Stratospheric humidity analysis

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Outline

Extra-tropical lower-most stratospheric moist bias

Stratospheric humidity analysis is turned OFF in ERA5.
What happens if we turn it on?

Conclusion & outlook

Extra-tropical lower-most stratospheric moist bias

- ECMWF's lowermost stratospheric humidities are around 150 % of the observed values on average (vs radiosondes, MLS, lidar, aircraft)

- co-located cold bias forms at a rate of -0.2 K day−1 in the forecast due to excessive LW radiative cooling from the additional moisture

- mean tropopause altitude increases by 100m day−1 (due to cooling above the tropopause)

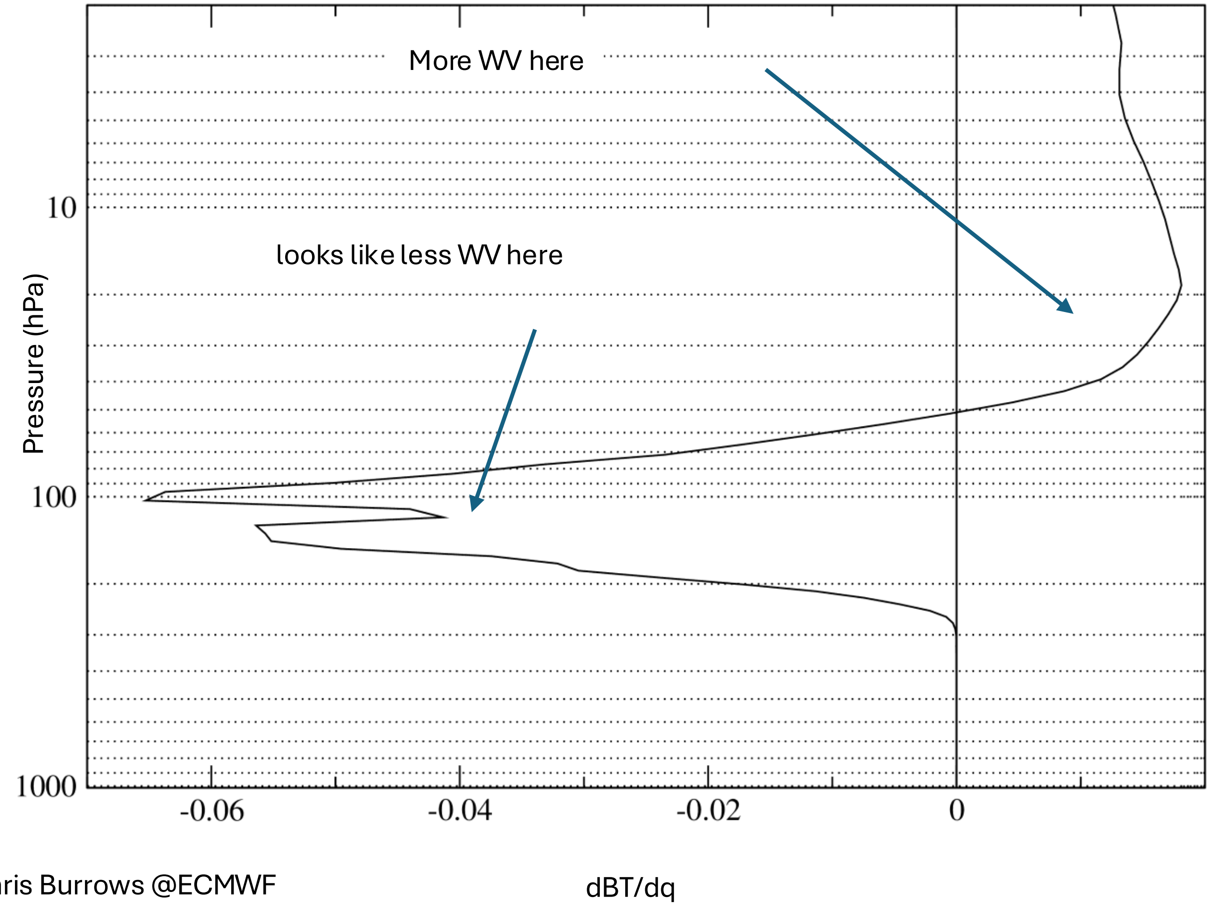
- <u>moist bias is uncorrected by the assimilation</u>

