EnKF and 4D-Var Data Assimilation with Chemistry Transport Model

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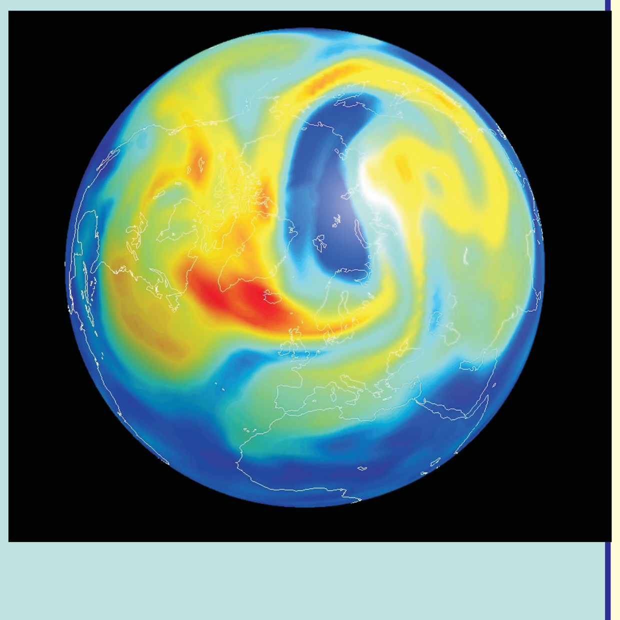
Abstract

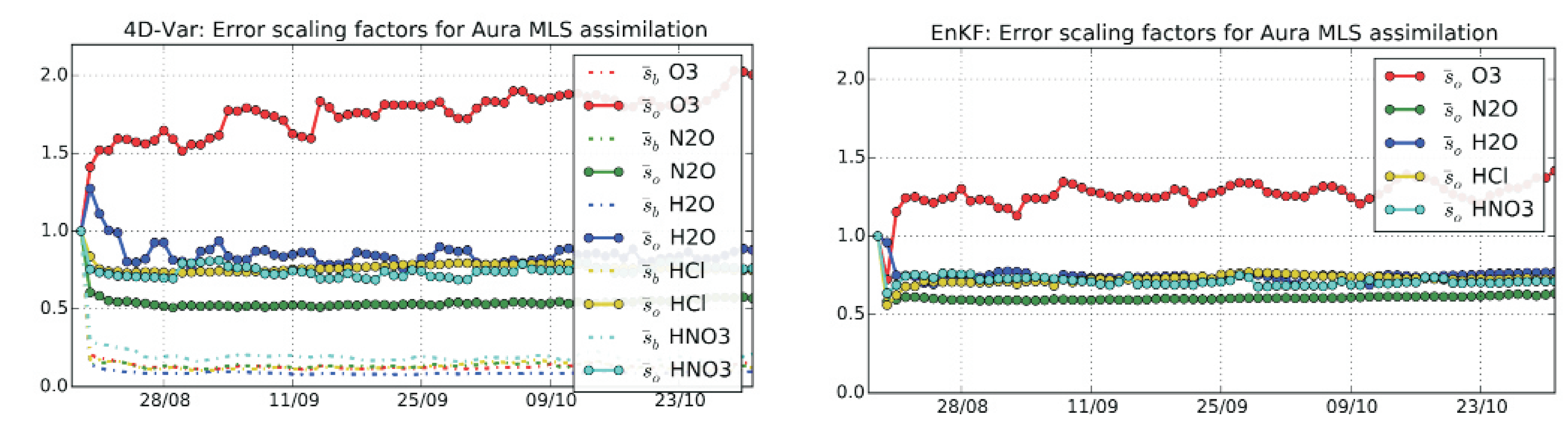
We compare two optimized chemical data assimilation systems, the ensemble Kalman filter (EnKF) and the 4D-Var, using a comprehensive stratospheric chemistry transport model (CTM) of the Belgian Assimilation System for Chemical ObsErvations (BASCOE). A strict comparison of both methods in the case of chemical tracer transport indicates that both methods provide essentially similar results. In the present work, we assimilate observations of ozone, HCl, HNO3, H2O and N2O from EOS Aura-MLS data into the BASCOE CTM with chemistry. Two new issues related to the use of full chemistry model with EnKF are taken into account. One issue is a large number of error variance parameters that need to be optimized. We estimate an observation error variance parameter as function of pressure level for each observed species using the Desroziers' method. For comparison purposes, we apply the same estimation in the 4D-Var data assimilation, where scale factors of both the background and observation error covariance matrices are estimated using the Desroziers' method.

