Representation of model error for data assimilation on convective scale

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Background information:

- Kilometre-scale ENsemble Data Assimilation (KENDA) system operationally run at DWD since May 2016 (Schraff et al. (2016))
- Data assim. scheme: Local Ensemble Transform Kalman Filter (LETKF)
- “Sufficient” background (analysis) spread $\sigma^b$ ( $\sigma^a$ ) to represent sampling error (due to limited size of ensemble) and model error:
  - Adaptive multi. inflation (Anderson (2008)): $P^b = \frac{1}{N-1}X^bX^{bT} \leftarrow \alpha P^b$
  - Relaxation method:
    1. Relaxation to prior perturbations (RTPP, Zhang et al. (2004))
      $X^a \leftarrow (1 - \alpha_p)X^a + \alpha_pX^b$ operational $\alpha_p = 0.75$
    2. Relaxation to prior spread (RTPS, Whitaker and Hamill (2012))
      $\sigma^a \leftarrow (1 - \alpha_s)\sigma^a + \alpha_s\sigma^b \leftrightarrow X^a \leftarrow \left(\alpha_s \frac{\sigma^b - \sigma^a}{\sigma^a} + 1\right)X^a$
      e.g., $\alpha_s = 0.95$ (Bick et al. (2016))
  - Additive inflation: $x^{a(i)} \leftarrow x^{a(i)} + \alpha_a \eta^{(i)}$

Currently in KENDA: random samples of climatological background error covariances from global EnVar data assimilation system for ICON. We call it “large-scale” additive inflation, denoted by “AIL”, operational $\alpha_a = 0.1$
Motivation

Whitaker and Hamill (2012) compare combinations of AIL (based on truncation error of 12-h forecast) with RTPS using two-level primitive equation global model. Ensemble size is 200, so sampling error is very small.

"when model error is the dominant source of unrepresented background errors, additive inflation alone outperforms any combination of RTPS and additive inflation."

Fig.: Contours of the ensemble mean background error using combinations of AIL and RTPS

Model error is prevailing at convective-scale

Question: AIL, RTPP/RTPS or else for convective-scale data assimilation?
Outline

1. Comparison of AIL, RTPP and combination
2. Comparison of AIL, RTPS and combination
3. Introduction of additive inflation based on model truncation error for KENDA
4. Conclusion and outlook
Experimental design:

**Period:** 00:00 UTC 27 May 2016 – 00:00 UTC 03 June 2016

**Weather situation:** atmospheric blocking, stationary thunderstorms

**Observations:** conventional data (AIREP, TEMP, PILOT, SYNOP) + radar reflectivity

**Data assim. scheme:** LETKF (also for radar reflectivity, using forward operator EMVORADO (Zeng et al. (2016))

**Assimilation window:** one hour

**Size of ensemble:** 40 members, and 20 members are used for 6-h ensemble forecasts, initiated at 10, 11, …, 18:00 UTC

**Localization:** adaptive horizontal localization for conventional data, constant horizontal localization (16 km) for reflectivity

**Observation error:** 10 dBZ for reflectivity
Study I: Comparison of AIL and RTPP (spread skill ratio & RMSE)

\[ E_{\text{RP}0.75} : \text{RTPP} \ (\alpha_p = 0.75) \text{ only}; \quad E_{\text{AIL}0.10} : \text{AIL} \ (\alpha_a = 0.1) \text{ only} \]

\[ E_{\text{AIL}0.10\text{RP}0.75} : \text{AIL} \ (\alpha_a = 0.1) + \text{RTPP} \ (\alpha_p = 0.75) \]

Verification of first guess ensemble against Radial Wind within assim. cycles
Study I: Comparison of AIL and RTPP (RMSE of ensemble forecast)

Verification of 6-h ensemble forecast against SYNOP

\[ E_{\text{RP}0.75} \approx E_{\text{AIL}0.10} \approx E_{\text{AIL}0.10\text{RP}0.75} \]
Study I: Comparison of AIL and RTPP
(Fraction skill score (FSS) of reflectivity in ensemble forecast)

