Study on representation error of radar data in convective-scale data assimilation

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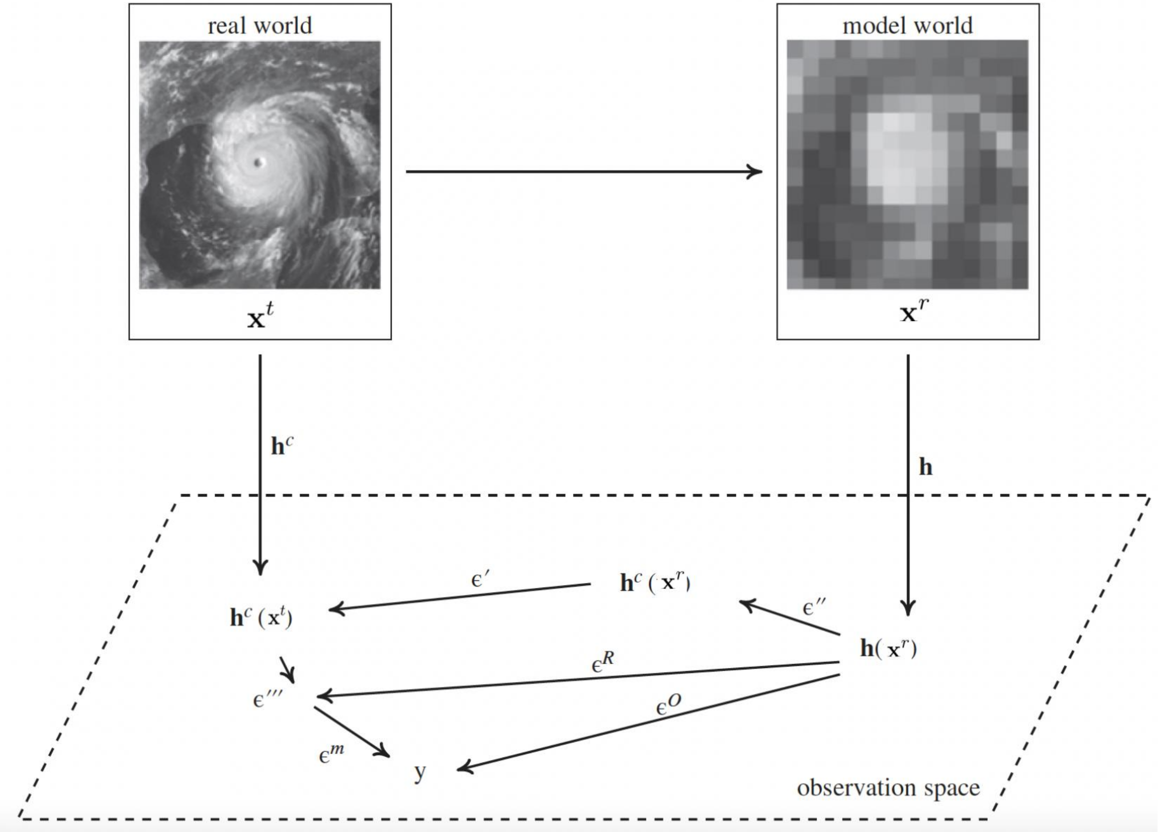
Definition of representation error

Representation error: basic difference between the modelled representation of an observation and what is actually observed



$\mathbf{x}^t$: True (continuum) state

$\mathbf{x}^r$: Model resolved state

$\mathbf{h}^c$: Continuum observation operator

$\mathbf{h}$: Discrete observation operator

ϵ^o : Observation error

ϵ^m: Measurement error

ϵ^R : Representation error

$\epsilon' := \mathbf{h}^c(\mathbf{x}^t) - \mathbf{h}^c(\mathbf{x}^r)$

Error due to unresolved scales and processes

$\epsilon'' := \mathbf{h}^c(\mathbf{x}^r) - \mathbf{h}(\mathbf{x}^r)$

Observation-operator error

ϵ''' : Pre-processing error

$\mathbf{y}$: Observation

$$\epsilon^o := \epsilon^m + \epsilon^R \quad ; \quad \epsilon^R := \epsilon' + \epsilon'' + \epsilon'''$$

Note: Observation error and model error are correlated through ϵ'

(Janjic et al. 2018, QJRMS)

Diagnositc method to determine obs. error

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$$\mathbf{x}^a = \arg\min_{\mathbf{x}} \quad J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b) + \frac{1}{2}(\mathbf{y}^o - \mathcal{H}(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{y}^o - \mathcal{H}(\mathbf{x}))$$

$\mathbf{B}$: Background error covariance $\mathbf{R}$: Observation error covariance

