Recent developments in KENDA

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KENDA : Km-Scale Ensemble-Based Data Assimilation (*Schraff et al. 2016, QJRMS*)

currently based on 4-D LETKF + latent heat nudging

- some recent KENDA developments
  - ICON-LAM (Limited Area Mode) vs. COSMO , 3-D vs. 4-D LETKF

    (Hendrik Reich, Christian Welzbacher, Christoph Schraff, Harald Anlauf, Klaus Stephan, Roland Potthast et al.!, DWD)
  - 3-D radar reflectivity in LETKF *(Thomas Gastaldo, Virginia Poli, ARPAE Bologna)*
  - GPS Slant Total Delay *(Michael Bender et al., DWD)*

- crowd-sourced data
  - project on car data, Ultra-Rapid DA (URDA)

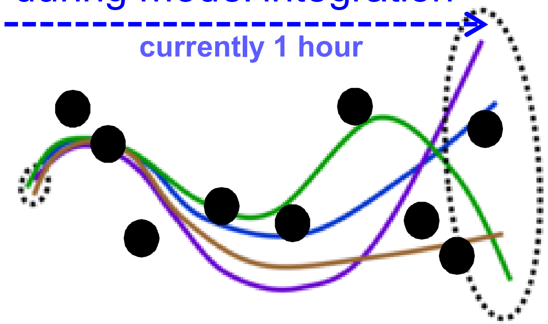
    (Walter Acevedo, Zoi Paschalidi et al., DWD)

3-D / 4-D LETKF: concept

COSMO

$H(\mathbf{x}) \rightarrow H(\mathbf{x}(t_{obs}))$
during model integration
currently 1 hour

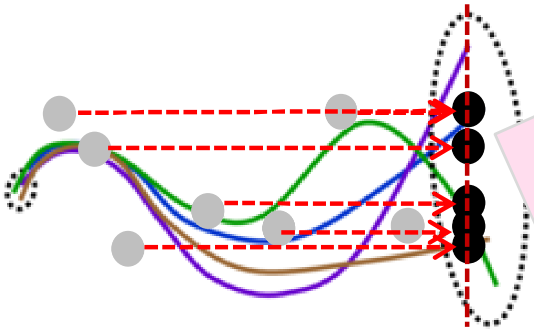
4D



→ **full 4-D** (o-b, P_b) (online)

$H(\mathbf{x}) \rightarrow H(\mathbf{x}_{FG}(t_a))$

3D

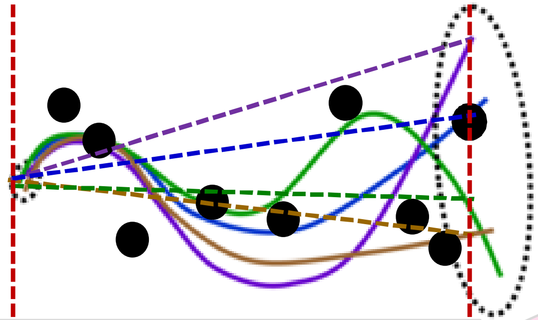


ICON-LAM vs. COSMO (3-D this talk)

→ **3-D** (o-b, P_b) (MEC)

$H(\mathbf{x})$: $\mathbf{x}(t_{obs})$ by interpolation betw. $\mathbf{x}_{ana}(t_a\text{-}1h)$ and $\mathbf{x}_{FG}(t_a)$

4D

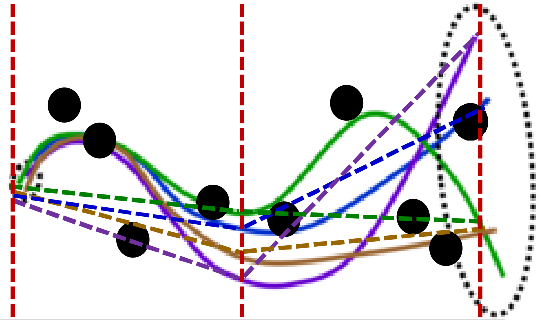


→ **interpol. 4-D (2 t.lv.)**

ICON-LAM (x time lev.)

$H(\mathbf{x})$: $\mathbf{x}(t_{obs})$ by interpolation betw. $\mathbf{x}_{ana}(t_a\text{-}1h)$, $\mathbf{x}(t_a\text{-}½h)$, $\mathbf{x}_{FG}(t_a)$

4D



→ **interpol. 4-D (3 t.lv.)**

ICON-DE vs. COSMO-DE with LHN

(27 May – 10 June 2016)

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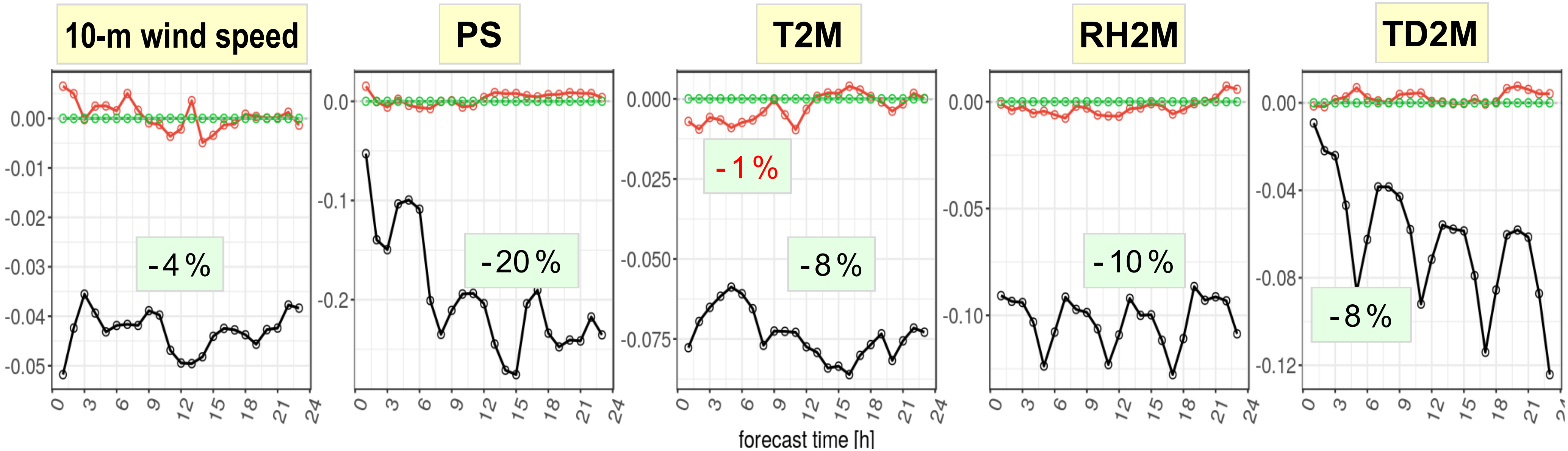
SYNOP verification
relative change of RMSE
vs. COSMO-DE 3-D



