Land-surface modelling at Météo-France: Operational implementation of ISBA and recent developments(CO2 and hydrology)

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1 Introduction

The ISBA (Interactions between the Soil, the Biosphere and the Atmosphere) surface scheme (Noilhan and Planton 1989) is implemented in the global and limited area meteorological models used at Météo-France. Since 1989, many improvements have been brought to ISBA e.g.: inclusion of gravitational drainage (Mahfouf and Noilhan 1996) and of sub-grid surface runoff (Habets 1998a), improvement of the treatment of snow (Douville et al. 1995), of surface evaporation over very dry soil (Braud et al. 1993) and of surface drag coefficient formulation (Mascart et al. 1995) inclusion of a reservoir for the total frozen soil (Bazile and Giard 1998) and of a third soil layer for the root zone (Boone et al. 1998), of 5 soil layers for the treatment of heat diffusion and recently inclusion of CO2 assimilation for interactive vegetation (Calvet et al. 1998). Therefore, in the most complex version of ISBA 13 prognostic variables are computed (5 for temperature, 3 for soil water, 2 for frozen and intercepted water, 3 for snow). On the other hand, the operational version is rather close to the initial version with 2 reservoirs for soil temperature and water content. Knowing the type of soil texture and vegetation, look up tables for soil and vegetation parameters are used in conjonction with simple aggregation rules (Noilhan and Lacarrère 1995) to specify the surface fields. ISBA has been calibrated for a wide range of surface conditions using data sets collected during large field experiments carried out in the last decade (see Noilhan and Mahfouf 1996 for a review). The calibrations embrace a large range of time (from days to years) and spatial scales (from single point to mesoscale). As an example, ISBA was validated recently against long term data sets for tropical soils and vegetation (Delire et al. 1997) and for a temperate grassland (Calvet et al. 1998). Finally, ISBA has been involved in all the PILPS phases 1 and 2 and selected for the phase 4b corresponding to on - line tests at mesoscale. In the following, a short review is proposed on the operational implementation of ISBA (section 1), and on recent developments in hydrology (section 2) and CO2 assimilation (section 3).

2 A summary on the operational implementation of the ISBA surface scheme in the Arpege NWP model

Two problems have to be solved for the use of an advanced land-surface scheme in a NWP model: the specification of the fields of surface properties and the initialisation of the soil variables. Of particular importance is the initialization of the deep soil reservoir because of its strong influence on the simulation of the Bowen ratio over time scales of several weeks.

Since march 1998, ISBA has been used operationally in the ARPEGE global NWP model (operational implementation described in detail by Giard and Bazile 1998). The grid box size is near 25 km over France. Two soil data bases are used to specify the total soil depth (ISLSCP data set) and soil coefficients (Webb et al. 1991) with a global resolution of 1°. Over Europe, vegetation properties (leaf area index, vegetation fraction and minimum surface resistance) are prescribed from a high resolution classification of vegetation derived from 2 km NOAA/AVHRR observations (Champeaux and Le Gléau 1995). The global coverage is obtained with a lower resolution of 1° using the Wilson and Henderson-Sellers (1985) data, look-up tables and parameter aggregation described in Giard and Bazile 1998.

The analysis of the 4 soil variables (surface and deep temperature, near-surface and deep soil water content) are computed every 6 hours. Surface increments are estimated from the analysis of 2m air temperature and relative humidity. The increments of 2m air temperature ΔT_{2m} are used to correct the surface temperature as well as the deep temperature with a damping. The main effort is for soil moisture analysis following the optimum interpolation method based on screen level analysis of T_2m and HU_{2m}

