Direct assimilation of VIS/NIR radiances and observation impact calculation in a limited-area LETKF system

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Hans Ertel Centre for Weather Research
Data Assimilation Branch
LMU München

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Hans-Ertel-Zentrum für Wetterforschung
Deutscher Wetterdienst

Content

The Hans Ertel Centre for Weather Research

Overview

- Virtual centre for research in the field of weather forecasting at German universities and research institutes funded by the DWD (German Weather Service)
- Funding periods: 2011 – 2014, (2015 – 2018, 2019 – 2021)
- Five branches:
  - Atmospheric dynamics and their predictability
  - Data assimilation
  - Model development
  - Climate monitoring and diagnostics
  - Ideal use of information provided through weather forecasting and climate monitoring to the benefit of the general public

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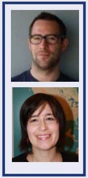
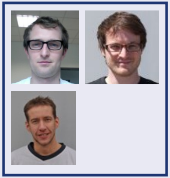
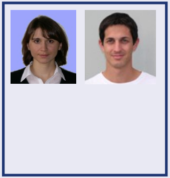
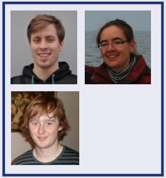
DWD

Data Assimilation Branch

Team



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

Institutions

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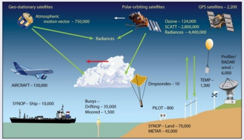
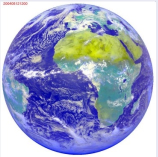
DLR O. Reitebuch, IPA

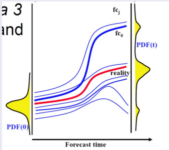
DWD R. Potthast, H. Anlauf, A. Cress, R. Faulwetter, C. Gebhardt, M. Köhler, C. Köpken-Watts, H. Reich, A. Rhodin, A. Schomburg, C. Schraff, O. Stiller, S. Theis

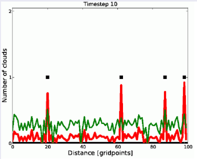
Data Assimilation Branch

Overview







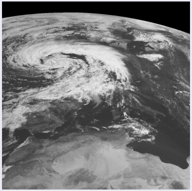


1) Observation Impact	2) Satellite observations	3) Ensembles	4) DA Methods
Tools to quantify the analysis and forecast impact of observations Monitoring of observations Optimized use of observations	VIS+NIR radiances MSG SEVIRI Improved AMV height assignment with lidar (ADM-Aeolus) (lightning)	Improved representation of uncertainty in EPS KENDA initial Perturbations Impact time of observations and flow-dependence of predictability	Suitable methodes for conv-scale DA Test with idealized toy-models Robust DA-methods for strongly non-linear systems with non-Gaussian error statistics

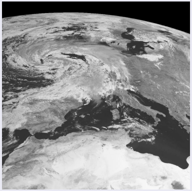
Content

Motivation: VIS/NIR vs. IR

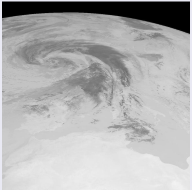
23 June 2004, 08 UTC, MSG-1 EUMETSAT



(a) VIS (0.6 μm)



(b) NIR (1.6 μm)



(c) IR (10.8 μm)

- Cloud information
- No fast forward operator
- Multiple scattering

- Temperature information
- RTTOV
- Scattering negligible

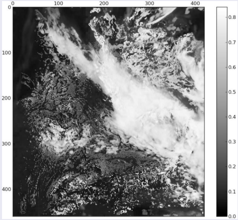
Operator

$$\mu \frac{\mathrm{d}I}{\mathrm{d}\tau} = \underbrace{-I}_{\text{Absorption}} + \underbrace{\frac{\omega}{4\pi}\int \mathrm{d}\varphi' \mathrm{d}\mu' \mathcal{P}\mathcal{I}}_{\text{Scattering}} + \underbrace{\frac{\omega}{4\pi}\mathcal{P}_0 \mathcal{S}_0 e^{-\frac{\tau}{\mu_0}}}_{\text{Incoming}} + \underbrace{(1-\omega)B(\tau)}_{\text{Emission}}$$

