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Centro Nacional de Supercomputación

USER'S GUIDE OF THE BSC-DREAM8B MODEL

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Mineral dust, BSC-DREAM8b

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Summary

The study of desert dust, its entrainment, transport and deposition is an area of growing importance in investigations of global environmental change because dust storms have great importance on the physical environment and the world's human inhabitants. Dust models are essential to complement dust-related observations, understand the dust processes and predict the impact of dust on surface level PM concentrations. Regional-scale models are well suited for simulation of dust storm events or for comparisons with in-situ observations.

The Earth Sciences Department from the Barcelona Supercomputing Center – Centro Nacional de Supercomputación (BSC-CNS; www.bsc.es) maintains a dust forecast operational system with the updated version of the former Dust Regional Atmospheric Model (DREAM) called BSC-DREAM8b v2.0 and conducts modelling research and developments. The model predicts the atmospheric life cycle of the eroded desert dust and was developed as a pluggable component of the Eta/NCEP (National Centers for Environmental Prediction) model. It solves the Euler-type partial differential non-linear equation for dust mass continuity and it is fully inserted as one of the governing prognosis equations in the atmospheric Eta/NCEP atmospheric model equations. The present document describes the BSC-DREAM8b mineral dust forecast system operational at BSC-CNS.



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1. Introduction

1.1. Main objective

The study of desert dust, its entrainment, transport and deposition is an area of growing importance in investigations of global environmental change because dust storms have great importance on the physical environment and the world's human inhabitants. Dust models are essential to complement dust-related observations, understand the dust processes and predict the impact of dust on surface level PM concentrations. Regional-scale models are well suited for simulation of dust storm events or for comparisons with in-situ observations.

Operational dust forecasts have been successfully developed and used for planning dust measurement campaigns within the framework of several European projects (e.g., MINATROC, ADIOS and EARLINET). Especially important is the role played by the models DREAM (Dust Regional Atmospheric Model; Nickovic et al., 2001) and SKIRON (Kallos et al., 1997; Nickovic et al., 1997a,b) that provide first operative dust forecast for North Africa and Europe. Currently, BSC-DREAM8b is operated and further developed at the Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS; www.bsc.es). In the present manuscript, BSC-DREAM8b mineral dust forecast system will be described.

1.2. Background

Atmospheric aerosol consists of material emitted directly from sources (primary component) and material formed by gas-to-particle conversion in the atmosphere (secondary component). These atmospheric aerosols can be emitted by a great variety of natural and anthropogenic sources resulting in a large variability of their chemical characteristics. With the possible exception of sea-salt aerosol, the dust loading in the atmosphere is the most abundant of all aerosol species (IPCC, 2001).

One environmental consequence of atmospheric dust loadings is their significance for climate through a range of possible influences and mechanisms (Kalu, 1987). Once in the atmosphere, dust particles interact with solar and thermal radiation, modulating the Earth radiation balance (Maenhaut et al., 1996; Moulin et al., 1997; Alpert et al., 1998; Miller and Tegen, 1998; Moulin and Chiapello, 2004), and causing large uncertainties in assessing climate forcing by atmospheric aerosols (IPCC, 2007). Dust interacts with clouds playing a role in the formation of rainfall (Kalu, 1987; Levin et al., 1996) and affects photolysis rates and ozone chemistry by modifying the UV radiation (Dentener et al., 1996; Dickerson et al., 1997; Martin et al., 2003; Liao et al., 2004). Desert dust deposition also influences the biochemical cycles of both oceanic and terrestrial ecosystems (Tegen and Fung, 1995; Swap et al., 1996; Mahowald et al., 2005).

Thus, the entrainment, transport and deposition of dust can present a variety of problems to inhabitants in and around desert areas such as deaths and damage caused in traffic accidents, road disruption, aviation operations and impacts in the human health, such as allergies, respiratory diseases and eyes infections (WHO, 2005). It is also thought to be linked to health risks, such as epidemics of lethal meningitis in the semi-arid sub-Saharan territory known as the Sahel belt (Thomson et al., 2006) and

increased incidences of paediatric asthma attacks in the Caribbean (Gyan et al., 2005). The seriousness of the problem inspired the development of the World Weather Research Programme (WWRP) and the Global Atmospheric Watch (GAW) Sand and Dust Storm Warning Assessment and Advisory System (SDS-WAS) Project (www.wmo.int/sdswas) was established in September 2004.

The main objective of SDS-WAS Project is to establish a WMO coordinated global network of SDS-WAS centers which is to enhance the ability of countries to deliver timely and quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities. Thus, these Regional Nodes deal with both operational and scientific aspects related to atmospheric dust monitoring and forecasting in their respective regions. In early 2008, WMO accepted the offer of the China Meteorological Agency to host a regional centre for the SDS-WAS Asia/Central-Pacific node of SDS-WAS. A partnership of two research Spanish institutions, BSC-CNS (www.bsc.es) and the Spanish National Agency of Meteorology (AEMET, www.aemet.es), hosted Northern Africa-Middle East-Europe (NA-ME-E; <http://sds-was.aemet.es/>) Node and its partners include several international organizations and institutions. The experience acquired with the management in coordination with AEMET of the WMO SDS-WAS NA-ME-E Regional Center and the demand of many national meteorological services led to the deployment of operational dust forecast services have been contributed to the creation of the first WMO Regional Meteorological Center specialized on Atmospheric Sand and Dust Forecast, the Barcelona Dust Forecast Center. On June 2014, the Barcelona Dust Forecast Center (BDFC; <http://dust.aemet.es/>), was publicly presented. The Center operationally generates and distributes predictions for the NA-ME-E region.

A variety of regional and global models of the dust aerosol cycle have been developed since early 1990s. Most of the modelling work was motivated by the need, for climate studies, to represent aerosol concentrations and their feedback onto radiation at the global scale. Dust generation and the parameterization of its deposition processes is a highly complex process and extremely variable on spatial and temporal scales that responds in a non-linear way to a variety of environmental factors, such as soil moisture content, type of surface cover or surface atmospheric turbulence (Knippertz and Todd, 2012).

Apart from the global scale dust models, a number of models have been developed to describe the dust cycle for key regions like the Sahara (e.g. Nickovic et al., 2001) and East Asia (e.g. Wang et al., 2000). A correct assessment of dust fluxes requires a precise knowledge of the surface properties of erodible terrains (Ginoux et al., 2012). While in earlier global models (e.g. Tegen and Fung, 1994) all desert surfaces were assumed to be potential dust sources, recent models (e.g. Ginoux et al., 2001; Tegen et al., 2002; Zender et al., 2003; Tegen et al., 2013) make an effort to take into account the influence of the different surface conditions on dust emissions. However, simplifications are required at the global level because of the lack of good datasets of soil texture, non-erodible soil elements and other properties required at the fine scales (Mahowald et al., 2005). Modellers generally assume a globally constant dust “tuning” emission factor which that minimizes the error of the modelled global dust concentrations and deposition fluxes when compared to observations.



2. Model description

2.1. History of the model

DREAM is a successor of the single particle size dust model (Nickovic and Dobricic, 1996), first ever performed successful operational dust forecast was run in the Tunisian Meteorological Service. During 1996-1998, routine daily dust forecasts were available within the SKIRON project of the University of Athens. Further model developments continued in ICoD, University of Malta, and resulted to DREAM – the model with four particle bins and improved parameterizations for dust emission, deposition and advection; it was run daily during 1998-2005. In May 2005, operational DREAM dust forecasting system was transferred to Environmental Modelling Laboratory of the Technical University of Catalonia (UPC) and after September 2006, the model runs in the Barcelona Supercomputing Centre-Centro Nacional de Supercomputación (BSC-CNS, <http://www.bsc.es/projects/earthscience/BSC-DREAM/>).

Unlike the original DREAM (Nickovic, 2001) version, from 2003 onwards a research version of the model started to emerge. Following the idea of improving weather forecasts by including the dust radiative effect, an online interactive dust-radiation scheme was under development in the period 2002-2005 showing the positive impact of including dust-radiation interactions in the short-term weather forecast. A set of updates were included (Nickovic 2002; 2005): 1) a source function based on the arid and semi-arid categories of the 1 km USGS land use data; 2) a more detailed particle size distribution which includes 8 size bins within the 0.1-10 μm radius range and a particle size distribution (Tegen and Lacis, 1996); and, 3) in cooperation with the Oceanographic Institute (Erdemli, Turkey). All these achievements were included in the BSC-DREAM8b model (Pérez et al, 2006a, b). The main features of the updated operational model version (BSC-DREAM8b version 2.0) described in detail by Basart et al. (2012b) are: 1) a source function based on a topographic preferential source mask from Ginoux et al. (2001) and 2) a new dry deposition scheme based on Zhang et al. (2001).

In the last years, the BSC-DREAM8b model is one of the reference dust model for dust research and forecasting in North Africa and Europe for a large number of organizations. This motivated the development of a mineral dust database of the BSC-DREAM8b model simulations (<http://www.bsc.es/earth-sciences/mineral-dust/catalogo-datos-dust>).

2.2. The DREAM model

DREAM (Nickovic et al., 2001) predicts the atmospheric life cycle of the eroded desert dust and was developed as a pluggable component of the Eta/NCEP (National Centers for Environmental Prediction) model. DREAM solves the Euler-type partial differential non-linear equation for dust mass continuity and it is fully inserted as one of the governing prognosis equations in the atmospheric Eta/NCEP atmospheric model (Mesinger et al., 1988; Janjic, 1994; Zhao and Carr, 1997). In the horizontal, the semi-staggered Arakawa E grid is used. The vertical coordinate of the model (Mesinger et al. 1988) is defined by

$$\eta = \frac{(p - p_T) (p_{ref}(z_S) - p_T)}{(p_S - p_T) (p_{ref}(0) - p_T)}$$

Here, p_T is the pressure at the top of the model atmosphere, p_{sfc} and z_{sfc} are the pressure and the height of the model bottom boundary, p_{ref} is a reference pressure vertical profile (e.g. pressure of the standard atmosphere).

The concentration equation simulates all major processes of the atmospheric dust cycle (Fig. 2.1). During the model integration, calculation of the surface dust injection fluxes is made over the model points declared as deserts. Once injected into the air, dust aerosol is driven by the atmospheric model variables: by turbulent parameters in the early stage of the process when dust is lifted from the ground to the upper levels; by model winds in the later phases of the process when dust travels away from the sources. Finally, by thermodynamic processes and rainfall of the atmospheric model and land cover features which provide wet and dry deposition of dust over the Earth surface.

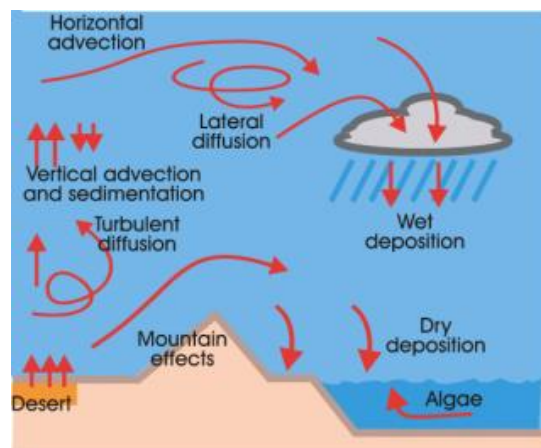


Figure 2.1 Injection, transport and deposition processes of dust.

One of the key components of the dust model is the treatment of the sourcing terms in the concentration continuity equation. Failure to adequately simulate/predict the production phase of the dust cycle leads to wrong representation of all other dust processes in the model. Therefore, special attention is made to properly parameterize the dust production phase. Wind erosion of the soil in the model parameterization scheme is controlled mainly by the following factors: type of soil, type of vegetation cover, soil moisture content, and surface atmospheric turbulence. The major input data used to distinct the dust productive soils from the others are a global data set on land cover. Another data participating in dust production calculations is a global soil texture data set from which particle size parameters are evaluated.

In DREAM, concentration is used as a surface condition. The released surface concentration of mobilized

particles and the corresponding surface vertical flux depend on the structure and state of the soil and the turbulent regime of the lower atmosphere. The vertical flux of dust is also a function of friction velocity and soil moisture. Its main components are summarized in the Fig. 2.2 and they are:

- Dust production scheme adapted from Shao et al. (1993) with introduced viscous sub-layer (Janjic, 1994).
- Particle size distribution effects.
- Soil wetness effects on dust production (Fecan et al., 1999).
- Dry (Giorgi, 1986) and wet deposition.
- Horizontal and vertical advection, turbulent and lateral diffusion (Janjic, 1994, 1997) represented as for other scalars in the Eta/NCEP model.

The initial state of dust concentration in the model is defined by the 24-hour forecast from the previous-day model run. The model at the starting day is run using “cold start” conditions, i.e., the zero-concentration initial state. The model needs about 2-5 days for spinning up and for establishing reliable dust concentration conditions, depending on the study region.

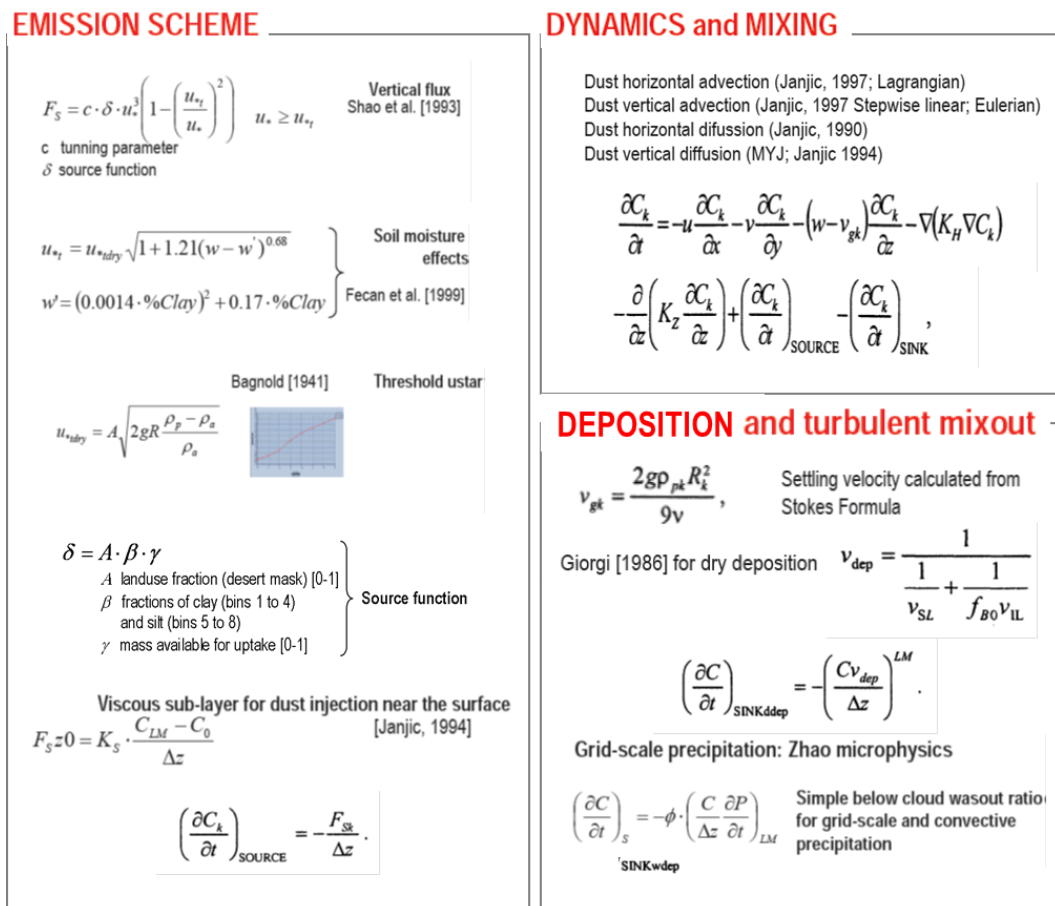


Figure 2.2 Parametrizations equations of the Injection, transport and deposition processes of dust.

The model qualitative and quantitative evaluation studies performed using different datasets outline the good skills of the model (e.g. Balis et al., 2006; Pérez et al., 2006a; Jiménez-Guerrero et al., 2008, Todd et al., 2008; Haustein et al., 2009).

2.3. The BSC-DREAM8b model

The updated BSC-DREAM8b model is delivering operational dust forecasts (www.bsc.es/projects/earthscience/DREAM) over North Africa-Europe-Mediterranean and East-Asia regions (*Fig. 2.3*) in the last years.

