Testing EULAG as a prospective dynamical core of the NWP model – results for a convective supercell

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INTRODUCTION

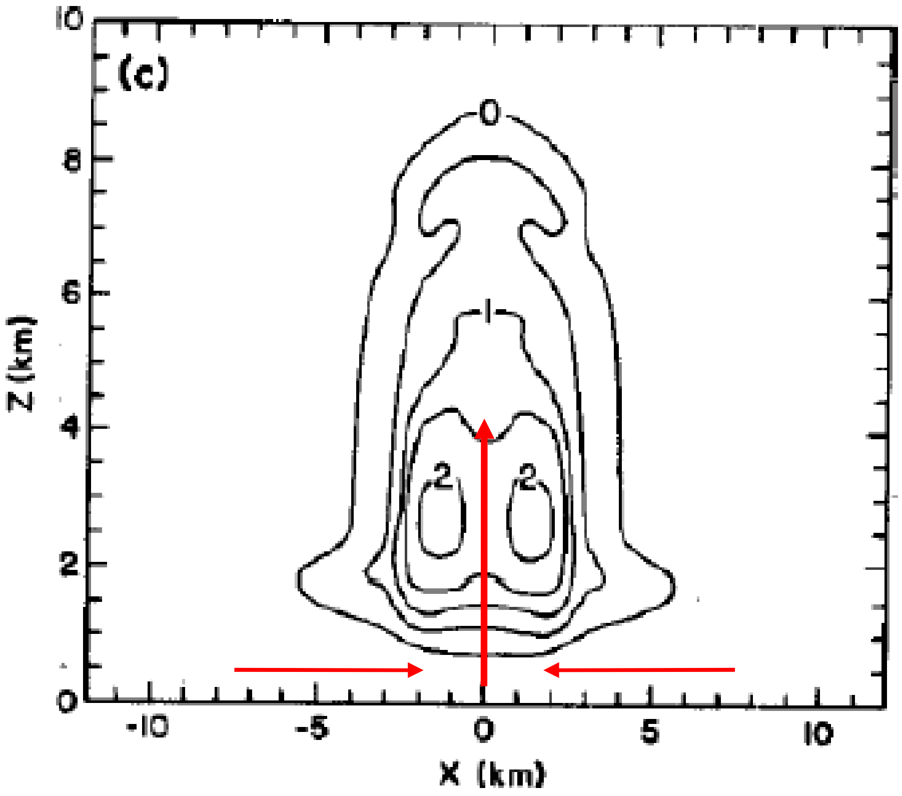
The objective of this experiment is to verify ability of the model to reconstruct a fully 3-dimensional problem related to the real atmosphere, with moist processes included (the next step after a series of 2D idealized dry tests).

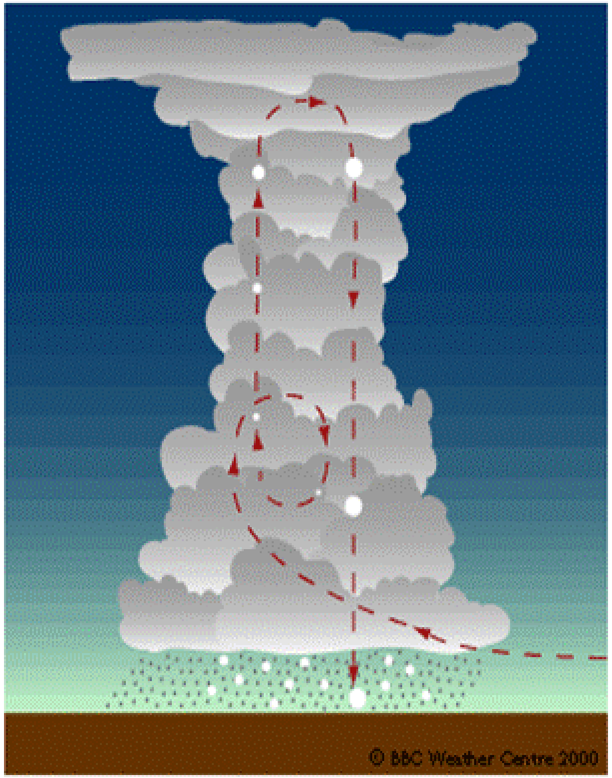
The two reference experiments:

1. Klemp and Wilhelmson, 1978, JAS (KW78)
2. Weisman and Klemp, 1982, MWR (WK82)

Both were simulated using anelastic nonhydrostatic model EULAG.

SUPERCELL – HOW IT WORKS?

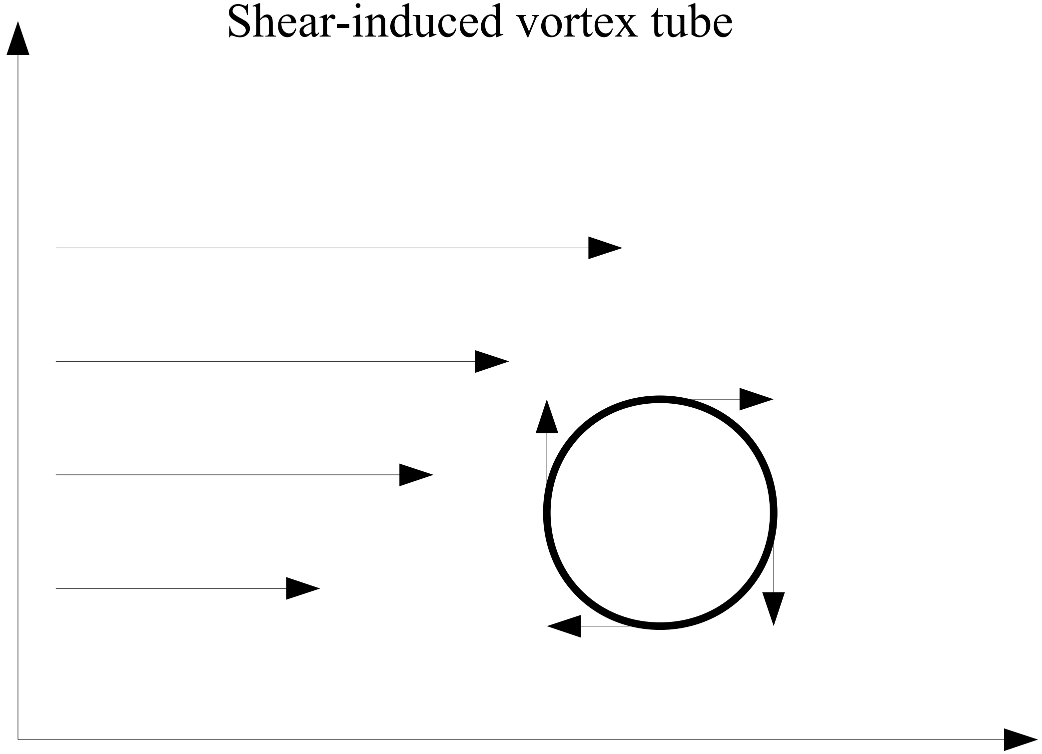




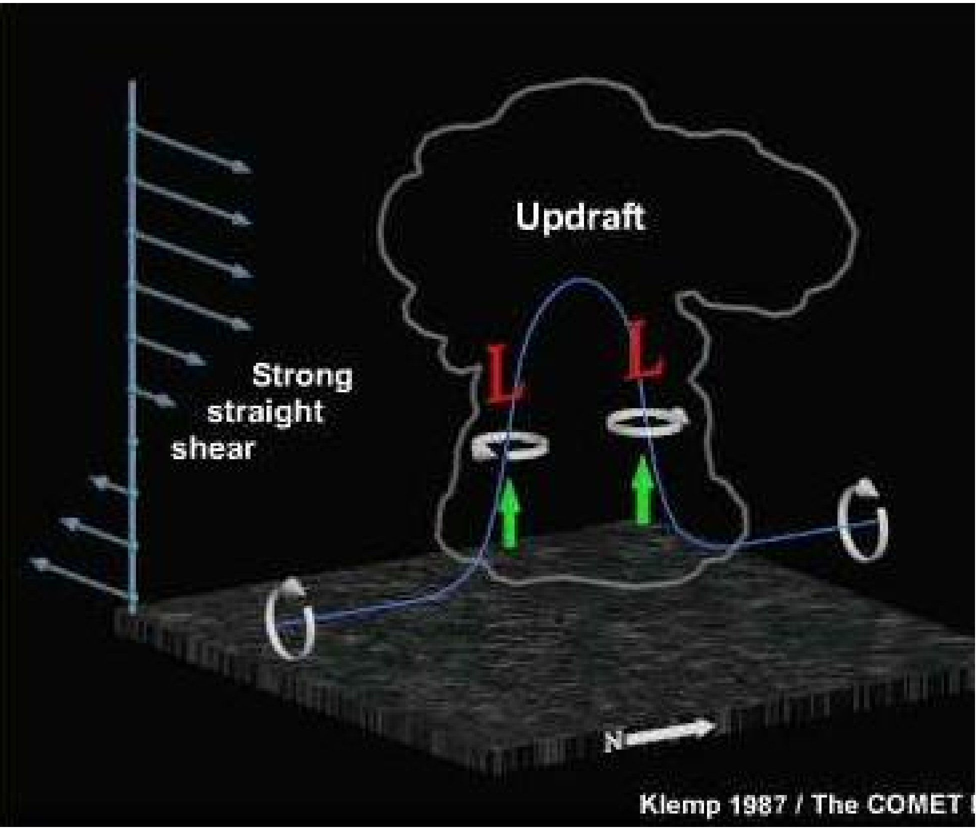
$$CAPE = \int_{z_f}^{z_n} g \left(\frac{Tv_{parcel} - Tv_{env}}{Tv_{env}} \right) dz$$

SUPERCELL – HOW IT WORKS?

Shear-induced vortex tube



SUPERCELL – HOW IT WORKS?



