SPECIAL PROJECT:

“Assimilation of geostationary ozone measurements for global ozone monitoring”

Project duration: Oct 2006- Oct 2009

FINAL REPORT

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Abstract

Ozone retrievals from geo-stationary SEVIRI IR measurements (with decreased spatial resolution) are assimilated with the ECMWF 4D-Var with the aim to improve lower-stratospheric ozone field estimates. After optimizing quality criteria, the bias of the observations against the model had been found to be intrinsically linked to the retrieval characteristics. A variable top-hat function has to be introduced as an observation operator to remedy this effect. Subsequent SEVIRI ozone assimilation resulted in an improvement of up to 20% for ozone forecast skills in the lower stratosphere in a latitude band of 10-30 S, only. The effect on the wind fields were found small (up to 2%). Globally averaged, both effects on winds and ozone forecast skills were negative. We conclude the assimilation methodology needs to be developed to make full use of the information content of the SEVIRI ozone observations.

1. Introduction

The idea of the proposal is to investigate the usefulness of assimilating SEVIRI ozone retrievals into NWP models. One aim is to improve the modelled stratospheric ozone fields. A second aim is to use 4D-Var assimilation to possibly exploit the tracer information of the stratospheric ozone (see e.g., *Riishojgaard, 1996* and *Peuch et al., 2000*). If NWP models could make positive use of this tracer information, then the wind fields should be improved. The measures of success are the forecast skills (ACC) and the comparisons of the SEVIRI data to independent data.

2. Data

Partial columns (covering 353-29 hPa) of stratospheric ozone have been retrieved from the SEVIRI IR 9.7 µm measurements of geostationary satellite MSG (*Siddans et al., 2007*), see an example retrieval field in Fig.1. In order to assimilate SEVIRI observation into the ECMWF model we had to re-sample our SEVIRI ozone partial columns at a spatial resolution of 0.5 x 0.5 degrees, a resolution similar to that of the T159 model used. This choice also makes the measurement’s random noise smaller, thereby increasing the observation signal-to-noise ratio. A hourly observation frequency was chosen as a compromise between high revisitation rate and availability of computational resources.

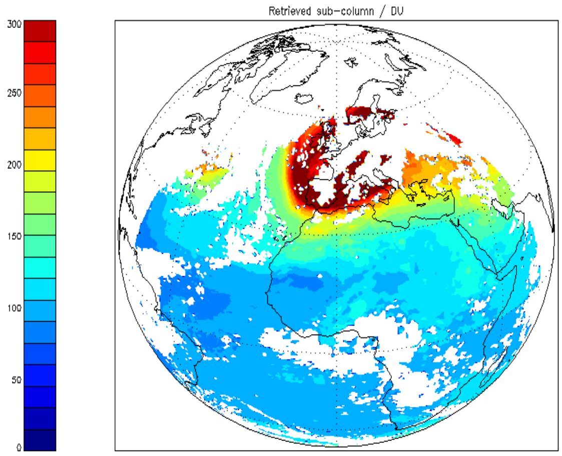

Fig.1: An example of the partial ozone columns (353-29hPa) in Dobson units [DU] as retrieved from the SEVIRI IR 9.7 µm measurements 11 UTC on 21 Feb 2006.

3. Data assimilation experiments

We used the data assimilation system implemented at ECMWF that uses revised coefficients (version 2.3) for the linearised ozone chemistry scheme, supplied by Daniel Cariolle (CERFACS). The assimilation includes standard meteorological observations (e.g., sonde, aircraft, satellite data) and ozone satellite data (total column from Sciamachy and partial column from NOAA-16 SBUV/2). Experiments were performed with the IFS cycle 31R1 (which was operational at ECMWF until September 2006) and later moved to the upgraded IFS cycle 32R3. For each "active" SEVIRI assimilation experiment, we also run a corresponding "passive" experiment (where SEVIRI ozone retrievals are compared against the model but are not assimilated. i.e., do not influence the ozone analysis or the meteorological analysis). Several assimilation experiments have been carried out to fine-tune quality control and bias correction procedures.

