Towards an operational use of the Kilometre-scale Ensemble Data Assimilation (KENDA)

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... and many colleagues from CH, D, I, RU ...
... in particular Hendrik Reich (DWD), Daniel Leuenberger (MCH)

→ Local Ensemble Transform Kalman Filter (LETKF) system developed

(pre-) operational use of KENDA

- **MeteoSwiss:** KENDA operational for EPS (COSMO-E: $\Delta x = 2.2$ km) since 19 May 2016

- **DWD:** KENDA run in pre-operational suite for deterministic + EPS forecasts with COSMO-DE ($\Delta x = 2.8$ km) since May 2016

- **ARPAE-SIMC:** start pre-operational suite with (Italy) KENDA-IC for 2.2 km EPS soon (Oct.?)

- **COMET:** KENDA code adapted to include required capabilities of COMET system and run in a parallel suite ($\Delta x = 10$ km)
KENDA-LETKF: (pre-) operational setup, incl. deterministic analysis / forecast

KENDA: 4D-LETKF + LHN (latent heat nudging for assimilation of radar precip)

K: Kalman Gain for ensemble mean

(pre-) operational settings:
- conventional obs types only (radiosonde, aircraft, wind profiler, synop)
- adaptive horizontal localisation (keep # obs constant, 50 km ≤ s ≈ std dev ≤ 100 km)
- adaptive multiplicative covariance inflation (obs-f.g. statistics) + RTPP ($\alpha_p = 0.75$)
- explicit soil moisture perturbations (only DWD), …
operational KENDA implementation

by Daniel Leuenberger et al.

- lateral BC in EPS (forecast component): (6 h old) IFS ENS

- lateral BC in DA cycle:
  - perturbations from 30 – 42 h old IFS ENS perturbations
  - centred around the latest HRES forecast
spread / skill ratio of first guess
(27 July – 28 Aug. 2015)

KENDA for COSMO-E analysis performance
by Daniel Leuenberger et al.

 operational setting
with SPPT (stochastic perturb. of physics tendencies)
with SPPT + soil moisture perturb.
COSMO-E outperforms COSMO-LEPS ($\Delta x=7$km) by Daniel Leuenberger et al.

precip > 5 mm/12h
Brier Skill Score
(w.r.t. climatology, 300 stations
July – August 2014)

2-m temperature
RPSS
(w.r.t. climatology,
March – May 2016)

COSMO-E with KENDA IC also better than with IC downscaled from IFS-ENS

towards an operational use of KENDA
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pre-operational parallel suite at DWD, comparison to operational nudging setup

- **KENDA-LETKF**: conventional obs, plus humidity data from 9 aircrafts,

- benchmark: operational **nudging** uses 2-m humidity data (with limited weight), continues to nudge new obs in first 30 minutes of forecast

- lateral BC from operational global ICON EnVar system, with resolution: deterministic global 13 km / EU 6.5 km, ensemble global 40 km / EU 20 km
results shown for:

- **Period A**: ~ August ( + Sept.): mainly *frontal* precip, dry periods
  → meteorologically not too interesting

- **Period B**: ~ end May – mid June: lots of local, often stationary, *heavy convection* over Germany: *high-impact weather*!
  → meteorologically highly interesting, but affected by bugs (expect small degradation of KENDA results)
  - no use of any aircraft obs in 30 % of the hourly analyses
  - in ensemble part: no updating of climatological fields since 2 May
  → activity of vegetation underestimated (evapotranspiration !)
  → only scores on precipitation shown
pre-operational parallel suite, **deterministic**: radiosonde verification  
(26 July – 27 Sept. 2016)

**KENDA-LETKF vs. nudging**

<table>
<thead>
<tr>
<th>T</th>
<th>RH</th>
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<td><img src="image" alt="Graph" /></td>
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**rmse**  
(averaged over lead times & initial times)

- **better**  
- **worse**

**KENDA**: neutral  
(similar results for convective period)
KENDA-LETKF vs. nudging

- ff-10M
- RH 2M
- T 2M
- dd-10M
- Td 2M
- ps

- T 2M German stations

- KENDA: worse for 2-m humidity in first 6 hours and for surface pressure ‘ps’
  (‘ps’: mainly bias (lateral BC with bias) : (~ geostrophic) balance issue, under investigation)
- 2-m temperature slightly better, otherwise neutral
pre-operational parallel suite, deterministic: radar verification  (26 July – 29 August 2016)

mostly frontal precip, some post-frontal showers

0.1 mm/h

1-hrly precip FSS (30 km)

1 mm/h

KENDA: only small, but long-lasting improvements in 12-UTC runs

KENDA oper. Nudging

☑️ KENDA: only small, but long-lasting improvements in 12-UTC runs
pre-operational parallel suite, deterministic: radar verification (26 May – 12 June 2016)

lots of local, often stationary, heavy convection (high-impact wea.)