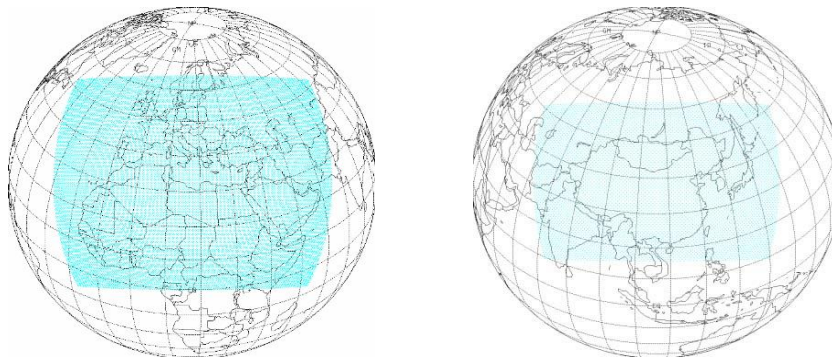


Figure 2.3 North Africa-Europe-Mediterranean and East-Asia forecast domains of DREAM.

The BSC-DREAM8b operational model version (version 2.0) described in detail by Pérez et al. (2006b) and Basart et al. (2012b) includes a more detailed bin method in which the two first categories (clay and small silt) are divided into 8 size bins between 0.1 and 10 μm . In this interval, the aerosol effects on solar radiation are most significant. The bin intervals are the same as used by Tegen and Lacis (1996) (see Table 2.1) and source distribution derived from D’Almeida (1987) are implemented in BSC-DREAM8b v2.0. Moreover, grid points acting as desert dust sources are specified using arid and semiarid categories of the global USGS 1-km vegetation data set as well as a preferential source mask based upon topographical approach from Ginoux et al. (2001). Modelling studies show that inclusion of “preferred” source regions improves the realism of the model dust load in the vicinity of the sources. Another data participating in dust production calculations is the FAO 4-km global soil texture data set from which particle size parameters are evaluated.

In this latest version, dry and wet deposition schemes have been updated improving the description of the dust transport. The new dry deposition scheme is based on Zhang et al. (2001) and takes into account Brownian diffusion, interception and impaction are considered. Moreover, gravitational settling based on the seminal work by Slinn (1982) is also included.

Therefore, the main features introduced are:

- Eight size transport bins between 0.1 and 10 μm range are considered
- Dust radiative feedbacks on meteorology.
- Updated dry and wet deposition schemes
- Grid points acting as desert dust sources are specified using arid and semiarid categories of the global USGS 1-km vegetation data set, a preferential source mask and the FAO 4-km global soil texture data set.

Table 2.1 Transport bins and sub-bin distribution parameters. From left to right: bin number, minimum and maximum radius of each size bin, effective radius of each bin, number median radius of the distribution, geometric standard deviation, extinction efficiency at 532 and 1064 nm (extracted from Pérez et al. 2006a).

Bin	r_{\min} - r_{\max} (μm)	r_{eff} (μm)	r_n	σ_g	Q_e 532 nm	Q_e 1064 nm
1	0.1-0.18	0.15	0.2986	2	1.373	0.217
2	0.18-0.3	0.25	0.2986	2	3.303	1.043
3	0.3-0.6	0.45	0.2986	2	3.245	3.300
4	0.6-1	0.78	0.2986	2	2.413	3.509
5	1-1.8	1.3	0.2986	2	2.262	2.293
6	1.8-3	2.2	0.2986	2	2.260	2.282
7	3-6	3.8	0.2986	2	2.162	2.217
8	6-10	7.1	0.2986	2	2.108	2.164

Soil Preprocessing

BSC-DREAM8b v2.0 uses USGS vegetation dataset to determine vegetation types. This dataset has a spatial resolution of 30 seconds of arc (1 km at the equator). These 100 vegetation types are then transformed into 13 SSiB vegetation types (Fig.2.4 and Table 2.2).

Table 2.2. SSiB Vegetation Types (Dorman and Sellers, 1989)

Type	Description
1	Broadleaf-evergreen trees (tropical forest)
2	Broadleaf-deciduous trees
3	Broadleaf and needle leaf trees (mixed forest)
4	Needle leaf-evergreen trees
5	Needle leaf-deciduous trees (larch)
6	Broadleaf tress with groundcover (savannah)
7	Groundcover only (perennial)
8	Broadleaf shrubs with perennial groundcover
9	Broadleaf shrubs with bare soil
10	Dwarf trees and shrubs with groundcover (tundra)
11	Bare soil
12	Cultivations (The same parameters for the Type 7)
13	Glacial

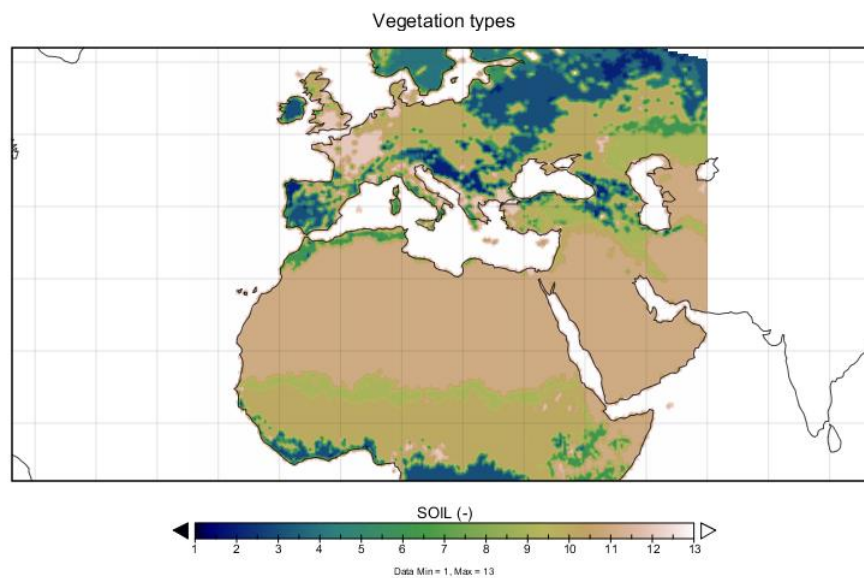


Figure 2.4 SSiB Vegetation Types distribution according to (Dorman and Sellers, 1989) for the North Africa-Mediterranean-Europe-Middle East region.

Furthermore, BSC-DREAM8b v2.0 uses FAO soil classification (FAO, 1988) to characterize soil texture. The global dataset has a spatial resolution of 2 minutes in a regular latitude/longitude grid (approximately 4km at the equator). These 133 different FAO soil types are transformed into 9 Zobler types. For each of the 9 Zobler soil types a fraction of Clay, Silt and Sand is assigned according to Nickovic et al. (2001) (Fig.2.5 and Table 2.3).

Table 2.3. The 9 Zobler soil types a fraction of Clay, Silt and Sand is assigned according to Nickovic et al. (2001). A maximum soil moisture (w') above which there is no emission, is defined as well for each soil type. SSiB Vegetation Types (Dorman and Sellers, 1989)

Type	Zobler	Cosby et al.	Clay	Silt	Sand	w' (%)
1	Coarse	Loamy sand	0.12	0.08	0.80	2.5
2	Medium	Silty clay loam	0.34	0.56	0.10	6.8
3	Fine	Light clay	0.45	0.30	0.25	11.5
4	Coarse-medium	Sandy loam	0.12	0.18	0.70	2.5
5	Coarse-fine	Sandy clay	0.40	0.10	0.50	10.0
6	Medium-fine	Clay loam	0.34	0.36	0.30	6.8
7	Coarse-med-fine	Sandy clay loam	0.22	0.18	0.60	3.5
8	Organic	Loam	0	0	0	0
9	Land ice	Loamy sand	0	0	0	0

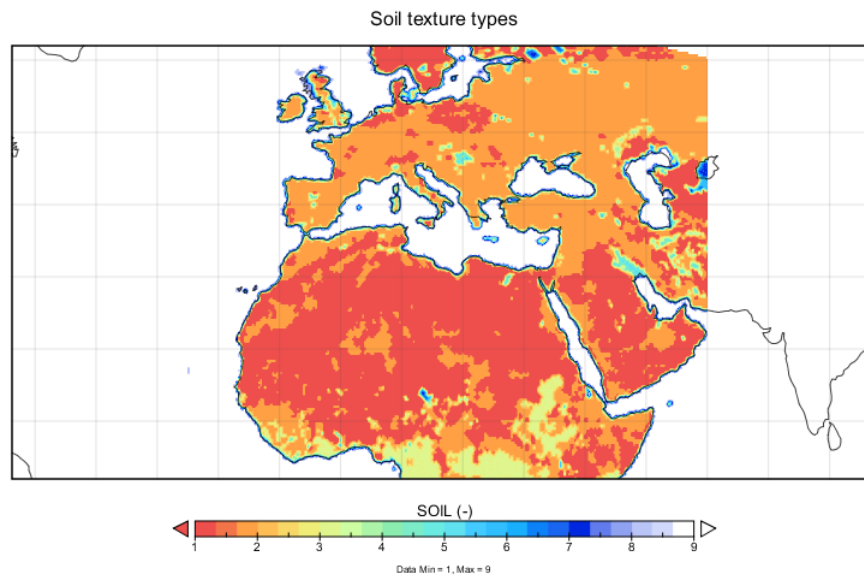


Figure 2.5 . The 9 Zobler soil types distribution a fraction of Clay, Silt and Sand is assigned according to Nickovic et al. (2001) for the North Africa-Mediterranean-Europe-Middle East region.

Dust-radiation interactions

In the BSC-DREAM8b v2.0 model, dust is treated as a radiatively active substance interacting with both short and long-wave radiation. Within every model time step both aerosol and atmospheric fields are updated due to their mutual influences. In order to couple dust and radiation processes, a radiative transfer model including aerosol effects developed at the Goddard Climate and Radiation Branch has been implemented into the NCEP/Eta atmospheric model replacing the Geophysical Fluid Dynamics

Laboratory radiation package.

The solar radiation parameterization (Chou and Suarez, 1999) includes the absorption due to water vapour, O₃, O₂, CO₂, clouds, and aerosols. Interactions among the absorption and scattering by clouds, aerosols, molecules (Rayleigh scattering), and the surface are fully taken into account. There are eight bands in the ultraviolet and visible region and three bands in the infrared region. Fluxes are integrated virtually over the entire spectrum, from 0.175 μm to 10 μm. Band intervals are listed in *Table 2.1*. A maximum random approximation is adopted for the overlapping of clouds at different heights. Reflection and transmission of a cloud and aerosol-laden layer are computed using the d-Eddington approximation. Fluxes are then computed using the two-stream adding approximation. The long-wave radiation parameterization (Chou et al., 2001) is based on the 1996 version of the Air Force Geophysical Laboratory HITRAN database (Rothman et al., 1998). The parameterization includes the absorption due to major gaseous absorption (water vapour, CO₂, O₃) and most of the minor trace gases (N₂O, CH₄, CFCs), as well as clouds and aerosols. The thermal infrared spectrum is divided into nine bands and a sub-band (from 0 to 3000 cm⁻¹) (*Table 2.4*). Scattering due to clouds and aerosols is included by scaling the optical thickness. The gaseous transmission function is computed either using the k-distribution method or a table look-up method. For a cloud layer the optical thickness is parameterized as a function of cloud water/ice amount and the effective particle radius, whereas the single-scattering albedo and asymmetry factor are parameterized as a function of the effective particle radius. The effective particle radius is, in turn, parameterized as a function of cloud water/ice concentration and temperature. Aerosol optical properties as functions of spectral band, height, and species are input parameters to the radiation routine.

Table 2.4 Spectral Bands in the Solar and Thermal Wavelengths in the Radiation Module

Band Number	Solar Wavelength, μm	Thermal Wave Number, cm ⁻¹
1	0.175– 0.225	0-340
2	0.225– 0.245 0.260– 0.280	340-540
3	0.245– 0.260	540-800
4	0.280– 0.295	800-980
5	0.295– 0.310	980-1100
6	0.310– 0.320	1100-1215
7	0.320– 0.400	1215-1380
8	0.400– 0.700	1380-1900
9	0.70– 1.22	1900-3000
10	1.22– 2.27	
11	2.27– 10.0	

In the BSC-DREAM8b v2.0 dust-radiation scheme, eight dust size bins is used. The bin intervals are taken from Tegen and Lacis (1996) as listed in *Table 2.1*. Within each transport bin, dust is assumed to have time-invariant, sub-bin log-normal distribution (Zender et al., 2003) employing the transport mode with mass median diameter of 2.524 μm (Shettle, 1984) and a geometric standard deviation of 2.0 (Schulz et al., 1998). The analytic sub-bin distribution allows accurate prescription of physical and optical

properties known to vary across the bin width. *Table 2.1* indicates the calculated extinction efficiency factor for 532 and 1064 nm.

For each size bin and wavelength we calculate the extinction efficiency, single-scattering albedo and asymmetry factor with a Mie-algorithm based on the work of Mishchenko et al. (2002). Each particle is assumed to be homogeneous and spherical. Although there is sufficient experimental evidence that nonsphericity of desert dust can result in significantly different scattering properties than those predicted by Mie theory (Mishchenko et al., 2000), its effect upon radiative fluxes and albedos is small (Lacis and Mishchenko, 1995). Complex refractive indices are taken from the Global Aerosol Data Set (GADS) (Koöpke et al., 1997) although it has to be signaled that recent in situ measurements of dust absorption at solar wavelengths suggest that the adopted indexes of refraction could be excessively absorbing (Kaufman et al., 2001). Finally, a weighted integration across the spectral band width is done with the extraterrestrial solar irradiance spectrum for the solar wavelengths and the Planck function for long-wave wavelengths. Mean values of optical thickness $\tau(\lambda)$, single-scattering albedo, and asymmetry factor are in turn derived for each spectral band ($\Delta\lambda$) and atmospheric layer. In this case, $\tau(\lambda)$ and the $\alpha(\lambda)$ are related to column mass loading and mass concentration, respectively, by:

$$\tau(\lambda) = \sum_1^8 \tau_k(\lambda) = \sum_1^8 \frac{3}{4\rho_k r_k} M_k Q_{ext}(\lambda)_k$$
$$\alpha(\lambda) = \sum_1^8 \alpha_k(\lambda) = \sum_1^8 \frac{3}{4\rho_k r_k} C_k Q_{ext}(\lambda)_k$$

where for each size bin k : $\tau_k(\lambda)$ is the AOD, $\alpha_k(\lambda)$ the extinction coefficient, ρ_k is the particle mass density, r_k is the effective radius, M_k is the column mass loading, C_k is the concentration and $Q_{ext}(\lambda)_k$ is the extinction efficiency factor which was calculated using Mie scattering theory.

2.3.1. Bibliography related with BSC-DREAM8b

All the details of BSC-DREAM8b model description presented in the present manuscript have been described in detail in the following publications:

1. Nickovic, S., Kallos, G., Papadopoulos, A., and Kakaliagou, O.: A model for prediction of desert dust cycle in the atmosphere, *J. Geophys. Res.*, 106, D16, 18113-18129, doi: 10.1029/2000JD900794, 2001.
2. Pérez, C., Nickovic, S., Baldasano, J. M., Sicard, M., Rocadenbosch, F., and Cachorro, V. E.: A long Saharan dust event over the western Mediterranean: Lidar, Sun photometer observations, and regional dust modeling, *J. Geophys. Res.*, 111, D15214, doi: 10.1029/2005JD006579, 2006.
3. Pérez, C., Nickovic, S., Pejanovic, G., Baldasano, J. M., and Ozsoy, E.: Interactive dust-radiation modeling: A step to improve weather forecasts, *J. Geophys. Res.*, 111, D16206, doi: 10.1029/2005JD006717, 2006.



4. Basart, S., Pérez, C., Nickovic, S., Cuevas, E. and Baldasano, J.M.: Development and evaluation of the BSC-DREAM8b dust regional model over Northern Africa, the Mediterranean and the Middle East, *Tellus B*, 64, 18539, doi: <http://dx.doi.org/10.3402/tellusb.v64i0.18539>, 2012b.

These articles are available at BSC website (www.bsc.es/projects/earthscience/DREAM/).

3. BSC-DREAM8b evaluation results

The present section includes a review of the BSC-DREAM8b model evaluation activities. The model has been evaluated and analysed in several studies which are specific about three aspects: 1) a near-real time daily evaluation of the model forecasts, 2) for Europe and the Mediterranean Basin, as well as, 3) for Northern Africa and Middle East. Table 3.1 lists the references related to the evaluation results included in the present section.

