Collaborative Project

CLIM-RUN

Climate Local Information in the Mediterranean region Responding to User Needs

WP 2 – WP New Climate modeling and analysis tools
Task XX.YY Task TITLE

New Modeling Tools

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1. Introduction.

Within the CLIM-RUN project a strategy of a bottom-up approach is chosen. This deliverable done within the WP2 is listing the possible new modelling tools which can be carried out and develop by and within the three following institutes: CNRM (Centre National de Recherche Météorologiques, Météo-France, France), ENEA (Italian National Agency for New Technologies, Energy and the Environment, Italy) and ICTP (International Centre for Theoretical Physics, Italy). Those new climate modelling tools can be developed to support the targeted requested climate information for the different case studies such as tourism, forest fire, energy over different location around the Mediterranean area. Depending on the stakeholder needs, the choice of new modelling design will be implemented.

However, those improvements can only be carried out within the feasibility of the modelling tools. Their limits should be know and consider by the stakeholders. For example, those new modelling tools cannot provide variables such as thunderstorm, ecosystem, air and water pollution..

This deliverable gives an exhaustive list of possible improvements which can be carried out by the different group. However, only some of those improvement will be implemented in the new modelling tools. One possible improvement can be to provide very high resolution information over a particular area characterised by a complex topography, fine coast lines and diverse land-use which can characterised the location of the case study. To deliver this information, the RCMs (Regional Climate Models) can be used at a resolution of about 10-15 km with sub-grid land-surface physics reaching scales of 0.5-1 km. Another possible improvement is the inclusion of new components in the Mediterranean regional climate system. Those components can be the inclusion of an ocean, rivers, cities, glaciers, snow cover, in on-line or off-line mode, leading to the development of new comprehensive and state of the art modelling tools. Finally, those new modelling tools can be use to downscale different period of time. Those period of time can focus on decadal predictions or/and climate projections or past climate reanalysis of the last 50 years.

The increase in resolution and the inclusion of new components of climate system target in particular an improvement in the representation of extreme events and local information such as intense precipitations event, floods, droughts, heat waves, wind storms. Those improvement and new implementations are a clear added value towards stakeholders carried out within this European project.

2. Possible improvements.

The new modelling tools will carried out by the three following institutes: CNRM, ENEA and ICTP. The possible directions are on the development of a newly fully coupled regional climate system model (RCSM), the increase of resolution, the inclusion of new components and the coverage of different period of time. Those possible improvements have shown some possible added value according to previous studies.

- The use of the new RCSM which includes an interactive ocean has shown to better represented the sea surface temperature (SST) due to the retroaction between the ocean and the atmosphere (Artale et al., 2010, Dubois et al., submitted). Under climate change scenario, the RCSM have shown to have a positive feedback compared to the ARCM (Atmosphere Regional Climate Model) with an enhanced response (Somot et al., 2008). Those implementations can valuable tools for the climate change scenario as well as for the case study close to coastal area.
- The increase in the model resolution have shown to give a better representation of the winds, extreme events over the complex coastline and topography of the Mediterranean region in recent studies (Herrmann et al., 2011, Colin, PhD. Thesis). Over the ocean, the increase in resolution improved the intense surface fluxes and thus oceanic convection, surface currents.

Within, the existing RCSM a range of possible new components can be implemented within the CLIM-RUN project and are covering different aspects of the climate system.

- In the ocean model, a more realistic representation of sea level height, the tidal effect and the wave can included given a clear added information for the coastal region and coastal conditions (Jorda et al., 2010, Sannino et al., 2004).
- In the land surface model, a surface tilling including sub-surface such as nature, forest, town, sea, water can be implemented (Masson et al., 2003; Giorgi et al., 2003). This

involve the possibility of including an urban model which can take into account the urban heat inland (Hambi et al., 2008). Another possibility is the inclusion of an interactive lake model predicting the vertical structure and mixing conditions over the lake (Hostetler et al., 1993; Mironov et al., 2003).

- In the atmosphere model, the inclusion of interactive aerosols affect can improve the radiative solar flux and the cloud cover (reference).

Those different model configurations can be used to simulation different time period.

- The past period covering the ERA40 period from 1960 to 2001 or the ERA Interim period from 1989 to 2008.
- Climate change scenario following different emissions scenario such as: RCP4.5 or RCP 8.5.
- Decadal predictions simulations can also be carried out.

The table below describes briefly the possible modelling improvements or configurations that can be carried out. This list gives an overview to the stakeholders of the different possibilities including the possible resolution, model used. Depending on the case study and on the specific needs one directions can be chosen more than another one.

The possible model improvements is detailed below for each institute where the model parameterisations and set up is describe.

Institute	Interactive fully coupled modelRCSMs	New components	Resolution (space/time)	Improving/test	Temporal horizon
ENEA	Atmosphere: RegCM up to 25km Ocean: MITgcm-1/8° Land+ Hydrology:BATS River: IRIS	Sea level (pressure effect) Wave model Tides effect	Up to 1/16° (for stand-alone oceanic simulations)	SST skin layer Diurnal cycle	ERA40 ERAI RCP 4.5-8.5 sce. ECHAM5-CNRM-CM5
ICTP	RegCM4 (coupled with interactive aerosols, Lake; Sub-grid land surface, tiling)	Interactive chemistry and vegetation Urban land use Ocean (ROMS)	10-15 km tiling - 1km	RegCM4 New and modified physics options (convection, clouds, Planetary Boundary Layer (PBL), land surface)	ERAI RCP 4.5-8.5 (Different GCMs) Decadal predictions
CNRM	Atmosphere: ALADIN-50km Ocean: NEMOMED-1/8° Land + Hydrology: ISBA-50km River: TRIP-50km	Urban Lake Aerosols Wave Sea level	Atmosphere: 10 km Diurnal cycle: every 3h Surface tiling (SURFEX) snow cover (off-line)	Cloud Snow cover Shortwave radiation Air-sea fluxes Extremes Convection Boundary layer Aerosols spectral nudging	ERA40 ERAI RCP 4.5-8.5 CNRM-CM5 EC-Earth

Table 1: List of the possible improvements which can be carried out by the different institutes.

3. Models

3.1 The CNRM model.

The possible improvement which can be carried out at the CNRM are listed and describe below.

3.1.1: Model configuration:

3.1.1.a- The Atmospheric regional climate model – ALADIN-Climate:

The ARCM is the atmospheric regional model that the CNRM will be used for the new developing tools and simulations within the CLIM6RUN projet. The atmospheric regional model used is ALADIN-Climate (Aire Limitée Adaptation Dynamique development InterNational). It is a spectral limited area model developed for short-range forecast (Budnova et al., 1993). It is used here in its climate version based on cycle 32 of ARPEGE/IFS from the ECMWF. It is a spectral, semi-implicit and semi-Lagrangian model. The convection scheme is a mass-flux scheme with convergence of humidity closure (Bougeault, 1985). The cloud scheme is a statistical scheme from Ricard and Royer (1993) and the large-scale precipitation parameterization is from Smith (1990). The radiative scheme includes greenhouse gases, water vapor, ozone and five aerosols classes from Morcrette (1990). The domain is not periodic, so a bi-periodicization is needed by adding an extension zone for the Fourier transforms (Budnova et al., 1993). The model is used at high resolution with a resolution of 50 kms in his central zone (Radu et al., 2008). The vertical discretisation is 31 vertical levels, mostly located in the troposphere. The time step is 30 minutes.

The regional model is an one-way nested model with its lateral boundaries driven by atmospheric reanalyses or global climate model. There is no feedbacks from the local to the global dynamics. The regional model is able to develop medium-scales features consistent with the large-scale state of the atmosphere. In ALADIN-Climate, an another low-pass filter known as large scale spectral nudging can be used. In this technique, the large-scale component of regional model fields are nudged towards the corresponding large-scale component of nesting fields, throughout the model domain. The spectral nudging method is applied in order to achieve a better representation of large-scale climate over the limited domain.

