Hans-Ertel-Centre for Weather Research, Data Assimilation Branch

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Hans-Ertel-Centre for Weather Research

Five DWD-funded research groups in key areas of weather forecasting and climate research:

➔Atmospheric dynamics and their predictability (University Bonn and IfT Leipzig)

➔Data assimilation (LMU München)

➔Model development (MPI Hamburg)

➔Climate monitoring and diagnostics (Universities Bonn and Cologne)

➔Use and communication of forecasts (U. Berlin and partners)

Initially funded for up to 4 years (2011-2014), possible extension for 8 further years

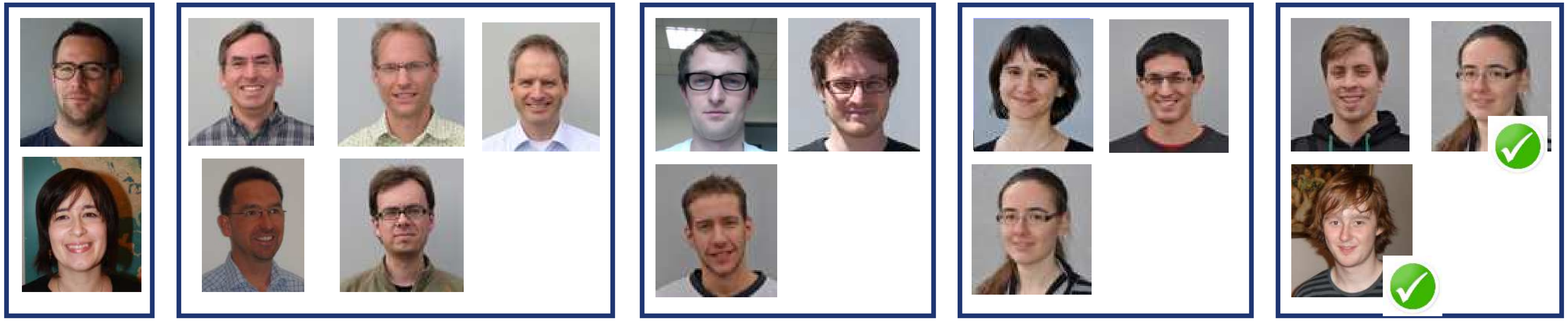
Basic research with long-term focus (~10 years) that composites DWD research

Innovative research, improvement of DWD modeling and forecasting system

Facilitate collaboration of universities, research centers and DWD

Hans-Ertel-Centre for Weather Research, Data Assimilation Branch

Ensemble-based convective-scale data assimilation and the use of remote sensing observations



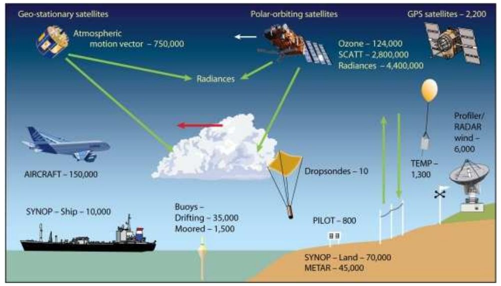
Project lead | Additional supervisors | Post-Docs | PhD students | Master students

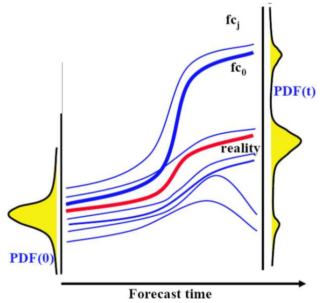
LMU: M. Weissmann, R. Buras, G. Craig, K. Folger, M. Haslehner, F. Heinlein, C. Keil, P. Kostka, C. Kühnlein, H. Lange, B. Mayer, M. Sommer, M. Würsch

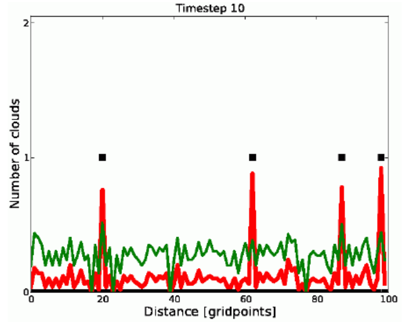
DLR: O. Reitebuch

DWD: T. Janjic-Pfander, R. Potthast, H. Anlauf, A. Cress, R. Faulwetter, C. Gebhardt, M. Köhler, C. Köpken-Watts, H. Reich, A. Rhodin, A. Schomburg, C. Schraff, O. Stiller, S. Theis