- moist bias is due to transport (dynamics and parametrized turbulent mixing) across the tropopause

- similar across horizontal resolutions and no evidence yet that it is improved by vertical resolution

Stratospheric humidity analysis turned OFF

Water vapor (WV) Jacobian for one of the infrared satellite radiance channels, which is sensitive to water vapour



Chris Burrows @ECMWF

- There are no clean stratospheric WV channels – the sensitivity to stratospheric WV is in the tails of tropospheric WV channels
- Humidity-sensitive channels with peak sensitivity in the upper troposphere often have a long tail of sensitivity in the stratosphere, up to 1hPa, but the bias correction is performed mainly against the upper tropospheric model column
- This results in a **null space** where we could have multiple configurations of WV in the atmosphere which match the same measured radiance
- This could give systematic drift depending on the accumulated residual of bias corrections
- Small errors in the upper troposphere (UT) can significantly affect WV in the lower stratosphere (LS): 0.01% UT tendency $\Rightarrow$1% LS tendency
- Analysis increments forced to be zero above the tropopause to counteract the tendency to generate spurious WV increments in the stratosphere

Stratospheric humidity analysis turned ON

The current ECWMF data assimilation has no observations to control lower stratosphere humidity, so humidity background errors tapered to low values above the tropopause

$$J(\mathbf{x}) = \underbrace{(\mathbf{x}_b - \mathbf{x})^T \mathbf{B}^{-1} (\mathbf{x}_b - \mathbf{x})}_{J_b\text{: background constraint}} + \underbrace{[\mathbf{y} - \mathbf{h}(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{h}(\mathbf{x})]}_{J_o\text{: observation constraint}}$$

What happens if we turn the humidity background error on in the stratosphere?

CTL: Assimilation of operational data

+ Allow stratospheric humidity increments in 4D-Var
+ Extend the vertical usage of radiosonde RS41 WV up to 60 hPa
+ Assimilate EOS-Aura Microwave Limb Sounder (MLS) WV profiles

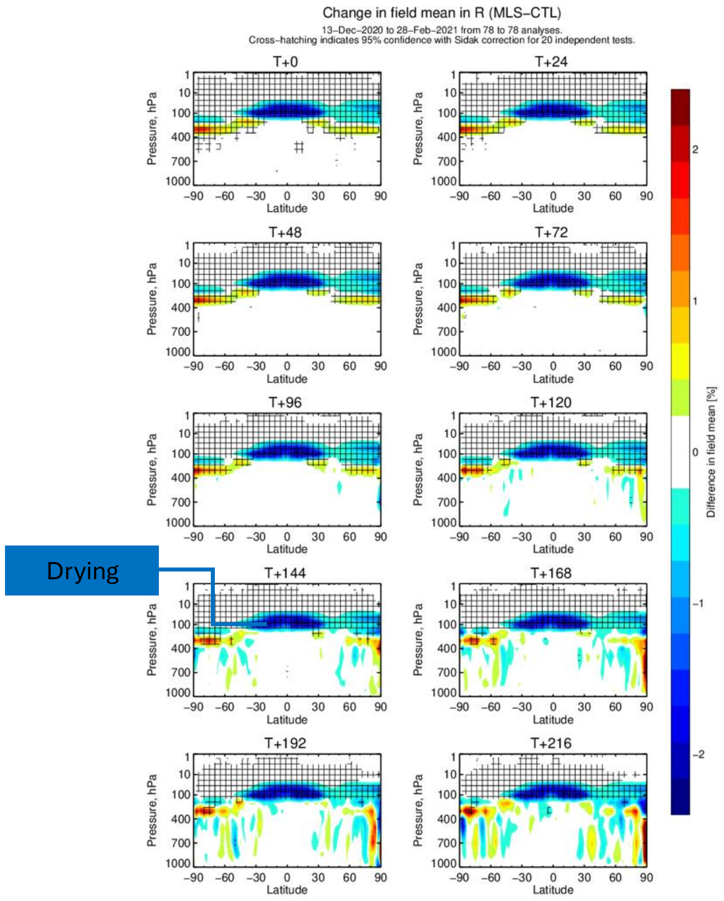
MLS: Stratospheric WV analysis + RS41 + MLS

