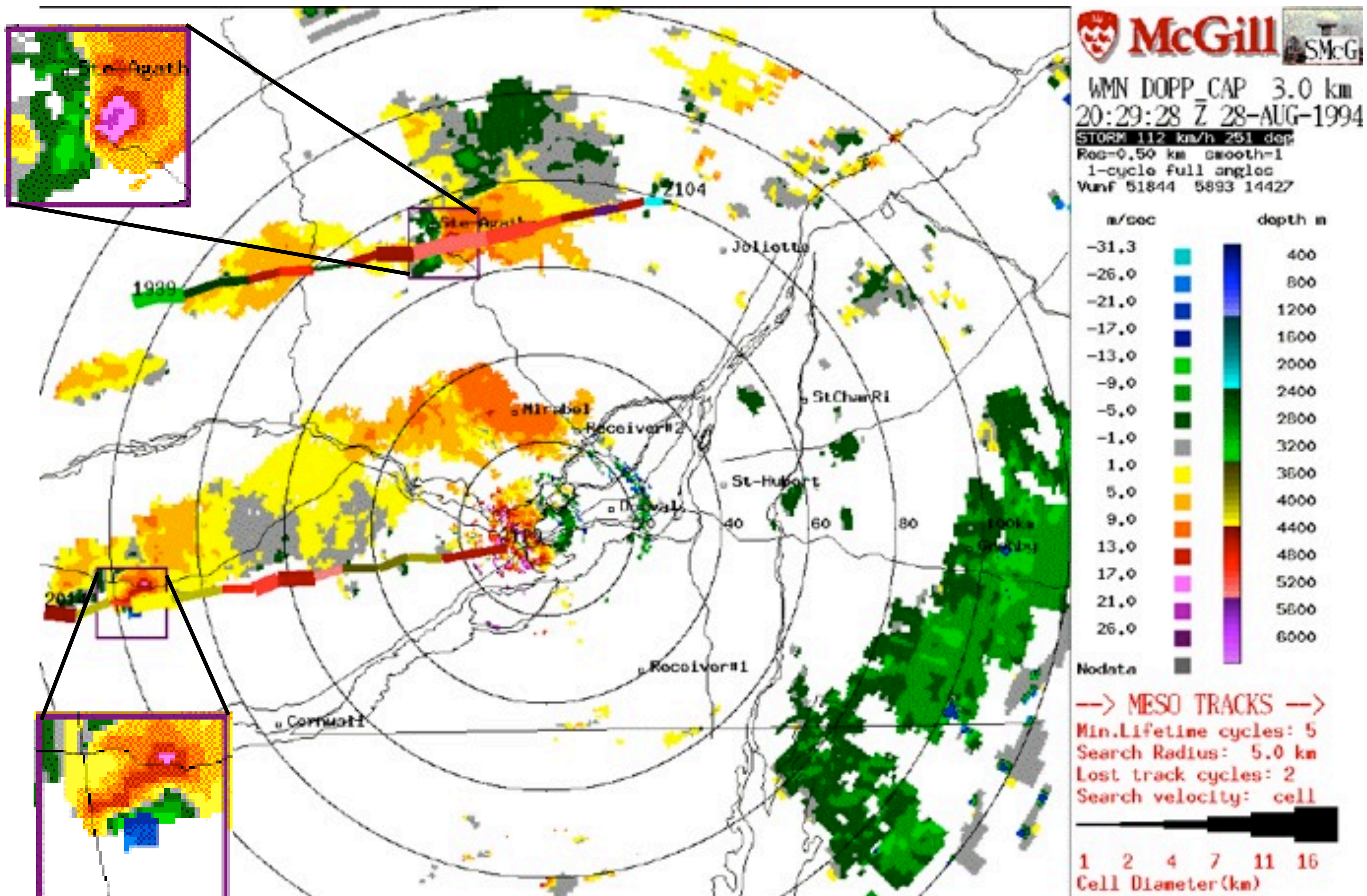
Data and data assimilation at MRO

Present use of radar information is qualitative

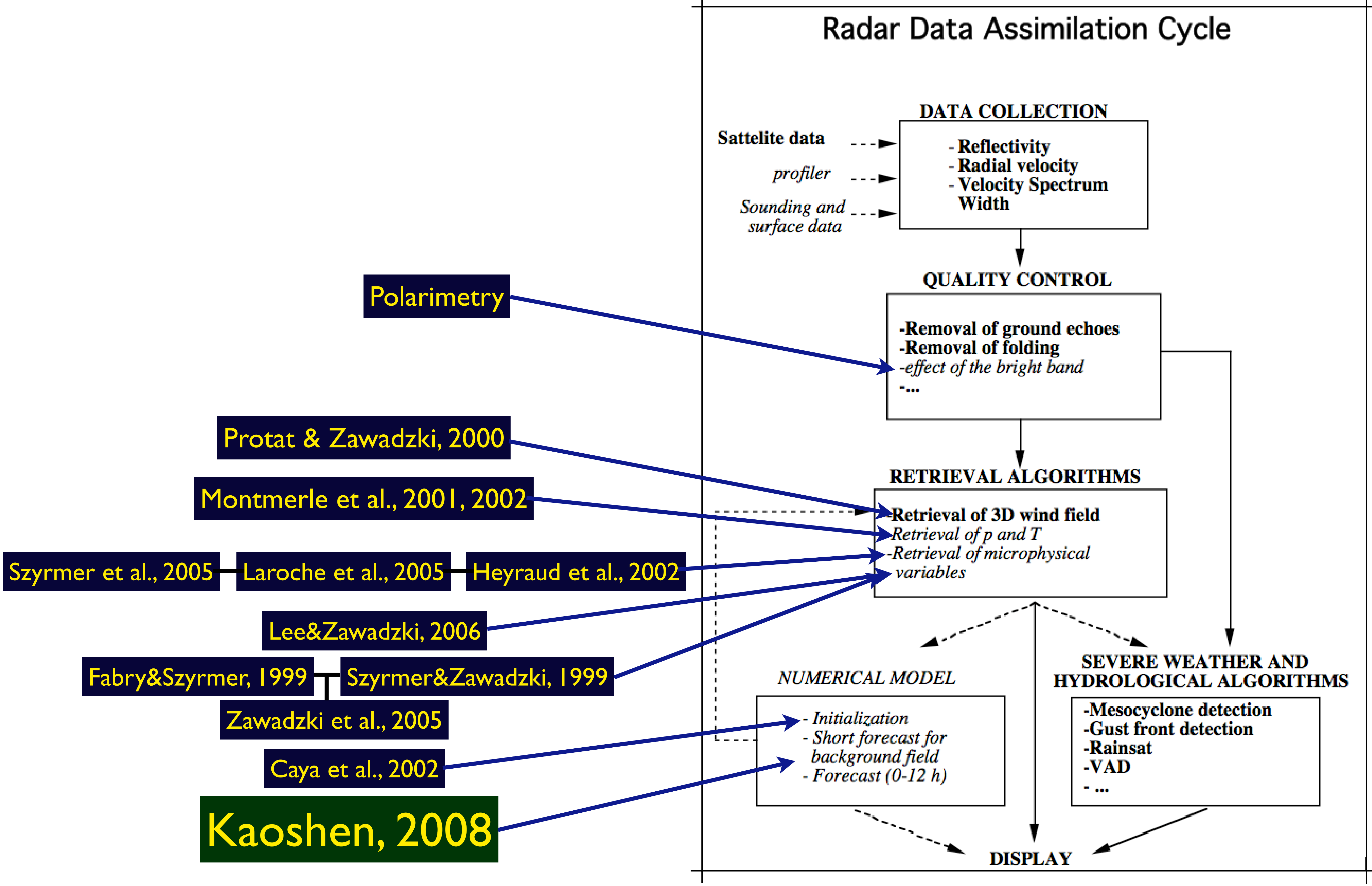
Example: mesocyclone detection is based on the measurement of a single velocity component and consequently inherently ambiguous



Acknowledgements: an alternative approach to radar data interpretation was suggested long ago

The idea as outlined in 1994:

(Laroche PhD Thesis)



Outline

Extensive effort in microphysics description
compatible with radar observations

Development of retrieval and radar data assimilation methods based on model as week constraint

Study of model errors

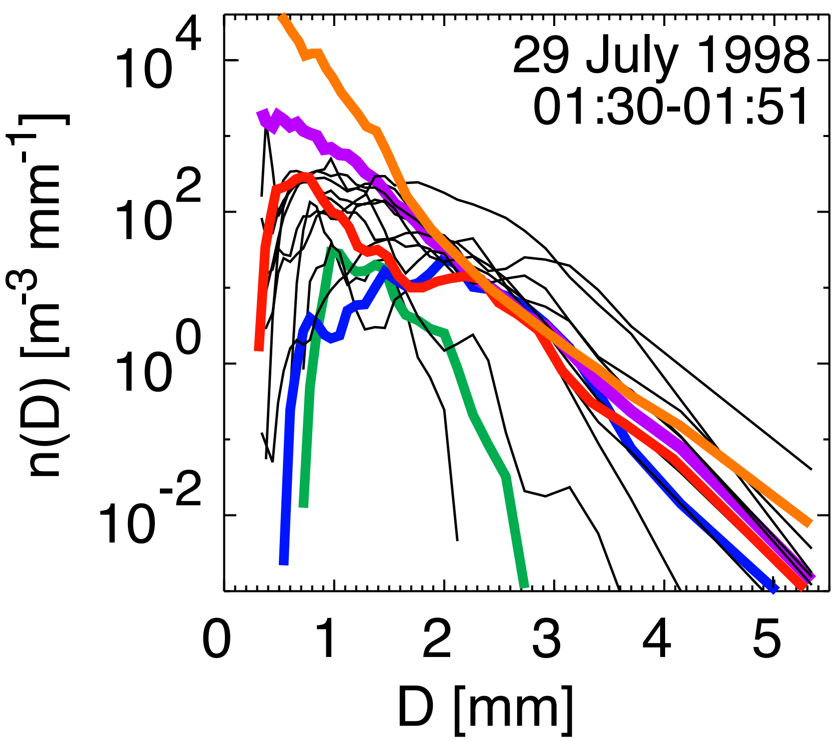
Study of structure of errors of radar measurements

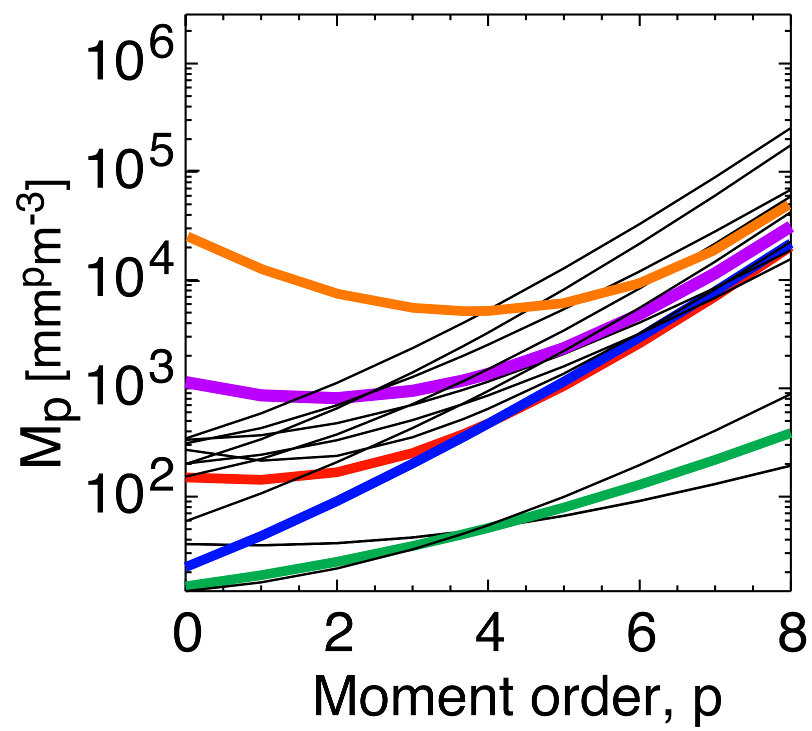
Expanding our operational radar capability

Nowcasting techniques as standart of performance

Improving Microphysics

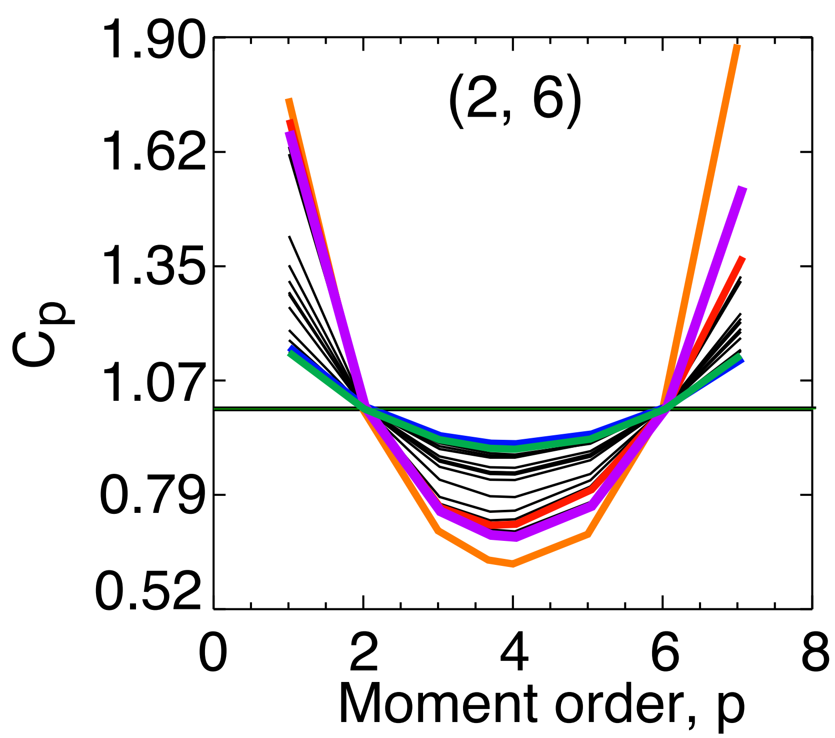
Moment representation of PSDs and of microphysical processes

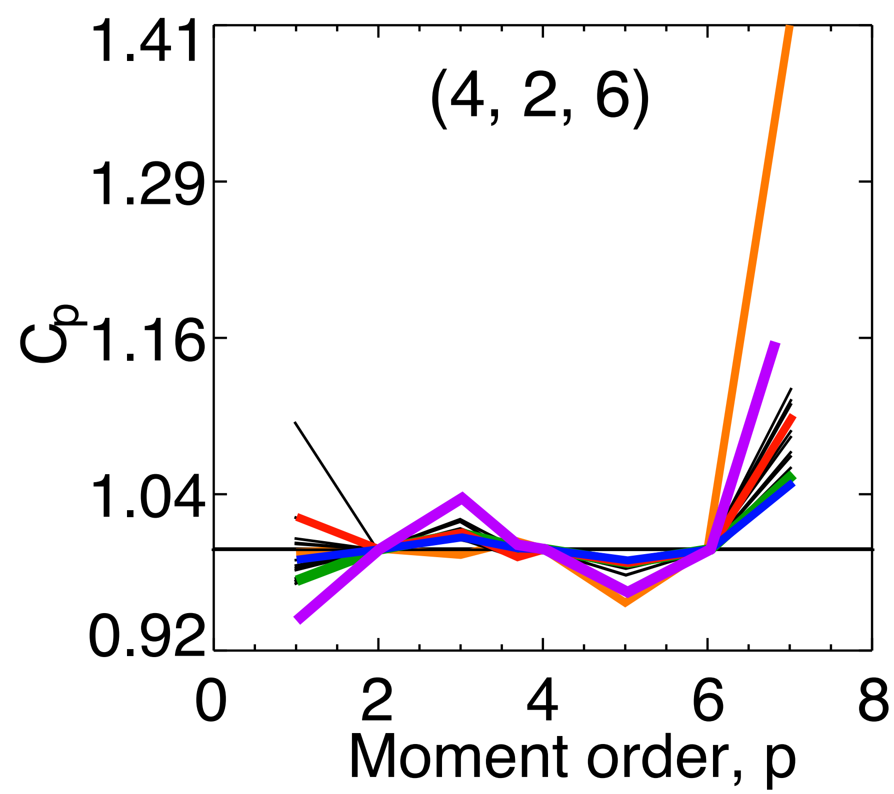




$$M_p = C_p^{\{i,j\}} M_i^{(j-p)/(j-i)} M_j^{(p-i)/(j-i)}$$

$$M_p = C_p^{\{i,j,k\}} M_i^{(1-x_p)(j-p)/(j-i)} M_j^{(1-x_p)(p-i)/(j-i)+x_p(k-p)/(k-j)} M_k^{x_p(p-j)/(k-j)}$$