The atmospheric model grid covers most of Europe and North Africa and the ocean model grid covers the Mediterranean sea and a buffer zone in the Atlantic ocean (Figure III-1).

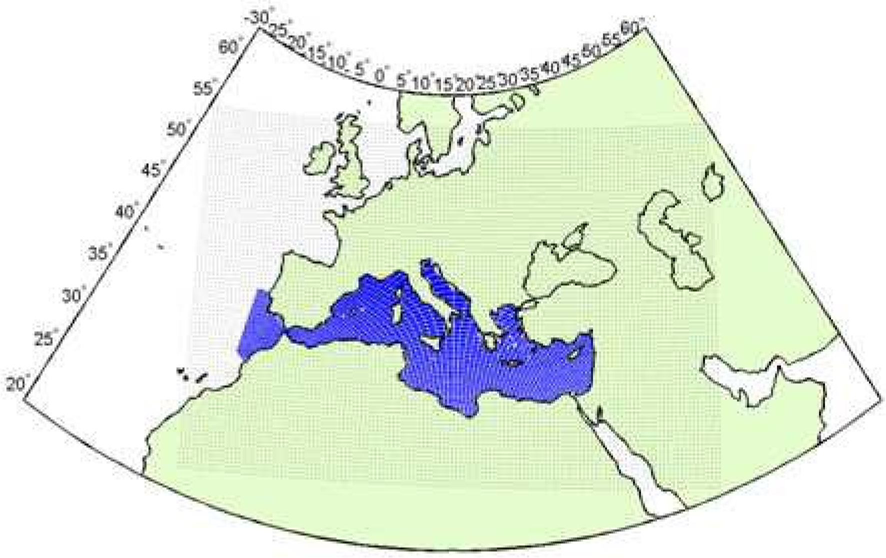

Figure III-1 : Model grid. In light blue the region covered by the atmospheric model ALADIN-Climat and in dark blue the region covered by the oceanic model NEMOMED8.

3.1.1.b- The CNRM-RCSM:

The ARCMs can be used as a RCSM (Regional Climate System Model) which is a fully coupled system of the Mediterranean region coupling: ALADIN-50km/ISBA-50km/TRIP-50km/NEMOMED-1/8°.

The atmospheric model is ALADIN-Climate which is described in the previous paragraph with a 50 km resolution. It is coupled to NEmOMED-1/8° for the ocean model, ISBA for the Land and Hydrology model and TRIP for the river runoff model.

The oceanic model NEMOMED8 is an eddy-permitting regional model of the Mediterranean sea (Sevault et al., 2009, Beuvier et al., 2010); a regional version of the 3-D primit-

ive equation numerical model Ocean Parallel (Madec et al., 1998). The model domain extents over the Mediterranean sea with an Atlantic buffer zone at the West and the Black sea is represented as a river at the East (Sevault et al., 2009). The model uses the Arakawa's grid with a horizontal resolution of 1/8° x 1/8° cos (Φ), where Φ is the latitude. It is equivalent to about 9 to12 km, thus the model has 394 x 160 grid points (Akawa, 1972). They are 43 vertical levels, mostly in the upper ocean. The grid is tilted and stretched at the Strait of Gilbraltar for a better resolution of the flow on the SW-NE axis at the Strait (which is represented by two grid point) (Drillet et al., 2005). The ocean bathymetry is based on ETOPO5x5 data base represented by 43 vertical level with the deepest one using a partial step for the last level which allows a more realistic topography (Smith and Sandwell, 1997). The time step is 20 minutes. The model uses the free surface parameterization (Roullet and Madec, 2000), which induced that the volume of the Mediterranean sea is not conserved (due to a net loss of water by evaporation). To conserved the volume, the evaporated water over the whole Mediterranean basin is redistributed in the Atlantic buffer zone, with a weight which is stronger with the distance to the Strait of Gibraltar (Béranger et al., 2005). The horizontal eddy diffusivity is 125 $m^2.s^{-1}$ for the tracers and a horizontal viscosity coefficient is 1 x 10^{10} $m^4.s^{-2}$ for the velocity. The vertical eddy diffusivity uses the 1.5 turbulent closure scheme from Blanke and Delecluse (1993), where the vertical diffusivity coefficient is increased to 50 $m^2.s^{-1}$ in case of an unstable stratification. The model uses a no-slip lateral boundary condition and the bottom friction is quadratic. The Atlantic buffer zone stretches from 11°W to the Strait of Gibraltar. It is zone, where a 3D-restoring towards a seasonal climatology in temperature and salinity taken from the MedAtlas-II climatology (MEDAR/MEDATLAS Group, 2002) is applied (Reynaud,1998).
The coupling between the atmospheric and oceanic model is done with the coupler OASIS3 (Valke, 2006) with a daily coupling.

The land surface scheme ISBA (Interactions Soil Biosphere Atmosphere) was initially developed by Noilhan and Planton (1989), Mahfouf et al. (1995). It is a relatively simple scheme that contains the basic physics of the land surface processes, but needs only a minimum of parameters. Soil and vegetation properties are derived from the global high-resolution ECOCLIMAP dataset (Masson et al., 2003) after aggregation onto the ARPEGE horizontal grid. Both the distribution and phenology of the vegetation caver are prescribed and do not interact with climate variability. A snow scheme, described in Douville et al. (1995a and 1995b) is used to compute the evolution of snow mass, snow albedo and snow density in each grid cell. In the presence of snow, the ECOCLIMAP snow-free albedo is modified according to a diagnostic snow fraction depending on snow mas, vegetation roughness length and subgrid orography. In the present study, the minimum and maximum snow albedo have been slightly decreased (0.45 and 0.80 respectively) compared to Douville et al. (1995b). ISBA computes a single surface energy budget using a composite surface temperature. Four layers are used to describe the vertical profile of soil temperature. Four layers are used to describe the vertical profile of soil temperature. The soil hydrology is based on the force-restore approach, with a prognostic surface reservoir included in the total reservoir (Noihan and Planton, 1989). Compared to the original version of ISBA, it includes a deep drainage (Mahfouf and Noilhan, 1996) that has been slightly mofied to account for a residual drainage below the field capacity. Moreover, the sub-grid runoff has also been introduced based on the Variable Infiltration Capacity approach (Chapelon et al., 2000).

Total runoff is interpolated on a 1° by 1° horizontal grid by means of the OASIS coupled to be converted into river discharge and transported to the ocean using the TRIP (Total Runoff Integrated Patways) river routing scheme (Oki and Sud, 1998; Decharme et al., 2010). The water outflow produced at any river mouth is delivered at the near most ocean grid cell. As this amount of water can be huge for the biggest rivers, it is shared between several grid cell to avoid unphysical ocean surface salinities. The timestep used in TRIP is 3h.

3.1.1.c- SURFEX (SURFace Externalisée):

Another important feature of the ARCMs is the possibility to use the SURFEX-subgrid surface model. The surface model SURFEX (SURFace EXTernalisée), which is run using a standardised interface within the atmospheric component ALADIN-Climate, simulates the exchanges of momentum, heat, water, carbon dioxide concentration or chemical species between the surface and the atmosphere. It includes surface tilling, lake, sea/ocean, town and vegetation/soil subgrid.

- Surface tilling:

It uses the concept to 'tile' to describe the surface (nature, town, sea, water) and can perform different parameterizations. Each surface is known though the global ECOCLIMAP database (Masson et al., 2003). SURFEX computes the average surface fluxes over the nature, town, sea and water weighted by their respective fraction and sends them back to the atmosphere.

