Observations in convective-scale ensemble data assimilation: Actual and potential impact

T. Necker, S. Geiss and M. Weissmann
Hans-Ertl-Center for Weather Research, Data Assimilation Branch
Ludwig-Maximilians-University, Munich, Germany

T. Miyoshi
RIKEN institute, Kobe, Japan

J. Ruiz
University of Buenos Aires

Research in cooperation with the group of **R. Potthast** at DWD

Outline

Part I: Introduction & motivation

Part II: 'Actual' observation impact – EFSOI

(EFSOI: Ensemble Forecast Sensitivity to Observation Impact)

- Results for DWD System (40-member)

Part III: 'Potential' impact of observations – ESA

(ESA: Ensemble Sensitivity Analysis)

- Results for Japanese 1000 member ensemble [Poster by S. Geiss]
- Comparison with DWD System (40-member)

Part IV: Summary & conclusions

Introduction – Observations in convective-scale NWP

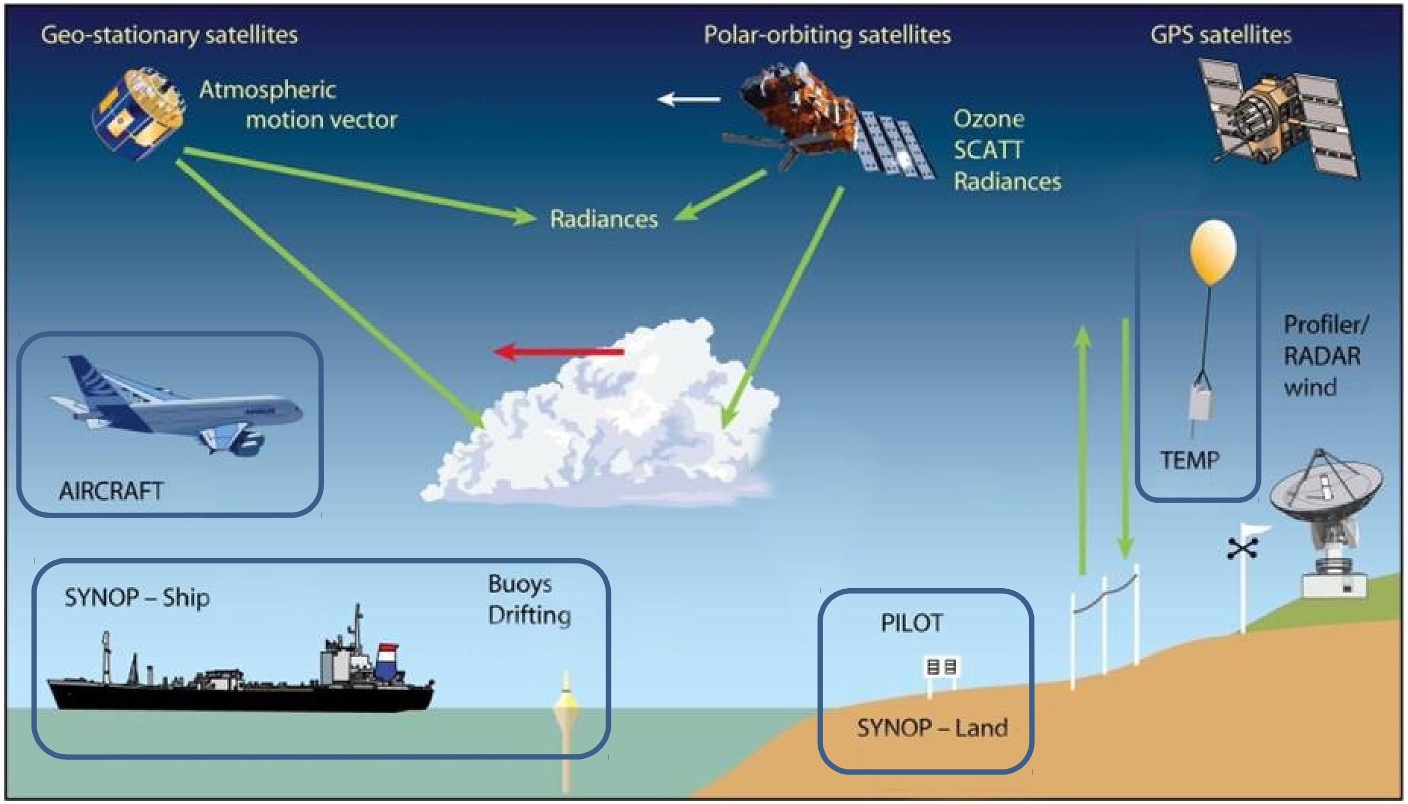
What observations do we need for convective-scale DA?

✉ This time, we provide several answers

COSMO-KENDA
- Conventional (SYNOP, AIREP, PROF, TEMP)

Not operational:
- Satellite (IR, NIR, VIS)
- Radar (Wind, reflectivity)
- GPS/GNSS (Humidity)

Not yet exploited:
- Other (lidar, smart phones, webcams, etc.)