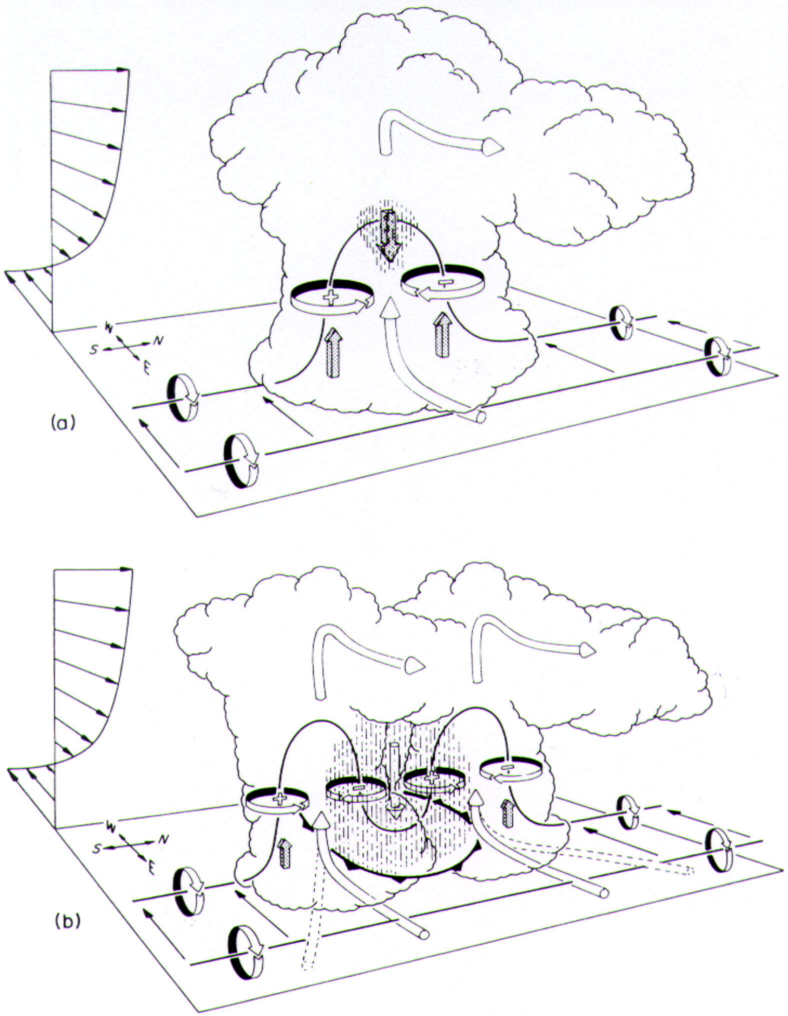
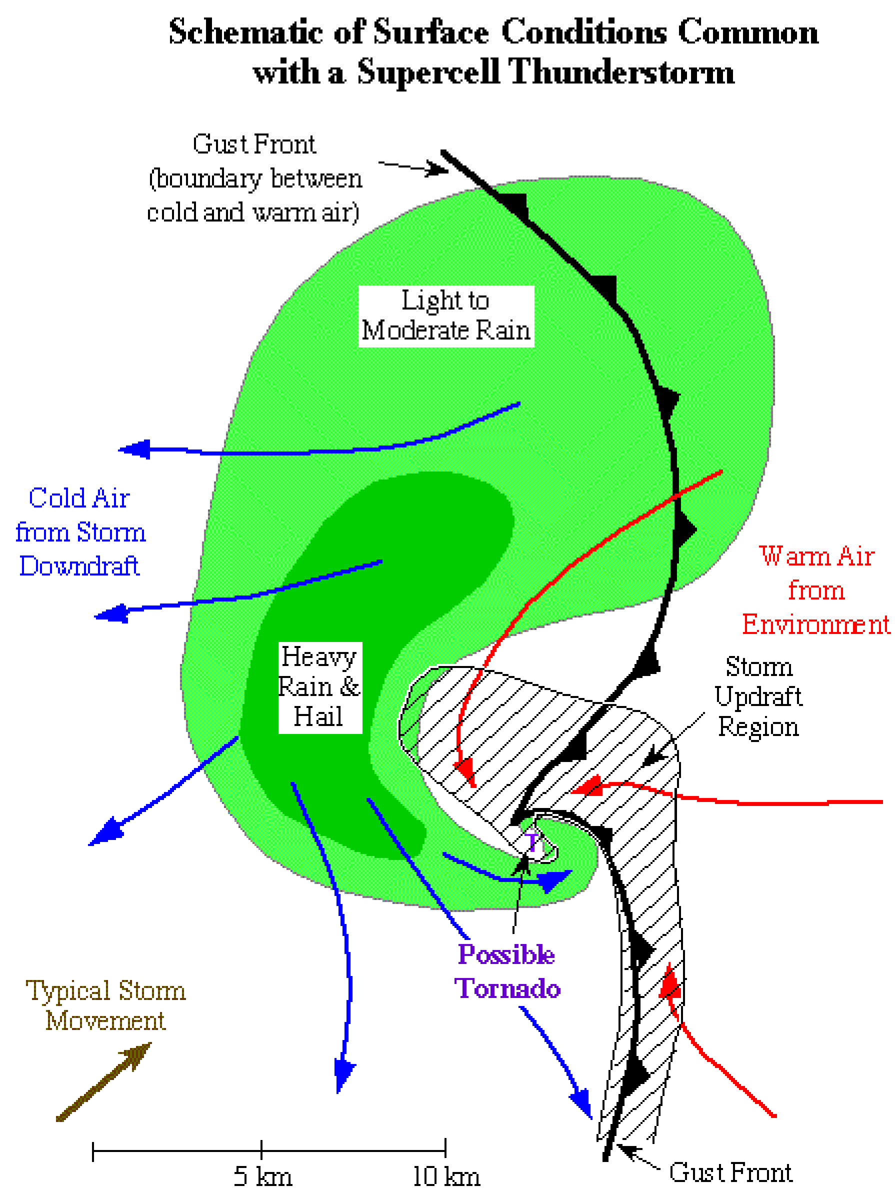
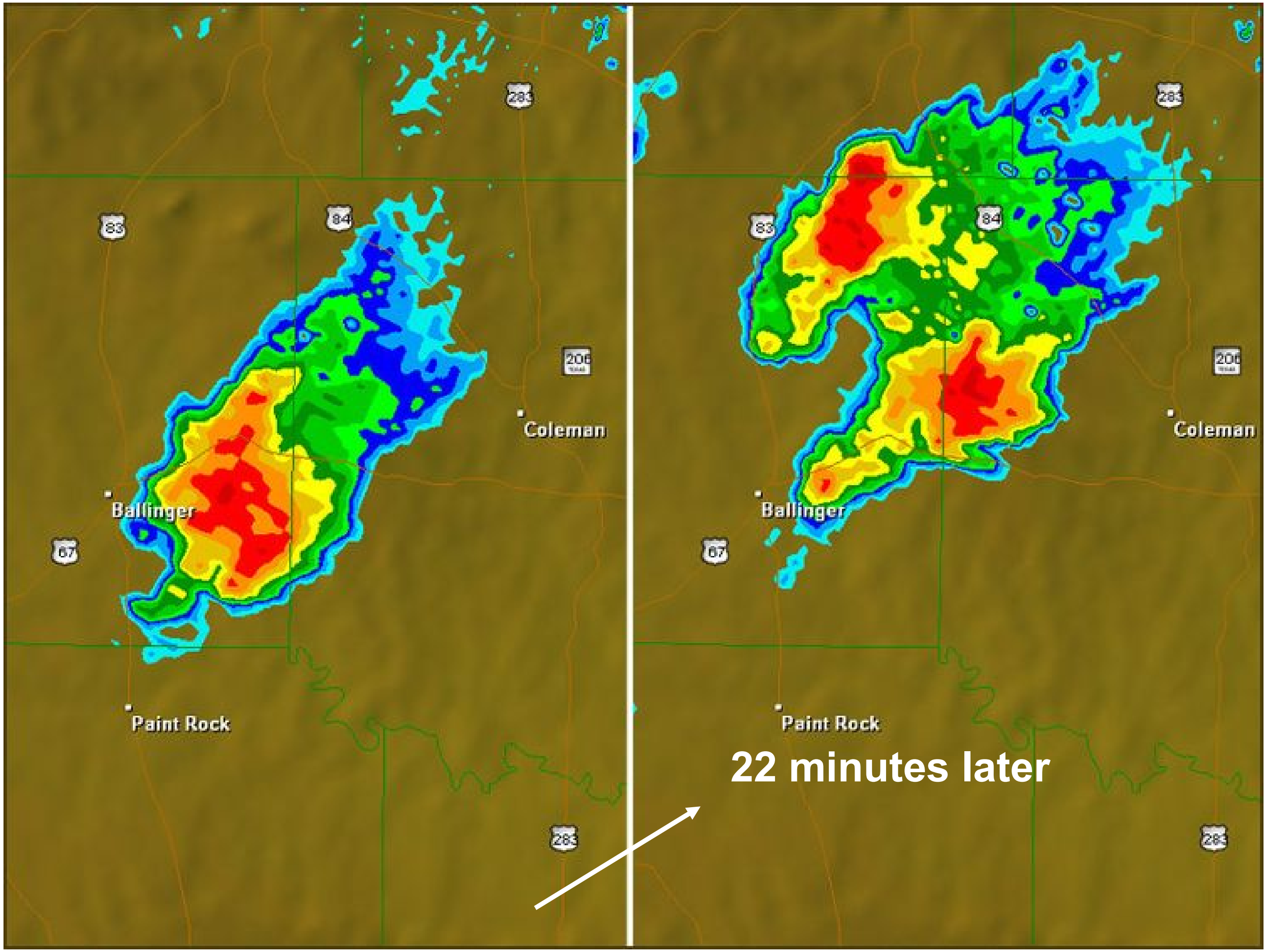


Fig. 11.28 Schematic drawing showing the deformation of vortex tubes (solid lines) by evolving supercell convection in unidirectional shear. Cylindrical arrows show the direction of storm-relative flow. Shaded arrows depict accelerations due to nonhydrostatic pressure perturbations and water loading and evaporation. [*From Klemp (1987).*]

SUPERCELL – HOW IT WORKS?

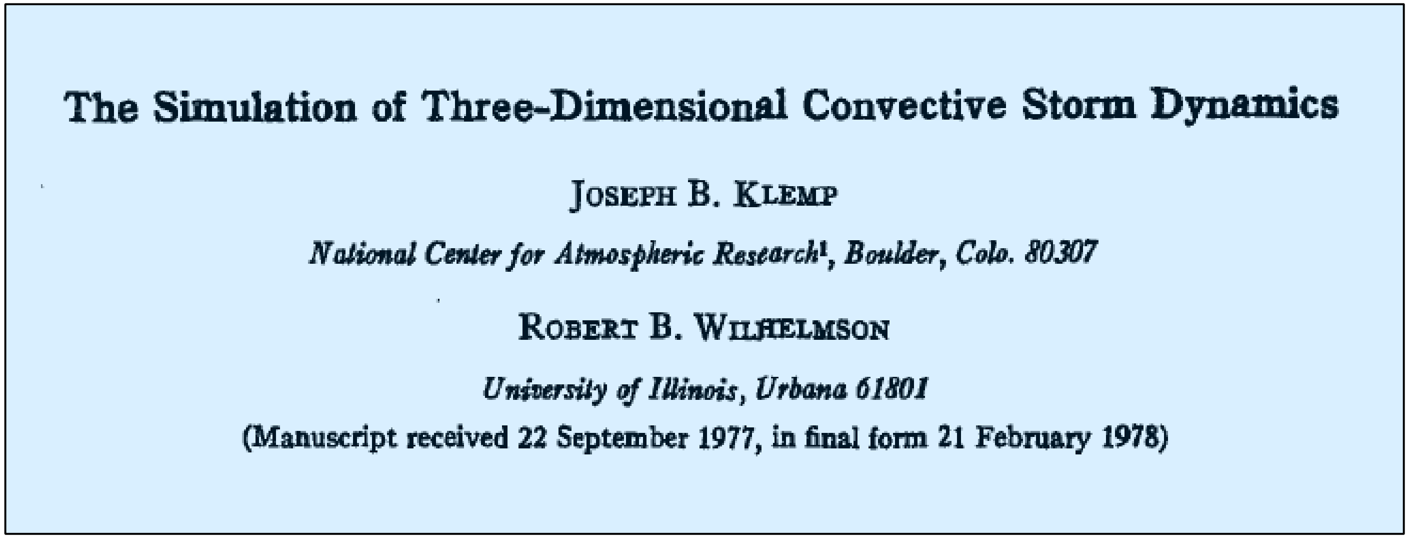


SUPERCELL – HOW IT WORKS?



