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Including supersaturation with respect to ice in water vapour analyses

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The analysis of water vapour in atmospheric data assimilation systems has a non-linear dependency on the temperature through the saturation vapour pressure, which limits supersaturation with respect to (wrt) water to insignificant amounts in the atmosphere. However, there can be significant supersaturation with respect to ice, and when this is represented in forecast models, it is beneficial that the data assimilation includes this additional temperature dependency in the design of the water vapour analysis. These changes mostly affect the upper troposphere, where supersaturation wrt ice exceeding 50% is observed. A summary will be given of the design and the results of accommodating for supersaturation with respect to ice in the ECMWF 4D-VAR system, in particular with respect to the asymmetries and inhomogeneities of the analysis increments. The correct treatment of supersaturation is one of the prerequisites for extending the analysis to include cloud related variables.

Before taking into account supersaturation, the ECMWF water vapour control variable was linearized relative humidity normalized by a relative humidity dependent background error variance. This control variable removes much of the spatial inhomogeneity associated with the humidity analysis. In addition, asymmetries in the increments close to zero and saturation are counteracted by using the background error variance for the mean of the current and analysed state, introducing additional a nonlinearity in the control variable transform which is treated at the outer loop level in 4D-VAR.

When introducing supersaturation wrt ice, the background error variances necessary for the control variable transform were obtained from a new set of forecast difference statistics from model integrations which allowed supersaturation. The temperature part of the linearized relative humidity was also removed outside cloudy regions to be consistent with the forecast difference statistics.

An immediate result of allowing supersaturation with respect to ice in the analysis was to make the frequency distribution of relative humidity wrt ice very similar in the analysis and the forecast. Before, the analysis truncated all supersaturation at each analysis cycle. Even though it only takes a few hours for the model supersaturation to spin up in the upper troposphere, a systematic removal of water vapour by the analysis degrades the forecast. This effect carries directly over to cloud cover. Before, monthly zonal averages showed that upper tropospheric cloud cover was reduced by up to four percent in each analysis (which was then regained during the forecast, but at the cost of accuracy). After introducing supersaturation wrt ice in the analysis, the systematic increment is mostly gone with plus/minus one percent systematic differences at most, but now in smaller areas.

The effect of the state dependent control variable transform on the increments is to make them asymmetric in regions with large gradients in either temperature or humidity. This will be illustrated by cases showing the flow dependent nature (in horizontal and vertical) of the increments close to fronts, on the borders of clear and cloudy regions, and in the presence of supersaturation.