Project overview





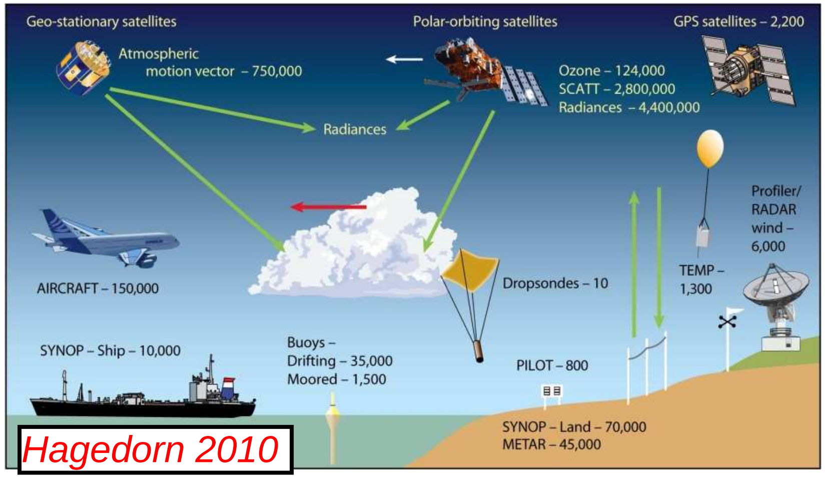


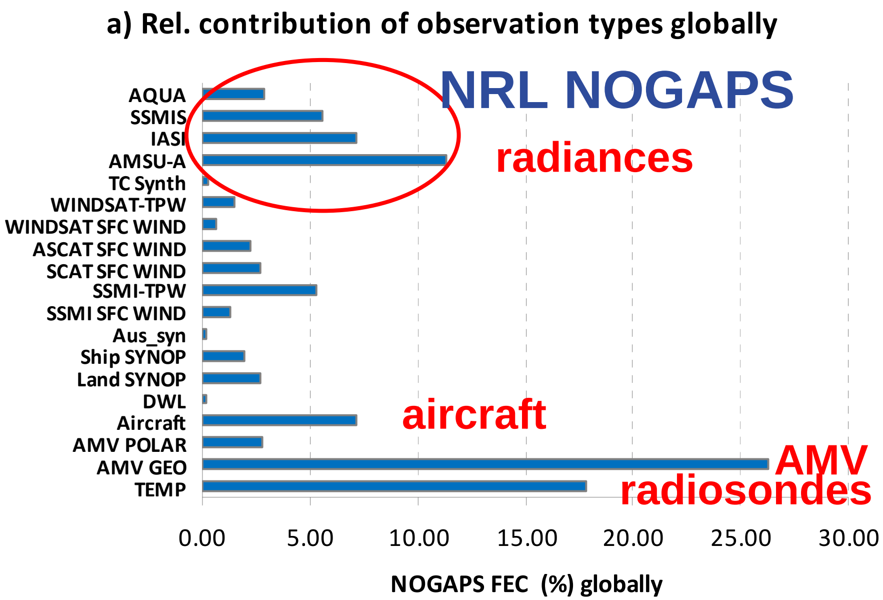
1) Observation Impact	2) Satellite observations	3) Ensembles	4) DA Methods
Tools to quantify the analysis and forecast impact of observations	Assimilation of additional non-standard satellite observations	Improved representation of uncertainty in EPS	Suitable methodes for conv-scale DA
Monitoring of observations	VIS+NIR radiances MSG SEVIRI	Influence of EPS initial perturbations	Robust methods for non-linear systems with non-Gaussian errors
Optimized use of observations	Improved AMV height assignment with lidar	KENDA perturbations	Various toy models, nudging particle filter
	(ADM-Aeolus, lightning)	Impact time of observations and flow-dependence of predictability	Tests with idealized KENDA/COSMO

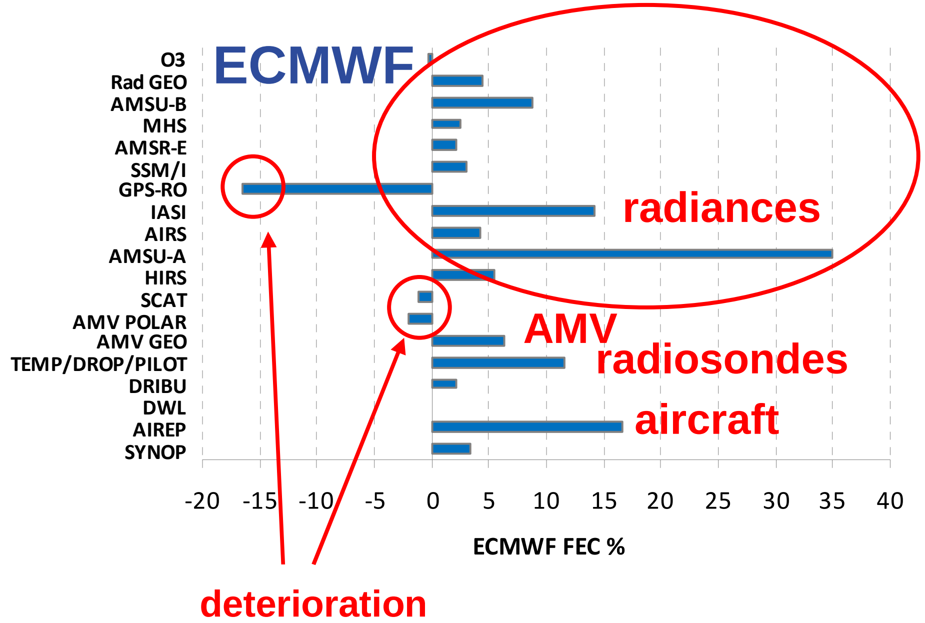
Adjoint observation impact

(Weissmann, Langland, Cardinali et al., QJ 2012)

