Cloud Resolving Model **R**adar **Sim**ulator (CR-SIM)

Aleksandra Tatarevic and Pavlos Kollias
Mariko Oue

Applied Radar Science Group

www.radarscience.weebly.com

APPLIED RADAR SCIENCE GROUP

About the CR-SIM

- Designed to directly accept the high resolution CRM output (e.g., WRF, ICON, RAMS), and outputs the simulated radar observables at the model vertical and horizontal resolution

- Microphysical packages implemented:

  - **MP_PHYSICS=8** – WRF with the Thompson bulk microphysical scheme (Thompson et al, 2008)
  - **MP_PHYSICS=9** – WRF with the Milbrandt and Yau 2-bulk microphysical scheme (Milbrandt and Yau 2005a, 2005b)
  - **MP_PHYSICS=10** – WRF with the Morrison 2-moment bulk microphysical scheme (Morrison et al, 2015)
  - **MP_PHYSICS=20** – WRF with the spectral bin microphysical scheme (Fan et al., 2012)
  - **MP_PHYSICS=30** – ICON with the 2-bulk microphysical scheme (Seifert and Beheng 2006)
  - **MP_PHYSICS=40** – RAMS with the 2-bulk microphysical scheme

  *(**implementation of Morrison P3 scheme is planned (Morrison and Milbrandt, 2015)**)*

- *The hydrometeor classes* from the WRF model (cloud, ice, rain, snow, graupel) are represented "*the scattering types*" for which the look-up tables are build

- The scattering LUT's are obtained by using the Mueller-matrix-based code kindly provided by Dr. J. Vivekanandan and fully described in Vivekanandan et al. (1991) and Vivekanandan and Bringi (1993).

Look up tables - the scattering types

Type	Diameter range	Bin resolution	Temperature [° C]	Density [gr/cm^3]	Shape [a/b is the axis ratio- ratio of minor to major axis]	Orientation [2σ truncated Gaussian, with mean canting angle θ and standard deviation σ ; Random in azimuthal direction]
cloud	1 μm -250 μm	1 μm	[-20° 20°] , every 2°	1	Spherical	-
rain	100 μm – 9 mm	10 μm	[0° 20°] every 2°	1	Oblate a/b according to Brandes et al., 2002	θ=0°, σ=5°
ice	3 μm – 1.5 mm	1 μm	-20°	[0.4 -0.9] Every 0.1 gr/cm^3	Oblate a/b=0.2	θ=0°, σ=0.5°
snow	100 μm – 5 cm	10 μm	-20°	[0.1 -0.6] Every 0.1 gr/cm^3	Oblate a/b=0.6	θ=0°, σ=0.5°
graupel	5 μm – 5 cm	10 μm	-20°	0.5	Oblate a/b=0.8	θ=0°, σ=0.5°

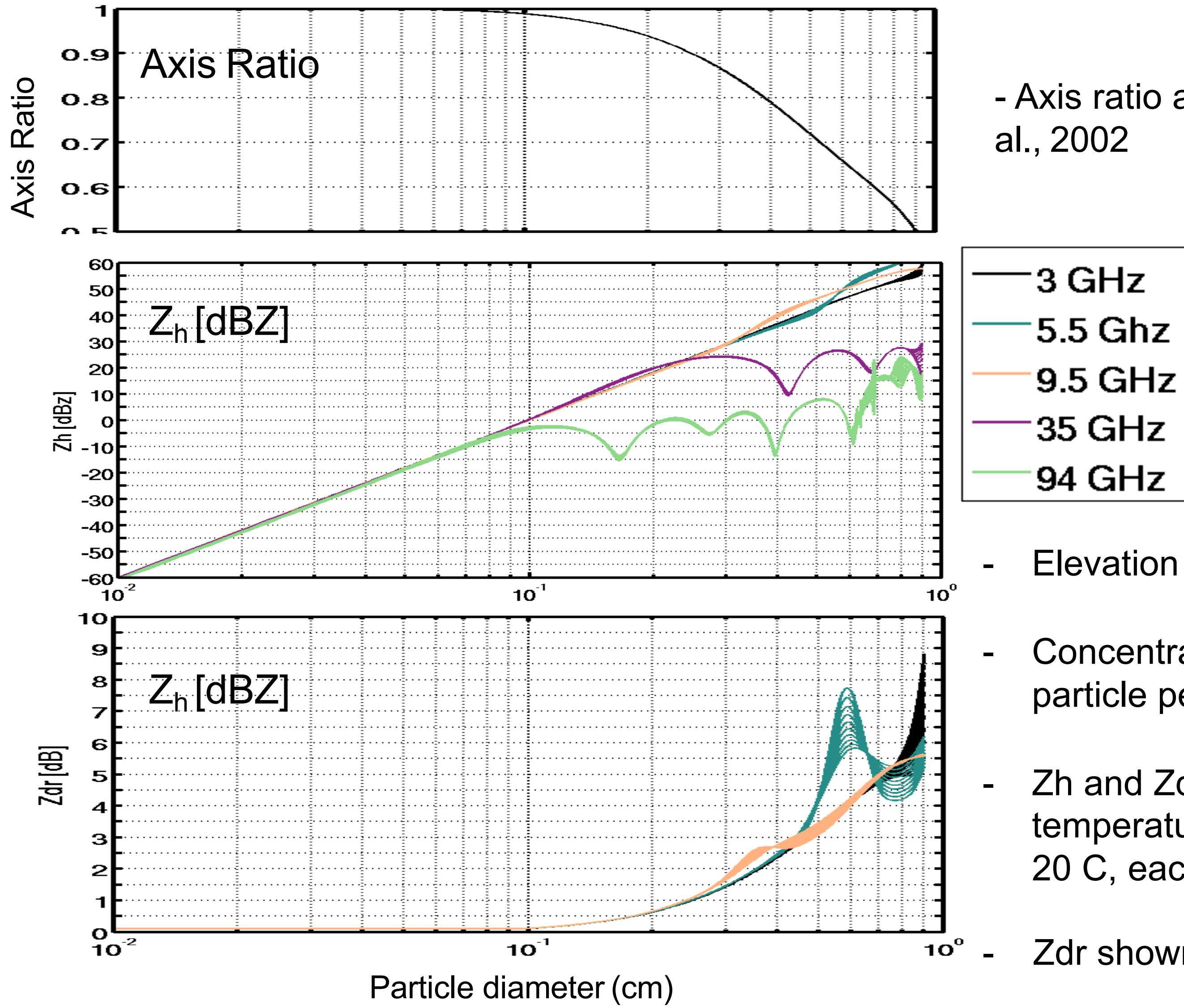
Ice : simple models of plate-type ice crystals, e.g., stellar or dendritic crystals which orient themselves by their long dimension in the horizontal plane

- the radar specific parameters

-frequency **3 GHz , 5.5 GHz, 9.5 GHz, 35 GHz, 94 GHz**

-elevation **0 – 90 ° , every 1**° for non-spherical hydrometers
fixed (arbitrarily to 90°) for the spherical particles (cloud)

Rain Zh and Zdr in function of diameter at different temperatures



- Axis ratio according to Brandes et al., 2002

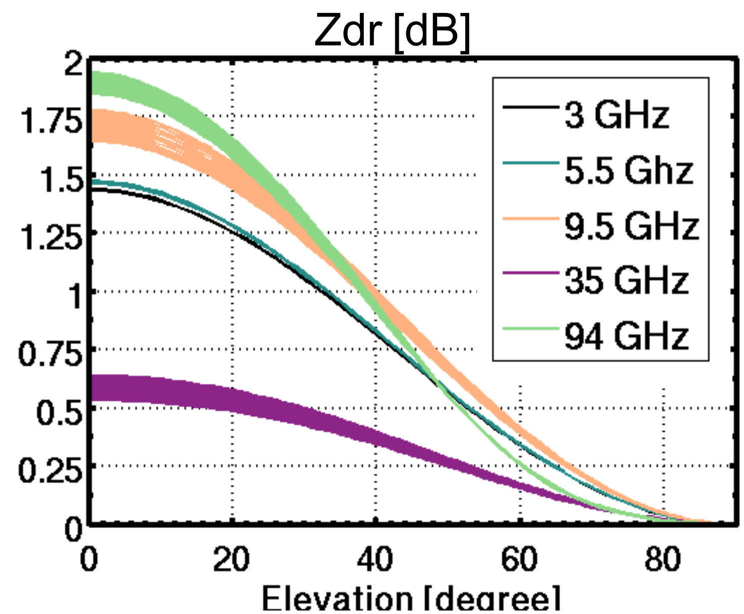
- Elevation angle fixed at 0 degree
- Concentration of particles =1 particle per m^3 per size.
- Zh and Zdr values at all temperatures are plotted (from 0 to 20 C, each 2 degrees)
- Zdr shown at 3, 5.5 and 9.5 GHz

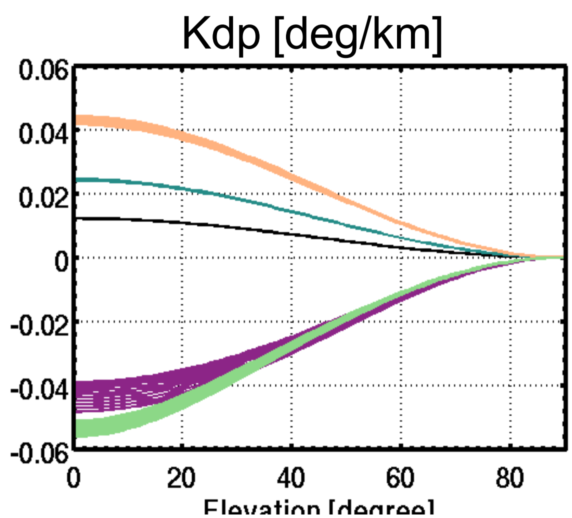
Look up table - Rain

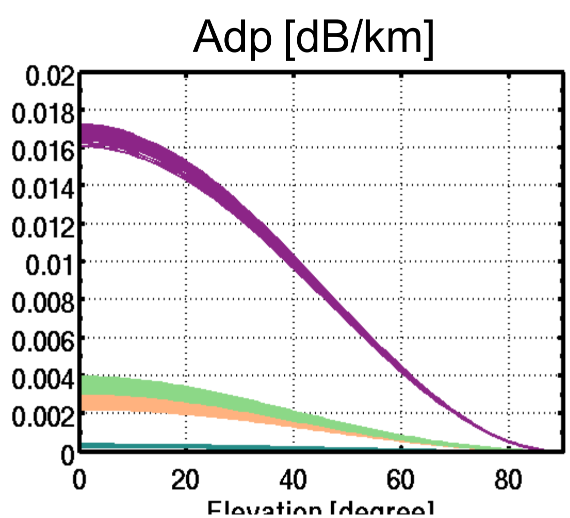
-Rain Zdr, Kdp, Adp, LDR at all temperatures (0-20 C, per 2C) in function of elevations for a fixed diameter 0.3 cm (20 dBZ at Raleigh)

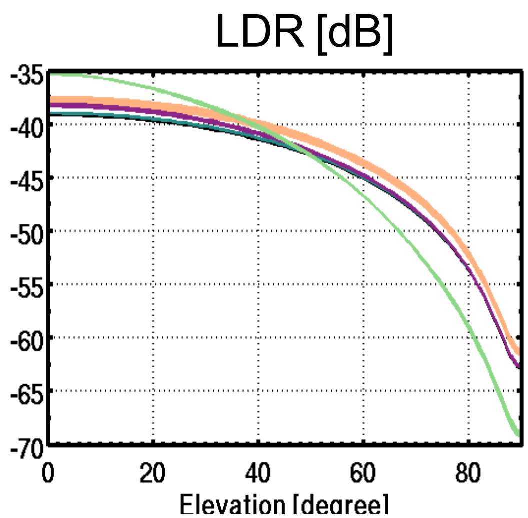
-The axis ratio a/b=0.7.

-Concentration of particles is 1 particle per m^3 per size.



