CAMS Service Evolution

D1.3 Implementation of dust input in the observation operator used in ARPEGE-IFS for infrared brightness temperatures and monitoring of IASI observations

Due date of deliverable	30.06.2025
Submission date	30.06.2025
File Name	CAMAERA-D1.3-V1.1
Work Package /Task	WP1 Task 1.3 - Preparation for infrared L1 data assimilation
Organisation Responsible of Deliverable	Météo-France
Author name(s)	Vincent Guidard
Revision number	1.1
Status	
Dissemination Level	

Funded by the European Union

The CAMAERA project (grant agreement No 101134927) is funded by the European Union.
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1 Executive Summary

In this task, we have implemented the link between the dust model variable and the RTTOV simulator in the ARPEGE/IFS assimilation system. We have also provided guidance for IASI pixels to be selected for dust assimilation in ARPEGE/IFS from IASI radiance, thanks to the Aerosol Detection Scheme. The monitoring of identified pixels and of the statistics of observations minus clear-sky simulations showed expected behaviours.

This preparatory work enables us to be ready for the next step, which is the actual assimilation of clear and dust IASI L1 observations in ARPEGE/IFS to improve the model dust field.

Table of Contents

2 Introduction

2.1 Background

The European Union's flagship Space programme Copernicus provides a key service to the European society, turning investments in space-infrastructure into high-quality information products. The Copernicus Atmosphere Monitoring Service (CAMS, https://atmosphere.copernicus.eu) exploits the information content of Earth-Observation data to monitor the composition of the atmosphere. By combining satellite observations with numerical modelling by means of data assimilation and inversion techniques, CAMS provides in near-real time a wealth of information to answer questions related to air quality, climate change and air pollution and its mitigation, energy, agriculture, etc. CAMS provides both global atmospheric composition products, using the Integrated Forecasting System (IFS) of ECMWF - hereafter denoted the global production system -, and regional European products, provided by an ensemble of eleven regional models - the regional production system.

The CAMS AERosol Advancement (CAMAERA) project will provide strong improvements of the aerosol modelling capabilities of the regional and global systems, on the assimilation of new sources of data, and on a better representation of secondary aerosols and their precursor gases. In this way CAMAERA will enhance the quality of key products of the CAMS service and therefore help CAMS to better respond to user needs such as air pollutant monitoring, along with the fulfilment of sustainable development goals. To achieve this purpose CAMAERA will develop new prototype service elements of CAMS, beyond the current state-of-art. It will do so in very close collaboration with the CAMS service providers, as well as other tier-3 projects. In particular CAMAERA will complement research topics addressed in CAMEO, which focuses on the preparation for novel satellite data, improvements of the data assimilation and inversion capabilities of the CAMS production system, and the provision of uncertainty information of CAMS products.

2.2 Scope of this deliverable

2.2.1 Objectives of this deliverables

This deliverable reports on the preparation for the IASI L1 data assimilation in ARPEGE/IFS, which covers the implementation of the link between the desert dust variable and the RTTOV observation operator in ARPEGE/IFS, and the monitoring of the IASI data to define the parameters for assimilation.

2.2.2 Work performed in this deliverable

In this deliverable the work as planned in the Description of Action (DoA, WP1 T1.3) was performed.

2.2.3 Deviations and counter measures

No deviations have been encountered.

2.2.4 CAMAERA Project Partners:

HYGEOS	HYGEOS SARL
ECMWF	EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS
Met Norway	METEOROLOGISK INSTITUTT
RC.io	RESEARCHCONCEPTS IO
BSC	BARCELONA SUPERCOMPUTING CENTER-CENTRO NACIONAL DE SUPERCOMPUTACION
KNMI	KONINKLIJK NEDERLANDS METEOROLOGISCH INSTITUUT-KNMi
SMHI	SVERIGES METEOROLOGISKA OCH HYDROLOGISKA INSTITUT
FMI	ILMATIETEEN LAITOS
MF	METEO-FRANCE
TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
INERIS	INSTITUT NATIONAL DE L ENVIRONNEMENT INDUSTRIEL ET DES RISQUES - INERIS
IOS-PIB	INSTYTUT OCHRONY SRODOWISKA - PANSTWOWY INSTYTUT BADAWCZY
FZJ	FORSCHUNGSZENTRUM JULICH GMBH
AU	AARHUS UNIVERSITET
ENEA	AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

3 Link between the dust control variable and the RTTOV observation operator

3.1 Rationale

The two models ARPEGE and IFS, which have been jointly developed since the late 1980s, share large parts of their code, mainly in the assimilation part of it. The present work is thus relevant to both models, including IFS-Compo (namely CAMS global).

The satellite infrared data are assimilated in the form of top-of-the-atmosphere radiances (so called level 1 L1) both in ARPEGE and IFS in their Numerical Weather Prediction (NWP) operational models, for variables such as atmospheric temperature and humidity, and surface temperature. Previous studies carried out in ARPEGE have also used this framework and this approach to add ozone on top of the NWP variables (Coopmann et al, 2020). Ozone is also part of the operational control variable in IFS. The thermodynamic variables, as well as some gaseous compounds, are already input from the models to RTTOV in ARPEGE and IFS. The dust variable is not.

More advanced assimilation of IASI L1 data for atmospheric composition has been explored in the chemistry transport model MOCAGE for carbon monoxide, and also for desert dusts (El Aabaribaoune, 2022). This work has either been transferred to operations (ozone and CO in MOCAGE from IASI and CrIS L1) or pursued in research mode (Étienne Gruet's PhD which is on going). The results show encouraging impact.

The aims of the task 1.3 within WP1 of CAMAERA is to input the dust variable from the model to RTTOV in ARPEGE/IFS and monitor IASI L1 data in that frame. The ultimate goal after this preparatory phase is the actual assimilation of IASI L1 data for dust in ARPEGE/IFS.

3.2 Technical frame and work

The developments made in this task are done in the version (aka cycle) 49T1 of the ARPEGE code, which is compatible with the cycle 49R1 of the IFS code. In these versions, RTTOV is implemented in its version 13.2. In this RTTOV version, aerosols can be represented in various ways, including the representation used in IFS, known as "CAMS aerosols" in RTTOV (Saunders el al, 2020).

Technical modifications have been made in several routines from ARPEGE/IFS so that the dust variable is forwarded to RTTOV in a consistent way with other meteorological and gaseous variables.

