1.1 Description of the Numerical Weather Prediction System WRF

The WRF (Weather Research and Forecasting Model), is a state-of-the-art meso-scale numerical weather prediction model designed to meet the needs of both atmospheric research and business sectors. In its latest version (version 4.2) the WRF consists of a dynamic Eulerian kernel (ARW), a data assimilation system (WRFDA), subroutines for pre-processing static geographical data and dynamic atmospheric fields, to determine the initial condition and lateral boundary conditions of the integration domains, as well as subroutines for post-processing the forecast data, while the software architecture enables its application and easy scaling to computational platforms that allow parallel processing.

The model satisfies a wide range of meteorological applications on a spatial scale, spanning from hundreds of meters to thousands of kilometers. The effort to develop the WRF began in the late 1990s and is the result of the collaboration of several US research institutes (NCAR, National Center for Atmospheric Research, NCEP National Centers for Environmental Prediction, FSL, Forecast Systems Laboratory, AFWA, Air Force Weather Agency etc.). WRF allows researchers to produce simulations of both real-time atmospheric data (observations, analyzes) and ideal atmospheric conditions. The WRF provides a wide range of parameterizations of physical processes, such as microphysics, vertical transport, surface physics (types and types of terrain), planetary boundary layer, radiation, etc. [1]. Figure 1 below illustrates the execution flow chart of the WRF numerical weather prediction model.

The flowchart depicts the sources of external data used by the model and mainly refers to atmospheric fields of analysis and forecasts from other numerical weather forecasting models, the system of pretreatment of these data and their interference with the horizontal and vertical grid of the model, ARW kernel that performs the equation solving and finally the system of postprocessing of the predictor variables and the calculation of the atmospheric diagnostic fields.

[1] Skamarock, William C., and Joseph B. Klemp. "A time-split nonhydrostatic atmospheric model for weather research and forecasting applications." *Journal of Computational Physics*227.7 (2008): 3465-3485.

