Developments in ECMWF humidity background errors

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Today we will talk about...

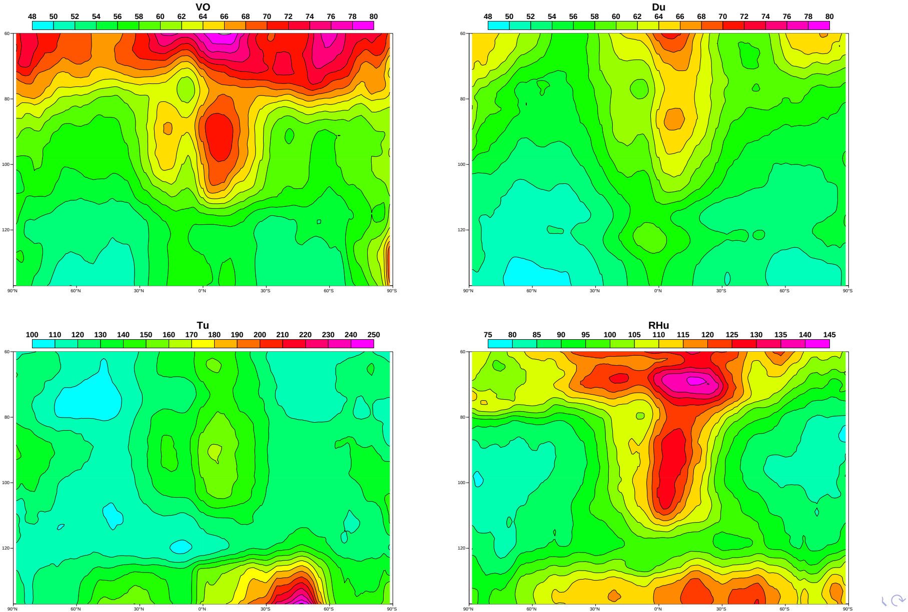
1. Background errors from the EDA
2. EDA humidity background error variances
3. Diabatic balance operator
4. Stratospheric humidity analysis?

Background errors from the EDA

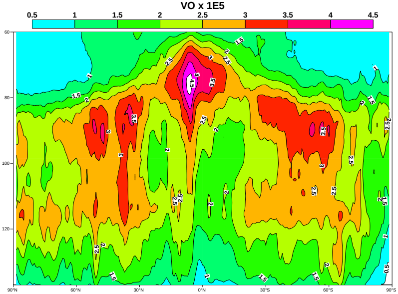
The Ensemble of Data Assimilation (EDA) is input to update the background error covariance matrix **B** every analysis cycle:

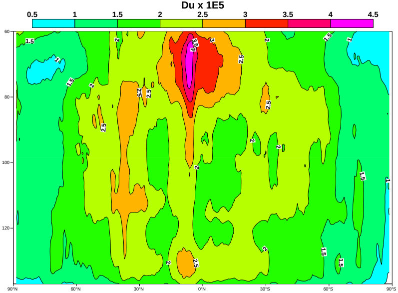
- EDA has 25 members at ca. 18km resolution, half of the operational 4D-Var/forecast 9km resolution.
- Standard deviations fully flow-dependent for all analysis variables.
- Correlations partially flow-dependent with climatological length-scales mixed in for low wavenumbers in particular (30% flow dependent up to T63, growing to ca. 90% at T399).
- Let's have a look...

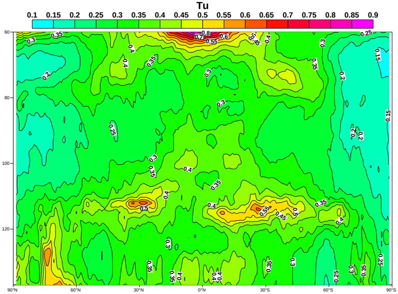
Lengthscales **B** [km], zonal ave 100hPa–sfc

