Best Estimate Sedimentation Doppler Velocity from EarthCare Cloud Profiling Radar

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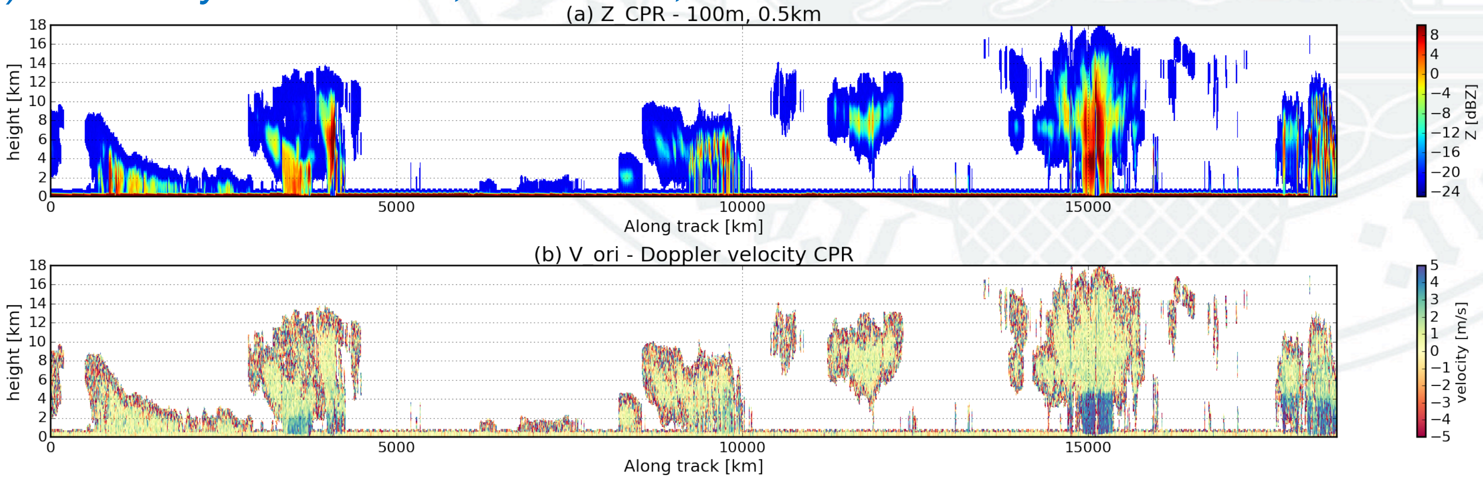
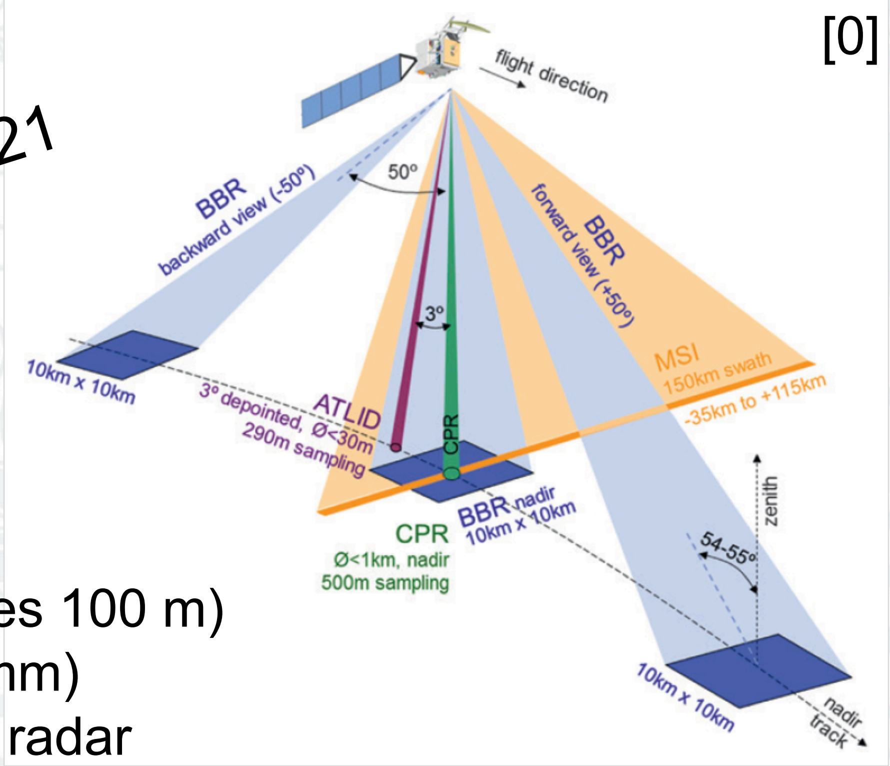


EarthCARE mission & the Cloud Profiling Radar (CPR)

- Earth Clouds, Aerosol and Radiation Explorer (EarthCARE) mission
  - Joined mission between ESA and JAXA
- Instruments:
  - CPR - Cloud profiling radar
  - ATLID - High spectral resolution lidar
  - MSI - Multispectral imager
  - BBR - Broadband radiometer

Launch 2021



- CPR - Cloud profiling radar
  - Food-print: 0.5 km (0.8 km at ground)
  - Resolution volume: 0.5 km (Oversampling enables 100 m)
  - Frequency: 94.05 GHz (W-band, λ=3.2 mm)
  - Doppler capability – first space-borne Doppler capable radar
    - Highly influenced measurement – satellite motion, NUBF, miss-pointing

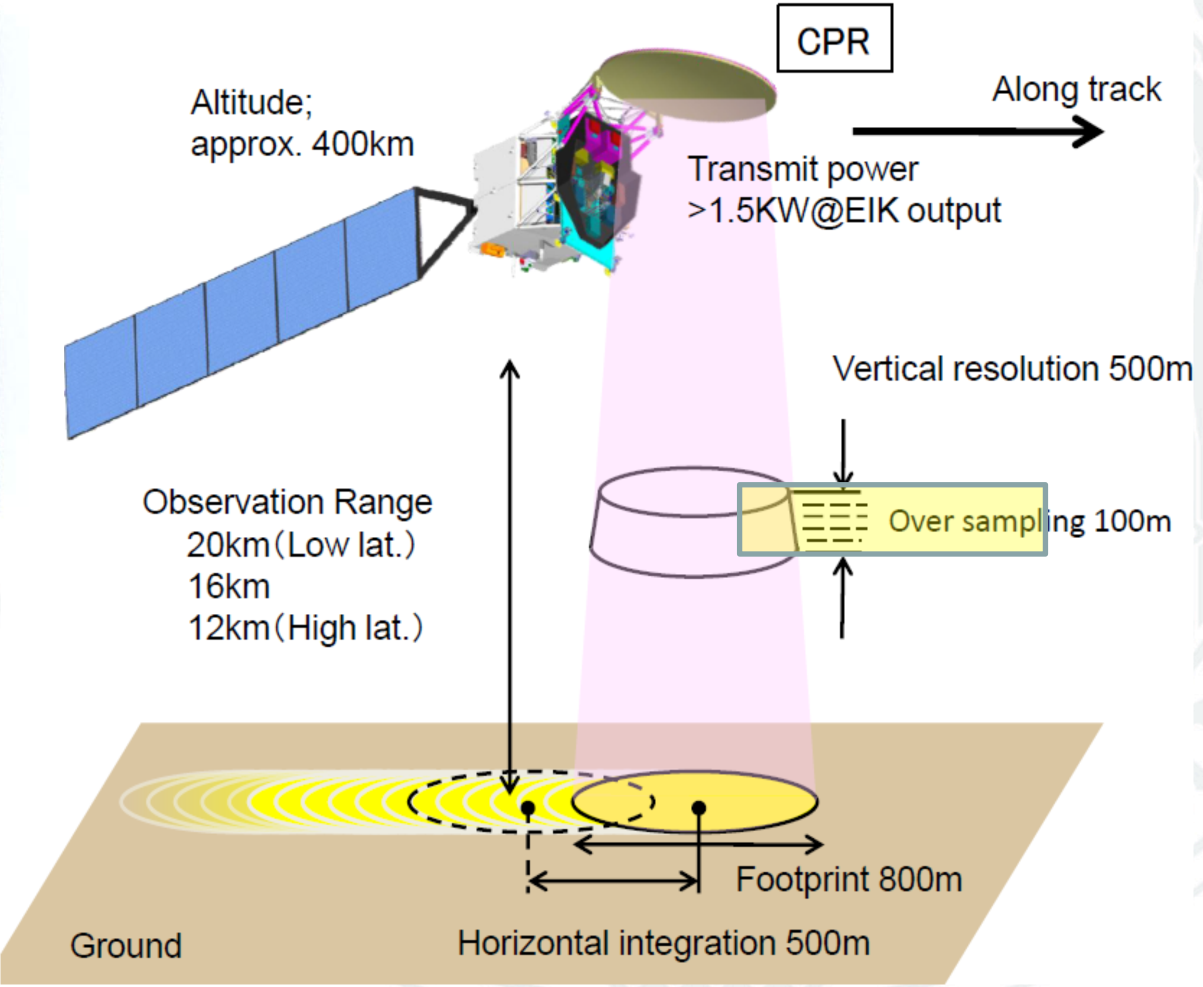
➢ **How can we make best use of the CPR Doppler velocity**

[0] Illingworth et al., 2015, BAMS

EarthCARE Cloud Profiling Radar (CPR)

- 94 GHz Doppler radar
- Antenna diameter: 2.5 m
- Sensitivity: -35 dBZ
- Better sampling:
  - of high ice clouds
  - of liquid water clouds

FIG. 5. The 2.5-m antenna for the 94-GHz radar.