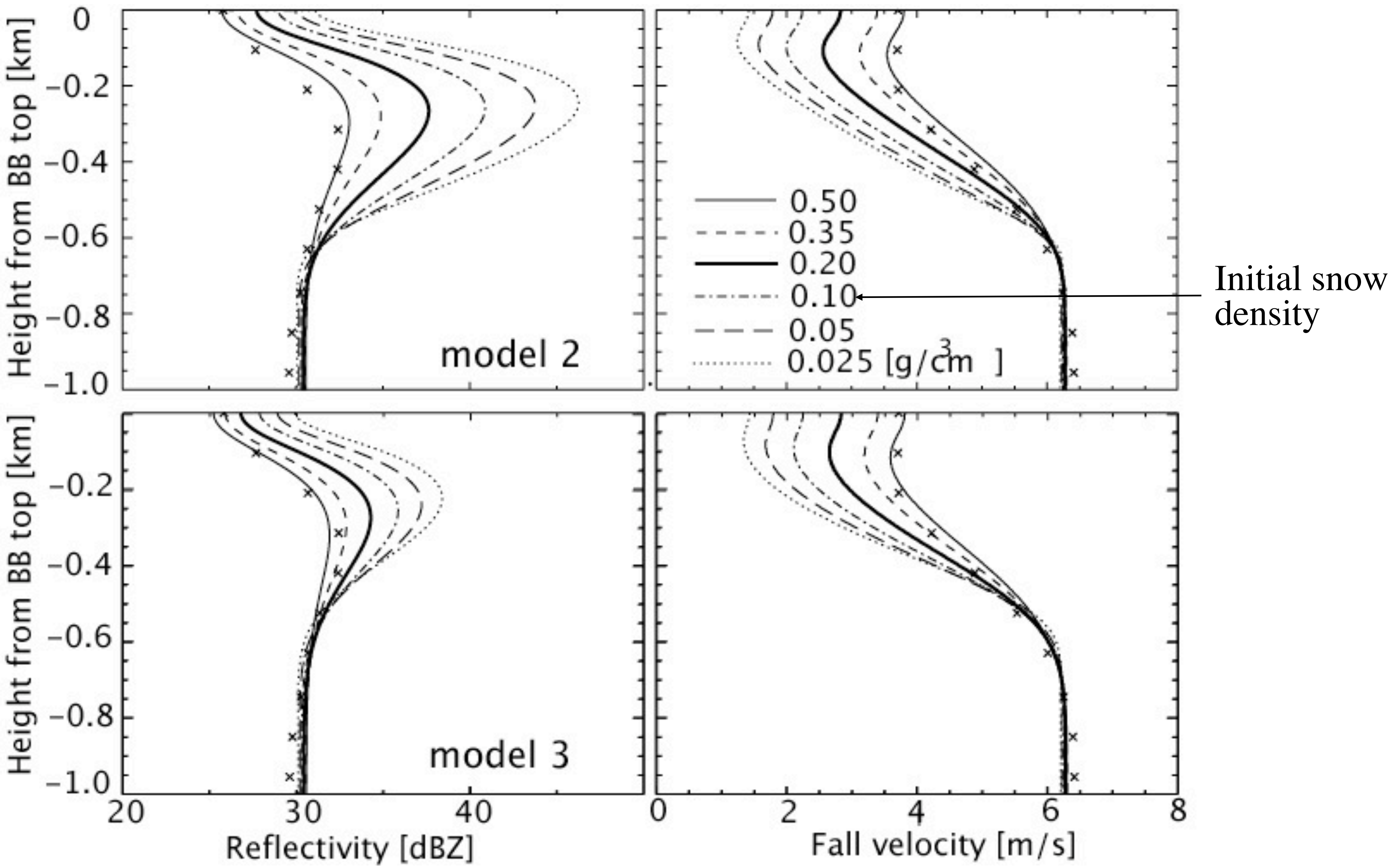


Szyrmer, W., S. Laroche and I. Zawadzki, 2005: A Microphysical Bulk Formulation Based on Scaling Normalization. Part I: Description. *J. Atmos. Sci.* **62**, 4206-4221.

Electromagnetic and microphysical modeling of the melting snow bright band intensity as a function of snow density (of degree of riming)

Change in BB intensity with density

Change in fall velocity with density



From: Zawadzki, Szyrmer and Fabry: Super-cooled cloud, riming of snow and bright band intensity. JAM, 2001.

Final model for snow velocity

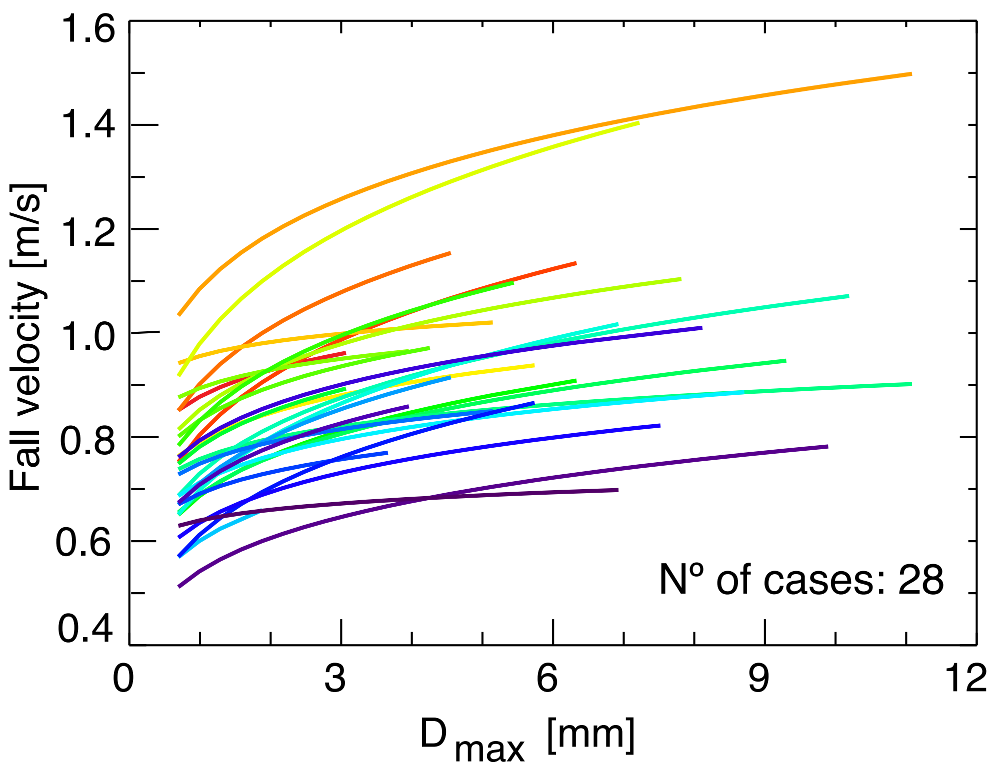
From HVSD and VertiX measurements at CARE

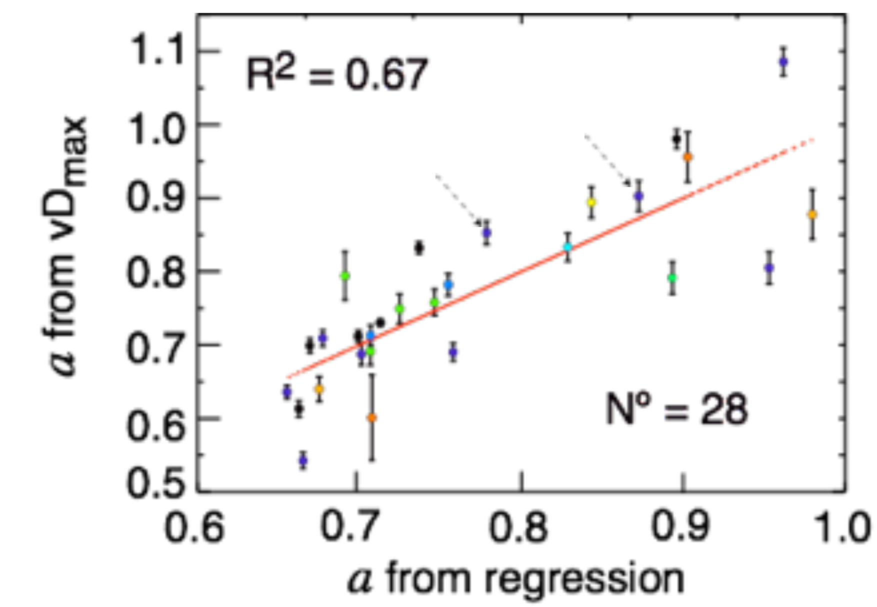
$V = aD^b$ expressed in terms of depth of precipitation and surface temperature:

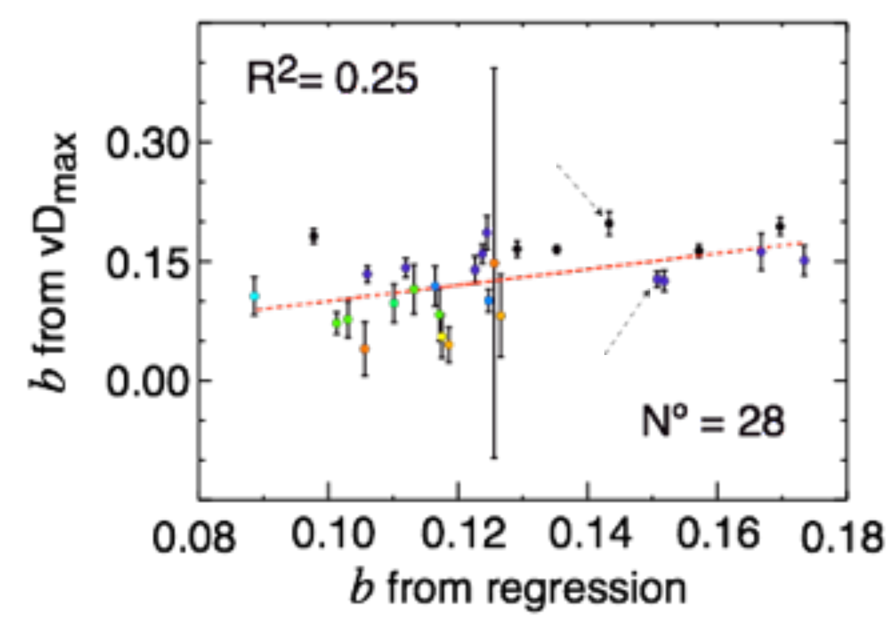
a = [0.67 ± 0.049] + [0.046 ± 0.012] H + [0.006 ± 0.003] T_s

b = [0.069 ± 0.027] - [0.003 ± 0.007] H - [0.004 ± 0.002] T_s

Observed fall velocities:

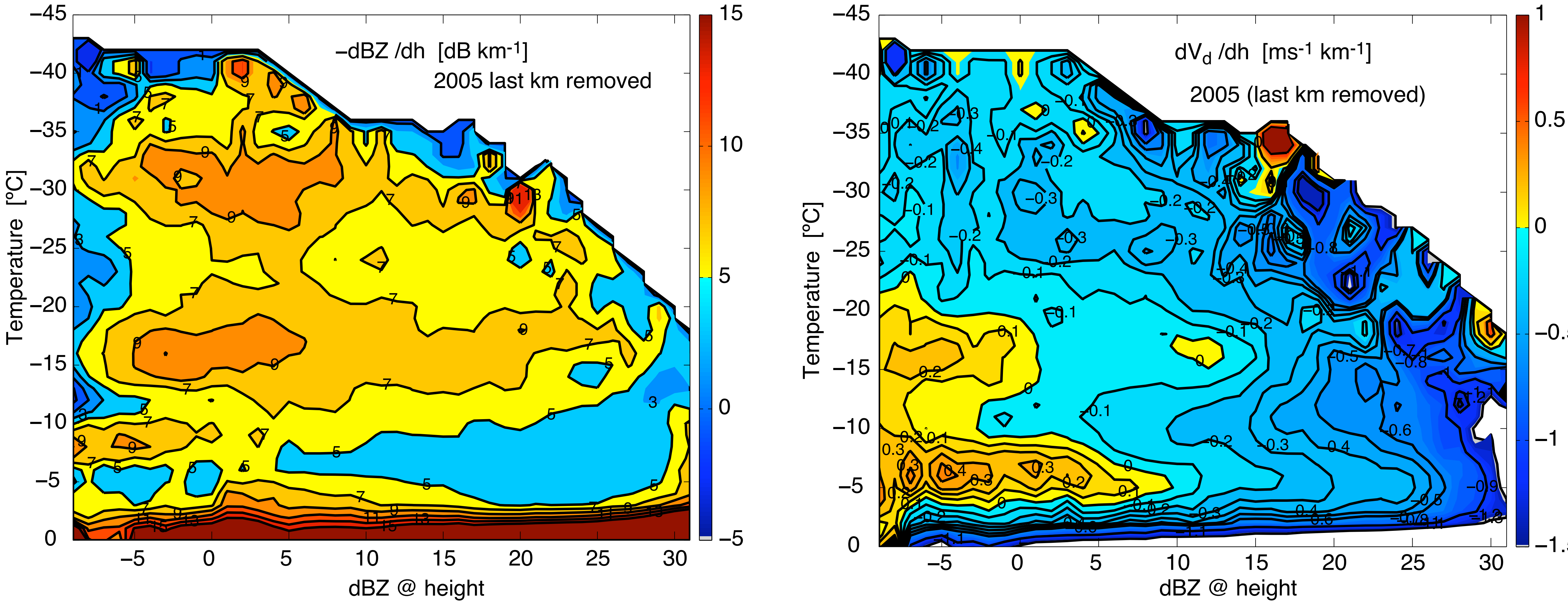






On the growth of snow

A year average of vertical gradients of snow reflectivity and Doppler velocity



Relationship between fall velocity and density of snow

Relation derived from the boundary layer theory between Reynolds number **Re** and Best/Davies number ***X*** (Böhm 1989; Mitchell 1996, …)

$$\mathrm{Re} = \frac{\delta_0^{\,2}}{4}\left[\left(1 + \frac{4X^{1/2}}{\delta_0^{\,2}C_0^{1/2}}\right)^{1/2} - 1\right]^2$$

$$\mathrm{Re} = \frac{uD}{\nu} \qquad X = \frac{2g}{\rho_a \nu^2} D^2 \frac{m}{A_{eff\perp}}$$

δ_0, C_0: constants

u, m: particle's terminal velocity and mass

D : characteristic dimension of the particle taken as the major side-view dimension

ν : kinematic viscosity

$A_{eff\perp}$: effective particle's area projected normally to the flow

Estimation of $A_{eff\perp}$ from area-ratio:

$$A_r \equiv \frac{A_{eff}}{\pi/4\,D^2} = \left(\frac{D_{eq}}{D}\right)^2$$

Assuming the same for horizontal and side view

$$A_{eff\perp}/A_{eff} = f(\alpha, \varepsilon) \quad \text{from Schefold 2004}$$

α: canting angle; ε: side projected axial ratio

Calculations:

From HVSD measurements we get:

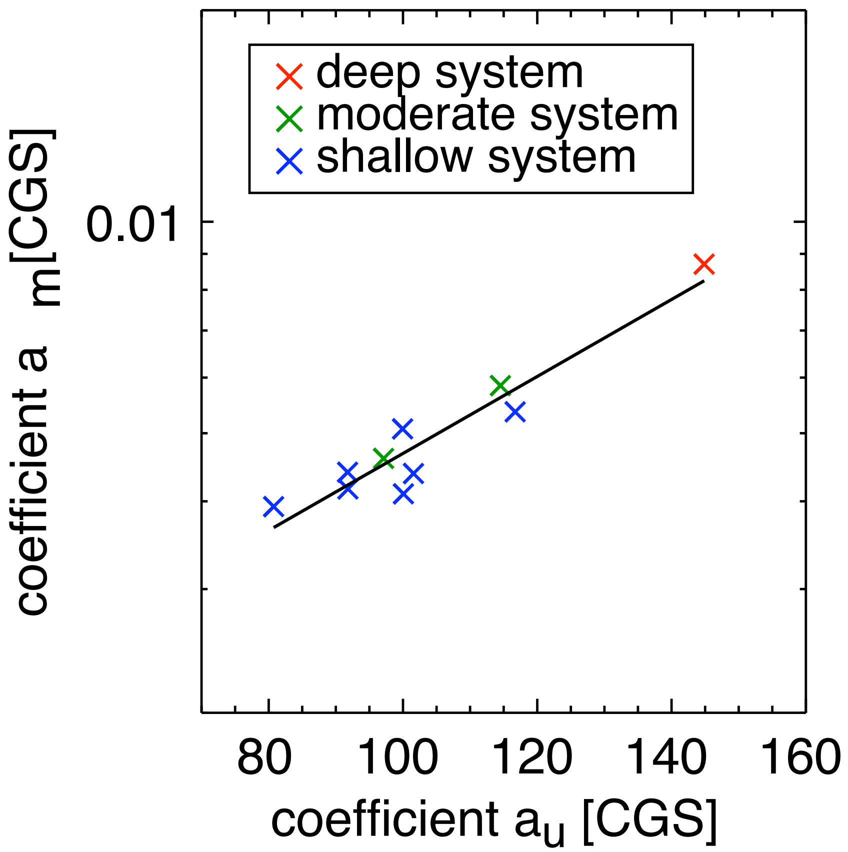
$$u(D) = a_u D^{b_u} \quad \text{and} \quad A_r(D) = a_r\left[\exp(-b_r D) - 1\right]$$

Using mean b_u= 0.15 and the Re-X relationship power-law fitting to the calculation gives