In the present study, all prognostic variables in ARPEGE (temperature, pressure, wind, humidity) are directly available to RTTOV. An on-line capacity to model aerosols and chemistry is being built in ARPEGE but is not ready yet for the present study. In order to input dust aerosols to RTTOV, we have used the information provided by the chemistry transport model MOCAGE of Météo-France. Dust fields have been interpolated from MOCAGE geometry onto ARPEGE geometry and added to ARPEGE variables in the files used in the assimilation. Therefore, the dust field is available to be forwarded to RTTOV.

4 Monitoring of IASI L1 data in dust events

4.1 Aerosol detection in observations

The Cloud and Aerosol Detection Scheme (CADS), developed within the NWP Satellite Application Facility (SAF) of Eumetsat (https://nwp-saf.eumetsat.int/site/software/cloud-and-aerosol-detection/documentation/), is already implemented in ARPEGE/IFS and is relevant to infrared sensors such as IASI.

The cloud detection scheme, based on McNally and Watts (2003), has been used for many years in operations both in ARPEGE and IFS to identify clear and cloudy channels in each pixels It will not be further detailed here.

The aerosols detection part of CADS relies only on IASI L1 radiances themselves in several micro-window regions of the spectrum. It can identify, in each pixel, the following cases:

- over sea
  - no aerosol
  - desert dust
  - volcanic ash
  - other aerosols
- over land
  - no aerosol
  - aerosols (no type identification)

The aerosol detection scheme requires that these specific channels are provided to the assimilation. Namely, these channels are:

748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 1335, 1336, 1337, 1338, 1339, 1340, 1341, 1342, 1343, 1344, 1345, 1777, 1778, 1779, 1780, 1781, 1782, 1783, 1784, 1785, 1786, 1787, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361

As those channels are not part of the reduced dataset from IASI which is used in operations at Météo-France in ARPEGE, a first step has been to fetch the IASI full spectral resolution in the form of Principal Component analysis Scores (PCS) from the Eumetsat Archive via the User Portal : https://user.eumetsat.int/catalogue/EO:EUM:DAT:METOP:IASPCS01 Then the radiances have been reconstructed from the PCS data, and the channels mandatory for the aerosol detection scheme have been added to the regular sets of channels used in ARPEGE.

In addition to the CADS, IASI data come with independent information on clouds from the companion imager AVHRR: cloud cover within the IASI pixel.

Both sets of information can be combined, as shown in Figure 1 for the whole day of the 18th December 2025. One can noticed that the vast majority of IASI pixels have clouds and no aerosols (grey pixels in the figure).

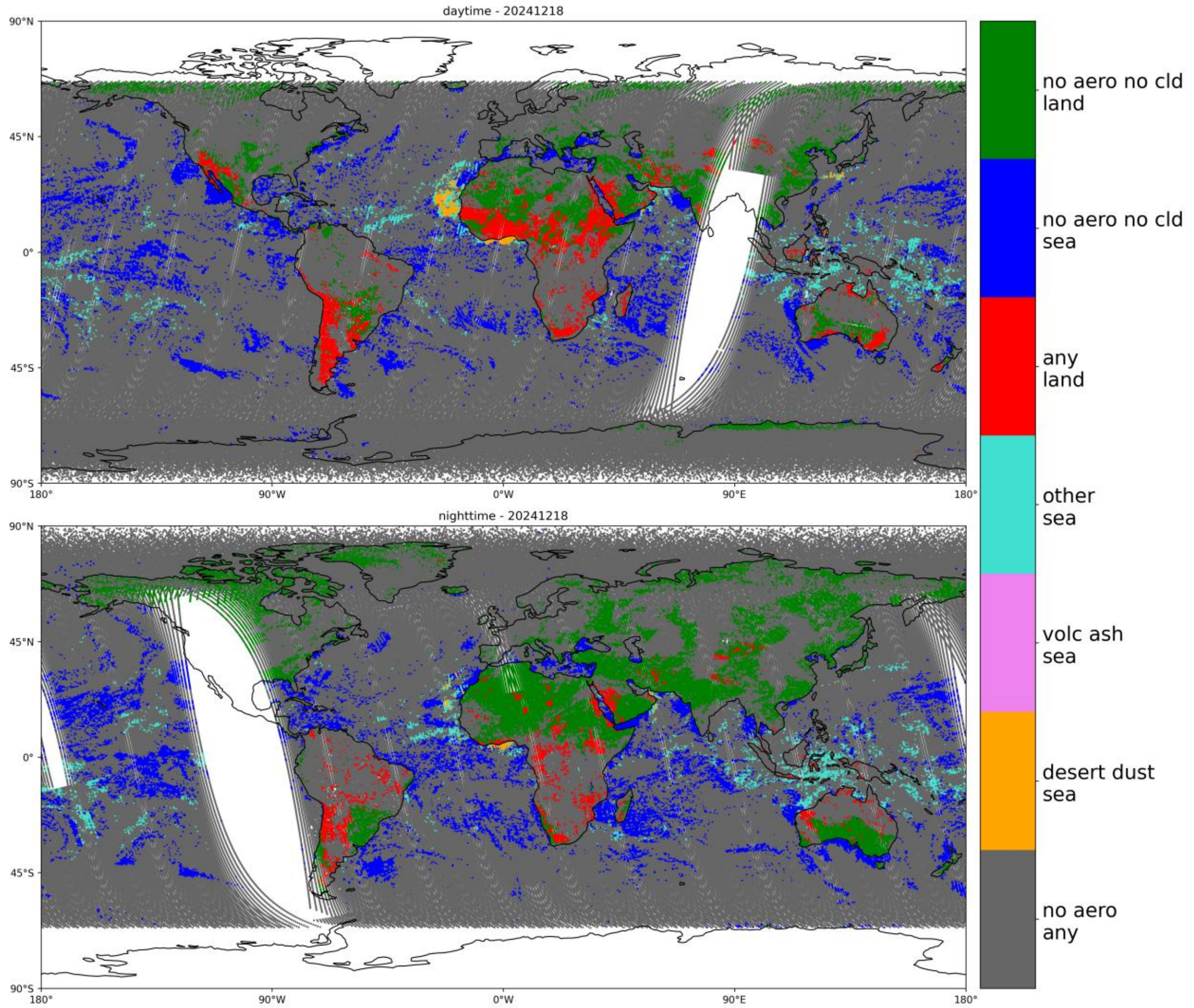

Figure 1: Combined information on clouds and aerosols in IASI pixels from the aerosols detection scheme and AVHRR cloud cover information, splitted between daytime (top) and nighttime (bottom), on 18 December 2024.