Table 3.1 Publication's list of the BSC-DREAM8b model evaluation and analysis works.

Study Region	Reference	Model version	Time period
North Africa-Middle East-Europe	Basart et al. (2009)	BSC-DREAM8b	Annual (2004)
	Basart et al. (2012b)	BSC-DREAM8b	Annual (2004)
	Amiridis et al. (2013)	BSC-DREAM8b	Long-term (2007-2011)
Europe	Papayannis et al. (2008)	DREAM	Long-term (2000-2002)
	Pay et al. (2010)	BSC-DREAM8b	Annual (2004)
	Basart et al. (2012a)	BSC-DREAM8b	Annual (2004)
Western Mediterranean	Pérez et al. (2006a)	BSC-DREAM8b	Dust event (April 2002)
	Pérez et al. (2006b)	BSC-DREAM8b	Dust event (June 2002)
Spain	Jiménez-Guerrero et al. (2008)	DREAM	Dust event (June-July 2006)
	Pay et al. (2012)	BSC-DREAM8b	Annual (2004)
Portugal	Borrego et al. (2011)	BSC-DREAM8b	Annual (2010)
	Monteiro et al. (2015)	BSC-DREAM8b	Annual (2011)
	Tchepel et al. (2013)	BSC-DREAM8b	Dust event (July 2006)
Italy	Kishcha et al. (2007)	DREAM	Long-term (2001-2003)
	Gobbi et al. (2013)	BSC-DREAM8b	Long-term (2001-2004)
	Mona et al. (2014)	BSC-DREAM8b	Long-term (2000-2012)
Eastern Mediterranean	Balis et al. (2006)	DREAM	Dust event (Aug-Sep 2003)
	Tsekeri et al. (2013)	BSC-DREAM8b	Dust event (Jul-2011)
Greece	Papayannis et al. (2009)	DREAM	Long-term (2004-2006)
	Amiridis et al. (2009)	BSC-DREAM8b	Dust event (May 2008)
	Papanastasiou et al. (2010)	BSC-DREAM8b	Long-term (2001-2007)
Central Europe	Klein et al. (2010)	BSC-DREAM8b	Dust event (May-June 2008)
Georgia	Kokkalis et al. (2012)	BSC-DREAM8b	Dust event (May 2009)
Tropical Eastern North Atlantic	Alonso-Pérez et al. (2011)	DREAM	Long-term (1958-2006)
	Gama et al. (125)	BSC-DREAM8b	Annual (2011)
North-Central Africa	Todd et al. (2009)	BSC-DREAM8b	Dust event (BodEx, Mar 2005)
Morocco	Haustein et al. (2009)	BSC-DREAM8b	Dust event (SAMUM, May-Jun 2006)

Finally, this section also presents some studies in which the dust simulations from BSC-DREAM8b are used as research and forecasting tools as well as a list of several projects where the model is involved.

3.1. Previous evaluation studies about the DREAM model

The original DREAM model had been evaluated and used in different study cases in the past years as show in the following publications:

1. Alonso-Pérez, S., Cuevas, E., Perez, C., Querol, X., Baldasano, J. M., Draxler, R., and de Bustos, J. J. (2011): Trend changes of African airmass intrusions in the marine boundary layer over the subtropical Eastern North Atlantic region in winter, *Tellus B*, 63, 255-265, doi: 10.1111/j.1600-0889.2010.00524.x.
2. Balis, D., Amiridis, V., Kazadzis, S., Papayannis, A., Tsaknakis, G., Tzortzakis, S., Kalivitis, N., Vrekoussis, M., Kanakidou, M., Mihalopoulos, N., Chourdakis, G., Nickovic, S., Perez, C., Baldasano, J. M., and Drakakis, M. (2006): Optical characteristics of desert dust over the East Mediterranean during summer: a case study, *Ann. Geophys.*, 24, 807–821.
3. Jiménez-Guerrero, P., Pérez, C., Jorba, O., and Baldasano, J. M. (2008): Contribution of Saharan dust in an integrated air quality system and its on-line assessment, *J. Geophys. Res. Lett.* 35.
4. Kishcha, P., Alpert, P., Shtivelman, A., Krichak, S. O., Joseph, J. H., Kallos, G., Katsafados, P., Spyrou, C., Gobbi, G. P., and Barnaba, F. (2007): Forecast errors in dust vertical distributions over Rome (Italy): Multiple particle size representation and cloud contributions, *J. Geophys. Res.*, 112, D15205, doi:10.1029/2006JD007427.
5. Gama, C., Tchepel, O., Baldasano, J.M., Basart, S., Ferreira, J., Pio, C., and Borrego, C. (2015) Seasonal patterns of Saharan dust over Cape Verde – a combined approach using observations and modelling, *Tellus B*, 67, 24410.
6. Papayannis, A., Amiridis, V., Mona, L., Tsaknakis, G., Balis, D., Bösenberg, J., Chaikovski, A., De Tomasi, F., Grigorov, I., and Mattis, I. (2008): Systematic lidar observations of Saharan dust over Europe in the frame of EARLINET (2000–2002), *J. Geophys. Res.*, 113.
7. Papayannis A., R. E. Mamouri, V. Amiridis, S. Kazadzis, C. Pérez, G. Tsaknakis, P. Kokkalis and J.M. Baldasano (2009): Systematic lidar observations of Saharan dust layers over Athens, Greece in the frame of EARLINET project (2004–2006), *Annales Geophysicae*, 27, 3611–3620.

3.2. Near-real time evaluation of BSC-DREAM8b

A *daily evaluation system* with AERONET and satellite data is included in the operational BSC-DREAM8b v2.0 website (<http://www.bsc.es/earth-sciences/mineral-dust/bsc-dream8b-forecast/nrt-evaluation>).

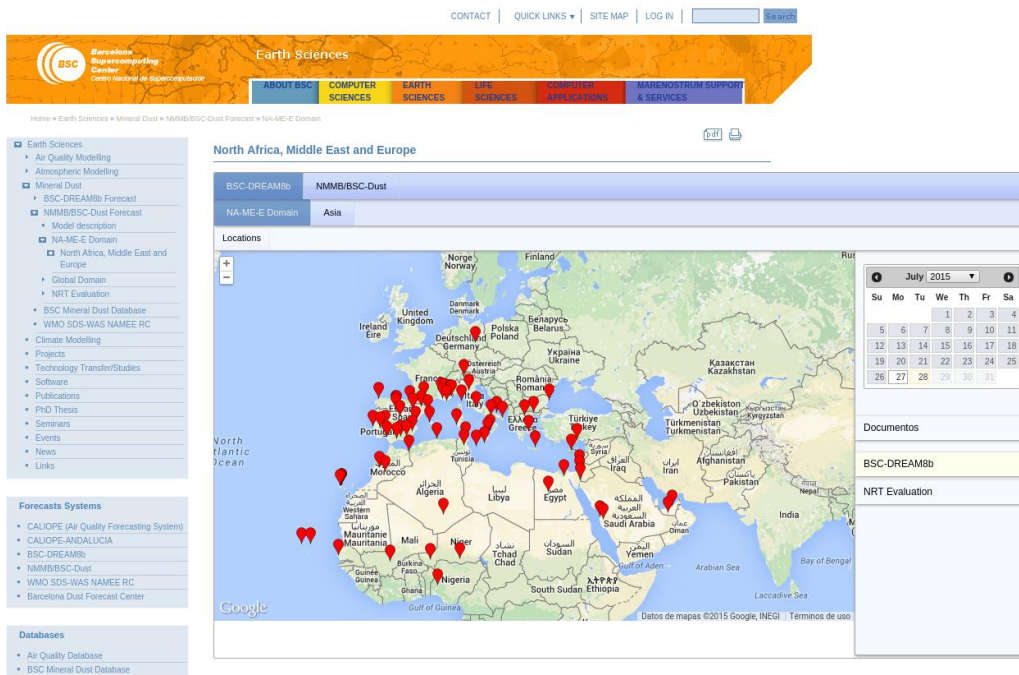


Figure 3.1 Caption of the BSC-DREAM8b daily evaluation website (<http://www.bsc.es/earth-sciences/mineral-dust/bsc-dream8b-forecast/nrt-evaluation>). In the image the spatial distribution of the 74 AERONET sunphotometers used in the model comparison.

The BSC-DREAM8b v2.0 model outputs are compared with the direct-sun observations from the Aerosol Robotic Network (**AERONET**; <http://aeronet.gsfc.nasa.gov/>). The comparison of model forecasts to AERONET aerosol optical depth (AOD) at 550nm for selected dust-prone stations includes time series with 1-hourly data for the last 15 days and for the last month in the archive section. For the forecast daily evaluation, Version 2-Level 1.5 of AERONET products are used. Level 1.5 data is automatically cloud screened (Smirnov et al., 2000) but may not have final calibration applied. Currently, 72 AERONET sites in Northern Africa, Middle East and Europe (Fig. 3.1) are used in the model comparison of AOD. Moreover, in those stations where the spectral decomposition algorithm (SDA) retrieval (O’Neill et al., 2003) is available additional comparison of the AOD fine and coarse are included.

In the case of satellite products, the model outputs are qualitatively compared **MSG/RGB** and **MODIS** images.

- Thus, the BSC-DREAM8b v2.0 model simulations are qualitatively compared against the **MSG/RGB** dust product every 6 hours for 3 different domains: Sahara-Sahel, Europe and Spain. Fig. 3.2 shows an example corresponding to a desert dust event for 5th April 2011. In this RGB combination, dust appears pink or magenta.

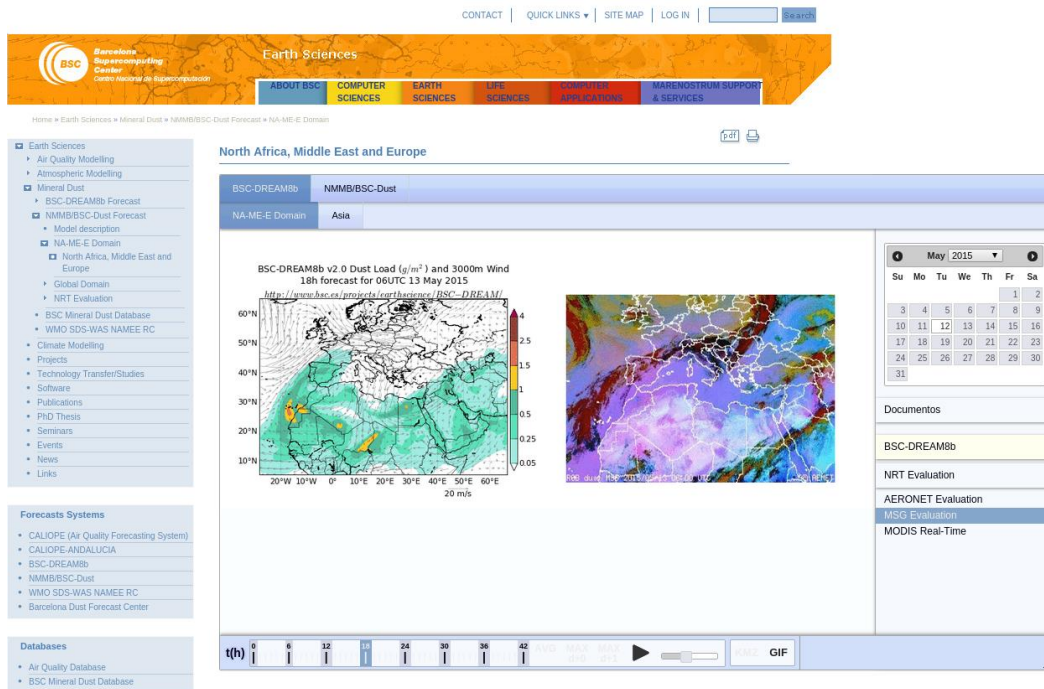


Figure 3.2 Caption of the BSC-DREAM8b daily evaluation website (<http://www.bsc.es/earth-sciences/mineral-dust/bsc-dream8b-forecast/nrt-evaluation>). In the image, the BSC-DREAM8b simulation (top panel) vs. the MSG/RGB image (bottom panel) corresponding to desert dust event on 13th May 2015.

- For **MODIS**, photo-like imagery is available within a few hours of being collected and the science community uses these images in projects like AERONET. The images shown in the BSC website are collected directly from the AERONET Data Synergy Tool of NASA Goddard Space Flight Center (http://aeronet.gsfc.nasa.gov/cgi-bin/bamgomax_interactive) and they show the latest MODIS image available for the selected AERONET site. Fig. 3.3 shows the MODIS image corresponding to Palma de Mallorca site during a desert dust event on 17th June 2012.

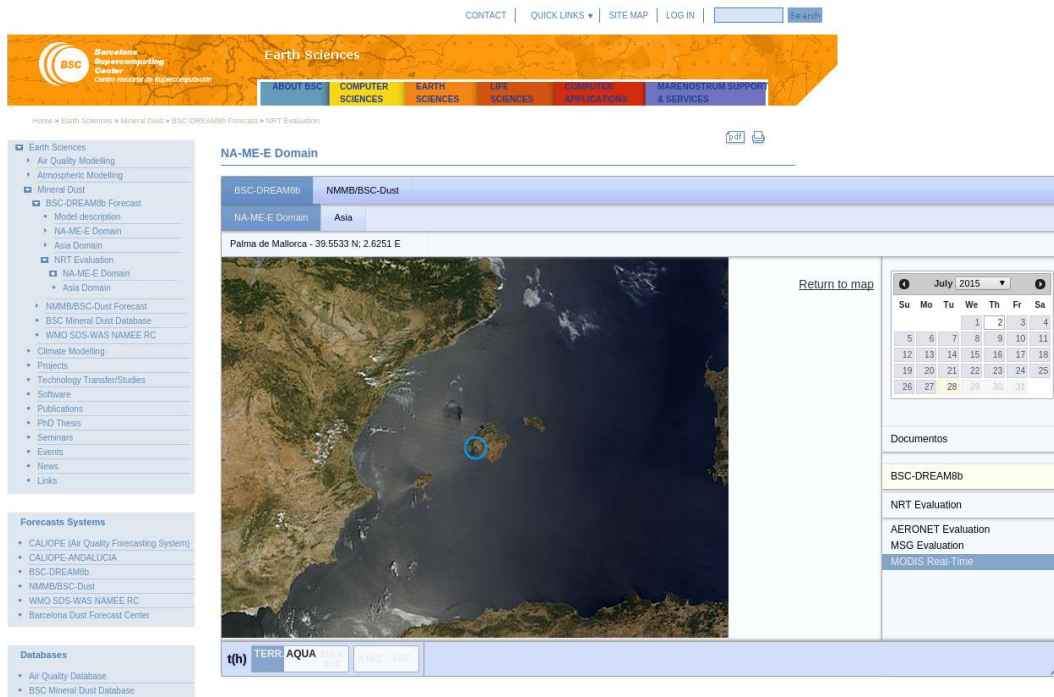


Figure 3.3 Caption of the BSC-DREAM8b daily evaluation website (<http://www.bsc.es/earth-sciences/mineral-dust/bsc-dream8b-forecast/nrt-evaluation>). In the image the MODIS image corresponding to Palma de Mallorca site on 17th June 2012.

3.3. European and the Mediterranean evaluation of BSC-DREAM8b

Ground-based observations from observation networks as EARLINET, AERONET and EMEP; and satellite products outlined the good skills of BSC-DREAM8b concerning both the horizontal and vertical extent of the dust plume in **Europe and the Mediterranean** as shown in the following publications:

1. Basart, S., Pay, M. T., Jorba, O., Pérez, C., Jiménez-Guerrero, P., Schulz, M., and Baldasano, J. M. (2012a): Aerosols in the CALIOPE air quality modelling system: evaluation and analysis of PM levels, optical depths and chemical composition over Europe, *Atmos. Chem. Phys.*, 12, 3363-3392, doi: 10.5194/acp-12-3363-2012a.
2. Papanastasiou, D. K., Poupkou, A., Katragkou, E., Amiridis, V., Melas, D., Mihalopoulos, N., Basart, S., Pérez, C., and Baldasano, J. M. (2010): An Assessment of the Efficiency of Dust Regional Modelling to Predict Saharan Dust Transport Episodes, *Advances in Meteorology*, 2010, 154368, doi:10.1155/2010/154368.
3. Pay, M. T., Piot, M., Jorba, O., Gassó, S., Gonçalves, M., Basart, S., Dabdub, D., Jiménez-Guerrero, P., and Baldasano, J. M. (2010): A Full Year Evaluation of the CALIOPE-EU Air Quality Modeling System over Europe for 2004, *Atmos. Environ.*, 44, 3322-3342, doi:10.1016/j.atmosenv.2010.05.040.
4. Pay, M. T., Jiménez-Guerrero, P., Jorba, O., Basart, S., Querol, X., Pandolfi, M., and Baldasano, J. M. (2012): Spatio-temporal variability of concentrations and speciation of particulate matter

across Spain in the CALIOPE modelling system, *Atmos. Environ.*, 46, 376–396 doi:10.1016/j.atmosenv.2011.09.049.