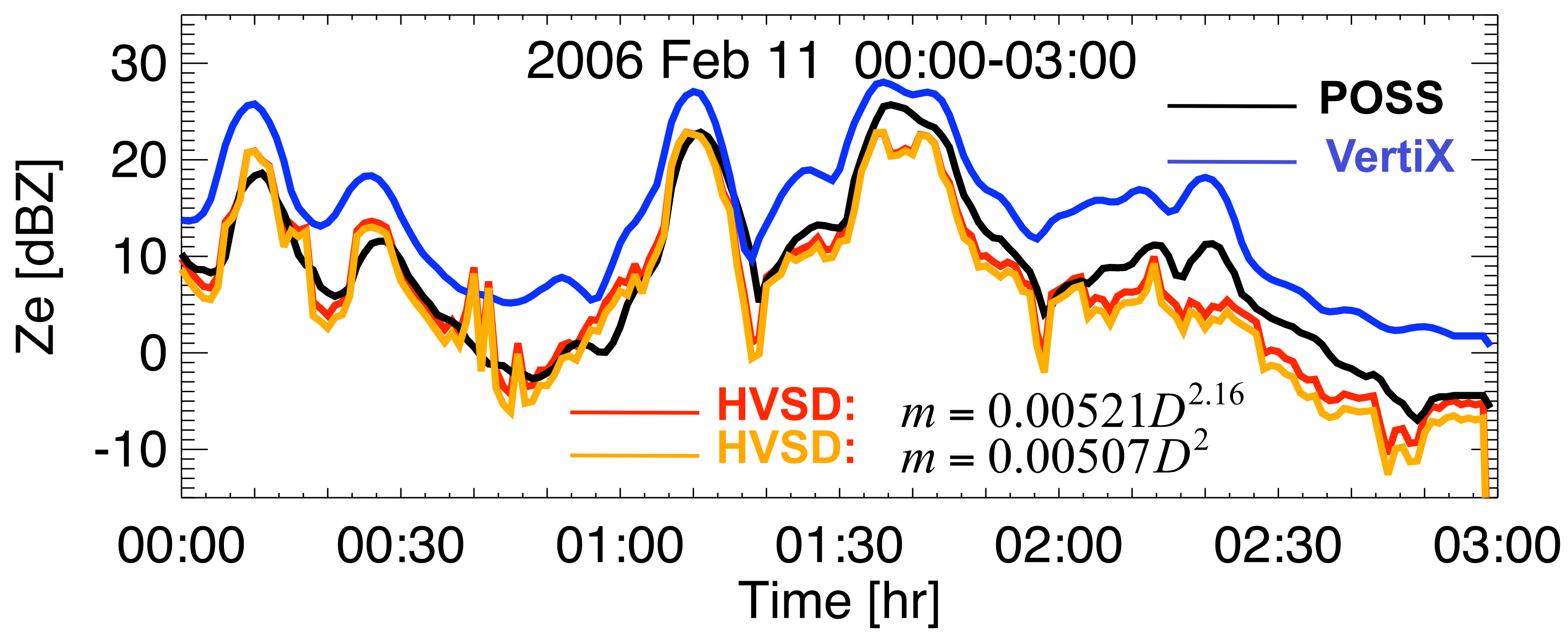
$$m(D) = a_m D^{b_m}$$

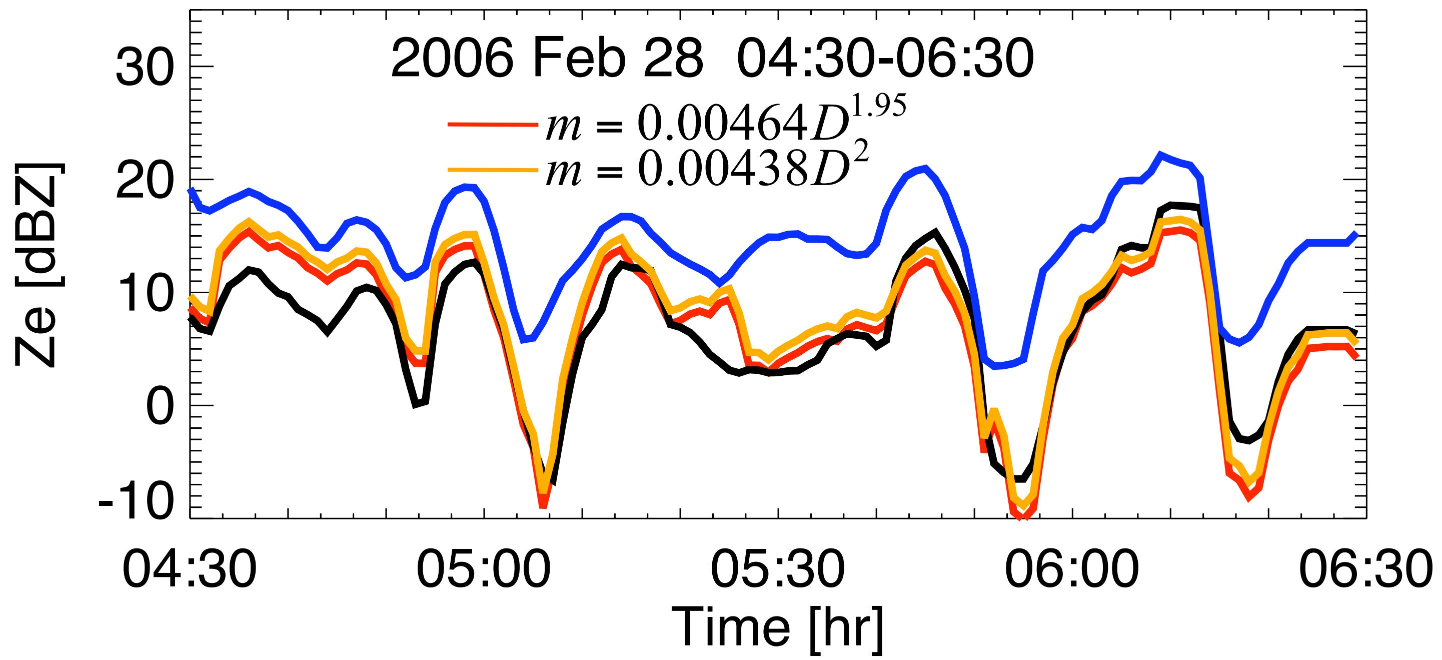
Relationship between fall velocity and density of snow

Retrieved relation between a_m and a_u for fixed exponents: b_m=2, b_u=0.15



VALIDATION:
Two examples of time series of 5-min averages of Z_e measured by POSS and VertiX at ~250m, and computed from HVSD for retrieved mass

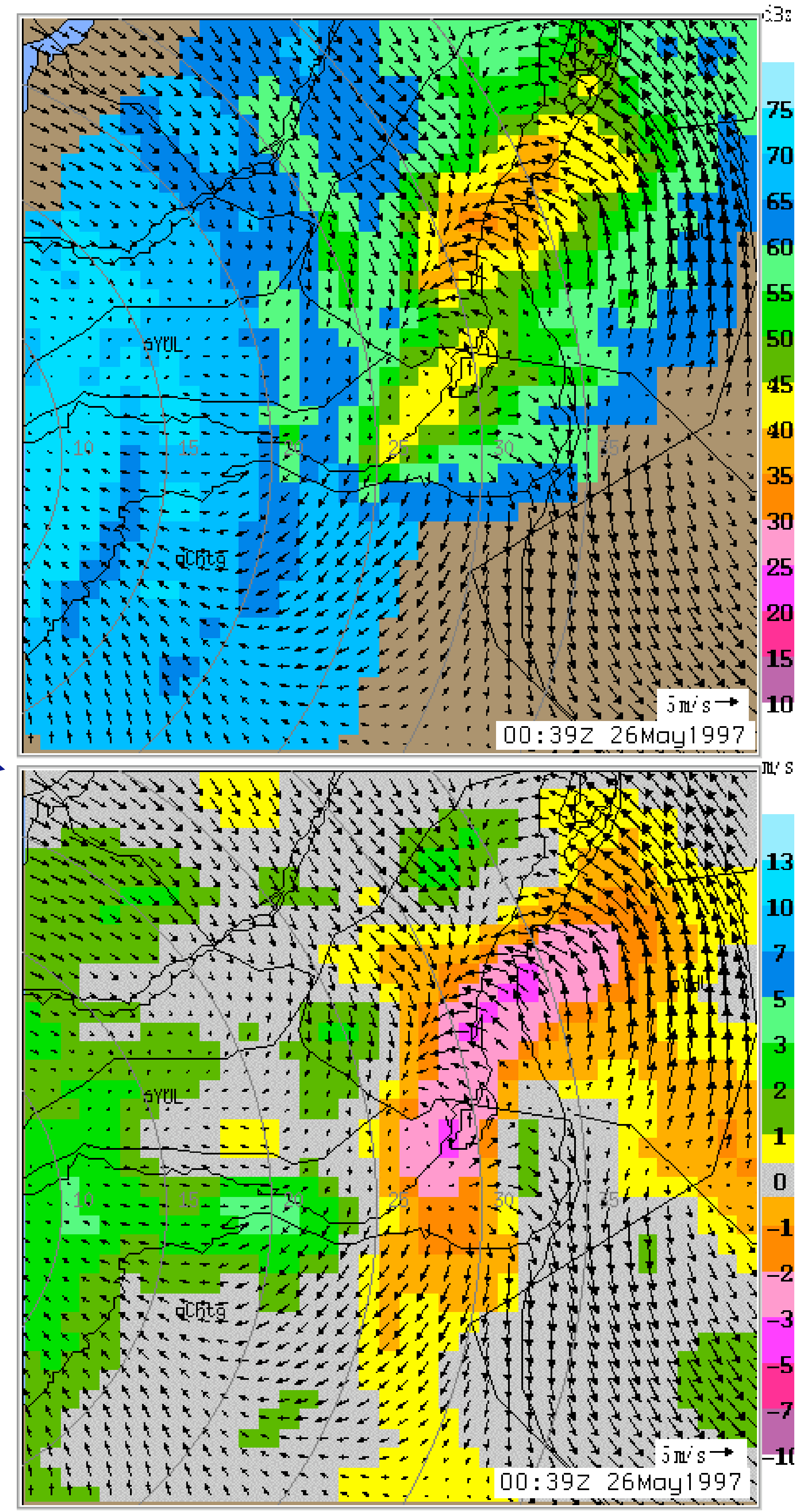




Retrievals, etc

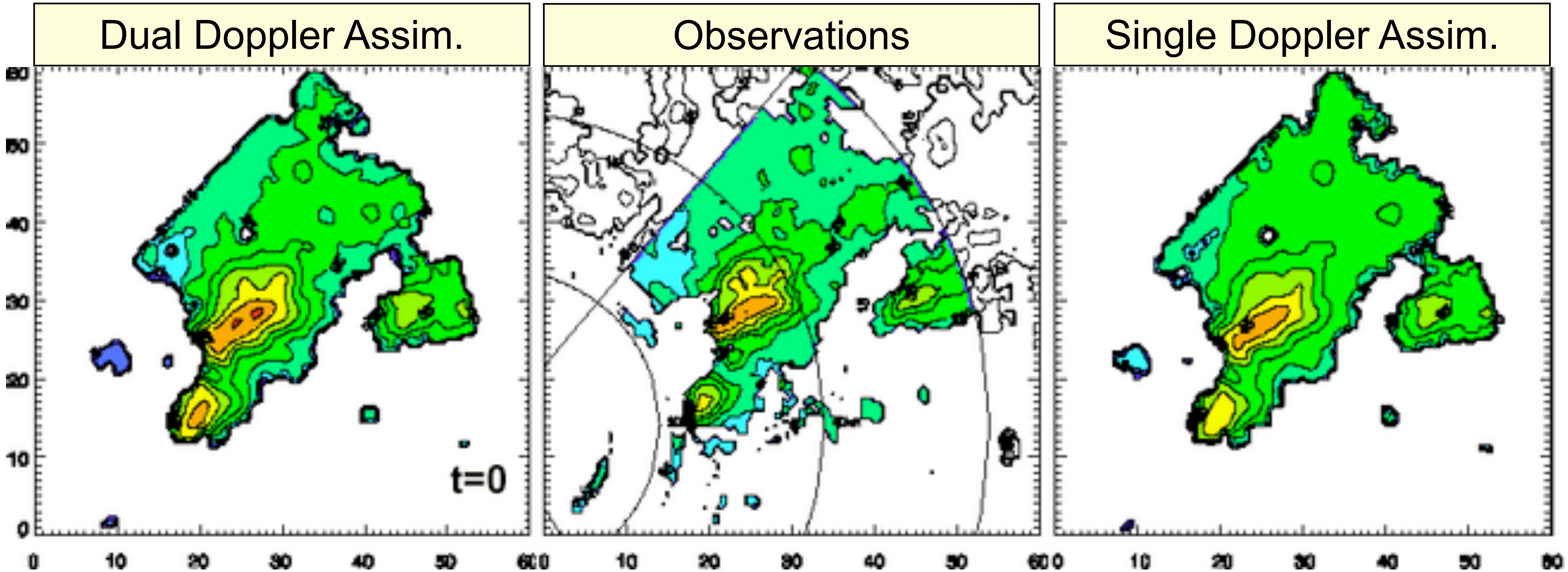
3-D wind fields from BINET ("dual Doppler")

Protat & Zawadzki, 2000

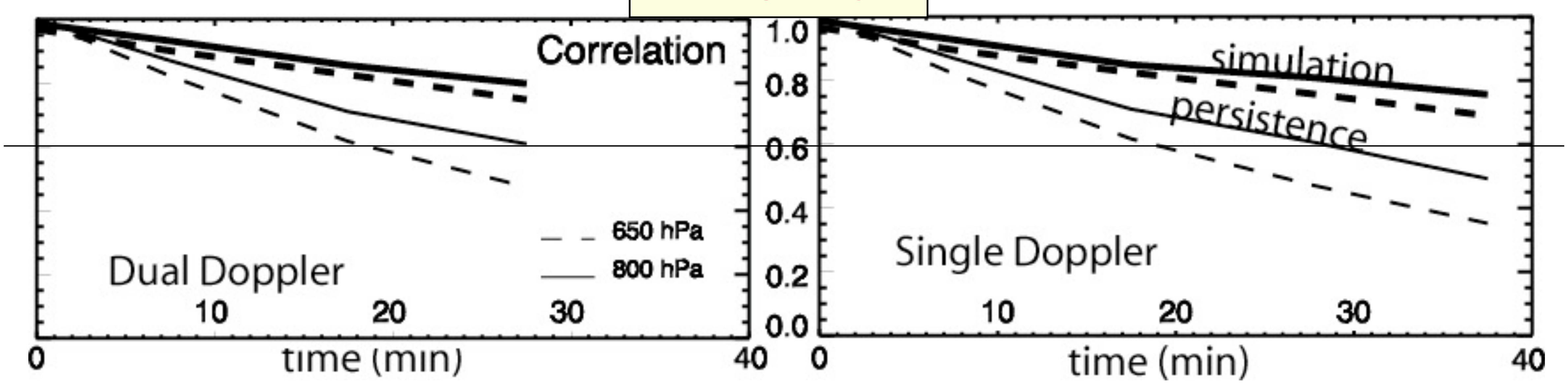


First attempt at assimilation with BINET (model as weak constraint)

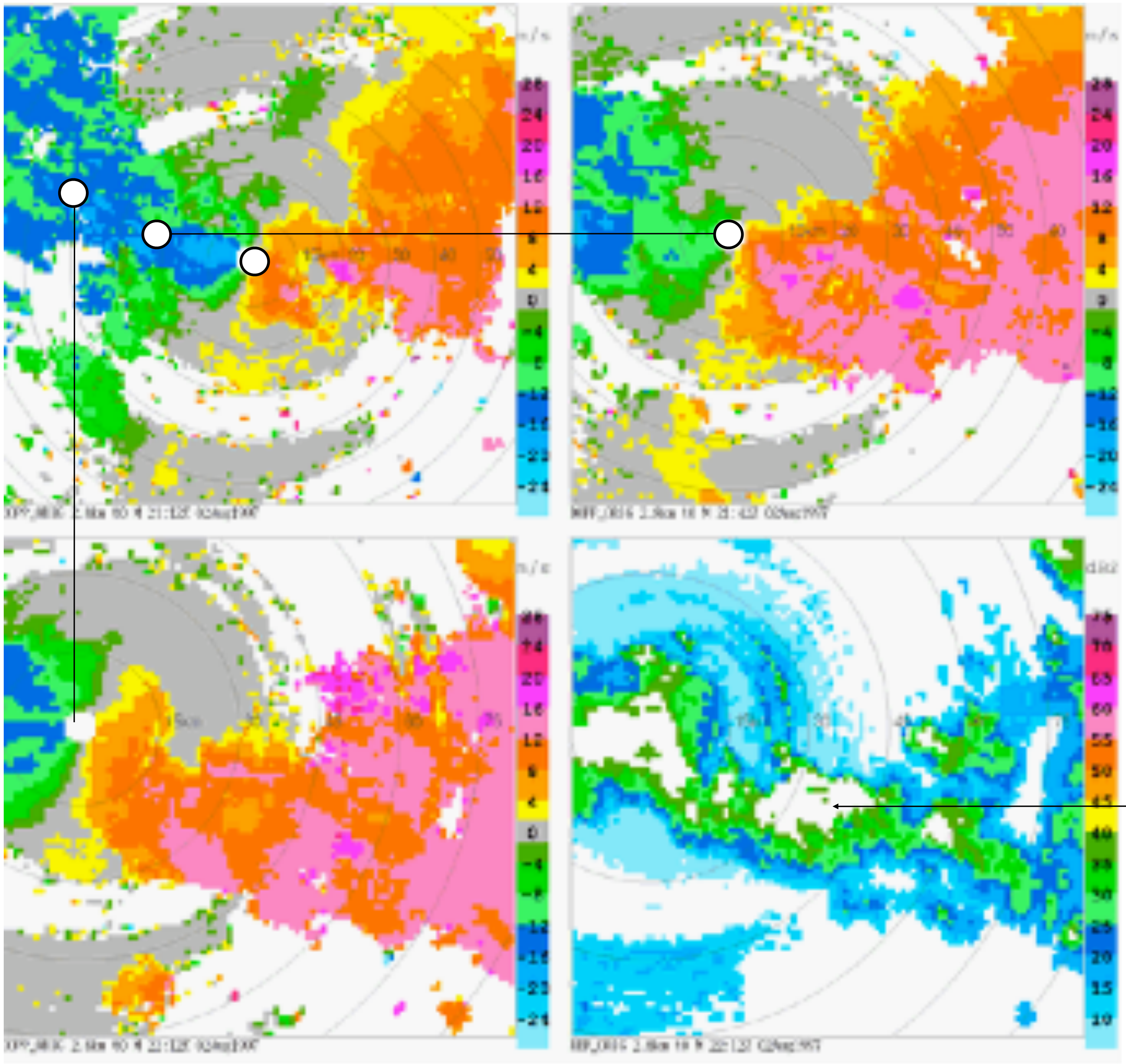
Montmerle et al., 2001, 2002



EVALUATION:



Background wind for single Dopple radar



Initial background field is derived from single Doppler data over a time period (10 - 20 min) assuming frozen turbulence (synthetic dual-Doppler) and linear wind.

