Multi-lag Processing to Improve Polarimetric Radar Data Quality

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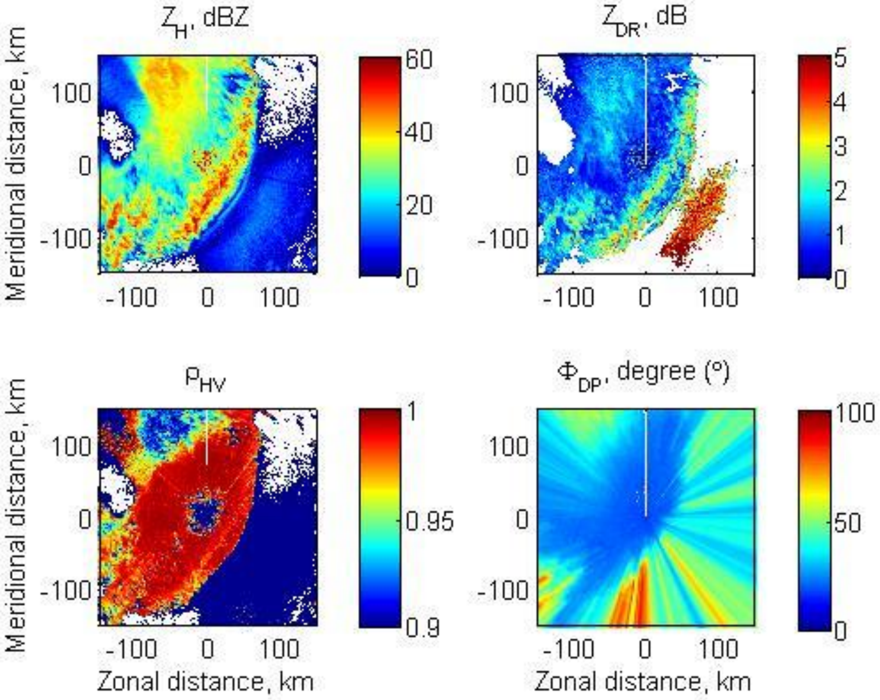
Outline

- Existing estimators
- Multi-lag estimators
- Test with simulations
- Test with OU' data
- Summary



Moment data are obtained from correlation estimates

- Correlation functions are estimated from time-series data (Doviak&Zrnic 1993)

$$\hat{C}_{\mathrm{h,v}}(nT_s) = \frac{1}{M-n}\sum_{m=1}^{M} V^{*}_{\mathrm{h,v}}(mT_{\mathrm{s}})V_{\mathrm{h,v}}((m+n)T_{\mathrm{s}})$$

$$\hat{C}_{\mathrm{hv}}(nT_s) = \frac{1}{M-n}\sum_{m=1}^{M-n} V^{*}_{\mathrm{h}}(mT_{\mathrm{s}})V_{\mathrm{v}}((m+n)T_{\mathrm{s}})$$

- Auto- and Cross-correlation function

$$C_{\mathrm{h,v}}(nT_s) = S_{\mathrm{h,v}}\rho(nT_{\mathrm{s}})\exp(-\frac{j\pi n\bar{v}}{v_{\mathrm{N}}}) + \bullet_{\mathrm{h,v}}\delta_n$$

$$C_{\mathrm{hv}}(nT_s) = \sqrt{S_{\mathrm{h}}S_{\mathrm{v}}}\rho_{\mathrm{hv}}\rho(nT_{\mathrm{s}})\exp(-\frac{j\pi n\bar{v}}{v_{\mathrm{N}}} + j\phi_{\mathrm{dp}})$$

Conventional estimators

- Widely accepted and used (Doviak&Zrnic 1993)

$$\hat{S}_{\mathrm{h,v}} = \hat{C}_{\mathrm{h,v}}(0) - \hat{N}_{\mathrm{h,v}}$$

$$\hat{Z}_{DR} = 10 \cdot \log_{10}\left(\frac{\hat{S}_h}{\hat{S}_v}\right)$$

$$\hat{\rho}_{\mathrm{hv}} = \frac{|\hat{C}_{\mathrm{hv}}(0)|}{(\hat{S}_{\mathrm{h}} \cdot \hat{S}_{\mathrm{v}})^{1/2}}$$

$$\hat{\sigma}_{\mathrm{h,v}} = \frac{\lambda}{2\sqrt{2}\pi T_s}\sqrt{ln(|\hat{S}_{\mathrm{h,v}}|) - ln(|\hat{C}_{\mathrm{h,v}}(T_S)|)}$$

  – Variable noise, difficult to estimate
  – Error in Z_{DR}
  – Reduced ρ_{hv}

Lag-one estimator

- Melikov et al. (2004/2006) developed

$$\hat{S}_{\mathrm{h,v}}^{(1)} = |\hat{C}_{\mathrm{h,v}}(T_s)|$$

$$\hat{Z}_{DR}^{(1)} = 10 \cdot \log_{10}\left(\frac{|\hat{C}_{\mathrm{h}}(T_s)|}{|\hat{C}_{\mathrm{v}}(T_s)|}\right)$$

$$\hat{\rho}_{\mathrm{hv}}^{(1)} = \frac{|\hat{C}_{\mathrm{hv}}(-T_s)| + |\hat{C}_{\mathrm{hv}}(T_s)|}{2 \cdot [|\hat{C}_{\mathrm{h}}(T_s) \cdot \hat{C}_{\mathrm{v}}(T_s)|]^{1/2}}$$