ECOCLIMAP, a new complete surface parameter global dataset at a 1-km resolution, is presented. It is intended to be used to initialize the soil–vegetation–atmosphere transfer schemes (SVATs) in meteorological and climate models (at all horizontal scales). The database supports the "tile" approach, which is utilized by an increasing number of SVATs. Two hundred and fifteen ecosystems representing areas of homogeneous vegetation are derived by combining existing land cover maps and climate maps, in addition to using Advanced Very High Resolution Radiometer (AVHRR) satellite data. Then, all surface parameters are derived for each of these ecosystems using lookup tables with the annual cycle of the leaf area index (LAI) being constrained by the AVHRR information. The resulting LAI is validated against a large amount of in situ ground observations, and it is also compared to LAI derived from the International Satellite Land Surface Climatology Project (ISLSCP-2) database and the Polarization and Directionality of the Earth's Reflectance (POLDER) satellite. The comparison shows that this new LAI both reproduces values coherent at large scales with other datasets, and includes the high spatial variations owing to the input land cover data at a 1-km resolution. In terms of climate modeling studies, the use of this new database is shown to improve the surface climatology of the ARPEGE climate model.

- Urban modelling:

The town energy balance (TEB) model is the first surface schmes dedicated to urban surfaces to reproduce urban climate features in high resolution atmospheric models (Hambi, R. and V. Masson , 2008). It is a urban canopy model based on the concept of urban canyon. It calculates the climate conditions, the drag force and energy fluxes of a town or neighbourhood. It includes a vertical discretization of the air. The effect of the snow and urban vegetation is also included.

- Lake modeling:

FLake is a freshwater lake model capable of predicting the vertical temperature structure and mixing conditions in lakes of various depth on time scales from a few hours to many years (Mironov et al., 2003). The model is intended for use as a lake parameterisation scheme in numerical weather prediction, climate modelling, and other numerical prediction systems for environmental applications. FLake can also be used as a stand-alone lake model, as a physical module in models of aquatic ecosystems, and as an educational tool. FLake is a bulk model. It is based on a two-layer parametric representation of the evolving temperature profile and on the integral budgets of heat and kinetic energy for the layers in question. The structure of the stratified layer between the upper mixed layer and the basin bottom, the lake thermocline, is described using the concept of self-similarity (assumed shape) of the temperature-depth curve. The same concept is used to describe the temperature structure of the thermally active upper layer of bottom sediments and of the ice and snow cover. The result is a computationally efficient bulk model that incorporates much of the essential physics. FLake incorporates (i) a flexible parameterisation of the temperature profile in the thermocline, (ii) an advanced formulation to compute the mixed-layer depth, including the equation of convective entrainment and a relaxation-type equation for the depth of a wind-mixed layer, both mixing regimes are treated with due regard for the volumetric character of solar radiation heating, (iii) a module to describe the vertical temperature structure of the thermally active layer of bottom sediments and the interaction of the water column with bottom sediments, and (iv) a snow-ice module. Empirical constants and parameters of FLake are estimated, using independent empirical and numerical data. They should not be re-evaluated when the model is applied to a particular lake. In this way, FLake does not require re-tuning, a procedure that may improve an agreement of model results with a limited amount of data but should generally be avoided as it greatly reduces the predictive capacity of a physical model.

3.1.2: Model improvements:

Different possible improvement can be carried in the different model component to answer some of the stakeholders needs within CLIM-RUN.

3.1.2.a- Atmosphere model:

- aerosols off-line:

The variability of the aerosols can be taken into account with the newly developed optical depth for different aerosols. The optical depths of the five types of tropospheric aerosols are taken from an LMDZ-INCA simulation forced with CMIP5 prescribed emissions (Szopa *et al.*, submitted, Schulz, 2007). For sea salt aerosols, the optical depths provided by LMDZ-INCA are re-scaled to obtain a global averaged optical depth equal to the value obtained with the Tegen data (Tegen *et al.,* 1997). This scaling is done since Tegen data is the original data used in ALADIN-Climat (which is potentially tuned according to this data) and the integrated optical depths obtained with LMDZ-INCA are 5 times higher than with Tegen. With such a scaling, the geographical distribution of sea salt is governed by LMDZ-INCA but the total optical depth corresponds to Tegen. For sea salt and sand dust, the optical depths are fixed to their pre-industrial values. On the contrary, for sulphate, organic and black carbon aerosols optical depths evolve following the LMDZ-INCA HIST simulation.. An eleven-year smoothing is applied on raw data to retain the low frequency evolution of the aerosols fluctuations. Higher interannual variability is not related to emissions variability but to the internal variability of the LMDZ-INCA model that one does not seek to reproduce within the HIST framework. Volcanic eruptions are also taken into account by prescribing the zonal mean optical thicknesses of the related stratospheric aerosols as diagnosed from Amman *et al.* (2007).

- Snow cover

The French mountain areas assessment can be carried out by the use of a joint approach based on dynamical downscaling using 12 km resolution RCMs and statistical downscaling using the SAFRAN 8 km meso-scale analysis (Quintana-Segui et al., 2008) as the observed dataset needed to build the transfer function. Mountain local climate is the product of complex multi-scale interactions depending on atmospheric stratification and moisture content, surface energy balance and topography combined with the synoptic and meso-scale forcing. High-resolution (1-3 km), nonhydrostatic, full-physics, state-of-the-art meso-scale models are currently the best tools to study and represent the high spatial and time variability of the mountain ranges circulation and climate as well as the severe weather events occurring in these areas (heavy precipitation events and related flooding episodes, strong wind events, intense drought). However 2 km resolution non-hydrostatic 30-year simulations over France will not be technically affordable before several years (at least ten years if we extrapolate computer progress of the last 20 years). The choice of 12 km is thus a good compromise, based on very recent results. In particular, Déqué and Somot (2008) as well as preliminary results of the above-mentioned CECILIA EU-FP6 project indicate that the French RCM ALADIN at 12 km resolution largely improves the stationary features of the precipitation field in the range 12-50 km. The weather type-based statistical method will be adapted: the weather types were originally selected to represent rainfall regimes over whole France and a specific treatment may be necessary to represent the circulation patterns relevant for the mountain areas. It then will be used to produce climate scenarios for mountain areas from the IPCC AR4 (the CMIP3 database) as well as from the set of RCM simulations realized within the project.

- Test on the atmospheric physics

The parameterization schemes fully benefit from being tested in different modelling tools, more or less forced, from the Single Column Model to the 3D coupled GCM, going through LAM and 3D forced GCM simulations. It is particularly interesting to evaluate the behaviour of the parameterization schemes in specific regions where data are available for evaluation. These data may be either observations or, for some parameters which can not be observed, parameters simulated by a high-resolution model, like Cloud-Resolving Model (e.g. Méso-NH). Besides, some failures of the ALADIN RCM are probably linked with atmospheric parameterization schemes: the model simulates too much rain and evaporation in a too intense water cycle, not enough extreme rainfall, too many rainy days and too weak extreme evaporation events, too high surface short-wave radiation. These problems can be investigated with sensitivity tests of the RCM results to the parameterization schemes. NWP type evaluation (case-study) of the model helps to diagnose rapid growth errors in a correct large-scale context.

i. Explore the sensitivity to the representation of radiation (different versions of the ECMWF radiation scheme).A new longwave radiation scheme can be used based on the Rapid Radiation Transfer Model (RRTM, Mlawer *et al.*, 1997) included in the IFS ECMWF model. The radiative transfer equation is solved by a two-stream method. The RRTM scheme computes fluxes in the spectral range encompassing the 10–3000 cm^{-1} band. The computation is organized in 16 spectral bands and includes line absorption by H2O, CO2, O3, CH4, N2O, CFC-11, CFC-12, and aerosols. The shortwave part of the scheme, originally developed by Fouquart and Bonnel (1980), integrates the fluxes over the whole shortwave spectrum between 0.2 and 4 mm. The scheme includes Rayleigh scattering, absorption by water vapour and ozone, both varying in space and time, and by CO2, N2O, CO, CH4, and O2, which are treated as uniformly mixed gases. The parameterization can be upgraded by increasing its spectral resolution from 4 to 6 bands, leading to three bands in the UV-visible spectral range (185–250nm, 250–440nm and 440–690nm) and three bands for the near infrared (690–1190nm, 1190–2380nm and 2380–4000nm). Five tropospheric aerosol types are used: sulphate, organic, black carbon, sea salt and sand dust. Volcanic aerosols can also be specified as a stratospheric aerosol type. As the heating rate associated with historical eruptions was largely overestimated in the former version of the model (SPARC CCMVal, 2010), the optical properties of stratospheric aerosols associated to volcanoes eruptions have been revised (in particular their diffusion has been increased). A simple parameterization of the indirect forcing of sulphate aerosols has been introduced following Quaas and Boucher (2005), representing that at constant cloud liquid water content, increasing aerosol concentration leads to a larger concentration of cloud droplets of small radius and increases cloud reflectivity. The ozone-mixing ratio is a prognostic variable with photochemical production and loss rates computed by a 2-D zonal chemistry model (MOBIDIC, Cariolle and Teyssèdre, 2007).

ii. Explore the sensitivity of the results to two physics packages available at CNRM (operational NWP version and GIEC AR5 version).

iii. More specifically study the sensitivity to the convective scheme, the turbulence scheme and the coupling convection-boundary layer by using different convection schemes (operational -Bougeault, 1985- or under development) with the same turbulence scheme (prognostic scheme for the turbulent kinetic energy, Cuxart et al., 2000) or testing the behaviour of different turbulence schemes.