ICON-DE 3-D
COSMO-DE 3-D
COSMO-DE 4-D

similar error reductions in terms of std. dev. (except for PS where both std and bias are strongly reduced)

Summary
(ICON-LAM vs. COSMO, 3-D vs. 4-D LETKF)

- **3-D** LETKF *only slightly* worse than **4-D** LETKF (1-h LETKF cycling)
- **interpolated 4-D** LETKF (→ ICON-LAM) ~ as good as online 4-D LETKF

  (2-week convective summer period)

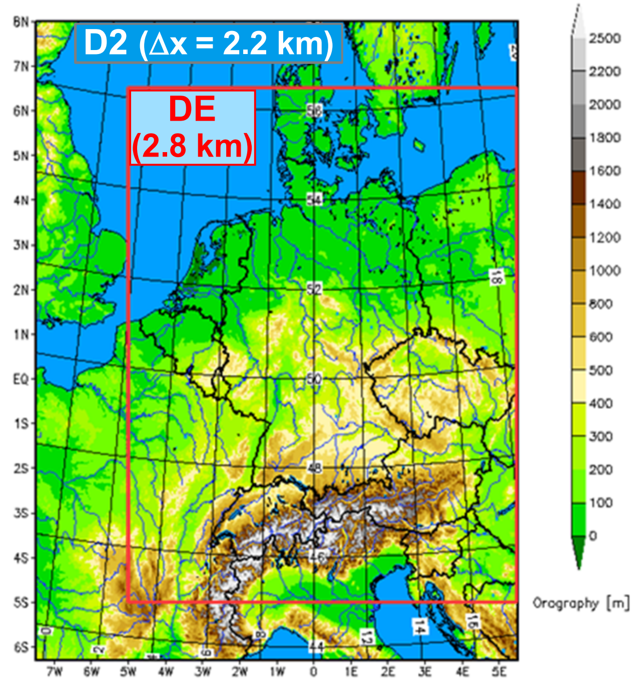
- (**3-D** LETKF + LHN:) **ICON-DE** much better than COSMO-DE in most variables

  (upper-air troposphere; wind, T also better, RH slightly worse ;
  precip ~ neutral (LHN needs further tuning))

  (summer & winter periods)

- **4-D** LETKF ICON-D2 (Δx = 2.2 km)
  experiments underway

- Plan: **ICON-D2**
  - pre-operational parallel suite autumn 2019
  - operational 12 / 2020

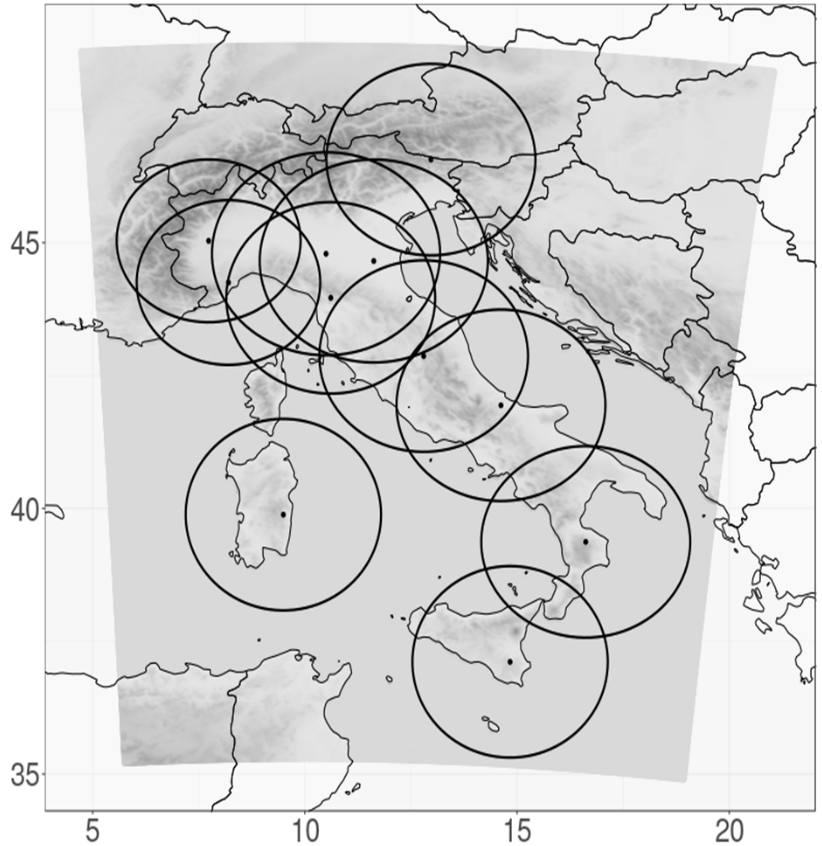


radar reflectivity Z
impact experiments at ARPAE (Bologna)

arpae emilia-romagna

Setup

- 1-hrly LETKF 2.2 km
- reference: conv. obs (TEMP, SYNOP, aircraft, wprof) in LETKF
  + continuous **LHN**
- **Radar Z**: superobbing 10 km,
  1 scan per hour (closest to analysis time, i.e. 3-D approach for radar obs)
  (replacing LHN)



- evaluated: deterministic forecast every 3 hrs

  3 periods (72 – 123 forecasts)

