DUST REGIONAL REANALYSIS UPDATE

EXTENSION TO 2019

BDRC-2025-004

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Summary

This document presents a temporal extension of the decadal high-resolution dust regional reanalysis for Northern Africa, the Middle East and Europe for the period 2007-2019. The original reanalysis (2007-2016) was produced in the framework of the ERA4CS DustClim project and is documented by Di Tomaso et al. [2022]. This report is the follow-up of the two previous reports that described the extension to year 2017 and 2018 (Karnezi et al. 2023, 2024). Given the end of availability of ERA-Interim in 2019, the systematic differences introduced in 2017 due to the switch from MODIS Collection 6.0 to 6.1 and technical difficulties in porting the former model configuration to the current BSC supercomputer, the 2019 reanalysis has been computed using a new and profoundly revised model and assimilation configuration. We describe here the revised configuration (DustClim 2.0) and analyze differences with the former configuration during an overlap year (2018). We recompute then climatological values and yearly anomalies of dust optical depth and surface dust concentrations for the full period. We also computed a regional validation against decade-long time series of AERONET coarse AOD measurements and surface concentrations of dust PM10 over a reference year. The updated reanalysis configuration is found to improve dust optical depths and surface concentrations across the domain, especially in regions far from dust sources. The new configuration is currently the candidate to extend the dust reanalysis to upcoming years (2020-2024). However, significant changes in dust concentrations between Dustclim and Dustclim 2.0 will require to recompute the full multi-decadal time series later to ensure temporal consistencies across the entire period.

Contents

1. Background

Over the past decade, there has been growing recognition of the significant role that sand and dust storms (SDS) have on weather, climate and atmospheric chemistry, as well as their adverse impacts on life, health, environment, property, and economy. All this has generated a high societal and research interest to better understanding atmospheric dust processes, predict dust events and prevent or mitigate their unwanted impacts. Understanding, managing and mitigating SDS risks requires the availability of relevant dust information on past trends and current conditions as well as the provision of skillful forecasts and projections. To achieve these objectives, one of the major challenges is the lack of historical and routine dust observations - mainly in the countries most affected by SDS - which represent a key element for the reconstruction of comprehensive dust information. To cover this gap and overcome the sparse coverage, low temporal resolution and partial information provided by local-scale in situ or remote sensing measurements, high resolution reanalysis with the assimilation of dust-related satellite products over source regions and the thoroughly evaluation of their products represent a powerful tool able to describe with accuracy the dust variability and trends. This also provides extensive information for the socio-economic evaluation of major events, and their short (direct) and long-term (induced) impacts on society.

The first 2007-2016 MONARCH dust regional reanalysis was produced in the context of the "Dust Storms Assessment for the development of user-oriented Climate services in Northern Africa, the Middle East and Europe" (DustClim) project in which the Barcelona Supercomputing Center (BSC) and the Spanish State Meteorological Agency (AEMET) took part. The DustClim project was a 3-years project conducted in the framework of the European ERA4CS Joint Call for Transnational Collaborative Research Projects. DustClim sought to produce and deliver an advanced dust regional model reanalysis for Northern Africa, Middle East and Europe covering the satellite era of quantitative aerosol information, and to develop dust-related services tailored to specific socio-economic sectors.

The regional dust reanalysis has been produced using the mineral dust module of the MONARCH chemical weather system (Di Tomaso et al., 2017; Pérez et al., 2011; Klose et al., 2021) and by assimilating satellite observations of aerosol optical depth (AOD) with specific observational constraints for dust (Di Tomaso et al., 2022). The evaluation of the reanalysis performance was carried out using independent datasets grouping observations of variables that are included in the model simulations and are relevant for its scoring (M. Mytilinaios et al., 2021).

During the ongoing contract between AEMET and the BSC, it has been agreed to extend the original reanalysis in time to cover more recent years. Two additional years or reanalysis (2017-2018) have been computed and evaluated recently (Karnezi et al. 2023, 2024). This work highlighted already some challenges in extending the original DustClim reanalysis in the future: the transition of MODIS retrievals from Collection 6.0 (not available anymore) to 6.1 introduced systematic differences in dust optical depth over Middle East. Additionally, meteorological forcings from ERA-Interim used until 2018 stopped being available during 2019. Finally, the BSC supercomputer has been upgraded in 2024 and porting the former model and assimilation workflow to the new machine was estimated to be a significant effort. Given that homogeneity between past and future reanalysis production could not be ensured anymore at this point we took this year the opportunity to revisit the entire reanalysis configuration, based on recent progress on operational near-real time assimilation (Karnezi et al. 2025). This effort has two additional goals:

1. tackle some limitations of the original DustClim reanalysis, in particular the limited satellite constrains far from sources regions, and the absence of a control run simulation with no assimilation
2. provide a new framework for low latency continuous updates of the reanalysis using the latest generation of satellite instruments (VIIRS)

The report is structured as follows: section 2 recalls the main information about the new model configuration, assimilated observations and data assimilation methodology, section 3 includes the validation for the new reanalysis configuration compared to DustClim for the year 2018 for both dust optical depth and dust PM_{10} concentrations, section 4 reports annual and monthly climatology of dust optical depth and surface concentrations for the entire time-series (2007-2019), and section 5 presents the corresponding validation against the AERONET network of ground-based sun-photometers.

2. DustClim 2.0 configuration

Model configuration

The MONARCH model has been run on the domain of the WMO Barcelona Dust Forecast Center bounded by latitude 25° West and 60° East and longitude 0° South and 65° North (Northern Africa Middle East and Europe, NAMEE), at 0.10° x 0.10° horizontal resolution, with 40 vertical layers, with top pressure of the domain at 5000 Pa, using a temporal integration step of 20 seconds. Spatial domain and resolution have not been changed with respect to DustClim, but one main novelty is that a reference model configuration (control simulation) is established now to discriminate between model's dust tendencies and those introduced by satellites assimilation. The DustClim reanalysis did not provide a single reference control simulation because each member of the reanalysis ensemble was based on a different dust emission scheme or meteorological input. The reference model configuration is taken the same as the current BDRC daily dust forecast (Karnezi et al. 2025), which has been optimized and tuned during the past years over the NAMEE region (Karnezi et al. 2023, 2024). We remind below main choices retained for the dust model configuration and differences with respect to DustClim:

- 8 dust bins (0.2-20 μm)
- Dust emission scheme from Ginoux (2001) updated with friction velocity (Klose et al. 2020) ***instead of three different emission schemes in the original DustClim***
- Source function from MODIS DB C6 based frequency of occurrence (climatology) derived at 0.1 degrees from Ginoux (2012)
- Standard desert mask based on monthly vegetation fraction Based on MODIS C5 monthly LAI climatology
- Emitted size distribution from Kok (2011)
- OPAC tri-axial spheroids extinction coefficients ***instead of spherical particles in the original DustClim***
- Online interaction between dust and radiation

The input meteorology (initial and boundary conditions) has been changed from ERA-Interim to ERA-5 (Hersbach et al. 2020), which replaced the former in 2019. Simulation output is provided every 3 hours (3:00, 6:00, ... 0:00 UTC) which is also the time resolution of the reanalysis product.

A 4-years long control simulation (2018-2022) has been conducted to ensure that the skills of the reference model are satisfactory over a longer period than those usually tested for operational forecasts upgrades (1 year, Karnezi et al. 2025). Results are not presented in this report but indicate that the reference model has stable performances across multiple years, in line with those discussed in Karnezi et al. (2025).

