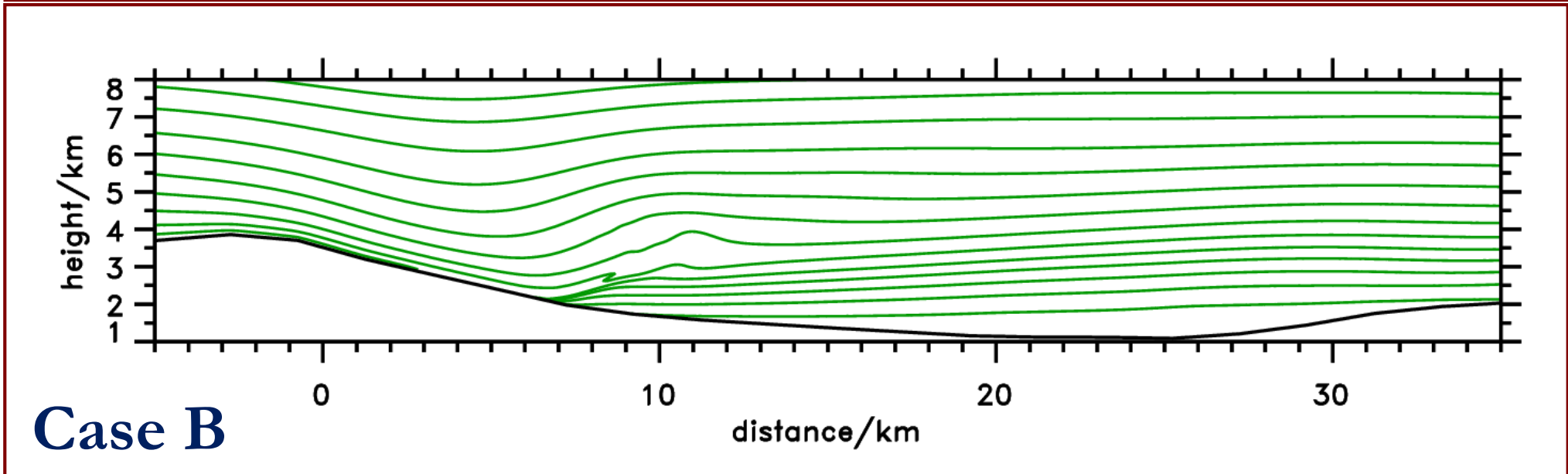
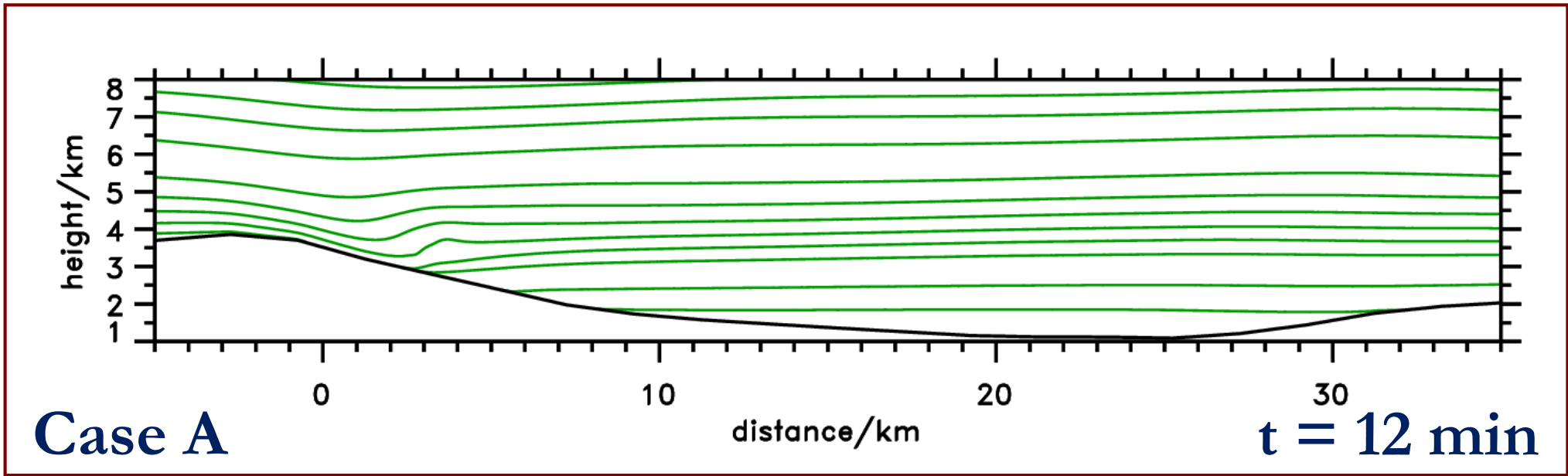
Temporal Evolution of Simulated Isentropes



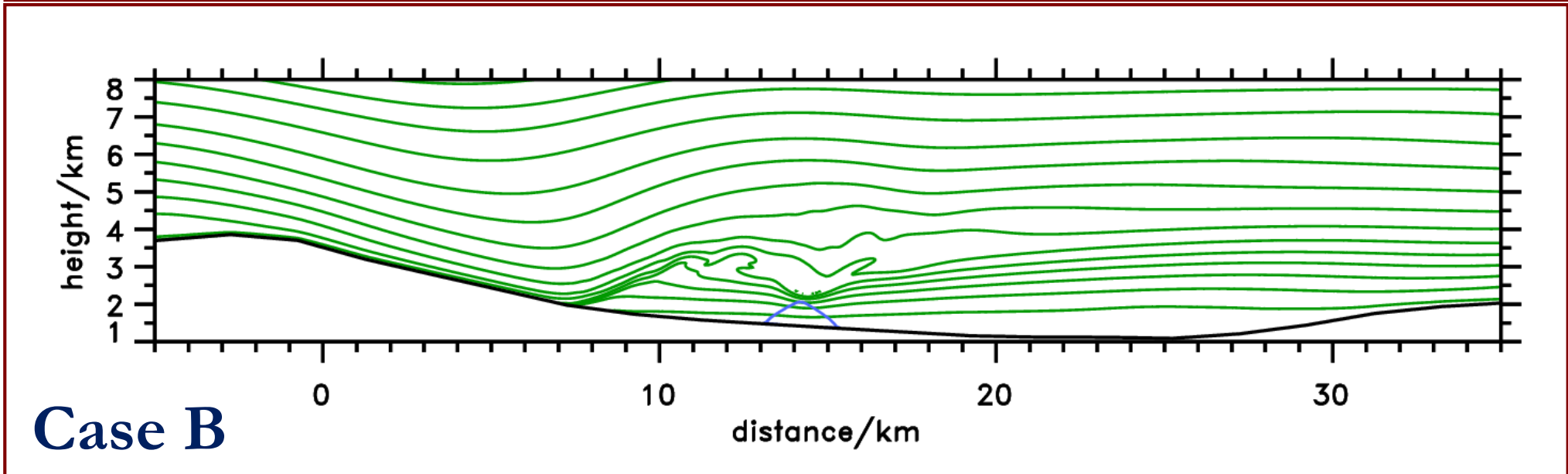
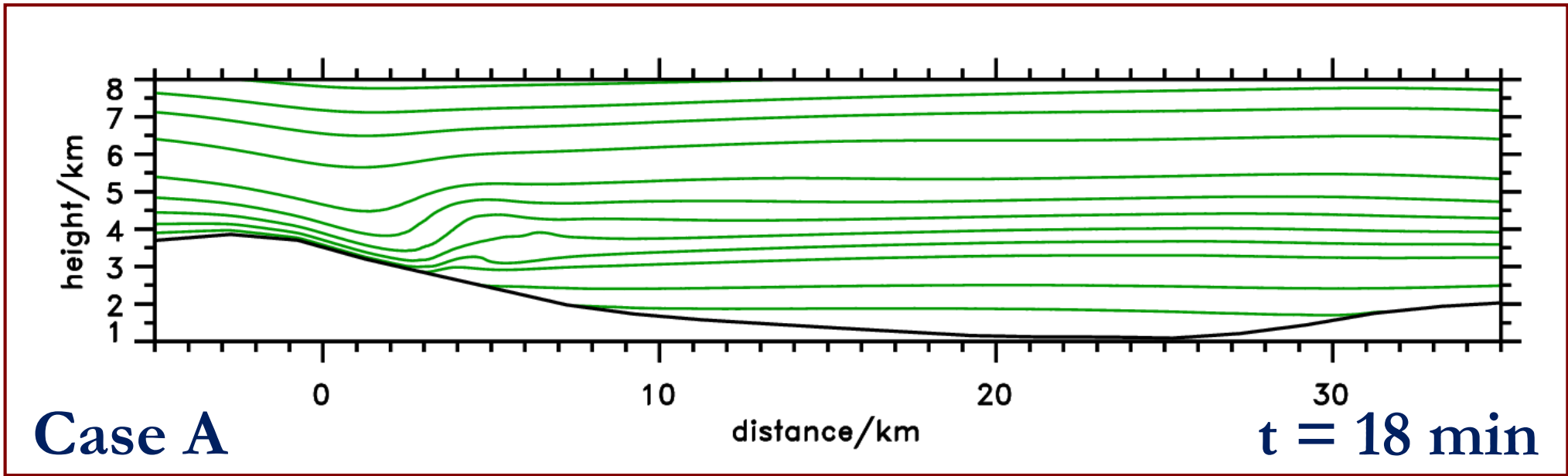
