Impact of observations on the AROME-France convective-scale data-assimilation system

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The theory of linear statistical estimation, based on the minimization of the estimation error variance, provides an estimate of the true state of the atmosphere, the analysis, as a combination of two sources of information, the background and the observations, weighted with error covariances that represent the uncertainty associated to each kind of information. It can be shown that, if observation and background error covariance matrices are well specified, the analysis error covariance matrix is given by $\mathbf{A} = \mathbf{B} - \mathbf{KHB}$ where $\mathbf{B}$, $\mathbf{K}$ and $\mathbf{H}$ respectively stand for the assumed background error covariance matrix, the Kalman gain matrix and the linearized observation operator. The total variance reduction provided by the assimilation of the observation $r=\mathrm{Tr}(\mathbf{B})-\mathrm{Tr}(\mathbf{A}) = \mathrm{Tr}(\mathbf{KHB})$ is a measurement of the ability of a data assimilation (DA) system to pull the analysis from the background with respect to the observations (Tr stands for the trace of a matrix). A direct estimate of the variance reduction $\mathrm{Tr}(\mathbf{KHB})$ is not possible in practice in an operational variational DA, since neither $\mathbf{B}$ nor $\mathbf{K}$ are explicitly known. Desroziers et al. (2005) proposed to estimate the variance reduction, and the contributions of the different observation types, with a randomization method in the global ARPEGE 4D-Var. This method, implemented in the AROME-France convective-scale 3D-Var scheme (Brousseau et al., 2013) allows one to investigate observation impact depending on the control variable field, model levels, date, analysis time, and spatial scales considered.

The observations with the largest impact in the AROME-France 3D-Var system are given by aircraft (for temperature and wind fields) and radar (specific humidity and wind fields) observations in the middle and high troposphere, in accordance with the vertical distribution of these observations (Figure 1). Screen-level measurements (2 m temperature, 2 m relative humidity and 10 m wind) are the main contributors at the lowest atmospheric levels. These large impact values are explained by the number of these observations assimilated at each analysis time. On a rainy day, aircraft, radar and screen-level observations account for respectively 22%, 30% and 18% of the total account of assimilated observations. One can note that it is possible to evaluate the impact of an observation of a given physical quantity (resp. at a given model level) on the analyzed field of an other physical quantity (resp. on other levels) through the $\mathbf{B}$ matrix cross- (resp. vertical) correlations. The total variance and the different observation contributions are also evaluated depending on the spatial scale of the analyzed fields: most of variance reduction concerns length scales above 100 km with a maximum around 500-800 km. Only the radar measurements, with an horizontal density of 15 km, contribute to the variance reduction at scales lower than 100 km.

This *a posteriori* diagnostic provides rich and useful information on the impact of the different observation types on the analysis. It is not intended to replace Observing System Experiments but rather to complement them to optimize the design of observing networks and their use in various data assimilation systems, particularly at convective scale.

References:

Desroziers G., Brousseau P. and Chapnik B. 2005. Use of randomization to diagnose the impact of observations on analyses and forecasts. Quart. J. Roy. Meteor. Soc. 13 : 2821–2837.