The second issue in EnKF, the background error covariance is modelled with an adjustable parameter using chi2. We found that it is adequate to have the same value of this parameter based on the chemical tracer formulation that is applied for all observed species. This is an indication that the main source of model error in chemical transport model is due to the transport. The second issue in EnKF with comprehensive atmospheric chemistry models is the noise in the cross-covariance between species, that occurs when species are weakly chemically related at the same location. These errors need to be filtered out, in addition to a localization based on distance. The performance of two data assimilation methods was assessed through an eight-month long assimilation of limb sounding observations from EOS Aura-MLS. We discuss the differences in results and their relation to stratospheric chemical processes. Generally speaking, EnKF and 4D-Var provide results of comparable quality but differ substantially in presence of model error or observation biases. If the erroneous chemical modelling is associated with moderately fast chemical processes, but whose life-times are longer than the model time step,then EnKF performs better, while 4D-Var develops spurious increments in the chemically related species. If, on the other hand, the observation biases are significant, then 4D-Var is more robust and is able to reject erroneous observations, while EnKF does not.



Set-up of EnKF and 4D-Var:

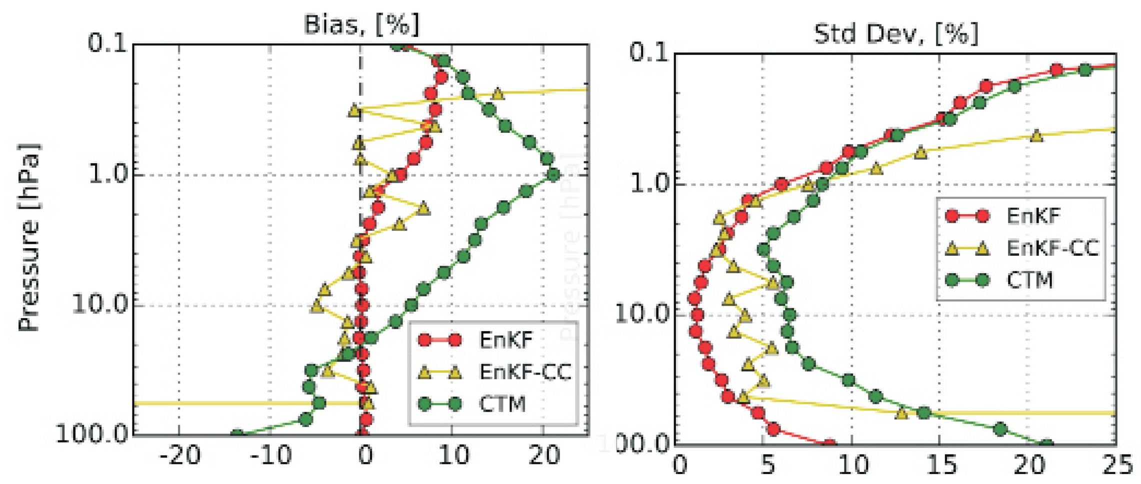
- common model:
  - 58 chemical stratospheric speices, 208 reactions
  - ERA-Interim thermodynamical forcing
  - 3.75 degrees longitude x 2.5 degrees latitude x 60 ERA-Interim vert.levels
- identical observations, obs.operator, BgQC
- EOS Aura-MLS O3, N2O, H2O, HNO3, HCl vertical profiles are assimilated
- ACEFTS N2O data are used for validation
- MIPAS IMK CH4 and NOx data are used for validation
- similar initial background error covariance matrix using homogenious and isotropic spatial correlations computed in the spectral space
- Desroziers ' estimation of obs.error and background covariance for 4D-Var
- Desroziers ' estimation of obs.error covariance for EnKF
- 4D-Var 24h assimilation window
- 0.5h ensemble forecast for EnKF
- fixed background error covariance for 4D-Var within its assimilation window of 24h
- EnKF background error covariance matrix is computed using ensemble perturbations, evolving in time
- EnKF scheme with perturbed observations
- Small ensemble N = 20 members
- 4DVar: 10 direct and 10 adjoint model simulations