NOAA Doppler radar reflectivity (Texas, 2008)

KW78


The Simulation of Three-Dimensional Convective Storm Dynamics

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University of Illinois, Urbana 61801

(Manuscript received 22 September 1977, in final form 21 February 1978)

Grid: uniform,

dx=dy=1km, dz=500m

domain size: 24x24x10 km (additionally 32x32 and 256x256)

Subgrid-scale processes:

1) TKE scheme, Pr=0.33 $K_m = c_m TKE^{1/2}(\Delta x \Delta y \Delta z)^{1/3}$

2) ILES (implicit large-eddy simulation)

Moist processes:

bulk parametrization (instantaneous saturation adjustment, Kessler scheme, warm rain only)

$$A_r = k_1(q_c - a),$$

$$C_r = k_2 q_c q_r^{0.875},$$

$$E_r = \frac{1}{\bar{\rho}} \frac{(1 - q_v/q_{vs}) C (\bar{\rho} q_r)^{0.525}}{5.4\times 10^5 + 2.55\times 10^6/(\bar{\rho} q_{vs})},$$

$$V = 3634(\bar{\rho} q_r)^{0.1346}\left(\frac{\bar{\rho}}{\rho_0}\right)^{-\frac{1}{2}}$$

Boundary conditions:

open b.c. (additionally periodic)

Initial conditions:

realistic sounding

Time integration:

24 min for unsheared environment

36 min for a shear flow

40 min for veering wind

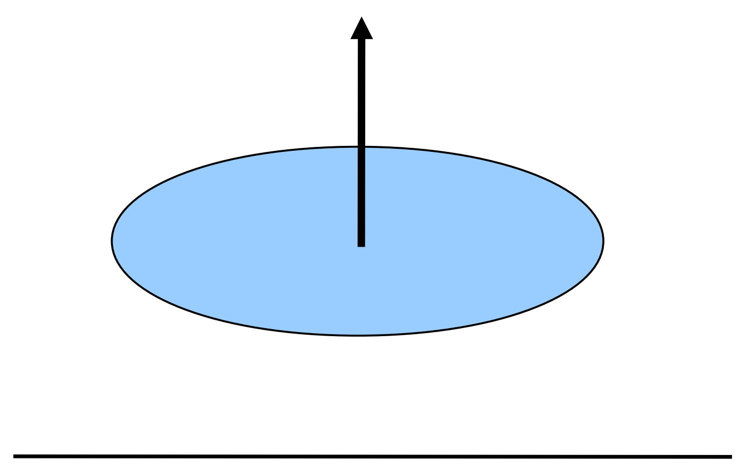
Details of setup agreed (?) with KW78

KW78 — Setup of the experiment

$$\theta' = \Delta\theta_0 cos^2 \frac{1}{2}\pi\beta$$

$$\beta = \left(\left(\frac{x - x_c}{x_r}\right)^2 + \left(\frac{y - y_c}{y_r}\right)^2 + \left(\frac{z - z_c}{z_r}\right)^2 \right)^{1/2}$$

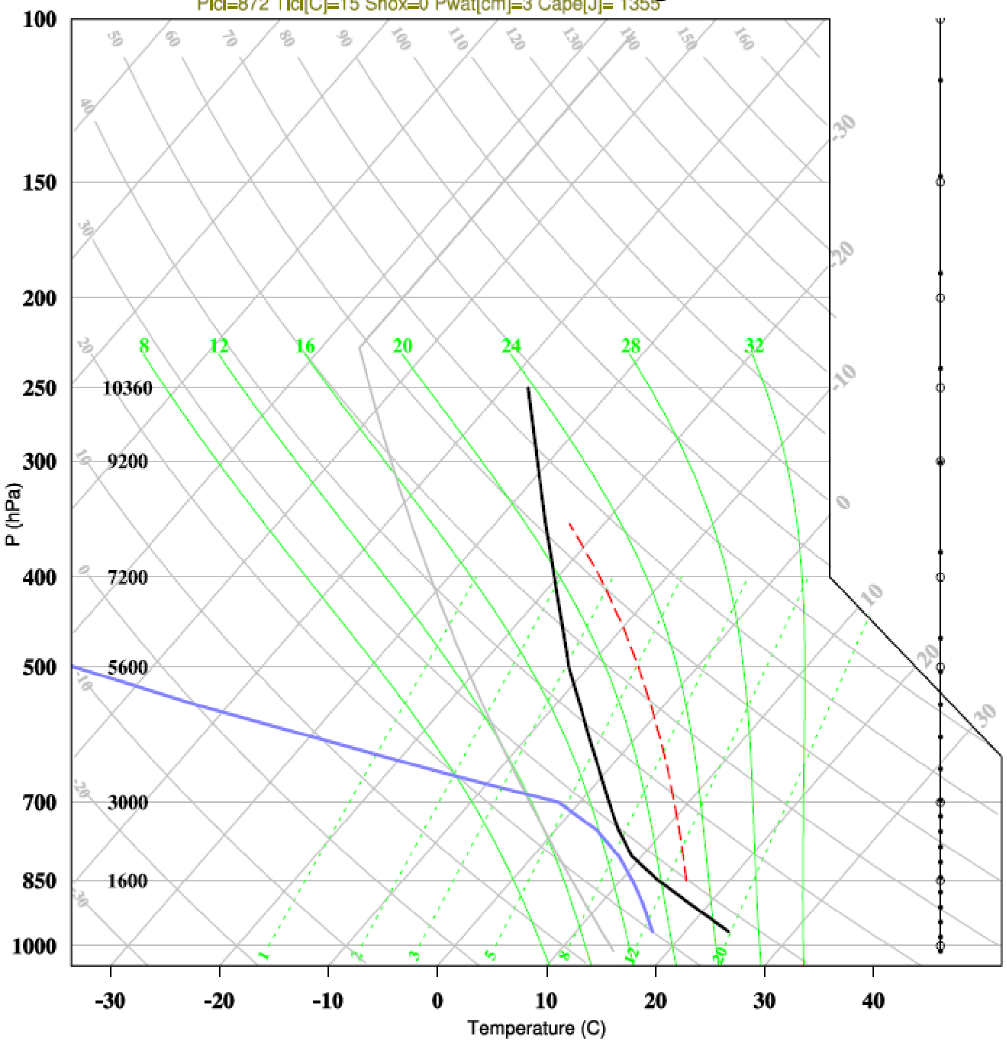
$z_c = 1500$ m, $x_r = y_r = 10.8$ km, $z_r = 2000$ km and $\Delta\theta = 1.5^O$ C



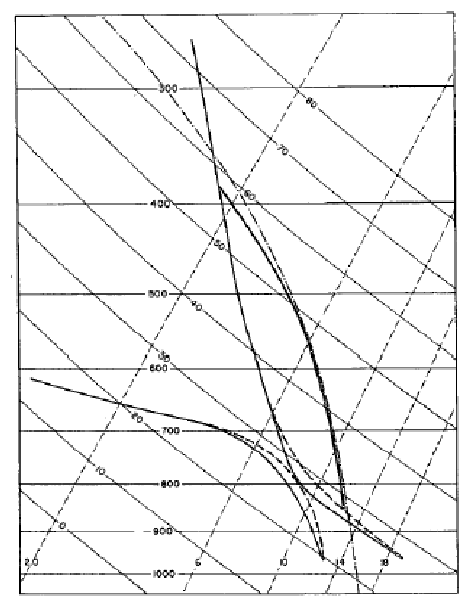
Initial soundings

EULAG's initial profiles of tempreature and humidity - from Fig.1 of KW78. Accuracy of the profile is limited. Slight (~0.2K) modifications of the temperature at different levels may significantly change CAPE (~5-10%)

EULAG's initial sounding



KW78



KW78

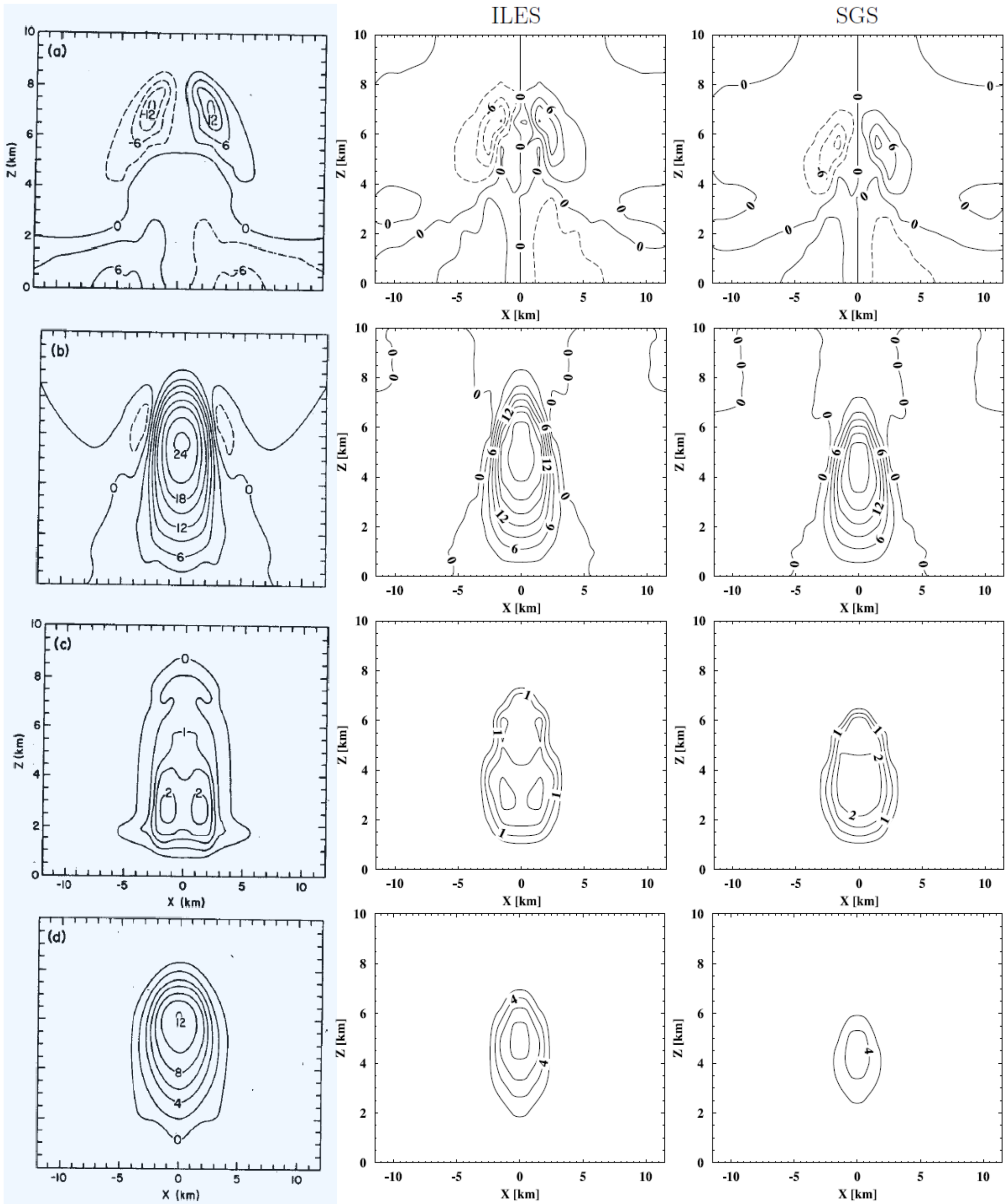
No shear simulations

U (m/s)
ΔU=3m/s

W (m/s)
ΔW=3m/s

qc (g/kg)
Δqc=0.5g/kg

qr (g/kg)
Δqr=2g/kg



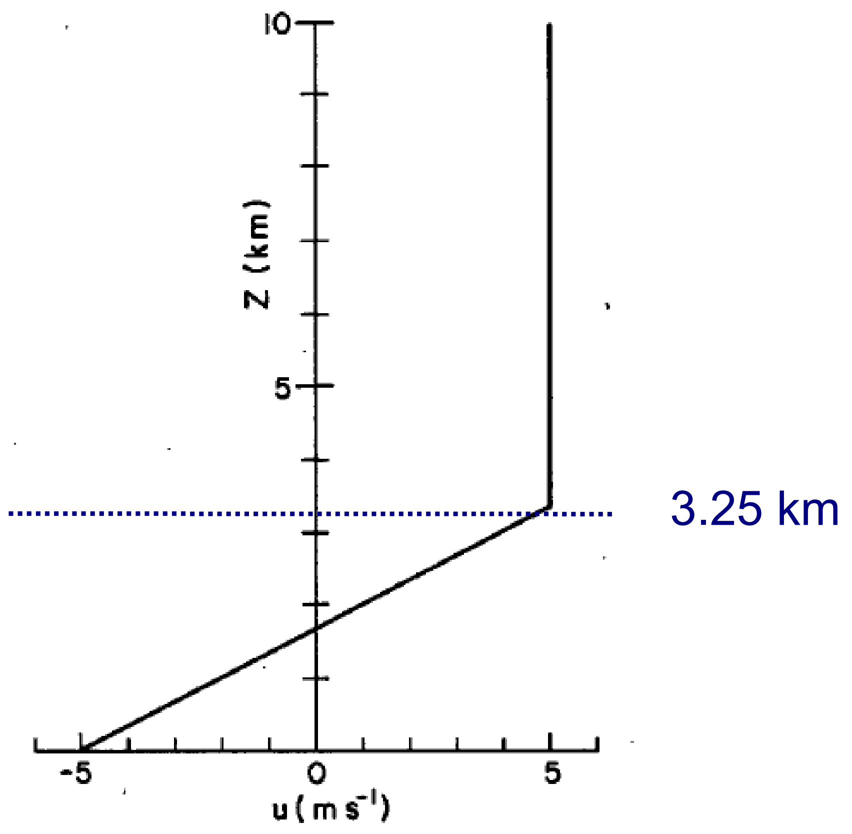
X-Z crossection at y=0

time=24min

ILES – implicit large-eddy simulation (no explicit subgrid-scale mixing)

