

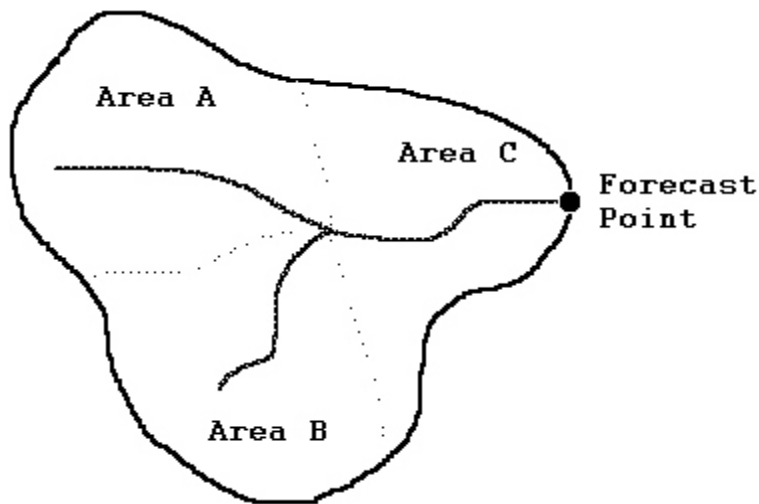
II.3-ASSIM ASSIMILATOR OPERATION

Description

For a forecast system to be accurate, the rainfall/runoff model employed must have an accurate representation of the current hydrological conditions. One problem that often arises is that soil moisture states in the model may become inconsistent with actual hydrologic conditions. These inconsistencies may arise from a number of sources, including errors in observed precipitation, errors in snowmelt simulation and general limitations of the rainfall/runoff model.

The Assimilator Operation (adopted from Koren and Schaake, 1993) is a soil moisture updating technique which modifies current soil moisture states. The Assimilator Operation uses the iterative Rosenbrock Optimization Technique (Rosenbrock, 1960) to estimate the current 'optimal' soil moisture states. Initial soil moisture states and input precipitation are varied over the run period and an objective function that includes the difference between observed and simulated flows, precipitation adjustments and state adjustments, is minimized.

For example, in the following figure, three separate subareas drain to a downstream forecast point.



For the run period, the Assimilator Operation will modify each subarea's mean areal precipitation as well as their initial soil moisture states, thereby generating a simulated discharge that closer resembles the outlets observed discharge. The simulated discharge improvement will be offset by a cost associated with the precipitation and states modification. This cost is formulated in an objective function described below.

Objective Function

The optimization scheme used by the Assimilator Operation minimizes a three term objective function:

$$\text{Objective Function} = F_q + F_p + F_s$$

F_q represents the error associated with the discharge component. Similarly, F_p and F_s portray the errors associated with the precipitation and soil moisture state terms respectively.

The following three sections explicitly detail each of the three objective function terms and the method by which each of these terms is calculated.

Discharge Term

The discharge term, F_q , represents the overall 'closeness' of fit of the simulated discharge to the observed discharge at the forecast point. The equation used to calculate F_q is as follows:

$$F_q = W_q \sum_{i=1}^{NQ} \left| \frac{\sum_{j=1}^{NDQ} QS_{i,j} - \sum_{j=1}^{NDQ} QO_{i,j}}{QTOTAL} \right|$$

where	F_q	is the overall value of discharge term
	W_q	is the overall weight of discharge term (specified by user)
	NDQ	is the number of days per period of discharge (specified by user) NDQ is set to a value greater than one in order to minimize errors introduced by timing inconsistencies
	NQ	is the number of periods of discharge (computed from the number of days of observed data and the value of NDQ)
	$QS_{i,j}$	is the simulated discharge at day j in period i
	$QO_{i,j}$	is the observed discharge at day j in period i
	QTOTAL	is the summation of the observed discharge over the run period

If at least 70 percent of the daily discharge data values in the run period are not available an Assimilator optimization will not be performed.