4.2 Monitoring of IASI L1 data over a dust event

The period of study spans from December 2024 18^{th} to 29^{th}, during which a dust plume is formed over the Sahara desert and then transported over the Atlantic Ocean towards America. Some local export stays in the Gulf of Guinea. Some very small plumes can be detected West of Australia and East of China. The full sequence is given in Figures 1 to 12.

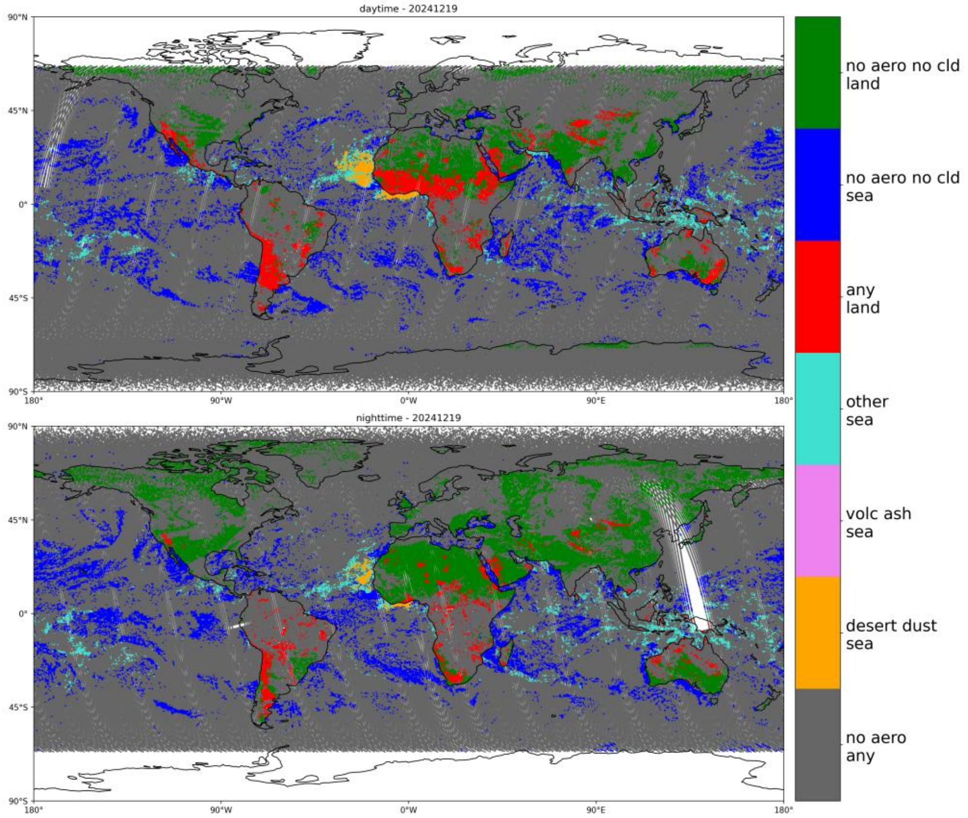

Figure 2: Same as Figure 1 but on 19 December 2024

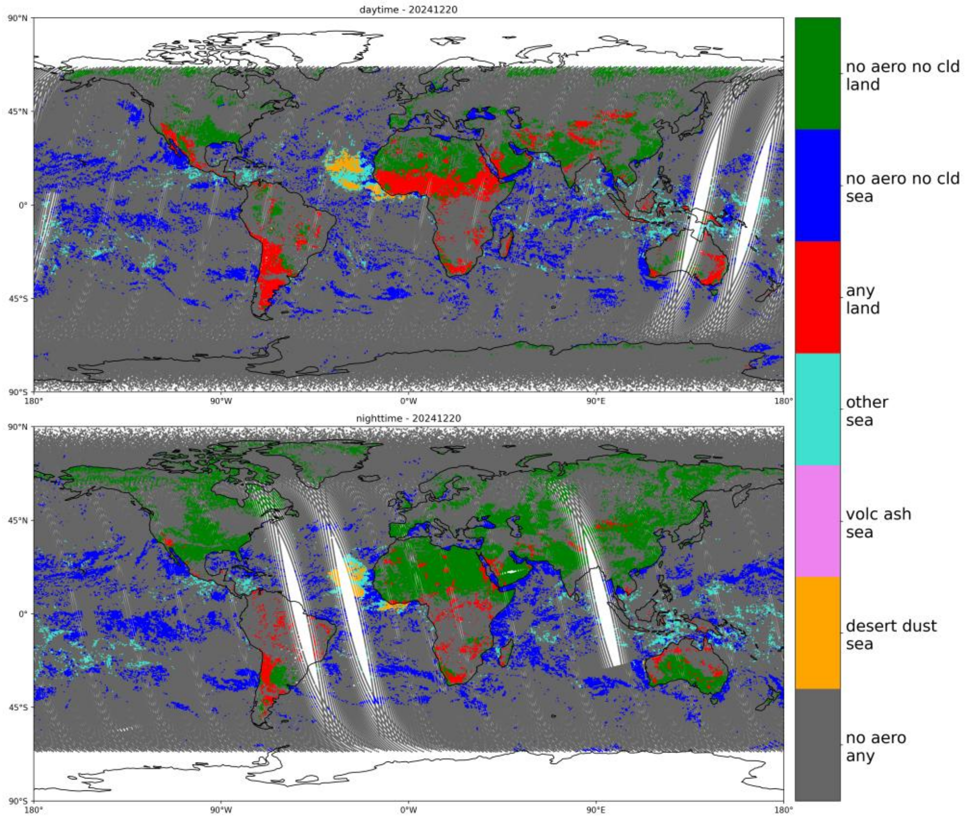

Figure 3: Same as Figure 1 but on 20 December 2024

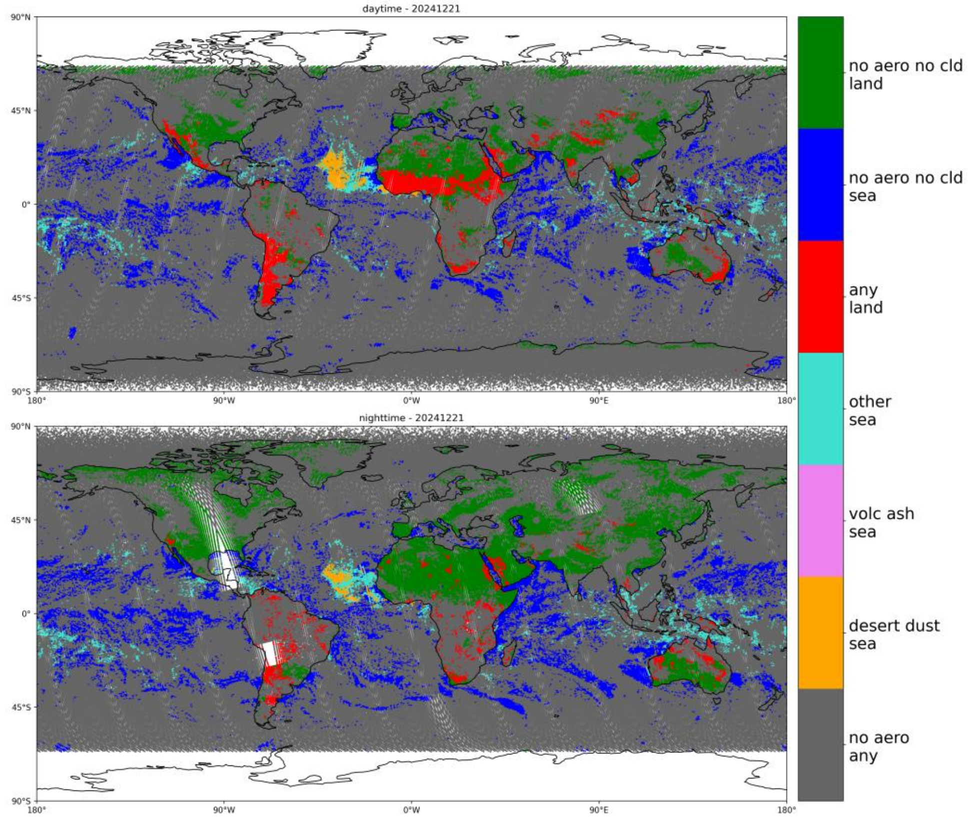

Figure 4: Same as Figure 1, but on 21 December 2024

