SIMULATION OF LOCAL CLIMATE IN ISLANDS ENVIRONMENTS USING A GIS INTEGRATED MODEL

Emerging technologies for sustainable land use and water management.
September 1- 3, 1999, Lausanne - Switzerland

E. Brito de AZEVEDO, L. Santos PEREIRA, Bernard ITIER

Abstract:

GIS (Geographic Information System) have become an obvious choice for the reconciliation, manipulation and storage of spatially distributed data of land surface characteristics (e.g. topography, vegetation, canopy structure, soil physics and land use). In a more sophisticated level GIS can provide this information as boundary conditions to the environmental modeling efforts. Merging these abilities, and adding temporality to the spatial relationships between the boundary conditions and the radiative and advective atmospheric regime, the physically-based model CIELO (Clima Insular à Escala LOcal) was developed. The model presented in this paper was created to generate the spatial distribution of the climatic variables at a scale compatible with the needs for applied purposes in island environments (agriculture, forestry, and hydrology).

INTRODUCTION

In small oceanic islands climatology is of utmost importance to the hydrology and water management since it affects the only impute of freshwater and controls the output due to evapotranspiration (FALKLAND, 1991).

Unfortunately, in these environments, the available surface meteorological information is rare and becomes from locations choosed to be representative at a regional or synoptic scale. So, this information doesn't reflect deep climate differentiation that can be observed at local scale.

Important local mechanisms like the orographically induced adiabatic cooling, foehn effect or the influence of topography on radiation balance, have a prominent role in the climatic spatial differentiation (Barry, 1992). Advective transport of air - and the consequent adiabatic cooling due to the orographic obstacle - is determinant in the configuration of the temperature and humidity fields. The same mechanism is in the origin of the orographic clouds cover that, besides the direct role as water source by the reinforcement of precipitation, have an indirect but important interference on the local water balance. Since the orographic clouds act like a filter to direct solar radiation and as a source of long-wave radiation they affect the local balance of energy. Also, the saturation (or near saturation) conditions that they provide

constitute a barrier to water vapour diffusion in the mechanisms of evapotranspiration. Topographic factors like slope, aspect and orographic mask have also significant importance in the local energy balance.

Since we can have the cartography of the relevant factors from a GIS (Geografic Information Sistem), we can use it as a spatial distributed quantitative database. As GIS can, also, provide the factors topology (the spatial relationship between static parameters and aerodynamics) we can use numerical modelling techniques in order to simulate spatially distributed environmental local scale processes. The external forcing regime and the boundary conditions (dynamics and the initial state parameters of the air) can be provided by the atmospheric synoptic conditions (or by the regional scale climate) that can be taken from a weather station (reference station) that "know" its position in the orographic and dynamic regime context.

It was based in this methodology that CIELO model (Clima Insular à Escala LOcal) (Azevedo, 1996) has been recently developed, calibrated and validated for the Terceira Island, Azores (Fig.1).

THE CONCEPTUAL APPROACH.

The domain of computation of the CIELO model is a raster GIS that is parameterised with a Digital Elevation Model (DEM) which is virtually oriented according to the direction of the air circulation (cf. Fig 2). For this purpose a specific algorithm, called



Rotacional Terrain Model (RTM), is applied.

Fig.1 – The Terceira Island represented by the Digital Elevation Model.