- Biased estimates for power, large errors in Z_{DR} and ρ_{hv}

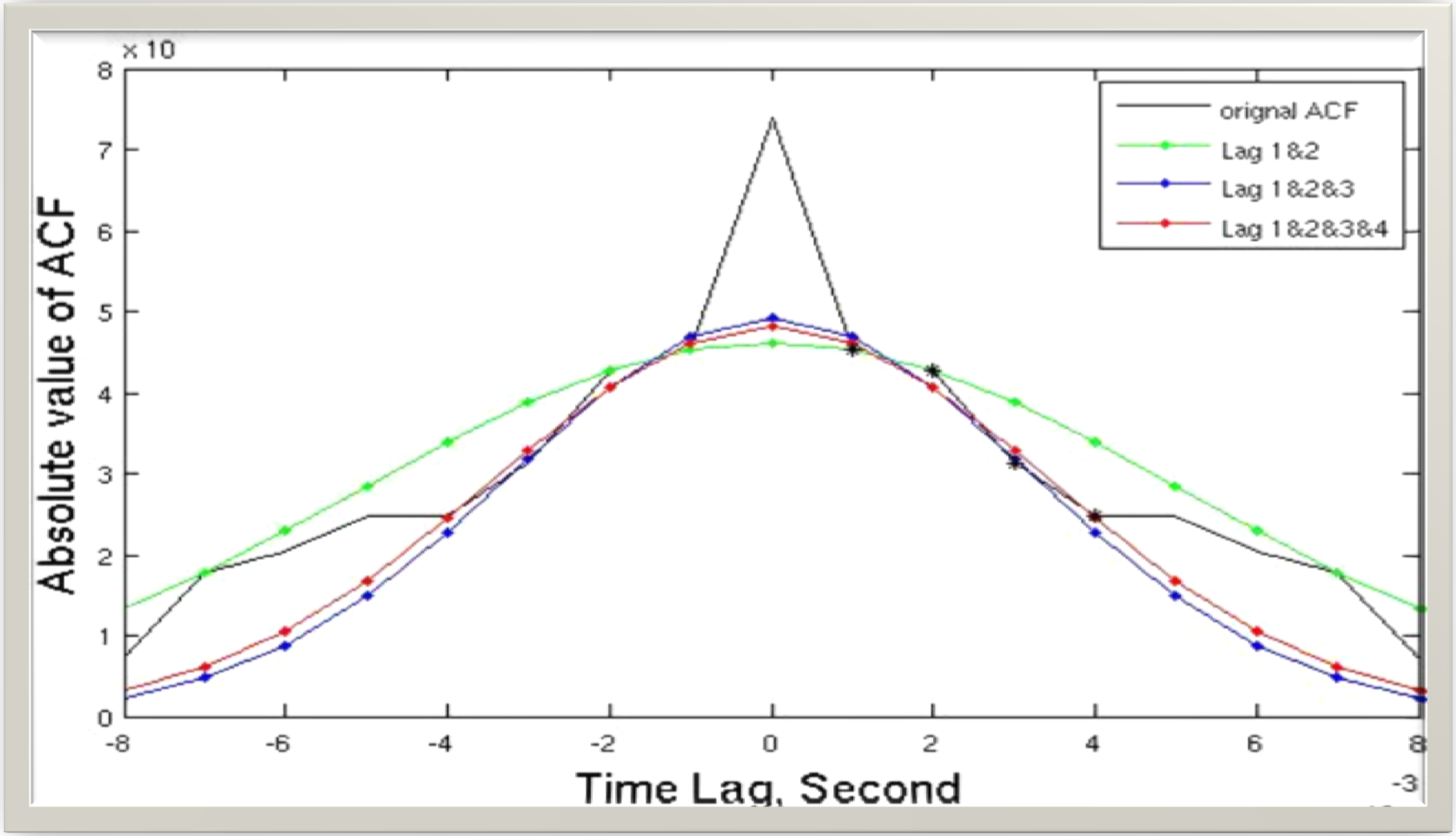
Multi-lag processing

(Cao et al. 2010, Lei et al. 2011, Zhang et al. 2004)

- Existing moment estimators depend mainly on lag-zero and lag-one correlation estimates that are contaminated by noise and estimation error
- The multi-lag estimator, excluding lag-zero auto-correlation and using more available lags, is introduced
- Because lag-zero of auto-correlation estimates is excluded, it is expected to data quality can be improved at low SNR.

Multi-lag processing

- Gaussian fit to multi-lag correlation estimates (depending on σ_v and SNR).



Fitting procedure

- Zero-mean Gaussian correlation function with two parameters

$$y_n = \ln(|C_{\mathrm{h,v}}(nT_{\mathrm{s}})|) = an^2T_{\mathrm{s}}^2 + b$$

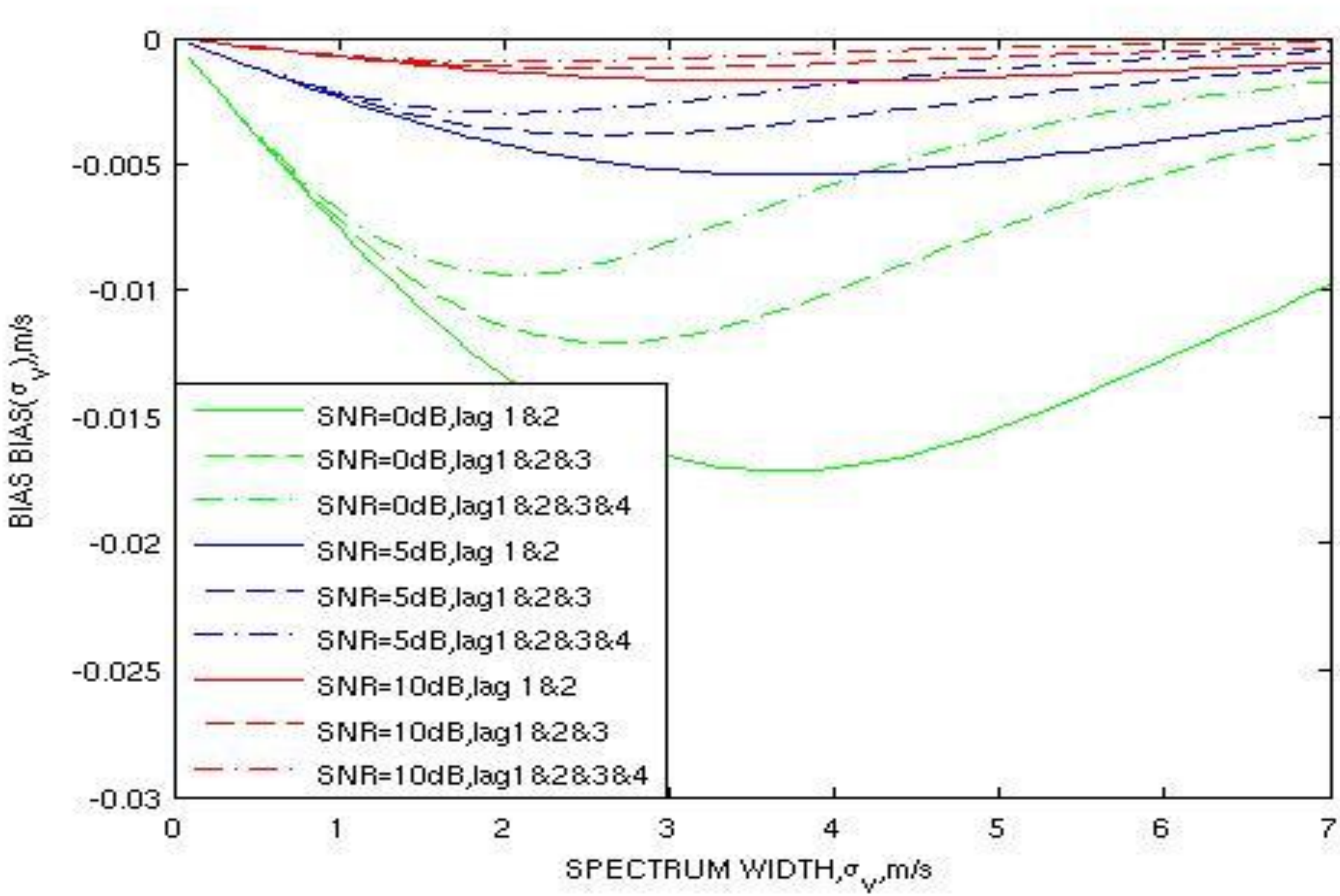
$$\chi(\hat{a},\hat{b}) = \sum_{n=1}^{N}(n^2\hat{a}T_s^2 + \hat{b} - \hat{y}_n)^2$$