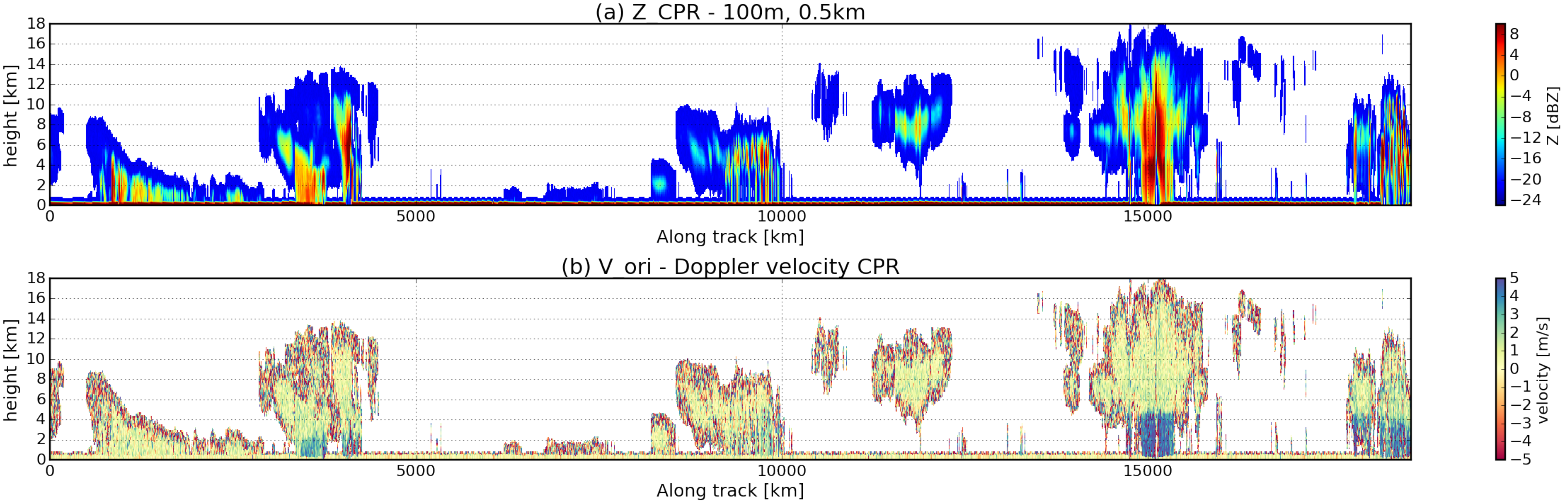
- Doppler velocity:
- PRF: 6100-7500 Hz (variable)
- Nyquist velocity: $\pm$ 4.8 - 6.0 ms^{-1}
- Doppler velocity influenced by
  - antenna miss-pointing
  - Non Uniform Beam Filling (NUFB)
  - satellite motion
  - multiple scattering

➢ Noisy CPR Doppler velocity measurement

Kollias et al., 2014; Illingworth et al., 2015; Burns et al., 2016; Nakatsuka et al., 2008

How does the CPR perform?

- Simulation of the signals based on the EarthCare test scenes
  - Global Environmental Model (GME) from Environment Canada Resolution
- Forward simulations of the EarthCare CPR [1,2]
  - Including the correction for the antenna miss-pointing
  - Including the correction for the Non Uniform Beam Filling (NUFB)
  - Including the correction of the Satellite motion



[1] Kollias et al., 2014; [2] Sy et al., 2014, IEEE

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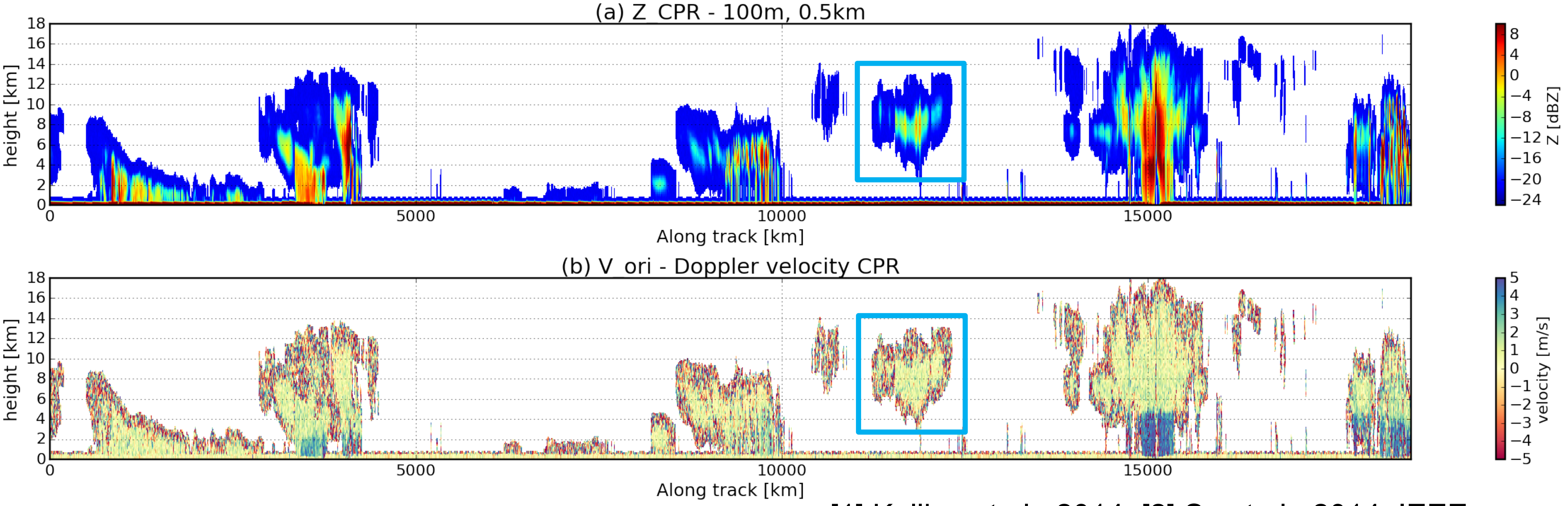


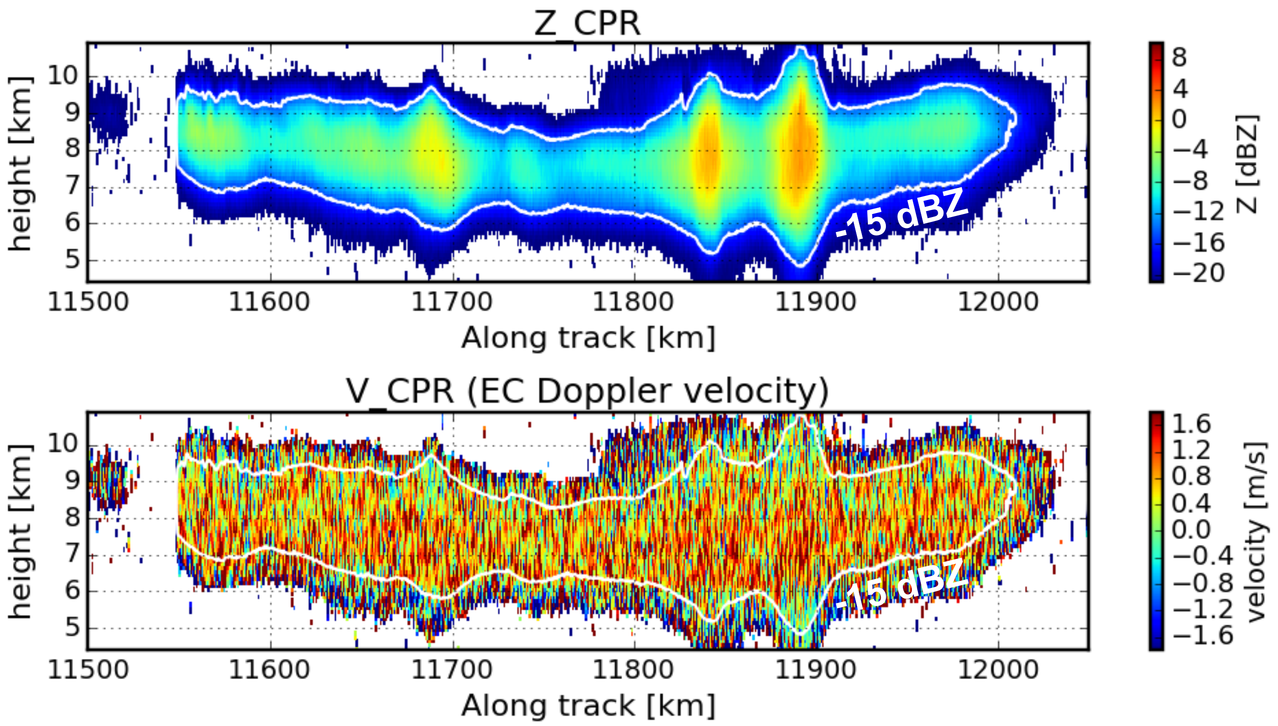
[1] Kollias et al., 2014; [2] Sy et al., 2014, IEEE

Simulated CPR Doppler velocity

- Noisy Doppler velocity measurements
- RMSE > 0.9 m/s

- How to make make us of the Doppler velocity measurements?
  - microphysical analysis or retrievals

- V_CPR = V_air + V_true
  - V_CPR: Doppler velocity
  - V_air: air motion (vertical)
  - V_true: hydrometeor terminal fall velocity



