

## **PRELIMINARY RESULTS ON THE VERIFICATION OF THE WATER BALANCE ASPECTS OF THE REGCM3 REGIONAL CLIMATE MODEL ON YEARLY SCALES.**

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### **ABSTRACT**

*In this report some preliminary results obtained implementing the RegCM3 regional climate model to downscale, at the relatively high horizontal spatial resolution of about 25km, one year (the 1982) of the ECMWF ERA40 reanalysis in the Western Europe and Mediterranean area, are discussed. The main aim of this work is to assess the performance of the RegCM3 describing the runoff (R), the precipitation (P) and the evapotranspiration (E) components of the hydrological budget. This has been made comparing the monthly precipitation averages for 1982 against a gridded dataset, at spatial resolution of 0.5°, of measured data (CRU dataset) and then checking physical consistency of the simulated P field with the corresponding R and E fields.*

### **1 INTRODUCTION**

One of the objectives of the WP4<sup>1</sup>, of the CLIMB project, is to implement robust procedures of intercomparison and verification (auditing) to evaluate reliability of the output of different climate models.

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<sup>1</sup> A complete description, extracted from the final CLIMB project proposal Description of Work (DoW), of the objectives of the WP4 can be found in the Appendix A.

The output of these climate models will be used to assess the main trends and climatic change impact for the water balance, in the basins of interest for CLIMB, that will be then used in WP5 as boundary conditions for the hydrologic models.

WP4 has also the objective of transferring information from the large scales, described by global scale climatic models, to the smaller scales relevant for hydrological modeling in all the basins that are object of hydrological investigation by the project partners. This will be accomplished using the current state-of-the-art on statistical downscaling procedures, dynamical downscaling and regional climate models.

In particular the focus in this report is on the downscaling of meteorological fields obtained using a well known Regional Climate Model, the RegCM3 (Giorgi et al. 1993a, Giorgi et al. 1993b). RegCM3<sup>2</sup> is a 3-dimensional,  $\sigma$ -coordinate, primitive equation regional climate model. Version 3 of RegCM is the latest. It is developed and supported mainly by scientists of the International Center for Theoretical Physics (ICTP).

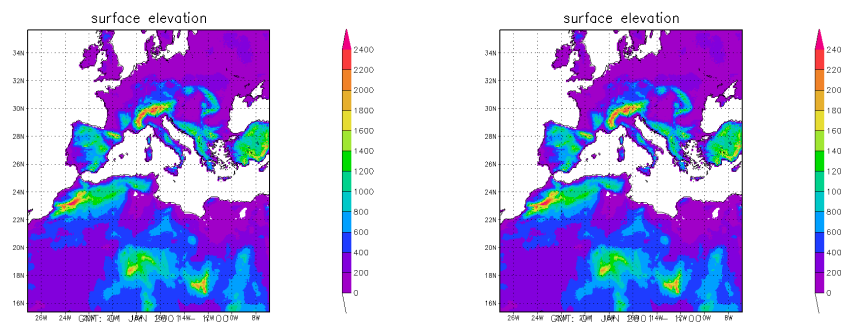
Within the model cascade made up by: global climate model, regional climate model and hydrology model each of the models has the effect of amplifying the uncertainty of the final results. These uncertainties have also the effect of introducing relevant physical inconsistencies. For this reason it is fundamental to establish in detail what are the limits and/or the errors, from a physical point of view, introduced by the use of a regional climate model to describe the water balance components that generate the input for the hydrological models.

This report summarize preliminary results obtained using RegCM3 to simulate the "climate" of a year, the 1982, in the domain showed in figure 1, and it is organized as follows: after this introduction we will briefly resume basic features of the RegCM3 model and more specifically we will discuss some aspects related to its soil physical parameterization. After a description of data type used as initial and boundary conditions and of the methodologies used to execute the simulations, we will discuss the result obtained describing the model water balance components at the soil

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<sup>2</sup> RegCM3 is freely available at <http://www.ictp.trieste.it/~pubregcm/RegCM3/>

interface. This will be done comparing monthly cumulated precipitation against measured gridded data of the CRU archive (Mitchell et al., 2004) as well as checking physical consistency between the three water balance fields at the soil interface: precipitation (P), evapotranspiration (E) and runoff (R). Then, after discussing the benefits, that can be drawn using in RegCM3 a more detailed description both of the orography and of the soil type, for the description of E and R we will draw some conclusion and give some indication about future work.



**Figure 1.** Orography and Land Sea mask contours. To the left the orography at the spatial resolution of 25 km is shown. To the right the same fields at the “augmented” spatial resolution of 6.25 km.

## 2 THE CLIMATE MODEL

The Regional Climate Model RegCM is based upon the concept of one-way nesting, in which large scale meteorological fields coming from General Circulation Model runs provide initial and time-dependent meteorological lateral boundary conditions for a higher resolution limited area domain.