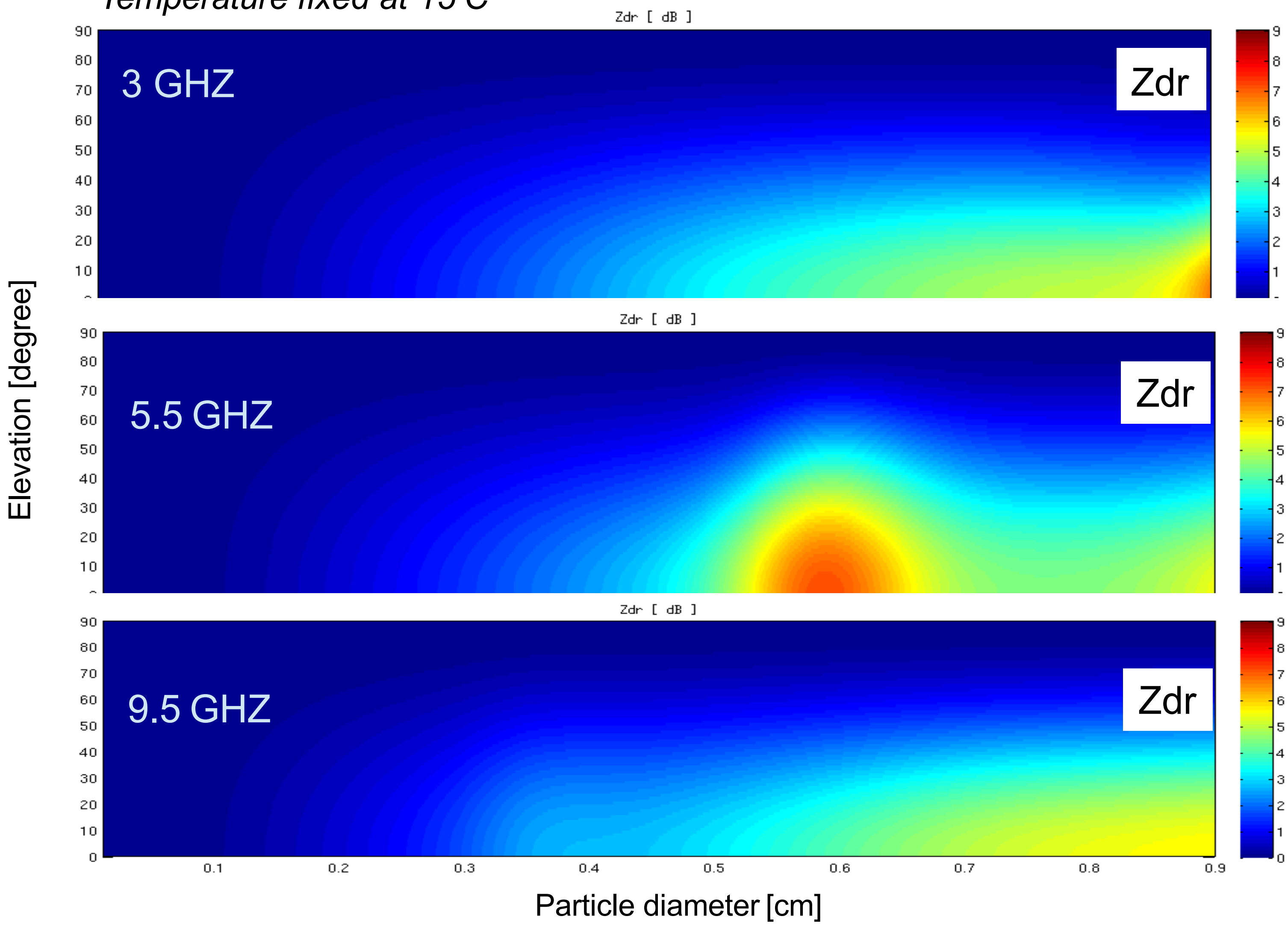






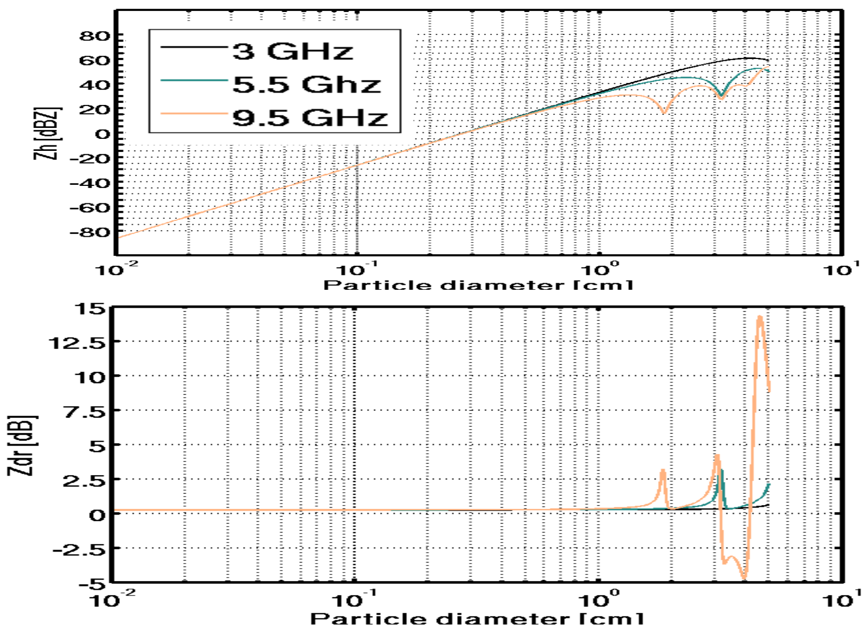
Rain Zdr in function of size at all elevations

Assumed concentration: 1 particle per m^3 per size
Temperature fixed at 15 C

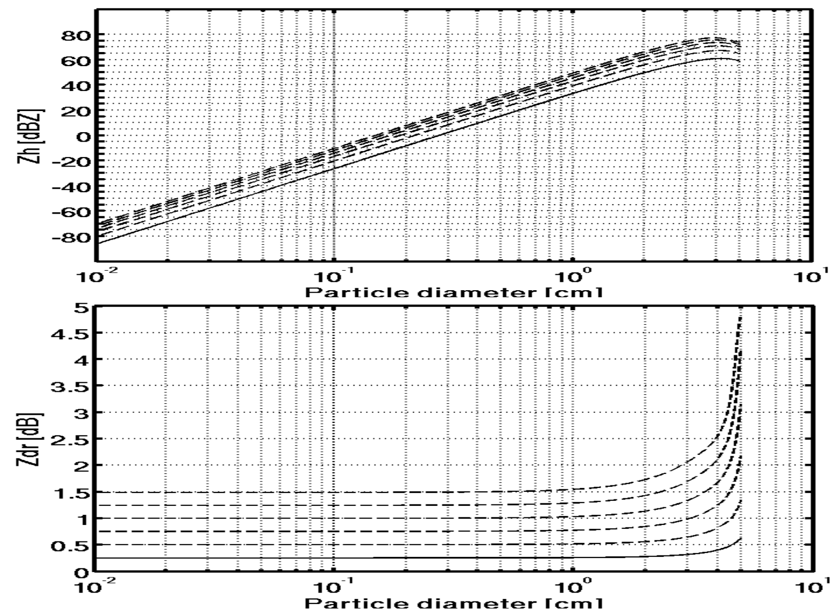


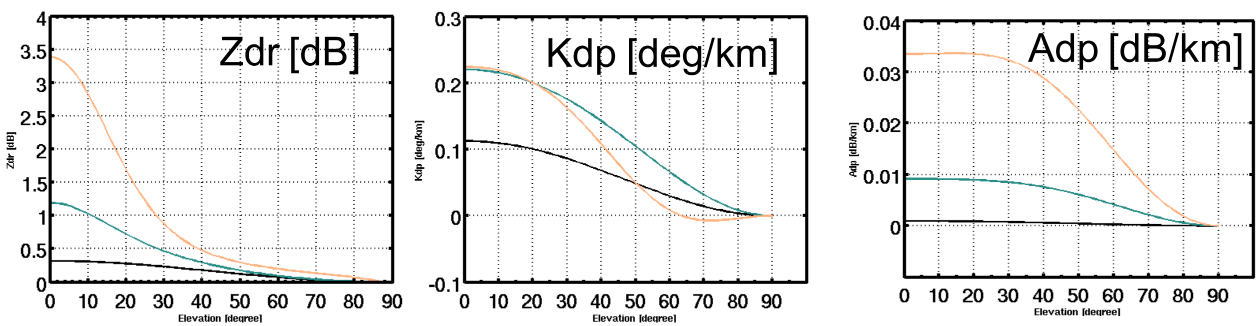
Look up table – Snow

Zh and Zdr at 3 GHz, 5.5 GHz and 9.5 GHz in function of diameter for snow density fixed to 0.1 gr/cm^3,
Elevation angle 0 degree and axis ratio 0.6.
Assumed concentration is 1 particle per m^3 per size.



Zh and Zdr at 3 GHz, in function of diameter for snow densities from 0.1 gr/cm^3 (solid line) to 0.6 gr/cm^3 (dashed lines).
Elevation angle 0 degree and axis ratio 0.6. Assumed concentration is 1 particle per m^3 per size.

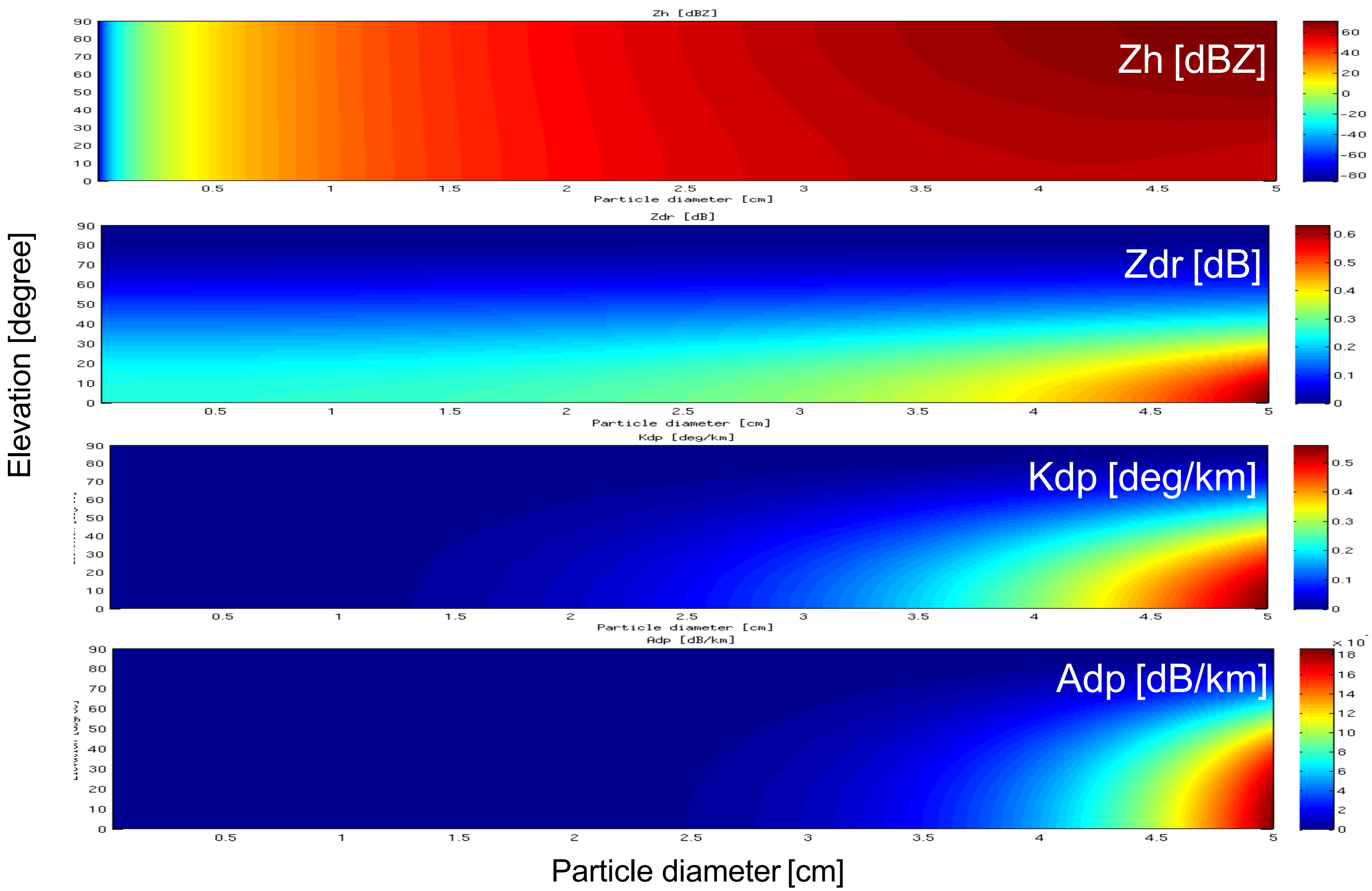




Zdr, Kdp, Adp in function of elevation for fixed diameter (3 cm, ~20 dBZ at 3 GHz).
Snow density is 0.1 gr/m^3.
Axis ratio 0.6. Assumed concentration is 1 particle per m^3 per size.

Look up table – Snow

Zh, Zdr Kdp and Adp in function of diameter at different elevations
Snow density is 0.1 gr/cm^3, axis ratio 0.6, radar frequency 3 GHz.
Assumed concentration: 1 particle per m^3 per size.



CRSIM – USER parameters

- The names of the ***input and output files***
- ***The microphysics scheme ID*** (MP_PHYSICS=8, 9, 10, 20, 30, or 40)
- ***Domain size*** for the ***CRSIM*** simulation <= than the input WRF scene
- *The names of the assigned* ***scattering type to each hydrometeor class***

  Each scattering type is defined by unique characteristics regarding **the specific assumptions about the particle shape and orientation** which are defined when running the t-matrix and Mueller-matrix codes

  For example rain with axis ratio as in Brandes et al, **2σ truncated Gaussian, with mean canting angle θ =0 and standard deviation σ=5 is the one possibility of scattering types for rain.** Rain with axis ratio based on Andsager et al (1999), and the same parameters for the orientation distribution would an other possibility for the rain scattering type.

