All-sky microwave radiances assimilated with an ensemble Kalman filter

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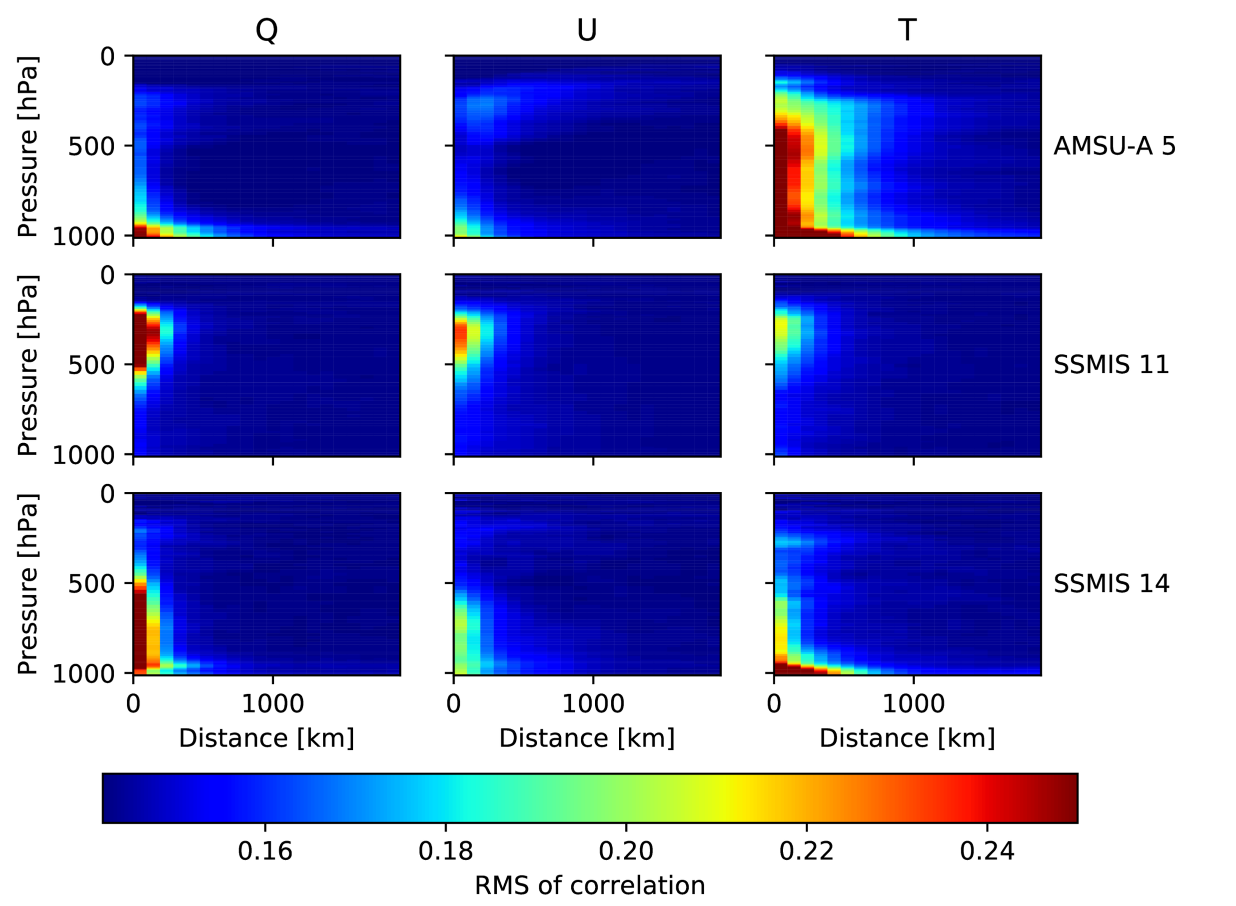
1. An ensemble Kalman filter version of the IFS, adapted for all-sky assimilation

This study compares the impact of all-sky assimilation in the EnKF and 4D-Var, using these configurations:

- The LETKF version of the IFS reported by Hamrud et al. (2015) updated to IFS cycle 42r1, with capability to assimilate all-sky observations, which were excluded in the original work. Most tests are run with 50 ensemble members.
- An adapted version of the IFS using 4D-Var with 3 inner loops and static background error covariances (rather than the normal ensemble-based errror covariances of the operational IFS, which is a hybrid-4D-Var system).