Event	Start	End	Type of event
Sept. 2018	31/08 - 00UTC	09/09 - 00UTC	thunderstorms
Oct. 2018	30/09 - 15UTC	14/10 - 00UTC	organized thunderstorms
Nov. 2018	26/10 - 12UTC	11/11 - 00UTC	stratiform precipitation

radar reflectivity Z
impact experiments at ARPAE

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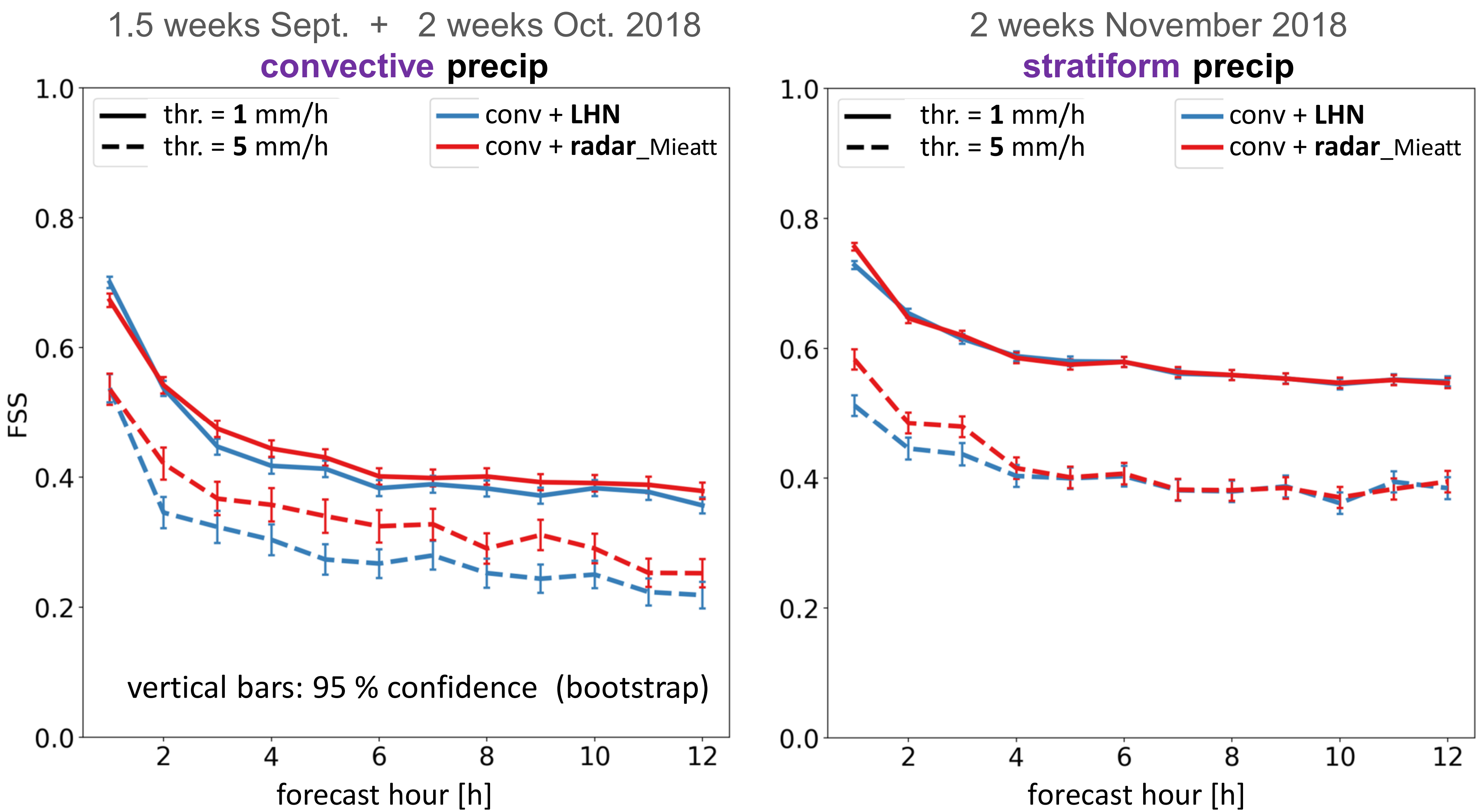
FSS (**0.2°**) for **1-h precip** vs. radar composite adjusted by rain-gauges



Results at ARPAE: assimilation 3-D reflectivity by LETKF compared to LHN

- **precip**: statistically **significantly better**,
  especially for heavy and non-organized precip;

  upper-air: better RMSE (T, RH, mainly **wind**),

  surface: similar (T2M slightly improved, RH2M + ps slightly degraded, 10-m wind neutral)

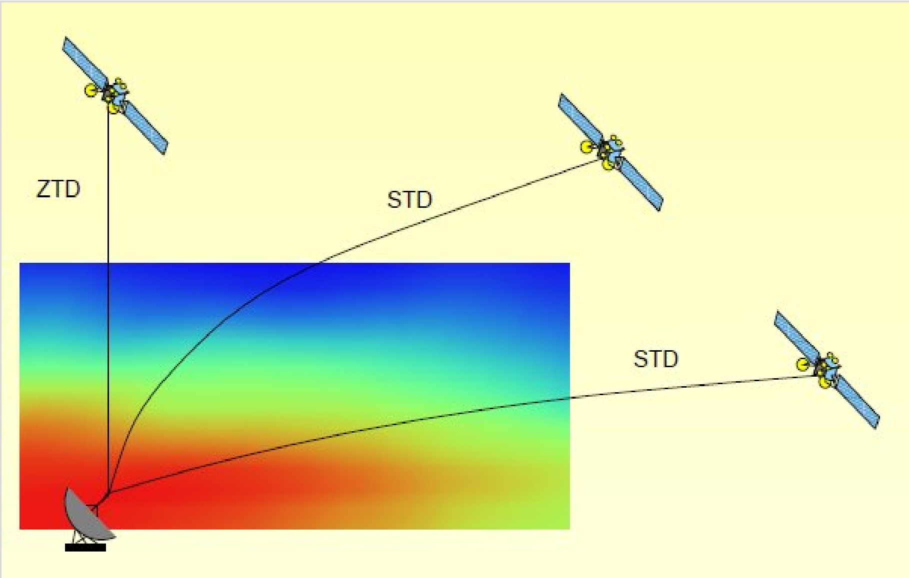
- plan: replace LHN by 3-D radar reflectivities in operational suite next year