The RegCM core is a compressible, finite difference model with hydrostatic balance and vertical  $\sigma$ -coordinates. The dynamical part of the model uses a split-explicit time integration scheme. The horizontal grid has an Arakawa-Lamb B-staggering of the velocity variables with respect to the scalar variables. RegCM model

derives and then is very similar to the hydrostatic version of Mesoscale Model version 5 (MM5; Grell et al., 1994). For general information about the dynamical core of RegCM and its implementation we refer directly to the papers cited in the bibliography (Giorgi et al. 1993a, Giorgi et al. 1993b). In the following part of this section we will only illustrate, in some more detail, the physical parameterizations of the model, that strongly affect the fields related to the different components of the hydrological balance.

## **2.1 Climate model physics**

Since the MM5 model was designed to describe meteorological events, a number of physics parameterizations were necessarily replaced, for application to climate studies. What follows is a brief description of the fundamental physics parameterizations used in RegCM.

The role of vegetation and soil moisture in modifying the surface-atmosphere exchanges of momentum, energy, and water vapor is described by the Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson et al., 1986). BATS has a vegetation layer, a snow layer, a surface soil layer 10 cm thick, one root zone layer 1-2 m thick, and a third deep soil layer 3 m thick. Prognostic equations are solved for the soil layer temperatures using a generalization of the force-restore method of Deardoff (1978).

The soil hydrology calculations include predictive equations for the water content of the soil layers. These equations account for precipitation, snow melt, canopy foliage drip, evapotranspiration, surface runoff, infiltration below the root zone, and diffusive exchange of water between soil layers. The soil water movement formulation is obtained from a fit to results from a high-resolution soil model. The surface runoff rates are expressed as functions of the precipitation rates and the degree of soil water saturation.

Sensible heat, water vapor, and momentum fluxes at the surface are calculated using a standard surface drag coefficient formulation based on surface-layer similarity theory. The drag

coefficient depends on the surface roughness length and on the atmospheric stability in the surface layer. The surface evapotranspiration rate depends on the availability of soil water. BATS has 20 vegetation types: soil textures ranging from coarse (sand), to intermediate (loam), to fine (clay); and different soil colors (light to dark) for the soil albedo calculation.

In the latest release version, additional modifications have been made to BATS in order to account for the sub grid variability of topography and land cover using a mosaic-type approach (Giorgi et al., 2003a). This modification adopts a regular fine-scale surface sub grid for each coarser model grid cell. Meteorological variables are disaggregated from the coarse grid to the fine grid based on the elevation differences. The BATS calculations are then performed separately for each sub grid cell, and surface fluxes are re-aggregated onto the coarse grid cell for input to the atmospheric model. This parameterization showed a marked improvement in the representation of the surface hydrological cycle in mountainous regions (Giorgi et al., 2003a).

The radiative transfer scheme is the Community Climate Model version 3 (CCM3; Kiehl et al., 1996). This model is based on four parameters: cloud fractional cover, the cloud liquid water content, the cloud effective droplet radius and cloud ice. Briefly, the solar component, which accounts for the effect of O<sub>3</sub>, H<sub>2</sub>O, CO<sub>2</sub>, and O<sub>2</sub>, follows the  $\delta$ -Eddington approximation and it includes 18 spectral intervals from 0.2 to 5  $\mu\text{m}$ . The cloud scattering and absorption parameterization follow that of Slingo (1989), whereby the optical properties of the cloud droplets (extinction optical depth, single scattering albedo, and asymmetry parameter) are expressed in terms of the cloud liquid water content and an effective droplet radius. When cumulus clouds are formed, the grid-point fractional cloud cover is such that the total cover for the column extending from the model-computed cloud-base level to the cloud-top level (calculated assuming random overlap) is a function of horizontal grid-point spacing. The thickness of the cloud layer is assumed to be equal to that of the model layer, and

different cloud water content is specified for middle and low clouds.

The planetary boundary layer scheme, developed by Holtslag et al. (1990), is based on a non-local diffusion concept that takes into account countergradient fluxes resulting from large-scale eddies in an unstable, well-mixed atmosphere.

Convective precipitation is computed using one of three schemes:

1. Modified-Kuo scheme (Anthes,1977);
2. Grell scheme (Grell,1993);
3. MIT-Emanuel scheme (Emanuel, 1991; Emanuel and Zivkovic-Rothman,1999).

In addition, the Grell parameterization is implemented using one of two closure assumptions:

- the Arakawa and Schubert closure, (Grell et al., 1994);
- the Fritsch and Chappell closure (Fritsch and Chappell, 1980).

A large-scale cloud and precipitation scheme which accounts for the sub grid-scale variability of clouds (Pal et al., 2000) is included. Sub grid Explicit Moisture Scheme (SUBEX) is used to handle nonconsecutive clouds and precipitation resolved by the model. This is one of the new components of the model. SUBEX accounts for the sub grid variability in clouds by linking the average grid cell relative humidity to the cloud fraction and cloud water following the work of Sundqvist et al. (1989).

The ocean surface fluxes scheme by Zeng (Zeng et al.,1998) describes all stability conditions and includes a gustiness velocity to account for the additional flux induced by boundary layer scale variability.