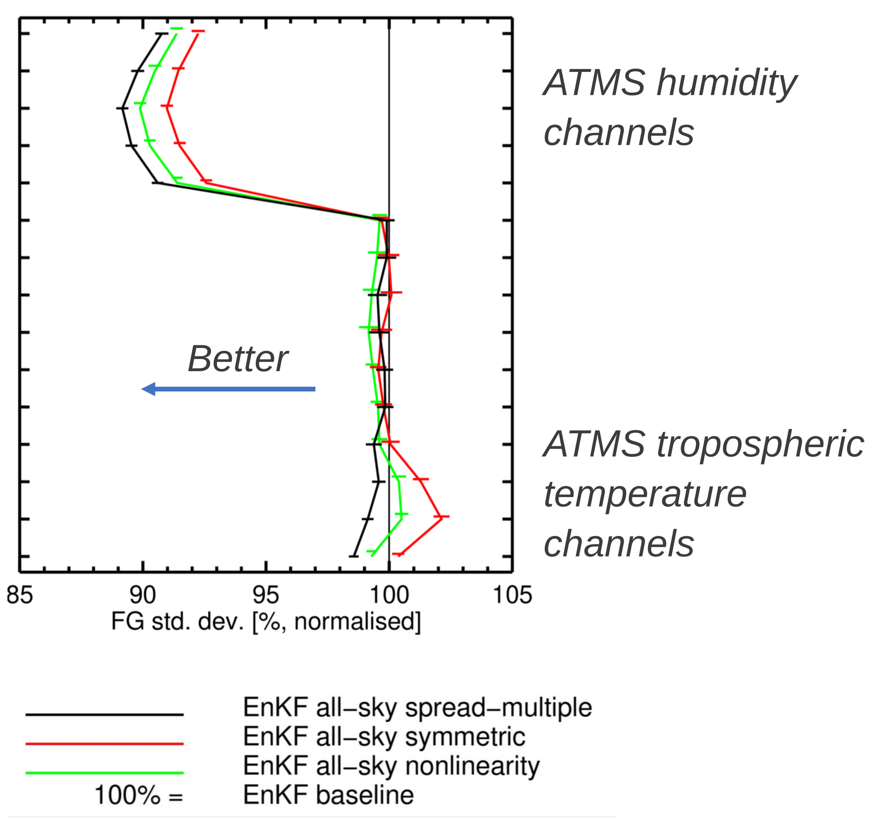
Both run at the same TCo319 resolution (approx. 39 km horizontal grid) with 137 vertical levels, and with 6-h analysis cycling.

The ensemble correlations (right) reveal the ability of the EnKF to infer dynamical information from clear-sky temperature sounding observations (top row) and all-sky humidity, cloud and precipitation observations (bottom two rows). Correlations with the all-sky humidity observations are on shorter horizontal and vertical scales than the deeper correlations from the temperature sounder. This is consistent with the need to reduce localisation lengths for the all-sky observations (not shown) which improved perfomance. Also, the all-sky observations are clearly a source of wind information.



RMS of correlations of the background forecast variables (columns: Q= specific humidity; U=zonal wind component; T=temperature) with observations from clear-sky AMSUA channel 5, all-sky SSMIS channels 11 and 14 (rows). Correlations represent the northern hemisphere (North of 20◦).