4. Results

4.1 Bias removal

From a study of the innovations as a function of the **number of cloudy observations** (cloud flagging was provided by RAL) within each 0.5 x 0.5 degree box we concluded that a suitable criterion was to assimilate only re-sampled SEVIRI data with at least 50 % of the original observations considered to be cloud-free in the 0.5 x 0.5 degree box. In this way, the largest biases, both negative and positive, were suppressed, especially around the periphery of the field of view. With this choice we experience a significant reduction of the amount of data for assimilation (about 2/3 of data flagged as rejected)

Another important influence on bias was the **shape of the ozone profile**. A comparison between the partial ozone columns of the SEVIRI data and integrated partial ozone columns derived from the ozonesondes of central Europe stations (Payerne, Praha and Legionowo) shows an average departure of about 20 DU, which is of the order of the mean innovation over the same locations, showing that the model ozone profiles are realistic. The shape of the ozone profile has a latitudal bias dependency, but also varies with longitude, following the total ozone distribution (when the latter is not symmetric in longitude). Thus any biases caused by the shape of the ozone profile (or the deviation of the actual ozone profile from the assumed *a priori* in the retrieval) also have flow dependent characteristics.

To illustrate where this bias is coming from, we consider the sensitivity of the SEVIRI retrieval as a function of height (see lines with stars in Fig.2). We use the averaging kernel to assess at which heights the variations in the true ozone have an impact on the retrieval result. These averaging kernels (i.e., "SEVIRI sensitivity") vary strongly with temperature and vertical ozone distribution (i.e., with latitude), and peak at lower levels in higher latitudes (see Fig. 2 left).

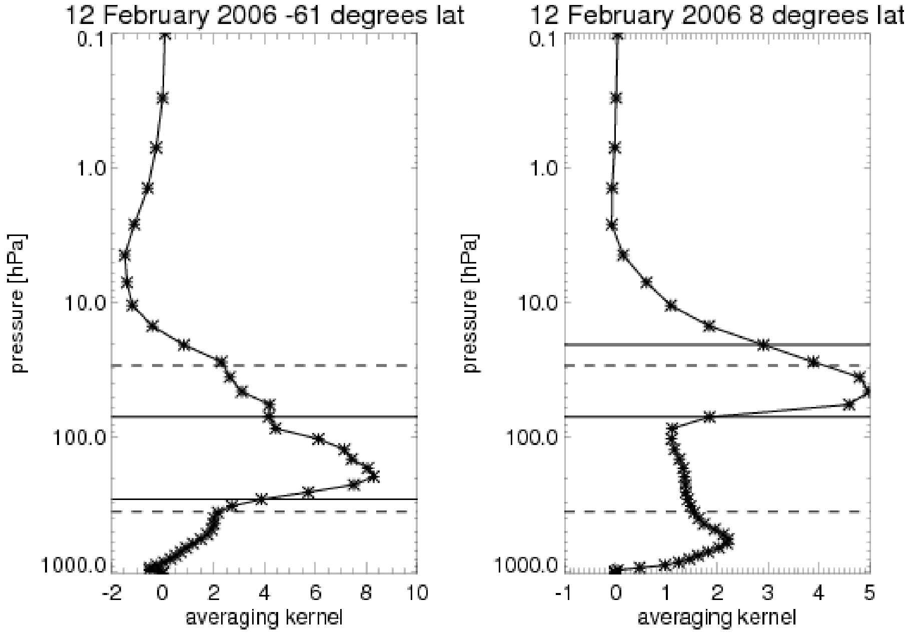

Fig. 2: Example for fixed observation operator (dashed lines), applied variable (solid) and actual averaging kernel (stars). for two SEVIRI observations at -61 degree latitude (left panel) and at 8 degree latitude (right panel) acquired on 12 February 2006. The figure shows the typical latitude dependent variability in the kernels, which is due to the ozone profile and temperature change with latitude.