Estimating observation impact (i.e. contribution to the reduction of forecast error by observations)



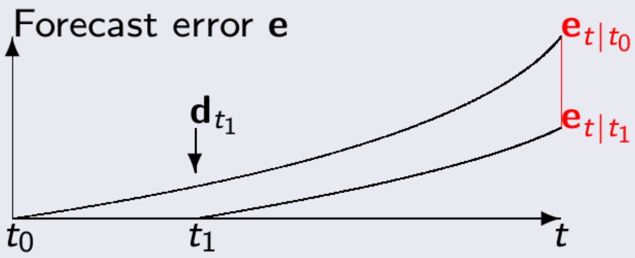




Estimation observation impact in COSMO/KENDA

No adjoint available for COSMO

Ensemble-based method base on Liu and Kalnay (2008), Li. Et al. (2010) and Kalnay et al. (2012)



$$J = \frac{1}{2}\left(|\mathbf{e}_{t|t_1}|^2 - |\mathbf{e}_{t|t_0}|^2\right)$$ Forecast error difference

$$\mathbf{e}_{t|t_0} = \overline{\mathbf{x}}_{t|t_0} - \overline{\mathbf{x}^v}_t$$ Error of forecast initialized at t_0

$$\mathbf{e}_{t|t_1} = \overline{\mathbf{x}}_{t|t_1} - \overline{\mathbf{x}^v}_t$$ Error of forecast initialized at t_1

The total contribution of all observations is known (forecast error difference)

We want to estimate the (relative) contribution of a subset without rerunning the analysis and forecast

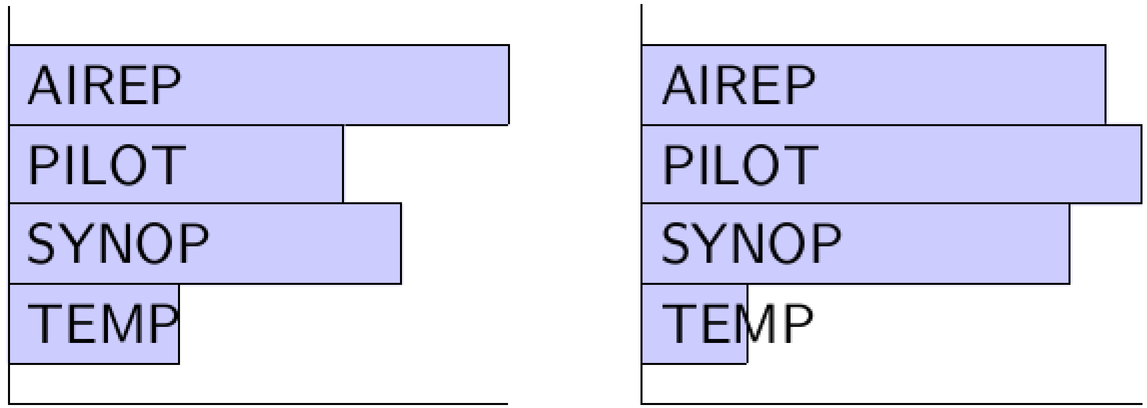
$$J = \left\langle \mathbf{v}_0, \frac{1}{2}\tilde{\mathbf{K}}_0^{\mathrm{T}} \mathbf{X}_{t|-6}^{f\mathrm{T}} \left[\mathbf{e}_{t|-6} + \mathbf{e}_{t|0}\right] \right\rangle$$

v innovation vector
X ensemble forecast perturbations
K Kalman gain

Impact of subset:
substitute innovation vector with subset of interest

Matthias Sommer

First observation impact results (lead time = 0h)



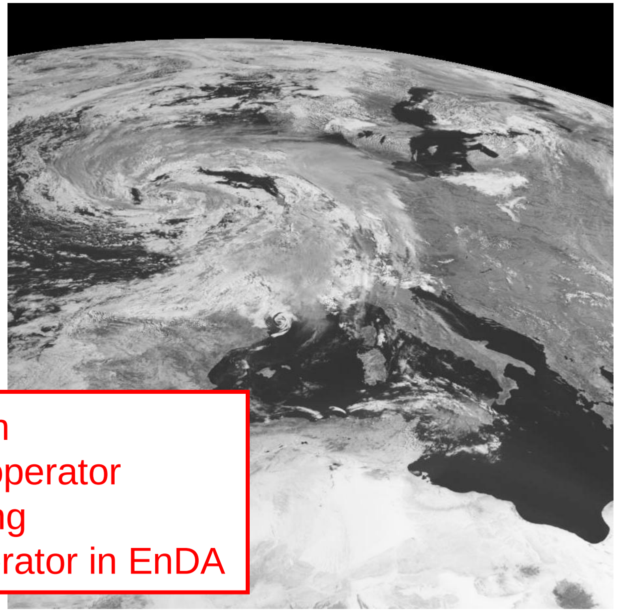
(a) DD (Method 3) (b) K12 (Method 4)