2. New all-sky observation error models for EnKF

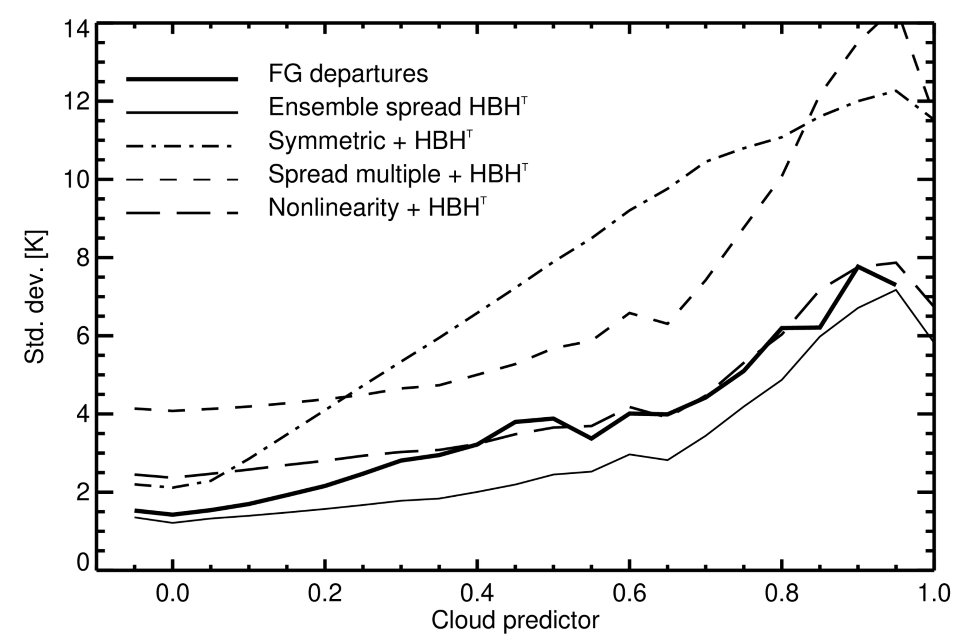


Normalised std. dev. of background departures (6 hour forecasts) from assimilated ATMS observations.

Three error models were tested (note that observation error correlations are not yet considered, only variances):

1. The normal 'symmetric' observation error model
2. A 'nonlinearity' approach based on the consistency, in observation space, between the ensemble mean and the unperturbed control forecast
3. A 'spread multiple' approach, i.e. a multiple of the prior spread in observation space, assuming that the major error in cloud and precipitation-affected observations is an error of representation and/or model error with similar characteristics to the background error.

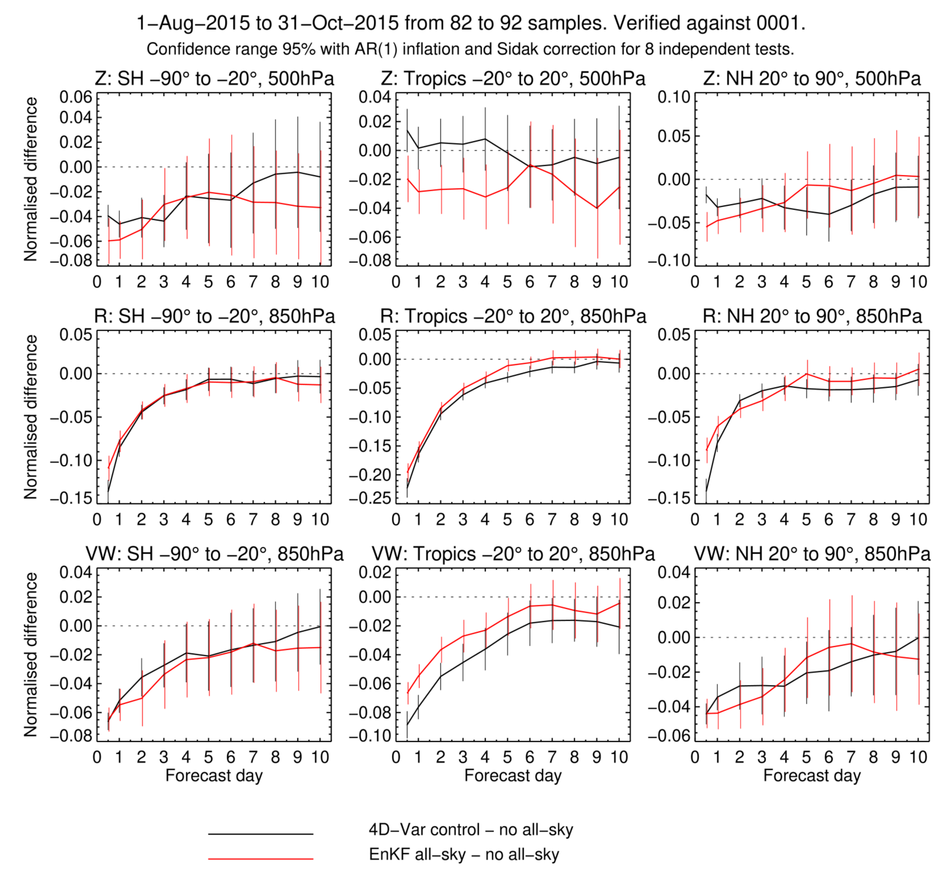
The key distinctions of these new error models compared to the symmetric approach are that (i) they do not rely on the observation at all, but only the background ensemble, to inflate the observation error in the presence of cloud; and (ii) they take account of the presence of cloud in any of the ensemble members, rather than just in the ensemble mean or control forecast (which is why the symmetric model, based on the average of cloud in the control and the observations, works badly here).