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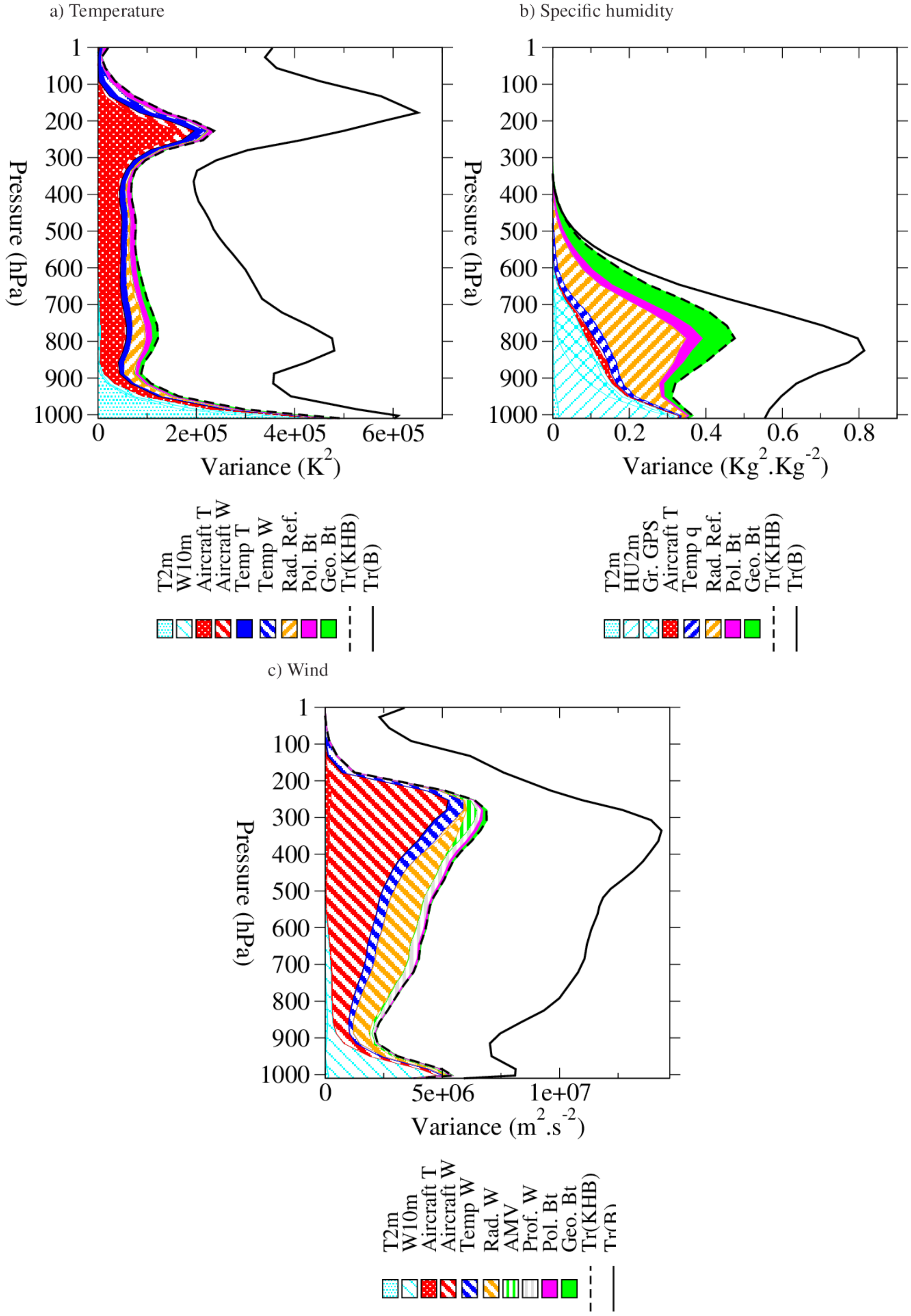

*Figure 1: Vertical profile of the background error total variance (Tr(**B**): plain line), variance reduction (Tr(**KHB**): dashed line) and observation subset contributions to Tr(**KHB**) (shaded areas) averaged on 3 May 2010 for temperature (a), specific humidity (b) and wind (c). T2m: 2 m temperature; W10m: 10 m wind; Aircraft T, W: aircraft temperature, wind; Temp T, q, W: radio-sounding temperature, specific humidity, wind;Rad. Ref., W: radar reflectivity, doppler wind; Pol. Bt: brightness temperature on board polar platform; Geo. Bt: brightness temperature on board geostationary platform; HU2m: 2 m relative humidity;Gr. GPS: Ground-based GPS zenith total delay; AMV: atmospheric motion vector; Prof. W: wind profiler.*