# Cloud condensate control variable transform and background errors

Elías Valur Hólm[1], Jiandong Gong[2] and Philippe Lopez[1], [1]European Centre for Medium-Range Weather Forecasts, Reading, UK, [2]National Meteorological Center, China Meteorological Administration, Beijing, China.

## 1 Tangent linear cloud variables

Additional 3D variables $\delta q_l$ and $\delta q_i$ are advected by the tangent linear model using updated linear cloud physics. Background error is in terms of cloud condensate $\delta q_c = \delta q_l + \delta q_i$. Transform back from cloud condensate control variable uses temperature dependent splitting, $\delta q_l = \alpha(T^b)\delta q_c$, $\delta q_i = (1-\alpha(T^b))\delta q_c$.

## 2 Balanced and symmetric control variable

The control variable includes grid point balance operator between temperature $\delta T$, specific humidity $\delta q_v$ and cloud condensate $\delta q_c$ increments (mainly reflecting cloud condensation effects). Balance coefficients $Q_{cq}$ and $Q_{qT}$ are determined from model level and relative humidity background $rh^b$ dependent regression,

$$\begin{pmatrix} (\delta\hat{q}_c)_u \\ (\delta\hat{q}_v)_u \\ \delta\hat{T} \end{pmatrix} = \begin{pmatrix} 1 & -Q_{cq}(rh^b) & 0 \\ 0 & 1 & -Q_{qT}(rh^b) \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \delta\hat{q}_c \\ \delta\hat{q}_v \\ \delta\hat{T} \end{pmatrix}$$

where $\delta\hat{T} = \delta T rh^b L_v/[R_v(T^b)^2]$, $\delta\hat{q}_v = \delta q_v/q_s(T^b)$ and $\delta\hat{q}_c = \delta q_c/\sigma_{cc}(q_s(T^b)-q_s(T_l))$, using liquid temperature $T_l$. This is followed by normalisation by background error standard deviations,

$$\begin{pmatrix} \delta\tilde{q}_c \\ \delta\tilde{q}_v \\ \delta\tilde{T} \end{pmatrix} = \begin{pmatrix} \delta\hat{q}_c/\sigma_{cr}(rh) \\ \delta\hat{q}_v/\sigma_q(rh) \\ \delta\hat{T}/\sigma_T \end{pmatrix}$$

A statistical regression on a large sample of ensemble forecast differences determines $\sigma_{cc}(q_s(T^b)-q_s(T_l))$ $\sigma_{cr}(rh)$, and $\sigma_q(rh)$. To obtain symmetric error distributions, the regressions are made on forecast differences stratified against $rh^b + \frac{1}{2}\delta rh$ and $q_s(T^b) - q_s(T_l^b + \frac{1}{2}\delta T_l)$ instead of the background values. In 4D-VAR using multiple outer loops, this nonlinear transform is performed at outer loop level.