$$\begin{cases} \dfrac{\partial\chi(\hat{a},\hat{b})}{\partial\hat{a}} = 0 \\ \dfrac{\partial\chi(\hat{a},\hat{b})}{\partial\hat{b}} = 0 \end{cases} \Rightarrow$$

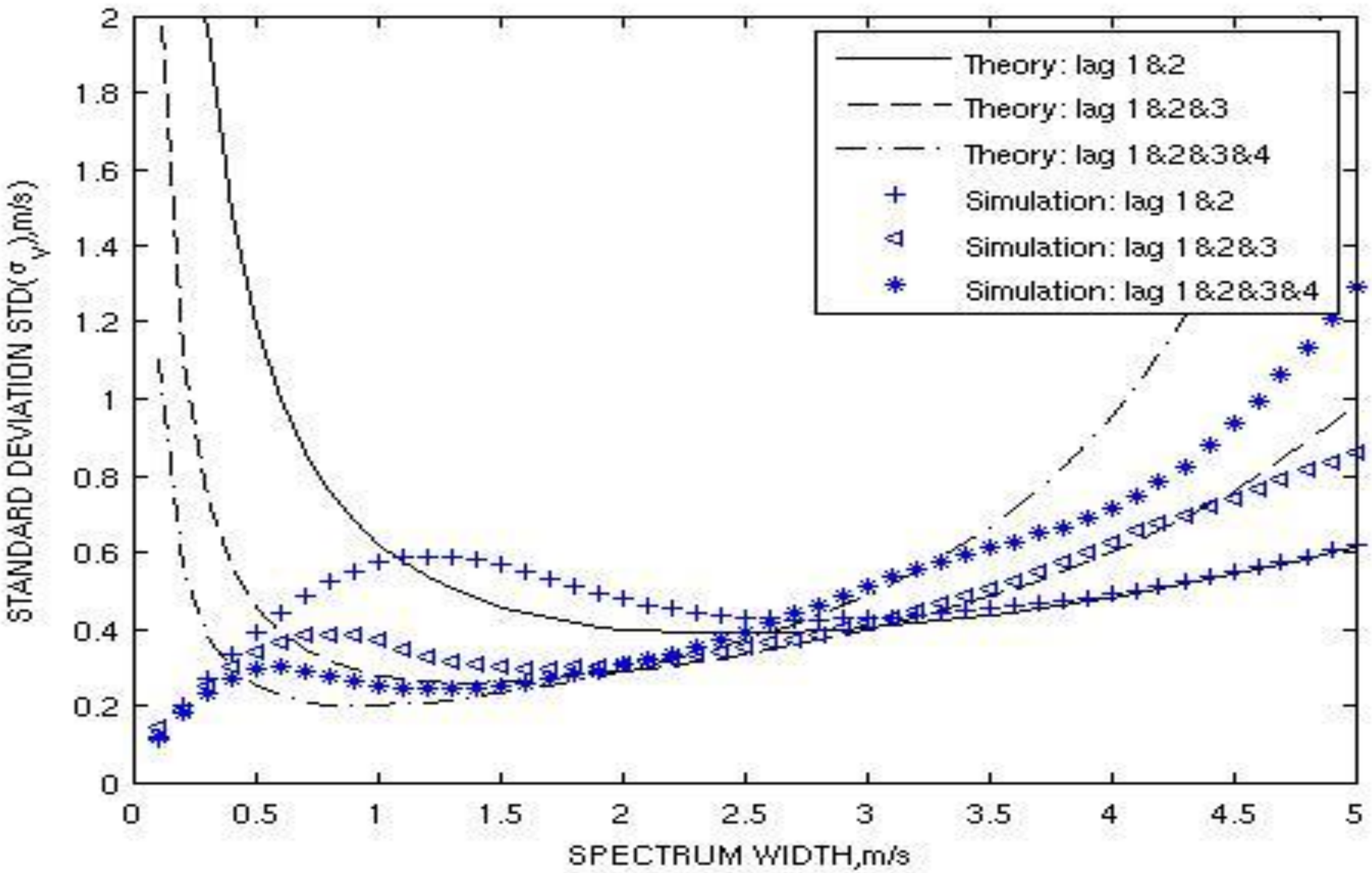
$$\hat{a} = \frac{30\sum_{n=1}^{N}[6n^2 - (N+1)(2N+1)]\hat{y}_n}{T_s^2 N(N-1)(N+1)(2N+1)(8N+11)}$$

$$\hat{b} = \frac{6\sum_{n=1}^{N}(3N^2 + 3N - 1 - 5n^2)\hat{y}_n}{N(N-1)(8N+11)}$$