Temporal Evolution of Simulated Isentropes



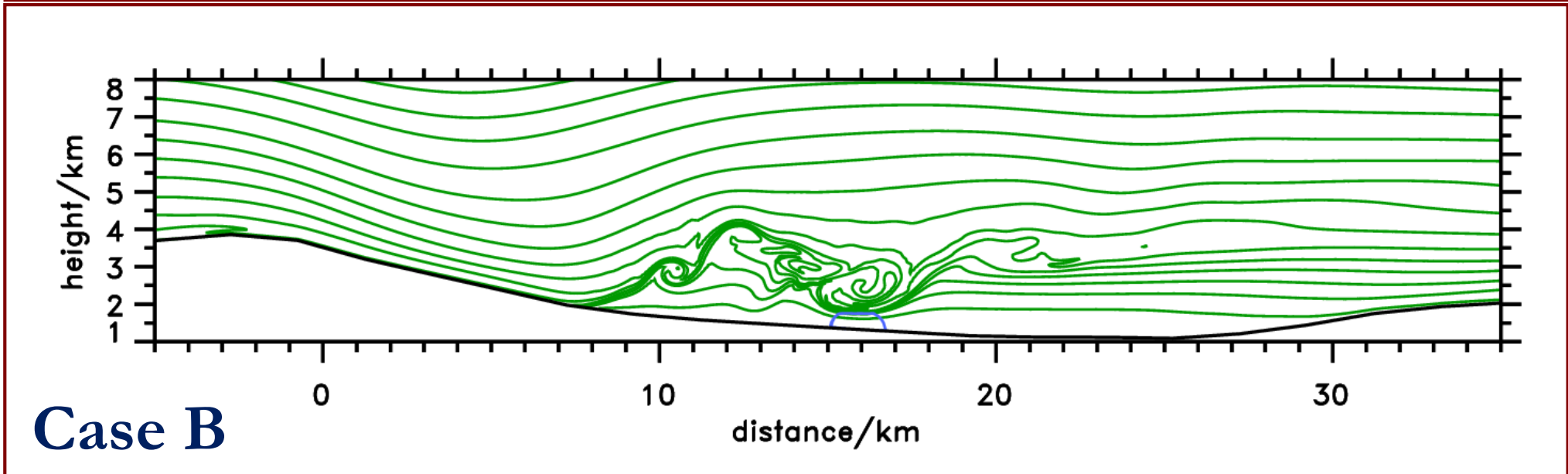
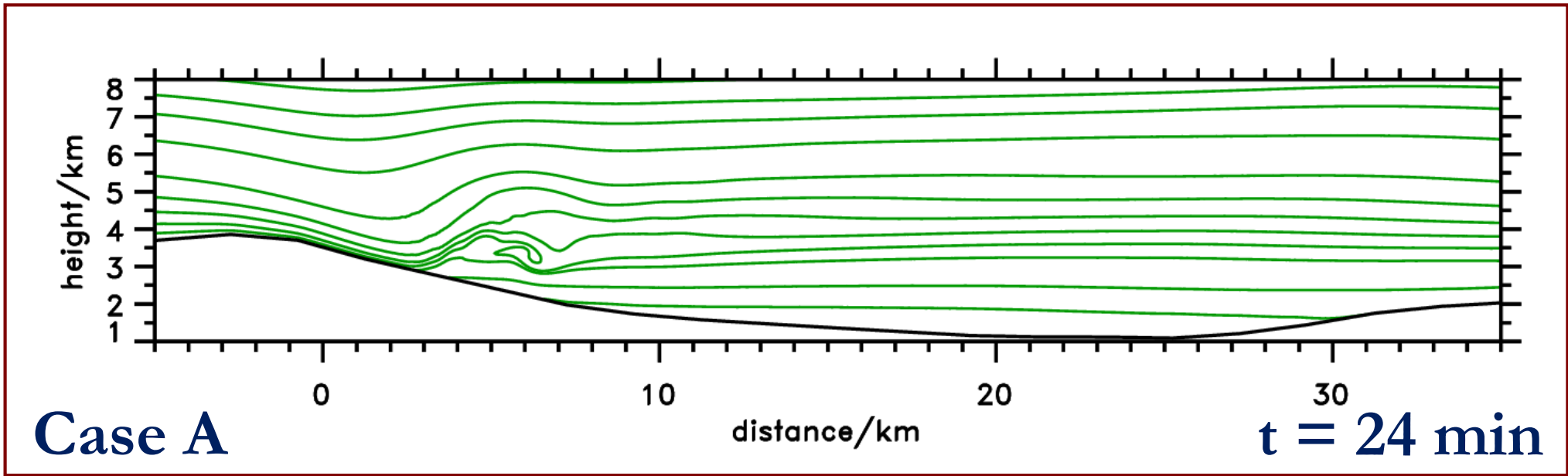
Temporal Evolution of Simulated Isentropes



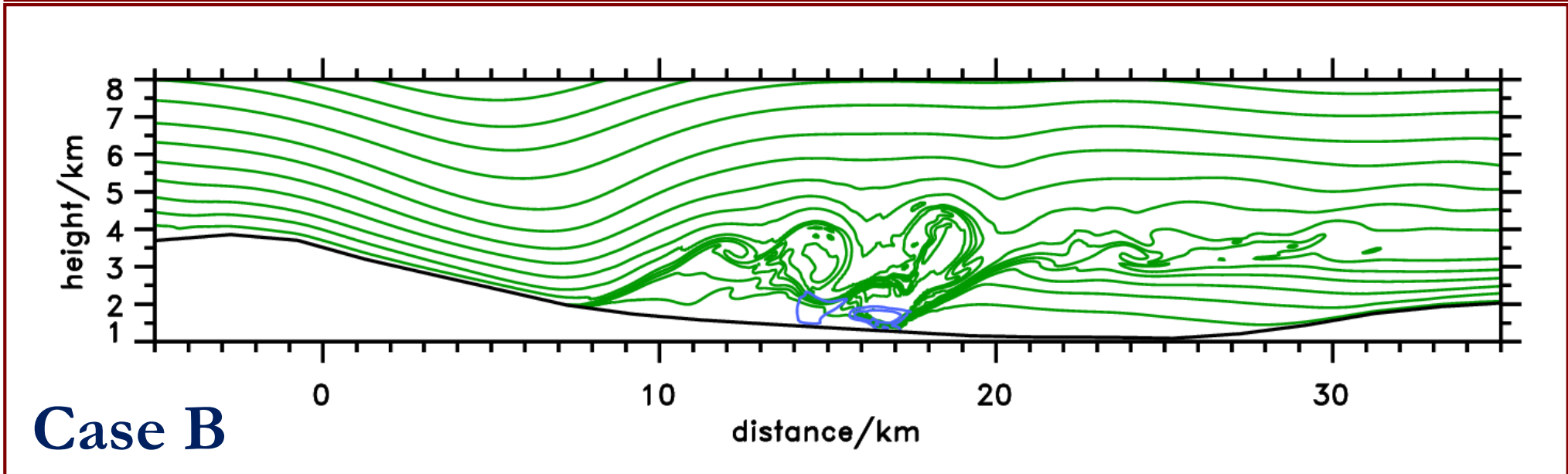