SGS – explicit subgrid-scale mixing parametrization used

Idealized external shear flow:



KW78

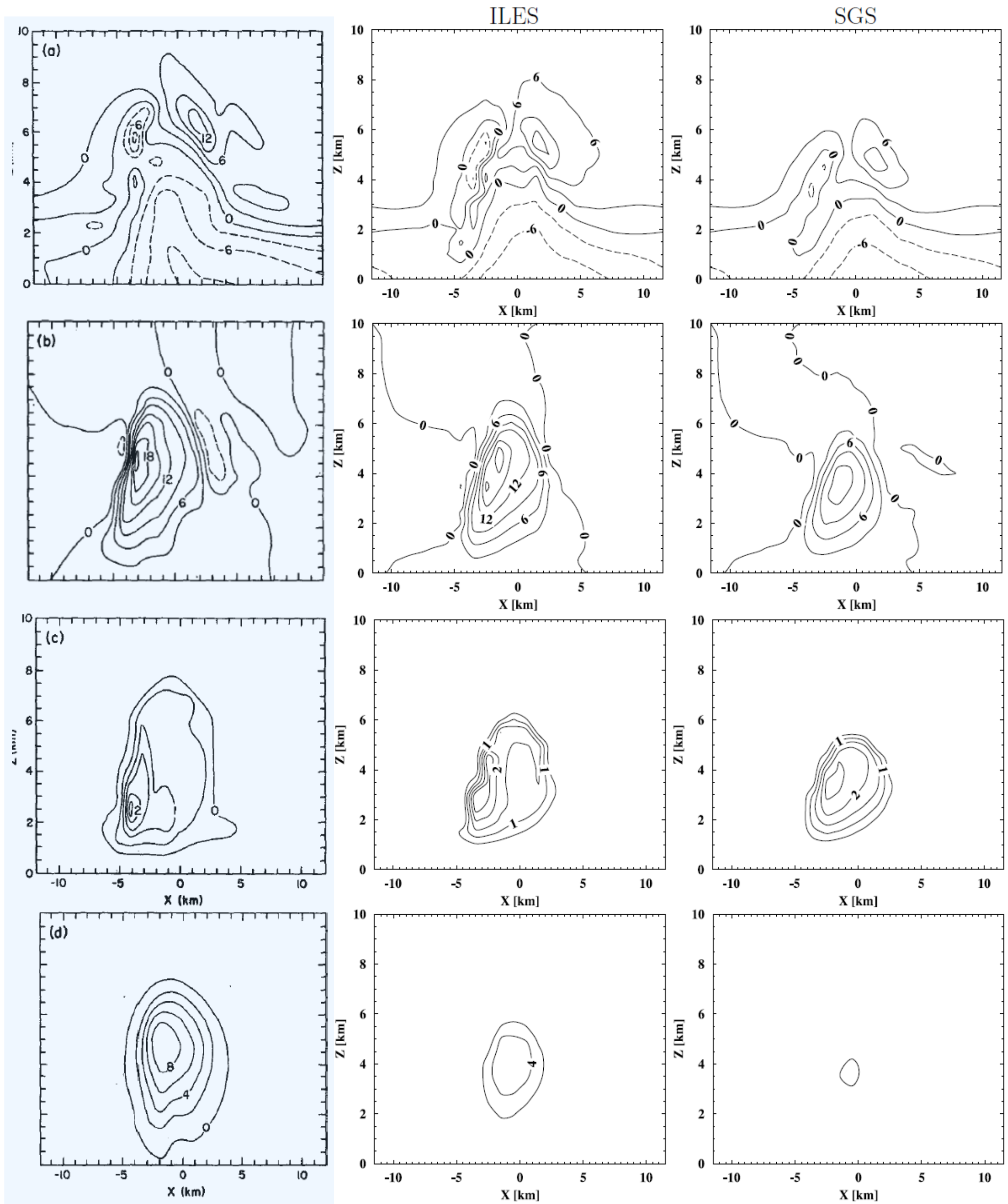
Simulations with a shear flow

U (m/s)
ΔU=3m/s

W (m/s)
ΔW=3m/s

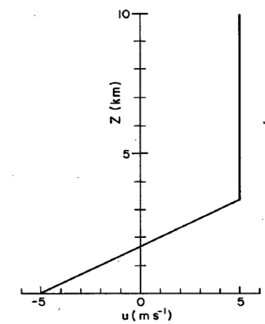
qc (g/kg)
Δqc=0.5g/kg

qr (g/kg)
Δqr=2g/kg



X-Z crossection at y=0

time=24min



ILES – implicit large-eddy simulation (no explicit subgrid-scale mixing)