Precipitation Term

The precipitation term, F_p , is the portion of the objective function which represents the overall precipitation error. This precipitation error represents the difference between the optimized Assimilator precipitation and the amount estimated from observations. In the Assimilator Operation, the decision variable is represented by K_p . K_p is a multiplier applied to precipitation for a particular time period.

For example, if the observed mean areal precipitation for a given area is equal to 11MM and the optimal Assimilator Kp multiplier is 1.2, then the precipitation amount used by the Assimilator Operation for the area and period in question is 11MM x 1.2 = 13.2MM.

The Assimilator Operation attempts to adjust precipitation for the run period only by the amount that will improve the objective function. The improvement will come from an decrease in the discharge term, Fq, of the objective function.

The equation used to calculate the precipitation term of the discharge function is as follows:

$$F_p = W_p \sum_{i=1}^{NB} \sum_{j=1}^{NPR} Wpb_i P_{i,j} |K_{p,i,j}^t - K_{p,i,j}^{t-1}|$$

where F_p is the overall value of precipitation term
 W_p is the relative weight of precipitation term (specified by user)
 NB is the number of subbasins (specified by user)
 NPR is the number of periods of precipitation per basin (computed from the number of days of the run period and the length of the precipitation period)
 $K_{p,i,j}^t$ is the average Kp for basin i in time period j, estimated by Assimilator optimization at time t ($K_{p,i,j}^{t-1}$ can be obtained from a previous Assimilator Operation run for time period j or $K_{p,i,j}^{t-1}$ can be set to 1.0)
 Wpb_i is the weight of precipitation for basin i (specified by user)
 Wpb_i^N is the normalized basin weight of precipitation for basin i (computed)

The Assimilator Operation includes an option to account for precipitation sensitivity. The precipitation sensitivity analysis option weights periods which are sensitive to changes in precipitation more heavily in the objective function. In other words, the larger the effect on simulated discharge from a change in precipitation for a period, the greater the weight that is assigned to that particular precipitation period.

The equations used to adjust the weights for precipitation sensitivity are as follows:

$$Wpb_{i,j} = Wpb_i^N \frac{\frac{\Delta Fq_{ij}}{\Delta Kp_{ij}}}{\left(\frac{\Delta Fq_{ij}}{\Delta Kp_{ij}} \right)} \quad \text{Kax over j}$$

where $j = 1..NPR$

$I = 1..NB$

If the sensitivity analysis option is turned off:

$$W_{pb_{i,j}} = W_{pb_i^N}: \forall j=1..NPR, i=1..NB$$

The Assimilator Operation performs the precipitation sensitivity by comparing the F_q resulting from $K_p = 1$ with the F_q resulting from $K_p = 1.2$.

Soil Moisture States Term

The states term, F_s , is the portion of the objective function which represents the error from modification of the initial states. The Assimilator Operation will modify the initial states depending on the state option chosen by the user. State options will be discussed in greater detail below. The equation used for calculating the F_s term of the objective function is as follows:

$$F_s = W_s \sum_{i=1}^{NB} W_{sb_i^N} \sum_{j=1}^{NKSP} |1 - K_{s_{i,j}}|$$

where W_s is the relative weight of state term (specified by user)
 W_{sb_i} is the weight of state term for basin i (specified by user)
 $W_{sb_i^N}$ is the normalized weight of state term for basin i (computed)
 $K_{s_{i,j}}$ is the optimized state multiplier for basin i , option j
 $NKSP$ is the number of K_s values per basin

Use of the Assimilator Operation

Using the Assimilator Operation to update the SAC-SMA states requires two executions of the Operational Forecast Program Function (FCEXEC).

In the first FCEXEC execution, the Assimilator Operation is set to optimize. In this pass the Assimilator Operation computes state and precipitation adjustments and prints a summary of the results, so that the user can review the adjustments.

In the second FCEXEC execution, the Assimilator Operation is set to incorporate and carryover must be saved. In this pass the precipitation and state adjustments determined in the optimization run are used in the simulation. Since carryover are being saved, any updated carryover values will reflect these adjustments.

