IMPLEMENTATION OF ENKF APPLIED TO FACIES HISTORY MATCHING USING CLASS SIMULATOR: Code Documentation

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1 Brief Summary

The accompanying code implements the automatic history matching of a 2D-simulation model using the Ensemble Kalman Filter (EnKF) technique based on adjusting the facies field instead of the porosity and permeability fields as is commonly the case. The code is written for a two-dimensional 2-phase flow problem but can easily be extended to a solve a three-dimensional 2-phase flow problem but the user has to modify the section of the main code that reads the input data file.

The sample input parameter and data files included along with the code applies specifically to a five-spot water flooding problem. The producers are constrained by minimum producing bottom hole pressure and the injector by the maximum (allowable) surface injection rate with a secondary constraint on the minimum bottom hole injection pressure. The historical data for history matching are:

1. The injector bottom hole pressure.
2. The water production rate of the producers.
3. The total liquid production rate of the producers.

The solution to the problem of coupling the EnKF routine with non-gaussian prior distributions (represented by the facies distribution) is non-trivial. Usually the constrained facies observations at any or all of the well locations may be violated after production data are assimilated. A number of approaches have been proposed in the literature on how to re-constrain the facies observations should these be violated. Within the code, correction of the violated constraints is achieved by iterating on the parameterized facies mismatch term (or the error in facies observations) until the mismatch is corrected. However, depending on the number of iterations carried out unrealistic changes may be made to the grid block pressures and saturations as a result of the underlying assumption of linearity inherent in the EnKF. To prevent inconsistent changes to the pressure and saturation fields during this step, it is judicious to limit the maximum number of allowable iterations. The code is structured in such a way that this maximum number is user-specified but it is ***strongly*** advised that this parameter be set to a value $\leq$ 4. The default value within the code is set at 4. After iterating to correct the facies mismatch and if the maximum iteration threshold is exceeded, ensemble members still having mismatched facies at the well locations are discarded and the simulation is continued with the remaining members of the ensemble. Because ensemble members are being discarded, it is necessary that a reasonable number of ensemble members are retained at each step to minimize sampling error. The code has a default minimum number of ensemble members set at 40 below which the simulation is terminated. This default minimum may be changed by the user but, again, it is strongly suggested that this minimum number of ensembles needed at each step be set at a value ≥ 40 to mitigate the problem of ensemble bias and variance deficiency, which appears to be a bigger problem when EnKF is applied to facies.

Currently, the code can only handle facies field generated generated by truncating a bi-Gaussian field using a non-standard truncation scheme (the intersecting threshold lines).

2 Petrophysical Properties

The following assumptions are made regarding the petrophysical properties of each facies

1. There is no uncertainty in our knowledge of the value porosity and/or permeability associated with each facies.
2. The petrophysical properties are homogeneous and constant for each facies.

3 Input Files

The input files required for executing the code include:

1. FACIES_MAP_ENSEMBLE.out: Contains the initial facies distribution field conditioned to the facies observations at the well locations.
2. PERM_ENSEMBLE.out: Contains the initial permeability distribution for all the models / realizations.
3. PORO_ENSEMBLE.out: Contains the initial porosity distribution for all the models / realizations.
4. Y1_ENSEMBLE.out: Contains the first Gaussian random field for all the models / realizations.
5. Y2_ENSEMBLE.out: Contains the second Gaussian random field for all the models / realizations.

6. parameters.inc: Contains the user specified model-related and simulation parameters.

7. REF_PRODUCTION.OUT: Contains historical data for history matching.

8. Truncation_map.dat: Contains the parameters for the truncation map based on the intersecting threshold lines. User needs to supply the perpendicular distance from the origin and the angle of orientation (in radians) which is anticlockwise positive from the x-axis.

The CLASS simulator has been compiled into an executable application called CLASS_SIM.exe

4 Output Files

The important output files to note are:

1. History matched production profile: The output in these files are ordered such that the time index is in the first column followed by *ne* columns of production data corresponding to the number of ensemble members used; where *ne* is the number of ensemble members. The last column has information corresponding to the historical data for the production data of interest. The name of the output files with the history matched production data are:

   - Prod1_WOPR.out and Prod1_WWPR.out
   - Prod2_WOPR.out and Prod2_WWPR.out
   - Prod3_WOPR.out and Prod3_WWPR.out
   - Prod4_WOPR.out and Prod4_WWPR.out
   - Inj_PWF.out

2. Final_Facies_Map_Lyr1.out: Final facies field after history matching.

3. Fcs_Mismtch_Sum.dat: Summary of the results from the facies mismatch correction step during the simulation.

<u>Nomenclature</u>:

1. Prodx: Producer X

2. Inj: Injector
3. WOPR: Oil Production Rate.
4. WWPR: Water Production Rate.
5. PWF: Flowing Bottom Hole Pressure.