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Interactive Comment

Interactive comment on “The Assimilation of Envisat data (ASSET) project” *by* W. A. Lahoz et al.

W. A. Lahoz et al.

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We thank Ref. 1 for his/her constructive comments. This is our response:

General comments:

1. The full name of the ASSET project is “Assimilation of Envisat data”. Its focus was on the atmospheric chemistry instruments aboard Envisat, viz., GOMOS, MIPAS and SCIAMACHY. Within ASSET, more work was done with the MIPAS data as this was better characterized at an earlier stage during ASSET.

To clarify matters, we will explicitly state at the start of the Abstract and in paragraph 1 of the Introduction that our focus is Envisat data.

In section 2.1.2 we explain why only MIPAS temperature data are used. We will extend this approach to other sections and include a general comment in the Introduction.

The assimilation of OMI, MOPITT and GOME data is quite properly dealt in other parts

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of the literature. MIPAS also has higher vertical resolution (by virtue of being a limb sounder) compared to nadir sounding instruments like OMI, GOME and MOPITT, but if we were not focused on Envisat then EOS-MLS would provide similar capabilities.

2. The issue of whether sensors/retrievals perform differently over land and over the ocean is not addressed here, as to our knowledge it is not a problem for profiles from limb sounders such as GOMOS and MIPAS, or for profiles retrieved from SCIAMACHY.

There is no known bias in SCIAMACHY total column ozone with respect to land/ocean differences.

3. This use of English is standard in papers in the atmospheric sciences literature. However, we are happy to change the text to clarify matters. For example, in p. 12776-27 we could say: "For levels above 1 hPa"

Specific comments:

1. Level 1 data are routinely assimilated in an operational Numerical Weather Prediction context, but rarely in chemical data assimilation. We would be happy to add a comment in the Introduction with appropriate references.

2. No. Satellite is correct.

3. To clarify matters, we propose to change the text at line 12775-18 to: "and ECMWF systems. This is done by using a relative humidity-like control variable which is calculated using background, rather than analysed, temperature. The Met Office has"

4. Here, the difference between the methods used to calculate the background errors is less important than the moist control variable used to assimilate the humidity. We propose to leave the text as it is.

5. For clarity, we will add the line: "The observation operators transform variables from model space to observation space" in line 12775-27. The Kalnay reference in line 12772-5 is a useful source of information on data assimilation nomenclature.

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6. In our view, for people familiar with the stratosphere and mesosphere and the distribution of tracers such as water vapour in this height region, Fig. 1 should be reasonably clear. However, to clarify matters, we are happy to change the text in p. 12776-15-21 to:

“very dry tropical tropopause (near 100 hPa) and the dehydration within the Antarctic stratospheric winter vortex (between 100 hPa and 50 hPa). The stratospheric presence of a layer of dry (˜3 ppmv) air around the 100 to 200 hPa level is indicative that some of the air coming into the stratosphere in the tropics in quickly transported towards the pole at these levels. The water vapour distribution shows that there is rapid poleward transport of dry air from the tropical tropopause region to the polar lower stratosphere. There is also slow upward transport of dry air at low latitudes via the Brewer-Dobson circulation. As the air is transported upwards, methane oxidation leads to an increase in humidity, which is reflected in the relatively moist air seen in the upper stratosphere and lower mesosphere. Near the stratopause (near 1 hPa) there is an overturning of the stratospheric air because of a change in the pattern of the Brewer-Dobson circulation. The upward low latitude transport is replaced by poleward transport, and associated downward transport at high latitudes. Thus, at high latitudes there is downward transport of the moist air from the upper stratosphere / lower mesosphere to the mid stratosphere, most especially in the winter high latitudes, where this downward transport is stronger”.

The referee also queries what is “UTLS”. This acronym is defined in p. 12774-5.

