Is it worth assimilating all channels in the IASI ozone band to improve ozone analysis in MOCAGE?

Clément Lavollée[1], Vincent Guidard[1,*], Emanuele Emili[2], Mohammad El Aabaribaoune[2]
[1] CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France
[2] CECI, Université de Toulouse, CERFACS, CNRS, Toulouse, France
* corresponding author: vincent.guidard@meteo.fr

Introduction

IASI measures the top of the atmosphere radiation at many wavelengths (8461 channels). As shows Fig 1, these channels are sensitive to numerous chemical species, in particular ozone. Studies by Emili et al. and El Aabaribaoune et al. (2021) used 284 channels in the long-wave ozone band their assimilation in the Chemistry Transport Model MOCAGE to analyse ozone and surface temperature. Information brought by these channels can be redundant.
The aim of this study is to evaluate the information content of various channel selections among this 284-channel set and evaluate their impact on the quality and the convergence of the assimilation in MOCAGE. Then, some refinements of the assimilation settings are explored.

1- Degrees of Freedom for Signal (DFS)

In our study, the DFS is used as a figure of merit.
$DFS = Tr(Id - (Id + BH^{T}R^{-1}H)^{-1})$, with Id the identity matrix
B the background error covariance matrix
R the observation error covariance matrix
H the Jacobian matrix.
In our case, control variables are ozone (Oz) and skin temperature (Tf).

$$B = \begin{pmatrix} B_{Oz} & 0 \\ 0 & B_{Tf} \end{pmatrix} \qquad H = \begin{pmatrix} H_{Oz} & HTf \end{pmatrix}$$

$$DFS_{Oz} = Tr(Id - (Id + B_{Oz}H_{Oz}^{T}R^{-1}H_{Oz})^{-1})$$
$$DFS_{Tf} = Tr(Id - (Id + B_{Tf}H_{Tf}^{T}R^{-1}H_{Tf})^{-1})$$
$$DFS_{Tot} = DFS_{Oz} + DFS_{Tf}$$

2- DFS and Ranking of Channels

Using the DFS as a figure of merit, we worked on 4873 profiles evenly distributed over the globe. We started by selecting the channel having the largest individual DFS_{Tot} in average over the whole profiles. Then we selected a second channel, which, together with the first selected, had the largest DFS_{Tot}. The process was iterated to rank all channels.

Fig. 1 shows the evolution of DFS: after a quick increase, the growth of DFS slows down by adding more channels. DFS for skin temperature reaches almost 1 with very few channels. 70% and 80% of the DFS_{Tot} are reached with 34 and 76 channels rp. Selections with 90 and 120 channels will also be assessed. Fig. 2 shows the selected channels.

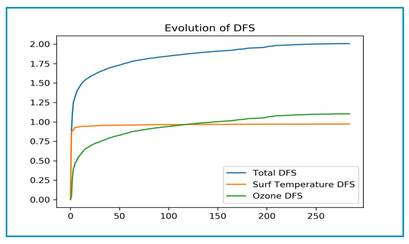

Fig1: DFS evolution

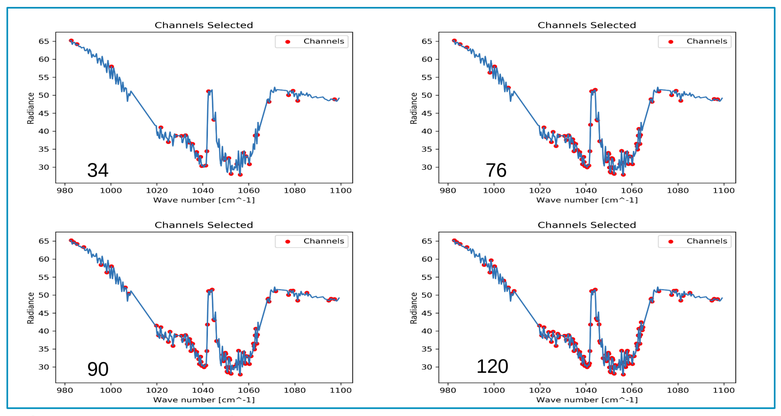

Fig2: Channel selections

3- Assimilation of Selections :

We will evaluate the 34, 76, 90 and 120 channel selections and the full channel list (called full channels), over the month of July 2021, in the assimilation of our chemistry transport model MOCAGE. An hourly 3D-VAR assimilation is used.