(Mahfouf 1991, Bouttier et al. 1993). The increments of the near surface and deep reservoirs are linearly related to ΔT_{2M} and ΔHU_{2M}. The four optimum coefficients are functions of the local surface characteristics and solar time. First, they have been computed from the ISBA statistics (Bouttier et al. 1998). Then, continuous relationships have been calibrated for each coefficient as a function of solar time, soil texture, vegetation fraction, minimum surface resistance and leaf area index (Giard and Bazile 1998). Although the optimum interpolation was defined many years ago, its practical use in an operational context is not an easy task. Besides the specific difficulties related to the implementation of a surface scheme in a global NWP (for instance, some values of ISBA coefficients had to be modified in order to counteract defficiencies in other parametrizations, e.g. the soil thermal inertia had to be increased to compensate the underestimation of atmospheric radiation), the main thrust for the soil moisture assimilation is to accurately select the atmospheric conditions for which soil moisture is informative. In many cases, the foreacst errors at screen level are not related to soil moisture and therefore, the soil corrections are not to be performed in such conditions. The Giard and Bazile's algoritm deactivates the moisture assimilation if the length of the day is too short, in case of ice/snow at the surface, dew formation and precipitation and strong low level wind. More over, a second set of contrainsts is used: a maximum theshold value is applied to the increment of the deep soil reservoir as well as a smoothing of the incements over one day. Finally, the last caution concerns the removal of long-term (3 days) systematic bias in order to avoid large drift in soil moisture.
After many sensitivity experiments (one-year long assimilation, detailed interpretation of 10 days assimilation with 72 h- forecasts in January and July 1995), the ISBA system (new data set and assimilation of surface parameters) has been compared with the old scheme (no vegetation) during two periods: from 97/ 25Sept. to 14 Oct. and from 1998/ 17 Feb. to 16 March. Objective verifications showed a significant improvement of the forecast near the surface. As an example, figure 1 shows the mean distance to synop observations of T_{2m} and HU_{2m} along the 11 last 72h-forecasts of the autumn parallel with suites over France. Biases and rms errors are reduced with the full ISBA modset, and the diurnal cycle on HU_{2m} errors is damped by a factor of 2. A comparable result was obtained for the second winter test (reduction of the wet and cold biases). The positive impact were also noted over all the globe (particularly in Africa and North America). Also interesting was the reduction of the cold bias over Norway by the introduction of soil freezing (Bazile and Giard 1997). As a result of the positive evaluation of the 2 suites, the whole ISBA modset was moved to operations on 1998/03/16 in the global Arpege model and in the Aladin limited area version. The next improvement will concern the high resolution vegetation data base which will be extended spatially. At the same time, variational methods to retrieve the soil parameters of ISBA from screen level parameters (Bouyssel et al. 1998) or from surface soil moisture microwave observations (Calvet et al. 1997) are investigated.