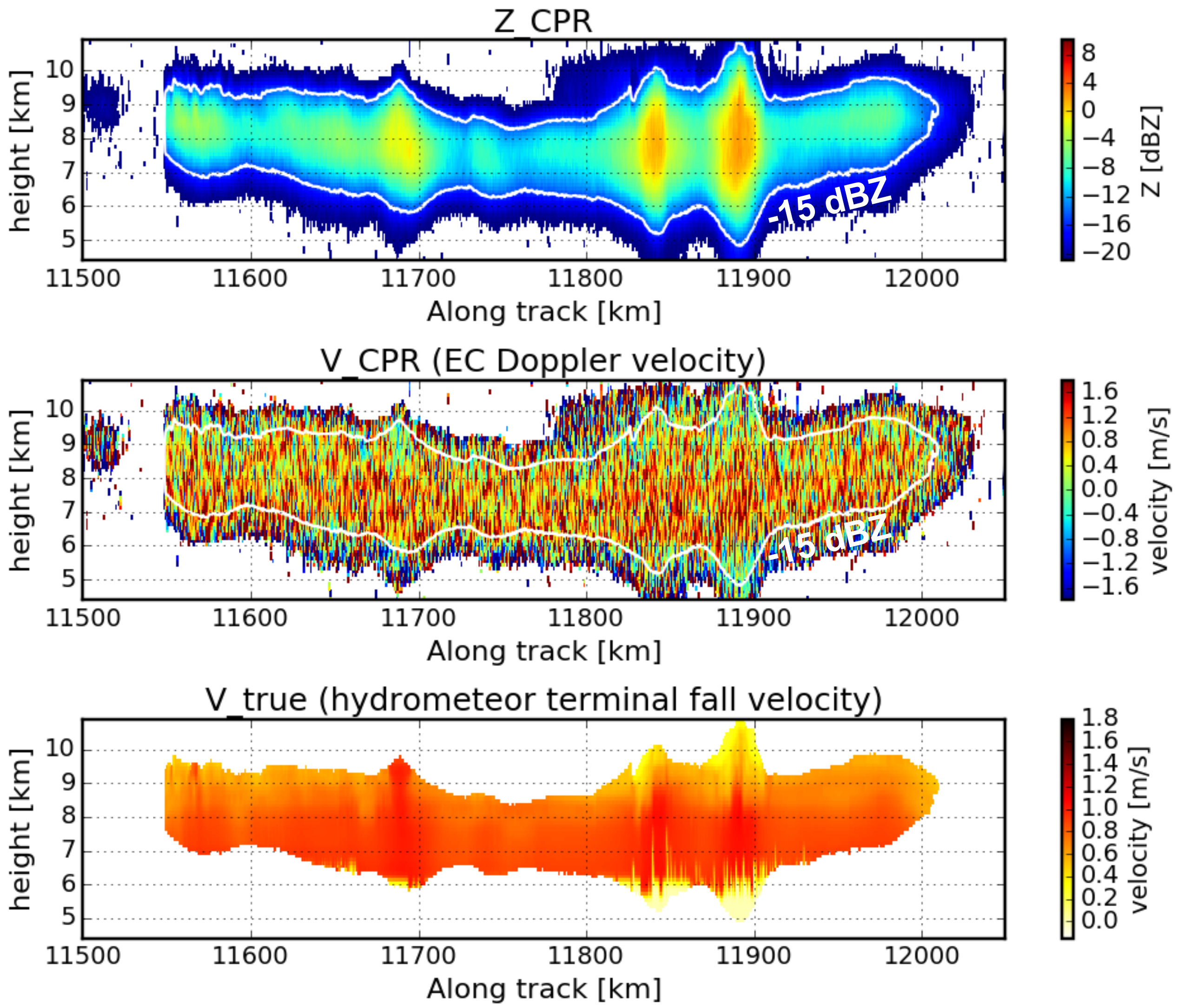
<u>Question:</u>

How can the quality of the Doppler velocity be improved?

Objectives:

Improve the Doppler velocity estimation for space for the EarthCare and future missions

- Statistical modeling (power-law fits)
- De-noising techniques (low pass filtering of the pulse pair correlation function)



V_CPR: Doppler velocity – V_air: air motion (vertical) – V_true: hydrometeor terminal fall velocity – Z_CPR: reflectivity

Statistical modeling (power-law fits)

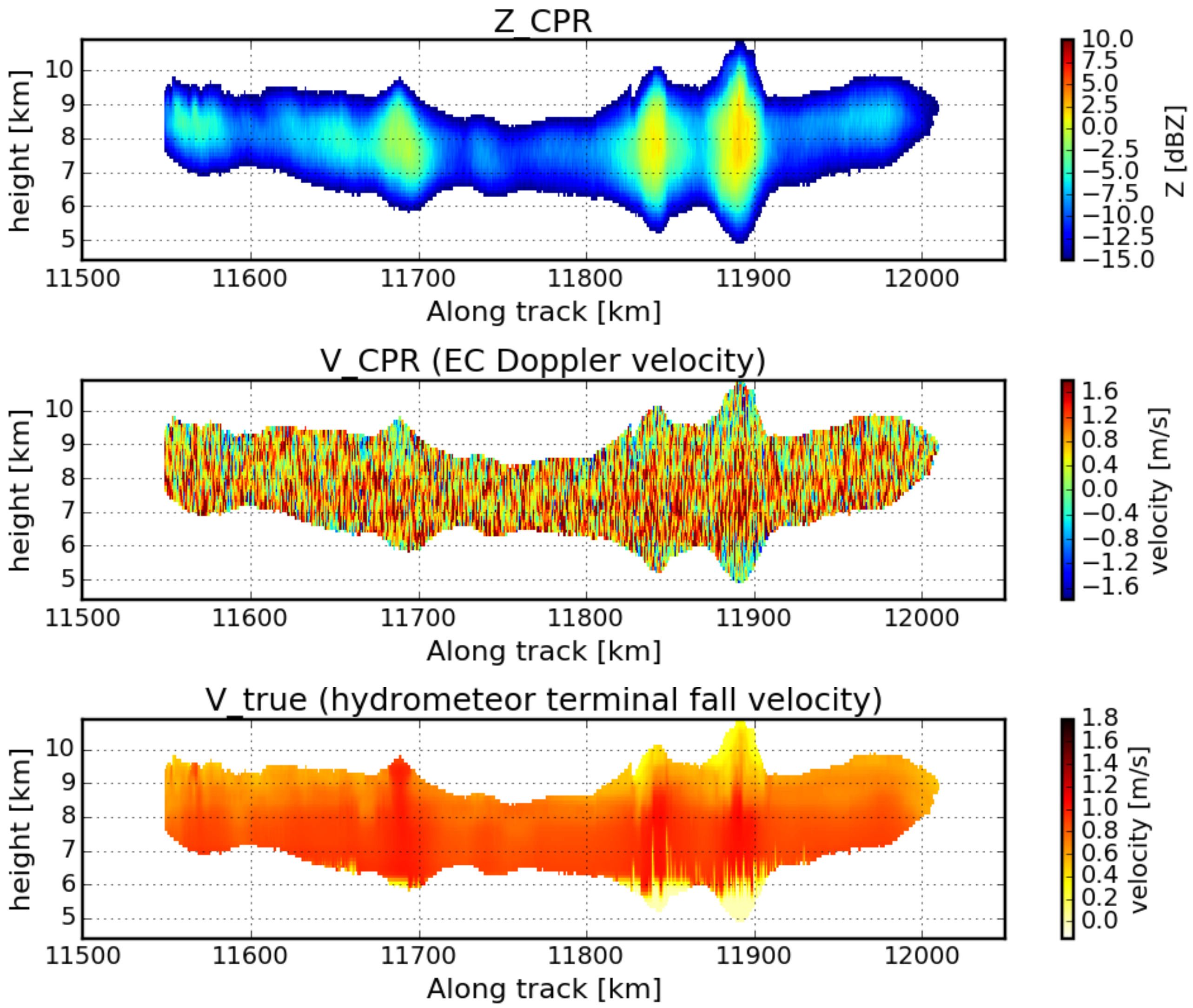
- V_CPR = V_air + V_true

- V_true is the reflectivity-weighted velocity of the particle size distribution in the sensing volume

Assumption: Sedimentation regimes

- V_air << V_true for long temporal averaging
- V_CPR dominated by V_true
- Using power-law fits to derive terminal particle fall velocity

$$Vt = a\ Z\_CPR^{\ b}$$



[3]

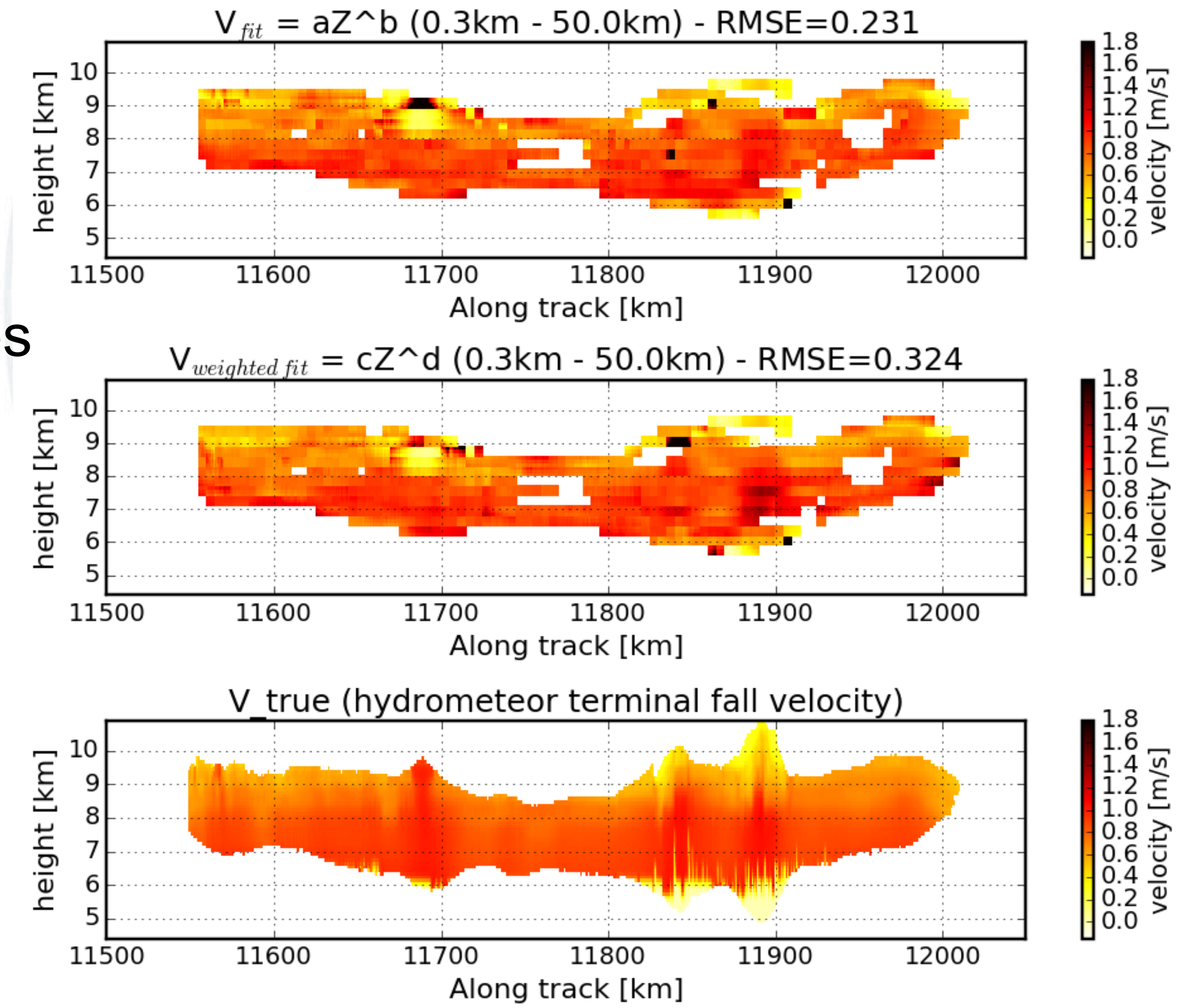
V_CPR: Doppler velocity – V_air: air motion (vertical) – V_true: hydrometeor terminal fall velocity – Z_CPR: reflectivity