Assimilation configuration

To prepare the transition from MODIS to current generation of aerosols sensors we opted for extending the reanalysis using only VIIRS, which is available starting in 2012 and replaces the afternoon overpass of AQUA used for DustClim. This choice will allow evaluating the impact of replacing MODIS (DustClim) with VIIRS in DustClim 2.0. In a follow-up phase of the project, we will examine the added value of including MODIS TERRA morning overpass in the past, because it could provide added observational constraint to the reanalysis.

We used VIIRS NASA Level 2 Deep Blue retrievals (v2, Lee et al. 2024), made publicly available on the NASA Level-1 and Atmosphere Archive & Distribution System Distributed Active Archive Center (LAADS DAAC). We assimilate VIIRS Total Aerosol Optical Depth at 550nm (Aerosol_Optical_Thickness_550_Land_Ocean_Best_Estimate) over the entire NAMEE domain (land and ocean) but only use observations flagged as dust contaminated by the retrieval algorithm (Hsu et al. 2019). This choice reduces the number of observations being used but avoids to a certain extent the correction of simulated dust with unrelated aerosols (e.g. smoke or anthropogenic pollution). Observation errors are assigned to a value of 0.05 $\pm$ 0.2 AOD as in Escribano et al. (2022). The observations preprocessor selects retrievals with Quality Assurance (QA) flag equal or greater than 3 and 2 respectively over ocean and land. Finally original satellite Level 2 retrievals (6 km resolution at nadir) are regridded and averaged into the MONARCH NAMEE grid (10 km resolution) at 3-hourly steps to match model outputs.

A Local Ensemble Transform Kalman Filter (LETKF) algorithm is used to compute 3D corrections to the modeled dust concentrations as described in Di Tomaso et al. (2017, 2022) and Escribano et al. (2022). The main step consists in executing an ensemble of model forecasts to represent the uncertainty of the dust prediction. We kept an ensemble of 12 members (as in DustClim) but with perturbations applied to: i) global emissions calibration factor (DCAL) ii) size dependent emissions calibration factors (DCALBIN1-8) iii) spatially varying emissions calibration factors (PERTMAP). The perturbations choice is the main differences with DustClim reanalysis, where ensemble members were based on a combination of different dust schemes and input meteorology. The new choice does not propagate uncertainties in dust emission scheme or meteorology but has a major practical advantage, being unbiased with respect to the control simulation. It allows focusing the efforts on calibrating perturbations for a single well-tuned model. Model equivalents of satellite optical depths at 550 nm are computed according to new MONARCH dust optical properties (OPAC tri-axial spheroids). Since the size of the ensemble is relatively small, localization is needed to avoid spurious assimilation corrections far away from satellite observations. The localization radius is set to 150 km horizontally and 1 grid point vertically as in DustClim.

3. Validation of new reanalysis configuration

As mentioned previously, a new reanalysis configuration (DustClim 2.0) was implemented for the period 2018–2019. The primary purpose was to enable comparison with the previous configuration used in earlier reanalysis efforts, focusing first on the year 2018, and subsequently extending the dataset to include 2019. This extension builds upon the previously delivered and established dataset covering 2007–2018. Figure 3.1 presents time series of annual dust optical depth over AERONET sites (see Sec 3.1, but temporal collocation not imposed in Fig 3.1), showing the 2007–2018 average from the previous configuration alongside results from the new configuration for the years 2018–2019. We remark generally a reasonable agreement between DustClim and DustClim 2.0 during the overlap year in terms of DOD values and monthly variability. Some differences in terms of peak DOD are found in Middle-East as well as in terms of DOD values during the last months of the year across most regions.

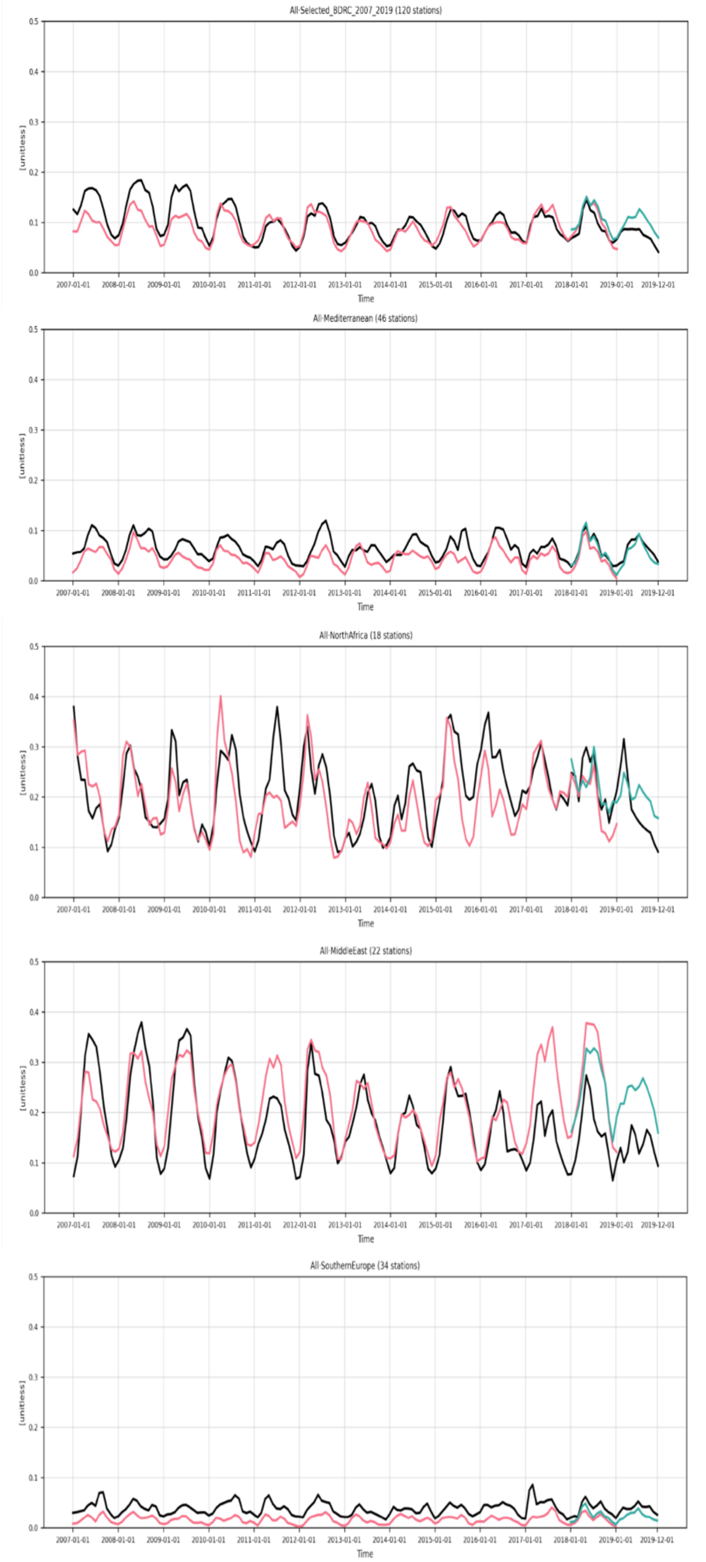

Figure 3.1 Time-series in monthly intervals (calculated from 3hourly measurements) for the whole period of 2007-2019 of O'Neill AODcoarse AERONET measurements (black line), DODcoarse from the previous reanalysis dataset (pink line) and DODcoarse from the new reanalysis dataset (green line). The first row is for the whole NAMEE stations, the second for the Mediterranean stations, the third for North Africa stations, the fourth for Middle East stations and the fifth for the Southern Europe stations.

