Infrared brightness temperature assimilation using an LETKF at convection-resolving resolutions

1. Introduction

Clouds and atmospheric water vapor strongly influence sensitive weather conditions through their combined effect on surface temperatures and precipitation. Small changes in the water vapor and cloud distributions can have a profound impact on the generation and subsequent evolution of high impact weather events, such as severe thunderstorms, heavy rainfall and tropical cyclones. Thus, an accurate and spatially representative specification of clouds and water vapor in datasets used to initialize high-resolution numerical weather prediction models is essential to produce accurate forecasts of cloud cover, precipitation, and storm evolution.

Challenge: Direct assimilation of cloud-affected SEVIRI radiances
Model: high-resolution COSMO-DE, a non-hydrostatic limited area model run at 2.8 km horizontal resolution, 50 vertical layers with explicit deep convection
Data assimilation method: Local Ensemble Transform Kalman Filter (LETKF; Hunt et. al., 2007) with RTTOV 10 as forward operator.
Observations: MSG SEVIRI brightness temperatures

2. Assimilation of SEVIRI radiances with LETKF

Motivation:

- Direct assimilation of SEVIRI radiances (instead of retrievals)
- Assimilation of all-sky brightness temperatures (water vapor and window channels) with LETKF for the regional COSMO-DE model of Germany
- Improved understanding of how the assimilation of water vapor sensitive infrared brightness temperatures impacts the analysis and forecast accuracy
- Position of clouds with the assimilation of window band brightness temperatures
- Results readily transferable to other assimilation systems (like after ABI GOES-R or AHI-Himawari-8 observations become available)
- Examine the sensitivity of the ensemble system to the observation error and horizontal localization radius
- Explore the impact of new vertical localization techniques as it is one of the challenges in the assimilation of satellite observations with Ensemble KalmanFilter methods

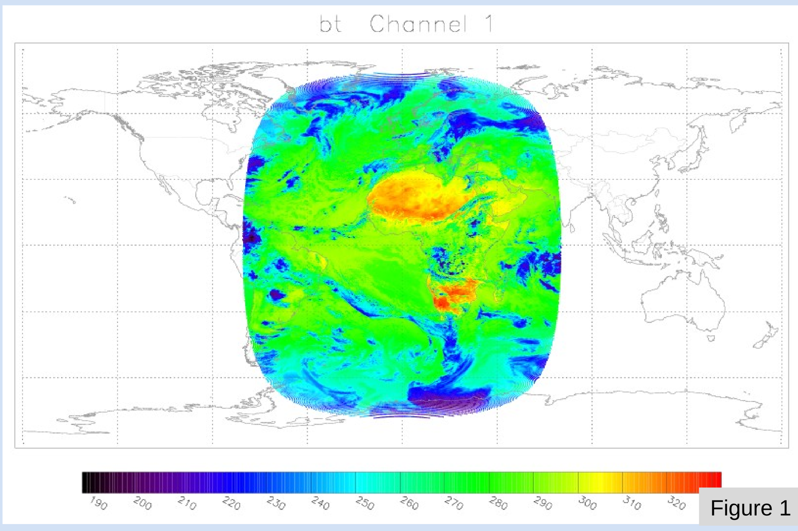
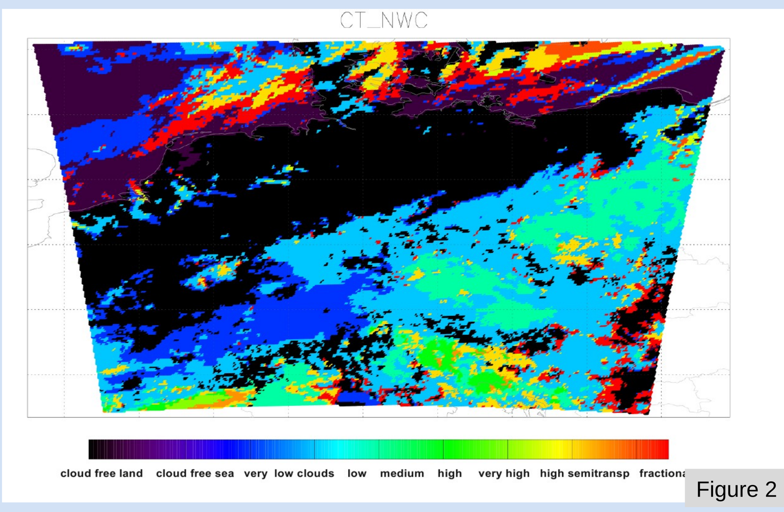