## 5 Single observation experiments

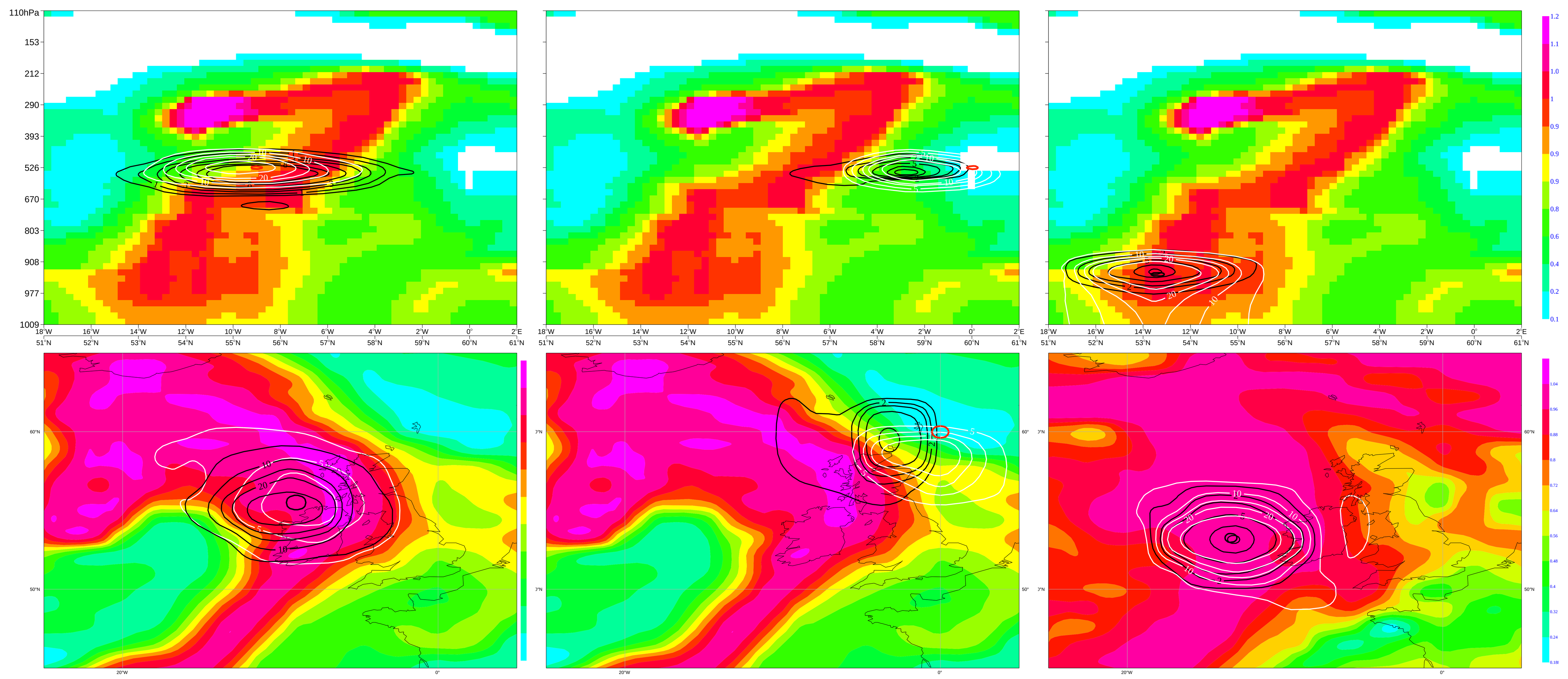

**Figure 5: Single cloud liquid observation (bold red/black circle) at start of 6H 4D-VAR window in nearly saturated area (left), very dry area with no background condensate (middle), and nearly saturated boundary layer (right): cloud condensate (black isolines) and specific humidity (white isolines) analysis increments [units 1E-6 kg/kg] and background relative humidity (colour).**

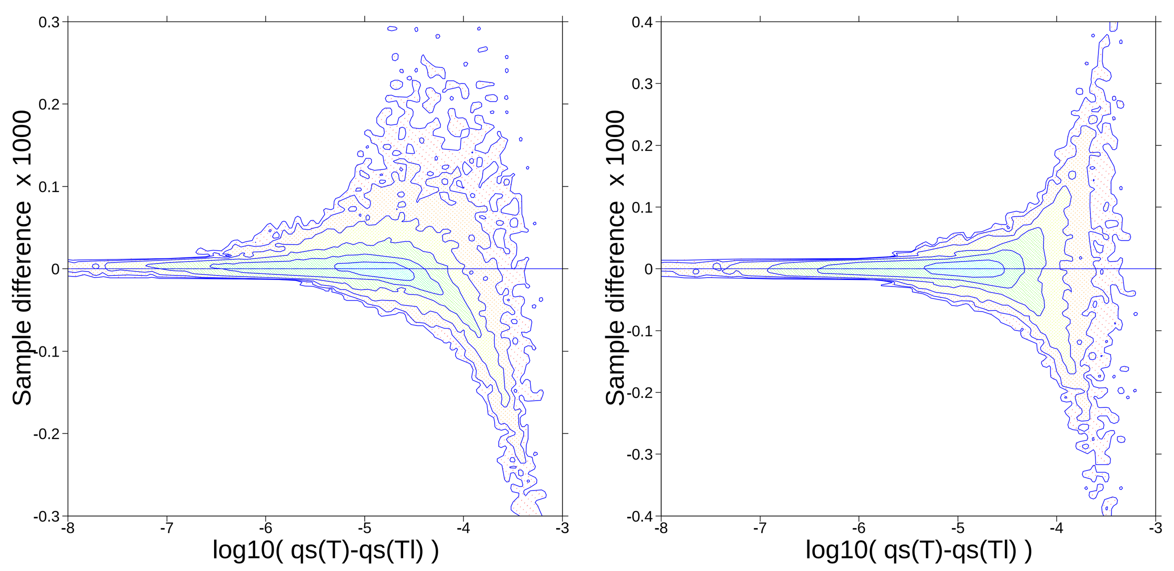


Figure 1: Symmetrizing of cloud condensate background error pdf by fitting $\sigma_{cc}$ against the frequency distribution along the mean of the background and analysis cloud condensate $q_s(T^b) - q_s(T_l^b + \frac{1}{2}\delta T_l)$ (right) instead of just the background $q_s(T^b) - q_s(T_l^b)$ (left).