EFSOI: Verification metrics

$$J(\boldsymbol{d}') \approx \frac{2}{N_e - 1} \boxed{\boldsymbol{e}_f^d} \cdot \boldsymbol{Y}_f^d \left(\boldsymbol{Y}_a^d\right)^T \boldsymbol{R}^{-1} \boldsymbol{d}'$$

$$\boldsymbol{e}_f^d = \overline{\boldsymbol{H}_{veri}\left(\boldsymbol{x}_f^d\right)} - \boxed{\boldsymbol{y}_{veri}}$$

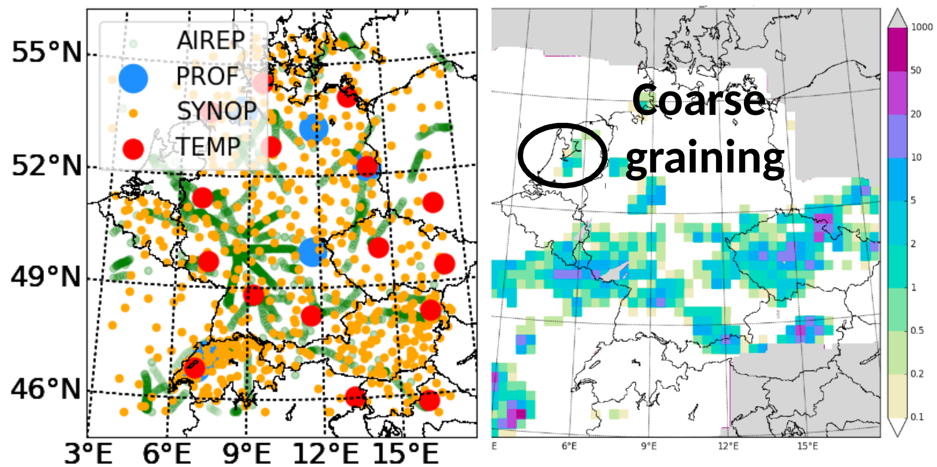
Goal
- J : Observation Impact

COSMO KENDA DATA
- N_e: Number of ensemble member
- $\boldsymbol{Y}_f^d$: Forecast ensemble in obs . space
- $\boldsymbol{Y}_a^d$: Analysis ensemble in obs. space
- $\boldsymbol{R}$: Observation error covariance matrix
- $\boldsymbol{d}$: Innovation vector $\boldsymbol{d} = \boldsymbol{y}_o - \boldsymbol{y}_b$

Verifi-cation metric
- $\boldsymbol{e}_f^d$: Forecast error
- $\boldsymbol{H}_{veri}$: Observation operator into verification space
- $\boldsymbol{x}^d{}_f$: Model equivalent for verification
- $\boldsymbol{y}_{veri}$: Observation used for verification