↓

Correct constructions $\mathbf{B}$ and $\mathbf{R}$ are essential

Desroziers diagnositcs (Desroziers et al. 2005) for construction of $\mathbf{R}$:

$$E[\mathbf{d}_a^o(\mathbf{d}_b^o)^T] = \mathbf{R}$$

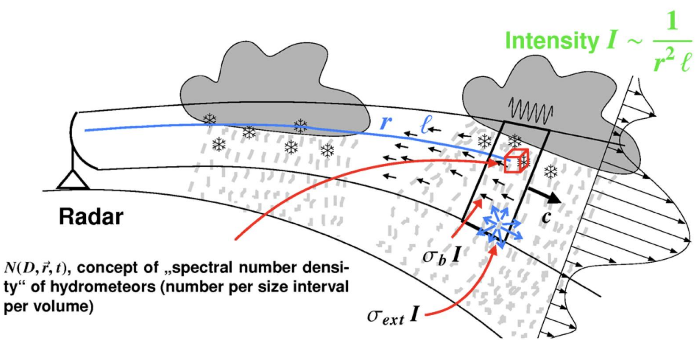
$$\mathbf{d}_a^o = \mathbf{y}^o - \mathcal{H}(\mathbf{x}^a)$$

$$\mathbf{d}_b^o = \mathbf{y}^o - \mathcal{H}(\mathbf{x}^b)$$

The initial work of Desroziers (2005) suggested applying the diagnostic in successive iterations. But most of the studies using the diagnostic in operational NWP to date have considered **only the first iterate** and still gained useful information.

- ECMWF uses it to calculate satellite interchannel error covariance
- Met-Office uses it to calculate radar radial wind error covariance

Radar forward operator “EMVORADO”

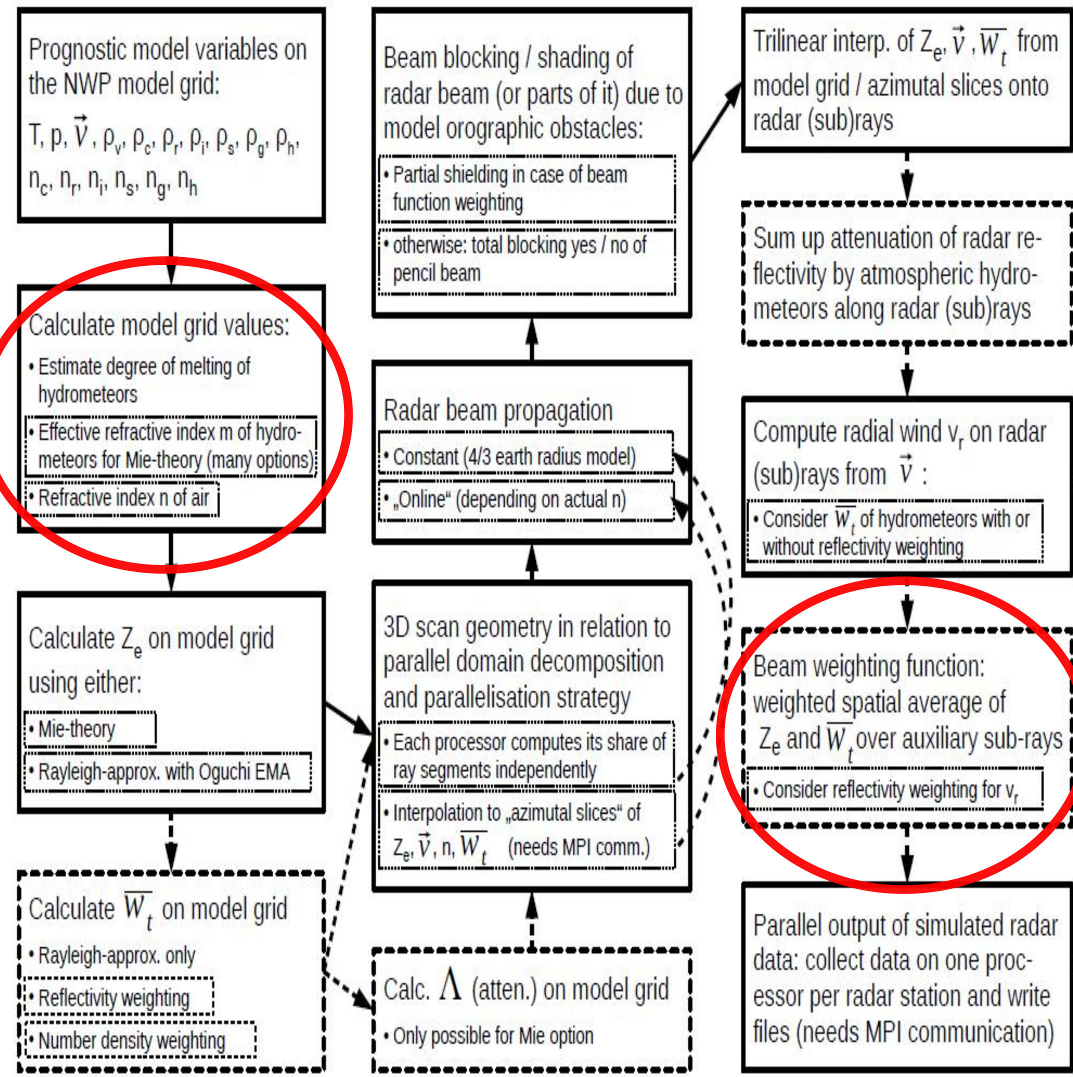


Efficient Modular VOlume scan RADar Operator - EMVORADO

highly modularized & parallelized

operational at DWD and ect.

