Climate Modelling User Group

Deliverable D2.3e

WP5.5: Recommendations to the CCI aerosol and cloud teams

Centres providing input: ECMWF, BSC

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0.1	23 January 2025	First draft
0.2	04 February 2025	Draft new section 1, "Recommendations summary"
0.3	20 February 2025	Implementation of suggested modifications

CMUG CCI+ Deliverable D2.3e

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1. Recommendations to ECV teams: summary

- Generate unbiased dust-targeted products such as visible dust Aerosol Optical Depth (AOD). This would be useful for and produce better skill in data assimilation and dust forecasting.
- Generate dust AOD with pixel-level uncertainties This would further enhance the accuracy of the data assimilation analyses and products.
- Investigate whether the aerosol uncertainties are underestimated due to underestimation of the retrieval uncertainty as the assimilation experiments performed better when an inflation factor is applied over the oceanic uncertainties. (Note that this may alternatively be inherent to the data assimilation system as part of the representation error.)
- Investigate ways to improve the cloud optical depth uncertainties and quality indicators as in their current form they were not applicable for data assimilation purposes.
- Continue the close dialogue and co-operation with the data users. Data assimilation users have different needs than climate model users. Thus, the documentation may not always cover the specific needs of the user and the 1-2-1 communication between the users and data providers is essential.

2. Purpose and scope of this report

This document summarises the main results of activities in the WP5.5 Clouds and Aerosol study CMUG-CCI+ and makes recommendations for the data providers based on these.

The aim of the study has been to exploit ESA CCI and CCI+ data of aerosols and clouds for assimilation in Earth System Models. For this purpose, we have used two ECVs, clouds and aerosols, and two different models and approaches for the assimilation. ECMWF assimilates operationally, in their 4D-Var system, aerosol optical depth in the Copernicus Atmosphere Monitoring Service for atmospheric composition forecasts, while limited cloud information is assimilated for Numerical Weather Prediction and reanalyses. In this study both aerosols and cloud information have been assimilated synergistically in the 4D-Var system.

BSC produces operationally daily forecasts of dust in the WMO Barcelona Dust Regional Centre. It produces forecasts with dust assimilation with an ensemble LETKF assimilation scheme. Dedicated dust observations are essential for this application, as well as for the constraint of the dust cycle in the Earth system. Using satellite dust optical depth, the MONARCH model at BSC has produced a 10-years dust reanalysis (Di Tomaso et al. 2022), which has been recently extended for one more year. WP5.5.1 has assessed the potential benefit of using most recent developments on CCI aerosol retrievals for dust data assimilation, with perspectives of being used for assimilation in future dust reanalysis, and for verification of past operational forecasts.

The full description of the work package and the results can be found in the final report D3.1e.

3. Summary of the main findings and recommendations from the WP5.5.1: Dust aerosol analysis in the BSC system

Lead partner: BSC
Authors: Jeronimo Escribano, Eleni Karnezi, Emanuele Emili and Calum Meikle

We have tested the assimilation of SLSTR SU v1.14 products in the BSC MONARCH-LETKF dust data assimilation system for the Godzilla extreme dust event of June 2020. Visual inspection shows an underestimation of the Dust AOD product of SLSTR-SU v1.14 (Figure 1). Coarse AOD, computed by AOD minus fine AOD, is also underestimating the aerosol optical load. Assimilation experiments using SLSTR SU v1.14 AOD were performed. For a model calibration agnostic to the extreme dust event of June 2020, the control run underestimates the dust plume. Assimilation experiments using SLSTR AOD show improvements in skill scores with respect to the control when ground-based AOD is used as reference. The skills are comparable to those assimilation experiments of the DOMOS project (with VIIRS and LIVAS). SLSTR assimilation that uses the pixel-level uncertainty of the SU product show better quantitative verification metrics with respect to AERONET than the experiment that assumes a linear model for the uncertainty. A possible overfitting of the observations is identified in the AOD analyses fields, which is possibly due the effect of an underestimation of the SLSTR AOD uncertainty over ocean in the data assimilation procedure.

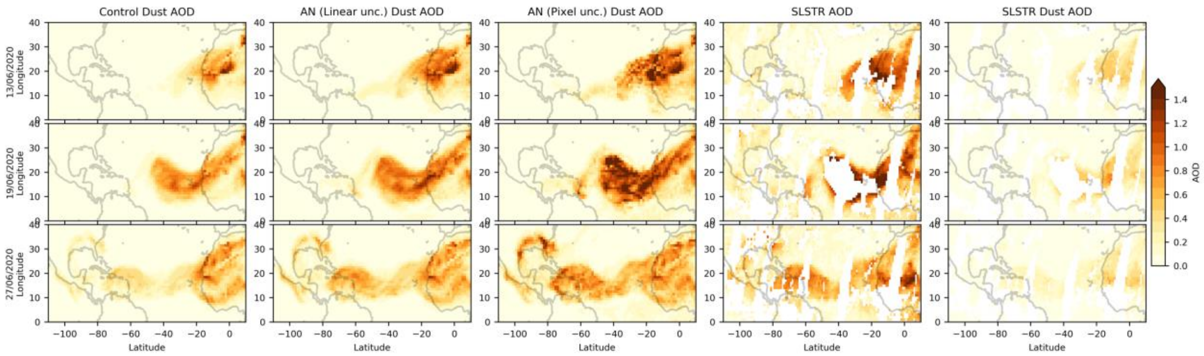

Figure 1: Control simulation Dust AOD, dust AOD analyses using both approaches for the uncertainty estimation of assimilate AOD in the assimilation system, and SLSTR AOD and SLSTR Dust AOD for 3 selected days of June 2020. Experiments were performed with standard calibration of dust emission strength, agnostic to the model low bias simulated in the extreme Godzilla dust event.

