Processing polarimetric X-band weather radar data with an Extended Kalman Filter framework

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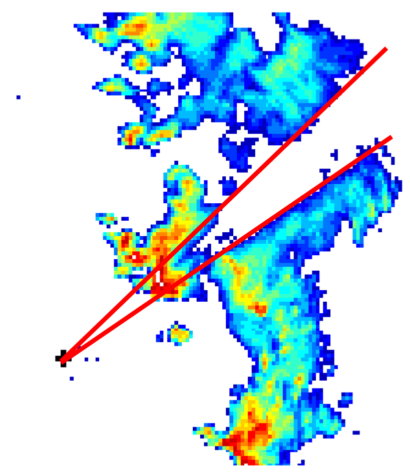
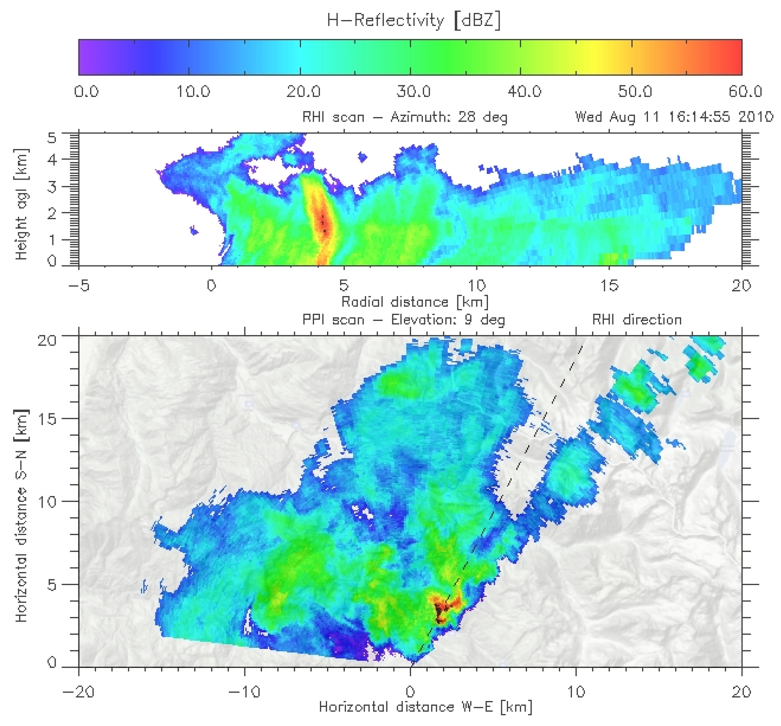
I- Context

Radar systems working at C-band (around 5 GHz) and at X-band (around 10 GHz) can be affected by severe **attenuation**.

C-band (Wideumont, IRM, Belgium)



X-band (MXPol, EPFL, Davos, CH)



Radar polarimetry has improved attenuation correction thanks to the linear relationship between the specific attenuation α and the specific differential phase shift on propagation Kdp.

But there are **difficulties in the estimation of Kdp** from the measured (total) differential phase shift (noise + diff. phase shift on backscatter δ).

II- Objectives

Development of a method to process (X-band) polarimetric radar data in a consistent way to **estimate δ, Kdp and attenuation**.

Taking advantages of the relationships between the different polarimetric radar variables, an algorithm based on **extended Kalman filtering (EKF)** is proposed.

It is developed and evaluated using **simulated and real radar data**.

III- Algorithm

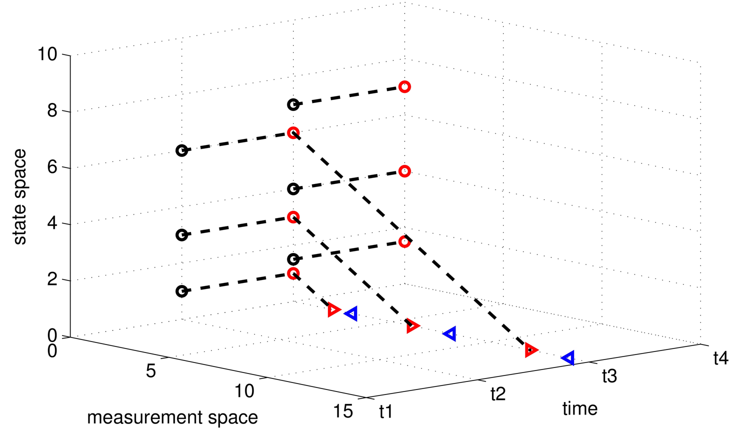
1. Extended Kalman filtering

Principle:

1. Propagation of state variables forward in time or space.

2. Prediction of the observations and comparison with real measurements.

3. Update of the state variables and propagation forward in time or space.



2. State and observed variables

State variables

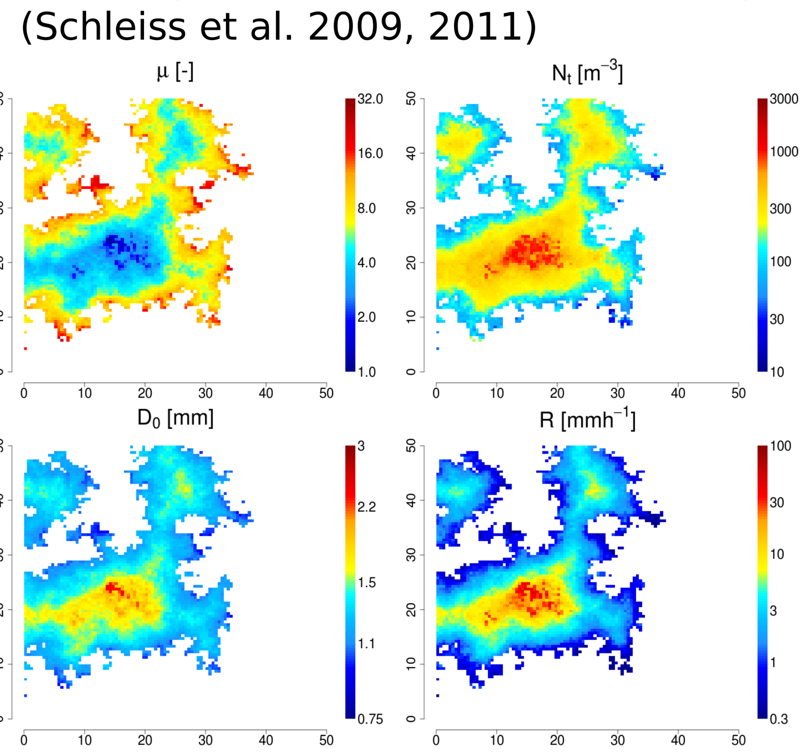
$\tilde{Z}_h$ Radar reflectivity at horizontal polarization [dBZ]
$\tilde{Z}_v$ Radar reflectivity at vertical polarization [dBZ]
$\tilde{K}_{dp}$ Spec. diff. phase shift on propagation [dBK]
δ Diff. phase shift on backscattering [deg]
Φ_{dp} Diff. phase shift on propagation [deg]