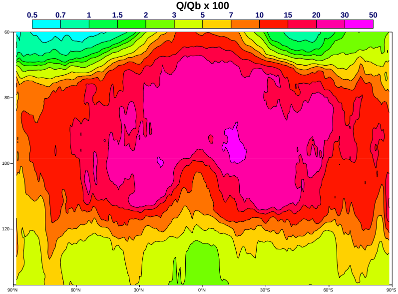


Standard deviations **B**, zonal ave 100hPa–sfc

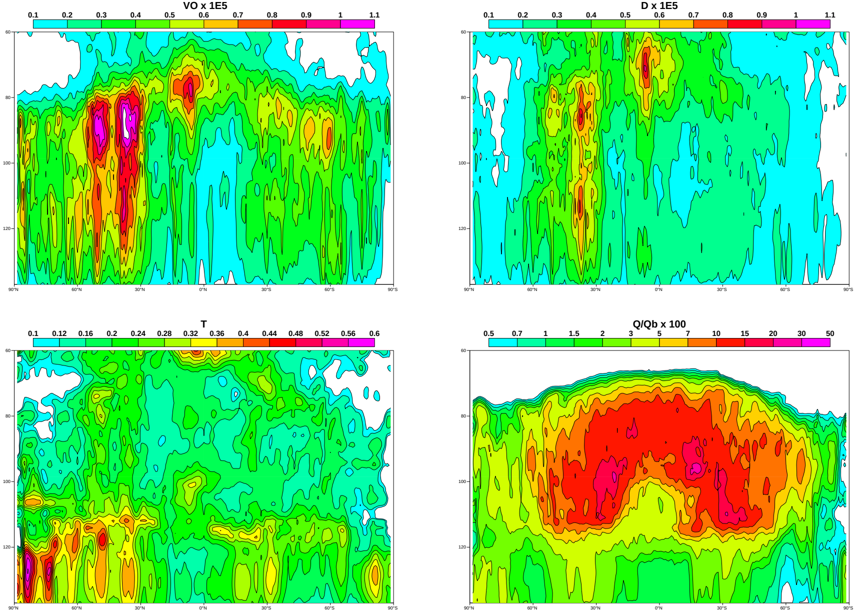




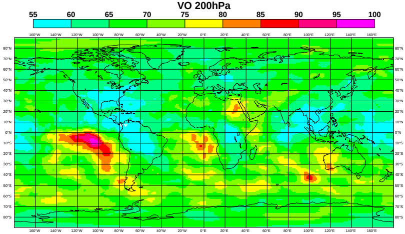


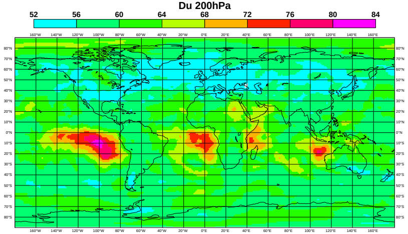


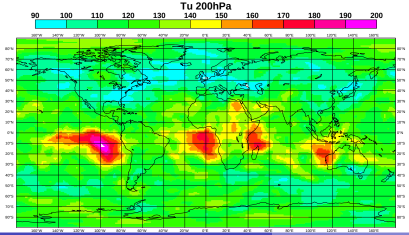
Analysis increments absolute values, zonal ave 100hPa–sfc