The Assimilator Operation should be run approximately once per week. A long run period (i.e. one month) will probably provide the best results.

The following Hydrologic Command Language Techniques used to control program flow and user options are defined for the Assimilator Operation:

- o ASSMRUN specifies the type of assimilation run that is to be performed. The user has the following options: 1) turn the Assimilator Operation off, 2) perform an optimization run or 3) carry out an incorporation run. Optimization runs are only allowed when carryover values are not being saved, whereas incorporation runs are only allowed while saving carryover.
- o ASSMPAR specifies if soil moisture states and/or precipitation are to be adjusted by the Assimilator Operation. Generally, precipitation and states are adjusted.
- o Technique KPTIME specifies whether the previous run precipitation adjustments should be used or a previous Kp of 1.0 should be assumed. The KPTIME option allows the user to compare a precipitation adjustment for a particular period to the value estimated in the previous execution of the Assimilator Operation for the same period. This option is used to dampen changes to the precipitation adjustment factor from one Assimilator Operation execution to the next. KPTIME must be employed when running consecutive optimization runs without incorporating results.
- o Technique PRECSEN specifies whether the precipitation sensitivity analysis option is to be used. The PRECSEN option is designed to place more weight on the objective function for periods where discharge is sensitive to changes in precipitation. Care should be exercised when using this option. Several test runs produced large changes in the precipitation adjustment factor for both periods with very little precipitation and for periods toward the end of the simulation that had little effect on the discharge.

Periods of Summation

The number of days in a precipitation period (NDP) will effect the number of periods of precipitation which are being optimized. Small values of NDP could produce long execution times.

The number of days in a discharge period (NDQ) will not effect execution times, however, using a value of NDQ as small as one day may lead to large values of Fq due to timing errors in streamflow.

Objective Function Weights

The Assimilator Operation requires that weights be specified for the

discharge, precipitation and state terms in the objective function. Experience will be required to determine the appropriate weights for a particular basin. In general, as user confidence in discharge, precipitation or state estimates increases, the corresponding weight should be increased. If multiple subareas occur in a basin, the user must also specify the relative basin weights. These weights should be based on the importance of the subareas in contributing to discharge. One could set these weights based on area.

Rosenbrock Optimization Parameters

The Rosenbrock procedure is a hill climbing search technique. Details of the procedure can be found in (Rosenbrock, 1960). Three parameters related to stopping criteria for the Rosenbrock Optimization routine must be specified by the user.

The first parameter is denoted MOPT. This variable controls the maximum number of iterations the search procedure may make before stopping. A value of 100 is probably adequate.

The second parameter is named DELTF. DELTF represents the minimum percentage change that must take place in the objective function from one trial to another, in order for the searching algorithm to continue. If DELTF is specified as 0.01 and the objective value of the last search was 5.00, the change in the objective function must be at least 0.05 for the search to continue.

The last parameter for the Rosenbrock Optimization technique is named VALUEF. VALUEF is a threshold variable that ensures whenever the current objective value is less than VALUEF, the searching algorithm stops. For example, if VALUEF is defined as 5.0 and the objective value for a particular search is returned as 4.5, the Rosenbrock Optimization technique returns the variables associated with the solution as optimal.

State Options

Currently, the Assimilator Operation has only been implemented for the SAC-SMA model. In addition, there exists only one valid state option (denoted as state option one) for the SAC-SMA model. For this option, Ks is treated as a multiplier, similar in nature to the precipitation multiplier Kp. The user specifies which of the six soil moisture states should be adjusted by Ks.

For further information on the SAC-SMA model see Section V.3.3-SAC-SMA.

References

Koren, V. and Schaake, J., (1993). 'Nile Technical Note #147: Updating Algorithm and Program'

Rosenbrock, H.H., 'An Automatic Method for Finding the Greatest or Least Value of a Function', The Computer Journal, Vol. 3, pp. 175-184, 1960.