5. Pérez, C., Nickovic, S., Baldasano, J. M., Sicard, M., Rocadenbosch, F., and Cachorro, V. E. (2006a): A long Saharan dust event over the western Mediterranean: Lidar, Sun photometer observations, and regional dust modeling, *J. Geophys. Res.*, 111, D15214, doi: 10.1029/2005JD006579, 2006a.
6. Pérez, C., Nickovic, S., Pejanovic, G., Baldasano, J. M., and Ozsoy, E. (2006b): Interactive dust-radiation modeling: A step to improve weather forecasts, *J. Geophys. Res.*, 111, D16206, doi: 10.1029/2005JD006717.

In Pérez et al. (2006a,b), the BSC-DREAM8b model is analysed in terms of AOD from AERONET sunphotometers and satellite images for a **single dust events** which affects the Western Mediterranean region during two events during April and June 2002. The results emphasize the capability of the model to correctly reproduce the timing increase of the observed dust peaks in the Western Mediterranean. Furthermore, Pérez et al. (2006b) demonstrated that the inclusion of dust radiation interactions induce significant improvements of the atmospheric temperature and mean sea-level pressure forecasts over dust-affected areas.

The model also has been evaluated for **an annual cycle and long-term periods**:

- In Papanastasiou et al. (2010), the BSC-DREAM8b model is evaluated in Greece, the performance of the model is assessed using model PM₁₀ predictions covering a 7-year period (2001-2007).
- The BSC-DREAM8b model has been annually evaluated (for the year 2004) in the framework of the CALIOPE air quality system (www.bsc.es/caliope; see Sect. 4.1) which provides air quality forecast for Europe (12km x 12km) and Spain (4km x 4km). For the evaluation of the European domain, Pay et al. (2010) and Basart et al. (2012) used daily PM₁₀, PM_{2.5} and aerosol components data from 55 stations of the EMEP/CREATE network and total, coarse and fine aerosol optical depth (AOD) data from 35 stations of the AERONET sun photometer network. The results showed that overall PM and AOD levels are underestimated by CALIOPE, the higher correlations of the PM₁₀ and the coarse mode AOD were largely due to the accurate representation of the African dust influence in the forecasting system by means the inclusion of the BSC-DREAM8b model outputs. For the Spanish domain, Pay et al. (2012) used a new data set of Saharan dust PM₁₀ concentration to evaluate the PM₁₀ contribution modelled by BSC-DREAM8b; the results also indicated that the BSC-DREAM8b was able to reproduce the daily variability of the observed levels of desert dust and most of the outbreaks affecting southern Spain for the year 2004.

3.4. Northern Africa and Middle East evaluation of BSC-DREAM8b

The BSC-DREAM8b model also has been evaluated in desert dust sources like **Northern Africa and Middle East** as presented in the following publications:

1. Basart, S., Pérez, C., Nickovic, S., Cuevas, E. and Baldasano, J.M. (2012b): Development and evaluation of the BSC-DREAM8b dust regional model over Northern Africa, the Mediterranean and the Middle East, *Tellus B*, 64, 18539, doi: <http://dx.doi.org/10.3402/tellusb.v64i0.18539>.
2. Gama, C., Tchepel, O., Baldasano, J.M., Basart, S., Ferreira, J., Pio, C., and Borrego, C. (2015) Seasonal patterns of Saharan dust over Cape Verde – a combined approach using observations and modelling, *Tellus B*, 67, 24410.
3. Hausteijn, K., Pérez, C., Baldasano, J. M., Müller, D., Tesche, M., Schladitz, A., Esselborn, M., Weinzierl, B., Kandler, K., and Hoyningen-Huene, W. v. (2009): Regional dust model performance during SAMUM 2006, *J. Geophys. Res. Lett.*, 36, L03812, doi: 10.1029/2008GL036463.
4. Todd, M. C., Washington, R., Martins, J. V., Dubovik, O., Lizcano, G., M'Bainayel, S., and Engelstaedter, S. (2008): Mineral dust emission from the Bodélé Depression, northern Chad, during BoDEx 2005, *J. Geophys. Res.*, 112, D06207.

The model has been evaluated and analyses in desert dust sources during **experimental campaigns** (BoDex and SAMUM) and for **an annual cycle**.

- The model intercomparison presented in Todd et al. (2008) in the framework of the *Bodélé Experiment 2005* emphasize the fact that most important differences between the different models raised from the meteorology and the emission scheme. In the work of Hausteijn et al. (2009), the original model version and the BSC-DREAM8b were compared using the dust dataset from *SAMUM 2006* field campaign. The increased transport bin resolution in BSC-DREAM8b respect the original model version (from 4 to 8 bins) was proven to be more efficient and adequate. In general, fairly good agreement between model results, AERONET data, and satellite observations with respect to their horizontal and vertical distribution is obtained. Furthermore, the modelled vertical extinction coefficient captured fairly well lidar observations.
- The comparison of the BSC-DREAM8b and AERONET observations for the year 2004 presented in Basart et al. (2012b) showed that overall; the simulated dust AOD at sources is generally weaker in BSC-DREAM8b than in the original DREAM model version with the exception of certain areas around of the Red Sea and the Middle East. This is partly explained by the increased transport bin resolution in BSC-DREAM8b respect the original model version (Hausteijn et al., 2009). In general, the model correctly reproduces the long-range transport towards Europe and North Atlantic regions The evaluation of the BSC-DREAM8b model also has highlighted limitations of the modelling system in desert dust source regions. The model underestimates the dust load in the Sahel and the Eastern Tropical North Atlantic regions in winter and spring. It also overestimates the dust load in Middle East in summer as well as in Northern Algeria and the dust transport towards the Western and Central Mediterranean mainly in spring. Furthermore, the inclusion of the preferential source mask in the emission scheme of the model better captures the background dust AOD and the timing of the observed dust peaks in the Mediterranean, Iberian Peninsula and North-Western Africa AERONET sites.

3.5. BSC-DREAM8b applications

The BSC-DREAM8b has been used for **dust research** and as **dust forecasting tools** in North Africa and the Mediterranean as highlighted in the following publications:

1. Amiridis, V., Kafatos, M., Perez, C., Kazadzis, S., Gerasopoulos, E., Mamouri, R. E., Papayannis, A., Kokkalis, P., Giannakaki, E., and Basart, S.: The potential of the synergistic use of passive and active remote sensing measurements for the validation of a regional dust model, *Ann. Geophys.*, 27, 3155-3164, 2009.
2. Amiridis, V., U. Wandinger, E. Marinou, E. Giannakaki, A. Tsekeri, S. Basart, S. Kazadzis, A. Gkikas, M. Taylor, J. Baldasano, and A. Ansmann Optimizing Saharan dust CALIPSO retrievals, *Atmos. Chem. Phys. Discuss.*, 13, 14749-14795, doi:10.5194/acpd-13-14749-2013, 2013.
3. Basart, S., Pay, M. T., Jorba, O., Pérez, C., Jiménez-Guerrero, P., Schulz, M., and Baldasano, J. M.: Aerosols in the CALIOPE air quality modelling system: evaluation and analysis of PM levels, optical depths and chemical composition over Europe, *Atmos. Chem. Phys.*, 12, 3363-3392, doi: 10.5194/acp-12-3363-2012, 2012.
4. Borrego, C., Monteiro, A., Pay, M. T., Ribeiro, I., Miranda, A. I., Basart, S., and Baldasano, J. M.: How bias-correction can improve air quality forecasts over Portugal, *Atmos. Environ.*, 45, 6629–6641, doi: <http://dx.doi.org/10.1016/j.atmosenv.2011.09.006>, 2011.
5. Klein, H., Nickovic, S., Haunold, W., Bundke, U., Nillius, B., Ebert, M., Weinbruch, S., Schuetz, L., Levin, Z., and Barrie, L. A.: Saharan dust and ice nuclei over Central Europe, *Atmos. Chem. Phys.*, 10, 10211-10221, 2010.
6. Kokkalis, P., Mamouri, R. E., Todua, M., Didebulidze, G. G., Papayannis, A., Amiridis, V., Basart, S., Pérez, C., and Baldasano, J. M.: Ground-, satellite- and simulation-based analysis of a strong dust event over Abastumani, Georgia, during May 2009, *International Journal of Remote Sensing*, 33, 2012.
7. Gama, C., Tchepel, O., Baldasano, J.M., Basart, S., Ferreira, J., Pio, C., and Borrego, C. (2015) Seasonal patterns of Saharan dust over Cape Verde – a combined approach using observations and modelling, *Tellus B*, 67, 24410.
8. Gobbi, G. P., Angelini, F., Barnaba, F., Basart, S., Cattani, G., Inglessis, M., Marconi, A. and Baldasano, J.M.: Particulate Matter Increase during Saharan Advections in the City of Rome (Italy): A Four-Year Study (2001-2004), *Atmos. Chem. Phys.*, acp-2012-1044, 2013.
9. Mona, L., Papagiannopoulos, N., Basart, S., Baldasano, J., Biniotoglou, I., Cornacchia, C., and Pappalardo, G.: EARLINET dust observations vs. BSC-DREAM8b modeled profiles: 12-year-long systematic comparison at Potenza, Italy, *Atmos. Chem. Phys.*, 14, 8781-8793, doi:10.5194/acp-14-8781-2014, 2014. 13, 31363-31407, 2014.
10. Monteiro, A., Fernandes, A.P., Gama, C., Borrego, C., and Tchepel, O.: Assessing the mineral dust from North Africa over Portugal region using BSC-DREAM8b model, *Atmospheric Pollution Research*, 6(1), 2015.
11. Papanastasiou, D. K., Poupkou, A., Katragkou, E., Amiridis, V., Melas, D., Mihalopoulos, N., Basart, S., Pérez, C., and Baldasano, J. M.: An Assessment of the Efficiency of Dust Regional Modelling to Predict Saharan Dust Transport Episodes, *Advances in Meteorology*, 2010, 154368, doi:10.1155/2010/154368, 2010.
12. Pay, M. T., Jiménez-Guerrero, P., Jorba, O., Basart, S., Querol, X., Pandolfi, M., and Baldasano, J. M.: Spatio-temporal variability of concentrations and speciation of particulate matter across Spain in the CALIOPE modeling system, *Atmos. Environ.*, 46, 376–396, 2012.
13. Pay, M. T., Piot, M., Jorba, O., Gassó, S., Gonçalves, M., Basart, S., Dabdub, D., Jiménez-Guerrero, P., and Baldasano, J. M.: A Full Year Evaluation of the CALIOPE-EU Air Quality Modeling System

over Europe for 2004, *Atmos. Environ.*, 44, 3322-3342, doi:10.1016/j.atmosenv.2010.05.040, 2010.

14. Tchepel, O., Ferreira, J., Fernandes, A.P., Basart, S., Baldasano, J.M. and Borrego, C.: Analysis of long-range transport of aerosols for Portugal using 3D Chemical Transport Model and satellite measurements, *Atmos. Environ.*, 64, 229-241, doi: 10.1016/j.atmosenv.2012.09.061, 2013.
15. Tsekeri, A., Amiridis, V., Kokkalis, P., Basart, S., Chaikovsky, A., Dubovik, O., Mamouri, R.E., Papayannis, A. and Baldasano, J.M.: Application of a synergetic lidar and sunphotometer algorithm for the characterization of a dust event over Athens, Greece, *British Journal of Environment and Climate*, 3(4), 531-546, doi: 10.9734/BJECC/2013/2615, 2013.

In the last years, the BSC-DREAM8b model simulations have been used as *research tool* in different studies:

- Amiridis et al. (2009) evaluated the BSC-DREAM8b dust simulations for a long-lasting Saharan dust event affected Greece on 18–23 May 2008, the comparison of the model using lidar measurements on 20th May showed that the model consistently reproduced the dust vertical distribution over Athens.
- Additionally to lidar, satellite and sun photometric measurements, the BSC-DREAM8b forecast model was used to study the dust transport in the work presented in Kokkalis et al. (2012) for a strong dust event over Abastumani, Georgia, during May 2009.
- From the 7-year period analysis of the BSC-DREAM8b dust simulations in Greece, Papanastasiou et al. (2010) highlighted that the dust regional modelling in general can be useful in the development of air pollution control strategies.
- Klein et al. (2010) established the correlation between ice nuclei and the presence of desert dust in one site in the Alps.
- Gama et al. (2015) combined the BSC-DREAM8b and NMMB/BSC-Dust model outputs with observations and back trajectories to characterise the dust transported from North Africa deserts to the Cape Verde Islands for a complete annual cycle (2011).
- Gobbi et al. (2013) combined the BSC-DREAM8b model outputs and lidar records to compute the increase in PM with respect to dust-unaffected previous days in Rome in the period 2001-2004.
- Mona et al. (2014) combined 12-years of the BSC-DREAM8b model outputs and lidar records from Potenza EARLINET lidar station were compared to evaluate the capability of BSC-DREAM8b to reproduce dust profiles in terms of dust layer geometrical and optical properties.
- Tchepel et al. (2013) assessed the contribution of long-range transport of mineral dust from North Africa to the air pollution levels in Portugal based on a combination of a modelling approach and satellite observation for July 2006.
- Tsekeri et al. (2013) performed the comparison of the BSC-DREAM8b model outputs and lidar records from Athens EARLINET lidar station for a single dust event over Greece on July 2011.

The model has also used as *dust forecasting* tool in several air quality systems in Europe:

- In the analysis of Pay et al. (2010; 2012) and Basart et al. (2012a), the BSC-DREAM8b is evaluated and analyse in the framework of the CALIOPE air quality system for Europe and Spain.



These studies highlight the importance of the contributions of desert dust to the air quality PM levels in southern Europe.

- Borrego et al. (2011) used the BSC-DREAM8b model outputs are analysed in three air quality modelling systems operate routinely with high-resolution over mainland Portugal for forecasting purposes, namely MM5-CHIMERE, MM5-EURAD, and CALIOPE for the year 2010.
- Monteiro et al. (2014) analysed the impact of the desert dust contributions over Portugal using the BSC-DREAM8b.

4. BSC-DREAM8b projects

The BSC-DREAM8b model has been used in different European projects as Diapason (<http://www.diapason-life.eu>) and EARLINET (<http://www.earlinetasos.org/>) for the analysis and prediction of Saharan dust. Furthermore, the BSC-DREAM8b v2.0 forecast dust simulations are used and/or participated in the framework of other projects like the CALIOPE system and the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) programme which are described below.

4.1. The CALIOPE air quality forecasting system

The *CALIOPE air quality forecasting system*, funded by the Spanish Ministry of the Environment and Rural and Marine Affairs (Ministerio de Medio Ambiente y Medio Rural y Marino), has the main objective to establish an air quality forecasting system for Spain. In this framework, a high-resolution air quality forecasting system, namely WRF-ARW/HERMES-EMEP/CMAQ/BSC-DREAM8b, has been developed and applied to Europe (12 km x 12 km, 1hr) as well as to Spain (4 km x 4 km, 1hr). The simulation of such a high-resolution model system has been made possible by its implementation on the MareNostrum supercomputer hosted by the Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS).

The natural mineral dust from BSC-DREAM8b v2.0 is added on-line to the anthropogenic contribution output of CMAQ. Thus, from BSC-DREAM8b v2.0 2 kinds of files (in NetCDF and GrADS formats) are generated every day for the 5 operative CALIOPE domains: Europe (D01), Iberian Peninsula (D02), Andalusia (AND), Barcelona (BCN) y Canary Islands (CAN). These files contain 72h of dust forecast (aerosol optical depth at 550nm and surface concentration) with 1-hourly time resolution.