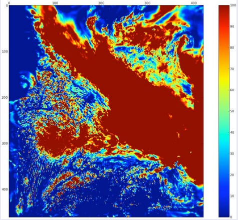
- COSMO-DE model fields: qv, qc, qi, qs, clc, htop/hbas_sc

Motivation: VIS/NIR vs. IR

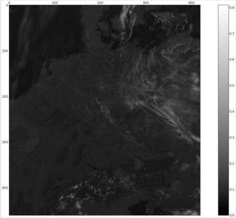
31 Juli 2011 12 UTC



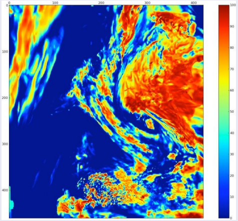
(d) VIS operator: Water clouds



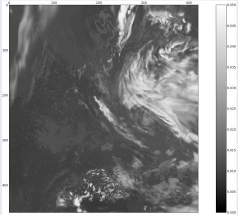
(e) Model: Low cloud cover



(f) VIS operator: Ice clouds



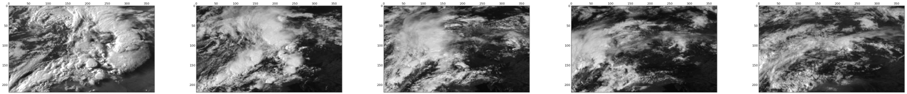
(g) Model: High cloud cover



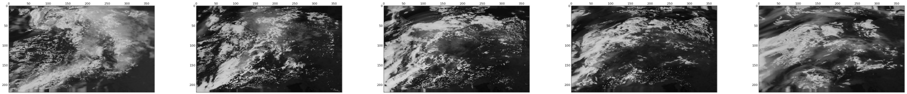
(h) RTTOV

Time series (22 June 2011; 06, 09, 12, 15, 18 UTC)

Observations



Forecasts



Comparison

- Overall cloud structures of the model appear realistic
- Differences of location, timing and the amount of clouds

Content

Introduction

Motivation

Assessment of observation impact can help . . .

- selecting/excluding data that improves/degrades forecast quality.
- tuning the assimilation system.
- optimizing the cost-benefit ratio of the observation system.

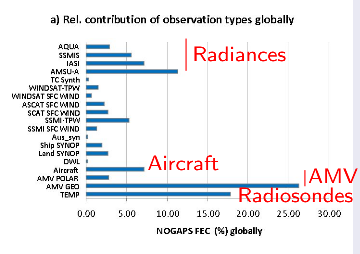


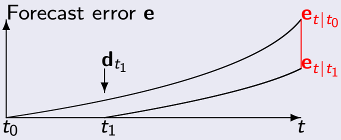
Figure: (From Weissmann, Langland et. al., 2012)

Methods for assessing observation impact

- Data-denial experiments: Very large computational resources needed.
- Adjoint-based methods: Not always available, e. g. for COSMO.
- Ensemble-based method (Liu and Kalnay, 2008; Kalnay et. al. 2012)

Formulation

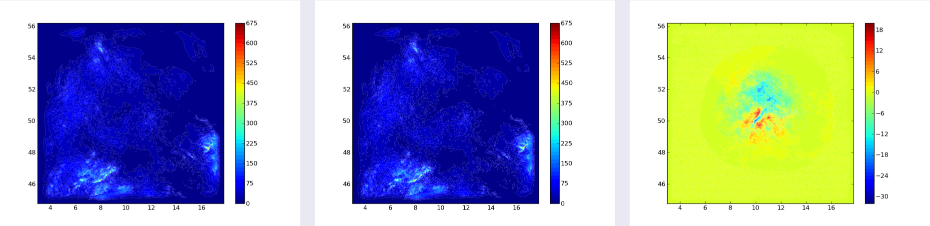
Measure for observation impact: Forecast error difference



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



(a) $|\mathbf{e}_{t|t_0}|^2$ (b) $|\mathbf{e}_{t|t_1}|^2$ (c) $J = \frac{1}{2}\left(|\mathbf{e}_{t|t_1}|^2 - |\mathbf{e}_{t|t_0}|^2\right)$

Derivation of method (Kalnay et. al. 2012)

