Water Research Institute
National Research Council

1° ESF MedCLIVAR Summer School

Climate Variability over the Mediterranean area: Atmospheric and Oceanic Components

Hydrobiological station and Aquarium of Rodhes 17 – 27 September 2008, Island of Rhodes GREECE

HYDROLOGICAL IMPACTS OF CLIMATE CHANGE ON CATCHMENT RESPONSE IN THE MEDITERRANEAN REGION

PhD student E. Bruno[1,2] ; supervisors U. Fratino[1], I. Portoghese[2] and M. Vurro[2]

1) Technical University of Bari, Italy 2) National Research Council, IRSA, Bari, Italy (emanuela.bruno@ba.irsa.cnr.it)

OBJECTIVES

► It is widely accepted that the global and regional scale water cycle has been changing since the last century due to the accumulation of anthropogenic greenhouse gases (GHS) and land use/ land cover change (IPCC 2007). In order to anticipate what could occur by the 21st century one can use various scenarios which describe the future development paths in various sectors such as energy, and estimate the emissions of greenhouse gases .

► The use of complimentary models is necessary to study the impact of these scenarios on living conditions. General Circulation Models (**GCMs**) transform the information about GHG and aerosol concentration fluctuations into information about the changes in the atmosphere and ocean conditions and circulation.

► However, the structure of GCMs is such that their space resolution (hundreds of kilometres) is too coarse and not adequate to describe the variability of extreme events at basin scale (Fig.1, Burlando and Rosso, 2002).

Identifying local climate scenarios for impact analysis, therefore, implies the definition of more detailed local scenarios (Fig. 2) by '**downscaling**' GCMs results (RCMs or LAM) or by **high-resolution GCMs** as for example the Météo France's ARPEGE/Climate model (Déqué, 2007) and the Japan Meteorological Agency 's prediction model JMA (e.g. in Kitoh *et alii*, 2008).

► A model is a simplification of a complex reality, then results from a model cannot be expected to fit exactly with a sample of observed data. Then it is necessary to perform a GCM output correction.

► The work undertaken during the PhD course aims at the investigation of major control factors of terrestrial water balance under climate changes and the consequent hydrological response.

► This work is being developed within the CIRCE-IP (6th FP) that focuses on the assessment of climate change impacts in the Mediterranean region. In particular, the Research Line 5 aims at producing an assessment of the expected variations of the water cycle likely to occur on the atmospheric, oceanic and terrestrial components due to global climate changes.

► The analysis is focused on the water cycle components at the catchment scale which is the typical scale of water resources planning. Therefore a fundamental requisite for the evaluation of climate change impacts on water resources is to bridge the **space-time gap** between the climate scenarios and the usual scale of the inputs for the water balance prediction models.

► For the hydrological response reasonable mathematical models for basin scale water balance simulations will be adopted, in which the meteorological input data are synthetic time series retrieved from global climate change scenarios issued by GCMs.

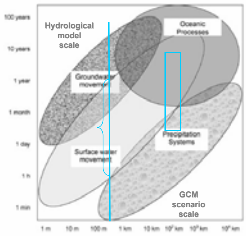


Fig.1 Time-space scales in the impact analysis

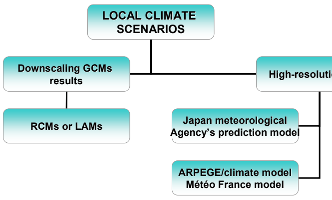


Fig.2 Identification of local climate scenarios for impact analysis

METHODS

DOWNSCALING AND OUTPUT CORRECTION

► In the assessment of climate change impacts we consider, as in Déqué work (2007)

$$Impact = Out(S) - Out(R)$$

S output of a model *Out* under climate conditions from a GHG emission scenario: provided by RCM

R output under reference (i.e. current climate) conditions : provided by observations

► This mixed approach leads to the inclusion of the model error in the *Impact* term, so it is better to use R as produced by the same RCM under present day conditions. Due to the imperfections of the RCM, data from S and R need to be postprocessed (Tab.1), so that S* and R* are used in impact equation.

