Combined Model of Cloudy Troposphere (CMCT) as compromise of Eulerian and Lagrangian approaches

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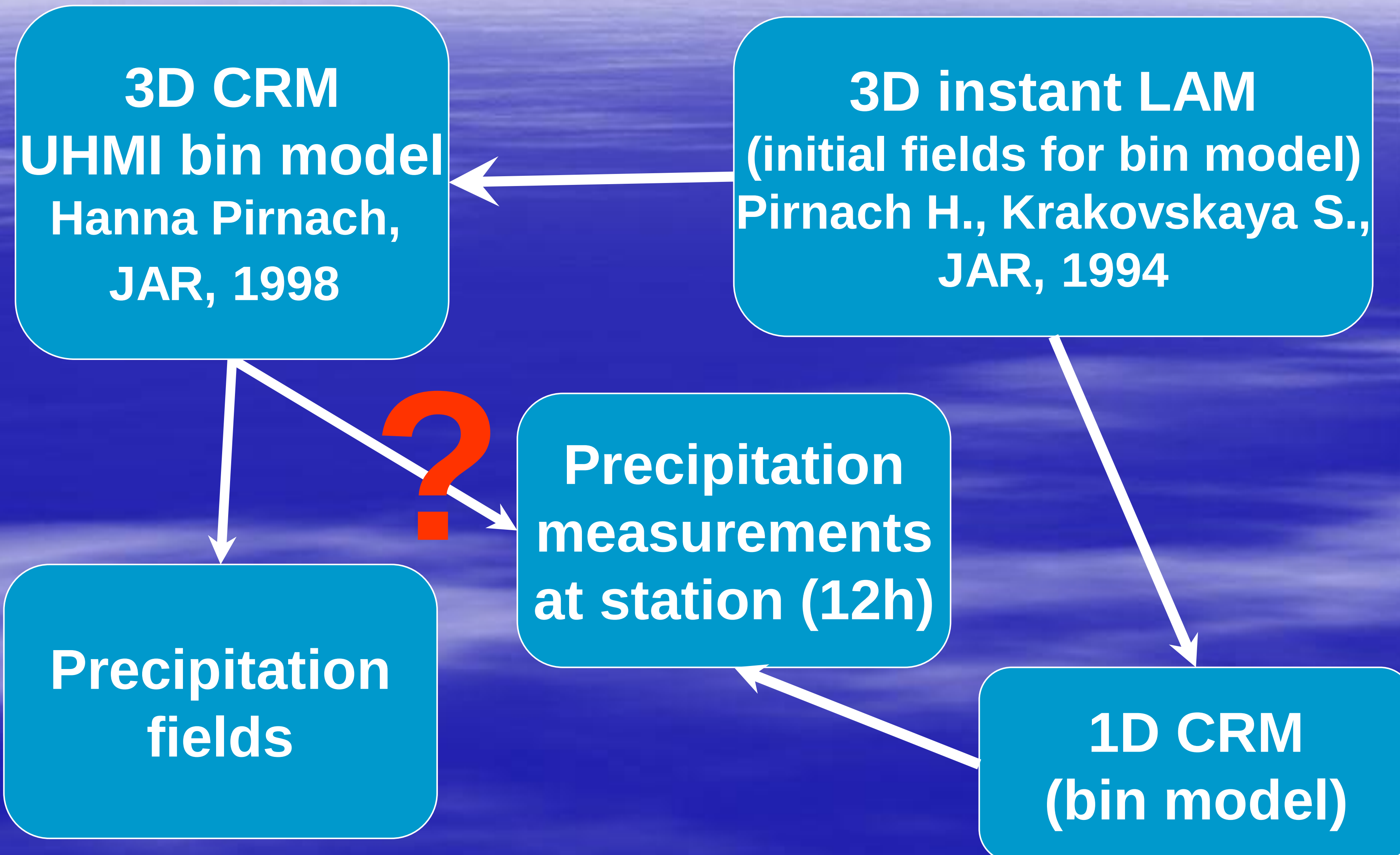
Motivation


3D CRM
UHMI bin model
Hanna Pirnach,
JAR, 1998
3D instant LAM
(initial fields for bin model)
Pirnach H., Krakovskaya S.,
JAR, 1994
?
Precipitation
measurements
at station (12h)
Precipitation
fields
1D CRM
(bin model)

COMBINED MODEL OF CLOUDY TROPOSPHERE (CMCT)

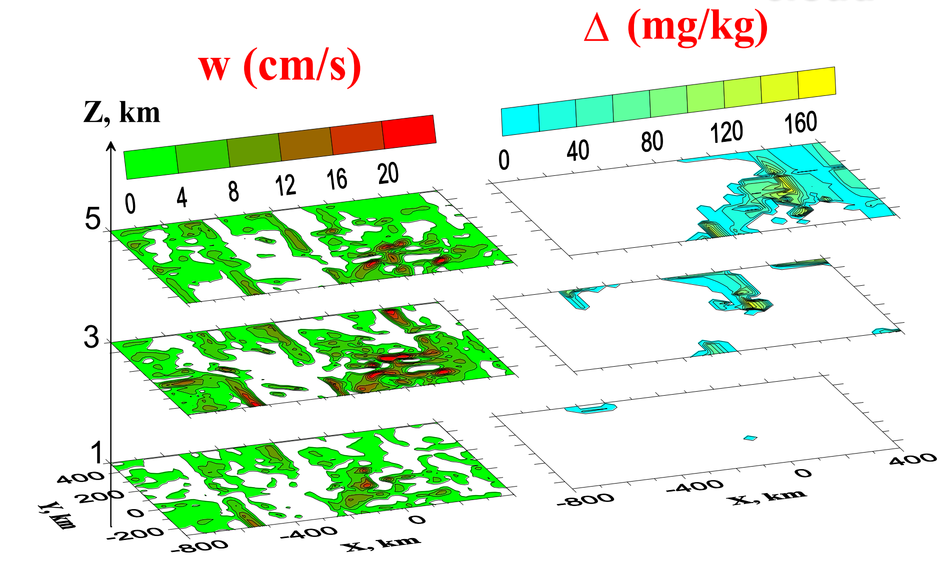
is the combination of 3D time-independent (instant) LAM and 1D CRM with explicit microphysics.

It means that initial thermodynamical characteristics in the vertical column where microphysics is calculated are stepwise updated as it moves along horizontal axes over the initial point of 3D domain (X_0, Y_0) at every time step (dt) in 1D model making a track over 3D domain with coordinates

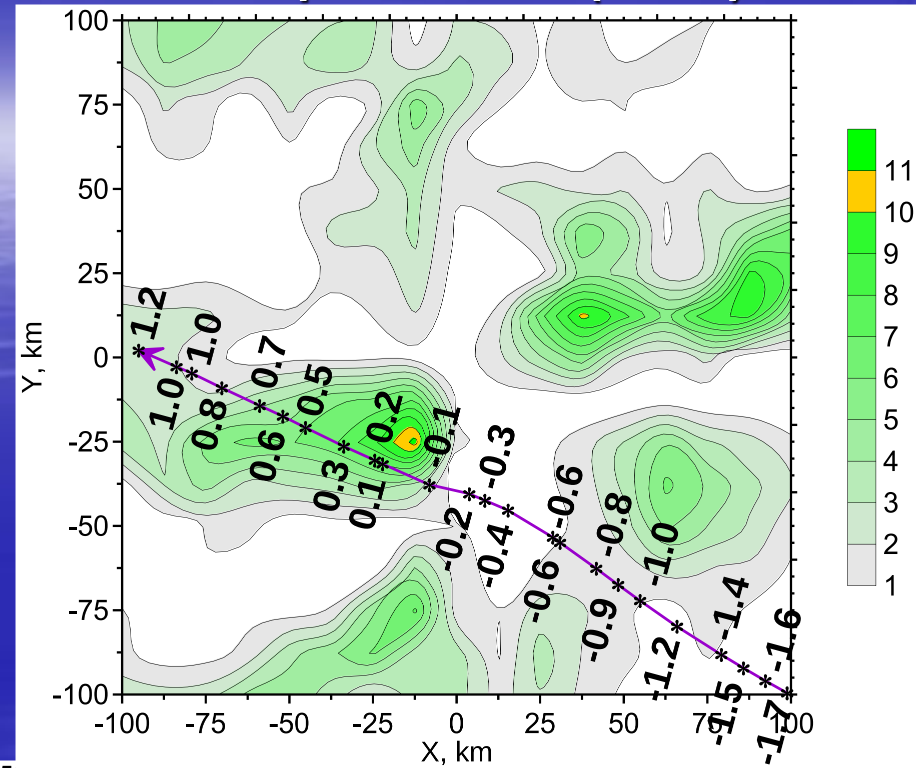
$$X_f = X_0 - \int_0^{t_e} u_f \, dt \qquad Y_f = Y_0 - \int_0^{t_e} v_f \, dt$$

Minus in equations means that the system moves opposite to the air mass displacement. The speed u_f, , v_f of this movement could be constant and determined by synoptic charts or variable and calculated from the data of 3-D LAM, e.g. as an average wind speed in layer up to height Z_f, or calculated at every vertical level.

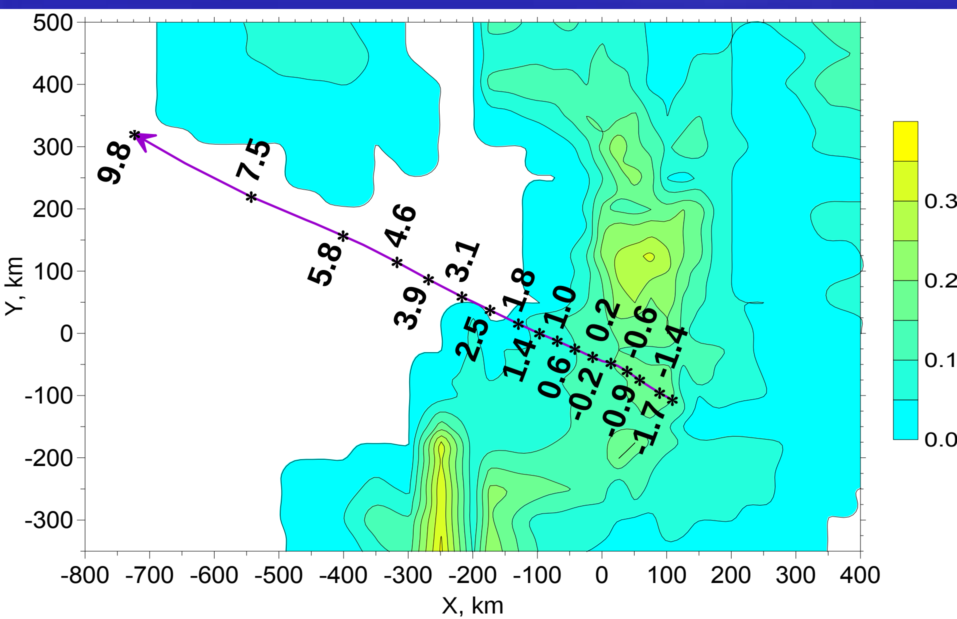
3-D LAM results with 1-D CRM trek (digits near trek – t_{cloud}, *h*)

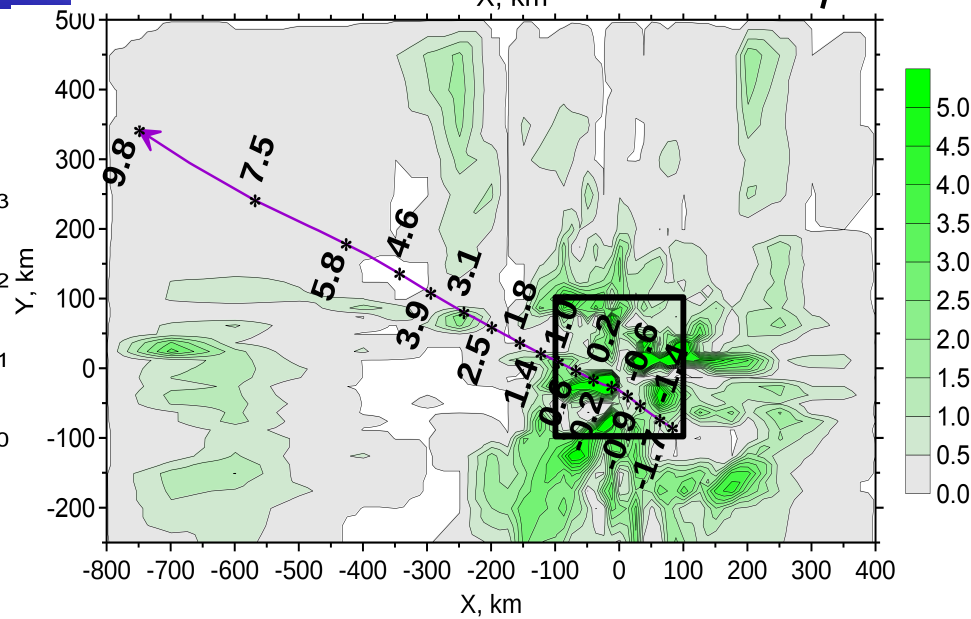


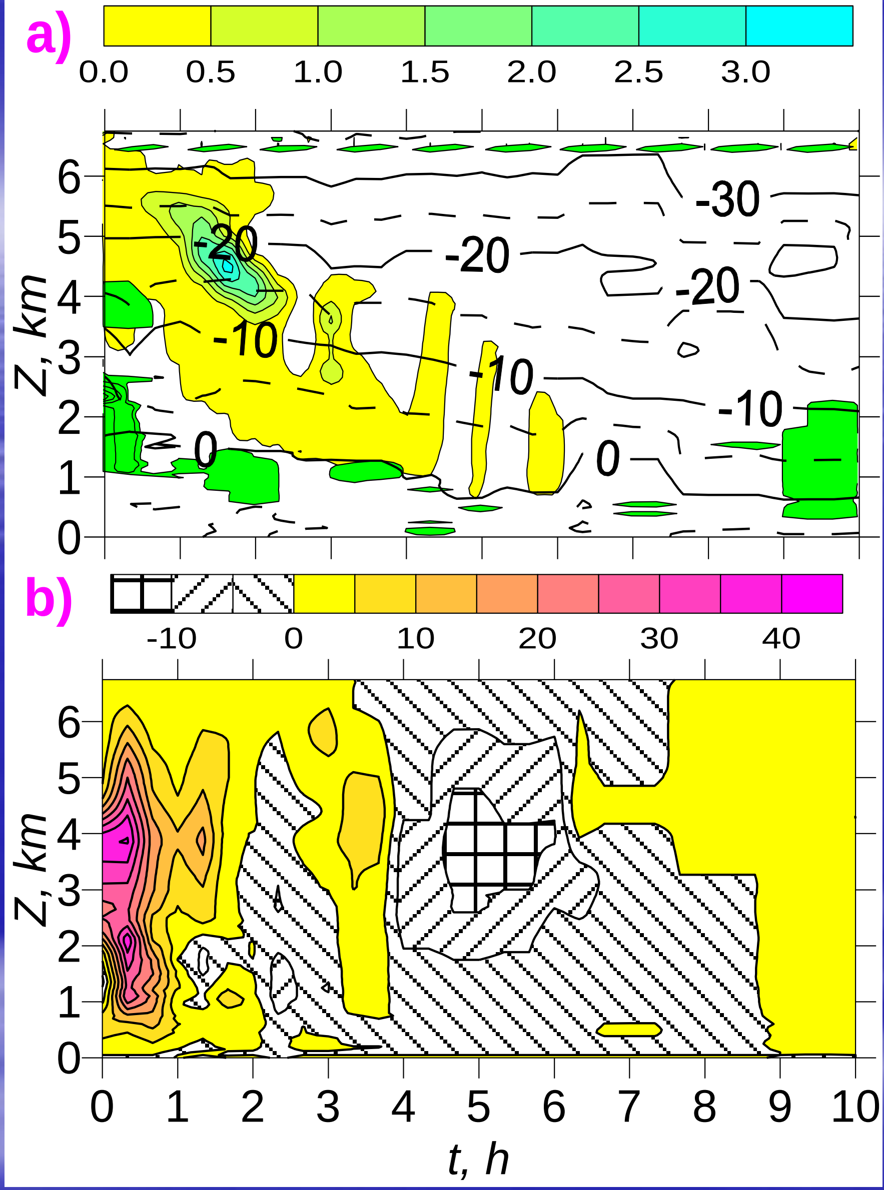
Precipitation rate (*mm/h*)