SGS – explicit subgrid-scale mixing parametrization

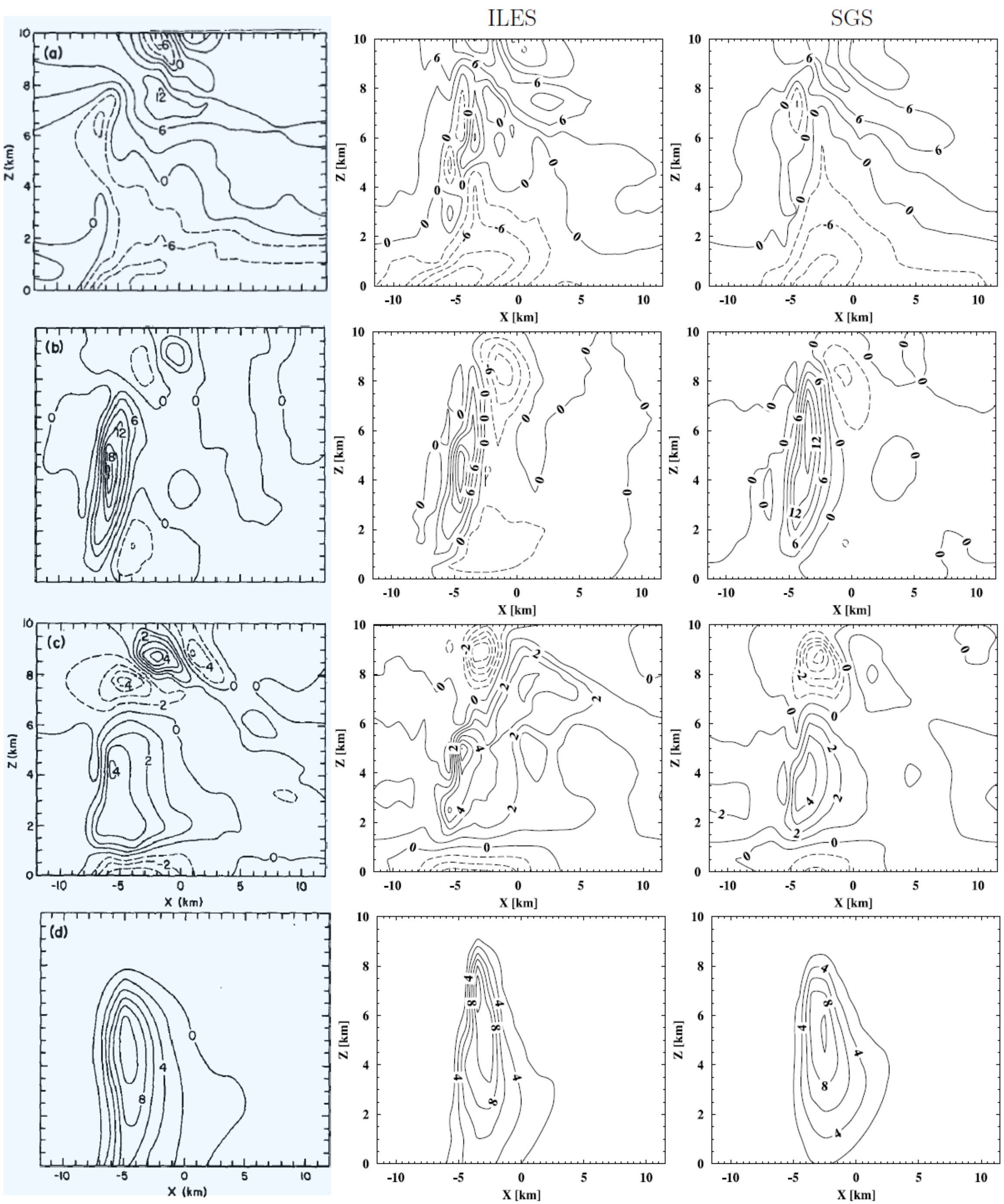
Simulations with a shear flow

U (m/s)
ΔU=3m/s

W (m/s)
ΔW=3m/s

Θ (K)
Δθ=1K

qr (g/kg)
Δqr=2g/kg

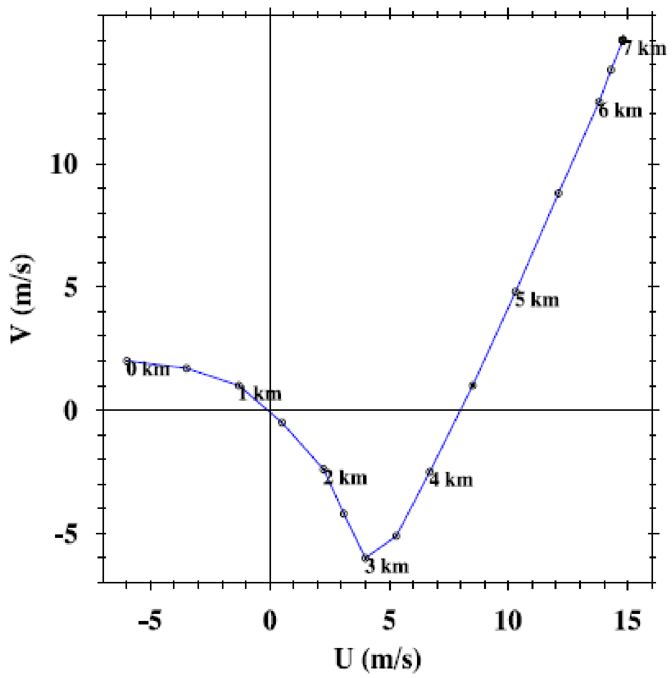


X-Z crossection at y=0

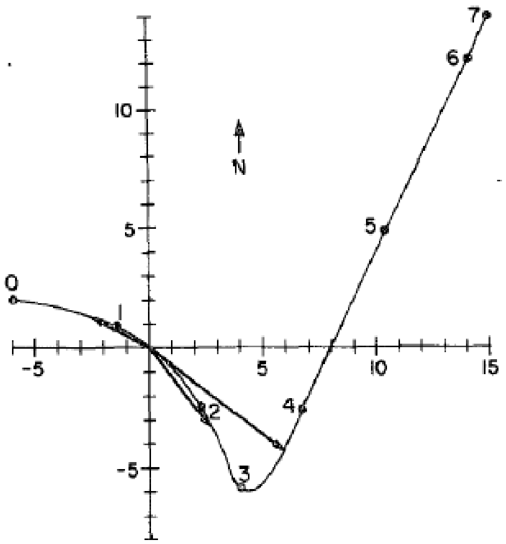
time=36min

Hodograph of horizontal velocity

EULAG

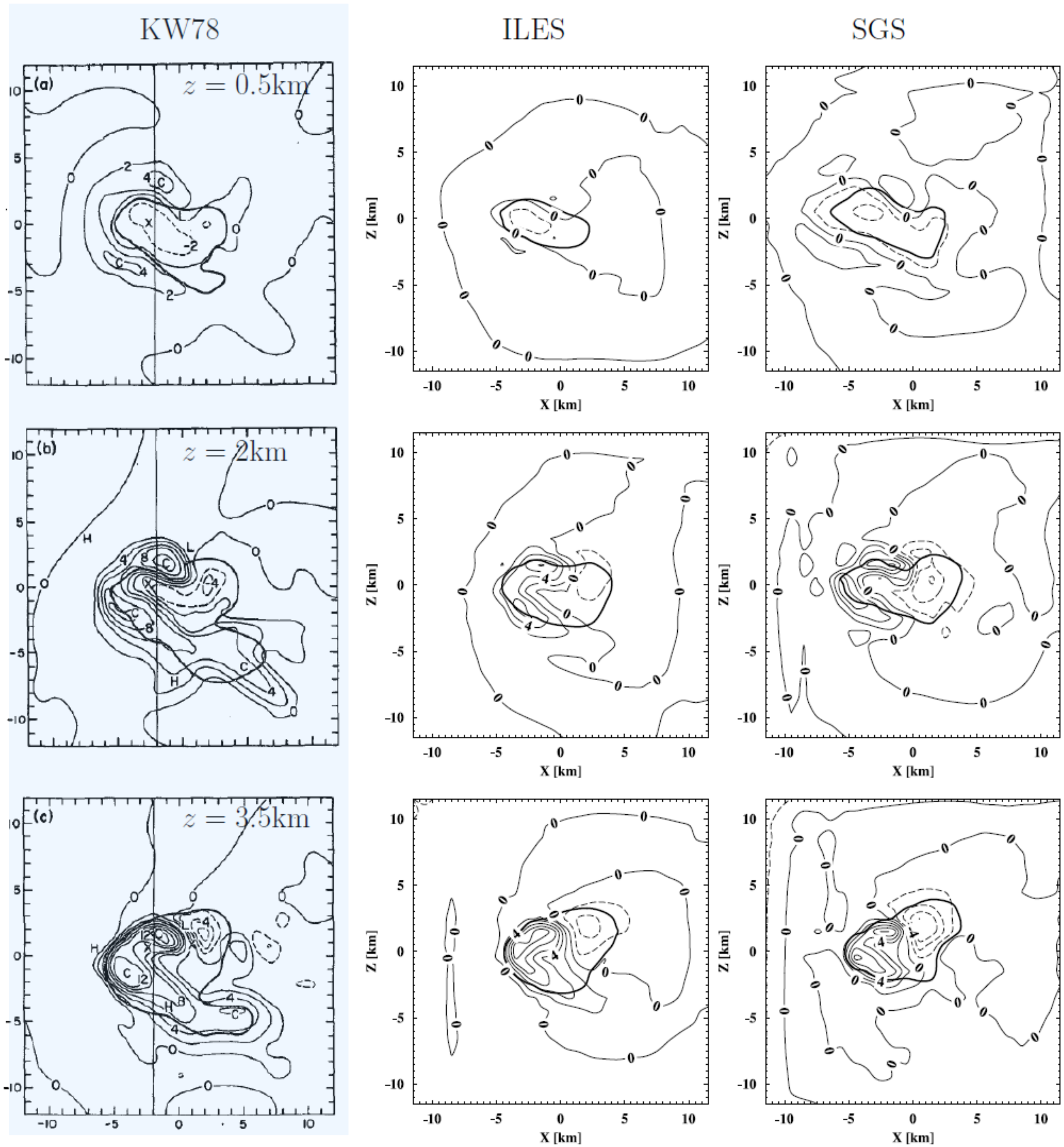


KW78



Comparison of vertical velocity field

- w>0 m/s (thin solid line)
- w<0 m/s (dotted line)
- qr>1g/kg (thick solid line)



X-Y crossection at y=0.5km, y=2km and y=3.5km

time=40min

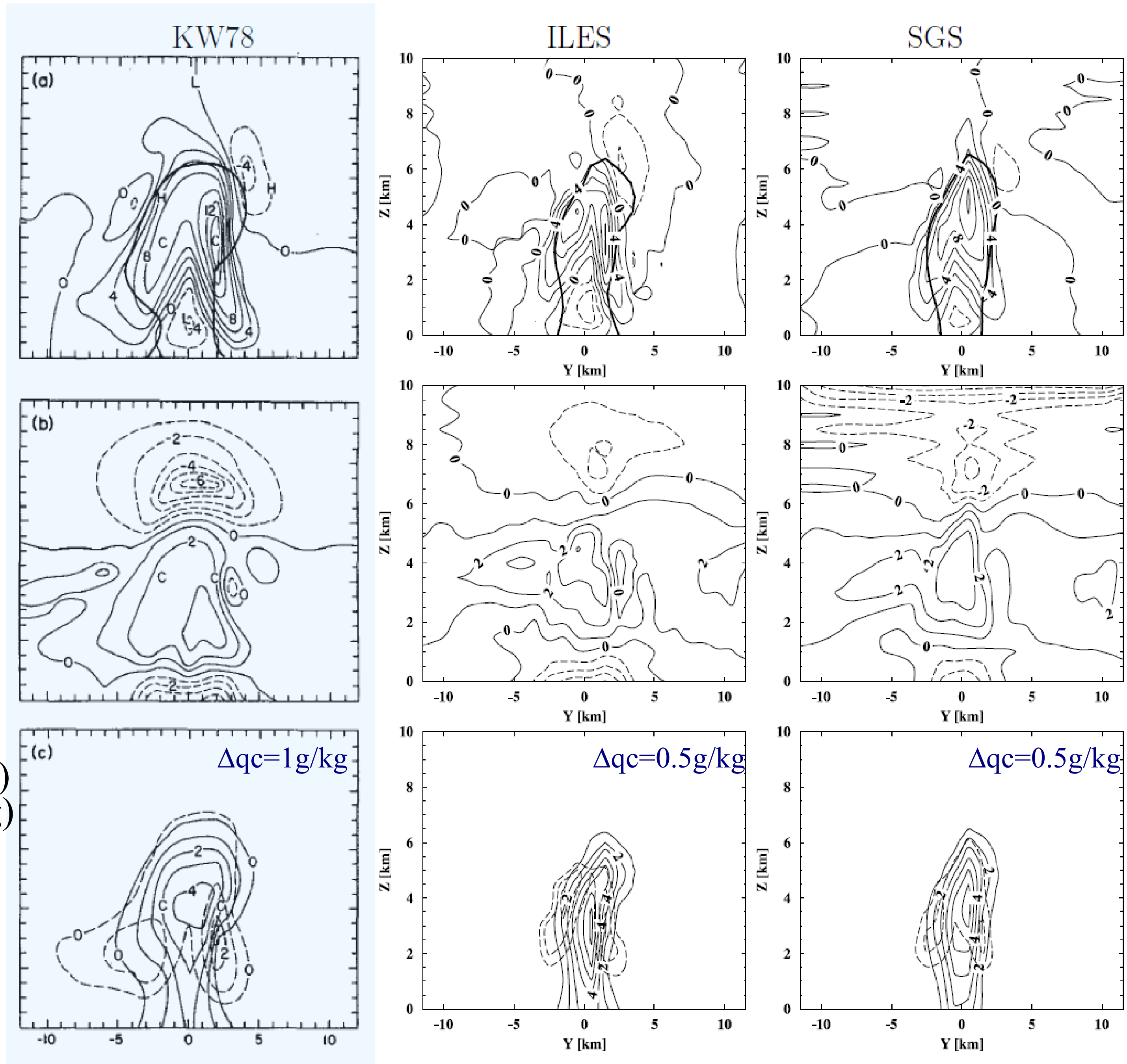
KW78

Simulations with veering wind

— w>0 (m/s)
…… w<0 (m/s)
— qr>1g/kg

— θ>0 (K)
…… θ<0 (K)

— qr>0 (g/kg)
…… qc>0 (g/kg)



X-Z crossection at y=2km

time=40min

O – open b.c., P – periodic b.c.

Setup name	u_{max} $[m/s]$	u_{min} $[m/s]$	w_{max} $[m/s]$	w_{min} $[m/s]$	$q_{c\ max}$ $[g/kg]$	$q_{r\ max}$ $[g/kg]$	θ'_{max} $[K]$	θ'_{min} $[K]$
No Shear								
256x256.P.24min	-11.876	11.876	22.506	-2.812	2.289	7.504	5.772	-3.480
32x32.O.24min	-10.876	10.876	22.270	-2.451	2.287	7.034	5.691	-3.228
32x32.P.24min	-10.877	10.877	22.270	-2.451	2.284	7.034	5.691	-3.228
24x24.O.24min	-11.295	11.295	21.741	-2.253	2.300	6.306	5.595	-3.294
24x24.P.24min	-11.296	11.296	21.742	-2.254	2.300	6.306	5.595	-3.291
With Shear								
256x256.P.24min	-8.636	12.240	17.970	-2.362	2.836	4.283	5.098	-2.741
32x32.O.24min	-8.508	11.744	17.039	-2.590	2.809	3.826	5.001	-2.631
32x32.P.24min	-8.484	11.709	17.001	-2.534	2.805	3.816	5.000	-2.639
24x24.O.24min	-8.254	11.592	15.364	-2.099	2.632	3.132	4.732	-2.265
24x24.P.24min	-8.241	11.451	15.356	-2.172	2.653	3.120	4.736	-2.269
256x256.P.36min	15.791	-10.929	20.568	-8.185	1.561	12.389	5.378	-7.551
32x32.O.36min	15.653	-11.332	19.601	-8.507	1.571	12.182	4.714	-6.352
32x32.P.36min	15.425	-11.212	19.509	-8.472	1.581	12.180	4.741	-6.506
24x24.O.36min	13.072	-11.290	19.728	-7.609	1.113	11.138	4.299	-5.076
24x24.P.36min	12.772	-11.229	19.530	-7.753	1.167	11.163	4.315	-5.105

resolution

Evaluation of domain size effects

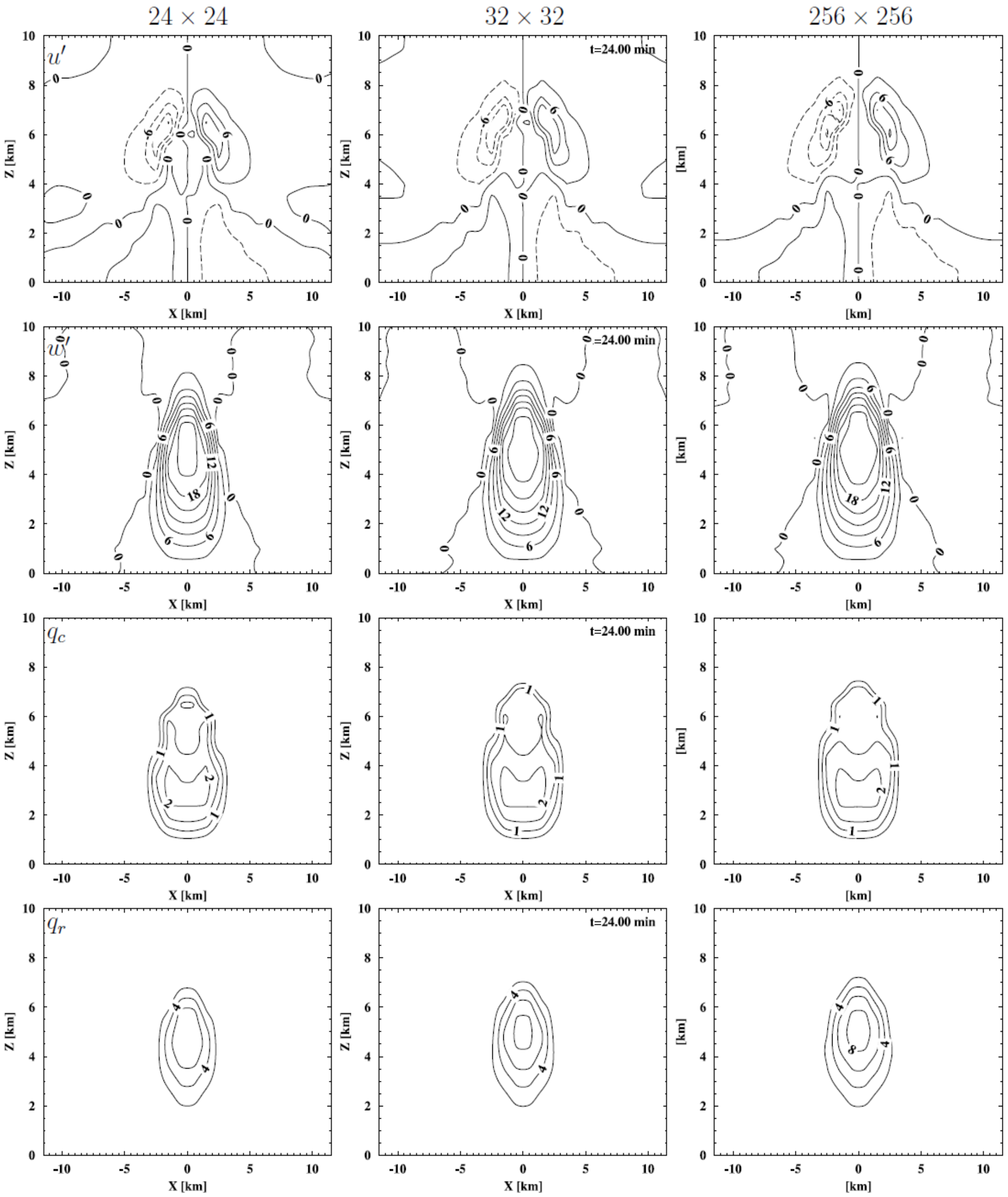
Domain size is different but grid spacing is fixed.