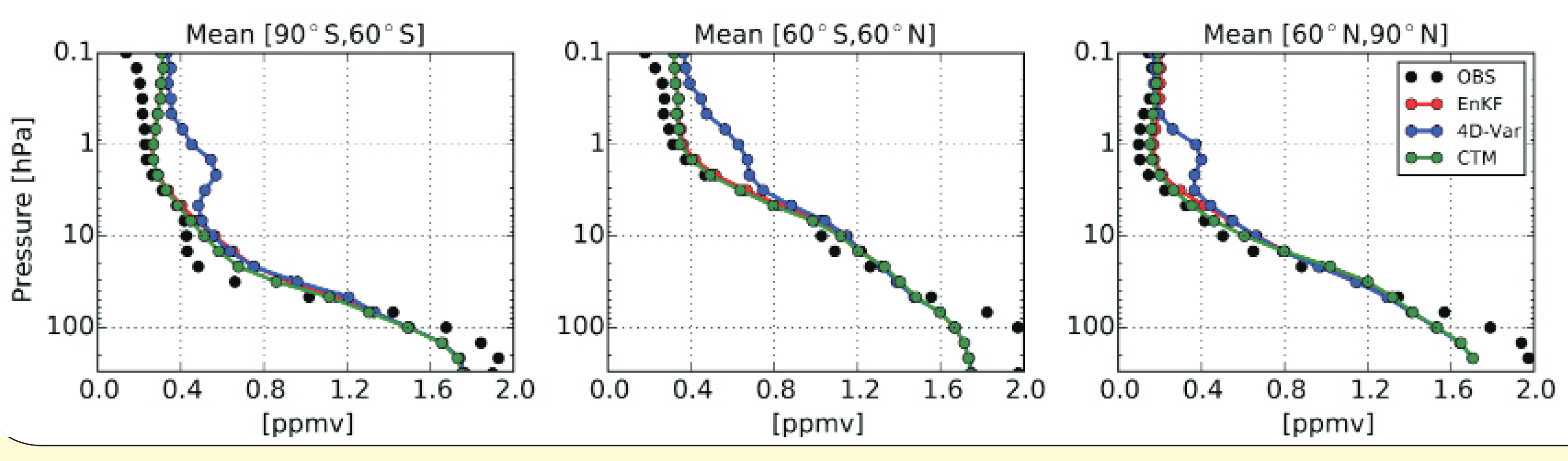
Desroziers ' method estimated background and observation error covariance scale factors for 4D-Var (left) and observation error covariance scale facor for EnKF (right) for the period April-November 2008.