The representation of dust emission processes is a key element in a dust model and depends on the wind conditions, the soil

characteristics and the particle size. Following Marticorena and Bergametti (1995) and Alfaro and Gomes (2001), here the dust emission calculation is based on parameterizations of soil aggregate saltation and sand blasting processes.

The USGS Global Land Cover Characterization and Global 30 Arc-Second Elevation datasets<sup>3</sup> are used to create the terrain files.

### **3 DATA AND METHODS**

Being a limited area model the run of the RegCM3 model requires, besides the specification of the atmospheric initial conditions (IC), the time dependent upgrade of the atmospheric lateral boundary conditions (BC), as well. As IC and BC we have used the ERA40 (Uppala, 2005) reanalysis fields produced by the European Centre for Medium-range Weather Forecast (ECMWF). A brief description of this reanalysis data will be given in section 3.1.

For the verification of the precipitation field we have used a well known and verified data set, named CRU that will be presented in section 3.2.

#### **3.1 ECMWF ERA-40 reanalysis data**

The reanalysis projects were done in an effort to improve the accuracy of global climate assessment over the last 50 years especially for the early period when computing tools were not so powerful as today and more specifically to give a new potential for studying longer term trends and fluctuations such as, for example, El Niño and QBO<sup>4</sup>.

ERA-40 is an ECMWF re-analysis (Uppala et al., 2005), of the global atmosphere and surface conditions covering the period from mid-1957 to 2001. Analysis involves comprehensive use of satellite data, starting from the early Vertical Temperature Profile Radiometer data in 1972, then later including TOVS, SSM/I, ERS

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<sup>3</sup> Freely available at: <http://edc2.usgs.gov/glcc/glcc.php>

<sup>4</sup>The QBO (quasi-biennial oscillation) is a quasi-periodic oscillation of the equatorial zonal wind between easterlies and westerlies in the tropical stratosphere with a mean period of 28 to 29 months.

and ATOVS data. Cloud Motion Winds have been used be used from 1979 onwards.

The ERA-40 re-analysis have been obtained applying to these observations the three dimensional variational technique using the T159L60 (about 1.125° in a lat/long regular grid) version of the ECMWF Integrated Forecasting System to produce an analysis every six hours. The preliminary results discussed in this report have been obtained using the ERA-40 data at half of the effective resolution (2.25°), because this data were more easily accessible than those to the maximum resolution. During the prosecution of the activities we plan to use ECWF reanalysis at maximum resolution.

### **3.2 CRU dataset**

The gridded data set we used to validate the regional climate model simulation is made available by the Climatic Research Unit (CRU) at the University of East Anglia (UEA). Data used to create this dataset come from weather stations around the world that are generally run by National Meteorological Services (NMS).

Methods used to create this dataset are described in literature and a detailed list of references can be found for example at <http://www.cru.uea.ac.uk/cru/data/temperature/> and in the linked FAQs

Of the many version of the dataset available, with different spatial resolution or covering different parts of the world, we have used the one named CRU TS 2.02 available at [http://www.cru.uea.ac.uk/cru/data/hrg/cru\\_ts\\_2.02/](http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_2.02/). This data-set is made of 1200 monthly grids of observed climate, covering the period 1901-2000, at global scale and at 0.5 degree resolution. Five climatic variables are available: cloud cover, diurnal temperature range, vapor pressure, precipitation and temperature.

### **3.3 Methods**

Although it could be easily found on the documentation accompanying the model, just for internal documentation purpose,



we briefly describe here the procedure we used to implement the RegCM3 code.

The code has been downloaded from:  
<http://www.ictp.trieste.it/~pubregcm/RegCM3>

RegCm consists of 4 parts:

- Pre-processing
- Model computational core
- Post-processing
- Date comparison against "measured data".

Preprocessing is made in two steps:

- Domain and computational grid creation, namely digital elevation model and soil type interpolation on the model. Data are generally stored in the *Preproc/Terrain* and in the *Input* directories.
- Creation of initial and boundary conditions on the model grid. Data are stored in the *Preproc/ICBC* and in the *Input* directories.

Preprocessing configuration is specified within the file *domain.param* contained in the *Terrain* directory. In this file, the map projection type, the center of the domain, the time length of integration, the space resolution and data type used as input are specified.

What follows is the list of the more significant parameters specified within the file:

- Integer value specifying the geographical projection type (Lambert Conformal in our case)
- *iy* number of points in the latitude direction (*iy*=180 in our case)
- *ix* number of points in the longitude direction (*ix*=180 in our case)
- *kz* number of vertical levels (*kz*=36 in our case)
- *nsg* number of sub-grid points in each direction (in our case *nsg* was 1 or 4)
- *ds* grid space resolution expressed in km (25km in our case)
- *clat* latitude of the center of the domain
- *cont* longitude of the center of the domain