(Zeng et al. 2016, QJRMS)



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Evaluation of EMVORADO

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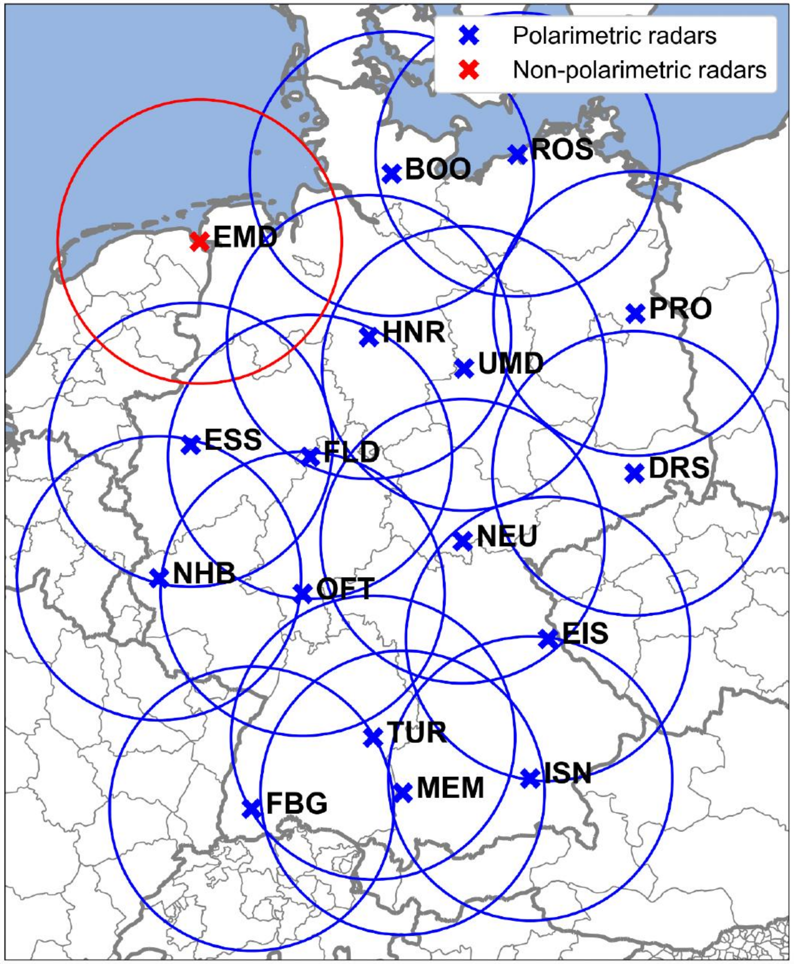
- Hindcasting runs with ICON-D2 model (operational region model of DWD, resolution of 2 km) for one-month convective period in June 2020 over Germany, driven by hourly lateral boundary conditions