Matthias Sommer

Assimilation of VIS/NIR radiances

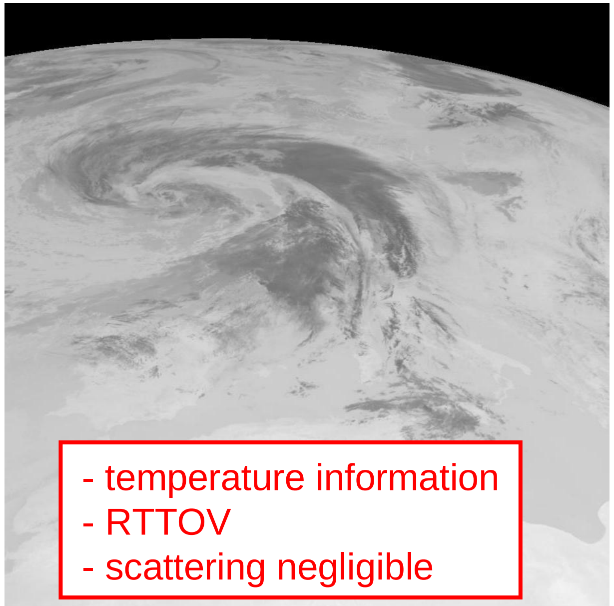
VIS (0.6 μm)

NIR (1.6 μm)



- cloud information
- no fast forward operator
- multiple scattering
- only forward operator in EnDA

TIR (10.8 μm)

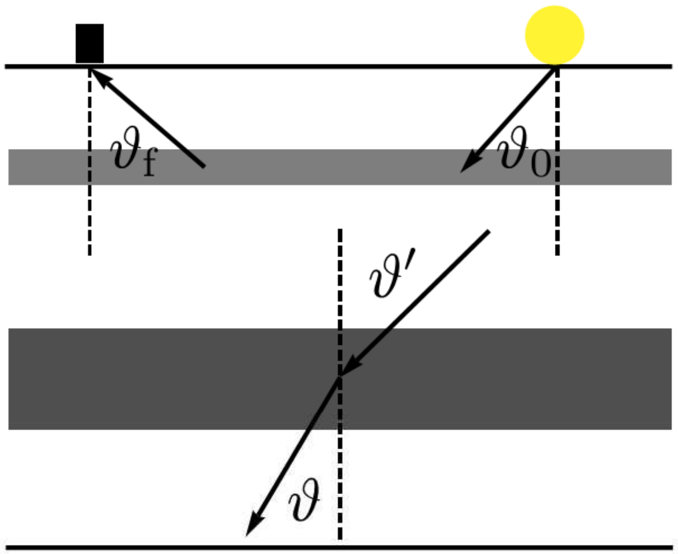


- temperature information
- RTTOV
- scattering negligible

- MW and IR radiance assimilation is now standard at least for global DA, but assimilation of VIS+NIR
- Traditionally clouds are often seen as contamination in data assimilation, recent efforts to gain more T/q information in the presence of clouds
- We want to "actively" assimilate clouds, i.e. create and remove clouds
- EnDA has the advantage that only the forward operator is required, but no adjoint or linearization