Following Kalnay et al. 2012
Reformulated by Sommer & Weissmann 2016

CONVENTIONAL **PRECIPITATION**

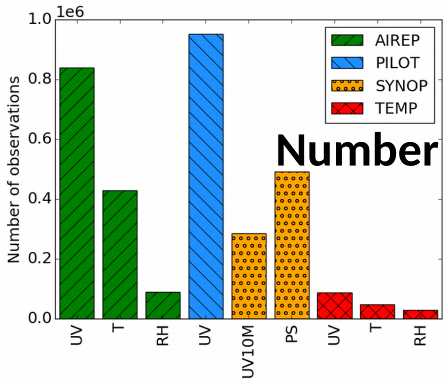


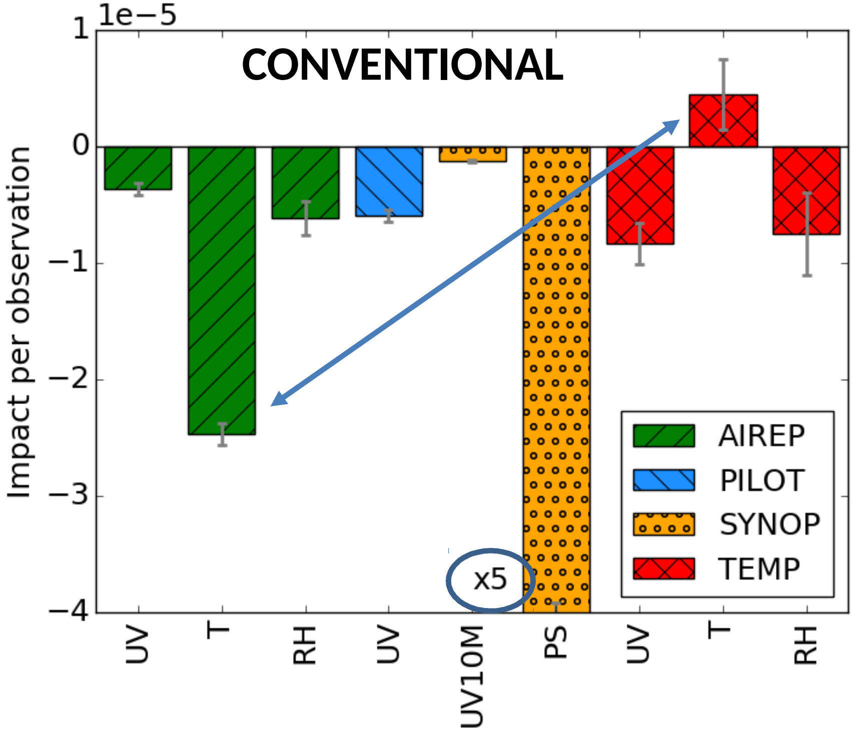
Experimental setup

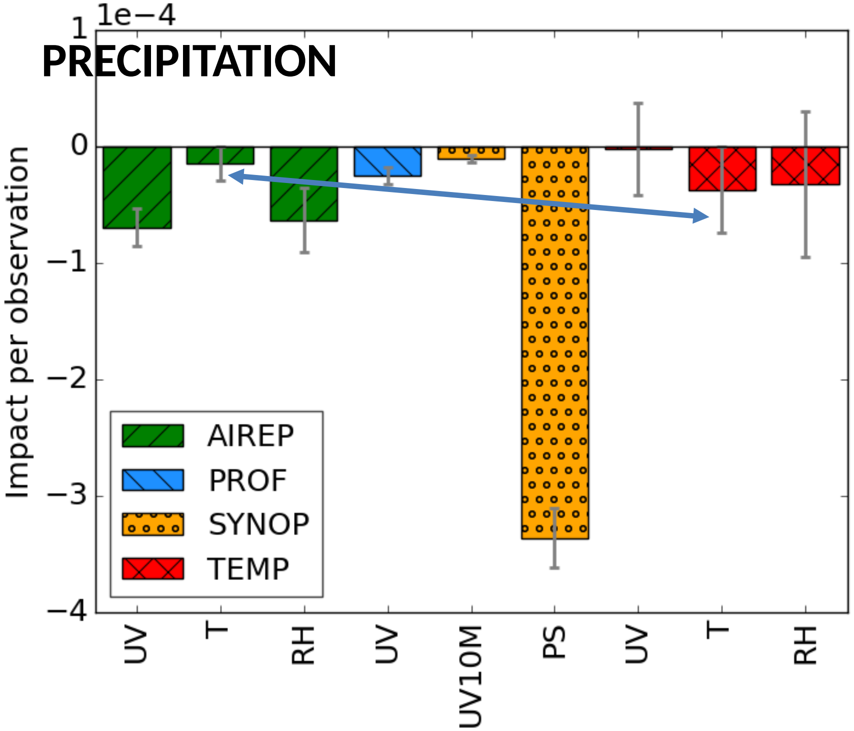
- Six week summer period
- 3h forecasts
- COSMO-DE / KENDA system with 40 members

Impact per observation

- Independent verification metric required
- Systematic differences due to biases:
  Overestimation of aircraft T and SYNOP PS and under-estimation of radiosonde T impact for CONV metric

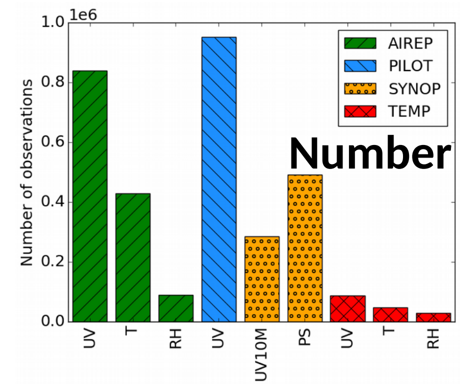


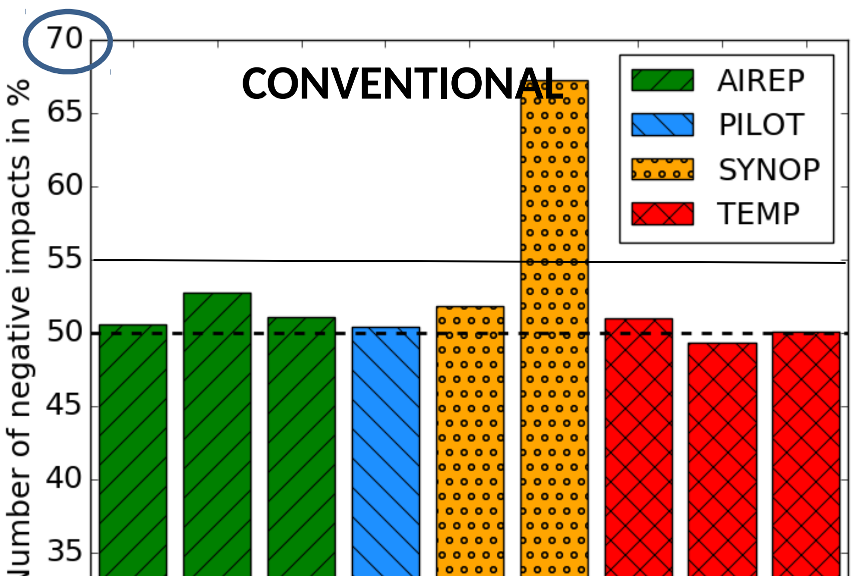


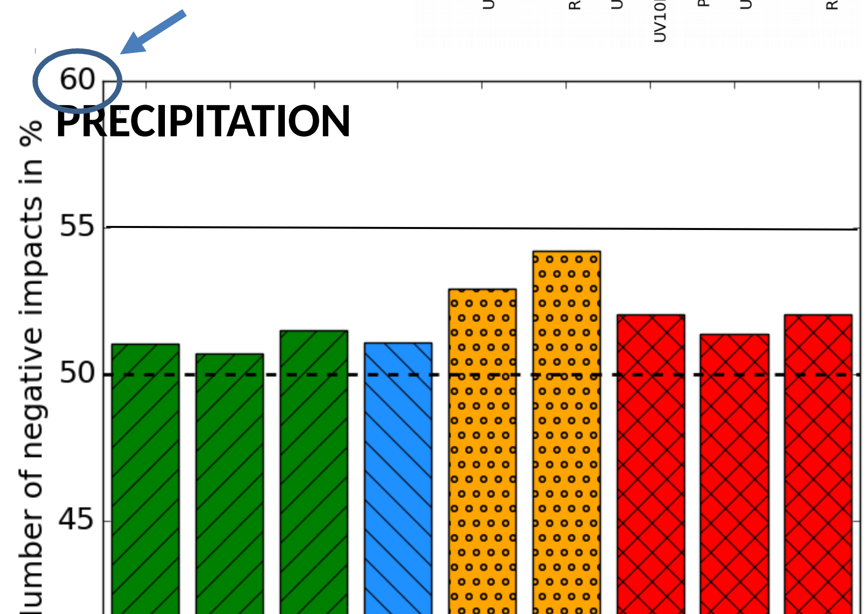


Fraction of beneficial impacts

- Temporally averaged fractions (6 weeks)
- Very high or low fraction of beneficial impacts can be an indication for biases (aircraft/radiosonde T and SYNOP PS)







Necker, T. et al 2018: The importance of appropriate verification metrics for the assessment of observation impact. *Q. J. R. Meteorol. Soc.*: submitted.