FSS with scale of 30 km for different thresholds 30 and 40 dBZ: the higher, the better

![Graph showing FSS for different thresholds and forecast times]

- E_AIL0.10 is generally higher than E_RP0.75.
- E_AIL0.10RP0.75 is approximately equal to E_RP0.75.
Study I: Comparison of AIL and RTPP
(reflectivity composite in initial time & forecast)

14:00 30 May, 2016

1. Column: Reflectivity composite
Initial time

2.&3. Columns: How much percent of ensemble members exceed 30 dBZ
3 h
Study I: Comparison of AIL and RTPP (Fraction skill score of precipitation forecast)

FSS for different precip. rate thresholds 0.1, 1.0 & 5.0 mm/h and scales 14,…, 560 km

0.1 mm/h: $E_{\text{AIL}0.10} \approx E_{\text{AIL}0.10\text{RP}0.75} \approx E_{\text{RP}0.75}$

1.0 mm/h: $E_{\text{AIL}0.10} > E_{\text{AIL}0.10\text{RP}0.75} \approx E_{\text{RP}0.75}$

5.0 mm/h: $E_{\text{AIL}0.10} > E_{\text{AIL}0.10\text{RP}0.75} \approx E_{\text{RP}0.75}$
Study II: Comparison of AIL and RTPS (spread skill ratio & RMSE)

\[ E_{RS0.95} : \text{RTPS} \ (\alpha_s = 0.95) \ \text{only}; \quad E_{AIL0.10} : \text{AIL} \ (\alpha_a = 0.1) \ \text{only} \]

\[ E_{AIL0.10RS0.95} : \text{AIL} \ (\alpha_s = 0.1) + \text{RTPS} \ (\alpha_a = 0.95) \]

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5.0 mm/h:  \( E_{AIL0.10} \approx E_{AIL0.10RS0.95} \approx E_{RS0.95} \)
Introduction of additive inflation based on model truncation error for KENDA (Whitaker and Hamill (2012))

- Model truncation error is one of important sources of model error
- The refinement of the horizontal resolution improves the convective-scale precip. forecasts (e.g., Clark et al. (2016))
- Creation of sample archive for model truncation error

Approach: choose $t = 1$ hour, $x^{a(i)} \leftarrow x^{a(i)} + \alpha_b \eta^{(i)}$

$\eta^{(i)}$ samples represent **unresolved/small-scale** model error.
We call it “small-scale” additive inflation, denoted by “**AIS**”
Introduction of additive inflation based on model truncation error
(Histogram of model error samples)
Study III: Comparison of AIL and AIL+AIS (spread skill ratio & RMSE)

**E_AIL0.10**: AIL \( (\alpha_a = 0.1) \) only

**E_AIL0.10AIS1.25**: AIL \( (\alpha_a = 0.1) \) +

AIS \( (\alpha_b = 1.25) \) with \( u, v, T, Q_v \) perturbed

Verification of first guess ensemble against Radial Wind within assim. cycles
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FSS for different precip. rate thresholds 0.1, 1.0 & 5.0 mm/h and scales 14,…, 560 km

- 0.1 mm/h: $E_{\text{AIL}0.10} \approx E_{\text{AIL}0.10AIS1.25}$
- 1.0 mm/h: $E_{\text{AIL}0.10AIS1.25} \approx E_{\text{AIL}0.10}$
- 5.0 mm/h: $E_{\text{AIL}0.10AIS1.25} \approx E_{\text{AIL}0.10}$
Conclusion and Outlook

Conclusion:

1. Large-scale additive inflation alone outperforms RTPP, RTPS and combination both in cycling and short-term precip. forecast for convective-scale data assimilation

2. Small-scale additive inflation based on model truncation error further improves large-scale additive inflation for short-term precip. forecast

Outlook:

1. To tune small-scale additive inflation

2. To compare small-scale additive inflation with warm bubbles and stochastic boundary layer perturbations

3. Papers in preparation:


Reference


Thank you for your attention
Surface pressure tendency of during one day cycling