  NOTE : *The new scattering types can be added without the changing of the* ***CRSIM*** code

- **Radar frequency (**3 GHz, 5.5 GHz, 9.5 GHz, 35 GHz, 94 GHz**)**
- **The horizontal position and height of the radar** in the input WRF domain
- **The scanning mode**: **fixed elevation** angle (90 for example for vertically pointing) **or 'ppi' mode**, where, the elevation of each WRF grid point (belonging to the *CRSIM* domain) is determined in function of distance to the radar origin
- Lidar simulation options
- Postprocessing options

CRSIM algorithm flowchart

Read USER parameter file

Read WRF input file(s), reconstruct needed meteorological variables and extract domain for the srsim simulation

For each grid point of the srsim domain

For each hydrometeor type with water content >0

Determine elevation angle

IF MP_PHYSICS=10 reconstruct the PSDs and compute the bin fall velocities

Determine:
-The nearest LUT elevation angle,
-The nearest LUT temperature if liquid
-The nearest LUT density if solid
Read LUT for the scattering type assigned to this hydrometeor, compute radar simulated variables at desired sizes and save what is needed for computation of variables for the "total" hydrometeor content

Compute radar simulated variables for the "total" hydrometeor and finalize computation of those variables for each present hydrometeor type

Write output netcdf files

CRSIM OUTPUT (1)

DIMENSION NAMES	Description
nx	Number of grid boxes along the horizontal E-W axis
ny	Number of grid boxes along the horizontal N-S axis
nz	Number of grid boxes along the vertical axis at WRF resolution
nht	Number of hydrometeor species

VARIABLE	DIMENSION	UNITS	DESCRIPTION
Zhh	[nx, ny, nz]	mm^6/m^3	Reflectivity at hh polarization
Zvv	[nx, ny, nz]	mm^6/m^3	Reflectivity at vv polarization
Zvh	[nx, ny, nz]	mm^6/m^3	Reflectivity at vh polarization
Zdr	[nx, ny, nz]	-	Differential reflectivity
LDRh	[nx, ny, nz]	-	Linear Depolarization Ratio
RWV	[nx, ny, nz]	m/s	Reflectivity Weighted Velocity
DV	[nx, ny, nz]	m/s	Doppler Velocity, positive downward
DV90	[nx, ny, nz]	m/s	Vertical mean Doppler velocity (el=90º)
SW	[nx, ny, nz]	m/s	Spectrum width
Kdp	[nx, ny, nz]	deg/km	Specific Differential Phase
Adp	[nx, ny, nz]	dB/km	Differential Attenuation
Ah	[nx, ny, nz]	dB/km	Specific Horizontal Attenuation
Av	[nx, ny, nz]	dB/km	Specific Vertical Attenuation
Zmin	[nx, ny, nz]	dBZ	Minimum detectable reflectivity

The ***CRSIM* output** consists of **6 netcdf files*** (for each hydrometeor type separately, five in total, and the main output file with the total hydrometer content), each with the same structure

* depends on the number of hydrometeor types

Note:

LUTs contain info for computation of other polarimetric variables than reported in the output; if needed, those variables can be easily added

CRSIM OUTPUT (2)

VARIABLE	DIMENSION	UNITS	DESCRIPTION
elev	[nx, ny, nz]	degrees	**Elevation angle from horizontal**
azim	[nx, ny, nz]	degrees	**Azimuth angle (EAST=0º, NORTH=90º)**
range	[nx, ny, nz]	m	**Radar range**
height	[nx, ny, nz]	m	**Height**
temp	[nx, ny, nz]	degrees C	**Temperature**
wcont	[nx, ny, nz]	kg/m^3	**Water content**
rho_d	[nx, ny, nz]	kg/m^3	**Dry air density**
u	[nx, ny, nz]	m/s	**U component of horizontal wind**
v	[nx, ny, nz]	m/s	**V component of horizontal wind**
w	[nx, ny, nz]	m/s	**Vertical air velocity**
x_scene	[nx]	m	**Scene extent in E-W direction**
y_scene	[nx]	m	**Scene extent in E-W direction**
Av	[nx, ny, nz]	dB/km	**Specific Vertical Attenuation**
elev	[nx, ny, nz]	degrees	**Elevation angle from horizontal**
height	[nx, ny, nz]	m	**Height**
temp	[nx, ny, nz]	degrees C	**Temperature**
w	[nx, ny, nz]	m/s	**Vertical air velocity**
wcont	[nx, ny, nz]	kg/m^3	**Water content**

CRSIM OUTPUT (optional)

DIMENSION NAMES	Description
nx	Number of grid boxes along the horizontal E-W axis
ny	Number of grid boxes along the horizontal N-S axis
nz	Number of grid boxes along the vertical axis at WRF resolution
n_layers	Number of cloud layers for ARSCL =10

VARIABLE	DIMENSION	UNITS	DESCRIPTION
mpl_wavel	[nx, ny, nz]	m^-1 st^-1	**MPL wavelength**
mpl_back_obs	[nx, ny, nz]	m^-1 st^-1	**MPL observed backscatter**
mpl_back_true	[nx, ny, nz]	m^-1 st^-1	**MPL true backscatter**
mpl_ext	[nx, ny, nz]	m^-1 st^-1	**MPL extension coefficient**
mpl_rayleigh_back	[nx, ny, nz]	m^-1 st^-1	**Molecular backscatter**
mpl_lidar_ratio	[nx, ny, nz]	-	**MPL lidar ratio**
aero_back_obs	[nx, ny, nz]	m^-1 st^-1	**MPL aerosol observed backscatter**
aero_back_true	[nx, ny, nz]	m^-1 st^-1	**MPL aerosol true backscatter**
aero_ext	[nx, ny, nz]	m^-1 st^-1	**MPL aerosol extension coefficient**
aero_lidar_ratio	[nx, ny, nz]	m^-1 st^-1	**MPL aerosol lidar ratio**
ceilo_back_obs	[nx, ny, nz]	m^-1 st^-1	**Ceilometer observed backscatter**
ceilo_back_true	[nx, ny, nz]	m^-1 st^-1	**Ceilometer true backscatter**
ceilo_ext	[nx, ny, nz]	m^-1 st^-1	**Ceilometer extension coefficient**
ceilo_first_cloud_base	[nx, ny]	m	**Ceilometer first cloud base height**
arscl_cloud_mask	[nx, ny, nz]	-	**Cloud mask from radar, mpl, ceilo_first_cloud_base**
arscl_cloud_source_flag	[nx, ny, nz]	-	**Instrument source flag for cloud detection**
arscl_cloud_layer_top_height	[nx, ny, n_layers]	m	**Top heights of cloud layers for up to 10**
arscl_cloud_layer_top_height	[nx, ny, n_layers]	m	**Top heights of cloud layers for up to 10**

WRF Input scene

WRF V3.4.1 simulation with Morrison 2-moment microphysical scheme for the MC3E May 20 case

Grid : 600 x 510 km in horizontal; 1 km resolution and 50 eta levels

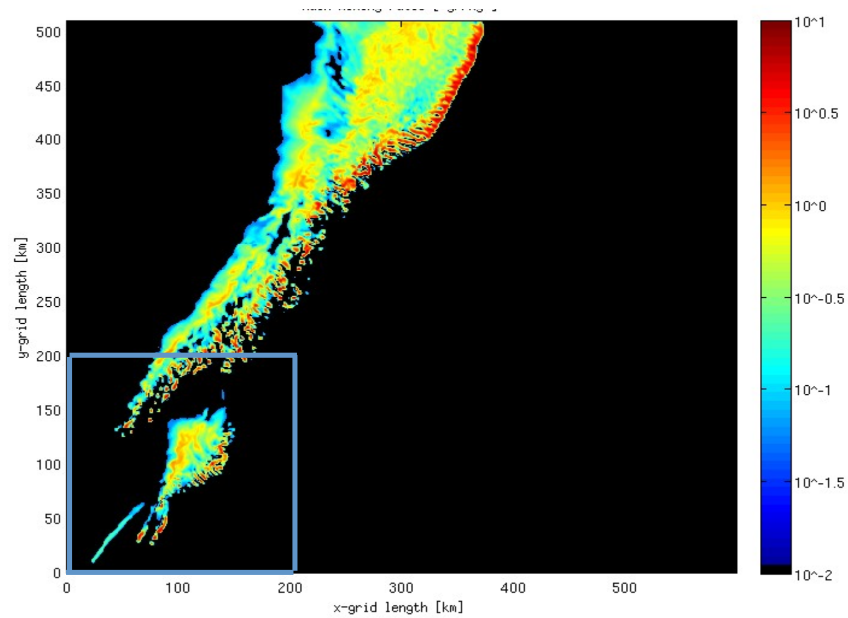
(About 40 eta levels in vertical up to 15 km)

Vertical resolution : variable

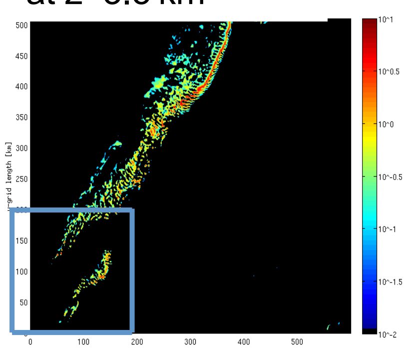
~ 60 m - ~250 m in the lowest 3 km (~2 grid points)

~ 440m - ~450 m from 3 km to 15 km (~28 grid points)

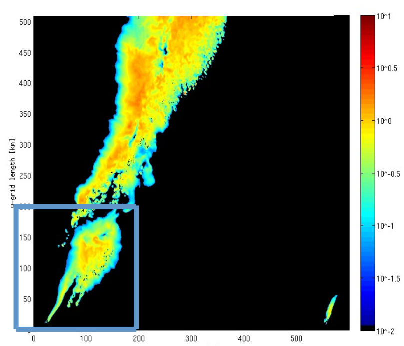
rain mixing ratio at z=3.5 km



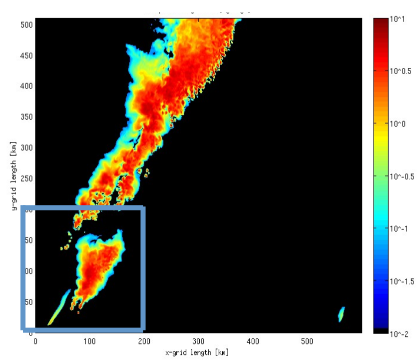
cloud mixing ratio at z=3.5 km



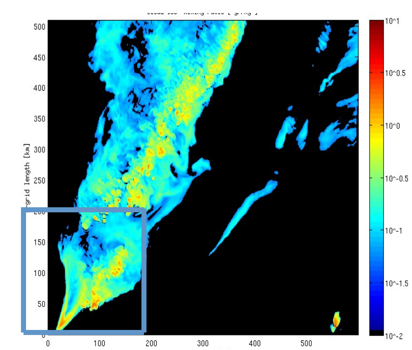
snow mixing ratio at z=7 km



graupel mixing ratio at z=7 km



ice mixing ratio at z=10 km



Morrison 2-moment microphysical scheme [MP_PHYSICS=10]

-**<u>5 hydrometeor classe</u>**s : **cloud, rain, ice, snow, graupel**

- particles assumed spherical, with fixed with ***fixed size-independent densities per hydrometeor class*** (cloud and rain 0.997 gr/cm^3,ice 0.5 gr/cm^3, snow 0.1 gr/cm^3, graupel 0.4 gr/cm^3)

- **The output prognostic moments** are

mixing ratio	**Qc, Qr, Qi, Qs, Qg**	**in kg/kg**
Total number concentration	**Nr, Ni,Ns,Ng**	**in 1/kg**

(~*for cloud, the total number concentration, Nc is fixed*~)

- **The Gamma distribution with a fixed shape factor** is assumed **for each hydrometeor size distribution**

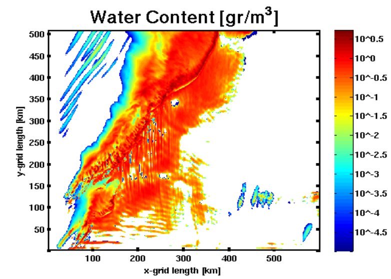
$N(D)=N_0 D^{\mu} e^{-\lambda D}$ *gamma function*

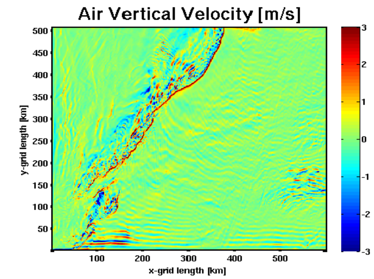
N0 intercept
μ shape ***fixed***
λ slope

-for rain, ice, snow, graupel μ=0, so in fact we have exponential distribution
-for cloud, μ is determined in function of droplet number concentration (Nc) and density of dry air, according to Martin et al., 1994

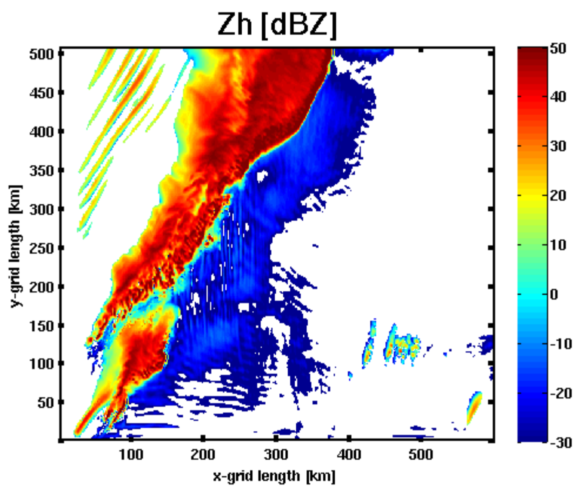
-**The fall velocity size relationships** for hydrometeor classes are specified

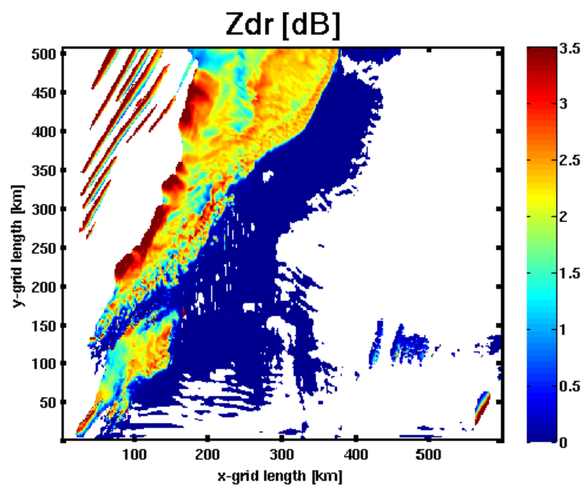
Cross sections of the *CRSIM* output at fixed height