U (m/s)
ΔU=3m/s

W (m/s)
ΔW=3m/s

qc (g/kg)
Δqc=0.5g/kg

qr (g/kg)
Δqr=2g/kg



Summary of KW78 experiment:

- Dynamical fields are in good agreement with KW78 results for unsheared environment, shear flow and veering wind;
- Influence of boundary conditions is negligible, especially for large horizontal domain size;
- The solution is strongly influenced by the subgrid-scale mixing;
- Most significant difference concerns the moist fields: EULAG's simulations seem to produce lower amount of cloud and rain mixing ratio;

WK82

The Dependence of Numerically Simulated Convective Storms on Vertical Wind Shear and Buoyancy

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National Center for Atmospheric Research,[1] Boulder, CO 80307

(Manuscript received 9 October 1981, in final form 2 February 1982)

Grid: uniform (WK82 uses stretched grid),
dx=dy=2km, dz=350m
domain size: 128x128x17.5 km

Subgrid-scale processes:
1) TKE scheme, Pr=0.33
2) ILES (implicit large-eddy simulation)

Moist processes:
bulk parametrization, Kessler scheme

Boundary conditions:
open b.c. (additionally periodic)

Initial conditions:
realistic sounding

Integration time:
120 min

Setup details agreed with WK82

WK82

Initial profiles

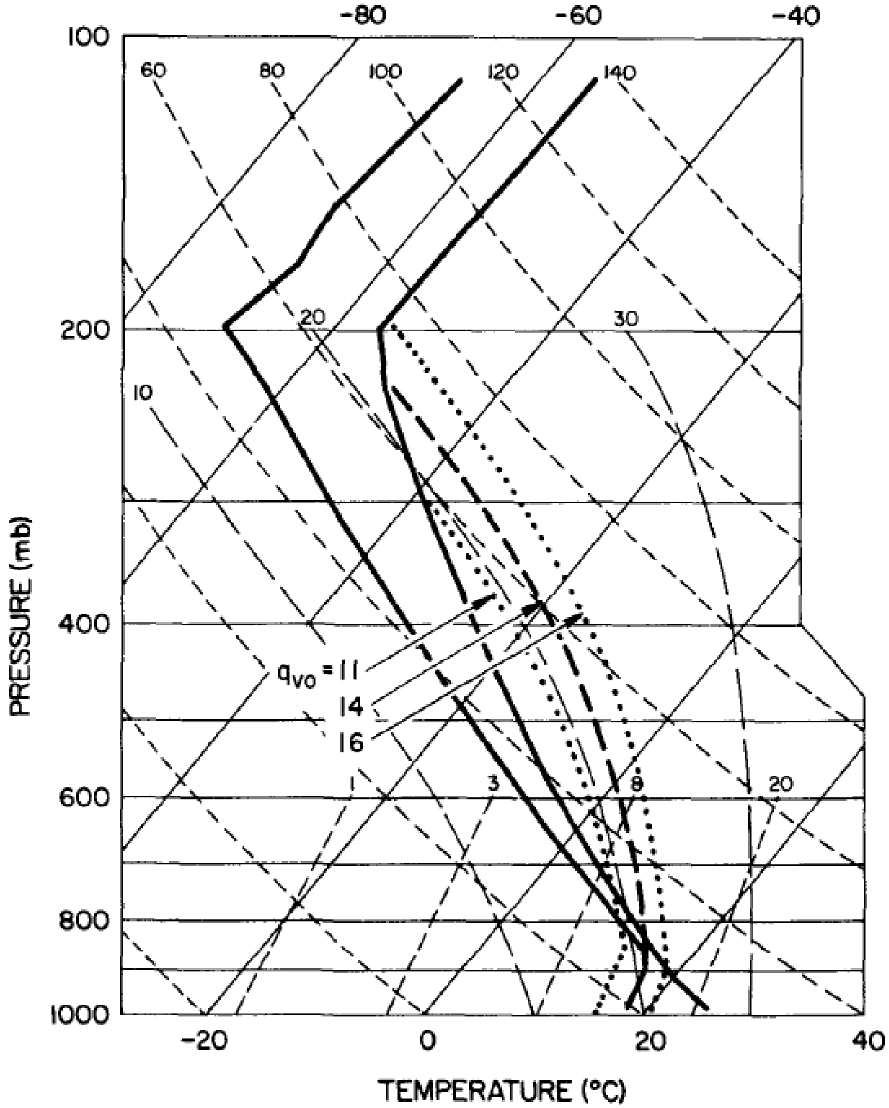
Analytic profiles of potential temperature and relative humidity

$$\bar{\theta}(z) = \begin{cases} \theta_0 + (\theta_{tr} - \theta_0)\left(\dfrac{z}{z_{tr}}\right)^{5/4}, & z \leqslant z_{tr} \\ \theta_{tr} \exp\left[\dfrac{g}{c_p T_{tr}}(z - z_{tr})\right], & z > z_{tr} \end{cases}$$

$$H(z) = \begin{cases} 1 - \dfrac{3}{4}\left(\dfrac{z}{z_{tr}}\right)^{5/4}, & z \leqslant z_{tr} \\ 0.25, & z > z_{tr} \end{cases}$$

$z_{tr} = 12$ km, $\theta_{tr} = 343$ K and $T_{tr} = 213$ K

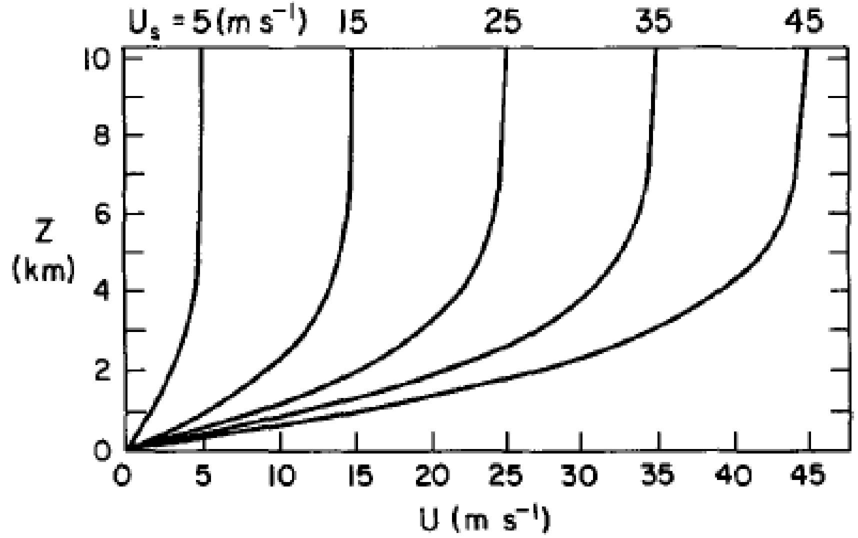
$\theta_0 = 300$ K



Horizontal velocity profile in x-direction
(analytic)