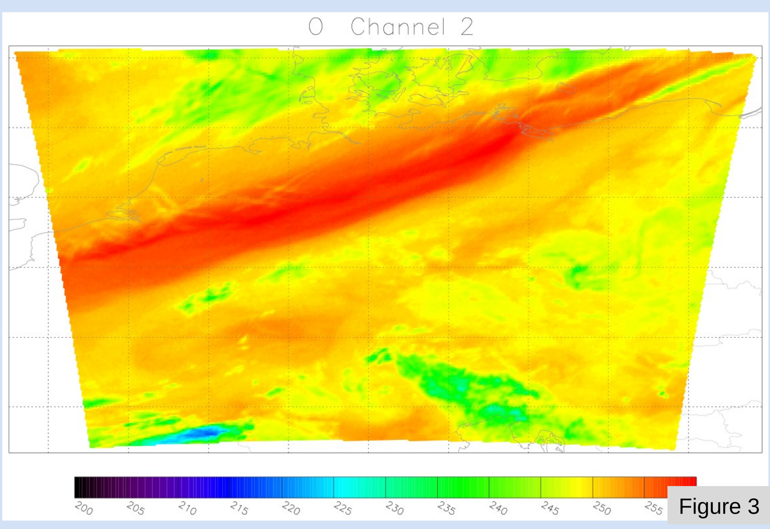
Figure 1. SEVIRI infrared brightness temperatures. SEVIRI is a 12-channel imager instrument in MSG (Meteosat Second Generation). SEVIRI produces images of the Earth every 15 minutes. Horizontal resolution: 3Km at nadir / ~5Km for Europe.

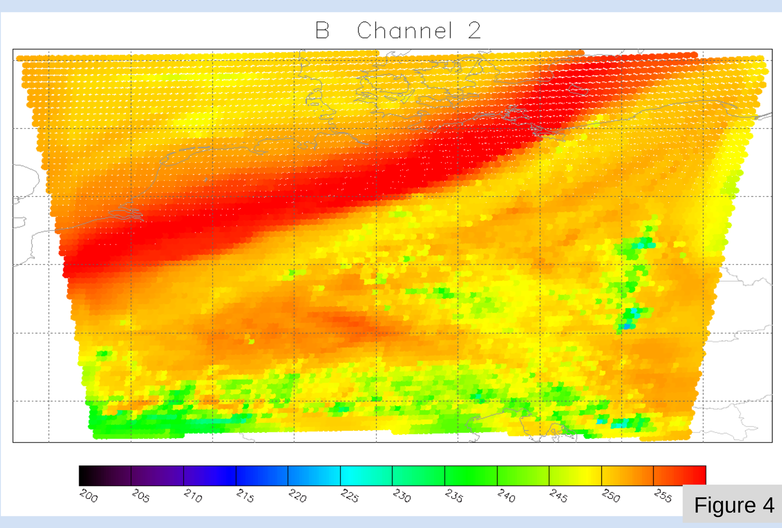
3. Monitoring experiments with LETKF

Water vapor (WV 6.2, WV 7.3) and window channel (IR 8.7) brightness temperatures monitoring test case from 2011-06-01 00:00 to 2011-06-06 12:00
Flow regimes, based on cloud evolution, during the 6-day period:

- 01 - high clouds initially, lots of low clouds later
- 02 - low clouds with extensive clear sky areas
- 03 - high clouds with extensive clear sky areas
- 04 - clear skies initially, then lots of convection in south
- 05 - clear skies, then widespread convection in west
- 06 - widespread convection in north, mixture of clouds later