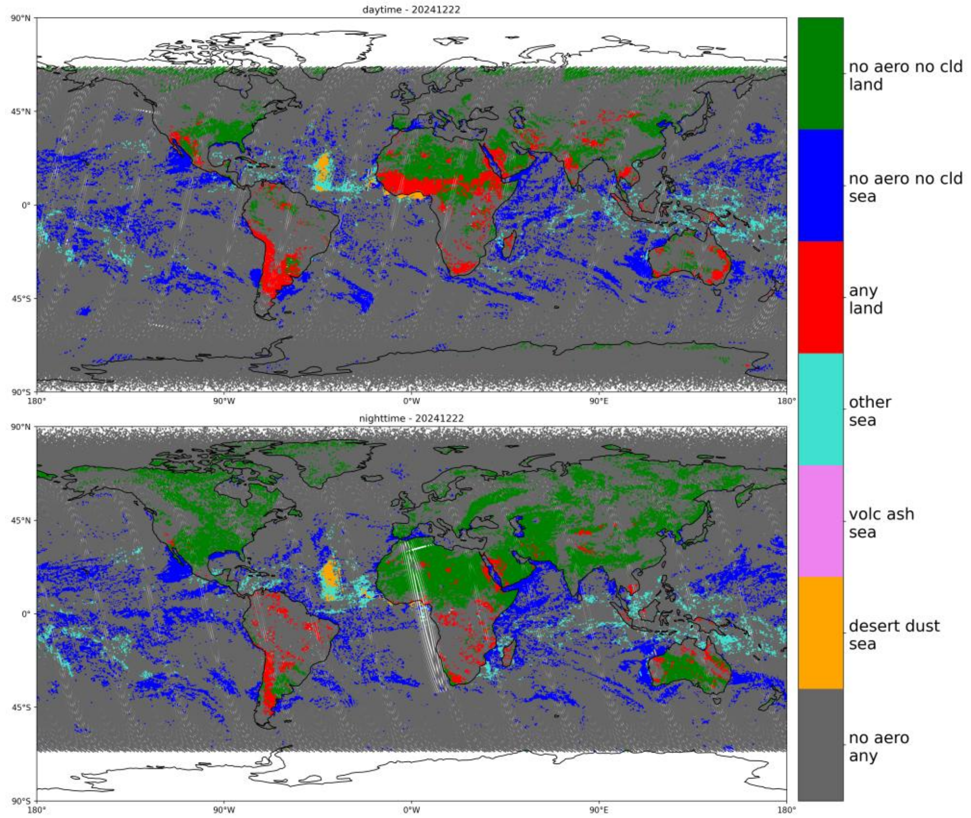

Figure 5: Same as Figure 1, but on 22 December 2024

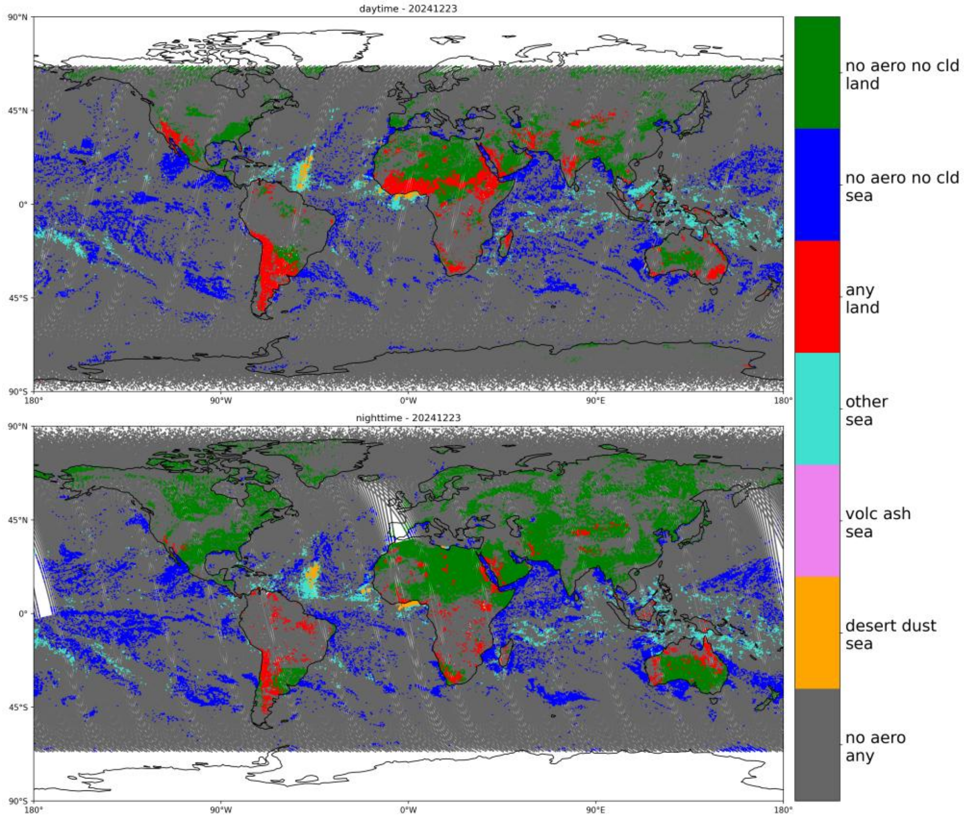

Figure 6: Same as Figure 1, but on 23 December 2024

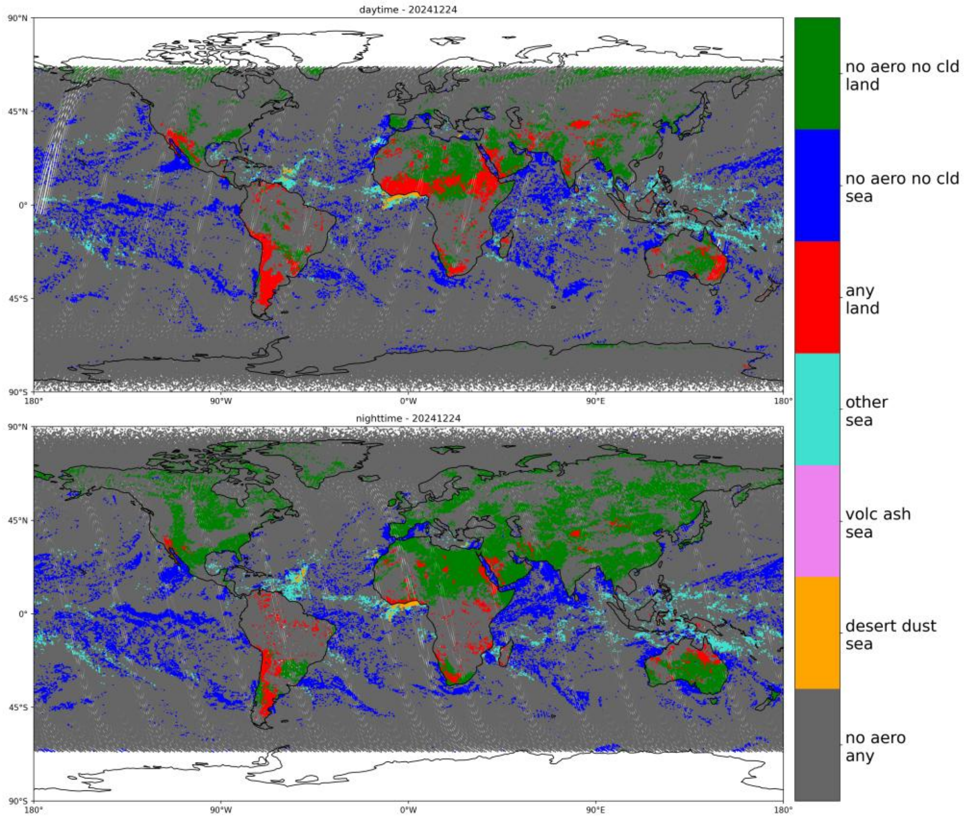

Figure 7: Same as Figure 1, but on 24 December 2024

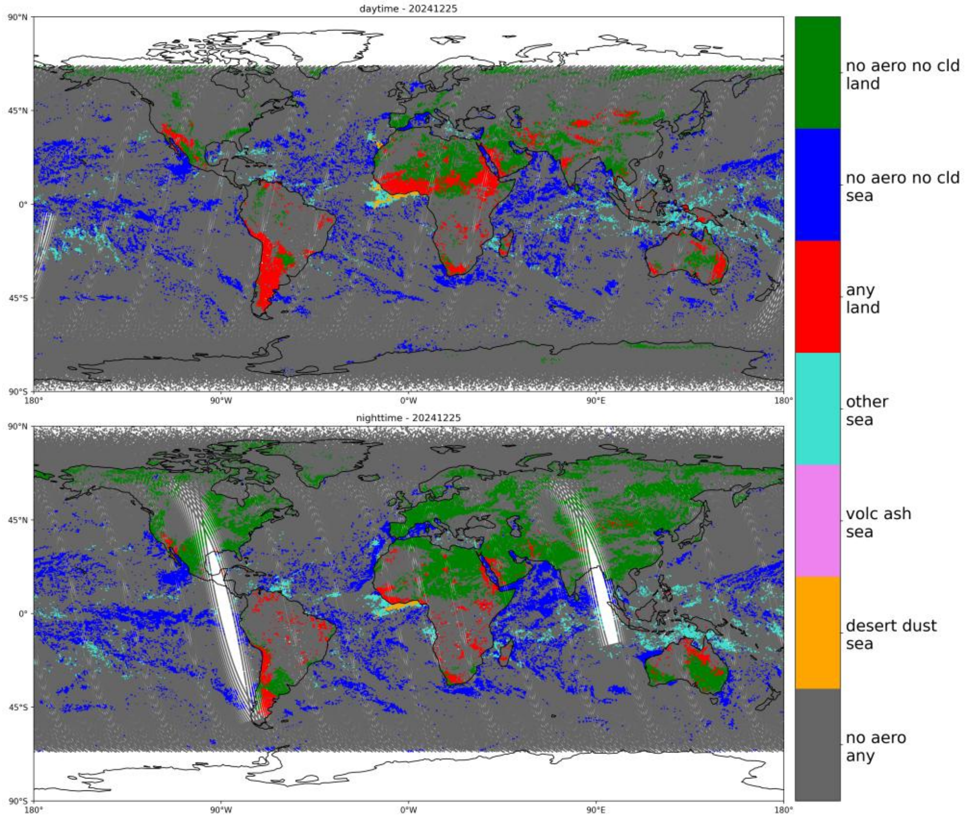

Figure 8: Same as Figure 1, but on 25 December 2024

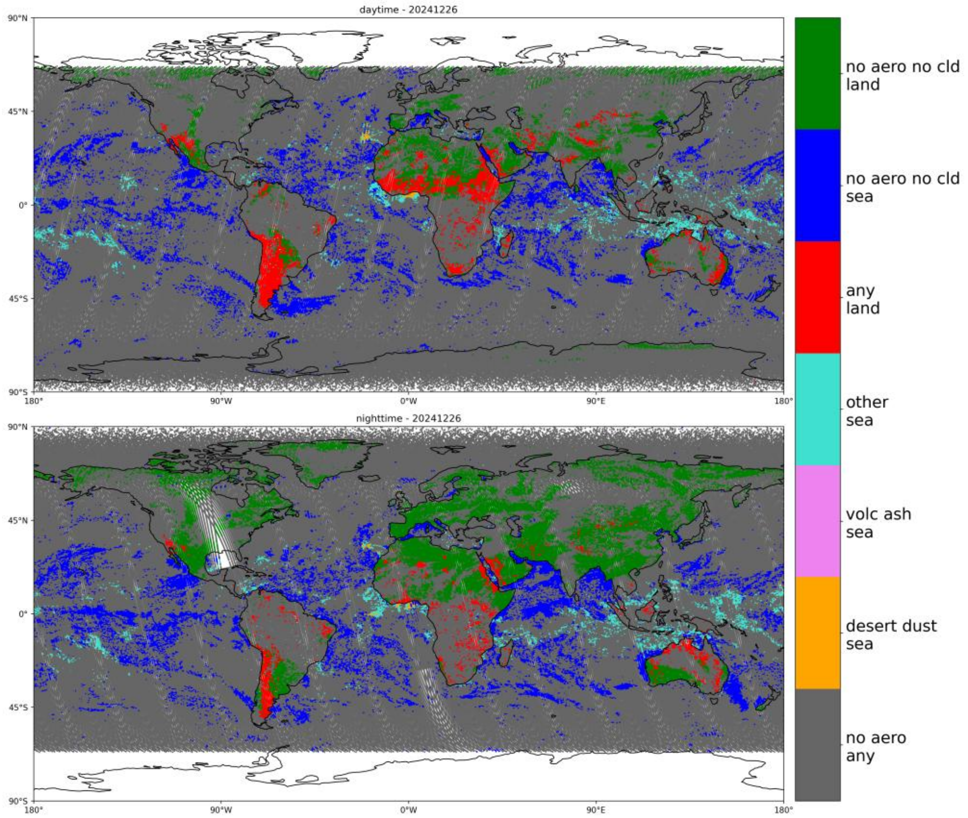

Figure 9: Same as Figure 1, but on 26 December 2024

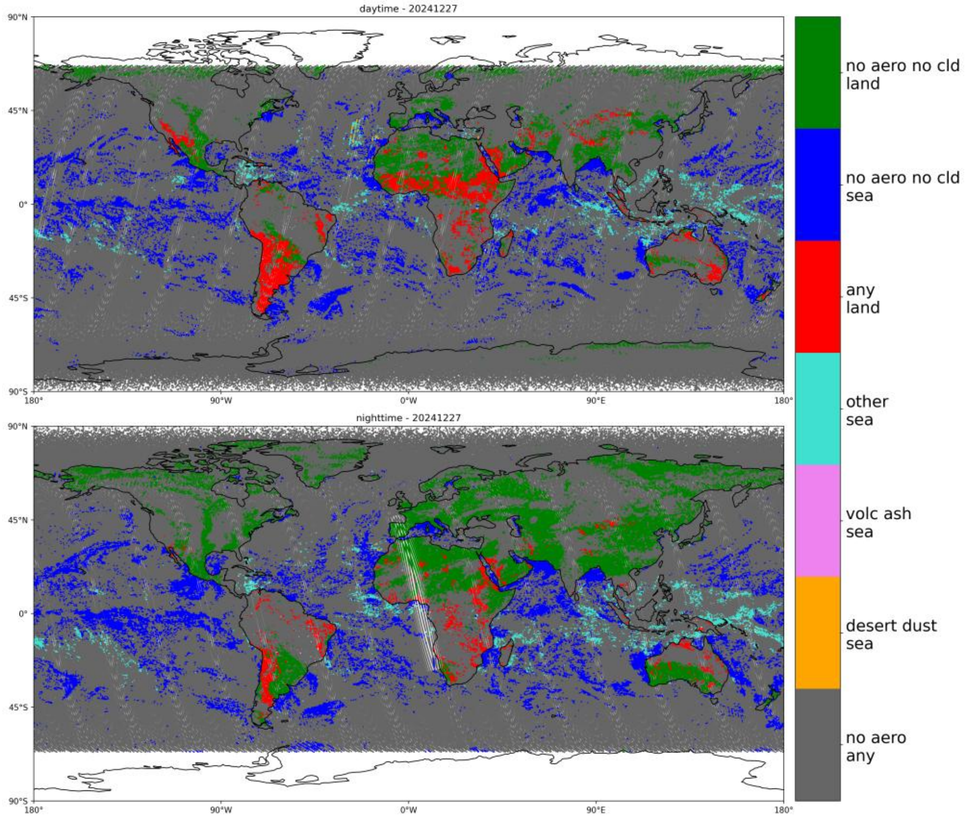

Figure 10: Same as Figure 1, but on 27 December 2024

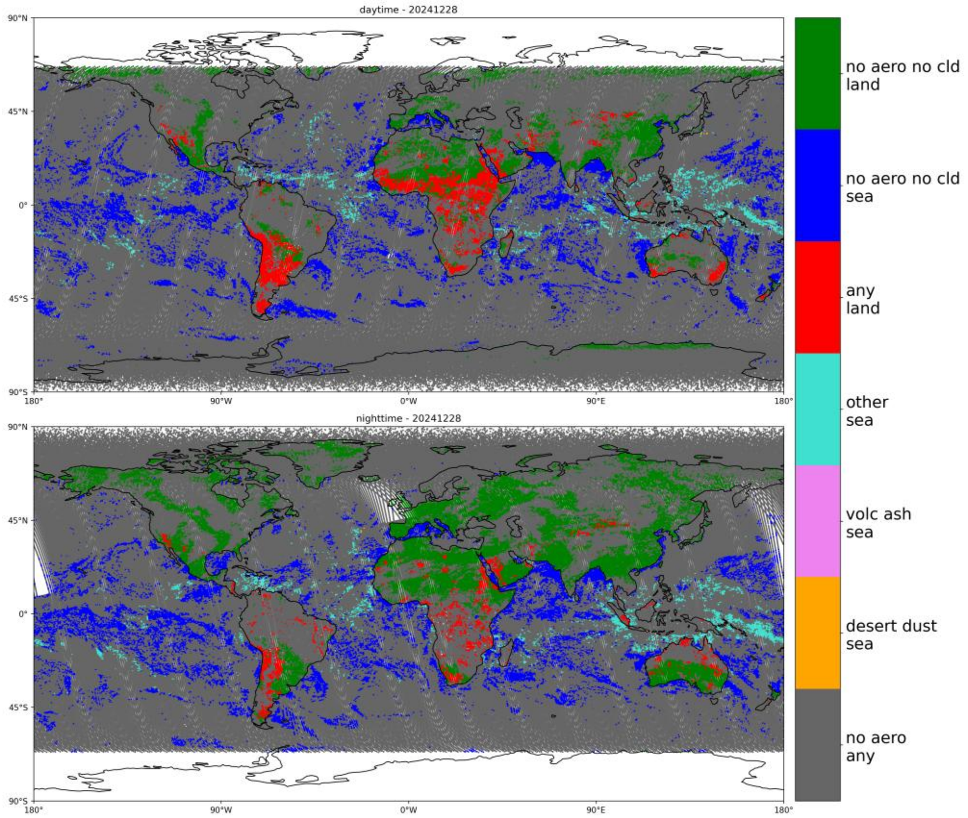

Figure 11: Same as Figure 1, but on 28 December 2024

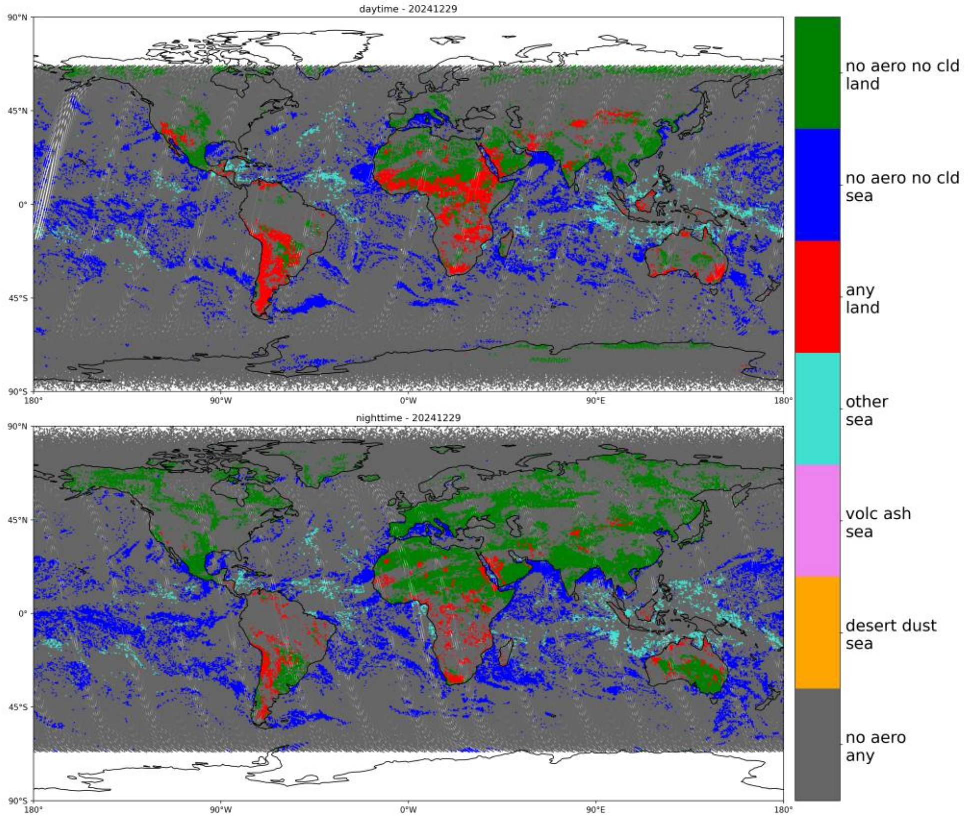