- *n<sub>typec</sub>* resolution of the global terrain and land-use data (*n<sub>typec</sub>*=2 expressed in minutes)
- *i<sub>byte</sub>* integer specifying the kind of direct access open statements (1 or 4) 1 for IFC8, SGI, DEC; 4 for PGI, IFC7, SUN, IBM
- *IDATE1* starting date of the simulation in the format YYYYMMDDHH (in our case: 1982010100)
- *IDATE2* date of the end of the simulation (1982020100 in our case)
- *DATTYP* analysis dataset (for us: ERA40, ECMWF reanalysis datasets 40 years 2.5 degrees data set, L23 1957–2002).
- *SSTYP* Sea Surface Temperature dataset. *SSTYP*=GISST for us. GISST is a one-degree monthly gridded data set (18 71-2002) available from the Hadley Centre Met Office at <http://badc.nerc.ac.uk/data/gisst/>
- *NPROC* is the number of CPUs used in a parallel run

For the compilation a few Makefile are available depending on the architecture and the compiler in use. We used the *Makefile\_IFC8* specific for the Intel FORTRAN compiler as we run the code on a cluster of CPU Intel based PC's.

After executing *./terrain.x* script two files are created within the *INPUT* directory: *DOMAIN.INFO* and *DOMAIN.CTL* containing digital elevation model and type of soil data necessary to create the model input.

As already specified above after this step, the procedure of interpolation of initial and boundary conditions on the model grid can be executed. This can be done entering the directory *ICBC* where the execution of the previous *terrain.x* script should have generated the *icbc.param* file containing all the necessary data to execute the preprocessing *./icbc.x* script. As for the step before the correct *Makefile* must be selected.

After this step is completed within the *INPUT* directory the *RegCM/Input/ICBC.YYYYMMDDHH* files should have been created (one for each month of simulation) and the corresponding descriptor file (CTL extension) to visualize data using grads.

It is worth remembering that some minor modifications to the *terrain.f* and *icbc.f* codes have been made necessary to be able to use 36 vertical levels. Currently there is a limitation to the dimension of the horizontal grid extension; in fact maximum number of points in the two horizontal directions is 180, which is also our domain dimension. Clearly if necessary this limitation can be removed.

After this step is completed the compilation of the *regcm* code on the *Main* directory can be made. To do this you must enter the Common directory and modify the *regcm.in* file that contains the parameters specifying the model parameterization and copying it to the directory chosen as Output. Once more, the right Makefile must be chosen and if necessary one containing the version with the instruction to compile the parallel version of the code (Options) can be selected. Once entered the Output directory the *./regcm.x* can be executed.

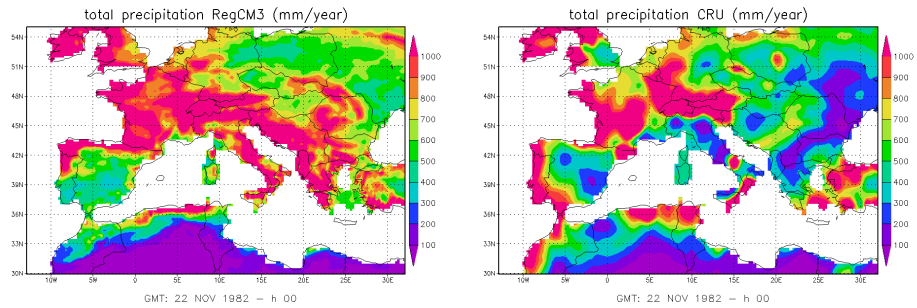
The output files are:

- OUT\_HEAD some information about the domain
- SAV.DATE restart file
- SRF.DATE output for surface variables
- ATM.DATE output of 3d variables
- RAD.DATE radiation model output

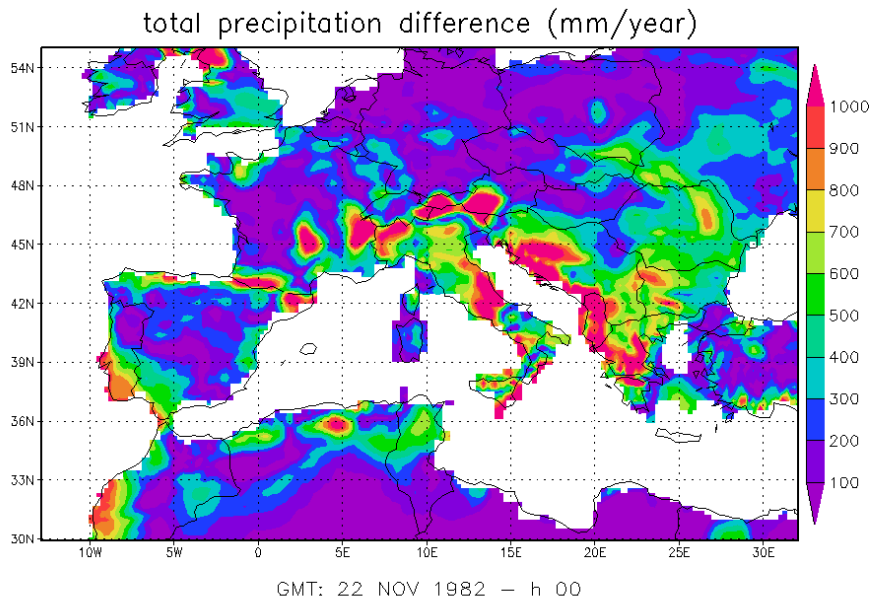
RegCM postprocessor converts these model output files to new output files of averaged variables in commonly used formats such as NetCDF or GrADS. You will need to modify the *postproc.in* file in your working directory to specify how to average the variables (daily, monthly, ect) and the file format. Then run the *postproc.x* script which will compile and execute the program.