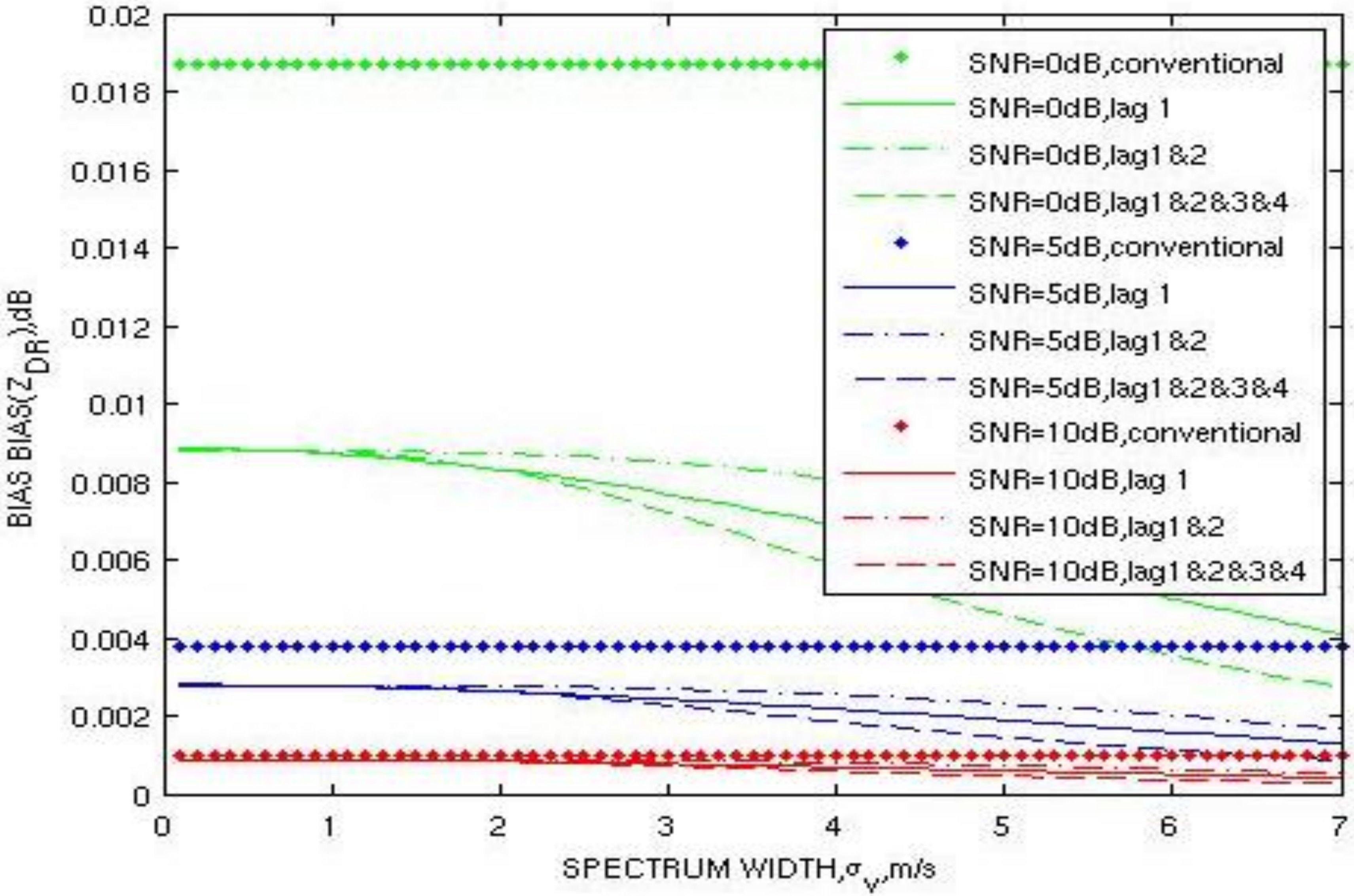
Bias of spectrum width estimates



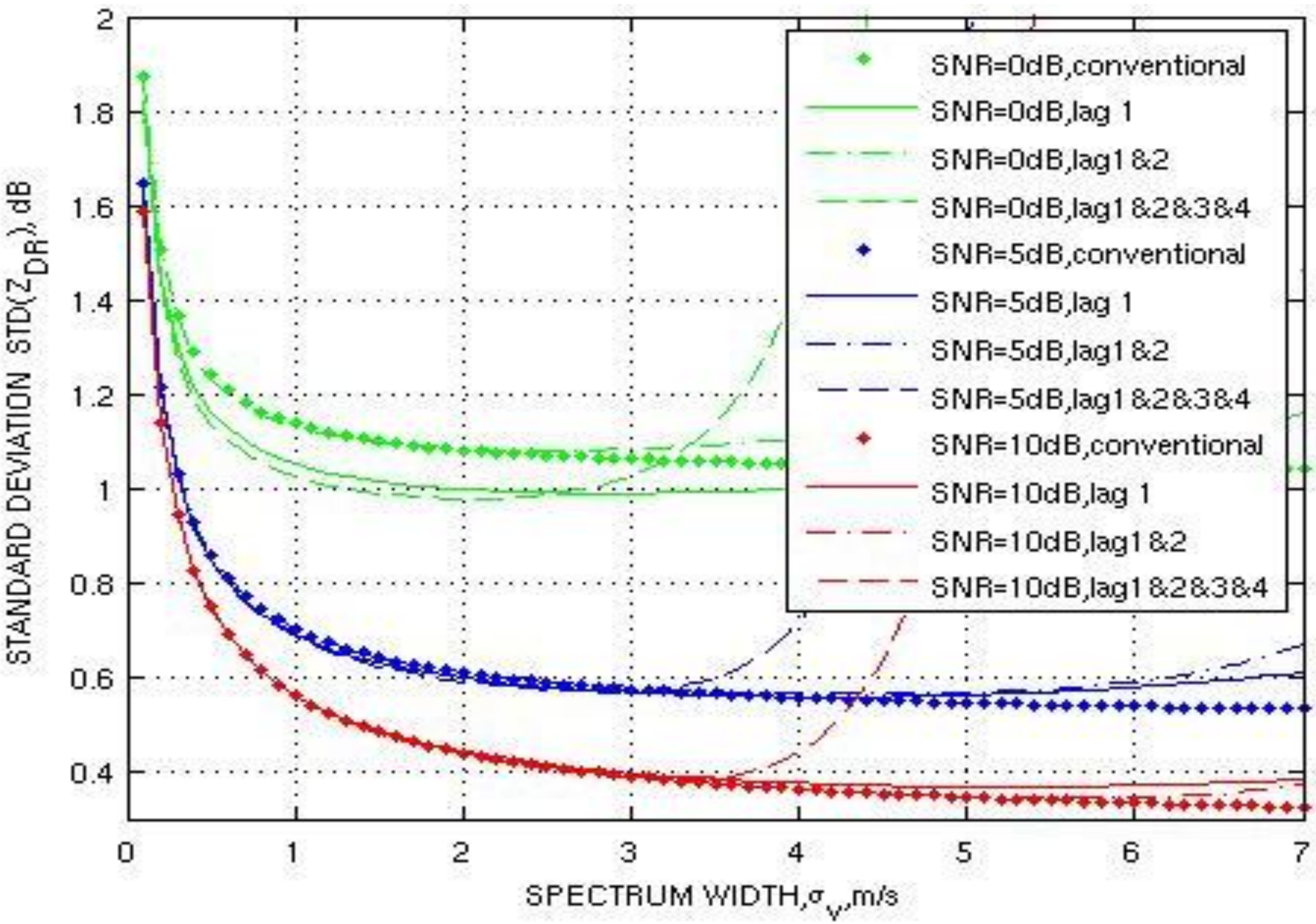
Standard deviation of spectrum width estimates