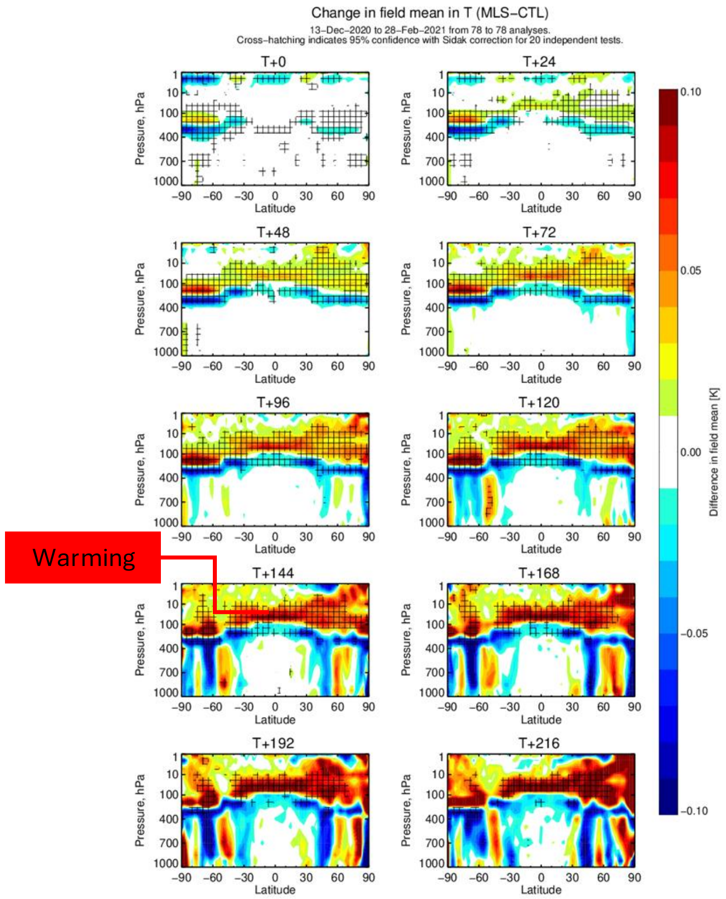
Longname:	MLS/Aura Level 2 Water Vapor (H2O) Mixing Ratio V005
DOI:	10.5067/Aura/MLS/DATA2508
Version:	005
Format:	HDF-EOS5
Spatial Coverage:	-180.0,-82.0,180.0,82.0

Data Resolution

Spatial:	165 km x 3 km
Vertical:	1.5 - 6 km
Temporal:	1 day

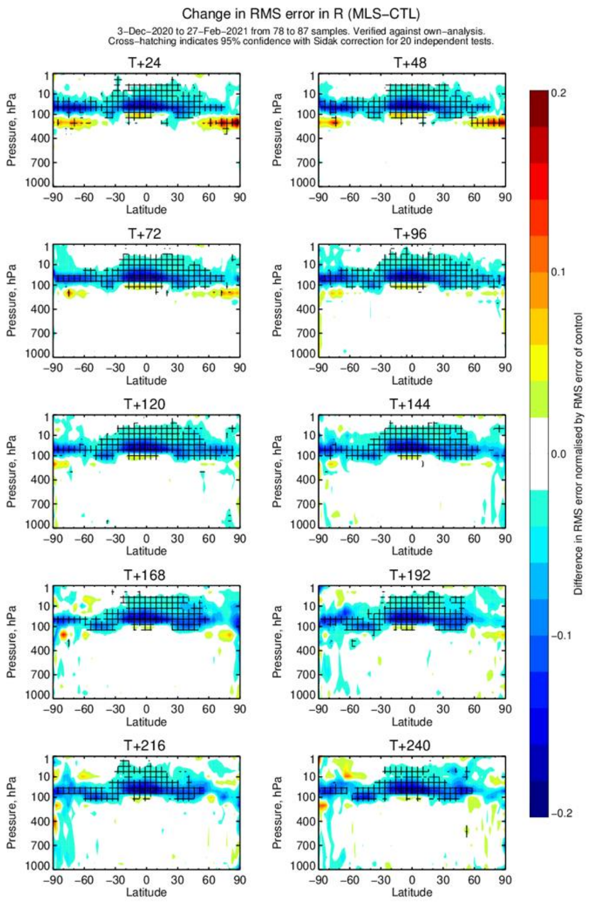
Stratospheric humidity analysis turned ON