Figure 12: Same as Figure 1, but on 29 December 2024

Over this event, we will focus on pixels over sea, as the aerosol detection scheme does not allow for a type identification over land. In Figure 13, the count of the pixels identified as “dust” and as “clear and no aerosol” over sea is given by day, in a logarithmic scale. The number of clear pixels is roughly constant, while the number of dust pixels decreases as the event reaches its end.

The statistics of observed values compared to simulated values of brightness temperatures (so-called innovations) are also monitored. The simulation here are made assuming that the aerosol concentration from ARPEGE is zero, as in clear sky. The average and standard deviation of the innovations are given in Figure 14 both for clear and dust pixels. Note that no bias correction is applied in these statistics. Clear pixels have very smooth statistics, with average close to zero for most of channels and standard deviation between 0.2 and 1 K. Statistics for clear pixels show high values for channels between number 1400 and 1700 (ie. between ~1000 and ~1100 cm^{-1}), which correspond to the ozone band. Indeed, ARPEGE does not implement a prognostic ozone nor modification of ozone during the assimilation, which explains the high values.

The statistics for dust pixels show larger standard deviations from channel number 300, ie. tropospheric channels which can be affected by the presence of dust. The standard deviations for ozone channels are larger than for other channels (same explanation as above) but less than for clear pixels, as the regions covered by the dust pixels does not cover the full globe contrary to the clear pixels. The average of innovations for dust pixels clearly shows a decrease towards negative value between channels 400 and 1400, and then an opposite slope for channels from 1800 to 2400. This feature is the well-known V-shape signature of dusts in the infrared spectrum.

The monitoring of the IASI L1 data over this particular dust event shows that the addition of the IASI dust pixels in ARPEGE monitoring show expected results.