Bias of differential reflectivity estimates



Standard deviation of differential reflectivity estimates



Test with simulated data

- NWP model (ARPS) by predicts wind field and microphysical variables: number concentration and water mixing ratios for cloud water&ice, rain, snow and graupel
- True radar variables are calculated.
- Time-series datat generated

Simulation based on ARPS output

- Time series generated from NWP model output

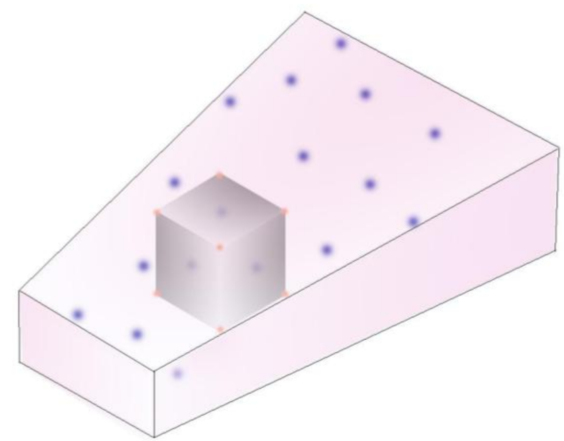
Signal amplitudes and phases determined from ARPS (Xue et al. 2000): mixing ratio for rain, snow and hail, wind, and turbulence.

$$V_h = \sum_{l=1}^{n} A_{hl} \exp(-j\phi_{hl}) + n_h$$

with

$$A_{hl} = \frac{1}{r^2}\left(\ldots Z_{hl}\right)$$

$$\phi_{hl} = 2\int_{0}^{r_l} (k_0 + K_{hl})\, dr$$

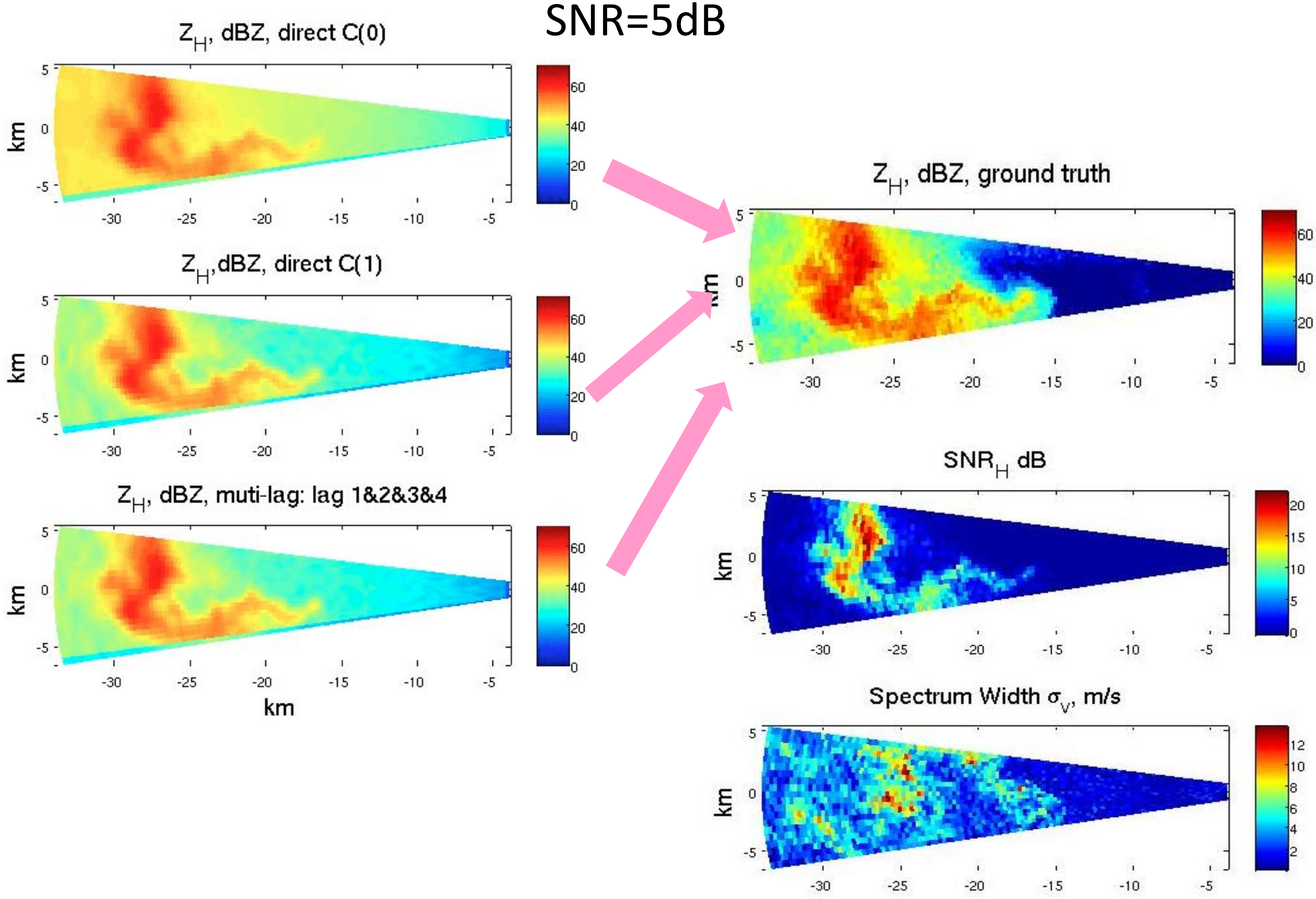


Cheong, B.L., Palmer, R.D., and Xue, M.,2008: A time series weather radar simulator based on high-resolution atmospheric models. *J. Atmos. Oceanic Technol*.,25, 230-243