The assessment of the reanalysis skills is done comparing the analysis fields against dust optical depth (DOD) and PM_{10} observations. Standard statistics such as correlation coefficient (r), mean bias error (MB), mean fractional bias in % (MFB), mean fractional error in % (MFE) and root mean square error (RMSE) are used to measure the skill of the model at specific locations or for groups of sites. The definition of these statistics is reported in the next Table (Table 3.1). For this study we used the so-called *flattened* computations, which consist in using all data points over the time record, across all selected stations. Hence, the reported statistics represent the skills of the reanalysis in predicting local and 3-hourly measurements for the ensemble of selected sites.

Table 3.1 Validation metrics used in this study and their definition.

Metric	Definition
Mean bias (MB)	$\mathrm{MB} = \frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)$
Root mean square error (RMSE)	$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)^2}$
Pearson correlation coefficient (r)	$r = \frac{\sum_{i=1}^{N}(M_i - \overline{M}) \cdot (O_i - \overline{O})}{\sqrt{\sum_{i=1}^{N}(M_i - \overline{M})^2} \cdot \sqrt{\sum_{i=1}^{N}(O_i - \overline{O})^2}}$
Mean fractional bias (MFB)	$\mathrm{MFB} = \frac{1}{N}\sum_{i=1}^{N}\frac{2 \cdot (M_i - O_i)}{M_i + O_i}$
Mean fractional error (MFE)	$\mathrm{MFE} = \frac{1}{N}\sum_{i=1}^{N}\frac{2 \cdot \lvert M_i - O_i \rvert}{M_i + O_i}$

3.1 Dust optical depth (DOD) observations: the global AERONET network

Dust-filtered AOD observations from AERONET (Aerosol, Robotic NETwork; Holben, 2001: http://aeronet.gsfc.nasa.gov/) are used for the assessment of the model results. The dust-filtering considered here is based on the Spectral Deconvolution Algorithm (SDA, also known as O'Neill; O'Neill et al., 2003) AERONET products that provide AODcoarse and AODfine fractions. AODcoarse observations are fundamentally associated with maritime/oceanic aerosols and desert dust. Since sea-salt is related to low AOD (< 0.03; Dubovik et al., 2002) and mainly affects coastal stations, high AODcoarse values are mostly related to mineral dust (i.e. DODcoarse). For the present evaluation exercise, we use the SDA Version 3 cloud-screened and quality assured (Level 2.0) observations. For comparison, modeled DODcoarse fields are bilinearly interpolated over the AERONET stations. Because AERONET data are acquired at 15-min intervals on average, all AERONET measurements within ±90 min of the model outputs have been averaged and used for the model comparison on a 3-hourly basis.

All AERONET stations that are available for the period 2007-2019 and are included in the North Africa, Mediterranean and Middle East (NAMEE) domain, as described in Di Tomaso et al. (2022) are used in the evaluation. In Figure 3.2 we show the AERONET stations used as well as the correspondent region.

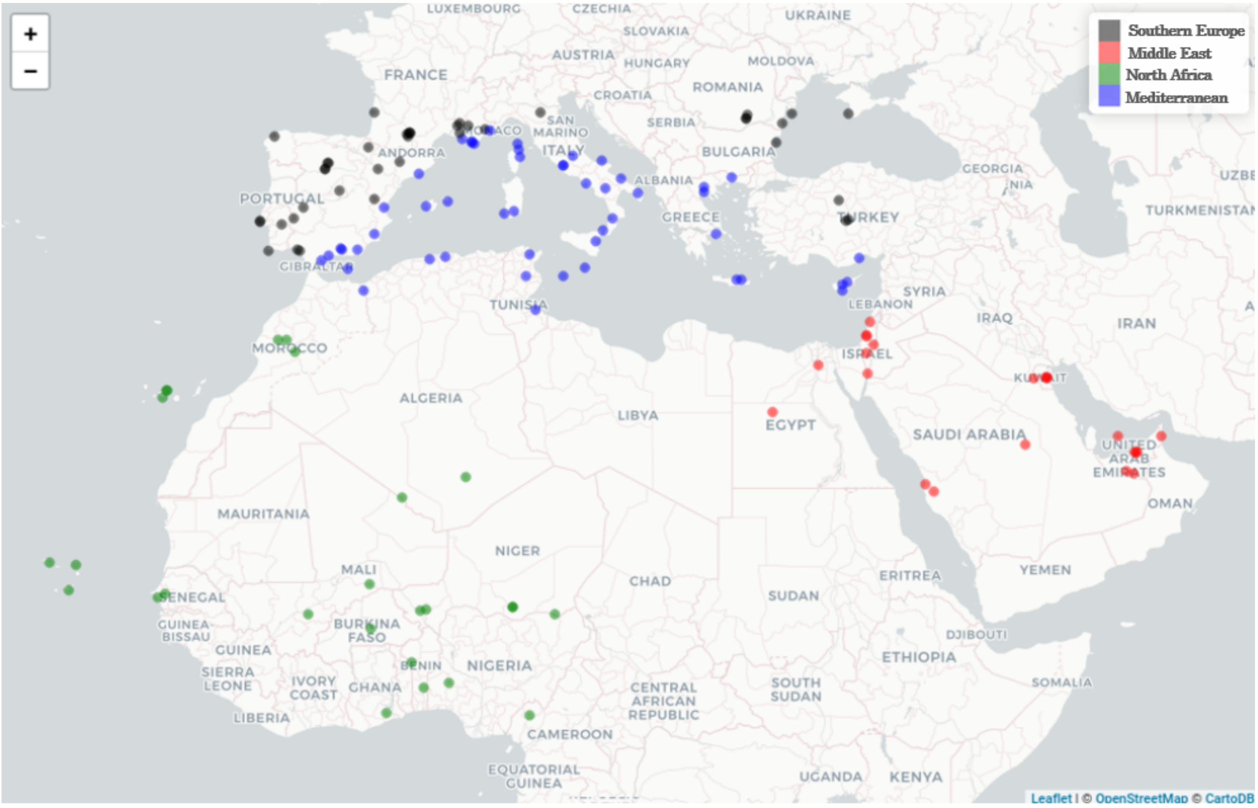

Figure 3.2 The AERONET stations used in this study per region they cover. With blue are represented the Mediterranean station, with green the North African stations, with red the Middle East stations and with blue the remaining Southern Europe stations.

3.2 DOD evaluation for the year 2018

Time series of collocated modeled and observed values for 2018 were constructed for the NAMEE domain, including a total of 64 AERONET stations, and for its subregions: the Mediterranean (25 stations), North Africa (10 stations), Middle East (10 stations), and Southern Europe (19 stations). The maps showing the number and location of sites in the NAMEE region as well as in the subregions are shown in Figure 3.3. All AERONET O'Neill measurements were extracted and used for model comparison on a 3-hourly basis, with results presented in Figure 3.4 after daily averaging.

Both reanalysis configurations capture the seasonal and interannual variability of mineral dust across the NAMEE regions. The new reanalysis configuration shows a better fit to the observations, particularly during peak dust events, indicating improved representation of dust events in both the NAMEE region and its subregions. In the Middle East, some overprediction persists, consistent with findings from the previous report for 2017 and 2018. That report noted that upgrading assimilated observations from MODIS Deep Blue Collection 6.0 to 6.1 introduced a systematic bias of approximately 0.1 in coarse DOD starting in 2017. This is consistent with the new configuration, where assimilated VIIRS satellite observations also slightly overestimate DOD; however, the overprediction is reduced in the updated reanalysis.