Outline

Part I: Introduction & motivation

Part II: 'Actual' observation impact – EFSOI

(EFSOI: Ensemble Forecast Sensitivity to Observation Impact)

- Results for DWD System

Part III: 'Potential' impact of observations – ESA

(ESA: Ensemble Sensitivity Analysis)

- Results for Japanese 1000 member ensemble [Poster by S. Geiss]
- Comparison with DWD System (40-member)

Part IV: Summary & conclusions

Method – Ensemble sensitivity analysis (ESA)

The **sensitivity S_i** of a **forecast metric J** to an **initial analysis x_i** is defined by Ancell and Hakim (2007) as

$$S_{\mathbf{i}} = \frac{cov(\mathbf{J}, \mathbf{x_i})}{var(\mathbf{x_i})} \,.$$

x_i : Independent analysis variable at grid point i [1 x N]
J : Dependent forecast variable (e.g. precipitation) [1 x N]
N : Ensemble size

How to compare a large set of quantities and forecasts?

1. Normalize with ensemble spread to get ***dimensionless correlations***
2. Sum absolute correlation values over domain and all forecasts to get ***absolute sensitivity***
3. Normalize absolute sensitivities with total of all sensitivities to get the ***relative sensitivity*** per quantity [%]

Method – Experimental setups

SCALE-RM model (Japanese)

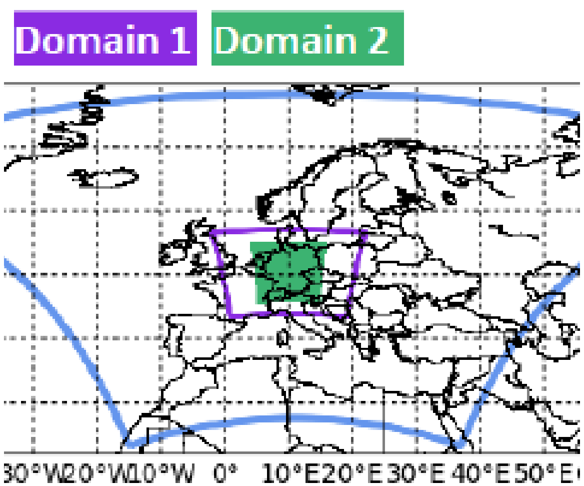
- 1000 member
- 15 km LETKF with downscaling to 3 km
- 350x250 grid points with 30 levels
- Short period (3 days/ 10 x 14-h-forecasts)

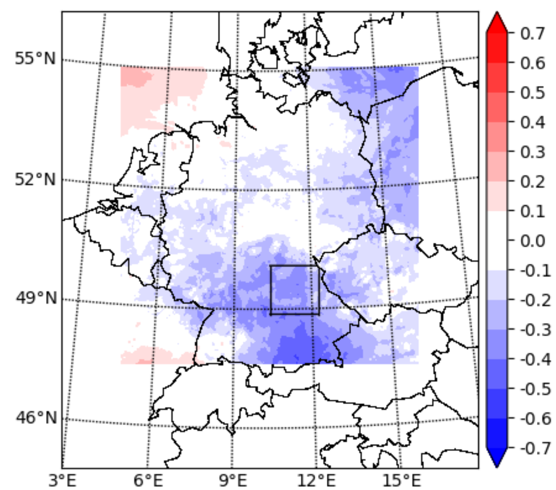
COSMO-DE model (German)

- 40 member
- 2.8 km grid spacing
- 300x300 grid points with 50 levels
- Longer period (6 weeks/ 70 x 12-h- forecasts)

-> Note: Precipitation forecast metric J is coarse grained to boxes of 50x50 grid points

Domain 2: Downscaling for the conv.-scale simulations over Germany





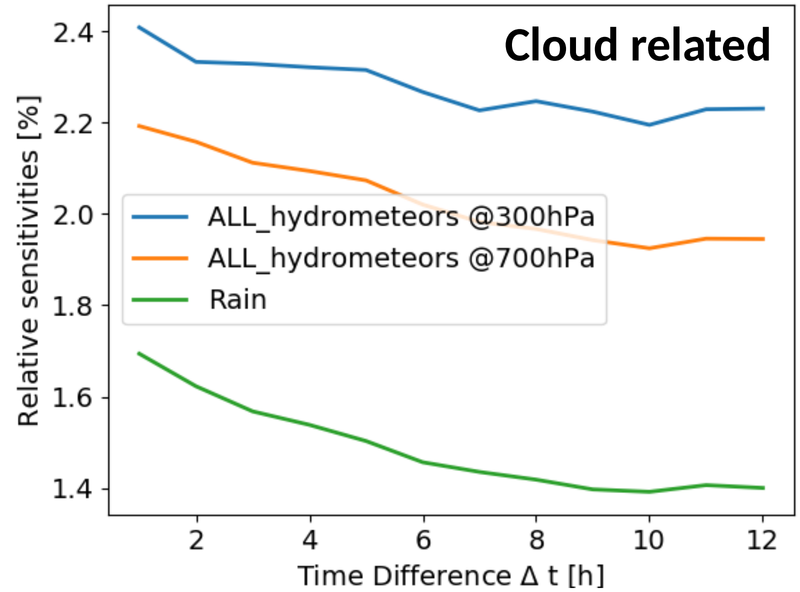
Sensitivity of the coarse grained precipitation box on the initial surface pressure field PS