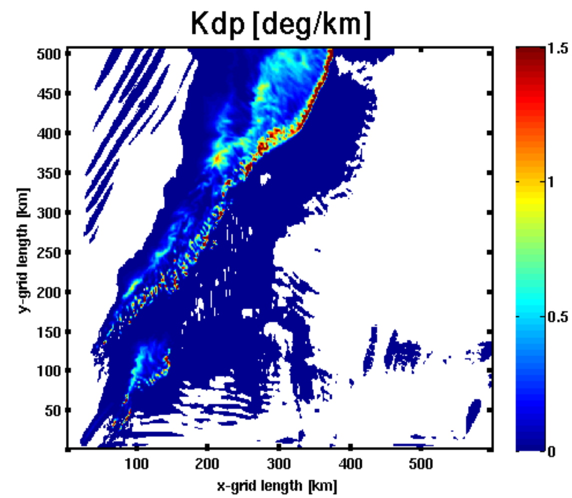


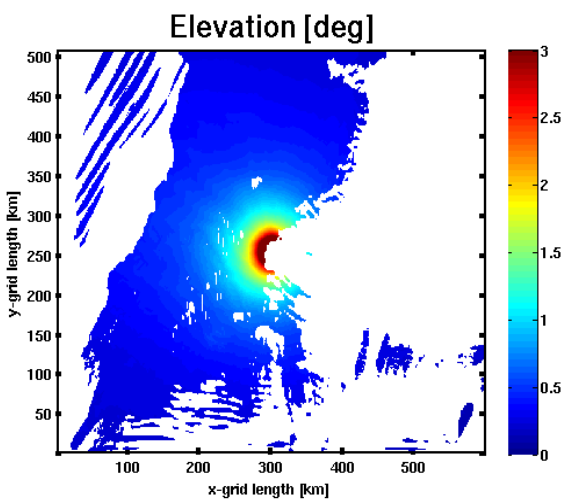


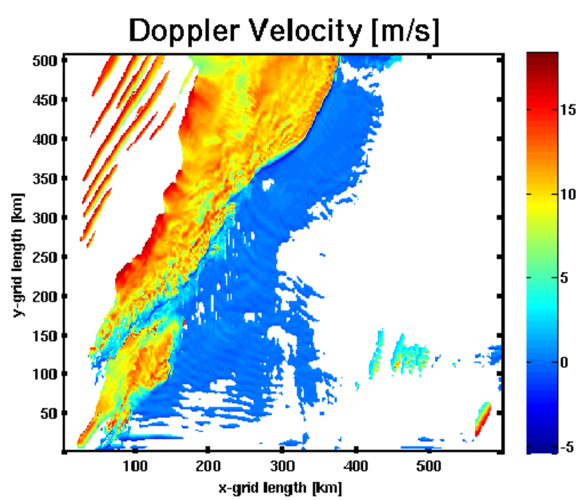
At 1 km height

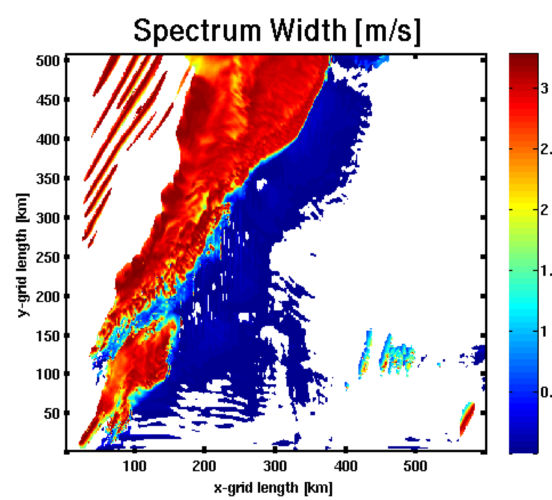






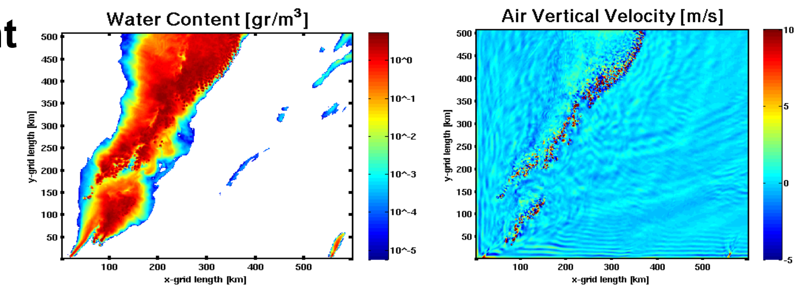


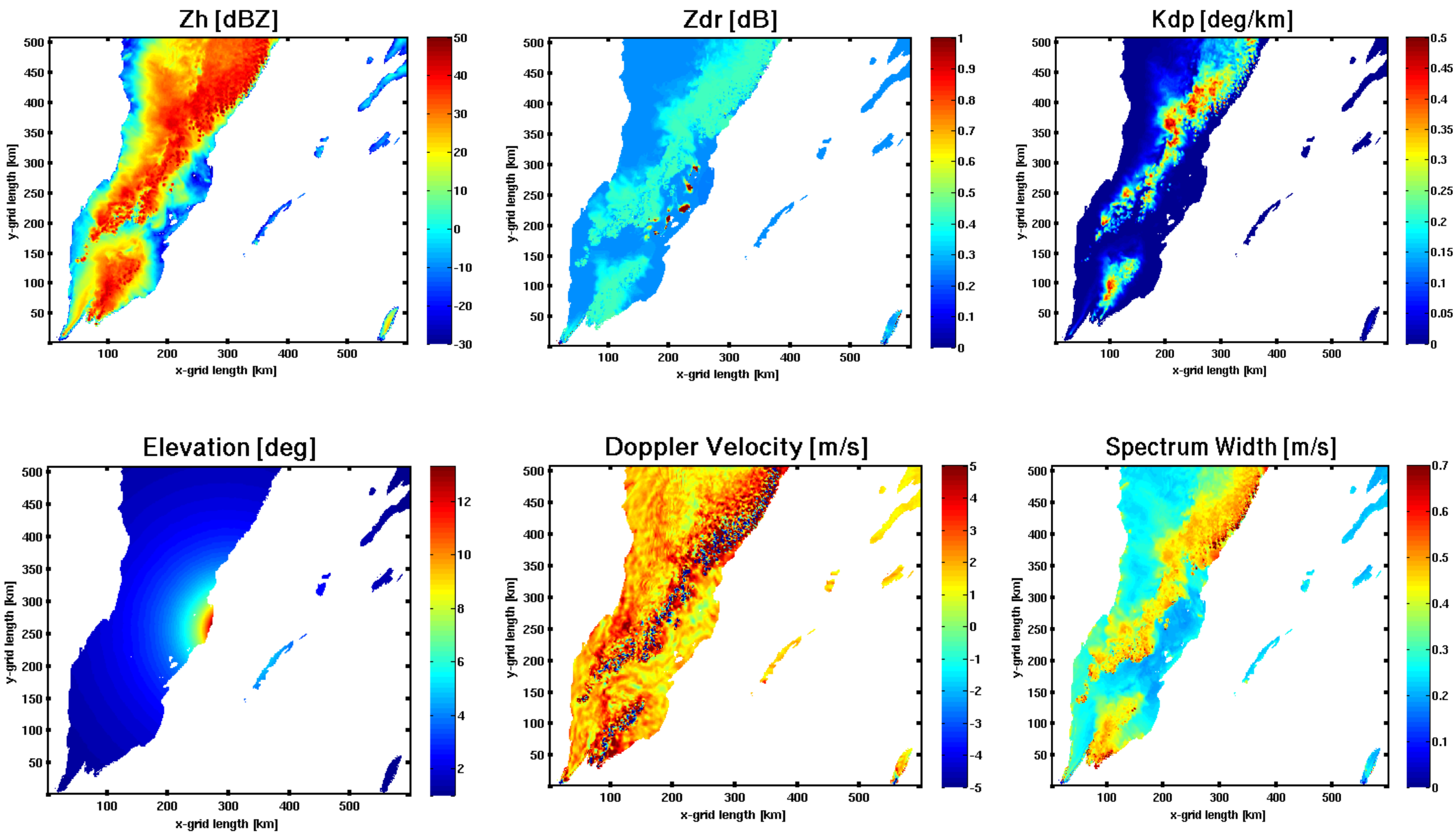


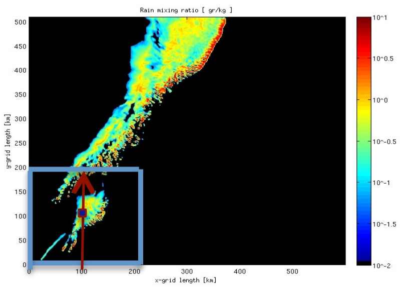


Cross sections of the *CRSIM* output at fixed height

At 7 km height

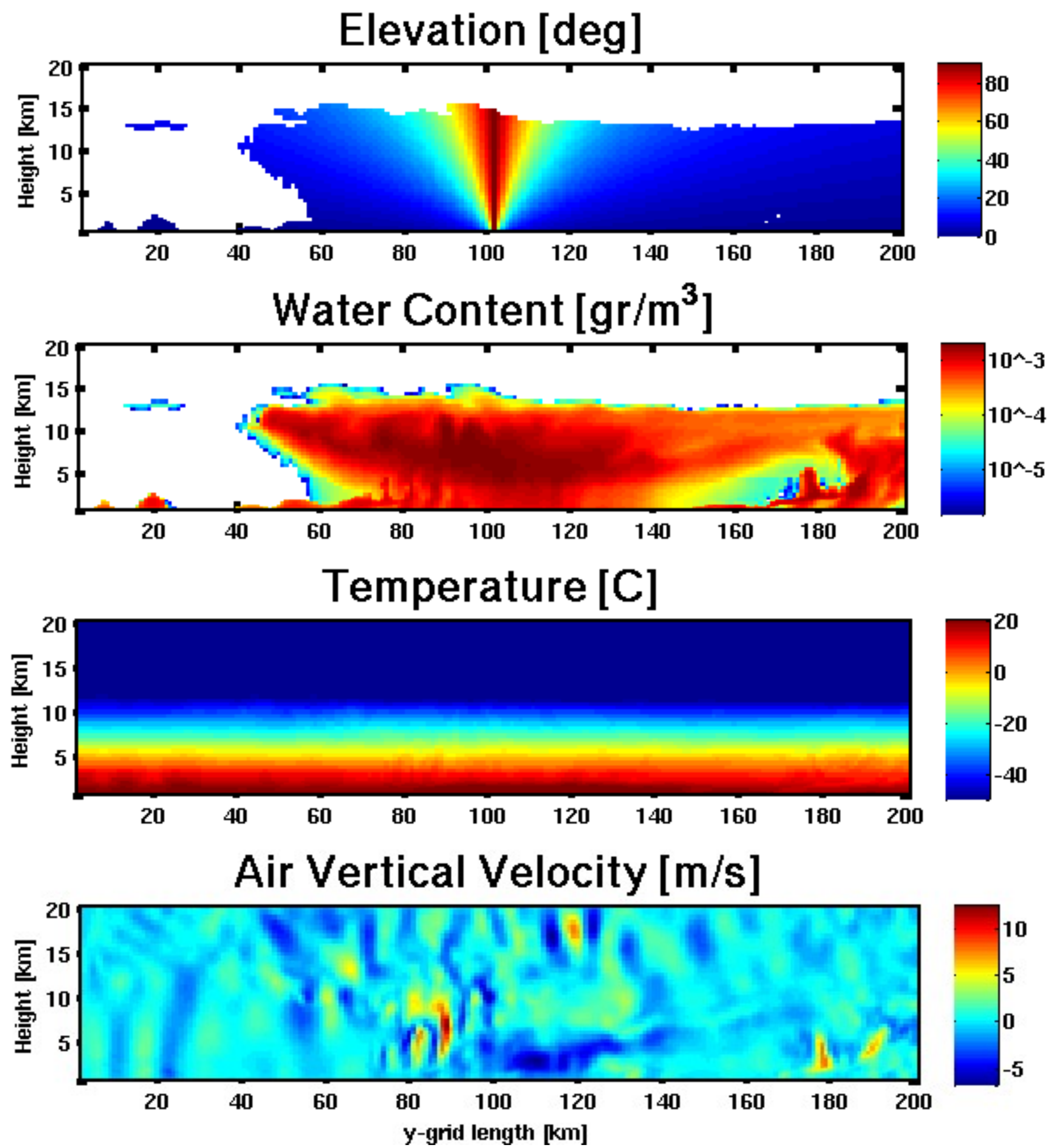