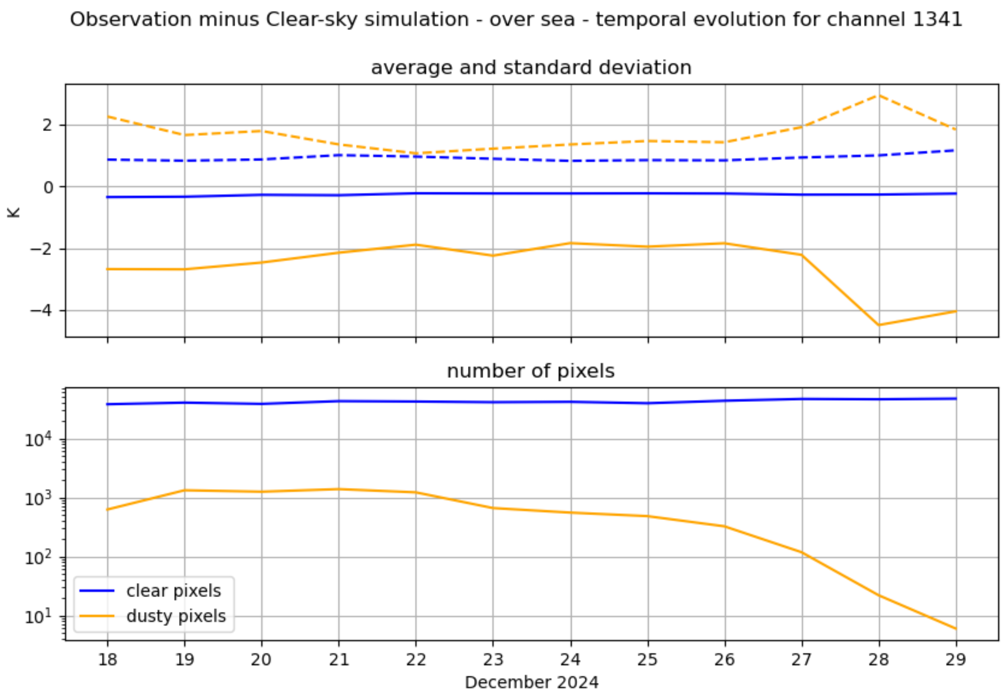

Figure 13: Daily evolution of observations minus simulations statistics for the IASI channel number 1341 [980 cm^{-1}] (top) and number of clear and dust pixels (bottom)

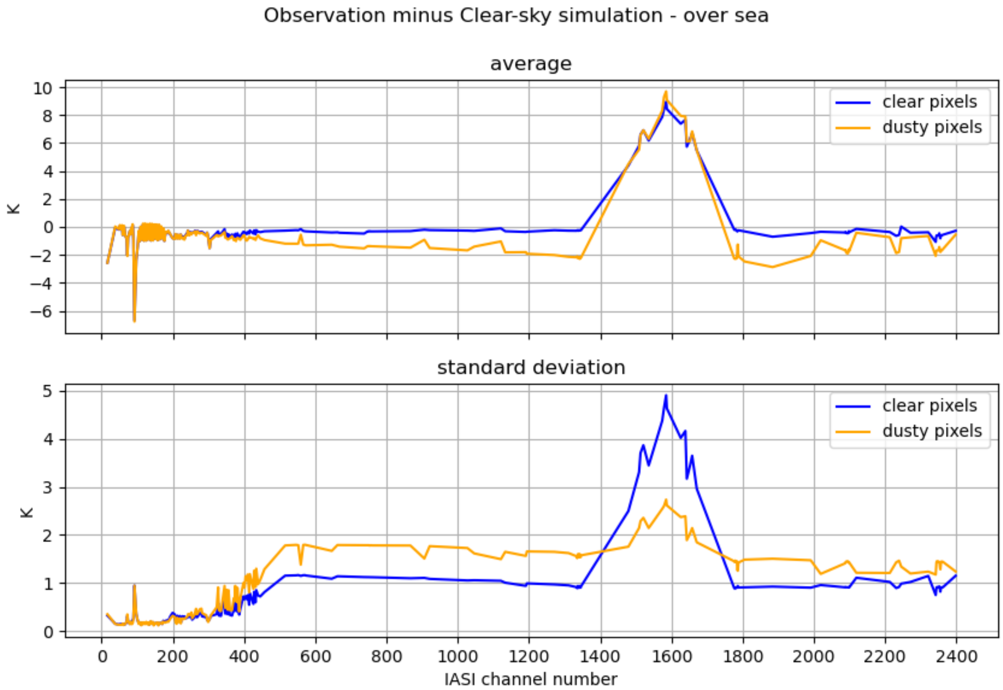

Figure 14: Statistics over the full study period of avaerage (top) and standard deviation (bottom) of IASI observations minus clear-sky simulations for selected channels in the IASI first band

5 Conclusion

In this document we have described the implementation of the link between the dust model variable and the RTTOV simulator in the ARPEGE/IFS assimilation system. We also provided the guidance for IASI pixels to be selected for dust assimilation in ARPEGE/IFS from IASI radiance, thanks to the Aerosol Detection Scheme. The monitoring of identified pixels and of the statistics of observations minus clear-sky simulations showed expected behaviours.

This preparatory work enables us to be ready for the next step, which is the actual assimilation of clear and dust IASI L1 observations in ARPEGE/IFS to improve the model dust field.

6 References

Coopmann, O., V. Guidard, N. Fourrié and B. Josse. Use of a variable ozone in radiative transfer model for the global Météo-France 4D-VAR system. QJRMS, https://doi.org/10.1002/qj.3869

El Aabaribaoune, Mohammad (2022). Assimilation des luminances IASI dans un modèle de chimie transport pour la surveillance de l'ozone et des poussières désertiques. PhD thesis from Toulouse University. http://thesesups.ups-tlse.fr/5584/

Saunders et al (2020). RTTOV v13, Science and validation report. https://nwp-saf.eumetsat.int/site/download/documentation/rtm/docs_rttov13/rttov13_svr.pdf

Document History

Version	Author(s)	Date	Changes
1.0	Vincent Guidard	20/06/2025	Initial version
1.1	Vincent Guidard	25/06/2025	Changes after reviews

Internal Review History

Internal Reviewers	Date	Comments
Melanie Ades	23/06/2025	Clarification about dust aerosols in RTTOV
Samuel Remy	23/06/2025	Formatting changes