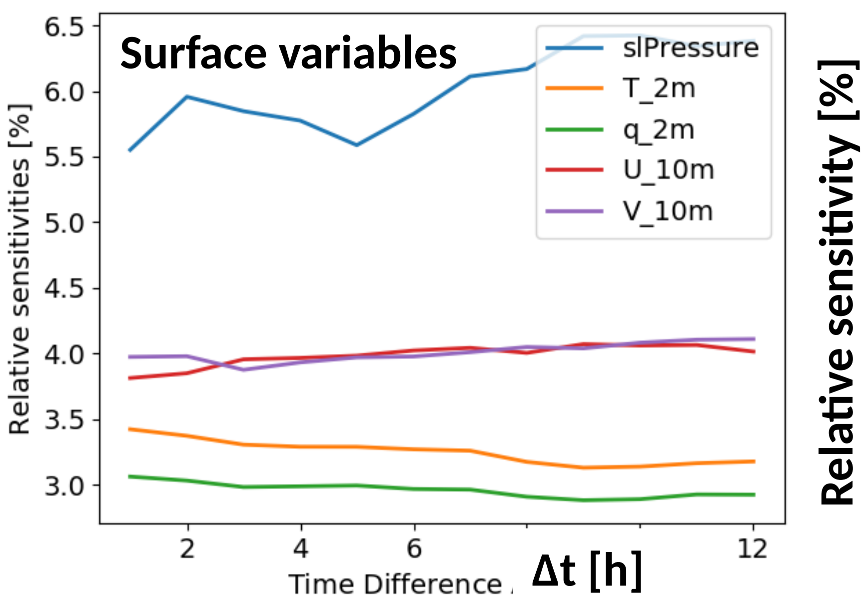
Relative sensitivities (1000)

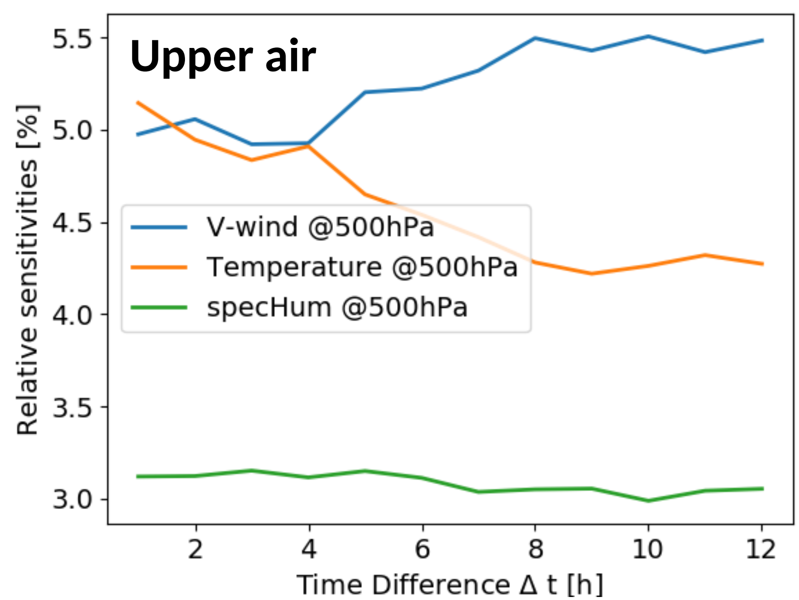
1000 member – 10 forecasts | 28 – 31 Mai 2016

Sensitivities:

- Pressure > Wind > Temperature > Humidity
- Less for cloud related quantities
- Pressure and wind influenced by large scale forcing (✉ increasing)





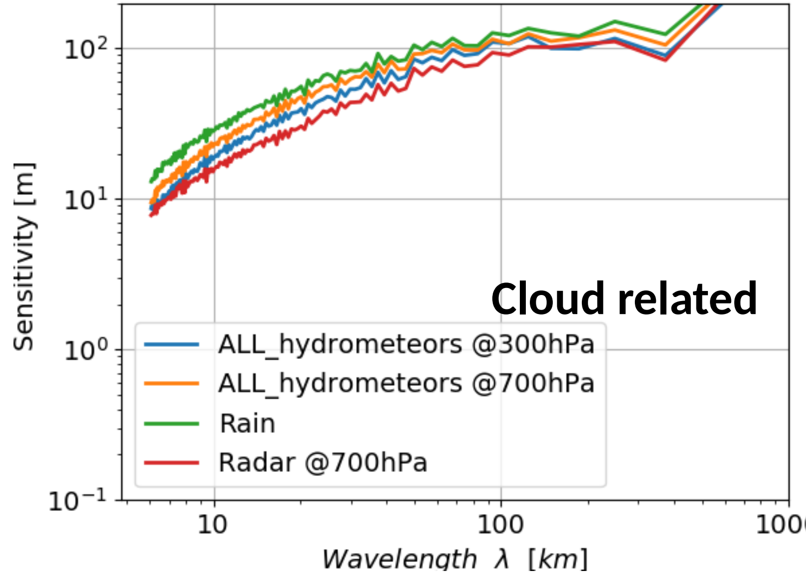


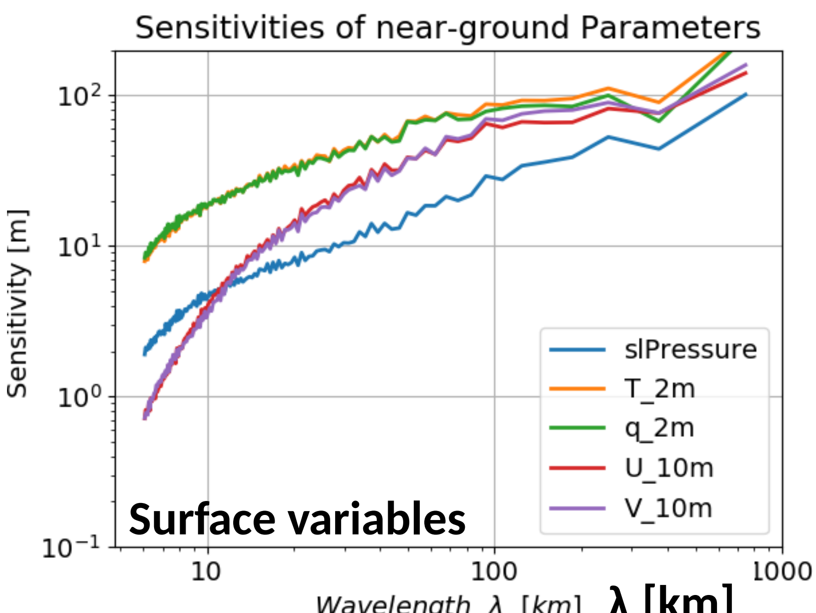
Scale analysis

1000 member – 10 forecasts | 28 – 31 Mai 2016

On smaller scales (10 km – 100 km):