3 Coupling ISBA with a macroscale hydrological model applied to the Rhone basin

For three years, a French cooperative program (Météo-France, Cemagref/Lyon, Ecole des Mines de Paris/CIG, CNRS/CETP Velizy) has aimed at developing a coupling between a meteorological and a hydrological model at mesoscale. The program is applied to the Adour basin (area of 14500 km2 e.g. Hapex-Mobilhy area) and to the Rhone basin (86496 km2). The first step of the program is to couple ISBA with the distributed macroscale hydrological model MODCOU (Ledoux et al. 1989) in order to compute the hydrological and atmospheric interactions with a common interface. The coupled ISBA-MODCOU model has two time steps (Habets 1998): a fast time step to solve the daily cycle of surface energy and water budget, and a slow time step (one day) to solve the water routing at the surface and the evolution of the water table in MODCOU. Presently, the system is forced by observed atmospheric quantities at screen level (in the future, the atmospheric information will be provided by the mesoscale model). The two water fluxes computed by ISBA (the sub-grid scale surface runoff and the gravitational drainage at the bottom of the deep soil layer) are accumulated over the day and then transferred to the subsurface and subterrain components of MODCOU. At the moment, there is no feedback from MODCOU to ISBA via the water table. In addition to the classical atmospheric outputs of ISBA (surface fluxes and soil variables), the system simulates the daily river flows and the level of the water table with a spatial resolution between 1 km (grid box including a river) to 4 km. The ISBA-MODCOU system was calibrated first in the Adour basin using the Hapex-Mobilhy data set. Habets et al. (1998) show that the model is able to correctly simulate the daily riverflows at 33 gauging stations as well as the soil water content and real evaporation observed at 12 sites during the experiment. The whole system has been transfered to the French part of the Rhone basin. Figure 2 shows the two hydrological simulation domains (surface water and groundwater domains) and the regular atmospheric domain with a spatial resolution of 8 km. The present objective is to calibrate the system on the long term (period ranging from 1980 to 1995) using daily observations of river discharges which are available at 150 stations. The atmospheric forcing is obtained from a dense surface network (1720 precipitation stations, 70 synoptic stations including 17 sites with global radiation observations). The atmospheric parameters are interpolated on the regular domain using various methods taking into account the orography (so-called 'Aurelhy method') or the large scale atmospheric analysis (the SAFRAN method described by Etchevers et al. 1998) in the Alps domain. Special attention is devoted to the estimation of snowfall (figure 3) because of its great importance on the Rhone river discharge. Concerning the soil and the vegetation types, the surface properties are obtained from three data bases available for France with a 1 km resolution: the soil data base prepared by INRA, the Corine data base for vegetation and the AVHRR classification of Champeaux and Le Gléau (1995). Habets integrated the ISBA-MODCOU system for the hydrological year august 1987 to July 1998. Following a rather simple calibration, the coupled model satisfactorilly simulates the river flows of the main rivers where the human influence is relatively weak. For instance, the statistics at Macon, the outlet of the Saone river, are very good. On the other hand, at the moment the model is not able to correctly simulate the observed flows of the Alpine rivers (Isere and Durance) because of the effects of dams which are not accounted for. If these last river flows are imposed in the simulation, the Rhone flow at Beaucaire is simulated reasonably well (figure 3 e) : the error on the annual discharge is lower than 5 % and the efficiency is higher than 0.8. Once calibrated against observed river flows, the coupled model is used to analyse the spatial variability of the various terms of the water budget. Figure 3 c d show the very high spatial variability of annual evaporation and total runoff in the Rhone basin. Because of the snow, annual evaporation is very low over the mountainous area (400 mm a year in the Alps) where the total runoff is particularly large. On the other hand, the Mediteranean zone exhibits a very low runoff and high evaporation.

Now the perspective of the Rhone and Adour projects are to validate the simulations on the long term (period of 15 years) and to pay a special attention to the representation of the snow processes. Once validated, the system can be used as a powerfull tool to evaluate the possibility of forecating large scale and slow river flows and, of course, to evaluate the impact of climatic changes on the regional water ressources.

4 CO2 assimilation in ISBA for interactive vegetation

Representation of CO2 exchanges at the surface-atmosphere interface is an important challenge for assessing the impact of climatic change on the surface energy and water budgets. Calvet et al. (1998) modified the ISBA scheme in order to account for the atmospheric CO2 concentration on the stomatal aperture. The first objective of the ISBA-Ags version is to describe more realistically the functional relationship between stomatal aperture and photosynthesis. The physiological stomatal resistance scheme proposed by Jacobs (1994) is employed to describe the photosynthesis at the leaf level. The scheme has been scaled up to the plant canopy and the plant response to the soil water stress has been included. An important option of the ISBA-Ags version is that the computed vegetation assimilation can be used to feed a simple growth submodel and to predict the density of vegetation cover. Three parameters are needed to calibrate the Ags version: the mesophyll conductance, the leaf time expectancy and the effective biomass per unit leaf area. Calvet et al. (1998) decribe calibration tests of the scheme against data from 6 micrometeorological databases for vegetation ranging from temperate grasslands (Cabauw and Murex data sets), crop sites (Hapex-Mobilhy and INRA - Castanet and INRA - Avignon) and tropical forest (Arme data set). The study shows that the Ags version is able to simulate the water budget and the CO2 flux correctly. Also, the leaf area index predicted by the calibrated surface scheme agrees well with observations over canopy types ranging from short cycled crops to evergreen grasslands or forests. Once calibrated, the ISBA-Ags scheme seems able to adapt the vegetation density in response to changes in the precipitation distribution.

The next step for ISBA-Ags will be its inclusion in the previouslly described ISBA-MODCOU in order to simulate the adaptation of the annual vegetation cycle to the interannual variability of precipitation and to learn more on the importance of vegetation - precipitation feedbacks.