## 3 Wavelet B

Cloud condensate has been added to a global wavelet B formulation. By averaging over seasons a large sample is obtained which fills the troposphere. Stratospheric correlations are added, but have no effect due to cloud condensate error variances set to very low values above the tropopause. There is considerable geographical variation of the correlations.

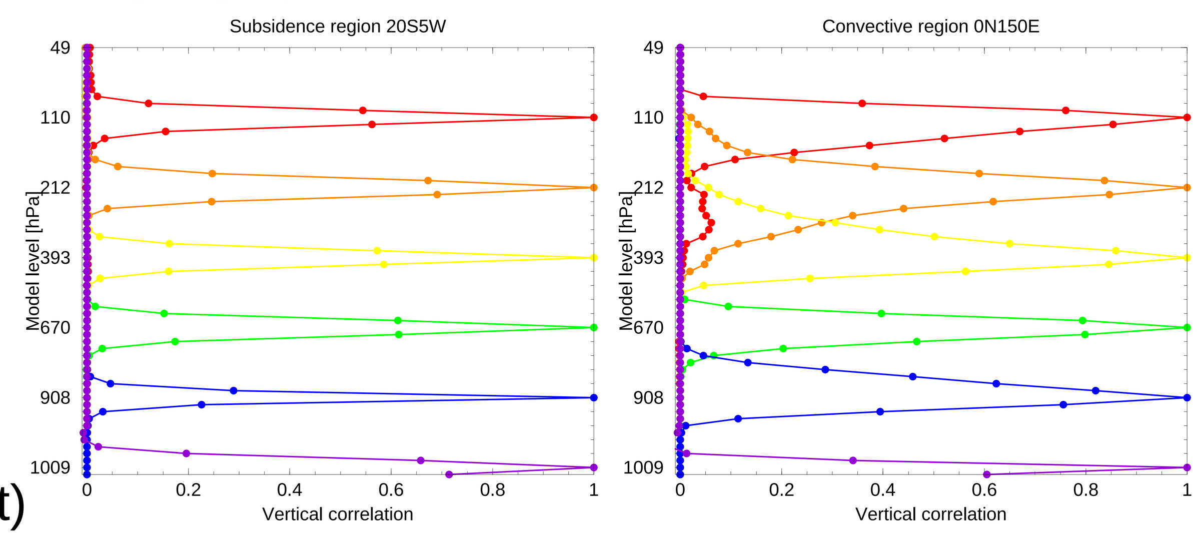


Figure 2: Vertical background error correlation geographical variation in the wavelet B (averages over seasons).

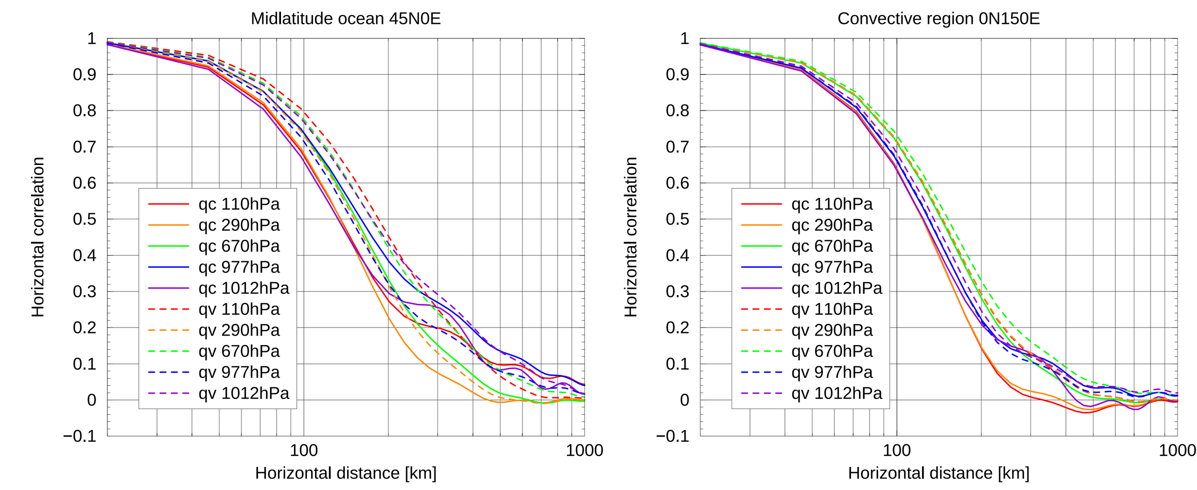


Figure 3: Horizontal background error correlation geographical variation in the wavelet B (averages over seasons).