- Air-sea fluxes:

Test on the air-sea fluxes can done on the air-sea fluxes parameterisation (Louis, 1979 vs ECUME versus modified ECUME). A change in the parameterization used to compute the neutral exchange coefficients for moisture, momentum and temperature : twin simulations will be performed using first the Louis (1979) formulation, then the ECUME multicampaign parameterization (Belamari and Pirani, 2007),

3.1.2.b- Ocean model :

- Wave model

The wave effect can be taken into account. The waves can be implimented trough a transfert coefficient in the atmospheric parameterisation taking into account the age and the slope of the wave (Donelan et al., 1993; Jones and Toba, 1995). For example, Makin et Stam (2003) estimated the stress with a wave parameterisation from the wind at the surface. Also, the wave model can be coupled and forced by an atmospheric model (MFWAM, Lefèvre et al. 2009, new weather forecast model at Météo France). This method is already used at ECMWF (Richardson et al., 2008). When coupled the stress induced by the wave are calculated from the energy induced by the wave. The retroaction is calculated from the atmospheric through a kinetic energy or stress at the surface.

- sea level:

The Mediterranean sea level is very complex and it is influenced by various complex processes such as mass fluctuations (e.g. additional water input), variation on the density structure (steric effect), changes in circulation, waves, atmospheric pressure variations and changes of the hydrographic conditions of incoming Atlantic water. These different components contribute to sea level change at different time scales, from daily to interdecadal (Jorda et al., in revision). So far, those influences are not included in NEMOMED8 are will be included.

- Skin layer:

The use of a skin temperature (instead of the so-called SST) in the bulk computation can be implemented.

3.1.3: Possible simulation strategies:

3.1.3.a- Domain:

In its common version the ALADIN-Climate model is used at a 50 kms resolution over the Mediterranean region. It can be run at much higher resolution. The impact of the spatial horizontal resolution on the various terms of the Mediterranean water budget (E, P, R), the extreme precipitation over land and extreme evaporation and wind over sea has been extensively tackled at CNRM during the last years with 50, 25 km or 10 kms as the highest spatial resolution over the whole Mediterranean basin with ALADIN (Herrmann and Somot 2008, Sanchez-Gomez et al. 2009, Elguindi et al. 2010, Colin et al. 2010 and Hermman et al., 2011). The ARCM can be thus run at 10 kms for the Mediterranean region over different period of time.

3.1.3.b- Period of time:

The different configuration of the model can be used to simulate past or future climate.

- For past climate, the period covered can be over:
  - the ERA40 period: 1958-2001,
  - the ERA Interim period: 1979-2010

- For the scenario, the period covered is between 1950-2100.
  - The period 1950-2005 is forced by observed greenhouse gases concentrations,
  - for the period 2005-2100 is forced by a greenhouse gases concentrations following a emissions scenarios: RCP4.5, RCP8.5. The boundary conditions of the RCSM can by provided from different GCMs: CNRM-CM5, EC-Earth.

3.1.4 :References

Arakawa A (1972) Design of UCLA general circulation model. University of California, no. 7, 116 pp

Amman, C.M., F. Joos, D.S. Schimel, B.L. Otto-Bliesner, R.A. Tomas, 2007: Solar influence on climate during the past millemnium: results from transient simulations with the NCAR climate system model. Proc Natl Acad. Sci., 104: 3713-3718.

Béranger K, Mortier L., Gasparini G., Gervasio L., Astraldi M. and Crépon M., 2004 : The dynamic of the Sicily Strait: A comprehensive study from observations and lodels. Deep-Sea Res., Part II, 51(4-5),411-440

Beuvier J., F. Sevault, M. Herrmann, M. Rixen, W. Ludwig, E. Stanev, K. Béranger, A. Theocharis, S. Somot (2009) Modelling the Mediterranean Sea interannual variability over the last 40 years: focus on the EMT, JGR-Ocean (in preparation)

Radu, R., Déqué, M., Somot, S. (2008) Spectral nudging in a spectral regional climate model. Tellus. 60A(5):898-910. doi: 10.1111/j.1600-0870.2008.00341.x

Sevault F., Somot S., Beuvier J. (2009) A regional version of the NEMO ocean engine on the Mediterranean Sea: NEMOMED8 user's guide. Note de centre n°107. Groupe de Météorologie de Grande Echelle et Climat. CNRM. mai 2009

Valcke, S. (2006) : Oasis3 user guide (prism 2-5). Tech. Rep., PRISM Support Initiative Report n°3, CERFACS, Toulouse, France, 64pp.

Masson V., J.-L. Champeaux, F. Chauvin, C. Meriguet and R. Lacaze, 2003 : A global database of land surface parameters at 1km resolution in meteorological and climate models, J. Climate, 16, 1261-1282. article

Déqué M., E. Martin, N. Kitova, 2011, Response of the snow cover over France to climate change, Research activities in Atmospheric and Oceanic Modelling, 41, 7.11-7.12

Hambi, R. and V. Masson, 2008: Inclusion of a drag approach in the town energy balance (TEB) scheme: offline 1-d validation in a street canyon. Journal of applied Meteorology and Climatology, 47, 2627-2644.

Fouquart, Y., and B. Bonnel, 1980: Computations of solar heating of the earth's atmosphere: A new parametrization. *Beitr. Phys. Atmosph*., 53, 35-62.

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. *J. Geophys. Res*., 102, 16663-16682.

Tegen, I., P. Hollrig, M. Chin, I. Fung, D. Jacob and J. Penner, 1997: Contribution of different aerosol species to the global aerosol extinction optical thickness: estimates from model results. *J. Geophys. Res.,* 102, 23895-23915, doi:10.1029/97JD01864.

Fouquart, Y., and B. Bonnel, 1980: Computations of solar heating of the earth's atmosphere: A new parametrization. *Beitr. Phys. Atmosph*., 53, 35-62.

Quintana-Seguí, P., P. Le Moigne, Y. Durand, E. Martin, F. Habets, M. Baillon, C. Canellas, L. Franchisteguy and S. Morel, 2008: Analysis of Near-Surface Atmospheric Variables: Validation of the SAFRAN Analysis over France. J. Appl. Meteor. Climatol., 47, 92–107.

Mironov, D., A. Terzhevik, E. Heise, and F. Beyrich, 2003: Parameterization of lakes in NWP: description of a lake model and single-column tests. Fifth International SRNWP-Workshop on Nonhydrostatic Modelling. Abstracts, Deutscher Wetterdienst, Geschaeftsbereich Forschung und Entwicklung, Arbeitsergebnisse Nr. 78, E. Heise and J. Steppeler, Eds., October 2003, Offenbach am Main, Germany.

Donelan, M.; Dobson, F.; Smith, S. & Anderson, R., 1993, On the dependence of sea surface roughness on wave development, Journal of Physical Oceanography, 23, 2143-2149.

Jones, I.S.F. and Toba, Y., 1995, Comments on " On the dependence of sea surface roughness on wave development", Journal of Physical Oceanography, 25, 1905-1907.