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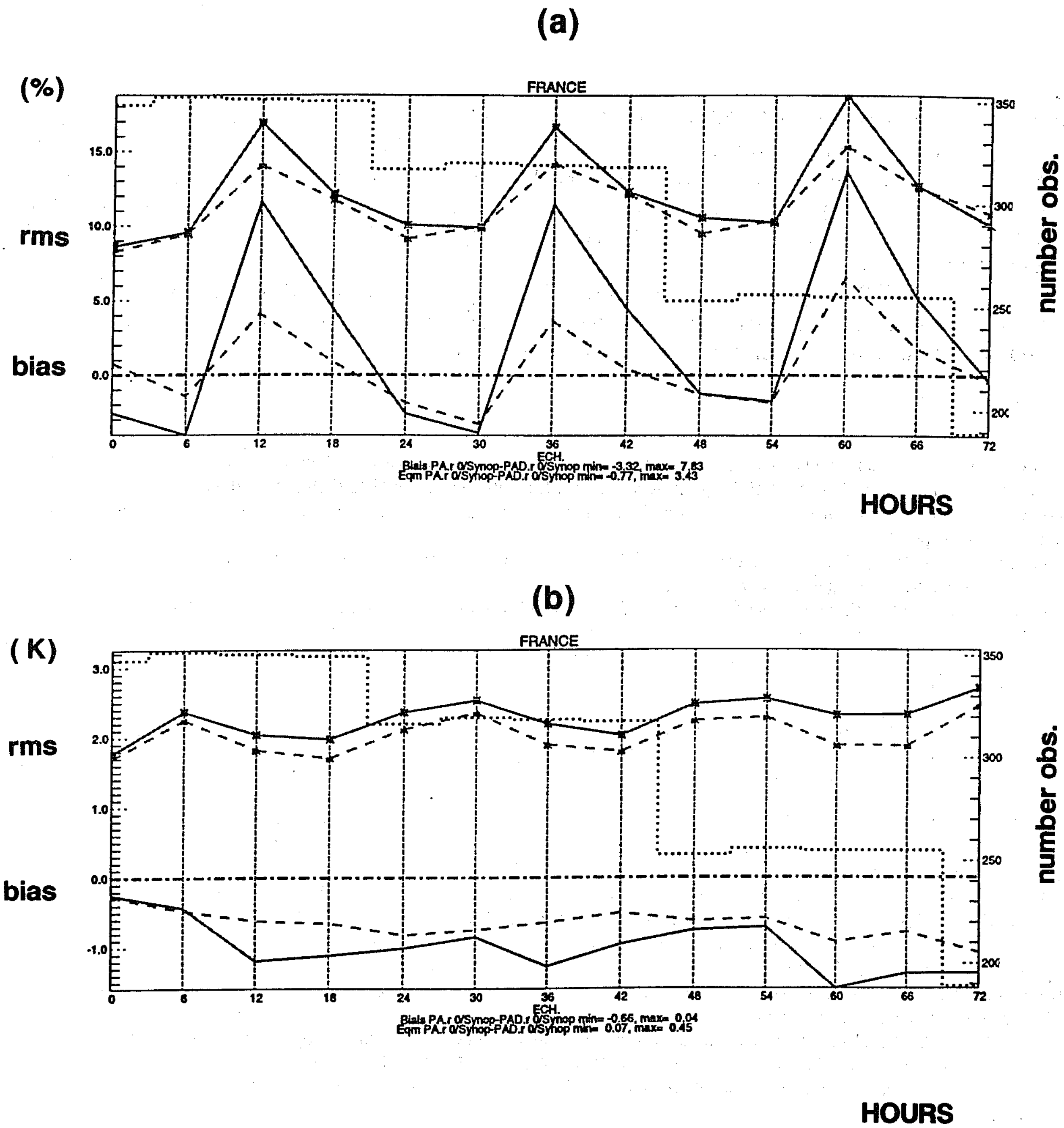

Figure 1: Distance to HU2m (a) and T2m (b) observations averaged along 6 72h-forecats over France during the first parralel suite (autumn 1997): Full line: old surface scheme, dashed line ISBA surface scheme, dotted line: number of synop observations. The surface analysis is performed every 6 hours for the two systems