Observed variables

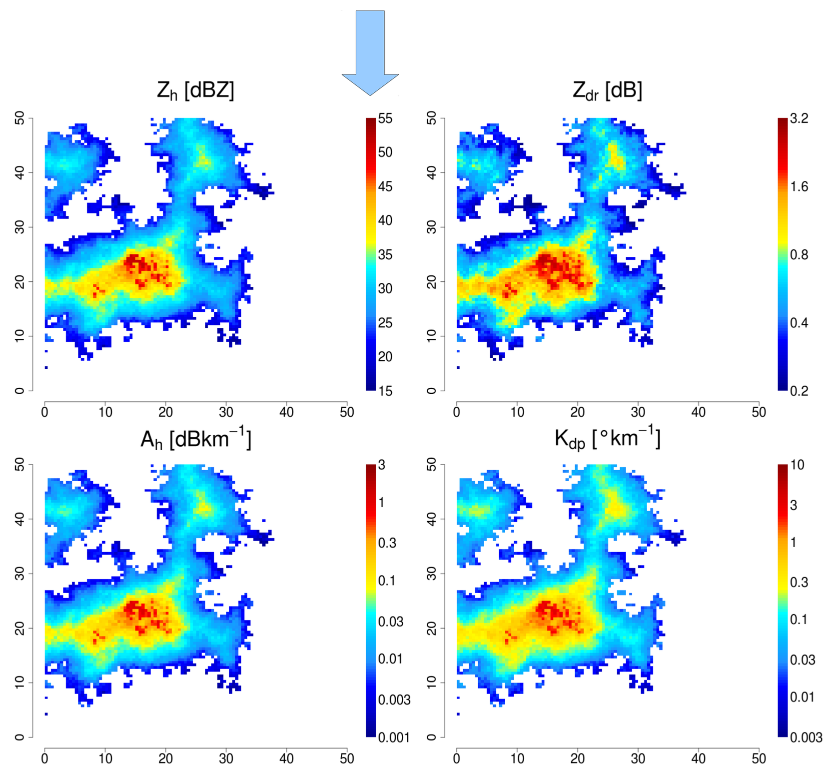
$\tilde{Z}_h^m$ Measured attenuated radar reflectivity at hor. polarization [dBZ]
$\tilde{Z}_v^m$ Measured attenuated radar reflectivity at ver. polarization [dBZ]
Ψ_{dp} Measured total differential phase shift [deg]

To build the observation model, relationships between the state and observed variables must be established.

To do so, we use simulated radar data, from simulated DSD fields (Schleiss et al. 2009, 2011)



Drop shape (Andsager et al., 1999) + T-matrix



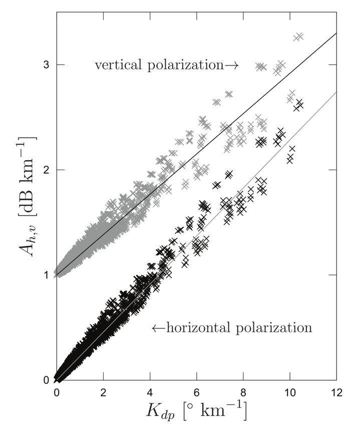
3. Relationships between state and observed variables

Observed differential phase shift

$$\begin{aligned}\Psi_{dp}(i) &= -2\Delta r 10^{\tilde{K}_{dp}(i)/10} + \Phi'_{dp}(i) + \delta_{hv}(i)\\ \Psi'_{dp}(i) &= +2\Delta r 10^{\tilde{K}_{dp}(i)/10} + \Phi_{dp}(i) + \delta_{hv}(i)\\ 0 &= \Phi'_{dp}(i) - \Phi_{dp}(i) - 2\Delta r 10^{\tilde{K}_{dp}(i)/10}\end{aligned}$$

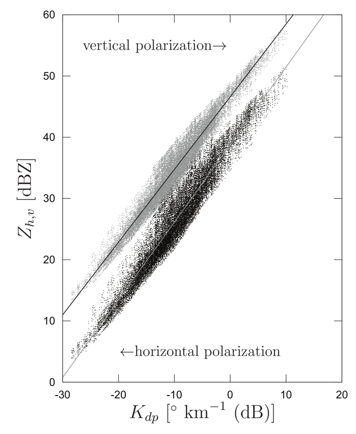
where $\Phi'_{dp}(i) = \Phi_{dp}(i+1)$ and $\Psi'_{dp}(i) = \Psi_{dp}(i+1)$

Observed (att.) radar reflectivities



$$\begin{aligned}\tilde{Z}_h^m(i) &= -0.229\Phi_{dp}(i) + \tilde{Z}_h(i)\\ \tilde{Z}_v^m(i) &= -0.192\Phi_{dp}(i) + \tilde{Z}_v(i)\end{aligned}$$