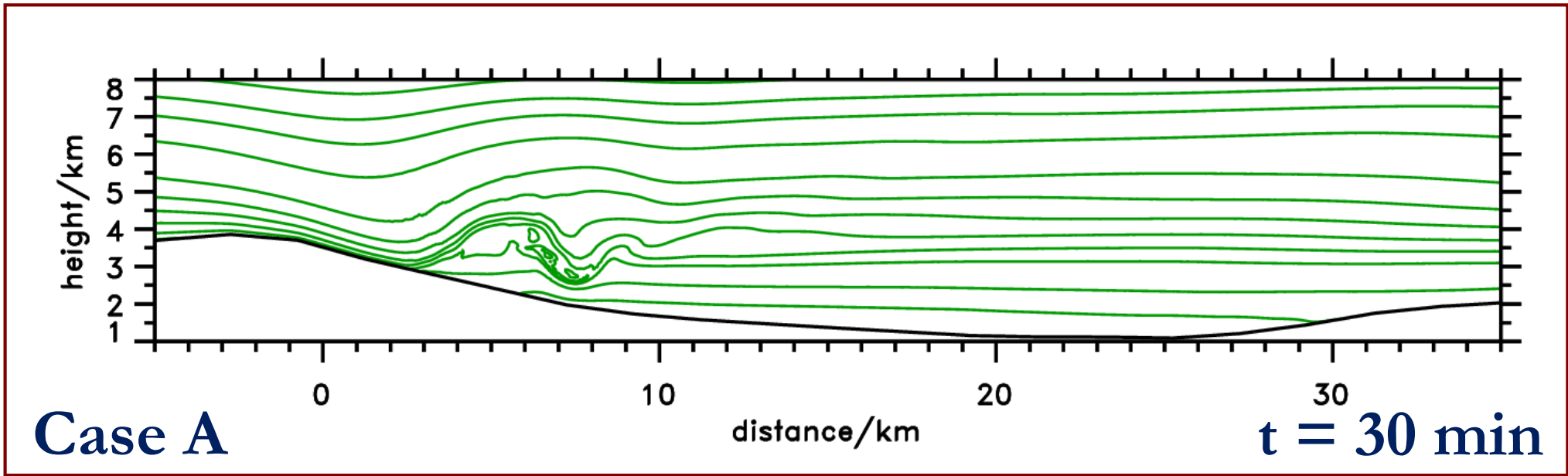
Temporal Evolution of Simulated Isentropes



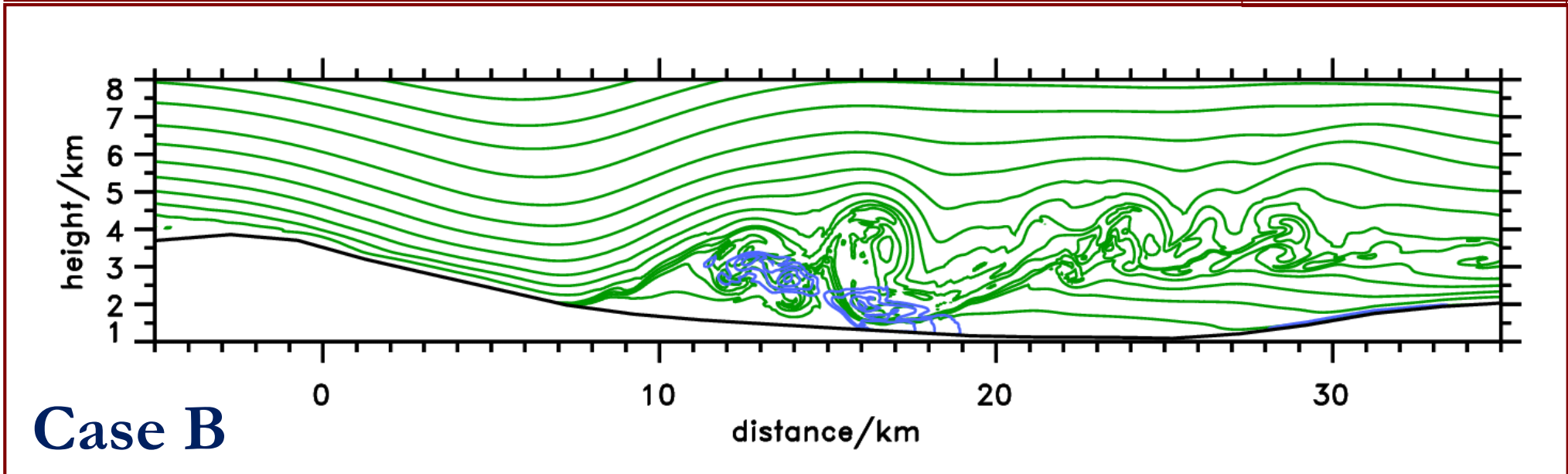
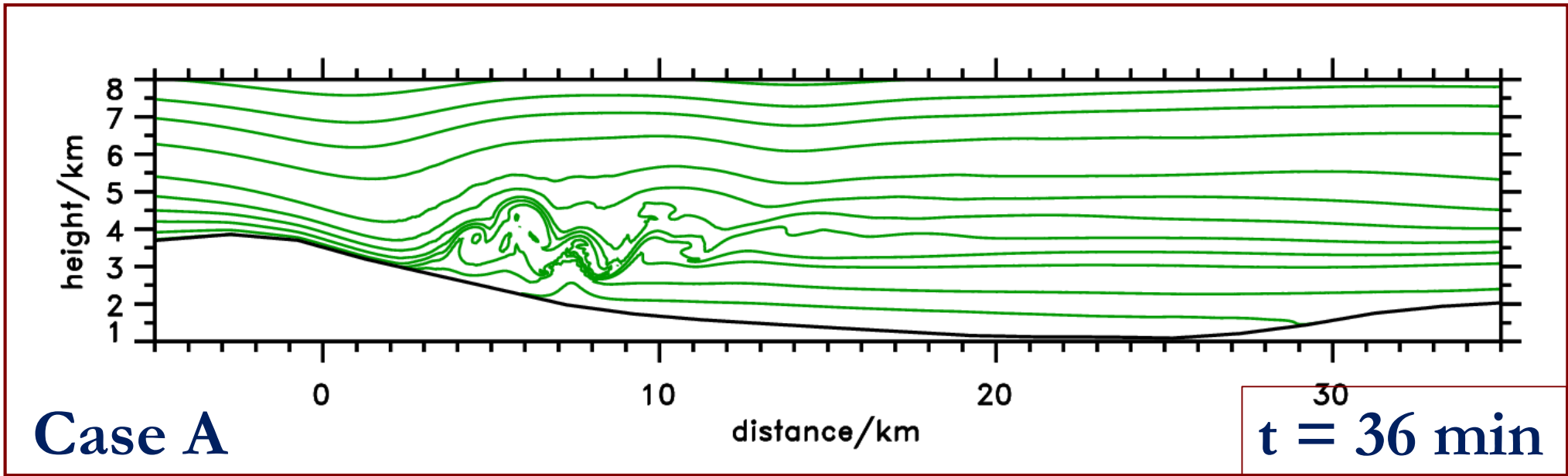