DWD:

- implemented in ICON-LAM, tests underway (will not be made operational in COSMO)

GPS STD (Slant Total Delay)

GPS (GNSS) STD: **humidity** integrated over (slant) path from ground station to GNSS (GPS) satellite, all weather obs



- STD (slant total delay), elevation ε = 7°– 90°

  → after thinning ~ 2000 obs/h

- ZTD (zenith total delay):

  mapping of delays to 1 zenith info,

  < 300 obs/h

- 300 stations in COSMO-DE domain, thinning (3-D approach)
- no consistent positive impact → improved bias correction, bug fixes, etc.
- many higher-elevation STD provide info similar to each other & to ZTD (→ redundant info)

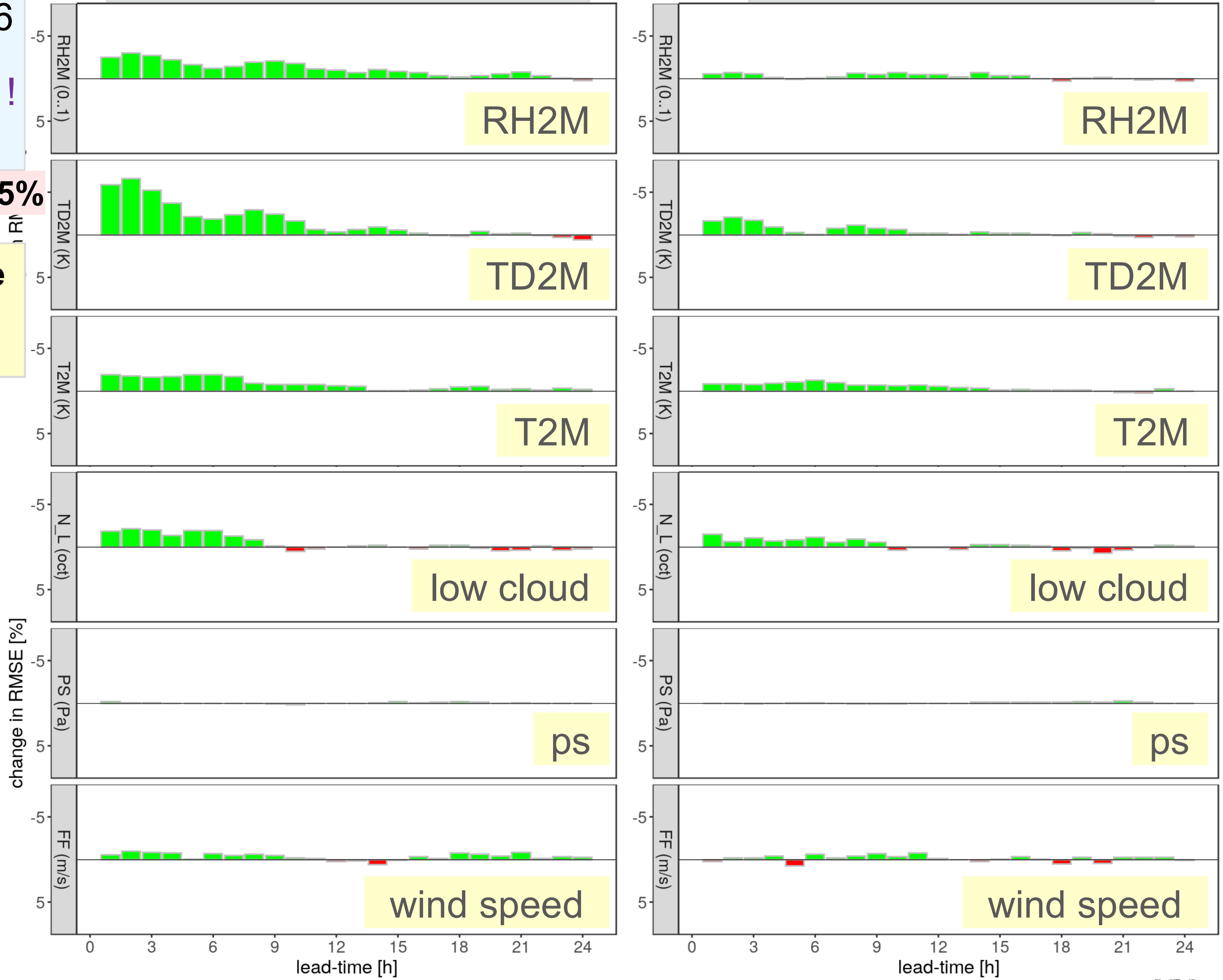
→ new experiment: assimilate **ZTD + low-elevation STD** (7° < ε < 25°)

GPS STD
convective summer period

Synop verif. (GER)
25 May – 1 July 2016

→ **5 weeks !**

% change of **rmse**
(as function of lead time)