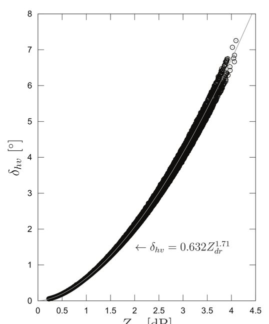
Radar reflectivities and specific diff. phase shift



$$\begin{aligned}-38.8 &= 1.27\tilde{K}_{dp}(i) - \tilde{Z}_h(i)\\ -36.6 &= 1.19\tilde{K}_{dp}(i) - \tilde{Z}_v(i)\end{aligned}$$

Differential radar reflectivity and differential phase shift on backsc.

$$0 = 0.632\left(\tilde{Z}_h(i) - \tilde{Z}_v(i)\right)^{1.71} - \delta(i)$$



Observation and state vectors

$$\mathbf{o}(i) = \begin{bmatrix}\Psi_{dp}(i)\\ \Psi'_{dp}(i)\\ \tilde{Z}_h^m(i)\\ \tilde{Z}_v^m(i)\\ -38.8\\ -36.6\\ 0\\ 0\end{bmatrix} \qquad \mathbf{s}(i) = \begin{bmatrix}\Phi_{dp}(i)\\ \Phi'_{dp}(i)\\ \tilde{Z}_h(i)\\ \tilde{Z}_v(i)\\ \tilde{K}_{dp}(i)\end{bmatrix}$$

Observation model

$$\begin{aligned}\Psi_{dp}(i) &= -2\Delta r 10^{\tilde{K}_{dp}(i)/10} + \Phi'_{dp}(i) + \delta_{hv}(i)\\ \Psi'_{dp}(i) &= +2\Delta r 10^{\tilde{K}_{dp}(i)/10} + \Phi_{dp}(i) + \delta_{hv}(i)\\ \tilde{Z}_h^m(i) &= -0.229\Phi_{dp}(i) - \tilde{Z}_h(i)\\ \tilde{Z}_v^m(i) &= -0.192\Phi_{dp}(i) - \tilde{Z}_v(i)\\ -38.8 &= 1.27\tilde{K}_{dp}(i) - \tilde{Z}_h(i)\\ -36.6 &= 1.19\tilde{K}_{dp}(i) - \tilde{Z}_v(i)\\ 0 &= \Phi'_{dp}(i) - \Phi_{dp}(i) - 2\Delta r 10^{\tilde{K}_{dp}(i)/10}\\ 0 &= 0.632\left(\tilde{Z}_h(i) - \tilde{Z}_v(i)\right)^{1.71} - \delta_{hv}(i)\end{aligned}$$

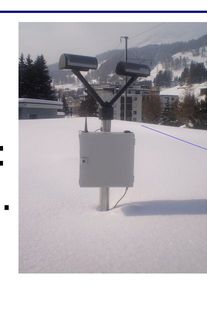
Propagation model

$$\begin{aligned}\mathbf{s}^{(-)}(i+1) &= \mathbf{s}^{(+)}(i)\\ \Phi_{dp}^{(-)}(i+1) &= \Phi_{dp}'^{(+)}(i)\\ \Phi_{dp}'^{(-)}(i+1) &= \Phi_{dp}'^{(+)}(i) + \Delta r 10^{\tilde{K}_{dp}^{(+)}(i)/10}\end{aligned}$$