Total impact of observations $\mathbf{d}_{t_1}$ on forecast

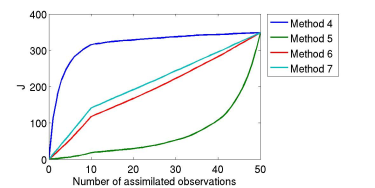
$$J = \frac{1}{2}\left(|\mathbf{e}_{tt_1}|^2 - |\mathbf{e}_{tt_0}|^2\right)$$
$$\approx \frac{1}{2}\left(\mathbf{e}_{tt_1} + \mathbf{e}_{tt_0}\right)^T \frac{1}{K-1} \mathrm{X}_{tt_1} \mathrm{Y}_{t_1}^{aT} \mathrm{R}^{-1} \mathbf{d}_{t_1}$$

Approximations:

$$\mathrm{Y}^a \approx \mathrm{H}\mathrm{X}^a$$
$$\bar{\mathbf{x}}_{tt_1} - \bar{\mathbf{x}}_{tt_0} \approx \mathrm{M}_{tt_1}(\overline{\mathbf{x}^a}_{t_1} - \bar{\mathbf{x}}_{t_1 t_0})$$

Partial impact

$$J \approx \frac{1}{2}(\mathbf{e}_{t|t_1} + \mathbf{e}_{t|t_0})^T \frac{1}{K-1} \mathrm{X}_{tt_1} \mathrm{Y}_{t_1}^{aT} \mathrm{R}^{-1} \mathbf{d}_{t_1}$$
$$= J_1 + \cdots + J_r$$
$$J_s = \underbrace{\frac{1}{2} \sum_{p=p_s}^{p_{s+1}} \left((\mathbf{e}_{t|t_1} + \mathbf{e}_{t|t_0})^T \frac{1}{K-1} \mathrm{X}_{tt_1} \mathrm{Y}_{t_1}^{aT} \mathrm{R}^{-1} \right)_p (\mathbf{d}_{t_1})_p}_{\text{Contribution of observations } p_s \ldots p_{s+1}}$$



DWD Assimilation and forecasting systems

Consortium for **S**mall-scale **M**odelling (COSMO)

- Operational limited-area model of Deutscher Wetterdienst
- Grid point model of non-hydrostatic equations
- Horizontal resolution: 2.8 km; 50 vertical levels

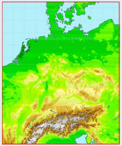


Figure: COSMO-DE domain ($\approx$ 1200 km $\times$ 1200 km)

Kilometer-scale **E**nsemble **D**ata **A**ssimilation (KENDA)

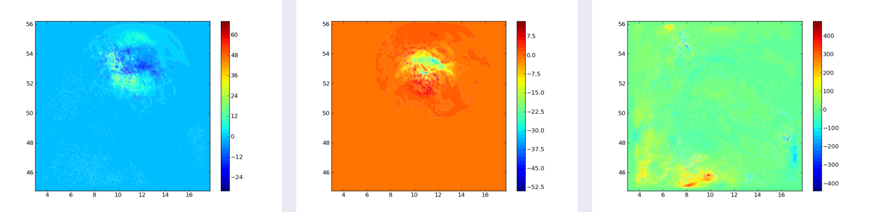
- **L**ocalized **E**nsemble **T**ransform **K**alman **F**ilter for use with COSMO-DE (in development)

Experimental settings

- 3h update (later $\approx$ 15 min)
- Observations used: TEMP, AIREP, PILOT, SYNOP
- 2 day period

Localization

Observation impact ($t = t_1$)



(a) Data denial (b) Approximation with localization (c) Approximation without localization

Approximation of Localization

$$J = \frac{1}{2}\left(|\mathbf{e}_{tt_1}|^2 - |\mathbf{e}_{tt_0}|^2\right)$$

$$\approx \frac{1}{2}\left(\mathbf{e}_{tt_1} + \mathbf{e}_{tt_0}\right)^T \frac{1}{K-1} \mathrm{M}_{tt_1}\left[\mathrm{X}^a_{t_1} {\mathrm{Y}^a_{t_1}}^T \mathrm{R}^{-1}\mathbf{d}_{t_1}\right]$$