Philipp Kostka

VIS/NIR forward operator based on libRadtran



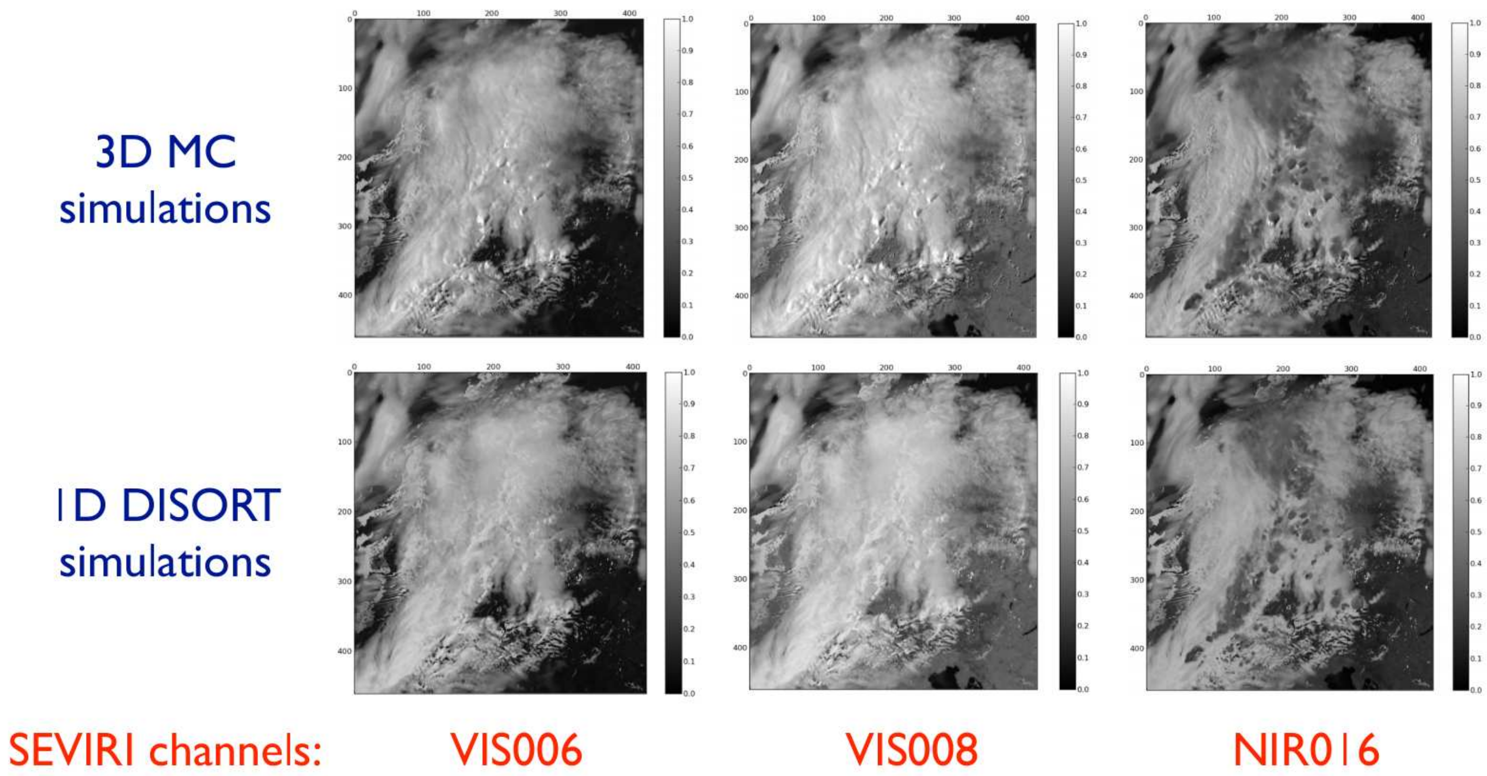
- COSMO-DE model fields:
  qv, qc, qi, qs, clc, htop/hbas_sc, (ps, t)
- MODIS albedo and satellite geometry
- discrete ordinate method [Stamnes et al. 1988]
- mapping to observation space

absorption — scattering — incoming — emission

$$\mu \frac{\mathrm{d}I}{\mathrm{d}\tau} = \underbrace{-I}_{\text{absorption}} + \underbrace{\frac{\omega}{4\pi}\int \mathrm{d}\varphi'\mathrm{d}\mu'\,\mathcal{P}(\ldots)\,I(\ldots)}_{\text{scattering}} + \underbrace{\frac{\omega}{4\pi}\mathcal{P}_0(\ldots)\,S_0\,\mathrm{e}^{-\tau/\mu_0}}_{\text{incoming}} + \underbrace{(1-\omega)\;B(\tau)}_{\text{emission}}$$

Philipp Kostka

Evaluation of operator with 3D Monte-Carlo simulation



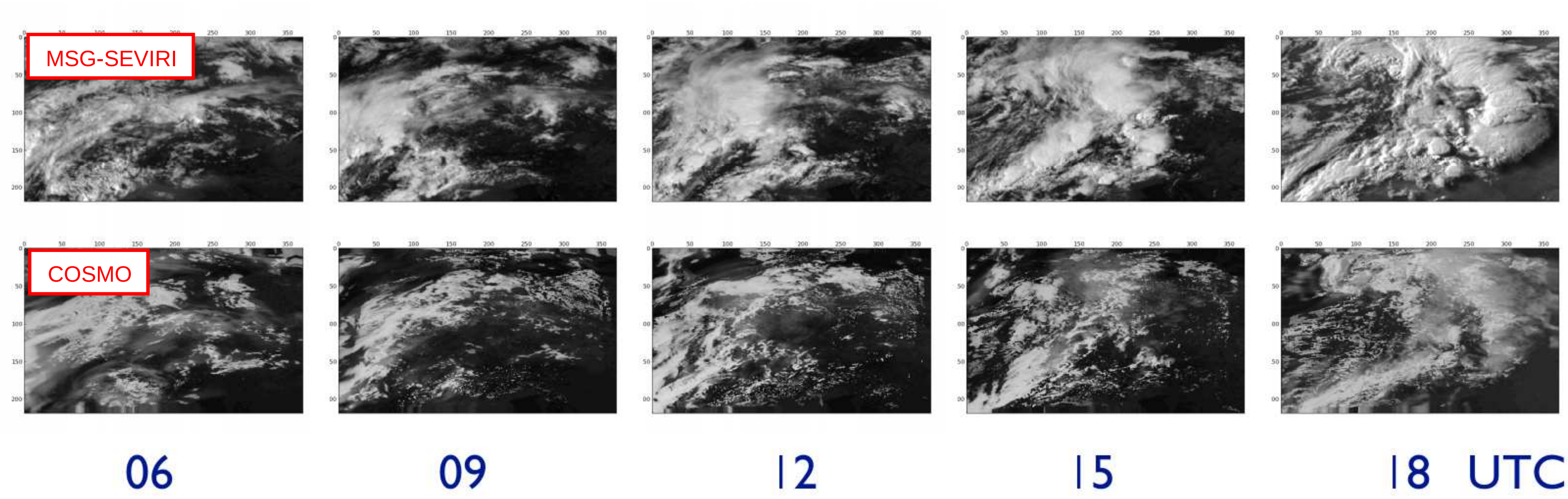
Absolute bias less than 1%

After parallax correction (grid transformation), mean absolute difference less than 6% 06-15 h, but 21% at 18h