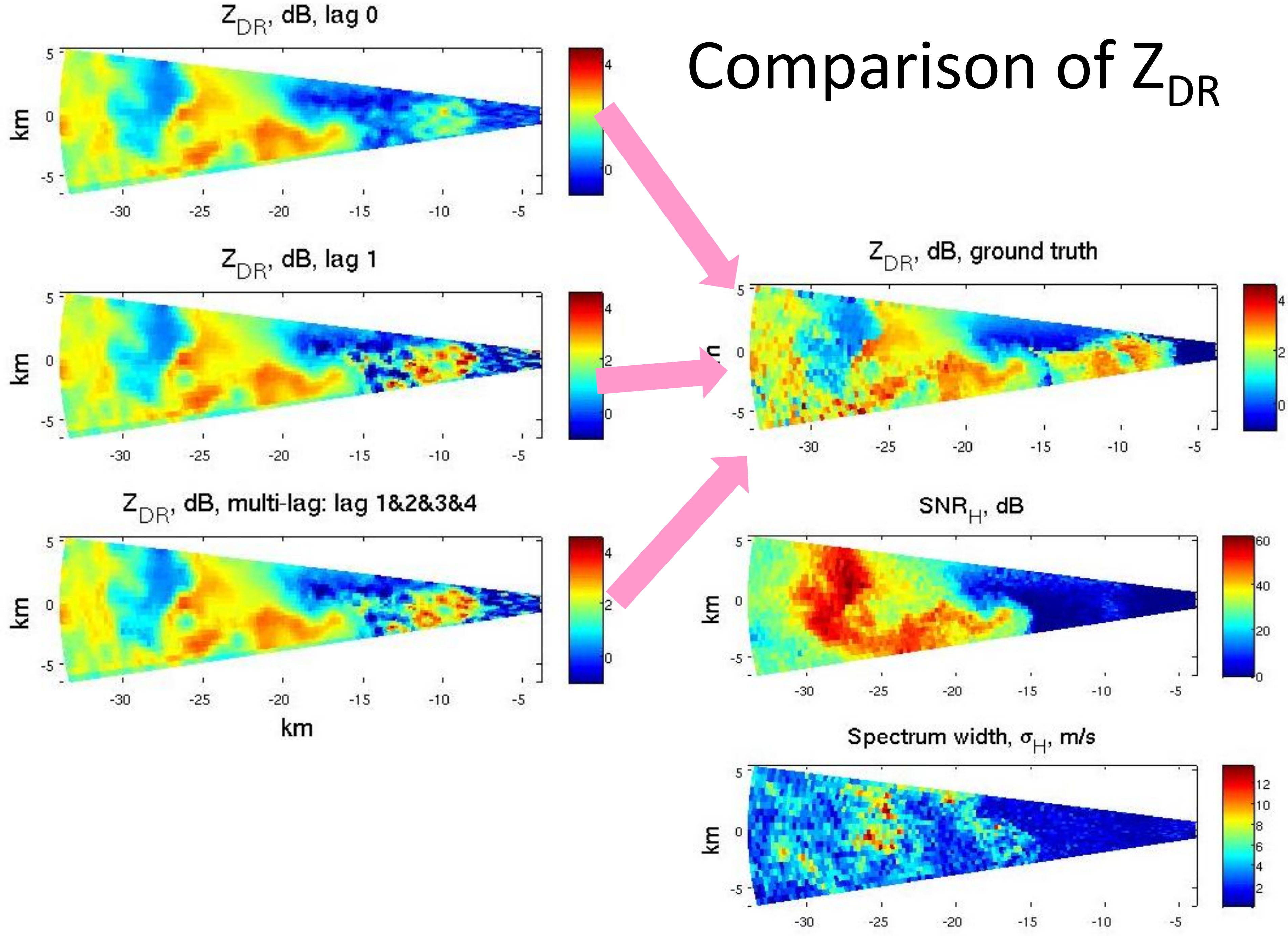
Zhang, G, 2008: METR/ECE 6613 - Weather Radar Polarimetry, lecture notes,