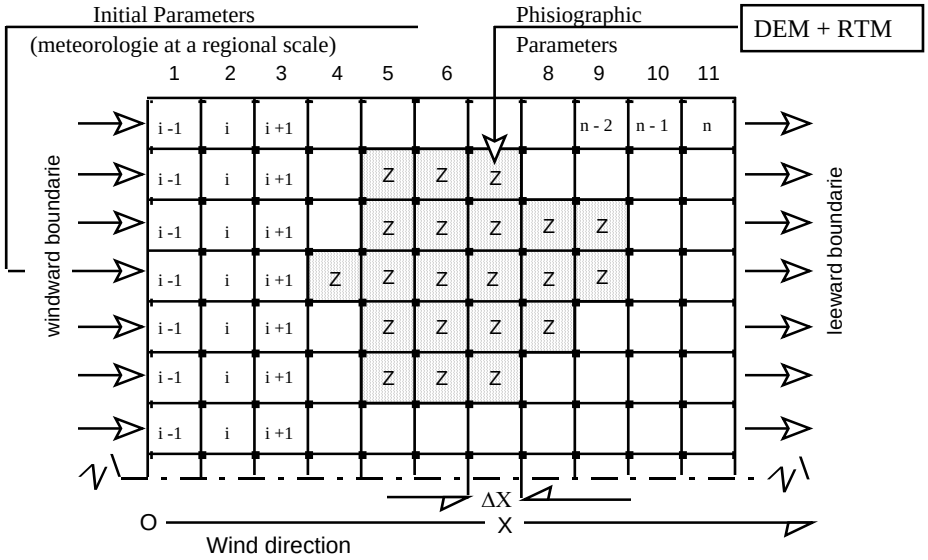


Fig. 2 - The domain of computation of the CIELO model.

The model CIELO consists of two main sub-models. One, for the advective component, where the Foehn effect is assumed, reproduces the dynamic and thermodynamic processes regulating the variation of air temperature and humidity, cloudiness of local orographic origin, and precipitation. The second, for the radiative process, namely influenced by orographic clouds "produced" by the advective sub-model and taking in to account the shadow produced by the relief, generates the radiative variables adjusted to the topography.

In the construction of the CIELO model it was assumed that the behaviour (conservative relationship of heat, and water substance in two phases) of a single hypothetical layer of air, characterised by the regional scale meteorology, in advective and adiabatic progression against the orographic obstacle (boarding and passing over the Island), in the context of a synoptic frame, is related with the evolution of the different meteorological fields (Fig. 3). The regional meteorological conditions of the air are furnished by the data of a typical synoptic wheather station (the reference station). The fields of air pressure, air temperature and relative humidity (calculated from the initial water content of the air and from the local scale evolution of the actual and saturation vapour pressure) are directly calculated for each cell from the evolution of the state parameters of the air layer affected by the adiabatic mechanisms (AZEVEDO *et al.*, 1998). From the conservative relationship of the water balance in the interior of the air layer in progression over the territory a ratio (α) of water deposition (calibrated against a local scale pluviometric data) is assumed as a source that provides the information to a numerical precursory "pattern" of the real field of the orographic precipitation. The absolute field of the orographic precipitation is obtained from the product of this initial numerical field to a scale factor (D) that is obtained, from a linear model, as a dependent variable of the precipitation observed at the reference station. The meaning of this approach comes from the presumption that the precipitation observed at the reference station will reflect the contribution of all the important precipitation factors that can not be directly monitored from surface (convergent regime, the regional instability and the precipitable water content in altitude). The absolute field of the total precipitation (orographic + regional) comes from the sum of the regional precipitation (observed at the reference station and considered equal over all the territory) and the field of orographic component (model).