0.1 mm/h

1-hrly precip FSS (30 km)

1 mm/h

0-UTC runs

KENDA oper. Nudging

12-UTC runs

✓ KENDA: long-lasting improvements after first 2 – 4 hours in summer convective period
pre-operational parallel suite, deterministic: radar verification  (26 May – 29 August 2016)

complete summer (3 months)

0-UTC runs

12-UTC runs

KENDA oper. Nudging

0.1 mm/h

1-hrly precip FSS (30 km)

1 mm/h

✓ KENDA: on average rather small, but long-lasting improvements in summer
pre-operational parallel suite, deterministic: radar verification (26 May – 12 June 2016)

**daily cycle of precip amount**

lots of local, often stationary, heavy convection (high-impact weather)

- KENDA: better daily cycle of (convective) precip, particularly in afternoon of 12-UTC runs → KENDA makes less correction to the moist bias of the model (climatology)
- not always good to correct model biases in the analysis!
pre-operational parallel suite, EPS

• EPS with KENDA IC vs. EPS with nudg./multi-model IC (operational “COSMO-DE-EPS”)
  • nudg./multi-model: operational deterministic analysis (nudging) + perturbations from 4 global model systems
  • LBC: perturbations from 4 global model systems (“BCEPS”)
  • perturbed physics parameters

thanks to Christoph Gebhardt + Felix Fundel for plots
pre-operational parallel suite, EPS (probabilistic): radiosonde verification  (26 July – 31 August 2016)

**KENDA-LETKF** vs. nudg./multi-model

CRPS (averaged over lead times & initial times)

- **T** (temperature)
- **RH** (relative humidity)
- **zonal wind**
- **merid. wind**

**KENDA:** much better CRPS
pre-operational parallel suite, EPS (probabilistic): radiosonde verification (26 July – 31 August 2016)

- - - - KENDA
- - nudg./multi-model

12-h forecasts

KENDA: much better (larger) spread, also slightly smaller errors (rmse)
KENDA-LETKF vs. nudg./multi-model

- PS
- RH2M
- FF
- N
- T2M
- TD2M
- GUST_1h
- T1N
- H

Reduction of CRPS [%]

- KENDA: much better CRPS in all variables except surface pressure

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pre-operational parallel suite, EPS (probabilistic): surface verification  (26 July – 31 August 2016)

10-m wind gusts

KENDA-LETKF nudg./multi-model

0-UTC runs

12-UTC runs

✓ KENDA: better spread + skill + BSS (for 14 m/s + 18 m/s, due to improved reliability)

Towards an operational use of KENDA
pre-operational parallel suite, EPS (probabilistic): radar verification (20 May – 21 June 2016)

1-hrly precipitation

Brier skill score (averaged over lead times 1 – 27 h)

0-UTC runs

KENDA-LETKF nudg./multi-model

12-UTC runs

BSS 1 mm/h

BSS 5 mm/h

KENDA: BSS better for all thresholds, long-lasting
pre-operational parallel suite, EPS (probabilistic): radar verification (20 May – 21 June 2016)

**precipitation**

- **KENDA-LETKF** nudg./multi-model

**reliability** 1 mm/h

- Average agreement between forecast & observations; related to (cond.) bias
- The lower the better

**resolution** 1 mm/h

- Ability of forecast to separate one type of outcome from another
- The higher the better

- 0-UTC runs
- 12-UTC runs

✓ KENDA: better reliability and (not susceptible to calibration:) resolution
pre-operational parallel suite, EPS (probabilistic): radar verification (26 July – 31 August 2016)

1-hrly precipitation

Brier skill score
(averaged over lead times 1 – 27 h)

0-UTC runs

KENDA-LETKF nudg./multi-model

12-UTC runs

BSS 1 mm/h

resolution 1 mm/h

ability of forecast to separate one type of outcome from another

the higher the better

✓ KENDA: BSS (resolution (neutral for 0.1mm/h) + reliability) better for all thresholds, long-lasting
pre-operational parallel suite: summary of results

(convective) precip; EPS overall (spread + errors)

deterministic (overall, vs. nudging)

Td2m

surface pressure (at DWD pre-op, bias in LBC)
→ KENDA operational at DWD (det + EPS) in late 2016 or 1st half 2017, depends on
  – data base
  – winter period with pre-operational configuration (LBC!)
Further developments on KENDA

use of additional obs:

- GNSS slant total delay  (8-day test: positive impact on precip (in addition to LHN))
- SEVIRI WV all-sky approach for cloud info  (cloud dep. obs errors + bias corr.)
- radar reflectivity + radial velocity  (sensitivity tests)
- screen-level obs  (sensitivity tests)
- Mode-S : tests at DWD & MeteoSwiss soon
- etc.

further tasks

- non-Gaussianity: promising research ongoing with
  - hybrid LETK-PF applied to COSMO  (Sylvain Robert, ETH)
  - hybrid VarEnKF-PF applied to ICON  (Roland Potthast, DWD)
- further refinement of LETKF, soil moisture analysis using sat obs in LETKF framework, ...
Further developments: KENDA for ICON

- 2017: start porting KENDA from COSMO to **ICON-regional**
  → implement also hybrid (4-D) EnVar, compare with pure 4-D LETKF

motivated by some advantages:
- very positive experience with (3-D) EnVar for global ICON;
  KENDA 4-D LETKF: large improvement for EPS, not for deterministic
- conceptual advantages of VAR (localisation, Var-BC / -QC,…) + hybrid (B-matrix)
- further code unification with global DA at DWD
- capability to use KENDA code without need to run ensemble (3DVar, poor man’s EnVar)

some disadvantages:
- trade-off between 4-D capability and the need to interpolate + amount of I/O
- increased complexity, need of tangent linear / adjoint obs operators
KENDA system: outlook

surface pressure, 12-UTC runs

- rmse
- bias
- std dev

KENDA nudging

- surface pressure: (~ geostrophic) balance issue, under investigation (lateral BC with bias)
KENDA-O overview, Task 2 (high-res. obs): GNSS-STD, first trial for use in KENDA

8 days
17 – 24 May 2014

1-hrly precip
FSS (30 km)
1 mm/h

CONV only
CONV + GNSS
CONV + LHN
CONV + LHN + GNSS

✓ 1 mm/h: slightly better for 0-, 6-, 18-UTC runs
10-m wind gusts

KENDA-LETKF nudg./multi-model

0-UTC runs

12-UTC runs

KENDA: better spread + skill + BSS (for 14 m/s + 18 m/s, due to improved reliability)