Temporal Evolution of Simulated Isentropes



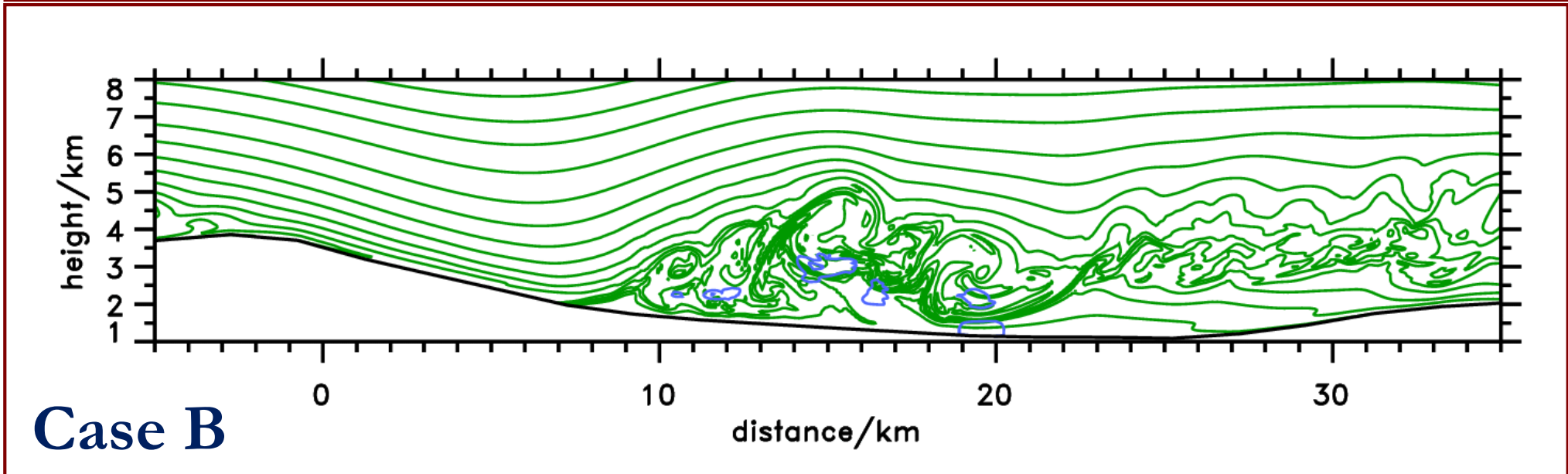
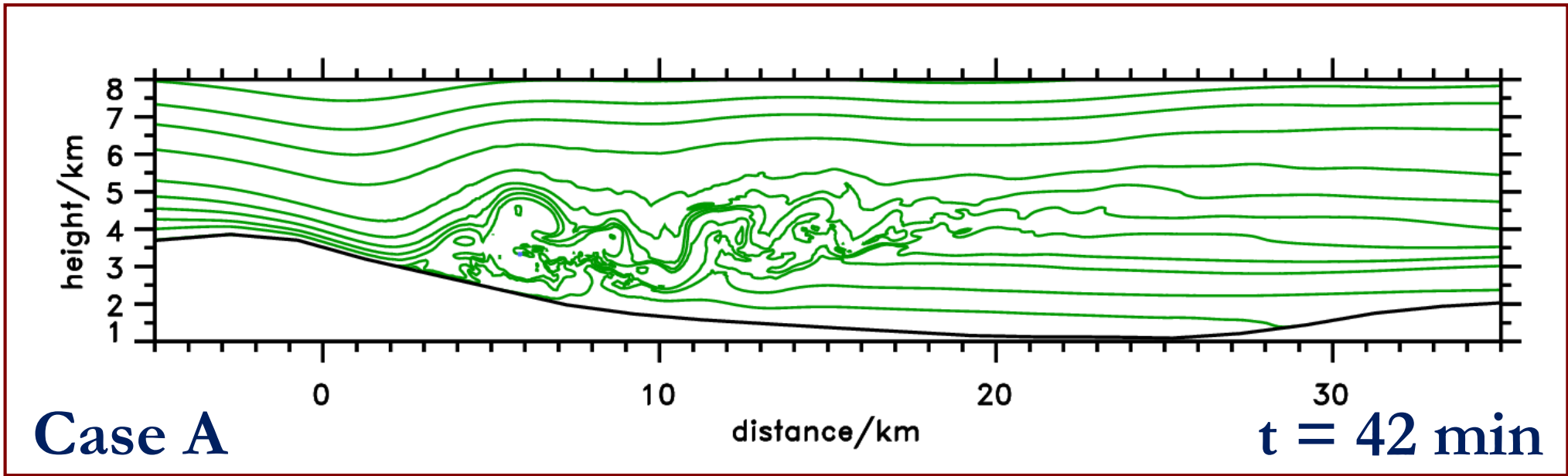
Temporal Evolution of Simulated Isentropes



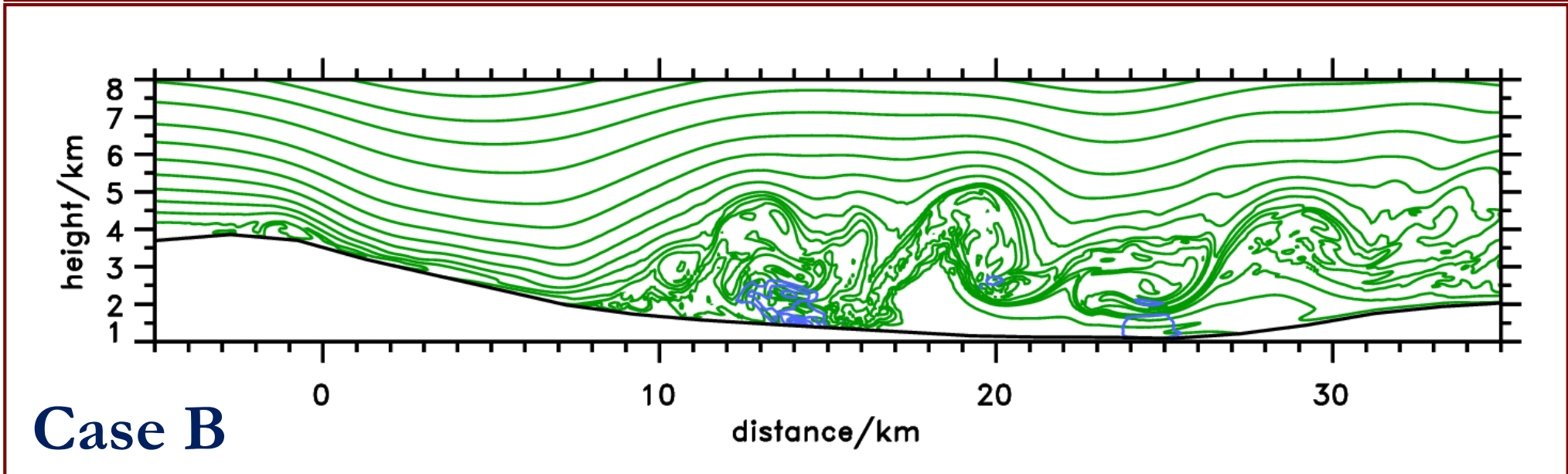