[3] Kalesse & Kollias, 2013, JC

Statistical modeling (power-law fits)

- fit per 50km x 0.3km
- fit per 2dBZ bined and averaged V_CPR
- discard bins with low number of data point

➢ Improved of hydrometeor fall velocities



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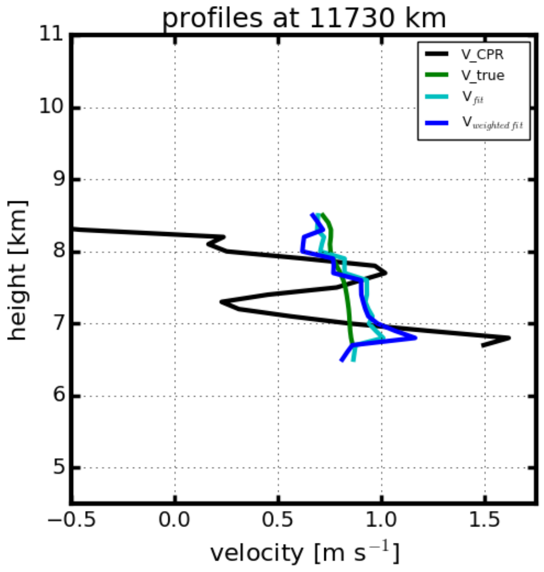
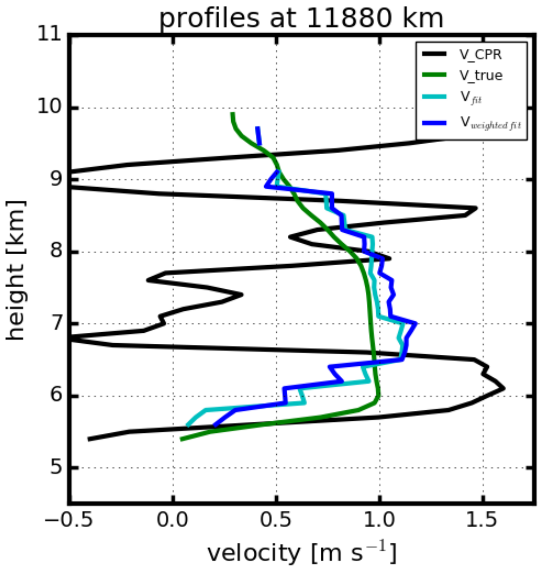
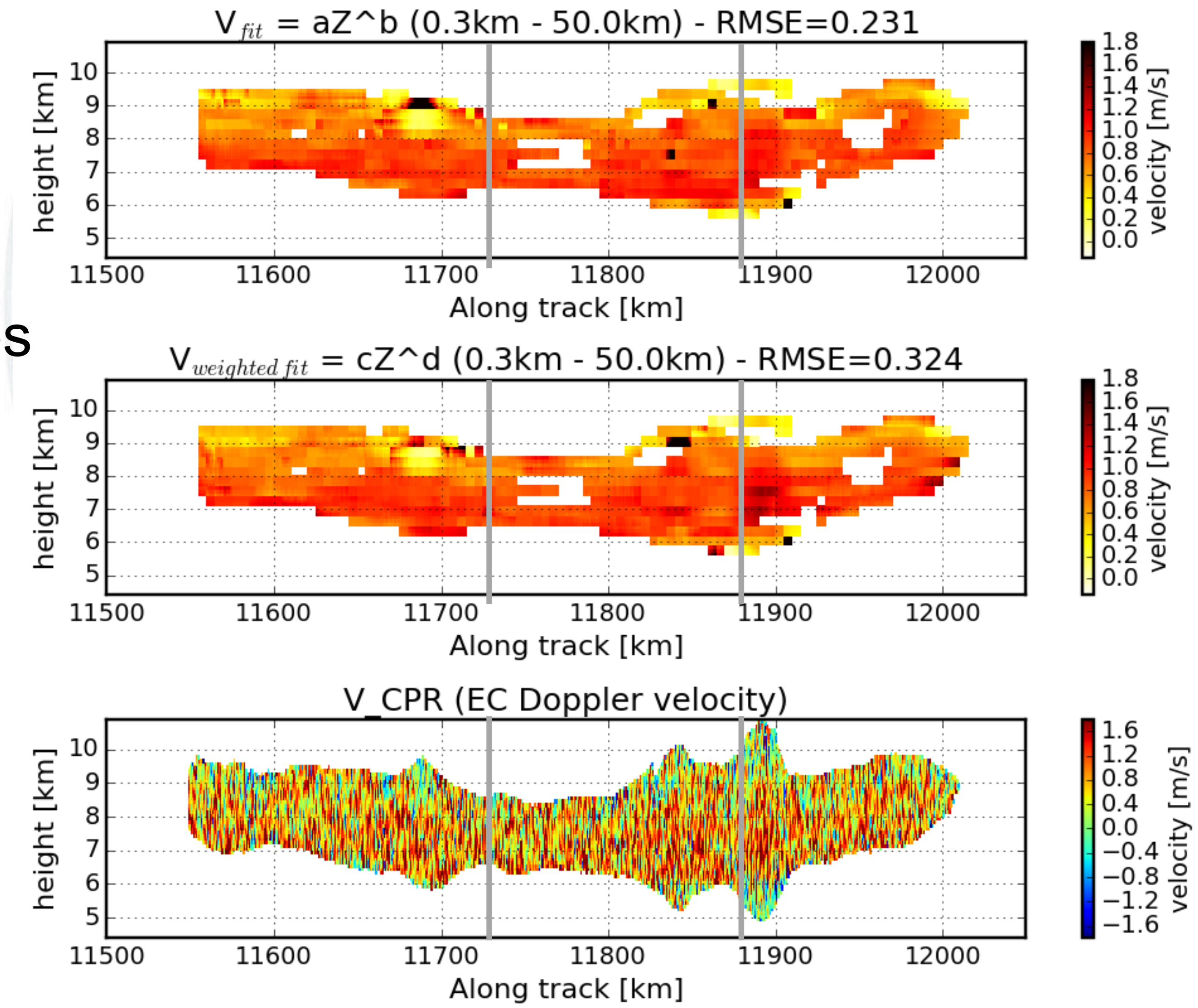
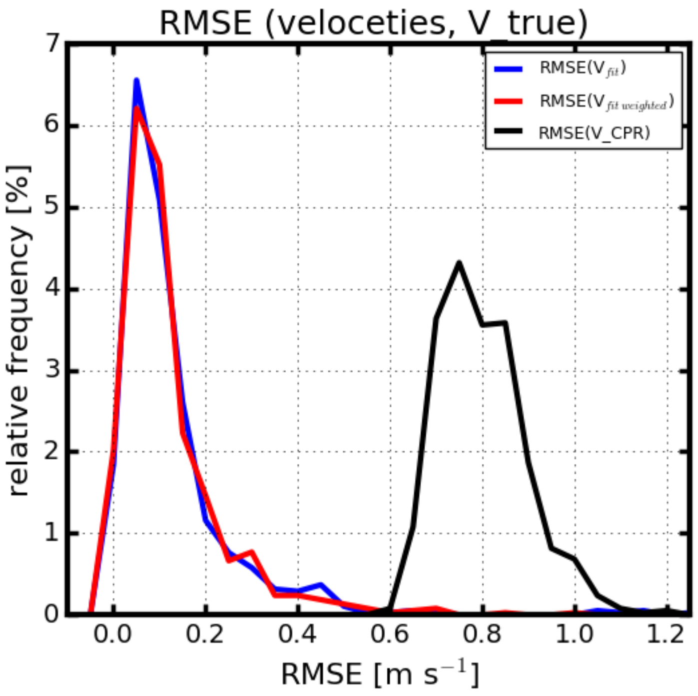