Table 3.2 summarizes the number of samples (3-hourly measurements) and verification statistics, including correlation (r), mean bias (MB), root mean square error (RMSE), mean fractional bias (MFB), and mean fractional error (MFE) in percentage, for AODcoarse O'Neill. The new configuration achieves a correlation of 0.83 across all NAMEE stations, compared to 0.79 for the previous configuration, and exhibits lower biases across NAMEE and its subregions. These results confirm that the new reanalysis more accurately captures dust events, both near source regions and downwind.

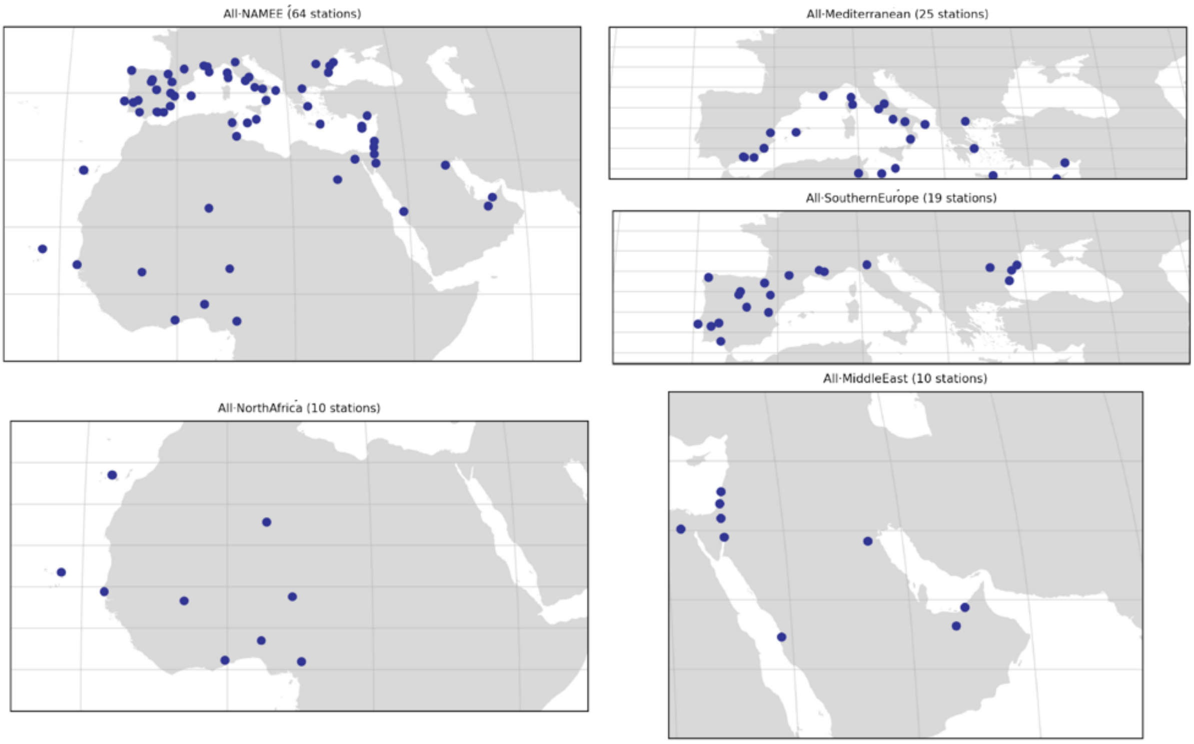

Figure 3.3 The AERONET stations for NAMEE and the sub-regions used for the validation year 2018 are shown.

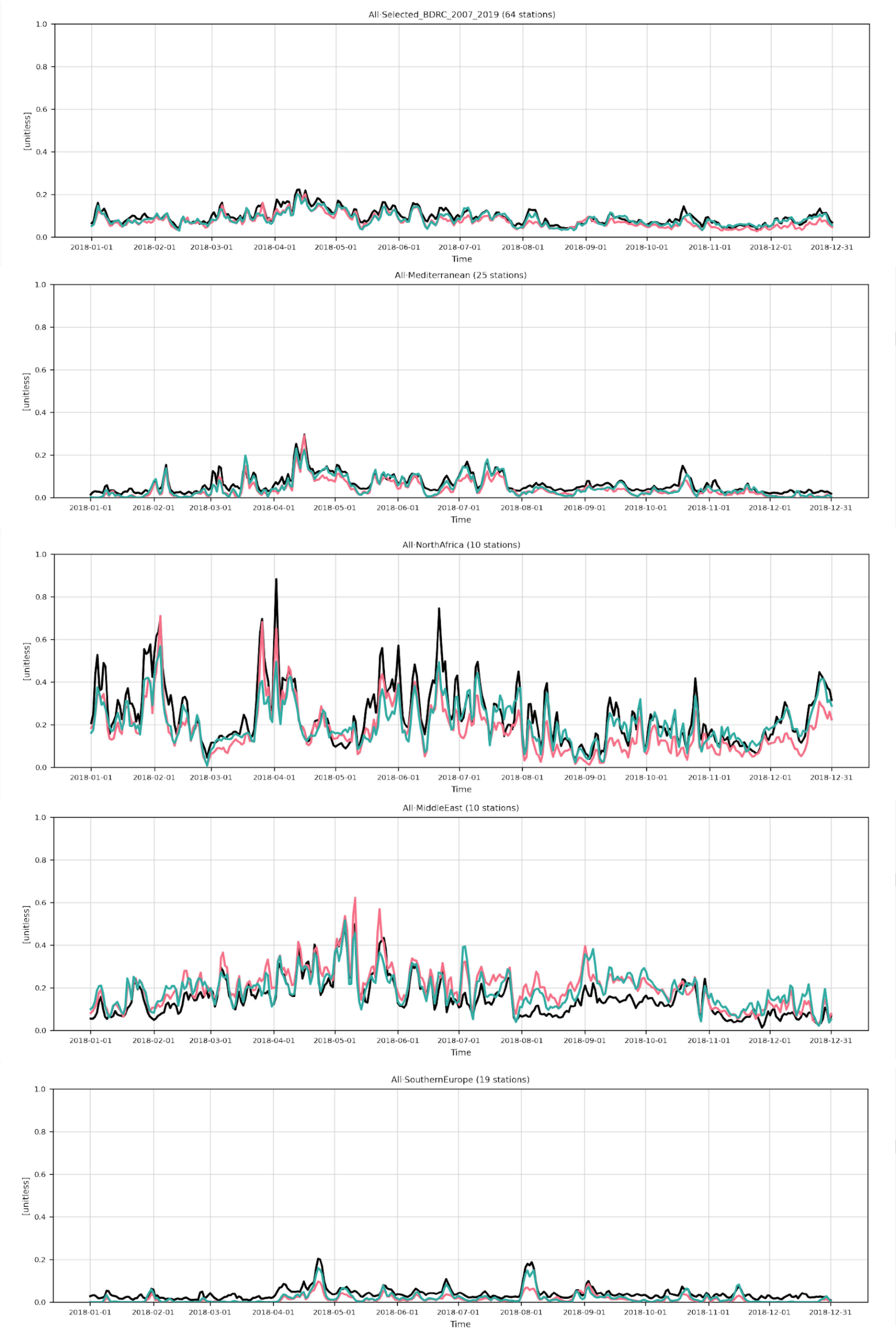

Figure 3.4 Time-series in daily intervals (calculated from 3hourly measurements) for the year 2018 of O'Neill AODcoarse AERONET measurements (black line), DODcoarse from the DustClim dataset (pink line) and DODcoarse from the DustClim 2.0 dataset (green line). The first row is for the whole NAMEE stations, the second for the Mediterranean stations, the third for North Africa stations, the fourth for Middle East stations and the fifth for the Southern Europe stations.