Standard deviation of the ensemble departures, background spread, and total error models, binned as a function of cloud proxy variable computed from the control member : SSMIS F-17 channel 11 (183±1 GHz)

3. All-sky assimilation has similar impact in EnKF and (static) 4D-Var

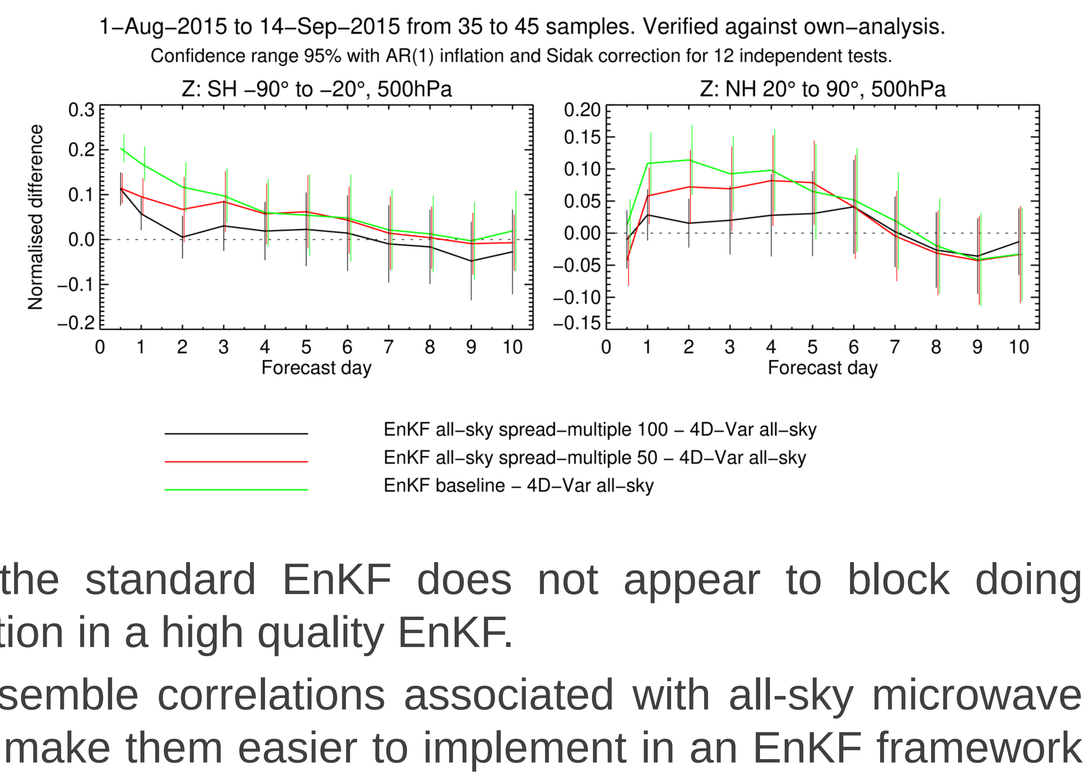
The impact of adding 8 all-sky sensors, globally over ocean, sea-ice and land scenes, was tested in both the EnKF and 4D-var systems, in the context of the otherwise full observing system. The sensors activated were SSMIS F-17, F-18, GMI, AMSR2, and four MHS from NOAA and Metop platforms.