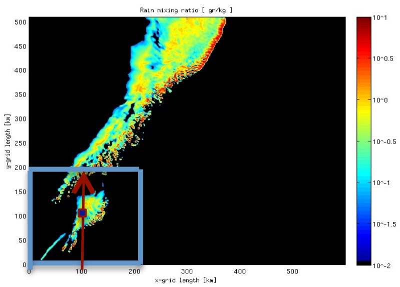




Radar is positioned at center of the small domain, 3 GHz

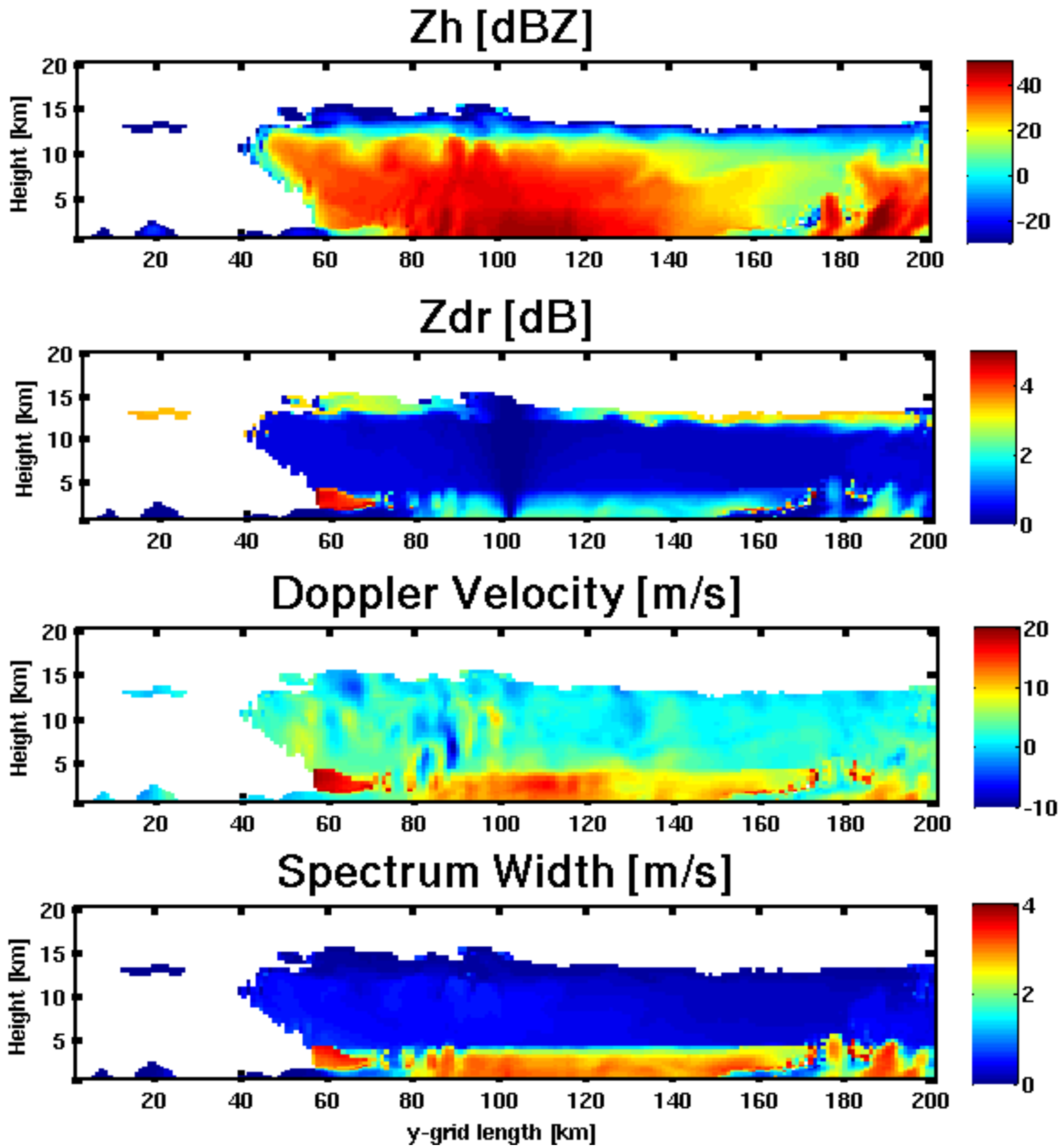
WRF INPUT



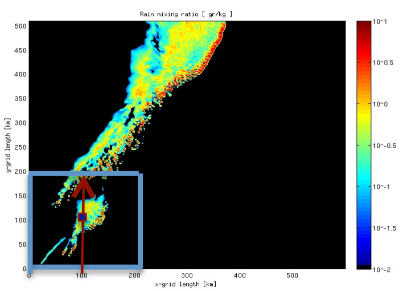


Radar is positioned at center of the small domain, 3 GHz

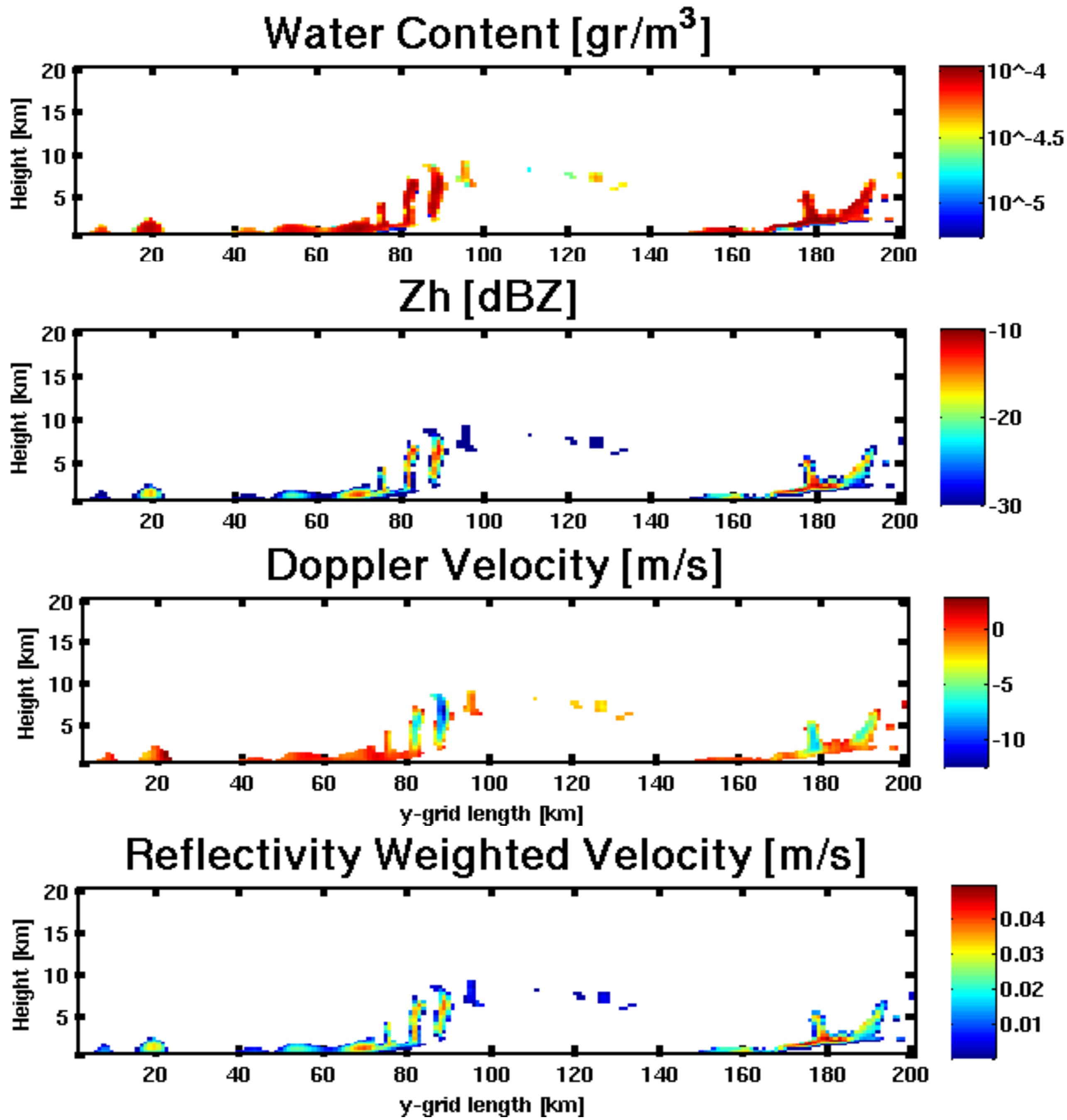
CRSIM OUTPUT



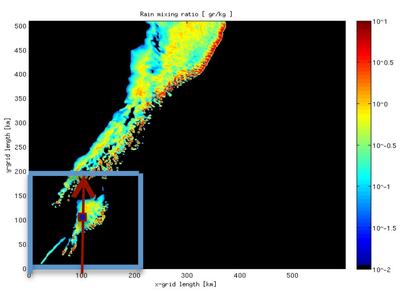
CLOUD ONLY



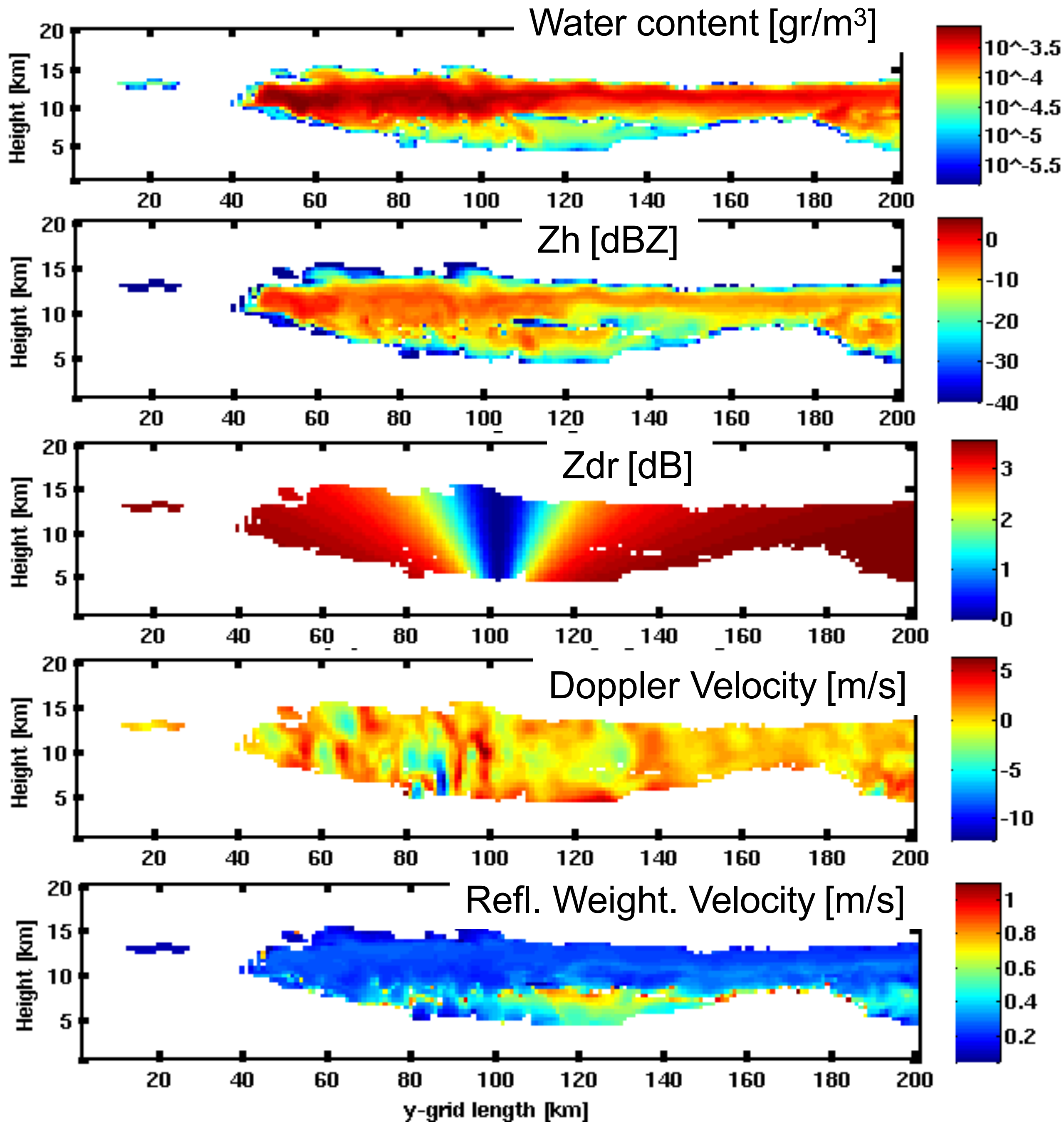
Radar is positioned at center of the small domain, 3 GHz