Convective regions are eliminated by an iterative method in which data far from linearity are not considered.

Caya, A., S. Laroche, I. Zawadzki and T. Montmerle, **2002:** Using Single-Doppler Data to Obtain a Mesoscale Environmental Field. J. of Atmos. and Oceanic Tech, **19**, 21–36.

The Present Assimilation System

Regional model (GEM-LAM) forecast as background for the initial cycle of assimilation

Chung, K-S., I. Zawadzki, M.K. Yau, and L. Fillion, 2009: Short-term forecasting of a midlatitude convective storm by the assimilation of single Doppler radar observations. Mon. Wea. Rev., In print

Present state of the Model Governing Equations

$$\frac{du}{dt} - fv + R(T^* + T')\frac{\partial \pi}{\partial x} = \varepsilon_{mx}^{q}$$

$$\frac{dv}{dt} + fu + R(T^* + T')\frac{\partial \pi}{\partial y} = \varepsilon_{my}^{q}$$

$$\frac{dw}{dt} - g\frac{T'}{T^*} + g\frac{(M + Q_c)}{\rho} + R(T^* + T')\frac{\partial \pi}{\partial z} = \varepsilon_{mz}^{q}$$

$$\frac{d\pi}{dt} - \frac{wg}{RT^*} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} - \frac{1}{(T^* + T')}\frac{dT'}{dt} = \varepsilon_{co}^{q}$$

$$\frac{dT'}{dt} - \alpha(T^* + T')\left[\frac{dq'}{dt} - \frac{wg}{RT^*}\right] - L = \varepsilon_{th}^{q}$$

$$\frac{d_M M}{dt} + \frac{Mw}{H} + M\frac{\partial V_t}{\partial z} - S(M, m) = \varepsilon_{M}^{q}$$

$$\frac{dm}{dt} + \frac{mw}{H} - wG + S(M, m) = \varepsilon_{m}^{q}$$

The cost function

$$J(\mathbf{x}) = J_b + J_o + J_m$$

$$= Background + Observation + Model$$

$$= (x - x^b)^T B^{-1} (x - x^b) + (H(x) - y)^T R^{-1} (H(x) - y) + \varepsilon^{q^T} Q^{-1} \varepsilon^q$$

x : control variables (ex: u,v,w, p, t)
y : observations
H: observation operator
ε^q : model residuals

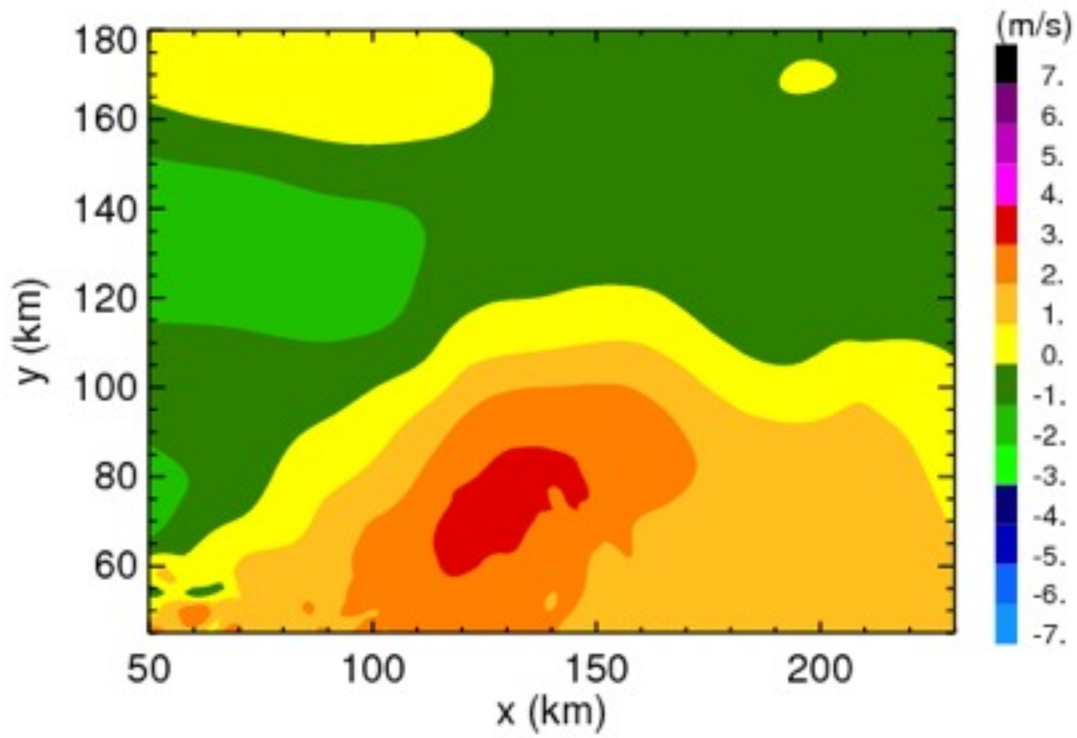
B : background error covariance matrix → *Recursive filter*
R : observation error covariance matrix → *To be determined*
Q : model error covariance matrix → *To be determined*

Minimizing the cost function J → Analysis field

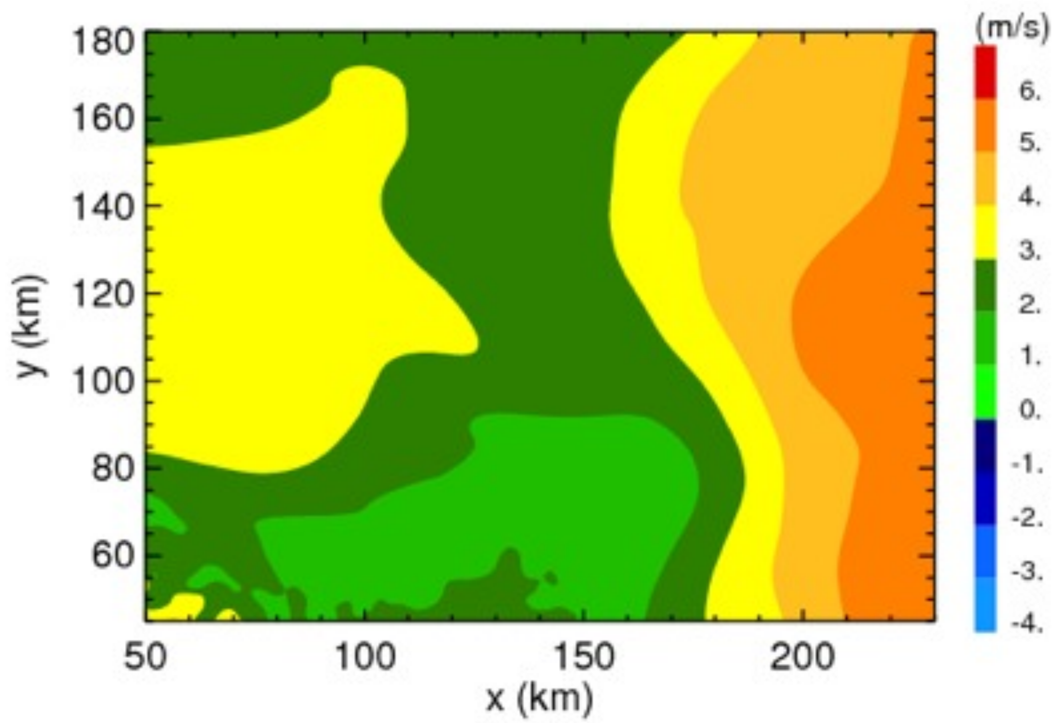
Element of Mesoscale Analysis System (MAS)

1. Background field
(from MC2 model previous forecasts)

The model did not forecast any precipitation in the region

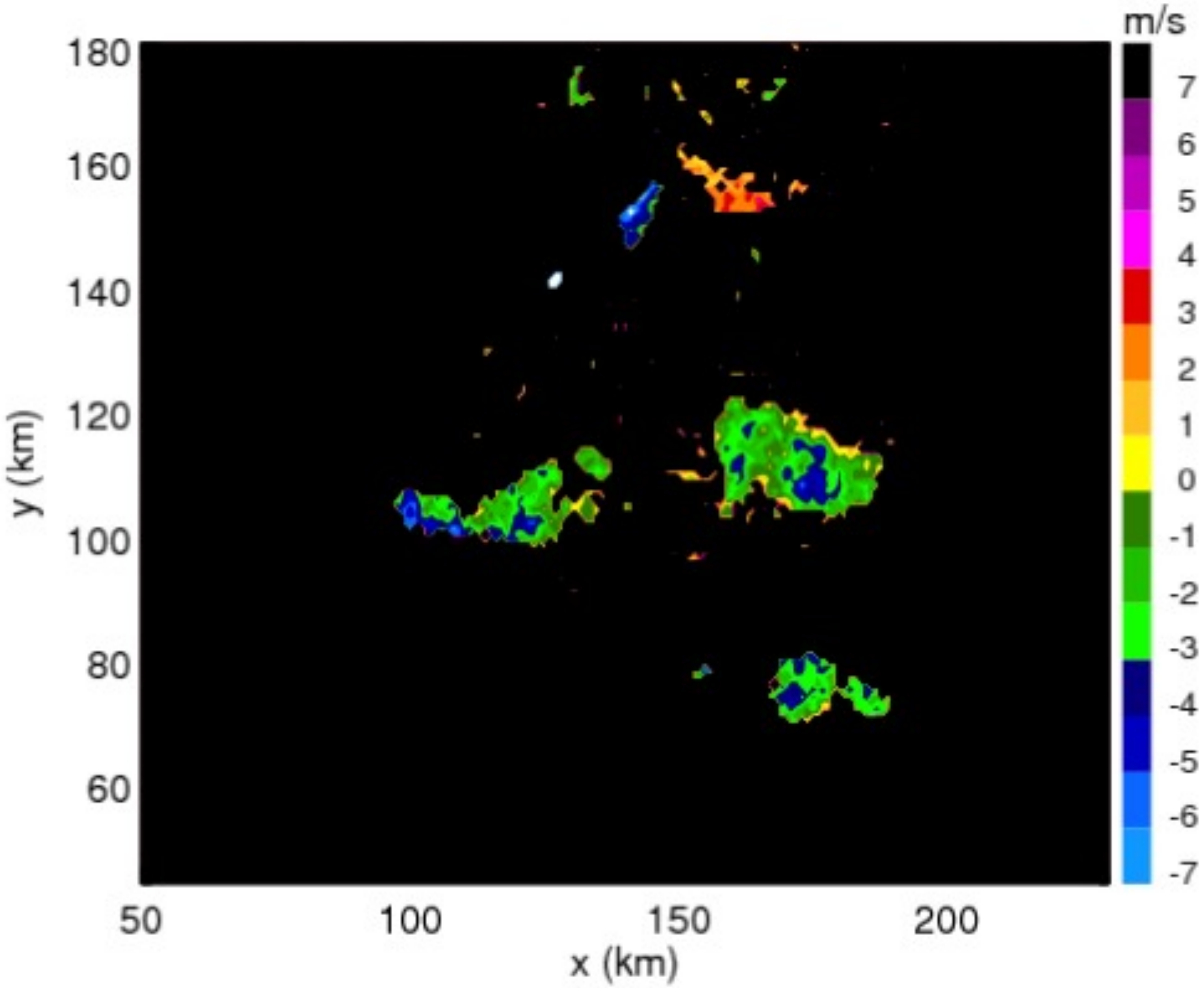


Horizontal wind (u component)

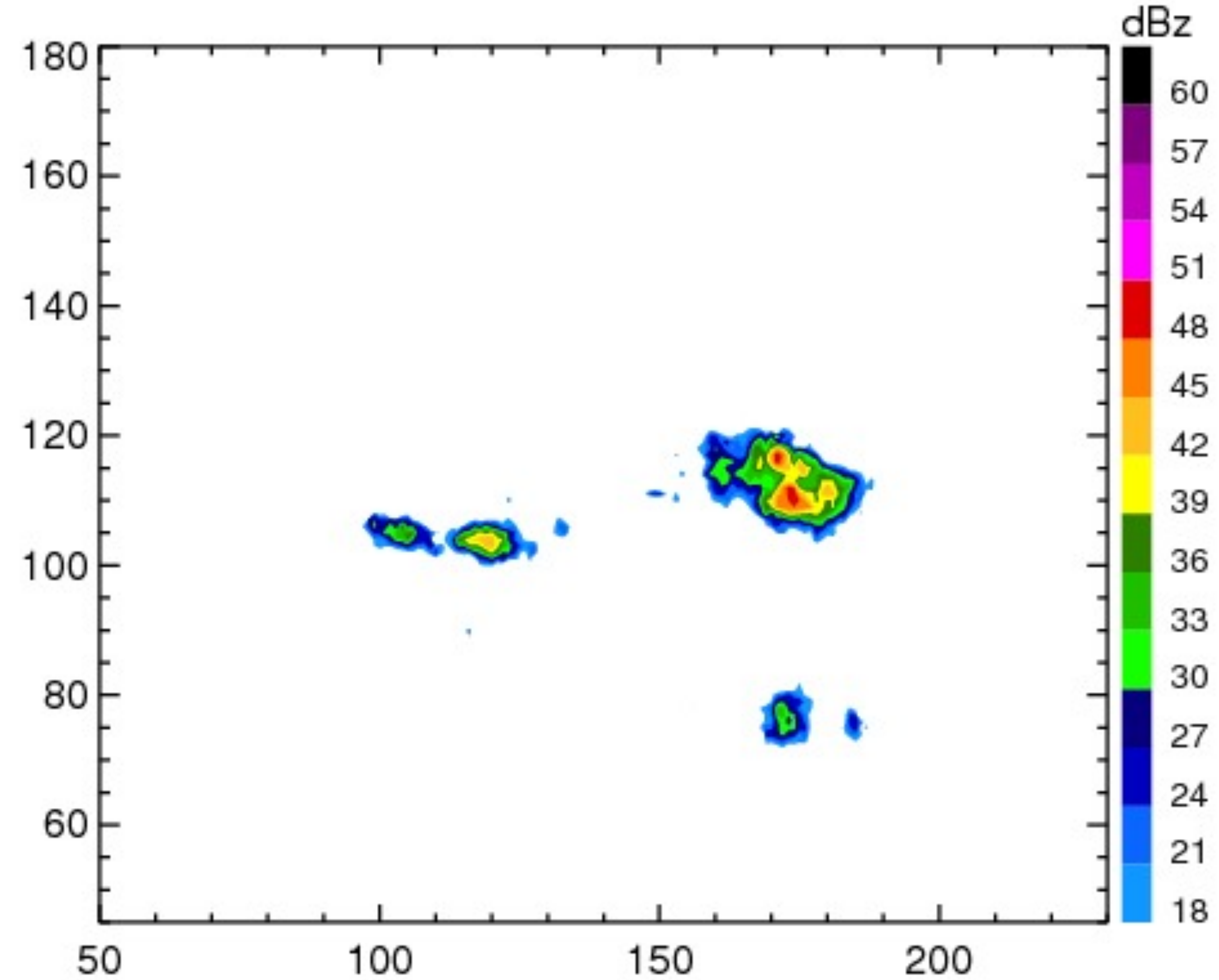


Horizontal wind (v component)