Philipp Kostka

Time Series: Observation vs. 3h-Forecasts

(22.06.2011, VIS006)



(without parallax correction)

Philipp Kostka

Representation of uncertainty in COMSO-DE-EPS

⇒ Subproject goal: Improved representation of uncertainty in convective-permitting LAM ensemble COSMO-DE-EPS

Main future extensions planned:

- Convective-scale initial condition perturbations from KENDA (under development at DWD and LMU)
- stochastic boundary layer parameterisation by means of perturbed tendencies (under development at LMU)

Current results:

- Analysis of the (pre-)operational COSMO-DE-EPS
  - EPS behaviour and impact of different perturbations, in particular initial condition perturbations (ICPs) based on downscaling approach
  - Dependence upon synoptic-scale conditions, i.e. forecasts in weak and strong forcing regimes are considered separately

Impact of initial condition perturbations (ICP) in COSMO-DE-EPS (1)

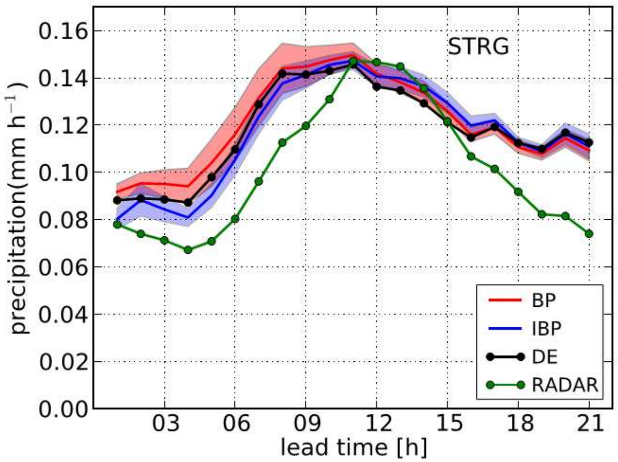
→ How effective are large-scale ICPs based on downscaling approach for LAM EPS precipitation forecasts at convection-permitting resolution, particularly in weak forcing conditions ?

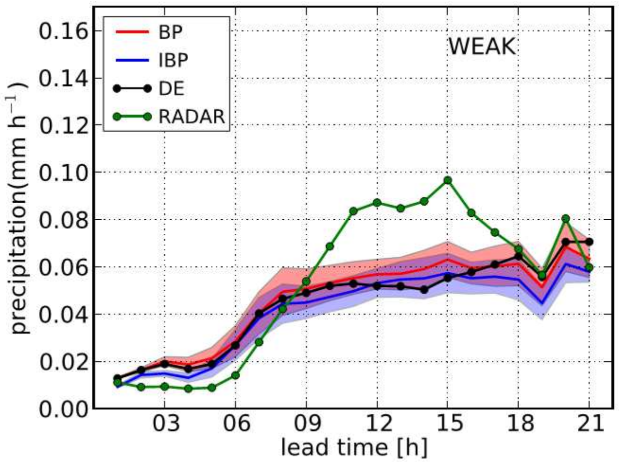
Regime-dependent comparison of precipitation forecasts of two 20-member convection-permitting LAM EPS, for 3.5 month period in summer 2011:

(i) "IBP": pre-operational COSMO-DE-EPS with (IC+BC+PY) perturbations

(ii) "BP": special COSMO-DE-EPS with only (BC+PY) perturbations

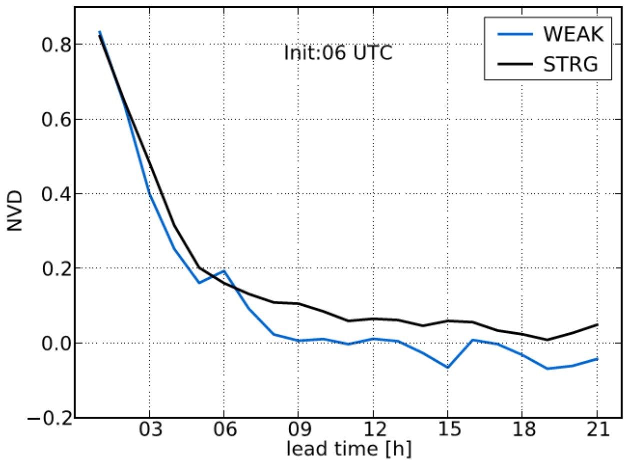
Diurnal cycle of precipitation for strong (83) versus weak (16) forcing days:





Christian Kühnlein

Impact of initial condition perturbations (ICP) in COSMO-DE-EPS (2)



Normalised variance difference (e.g. Gebhardt et al., 2011):

$$NVD = \frac{var(P_{IBP}) - var(P_{BP})}{var(P_{IBP}) + var(P_{BP})}$$

Selected results:

→ response of the EPS (diurnal cycle of averaged precipitation, bias, ensemble variance) very different under strong and weak forcing conditions

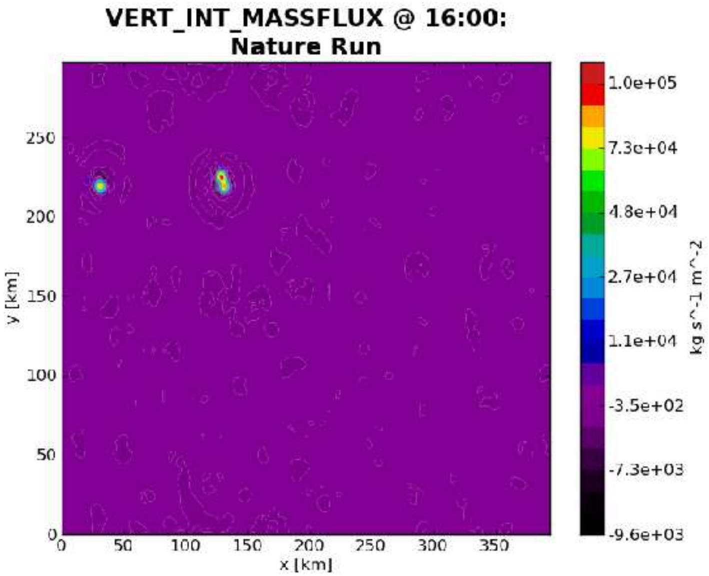
→ ICPs based on downscaling approach similarly effective in weak and strong forcing conditions

→ impact of ICPs on ensemble variance and probabilistic forecast measures generally positive

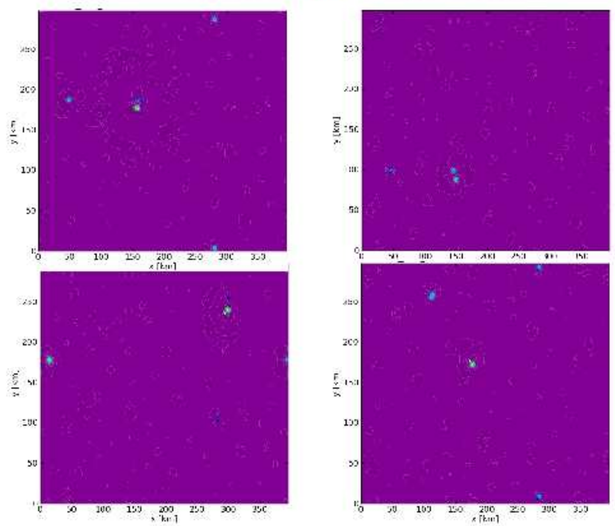
→ impact of ICPs is largest in the first ∼6 forecast hours and are overridden by lateral boundary condition perturbations and physics perturbations later on

Data assimilation studies with idealized KENDA/COSMO

- Localised Ensemble Transform Kalman Filter (LETKF) of COSMO-KENDA
- assimilation of doppler radar observations
  - radial wind
  - rain, no-rain
- synthetic observations drawn from artificial COSMO nature run (2km resolution)
- purely stochastic convection initialized by boundary layer noise
- 50 member ensemble with same sounding but random convection



50 member ensemble



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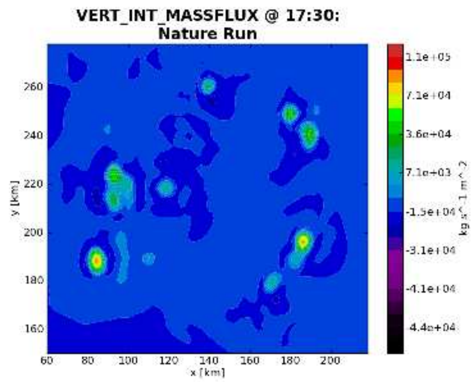
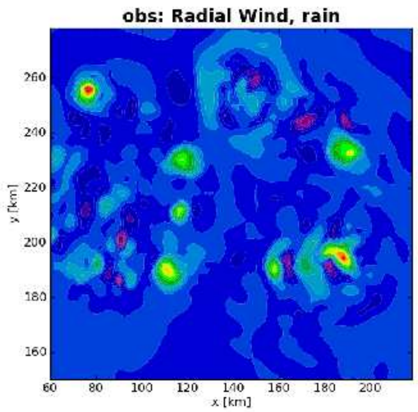
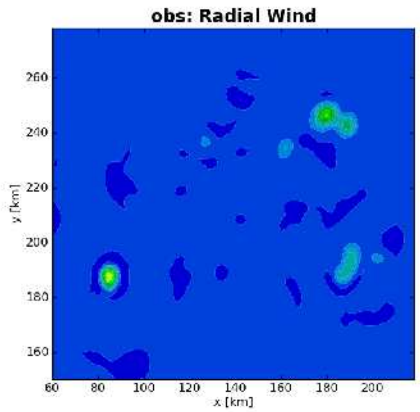
Sensitivity studies with different observations