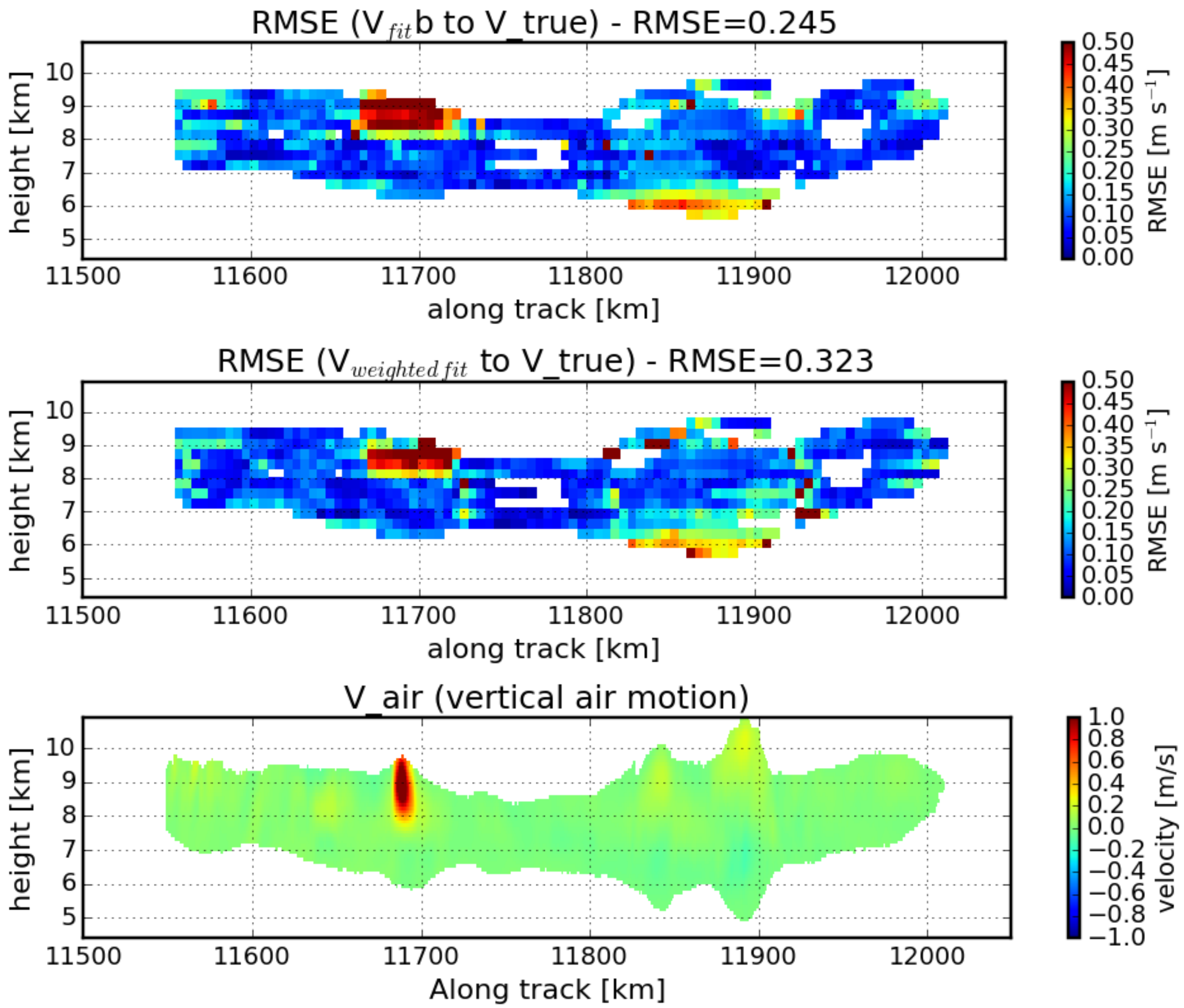




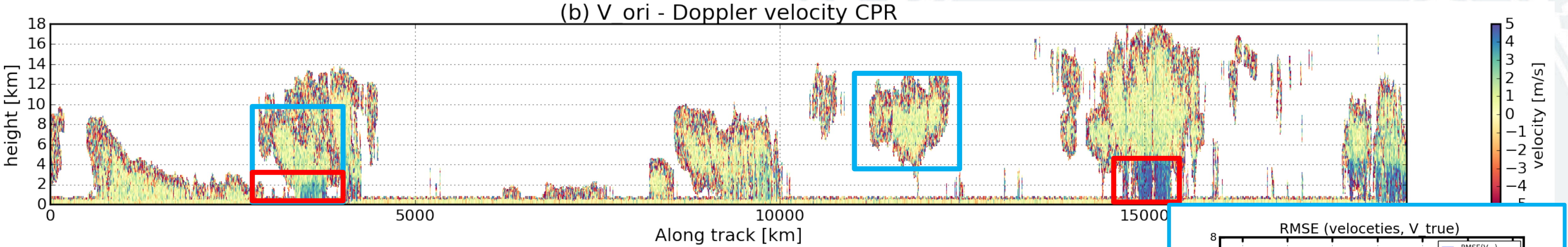
Statistical modeling (power-law fits)

- Reduction of the RMES
  - RMSE(V_CPR) = 0.84 m/s





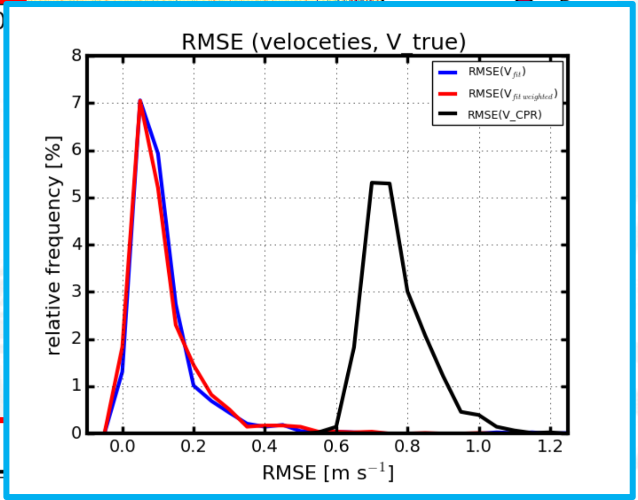
Summary: statistical modeling (power-law fits)

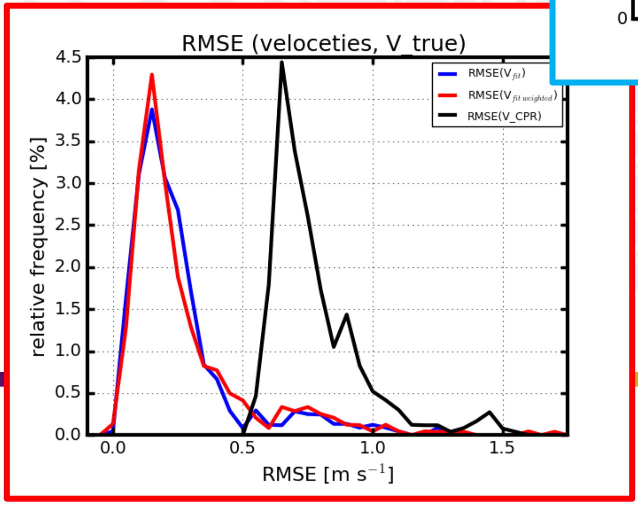


Retrieval of hydrometeor fall velocities within sedimentation regimes

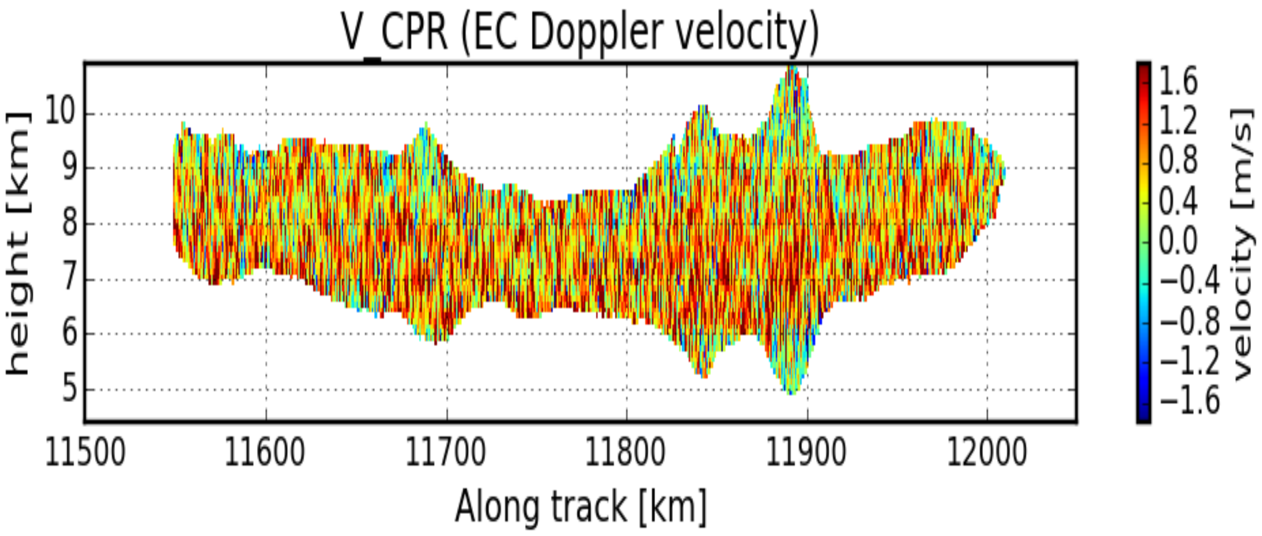
- decreasing of RMSE
- Improved retrieval of hydrometeor terminal fall velocity

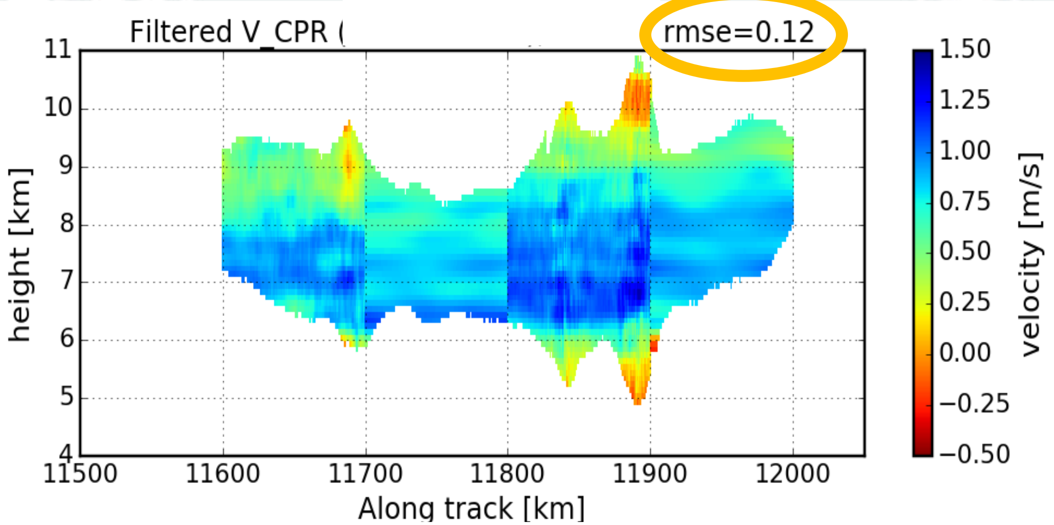
Can we also improve the Doppler velocity estimates and improve the Vt even further?