7. It is difficult to generalize on the resolution required in EO data to reduce/eliminate problems from the assumption of no horizontal correlations. This depends, e.g., on the observation type. For stratospheric water vapour, where there is dehydration (e.g. at the vortex edge), a horizontal resolution which is as high as possible is required; elsewhere, the water vapour is determined by transport, so in the stratosphere a wavenumber-3 resolution may be enough.

Because of the difficulty to generalize on this point, we propose to not address directly the referee's comment.

However, we propose to make more precise the sentence in p.12777-10 as follows:

Replace "The lack of any horizontal error correlations in the BASCOE assimilation scheme appears not to be a problem due to the high spatial and temporal frequency of the MIPAS humidity data."

With: "The lack of any horizontal error correlations in the BASCOE assimilation scheme appears not to be a problem because the MIPAS daily coverage is comparable to the BASCOE horizontal resolution."

8. MIPAS accuracy is already discussed at the end of p. 12774 and start of p. 12775.

9. We will give a list of the operational data assimilated for the Met Office and/or ECMWF. For ECMWF, we could say: "The operational data used for ECMWF encompassed a comprehensive blend of conventional (e.g., radiosondes, aircraft reports, profiler data, surface weather stations) and satellite observations. The satellite data included: clear-sky radiances from 4 AMSU-A instruments (NOAA-15, -16, and -17 and Aqua), AIRS, AMSU-B, SSMI, and four geostationary satellites; Atmospheric Motion Vectors (AMVs) from geostationary and polar satellites; scatterometer data; and radio occultation bending angle information from CHAMP. Ozone retrievals from SBUV on NOAA-16 were also assimilated."

10. It can be shown that, if the biases and covariances of all data error are correctly specified, addition of new independent data will result in a closer fit of the analysis to those data. This is not always the case (as is shown in Fig. 3), as, for example, there could be errors in how the data assimilation scheme is set-up. We propose to add a comment to this effect.

11. We agree with the reviewer that comparison against independent observations is much more significant. We propose to modify the text in p. 12779-24-ff to something

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along the following lines:

"Because comparison against independent data is much more significant than comparison against the assimilated observations, the ECMWF analyses were also compared against independent data from HALOE. This comparison (Fig. 4) shows that the information introduced through MIPAS has a strong impact on the system. The bias of the analysis against HALOE"

12. We say that the bias chiefly increases in the upper stratosphere/lower mesosphere (which is what the referee is saying), and that this is especially so in the northern hemisphere mid latitudes. These changes are greater than 5 K in some places (compare the red and green curves at ˜1 hPa in the right-hand panel of Fig. 4), which to us seem significant.

13. No. What we are saying is that the bias correction of the upper peaking satellite channels may be poor, leading to biases in the analyses which the addition of MIPAS temperatures appears to correct.

14. We mean the direct assimilation of radiances.

15. The assumption of horizontal homogeneity can indeed introduce an error, as is discussed further below in the manuscript (see 12784-16). However, the assumption is also made in ESA's retrieval processing, and provides a reasonable starting point for these first experiments. We propose to modify the text to clarify this:

Rephrase 12783-2-ff as follows: "In these first experiments we use an observation operator which assumes local horizontal homogeneity for the radiative transfer calculations, as is done in ESA's routine retrieval processing (Ridolfi et al. 2000). Subsequent experimentation relaxed this assumption, as further described below. We assimilate clear radiances from 260 selected"

Rephrase 1284-15-ff as follows: "introduce a considerable forward model error which can frequently exceed by far the instrument noise for lower tangent altitudes and more

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strongly absorbing channels (Bormann and Healy, 2006). Use of a 2-D radiative transfer model leads to smaller 'First Guess' departures for these radiances. The smaller 'First Guess' departures translate into smaller analysis increments"

16. We thank the referee for the positive comments.

17. In the general formulation of 4d-var, there are 3 error contributions to the penalty function: from observations (O); from forecasts (F), arising from errors in the initial conditions; and from the model itself (Q by convention), arising from its temporal evolution. It is common to assume in 4d-var that the model is "perfect" (also known as "strong-constraint" 4d-var), i.e., the Q error term is ignored; the F error term is generally retained (as is the O error term).