Lefèvre, J-M, L.Aouf, C Bataille, F. Ardhuin, P. Queffeulou, 2009, Apport d'un nouveau modèle de vagues de 3° génération à Météo France, Actes de conférence des Ateliers de Modélisation de l'Atmosphère, 27-29 janvier 2009, Toulouse, France.

Makin V. K. and Stam M., 2003, New drag formulation in NEDWAM. KNMI Technical Report no. 250.

Richardson, D.S., et al., 2008, Verification statistics and evaluations of ECMWF forecasts in 2007-2008, ECMWF Technical Memorandum 578.

Szopa S.A.Cozic, M. Schulz, Y. Balkanski, D. Hauglustaine, 2012, Changes in tropospheric aerosol and reactive gases burdens and concentrations under IPCC-AR5 emissions scenariosfro 19850-2100.

3.2. The ENEA model:

3.2.1: Model configurations:

In order to provide a wide range of climate information for user's needs, several modelling tools could be taken into account by ENEA:

3.2.1.a: Coupled Simulations

The PROTHEUS coupled system is composed of the RegCM3 atmospheric regional model and the MITgcm ocean model. For a complete description of the coupled system the reader is referred to Artale et al. (2010). The coupling of RegCM3 and MITgcm is done with OASIS3 coupler (Valcke and Redler, 2006) that performs both the synchronization of the two models and the interpolation of coupling fields from the source to the target grid. Every 6 hours, the ocean model receives the wind stress components and the total heat and freshwater water fluxes from the atmosphere. At the same frequency, the atmospheric model updates the sea surface temperature patterns with those produced by the ocean model. No relaxation to climatology is applied. We provide 3-hourly surface 2D surface data, daily 3D data for the atmospheric component. We also provide daily 2D surface data and monthly 3D data from the ocean model.

In the followings we briefly review the main characteristics of the two models to emphasize the improvements with respect to the configuration adopted for the study of Artale et al. (2009). RegCM3 is a 3-dimensional, sigma-coordinate, primitive equation, hydrostatic regional climate model. Its description can be found in Giorgi et al. (1993a) and Giorgi et al. (1993b). Successive upgrades are described in Giorgi and Mearns (1999) and Pal et al. (2007). The model configuration adopted for the present purposes has a uniform horizontal grid spacing of 25 km on a Lambert conformal projection and 18 σ-levels. The simulation is performed over the entire Mediterranean Sea. The domain and the topography are shown in Figure2.

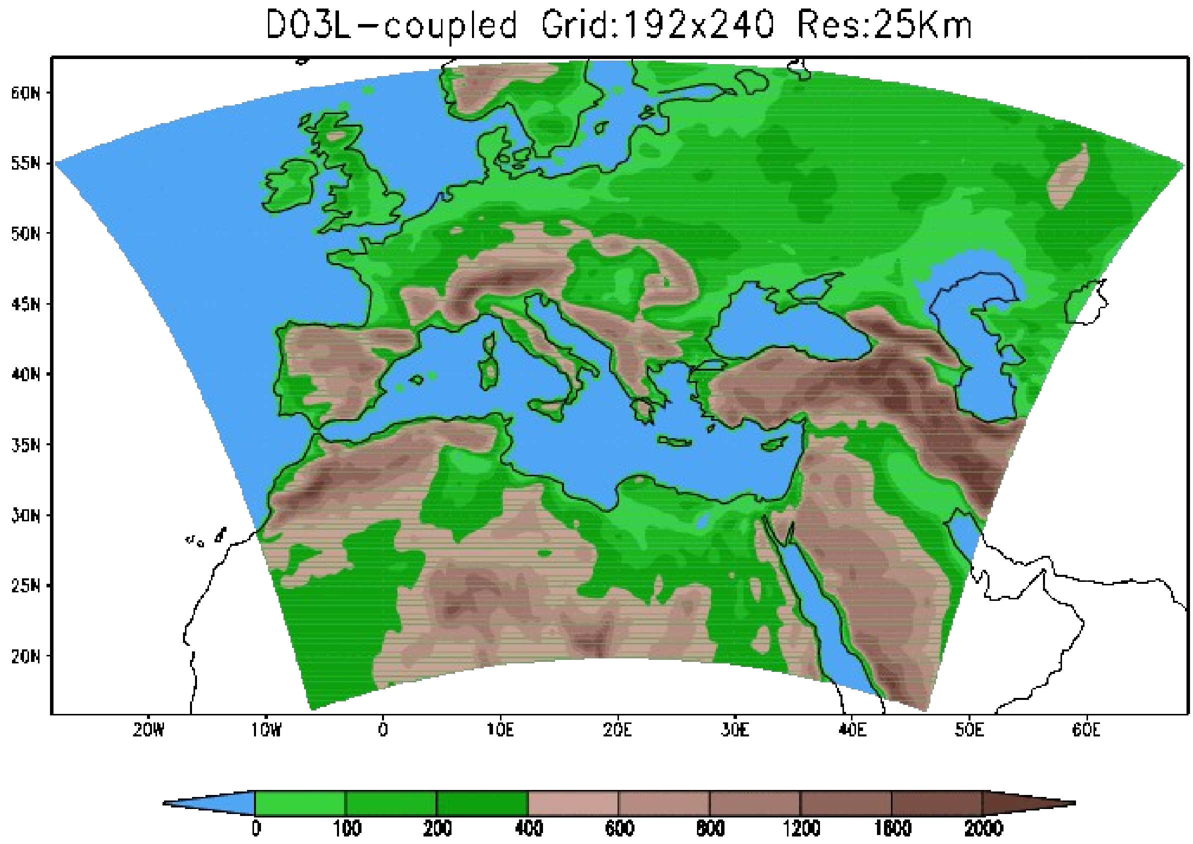

Figure IV-1.Domain and topography (in meters) for PROTHEUS simulations.

Lateral boundary conditions are supplied every 6 hours by interpolating horizontal wind components, temperature, specific humidity and surface pressure from the driving global atmospheric model.

The ocean component is based on the Mediterranean Sea model developed by Sannino et al (2009). It is characterized by a horizontal resolution of 1/8°× 1/8°, equivalent to rectangular meshes of variable resolution with the meridional side of about 14 Km and the zonal one ranging from about 9 Km in the northern part of the domain to about 12 Km in the southern part. The model has 42 vertical Z-levels with a resolution varying from 10 m at the surface to 300 m in the deepest part of the basin, and an intermediate resolution of about 40-50 m between the depths 200-700 m. The performance of the oceanic component of PROTHEUS system in reproducing the Mediterranean circulation is discussed thoroughly in Sannino et al. (2009). In particular, the configuration adopted for this study corresponds to the NOGR configuration discussed by Sannino and co-authors, characterized by an explicit (although at relatively low resolution) description of the Strait of Gibraltar. In particular, we use natural boundary conditions for salinity, i.e. precipitation, runoff and evaporation are treated as acting on the total volume of freshwater.

With respect to the simulations described in Artale et al. (2010), we substitute the observational monthly climatological river discharge dataset with monthly river discharges interactively computed from the RegCM3 total runoff.
River discharge is calculated by spatially integrating the simulated monthly mean total runoff over a large set of catchment basin. The integration is based on the Total Runoff Integrated Pathway (TRIP) dataset, which maps the land water flow directions onto a 0.5°x0.5° regular global grid (Oki and Sud 1998). By following the TRIP classification, we identify 148 river mouths discharging into the Mediterranean Sea (Fig.1c), and 50 river mouths discharging into the Black Sea. To derive a realistic estimate of the freshwater flux that reaches the Mediterranean Sea from the Black Sea through the Dardanelli Strait, the value for the total discharge in the Black Sea is rescaled (runtime) using coefficients computed from a preliminary standalone simulation. We derive the rescaling coefficient from the optimal linear fit with the Stanev climatology (Stanev et al, 2000). The rescaled water flux is then treated as a single river mouth for the Aegean Sea. The effect of the rescaling is to reduce the total discharge in the interior of the Black Sea, with larger impact during winter.