The comparison with observations is performed by scripts (Obs/CRU) provided for interpolating several observed data sets to your RegCM grid.

We use for verification the precipitation dataset(CRU) High Resolution Global Data, which is a global, land only data set available at 0.5 degree resolution and that is already be introduced in a previous section.



**Figure 2.** To the left yearly cumulated precipitation for the 1982 ([mm/year]) as simulated by the RegCM3 model. To the right, the same field, as given by the CRU dataset.



**Figure 3.** Yearly cumulated precipitation absolute differences between RegCM3 simulated values and values taken from CRU dataset.

## 4 RESULTS

The instantaneous water balance equation for an atmospheric column can be written as:

$$\frac{\partial Q}{\partial t} = E - P - D \quad (1)$$

where  $E$  and  $P$  are respectively the evapotranspiration and the precipitation rates.  $D$  the vertically integrated humidity flux divergence is given by:

$$D = \int_{p_s}^0 \vec{\nabla} \cdot (\vec{v}q) dp$$

with:  $q$  the specific humidity,  $v$  the horizontal wind,  $p_s$  the surface pressure and the atmospheric pressure  $p$  is the vertical coordinate. The first member in equation 1, is the net precipitable water rate entering the column.

For the vertically integrated surface and subsurface water the budget equation reads, instead:

$$\frac{\partial W}{\partial t} = -E + P - R \quad (2)$$

where  $R$  is the streamflow divergence or runoff and the first member is the time derivative of liquid surface and subsurface water including snow and soil water. It's tacitly assumed that subsurface water not appearing explicitly as surface runoff  $R$  is negligible.

Typical residence time for atmospheric water is of the order of ten days. Averaging the first equation for periods  $T$  of the order of one month we have then:

$$-\langle D \rangle_T = \langle C \rangle_T \approx \langle P \rangle_T - \langle E \rangle_T \quad (3)$$

where  $C$ , the convergence, is defined as the opposite of divergence  $D$ .

Typical time of residence of snow and in general of soil water is at least seasonal and in general first member of equation 2 is not negligible also at yearly scale as recharge or discharge of groundwater can be locally not negligible.

If we spatially integrate and average equation 2 over the area  $A$  covering an entire hydrological basin and average also over a period of at one or, better, more years we can write:

$$\langle R \rangle_{TA} \approx \langle P \rangle_{TA} - \langle E \rangle_{TA} \quad (4)$$

where the residual runoff, ignoring the groundwater contribution, is the net river discharge into the sea.

Once, also, equation (3) is spatially averaged and compared with equation (4) we obtain the following equation:

$$\langle C \rangle_{TA} \approx \langle P \rangle_{TA} - \langle E \rangle_{TA} \approx \langle R \rangle_{TA} \quad (5)$$

that says essentially that, at basin spatial scale and at some convenient temporal scale, atmospheric water discharge directly to the sea.

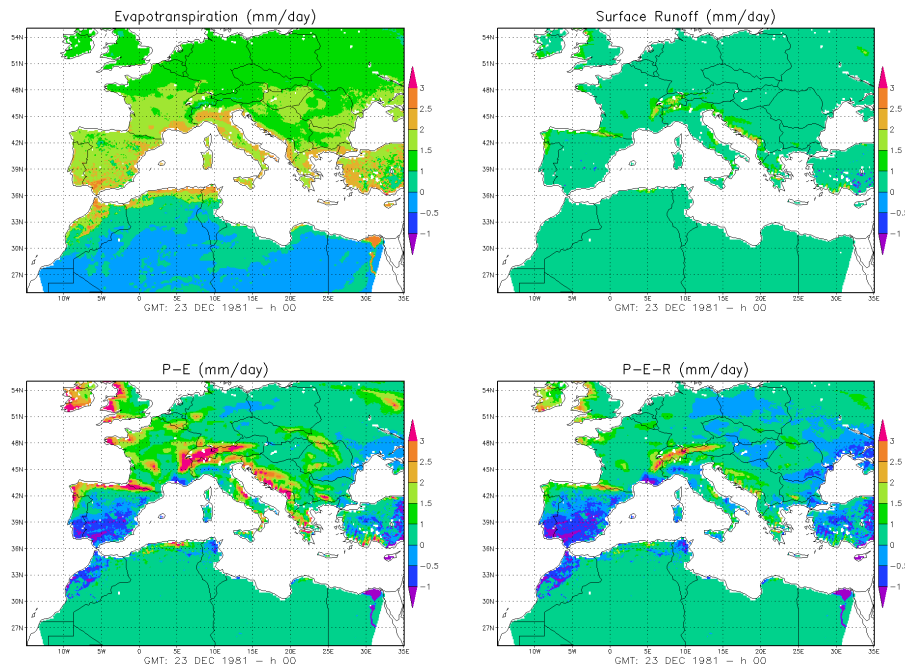
The equations above will be used to discuss the results obtained simulating with RegCM3 the “climate” of the year 1982 over the domain showed in Figure 1.