This hypothesis of a perfect model ("strong constraint" assimilation) has almost always been made so far in 4D-Var simply because "weak constraint" assimilation (where Q is included) has not yet reached a state of sufficient development.

In the work described in section 2.2, the 4D-Var system used for assimilating NOx data as well as neglecting Q, also neglects F. This is to keep the set-up simple but capable of producing results that show the essence of the method, viz., test of the assimilation of NOx and the feasibility of deriving temperature from the assimilation of NOx data.

To address these points, we propose the following modification to the text, 12786-12-13: "The CTM (a photochemical box model) is coupled to a 4D-Var scheme that assumes (as usual so far for 4D-Var) that the model is perfect, i.e., it has no errors associated with its temporal evolution. Furthermore, to keep the set-up simple but capable of producing results that show the essence of the method, we also neglect forecast errors arising from errors in initial conditions. Thus, the only error term retained is that from the observations."

On another point, we propose to improve the presentation of Figs. 7-8. Because of the involvement of Dr. Marion Marchand in the work outlined in section 2.2 and in helping

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improve these figures, we propose that she be added to the author list.

18. Section 2.3 discusses the different results from assimilating MIPAS and SCIAMACHY data. Roughly speaking, for a data assimilation system that is well set-up, we would expect the performance of the analyses to reflect the quality of the observations.

19. We are happy to change the text to "(50 - 2 hPa)."

20. We are happy to provide a listing of the analyses as indicated by the referee.

21. The "O" stands for "Order". We will change the text to remove any confusion.

22. It would appear this is loose writing on our part. What we actually want to say is what is stated in the next paragraph: "Most satellite instruments are currently unable to provide height-resolved profiles of constituents below tropopause levels."

An inference from this is that although there is a lot of height-resolved in situ data for the troposphere, this does not have global coverage, which can only be provided by satellites. Furthermore, although there is a lot of column data for the troposphere, this is not height-resolved.

We will clarify the text.

23. This is a problem of how the lower right hand panel of Fig. 12 has been depicted. If you depict the red and blue dots separately, one finds that the blue dots are closer to the 1:1 line than the red dots. We will redo Fig. 12 to address this.

To clarify the text, we also propose to make the following change in 12795-12-13:

"The bottom scatter plot indicates an improvement for assimilated NNORSY (Neural Network Ozone Retrieval System; Muller et al. 2003, JGR) neural network retrieved ozone profiles from GOME (efforts are underway to make SCIAMACHY neural network based retrievals available in the future), and MOZAIC aircraft in situ ozone observations. The horizontally banded structure in the red dots is associated with the coarse vertical resolution of the two highest model layers, where several levels of the retrieved

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profile are encompassed by a single model layer."

24. We will move this paragraph (12795-22 - 12769-05) to the Introduction, when we discuss the use of Envisat data (see response to general comment # 1).

25. By large meridional variability we mean large gradients in the North-South direction. This is the case for tracers near the Antarctic stratospheric polar vortex. We will clarify this.

26. See response to specific comment # 6.

27. We thank the referee for their comment.

28. We understand the referee means that the colour legends should all have the same scale.

The six upper "globes" (panel a) all refer to N2O5 and all have the same colour scale; the bottom two "globes" (panel b) refer to HNO3 and also have the same colour scale - but different from that for N2O5.

Since the maxima of N2O5 and HNO3 volume mixing ratios in the stratosphere differ approximately by a factor of 6, plotting the globes in panel a with the same colour scale as panel b would result in an unacceptable loss of contrast.

We also think that since panels a and b refer to different species, no comparison needs to be made between them.

We thus think there is no need to use identical scales.

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