To reproduce present climate and to validate the model, a control simulation driven by ERA-Interim dataset will be performed. Moreover, for the period 2005-2100 we will perform a regional simulations forced by a greenhouse gases concentrations following a emissions scenarios: RCP4.5, RCP8.5. The boundary conditions of the RCSM can by provided from different GCMs.

3.2.1.b: Stand-alone simulations

The single components of the PROTHEUS coupled system can be used in stand-alone configuration.

More in detail, the atmospheric component RegCM3 can be used at request for atmospheric time-slices simulations (up to 10-years) with higher temporal resolution (output frequency up to 1 hour) to better describe the diurnal cycle. For this kind of simulations, we can also improve for RegCM3 the module of skin temperature description that ICTP group has recently developed for RegCM4, based on Zeng and Beljaars (2005).

Similarly, stand-alone oceanic simulations (forced by coarser GCMs as well as RCMs simulations) can be obtained with higher resolution (up to 1/16°, with further zoom for particular regions of interest), with improved parameterizations to take into account, among others, the effect of atmospheric pressure onto the sea level height and the contribution of tides in determining the Mediterranean oceanic circulation.

Tidal forcing includes both the lateral and internal component. That means, tidal currents coming from the Atlantic Ocean propagating inside the Mediterranean basin through the Strait of Gibraltar, and tidal potential generating inside the basin. The main 4 tidal constituent are considered, two semidiurnal (M2 and S2) and two diurnal (K1 and O1). The lateral tidal forcing has been extracted from the tidal global model OTIS (Egbert et al., 2002).

The new improved version of the MEdMITgcm can also include an explicit representation of the atmospheric surface pressure that directly has an effect on the surface elevation. Surface elevation has been computed retaining all the non-linear effects.

MedMIT will be first forced at the surface with an atmospheric downscaling of the ERA-INTERIM data-base performed with the PROTHEUS system. Such a simulation will be used both to validate the model and to produce a present climate ocean control-run. Both components have been recently implemented and applied in Sanchez-Garrido et al 2011.

Finally, the PROTHEUS coupled simulations can be used to drive the WAve prediction Model (WAM; WAMDI group 1988), that can be implemented on the Mediterranean area at a resolution of 1/16°x1/16°. First, the model would be forced with wind fields coming from ECMWF analysis to perform a first validation analysis. Then, the model will be forced using wind fields coming from scenario simulation derived by the PROTHEUS coupled system. The bathymetry used will be the most resolved available at the moment.

3.2.2: Model improvements:

To summarise from the previous section, the list of the possible modelling tools that can be adopted (if needed) by ENEA group are such as:

- PROTHEUS regional coupled simulations with a new improved configuration for the Euro-Mediterranean region;
- Stand alone time-slices atmospheric simulations performed by RegCM3 with a SST skin layer module and with hourly surface fields outputs to better describe the diurnal temperature cycle.
- Stand-alone oceanic simulations performed by a new improved version of MEdMITgcm with a a spatial resolution up to 1/16°, with modules for considering the tidal forcing and the explicit representation of the atmospheric surface pressure on the oceanic surface elevation.
- Wave model (WAM model) up to 1/16°x1/16° resolution forced by operational analysis and by regional simulations.

3.2.3: Period of time:

The different configurations (Coupled as well as stand-alone) of the models can be used to simulate past or future climate.

- For past and present climate, the period covered can be over:

- the ERA Interim period

- For the scenario, the period covered is between 1860-2100.
  - The period 1860-2005 is forced by observed greenhouse gases concentrations,
  - for the period 2005-2100 is forced by a greenhouse gases concentrations following a emissions scenarios: RCP4.5, RCP8.5. The boundary conditions of the RCSM can by provided from different GCMs.

3.2.4: References

Artale V., Calmanti S., Carillo A., Alessandro Dell'Aquila, Marine Herrmann, Giovanna Pisacane, Paolo M. Ruti, Gianmaria Sannino, Maria Vittoria Struglia, Filippo Giorgi, Xunqiang Bi, Jeremy S. Pal, Sara Rauscher, 2010. An atmosphere-ocean regional climate model for the Mediterranean area: assessment of a present climate simulation. *Clim Dyn* 35, 721-740, DOI: 10.1007/s00382-009-0691-8

Egbert, G., and L. Erofeeva, 2002: Efficient inverse modeling of barotropic ocean tides. J. Atmos. Oceanic Technol., 19, 183–204.

Giorgi, F., Bates, G. and Nieman, S. (1993a). The multi-year surface climatology of a regional atmospheric model over the western united states, Journal of Climate 6: 75–95

Giorgi, F., Marinucci, M. and Bates, G. (1993b). Development of a second generation regional climate model (regcm2) i: Boundary layer and radiative transfer processes, Monthly Weather Review 121: 2794–2813.

Giorgi, F. and Mearns, L. O. (1999). Introduction to special section: Regional climate modeling revisited, Journal of Geophysical Research 104: 6335–6352

Oki, Taikan, Y. C. Sud, 1998: Design of Total Runoff Integrating Pathways (TRIP)—A Global River Channel Network. *Earth Interact.*, **2**, 1–37

Pal, J.S., F. Giorgi, X. Bi, N. Elguindi, F. Solmon, X.J. Gao, R. Francisco, A. Zakey, J. Winter, M. Ashfaq, F. Syed, J. Bell, N. Diffenbaugh, J. Karmacharya, A. Konare, D. Martinez-Castro, R. Porfirio da Rocha, L. Sloan and A. Steiner, 2007: Regional climate modeling for the developing world: The ICTP RegCM3 and RegCNET. *Bulletin of the American Meteorological Society*, 88, 1395-1409.

Sanchez-Garrido J. C., G. Sannino, L. Liberti, J. Garcia-Lafuente and L. Pratt, 2011. Numerical Modelling of Three-Dimensional Stratified Tidal Flow Over Camarinal Sill, Strait of Gibraltar JGR-ocean, *in press*.

Sannino, G., Herrmann, M., Carillo, A., Rupolo, V., Ruggiero, V., Artale, V.,Heimbach, P., 2009. An eddy-permitting model of the mediterranean sea with a two-way grid refinement at the strait of gibraltar. *Ocean Modelling* 30 (1), 56 – 72. DOI: 10.1016/j.ocemod.2009.06.002

Stanev, E. V., Le Traon, P.-Y., and L., P. E.: Sea level variations and their dependency on meteorological and hydrological forcing: Analysis of altimeter and surface data for the Black Sea., J. Geophys. Res., 105, 17,20317,216, doi:10.1029/1999JC900318, 2000.

Valcke S., R. Redler, 2006: OASIS3 User Guide, PRISM Suppport Initiative Report No 4, 60 pp.

WAMDI Group, The WAM model—A third generation ocean wave prediction model, J. Phys. Oceanogr., 18, 1775–1810, 1988.

Zeng X., Beljaars A., 2005: A prognostic scheme of sea surface skin temperature for modelingand data assimilation. *Geophys. Res. Lett.*,

3.3. The ICTP model:

3.3.1: Model configuration:

3.3.1.a: The ICTP-RegCM4 basic configuration:

The basic modelling tool that will be used by ICTP in CLIMRUN for targeted simulations is the newly developed fourth version of the ICTP regional climate model, RegCM4. This model version builds on development work carried out in the last two decades, first at the National Center for Atmospheric Research (NCAR), Boulder, CO, and then at ICTP (Dickinson et al. 1989; Giorgi et al. 1993a,b; Giorgi and Mearns 1999; Pal et al. 2007; Giorgi et al. 2011). RegCM4 is a community model which is used by a wide community of scientists for multiple applications, from process studies to paleoclimate and climate change simulation (Giorgi and Mearns 1999; Giorgi et al. 2006). The dynamical core of RegCM4 is essentially the same as the hydrostatic version of the Mesoscale Model system MM5 (Grell et al. 1994). It employs sigma-p coordinates and different horizontal projection grids, Lambert conformal, Mercator, rotated Mercator, Polar stereographic. It has been used at horizontal grid spacings of 10 – 200 km. Being a hydrostatic model, a grid spacing of 10 km represents its limit of application.