The hourly ozone analyses are validated against ozone-sondes from the WOUDC collection and MLS retrieved ozone profiles. Biases, standard deviation and root mean squared differences are computed.

Fig. 3 shows the vertical profiles of scores. The fewer channels in the selection, the better the scores. The vertical integrations of the scores are given in the table below.
We can notice that the number of iterations needed within the assimilation process decreases when the number of channels decreases.

Sélection		WOUDC			MLS		NITER
	Biais	ET	EQM	Biais	ET	EQM	
All Channels	2,73	1,96	4,02	3,05	3,53	4,66	90,6
34 Channels	2,67	1,88	3,91	3,03	3,48	4,63	57,2
76 Channels	2,65	1,90	3,93	3,03	3,49	4,62	65,5
90 Channels	2,66	1,91	3,94	3,04	3,50	4,63	68,6
120 Channels	2,65	1,91	3,95	3,04	3,50	4,62	72,0

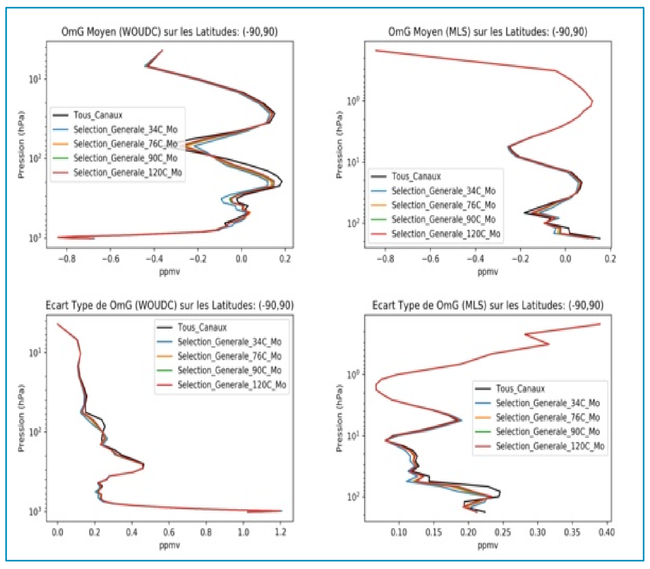

Fig 3: Vertical profiles of scores wrt WOUDC (left) and MLS (right), for biases (top) and standard deviations (bottom).

4- Observation error estimation: Desroziers Diagnostic

The Desroziers method can estimate, after an assimilation, a new observation-error covariance matrix R, using the formula $R_{Des} = E[\, d^{o}_{a} \, (d^{o}_{b})^{T} \,]$
with $d^{o}_{a} = y^{o} - \mathcal{H}(x^{a})$, $d^{o}_{b} = y^{o} - \mathcal{H}(x^{b})$.
y^{o} is the observation, x^{a} the analysis vector and x^{b} the background vector.
The process can be iterated
We used initially an R matrix from El Aabaribaoune et al. (2021). Then we apply Desroziers method on the assimilation of the 34 channel selection, starting with a R diagonal matrix (=0,7). The diagnosed matrix is called R1A. After one iteration (using R1A in the assimilation), we obtain the diagnosed R2A matrix.
Fig.4 shows the correlation parts and Fig.5 shows the standard deviations.