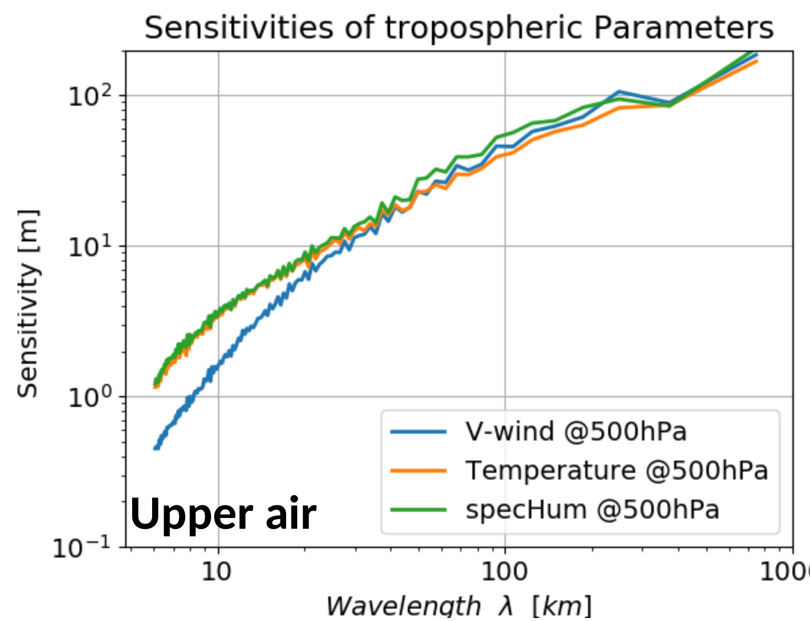
- Highest for
  - Humidity and temperature inside BL
  - Cloud related quantities & precipitation
- Lower for pressure & tropospheric quantities



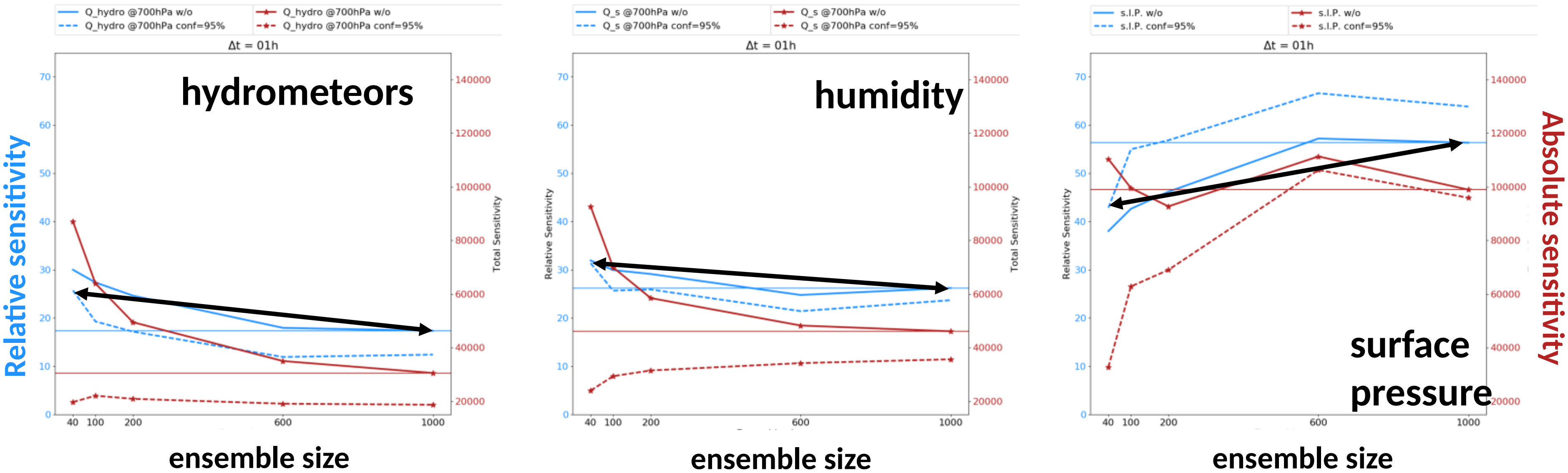


Sensitivity [m]

λ [km]



How to estimate sensitivities with a small ensemble size?