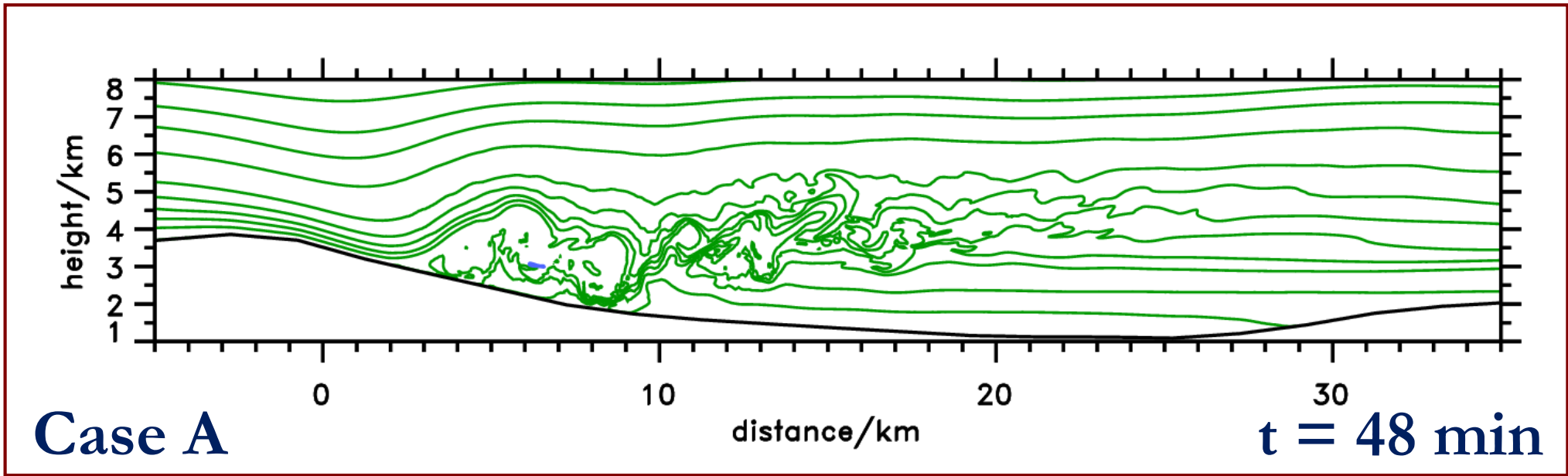
Temporal Evolution of Simulated Isentropes



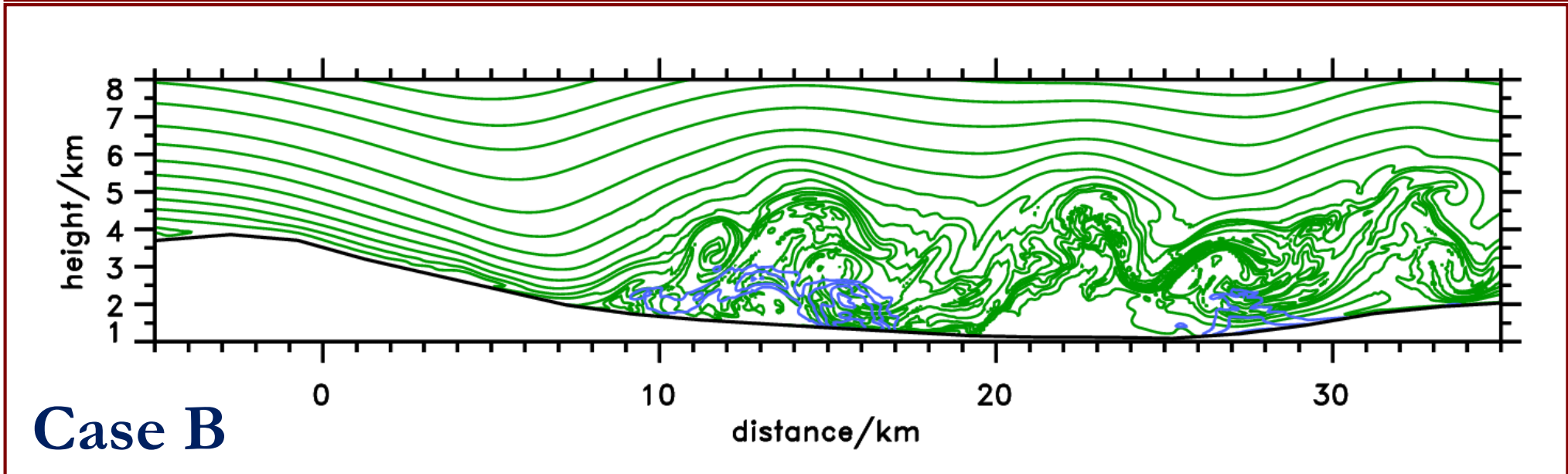
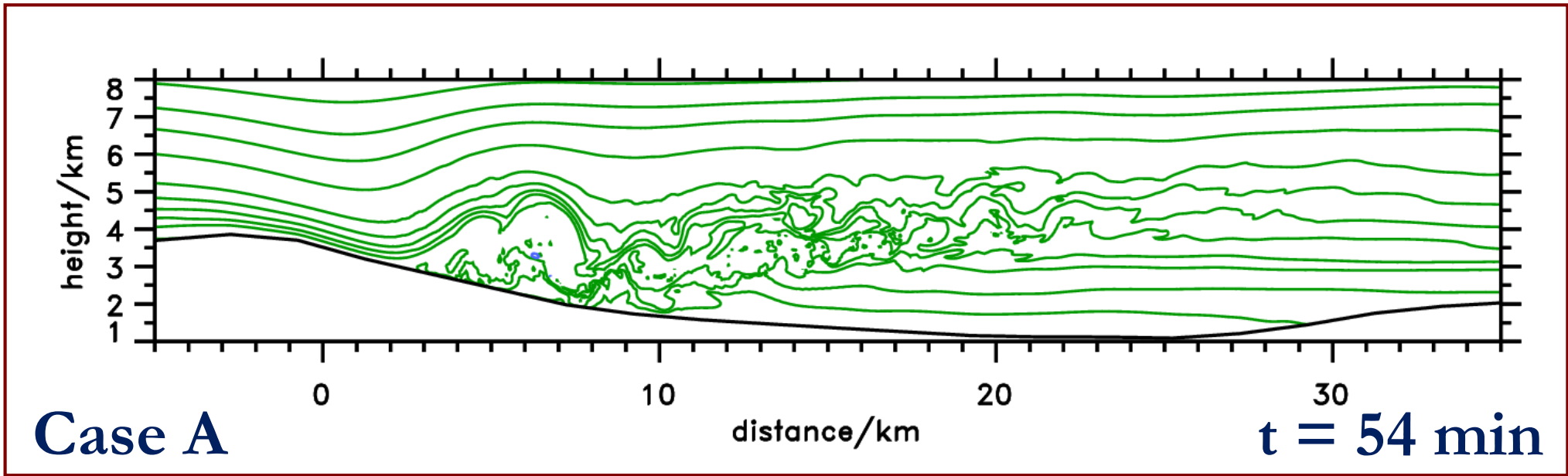
Temporal Evolution of Simulated Isentropes