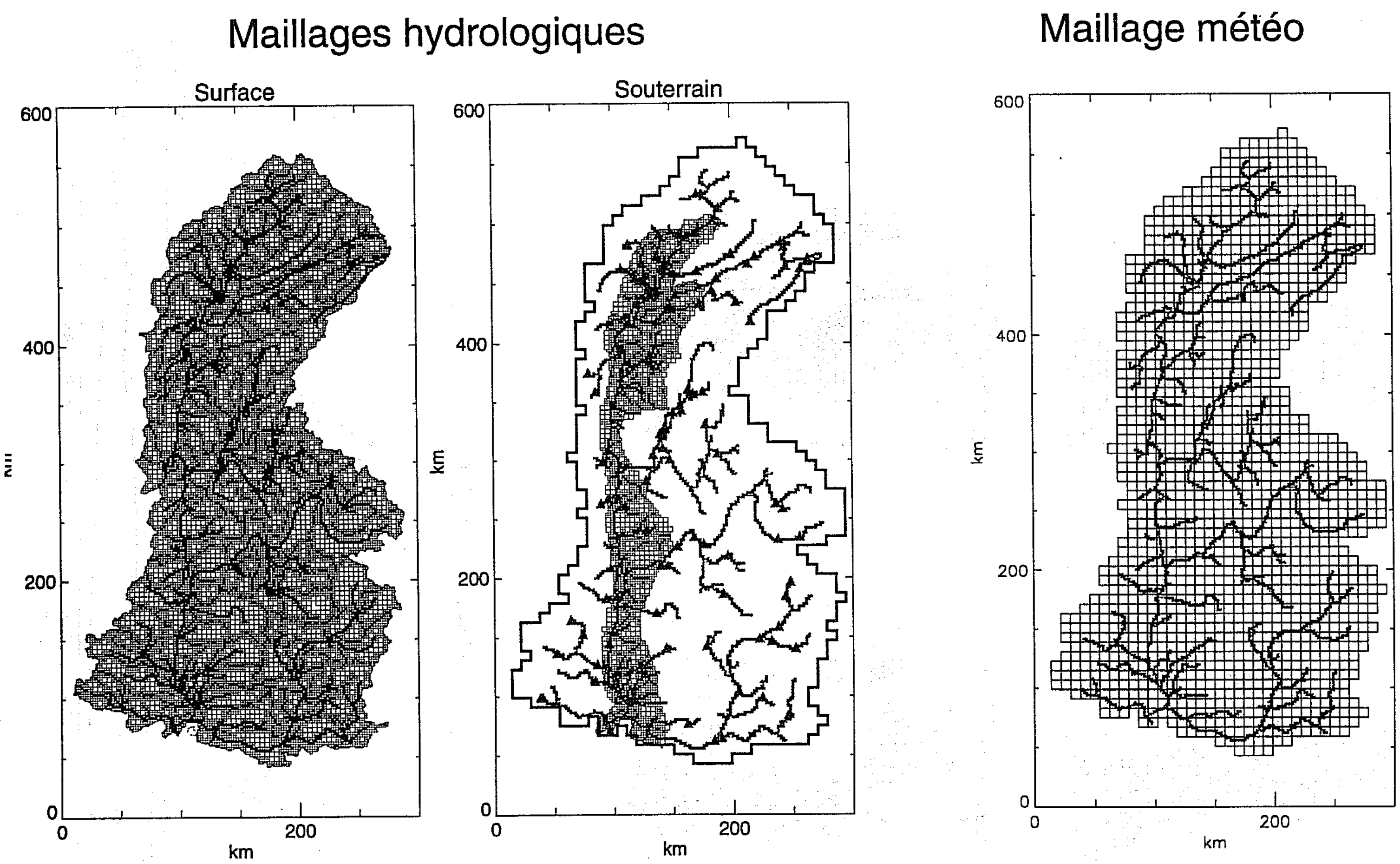

Figure 2: The hydrological domain for surface water (a) and groundwater (b) computed by the coupled ISBA-MODCOU model in the Rhone basin. The atmospheric forcing is interpolated with a resolution of 8 km using the SAFRAN method in the Alps (Etchevers et al. 1998).