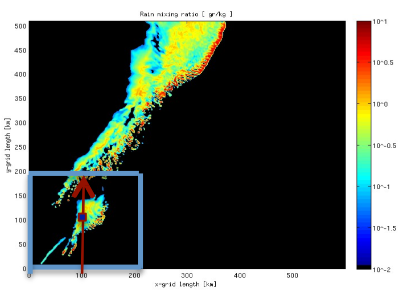
ICE ONLY



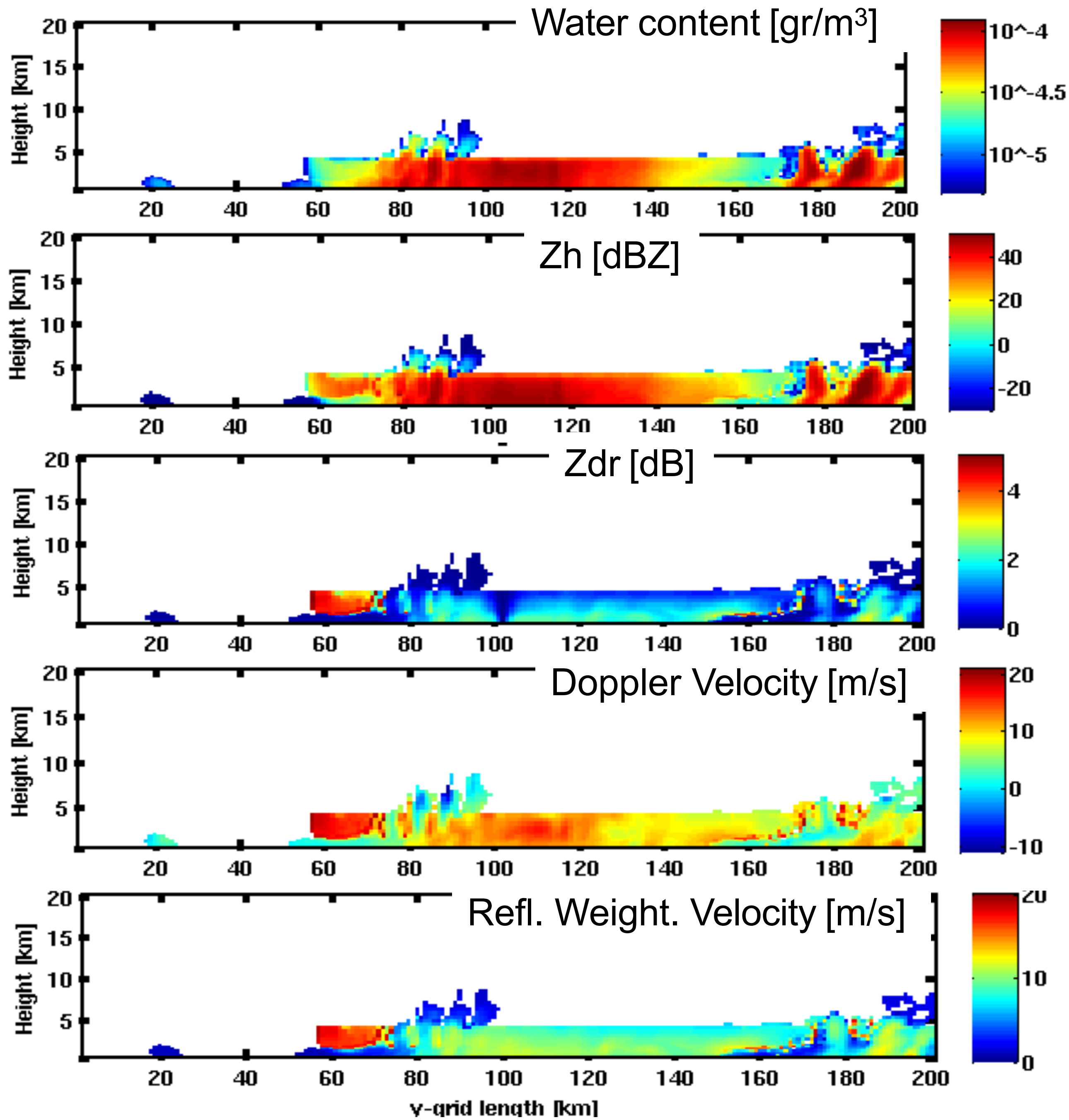
Radar is positioned at center of the small domain, 3 GHz



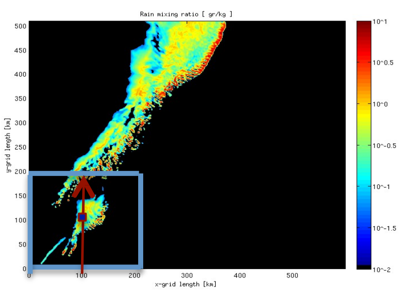
RAIN ONLY



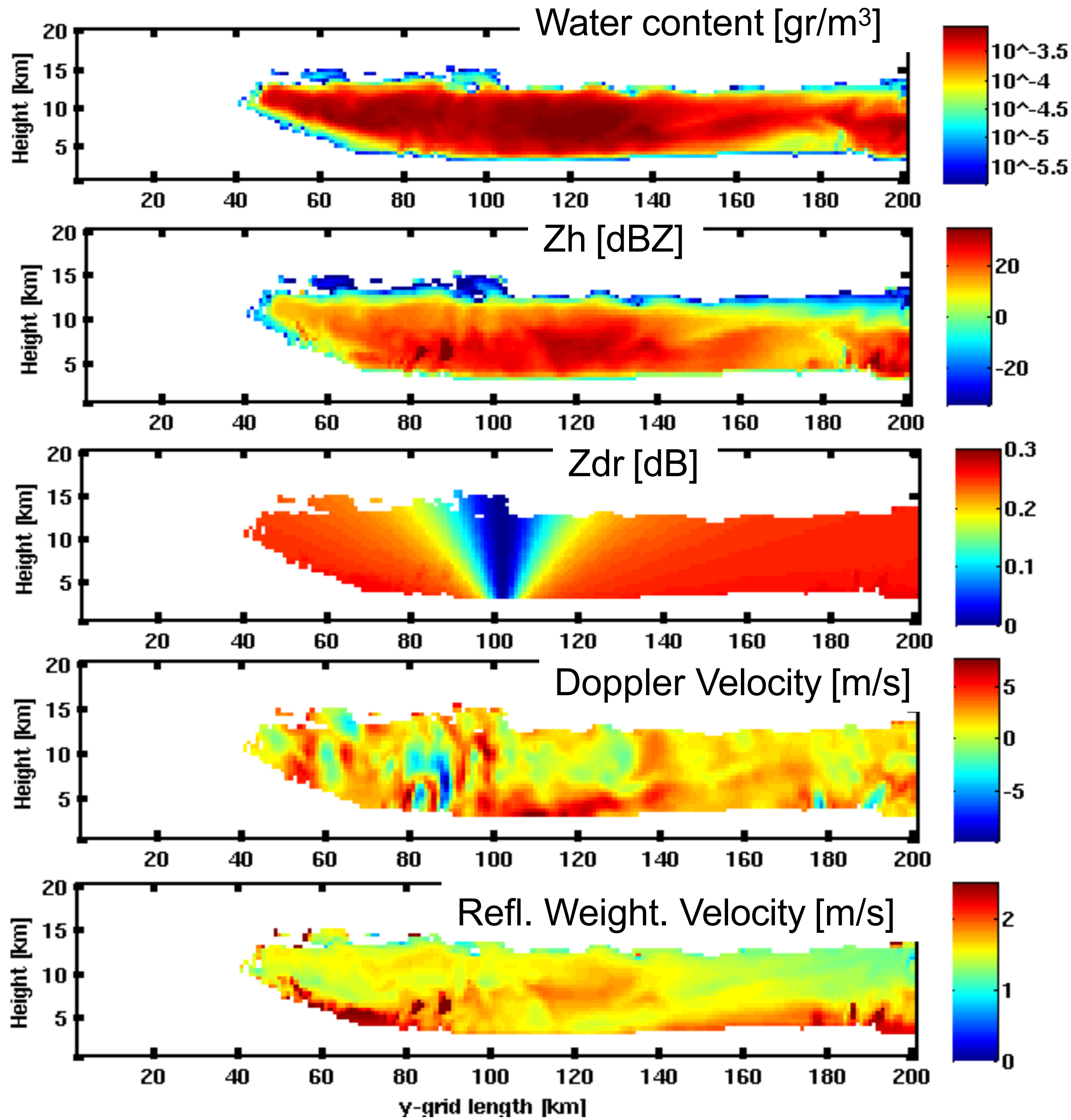
Radar is positioned at center of the small domain, 3 GHz



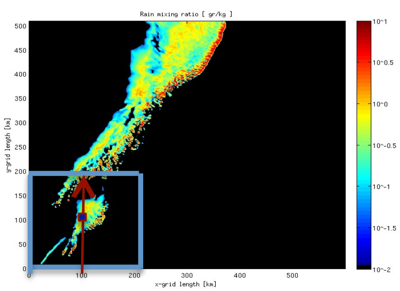
SNOW ONLY



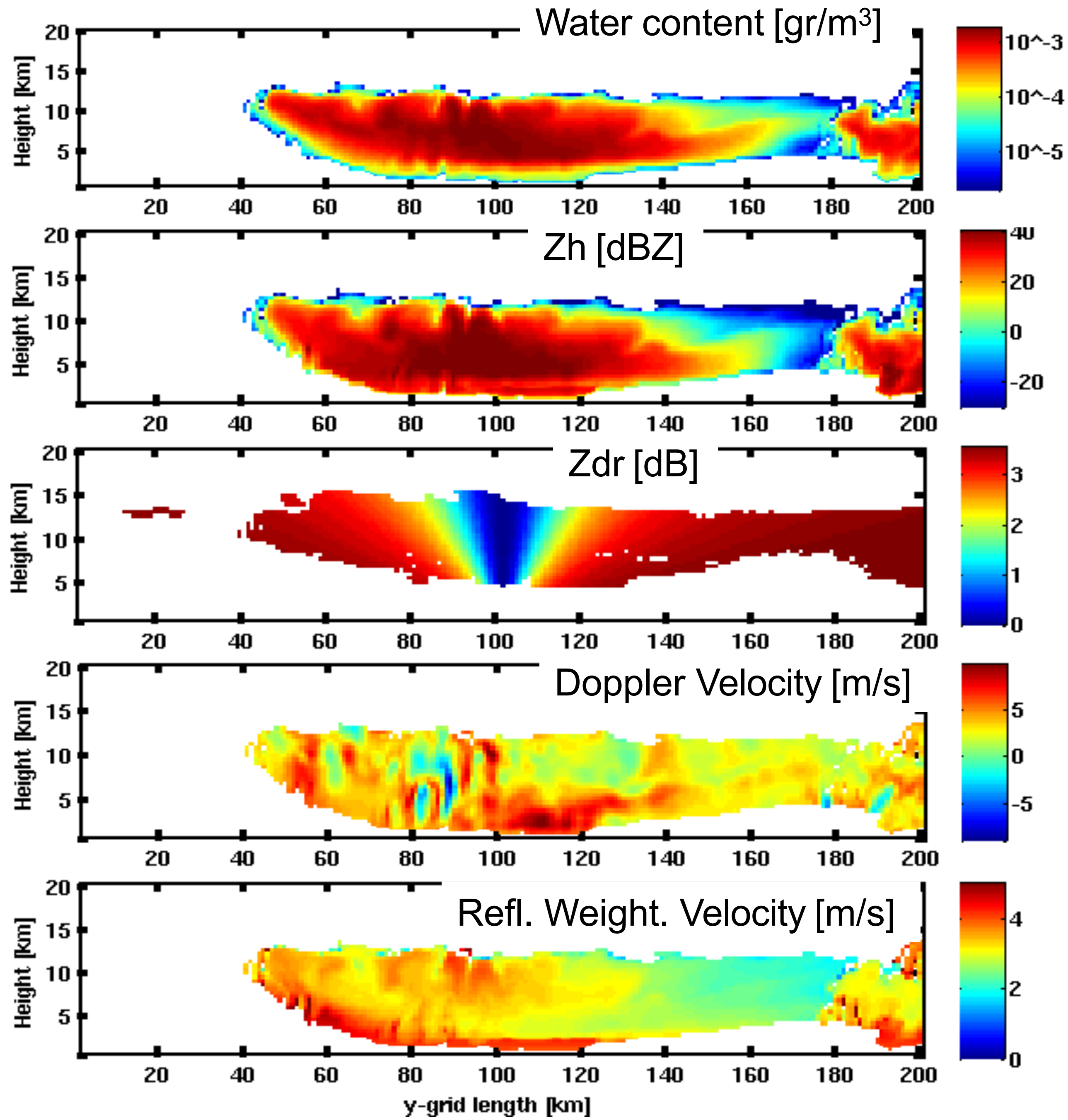
Radar is positioned at center of the small domain, 3 GHz