The shape of the averaging kernel was used to derive the appropriate observation operator (modelled as a top-hat function) for each SEVIRI observation individually. The non-zero segment of the observation operator was defined as the full-width at half maximum (FWHM) of the respective SEVIRI averaging kernel, with the pressure interval defined by the highest and the lowest pressure thresholds relating to the half maximum of the kernel, represented by the solid horizontal lines for the example shown in Fig. 2. The geographical distribution of lower and upper pressure threshold, which indicate the lower and upper bounds of SEVIRI sensitivity, respectively, showed the expected latitudinal dependency and also a wave-like pattern which is also present in the total ozone field. A band-like pattern is caused by changes in prior information used for SEVIRI retrievals over these bands.

With an individual sub-column range for each observation, the SEVIRI partial ozone column was recalculated by integrating the appropriate ozone profile provided by RAL between the two retrieval pressure levels more closely representing the FWHM of the retrieval averaging kernel. This variable observation operator (variable top-hat function according to the kernels, see solid lines in Fig. 2) and an amended quality control (cloud masking, land-sea masking, threshold for averaging kernel values) lead to a decrease in the flow dependency of the bias. Note that in Fig. 3 (left) some bias remains, which is dependent on the kernel-based quality criteria (i.e., thresholds for the averaging kernel peak values) for data rejection. However, we conclude that the issue should be addressed with a modified assimilation methodology rather than tweaking the quality criteria parameters. This leads to our follow-on ECMWF special project “Assimilation of trace gas retrievals using quasi-optimal assimilation”.

The following quality control checks were applied to the data: The retrieval cost function has to be less than 10, the temperature difference between the channels has to be less than 20 K and convergence of the retrieval is required. The cloud fraction is required to be less than 50%. The number of cloud free pixels is set to be more than 180 (note this removes high latitude measurements which might conceal problems in high-latitude data); Untypical kernels are excluded (sub-column must not extend beyond the upper troposphere, lower stratosphere and middle stratosphere). This quality control reduces the original number of about 60000 data points per hour to about 8000 per hour, equivalent to a data reduction by about 87%.

After masking clouds and land, and using the variable sub-column, an innovation bias still remains. As the observations for assimilation need to be unbiased, we consequently subtracted a constant ozone partial column value of 10.75 DU, calculated from the mean innovation bias over the first week of the passive assimilation.

The magnitude of the residual innovation bias after the subtraction of the 10.75 DU is about 5 DU. In order to accommodate for this residual bias we interpret it as being the effect of a systematic error of the observations that is additional to the standard SEVIRI random error estimated along with the retrieval. The time dependency of the bias matches the seasonal change in ozone (which is growing in the lower stratosphere during February and March), and a jump in bias at the beginning of March is suspected to be connected to the different a priori profiles used in the retrieval.

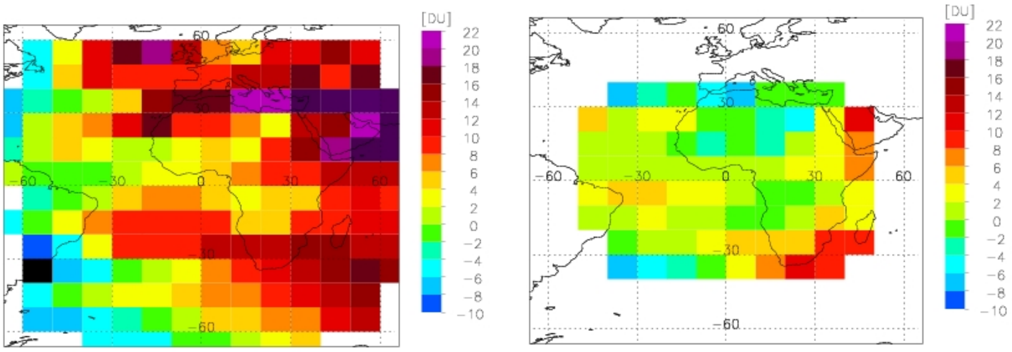

Fig. 3: The bias resulting from the original approach **(left)** has been reduced significantly **(right)** by using a variable top-hat function for the vertical observation operator and an amended quality control.