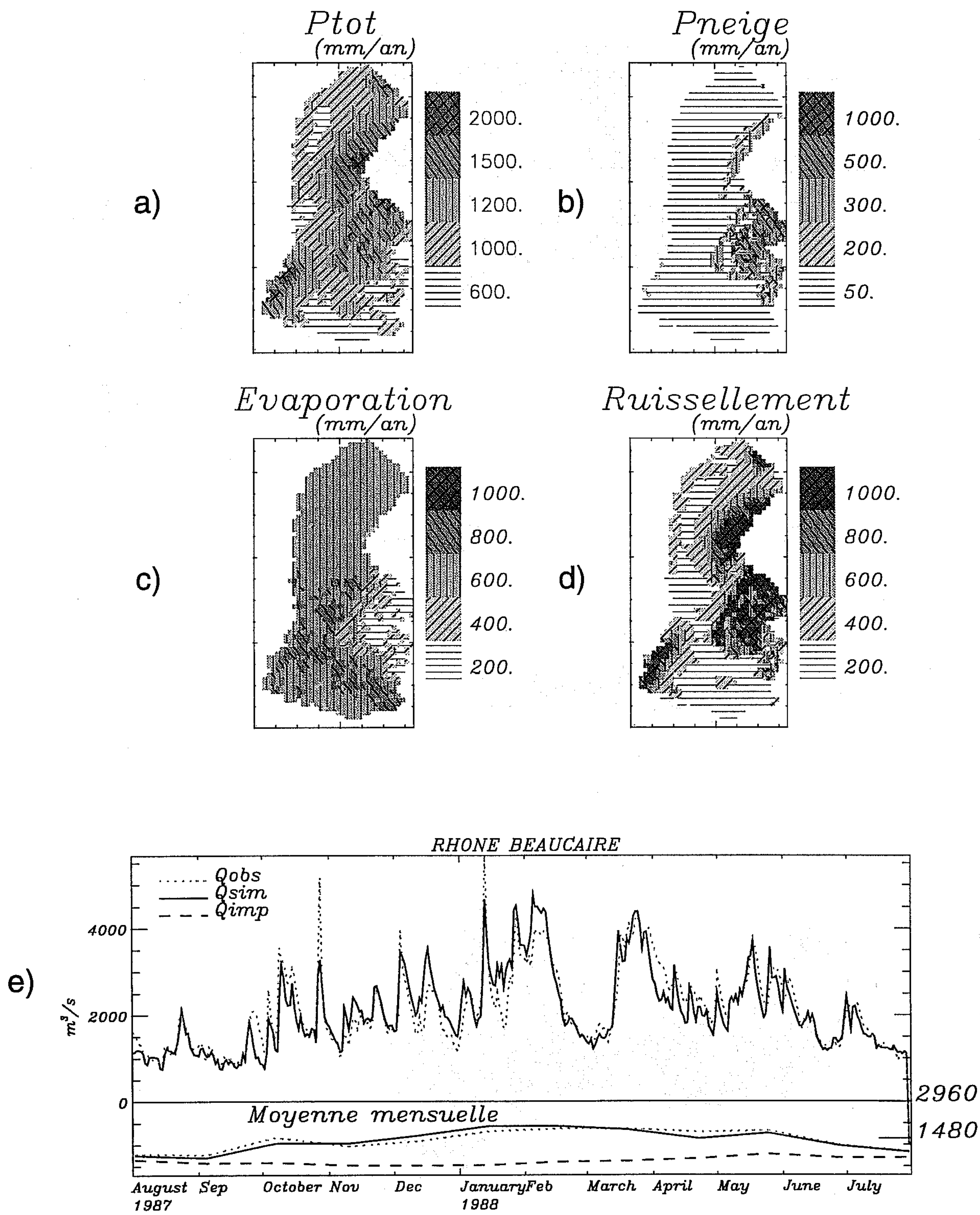

Figure 3: An example of input and output of the ISBA-MODCOU model in the Rhone basin: Observed annual total precipitation (a) and snowfall (b), computed total evaporation (c) and total runoff (d), observed and simulated daily riverflows at the outlet (Beaucaire) of the Rhone river (e).