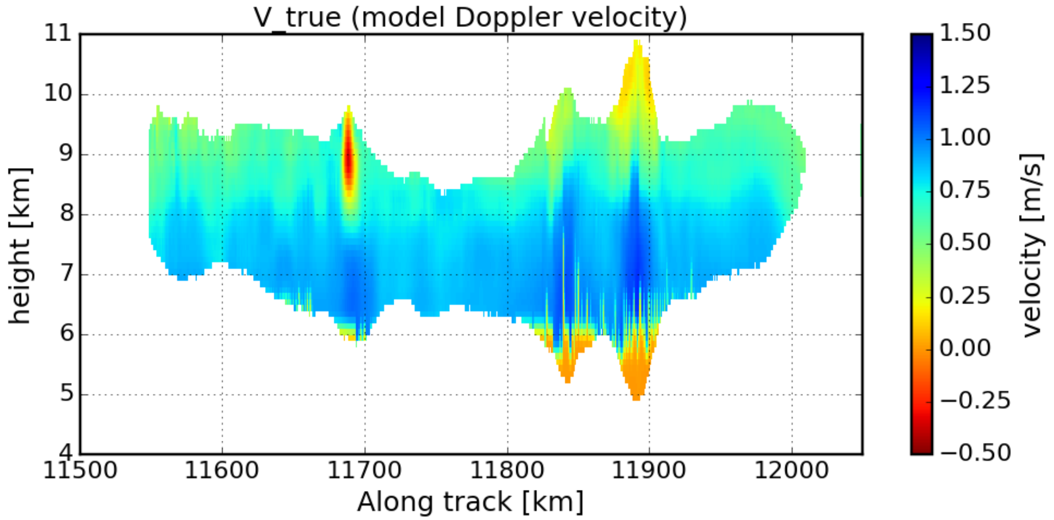
Low pass filtering of the V_CPR





Low pass filter to the measured pulse pairs correlation function to filter out fluctuations [4]

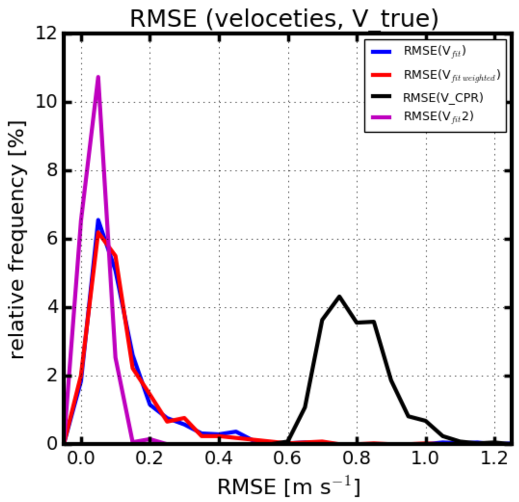
- FFT(pulse-pairs correlation time series)
- Appling a low-pass filter to the spectrum
- Invers FFT to derive the filtered velocity field

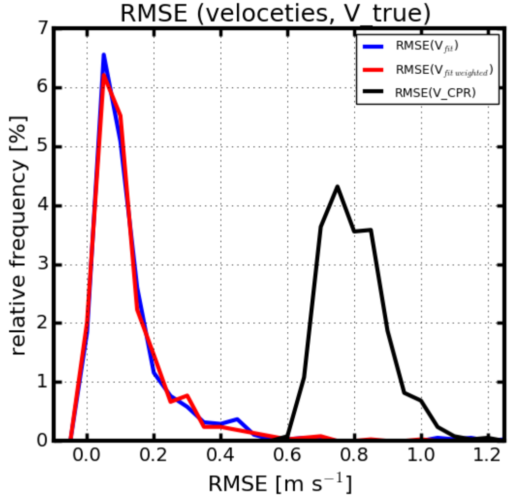


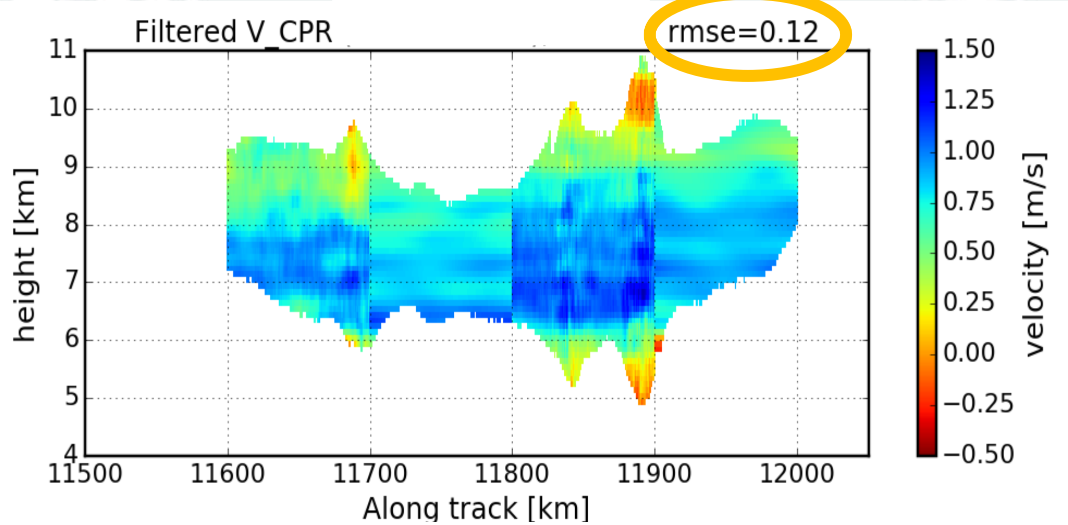
V_CPR: Doppler velocity from the model

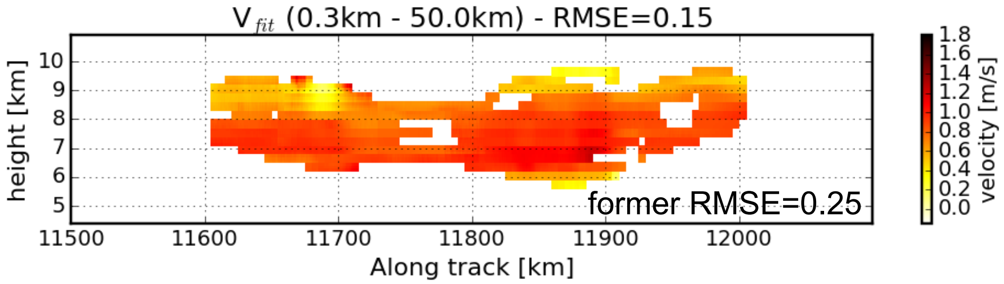
[4] Sy et al., 2014, IEEE

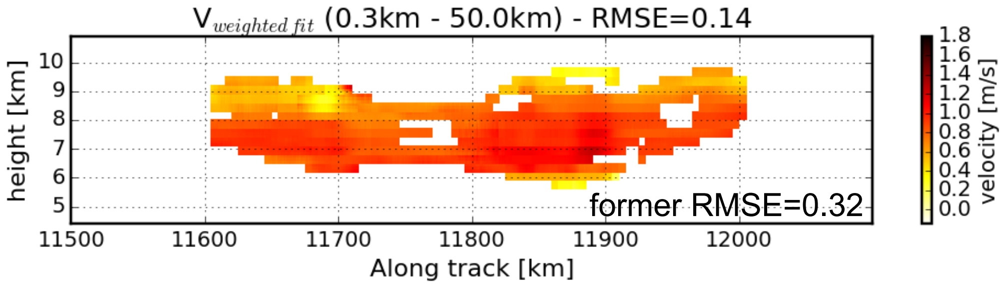
Low pass filtering + statistical filtering











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- FFT(pulse-pairs correlation time series)
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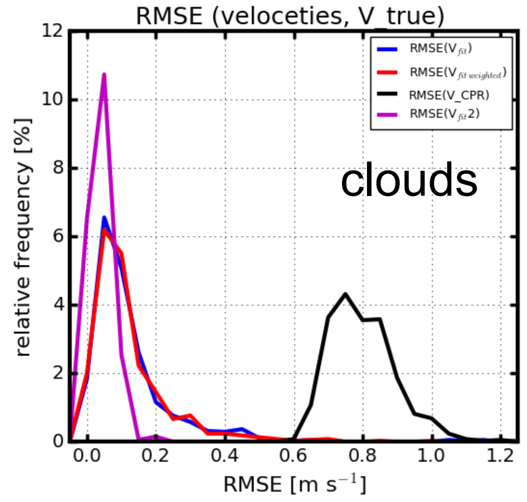
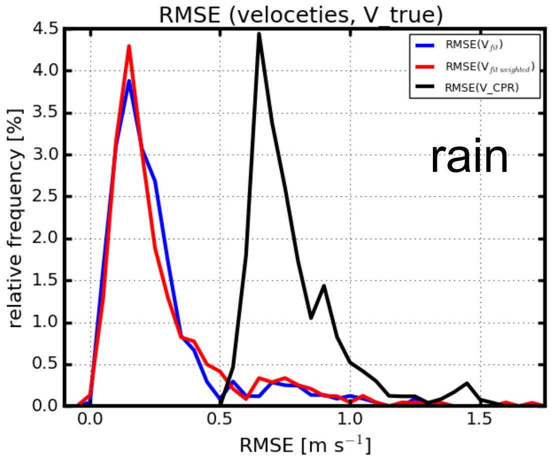
[4] Sy et al., 2014, IEEE