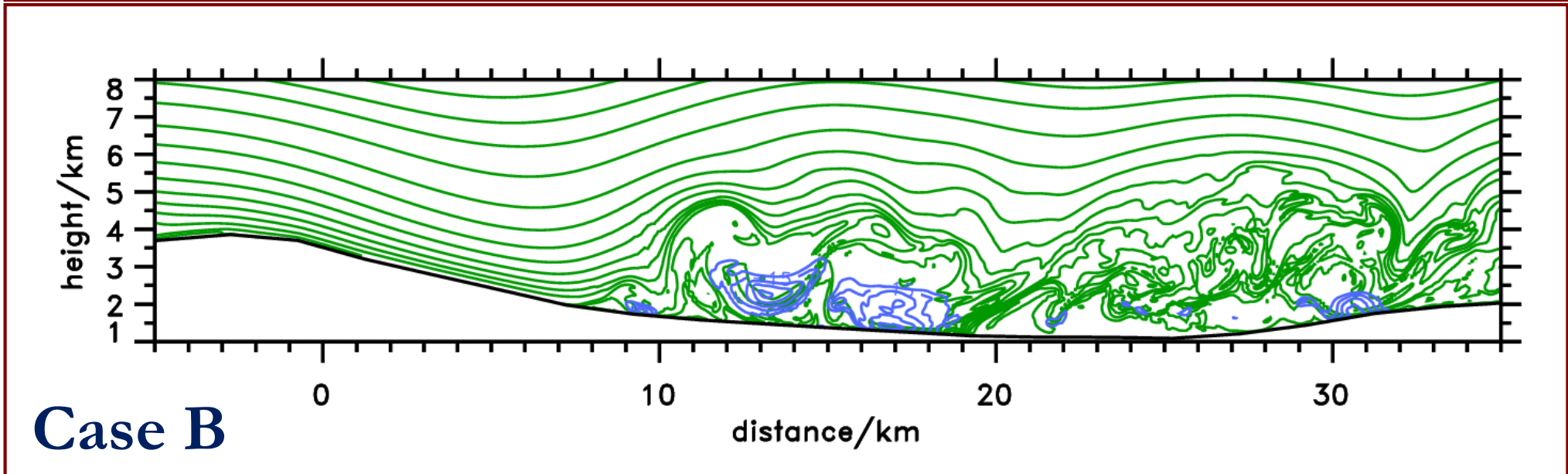
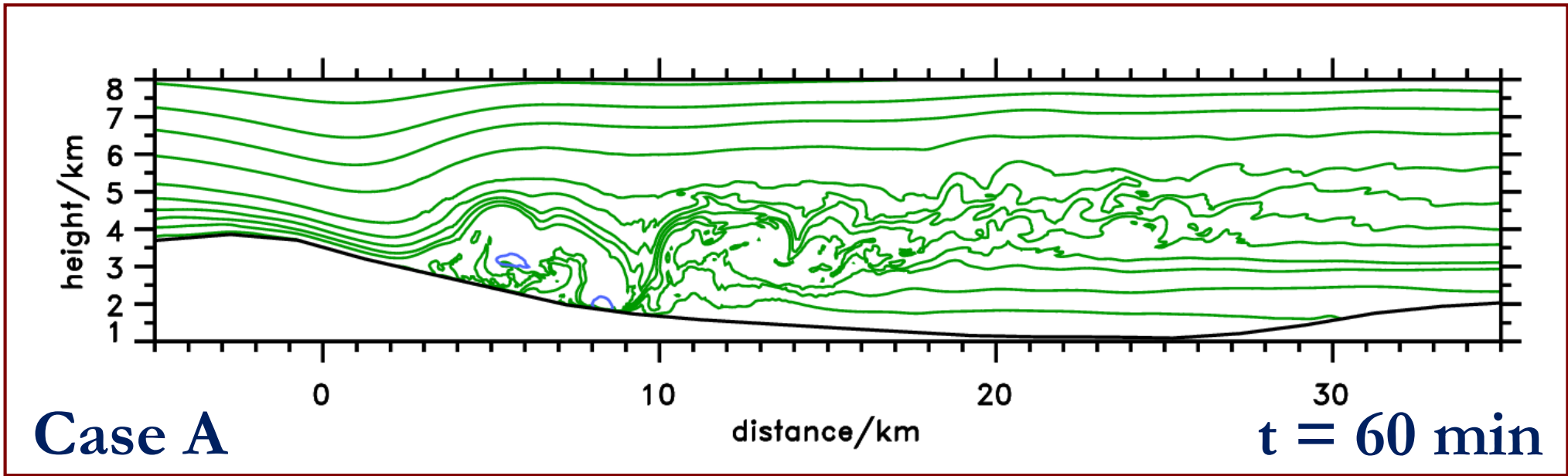
Temporal Evolution of Simulated Isentropes



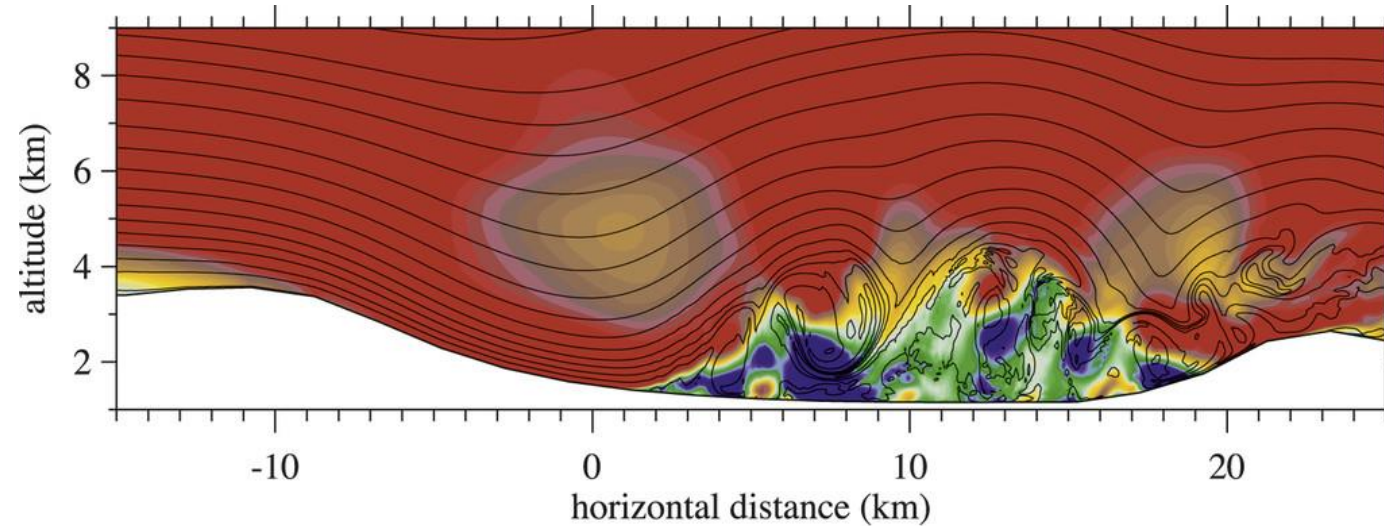
Temporal Evolution of Simulated Isentropes