Since our main goal is trying to assess the goodness of the hydrological budget estimate first of all we ask ourselves how well the precipitation is described by RegCM on time scales of a year. In Figure 2 the cumulated values of precipitation for 1982 obtained as output of RegCM3 simulation and the corresponding “truth” are shown. As it can be seen, apart from some specific features as for example the high precipitation spots in Ireland, North Africa, West France and Turkey, the two fields show quite different patterns indicating that the first great source of uncertainty on the hydrological budget estimate, at this space-time scale, is probably introduced by model precipitation estimate. In figure 3 the field difference between those in figure 2 is shown. The order of magnitude of the differences between simulated and “truth” is, in extended regions of the domain, the same of the “truth” itself. This is not really a problem as at least for big basins this differences will compensate when averaged over the entire basin area, since in some places they are positive and in other negative. It should also noted that, what we are really interested in, is the evaluation of the water balance components at climatic time scales (order of ten years at least) and also for this reason the differences shown in figure 3 are not a real issue. Strictly speaking the two fields are directly comparable only after a long enough averaging for both

has been made. We did this comparison just to have an idea of the level of uncertainty we must expect at yearly time scale. Comparison of monthly accumulated precipitation over the Danube catchment shown in figure 7 are comparable with long term averaged values of other climatic models that can be found in literature (see for example Figure 5a of Lucarini et al., 2007).

Figure 4 shows instead the yearly cumulated values, obtained with the RegCM3 model, of the other two hydrological budget components the Evapotranspiration E (upper left corner), the Runoff R (upper right corner) and two different combination obtained using the precipitation field P, shown in figure 2 (upper left plot).

Having cumulated these fields for a period of one year, we know that, if the water budget of the model is correctly described, equation 3 applies. This allow to interpret the left lower plot of figure 5, showing the variable P-E, as the atmospheric water contribution to the net surface water flux. As it can be seen areas of Europe where precipitation is huge, as for example the Alps, are wells of atmospheric water ( $P-E > 0$ ) whereas dry areas of Spain and north Morocco are described, at least during 1982, as sources of atmospheric water indicating hydrological stress due to scarce precipitation.

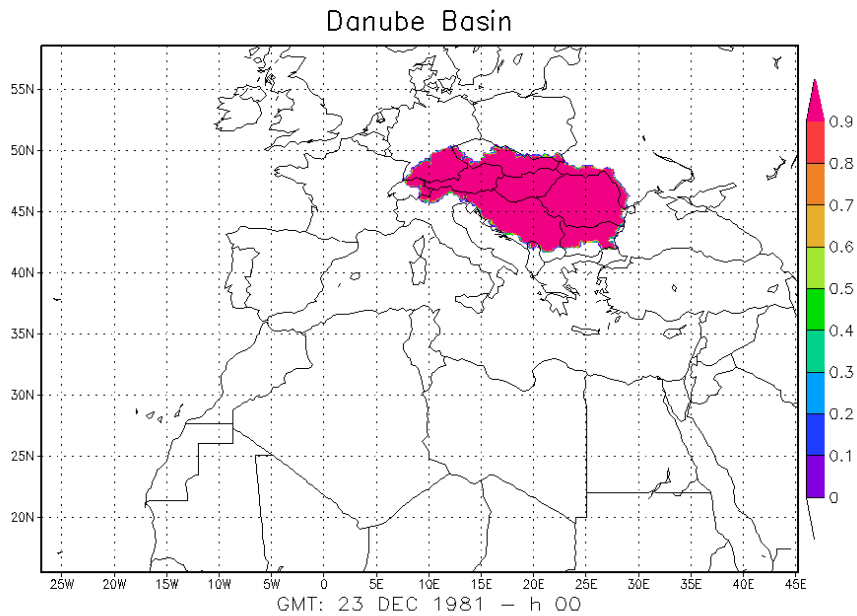


**Figure 4.** Maps showing yearly cumulated values of evapotranspiration  $E$ , surface runoff  $R$  and some hydrological budget indicators obtained combining them with the cumulated precipitation  $P$ . See discussion in the text.

It is also interesting to note the description of the atmospheric budget above the delta of the Nile where a source of water is located due, this time, to an excess of evaporation.

In the right lower portion of figure 4 the surface water budget:  $B=P-E-R$ , is plotted. As already discussed when introducing it, equation 5 is accurate only if an appropriate space and time average is made on the  $P$ ,  $E$  and  $R$  fields. If this averaging is not sufficient, there could be, locally, areas, as it can be verified from the cited plot, where excess of one of the budget components can substantially violate the surface water budget.