We have produced a new set of experiments to test and estimate better the AOD uncertainties over ocean by means of inflating the pixel-wise provided uncertainties. For this, we have re-calibrated the experiments to produce a less biases prior, targeted to this extreme dust event. All in all, we conclude that inflation of factor 2 to 3 of the uncertainty associated to the assimilated observation can provide:

- Better skill scores in comparison to the linear case or to the case without observational uncertainty inflation
- Less noise in spatial fields of analyses
- More consistent error diagnostics in the observational space

It is important to stress that the inflation of **R** implemented here has no one-to-one correspondence to the SLSTR observations uncertainty of AOD provided in the dataset. Following the terminology of Janjić et al. (2017), the **R** error covariance matrix accounts for the covariance of the observational error, which is the assimilated observational value minus the (unknown) true value. This observational error consists of the representation error and the measurement error. The uncertainty reported in the SLSTR product would be equivalent to the measurement error in the terminology of Janjić et al. (2017). The representation error includes the observation operator error, the pre-processing error and the errors due to unresolved scales and processes. Part of the inflation used here might account for errors in the observation operator (e.g. dust optics), errors in the aggregation and filtering of observations, the coarser model spatial and temporal resolution, or the assumption that most of the observed AOD in the plume corresponds to DOD.

Recommendations to CCI data providers

We have shown that SLSTR AOD can be ingested in an operational-like data assimilation workflow to produce dust forecasting and produce better skills. We might largely benefit from unbiased dust targeted products, as visible dust AOD. Experiments with SLSTR pixel-level uncertainties improve the accuracy of the data assimilation analyses and products. Dust AOD with pixel-level uncertainties should provide even better results. We also indicate that the experiments perform better when an inflation factor is applied over the oceanic uncertainties. We suggest that these uncertainties are underestimated in the data assimilation system, and this underestimation might be due underestimation of the retrieval uncertainty, but also might be inherent to the data assimilation system, as part of the representation error.

4. Summary of the main findings and recommendations from the WP5.5.2: Cloud/Aerosol analysis with the ECMWF system

Lead partner: ECMWF
Authors: Kirsti Salonen and Angela Benedetti

In the work package 5.5.2 the quality and impact of AOD and COD CCI products from SLSTR instrument have been assessed in the ECMWF system using the CAMS configuration. AOD data is v1.14 and COD based on v3.3, i.e. the COD data set used is not part of the official CCI data sets but same algorithms are used over the considered test periods, June 2020 and September 2021.

Quality assessment with passive monitoring experiments in the ECMWF system, i.e. AOD or COD are not actively assimilated into the system, indicate high and homogeneous quality for the AOD observations over sea. For COD positive observation minus background mean differences are seen over areas where there is typically marine stratus clouds, and negative mean differences especially in the tropics where thick convective clouds are frequently present.

The uncertainty estimate provided with AOD observations is sensible and can be used as scene dependent observation error in the assimilation with slight inflation. Sensitivity tests suggest inflation factor of 1.4 to be a reasonable choice. The uncertainty estimate provided with the COD observations is low in magnitude compared to the corresponding OmB standard deviation statistics. For quality screened data the OmB standard deviation statistics are still indicating magnitude of six times larger than the uncertainty estimate.

Impact assessment has been performed in depleted and in full observing system. Depleted system was used in the sensitivity tests and the final optimal configuration of joint AOD and COD assimilation was then tested in the full observing system framework. Both experiment configurations indicate degradation in temperature and humidity forecasts. However, some positive signal is seen for wind forecasts which can be due to the tracer advection effect of the 4D-Var assimilation. Verification against the AERONET observations indicate small but positive signal from assimilation of the CCI AOD and COD.

The results show that the CCI AOD product is mature and behaves in a similar way in the ECMWF system than the operationally used AOD products from other instruments. As a recommendation to the data providers, we only suggest continuing the close dialogue and co-operation with the data users.

The COD product was tested in assimilation for the first time. Thus, no similar maturity can be expected as that of the AOD product. We would suggest focusing on developing further the quality information provided with the data. This includes both the uncertainty estimates which in our understanding are significantly too low in the current version, and the quality flags which now only screen out very few observations and do not improve the fit to the model background. If the COD product is aimed for operational assimilation, also discussions of the data format would be useful. Global observation files covering 24 hours are not optimal without pre-processing in any operational assimilation system as the assimilation windows are typically much shorter.

Overall conclusion is that the main benefits of projects like this is to have the fruitful two-way conversation between the data providers and data users. The CCI AOD product is mature for assimilation usage and the uncertainty information provided is a realistic estimate to be used as observation error. The COD product has not been developed NWP data assimilation in mind and it would benefit from quality and uncertainty information designed more for data assimilation purposes. Also, the data format is not optimal in its current format for assimilation purposes.

References

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