Table 3.2. Number of samples (NDATA) and verification statistics (r, RMSE, MB, MFB and MFE) for the old and new reanalysis DODcoarse versus AERONET O'Neill AODcoarse for the year 2018 for the whole NAMEE and for the Mediterranean, North Africa, Middle East, and Southern Europe regions.

		NDATA	r	RMSE	MB	MFB	MFE
NAMEE	DustClim	43628	0.79	0.10	-0.02	-82.4	107.5
	DustClim 2.0		0.83	0.08	-0.01	-72.2	101.9
Mediterranean	DustClim	15850	0.80	0.06	-0.02	-97.7	110.6
	DustClim 2.0		0.84	0.05	-0.01	-86.7	105.3
North Africa	DustClim	5358	0.83	0.16	-0.07	-58.3	73.8
	DustClim 2.0		0.84	0.15	-0.03	-30.2	64.8
Middle East	DustClim	7746	0.70	0.15	0.05	23.1	67.9
	DustClim 2.0		0.70	0.13	0.04	18.8	67.1
Southern Europe	DustClim	14674	0.69	0.05	-0.03	-130.4	137.3
	DustClim 2.0		0.83	0.04	-0.02	-120	130.1

3.3 PM_{10} evaluation in Spain in 2018

The two reanalyses have been compared with PM_{10} dust-filtered observations in Spain provided by the CSIC-IDAEA (for the years 2018-2021) and available through the Spanish government website: (https://www.miteco.es). In this case 3-hourly outputs of our model are averaged on daily basis for the comparisons with the CSIC-IDAEA dataset. The validation metrics as in Table 3.1 are used in these comparisons. The number of samples (3-hourly measurements) and the verification statistics including the correlation (r), mean bias (MB), root mean square error (RMSE), MFB and MFE in % for daily PM_{10} are summarized (Table 3.3).

Both reanalysis runs successfully reproduce the observed daily variability of PM_{10} dust concentrations at the three stations shown in Figure 3.4 for 2018. In the new reanalysis, several peak values are reduced, leading to improved bias statistics for PM_{10}. Correlations increase at the Viznar (Granada) and El Atazar (Madrid) stations, while at the Las Palmas station the correlation decreases; however, the RMSE is substantially reduced from 88 to 69 $\mu g/m^3$.

Consistent conclusions are obtained from the annual statistics (Table 3.3) when considering all 29 stations. Although the overall correlation decreases from 0.39 to 0.32, the mean and fractional biases, RMSE, and fractional errors are all reduced in the upgraded configuration, reflecting a decrease in overestimation.

Table 3.3. Statistics computed for the two reanalyses configurations, old and the new proposed one for the for PM_{10} measurements of all CSIC stations in Spain for the year 2018. We report the total number of data (NData), the Correlation coefficient (r), the Root Mean Square Error (RMSE), the Mean Bias (Mean), the Mean Fractional Bias (MFB) and the Mean Fractional Error (MFE).

		NDATA	r	RMSE	MB	MFB	MFE
NAMEE	DustClim	1848	0.39	36.5	1.72	1.3	119.6
	DustClim 2.0		0.32	28.5	-0.66	-3.2	118.2

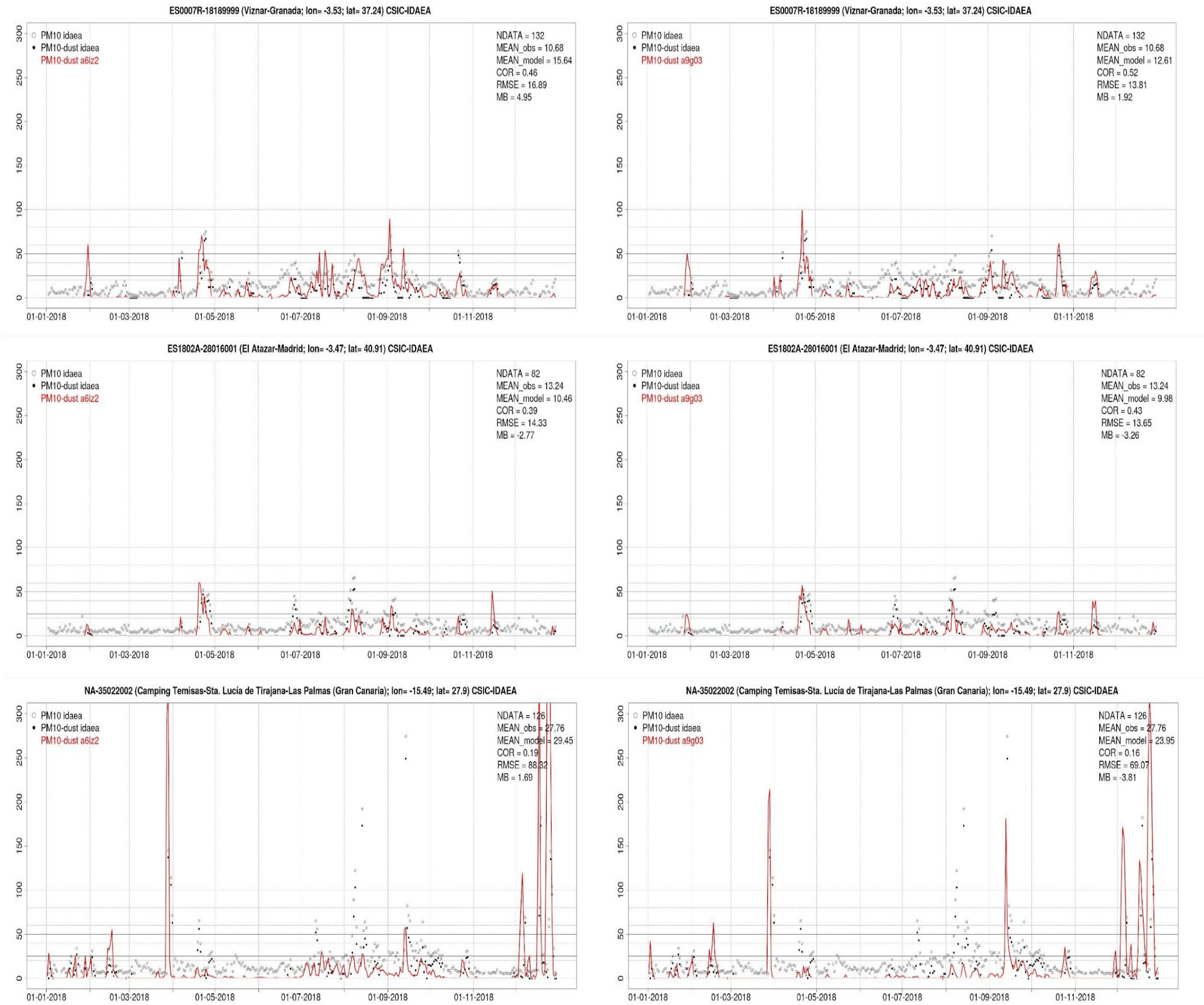

Figure 3.4 Daily PM_{10} time series. PM_{10} from CSIC-IDAEA (white circles, all aerosols), PM_{10}-dust from CSIC-IDAEA (black dots), PM_{10}-dust MONARCH (red line for 2018 over Viznar, Granada (first row), El Atazar, Madrid (second row) and Camping Temisas-Sta, Lucía de Tirajana, Las Palmas (third row). Left column: Previous Reanalysis. Right column: New Reanalysis. Skill scores per site and model are shown in the upper right corner (NDATA: available days, MEAN observations, MEAN model, correlation COR, RMSE, mean bias MB). Daily averages from the model are calculated using the 3-hourly dataset.