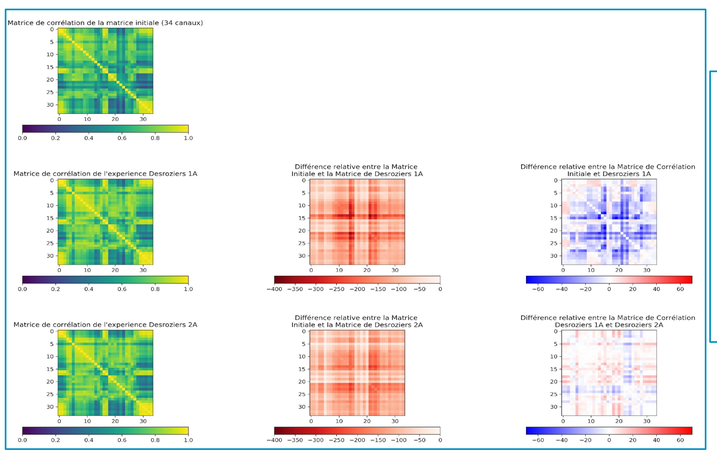

Fig 4: Initial and diagnosed observation error correlations, differences and relative differences

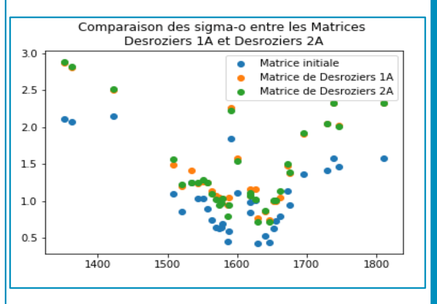

Fig 5: Initial and diagnosed sigma-o

5- Impact of R estimation on the assimilation

Assimilation experiments over one month and using 34 channels have been carried out. Three different settings have bee used for the observation error covariance matrix R: the initial matrix, the diagnosed matrix R1A and the diagnosed matrix R2A.

Same scores as for Fig. 3 are shown in Fig. 6. A synthesis is given in the table below. Using a R1A drastically lowers the iteration number (from 57 to 21) and scores are slightly better than with the initial matrix.

There is no significant improvement between R1A and R2A.

We can conclude that applying the Desroziers diagnostic once is enough to improve the assimilation results.

Sélection		WOUDC			MLS		NITER
	Biais	ET	EQM	Biais	ET	EQM	
All Channels	2,73	1,96	4,02	3,05	3,53	4,66	90,6
34 Channels Initial Matrix	2,67	1,88	3,91	3,03	3,48	4,63	57,2
34 Channels Desroziers 1A	2,60	1,87	3,87	2,96	3,44	4,59	20,8
34 Channels Desroziers 2A	2,59	1,85	3,85	2,95	3,43	4,58	20,9

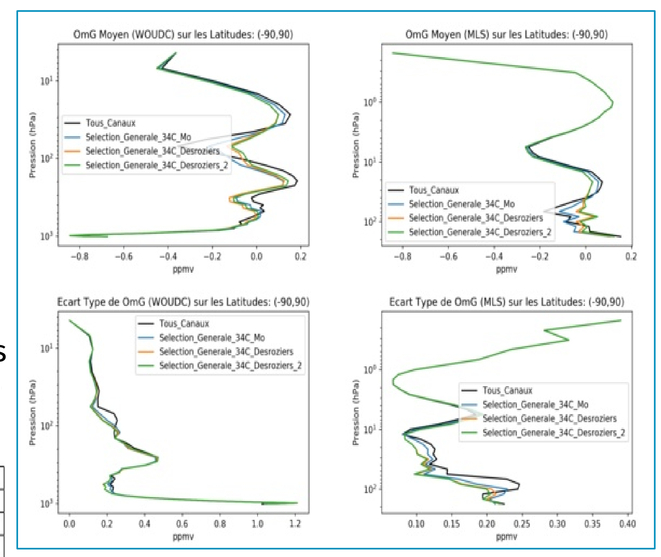

Fig 6: Vertical profiles of scores wrt WOUDC (left) and MLS (right), for biases (top) and standard deviations (bottom).

Conclusion

From 284 channels we extracted a shorter selection of 34 channels. We showed that results of this selection are better, and assimilation is faster.
Then applying the Desroziers method to this selection improves again the quality of results and the assimilation speed.

Perspectives

In this study, we used a list that contains channels sensitive to Ozone and skin temperature. Some channels can also be sensitive to other parameters, such as humidity. It could be interesting to add other variable to the control parameters, starting with humidity.

Acknowledgements

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