4.2 Ozone influence on wind fields

For the purpose of identifying the influence of SEVIRI ozone assimilation on the analysed wind fields, we use our best estimate for bias, removed the bias from the data, and run an active assimilation experiment and a corresponding passive one. The period studied was from 10 February 2006 0 UTC to 10 March 2006 21 UTC, the ECMWF IFS Cycle 32r3 was used with resolution T159L60.

The 4D-Var assimilation of SEVIRI ozone had an effect, albeit a small one, on the resulting wind fields. Especially in the tropical area of field of view of SEVIRI, a change of up to 5 m/sec can be observed, which correspond to a few percent in zonal wind speed (see Fig.4).

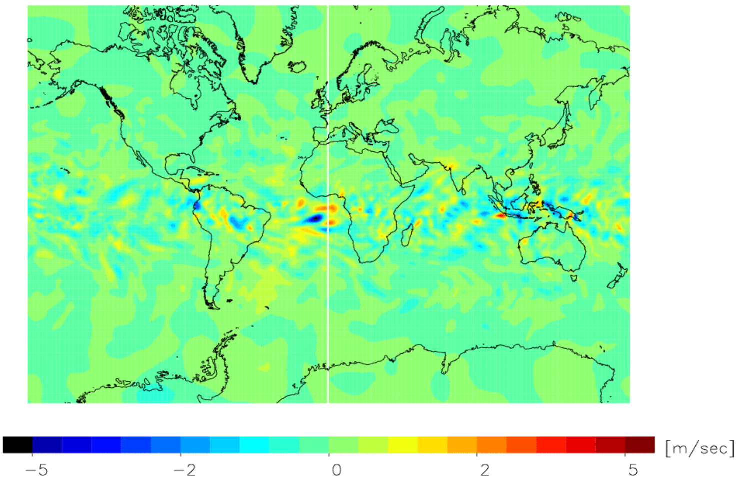

Fig.4: Zonal wind difference (active minus passive) on 20060227 at 150 hPa, showing our typical result: small changes in winds in the tropics, strongest within the SEVIRI disk, but also propagating around the globe.

The forecast skill has been measured by calculating the Anomaly Correlation Coefficient (ACC) with respect to ozone, zonal wind and meridional wind fields. The meridional means have been calculated for different heights, thus allowing to investigate differences in the vertical. Most of the Northern Hemisphere is well determined (note that the ACC is close to 1 for ozone in Fig. 5, and also for zonal winds the ACC is relatively near to 1 in Fig. 6.). In the Southern Hemisphere, at the region between 10°S and 40°S,and between 500 and 100 hPa, the forecast has no skill. It is the region where SEVIRI measurements are sensitive to, and indeed the active SEVIRI assimilation comes with an increased forecast skill (see the difference of active to passive SEVIRI assimilation in Fig.5 (right).

The forecast skill has been traced over 5 forecast days (see Fig. 6) for the most prominent region of positive influence (20-30°S, 400-150 hPa) of SEVIRI assimilation. The improvement of forecast skill in this region is consistent over time, and increasing with forecast length, reaching 20% for ozone at forecast day 5. Note however, this is only valid for the most prominent region of positive influence, and the globally averaged influence is a small negative one. Nevertheless one could extend this study to identify the regions where SEVIRI is found useful, and blacklist all SEVIRI measurements in other regions. We do not pursue this idea now, as we feel that the approach outlined in *Migliorini et. al., 2008,* might be the best way forward.