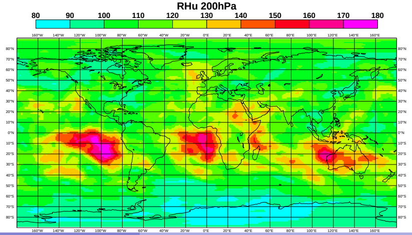


Lengthscales **B** [km], level 74 200hPa

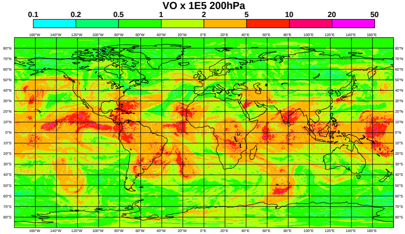


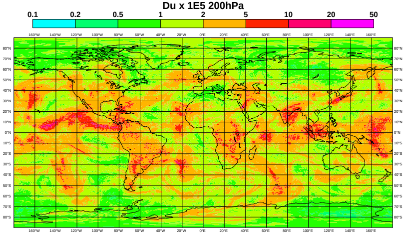


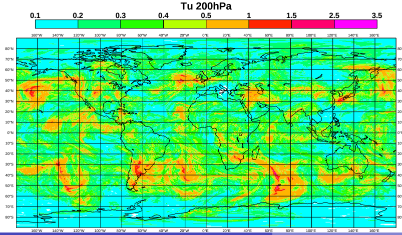


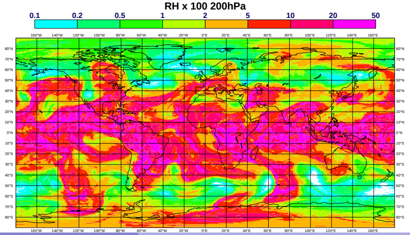


Standard deviations **B**, level 74 200hPa

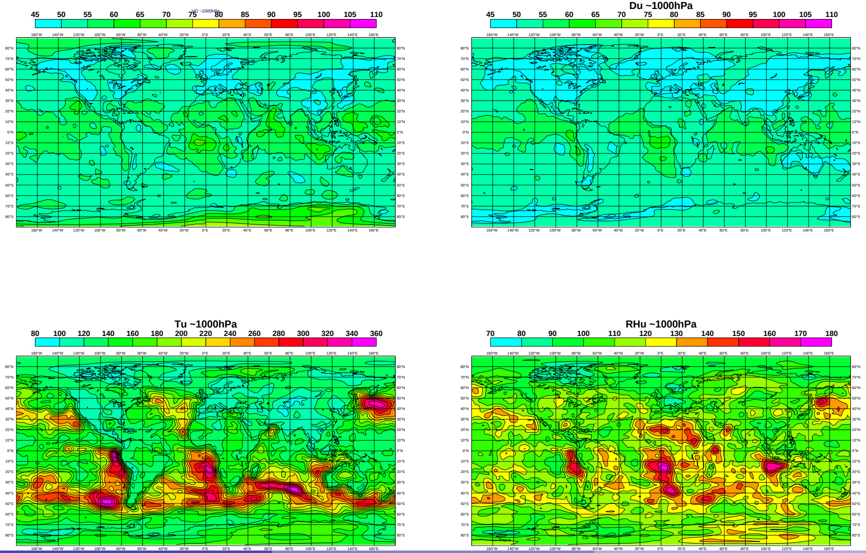




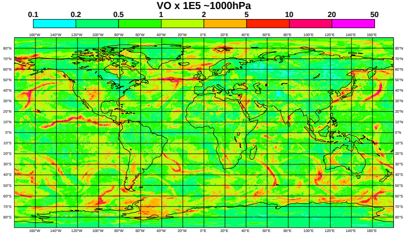


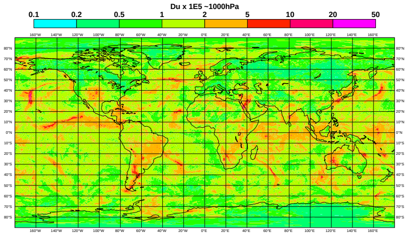


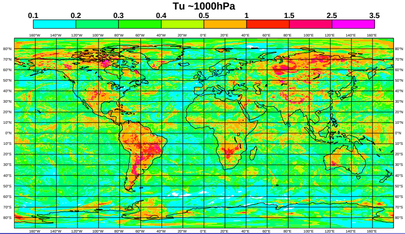
Lengthscales **B** [km], level 137 1000hPa