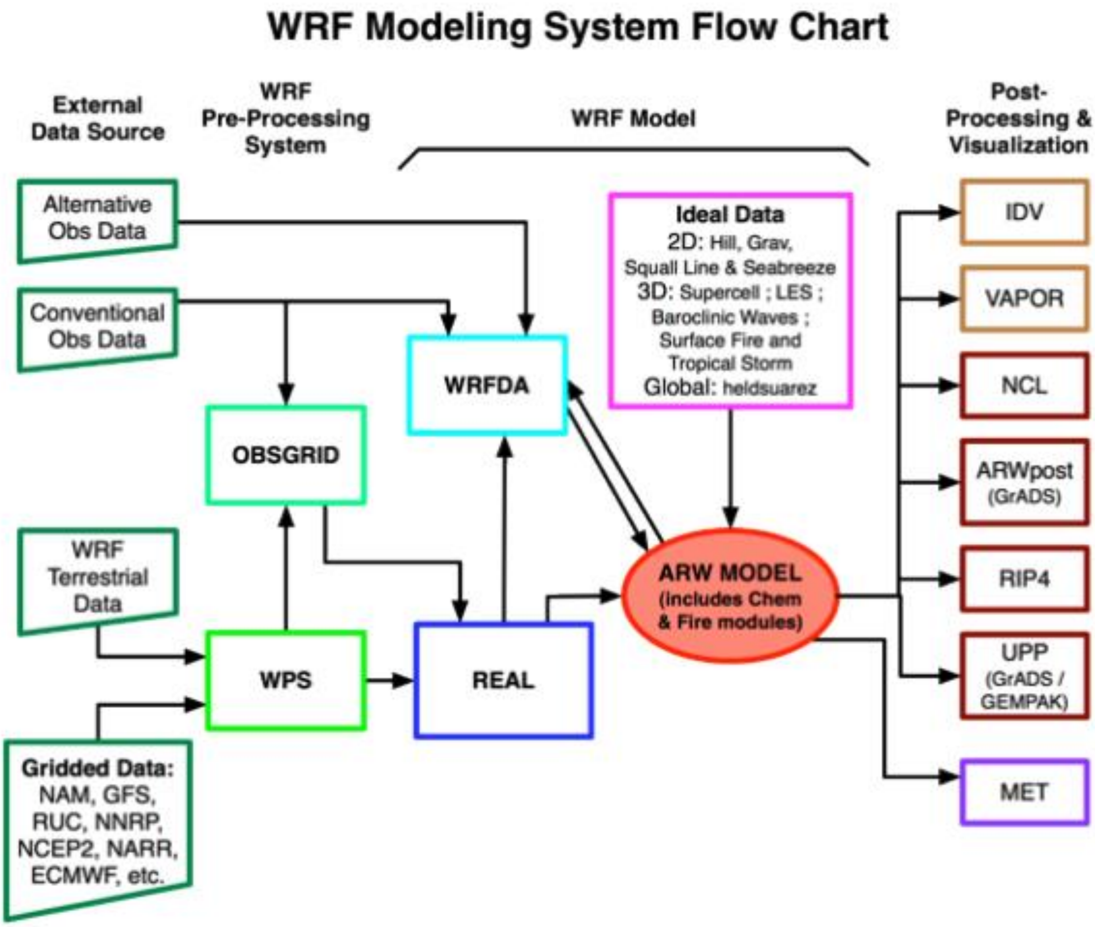

Figure 1 Flowchart of the WRF-ARW data assimilation system.

The numerical weather prediction model WRF version 4.1 operated on a daily basis in DRAXIS premises, producing high-resolution hourly forecasts for the next 7 days, providing atmospheric fields according to the meteorological data requirements.

1.2 Integration Domains, initial and boundary conditions

The WRF numerical model equations are integrated in four nested domains with a spatial resolution of 18 Km, 6 Km and 2 Km, for the d01, the nested domains d02 and d03, and the d04, respectively. D01 covers the wider area of Europe, North Africa and the Middle East. The nested domain d02 covers the Italian and Balkan Peninsulas, the nested domain d03 covers the Iberian Peninsula, while the nested domain d04 covers Greece, part of Albania, Skopje, Bulgaria and Turkey. Figure 2 illustrates the integration regions of the WRF model.