4. Climatology

The dust reanalysis data set consists of 12 dust related variables (Table 1 in Karnezi at al. 2023) which include upper air (dust mass concentrations and extinction coefficient), surface (dust deposition and solar irradiance fields, among them) and total column variables (e.g., dust optical depth and load). Some dust variables, such as concentrations and total load, are expressed for a binned size distribution that ranges from 0.2 to 20 μm in particle diameter. Both analysis and first-guess fields are available for the variables that are diagnosed from the control vector. The first-guess are model forward simulations initialized with an analysis. When available, the analysis field is the recommended output for that variable. A set of ensemble statistics are calculated and archived for each output variable, namely the ensemble mean, standard deviation, maximum and median. The spread among the ensemble members, represented by the standard deviation with respect to the ensemble mean, can be interpreted as a measure for the uncertainty in the mean estimates. While model fields have been produced on 40 vertical levels, the data are stored on 15 standard pressure levels between 1000 and 100hPa (i.e., 1000, 975, 900, 850, 750, 700, 600, 500, 400, 350, 300, 250, 175, 150, 100hPa). In that way the storage space is reduced while easing the use of vertical information. The full dataset, including the latest processed year 2019, is currently available at https://earth.bsc.es/thredds_dustclim/homepage .

A climatology of the reanalysis dust optical depth (DOD), vertical extinction profiles and dust surface concentrations for the period 2007-2016 can be found in Mona et al. (2021). Here we present the climatology for the annual DOD and dust surface concentration in Figure 4.1 for the period of 2007-2019 together with the anomalies of each year for the annual DOD and the dust surface concentration: in Figure 4.2 for years 2007 until 2013 and in Figure 4.3 for the years 2014 until 2019. Magnitude of anomalies in 2019 is in line with previous years for DOD. Surface dust concentrations are significantly smaller than climatological ones for a combination of multiple reasons related to the different configurations in DustClim and DustClim 2.0: revised MONARCH model parameterizations (e.g. dry and wet deposition), different dust optical properties, the average of different dust emissions schemes (three schemes used in DustClim) producing values that can differ significantly from each single scheme (Ginoux scheme used in DustClim 2.0).

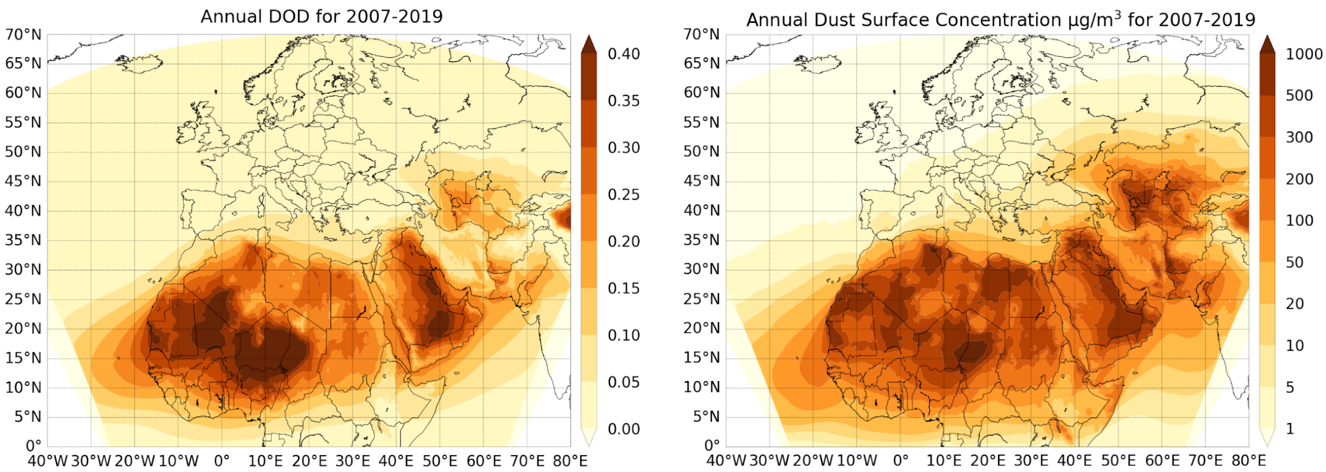

Figure 4.1 Climatology of Dust Optical Depth (DOD) (left column) and dust surface concentration (right column) averaged over the 13-year period, 2007-2019.

Monthly time series of annual mean dust optical depth (DOD) and dust surface concentration are presented in Figure 4.4. The figure also includes results for 2018 from the DustClim 2.0 reanalysis. Among the years shown, 2018—under both configurations—exhibits the highest overall DOD, with maximum average values occurring during the summer. Peak DOD is observed in April and June–July, while peak surface dust concentrations occur in January. Mean surface concentrations for both 2018 and 2019 are substantially lower in the new reanalysis configuration, consistent with the anomalies shown in Figure 4.3.

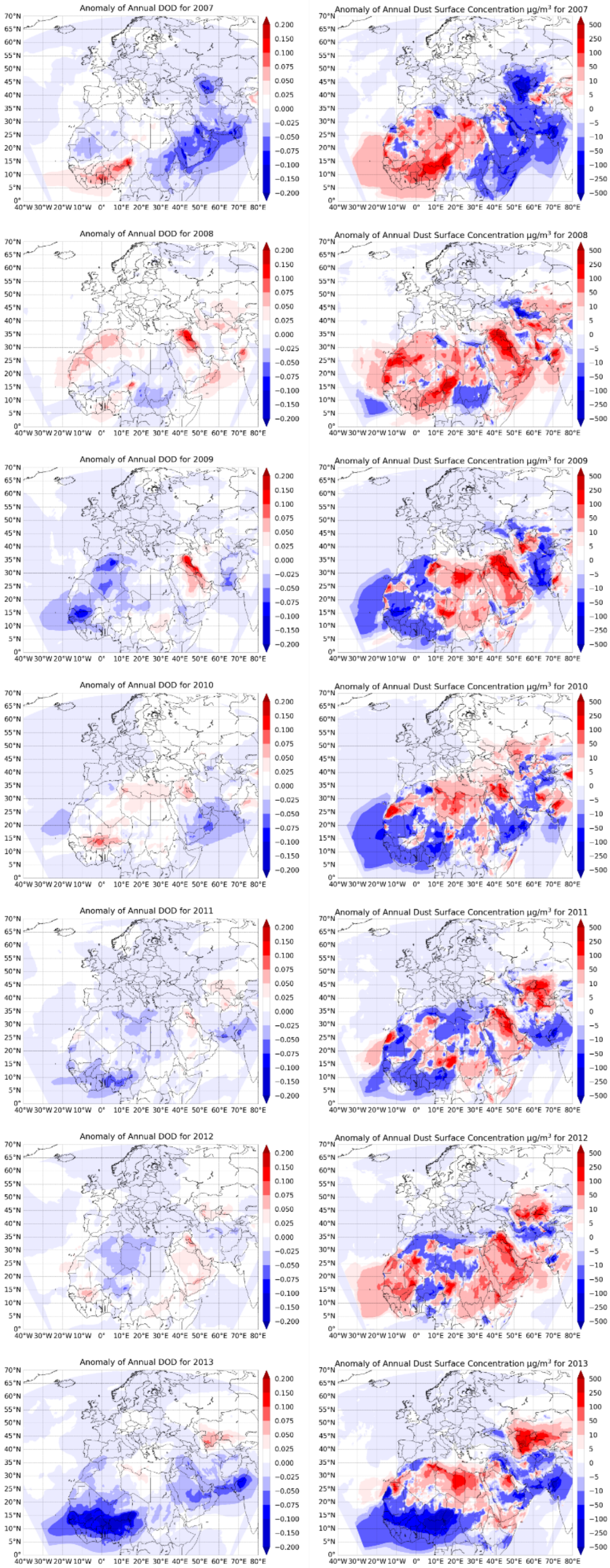

Figure 4.2 Yearly anomalies of Dust Optical Depth, DOD (on the left column) and dust surface concentration (on the right column) at 550 nm for the years 2007-2013.