- 17 C-band Doppler radar network of the DWD



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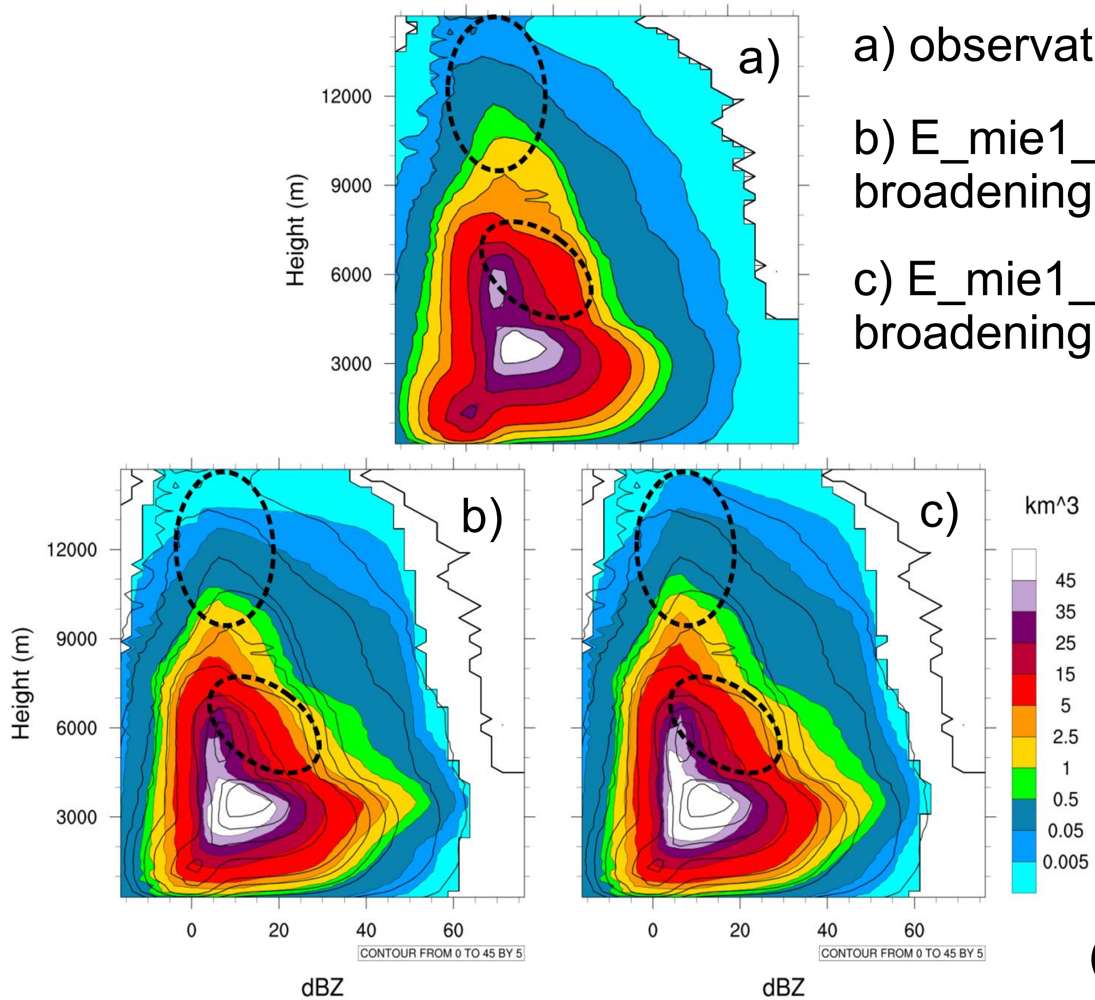
Sensitivity to beam broadening

Contoured Frequency by Altitude Diagrams (CFAD) of radar reflectivity



a) observations

b) E_mie1_lhn2： without accounting for beam broadening

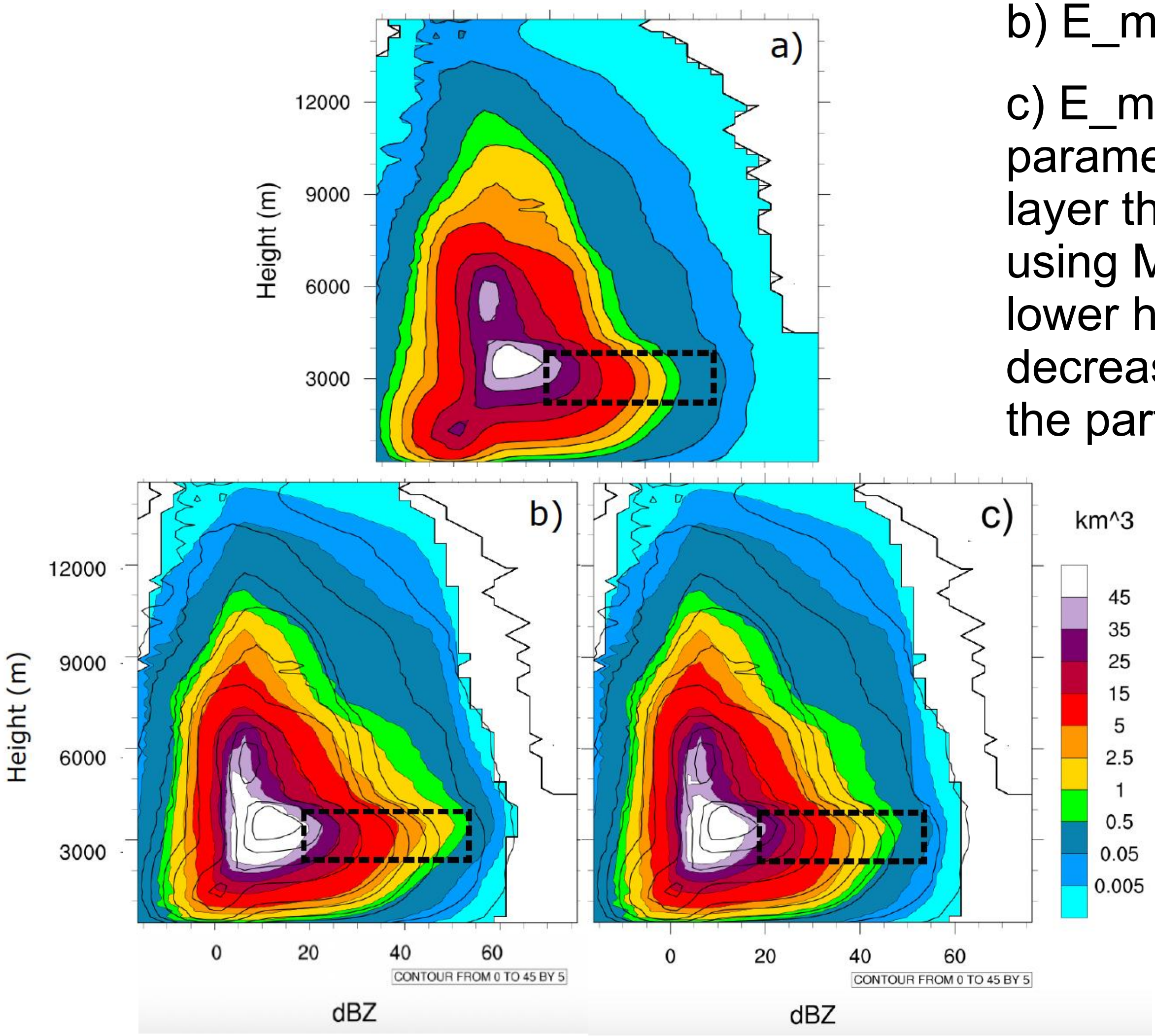
c) E_mie1_lhn2_bb: accounting for beam broadening