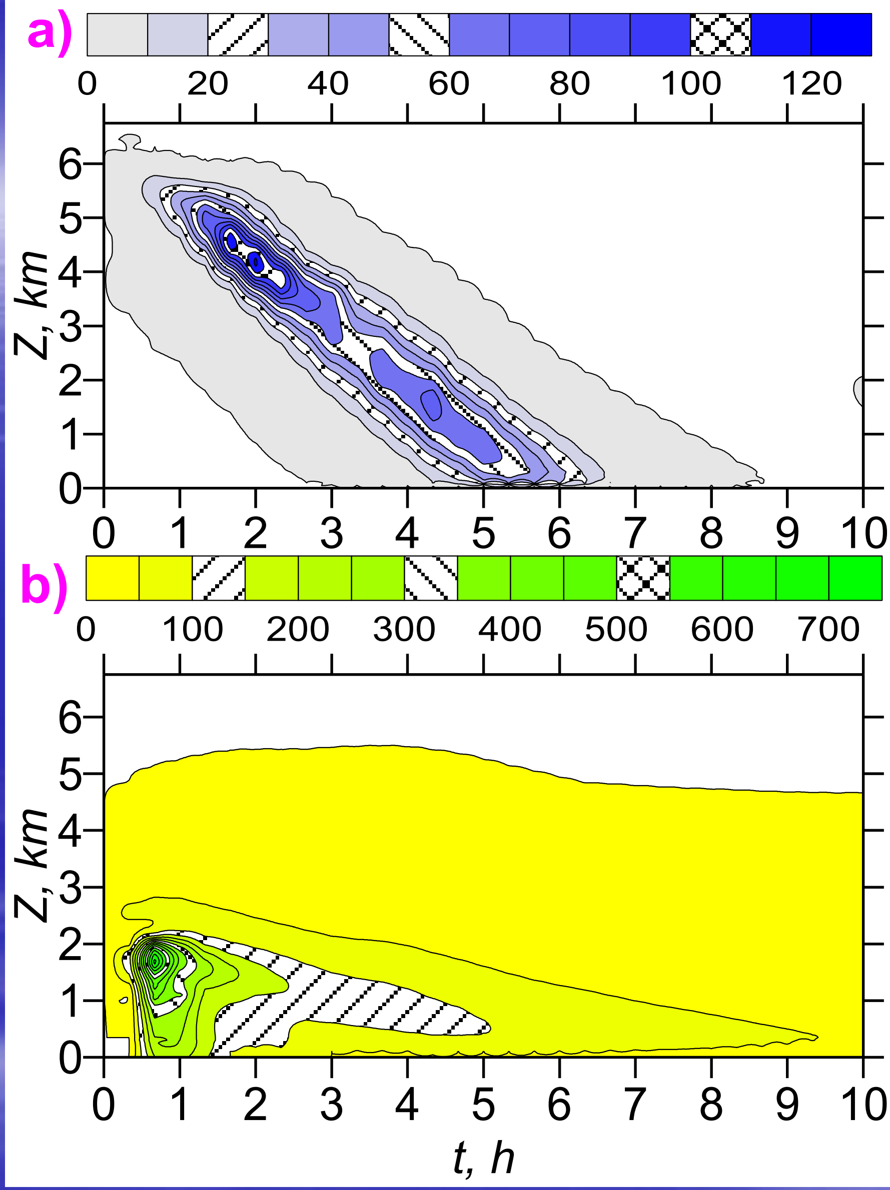


Integral ice supersaturation (*mm*)









Initial vertical and time development of:
(a) temperature (lines, ºC), water (green) and ice supersaturations (shading, mg/kg);
(b) vertical motions (cm/s)

Vertical and time development of:
(a) IC and (b) LWC (mg/kg)
In the run with unmodified freezing

1-D SPECTRAL CLOUD RESOLVING MODEL

1. The kinetic equation of cloud droplets ($k=1$) size distribution function (f_1):

$$\frac{df_1}{dt} + \frac{\partial}{\partial r}\left(\dot{r}_1 f_1\right) - v_1 \frac{\partial f_1}{\partial Z} = I_{\alpha 1} - I_{f1} - \sigma_2 f_1 - \sigma_3 f_1 + k_z \frac{\partial^2 f_1}{\partial Z^2}$$

2. The kinetic equation of cloud ice crystals ($k=2$) and raindrops ($k=3$) size distribution functions (f_k):

$$\frac{df_k}{dt} + \frac{\partial}{\partial r}\left(\dot{r}_k f_k\right) + \frac{\partial}{\partial r}\left(\dot{r}_{ck} f_k\right) - v_k \frac{\partial f_k}{\partial Z} = c_k I_{ak} \pm I_{fk} + k_z \frac{\partial^2 f_k}{\partial Z^2},$$

$c_2 = 1$, $c_3 = 0$

3. The equation of heat inflow:

$$\frac{dT}{dt} = \sum_{k=1}^{3} \alpha_k \varepsilon_k - \gamma_a w + k_z \frac{\partial^2 T}{\partial Z^2}$$

4. The equation of moisture inflow:

$$\frac{dq}{dt} = -\sum_{k=1}^{3} \varepsilon_k + k_z \frac{\partial^2 q}{\partial Z^2}$$

5. The state equation:

$$\rho = \frac{P}{RT}$$

$$\alpha_k = L_k / C_p$$

1-D SPECTRAL CLOUD RESOLVING MODEL

Cloud particles generation on *CCN* is parameterized as follows:

$$I_{\alpha 1} = N_{m0} w \delta(Z - Z_w)\delta(r - r_{10})\Theta(\Delta_1) + N_c \left(\frac{100\Delta_1}{q_{s1}}\right)^{K_c} \delta(r - r_{10})\Theta(\Delta_1 - \Delta_{1w})$$

The rate of growth of individual particles due to condensation (deposition) is:

$$\dot{r}_k = \frac{D\rho\Delta_k}{\Gamma_k \rho_k r} \qquad \Gamma_k = 1 + \alpha_k \beta_k, \qquad \beta_k = \partial q_{sk} / \partial T$$

and due to gravitational collection of droplets by spherical CP :

$$\dot{r}_{ck} = \frac{\rho_1 \rho \pi}{3\rho_k r_k^2} \int_{r_{1\min}}^{r_{1\max}} E(r_1, r_k)(r_1 + r_k)^2 (v_k - v_1) r_1^3 f_1(r) dr_1 \qquad E(r_1, r_k) = \left[1 - \frac{r_k R_0^3}{4 r_1^2 \left| r_k^2 - r_1^2 \right|}\right]^2$$

$$\sigma_k = \pi\rho \int_{r_{k0}}^{\infty} E(r_1, r_k)(r_1 + r_k)^2 (v_k - v_1) f_k(r) dr_k, \; k = 2, 3, \qquad R_0 = \sqrt[3]{\frac{1{,}214}{g}\left(\frac{9\eta}{\rho}\right)^2} \approx 14{,}5\mu m$$

where r_{k0} are min radii of CP; $E(r_1, r_k)$ are coefficients of collection.

ICE-FORMING PROCESSES IN 1-D CRM

The processes of condensational-depositional freezing on activated IN are parameterized as follows:

$$I_{\alpha 2} = A_s e^{B_s T_s} \frac{dT}{dt} \delta(r - r_{20}) \Theta\left(-\frac{dT}{dt}\right) \Theta(\Delta_1) \Theta(T_s), \quad T_S = T_{\lim} - T$$

The processes of droplets (I_{f1}) and raindrops (I_{f3}) freezing and the amount of frozen water CP (I_{f2}) are parameterized as follows:

$$I_{fk} = A_f e^{B_f T_S} r_k{}^3 f_k \Theta(T_S) \qquad I_{f2} = -(I_{f1} + I_{f3})$$

INTEGRAL CHARACTERISTICS OF A MIXED CLOUD

Cloud particles concentrations (N_k), their average sizes (r), ice and water contents (q_k), intensity of precipitation (j):

$$N_k = \int_{r_{k\,min}}^{r_{k\,max}} f_k dr \qquad q_k = \frac{4\pi\rho_k k_f}{3} \int_{r_{k\,min}}^{r_{ik\,max}} r_k^3 f_k dr_k$$

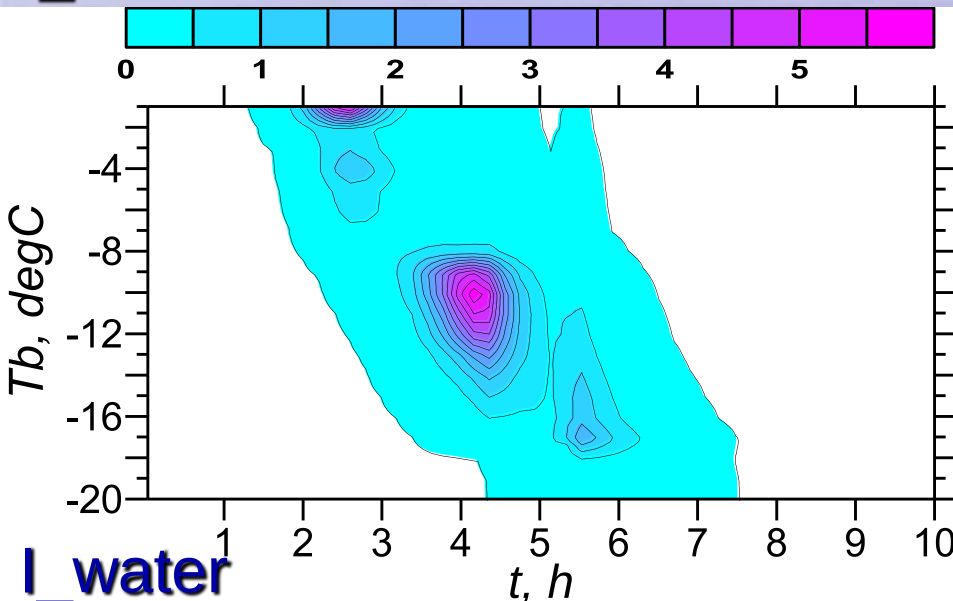
$$N_k \overline{r_k} = \int_{r_{k\,min}}^{r_{k\,max}} r_k f_k dr \qquad j = \sum_{k=2}^{3} \frac{4\pi\rho_k k_f}{3} \int_{r_{k\,min}}^{r_{k\,max}} (v_k - w) r_k^3 f_k(r) dr$$

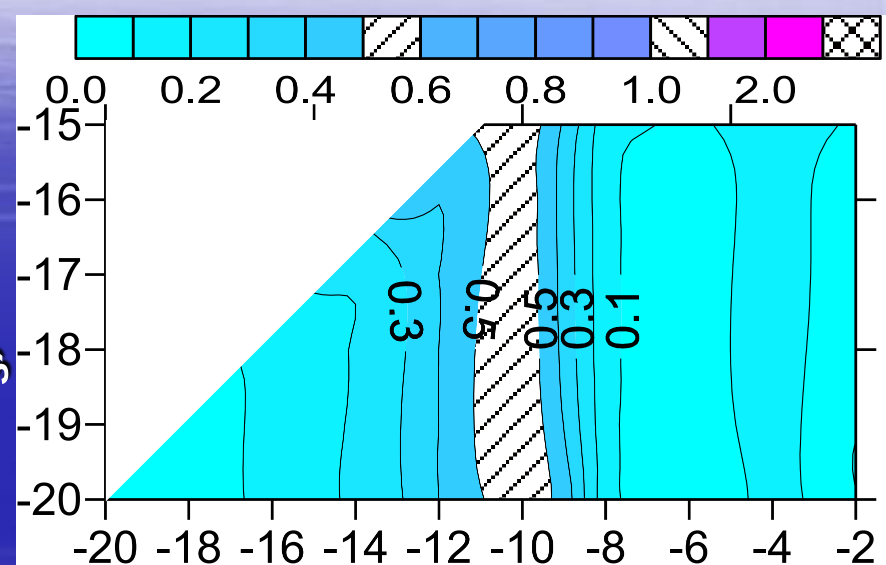
where r_{kmin} and r_{kmax} are minimum and maximum radii of CP.