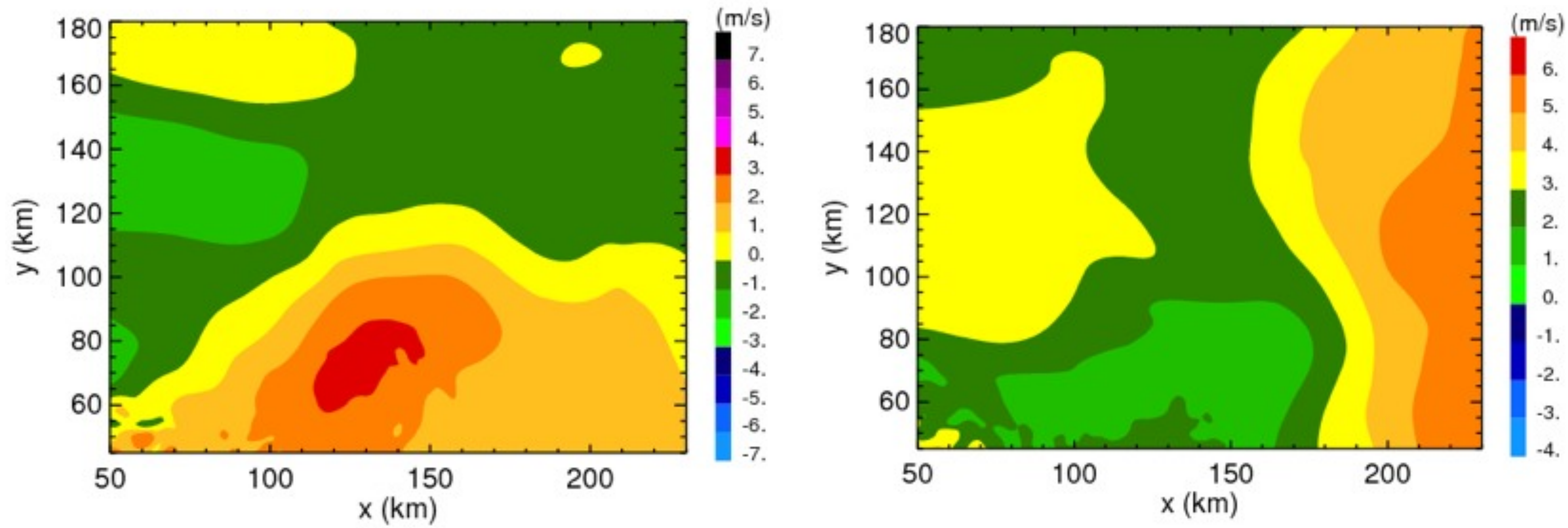
2. Radar observations



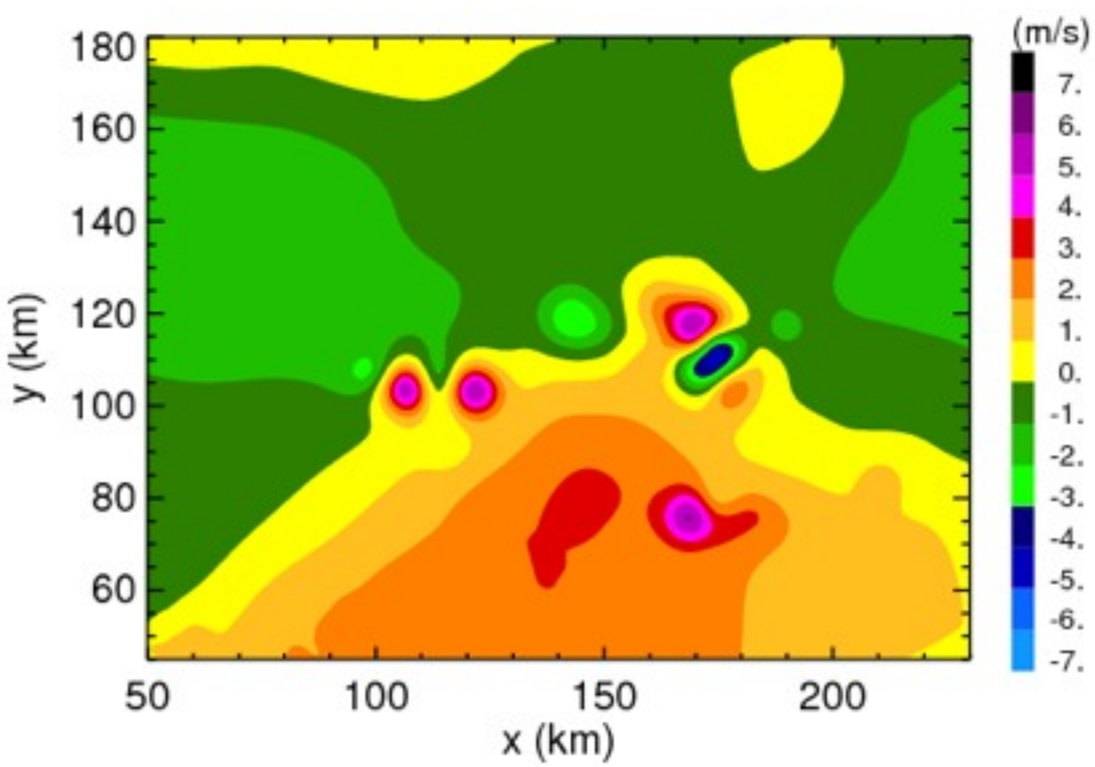
Doppler Wind



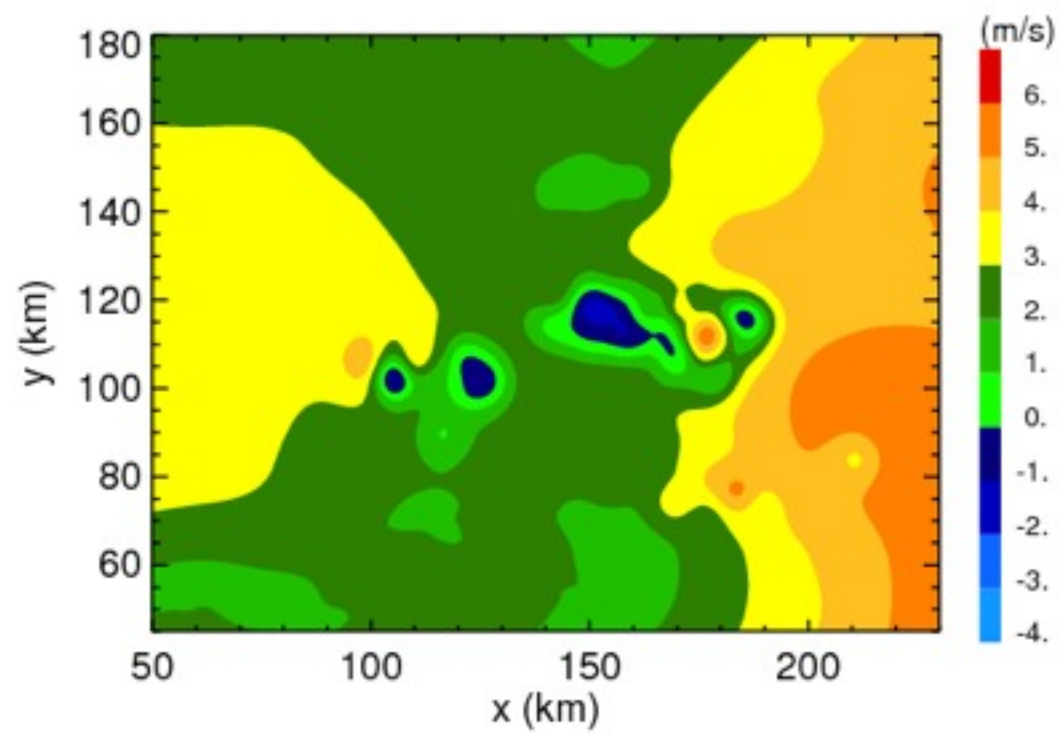
Reflectivity



Analysis field (after assimilation of radar data)

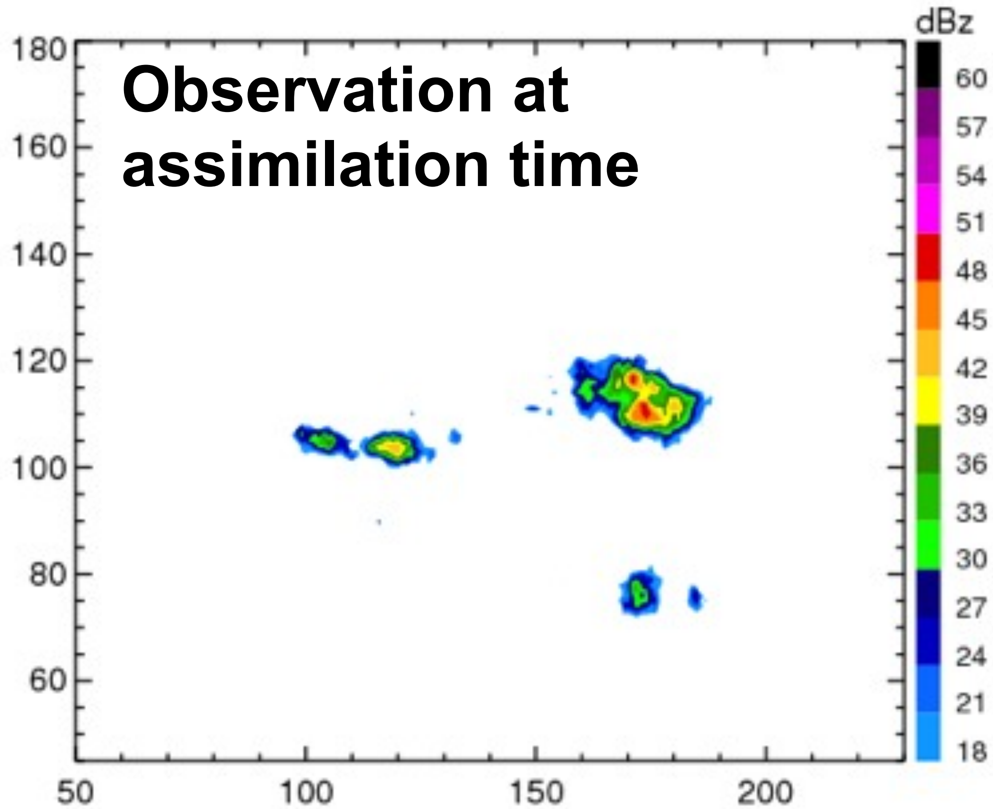


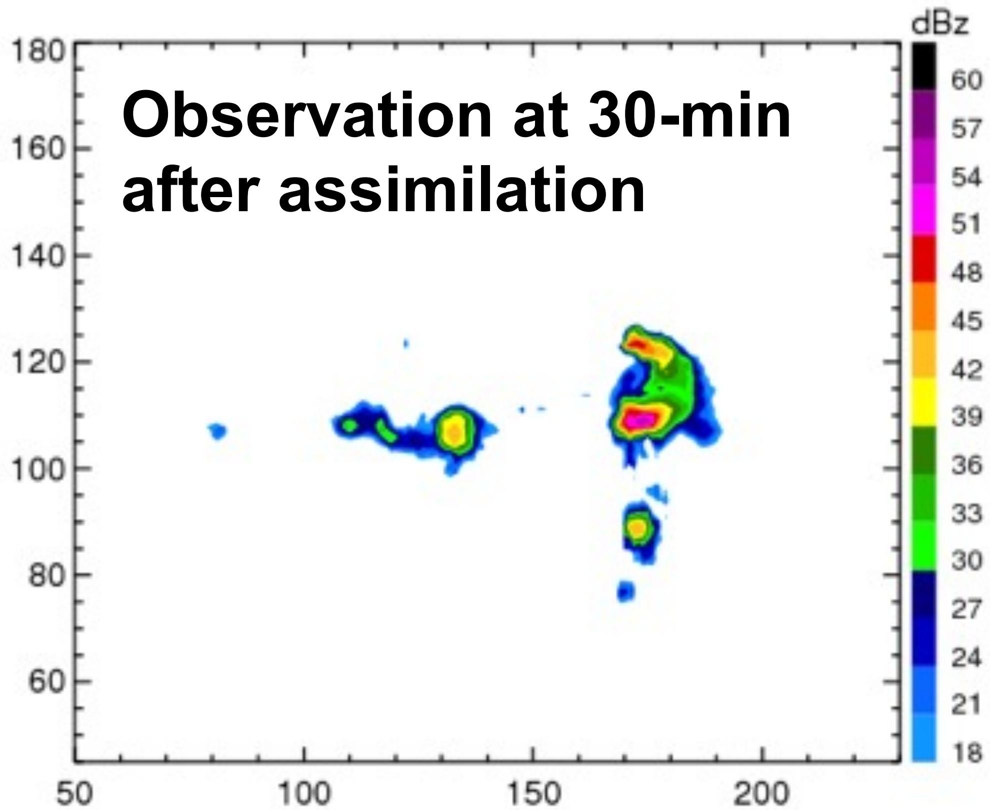
Horizontal wind (u component)

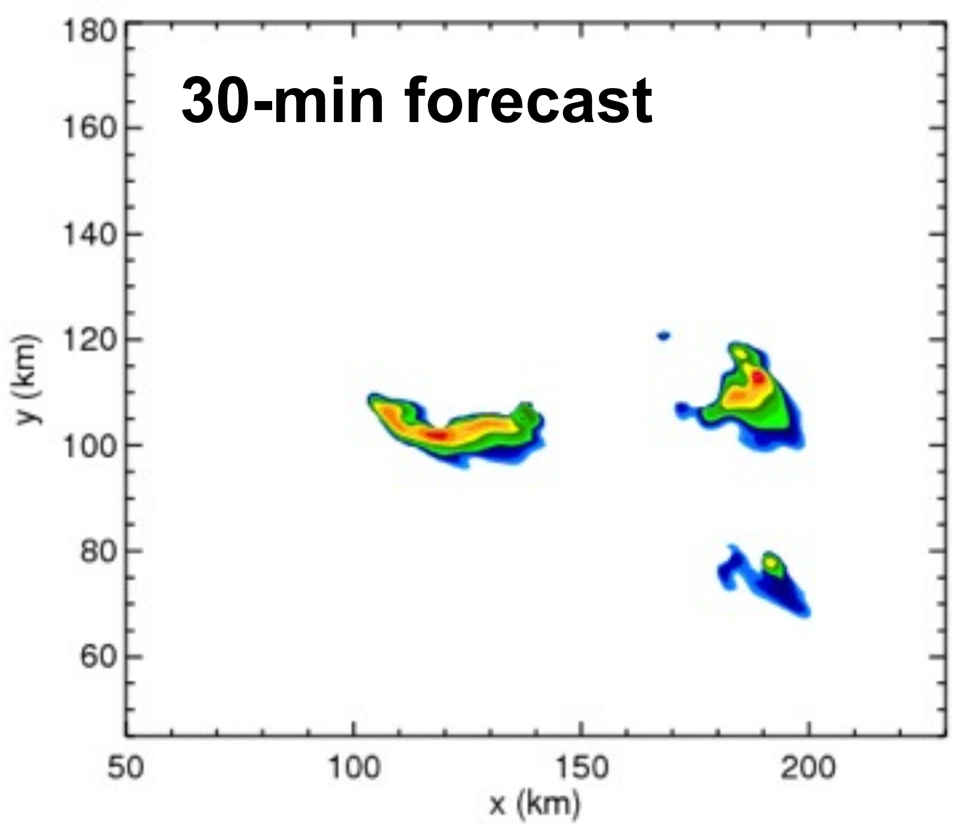


Horizontal wind (v component)

Effectiveness of the analysis is measured by capacity of prediction



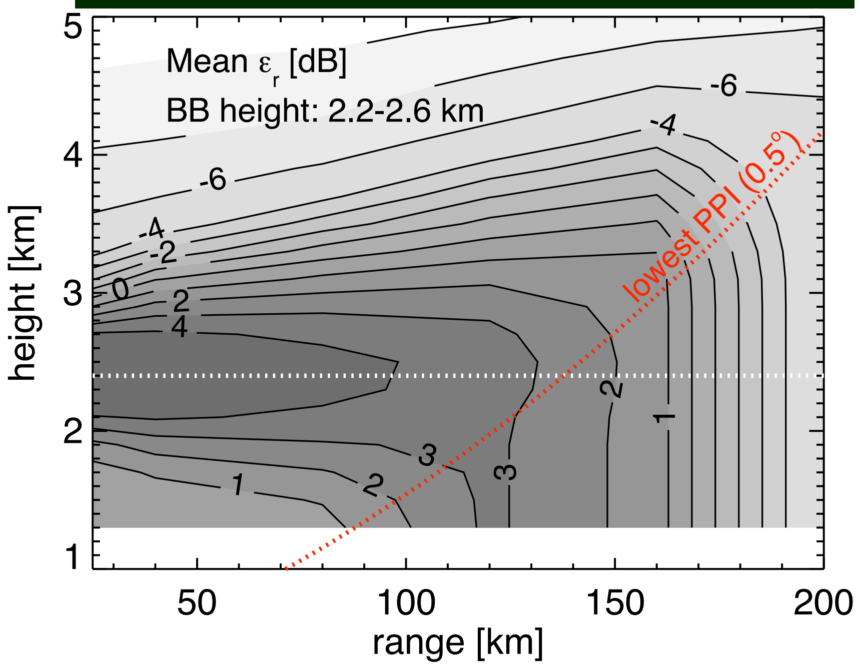




Error Structure of Radar Data

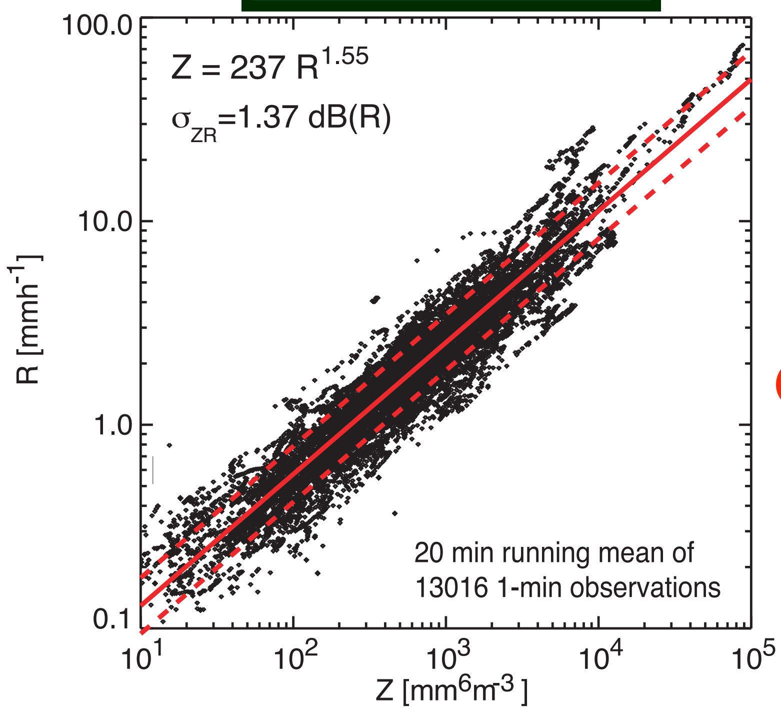
Error structure of radar surface precipitation