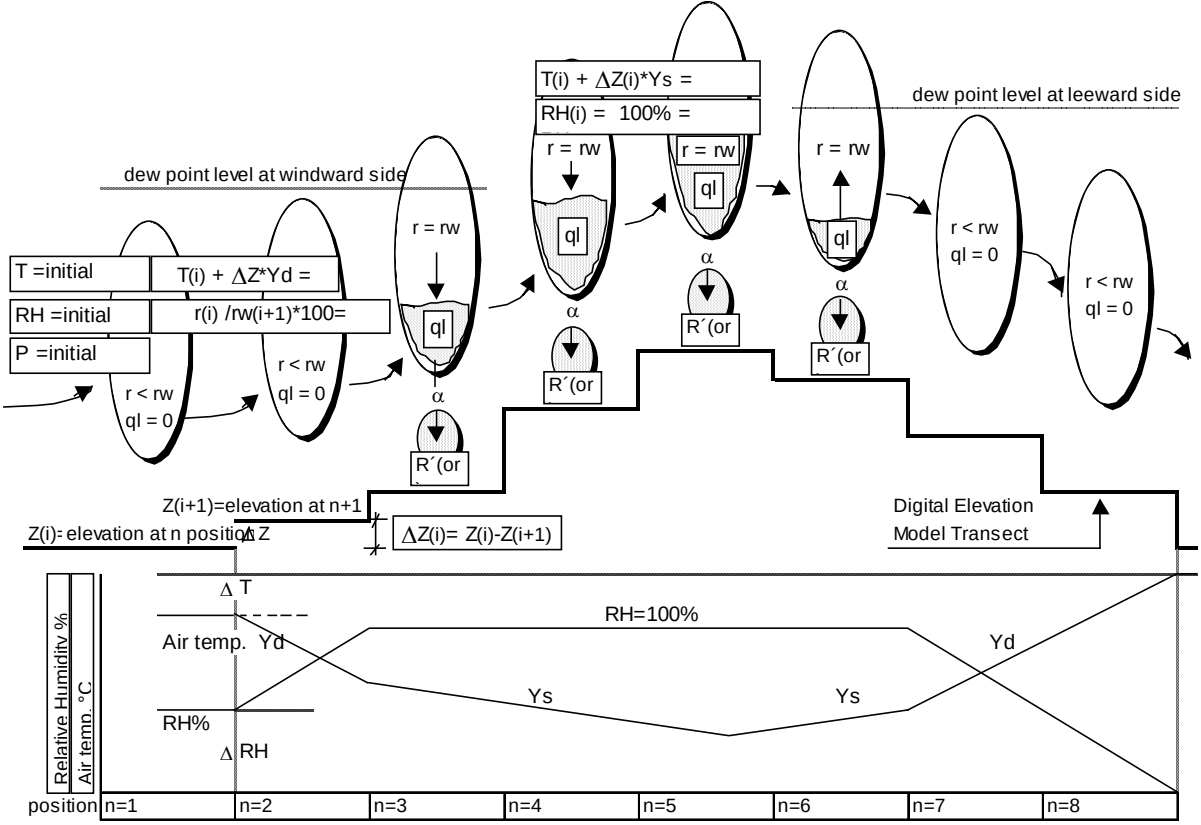


Fig. 3 – Conceptual approach for the unidirectional evolution of temperature (T) and relative humidity (RH). Symbols are: P = air pressure; Z = elevation; γd = dry adiabatic lapse rate; γs = saturated adiabatic lapse rate; ql = liquid water content per unit volume of air; a = fraction of ql which falls as rain; R´(or) = orographic rain; r = actual mixing ratio; rw = mixing ratio at saturation; ΔT, Δ RH = difference leeward - windward for T and RH

The spatial expression of the orographic clouds cover is assumed at the locations (cells) where the air layer, in adiabatic progression over the territory, have conditions to contain liquid water in suspension. The relative "thickness" (dimensional) of the orographic cloud cover is infered from the amount of liquid water inside the air layer over each cell (Fig. 4) (AZEVEDO, 1996).

Fig. 4 – Orographic cloud cover for a typical circulation from SW.

The regional radiative climate becomes from the radiation calculated for the top of the atmosphere (for average regional latitude), converted to the surface global radiation using the Angström approach (based in sunshine duration (n) at the reference station) (see e.g. ALLEN *et al.*,1994). The sunshine duration at local scale (n´) is calculated in each cell by taking into account an extinction coefficient related with the occurrence and "thickness" of the orographic cloud cover produced by the advective model. The direct component radiation is, later, adjusted by trigonometry to the orography, taking into account the shadow (orographic mask) produced by the relief (Fig.5 and 6) (AZEVEDO., 1996).