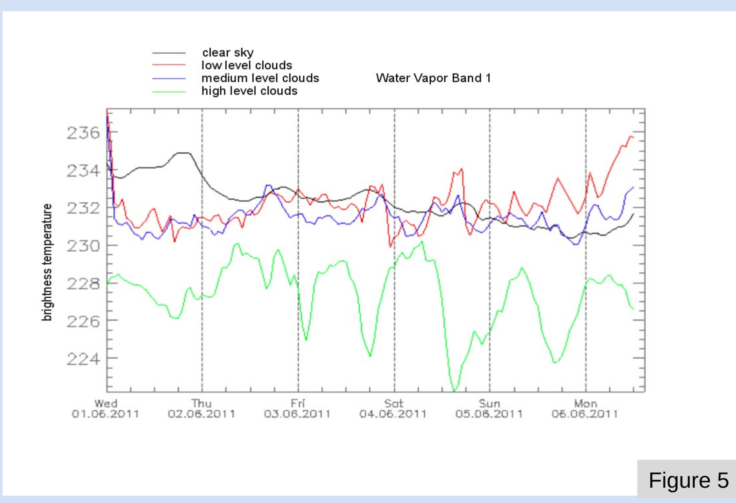
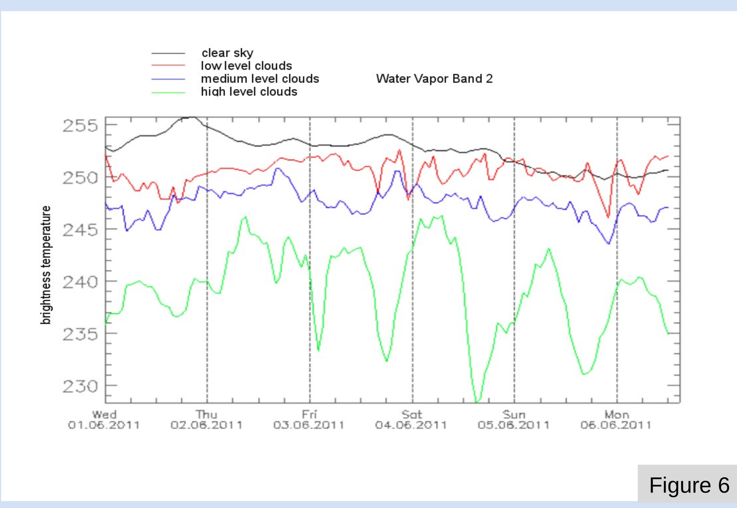
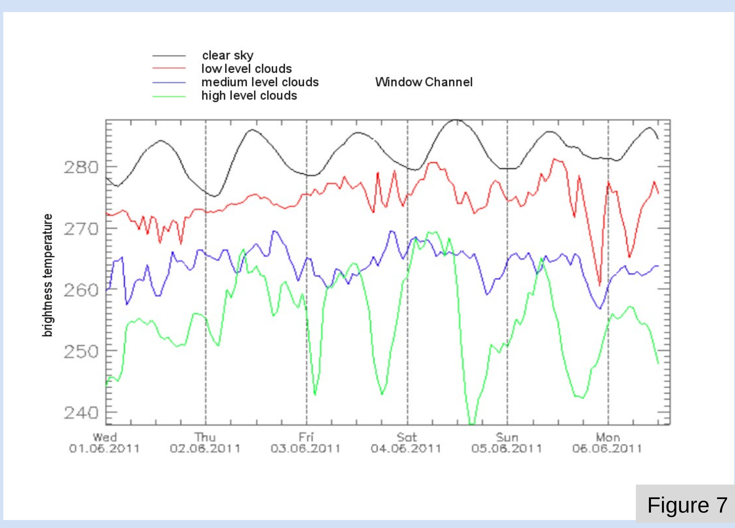