Comparison of Reflectivity

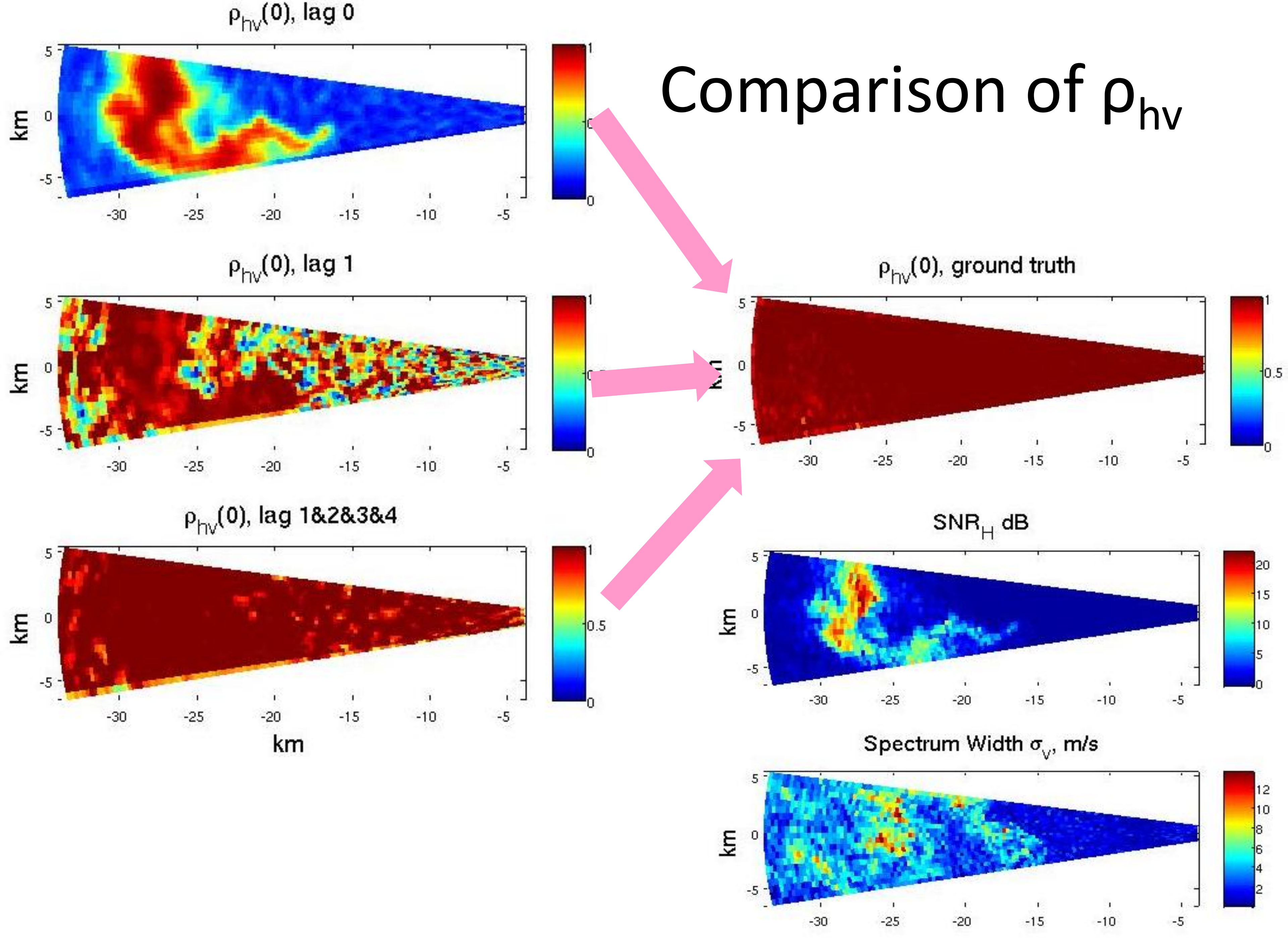
SNR=5dB



Comparison of Z_{DR}



Comparison of ρ_{hv}



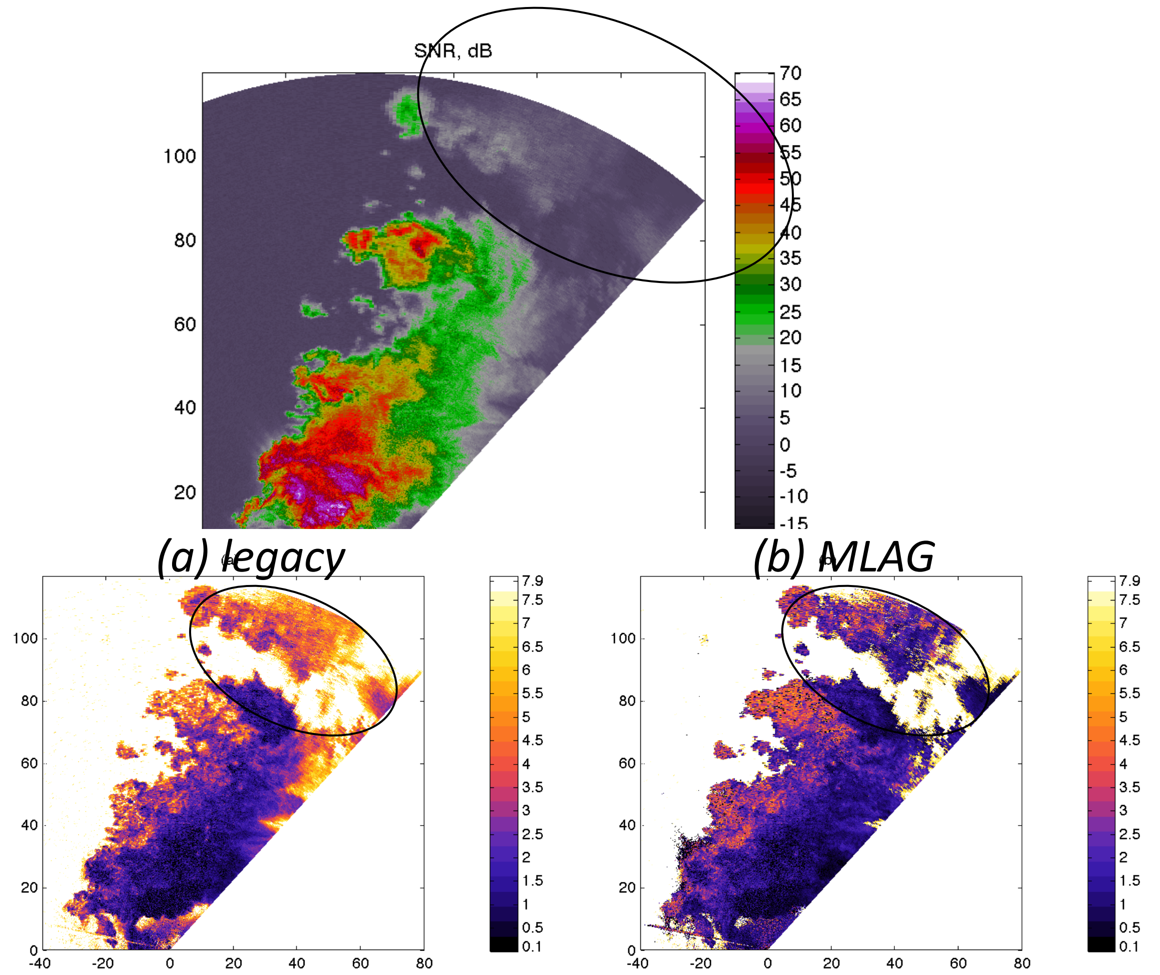
Adaptive fitting

- Adaptively determine the usable lags.
  - Error check (consistence, fitting)
- Use adaptive weighting for fitting.
  - Minimize the cost function

$$\chi = \sum_{n=1}^{N} \left[\left| \hat{C}_n \right| - \left| C(nT_s) \right| \right]^2 \left| C(nT_s) \right| \ ,$$

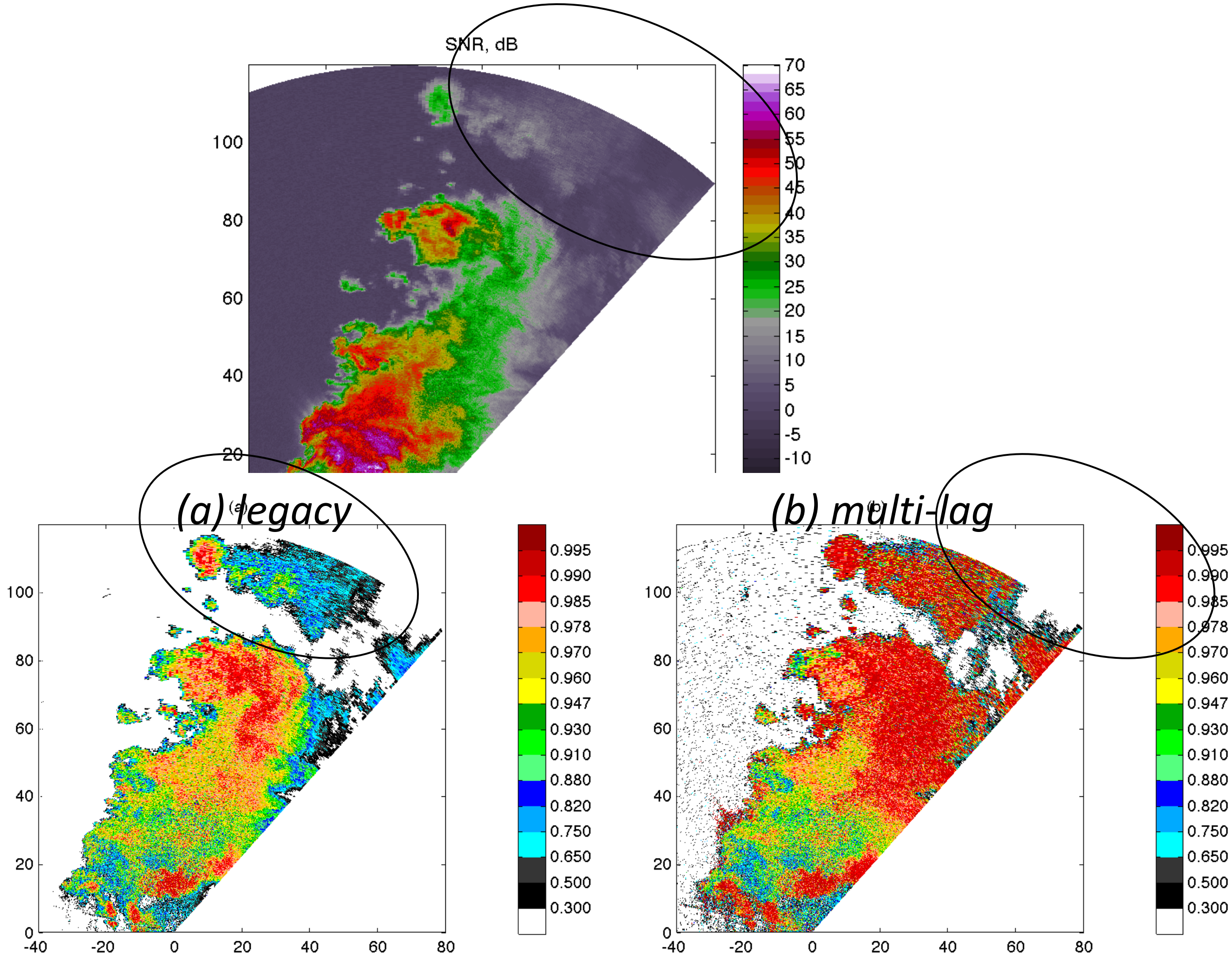
$$\left| C(nT_s) \right| = C(0) \exp\left(- \frac{(nT_s)^2}{2\tau_c^2} \right) \ .$$