Precipitation intensity (mm/h) in dependence of T_s and T_b

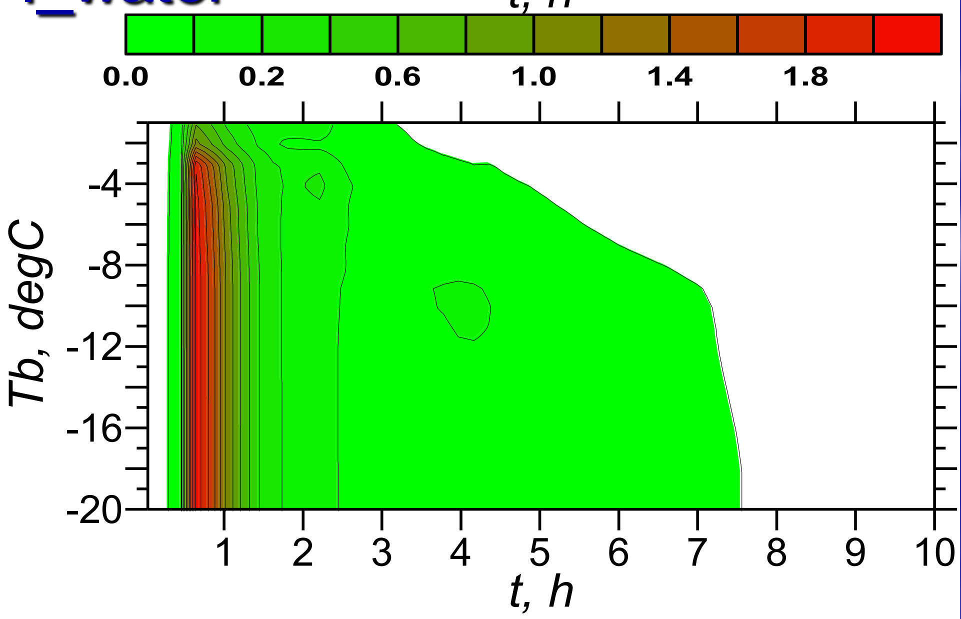
(pseudo-contact freezing)

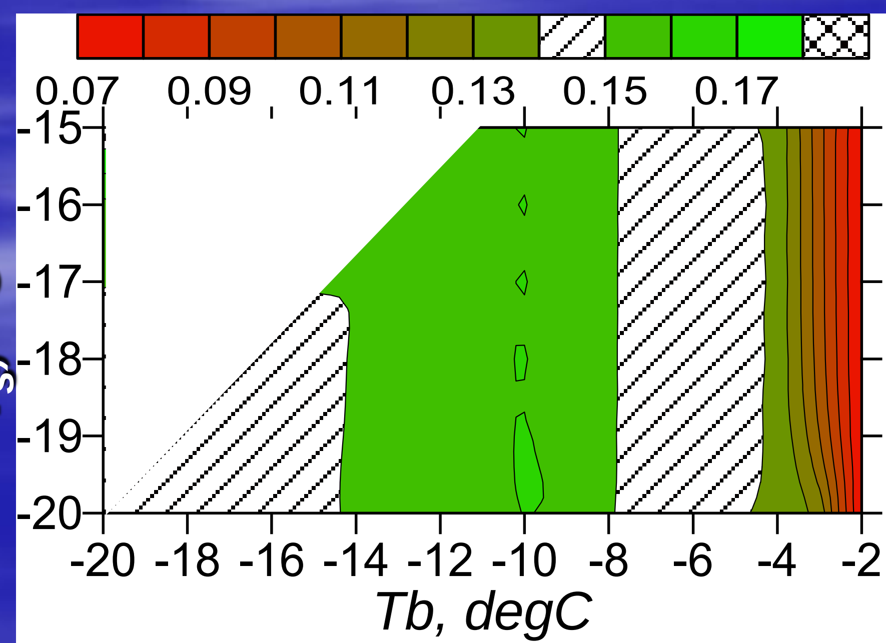
I_ice



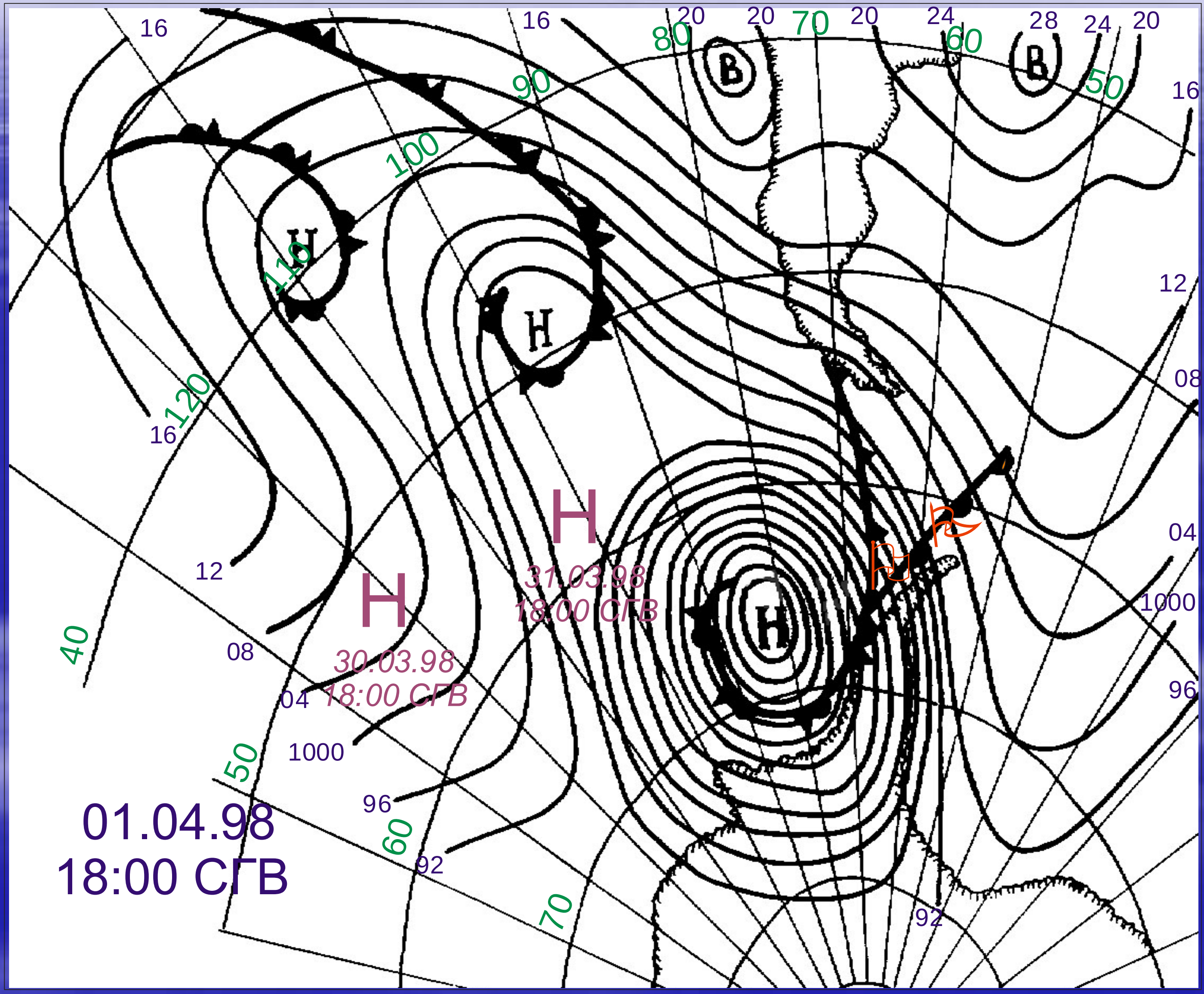


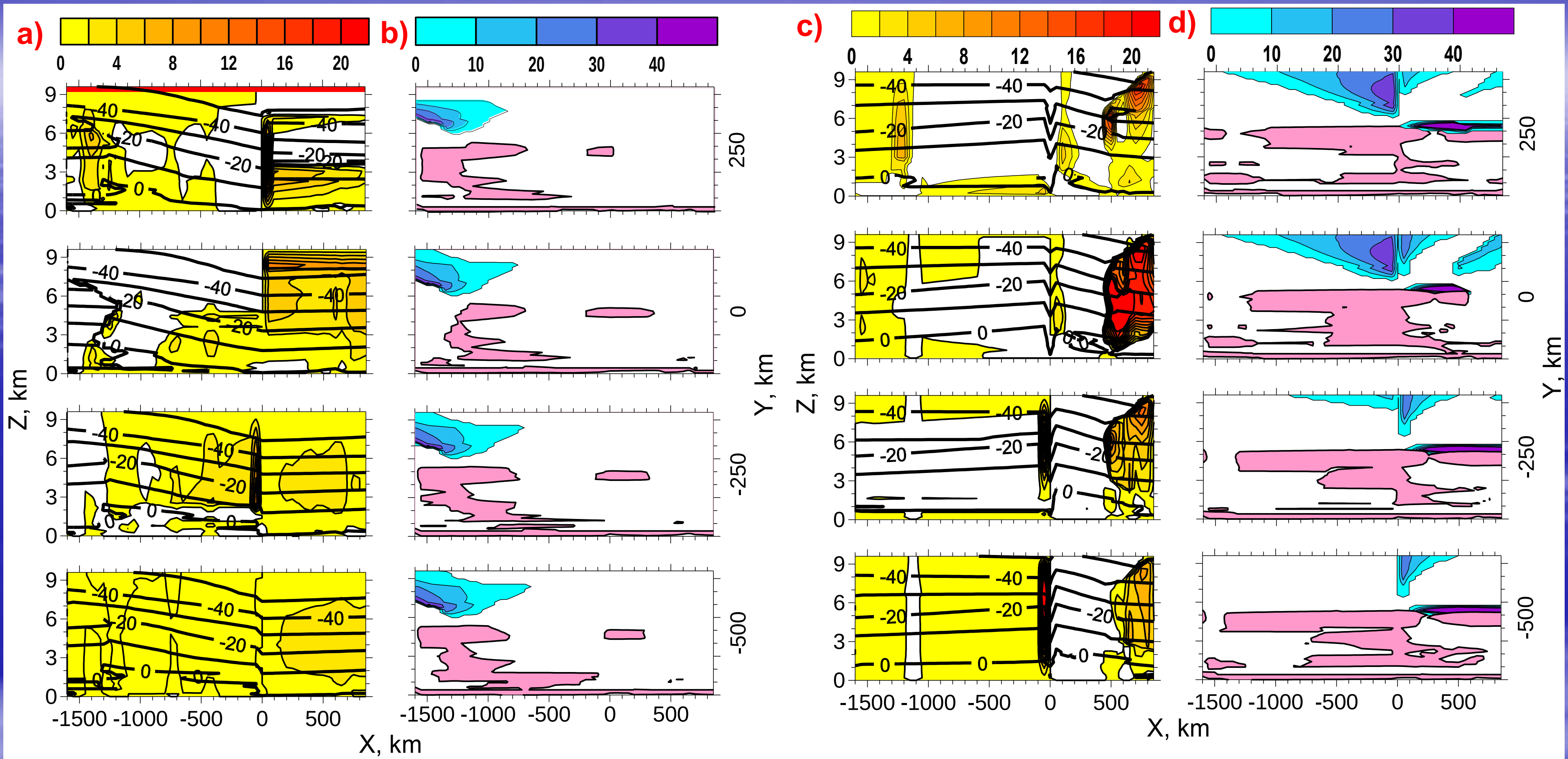
I_water





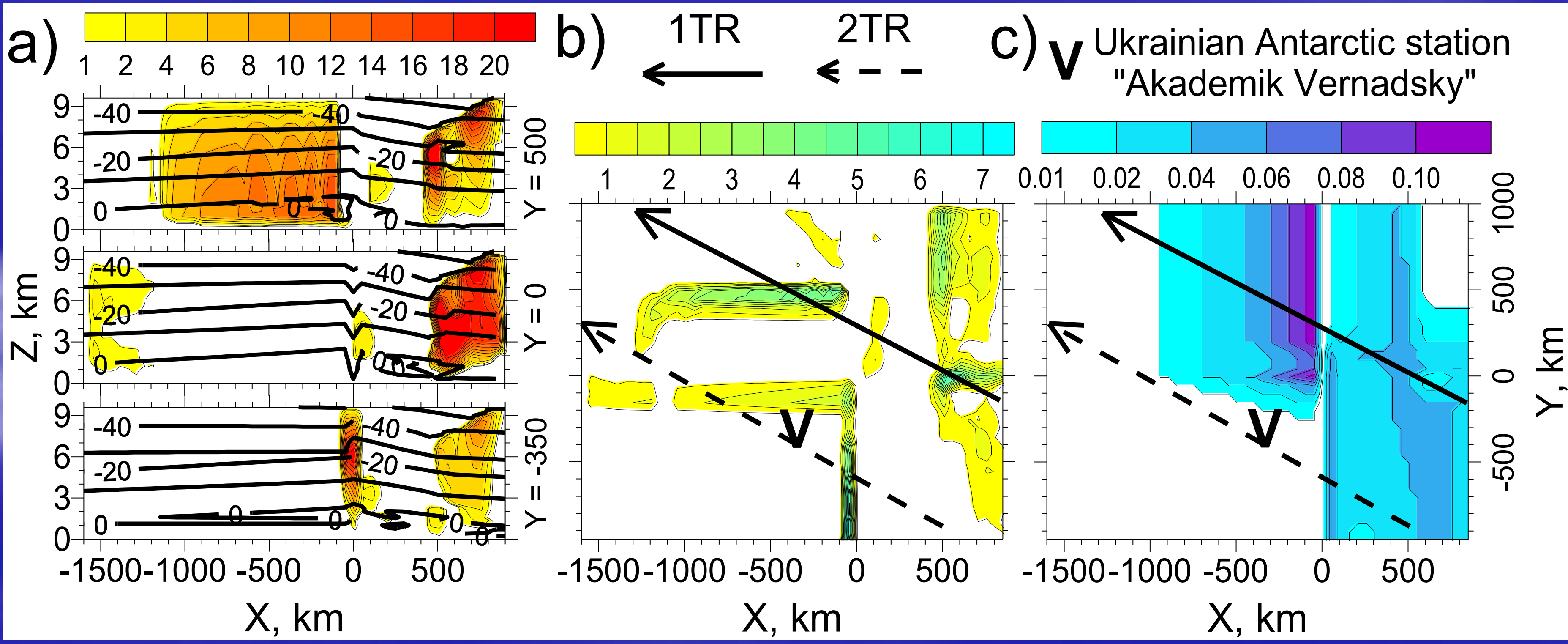
Synoptic map (H – center of the Low)