Cross-species correlations

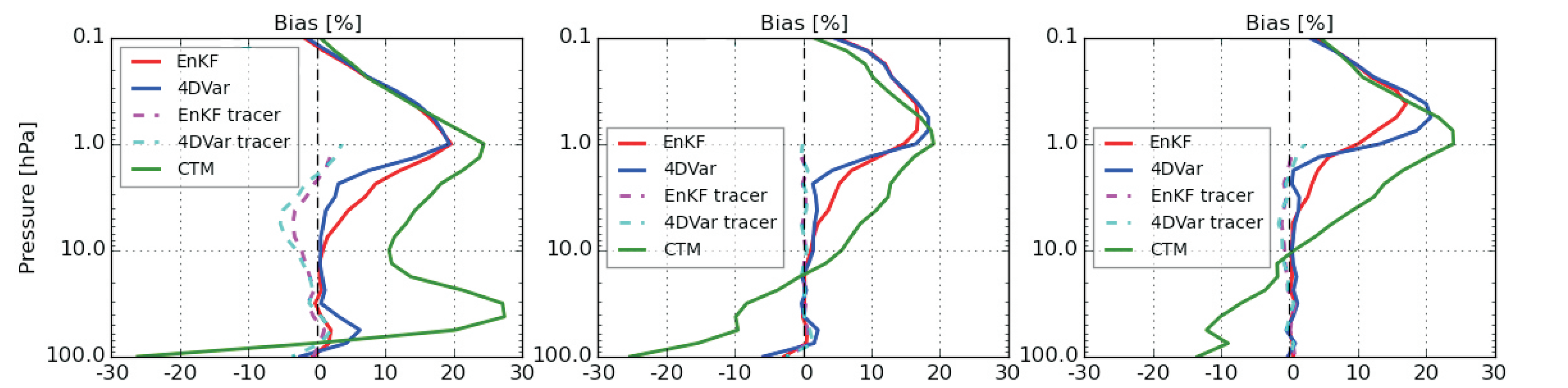
OmF bias and standard deviation between Aura MLS data and O3 analyses of EnKF with no cross-species correlations(red), EnKF with cross-species correlations (yellow) and CTM (green)



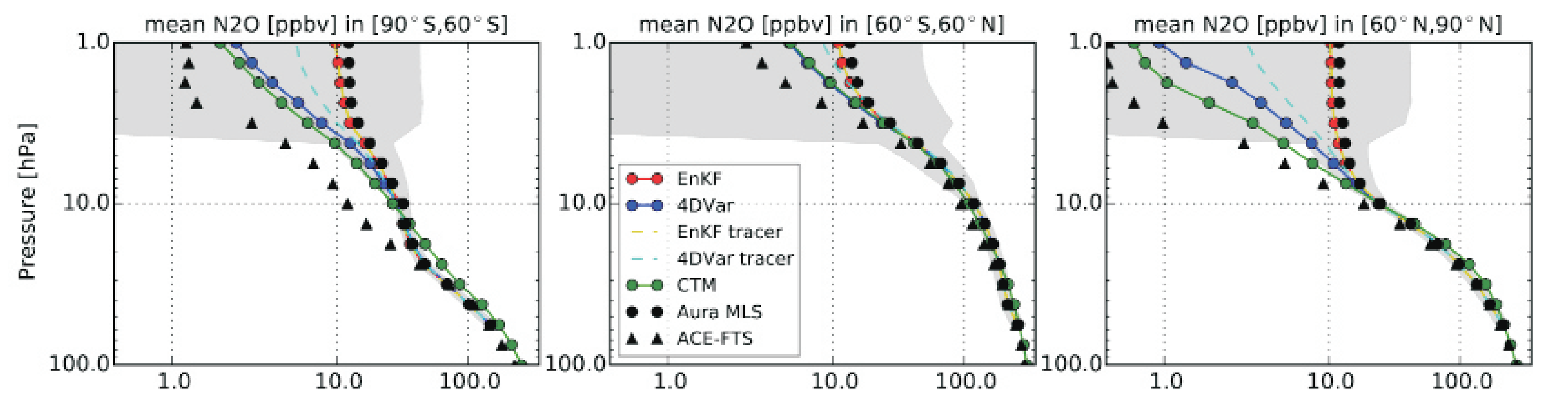
Impact on non-observed species: methane example