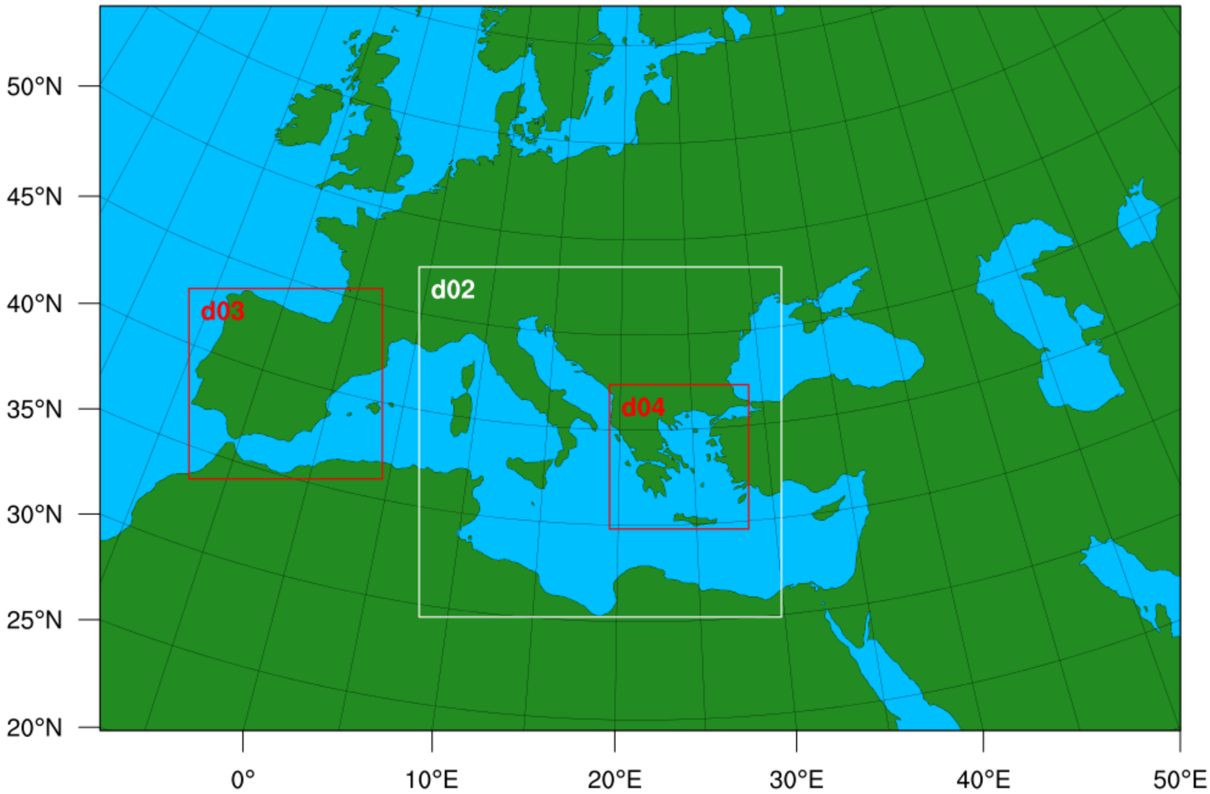

Figure 2 WRF Integration Domains

High resolution CORINE 2012 data, whose classes are grouped into the 24 USGS classes, are used to determine land use in all integration domains following the methodology described in the work of Pineda et. al. 2004[2] (Table 1)

In areas where CORINE data are not available, the model uses data from the existing WRF land use database, USGS 1997[3]. High spatial resolution SRTM[4] and SoilGrids[5] data are used to determine topography and soil mechanical properties, respectively.

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[2] Pineda, N., et al. "Using NOAA AVHRR and SPOT VGT data to estimate surface parameters: application to a mesoscale meteorological model." *International journal of remote sensing*25.1 (2004): 129-143.

[3] Links, Skip. "High-Resolution Land Use and Land Cover Mapping."

[4] https://cgiarcsi.community/data/srtm-90m-digital-elevation-database-v4-1/

[5] https://soilgrids.org/#!/?layer=TAXNWRB_250m&vector=1

Table 1 Grouping and matching CORINE land use classes to USGS classes

CORINE Code	Category Description	USGS Code	USGS Category Description
11	Urban	**1**	Urban and Built-Up Land
12	Non-Irrigated Arable Land	**2**	Dryland Cropland and Pasture
13	Permanently Irrigated Land	**3**	Irrigated Cropland and Pasture
14	Rice Fields	**3**	
15	Vineyards	**6**	Crops/Wood mosaic
16	Fruit Trees And Berry Plantations	**6**	
17	Olive Growes	**6**	
18	Pastures	**2**	Dryland Cropland and Pasture
19	Annual Crops & Permanent Crops	**6**	Crops/Wood mosaic
20	Complex Cultivation Patterns	**6**	
21	Mixed Agriculture & Natural Vegetation	**6**	
22	Agro-Forestry Areas	**6**	
23	Broad-Leaved Forest	**11**	Deciduous Broadleaf Forest
24	Coniferous Forest	**14**	Evergreen Needleleaf Forest
25	Mixed Forest	**15**	Mixed Forest
26	Natural Grassland	**7**	Grassland
27	Moors & Heathland	**9**	Mix Shrubland/Grassland
28	Sclerophyllous Vegetation	**9**	
29	Transitional Woodland-Shrub	**9**	
30	Beaches, Dunes & Sand Plains	**19**	Barren or Sparsely Vegetated
31	Bare Rock	**19**	
32	Sparsely Vegetated Areas	**19**	
33	Burnt Areas	**19**	
34	Glaciers & Perpetual Snow	**24**	Snow or Ice
35-38	Inland Marshes, Peatbogs, Salines	**17**	Herbaceous Wetlands
39	Intertidal Flats	**17**	
40-43	Inland Water	**16**	Water Bodies
44	Sea & Ocean	**16**	

For the definition of the initial and lateral boundary conditions the 00UTC Forecasts of the NCEP / GFS[6] (National Centers for Environmental Prediction / Global Forecast System) analysis and three-hour forecasts are used, respectively. Their spatial resolution is 0.25°x0.25° (latitude - longitude) and are operationally available from NCEP [ftp://ftpprd.ncep.noaa.gov]. High resolution data, which are operationally available from NCEP [ftp://ftpprd.ncep.noaa.gov] with spatial resolution of 1/12°x1/12° (about 0.083°x0.083°), are used to determine surface sea temperatures.