4.2. The WMO SDS-WAS programme

The Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) programme where the World Meteorological Organization (WMO) and it was established in September 2004 and its purpose is to achieve comprehensive, coordinate and sustained observations and modelling capabilities of the sand and dust storm, in order to improve its monitoring state, increase the understanding of its formation processes, and enhance prediction capabilities. The main objective of SDS-WAS Project is to establish a WMO coordinated global network of SDS-WAS centers which is to enhance the ability of countries to deliver timely and quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities. Thus, these Regional Nodes deal with both operational and scientific aspects related to atmospheric dust monitoring and forecasting in their respective regions. In early 2008, WMO accepted the offer of the China Meteorological Agency to host a regional centre for the SDS-WAS Asia/Central-Pacific node of SDS-WAS. Recently, a partnership of two research Spanish institutions, the Barcelona Supercomputing Center-Centro Nacional de Supercomputación (BSC-CNS; www.bsc.es) and the Spanish National Agency of Meteorology (AEMET, www.aemet.es), hosted Northern Africa-Middle East-Europe (NA-ME-E; <http://sds-was.aemet.es/>) Node and its partners include several international organizations and



institutions.

BSC-DREAM8b v2.0 is one of the regional mineral dust models included in the (NA-ME-E) Node of SDS-WAS. In this context, every day a NetCDF file is generated. This file contains 72h of dust forecast (aerosol optical depth at 550nm, surface concentration, dust load and emission) with 3-hourly time resolution.

5. BSC-DREAM8b v2.0 forecast system

In the present section, we will present the structure of the BSC-DREAM8b forecast system as well as the basic steps to configure one forecast domain.

5.1. BSC-DREAM8b forecast system at the BSC

5.1.1. Model configuration

Since 14th August 2012, the BSC operational version of the model is BSC-DREAM8b v2.0.

The model forecast has been performed in the following way:

- 72h forecasts of each day with outputs:
 - For North Africa-Mediterranean-Europe-Middle East forecast every 1h
 - For the Asia forecast every 3h
- Horizontal resolution in Arakawa E-grid:
 - For the North Africa-Mediterranean-Europe-Middle East forecast are $1/3^{\circ} \times 1/3^{\circ}$
 - For the Asia forecast $1/2^{\circ} \times 1/2^{\circ}$
- 24 z-vertical layers in the troposphere (~15km)
- The meteorological fields are initialized every 72h with the NCEP GFS analysis ($0.5^{\circ} \times 0.5^{\circ}$) and boundary conditions are updated every 6h with the NCEP GFS forecasts ($0.5^{\circ} \times 0.5^{\circ}$).
 - For the North Africa-Mediterranean-Europe-Middle East forecast initial and boundary conditions are the 12 UTC global NCEP forecast cycle.
 - For the Asia forecast initial and boundary conditions are the 0 UTC global NCEP forecast cycle.
- USGS 1-km vegetation dataset
- FAO 4-km global soil texture data

5.1.2. Model forecast products

At the moment, the system includes two forecast domains:

- a. North Africa-Mediterranean-Europe-Middle East domain, which are composite by 3 sub-domains:
 - Euro-Mediterranean
 - Spain
 - Sahara-Sahel
- b. Asia domain

For the 4 operational domains (i.e., Euro-Mediterranean, Spain, Sahara-Sahel and Asia domains), the BSC-DREAM8b website (www.bsc.es/projects/earthscience/DREAM/) includes forecast images every 6h of the followings parameters summarize in the next table:

Table 5.1. Summary dust forecast products available for each operational domain, in the present.

	Euro-Mediterranean	Sahara-Sahel	Spain	Asia
Parameter	Domain of forecast			
Surface concentration	✓	✓	✓	✓
Dry and wet deposition	✓	✓	✓	✓
Dust load	✓	✓	✓	✓
Vertical cross section	✓	-	✓	-
Vertical profiles	✓	-	-	-
Aerosol optical depth	✓	✓	✓	✓

Additionally to the daily forecast, the operational BSC website includes an archive section. Next, a summary of the available archive data in the BSC website is presented (see Table 5.2).

Table 5.2. The archive data of each forecast parameters for each operational domain are available from the referred date onward (in yyyyymm format)

	Euro-Mediterranean	Sahara-Sahel	Spain	Asia
Parameter	Domain of forecast			
Surface concentration	200506	200701	200701	200605
Dry and wet deposition	200506	200701	200701	200605
Dust load	200506	200701	200701	200605
Vertical cross section	200506	-	200701	-
Vertical profiles	200506	-	-	-
Aerosol optical depth	200602	200701	200701	200605

5.2. BSC-DREAM8b forecast system structure

The system has to be built with the user dream with the home directory: `/home/dream/`. The forecast system structure is organized as follows:

Directories		Description	
/OBLAST/		programs for setting up and visualize the domain parameters	
/dream/	/GRADSLIB/	object <i>tograds.o</i> needed for linkage during compilation	
	/avn4_05_12/	programs to download the global meteorological data	
	/input_data_05_12/	meteorological databases used in the pre-processing step	
	/ETA.1.a/	/WPS/	programs for decoding the gribbed meteorological global data
		/include/	include files (*.inc)
		/model/	the model itself (calculation) and part of the post-processing
		/mount/	programs for interpolation of the topography in the domain of simulation
		/namelist/	name list with all the necessary paths
		/output/	output files generated and needed during runtime
		/postproc/	post-processing routines (output Grads files generation)
		/postproc_netcdf_oper/	post-processing routines (output NetCDF files generation)
		/preproc/	routines for pre-processing: initialization, boundary conditions, vertical and horizontal interpolation, climatological SST and dust preparations
		/rad_gdfl	program for generation of the transmission functions needed by the radiation code
	/profiles/	post-processing routines for the extraction of dust parameters for specific locations	
	/SCRIPTS/	the main script for running the system	
/eta.1.a/	/soil/	programs for generation/interpolation of soil texture and vegetation	
	/grads/	*.ctl for grads files generation and access	
	/pictures/	program and grads scripts for map generation	

Every folder contains the corresponded *Makefile* for its compilation and 2 subdirectories:

- /src/** which contains the corresponded FORTRAN subroutines
- /exe/** which contains the executable files produced by the compilation

The BSC-DREAM8b Forecast System consists of these 3 major modules:

- *Pre-Processing System*: Its functions include two parts,
 - ✓ The *Set-up* of the model which includes the definition of simulation domains and model configuration and the interpolation of terrestrial data (such as terrain, land use, and soil types) to the simulation domain. This part is only executed when the model is installed.
 - ✓ *Pre-processing of the operational system* which includes a download, degrib and interpolation of the meteorological input data from the global meteorological model to this simulation domain, as well as, the initial and boundary conditions for the dust model.
- *Model Operational System*: This is the key component of the modeling system, which is composed of numerical integration program.
- *Post-Processing & Visualization tools*: This includes the GrADS and NetCDF outputs files with the conversion from E-Arakawa grid to georeference grid and the maps generation process.

The main operational script of the operational system is:

/home/dream/ETA.1.a/SCRIPTS/run12.sh

In the operational script (see an example in the APPENDIX A) the tasks are sequential and each one has to wait the previous to finish. Inside each task, there are many different subtasks, also done in sequential order (see Fig. 5.1).

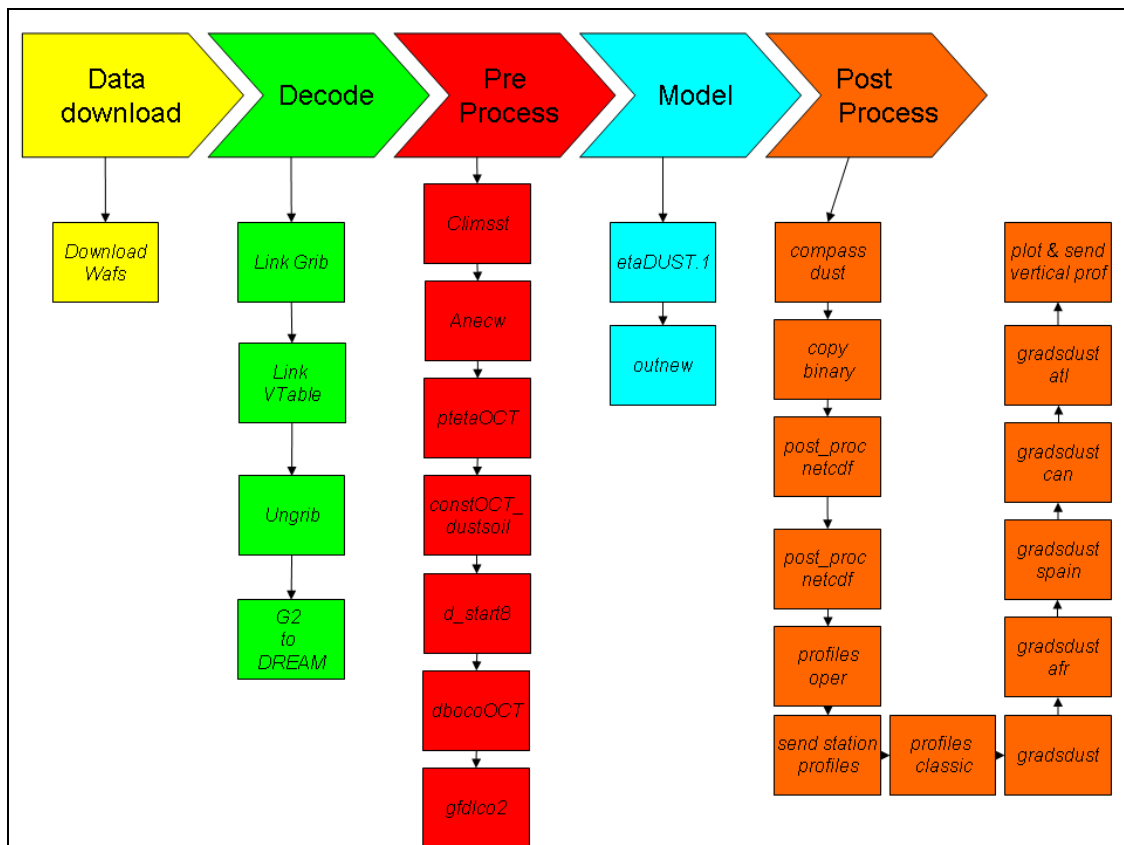


Figure 5.1: Operational script, divided by tasks.

The role of the script ETA.CSH is to wait for the finalization of the global meteorological data downloading and start the forecast system script: run12.sh

```
00 17 *** /home/dream/ /ETA.1.a/SCRIPTS/ETA.CSH > /home/dream/
/ETA.1.a/SCRIPTS/ETA.CSH.log
```

For example, for the operational forecast for the North Africa-Middle East-Europe domain (i.e. MEDI), the ETA.CSH script starts at 17:00 (local time of the server).

5.3. Software Installation

To build our DREAM system, we need an out-of-the-box Linux server. In the BSC, the standard Linux

distribution is Suse (REL or openSUSE), but any other major distribution could be used. This guide is written using OpenSuse 12.3 as distribution.

In hardware requirements, we strongly recommend Intel Fortran Compiler. We also hardly suggest a dual core computer if you want to run more than one DREAM instance. Also, we need a wide storage system, to store the large data amount created by the system.

5.3.1. Software

We need the following applications (you can use a package installer like Yast or Synaptic in order to install all this software):

Compilers:

- **GFORTTRAN:** almost everything is compiled with gfortran.
- **IFORT:** Intel FORTRAN Compiler. We used the 13.0.0 version.

Libs: g2-devel, libstdc++2.10-devel, libncurses5-devel, libreadline-devel, libjpeg, libpng, libjasper zlib and all the dependences to these libs.

GrADS: Version 1.9b4. The Grid Analysis and Display System (GrADS) is an interactive desktop tool that is used for easy access, manipulation, and visualization of earth science data. <http://www.iges.org/grads>.

NCL: Version 6.1.2. We can get binary executables compiled for many systems. In our case we only need the ncargf77 executable. Find in the annexes, a guide to install this application. <http://www.ncl.ucar.edu/>

WGrib2: this executable is not mandatory, but it's useful to open the meteorological input files from GFS. Source code can be downloaded at NCEP site (<http://www.cpc.ncep.noaa.gov/products/wesley/wgrib2/>)

TeX Live: software to build some LaTeX based pictures.

IMAGEMAGICK: software to convert and generate animated gifs. <http://www.imagemagick.org>.

NETCDF: NetCDF libraries v.4.0. You can get the source and installation instructions in http://www.unidata.ucar.edu/downloads/netcdf/netcdf-4_0_1/index.jsp

5.4. Model Set-up

The Set-up of the model includes the definition of simulation domains and model configuration and the interpolation of terrestrial data (such as terrain, land use, and soil types) to the simulation domain.

5.4.1. Spatial and temporal configuration of the model

The domain parameters (window location, resolution and vertical levels) are defined in `/home/dream/ETA.1.a/include/all.inc`. The following parameters are included:

- TLMOD**: Longitude of the center point of the domain
- TPHOD**: Latitude of the center point of the domain
- WBD**: Western boundary of the domain with respect to the center point (always <0)
- SBD**: Southern boundary of the domain with respect to the center point (always <0)
- DLMD**: longitudinal model grid resolution
- DPHD**: latitudinal model grid resolution
- DTB**: time step of the model, this variable depends on **DLMD** and **DPHD** values by means of the Courant-Friedrichs-Lewy (CFL) criteria.
- LM**: number of vertical levels

For example, for the operational domain North Africa-Mediterranean-Europe-Middle East at BSC (Fig. 2.1), the parameters included in `/home/dream/ETA.1.a/include/all.inc` will be:

```
C-----  
C Center of domain :  
  P A R A M E T E R  
  &(TLMOD=20.,TPHOD=35.)  
C-----  
C Domain parameters  
  P A R A M E T E R  
  &(WBD=-51.,SBD=-35.  
  &.,DLMD=1./3.,DPHD=1./3.,DTB=120.  
  &.,LM=24)  
C-----
```

`largewc.inc` includes `all.inc` and calculates some domain parameters needed. It also sets up other necessary parameters.

```
#include "all.inc"  
PARAMETER  
&(IM=-WBD/DLMD+1.5,JM=-2*SBD/DPHD+1.5)
```

- IM**: Number of mass grid points along the first row, essentially half the total number of grid points in the west-east direction due to the horizontal staggering of mass and wind points
- JM**: Number of rows in the north-south direction

In order to change the domain configuration, we will use `/home/dream/OBLAST/oblast.f`. With this routine, we will check if the new domain verifies the conditions of the model for its execution.

1. Introduce the TLM0D, TPH0D, WBD, SBD, DLMD and DPHD values in **oblast.f**
2. Compile the FORTRAN file: **ncargf77 oblast.f**
3. Execute the produced file (a.out): **./a.out**

When executing **a.out**, its outputs IMJM must be an odd number.

```
IM= 154
JM= 211
IMJM= 32389
```

Additionally, **gmeta** file in **/home/dream/OBLAST/** directory is produced which can be visualized by means of the **idt gmeta** command.

Change **oblast.f** inputs as long as your desired domain is set up by repeating the procedure. Once, the correct values are found, they will be included in **/home/dream/ETA.1.a/include/all.inc** and the corresponded time step (**DTB**).