GPS STD
convective summer period

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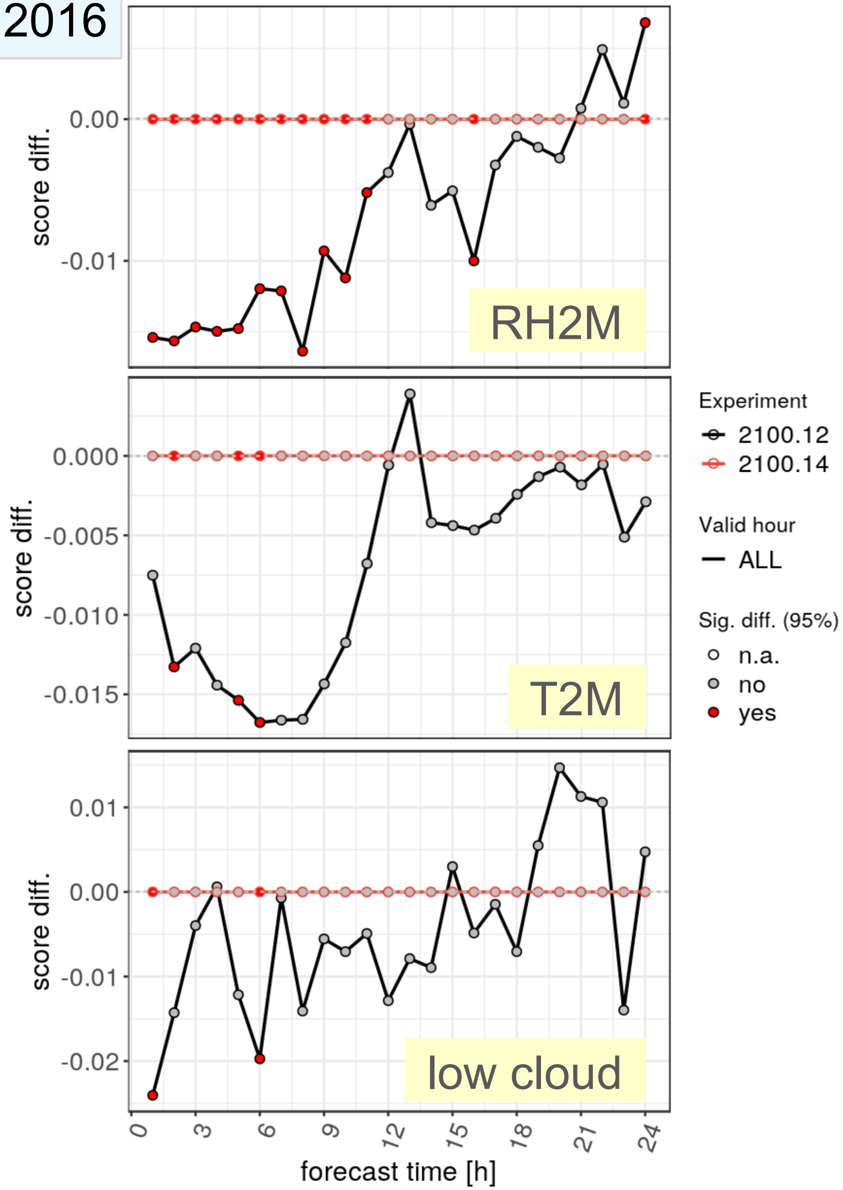
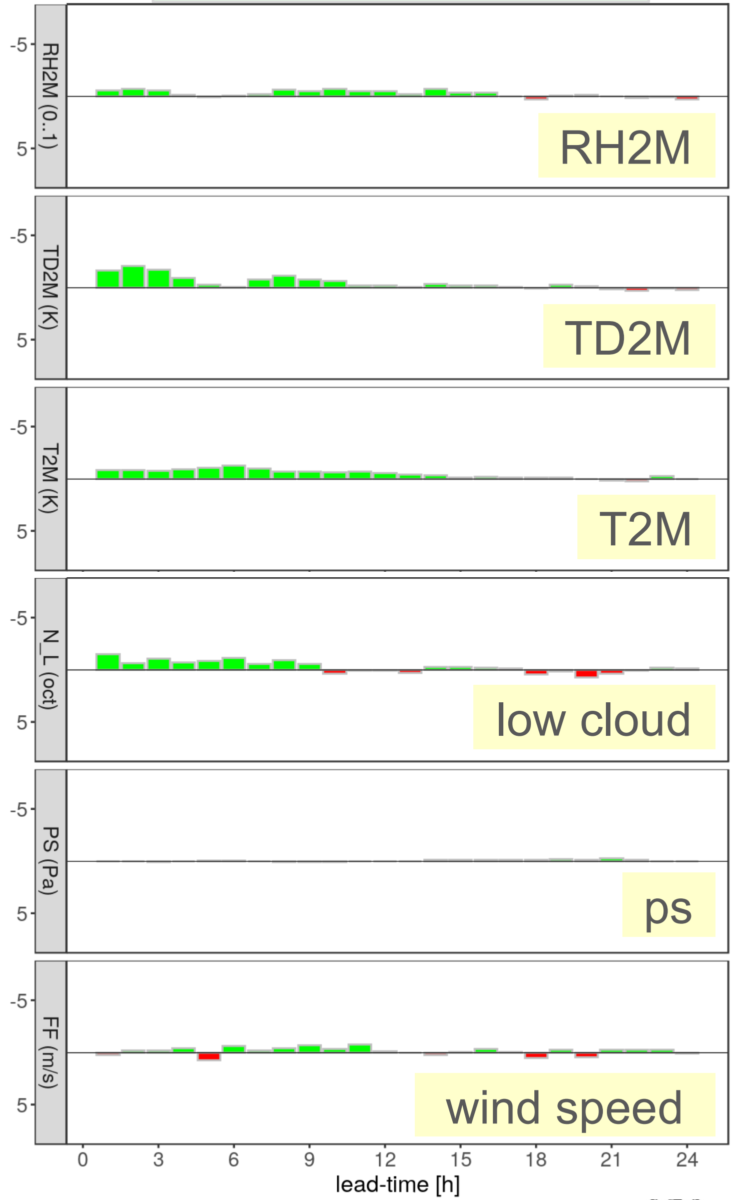
Synop verif. (GER)
25 May – 1 July 2016