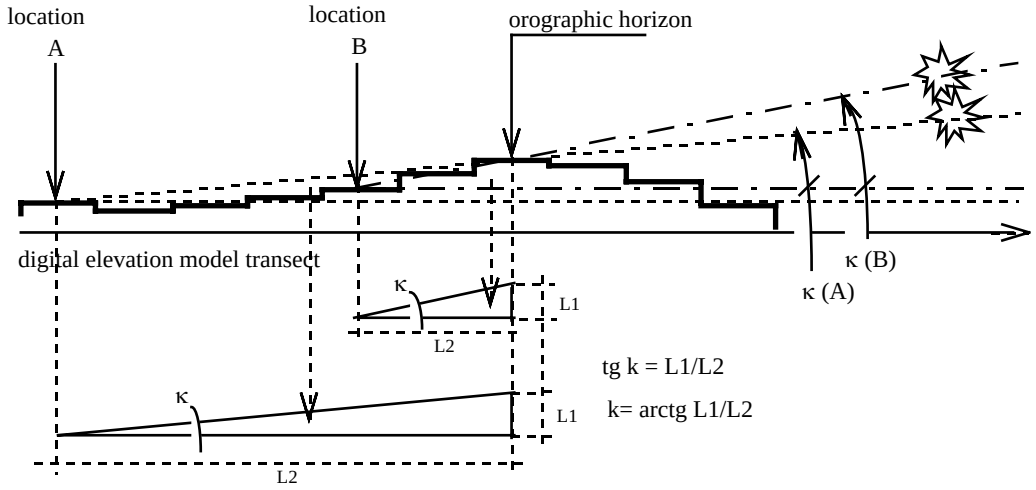
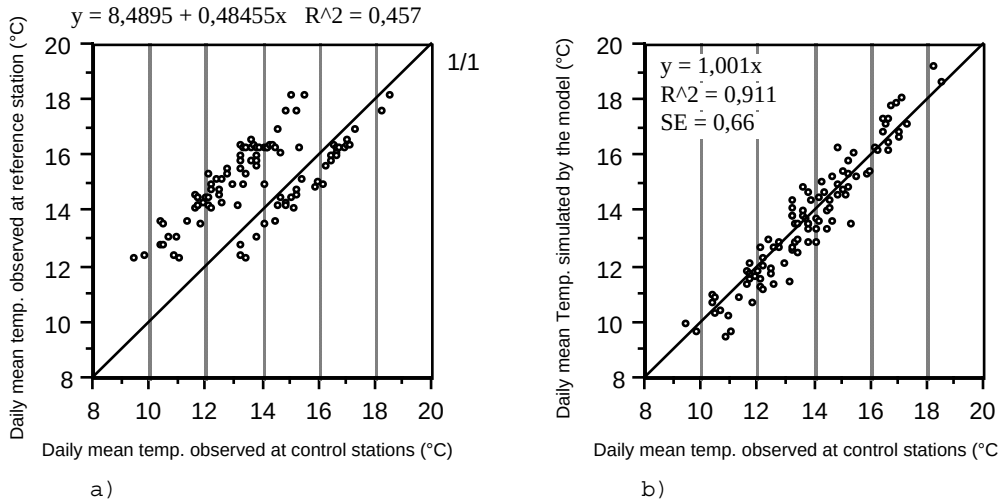