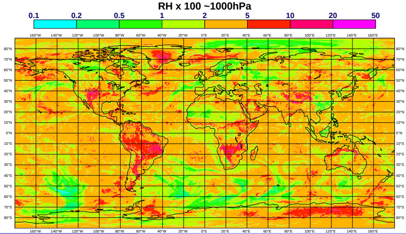


Standard deviations **B**, level 137 1000hPa





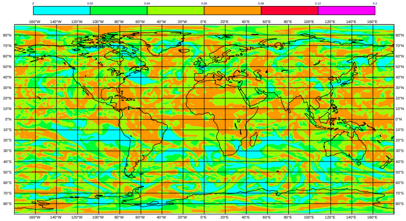


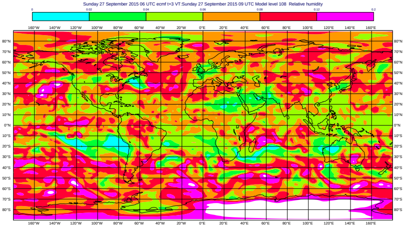


Humidity background error variances from the EDA

- Pre-July 2017: Humidity background error variances were climatological average for given background relative humidity value and model level through a climatological statistically determined fit.
- Now: Use relative humidity background errors σ_{rh} from EDA like for other variables.
- Humidity sensitive data used better, in particular MW/IR where the radiance signal is more accurately apportioned between humidity and temperature.
- In the tropics in particular, where absolute humidity is highest, this leads to more accurate wind adjustments throught the 4D-Var tracing effect.
- Results show improved O-B fits for wind and humidity sensitive observations and improved scores of wind in particular.

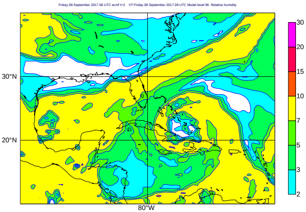
Relative humidity variances: background- vs. EDA-based

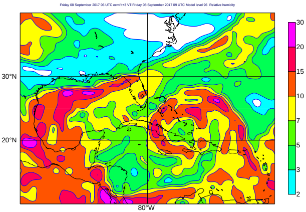




- Left: Old background-based RH stdev (750hPa, 2015092709)
- Right: New EDA-based RH stdev, about two times larger.

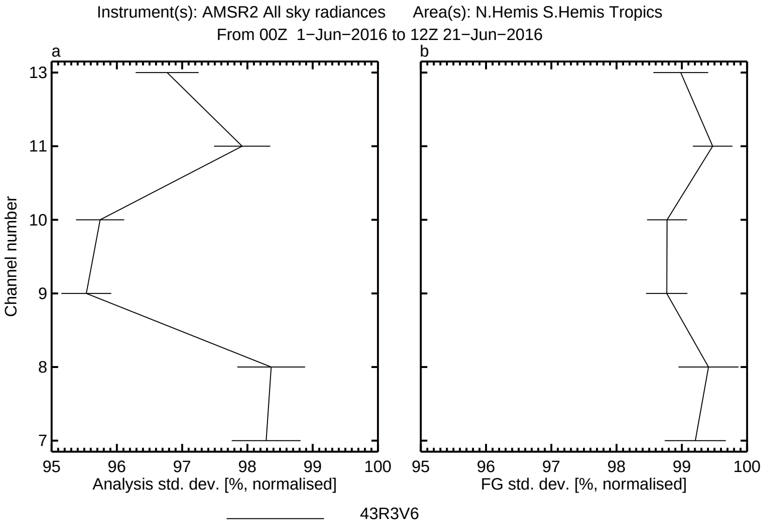
RH errors around TC's Jose and Irma 8 Sep 2017, 500hPa



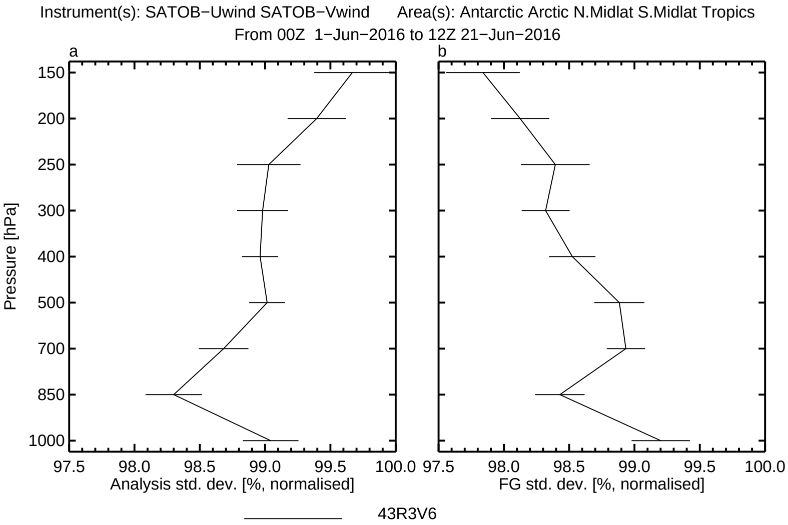


- Left: Old background-based RH stdev, "climatological average".
- Right: New EDA-based RH stdev, captures extremes of the day.
- Below: VIIRS image from NOAA's Suomi NPP satellite.