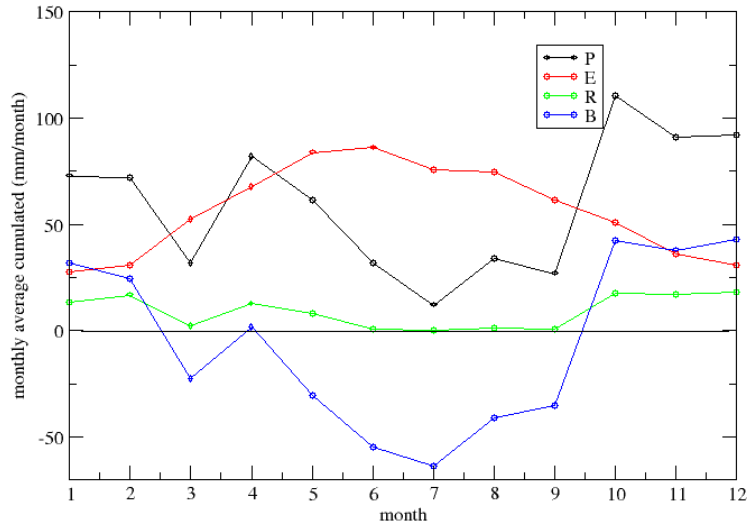


**Figure 5.** Map showing in red color the boundaries of the Danube basin.

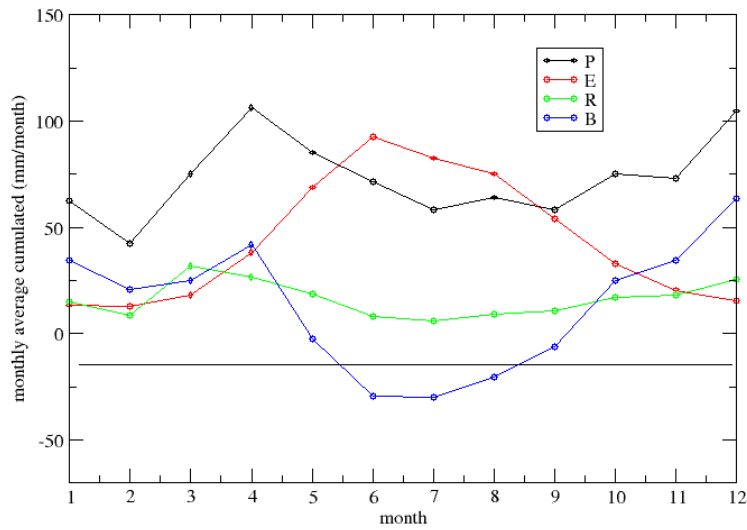
To overcome this problem we decided to verify the consistence of the surface budget applying equation 5 to the closed basin represented by the Sardinia Island and to the big Danube water basin (see figure 5).

First of all we verified consistency on a monthly time scale. Results for the two basins are shown on figures 6 and 7. As it can be seen the excess of evapo-transpiration with respect to precipitation ( $E > P$ ) as well as the water balance deficit ( $B < 0$ ), during the dry season are well described. To conclude this analysis is interesting to evaluate the same components when integrated during a whole year. This data are shown for the two basins in table 1. As it can be seen also at this time scale equation 5 is not strictly verified. This can be related essentially to two reasons: to the inadequacy of the model and to the particular weather of the year under study. That is, 1982 could had been a dry year for Sardinia ( $B < 0$ ) and a wet year for the Danube basin

( $B > 0$ ). To verify which of the two hypotheses is true in principle a longer period of integration is necessary. Nevertheless the model inadequacy can be discarded including in the water balance those seasonal components that have been neglected here, in view of the climatic nature of our study. These components are essentially two: the snow amount and soil water content changes between the final and initial condition. These two additional components, along with the corrected water balance, are shown within the grey portion of table 1. As it can be seen the residual water balance is greatly reduced, This residual portion, of the order of 1% with respect to the total precipitation amount can be considered negligible since the errors and uncertainties introduced by the climatic model are surely greater.



**Figure 6.** RegCM3 monthly averaged water balance components, for the 1982, for all the Sardinian Island.



**Figure 7.** As in Figure 6 but for the Danube basin.

Balance Component	Sardinia (mm/year)	Danube (mm/year)
Precipitation	718	877
Evapotranspiration	679	525
Runoff	107	196
Water Balance	-68	156
Snow Amount Change	0	45
Soil Water Change	-59	105
Corrected Water Balance	-9	6

**Table 1.** Averaged water balance components for the year 1982 for all the Sardinian Island and the Danube basin. See text body for details.

## 5 CONCLUSIONS

In this paper we discussed some results obtained simulating the atmospheric circulation of a year, over a vast region comprising Europe and northern Africa, with the regional climate model RegCM3 forced with ECMWF ERA-40 boundary conditions.

In particular, given the specific objectives of the CLIMB project, of which this work is part, we were interested in issues related to the estimation of the main components of water balance on climatic time scales.

To begin with the annual precipitation simulated by the model was compared with a dataset of gridded measured data. This comparison showed that, at yearly scale, the differences in the estimation of this component are of the same order of magnitude of the precipitation itself.

Missing similar measured data for evapotranspiration  $E$  and runoff  $R$  we were not able to directly quantify the uncertainty in their estimate. Assuming a relationship of proportionality between

precipitation and evaporation and runoff we can estimate that they have the same percentage differences.