ε_r structure due to extrapolation



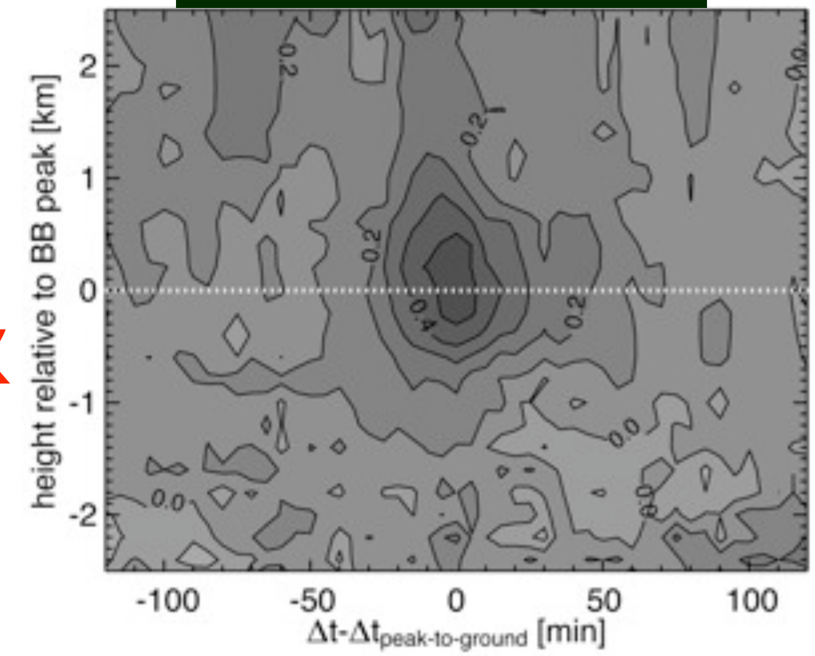
&

ε_{ZR} structure



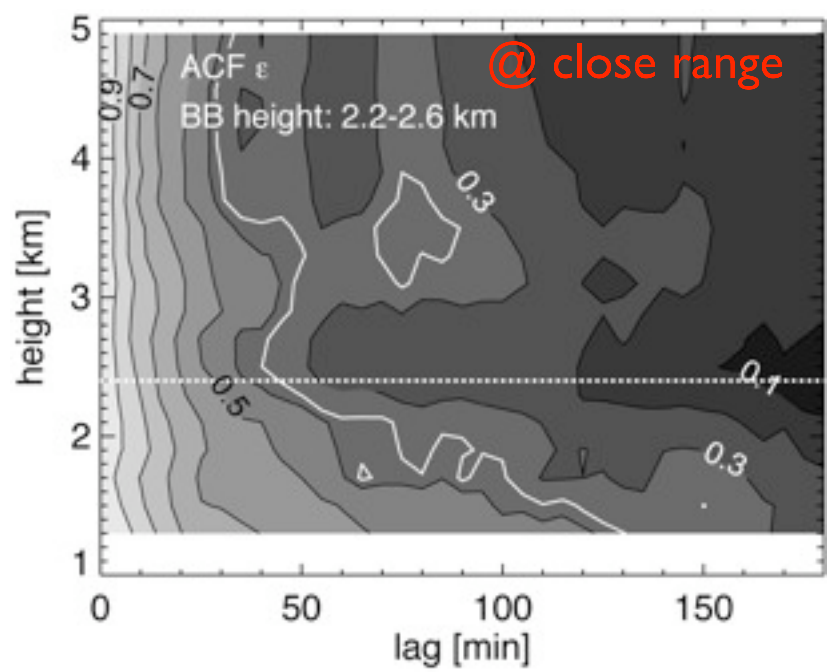
&

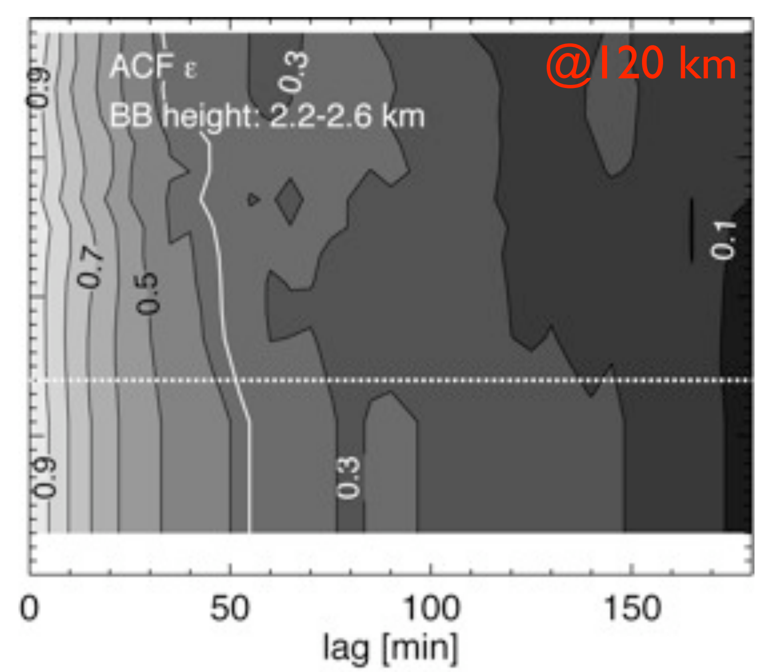
ε_r - ε_{ZR} CC



combining...

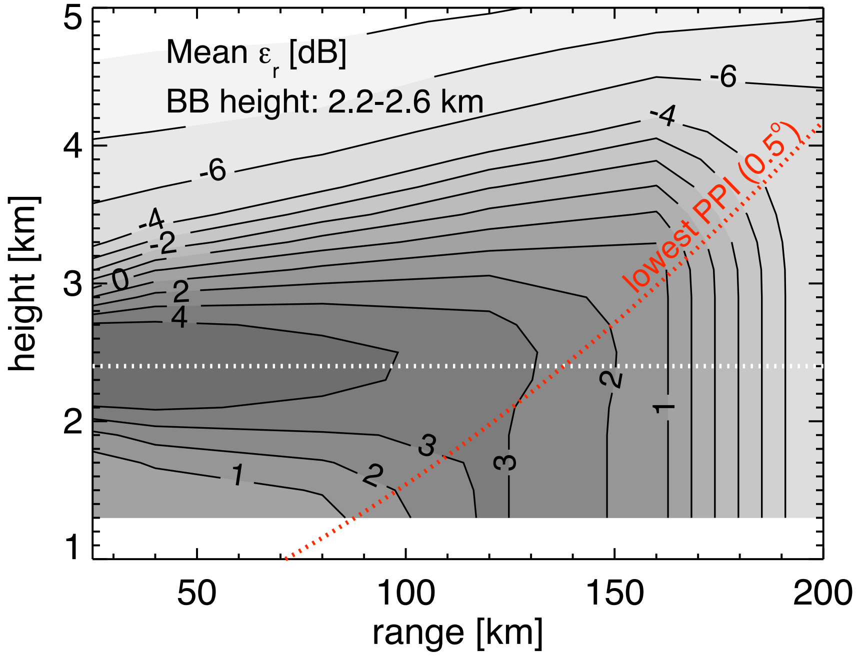
... we obtain





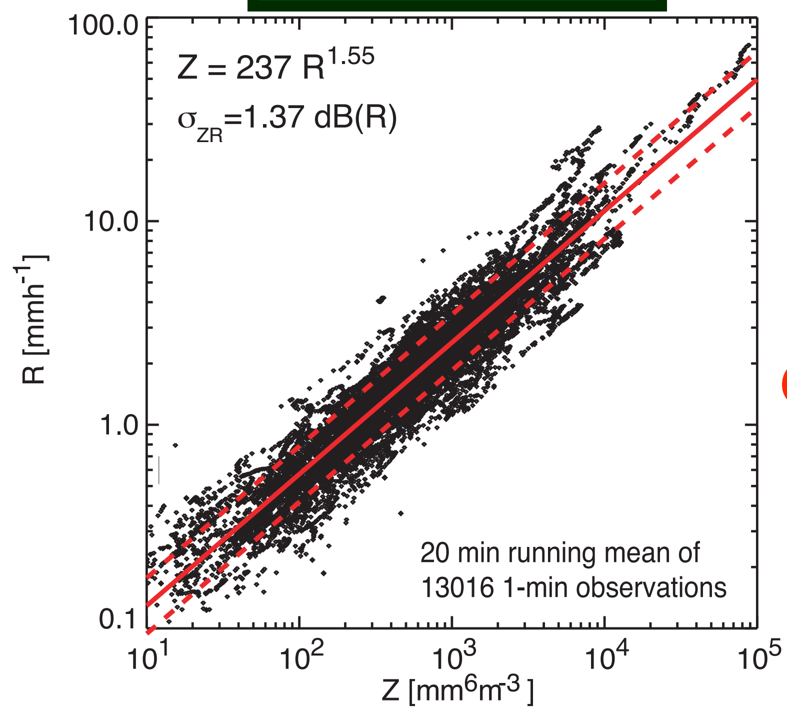
Error structure of radar surface precipitation

ε_r structure due to extrapolation



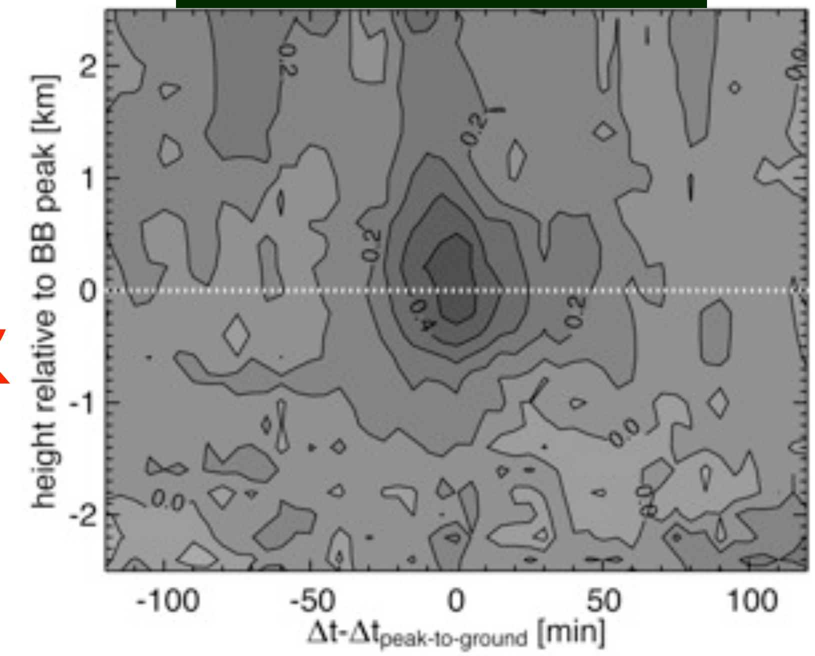
&

ε_{ZR} structure



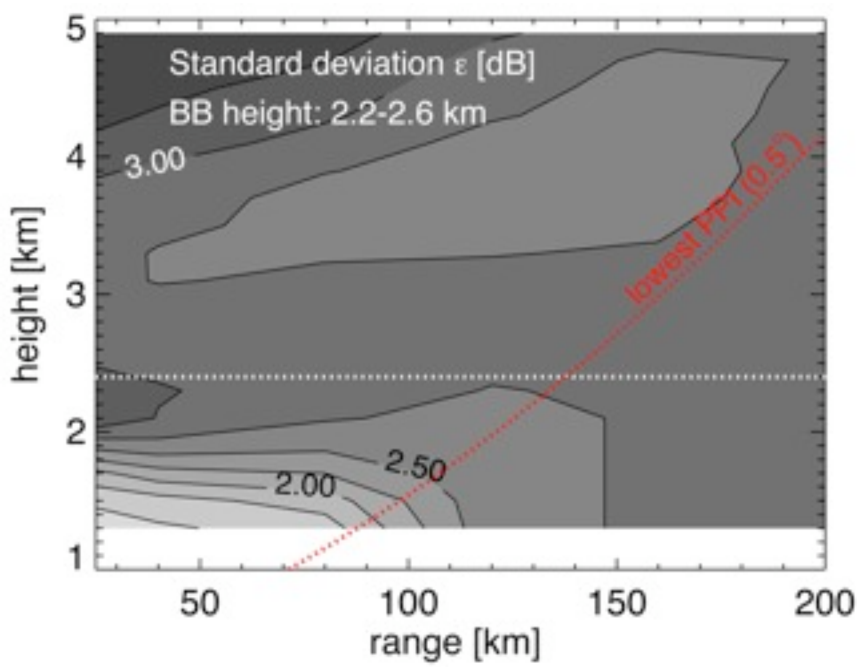
&

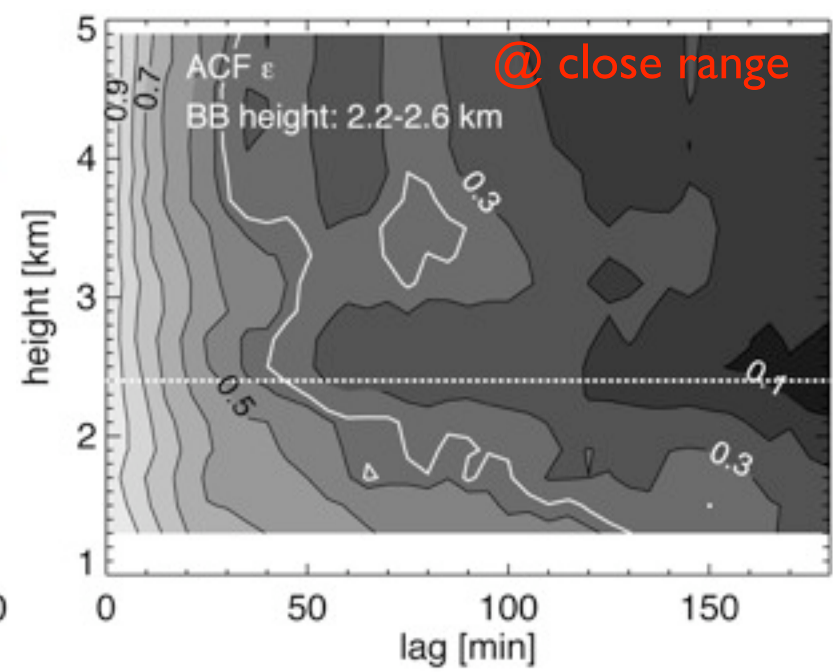
ε_r - ε_{ZR} CC

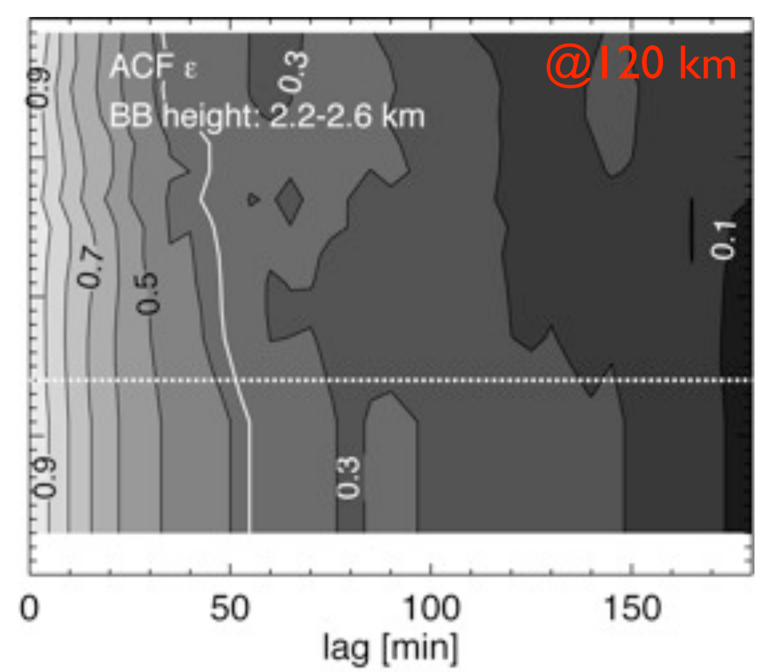


combining...