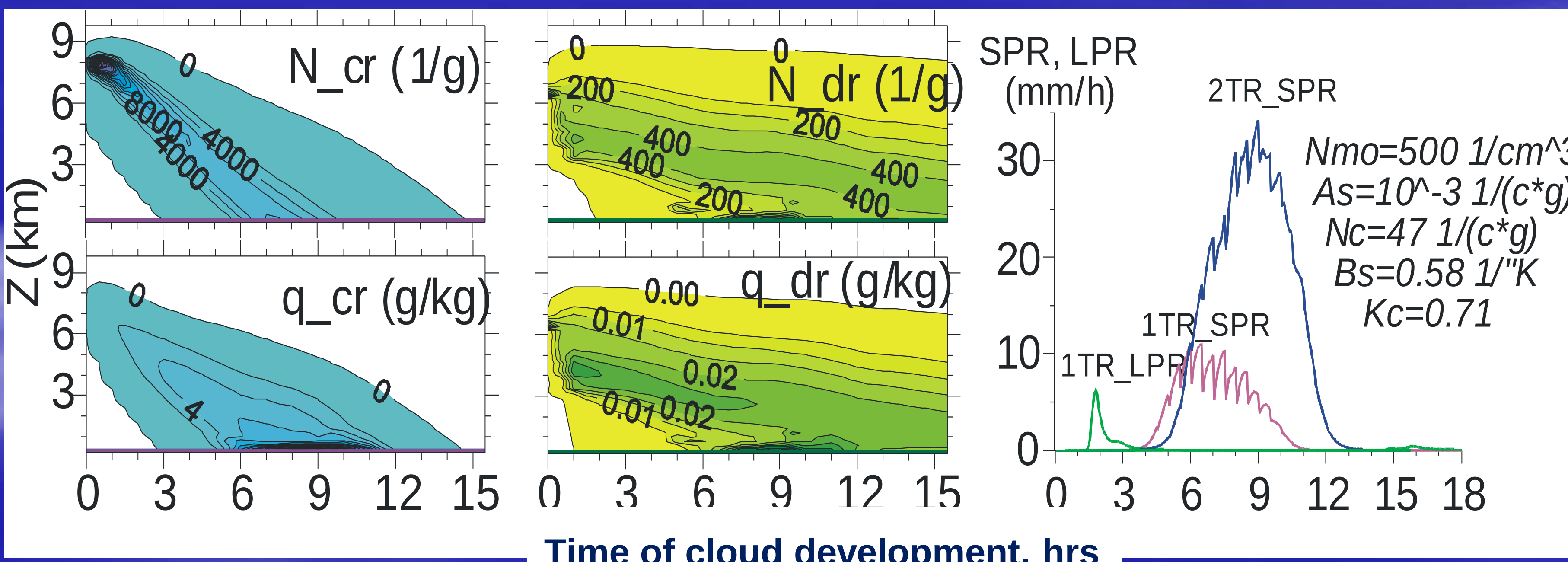
Vertical cross-sections for 00 СГВ 01.04.98 (a, b) and 00 СГВ 02.04.98 (c, d):
(a) and (c) temperature (lines with numbers, °C)
and up-drafts (yellow-red, cm/s);
(b) and (d) ice supersaturation (blue-violet, mg/kg)
and wet-instability (pink)

Results of 3D simulation for 00 UTC 02.04.98: (a) vertical cross-sections of temperature, *T* (°C), and updrafts, *w* (cm/s), (yellow-red); (b) vertically integrated thermodynamic rate of condensation as precipitation rate (mm/h) and (c) ice supersaturation (mm) with treks of 1D bin model

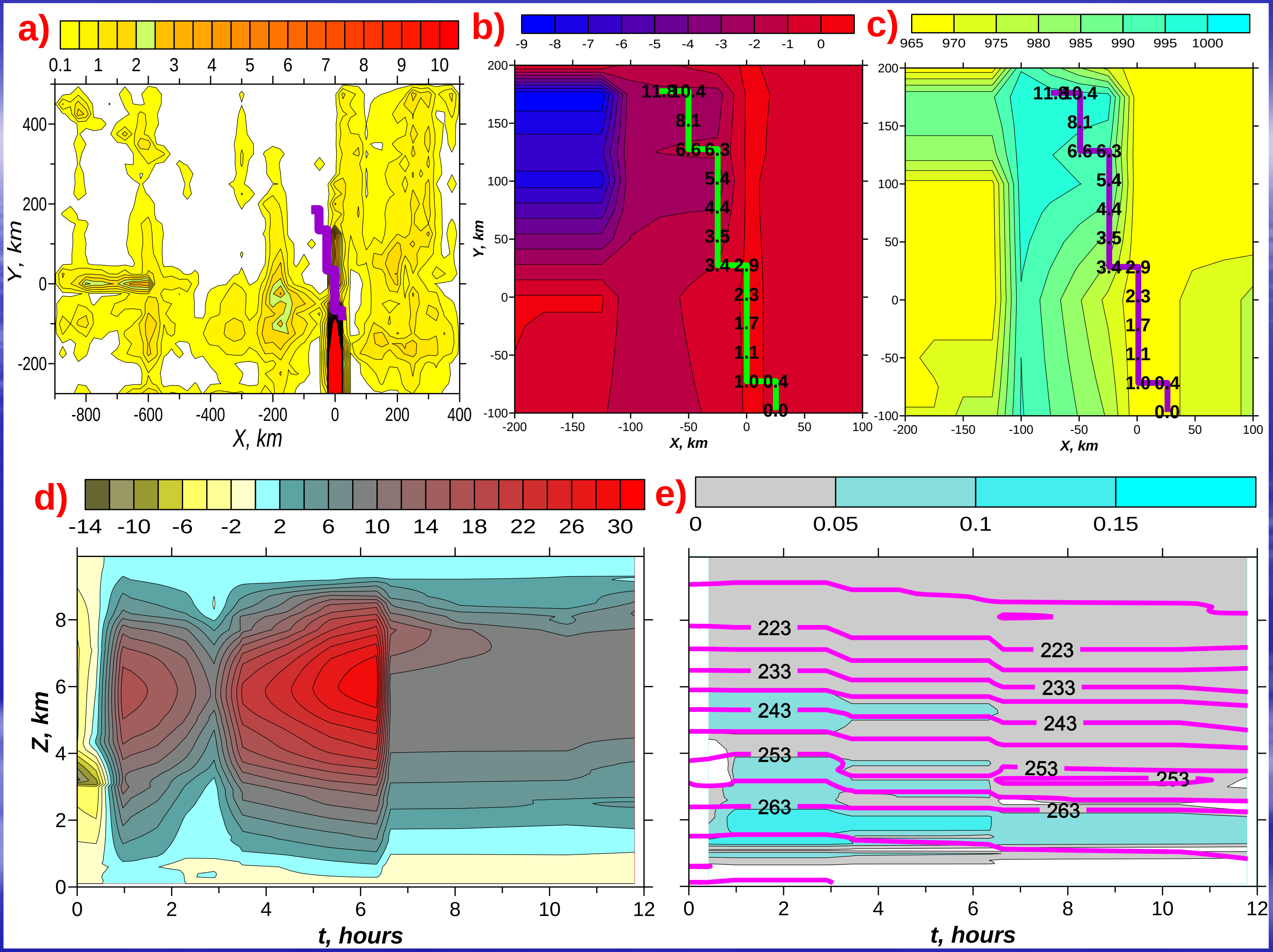


Integral microphysical characteristics of the cloud on the treks (1TR and 2TR) and rates of water precipitation (*LPR*) and snow precipitation (*SPR*) got in the simulation with pointed initial parameters:

N_cr and N_dr – ice crystal and drop concentrations,
q_cr and q_dr– ice and water contents



Results of the simulation for 20.06.1996 (central point (X,Y)=(0,0) is Bellinsgausen station)



(a) integral thermodynamic condensation rate (mm/h), (b) surface temperature (^{o}C) and (c) pressure (mb) with a track of the 1D model and vertical development of (d) vertical motions (cm/s), (e) ice supersaturation (mg/kg) and temperature (^{o}K) on the track with *t*

Liquid (S_{liq}) and solid (S_{sol}) precipitation sums for 12 h with their totals (S) in dependence of presence and intensity of cloud and precipitation formation mechanisms (20.06.1996)

N exp	***A_s***	***A_f for droplets***	***A_f for drops***	***E_{coa}***	***S_{liq_12h}, mm***	***S_{sol_12h}, mm***	***S_{12h}, mm***
1	1e-5	2e-3	2e-3	1	0.56	20.99	21.55
2	**1e-5**	**0**	**0**	**1**	**0.57**	**20.91**	**21.48**
3	1e-5	0	–	0	–	13.66	13.66
4	**0**	**2e-3**	**–**	**0**	**–**	**13.63**	**13.63**
5	**0**	**2e-3**	**2e-3**	**1**	**2.31**	**18.18**	**20.49**
6	1e-3	0	–	0	–	15.73	15.73
7	1e-3	2e-3	–	0	–	15.47	15.47
8	**1e-3**	**2e-3**	**2e-3**	**1**	**0.40**	**34.01**	**34.41**

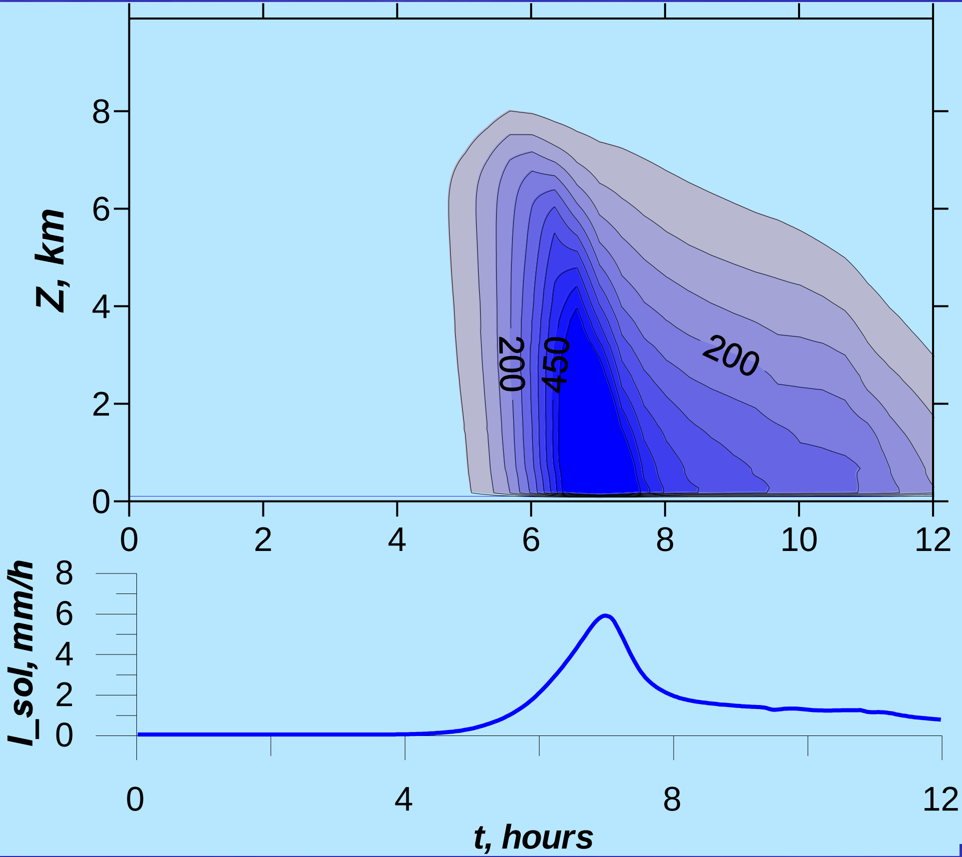
Ice content (mg/kg)

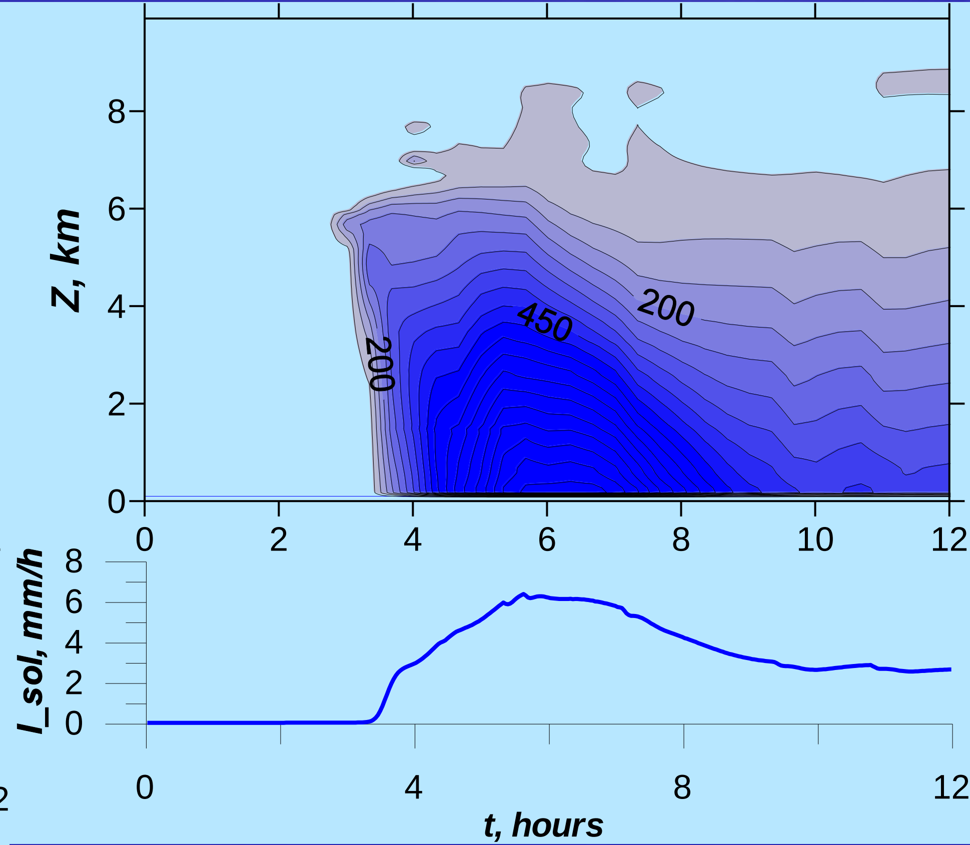
4

A_s=0,
E_{cr}=0, A_f=2e-3

8

A_s=1e-3,
E_{cr}=1, A_f=2e-3





CONCLUSIONS

- Mixed frontal rainbands over the Antarctic Peninsula were simulated with aid of CMCT and their mesoscale and microphysical features were analyzed.
- The study has confirmed that cloud microphysics obtained in the simulations for Antarctic clouds differ with the microphysical features of midlatitude clouds, particularly ice formation processes dominated and IC exceeded LWC.
- All ice formation processes were almost equally efficient in cloud and precipitation formation.