Conclusion and Outlook:

- EarthCare Doppler velocity is a noisy parameter
- In sedimentation regimes Vt can be retrieved (Kalesse & Kollias 2013, JC)
  - Decreasing RMSE(rain) > 0.5 m/s – before > 1 m/s
  - RMSE(cloud) > 0.3 m/s – before > 0.8 m/s
- Adaptive low pass filtering of the V_CPR

1) improves the quality of the estimated Doppler velocity
2) the quality of the retrieved Vt (RMSE(cloud) > 0.15 m/s)

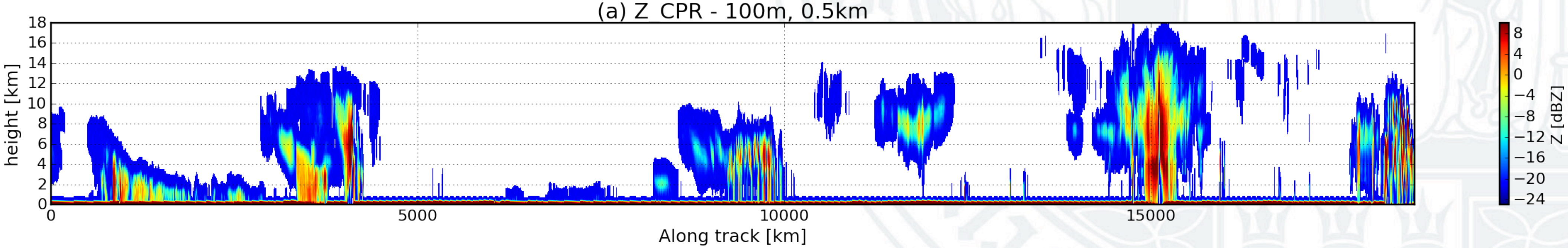


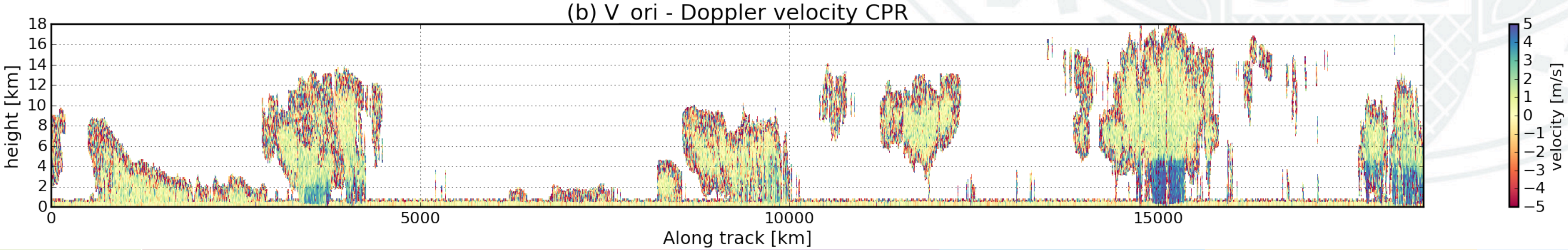


<u>Outlook:</u>

- Statistical modeling: improve quality check of the fits
- Low pass filtering: apply statistical filter selection based on measured data only

  ➔ to make technique operational

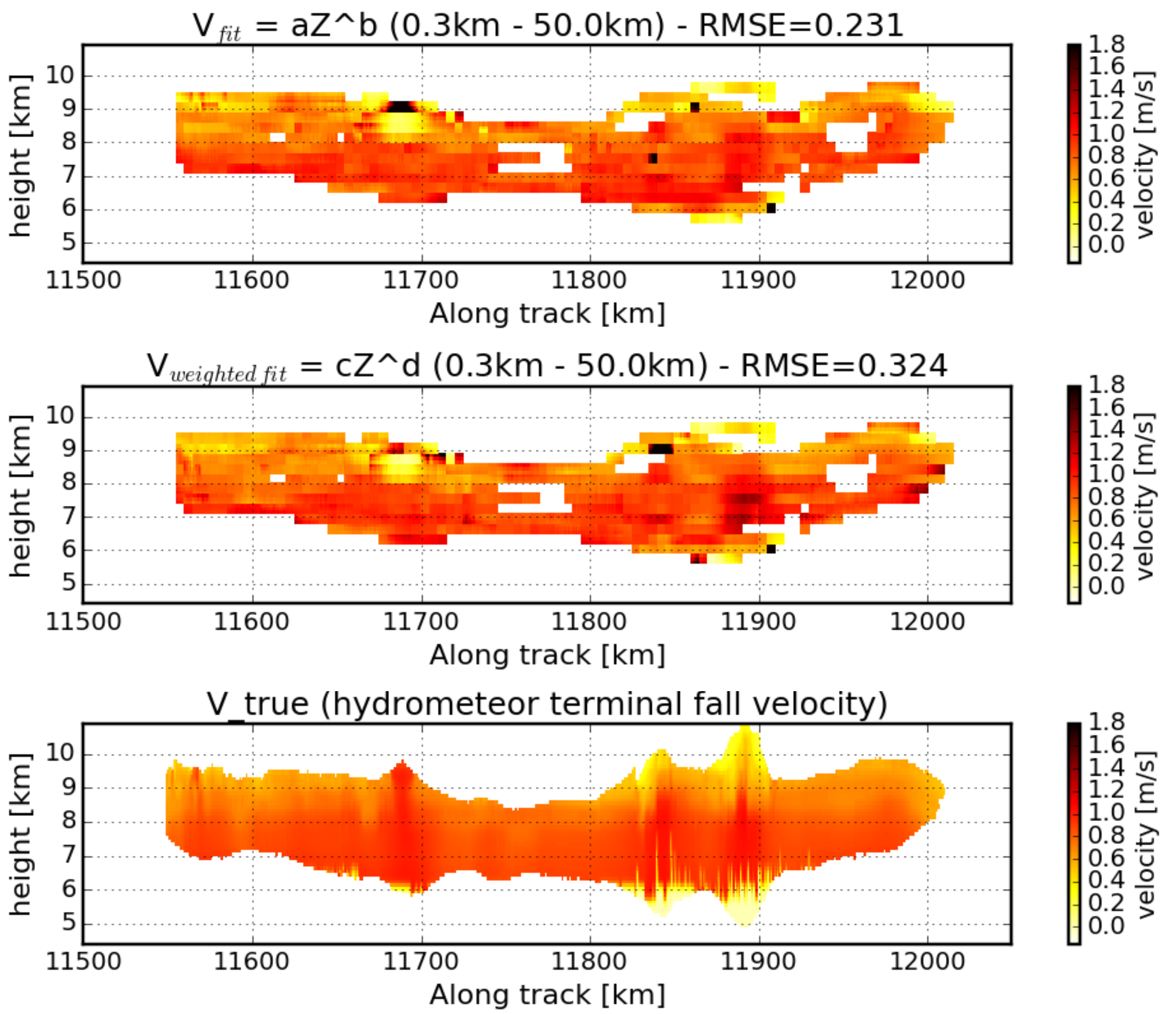

(a) Z_CPR - 100m, 0.5km
height [km]
Along track [km]
Z [dBZ]


(b) V_ori - Doppler velocity CPR
height [km]
Along track [km]
velocity [m/s]

Statistical modeling (power-law fits)

$$Vt = a\ Z\_CPR^{\,b}$$

- One fit per 50km x 0.3km
- 2dBZ bins to do the fit
- Quality check
- Analyze results against V_true
  - RMSE V_CPR: 0.84
- ➢ Significant reduction of the RMSE



Vt: hydrometeor terminal fall velocity – Z_CPR: reflectivity – V_true: hydrometeor terminal fall velocity (model)

[3] Kalesse & Kollias, 2013, JC

Statistical modeling (power-law fits)