Fig. 5 – Conceptual approach to the orographic mask (k) computation

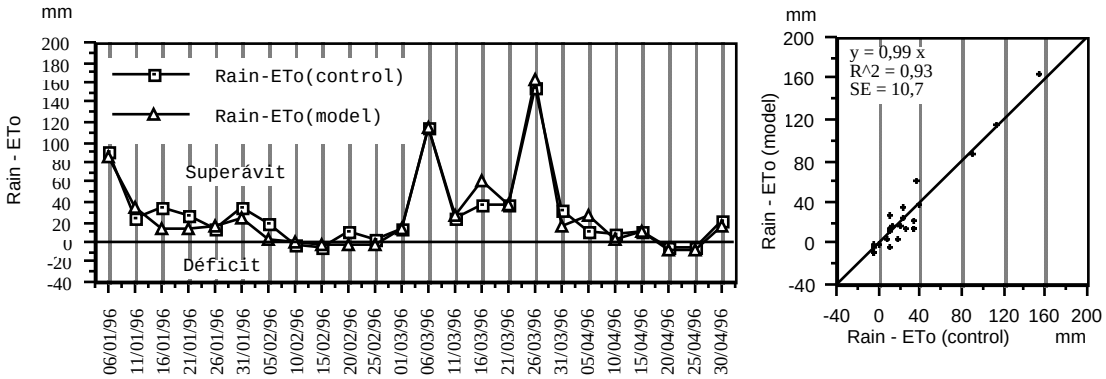
MODEL VALIDATION

The CIELO model was validated against data from a network of weather stations installed at critical points over the Terceira island (see e.g. AZEVEDO, 1996). The model as been tested at different time resolutions (hourly, daily and multiples of days) and, according to that, as been initialised with the time correspondent data from the reference station. The set of cell values from the numeric grid outputs, coincident with the sampling points has been statistically compared with the equivalent data observed (see e.g. AZEVEDO, 1996).



a) temperature observed at control stations vs. temperature at reference station;
b) temperature observed at control stations vs. temperature simulated by CIELO to the same location.

Fig. 7 – Validation of model CIELO for daily air temperature



Model CIELO vs. observed values

Fig.8 – Validation of model CIELO for Rain-ETo, from January to April 96: a) sequential 5 days balance; b) comparison of observed vs. simulated 5-day values (mm)

CONCLUSIONS.

From the model validation results (see e.g. AZEVEDO, 1996) we can admit (due to the spatial limitations of the Islands territories) the synoptic meteorology (or the regional scale climate) as the uniform external forcing regime that provides the frame, and the external boundaries parameterization, to the simulation of local scale climatic mechanisms affected by the local climatic factors.

From the conservative relationship of heat and water substance inside an hypothetical layer of air in progression over the territory (adiabatic processes and Foehn effect assumed) the model CIELO infers (spatially and quantitatively) the climatic fields of air pressure, air temperature, relative humidity (or vapor pressure), orographic clouds cover, rain and solar radiation.

As all the methodology has been developed in a GIS environment it can be applied in order to get a continuos cover of the islands for a specific climatic variable or, in a more elaborated way, for computing other climatic dependent models. Using the capabilities of the GIS, namely integrating other different spatially distributed parameters, the model CIELO can combine the several climatic variables and produce an highly elaborated spatially distributed output.

REFERENCES

1. ALLEN, R. G.; SMITH, M.; PEREIRA, L. S.; PERRIER, A. (1994) - An Update for the Calculation of Reference Evapotranspiration - *ICID Bulletin* , 43 (2): 35-92.

2. AZEVEDO, E. B. (1996) - Modelação do Clima Insular à Escala Local. Modelo CIELO aplicado à ilha Terceira – Ph. D. Thesis. Univerity of Azores.

3. AZEVEDO, E. B.; PEREIRA, L.S.; ITIER, B. (1998) – Modeling the Local Climate in Island Environments: water balance application – *Agri. Water Manag*. (accepted).

4. BARRY, R.G. (1992) - R.G. (1992) - Mountain Weather and Climate - (2nd ed.) Routledge, Chapman & Hall, Inc. New York, 402 p.

5. FALKLAND, A. (1991) – Hydrology and water resources of small islands: a pratical guide. – Unesco. Paris.

E. Brito de AZEVEDO
edubrito@dca.uac.pt

Ph.D., Auxiliar Professor of Department of Agriculture, University of Azores.

L. Santos PEREIRA
lspereira@isa.utl.pt

Professor, Department of Agricultural Engineering, Technical University of Lisbon.

Bernard ITIER
itier@bcgn.grignon.inra.fr

Head of Department of Environment and Agronomy, INRA, Paris Grignon.