A complex of the numerical models in the study of the catastrophic floods

<u>Svitlana Krakovska [1]</u>, Holger Goettel [2], Daniela Jacob [2] and Susanne Pfeifer [2]

(1) Ukrainian Hydrometeorological Research Institute (UHMI), Kiev, Ukraine
(2) Max Planck Institute for Meteorology (MPI-M), Hamburg, Germany

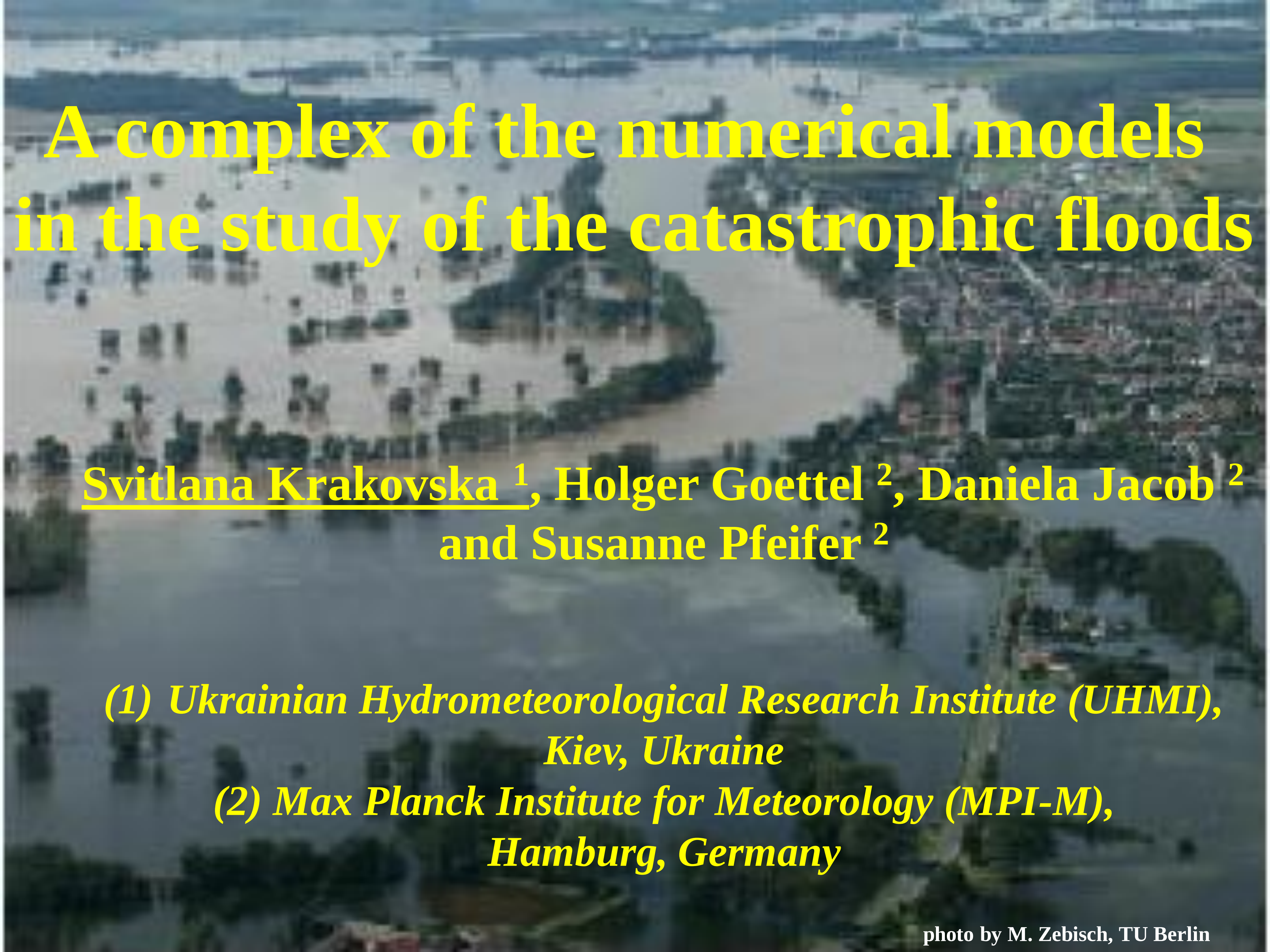


photo by M. Zebisch, TU Berlin

REMO forecast mode:

driven and initialized by ECMWF T106 Analysis;

initialized every day at 00:00 for 30 hrs simulation with 6 hrs model spin up

horizontaly: 109x121 (Elbe case) and 91x91 (Carpathians) grid points

with 1/12° interval;

verticaly: 27 levels

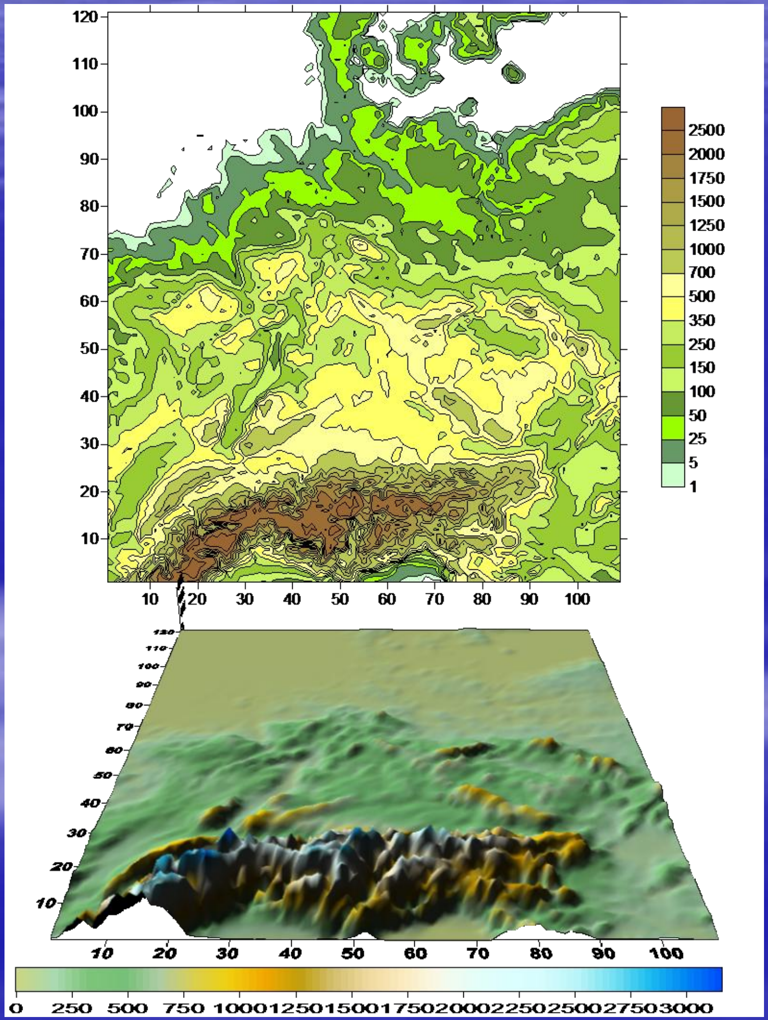
The vertical integral (*E*) of the thermodynamic rate of condensation in CMCT determines development of clouds and corresponds to the possible maximum of precipitation rate:

$$E = -\int_0^H \rho w \frac{\partial q_s}{\partial z} dz$$

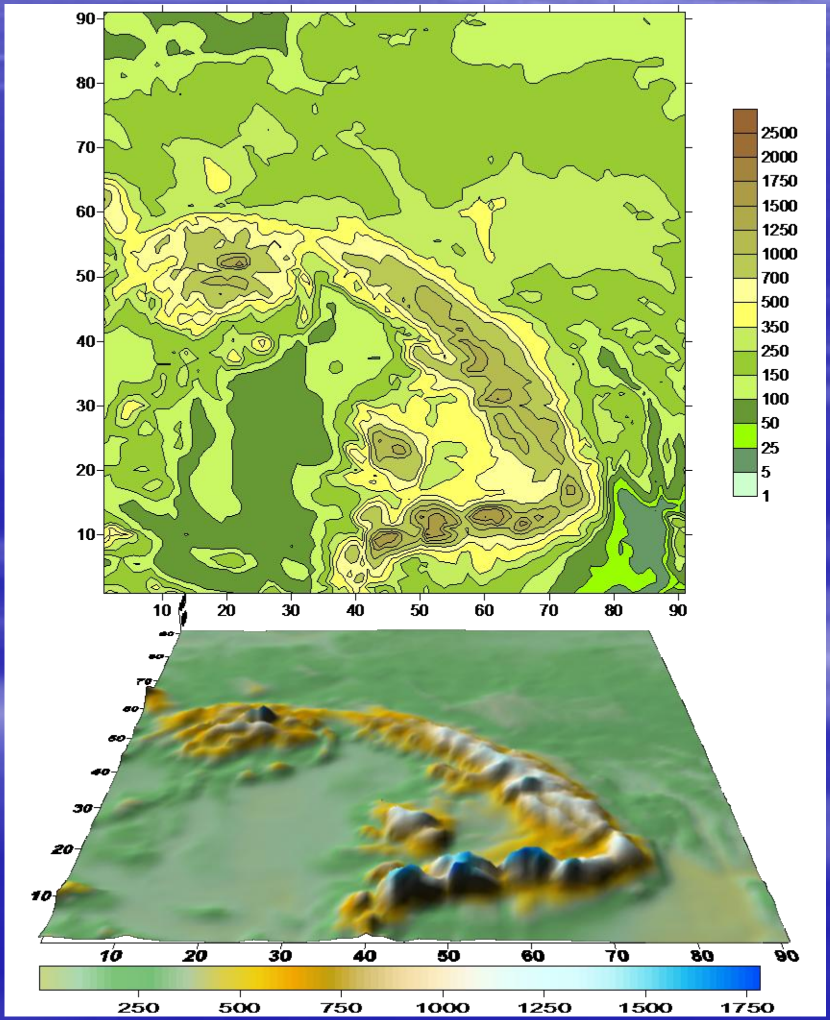
where ρ and q_s are the density and specific humidity of the air respectively; z is the height; H is the z-maximum; w is the vertical component of the wind velocity.

Models' domains and orography

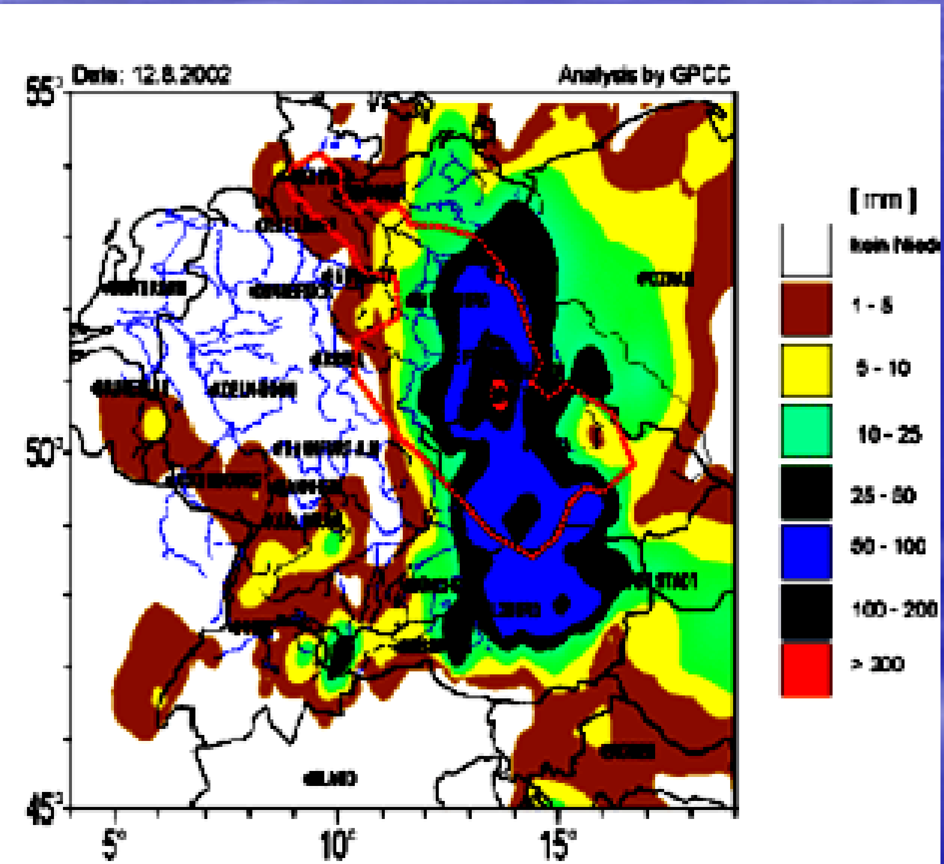
Elbe case
12-13.08.2002

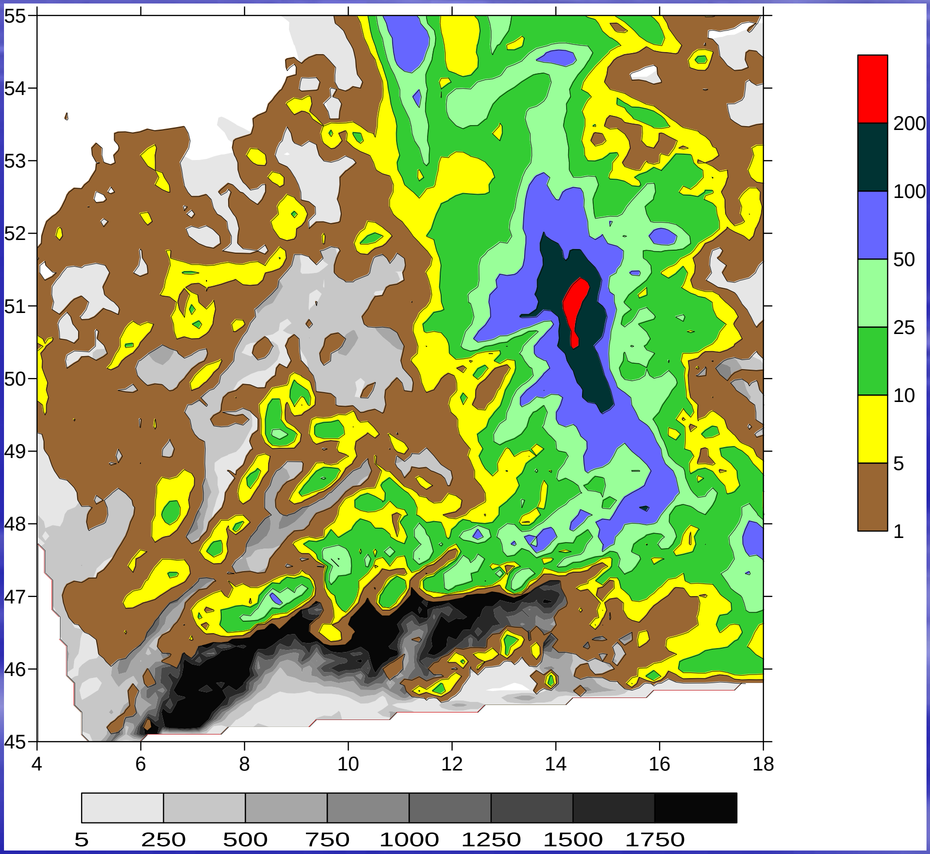


Carpathians
3-5.11.1998



Precipitation sum (mm) from GPCC and REMO (117.8 mm) from 07h 12.08.2002 to 06h 13.08.2002