RegCM4 can use different physics options. Radiative transfer processes are described via the package of the NCAR-CCM3 global model (Kiehl et al. 1996), with some modifications to account for separate calculations in cloud free and cloudy skies. The scheme includes the radiative effects of aerosols and all major greenhouse gases. Planetary boundary layer (PBL) processes are treated using a scheme derived from the non-local PBL module of Holtslag et al. (1990) with various modifications to the vertical diffusion profiles, particularly for very stable boundary layers. Resolvable scale precipitation is treated using the explicit moisture scheme of Pal et al. (2000), which allows the representation of warm cloud microphysics and fractional cloud cover. Three schemes are available for convective precipitation: the Kuo-Type scheme of Anthes (1977) (in the simplified form of Anthes et al. 1987); the mass flux scheme of Grell (1993) and the scheme of Emanuel and Zivkovic-Rothman (1999). RegCM3 also includes the option of using different convection schemes over land and ocean. Land surface processes can be described by two packages, the Biosphere-Atmosphere Transfer Scheme (BATS) of Dickinson et al. (1993) and the more advanced Common Land Model (CLM; Oleson et al. 2004, 2008; Steiner et al. 2009). Both schemes describe the land-atmosphere exchanges of heat, momentum and moisture, the surface hydrologic cycle, the cycle of snow cover and melt, and the effect of vegetation cover. Recently, a new urban surface type has been added to the BATS scheme.

RegCM4 can run with lateral boundary conditions either from reanalysis of observations (ERA-Interim, ERA-40, NCEP) or from different GCMs. Among such GCMs currently are HadGEM, ECHAM, CCMA, but the model can be quickly interfaced with any GCM. For the assimilation of lateral boundary conditions, the model uses a standard relaxation procedure applied to a lateral buffer zone whose width can be specified for different applications and using a vertically varying exponential relaxation function as described in Giorgi et al. (1993b). The model has been run for simulations of up to 150 years length for domains as large as covering the entire African continent and adjacent oceans. A new feature in regCM4 is the capability of running the model in Tropical Band configuration (RegT-band, Coppola et al. 2011), which makes it more similar to an AGCM. RegCM4 is a fully parallel code which scales well up to several hundred processors.

3.3.1.b: The sub-grid tiling scheme:

An important feature of RegCM4 for the CLIM-RUN project is the capability of using a sub-grid tiling scheme (Giorgi et al. 2003). Essentially, the model grid box (e.g.10 km size) is divided into a regular grid of land surface sub-grid tiles (e.g. 10x10 1 km boxes) accounting for sub-grid scale variations in land surface type and topography. Climatic variables, such as surface air temperature, moisture and precipitation, are disaggregated from the grid box to the sub-grid tiles and used as input for the surface process calculations. Land surface calculations are then carried out at each sub-grid tile, and surface fluxes thus obtained are then reaggregated to the model grid box and provided to the atmospheric model. This scheme, which can be considered as a hybrid dynamical statistical method allows us to reach very high horizontal resolutions without increasing the full model resolution to unmanageable scales. It can thus be used to obtain a first order evaluation of local effects and to produce high resolution scale climate information.

3.3.1.c: The coupled aerosol scheme:

RegCM4 includes a simplified aerosol module which is coupled both dynamically and radiatively to the climate component of the model (Solmon et al. 2006; Zakey et al. 2006; 2008). The aerosol scheme includes sulphate, organic carbon (OC) and black carbon (BC) particles, desert dust, and sea spray. Each aerosol is divided into size bins, for a total of 12 bins. For each bin a prognostic equation for the mass mixing ratio is calculated which includes transport by resolvable scale circulations, turbulence and cumulus convection, sources, parameterized chemical transformations and wet and dry removal mechanisms. Being a simplified scheme it can be applied to long term (up to multi-decadal) climate simulations. Only direct radiative effects, both in the solar and infrared portions of the spectrum, are currently included in the model. This aerosol module has been applied to a variety of regions, such as Africa (e.g. Konare' et al. 2005; Solmon et al. 2008), East Asia (Giorgi et al. 2002; Zhang et al. 2009), South Asia (Nair et al. 2011), and Europe (Solmon, work in progress).

3.3.1.d: The coupled lake model:

RegCM4 includes as an option a coupled one-dimensional lake model (Hostetler et al. 1993). The model includes vertical turbulent and convective mixing as well as heating by solar radiation. It has the option of producing surface ice cover and snow accumulation on top of the ice. To date it has been applied to lakes in the Continental U.S. (e.g. Hostetler et al. 1993) and the Aral sea (Small et al. 1999). It is currently being tested for the Caspian Sea.

3.3.1.e: The diurnal Sea Surface Temperature (SST) scheme:

A recent addition to RegCM4 is a scheme to simulate the diurnal cycle of sea surface temperature (Zeng and Beljaars 2005). The scheme essentially adds a diurnal perturbation to the mean daily SST computed from an energy balance model including radiative fluxes, sensible and latent heat flux and exchange with deeper water. It has been tested mostly for tropical domains, but it can be applied to the Mediterranean as well.

3.3.2: Model improvements:

A number of improvements are currently under way for potential use in CLIMRUN, as needed:

- Inclusion and testing of an urban land type (Kueppers 2008)
- Inclusion and testing of the Tiedtke (1989) convection scheme
- Inclusion and testing of the University of Washington PBL scheme (O-Brien et al. 2011)
- Improvement of cloud microphysics
- Inclusion of aerosol indirect effects
- Coupling with a full gas phase chemistry model (Shalaby et al. 2011)
- Coupling with the ROMS ocean model (Shchepetkin and McWilliams 2005)
- Activation and testing of the interactive biosphere component of CLM

3.3.3: Possible simulation strategies:

Domain:

Different targeted domains can be chosen to meet the needs emerging from the CLIMRUN stakeholder workshops (Figure V.1). The general approach will be to use first an intermediate resolution domain (e.g. 50 km) covering the Mediterranean region and then use the output from this simulation to drive high resolution experiments (10-15 km with 1-1.5 km sub grid tiling) over small domains targeting the selected areas of interest.

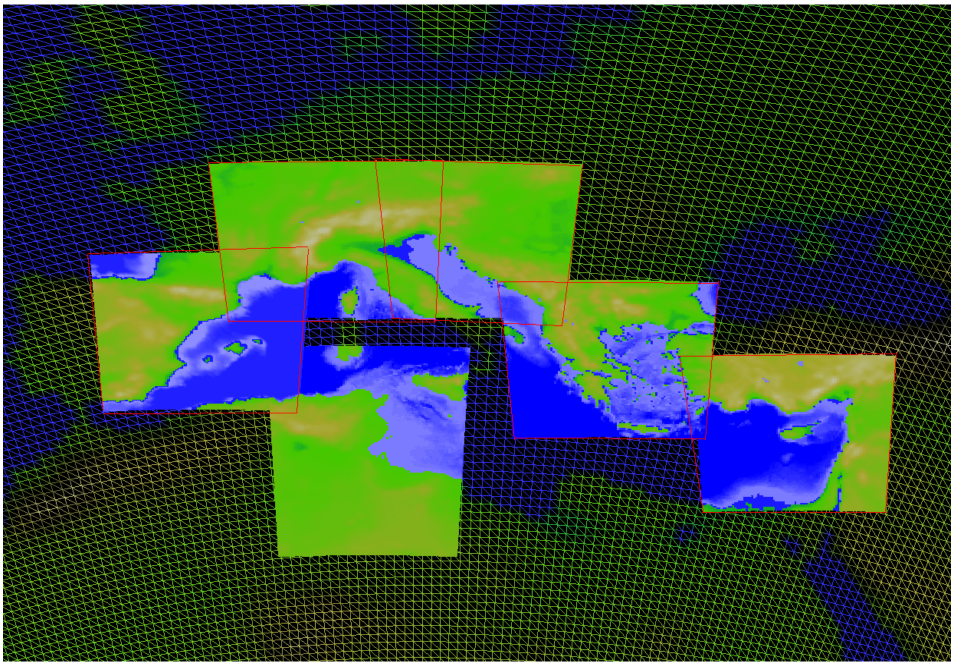

Figure V.1. Schematic depiction of the possible high resolution targeted domains to be used for the CLIMRUN case studies, as needed.