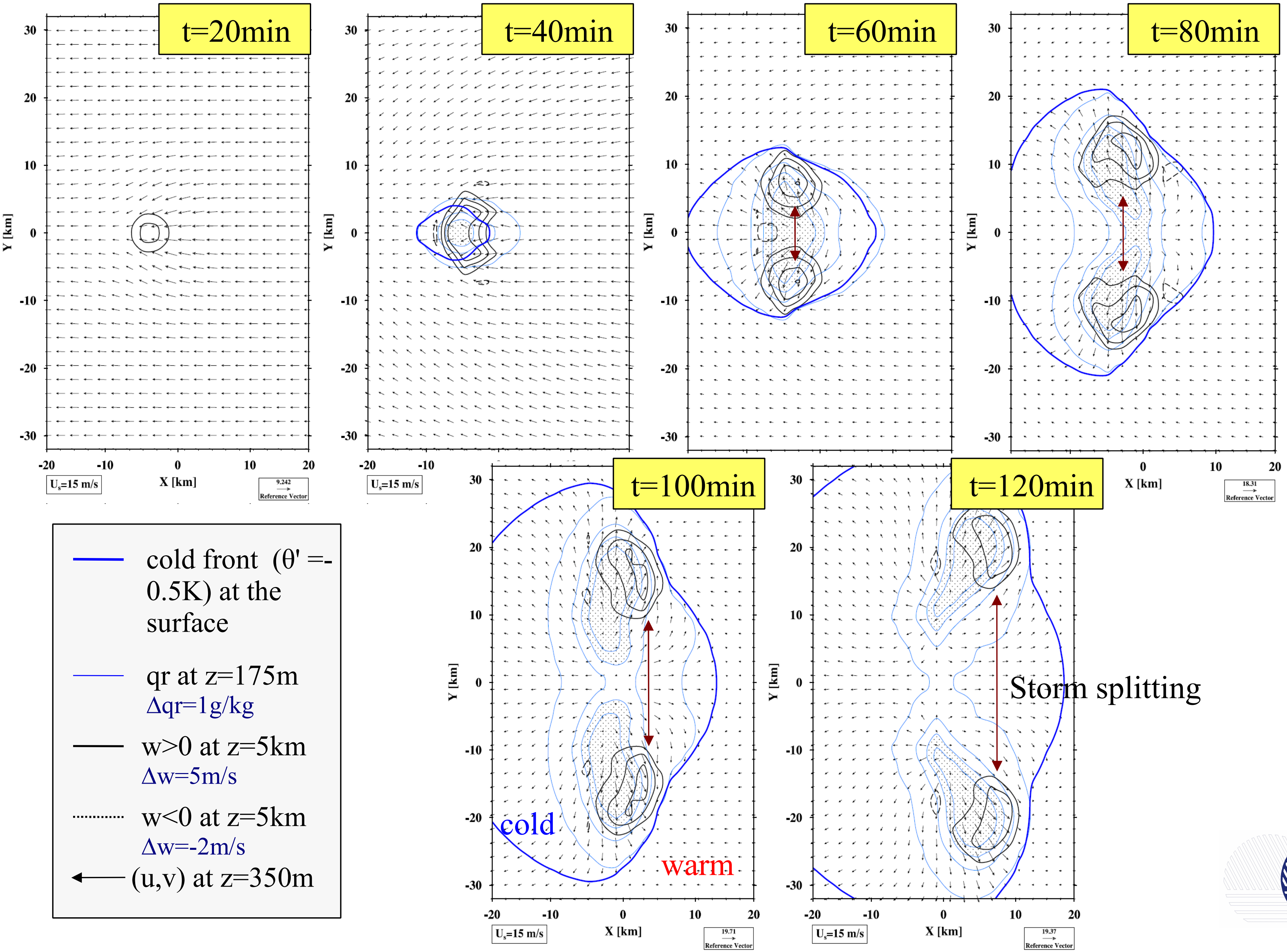
$$U = U_S \tanh z/z_s$$

$$z_s = 3 \text{ km}$$



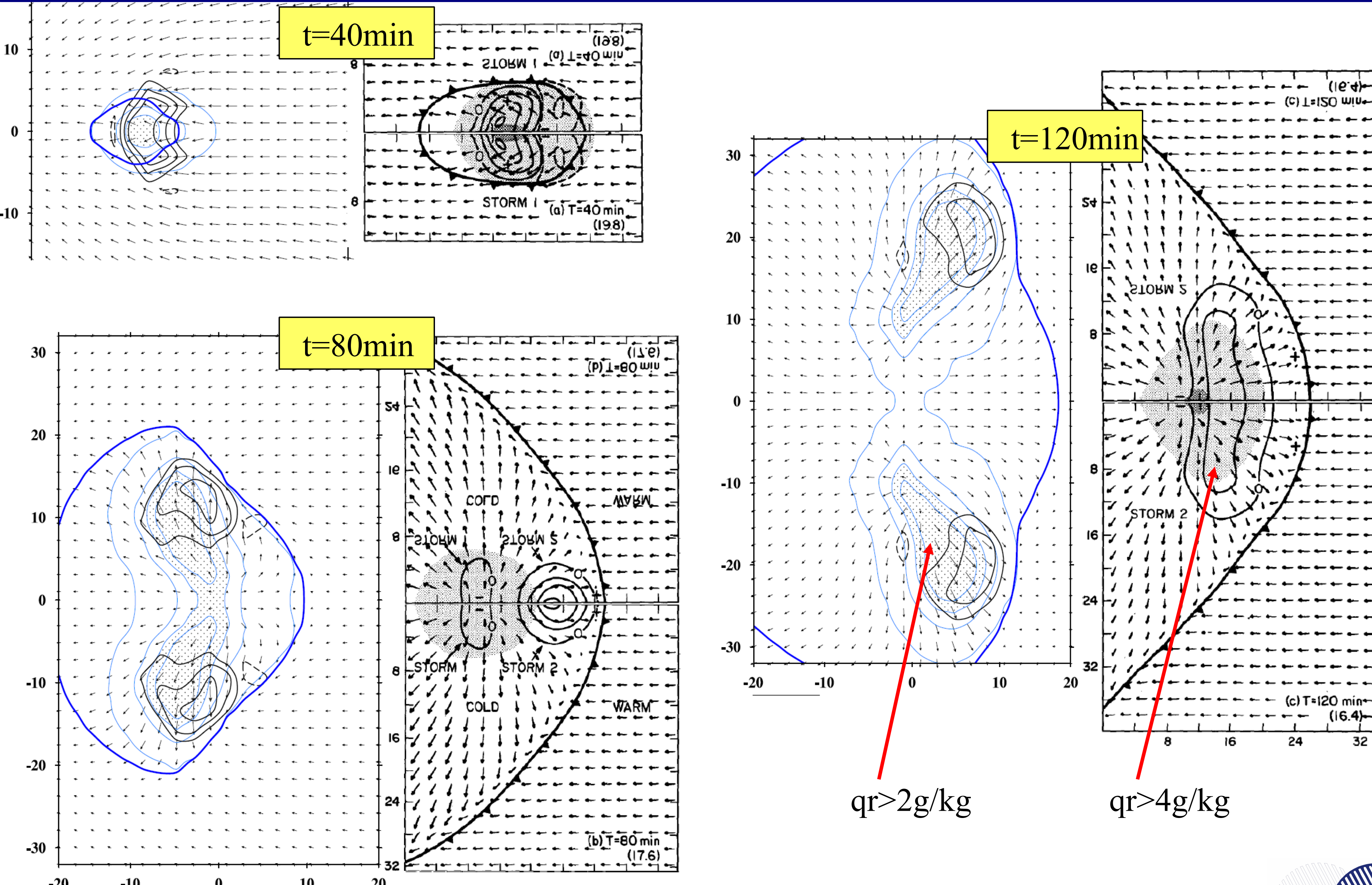
WK82

Wind shear, Us=15m/s



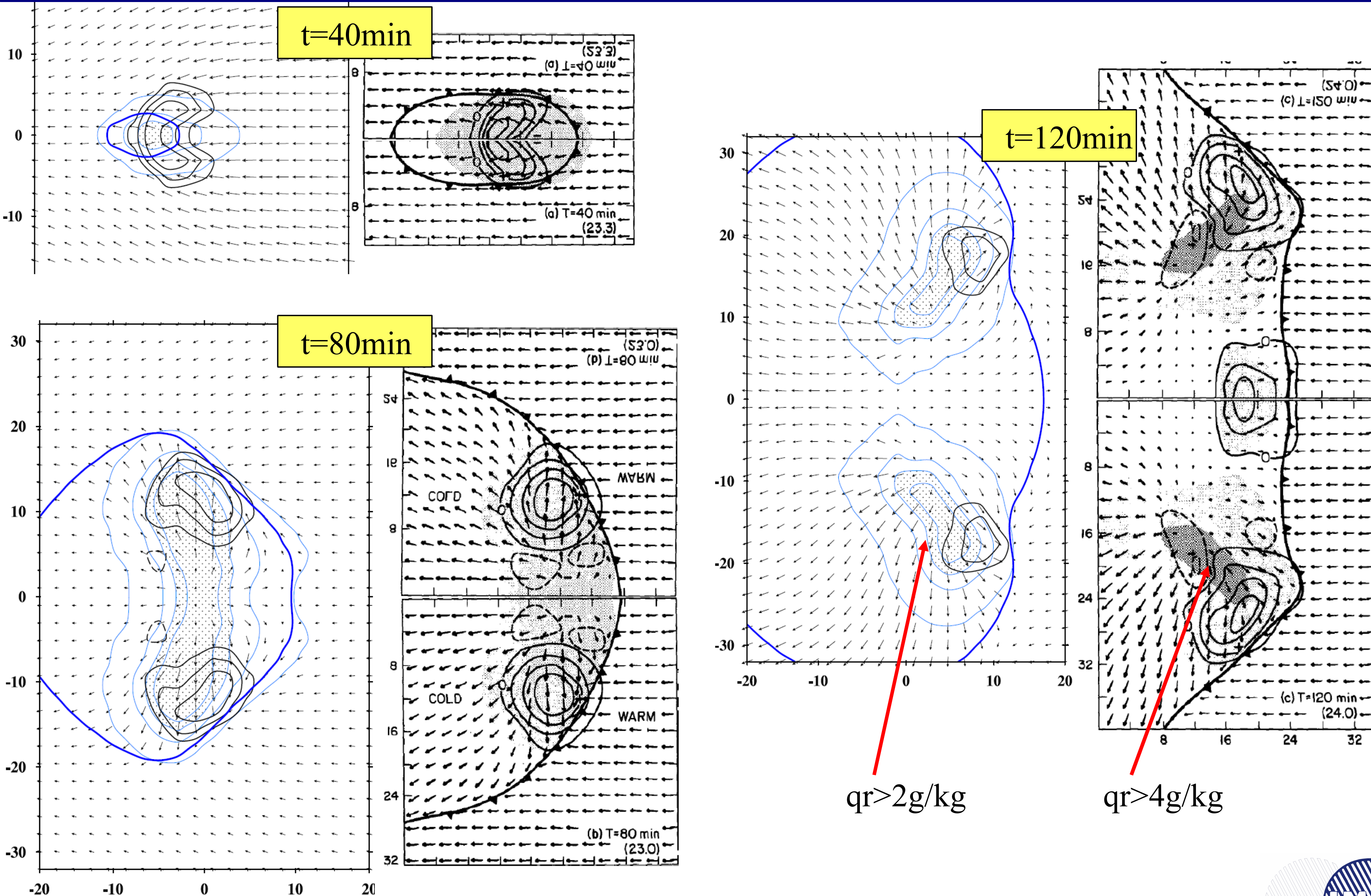
WK82

Wind shear, Us=15m/s



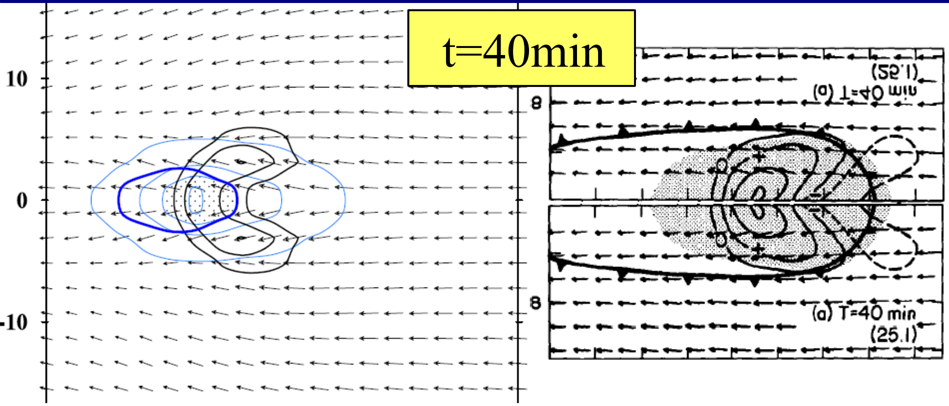
WK82

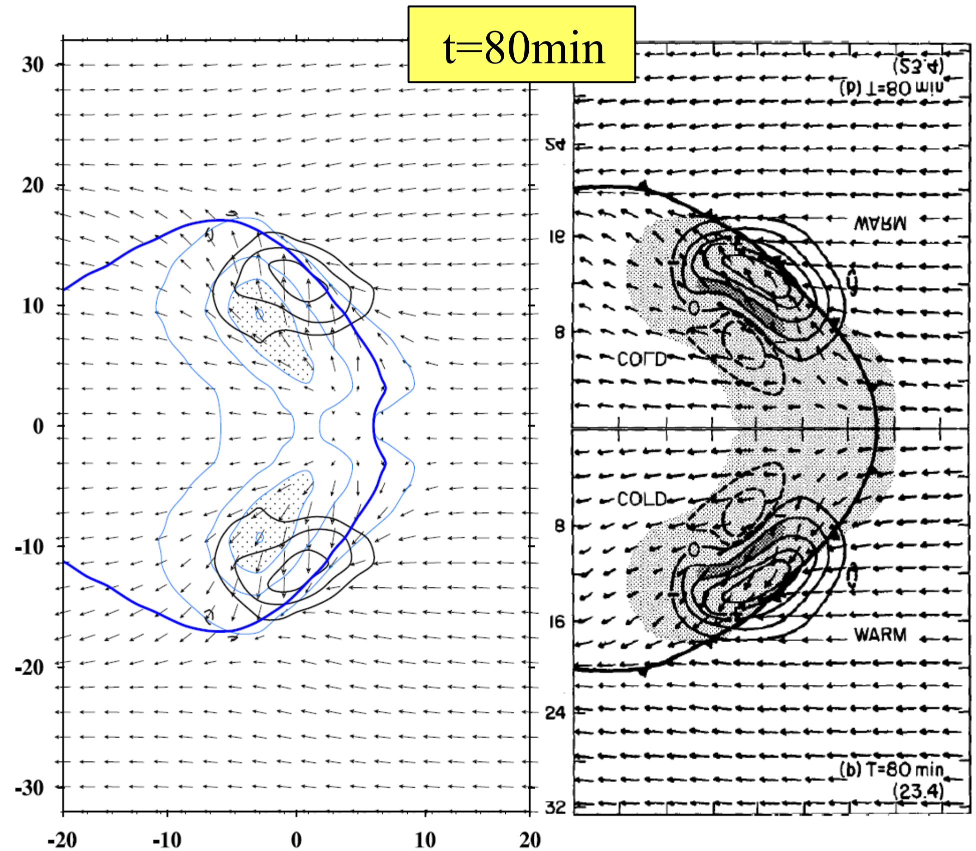
Wind shear, Us=25m/s

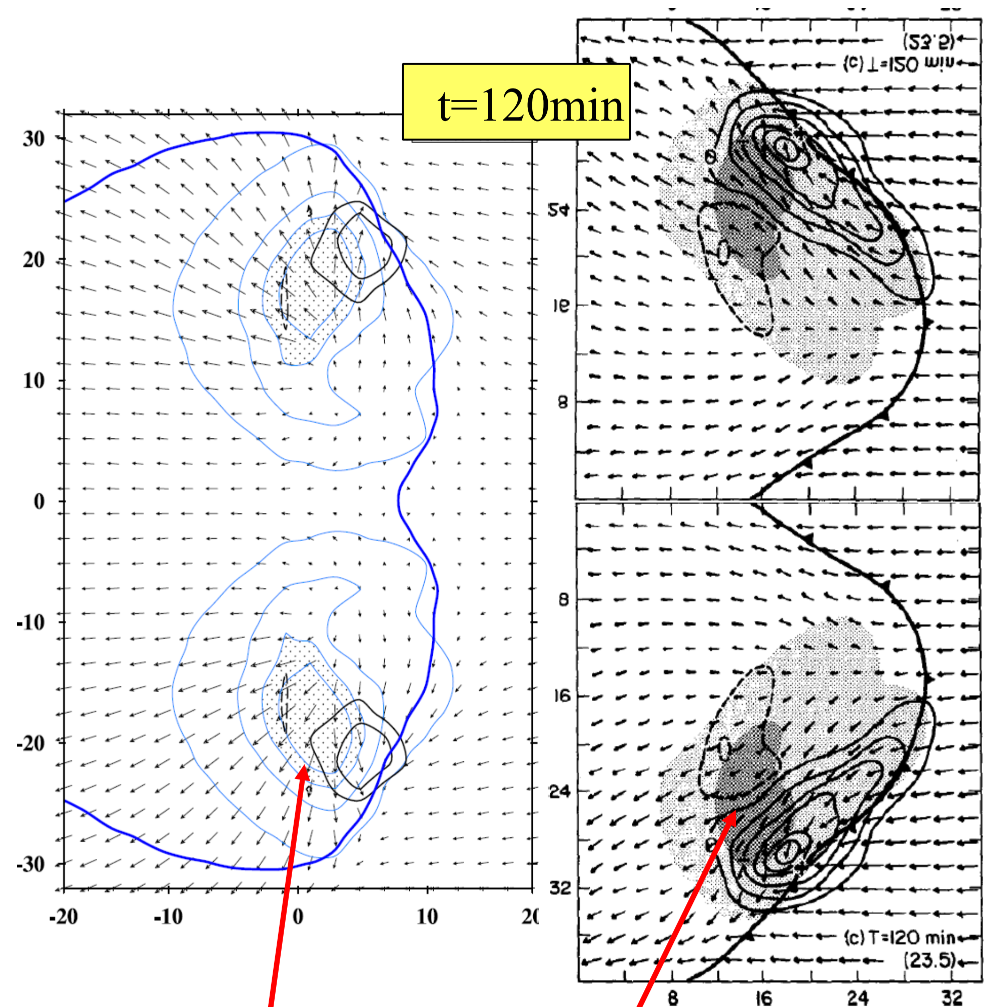


WK82

Wind shear, Us=35m/s





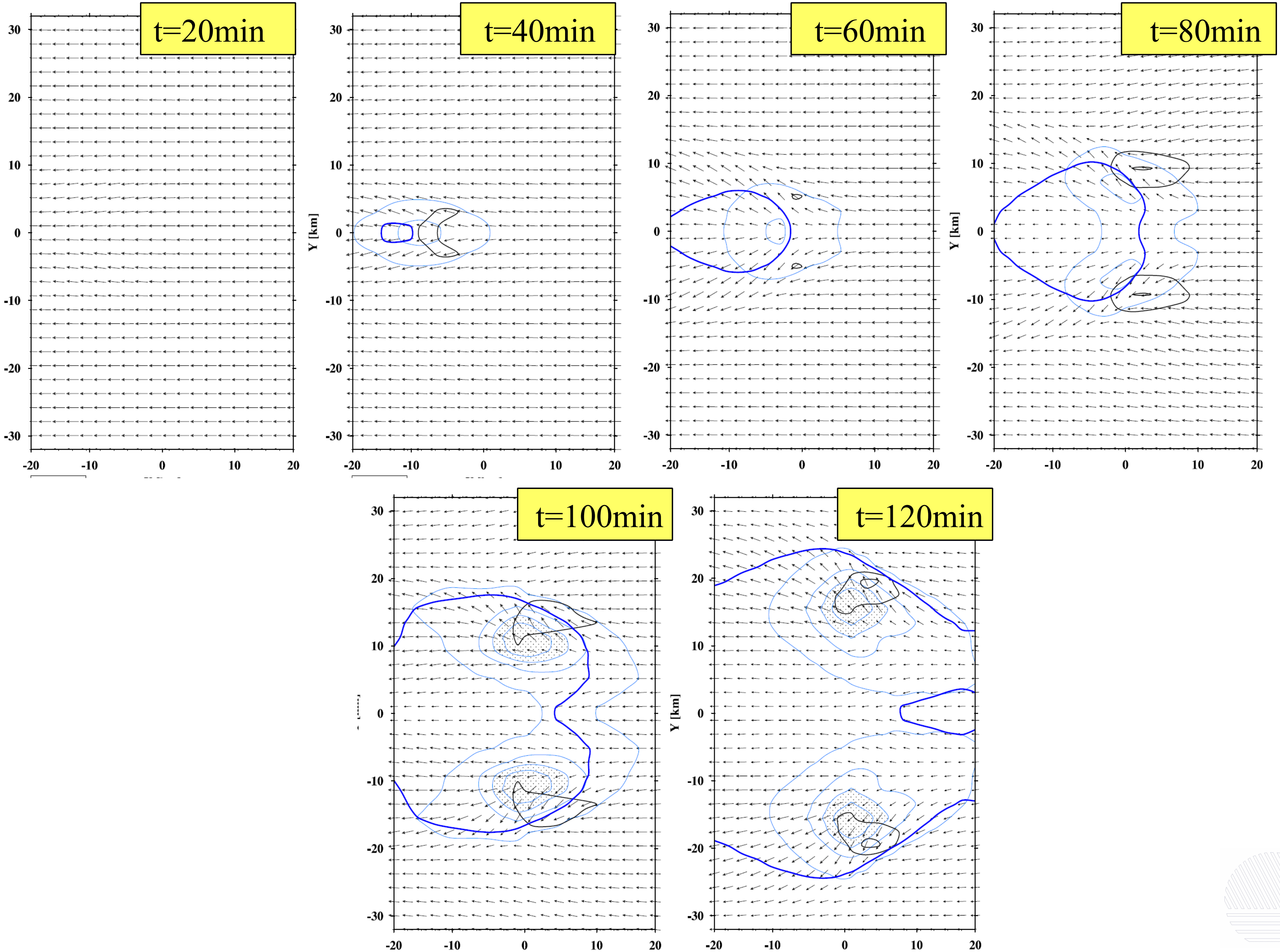


qr>2g/kg

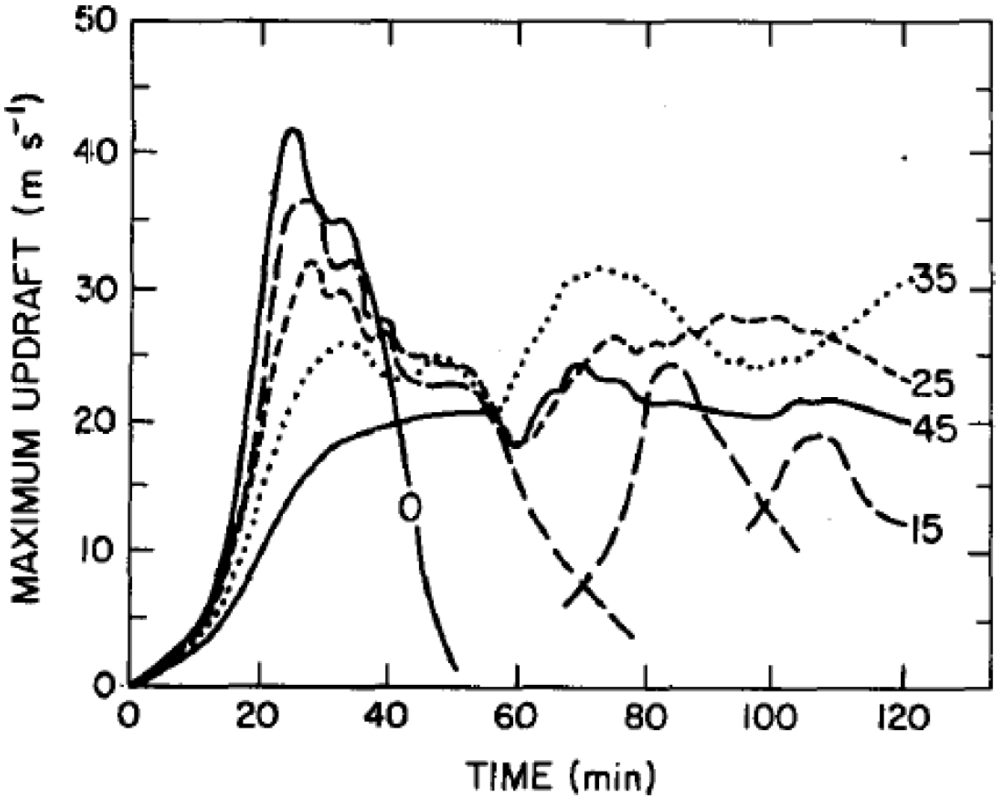
qr>4g/kg