E_mie1_lhn2_bb is closer to observations than E_mie1_lhn2 (see dashed ellipses)

(Zeng et al. 2022a&b, Remote Sen.)

Sensitivity to parametrizations in the Mie scattering scheme

CFAD of radar reflectivity



a) observations

b) E_mie1_lhn2_bb

c) E_mie2_lhn2_bb : with better parametrizations for the melting layer than E_mie1_lhn2_bb while using Mie-scattering scheme, e.g., lower height of melting layer, decreasing melting degree, change the particle morphology

E_mie2_lhn2_bb reduces overestimated reflectivities in E_mie1_lhn2_bb at the melting layer

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Convective-scale data assimilation

- Model: ICON-D2; Data assimilation system: KENDA (operational at DWD)
- 10 to 20 June 2020， hourly updated
- Conventional & radar reflectivity and radial wind data assimilated; LHN applied; Better EMVORADO settings in E_dwd2 than in E_dwd, i.e., smaller representation error due to error in forward operator in E_dwd2

EXP	Scattering scheme	Observations	Beam Broadening	LHN
E_dwd	Mie	conventional, radar	off	on
E_dwd2	improved Mie	conventional, radar	on	on

- Horizontal localization: 16 km for radar data; adaptive horizontal localization (radii vary between 50 and 100 km) for conventional data.
- $\mathbf{R} = 10 \cdot 10 \cdot \mathbf{I}\ [\mathrm{dBZ}^2]$ for reflectivity $\mathbf{R} = 2.5 \cdot 2.5 \cdot \gamma \cdot \mathbf{I}\ [\mathrm{m}^2/\mathrm{s}^2]$ for radial wind
- Deterministic forecasts at 00, 06, 12 and 18 UTC

Obs. error statistics estimated by Desroziers

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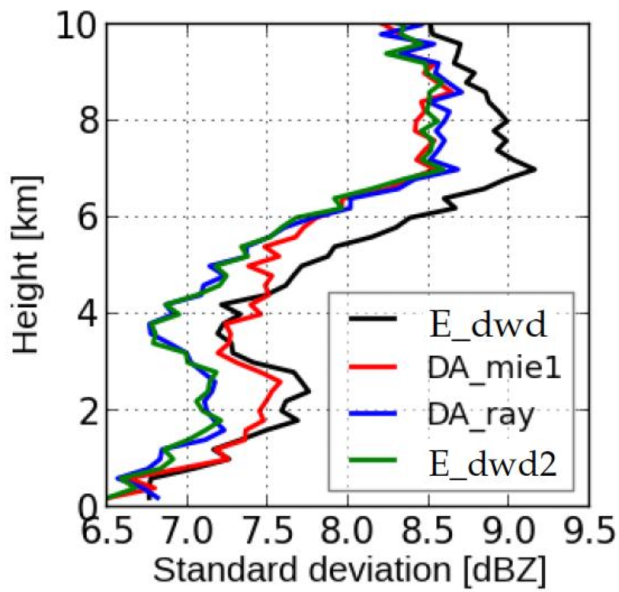
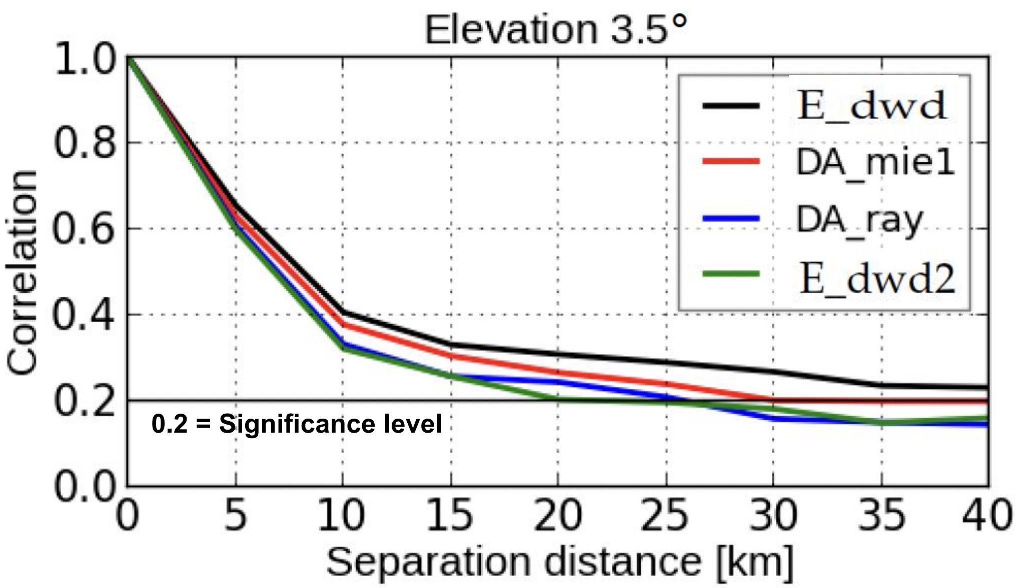
NOTE: Only E_dwd (in black) and E_dwd2 (in green) are relevant