Impact of all-sky assimilation in 4D-Var and LETKF configurations, using the spread-multiple error model and 50 members in the case of the LETKF run. Results use the operational 4D-Var analysis as the verification reference in each case. Negative changes indicate an error reduction, and mean that all-sky assimilation is beneficial.

4. With 100 members and all-sky assimilation, EnKF approaches static 4D-Var in troposphere

Adding all-sky assimilation does not change the conclusions of Hamrud et al. (2015): in the troposphere, the 50-member EnKF is still around 5%–10% worse than 4D-Var. A further, bigger improvement in the quality of the EnKF, comes from increasing the ensemble size from 50 to 100 members, bringing the EnKF to within 2% to 5% of the 4D-Var performance in the troposphere, but in the stratosphere (not shown) the agreement is much worse.



Normalised change in RMS error in the southern extra-tropics (left panel) and northern extra-tropics (right panel) of the 500 hPa geopotential forecast for EnKF experiments with respect to the all-sky 4D-Var experiment. Values above the zero line indicate worse performance with respect to 4D-Var..

5. Conclusions

We wanted to understand whether the assimilation of all-sky observations might challenge the linear and Gaussian restrictions of the pure ensemble approach, given the ability of incremental 4D-Var to make use of non-linear and non-Gaussian observations is considered a major advantage for all-sky assimilation.

- The increments generated from all-sky observations had similar patterns in the EnKF and in 4D-Var with correlations between them of around 0.3 in temperature, divergence and vorticity, and around 0.4 to 0.5 in specific humidity (not shown).
- The impact of adding all-sky observations on medium range forecast errors was around 2% – 4% in both EnKF and 4D-Var (consistent with results at the full operational 4D-Var resolution, Geer et al., 2017).
- The generation of wind increments confirms the expectation from other studies that show an EnKF is also perfectly capable of generating wind tracing from constituents like water vapour and also from cloud and precipitation observations.
- The ensemble correlations in the EnKF reveal the unique information content brought by all-sky microwave observations, particularly their strong indirect sensitivity to the wind field.
- The linearity inherent in the standard EnKF does not appear to block doing successful all-sky assimilation in a high quality EnKF.
- The relatively compact ensemble correlations associated with all-sky microwave observations may actually make them easier to implement in an EnKF framework than broader-based temperature-sounding observations.

Cautions:

- Cycling the assimilation every 6 hours (instead of the customary 12 hours used at ECMWF) has likely reduced the impact of nonlinearities and non-Gaussian effects in our experiments.
- Here we have compared EnKF to 4D-Var with a static (i.e. climatological) background error covariance. In practice, typical operational ensemble and 4D-Var systems use hybrid configurations, so it is hard to extrapolate our results to these operational configurations.

Further reading:

- Bonavita, Geer and Hamrud (2020, submitted to MWR, preprint will be available soon as an ECMWF tech. memo.)
- Hamrud, Bonavita and Isaksen (2015, MWR): "EnKF and hybrid gain ensemble data assimilation. Part I: EnKF implementation"
- Geer et al. (2017, QJRMetSoc): "The growing impact of satellite observations sensitive to humidity, cloud and precipitation"