This would lead us to assume an uncertainty in the estimation of the water balance as the sum of this three components.

On the other hand, the evaluation of the atmospheric and surface water budget, cumulated on annual scale and integrated in a closed basin, showed good agreement with what is expected from theoretical considerations, and with values found in literature, indicating formal correctness and physical consistency of the RegCM climate simulations .

In order to give more reliable estimations is still necessary to extend the period of integration in order to verify the hypothesis enunciated above, over climatic time scales.

This is what we intend to do in the coming months, first of all, by extending the analysis already carried out for the 1982 to the decade 1982-1991.

**Acknowledgements.** This report documents the activities carried on, by CRS4, during the first semester of the EU CLIMB project. The work has been also supported by the Sardinian Regional Authorities. We want also to thanks our colleagues Marta Dentoni, Costantino Soru and Pierluigi Cau who helped us to delimitate the boundaries of the Danube basin on the lat/lon regular grid in which CRU data are given.

## **APPENDIX A**

Since this will be classified as an internal CRS4 report for completeness we report here the technical.....

### **A.1 Objectives**

Several numerical climate models (global and regional) are used by the scientific community for reconstructing the past and present climate and predicting the future state of the Earth at different spatial and temporal scales. Recently, the outputs of a large set of climate models have been made available thanks to open data

access projects, such as the PRUDENCE project of the 5th European Union Framework Program for regional climate models, the ENSEMBLES project of the 6th European Union Framework Programme and the US project PCMDI/CMIP3 for global climate models. These data have constituted a crucial basis of the fourth report of the Intergovernmental Panel for Climate Change (IPCC4AR). Recent studies available in the international literature have critically addressed the problem of validating climate models, by assessing the discrepancies between outputs provided by different models as well as between model outputs and observations in appropriate “diagnostic spaces”.

1. Starting from these results, this WP will aim at designing robust procedures allowing for auditing (intercomparison and verification) of products coming from different climate models. These procedures will account for the statistics of the average and extreme fields, for the water balance conservation in atmosphere and for the problems related to spatial and temporal grid discretisations adopted in the different models.

The direct use of climate outputs for evaluating effects at the land surface (average runoff, floods, dynamics of soil moisture, agricultural efficiency, etc.) suffers for a space-time scale gap between atmospheric and hydrological processes. Similar problems may occur also when outputs of meteorological models are used for hydrological applications in (small) basins with short response time. In fact, even if non-hydrostatic meteorological models with at high spatial geometric resolution (1-5 km) are today available, the more reliable

meteorological forecasts are obtained on coarser scales, of the order of some tenths of kilometers. This occurs for several reasons including: the theoretical limits of predictability associated to the chaotic nature of Navier-Stokes equations, the scarce spatial density of observations over the world used to build the meteorological analysis, the adoption of numeric diffusion operators and of parameterization and closures representing unresolved sub-grid processes. To bridge the gap between the meteo-climatic model scales and the hydrological scales, suitable statistical and dynamical downscaling techniques must be applied to the output of the climatological models.

2. Starting from the current state-of-the-art on statistical and dynamical downscaling models, the WP will aim at building a bridge for transferring information from the large scales described by meteorological/climatic models and the smaller scales required for hydrological modeling in all the basins that are object of hydrological investigation by the partners of the project. More specifically, on one hand statistical downscaling will be performed with multifractal models able to provide efficiently ensembles of high resolution rainfall fields reproducing reliable small scale variability; on the other hand a high resolution dynamical downscaling model will be applied on selected extreme events with the twofold objective of providing high resolution fields for distributed hydrological models and for supplementary calibration of the statistical downscaling models.

The common aim of both objectives is to provide for each test site the climatologic/meteorological forcing which can be directly and easily used as input for hydrological applications. Specifically:

- sequences of fields extracted from the available outputs of global and regional climate models
- representative climate change scenarios of the mean states, fluctuations and extreme events derived by a rigorous auditing assessment process
- statistically and dynamically downscaled fields able to account for small scale variability.

## **A.2 Description of work**

1. Procedures for climate model output extraction at local basin scale: Content in keywords: Web/ftp data-extraction development, parameters and unit of measure standardization, storage optimization.
2. Climate Models Auditing: Content in keywords: Intercomparison and verification of climate model outputs, atmospheric water balance on representative basins
3. Current and climate change scenarios for the basins studied in the project: Content in keywords: Rigorous statistical

assessment of mean states, fluctuations and extremes of the atmospheric water cycle

4. Downscaling for small scale variability representation of the atmospheric forcing: Content in keywords: Multifractal downscaling models, dynamical downscaling models, limited area models

### **A.3 Deliverables**

- Month 12: sequences of fields (for each test-case basin in the project) extracted from the available outputs of global and regional climate models
- Month 24: representative climate change scenarios (for each test-case basin in the project) of the mean states, fluctuations and extremes derived by a rigorous auditing assessment process
- Month 36: statistically and dynamically downscaled fields which describe the small scale variability of rainfall and other meteorological forcing at the basins study-sites.

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