Period of time:

The model can be used to simulate different periods of past and future climate conditions.

- For past climate, options:
  - the ERA40 or NCEP period: 1958-2001,
  - the ERA Interim period: 1979-2008
  - the ECMWF analysis: 1989-2011.

- For scenario simulations, the period covered is 1950-2100.
  - The period 1950-2005 is forced by observed greenhouse gas concentrations,

- for the period 2005-2100 is forced by greenhouse gas concentrations following two reference concentration pathways: RCP4.5, RCP8.5. The boundary conditions for RegCM4 can be provided by different GCMs: HadGEM, CCMA, ECHAM and others.
- The possibility also exists, pending availability of forcing GCM data, to carry out decadal prediction experiments with initialized ocean conditions (e.g. up to 2035).

3.3.4: References:

Anthes RA (1977) A cumulus parameterization scheme utilizing a one-dimensional cloud model. Mon Wea Rev 105: 1423-1438.

Anthes RA, Hsie EY Kuo YH (1987) Description of the Penn State/NCAR Mesoscale Model Version 4 (MM4). NCAR Technical Note TN-282+STR 66pp.

Coppola E, Girogi F, Mariotti L, Bi X (2011) A tropical band version of RegCM4 : RegT-Band. Submitted to Climate Research.

Dickinson RE, Errico RM, Giorgi F, Bates GT (1989) A regional climate model for the Western United States. Climatic Change 15:383422.

Dickinson RE, Henderson-Sellers A, Kennedy P (1993) Biosphere-atmosphere transfer scheme (BATS) version 1e as coupled to the NCAR community climate model, Technical report, National Center for Atmospheric Research Technical Note NCAR.TN-387+STR, 72 pp.

Emanuel KA, Zivkovic-Rothman M (1999) Development and evaluation of a convection scheme for use in climate models. J Atmos Sci 56: 1766–1782.

Giorgi F, Mearns LO (1999) Introduction to special section: Regional climate modeling revisited. Journal of Geophysical Research 104:6335- 6352.

Giorgi F, Marinucci MR, Bates G (1993a). Development of a second generation regional climate model (regcm2): Boundary layer and radiative transfer processes. Monthly Weather Review 121: 2794–2813.

Giorgi F, Marinucci MR, Bates G, DeCanio G (1993b) Development of a second generation regional climate model (RegCM2), Part II: Convective processes and assimilation of lateral boundary conditions. Mon Weather Rev 121: 2814–2832.

Giorgi F, Bi X, Qian Y (2002) Direct radiative forcing and regional climatic effects of anthropogenic aerosols over East Asia: A regional coupled climate/chemistry-aerosol model study. J. Geophys Res 107:4439.

Giorgi F, Francisco R, Pal JS (2003) Effects of a sub-grid scale topography and landuse scheme on surface climate and hydrology. Part I: Effects of temperature and water vapor disaggregation. J Hydrometeorology 4:317-333.

Giorgi F, et al. (2006) Introduction to the TAC special issue: The RegCNET network. Theoretical and Applied Climatology 86:1-4.

Grell GA (1993) Prognostic evaluation of assumptions used by cumulus parameterizations. Mon Wea Rev 121:764–787

Grell G, Dudhia J, Stauffer DR (1994) A Description of the fifth generation Penn State/NCAR Mesoscale Model (MM5). NCAR technical note NCAR/TN-398 + STR, 121pp.

Hostetler SW, Bates GT, Giorgi F (1993) Interactive nesting of a lake thermal model within a regional climate model for climate change studies. J Geophys res 98: 5045-5057.

Holtslag A, de Bruijn E, Pan H-L (1990) A high resolution air mass transformation model for short-range weather forecasting. Monthly Weather Review 118: 1561– 1575.

Kiehl J, Hack J, Bonan G, Boville B, Breigleb B, Williamson D, Rasch P (1996). Description of the ncar community climate model (ccm3), National Center for Atmospheric Research Technical Note NCAR/TN-420+STR, 95 pp.

Konare A, et al. (2008) A regional climate modelling study of the effect of desert dust on the west African monsoon. Journal of Geophysical Research 113: D12206.

Kueppers LM (2008) Seasonal temperature response to land-use change in the western United States. Global and Planetary Change 60:250-264.

Nair VS, Solmon F, Giorgi F, Mariotti L, Babu SS, Krishna Moorty K (2011) Simulation of South Asia aerosols for regional climate studies. Submitted to Journal of Geophysical Research.

O'Brien TA, et al. (2011) A new turbulence parameterization for RegCM. Part I: Validation and stratocumulus validation. Submitted to Clim Dyn.

Oleson KW, et al. (2004) technical description of the Community Land Model, NCAR Technical Note NCAR/TN-461+STR, 186 pp.

Oleson KW, et al. (2008) Improvements to the Community Land Model and their impact on the hydrologic cycle. J Geophys Res 113:G01121.

Pal JS et al. (2007) Regional Climate Modeling for the Developing World: The ICTP RegCM3 and RegCNET. Bull Amer Meteor Soc 88: 1395–1409.

Pal JS, Small E, Eltahir E (2000) Simulation of regional-scale water and energy budgets: Representation of sub-grid cloud and precipitation processes within RegCM. Journal of Geophysical Research-Atmospheres 105: 29579–29594.

Shalaby A, et al. (2011) Implementation and evaluation of on-line gas phase chemistry within a regional climate model (RegCM-CHEM). In preparation.

Shchepetkin AF, McWilliams JC (2005) The Regional Ocean Modeling System: A split-explicit, free-surface, topography following coordinates ocean model. Ocean Modelling 9: 347-404.

Small EE, Sloan LC, Hostetler SW, Giorgi F (1999) Simulating the water balance of the Aral Sea with a coupled regional climate-lake model. J Geophys Res 104:6583-6602.

Solmon F, Giorgi F, Liousse C (2006) Aerosol modeling for regional climate studies: Application to anthropogenic particles and evaluation over a European/African domain. Tellus B 58:51–72.

Solmon F, et al. (2008) Dust aerosol impact on regional precipitation over western Africa, mechanisms and sensitivity to absorption properties. Geophys Res Lett 35:L24705.

Steiner AL, et al. (2009) Land surface coupling in regional climate simulations of the West Africa monsoon. Climate Dynamics 33:869-892.

Tiedtke, M (1989) A comprehensive mass-flux scheme for cumulus parameterization in large-scale models. Monthly Weather review 117:1779-1800.

Zakey AS, Solmon F, Giorgi F (2006) Implementation and testing of a desert dust module in a regional climate model. Atmos Chem Phys 6:4687–4704.

Zakey AS, Giorgi F, Bi X (2008) Modeling of sea salt in a regional climate model: Fluxes and radiative forcing. J Geophys Res 113:D14221.

Zeng X, Beljaars A (2005) A prognostic scheme of sea surface skin temperature for modeling and data assimilation. Geophys Res Lett 32:L14605.

Zhang D, Zakey AS, Gao X, Giorgi F, Solmon F (2009) Simulation of dust aerosol and its regional feedbacks over East Asia using a regional climate model. Atmos Chem Phys 9:1095-1110.

4. Conclusions:

This deliverable gives an exhaustive list of the possible new developing tools for each of the three institutes. It is a step to answer the demand from the different case study and user needs. Following all the case study meetings with the stakeholders, the requirements on the development will be identified and carried out for answer the targeted demand for each particular demand such as for example: solar radiation for the energy, snow cover for tourism in mountainous region, extremes events for forest fires.

It is the first time within an innovative European project that a bottom-up approach is carried out. This cooperative initiative between the institute developing the new modelling tools and different partners close to the case study will help to provide better answer for future climate and climate variability of identified regions.