Improving humidity **B** improves humidity: O-B for AMSR2



Improving humidity **B** improves wind: O-B for SATOB



Diabatic balance through linear saturation adjustment

Use linear saturation adjustment (based on Asai 1965, Hólm et al. 2002 (operational ECMWF), Hólm 2015 (current development)),

$$\delta T = \delta T_n + C^b a \frac{L}{c_p}\left(\delta q_{vu} - \frac{L q_s(T^b)}{R_v\left(T^b\right)^2}\delta T_n\right)$$

$$\delta q_v = \delta q_{vu} - C^b a\left(\delta q_{vu} - \frac{L q_s(T^b)}{R_v\left(T^b\right)^2}\delta T_n\right)$$

$$\delta q_c = \delta q_{cu} + C^b a\left(\delta q_{vu} - \frac{L q_s(T^b)}{R_v\left(T^b\right)^2}\delta T_n\right)$$

In matrix from this becomes

$$\begin{pmatrix} \delta T \\ \delta q_v \\ \delta q_l \\ \delta q_i \end{pmatrix} = \begin{pmatrix} 1 - \frac{L}{c_p} C^b a\gamma & \frac{L}{c_p} C^b a & 0 & 0 \\ C^b a\gamma & 1 - C^b a & 0 & 0 \\ -\alpha C^b a\gamma & \alpha C^b a & 1 & 0 \\ -(1-\alpha) C^b a\gamma & (1-\alpha) C^b a & 0 & 1 \end{pmatrix} \begin{pmatrix} \delta T_n \\ \delta q_{vu} \\ \delta q_{lu} \\ \delta q_{iu} \end{pmatrix}$$

Details of linear saturation adjustment

- Increments δT_n and δq_{vu} assumed uniform over the gridcell.
- Saturation adjustment takes place in the in-cloud portion C^b of the gridcell, with C^b approximated by a regression formula as a function of rh^b and model level.
- $q^b = q_s(T^b)$ in the in-cloud part of the gridcell.
- Cloud condensate adjustment distributed by $\alpha(T^b)$ between δq_l and δq_i with $\alpha(T^b)$ varying between 0 and 1 according to mixed-phase formula.
- The adjustment conserves total water.
- The adjustment is unchanged for δT and δq_v whether δq_l and δq_i are included or not.
- Here $a = \frac{1}{1+\frac{L^2 q_s(T^b)}{c_p R_v \left(T^b\right)^2}}$ and $\gamma = \frac{L q_s(T^b)}{R_v \left(T^b\right)^2}$

Where does this fit in? Start from the dynamic balance

The balance operator consists of the dynamic horizontal simplified and linearized nonlinear balance (Fisher, 2003), $\nabla^2 P_b = (f + \zeta) \times v_\psi + \frac{1}{2}\nabla(v_\psi \cdot v_\psi)$, combined with vertical balance operators (from statistical regression, Derber and Bouttier, 1999),

$$\begin{pmatrix} \delta\zeta \\ \delta\eta_n \\ \delta(T_n, p_s) \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ M & 1 & 0 \\ N & P & 1 \end{pmatrix} \begin{pmatrix} \delta\zeta \\ \delta\eta_u \\ \delta(T_u, p_{su}) \end{pmatrix}$$

and simplified and linearized version of quasi-geostropic ω-equation balance (Fisher, 2003), $\left(\sigma\nabla^2 + f_0^2 \frac{\partial^2}{\partial p^2}\right)\omega' = -2\nabla \cdot \mathbf{Q}$,

$$\begin{pmatrix} \delta\zeta \\ \delta\eta \\ \delta T \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ Q_2 & 1 & Q_1 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \delta\zeta \\ \delta\eta_n \\ \delta T \end{pmatrix}$$