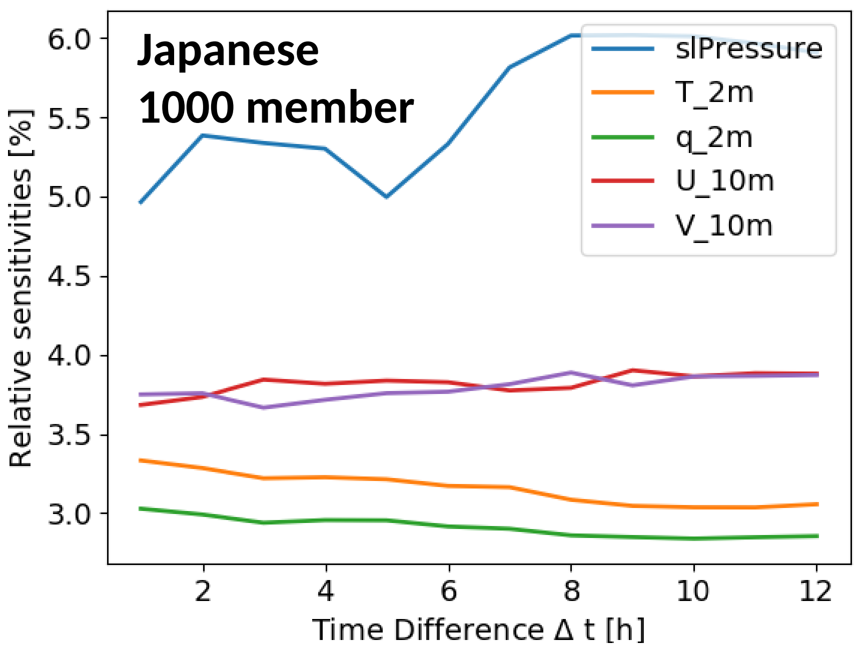


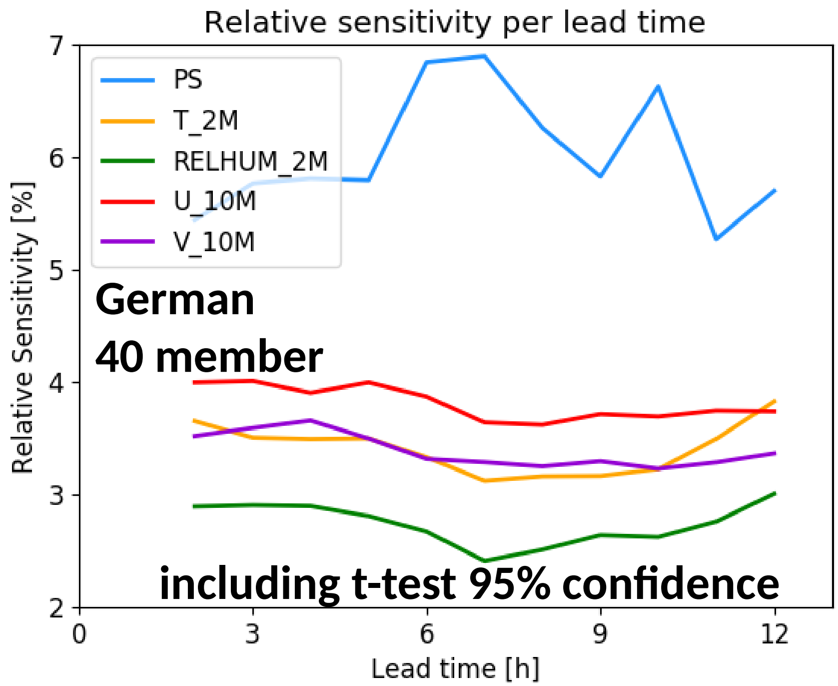
- Red solid lines: Absolute sensitivities increase with decreasing ensemble size due to spurious correlations (except for surface pressure)
- Red dashed lines: Confidence test reduces spurious correlations, but also removes some weak correlations that are presumably real
- Blue solid line @1000 and blue dashed line @40: Similarity of relative sensitivity, some overestimation of smaller relative sensitivities and underestimation of larger ones
- Given that some sensitivities extend across the domain, localization seems inappropriate

Relative sensitivities (1000 vs 40)

- Relative sensitivities of surface variables
- 40 member ensemble with 95% confidence level gives similar results as 1000 member
- Largest sensitivity of surface pressure is related to a strong large scale forcing