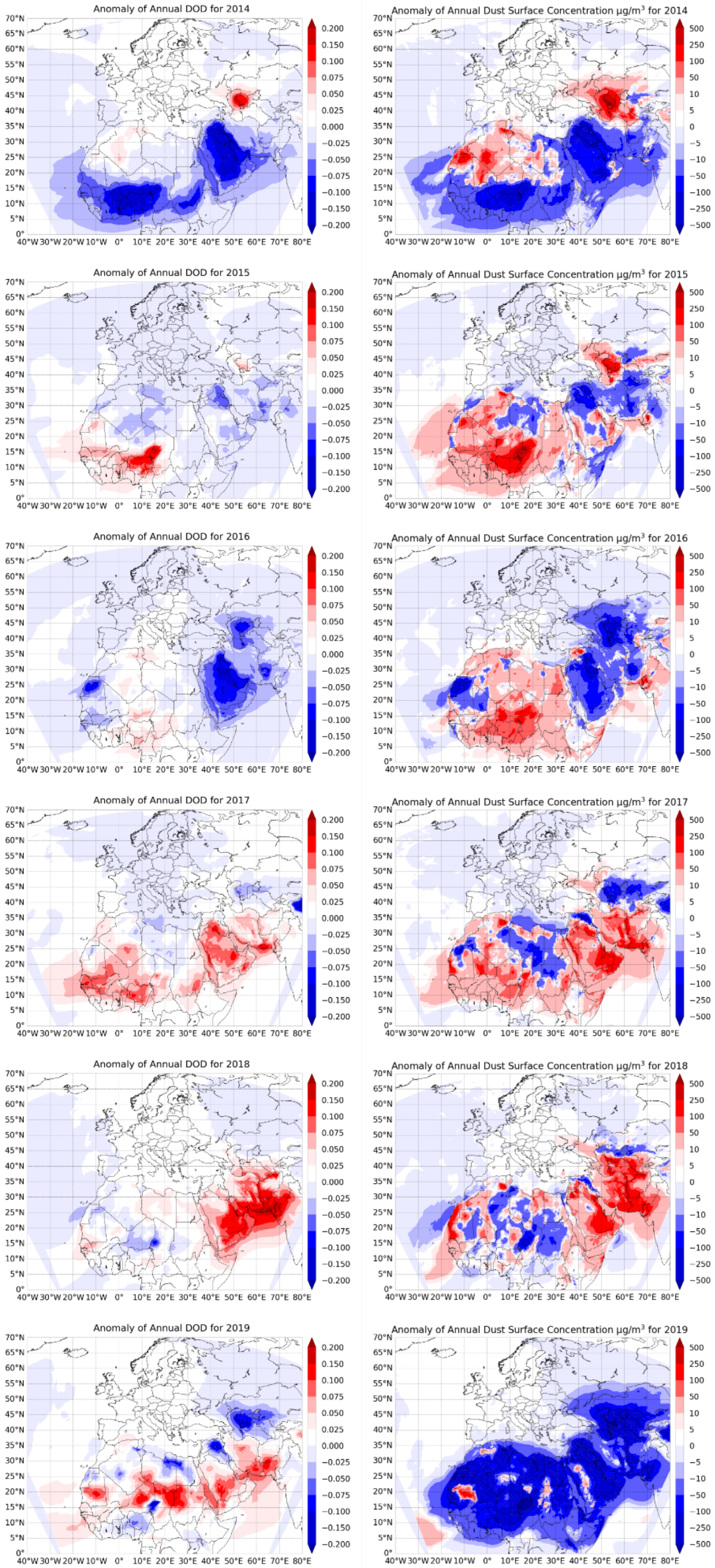

Figure 4.3 Yearly anomalies of Dust Optical Depth, DOD (on the left column) and dust surface concentration (on the right column) at 550 nm for the years 2014-2019.

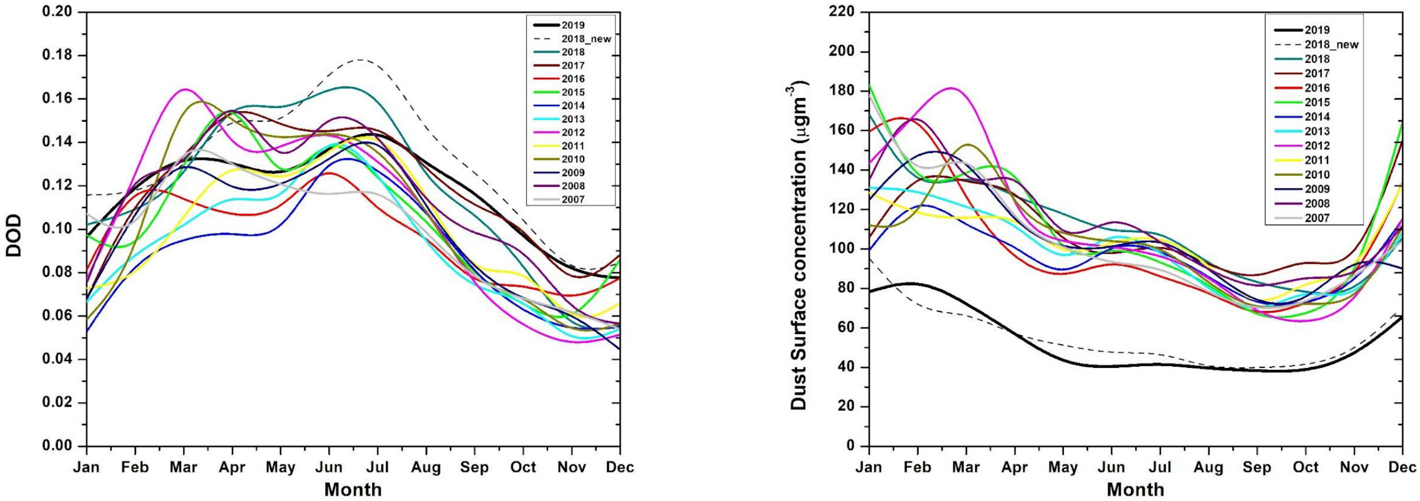

Figure 4.4 Time-series for monthly DOD (left column) and dust surface concentration (right column) for each year of reanalysis from 2007-2019. 2018 with both old and new reanalysis configuration (dash line). The different colors represent each year. The annual DOD for each year (from 2007 until 2019 respectively) was (0.1, 0.11, 0.1, 0.1, 0.1, 0.11, 0.09, 0.09, 0.1, 0.1, 0.12, 0.12, 0.12) and 0.13 for 2018 with the new reanalysis and the annual surface concentration was (106, 113, 105, 103, 104, 110, 100, 96, 111, 104, 111, 111, 54 μg m^{-3}) and 56 μg m^{-3} for 2018 with the new reanalysis.

5. Validation

The assessment of the reanalysis skills including now all years 2007-2019 is done comparing the analysis fields against dust optical depth (DOD) observations. We use the same methodology as in section 3 with the same standard statistics and for dust-filtered AOD observations from AERONET as in section 3.1.