All the changes in the source code will update by means of a compilation of the code in order to ensure that the new values will be incorporated in the vegetation, soil and mount interpolation model grid explained in the Sect. 5.3.3.

```
cd /home/dream/ETA.1.a/
make clean
make linux (executes the respective Makefile)
```

5.4.2. Model paths definition

The **name.list** file in **/home/dream/ETA.1.a/namelists/** specifies the paths used internally by the model. Most of the paths are relative and consistent with the structure of the system described in the previous section. For example, for the operational domain North Africa-Mediterranean-Europe-Middle East at BSC (Fig. 2.1):

```
$DECODING_NL
FN_GRIB = ' '
FN_NCARSST = '../input_data/SSTNH'
FN_LLSPL = '../output/decoding.llspl.'
FN_LLSST = '../output/decoding.llsst'
FN_LLSURFT = '../output/decoding.llsurft'
FN_LLSURFW = '../output/decoding.llsurfw'
FN_LSM = '../input_data/lsm.eco'
FN_LLSM = '../output/decoding.lllsm'
$END
!-----
$MOUNT_NL
FN_USNAVY = '/home/dream/ETA_DREAM/MEDI/OPER8N/input_data/usnavy.dat'
FN_E1 = ' '

```

```
FN_E2 = ' '
FN_A1 = ' '
FN_A2 = ' '
FN_GT30 = '/home/dream/DATA/GTOPO30/'
FN_MOUNT13 = '../output/mount.13'
$END
!-----
! Namelist SLOPES_NL used in:
$SLOPES_NL
FN_SLOPES = '../output/slopes.inp'
$END
!-----
$SOIL_NL
FN_SRZ = '../input_data/srztext.dat'
FN_FAO = '../input_data/faosoil.dat'
FN_TEXT4ETA = '../output/soil.text4eta'
FN_TEXTETA = '../output/soil.texteta'
FN_SOIL = '../output/soil.soil'
FN_OWE = '../input_data/owe14.img'
FN_VEG = '../output/soil.veg'
$END
!-----
$PREPROC_NL
FN_ANEC = '../output/preproc.anec.'
FN_SST = '../output/preproc.anec.sst'
FN_SURFT = '../output/preproc.anec.surft'
FN_SURFW = '../output/preproc.anec.surfw'
FN_NFCSTE = '../output/preproc.pteta.nfcste'
FN_NBCE = '../output/preproc.pteta.nbce.'
FN_NFCST = '../output/preproc.const.nfcst'
FN_NFCST2D = '../output/preproc.const.nfcst2d'
FN_NBC = '../output/preproc.boco.nbc.'
FN_NHIBU = '../output/preproc.const.nhibu'
FN_NHIBU2D = '../output/preproc.const.nhibu2d'
FN_MASKS = '../output/preproc.const.masks'
$END
!-----
$MODEL2D_NL
FN_VOUT = '../output/v_out.'
FN_POUT = '../output/p_out.'
FN_SOUT = '../output/s_out.'
$END
```

5.4.3. Topography, Vegetation and Soil texture

The global topography and vegetation files at 1-km resolution are located in: **/home/dream/DATA/GTOPO30**

The FAO soil data is located in: **/home/dream/input_data/faosoil.dat**

In order to generate and interpolate topography for the forecast domain, we must follow the following steps:

```
cd /home/dream/ETA.1.a/mount/  
make clean  
make linux  
cd exe  
./gt30mount
```

In order to generate and interpolate vegetation and soil texture for the forecast domain, we must follow the following steps:

```
cd /home/dream/ETA.1.a/soil/  
make clean  
make linux (discard compilation issues in texteta)  
cd soil/exe  
./gt30source  
./gt30vegetadirect  
./text4eta  
cd ..  
make linux  
cd exe  
./texteta (different to text4eta before)
```

The previous programs generate the following 6 files in **/home/dream/ETA.1.a/output/**

```
mount.13  
soil.soil  
soil.text4eta  
soil.veg  
source.dat  
smask.dat
```

5.4.4. Binary model forecast outputs description

The main model configuration outputs binary files are defined in:

/home/dream/ETA.1.a/model/src/fcstdata

For example, for the operational domain North Africa-Mediterranean-Europe-Middle East at BSC (Fig. 2.1)

```
$FCSTDATA
TSTART=00.0,TEND=72.0,TCP=99.0,RESTRT=.FALSE.,SUBPOST=.FALSE.,
NMAP=5,TSHDE=00.0,06.0,12.0,18.0,24.0,30.0,36.0,42.0,48.0,54.0,
60.0,66.0,72.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,
99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,
99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,
99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,99.0,
SPL=10000.,15000.,20000.,25000.,30000.,40000.,50000.,
70000.,85000.,100000.,
NPHS=4,NCNVC=2,NRADSH=1,NRADLH=1,
TPREC=90.0,THEAT=90.0,TCLD=90.0,
TRDSW=1.0,TRDLW=1.0,TSRFC=1.0,
HOUT=1.,PRINT_INIT=.T.,
PRINT_FIELDS=.F.,PRFIELDS=73.,
PRINT_GROUND=.F.,PRGROUND=73.,
PRINT_DUST=.T.,PRDUST=1.,
ZOcontant=.T.,FL_SLOPES=.F.,UPDATE_SM=.F.
$SEND
```

Explanation of the configure parameters:

- TSTART:** Sets the beginning forecast hour (=0.0)
- TEND:** Sets the ending forecast hour.
- RESTRT:** Logical switch that tells the model whether it is starting from an initial condition file (if =.FALSE.) or from a model restrt file (if =.TRUE.). Only works with .FALSE.
- SPL:** These are the pressure levels (in Pa) at which isobaric output can be generated by the post-processor.
- NPHS:** The physics package is called every NPHS time steps.
- NCNVC:** The frequency of calls to the convective parameterization.
- NRADSH, NRADLH:** The interval in hours between calls to the radiation schemes (shortwave and longwave).
- HOUT:** Specifies the interval in hours at which the model will generate output for meteorological variables.
- PRDUST:** Specifies the interval in at which the model will generate output for dust variables.

Deprecated variables:

- NMAP:** Specifies the number of times at which the model will generate output. It doesn't work.
- TSHDE:** List of the forecast hours for which the model will generate output. It doesn't work.

The next six values specify the number of hours over which the following types of parameters accumulate prior to being reset to zero.

- TPREC:** precipitation
- THEAT:** average latent heating associated with precipitation

TCLOD: average cloud fractions
TRDSW: short wave radiation
TRDLW: long wave radiation
TSRFC: surface fluxes (e.g., average sensible heat flux)

5.4.5. Global meteorological input data

The domain of the global meteorological forecast input files used as an initial and boundary conditions (NCEP or ECWMF) of the model is defined in:

```
/home/dream/ETA.1.a/include/largewc.inc
```

Explanation of the configure parameters:

BOWEST: West boundary
BOSOUT: South boundary
BOEAST: East boundary
BONORT: North boundary
DELON: Longitude resolution
DELAT: Latitude resolution

NOTE: These parameters are defined taking into account that the model domain must be inside these boundary conditions (NCEP or ECWMF). In the case of the present configuration the model uses NCEP/GFS global prediction data.

Next, generate decoding executables as follows:

```
cd /home/dream/ETA.1.a/include/  
make clean  
make linux
```

5.4.6. General compilation of the forecast system

After all the changes in the previous sections are included in the system, a general compilation of the forecast system is required.

The *Makefile* in **/home/dream/ETA.1.a/** executes the corresponded *Makefile* in the following subdirectories of **/home/dream/ETA.1.a/**:

decoding
mount
preproc
rad_gfdl
model

postproc
postproc_netcdf_oper

Thus, generate executables as follows:

```
cd /home/dream/ETA.1.a/  
make clean  
make linux
```

The GRADSLIB library is used to build and create all the executables dealing with GrADS files. It is located in the following path:

```
/home/dream/GRADSLIB
```

This directory contains object **tograds.o** needed for linkage during compilation.

Be careful if you are doing a mixed compilation (if you use different compilers for different parts of the model) because you'll need to link these files with the same compiler.

Depending on the compiler available, to build these objects:

```
ifort -O2 -c tograds.f  
ifort -O2 grb2grads.f tograds.o -o grb2grads
```

or

```
gfortran -O2 -c tograds.f  
gfortran -O2 grb2grads.f tograds.o -o grb2grads
```

5.5. Pre-Processing operational System

The Pre-processing operational system is a set of routines whose collective role is to prepare input data to the model Eta grid. The system includes a download of the data and the extraction of the meteorological fields.

5.5.1. Downloading and decoding meteorological global forecast data

The operational North Africa-Middle East-Europe forecast uses as the 12UTC 0.5°x0.5° global NCEP forecast cycle (GFS) as initial and boundary conditions. To get more information about these files, visit the following link:

<http://www.nco.ncep.noaa.gov/pmb/products/gfs/>

The script `get_gfs.sh` downloads this NCEP global data in:

```
00 17 * * * /home/dream/avn4_05_12/get_gfs.sh
```

This script connects to the NCEP FTP server and downloads 6 hourly files up to 72 hour forecast. If the files are not ready, waits and tries again. After download the global files are located in `/home/dream/input_data_05_12/`:

```
wafs.00.0P5DEG  
wafs.06.0P5DEG  
wafs.12.0P5DEG  
wafs.18.0P5DEG  
wafs.24.0P5DEG  
wafs.30.0P5DEG  
wafs.36.0P5DEG  
wafs.42.0P5DEG  
wafs.48.0P5DEG  
wafs.54.0P5DEG  
wafs.60.0P5DEG  
wafs.66.0P5DEG  
wafs.72.0P5DEG
```

The meteorological global fields used as initial and boundary conditions are provided in GRIB code. In order to introduce this data in the forecast system a decoding process of these meteorological files is required. Next, the routine that performs this stage of the pre-processing is described.

```
cd /home/dream/ETA.1.a/WPS/
```

g2_to_dream.x: extracts H, U, V and Q meteorological fields from meteorological global formatted files.

In this directory, there is the software needed to decode the NCEP global data files. Refer to further sections to know how to download these files. For the model 3.1.1 version has been used and it can be downloaded in:

http://www.mmm.ucar.edu/wrf/users/download/get_source.html

This version has been compiled with `ifort`. And we only need to build the binary `ungrib.exe`. Refer the WRF/WPS instructions to build the source. We also need to build the **g2_to_dream.f90** source. You can do it with:

```
ifort g2_to_dream.f90 -o g2_to_dream.x
```

Finally you have to give execution permission to the script **link_grib.csh**.

5.5.2. Pre-processing forecast system

The Pre-processing Forecast System is a set of routines whose collective role is to prepare input data to the model Eta grid. Each of the routines performs one stage of the preparation. Next, these routines are described.

```
cd /home/dream/ETA.1.a/preproc/src/
```

climsst.f: horizontal grid (IMT, JMT) Eta Indexing from the climatologically SST as a function of the month.

anecw.f: horizontal grid (IMT, JMT) Eta Indexing from global initial data of H, U, V and Q.

ptetaOCT.f: set up of the vertical Eta grid variables, and vertical interpolation of the pressure to Eta surface.

constOCT_dustsoil.f: convert initial fields in Eta coordinate from 2-D horizontal id (IMT, JMT) Eta Indexing into 1-D (IMJM), define dummy initial and boundary soil moisture and temperature values, and calculates constants needed for the 1-D version of the UB/NMC soil model.

d_start8.f: prepare constants/parameters from the dust model.

dbocoOCT.f: create the boundary condition files

```
cd /home/dream/ETA.1.a/rad_gfdl/
```

gfdlco2.f: interpolate transmission functions grid for which the transmission functions have been pre-calculated, to the grid structure.

After the pre-processing, the binary files interpolated to the model grid (i.e. E-Arakawa grid) are in **/home/dream/ETA.1.a/output/** generating the following files:

```
decoding.llspl.hhh  
preproc.anec.sst  
preproc.anec.hhh  
preproc.pteta.nfcste  
preproc.pteta.nbce.hhh  
soilsand  
preproc.const.nhibu2d  
preproc.const.nfcst2d  
preproc.const.masks  
preproc.boco.nbc.hhh
```

where *hhh* indicates the forecast time step respect the initial time.

5.6. Model Operational System

BSC-DREAM8b predicts the atmospheric life cycle of the eroded desert dust and was developed as a pluggable component of the Eta/NCEP model.

5.6.1. Governing dust equations

All the routines of the model itself are in `/home/dream/ETA.1.a/model/src/`. The most important part of BSC-DREAM8b is the routine for simulation/forecast of the atmospheric desert dust cycle `/home/dream/ETA.1.a/model/src/DP_DUST.f`. This subroutine contains the following basic components:

- Dust concentration initial conditions
- Dust production from sources (mainly given by means of empirical soil texture data set introduced while pre-processing is executed)
- Particle size distribution
- Dry (turbulent) and wet dust deposition
- Influence of ground wetness on dust production
- Effects of ground and vegetation types on dust process
- Dust radiative feedbacks on meteorology

This routine is easy pluggable to the Eta model code. Its use requires only several modifications of the following original model components/(sub)routines, denoted by adding the prefix `D_*.*` to the original name:

- `D_EBU.f`: primary run stream for the Eta model calling all subroutines needed. Also includes updates dust radiative feedbacks subroutines.
- `D_CUCNVC.f`: convective adjustment for deep and shallow convection
- `D_PDTE.f`: updates surface pressure tendency
- `D_PRECPD.f`: grid scale precipitation
- `D_TURBL.f`: updates the turbulent kinetic energy with vertical diffusion
- `D_SFCDIF.f`: surface diffusion using effective roughness
- `SANDC.COM`: is introduced in order to declare parameters/arrays specifically related to dust calculations.

Following, the different parts/sections of the main dust driver `DP_DUST.f` are explained. Each of these parts is similar to the respective subroutine in the Eta/NCEP original model.

- `INIT.f`: lateral boundary conditions
- `VTADV.f`: vertical advection
- `HDIFF.f`: horizontal diffusion
- `HZADV.f`: horizontal advection
- `DEPOS.f`: dust wet and dry deposition

All dust calculations are made in the concentration continuity equation, driven by the atmospheric part of the model. Calculations are performed on-line, together with those related to the other prognostic variables.

The file `/home/dream/ETA.1.a/model/src/ebuns_dp.inp` is read by `DP_DUST.f` subroutine at initial time.

```
§INPUTS
COUPLE_DUST=.t.,
STOREDUST=024.,
§END
```

If `COUPLE_DUST=.t`, the model start with the 24 hour predicted dust field from the previous day (`/home/dream/ETA.1.a/outputs/contam.024.dat`). For the forecast it is always set to true unless it is a new installation.

If `COUPLE_DUST=.f`, the models starts with cold dust initial conditions.

5.6.2. Model binary forecast outputs

After the model execution, the binary dust and meteorological data files of the model (i.e. E-Arakawa grid) are in `/home/dream/ETA.1.a/output/` generating the following files:

```
dfi.dat
htm.dat
contam.hhh.dat
s_out.hhh.dat
v_out.hhh.dat
v_out.hhh.Ddat
```

where *hhh* indicates the forecast time step respect the initial time.

5.7. Post-Processing

This section includes a description of the subroutines that converts the binary outputs files from E-Arakawa grid to regular lat-lon grid in GrADS and NetCDF output formats and the generation of the dust concentration maps.

It is important to highlight that the execution of the GrADS routines includes not only the generation of the GrADS output files but also the creation of meteorological binary files. Therefore, the GrADS routines (see Sect. 5.7.1) must be always executed.

5.7.1. GrADS dust forecast files

The description of the GrADS files are included in the headers, i.e. `*.ctl`. In these `*.ctl` files, window location, resolution, vertical levels, time and variables are described (see APPENDIX B). These parameters must be in concordance with the model configuration.

/home/dream/eta.1.a/grads/ contains the grads control file **.ctl* and binary data **.gdat* that are produced in the post-processing step. In the APPENDIX C, *DUST.ctl* and *CSFC.ctl* are presented.

The main GrADS output *CSFC.ctl* and *DUST.ctl* files need to be changed according to conversion from E-Arakawa grid to GrADS grid. This is done change the options of the **.ctl* files taking account the values included in **home/dream/ETA.1.a/include/all.inc** in the following way:

xdef (whole distance between western and eastern boundary)=|WBD|*1/DLDM*2
ydef (whole distance between southern and northern boundary)=|SBD|*1/DPHD*2
linear (xdef) 1st part (new western boundary of the domain)=WBD+TLMOD
linear (ydef) 1st part (new southern boundary of the domain)=SBD+TPHOD
linear (xdef) 2nd part (vertical model grid resolution)=DLDM
linear (ydef) 2nd part (horizontal model grid resolution)=DPHD

The grid conversion is now almost completed and the whole E-grid Eta-Domain should fit the GrADS domain interesting when creating all visual output files. The routines that create the GrADS files from the model outputs are:

/home/dream/ETA.1.a/model/src/outnew.f

Produces *DUST.gdat* which includes all the variables 4D (lat, lon, lev, time) and the following binary files interpolated to the model grid (i.e. E-Arakawa grid) used in the *DUST.gdat* generation:

p_out.hhh.dat
peta.dat

where *hhh* indicates the forecast time step respect the initial time.

/home/dream/ETA.1.a/postproc/src/compassdust.f

Produces *CSFC.gdat* which includes all the variables 3D (lat, lon, time)

The GrADS files that will be generated and they are included in the previous routines are described in *activectl.LST* file. They are found in:

/home/dream/ETA.1.a/model/exe/activectl.LST

```
/home/dream/ETA.1.a/model/exe -> /home/dream/eta.1.a/grads/  
DUST.ctl  tf=-999
```

/home/dream/ETA.1.a/postproc/exe/activectl.LST

```
/home/dream/ETA.1.a/postproc/exe -> /home/dream/eta.1.a/grads/  
CSFC.ctl  tf=-999
```


As shown in the APPENDIX C, in the operational forecasts system at BSC for the North Africa-Europe-Middle East domain, *DUST.gdat* and *CSFC.gdat* contain 1-hourly data, with 1/3^a of horizontal resolution and 24 vertical layers.