28-30 Mai 2016 : 5 forecasts

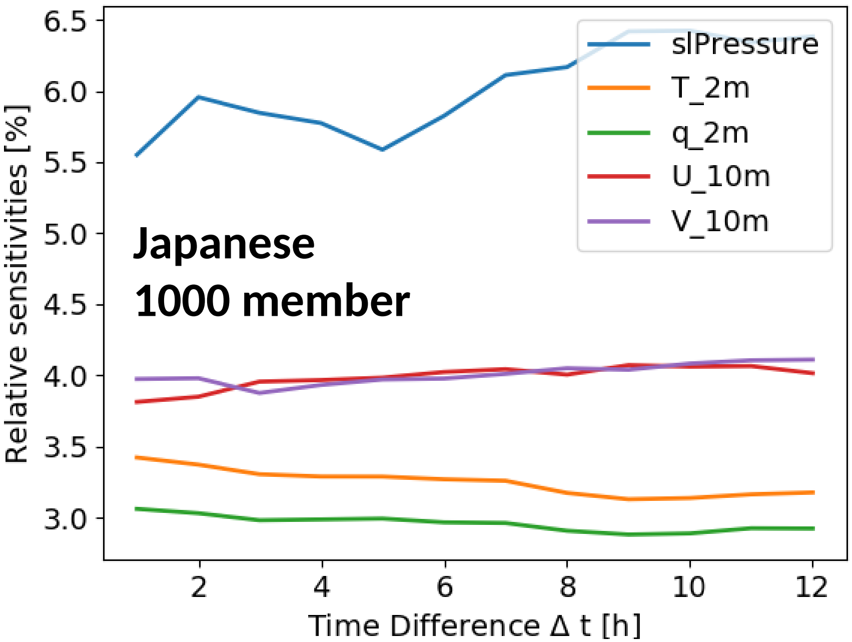




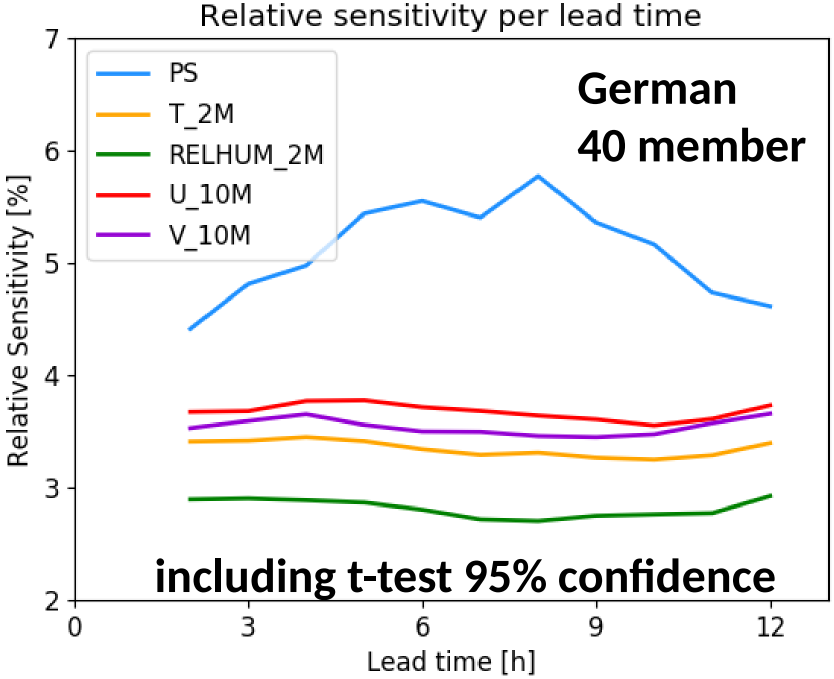
Lifetime of sensitivities (1000 vs 40 during 6-weeks)

- Both ensembles show similar results independent of ensemble size and model
- Sensitivity of surface pressure peaks at 7 hours lead time (40 member)
- Non-linearity: Sensitivities after 6 hours should be treated with caution (40 member)

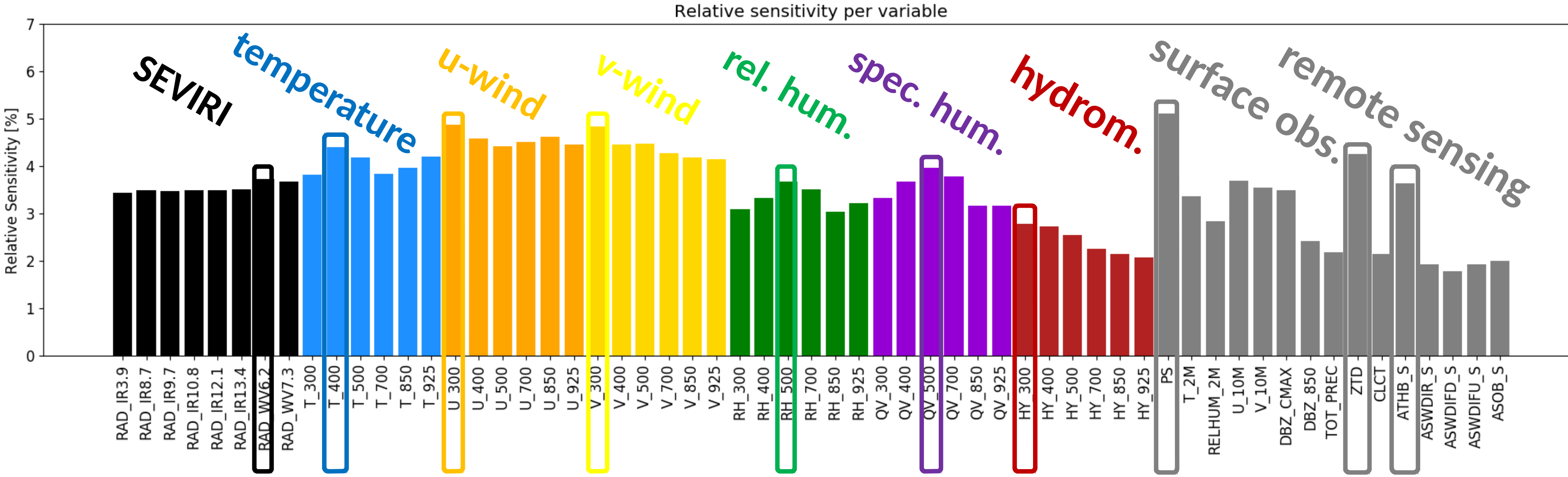
28-30 Mai 2016 : 10 forecasts



28-30 Mai 2016 : 70 forecasts



Relative sensitivities for 6 week summer period (40 member)



Ranking:

28-30 Mai 2016 : 70 forecasts all lead times

- Pressure levels with highest sensitivities:
  UV & HY at 300hPa / T at 400hPa / RH&QV at 500hPa
- Surface pressure (PS), Zenit Total Delay (ZTD) and thermal radiation are the most important surface quantities
- Precipitation has the highest sensitivity on SEVIRI WV channels

Summary

Conclusions – Actual observation impact

- Impact of 3.3 million conventional obs. in a **6 week summer period** was computed
- Revealed **sensitivity to biases** and the choice of the verification metric
- We recommend to **use independent observations and different metrics** for verification
- Observation impact in summer period:
  - **Surface pressure and upper air wind** observations show largest beneficial impact

Conclusions – Potential impact

- Potential impact of observed quantities on the precipitation forecast was investigated using different ensemble sizes (**1000 - 40 member**) and models (SCALE-RM/ COSMO-DE)
- Largest potential impact of **surface pressure and tropospheric variables**
- But **on scales relevant for convective-scale DA**, largest potential impact of **hydrometeors and boundary layer variables**
- The impact of **hydrometeor** assimilation is potentially much **longer lasting** than in real DA
- The **potential impact can be estimated** in relative terms **with a small ensemble size** using a confidence test, but some overestimation of smaller sensitivities
- Our study **assumes** that **all quantities could be assimilated** equally well