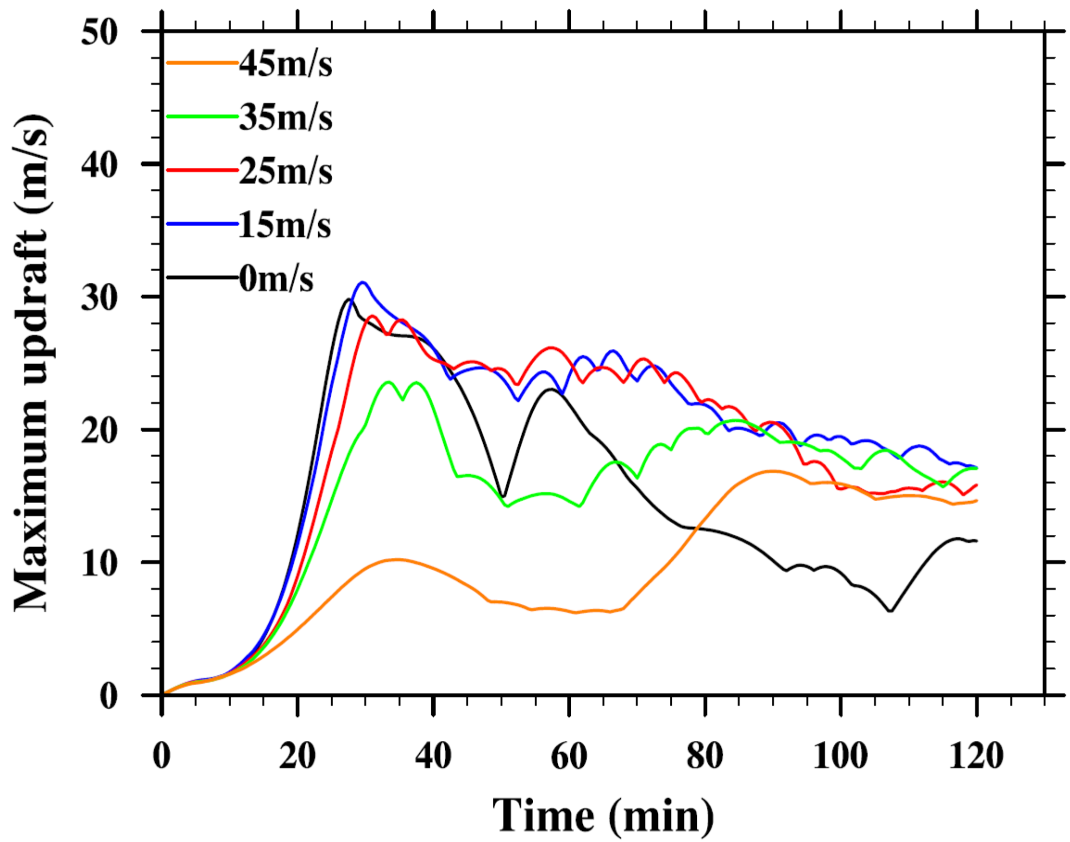
WK82

Wind shear, Us=45m/s



Comparison of maximum updraft velocity





Supercell behaviour <=> quasi-steady updraft

No shear → dies first
Larger shear → weaker development

Summary of moist experiments:

- Realistic reconstruction of storm splitting
- Similar shape and time evolution of cloud/rain fields and cold pool formation
- Storm splitting is observed for weaker shear flow
- All numerical solutions are in qualitative agreement, but with less vigorous dynamics and lower amount of cloudy/rain water