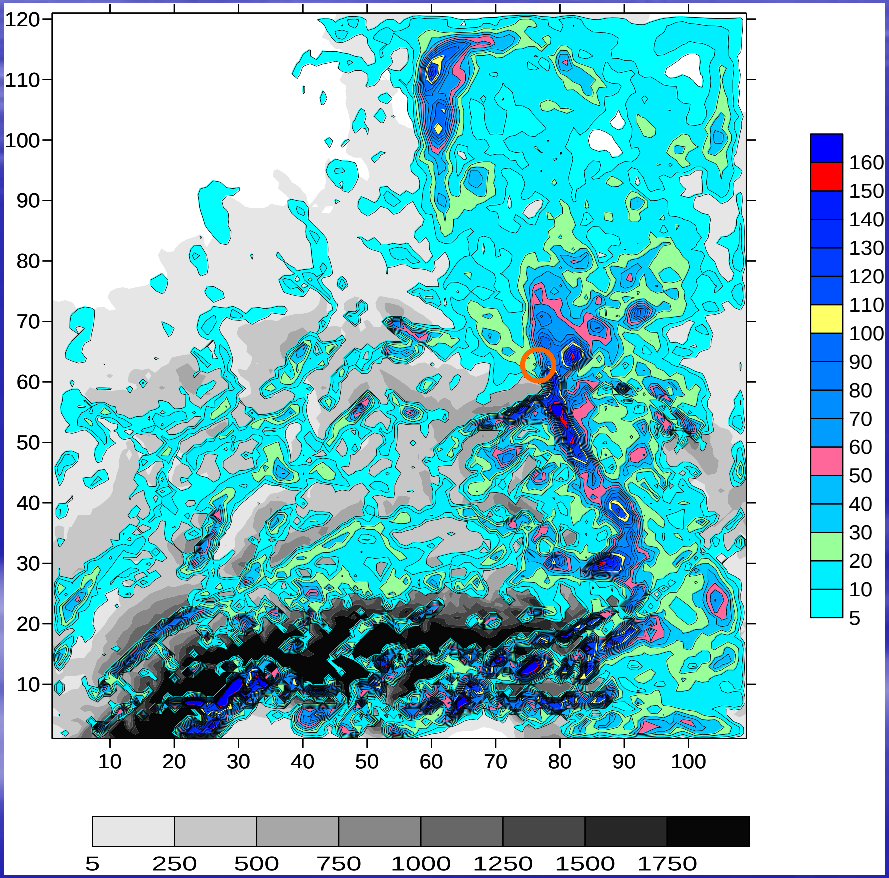


Dresden (13,77°; 51,13°) Daily precip. sum 158 mm

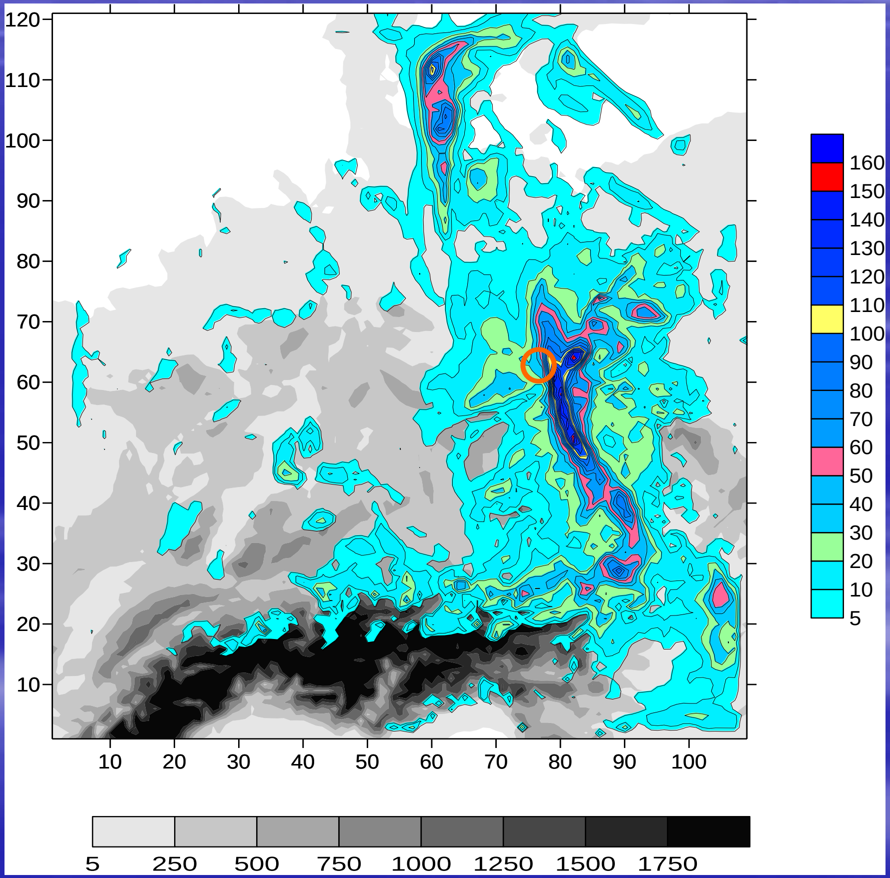
Precipitation sum *(mm)* 12.08

07-18 h

Rate (48.8 mm)



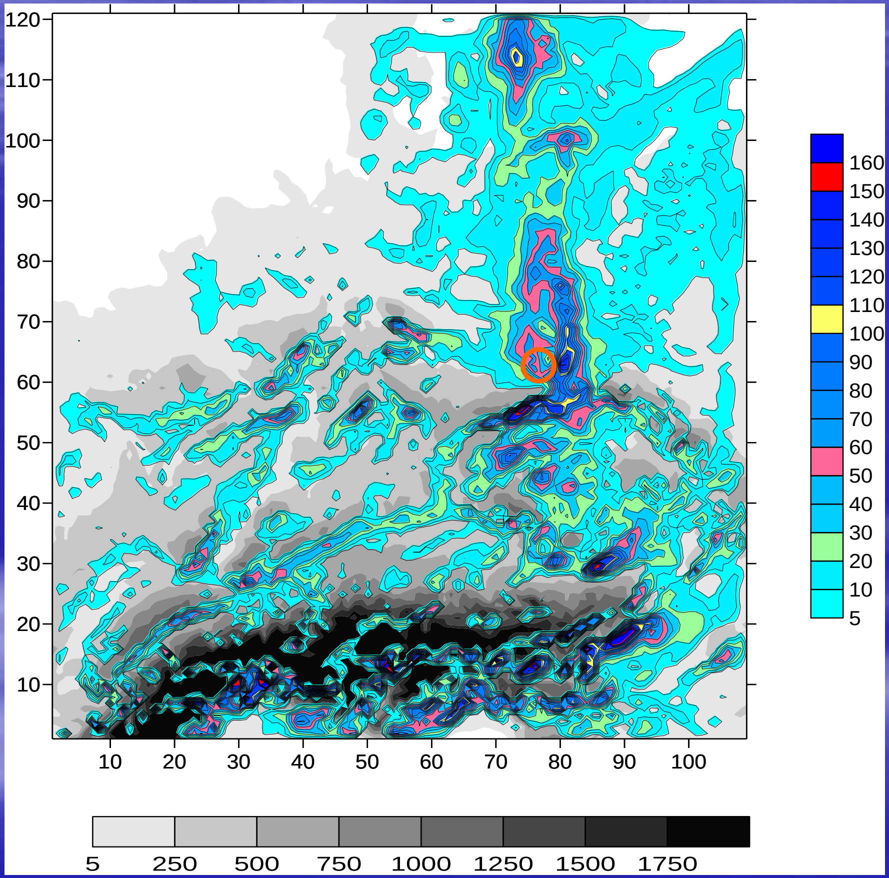
REMO (47.0 mm)

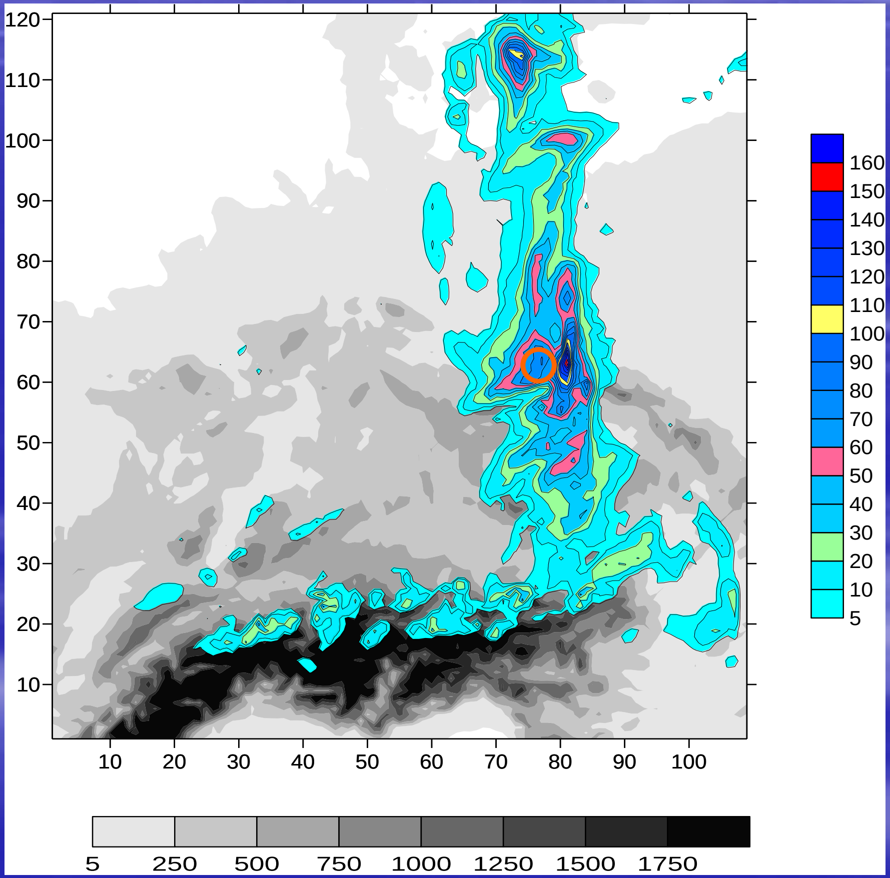


Precipitation sum *(mm)*

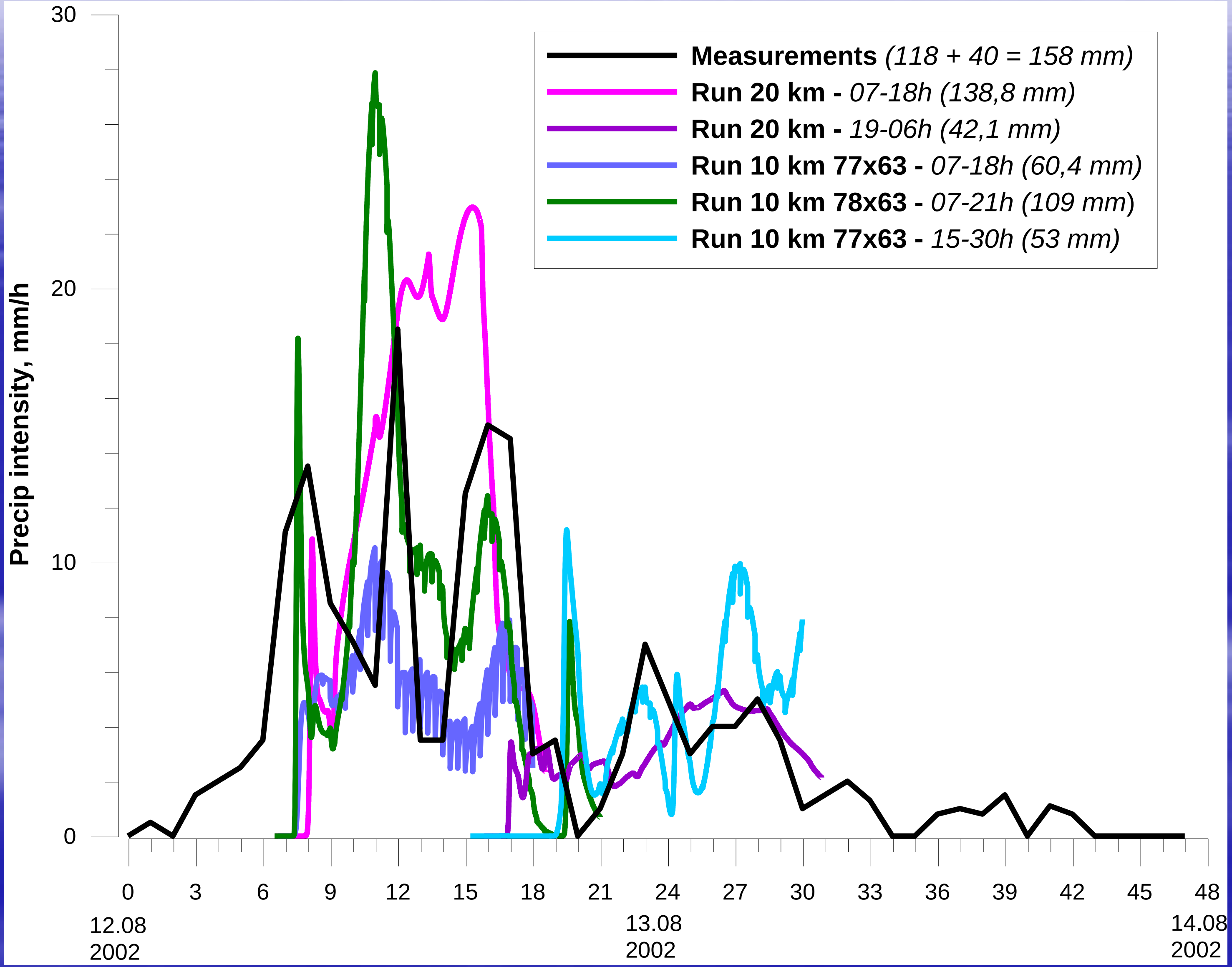
12-13.08 19-06 h

Rate (48.1 mm) *REMO* (70.8 mm)