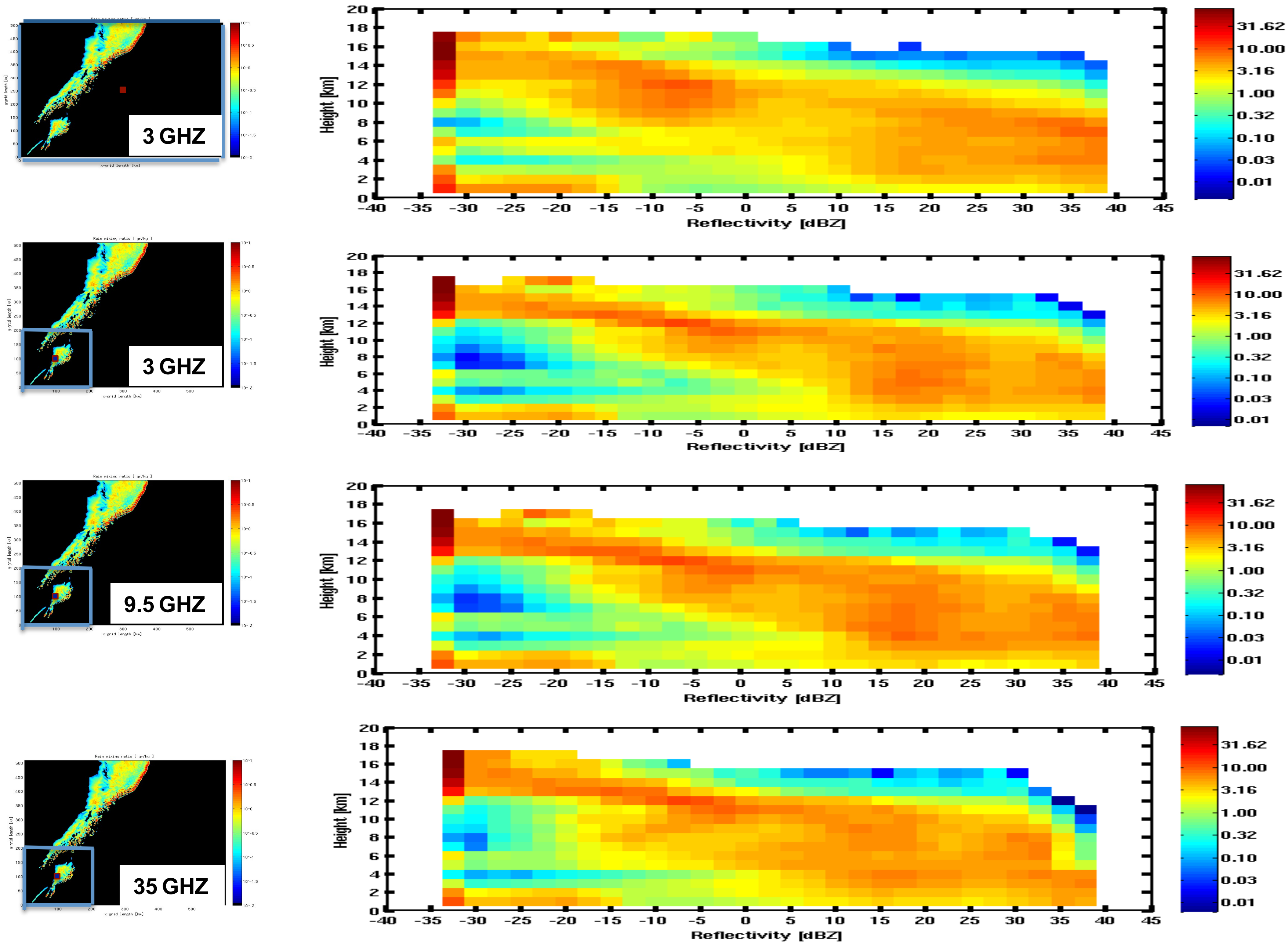
GRAUPEL ONLY



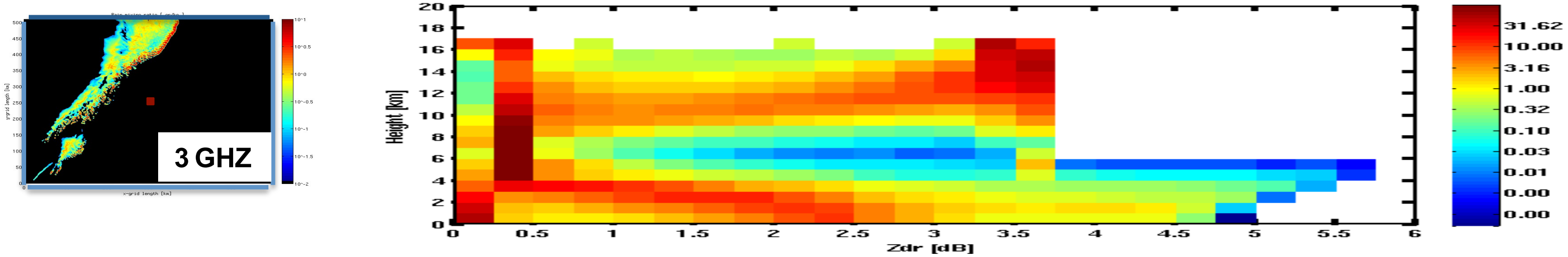
Radar is positioned at center of the small domain, 3 GHz