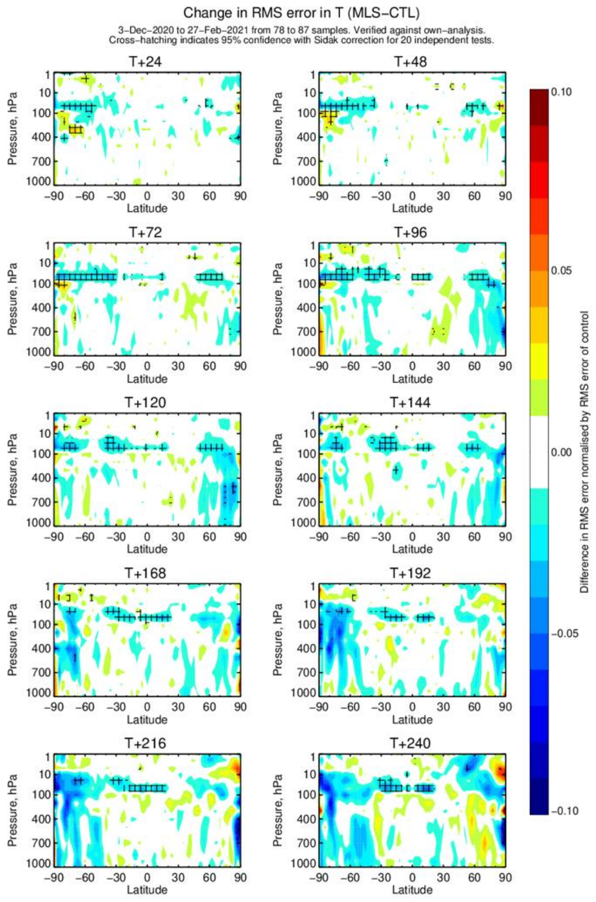




Change in the field mean in R & T based on 3 months of experimentation. Cross-hatched regions are statistically significant at 95%.

Forecast scores





Normalised change in root-mean-square error (RMSE), in the ***stratospheric WV + RS41 + MLS experiment*** *compared to the control, of T & R forecasts, verified against own analysis, and based on 3 months of experimentation. Blue cross-hatched areas indicate a significant reduction in forecast error and hence an improvement in forecast quality.*

Conclusion

What happens if we turn humidity analysis on in the stratosphere?

- The analysis of stratospheric humidity provides an additional source of predictability

- Implications for extended-range forecasting and reanalysis are expected to be significant

Weak constraint 4D-Var

Add an error term η in the model equation

$$x_k = \mathcal{M}_k(x_{k-1}) + \eta \quad \text{for } k = 1, 2, \cdots, K$$

Introduce additional controls to target an unbiased analysis and to move the assimilation away from a perfect-model trajectory

$$\begin{aligned} J(x_0, \beta, \eta) \quad = \quad & \frac{1}{2}(x_0 - x_b)^T \mathbf{B}^{-1}(x_0 - x_b) \\ + \quad & \frac{1}{2}\sum_{k=0}^{K}[y_k - \mathcal{H}(x_k) - b(x_k, \beta)]^T \mathbf{R}_k^{-1}[y_k - \mathcal{H}(x_k) - b(x_k, \beta)] \\ + \quad & \frac{1}{2}(\beta - \beta_b)^T \mathbf{B}_\beta{}^{-1}(\beta - \beta_b) \\ + \quad & \frac{1}{2}(\eta - \eta_b)^T \mathbf{Q}^{-1}(\eta - \eta_b) \end{aligned}$$

Model initial condition

Observation bias parameters

Model error

→ Introduce additional degrees of freedom to fit background and observations

→ The model error represents the systematic error which develops in the model over the assimilation window

→ The model error covariance matrix **Q** constrains the model error field