Figure 2. Cloud top height retrievals from NWC SAF are used to categorize the observed clouds as occurring in the lower, middle, or upper troposphere. NWC-SAF Cloud Type image for 2011-06-02 00:00 UTC.
Figure 3-4. 2011-06-02 00:00 water vapor band observations from SEVIRI in the first plot, and simulated brightness temperatures for the same time and channel in Fig. 4.
Figure 5-7. Averaged simulated brightness temperatures for the 6-days period, computed at hourly intervals. Distinguishing between clear sky, low, medium and high clouds for window channel and water vapor band. Low clouds (surface to 2 km AGL), middle (2 to 6 km AGL), and upper troposphere (6 to 14 km AGL)

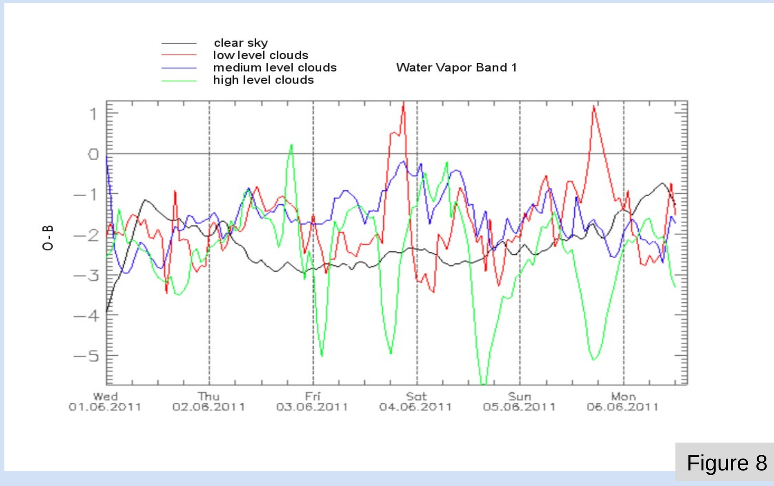


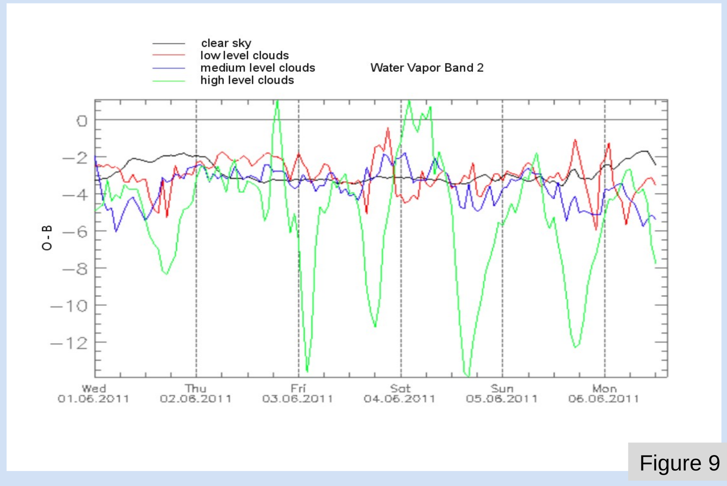


4. Cloud dependent Bias Correction

Observation minus Background

- In **Fig 8-10** are represented Observation minus Background for matching grid points for the whole 6-days period for water vapor bands and window channel, computed hourly
- Cloud dependent statistics evaluation: clear sky, low, medium and high level clouds