6-UTC forecast runs



STD + ZTD vs. ZTD



improvements by adding STD to ZTD are occasionally significant

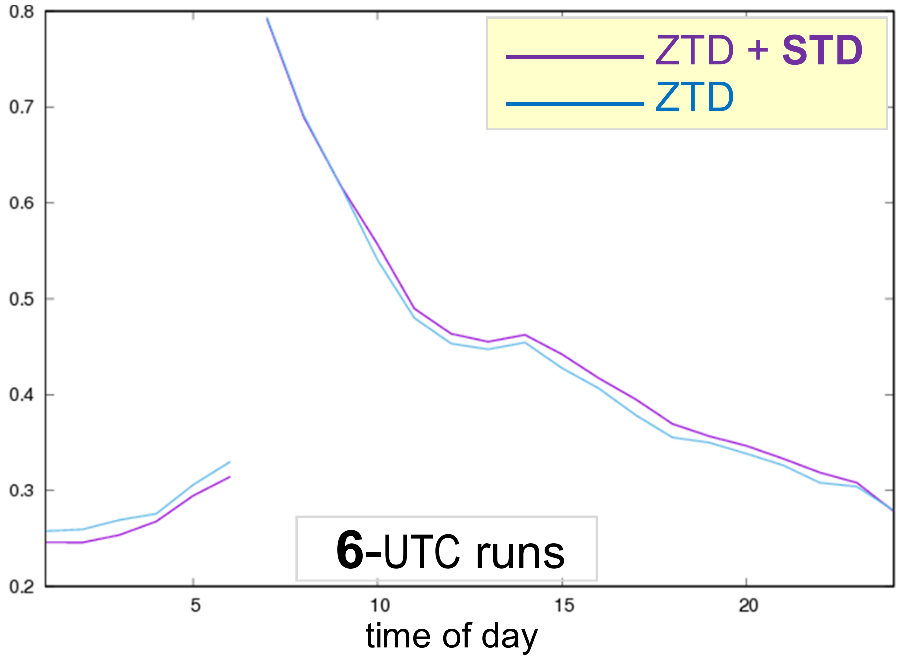
GPS STD
convective summer period

precip vs. radar
26 May – 28 June 2016

→ **5** weeks !

1-hrly precip
FSS
(30 km)

1 mm/h



- moderate positive impact from **ZTD** (upper-air, surface, precip (0-, 6- UTC runs))
- **small extra benefit by** adding (low-elevation) **STD** on top of ZTD, 'occasionally' significant (Synop verif.)
- future: – experiments with ICON-LAM (smaller model biases)
  – potential for enhanced benefit by improved bias correction of STD ?

Overview on use of additional obs

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DWD

- **GPS STD** — small extra benefit on top of ZTD
- radar **reflectivity** Z — ARPAE: better than LHN, soon operational (with COSMO); DWD: $\rightarrow$ ICON-LAM
- radar **radial wind** — small consistent positive impact after increasing obs errors where Z low
  $\rightarrow$ in parallel suite for COSMO soon
- **all-sky SEVIRI** IR + VIS — work ongoing $\rightarrow$ ICON-LAM
- **T2M**, RH2M: — (at last) resources since spring, work on conditional non-linear bias correction (*Otkin + Potthast 2019, MWR*)
  $\rightarrow$ ICON-LAM
- ongoing work on other obs, e.g. — wind lidar, Raman lidar, MW radiometer, …
  lightning, land surface temperature, …

crowd-sourced data: some general remarks

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- distinguish:
  - genuine crowd-source: by lots of single users (e.g. mobile phones,…)
  - operated networks (partners): wind parks, photovoltaic power networks, car manufacturers, road weather stations, etc.

    → projects:
    - DWD: renewable energy
    - DWD: car manufacturer (Audi)
    - MCH: meteo-drones

- need to cope with data of often reduced quality (+ missing meta data):
  - minimize conditional biases in obs increments $(H(\mathbf{x}) - \mathbf{y})$

    by modelling of micro climate of obs device / station,
    e.g. directional dependency of errors of wind obs from masts of wind parks, car microclimate, etc.

    → suitable 'situation-dependent' H and / or bias correction (of $\mathbf{y}$)
    e.g. conditional non-linear bias correction (*Otkin + Potthast 2019, MWR*), machine learning,…
  - similarly: quality control, specification of obs errors $\mathbf{R}$, time and spatial aggregation

Crowd-sourced data: motivation for project with AUDI

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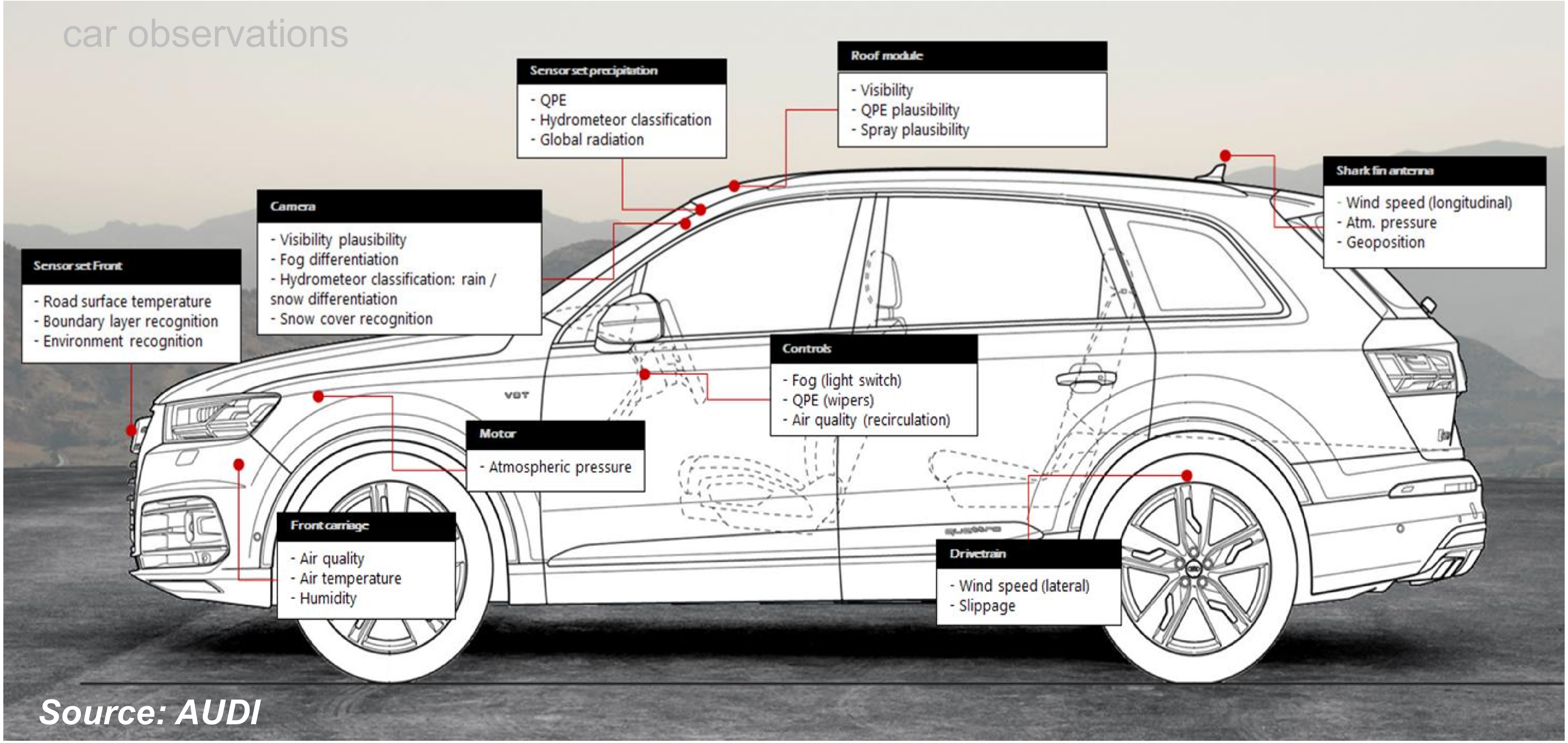
DWD