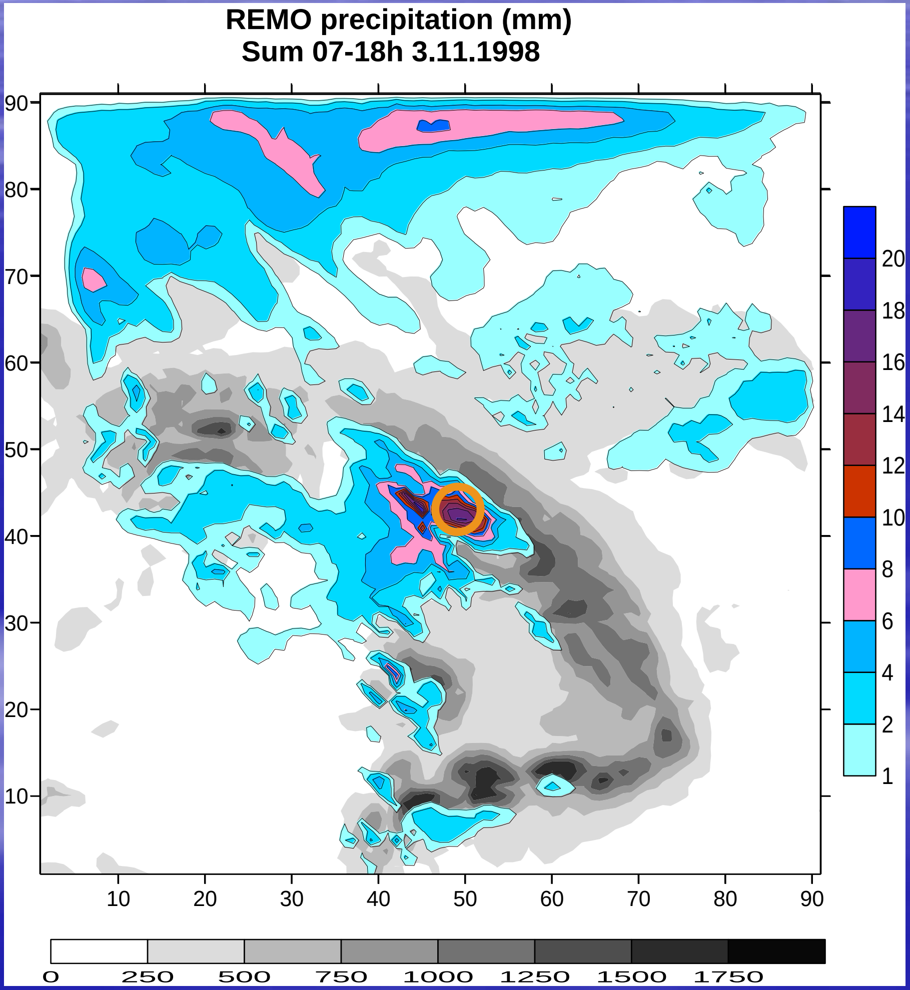
Microphysical results (Dresden)

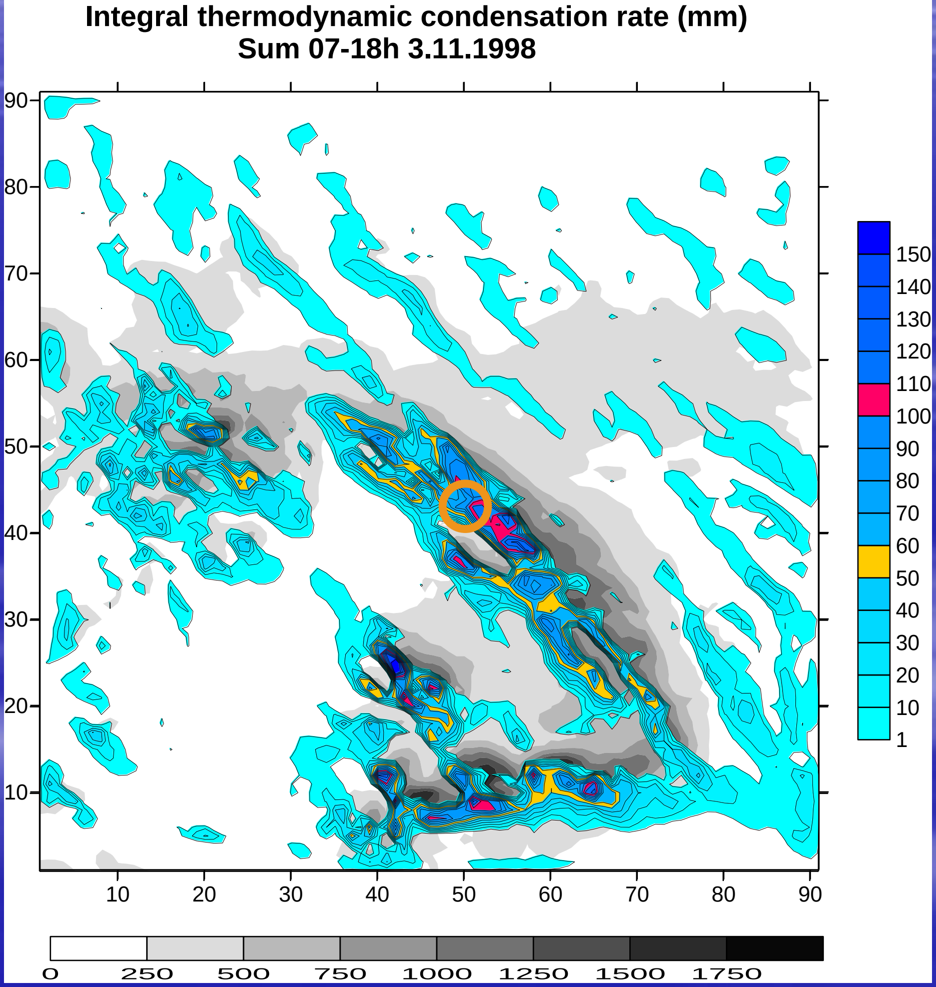


Results of REMO and CMCT (Carpathians)

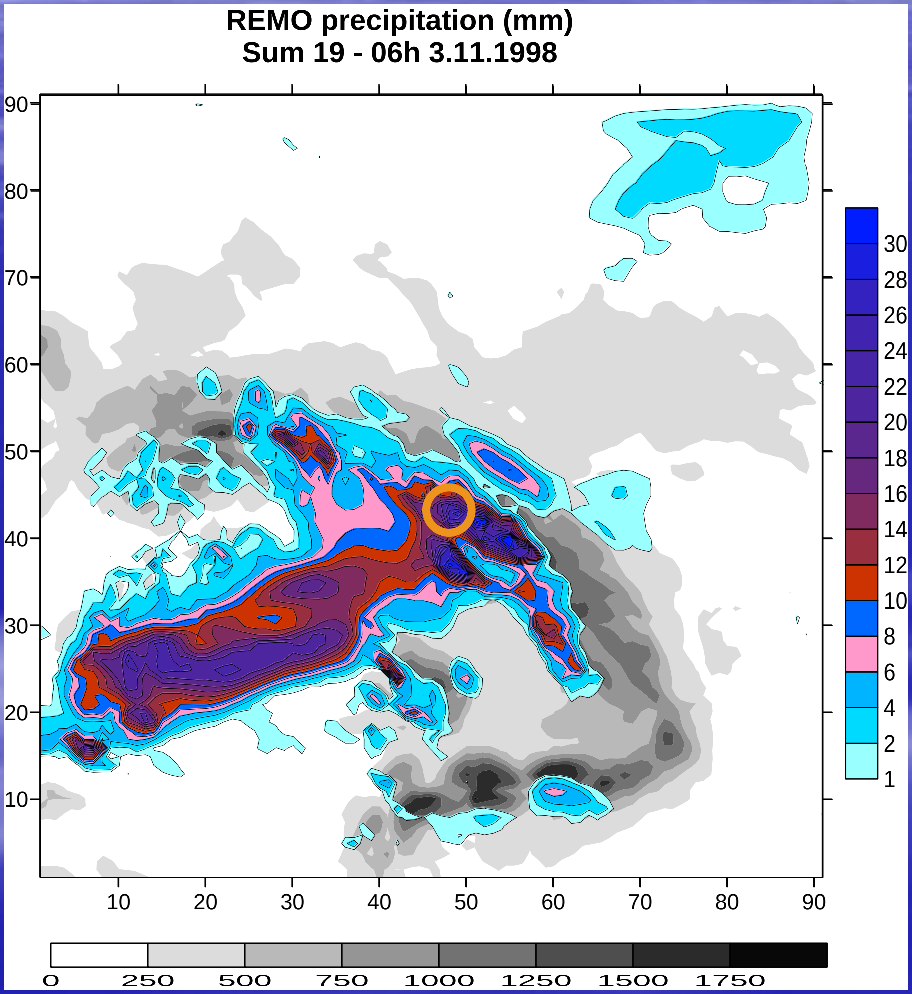
Measured: Mizhirja = 10,6 mm; Ust-Chorna = 5,2 mm

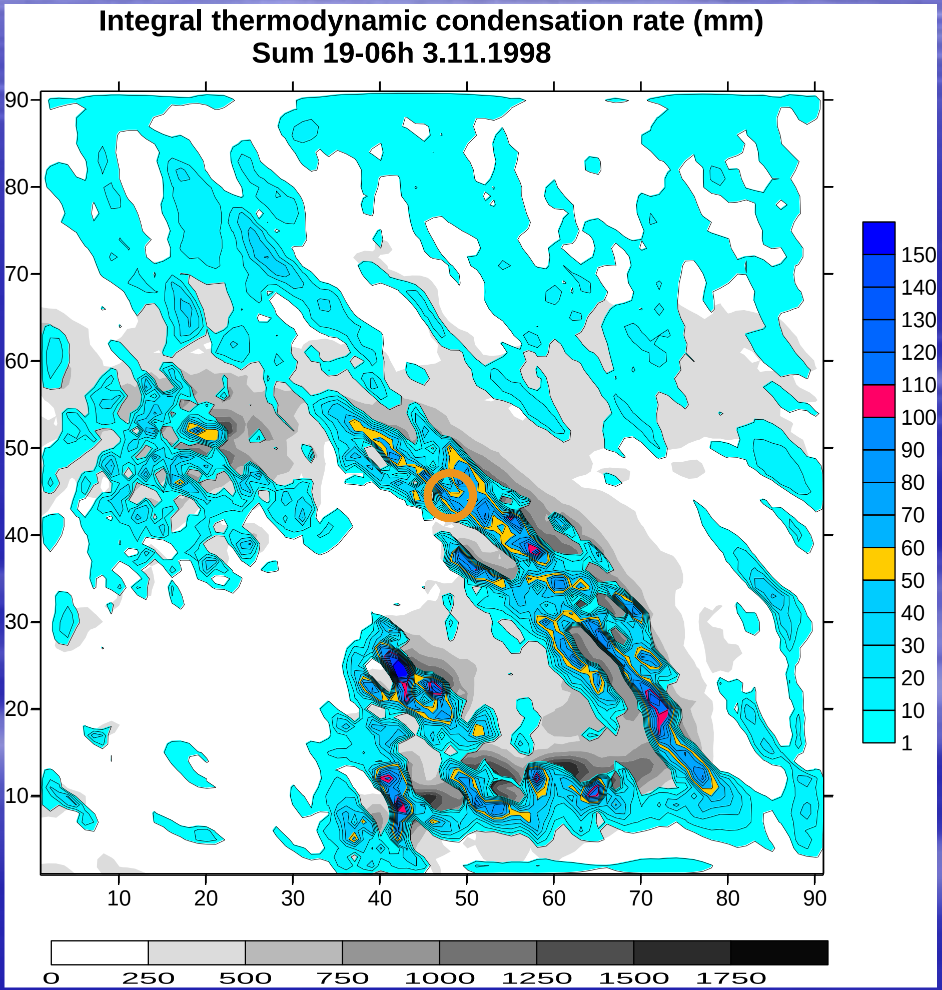
REMO – good; rate indicates further intensification up to 50 mm