Comparison of spectrum width

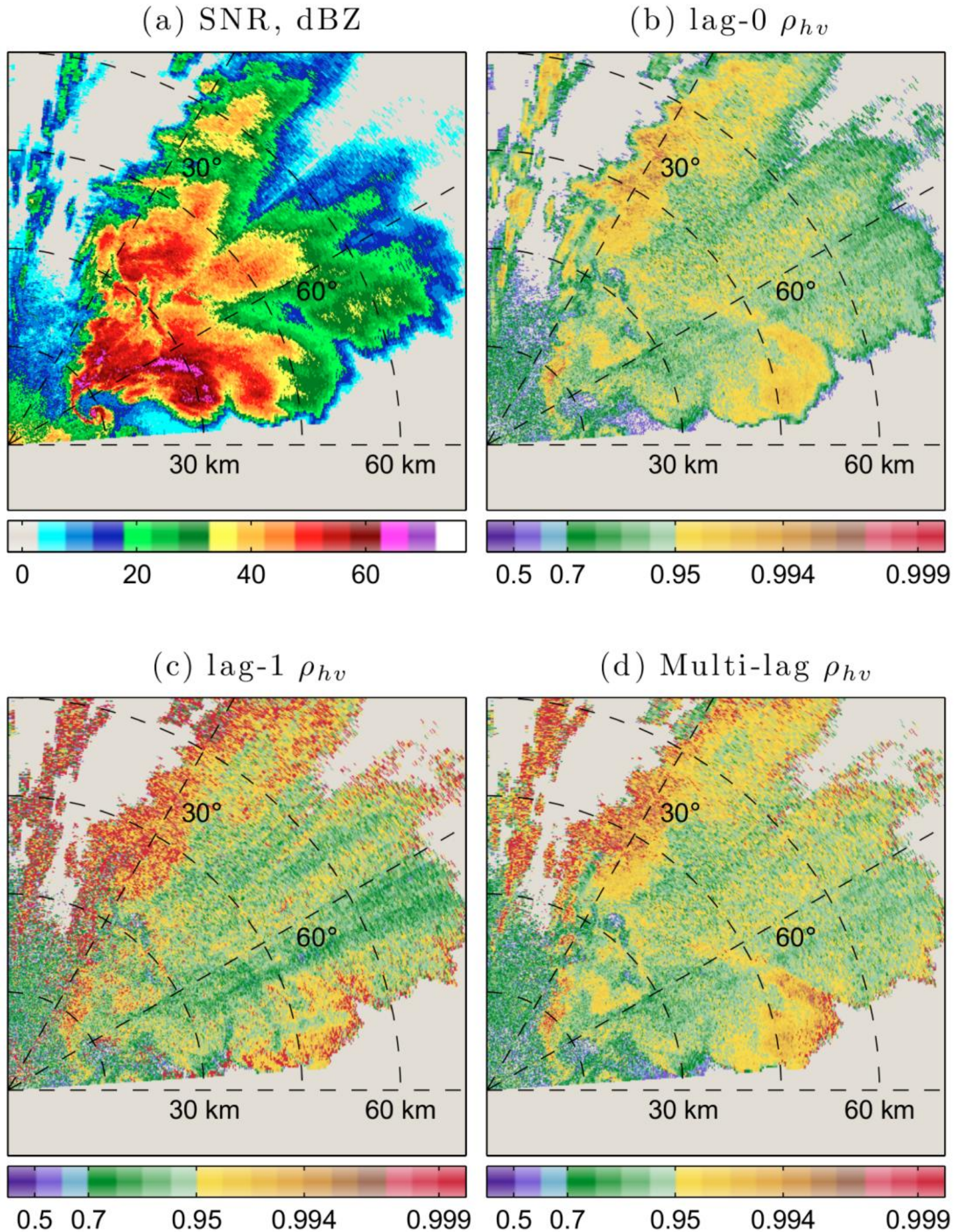


- The wide spectra caused by noise reduced

Comparison of correlation coefficient



- Correlation coefficient increased for weak echoes



(a) SNR, dBZ
(b) lag-0 ρ_{hv}
30°
60°
30 km
60 km
0
20
40
60
0.5
0.7
0.95
0.994
0.999
(c) lag-1 ρ_{hv}
(d) Multi-lag ρ_{hv}

Summary and discussions

- There is deficiency with existing moment estimator
- Multi-lag estimator is introduced to improve PRD quality
- The improvement has been demonstrated using simulated and OU' data
  - Significant improvements for power, σ_v and ρ_{hv} estimation.
  - Marginal Improvements for Z_{DR}, v_r, and Φ_{DP}
- It is expected more improvement with S-band PRD because of the longer correlation time.
- Look forward to testing/implementing with KOUN data