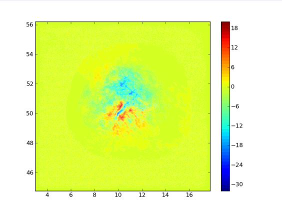
$$\stackrel{?}{\approx} \frac{1}{2}\left(\mathbf{e}_{tt_1} + \mathbf{e}_{tt_0}\right)^T \frac{1}{K-1} \left[\mathrm{M}_{tt_1}\mathrm{X}^a_{t_1} {\mathrm{Y}^a_{t_1}}^T \mathrm{R}^{-1}\mathbf{d}_{t_1}\right]$$

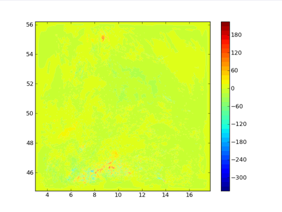
Impact on Analysis ($t = t_1$) and on Forecast ($t = 6h$)

Horizontal impact distribution

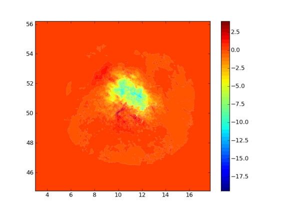
$t = t_1$ | $t = 6h$

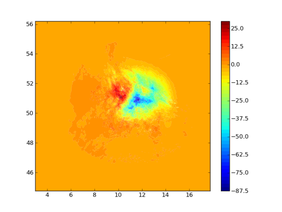
Data denial



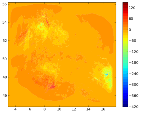
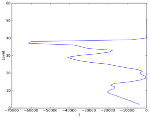
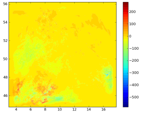
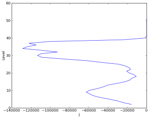
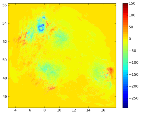
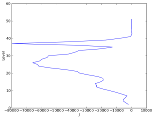
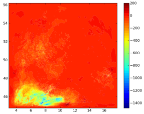
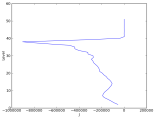


Approximation



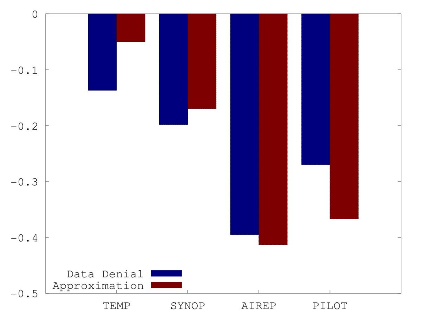


Observation Impact ($t = t_1$)

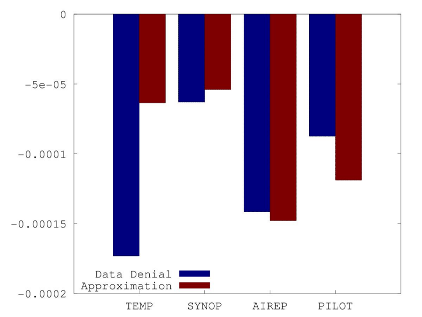
	TEMP		AIREP	
	Vertical sum	Horizontal sum	Vertical sum	Horizontal sum
Data Denial				
Approx.				

Observation Impact of different observation subsets on analysis

Observation impact



(d) Total Observation Impact



(e) Observation Impact per Observation

Conclusion and outlook

VIS/NIR radiances

- Slow forward operator for VIS/NIR radiances implemented

→ Implement and test operationally feasible operator

→ Study observation impact of assimilating VIS/NIR radiances

→ Operational assimilation of water clouds by VIS/NIR radiances

Observation Impact

- Approximation by (Kalnay et. al. 2012) implemented in KENDA
- Localization essential
- Good approximation for zero forecast interval

→ Operational observation impact monitoring

International Symposium on Data Assimilation 8-11 October 2012, DWD, Offenbach

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- Christina Köpken-Watts, DWD
- Roland Potthast, Uni Reading, DWD
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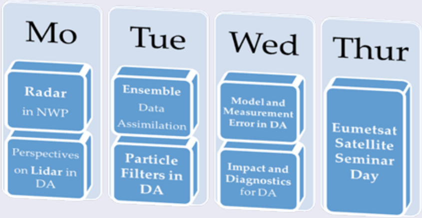
- Amos Lawless, Uni Reading



Registration

- `http://www.dwd.de/seminare`
- Registration Deadline for Poster: August 31, 2012