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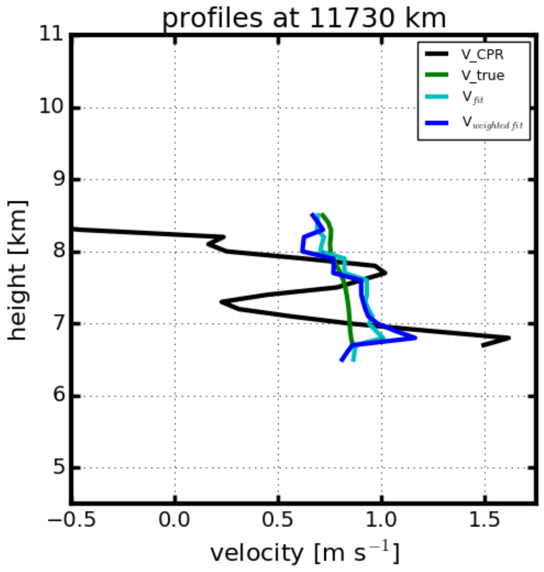
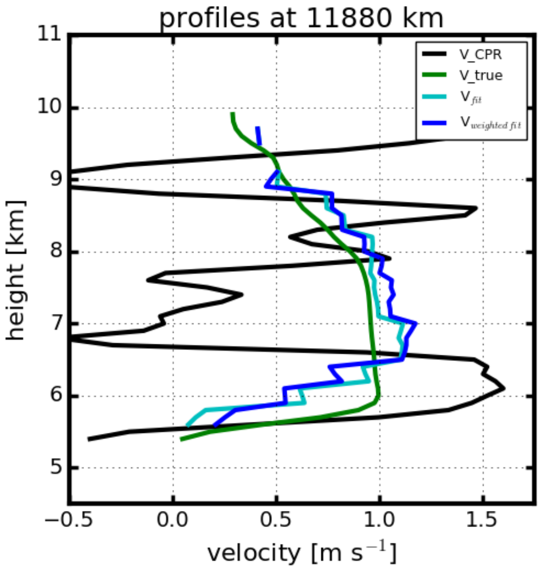
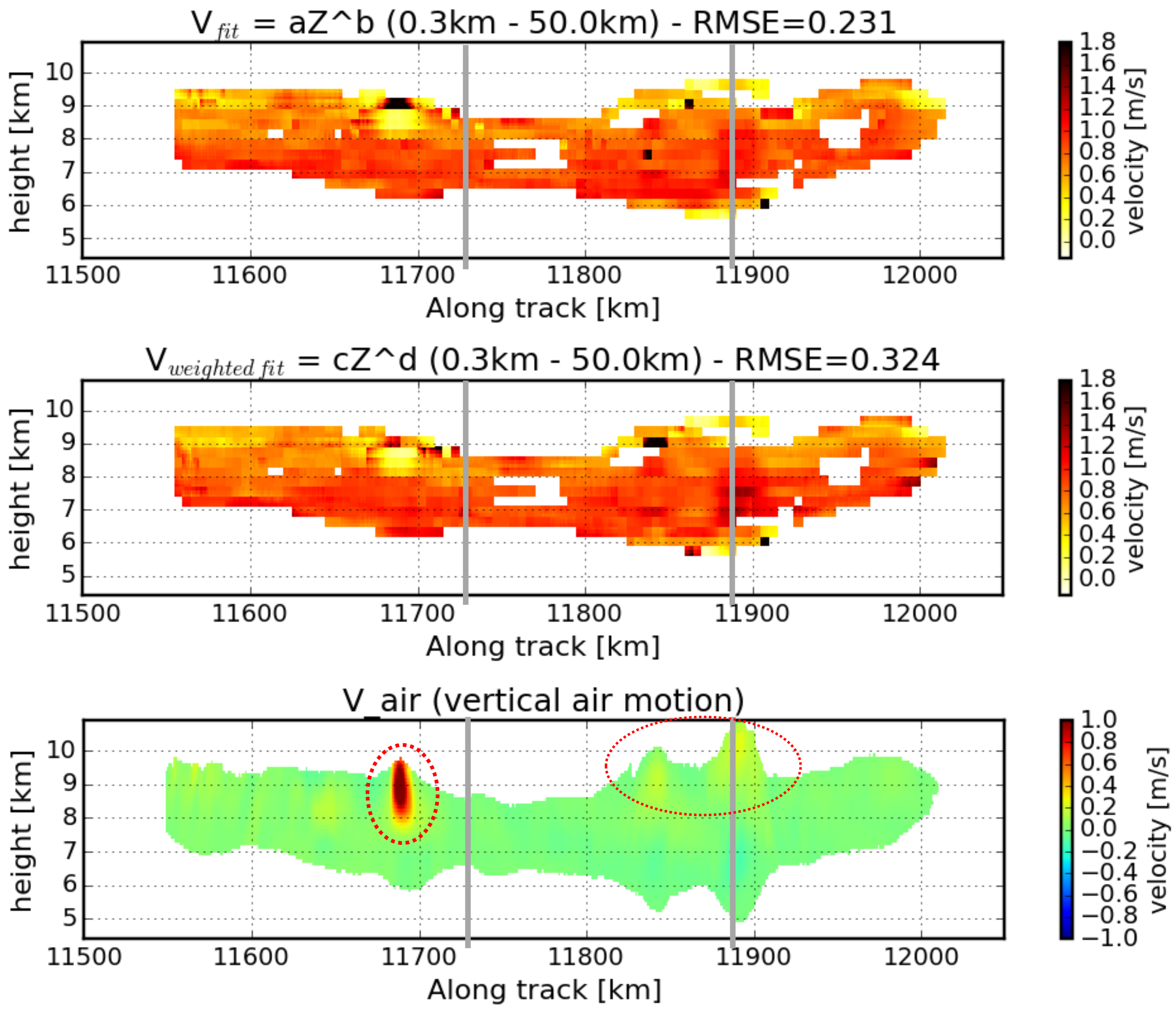
➢ Improvement of V_CPR field





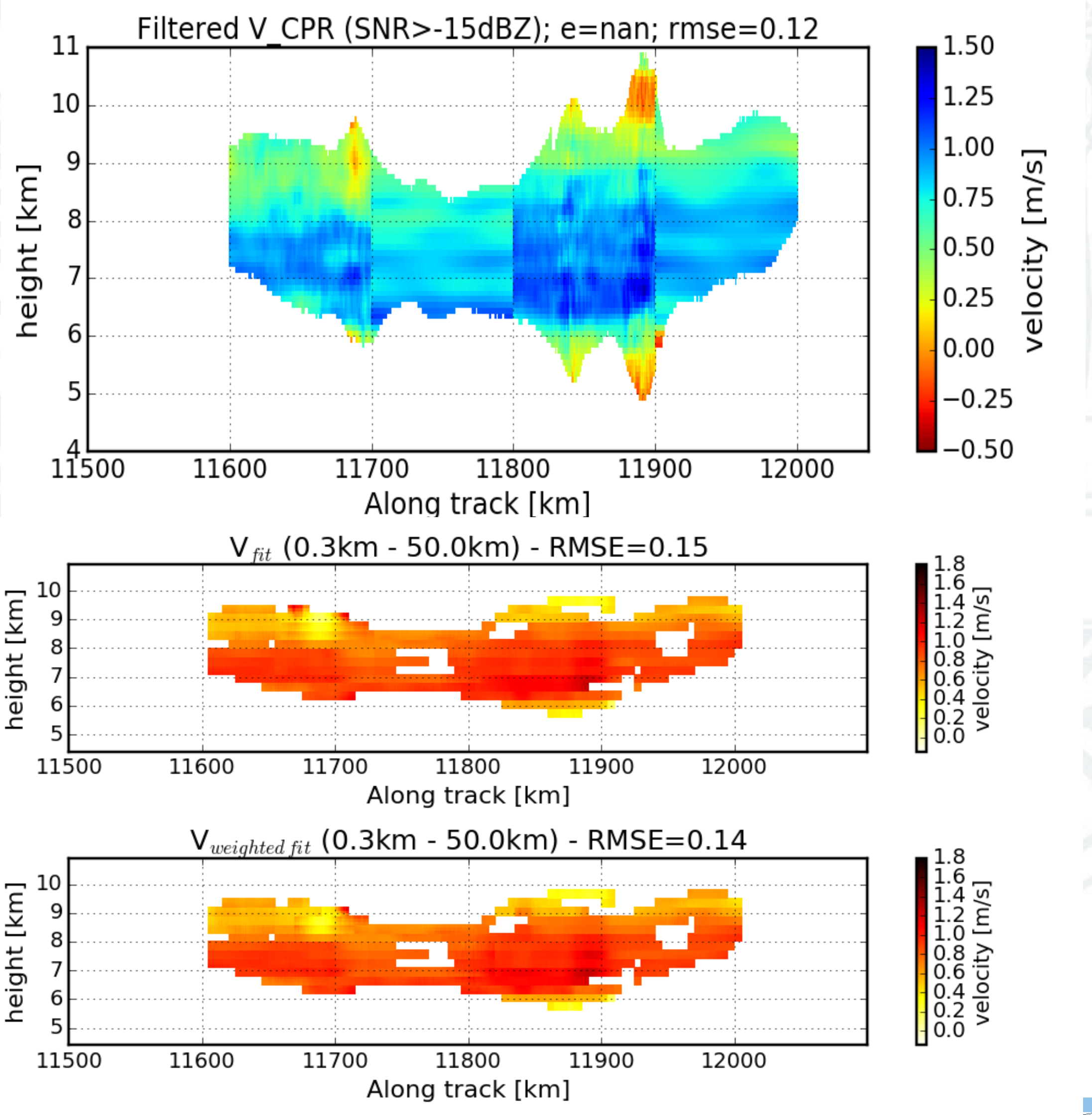


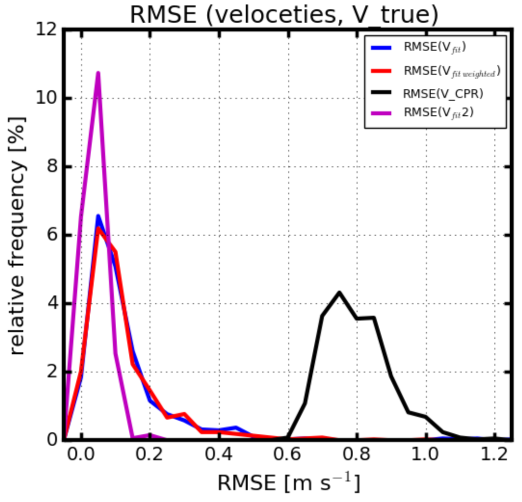
Low pass filtering of the V_CPR

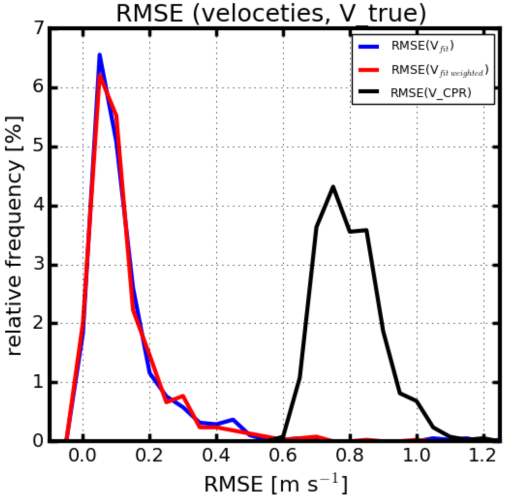
Applying a low pass filter to the measured pulse pair correlation function

- FFT(complex pulse pairs)
- Appling a low-pass filter
- Invers FFT of filtered data

- done in 100km steps along track







[4] Sy et al., 2014, IEEE

Doppler is challenging from space

Signal-to-Noise Dependent

~available at dBZ > -15

Doppler bias due to Non-Uniform Beam Filling

~0.2 ms^{-1} /$dBkm^{-1}$

Velocity aliasing

Nyquist velocity is 5-6 ms^{-1} and up- and downdrafts are ± 10 to 20 ms^{-1}

Attenuation

Multiple scattering

40% of convective cores observations above the freezing level will be useful. MS onset height ~ 8-10 km