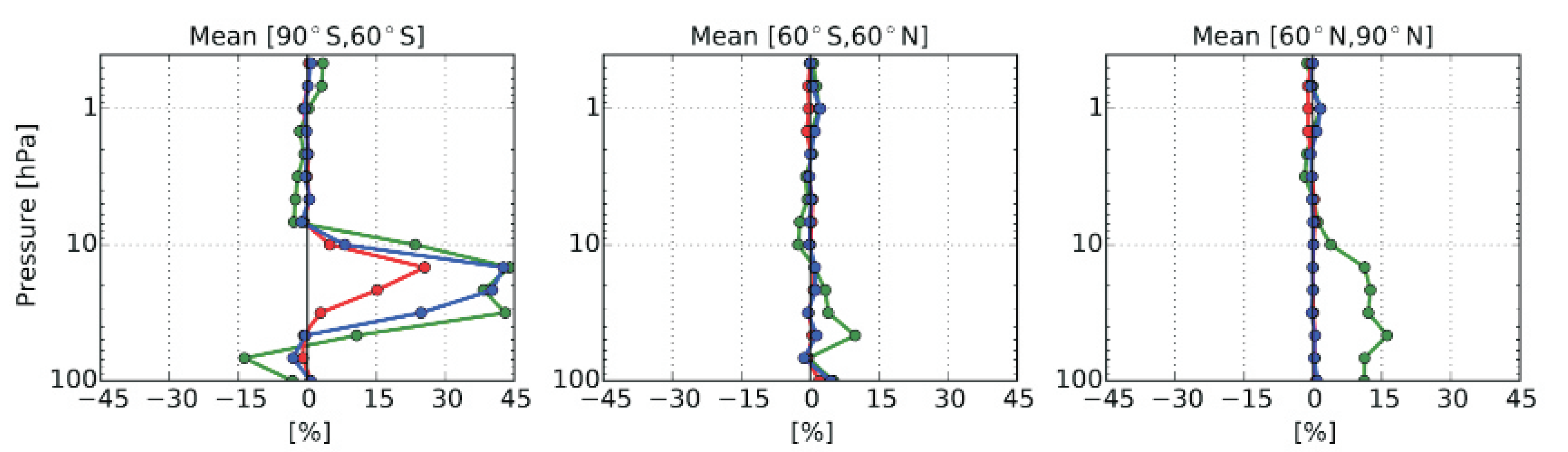
Results



Ozone OmF bias computed for the CTM (green), EnKF (red), 4D-Var (blue) based on the same model. The chemical tracer EnKF (dashed yellow) and 4D-Var (cyan) are also shown. OmF statistics is computed in percent with respect to the assimilated EOS Aura MLS data for the period September-October 2008 for the South Pole, Middle latitudes and the North Pole region(from left to right).



Mean N2O from CTM (green), 24 h forecasts from EnKF (red) and 4D-Var (blue), based on the same model, and Aura MLS (black dots)and ACE-FTS data (triangles).24 h forecast from chemical tracer EnKF (dashed yellow) and 4D-Var (cyan) assimilation are also shown.The grey area shows the precision of Aura MLS data. The statistics are computed for September-October 2008.



HCl OmF bias computed for the full chemistry CTM (green), EnKF (red) and 4D-Var (blue) OmF statistics is computed in percent with respect to the assimilated EOS Aura MLS data for the period May-June 2008.

Conclusions

1) Generally, both systems show similar performance
2) Differences do occur in the presence of a model or observation bias. EnKF handles better the model bias whereas 4D-Var, the observational bias.

Reference:

Skachko, S., Menard, R., Errera, Q., Christophe, Y., and Chabrillat, S.: EnKF and 4D-Var Data Assimilation with a Chemistry Transport Model, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-95, 2016.

Skachko, S., Errera, Q., Ménard, R., Christophe, Y., and Chabrillat, S.: Comparison of the ensemble Kalman filter and 4D-Var assimilation methods using a stratospheric tracer transport model, Geosci. Model Dev., 7, 1451-1465, doi:10.5194/gmd-7-1451-2014, 2014.