POSTPROCESSING CORRECTION METHODS		
Confident method	R*(d)= R(d) S*(d)=S(d)	if the model *Out* is reasonably linear without threshold values
Delta method	R*(d)=O(d) S*(d)=O(d)+<S-R>	if the observed daily data are available It assumes that the climate variability is unchanged in the scenario projection
Unbiasing method	R*(d)=R(d)+<O-R S*(d)=S(d)+<O-R>	it assumes a good variability of the RCM
Variable correction method	R*(d)=f(R(d)|O) S*(d)=f(S(d)|O)	*f* is a function build with the observation dataset O
Regime method	R*(d)=O(*d1*) S*(d)=O(*d2*)	*d1* and *d2* are dates properly chosen in the observation dataset
Let O(d) be an equivalent series of observed data, and <.> a multiannual average operator (Déqué, 2007)		

Tab.1 Post-processing correction method (Dèquè, 2007)

► As we are interested in extreme events impacts and then in the tail of the precipitation pdfs, the most suitable method is the **Variable correction method** (Déquè, 2007):

$$R^*(d)=f\,(R(d)|O)\ ,\ \ S^*(d)=f(\,S(d)|O)$$

If we use for *f(x)* the *q-q* function, then the *cdf*, and thus the pdf of the postprocessed reference R*(d) is exactly the same as the *cdf* or *pdf* of the observation (Déqué, 2007).

► The **Quantile-quantile (q-q) function** consists of plotting a model value against an observed one, both corresponding to the same probability. The two datasets are ranked by increasing order, the first pair (model, observation) corresponds to the first point in the diagram, the second pair to the second point, and so on. If the model *cdf* is the same as the observation one, the curve is a straight line along the diagonal.

Figure 3 shows the quantile-quantile plots for winter and summer and the precipitation variable, for the Paris area (Déqué, 2007). The model values correspond to the x-axis, the observation to the y-axis. If the model were perfect, the plots should align along the diagonal.

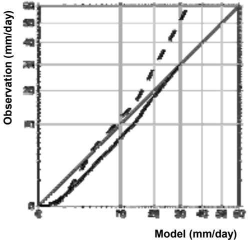


Fig.3 Q-Q plot in the Paris area (Dèquè, 2007) for model (x-axis) versus observation (y-axis) precipitation (mm/day), winter (solid line) and summer (dash line).
The model (ARPEGE/Climate) is too wet in the low precipitation (both seasons) and too dry in heavy summer precipitation. The underestimation of heavy summer precipitation is due to the fact that very intense convective events cannot be resolved at 50 km resolution.

► The ***Variable correction method* does not correct the temporal property of the series**. For some extremes based on duration (e.g. length of dry and wet spells), the correction based on q-q plot is not sufficient. For example if R(d) is less persistent than O(d), then R*(d) will be less persistent too (Dèquè, 2007).

► One possible way for the correction of the persistence features is to post-process some suitable **STARDEX** extreme indices (http://www.cru.uea.ac.uk/projects/stardex).

► In the case of precipitation, assuming a stochastic description of the arrival-duration-intensity processes (e.g. the Poissonian scheme, Fig.4), the q-q correction of such derived variables may be useful for the synthetic simulation of statistically homogeneous rainfall timeseries that mimic the persistency of daily observations (Fig.5).

► The statistical parameters characterizing **storm occurrence, storm intensity** and **duration** are in fact considered among STARDEX collection of extreme indices.

- The **occurrences** of rainfall events are given as a Poisson process with parameter λt so that the inter-arrival periods (dry durations) T between rainfall events are exponentially distributed and $E[T] = \lambda^{-1}$ is the mean period between storms ($\boldsymbol{m}_{dry}$).
- The **duration** of storm also is a random exp-distributed variable D and $E[D]= h^{-1}$ is the mean duration of storms ($\boldsymbol{m}_{wet}$).
- The **intensity** of storm also is a random exp-distributed variable I and $E[I]= x^{-1}$ is the mean intensity of storms ($\boldsymbol{m}_{I}$).