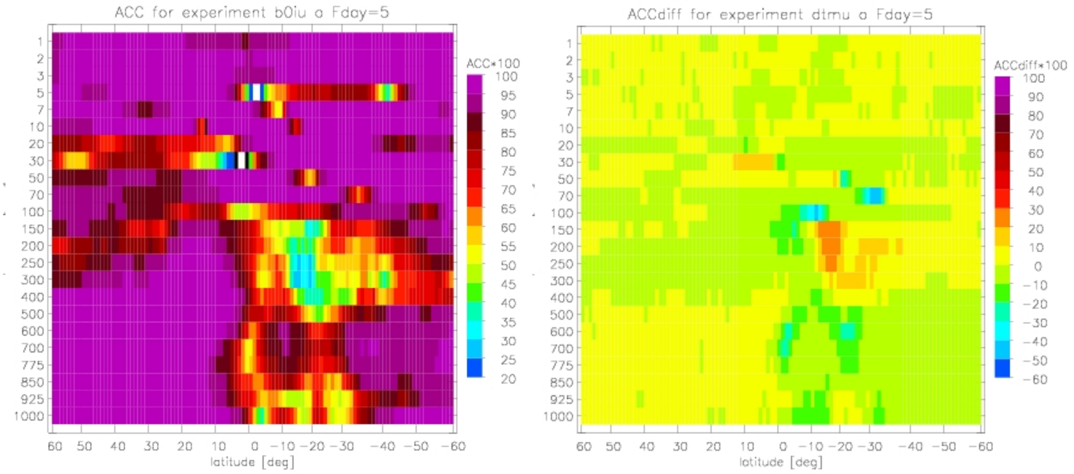

Fig. 5: Anomaly Correlation Coefficient (ACC) meridional mean (left) (right).

Although the regions of changed forecast skill for ozone (Fig. 5) match the regions of a changed forecast skill for the winds, the variations in forecast skills turn out to be both positive and negative influences in the Southern Hemisphere (see Fig. 6).

To give an idea about the magnitude of the influence on wind fields, see Fig. 7 (left) where SEVIRI ozone assimilation contributes to about 2% of skill in the lower stratosphere/upper troposphere in the region where SEVIRI ozone assimilation was found beneficial for ozone(10-30 S, 300-150 hPa). Again we want to stress that this region shows not a typical skill gain (which is globally averaged even negative), but that this region is selected for the most positive influence. This positive effect on zonal winds could well be a random one, as the scattered structure of skill gain (Fig. 6, left) indicates. For the meridional winds, effects are even more scattered.

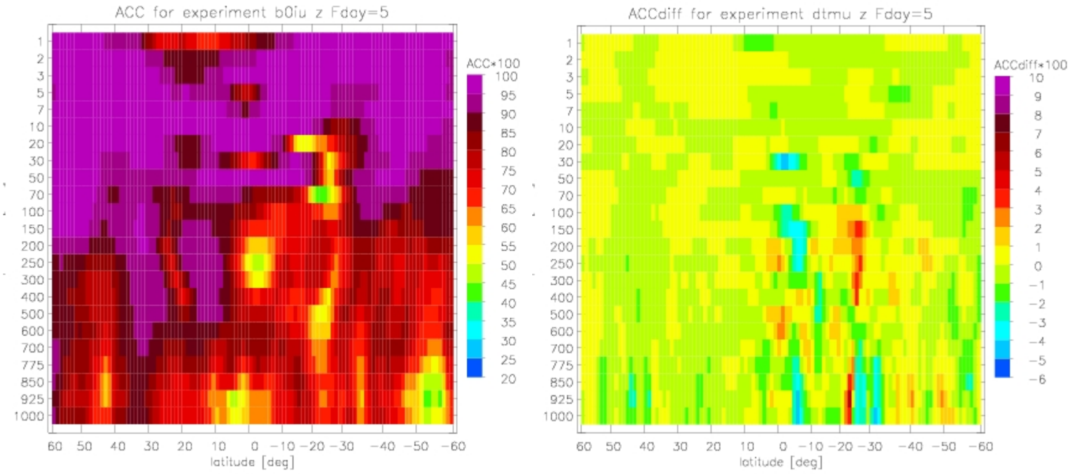

Fig. 6: Anomaly Correlation Coefficient (ACC) meridional mean (left) and the skill gain caused by SEVIRI ozone assimilation calculated as difference in skill between the active and the passive assimilation experiment (right).