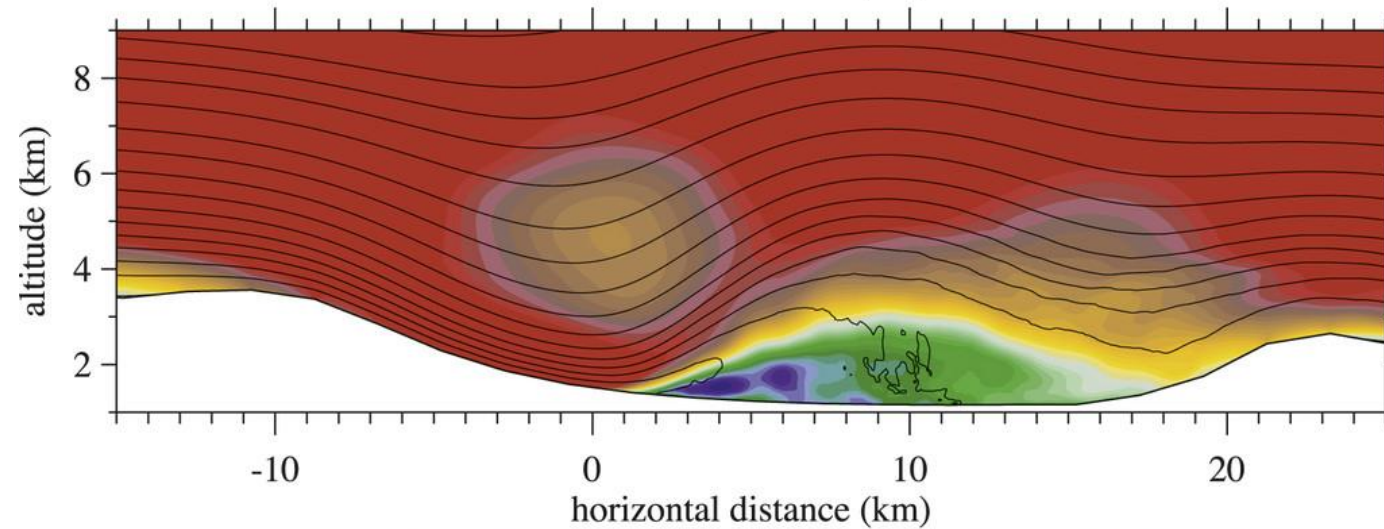
Temporal Evolution of Simulated Isentropes



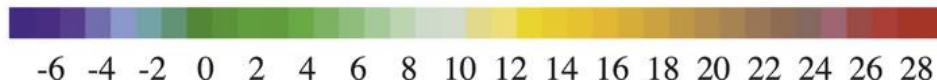
Rotor Concept



snapshot



temporal average
(60 min)



Kühnlein, C., A. Dörnbrack, and M. Weissmann, 2013: High-Resolution Doppler Lidar Observations of Transient Downslope Flows and Rotors. *Mon. Wea. Rev.*, **141**, 3257–3272, <https://doi.org/10.1175/MWR-D-12-00260.1>.