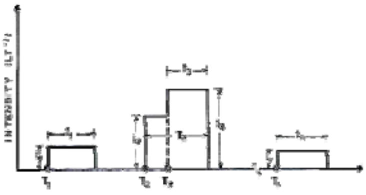
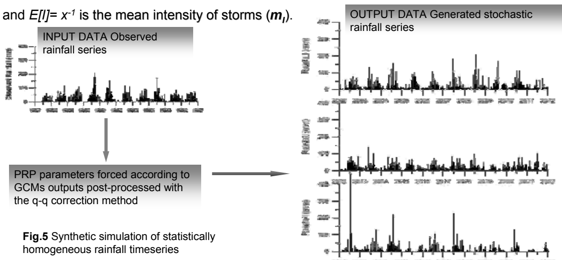


Fig.4 Schematic representation of Poison Rectangular Pulse (PRP) from Handbook of Hydrology, D. Maidment 1993



INPUT DATA Observed rainfall series

PRP parameters forced according to GCMs outputs post-processed with the q-q correction method

OUTPUT DATA Generated stochastic rainfall series

Fig.5 Synthetic simulation of statistically homogeneous rainfall timeseries

HYDROLOGICAL MODEL

► **DREAM** (**Distributed model for Runoff Et Antecedent soil Moisture simulation**), introduced by Manfreda *et alii* in 2005, will adopted to analyse the water cycle components at the catchment scale. DREAM is a semi-distributed hydrological model (Fig.7), suitable for continuous simulations. Within the model, the main hydrological processes are computed on a grid-based representation of the river basin that takes into account the spatial heterogeneity of hydrological variables using digital elevation models, soil and vegetation grid-maps.

► In particular the soil water content, which is the limiting factor of evapotranspiration from vegetation, is redistributed within river sub-basins according to the morphological structure of the basin exploiting the wetness index proposed by Kirkby (1975). While groundwater recharge is obtained as percolation through the vadose zone and is routed as a global linear reservoir.

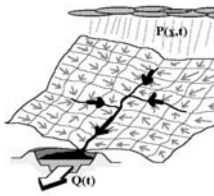


Fig.6 Hydrological model.

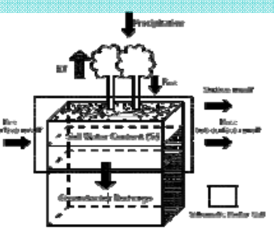


Fig.7 In-coming and out-going fluxes in a single grid cell.
The cell represents the control volume. (from Manfreda *et alii*, 2005)

Water balance equation at the cell scale (Fig. 7):

$$S_{t+1t} = S_t + I_t + RS_t - RG_t - ET_{veg} \quad (3)$$

where:

- **St=θtD** is the soil water content at time t
- **θt** is the volumetric soil moisture content
- **D** is the soil depth
- **It** the infiltration into the soil surface
- **ETveg** represents the water uptaken by the vegetation
- **RSt** the lateral flow exchange
- **RGt** the groundwater recharge during the time step 1t

DATA

► The area selected to perform the analysis of impact of a potential climate change on the water cycle components is the Apulia basin (Fig.8, Southern Italy). The region is representative of a Mediterranean climate and therefore located in one of region that are expected to suffer significantly from a global change.

► **GCMs scenarios:** datasets coming out from Research Line 2 of CIRCE project, with spatial resolution around 20 km and daily timestep.

► **Observed data:** daily climate datasets for the reference period 1961-1990.

REFERENCES
BURLANDO P. AND R. ROSSO, (2002). Effects of transient climate change on basin hydrology. 1. Precipitation scenarios for the Arno river, central Italy. Hydrological process, 16, 1151-1175.
DÈQUÈ M.(2007). Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: Model results and statistical correction according to observed values. Global and Planetary change, 57 Issue 1-2, 16-26.
IPCC, 2007. Climate change 2007: The Physical Science Basis. Contribution of Working group Ito the Fourth Assessment Report of IPCC; Cambridge University press: Cambridge, United Kingdom, and New York, USA pp 996.
KIRKBY, M.J.,(1975). Hydrograph modelling strategies. Progress in Physical and Human Geography, edited by: Peerl, R. F., Chrislhom , M.,D., and Haggett, P., Heinemmann, London, 69-90.
KITOH, A., A. YATAGAI, A. PINHAS, (2008). First super-high-resolution model projection that the ancient "Fertile Crescent" will disappear in this century. Hydrological Research Letter 2, 1-4.
http://www.cru.uea.ac.uk/projects/stardex