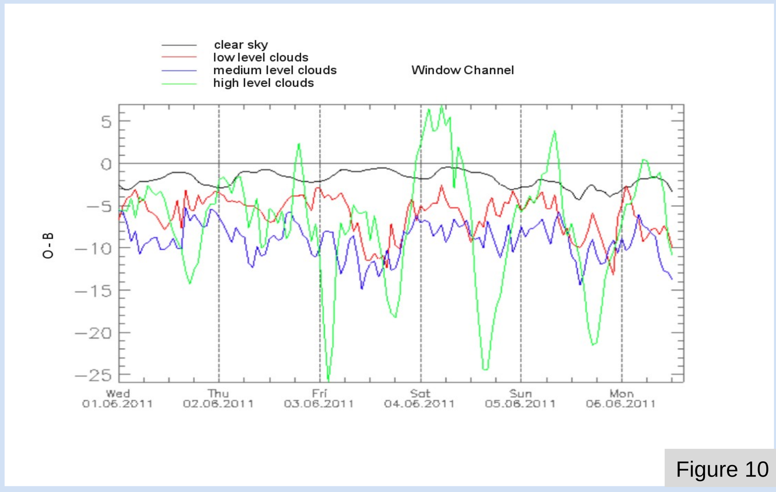


Fig 8-10. Strong biases with high-level clouds reaching maximum values in presence of storms. Clear-sky bias varies from -3 to -1K
The bias variability with time supports the implementation of time-evolving bias correction.
Outlier biases probably due to the presence of semi-transparent clouds. Work in progress to exclude them to the assimilation.

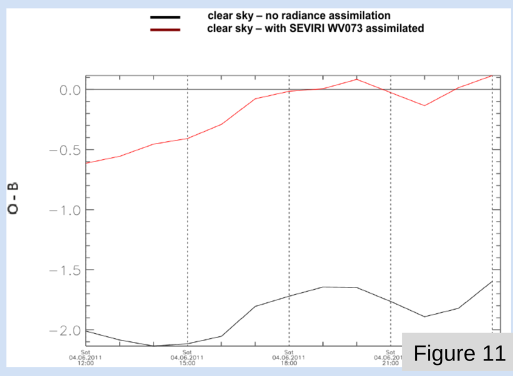
WV073 Assimilation Experiments

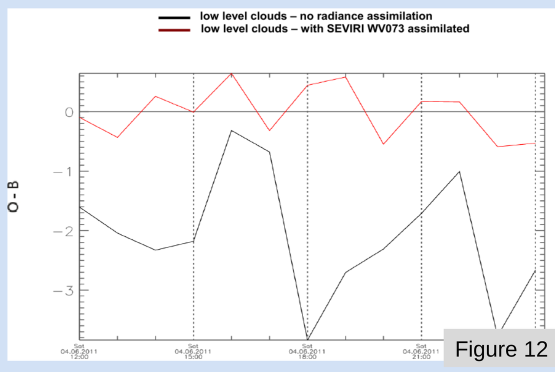
- 12 hours assimilation, hourly, from 2011-06-04 12:00 UTC to 2011-06-05 00:00 UTC
- bias correction value applied to the simulated observation (rather than to the real observations)

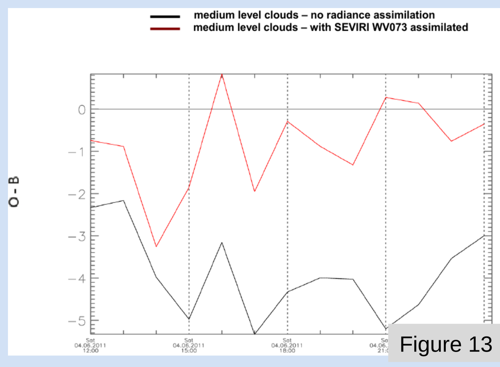
$$d_o = H(x^{(b)}) + y^{(b)}_{bc} - y^o$$

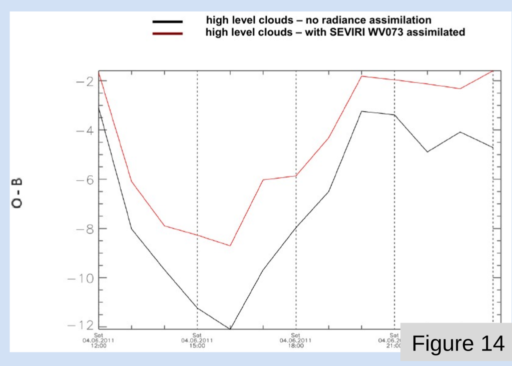
	Clear sky	Low-level clouds
y^{bc}	-2.9	-2.9
	Medium-level clouds	High-level clouds
y^{bc}	-3.1	-4.4