autonomous driving ⟵ depends strongly on weather conditions!

Crowd-sourced data: car observations



legal issues to make data available → currently data only from 1 car
(data anonymization)

observation operators under development

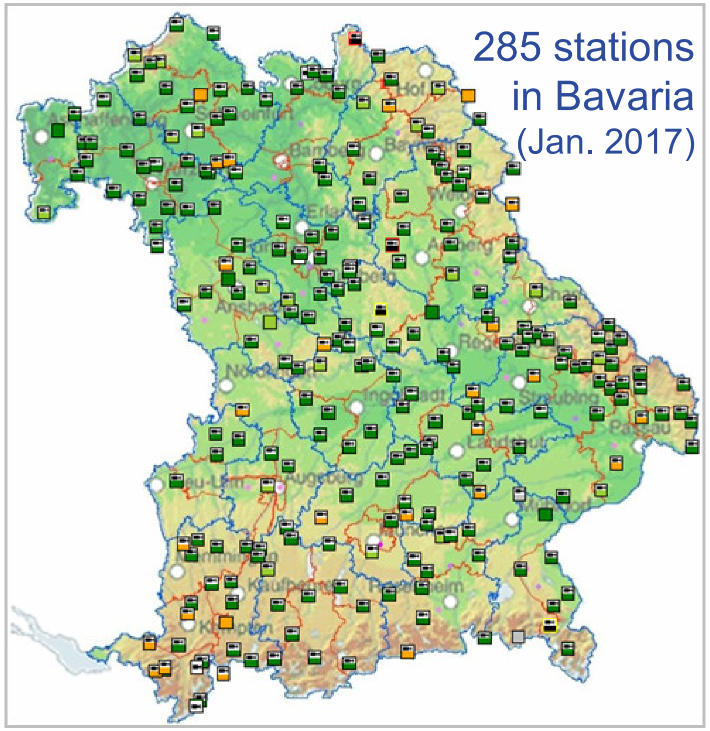
Crowd-sourced data: road weather stations

road weather stations

Source: Bavarian Administration

measured variables

- temperature (air + road + 30 cm depth)
- dew point
- wind (direction + velocity)
- precipitation (type + intensity)
- visibility
- road condition (dry, wet, ice, snow, …)



Ultra Rapid Data Assimilation (URDA)
for real-time weather (~ 5 – 60 min)

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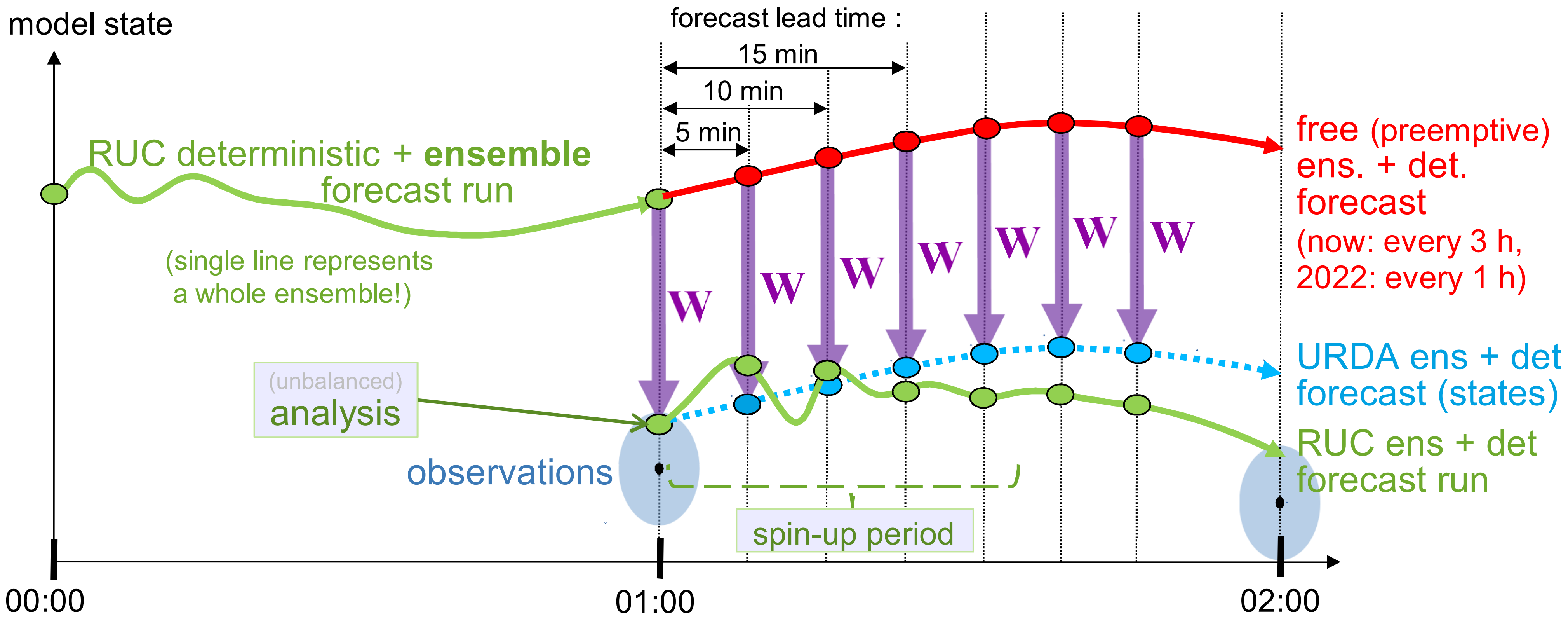