Standard deviation (Ele = 3.5)



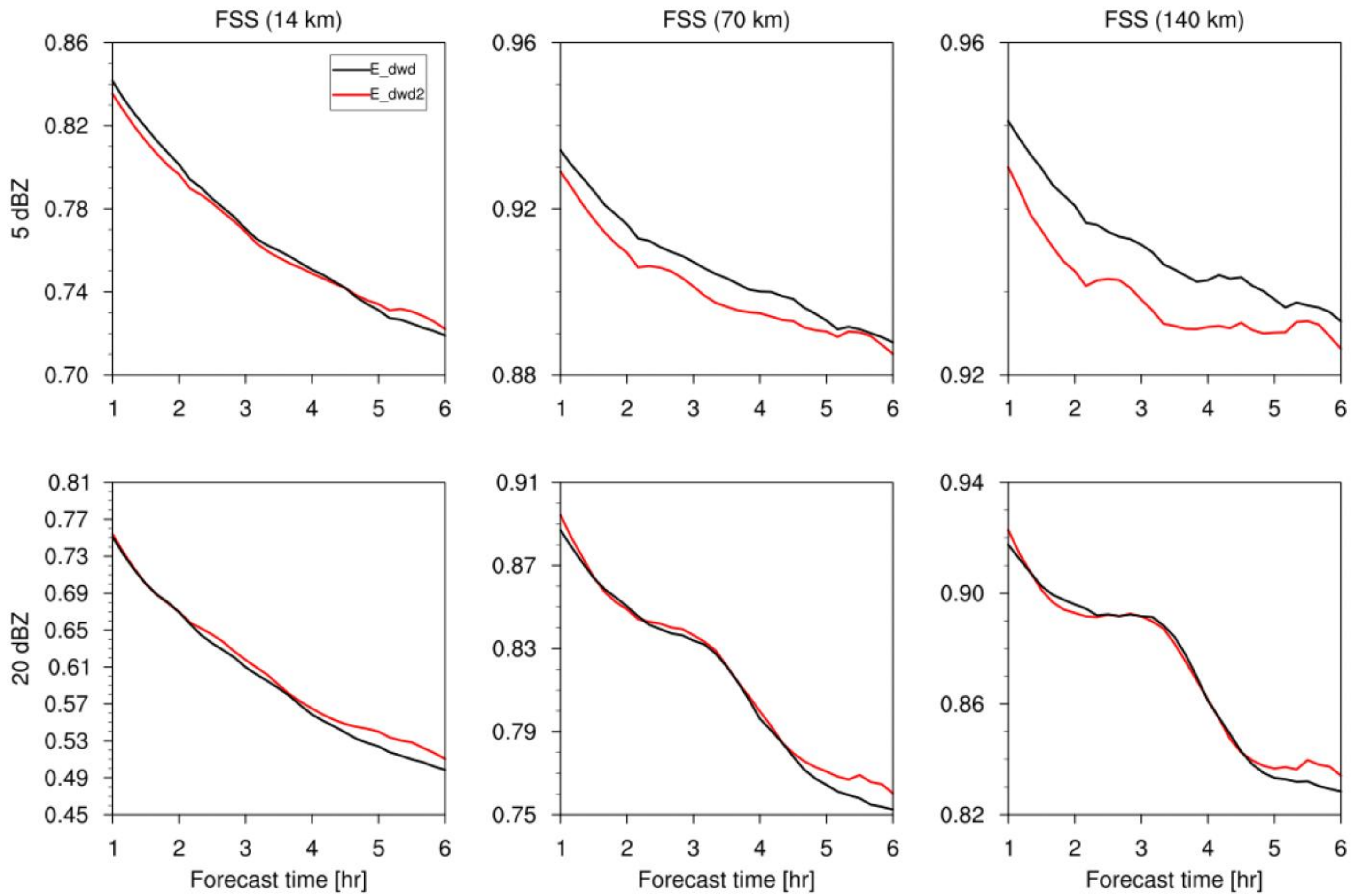
Correlation length (height = 2 km)