Total balance operator

The total balance operator consists of the dynamic nonlinear and vertical balance, linear saturation adjustment and ω- equation balance,

$$\begin{pmatrix} \delta\zeta \\ \delta\eta_n \\ \delta T_n \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ M & 1 & 0 \\ N & P & 1 \end{pmatrix} \begin{pmatrix} \delta\zeta \\ \delta\eta_u \\ \delta T_u \end{pmatrix}$$

$$\begin{pmatrix} \delta T \\ \delta q_v \\ \delta q_c \end{pmatrix} = \begin{pmatrix} \beta_{tt} & \beta_{tv} & \beta_{tc} \\ \beta_{vt} & \beta_{vv} & \beta_{vc} \\ \beta_{ct} & \beta_{cv} & \beta_{cc} \end{pmatrix} \begin{pmatrix} \delta T_n \\ \delta q_{vu} \\ \delta q_{cu} \end{pmatrix}$$

$$\begin{pmatrix} \delta\zeta \\ \delta\eta \\ \delta T \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ Q_2 & 1 & Q_1 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \delta\zeta \\ \delta\eta_n \\ \delta T \end{pmatrix}$$

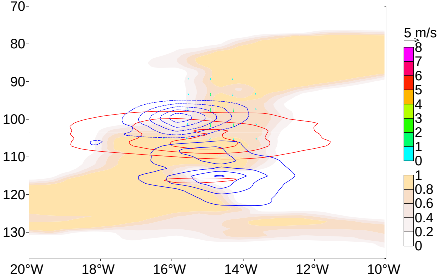
Apply saturation adjustment before ω-equation

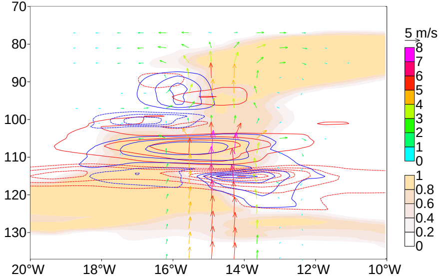
- Apply saturation adjustment just before the ω-equation in the balance operator.
- Then the final divergence dynamically supports the water vapour and cloud condensate changes in an adaptive way without any special treatment:

$$\begin{pmatrix} \delta\zeta \\ \delta\eta \\ \delta T \\ \delta q_v \\ \delta q_c \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ Q_2 + M + Q_1 N(1 - \frac{L}{c_p} C^b a\gamma) & 1 + Q_1 P(1 - \frac{L}{c_p} C^b a\gamma) & Q_1(1 - \frac{L}{c_p} C^b a\gamma) & Q_1 \frac{L}{c_p} C^b a & 0 \\ N(1 - \frac{L}{c_p} C^b a\gamma) & P(1 - \frac{L}{c_p} C^b a\gamma) & 1 - \frac{L}{c_p} C^b a\gamma & \frac{L}{c_p} C^b a & 0 \\ NC^b a\gamma & PC^b a\gamma & C^b a\gamma & 1 - C^b a & 0 \\ -NC^b a\gamma & -PC^b a\gamma & -C^b a\gamma & C^b a & 1 \end{pmatrix} \begin{pmatrix} \delta\zeta \\ \delta\eta_u \\ \delta T_u \\ \delta q_{vu} \\ \delta q_{cu} \end{pmatrix}$$

with $\delta q_c = \delta q_l + \delta q_i$ and $\delta T = \delta(T, p_s)$ and $\delta T_u = \delta(T, p_s)_u$.

Diabatic balance for single all-sky observation profile





- Left: Current $q - T$ balance operator.
- Right: Diabatic balance operator before ω-equation (no δq_c).
- Increments of temperature (red lines), humidity (blue lines) and wind (arrows).