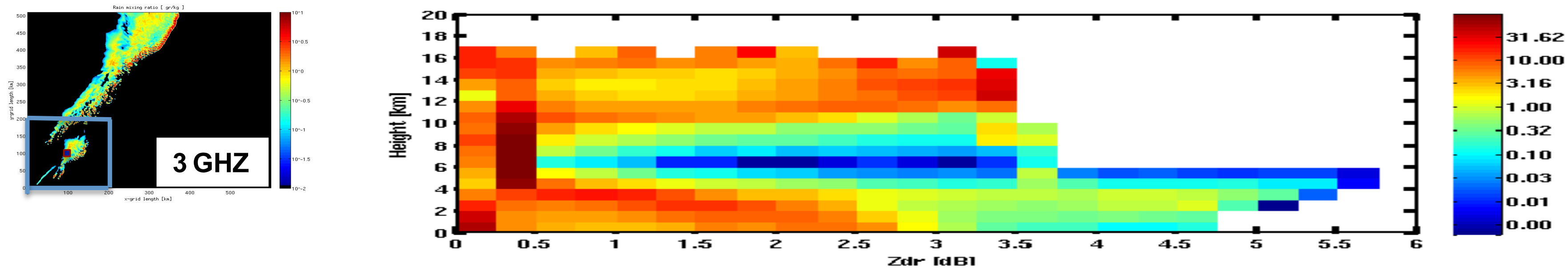


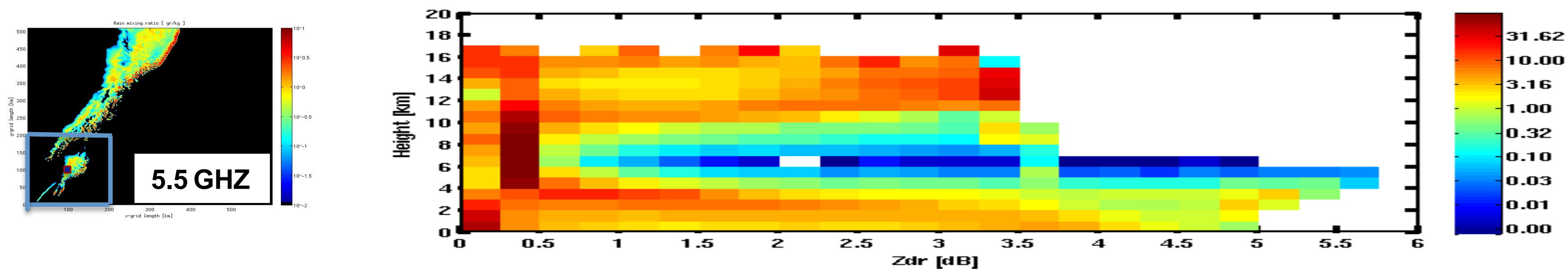
CFADs OF REFLECTIVITY

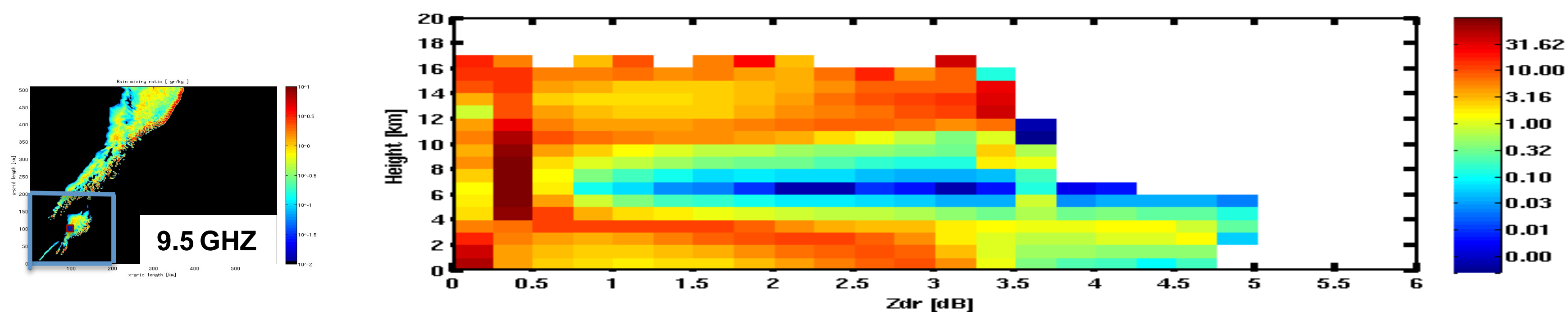


CFADs OF ZDR

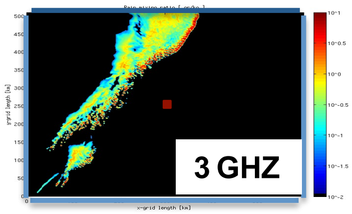

3 GHZ
Height [km]
Zdr [dB]
31.62
10.00
3.16
1.00
0.32
0.10
0.03
0.01
0.00
0.00

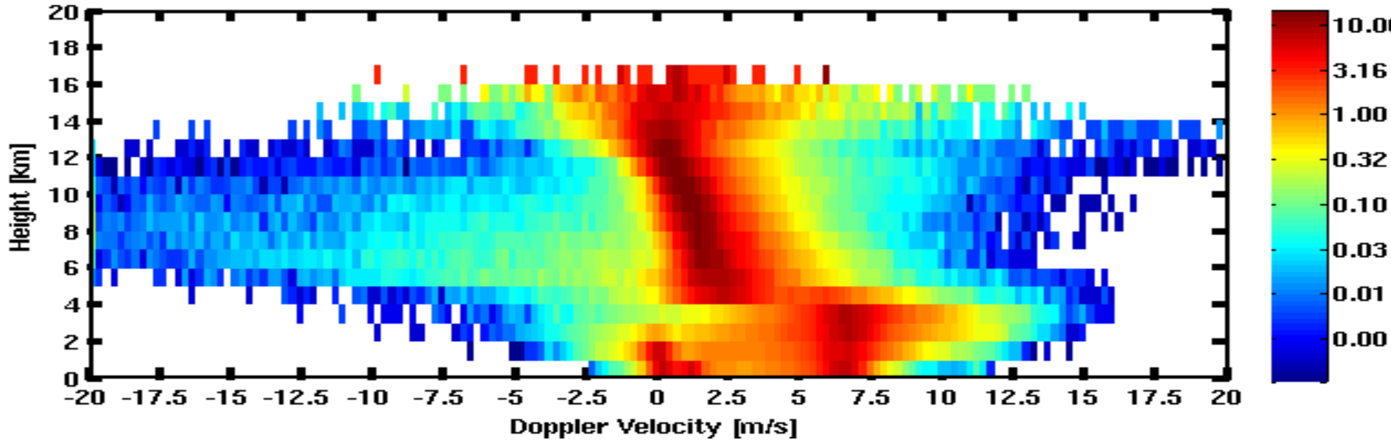

3 GHZ
Height [km]
Zdr [dB]
31.62
10.00
3.16
1.00
0.32
0.10
0.03
0.01
0.00

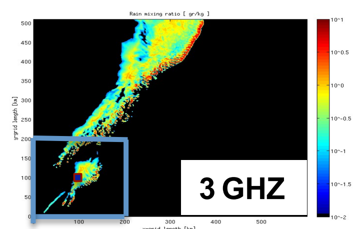

5.5 GHZ
Height [km]
Zdr [dB]
31.62
10.00
3.16
1.00
0.32
0.10
0.03
0.01
0.00

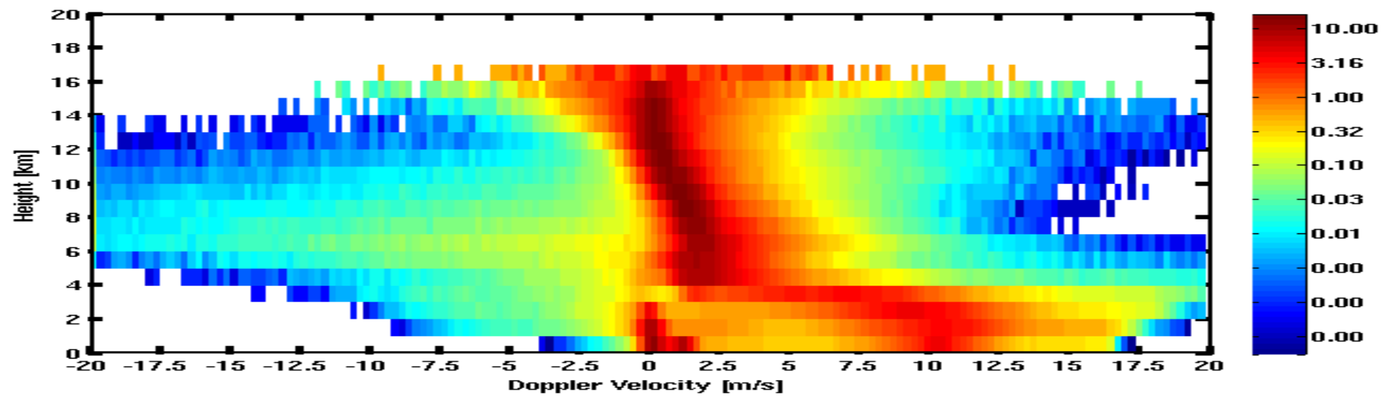

9.5 GHZ
Height [km]
Zdr [dB]
31.62
10.00
3.16
1.00
0.32
0.10
0.03
0.01
0.00

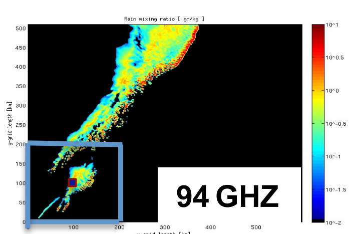
CFADs OF DOPPLER VELOCITY

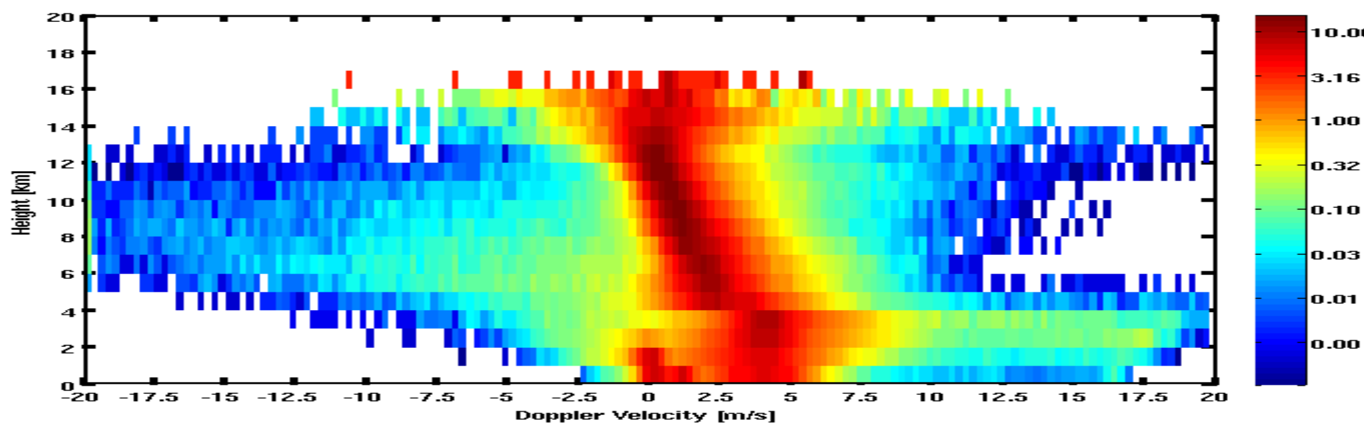




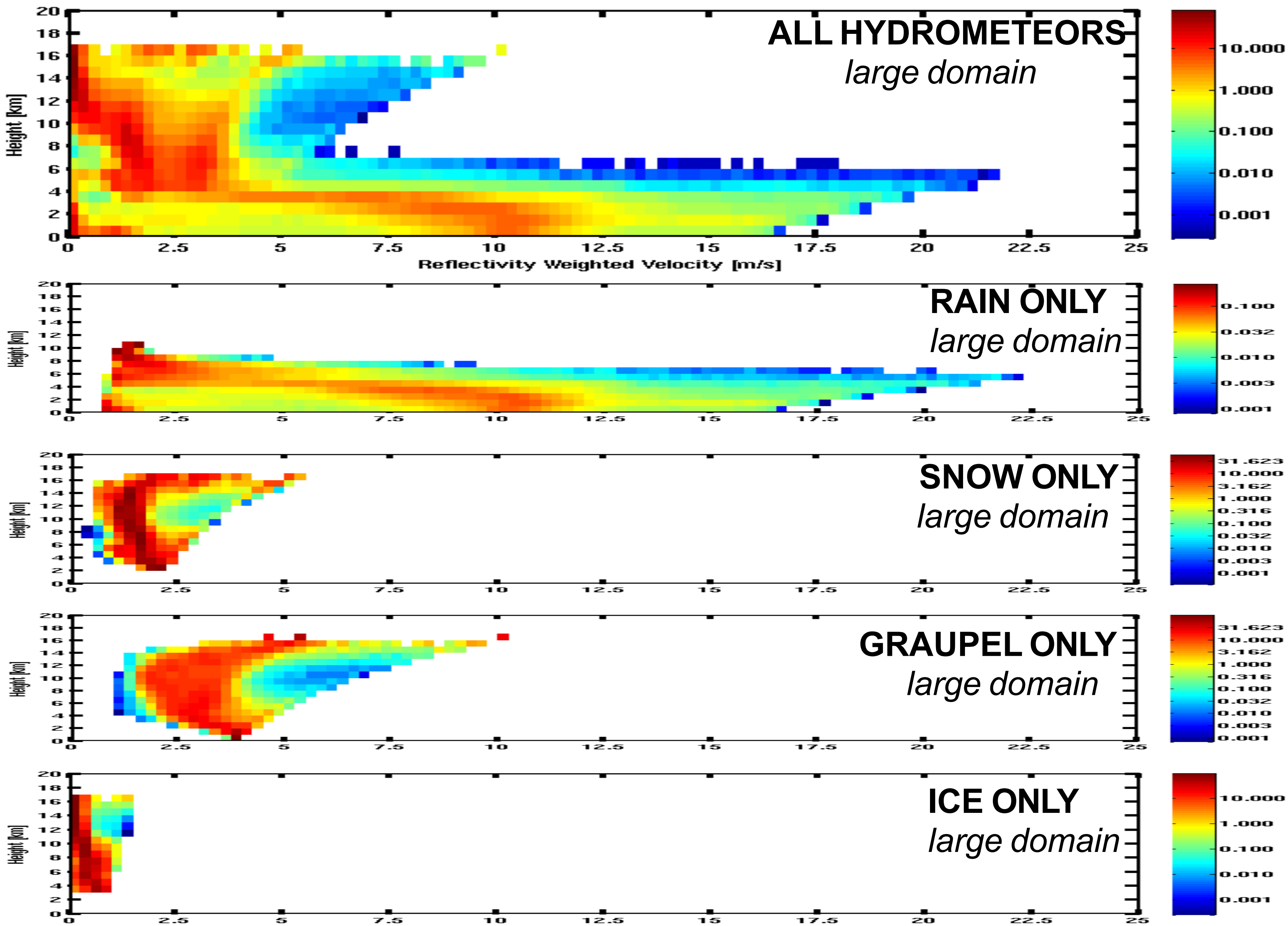




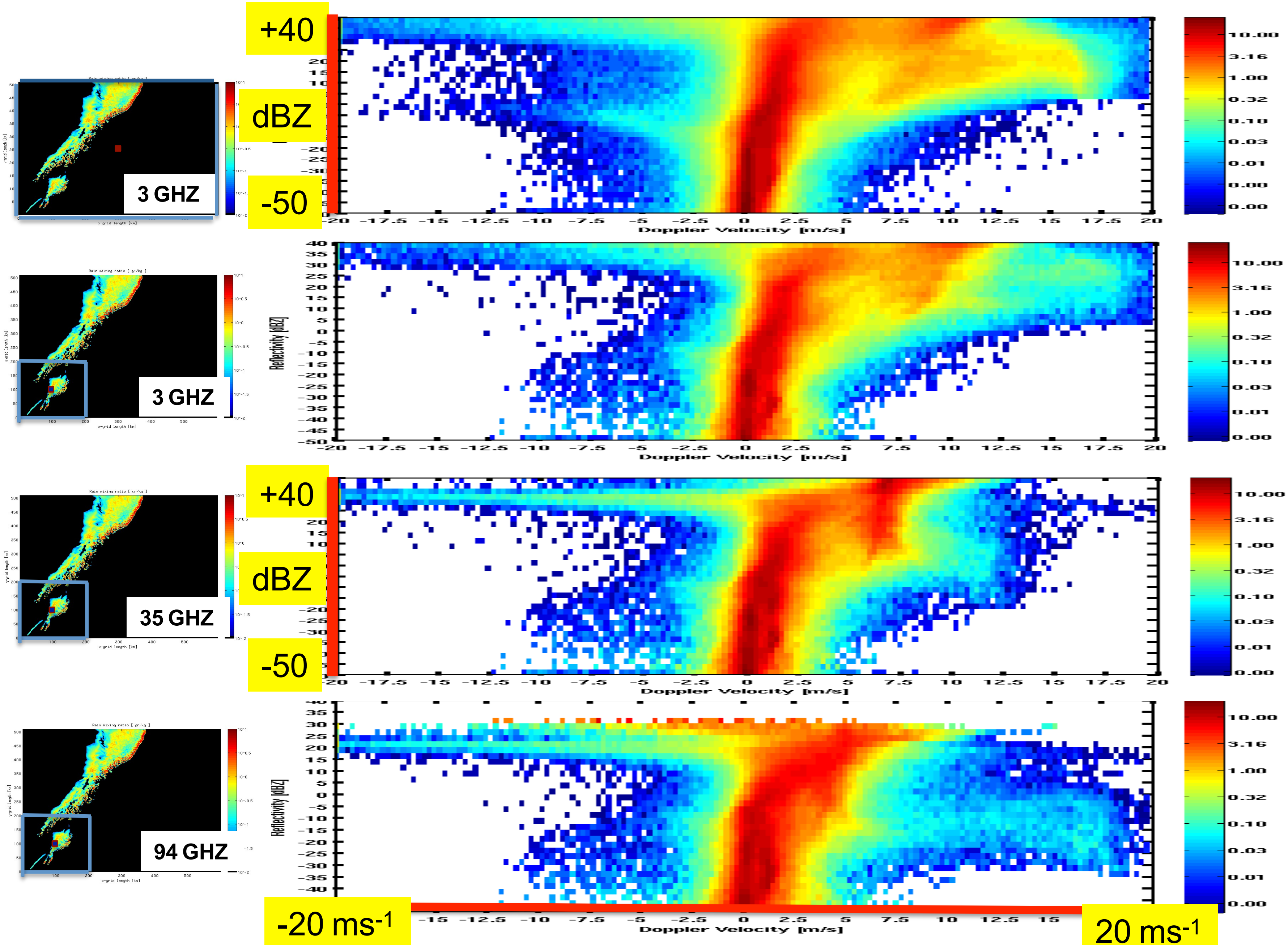




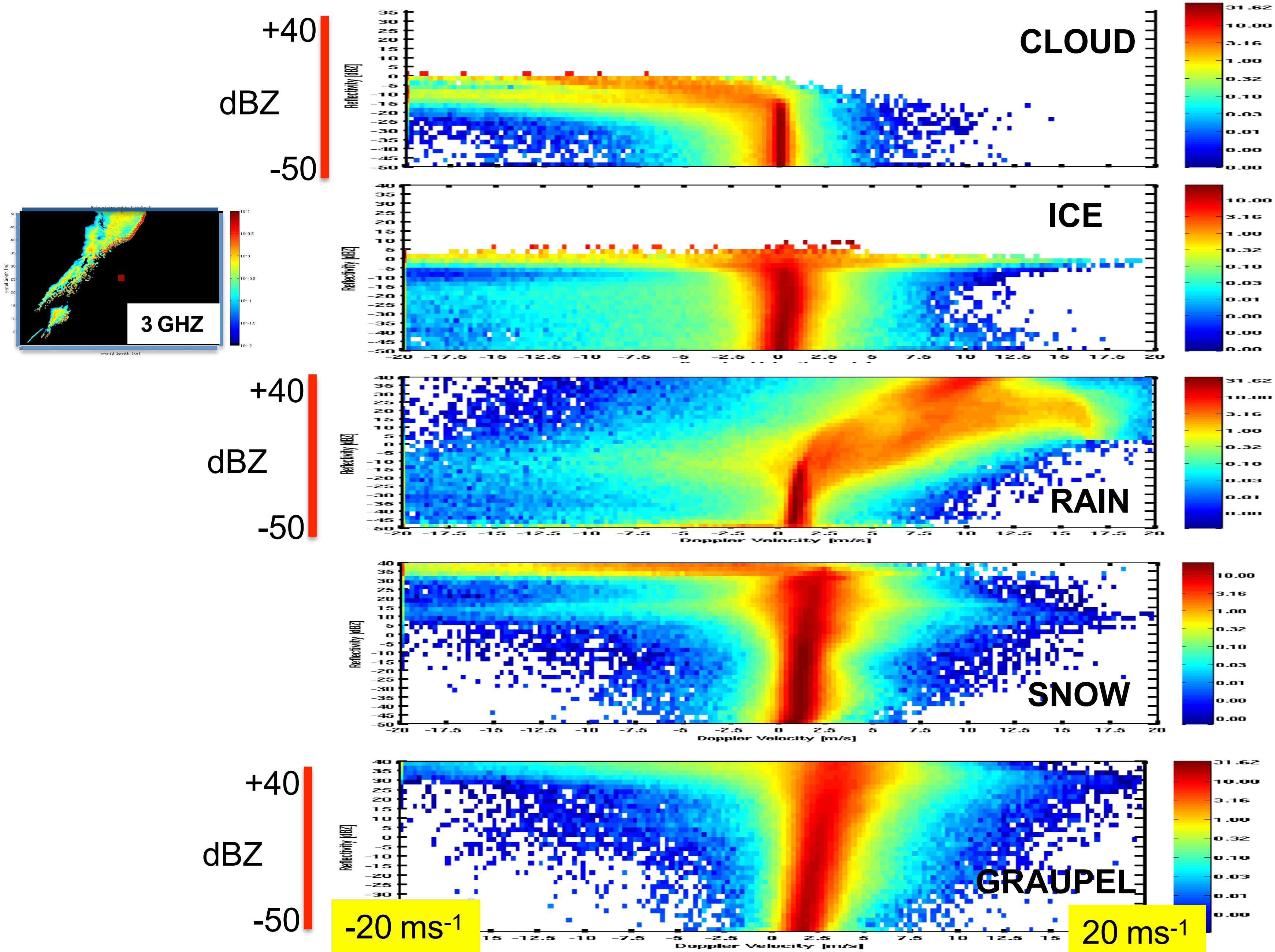
CFADs OF REFLECTIVITY WEIGHTED VELOCITY



CFADs OF DOPPLER VELOCITY WITH REFLECTIVITY



CFADs OF DOPPLER VELOCITY WITH REFLECTIVITY PER HYDROMETEOR CLASS



Summary

The CR-SIM is a simple (no instrument model) radar simulator suitable for Cloud Resolving Models (e.g., WRF, RAMS, ICON, SAM) with bulk and bin microphysics schemes.

Provides scanning radar observables (power and polarimetric variables) and profiling radar observables (mean Doppler velocity and spectrum width)

CR-SIM has a flexible framework that is expandable and can accommodate additional microphysical schemes and scattering LUT's.

The CR-SIM is written in Fortran 90 and an user manual is under development.