5.7.2. NetCDF dust forecast files

The description of the NetCDF files is included in their headers, in the same NetCDF file. These files contain the grid coordinates (in regular latitude and longitude), vertical levels, time and variables described. These parameters must be in concordance with the model configuration.

/home/dream/ETA.1.a/postproc_netcdf_oper/ contains all subroutines required for the NetCDF file generation. As a result, a NetCDF file will generate in:

/home/dream/ETA.1.a/output/netcdf_oper/

As shown in the APPENDIX D, in the operational forecasts system at BSC for the North Africa-Europe-Middle East domain, *BSC_DREAM8b_v2.nc* contains 1-hourly data, with 1/3^a of horizontal resolution (and regular lat-lon) and 24 vertical layers.

Although the model produces the outputs in binary files, we wrote a post process routine to build NETCDF files with are easier to manipulate,

To build the executable,

```
cd postproc_netcdf_oper
make clean
make linux
```

To generate the model outputs,

```
./model_output $cargnew
```

where *\$cargnew* is the date in YYMMDD.

The call to this executable is included in the main script of the forecast system (run12.sh)

5.7.3. Dust forecast maps generation

Next, these GrADS (i.e. *DUST.gdat* and *CSFC.gdat*) and NetCDF (i.e. *BSC_DREAM8b.nc*) output files will be used for map generation. The routine that create the maps from these output files (i.e. maps every 6 hours) is:

/home/dream/eta.1.a/pictures/gradsdust.f

This FORTRAN subroutine includes the command *gradsc [-bpc]* which refers to the execution of the grads scripts **.gs* for 5 different parameters:

- **dld4.gs**: dust load maps
- **sfc4.gs**: surface concentration maps
- **dep4.gs**: deposition maps
- **opt550.gs**: aerosol optical depth maps
- **crsc.gs**: vertical cross-section maps for a fixed latitude and longitude

These **.gs* scripts (except **crsc.gs**), includes the domain parameters defined in:

/home/dream/eta.1.a/pictures/area.gs.

These grads scripts are found in ***/home/dream/eta.1.a/pictures/***. These **.gs* scripts produce the forecast maps and plots **.eps*. Then they are converted into **.gif* using the binary *gxeps* (included in the GrADS distribution).

6. References

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7. APPENDIX A: The Operational Script, “Run12.sh”

```
#!/bin/sh
#set -x
#####

#MAKE ALL NECESSARY EXPORTS
export NCARG_ROOT=/usr/local/ncarg
export NCARG=/usr/local/ncarg
export GADDIR=/usr/local/lib/grads
export GASCRP=/usr/local/grads/lib
export MAGICK_TMPDIR=/home/dream
export LD_LIBRARY_PATH=/usr/local/lib:/usr/lib:/opt/intel/Compiler/11.1/059/lib/intel64

#INITIAL FORECAST TIME IN UTC
IHRST=12

#SET WORKING DIRECTORIES AND INPUT DATA DIRECTORIES
RUNHOME=/home/dream/ETA_DREAM/MEDI/OPER8N/ETA.1.a
RUNHOME2=/home/dream/ETA_DREAM/MEDI/OPER8N/eta.1.a
rm -f $RUNHOME/output/decoding*llspl*
SCRIPTS=$RUNHOME/SCRIPTS
DATADIR=/home/dream/input_data_05_12/wafs.
echo 'Running run12'
#####

#RETRIEVE CURRENT DAY, MONTH, YEAR FROM THE MACHINE
YEAR=`date +%Y`
year=`date +%y`
month=`date +%m`
day=`date +%d`
YEAR1=`date -d "+1day" +%Y`
month1=`date -d "+1day" +%m`
day1=`date -d "+1day" +%d`
YEAR2=`date -d "+2day" +%Y`
month2=`date -d "+2day" +%m`
day2=`date -d "+2day" +%d`
YEAR3=`date -d "+3day" +%Y`
month3=`date -d "+3day" +%m`
day3=`date -d "+3day" +%d`

hr=`date +%H`
hr=`expr $hr `
echo 'hr=' $hr

if [ $hr -le 16 ]; then
    day=`date -d "-1day" +%d`
    month=`date -d "-1day" +%m`
    year=`date -d "-1day" +%y`
    YEAR=`date -d "-1day" +%Y`
    YEAR1=`date +%Y`
    month1=`date +%m`
    day1=`date +%d`
    YEAR2=`date -d "+1day" +%Y`
    month2=`date -d "+1day" +%m`
    day2=`date -d "+1day" +%d`

```



```
YEAR3=`date -d "+2day" +%Y`
month3=`date -d "+2day" +%m`
day3=`date -d "+2day" +%d`
fi

#####
#OBTAIN DATE IN DDDMMYY and YYMMDD
carg=`printf "%.2d%.2d%.2d" ${day#0} ${month#0} ${year#0}`
cargnew=`printf "%.2d%.2d%.2d" ${year#0} ${month#0} ${day#0}`

echo $carg
echo $cargnew

date

#DECODES GLOBAL 0.5 x 0.5 DEG NCEP GRIB FILES,DECODED PARAMS:GEOP,T, U, V, RH
init_date="$YEAR"-"$month"-"$day"_12
end_date="$YEAR3"-"$month3"-"$day3"_12
int_sec=21600

cd $RUNHOME/WPS

rm $RUNHOME/WPS/FILE:*
rm $RUNHOME/WPS/GRIBFILE.*

$RUNHOME/WPS/link_grib.csh $DATADIR

sed -e "s/_INI_/$_init_date/" \
    -e "s/_END_/$_end_date/" \
    -e "s/_INT_/$_int_sec/" $RUNHOME/WPS/namelist.ungrib > $RUNHOME/WPS/namelist.wps

rm -f $RUNHOME/WPS/Vtable
ln -s $RUNHOME/WPS/ungrib/Variable_Tables/Vtable.DREAM $RUNHOME/WPS/Vtable

$RUNHOME/WPS/ungrib.exe

./g2_to_dream.x $carg 12 00 $RUNHOME/WPS/FILE:"$YEAR"-"$month"-"$day"_12
./g2_to_dream.x $carg 12 06 $RUNHOME/WPS/FILE:"$YEAR"-"$month"-"$day"_18
./g2_to_dream.x $carg 12 12 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_00
./g2_to_dream.x $carg 12 18 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_06
./g2_to_dream.x $carg 12 24 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_12
./g2_to_dream.x $carg 12 30 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_18
./g2_to_dream.x $carg 12 36 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_00
./g2_to_dream.x $carg 12 42 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_06
./g2_to_dream.x $carg 12 48 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_12
./g2_to_dream.x $carg 12 54 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_18
./g2_to_dream.x $carg 12 60 $RUNHOME/WPS/FILE:"$YEAR3"-"$month3"-"$day3"_00
./g2_to_dream.x $carg 12 66 $RUNHOME/WPS/FILE:"$YEAR3"-"$month3"-"$day3"_06
./g2_to_dream.x $carg 12 72 $RUNHOME/WPS/FILE:"$YEAR3"-"$month3"-"$day3"_12

mv decoding.llspl.* $RUNHOME/output/

#PRE-PROCESSING
cd $RUNHOME/preproc/exe
i=0
while test $i -le 12
do
    arg=`expr $i \* 6`
```



```
arg_dboco=$i

echo "===== IHR = "$arg" ====="
if test $i -eq 0 ; then
echo " climst "
#READ CLIMATOLOGICAL SST AS A FUNCTION OF MONTH AND WRITING IT IN THE HORIZONTAL GRID WITH
IMT, JMT ETA INDEXING
./climst $month
fi

echo " anecw \t" $arg
#HORIZONTAL INTERPOLATION FROM GLOBAL INITIAL DATA OF H,U,V,Q to IMT,JMT ETA INDEXING.
./anecw $arg

echo " ptetaOCT \t" $arg
#SET UP OF THE VERTICAL GRID VARIABLES, AND VERTICAL INTERPOLATION, PRESSURE TO ETA SURFACES
./ptetaOCT $arg

if test $i -eq 0 ; then
echo " constOCT_dustsoil \t"
#CONVERT INITIAL FIELDS IN ETA COORDINATE FROM TWO-DIMENSIONAL HORIZONTAL INDEXING (IMT,JMT)
INTO ONE-DIMENSIONAL (IMJM), DEFINE DUMMY INITIAL AND BOUNDARY SOIL MOISTURE AND TEMPERATURE
VALUES AND CALCULATES CONSTANTS NEEDED FOR THE ONE-DIMENSIONAL VERSION OF THE UB/NMC SOIL
MODEL.
./constOCT_dustsoil

echo " d_start8 \t"
#PREPARE CONSTANTS/PARAMETERS FOR THE DUST MODEL
./d_start8
fi

if test $i -gt 0 ; then
echo " dbocoOCT \t" $arg_dboco
#CREATE THE BOUNDARY CONDITION FILE
./dbocoOCT $arg_dboco
fi
i=`expr $i + 1`
done

cd $RUNHOME/rad_gfdl/exe
#INTERPOLATE TRANSMISSION FUNCTIONS GRID, FOR WHICH THE TRANSMISSION FUNCTIONS HAVE BEEN PRE-
CALCULATED, TO THE GRID STRUCTURE
./gfdlco2

#COPY PREVIOUS DAY OUTPUT TO THE ARCHIVE
cd $RUNHOME/output
cp contam.024.dat contam24$carg
cp contam.048.dat contam48$carg
cp contam.072.dat contam72$carg

mv contam24$carg archive/
mv contam48$carg archive/
mv contam72$carg archive/

#####

cd $RUNHOME/model/exe
#RUN THE MODEL
```

```
date
./etaDUST.1
date
echo "===== ETA finished successfully ====="
#-----
#-----
carg1=`printf "%.2d%.2d%.2d%.2d" $year $month $day $IHRST`
echo "carg1=$carg1"
#-----

#POST-PROCESSING
cd $RUNHOME/model/exe
i=0
  while test $i -le 72
  do
    arg=`expr $i \* 1`
    #GENERATE OUTPUT IN GRADS FORMAT
    ./outnew $arg
    i=`expr $i + 1`
  done

cd $RUNHOME/postproc/exe
i=0
  while test $i -le 72
  do
    arg=`expr $i \* 1`
    #GENERATE OUTPUT IN GRADS FORMAT
    ./compassdust $arg
    i=`expr $i + 1`
  done

cd $RUNHOME/output
mkdir archive_v_Ddat/v_Ddat20$cargnew
i=0
  #COPY SELECTED OUTPUT BINARY FILES TO ARCHIVE
  while test $i -le 72
  do
    arg=`expr $i \* 1`
    arg2=`printf "%.2d" $arg`
    cp v_out.0"$arg2".Ddat v_out20"$cargnew""$arg2"
    mv v_out20"$cargnew""$arg2" archive_v_Ddat/v_Ddat20$cargnew/.
    i=`expr $i + 1`
  done

done

#CREATE NETCDF FOR OPERATIONAL OUTPUTS
cd $RUNHOME/postproc_netcdf_oper/exe
./model_output $cargnew

cd $RUNHOME2/pictures

#CREATE MAPS AND PLOTS GENERATION, AND SEND THEM TO THE WEB SERVER
#MAPS FOR MEDITERRANEAN AND EUROPE

./gradsdust

date
exit
```

8. APPENDIX B: Using GrADS Data Files

GrADS supports two basic data types:

- a. gridded data data on a grid
- b. station data station or point observations.

The *data* and *meta* data (or information about the data) are kept in separate files. The *meta* data file contains a complete description of the data and the name of the file containing it, the data file is purely data with no space or time identifiers. The file which you open in GrADS is the data descriptor file (the meta data) or **.ctl* file. The **.ctl* is constructed to describe various data types and structures (e.g., binary and GRIB).

The raw data are on disk in either binary direct access or sequential unformatted form (IEEE floats and ints) or GRIB. The data are described by the data descriptor file, which contains:

- a. Name of the binary data set.
- b. Mapping between grid coordinates and world coordinates.
- c. Number of variables, abbreviations for variables.

The GrADS gridded may contain any number of variables at specified longitude, latitude, vertical levels, and time intervals. Latitudes can vary from north to south or from south to north (the default), and levels can vary from top to bottom or from bottom to top. GrADS views this data set as a giant “5-D” array—with X (longitude or lon) varying the fastest, then Y (latitude or lat), then Z (vertical level or lev), then the variable type, then T (time).

It is easier for us to think of the data set in terms of a sequence of horizontal grids, where longitude and latitude vary. Each horizontal grid represents a particular variable at a particular height and time. Each horizontal grid is the *same size* in any particular GrADS data set (if you have grids of different sizes, you must create separate data sets).

These grids are written to the data set in the following order: starting with a particular variable, grids for each vertical level (at a particular time) are written out in ascending order. Then the grids for the next variable are written out. When all the grids at a particular time have been written, grids for the next time are written.

Each binary gridded data set is described by a separate data descriptor file, essentially a table of contents for the binary data set. Following is an example of a simple data descriptor file:

DSET ua.dat

```
TITLE Upper Air Data
UNDEF -9.99E33
OPTIONS BYTESWAPPED
XDEF 80 LINEAR -140.0 1.0
YDEF 50 LINEAR 20.0 1.0
ZDEF 10 LEVELS 1000 850 700 500 400 300 250 200 150 100
TDEF 4 LINEAR 0Z10apr1991 12hr
VARS 6
  slp 0 0 sea level pressure
  z 10 0 heights
  t 10 0 temps
  td 6 0 dewpoints
  u 10 0 u winds
  v 10 0 v winds
ENDVARS
```

The data descriptor file is 'free format', ie each entry is blank delimited and may appear in any column. Comment records start with an asterisk ('*') in column 1. Comments may not appear in the list of variable records (between the vars and endvars records). Records may not be more than 255 characters long.

In this example, the binary data set is named *ua.dat*, the undefined, or missing, data value is -9.99e33, there are 80 grid points in the X direction, 50 in the Y direction, 10 levels, 4 times, and 6 variables. The variables z, t, u, and v have 10 levels, the variable td has 6 levels, and the variable slp has one level (see below for a more specific description of each entry).

A description of each record in the example GrADS gridded data descriptor file follows:

DSET data-set-name

This entry specifies the name of the binary data set. It may be entered in mixed case. If the binary data set is in the same directory as the data descriptor file, you may enter the filename in the data descriptor file without a full path name by prefixing it with a ^ character. For example, if the data descriptor file is:

```
/data/wx/grads/sa.ctl
```

and the binary data file is:

```
/data/wx/grads/sa.dat
```

you could use the following file name in the data descriptor file:

```
DSET ^sa.dat
```


instead of:

DSET /data/wx/grads/sa.dat

As long as you keep the two files together, you may move them to any directory without changing the entries in the data descriptor file.

TITLE string

A brief description of the contents of the data set. This will be displayed during a query command, so it is helpful to put meaningful information here.

UNDEF value

The undefined, or missing, data value. GrADS operations and graphics routines will ignore data with this value from this data set. This is a required parameter even if there are no undefined data.

OPTIONS BYTESWAPPED

Indicates the binary data file is in reverse byte order from the normal byte order of the machine. This would happen if you sent a file in binary format from, for example, a Sun to a PC. Putting this keyword in the descriptor file tells GrADS to swap the byte order as the data is being read.

XDEF number <LINEAR start increment> or <LEVELS value-list>

Defines the mapping between grid values and longitude. Specifically, *number* is the number of grid values in the X direction, specified as an integer number. Must be ≥ 1 . LINEAR or LEVELS indicates the grid mapping type.

For **LINEAR**:

start: the starting longitude, or the longitude for $X=1$. Specified as a floating point value where negative indicates degrees west.

Increment: the spacing between grid value in the X direction. It is assumed that the X dimension values go from west to east. Specified as a positive floating value.

For **LEVELS**:

value-list: List of 'number' values representing the longitude of each X dimension. May start and continue on the next record in the descriptor file (records may not be > 255 characters). There must be at least 2 levels (otherwise use LINEAR mapping).

YDEF number <mapping start increment> or <LEVELS value-list>

Defines the mapping between grid values and latitude. Specifically, *number*, is the number of grid values in the X direction, specified as an integer number.

For **mapping**:

Mapping: mapping type, specified as a keyword. Valid are:

LINEAR: Linear mapping

GAUSR15: Gaussian R15 latitudes

GAUSR20: Gaussian R20 latitudes

GAUSR30: Gaussian R30 latitudes

GAUSR40: Gaussian R40 latitudes

Start: for **LINEAR** mapping, the starting latitude, ie the latitude for $Y = 1$, and is specified as a floating point value, with negative indicating degrees south. For **GAUSRxx** mapping, the start value indicates the first gaussian grid number, where 1 would be the southernmost gaussian grid latitude.