- Smaller standard deviation and shorter correlation length in E_dwd2 than in E_dwd

6-hour reflectivity forecasts

Fractions Skill Score (FSS)



- E_dwd2 is not necessarily better than E_dwd in 6-h forecasts

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Data assimilation with only radar data

- Model: ICON-D2; Data assimilation system: KENDA (operational at DWD)
- 10 to 20 June 2020， hourly updated
- Better EMVORADO settings in E_r2 than in E_r

EXP	Scattering scheme	Observations	Beam Broadening	LHN
E_dwd	Mie	conventional, radar	off	on
E_r	Mie	radar	off	off
E_r2	improved Mie	radar	on	off

- Horizontal localization: 16 km for radar data; adaptive horizontal localization (radii vary between 50 and 100 km) for conventional data.
- Deterministic forecasts at 00, 06, 12 and 18 UTC

(Feng et al. 2023, Atmos. Res.)

Obs. error statistics & 6-h forecasts

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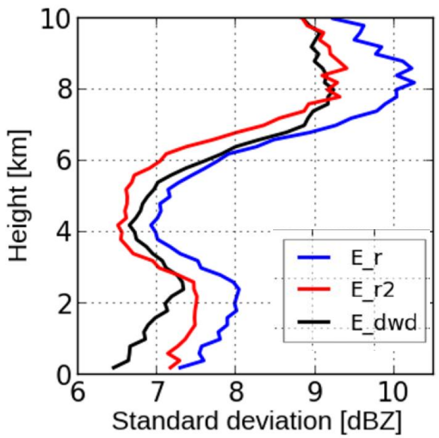
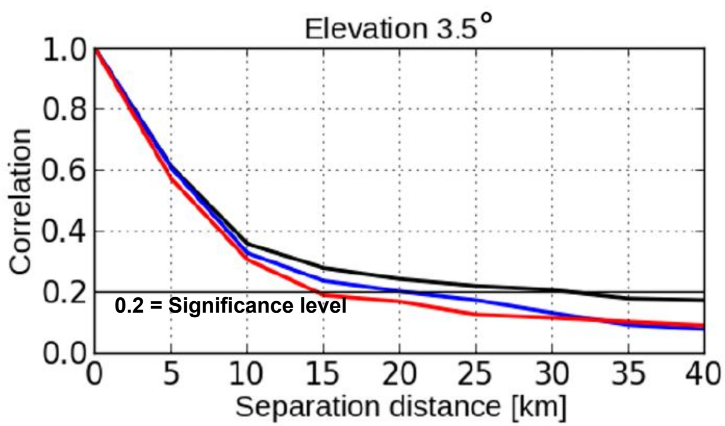
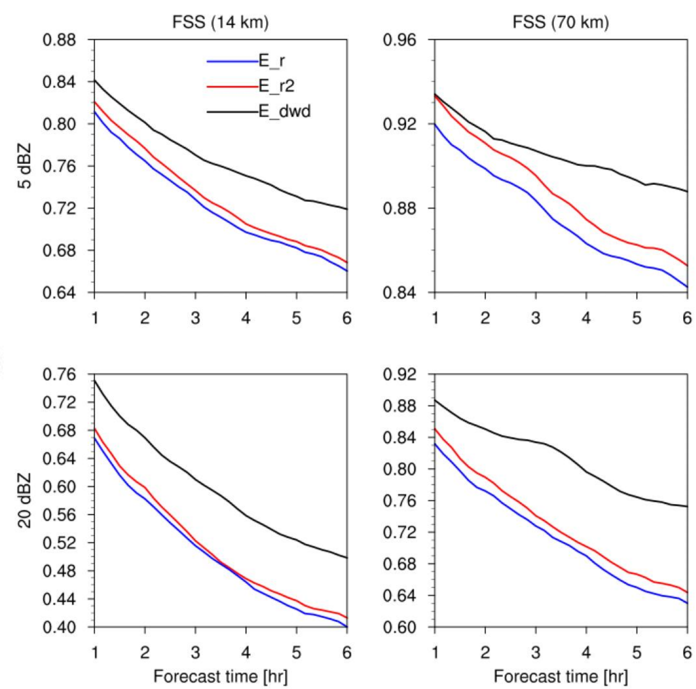
Standard deviation (Ele = 3.5)



Correlation length (height = 2 km)



FSS of 6-h reflectivity forecasts



- Smaller standard deviation and shorter correlation length in E_r2 than in E_r
- Better 6-h forecasts in E_r2 than in E_r
- Longer error correlation length in E_dwd (with conventional data assimilated and LHN) than in E_r and E_r2