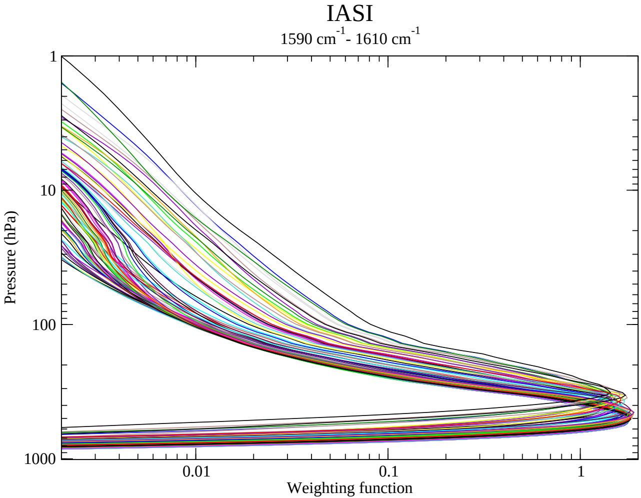
Development of humidity-cloud analysis

- Linearized saturation adjustment humidity-temperature applied before the ω-equation.
- Add cloud liquid and ice to control variables. Treat just like humidity, using EDA variances and diabatic balance (no zero variances, always a minimum value).

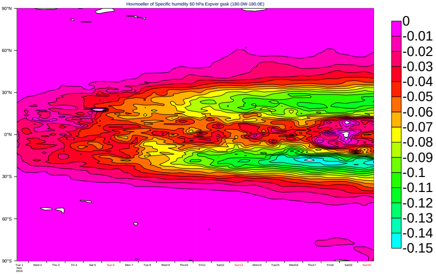
Stratospheric humidity analysis OFF – turn it ON?

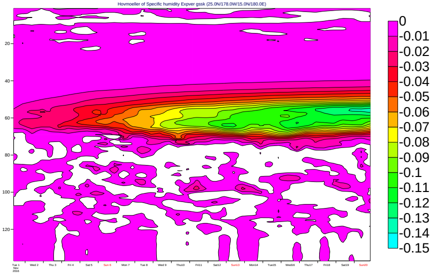
- There are long-standing issues with lower stratospheric model biases, which get worse if humidity sensitive radiances are assimilated in that region.
- Humidity sensitive channels with peak sensitivity in upper troposphere often have long tail of sensitivity in the stratosphere, up to 1hPa.
- Bias-correction of these channels is mainly against the upper tropospheric model column.
- This leaves any inaccuracies to affect the humidity in the lower stratosphere, where humidity values are much lower.
- Systematic analysis corrections in upper troposphere lead to systematic tendencies in the stratosphere.
- Radiation interaction of water vapour in the lower stratosphere then leads to degraded forecasts of temperature.
- Until we have better control over lower stratospheric humidity (through e. g. microwave limb sounders) we set the humidity background errors to low values above the 'humidity-minimum tropopause' to suppress humidity increments.

Weighting function selected IASI humidity channels



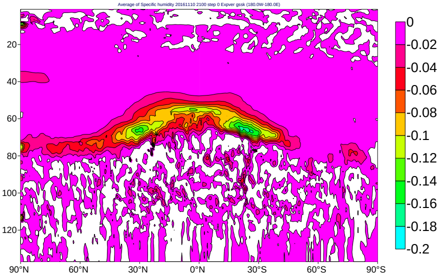
Stratospheric humidity analysis: ratio of q on/off

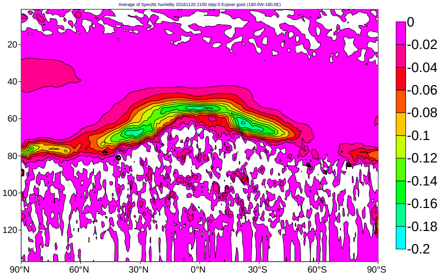


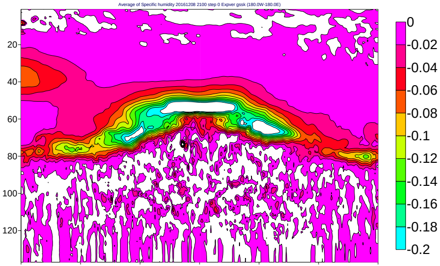


- Left: Hovmoeller model level 60 (100hPa)
- Right: Hovmoeller 15N-25N.
- Humidity still evolving after 40 days (-30%, next slide), ongoing for half a year from past experiments.

Stratospheric humidity analysis: zonav day 10, 20, 40







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