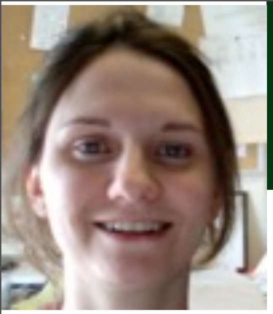
... we obtain





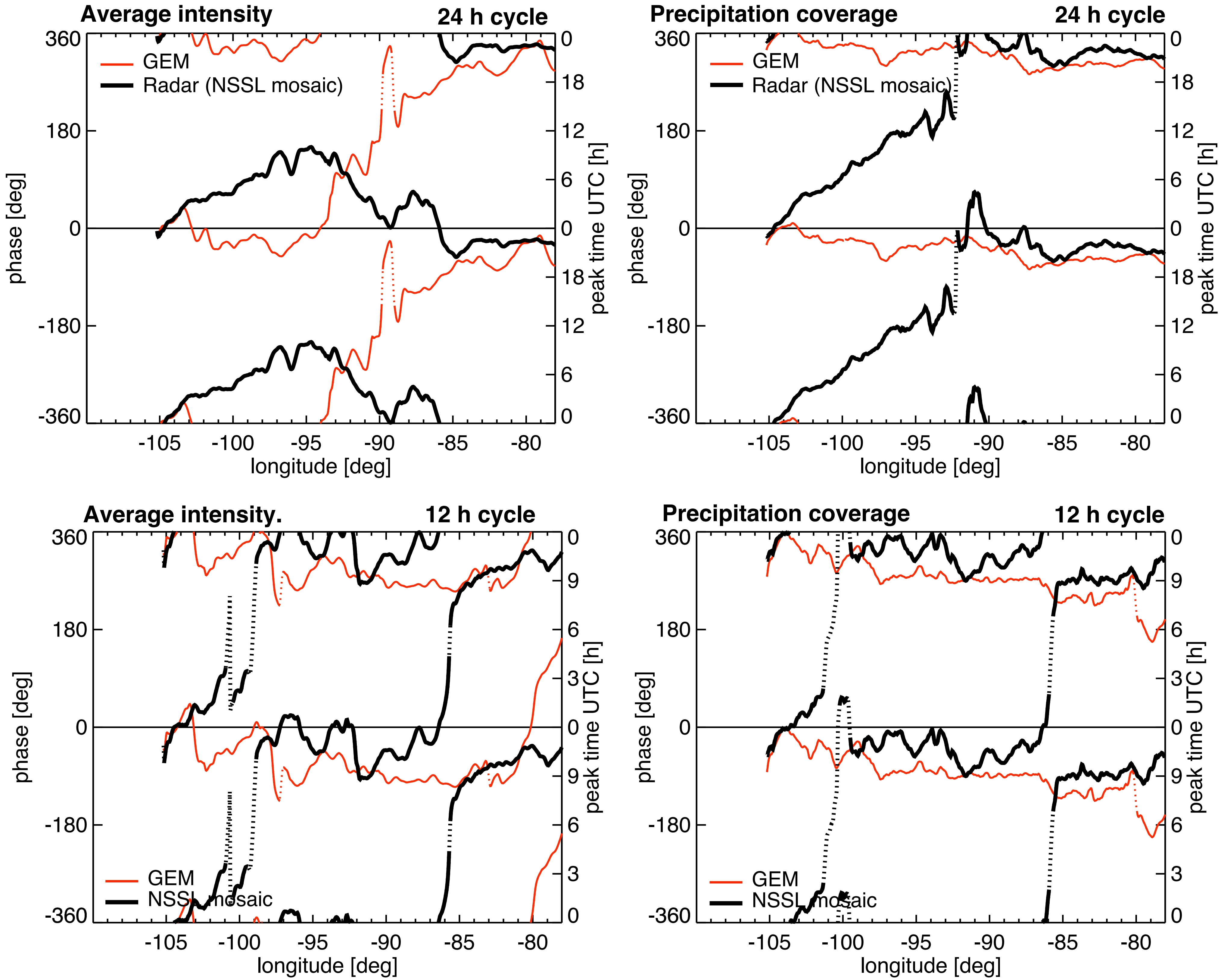


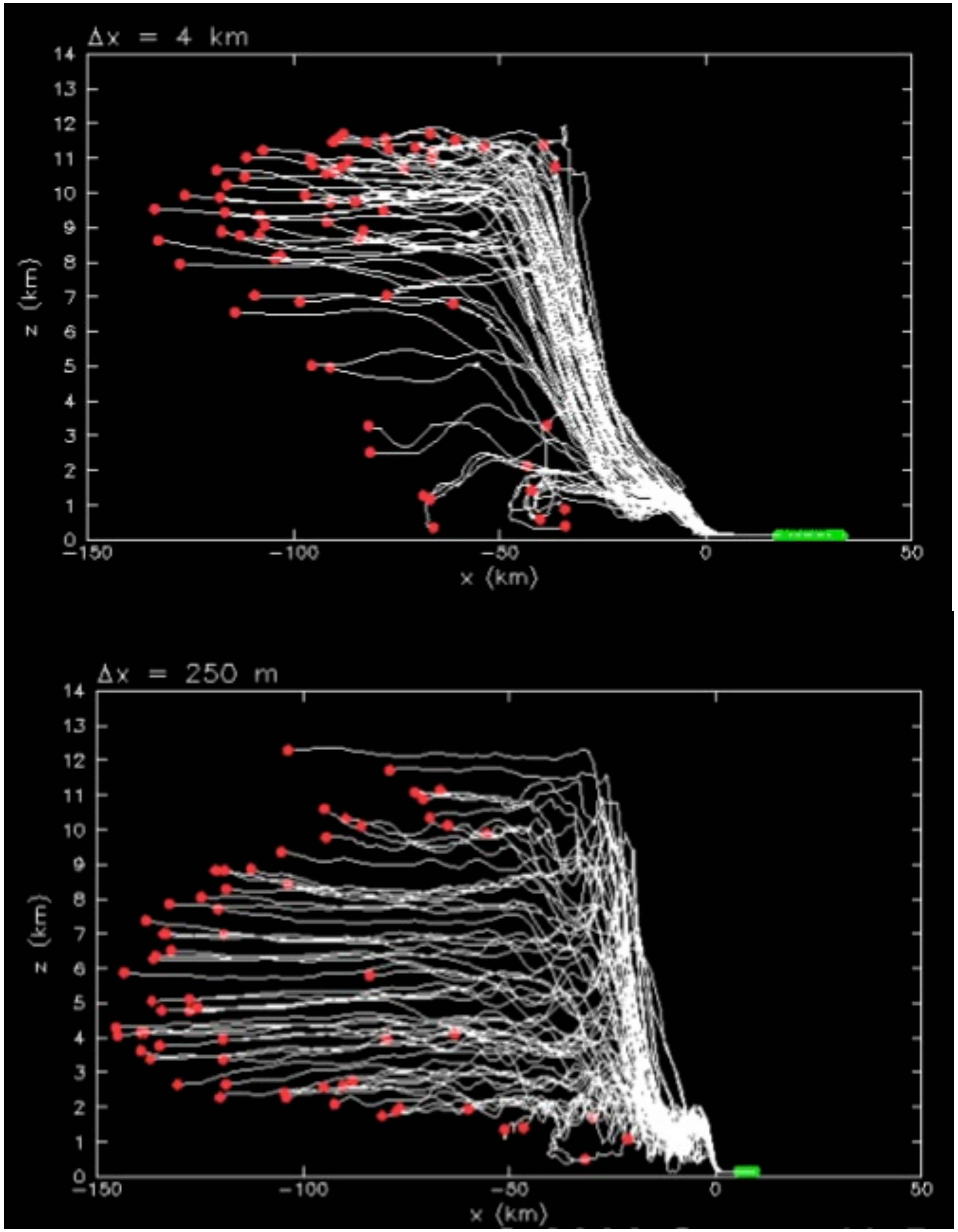
Model Errors



Models fail to correctly reproduce the diurnal cycle

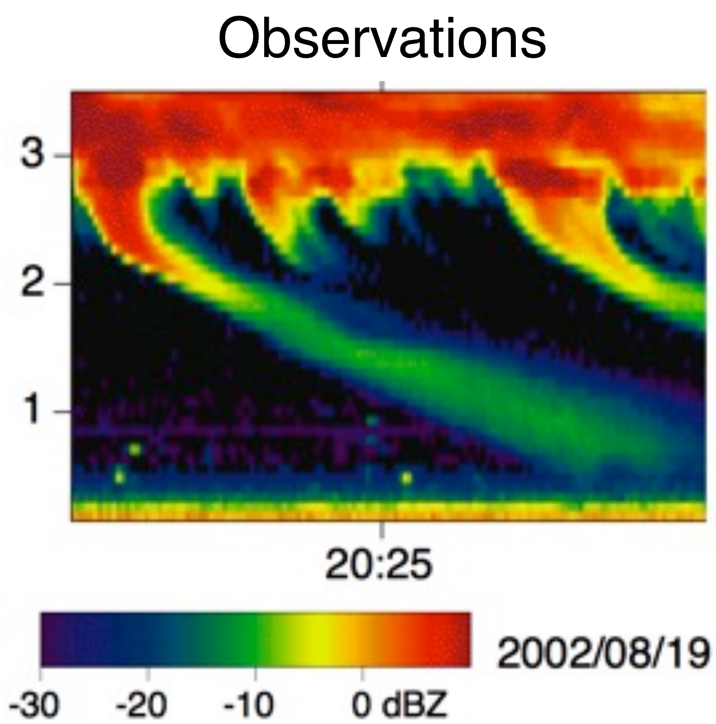
Summer precipitation

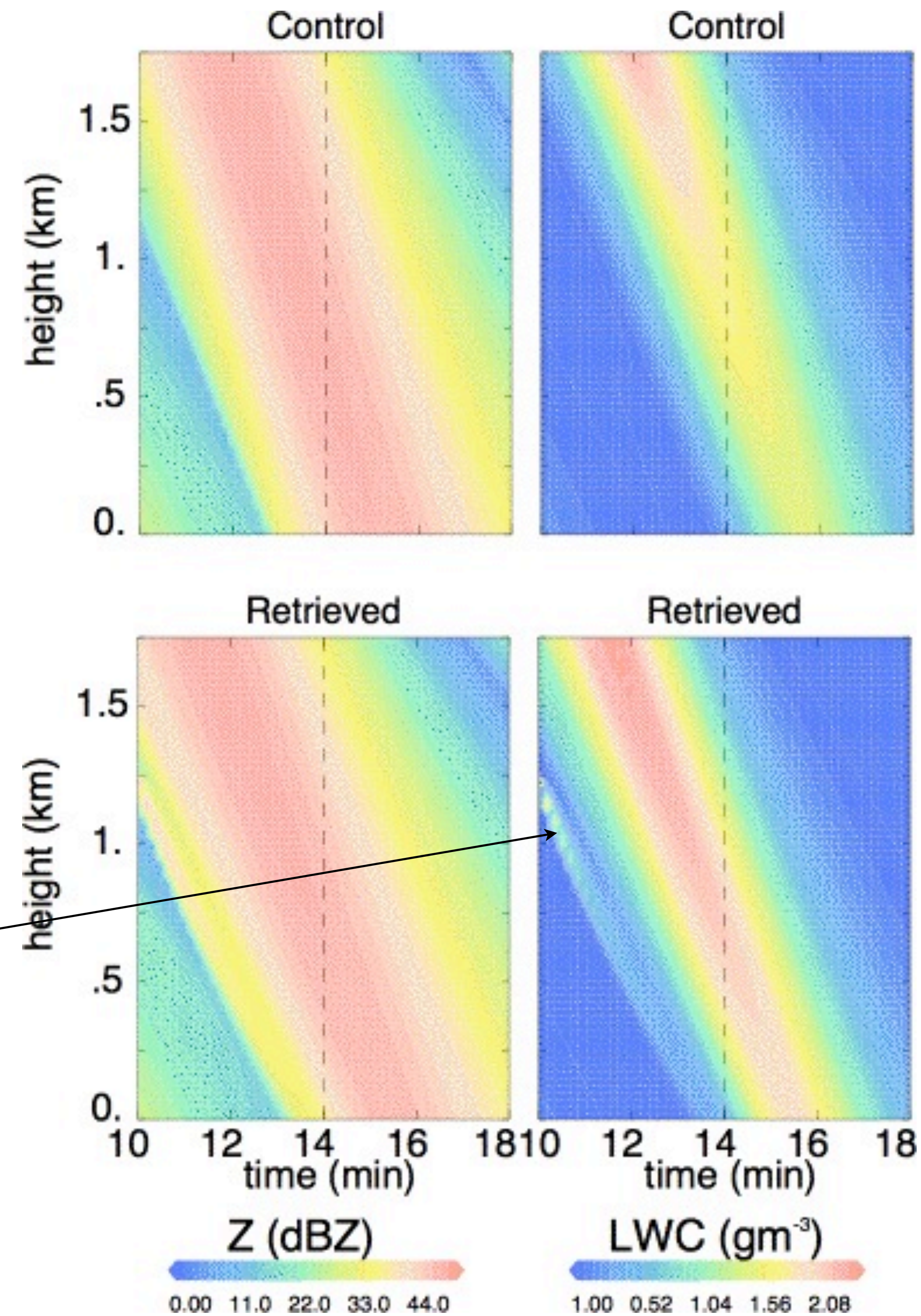



Δx = 4 km
z (km)
x (km)
Δx = 250 m
z (km)
x (km)

Effect of model erros on assimilation

Simulation using data assimilation (model as strong constraint) into a simple model of freely falling rain-shaft with a 2-parameter DSD representation. Note that 3 parameters are needed to correctly describe the DSDs of falling drops.



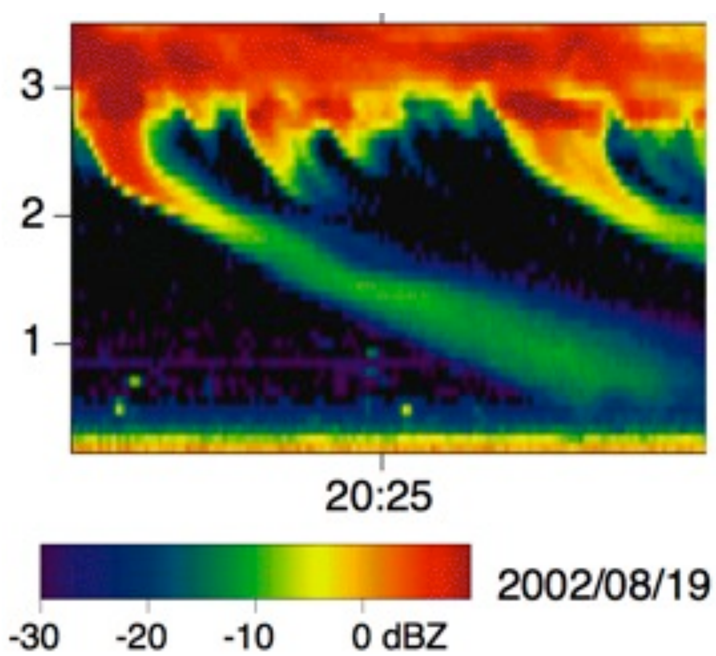


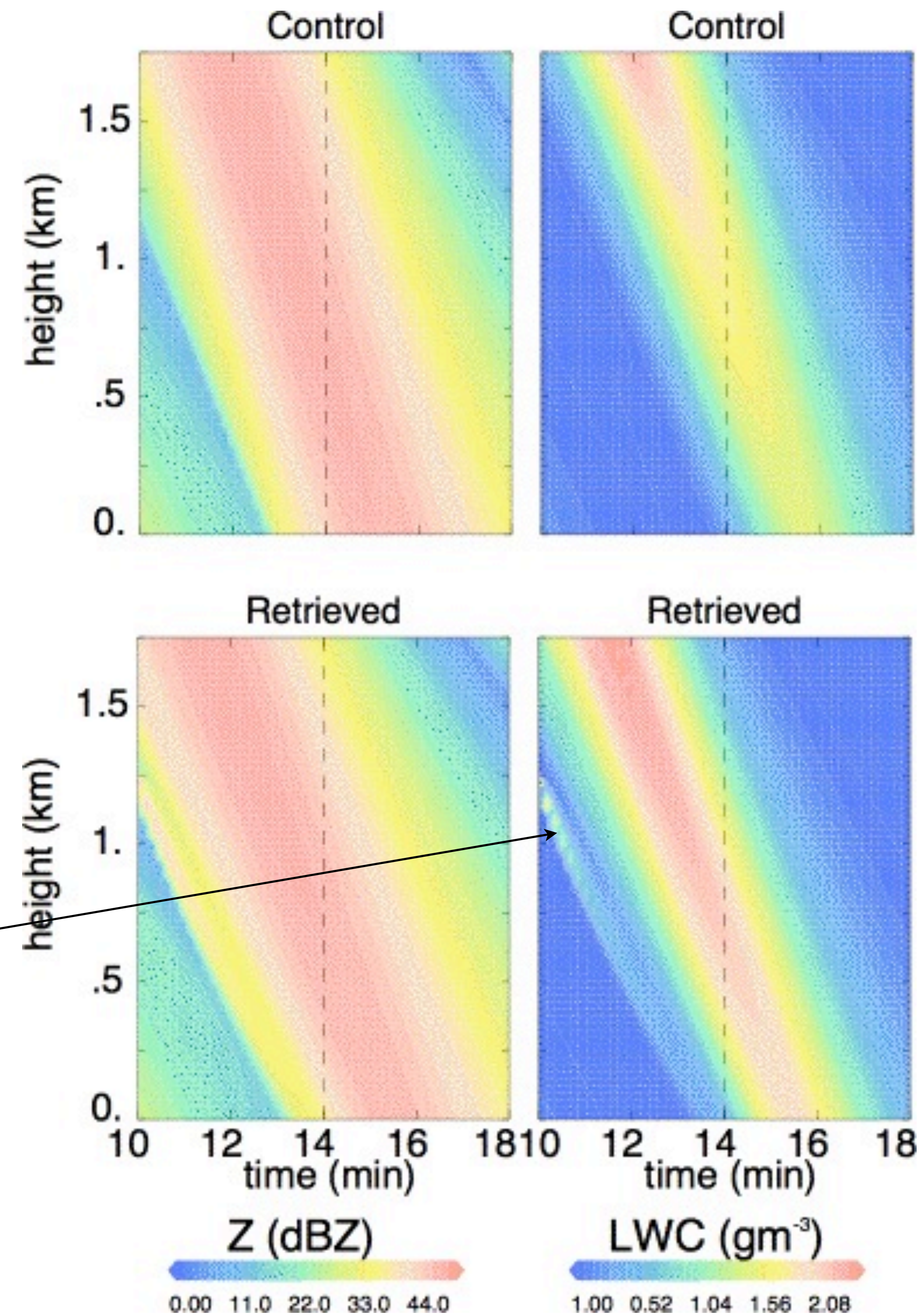
Note a second shaft due to model error

Effect of model erros on assimilation

Simulation using data assimilation (model as strong constraint) into a simple model of freely falling rain-shaft with a 2-parameter DSD representation. Note that 3 parameters are needed to correctly describe the DSDs of falling drops.