1.3 Model Physical Parameterizations

The WRF numerical weather prediction model, provides a multitude of configurations of physical processes occurring in the atmosphere and on the surface of the earth in terms of solar radiation, cloud microphysics, convective cloud development, planetary boundary layer, surface layer, and soil thermodynamics and hydrology.

To represent cloud microphysics, the model uses Thomson et. al. [7] (2008) microphysics scheme which supports 5 different types of hydrometeors and is ideal for high resolution simulations, while in terms of the cumulus convection scheme the model uses the KF-CuP[8] which is active only in the external integration domain. In the nested domains no cumulus convection parameterization scheme is used, because the spatial resolution of the grid allows the small-scale turbulence to be directly resolved from the microphysical scheme.

To configure the radiation for both long and short-wave radiation components, the model uses the RRTMG[9] scheme, with a 10 min run time and the slope_rad option enabled allowing the radiation scheme to be taken into account various calculations of topography and slopes of the soil.

The planetary boundary layer is configured by the Yonsei University[10] physical parameterization scheme with the topographic correction options for surface winds and vertical mixing due to heat loss due to radiation enabled. The revised Monin-Obukov MM5[11] scheme is used for the parameterization of the atmospheric boundary layer, while the NOAH-MP[12] scheme is used for the parameterization of the hydrological and thermodynamic soil processes.

Finally, to calculate a multitude of diagnostic variables such as the diameter of hailstones, the existence and velocity of a tornado, etc. the Air Force Weather Agency (AFWA) diagnostic tool suite is used.

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[6] https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs

[7] Thompson, Gregory, et al. "Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part II: Implementation of a new snow parameterization." *Monthly Weather Review* 136.12 (2008): 5095-5115.

[8] Berg, Larry K., et al. "Evaluation of a modified scheme for shallow convection: Implementation of CuP and case studies." *Monthly Weather Review* 141.1 (2013): 134-147.

[9] Iacono, Michael J., et al. "Radiative forcing by long-lived greenhouse gases: Calculations with the AER radiative transfer models." *Journal of Geophysical Research: Atmospheres*113.D13 (2008).

[10] Hong, Song-You, Yign Noh, and Jimy Dudhia. "A new vertical diffusion package with an explicit treatment of entrainment processes." *Monthly weather review* 134.9 (2006): 2318-2341.

[11] Jiménez, Pedro A., et al. "A revised scheme for the WRF surface layer formulation." *Monthly Weather Review* 140.3 (2012): 898-918.

[12] Niu, Guo-Yue, et al. "The community Noah land surface model with multiparameterization options (Noah-MP): 1. Model description and evaluation with local-scale measurements." *Journal of Geophysical Research: Atmospheres* 116.D12 (2011).

1.4 Post-Processing of Forecasts

The produced prognostic data from the WRF model are post-processed with the Unigied Post Processor (UPP) version 3.2 in order to produce destagered grids and diagnostic variables. UPP performs the following 2-steps process for the prognostic data:

1) Generate GRIB format files per forecast time for each model grid, where the primary results are first converted from Arakawa stagered C-grid to a destagered A-grid, and then inserted into a regular grid with constant step per geographic width and length (regular latitude-longitude grid). Normal grids are sub-regions of the four model integration domains and have a spatial resolution of 0.18°x0.18°, 0.06°x0.06°and 0.02°x0.02° for the external domain and the nested ones, respectively.

2) Calculation of diagnostic atmospheric fields which are inserted along with the atmospheric prognostic fields in GRIB files. Operationally generated atmospheric fields provided through the weather API are the following:

- Air Temperature at 2m Height
- Relative Humidity at 2m Height
- Wind Speed and Direction at 10m Height
- Precipitation and Precipitation Rate
- Reference Evapotranspiration
- Leaf Wetness
- Precipitation Types: Hail, Graupel, Ice Pellets and Snow
- Snow Height, density and cover
- Solar Radiation