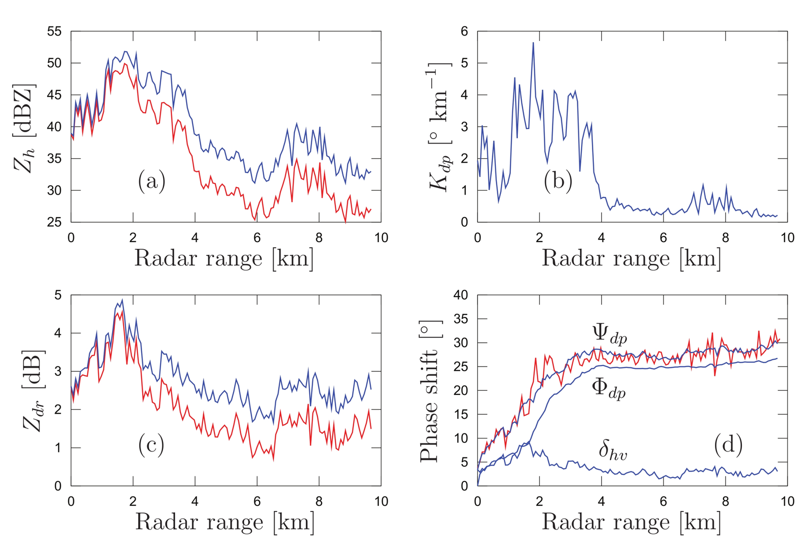
•Non-linear relationships
•Gaussian distributions (work with log)
→ Extended Kalman Filter

IV. Application to real data

Data collected with an X-band dual-pol radar in Davos (CH):
Freq = 9.41 GHz; beamwidth = 1.45 deg, range res = 75 m.
Disdrometer (Parsivel) in Davos for ground reference.
Collaboration with SLF.



1. Attenuation correction

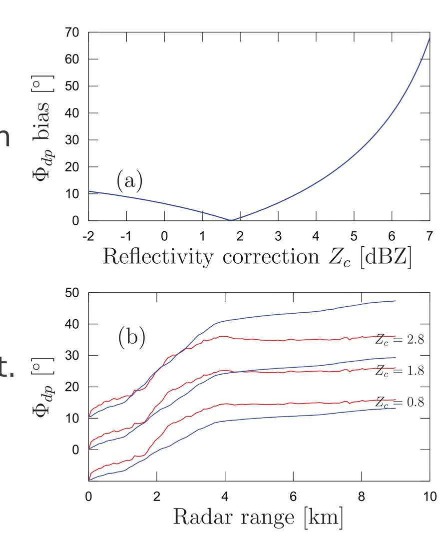


3. Radar calibration

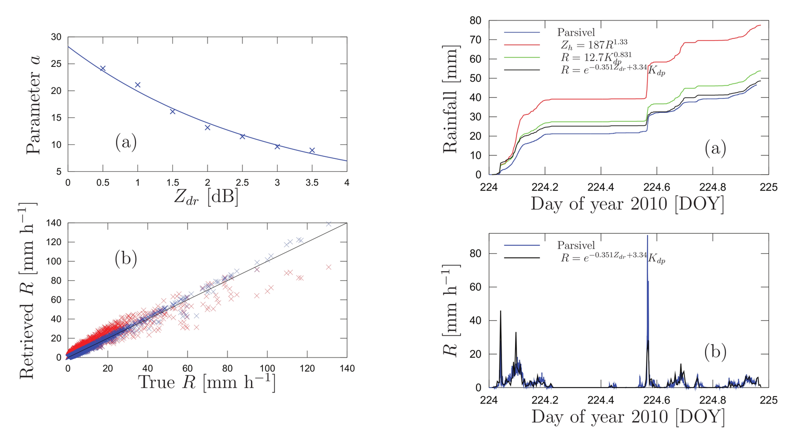
Varying calibration correction
Comparison of obtained Φ_{dp} and sum of K_{dp}.

Minimum difference
→ calibration correction.

Useful to monitor radome att.



2. Rain rate retrieval



Rain rate estimator: $R = f(K_{dp}, Z_{dr}) = e^{-0.351 Z_{dr}+3.34} K_{dp}$

Very good agreement with rain rate/amount measured at ground level with disdrometer

Indirect validation of Kdp and δ estimation attenuation correction

V- Conclusions:

For polarimetric radar, Kdp and δ are difficult to estimate, and so is attenuation.
• A new processing algorithm is proposed, based on extended Kalman filtering.
• Simulated radar data (from DSD fields) are used to parameterize the algorithm.
• It is applied to real radar data collected in the Swiss Alps, and give R estimates in very good agreement with observations from a ground-based disdrometer.
• Future work: thorough validation (using simulations?); parameterization for snowfall.

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