- Model-simulated cloud field from a given ensemble member is used to determine the cloud top height
- Bias statistics from the 3-day period previous to the assimilation date
- Optimal settings: **Observation error** 3.5 K, horizontal and vertical **localization** radii 35 km and 0.7 log pr units









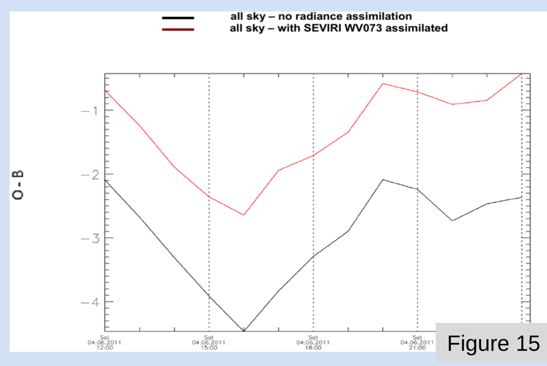
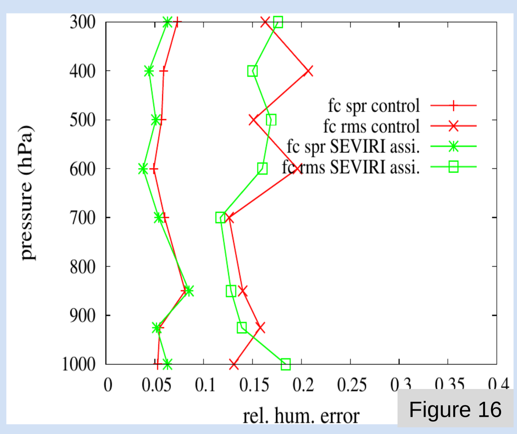
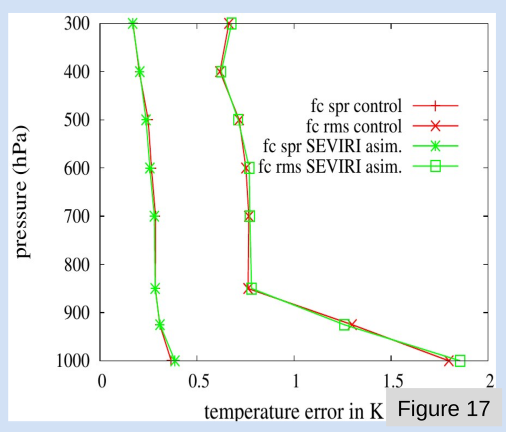


Fig 11-15. In red, O-B evolution for a control experiment where only convecional observations were assimilated. In the black line, the O-B for the experiment with the asimilation of conventional observations and the WV073 brightness temperature with the cloud dependent bias correction applied. The O-B bias for each cloud type is lower during most of the assimilation period when the infrared observations are assimilated.





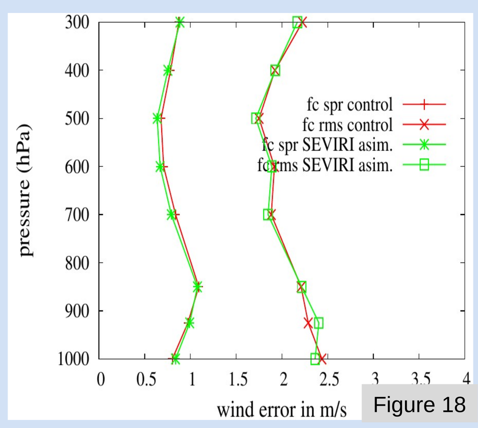


Fig 16-18. Vertical profiles, RMSE and spread for the Control and WV073 assimilation experiments. By the end of the assimilation period, large improvements were also evident in the relative humidity Fig. 16 field in the middle and upper troposphere, with smaller improvements in the wind field Fig. 17 and neutral impact on temperature Fig.18

5. Conclusions/Outlook

- Assimilation of cloud-affected brightness temperatures with an LETKF, with an adequate bias correction, improves the analysis and the skill assimilation cycle
- Distinguish between ice-clouds and water-clouds
- Develop a time-dependent bias correction values for each cloud type (use of predictors)

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