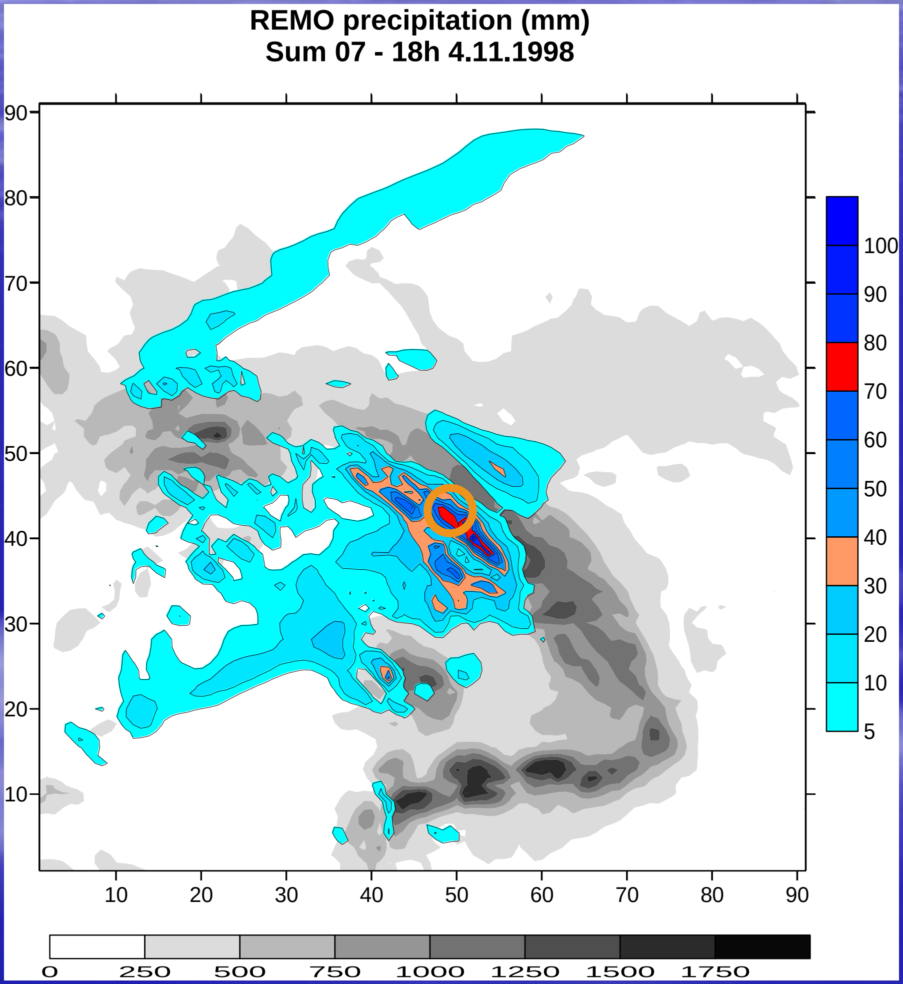


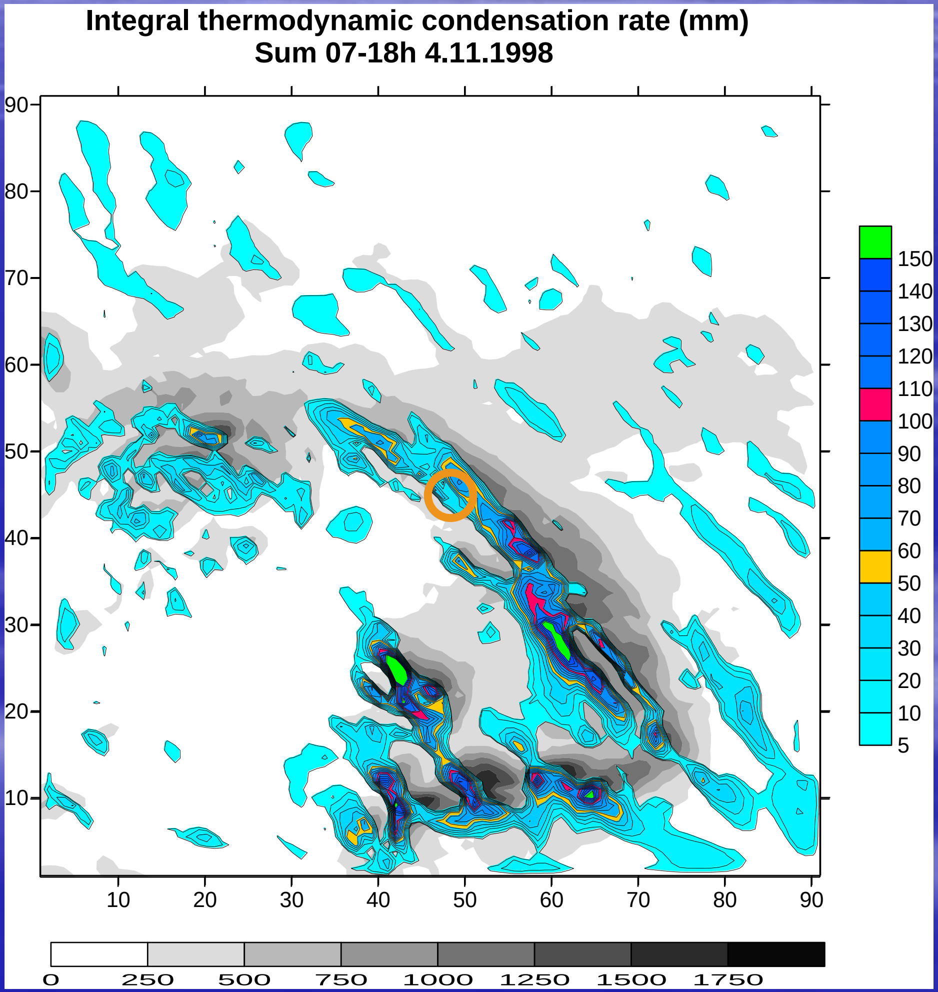
Measured: Mizhirja = *32,9* mm; Ust-Chorna = *64,2* mm
REMO – less (*15-30* mm); rate – *40-70* mm and indicates that precipitation intensity will be the same in the next period





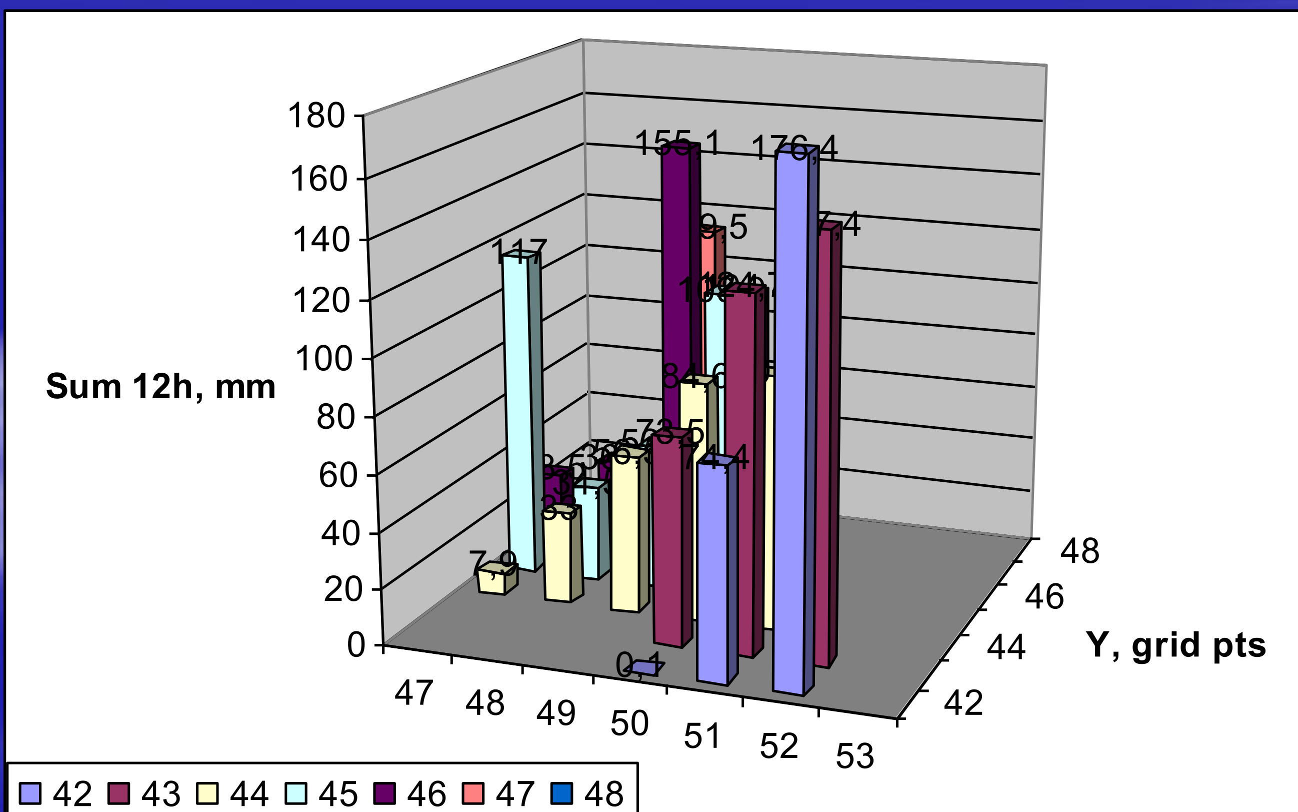
Measured: Mizhirja = *80,2* mm; Ust-Chorna = *71,0* mm
REMO – good (*max 70* mm); rate – *30-80* mm and indicates that precipitation intensity will be a bit less in the next period





12h precipitation sum from two microphysical runs started at 06h and 12h 04.11.1998

X x Y	*47*	*48*	*49*	*50*	*51*	*52*
47			119,5			
46	28,5	36,5	**155,1**	104,4		
45	117	34,5	52,4	109,9		
44	7,9	33	56,5	84,6	90,3	
43				73,5	124,7	147,4
42				0,1	74,4	**176,4**



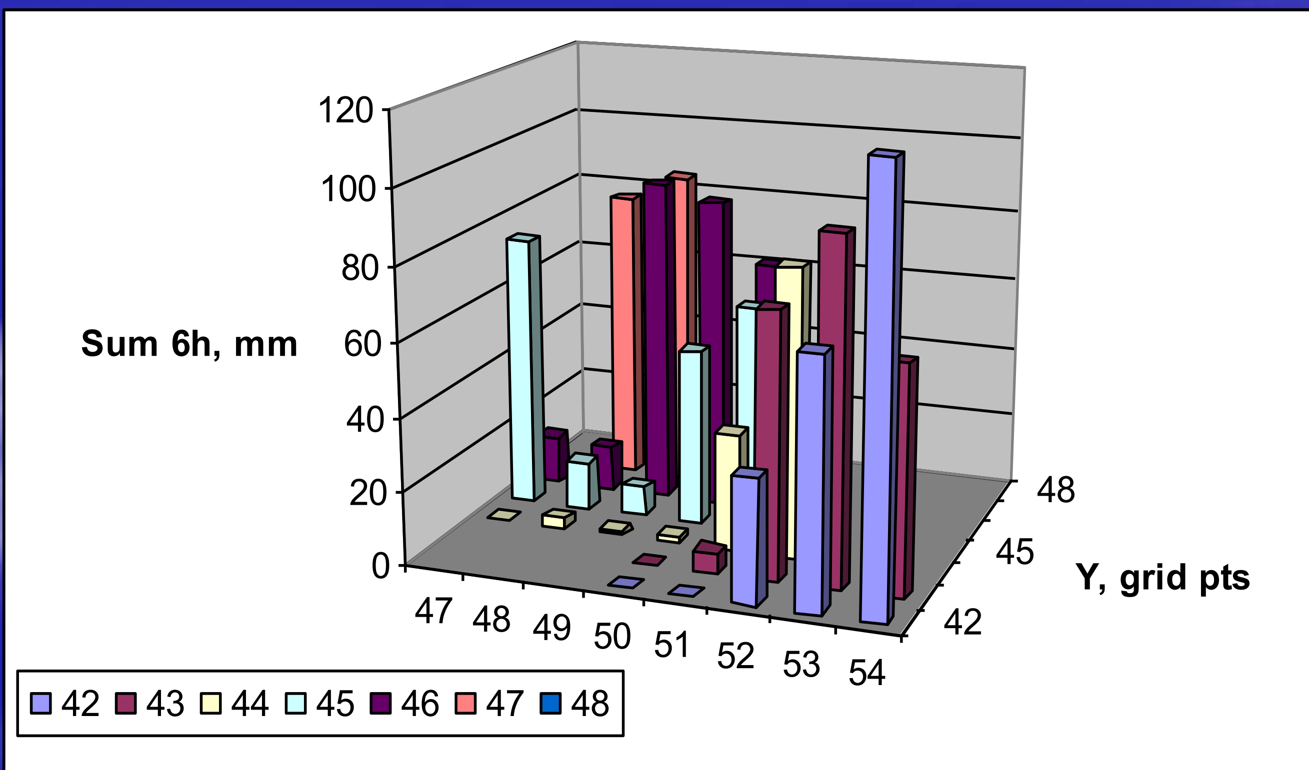
Mizhirja
47.3 x 44.4 pts
Gauge 80,2 mm

Ust-Chorna
50.4 x 42.4 pts
Gauge 71,0 mm

Aver. 20 gridboxes
81,3 mm
Snow - 10-30%

6h precipitation sum from the microphysical run started at 18h 04.11.1998

X x Y	*47*	*48*	*49*	*50*	*51*	*52*
47		80,7	88			
46	13,4	12,3	**89,5**	85,7	69,6	
45	74,8	12,9	8,1	48,3	62	
44	0	2,7	1,4	1,9	32	**78,6**
43				0	5,6	71,9
42				0	0	33,7



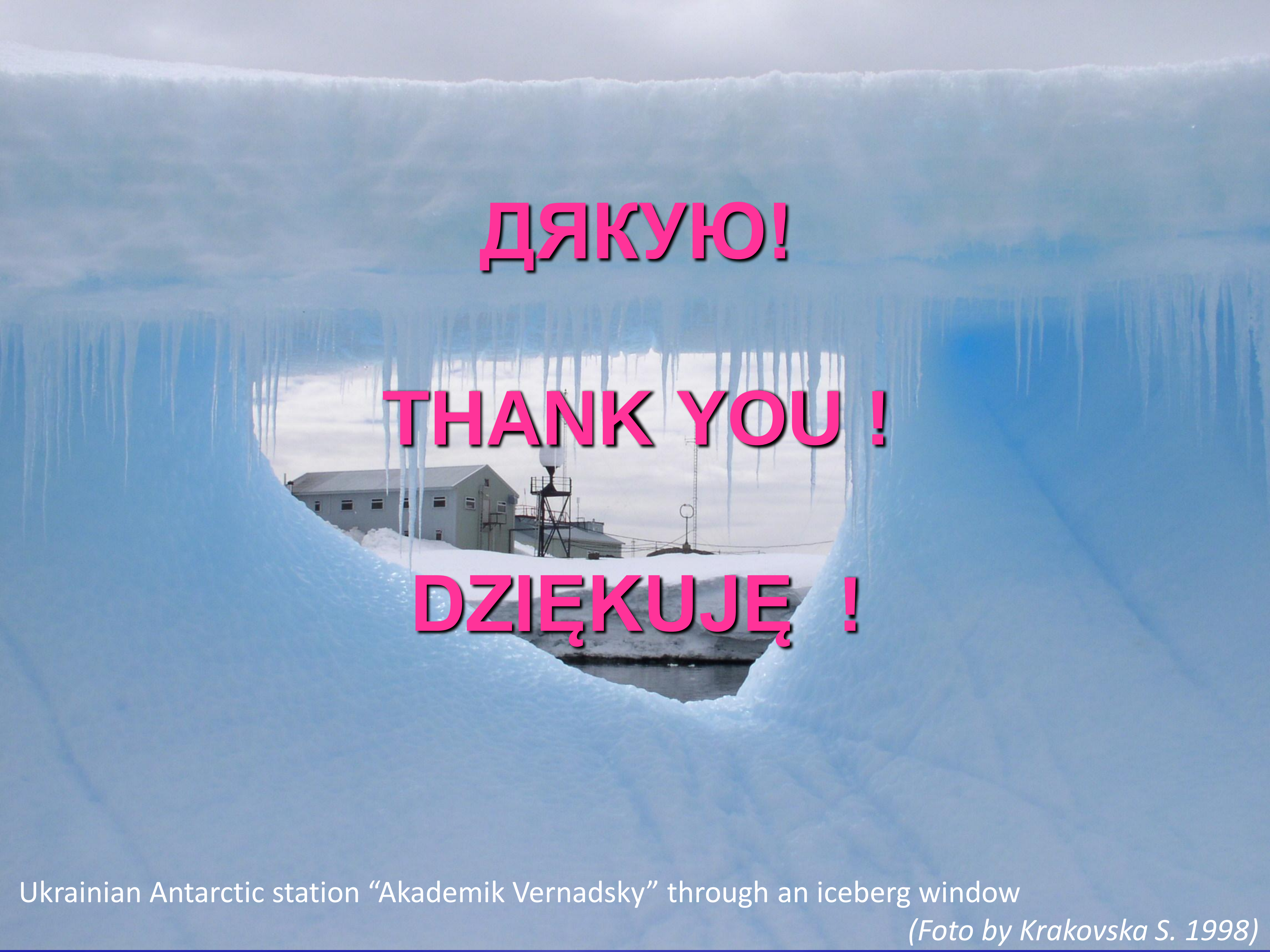
Mizhirja
47.3 x 44.4 pts
70,0 mm (12h)

Ust-Chorna
50.4 x 42.4 pts
66,1 mm (12h)

Aver. 30 gridboxes
44,1 mm (6h)
Snow - up to 60%

Conclusions

- Rates of condensation obtained in CMCT were close to maxima of precipitation intensities and indicated on cloud systems potentiality to produce heavy precipitation within next 3 - 6 hours.
- The spectral microphysical 1D model represented timing of precipitation development reasonably good
- The runs with spectral microphysics revealed the importance of cold processes in the clouds in particular for the colder cases in the Carpathians.
- All models still have problems with simulation heavy precipitation in mountainous regions due to complicated dynamical processes there.



Ukrainian Antarctic station "Akademik Vernadsky" through an iceberg window

(Foto by Krakovska S. 1998)