5.1 Evaluation for 2007-2019 reanalysis for DOD over NAMEE and subregions.

We constructed time-series of collocated modeled and observed values for the whole period from 2007 until 2019 for the NAMEE area for a total of 120 AERONET stations and for the subregions of the Mediterranean (46 stations), North Africa (18 stations), Middle East (22 stations) and Southern Europe (34 stations). All AERONET O'Neill measurements have been extracted and used for the model comparison on a 3-hourly basis and are shown in Figure 5.1 after monthly averaging.

The number of samples (3-hourly measurements) and the verification statistics including the correlation (r), mean bias (MB), root mean square error (RMSE), MFB and MFE in % for AODcoarse O'Neill are summarized (Table 5.1). Including one additional year (2019) does not alter the verification statistics with respect to those reported previously for 2007-2018 [Karnezi et al. 2023, 2024]. The updated table confirms the capabilities of the reanalysis to track well seasonal, inter-annual and geographical variability of mineral dust within the NAMEE region.

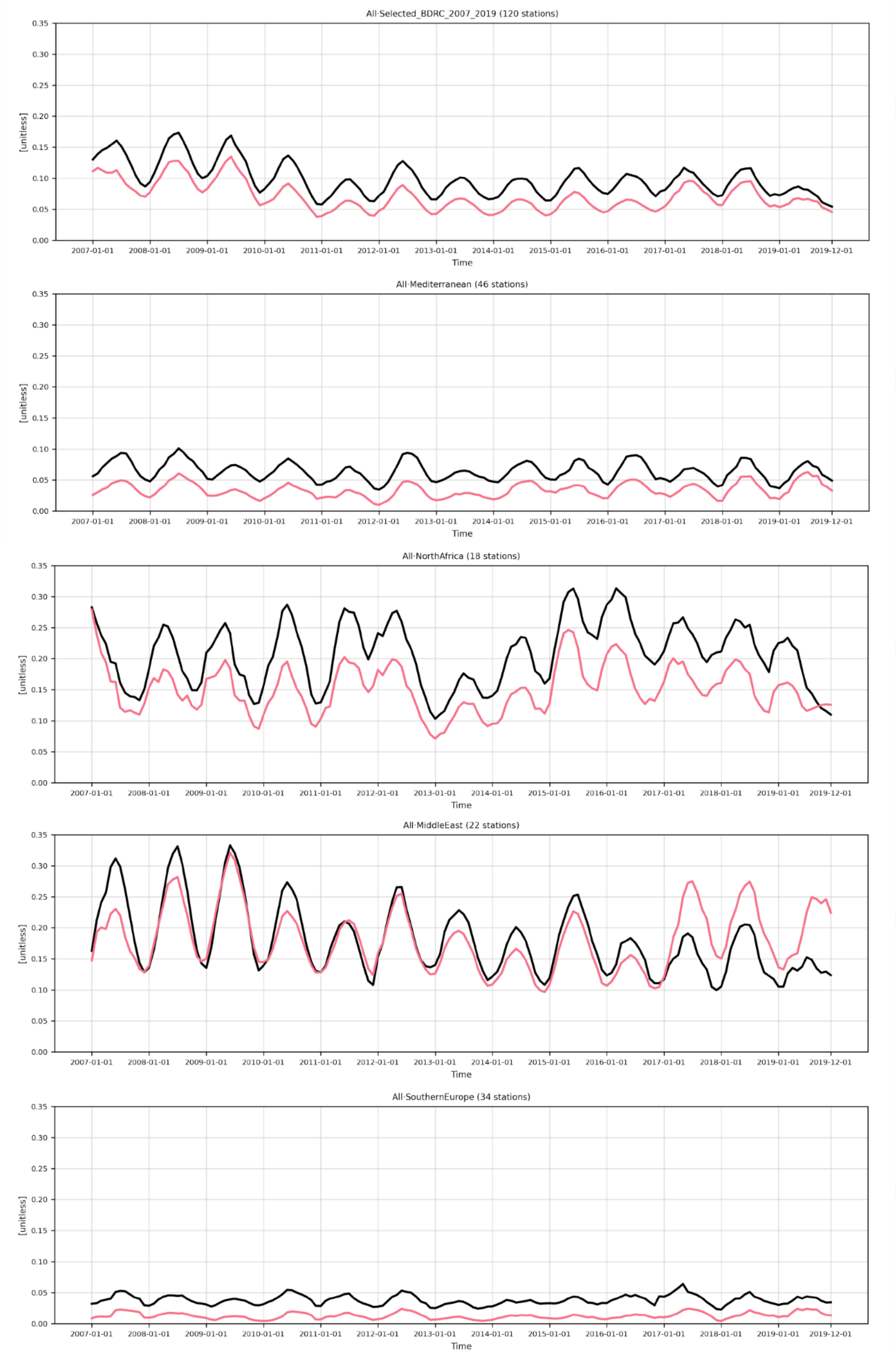

Figure 5.1 Time-series in monthly intervals (calculated from 3hourly measurements) for the whole period of 2007-2019 of O'Neill AODcoarse AERONET measurements (black line) and DODcoarse from the reanalysis dataset (pink line). The first row is for the whole NAMEE stations, the second for the Mediterranean stations, the third for North Africa stations, the fourth for Middle East stations and the fifth for the Southern Europe stations.

Table 5.1. Number of samples (NDATA) and verification statistics (r, RMSE, MB, MFB and MFE) for the reanalysis DODcoarse versus AERONET O'Neill AODcoarse for the entire period (2007–2019) for the whole NAMEE and for the Mediterranean, North Africa, Middle East, and Southern Europe regions.

	NDATA	r	RMSE	MB	MFB(%)	MFE(%)
NAMEE	453533	0.80	0.09	-0.03	-89.9	110.5
Mediterranean	173475	0.75	0.06	-0.03	-110.1	120.8
North Africa	58484	0.81	0.15	-0.05	-50.7	75.7
Middle East	87296	0.70	0.14	0.0	0.47	58.3
Southern Europe	134278	0.68	0.05	-0.02	-139.6	146.3

6. Conclusions and perspectives

In this report we introduced a new reanalysis configuration (DustClim 2.0) that introduces fundamental changes with respect to DustClim. These include changes in model configuration, assimilated observations and assimilation setup. We validated first for an overlap year (2018) with dust optical depth from AERONET for the NAMEE region and PM_{10} concentrations for Spain from CSIC dataset. We concluded that the DustClim 2.0 has better Dust Optical Depth (DOD) correlations and lower biases for all NAMEE and sub-regions and lower errors for PM_{10} concentrations. Then, we evaluated the additional year (2019) of DustClim 2.0 and recomputed climatological fields for (DOD) and dust surface concentrations for the full available period (2007-2019). While DOD values are comparable among DustClim 2.0 and DustClim ensuring somehow a temporal consistency between MODIS and VIIRS based reanalyses, surface concentrations differ significantly due to the changes of configuration. The extended 2007-2019 reanalysis dataset has been evaluated against AERONET AODcoarse measurements. Results are in line with those reported in previous publications (Di Tomaso et al., 2022) in terms of reanalysis skills across the different NAMEE sub-regions. The current extended dataset (Dustclim until 2018, Dustclim 2.0 since 2019) does not provide a consistent time series of dust concentrations across the full period. However, the results discussed in this report set a new framework for extending the DustClim reanalysis until current days and, possibly, update it back in the past, to ensure a temporally coherent time series covering the full era of quantitative aerosols spaceborne observations.

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