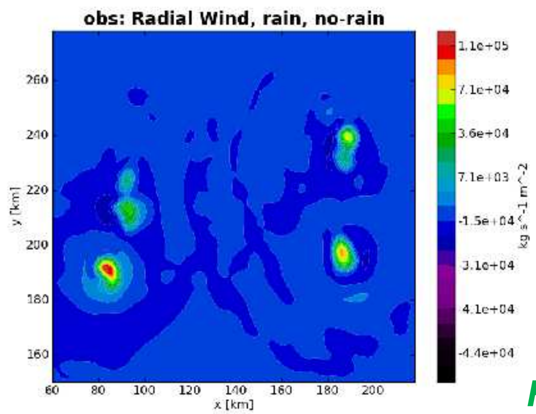
- 1) use of different types of synthetic observations



Analysis Ensemble Means of different experiments:







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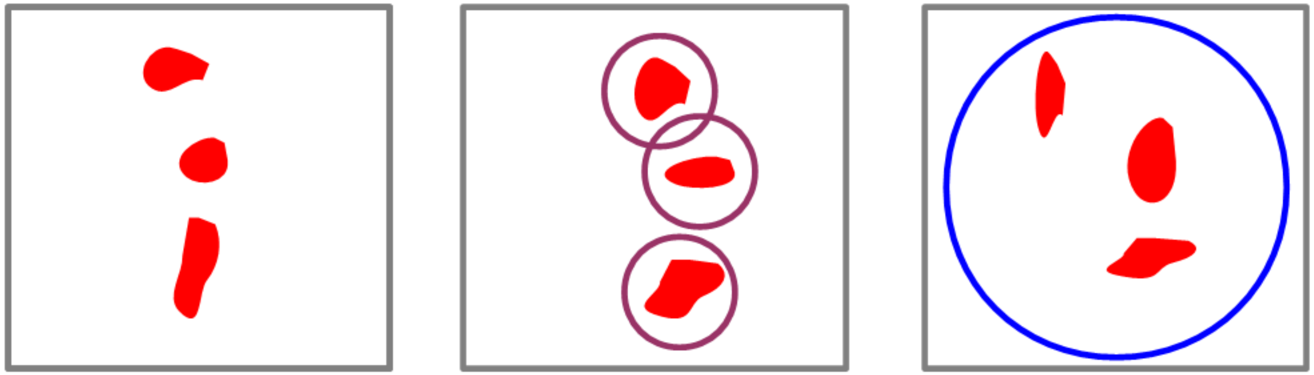
Sensitivity studies with different localization

- 2) assimilation of convective regions with small and big radius of background error covariance localisation (of the LETKF)
  - a) single cell assimilation (small localisation radius, ~10 km)
  - b) convective region assimilation (larger localisation radius ~50 km)

e.g. **Nature Run**: cells of squall line

a) Analysis: single cells taken from best fitting member(s)

b) Analysis: coarsely fitting squall line from coarsely fitting member(s)



regarding limited predictability of convection: does a) necessarily give a better mid-range forecast?

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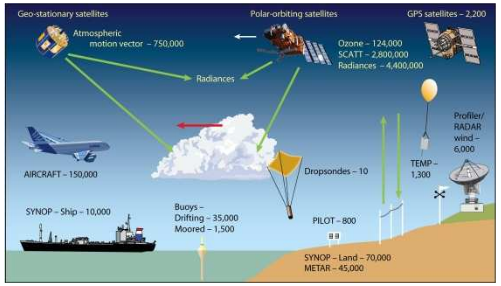
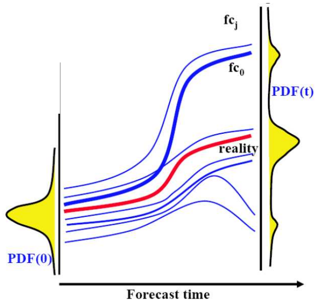
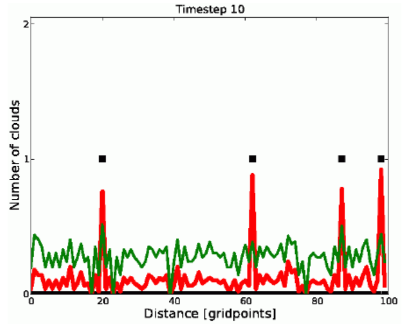
Status and results







1) Observation Impact

COSMO/KENDA installed @ MIM-LMU cluster

First calculation of observation impact technically successful

Sensitivity studies with less approximations and localization

2) Satellite Observations

Reasonably fast VIS-operator for case studies developed and implemented in COSMO/KENDA

First direct assimilation of VIS radiances

AMV height correction with airborne lidar

AMV comparison to layer winds

3) Ensembles

Completed master thesis on regime-dependence of predictability in EPS (see presentation Nov 2011)

Comparison of COSMO-DE-EPS with and without initial condition perturbations

Next step:
Investigating KENDA perturbations and their forecast impact

4) DA Methods

Three test environments developed/implemented:
-stoch. cloud model
-modif SW-model
-idealized COSMO/KENDA

Various DA methods implemented

Paper comparing LETKF and SIR in stoch. cloud model (Craig and Würsch, QJ 2012)