- RUC = Rapid Update Cycle → 1-hrly LETKF DA cycle (i.e. **based on ensemble filter**)
- **W** : LETKF transform matrix (defining linear combination of first guess ensemble members)

Properties:

- equivalent to standard sequential DA for linear model and observation operator [*Potthast & Welzbacher 2018*]:

  → URDA applicable only for (very) short lead times (≤ ~ 1 – 3 h) for which

  - non-linearity is sufficiently 'small'
  - local transform matrix (of **L**ETKF) still applicable to the local forecast
    (i.e. the influence of obs remain within localisation area)

- applicable to several assimilation steps from successive time intervals

- no model re-initialization / no additional forecast runs necessary

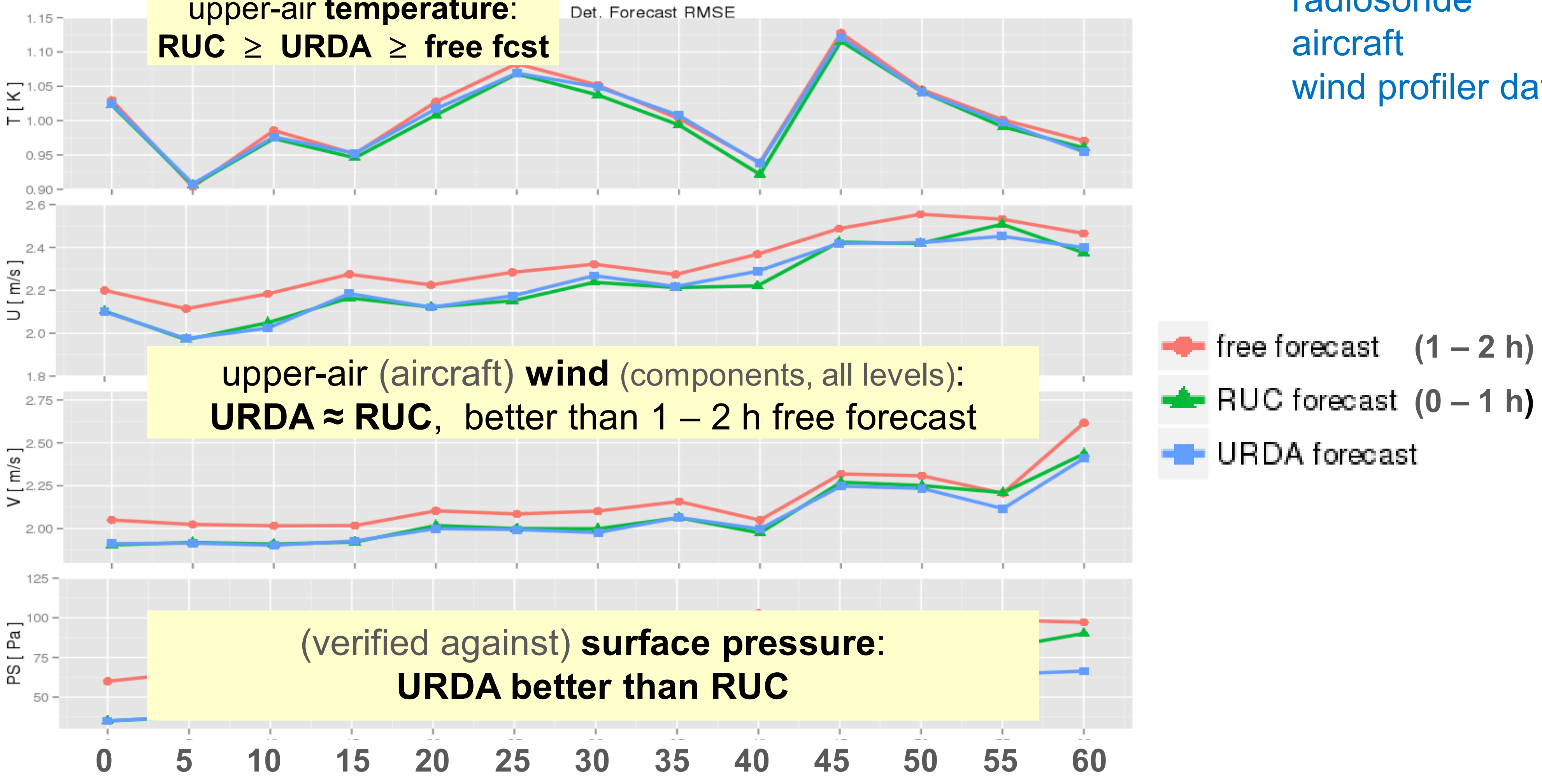
  → no need to update the whole model state;
  a reduced set of selected variables and grid points can be updated

  → very low computational costs
  enables forecasts updated very frequently + timely

Ultra Rapid Data Assimilation (URDA)
experiment (single case!)

RMSE vs. lead time (period 60 minutes)

assimilated: Synop pressure
radiosonde
aircraft
wind profiler data



URDA: quality comparable to RUC, no spin-up effects
→ great potential for very short lead times

summary

- **3-D LETKF** almost as good as **4-D LETKF**
- **ICON-LAM** much better than COSMO
- **3-D radar reflectivity** in LETKF beats Latent Heat Nudging (ARPAE)
- small extra benefit from (low-elevation) **GPS STD** on top of ZTD
- work on **crowd-sourced** data e.g. related to cars – new obs operators, bias correction, …
- (ensemble-based) **Ultra Rapid DA** (URDA) promising for real-time weather

Thank you for your attention