Increment: the spacing between grid values in the Y direction. It is assumed that the Y dimension values go from south to north. Specified as a positive floating point value. Used only for **LINEAR** mapping.

For **LEVELS**:

value-list: List of 'number' values representing the latitude of each X dimension. May start and continue on the next record in the descriptor file (records may not be > 80 characters). There must be at least 2 levels (otherwise use **LINEAR** mapping).

ZDEF number mapping <start increment> or <value-list>

Defines the mapping between grid values and pressure level. Specifically, *number* is the number of grid values in the X direction, specified as an integer number; and *mapping* is a mapping type, specified as a keyword. Valid are:

- a. **LINEAR**: Linear mapping
- b. **LEVELS**: Arbitrary pressure levels

For **LINEAR**:

Start: when mapping is **LINEAR**, this is the starting value, or the value when $Z=1$.

Increment: when mapping is **LINEAR**, the increment in the Z direction, or from lower to higher.

For **LEVELS**:

value-list: when the mapping is **LEVELS**, the specific levels are simply listed in ascending order. If there is only one level, use **LINEAR**, since **LEVELS** implies at least two levels.

TDEF number LINEAR start-time increment

Defines the mapping between grid values and time. Specifically, *number* is the number of times in the data set. Specified as an integer number.

start-time: The starting date/time value, specified in GrADS absolute date/time format. No intervening blanks are allowed in a GrADS absolute date/time. This is the value when T=1. The date/time format is: **hh:mmZddmmmyyyy** where:

hh = hour (two digit integer, 00 default)

mm = minutes (two digit integer)

dd = day (one or two digit integer, 01 default)

mmm = month (jan, feb, mar, apr, may, jun, jul, aug, sep, oct, nov, dec)

yyyy = year (2 or 4 digit integer, 2 digits implies a year between 1950 and 2049).

The month and year must be specified. Examples:

12Z1JAN1990

14:20Z22JAN1987

JUN1960

Increment: time increment. Specified in GrADS time increment format: **vvkk** where:

vv = an integer number, 1 or 2 digits

kk = an increment keyword,

mn = minutes

hr = hours

dy = days

mo = months

yr = year

Examples:

20mn: increment is 20 minutes

1mo: increment is 1 month

2dy: increment is 2 days

Further examples of a TDEF statement:

TDEF 24 LINEAR 00Z01JUN1987 1HR

The data set has 24 times, starting at 00Z on 1 Jun, 1987, with an increment of 1 hour.

TDEF 30 LINEAR 2JUN1988 1DY

The data set has 30 times, starting at 00Z on 2 Jun, 1988, with an increment of 1 day.

VARs number

Indicates the start of the records describing the variables in the data set. *Number* is the number of variable records. There are 6 variable records in this example, each with the following format:

abbrev levs units description

Abrev: a 1 to 12 character abbreviation for this variable. This abbreviation must start with an alphabetic character (a-z) and be composed of alphabetic characters and numbers. This abbreviation will be the "name" the variable is accessed by from within GrADS.

Levs: an integer value specifying the number of levels this variable has in the data set. It may not exceed the number of levels in the ZDEF statement. A levs value of 0 indicates this variable has one "level" that does not correspond to a vertical level.

Units: Used for GRIB data and special data format/structures. Put a value of 99 here. *Description*: A text description of the variable, max 40 characters.

ENDVARS

After the last variable record comes the **ENDVARS** statement. This ends the GrADS data descriptor file. Blank lines after the **ENDVARS** statement may cause GrADS open to fail!



9. APPENDIX C: DUST.ctl and CSFC.ctl

/home/dream/eta.1.a/grads/DUST.ctl

```
dset /home/dream/eta.1.a/grads/DUST.gdat
undef -999.
title eta model
xdef 255 linear -26 0.3333
ydef 195 linear 0.0 0.3333
tdef 73 linear 00Z23dec2003 1hr
zdef 24 levels 86 275 495 745 1027 1341 1687 2067 2481 2932 3421
  3949 4519 5135 5798 6513 7285 8120 9024 10006 11079 12257 13561 15022
vars 16
u 24 33,8,00 U Winds
v 24 34,8,00 V Winds
dc1 24 81,8,00 dc1
dc2 24 82,8,00 dc2
dc3 24 83,8,00 dc3
dc4 24 84,8,00 dc4
dc5 24 85,8,00 dc5
dc6 24 86,8,00 dc6
dc7 24 87,8,00 dc7
dc8 24 88,8,00 dc8
dc 24 99,8,00 dc
exta 4 100,8,00 ext350
extb 24 101,8,00 ext550
extc 24 102,8,00 ext1000
z 24 98,8,00 z
zsfc 0 97,1,00 V Winds
endvars
```

/home/dream/eta.1.a/grads/CSFC.ctl

```
dset /home/dream/eta.1.a/grads/CSFC.gdat
undef 1.e30
title eta model
xdef 255 linear -26.0 0.3333
ydef 195 linear 0.0 0.3333
tdef 73 linear 00Z25may2006 1hr
zdef 1 levels 1000
vars 53
dload 0 213, 105, 0 dust load
dload1 0 214, 105, 0 dust load bin 1
dload2 0 215, 105, 0 dust load bin 2
dload3 0 216, 105, 0 dust load bin 3
dload4 0 217, 105, 0 dust load bin 4
dload5 0 218, 105, 0 dust load bin 5
dload6 0 219, 105, 0 dust load bin 6
dload7 0 220, 105, 0 dust load bin 7
dload8 0 221, 105, 0 dust load bin 8
depd1 0 222, 105, 0 dry dep. bin 1
depd2 0 223, 105, 0 dry dep. bin 2
depd3 0 224, 105, 0 dry dep. bin 3
depd4 0 225, 105, 0 dry dep. bin 4
```



```
depd5 0 226, 105, 0 dry dep. bin 5
depd6 0 227, 105, 0 dry dep. bin 6
depd7 0 228, 105, 0 dry dep. bin 7
depd8 0 229, 105, 0 dry dep. bin 8
depw1 0 230, 105, 0 wet dep. bin 1
depw2 0 231, 105, 0 wet dep. bin 2
depw3 0 232, 105, 0 wet dep. bin 3
depw4 0 233, 105, 0 wet dep. bin 4
depw5 0 234, 105, 0 wet dep. bin 5
depw6 0 235, 105, 0 wet dep. bin 6
depw7 0 236, 105, 0 wet dep. bin 7
depw8 0 237, 105, 0 wet dep. bin 8
tmp1 0 91, 105, 0 surf. conc. bin 1
tmp2 0 92, 105, 0 surf. conc. bin 2
tmp3 0 93, 105, 0 surf. conc. bin 3
tmp4 0 94, 105, 0 surf. conc. bin 4
tmp5 0 95, 105, 0 surf. conc. bin 5
tmp6 0 96, 105, 0 surf. conc. bin 6
tmp7 0 97, 105, 0 surf. conc. bin 7
tmp8 0 98, 105, 0 surf. conc. bin 8
dflx1 0 201, 105, 0 surf. dust flux bin 1
dflx2 0 202, 105, 0 surf. dust flux bin 2
dflx3 0 203, 105, 0 surf. dust flux bin 3
dflx4 0 204, 105, 0 surf. dust flux bin 4
dflx5 0 205, 105, 0 surf. dust flux bin 5
dflx6 0 206, 105, 0 surf. dust flux bin 6
dflx7 0 207, 105, 0 surf. dust flux bin 7
dflx8 0 208, 105, 0 surf. dust flux bin 8
dod1 0 399, 105, 0 opt5501
dod2 0 400, 105, 0 opt5502
dod3 0 401, 105, 0 opt5503
dod4 0 402, 105, 0 opt5504
dod5 0 403, 105, 0 opt5505
dod6 0 404, 105, 0 opt5506
dod7 0 405, 105, 0 opt5507
dod8 0 406, 105, 0 opt5508
dod 0 417, 105, 0 opt550
t2mk 0 001, 105, 0 2 m temp.
u10k 0 007, 105, 0 u10k
v10k 0 008, 105, 0 v10k
endvars
```

10. APPENDIX D: BSC-DREAM8b.nc

/home/dream/ETA.1.a/output/netcdf_oper/

```
netcdf BSC_DREAM8b {
dimensions:
    longitude = 256 ;
    latitude = 196 ;
    level = 24 ;
    time = 73 ;
variables:
    float longitude(longitude) ;
        longitude:units = "degrees_east" ;
        longitude:description = "longitude. East positive" ;
    float latitude(latitude) ;
        latitude:units = "degrees_north" ;
        latitude:description = "latitude. North positive" ;
    float level(level) ;
        level:units = "meters" ;
        level:description = "level. Above sea level positive" ;
    float time(time) ;
        time:units = "hours since 2012-06-11 12:00:00.0" ;
        time:description = "time forecast" ;
    float aod550_dust(time, latitude, longitude) ;
        aod550_dust:units = "-" ;
        aod550_dust:description = "Dust optical depth at 550nm" ;
        aod550_dust:missing_value = -999.f ;
    float sconcdust(time, latitude, longitude) ;
        sconcdust:units = "kg/m^3" ;
        sconcdust:description = "Dust surface concentration" ;
        sconcdust:missing_value = -999.f ;
    float load_dust(time, latitude, longitude) ;
        load_dust:units = "kg/m^2" ;
        load_dust:description = "Dust load" ;
        load_dust:missing_value = -999.f ;
    float depw_dust(time, latitude, longitude) ;
        depw_dust:units = "kg/m^2" ;
        depw_dust:description = "Dust Wet deposition" ;
        depw_dust:missing_value = -999.f ;
    float depd_dust(time, latitude, longitude) ;
        depd_dust:units = "kg/m^2" ;
        depd_dust:description = "Dust dry deposition" ;
        depd_dust:missing_value = -999.f ;
    float acprec(time, latitude, longitude) ;
        acprec:units = "mm" ;
        acprec:description = "Accumulated precipitation" ;
        acprec:missing_value = -999.f ;
    float ccrt(time, latitude, longitude) ;
        ccrt:units = "-" ;
        ccrt:description = "Cloud cover" ;
        ccrt:missing_value = -999.f ;
    float seag(time, latitude, longitude) ;
        seag:units = "hPa" ;
        seag:description = "MSL pressure" ;
        seag:missing_value = -999.f ;
```



```
float conc_dust(time, level, latitude, longitude) ;
  conc_dust:units = "kg/m^3" ;
  conc_dust:description = "Dust concentration" ;
  conc_dust:missing_value = -999.f ;
float ext500_dust(time, level, latitude, longitude) ;
  ext500_dust:units = "1/m" ;
  ext500_dust:description = "Dust extinction profile at 550nm" ;
  ext500_dust:missing_value = -999.f ;
float th(time, level, latitude, longitude) ;
  th:units = "K" ;
  th:description = "Potential temperature" ;
  th:missing_value = -999.f ;
float u(time, level, latitude, longitude) ;
  u:units = "m/s^2" ;
  u:description = "U winds profile" ;
  u:missing_value = -999.f ;
float v(time, level, latitude, longitude) ;
  v:units = "m/s^2" ;
  v:description = "V winds profile" ;
  v:missing_value = -999.f ;
float z(time, level, latitude, longitude) ;
  z:units = "-" ;
  z:description = "z" ;
  z:missing_value = -999.f ;

// global attributes:
  Model = "BSC-DREAM8b" ;
}
```

11. APPENDIX E: Configuration receipts

To change the spatial horizontal resolution

1. Modify the post-processing routines to take into account the new configuration.

```
/home/dream/ETA.1.a/include/all.inc
```

2. Repeat the Set-up of the mode (see Sect. 5.4)
3. Make a general compilation of the model

```
cd /home/dream/ETA.1.a/  
make clean  
make linux (executes the respective Makefile)
```

4. Modify the post-processing routines (see Sect. 5.7.1 and Sect. 5.7.2) to take into account the new configuration.

To change the temporal resolution of the model outputs

1. Modify the model configuration file with the new output data in

```
/home/dream/ETA.1.a/model/src/fcstdata
```

Change the value of:

TEND: Sets the ending forecast hour.

2. Make a general compilation of the model

```
cd /home/dream/ETA.1.a/  
make clean  
make linux (executes the respective Makefile)
```

3. Modify the post-processing routines (see Sect. 5.7.1 and Sect. 5.7.2) to take into account the new configuration.

To change the number of simulated hours per run

1. Modify the model configuration file with the new output data in

```
/home/dream/ETA.1.a/model/src/fcstdata
```

Change the value of:

HOUT: Specifies the interval in hours at which the model will generate output for meteorological variables.

PRDUST: Specifies the interval in at which the model will generate output for dust variables.

2. Make a general compilation of the model

```
cd /home/dream/ETA.1.a/  
make clean  
make linux (executes the respective Makefile)
```

3. Modify the post-processing routines (see Sect. 5.7.1 and Sect. 5.7.2) to take into account the new configuration

To change the spatial vertical resolution

1. Modify the model configuration file with the new output data in

/home/dream/ETA.1.a/model/src/fcstdata

/home/dream/ETA.1.a/model/src/IRNEW.f

2. Repeat the Set-up of the mode (see Sect. 5.4)
3. Make a general compilation of the model

```
cd /home/dream/ETA.1.a/  
make clean  
make linux (executes the respective Makefile)
```

4. Modify the post-processing routines (see Sect. 5.7.1 and Sect. 5.7.2) to take into account the new configuration.

To change the global meteorological input data

1. Define the new input global meteorological data in

/home/dream/ETA.1.a/include/largewc.inc

2. Create the corresponding new decoding Fortran routine to read the new input global meteorological data. In the case of the present configuration the model uses NCEP/GFS global prediction data which is read it by:

/home/dream/ETA.1.a /WPS/g2_to_dream.x

3. Replace the corresponding part in the general script of the model:

/home/dream/ETA.1.a /SCRIPTS/run12.sh

```
#DECODES GLOBAL 0.5 x 0.5 DEG NCEP GRIB FILES,DECODED PARAMS:GEOP,T, U, V, RH
init_date="$YEAR"-"$month"-"$day"_12
end_date="$YEAR3"-"$month3"-"$day3"_12
int_sec=21600

cd $RUNHOME/WPS

rm $RUNHOME/WPS/FILE:*
rm $RUNHOME/WPS/GRIBFILE.*

$RUNHOME/WPS/link_grib.csh $DATADIR

sed -e "s/_INI_/$init_date/" \
    -e "s/_END_/$end_date/" \
    -e "s/_INT_/$int_sec/" $RUNHOME/WPS/namelist.ungrib > $RUNHOME/WPS/namelist.wps

rm -f $RUNHOME/WPS/Vtable
ln -s $RUNHOME/WPS/ungrib/Variable_Tables/Vtable.DREAM $RUNHOME/WPS/Vtable

$RUNHOME/WPS/ungrib.exe

./g2_to_dream.x $carg 12 00 $RUNHOME/WPS/FILE:"$YEAR"-"$month"-"$day"_12
./g2_to_dream.x $carg 12 06 $RUNHOME/WPS/FILE:"$YEAR"-"$month"-"$day"_18
./g2_to_dream.x $carg 12 12 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_00
./g2_to_dream.x $carg 12 18 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_06
./g2_to_dream.x $carg 12 24 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_12
./g2_to_dream.x $carg 12 30 $RUNHOME/WPS/FILE:"$YEAR1"-"$month1"-"$day1"_18
./g2_to_dream.x $carg 12 36 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_00
./g2_to_dream.x $carg 12 42 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_06
./g2_to_dream.x $carg 12 48 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_12
./g2_to_dream.x $carg 12 54 $RUNHOME/WPS/FILE:"$YEAR2"-"$month2"-"$day2"_18
./g2_to_dream.x $carg 12 60 $RUNHOME/WPS/FILE:"$YEAR3"-"$month3"-"$day3"_00
./g2_to_dream.x $carg 12 66 $RUNHOME/WPS/FILE:"$YEAR3"-"$month3"-"$day3"_06
./g2_to_dream.x $carg 12 72 $RUNHOME/WPS/FILE:"$YEAR3"-"$month3"-"$day3"_12
```

To change the activate/desactivate the radiative feedbacks

1. Modify the true/false flags in the following Fortran routine:

/home/dream/ETA.1.a/model/src/RADTRNS4D.f (in Lines 298-300)

2. Make a general compilation of the model



```
cd /home/dream/ETA.1.a/  
make clean  
make linux (executes the respective Makefile)
```