  Reasons: 1) due to application of LHN 2) due to longer horizontal localization radii for conventional data

→ Drawback of Desroziers diagnostics: clear dependency on data assimilation system, not purely estimates of obs. error

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Approximation of representation error due to unresolved scales and processes

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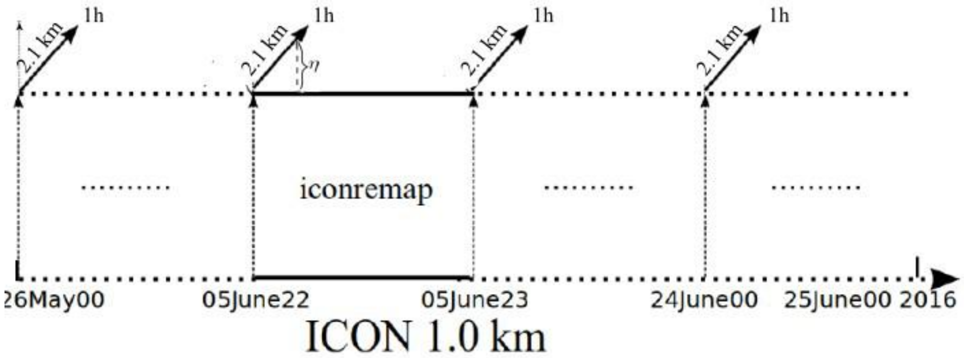
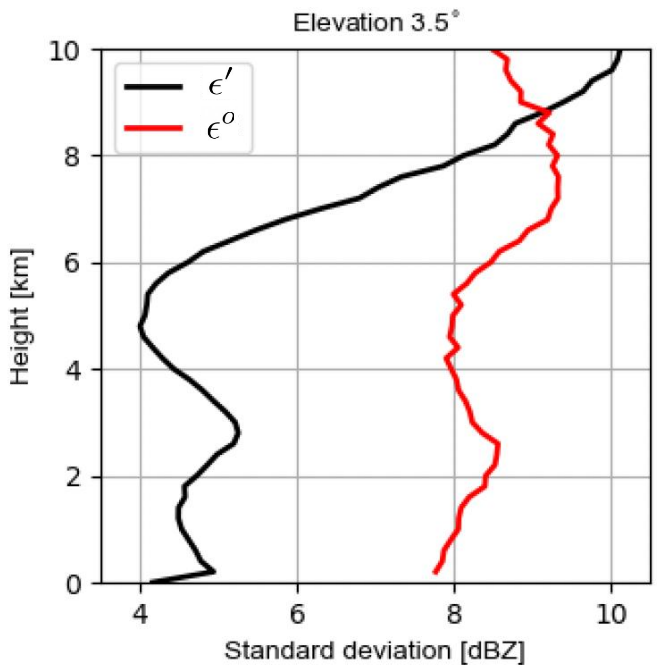
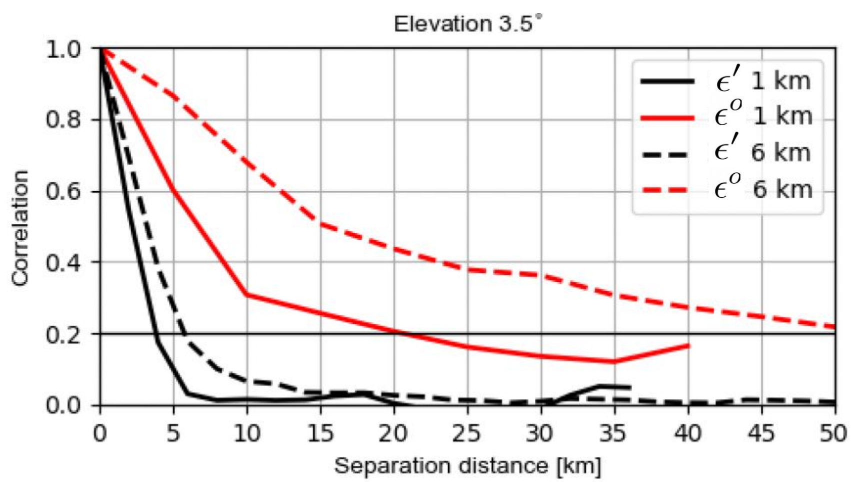
- Estimation of Representation Error due to unresolved scales and processes (ϵ'): **Consider model equivalents of radar data from a high-resolution model run as observations** and compare them with those from a low-resolution run



- Estimation of Observation Error (ϵ^o) by Desroziers (Recall: $\epsilon^o := \epsilon^m + \epsilon^R$; $\epsilon^R := \epsilon' + \epsilon'' + \epsilon'''$)





Error correlation length at different heights of 1 and 6 km

- Variation of standard deviations of ϵ' in line with ϵ^o up to 7 km
- Much longer correlation length scales of ϵ^o

(Zeng et al. 2021, AMT)

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