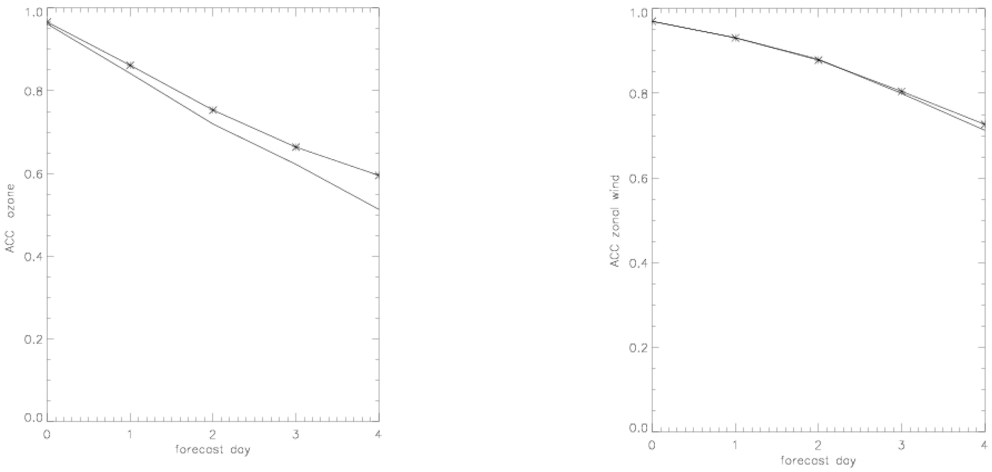

Fig. 7: Anomaly Correlation Coefficient (ACC) over time (forecast day 1 to 5) for ozone (left) and zonal winds (right) for the region of (10-30 S, 300-150 hPa).

5. Summary

From our 4D-Var assimilation experiments over the period between 10th February and 10th March 2006, the following conclusions can be drawn:

1. An indication has been found that assimilation of SEVIRI ozone retrievals can improve the ozone fields over the Southern Hemisphere (increase in forecast skill up to 20% at forecast day 5), with a consequent improvement for the zonal wind fields (increase in forecast skill up to 2% at forecast day 5).
2. Although the global effect is a negative one (for both ozone and winds), the assimilation of SEVIRI ozone might be found beneficial when all the regions are blacklisted where SEVIRI has not sufficient quality or where better quality data are available.
3. The current version of ozone retrievals still presents a bias with respect to ECMWF ozone analyses. The bias has diurnal variability (including over the sea), depends on the ozone field, and depends on

latitude and longitude and on the month of the year (possibly induced by the prior information used within SEVIRI retrievals).

4. With the current use of a variable top-hat function as observation operator, which improves the bias compared to the use of a fixed top-hat function, still a lot of vertical information is lost.

Note that the tuning of quality control influences the results, and also the limited time studied is not sufficient for generalization.

Conclusions

The remaining bias is dependent on the kernel-based quality criteria for data rejection. However, we suggest developments in the assimilation methodology are needed rather than a tweaking of the quality criteria parameters. The assimilation of satellite retrievals we used is sub-optimal because averaging kernels, *a priori* information and full observation error co-variances are not used. To overcome this problem, the satellite retrievals have been transformed according to the method of Migliorini et al., 2008. This lead to our follow-on project "Assimilation of trace gas retrievals using quasi-optimal assimilation", where the data analysis presented here will be revisited after appropriate theoretical developments.

References

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