Observations



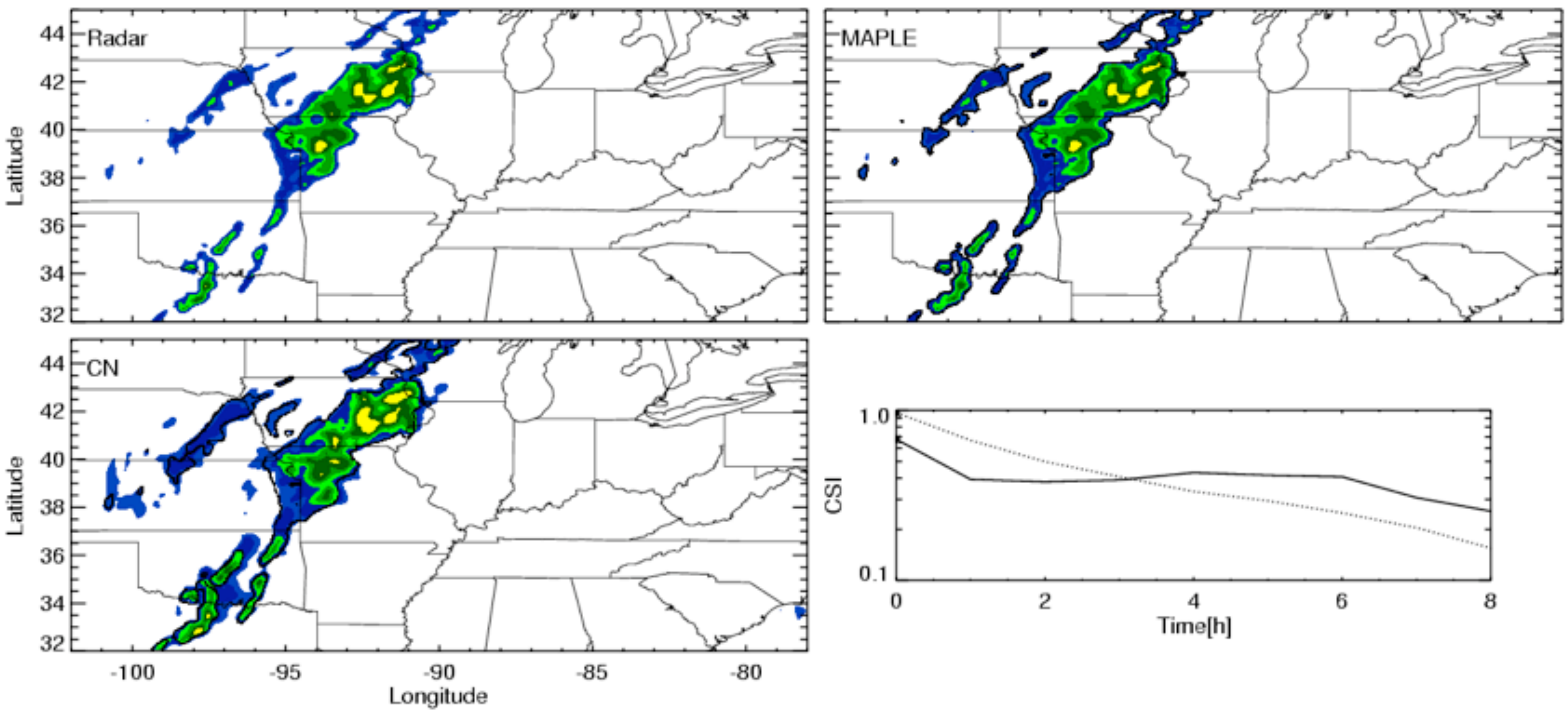


Note a second shaft due to model error

Encouraging signs

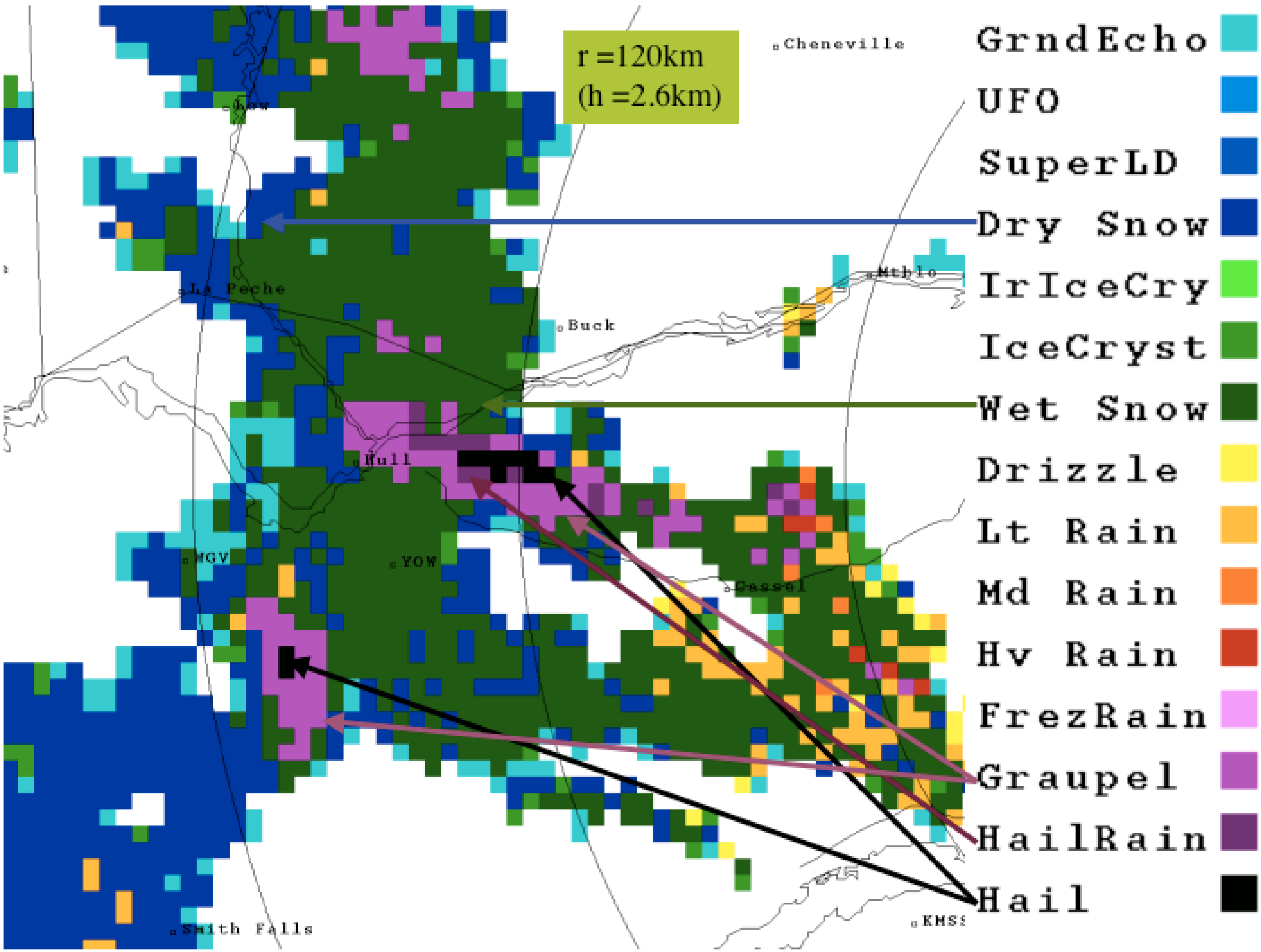
Our experience shows that, in spite of the uncertainties, assimilation leads to nowcast that can beat MAPLE

Experiments at OU with radar data assimilation show significant improvements in the first 8 hours and marginal improvement thereafter

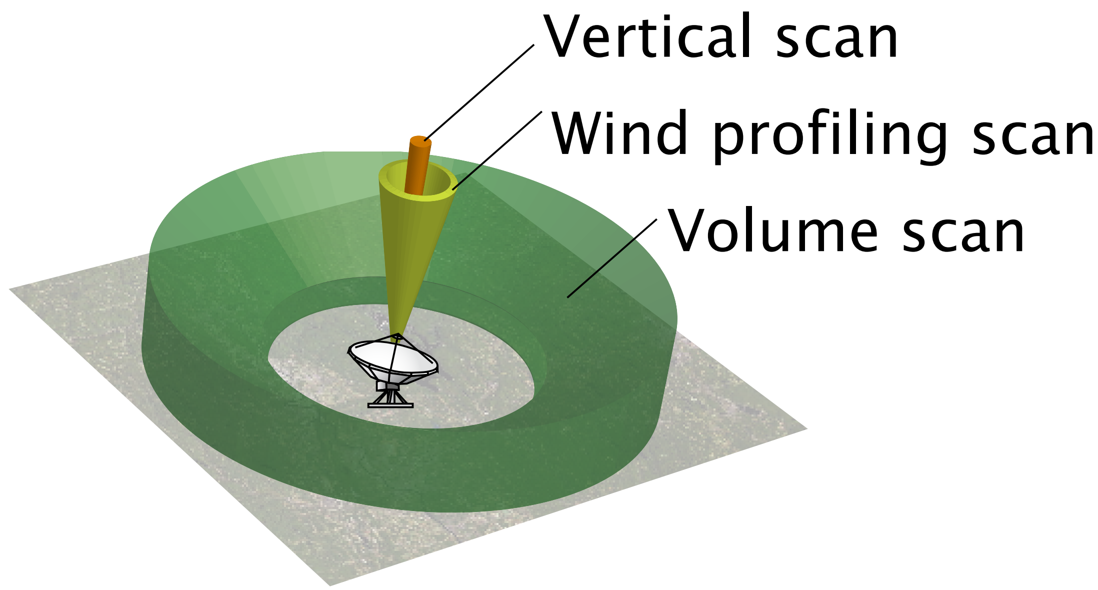


Adaptation of Hardware to Data Assimilation

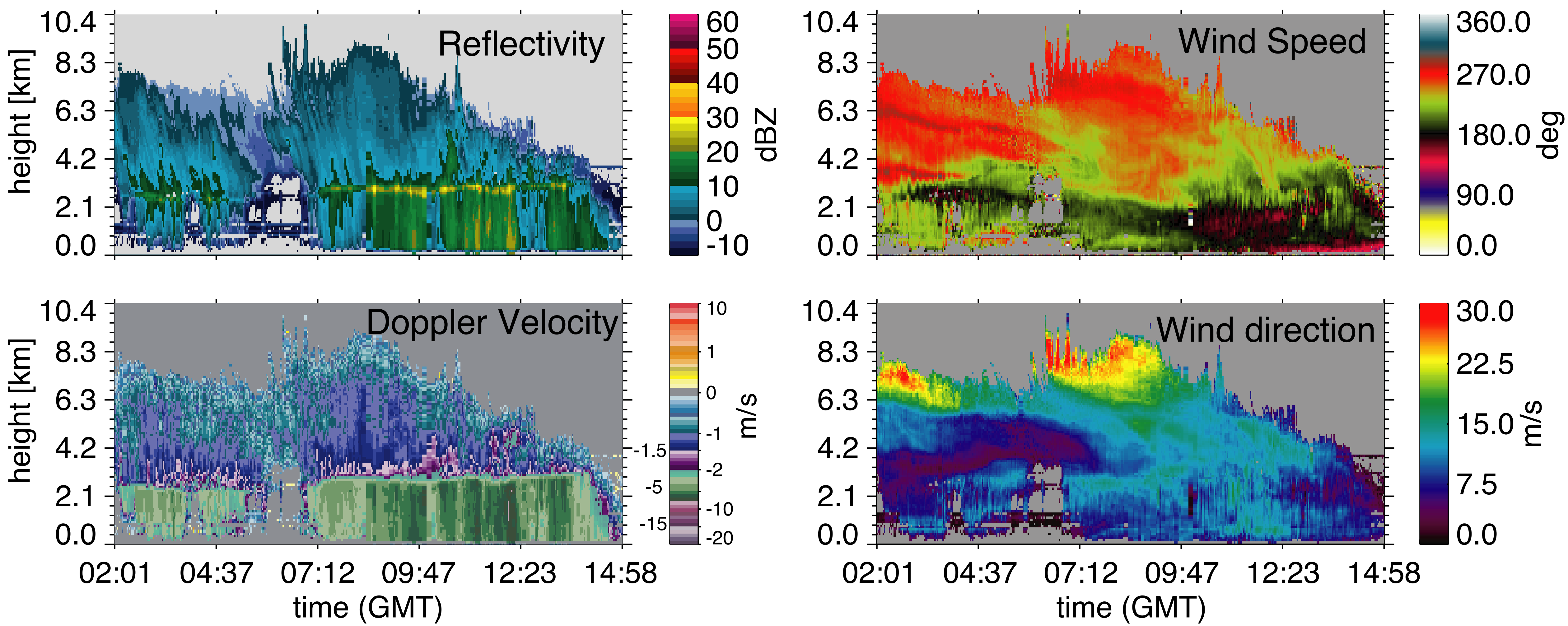
Target ID by polarimetry



Total scan



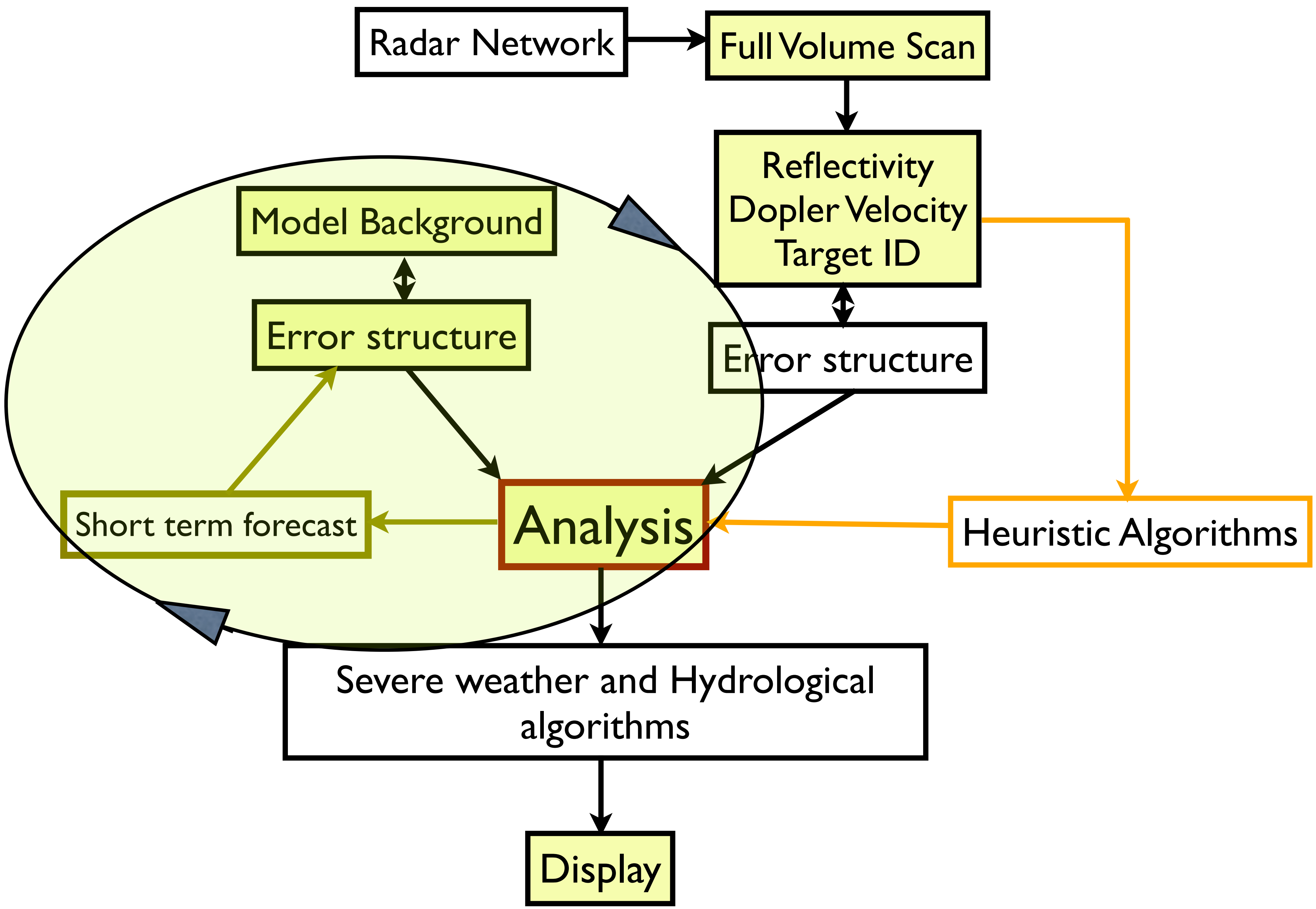
Vertical scan
Wind profiling scan
Volume scan



Reflectivity
Wind Speed
Doppler Velocity
Wind direction
height [km]
10.4
8.3
6.3
4.2
2.1
0.0
dBZ
60
50
40
30
20
10
0
-10
deg
360.0
270.0
180.0
90.0
0.0
m/s
10
1
0
-1
-2
-10
-20
-1.5
-5
-15
30.0
22.5
15.0
7.5
0.0
02:01
04:37
07:12
09:47
12:23
14:58
time (GMT)

MAS implementation

from RAdio Detection And Ranging
to a Mesoscale Analysis System



from RADAR
to MAS

TASKS

- Correct model time-space phase errors to obtain better initial background
- Determine forecast error structure to improve the recursive filter
- Determine error structure of the radar volume scans
- Use Lagrangian persistence of ANALYSIS for updating the background
- Put the microphysics into the model; expand microphysics
- Use ANALYSIS as initial conditions for the model and use the forecast for assessing effectiveness of MAS
- Use the 15 min forecast for updating the background
- Study the most effective way of sampling the atmosphere adaptively

ETC.

AND I NEED $200K/Y FOR THREE YEARS TO COMPLETE THE PROJECT