## 4 Flow-dependent variances

Flow-dependent variance $\sigma_{cc}\sigma_{cr}$ calculated from statistical regression agree reasonably with ensemble spread. Current work is introducing ensemble generated variances of the day for cloud condensate and further study performance in precipitating conditions.

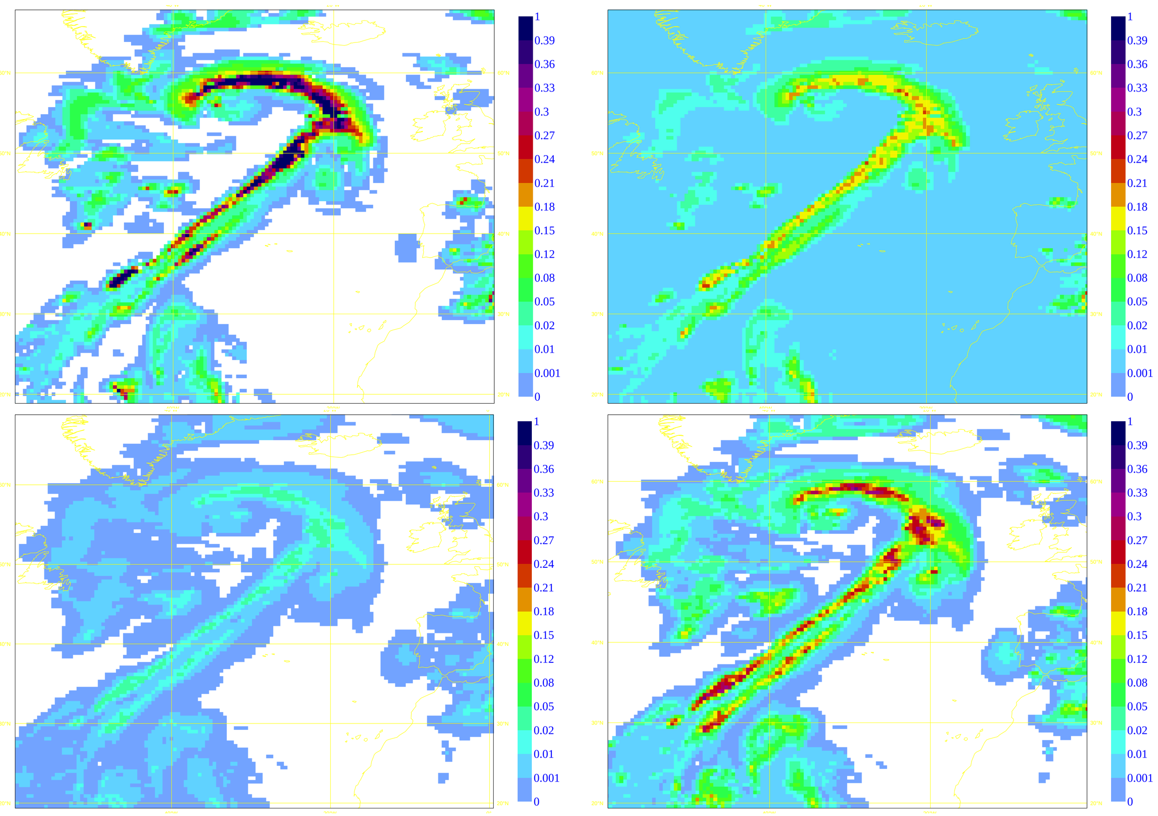

Figure 4: Cloud condensate background error standard deviation $\sigma_{cc}(q_s(T^b) - q_s(T_l^b + \frac{1}{2}\delta T_l))\sigma_{cr}(rh)$ (at ca. 670 hPa) from a flow-dependent statistical regression model compared with the ensemble spread from ten ensemble forecasts valid at the same time: background (upper left), statistically estimated standard deviation (upper right), ensemble mean (lower left), ensemble spread (lower right) [units 1E-3 kg/kg].

**Contact: Elias.Holm@ecmwf.int**