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NAME

MMA, A Computer Code for Multi-Model Analysis

ABSTRACT

This report documents the Multi-Model Analysis (MMA) computer code. MMA can be used to evaluate results from alternative models of a single system using the same set of observations for all models. As long as the observations, the observation weighting, and system being represented are the same, the models can differ in nearly any way imaginable. For example, they may include different processes, different simulation software, different temporal definitions (for example, steady-state and transient models could be considered), and so on. The multiple models may be calibrated by nonlinear regression or another method. Any calibration needs to be completed before application of MMA.

MMA can be used to rank models and calculate posterior model probabilities. These can be used to (1) determine the relative importance of the characteristics embodied in the alternative models, (2) calculate model-averaged parameter estimates and predictions, and (3) quantify the uncertainty of parameter estimates and predictions in a way that integrates the variations represented by the alternative models.

There is a lack of consensus on what model analysis methods are best, so MMA provides four default methods. Two are based on Kullback-Leibler information, and use the AIC (Akaike Information Criterion) or AICc (second-order-bias-corrected AIC) model discrimination criteria. The other two default methods are the BIC (Bayesian Information Criterion) and the KIC (Kashyap Information Criterion) model discrimination criteria. Use of the KIC criterion is equivalent to using the maximum-likelihood Bayesian model averaging (MLBMA) method. AIC, AICc, and BIC can be derived from Frequentist or Bayesian arguments. The default methods based on Kullback-Leibler information have a number of theoretical advantages, including that they tend to favor more complicated models as more data become available than do the other methods, which makes sense in many situations.

Many applications of MMA will be well served by the default methods provided. To

use the default methods, the only required input for MMA is a list of directories where the files for the alternate models are located.

Evaluation and development of model-analysis methods are active areas of research. To facilitate exploration and innovation, MMA allows the user broad discretion to define alternatives to the default procedures. For example, MMA allows the user to (a) rank models based on model criteria defined using a wide range of provided and user-defined statistics in addition to the default AIC, AICc, BIC, and KIC criteria, (b) create their own criteria using model measures available from the code, and (c) define how each model criterion is used to calculate related posterior model probabilities.

The default model criteria rate models based on model fit to observations, the number of observations and estimated parameters, and, for KIC, the Fisher information matrix. In addition, MMA allows the analysis to include an evaluation of estimated parameter values. This is accomplished by allowing the user to define unreasonable estimated parameter values or relative estimated parameter values. An example of the latter is that it may be expected that one parameter value will be less than another, as might be the case if two parameters represented the hydraulic conductivity of distinct materials such as fine and coarse sand. Models with parameter values that violate the user-defined conditions are excluded from further consideration by MMA.

Ground-water models are used as examples in this report, but MMA can be used to evaluate any set of models for which the required files have been produced.

MMA needs to read files from a separate directory for each alternative model considered. The needed files are produced when using the sensitivity-analysis or parameter-estimation mode of UCODE_2005, or the equivalent capability of another program.

MMA is constructed using modules and conventions for data-exchange files from the JUPITER API, and is intended for use on any computer operating system. MMA consists of algorithms programmed in Fortran90, which efficiently performs numerical calculations.

HISTORY

MMA Version 1.210 09/1/2011
- Changed revision number to 1.210
- Corrected error in code in which the values in the column of "XTWXOBS" of the *._mma file were incorrect
- Included latest versions of ucode and linear_uncertainty in the bin

directory
- Reran regressions for distribution files
- Differences in the results of the test problems include:
  #mout files will have a different version number and date
  _mma files due to revised calculation of "XTWXOBS"
  _rank files due to revised calculation of "XTWXOBS"
  _anals files involving KIC due to revised calculation of "XTWXOBS"
  Output files dependent on prior information because the
  interpretation of the uncertainty on prior information input
  changed in ucode but the input files for the regression runs
  distributed with MMA have not been changed. Those files include
  unusually large uncertainty on prior information.

MMA Version 1.200 09/18/2010
- Changed revision number to 1.200
- Corrected error in code in which the standard deviations rather than the variances were summed in evaluating MMA's eq. 2.16a
- Improved checking for analyses having the same prior
- Revised input for regression examples to define prior in native space
- Reran all regressions for distribution files
- Compiled with JUPITER API 1.4.0

MMA Version 1.100 10/26/2009
- Changed revision number to 1.100
- Added a new criterion named PriModProb which equals the prior model probability if it is input by the user, otherwise all included models are assigned equal probabilities (p=1/#models) that sum to one. Now prior model probability can be used as a criterion or as a term in the probability equation. This term now appears as a column in the _mma and the _rank files.
  The following input will rank models strictly by their prior model probability without regard to model fit.
  ```
  BEGIN ANALYSES TABLE
  nrow=1  ncol=3 columnlabels
  AnalysisLabel CritEqn        PrEqn
  ChooseAName   PriModelProb    1.*valcrit
  END ANALYSES
  ```
  Model probabilities are specified in the MODEL_PATHS block using keyword PriorModProb. If this is not specified then the default is for all models to have equal probability.
- A new example run illustrates an analysis based solely on prior model probabilities. It is in mma_1.100\test-win\01-Run_MMA and is executed using mma_modprob.bat. For this example the posterior probabilities resulting from the AICc analysis of ìmma_extensive.batî

were used as prior model probabilities so the results of the two analyses are nearly identical.
- Added an additional default analysis based on prior model probabilities so now there are 5 default analyses.
- Revised allocation of some arrays to facilitate application with very large numbers of observations.
- The highest ranked model is assigned a value of one and if two models have the same value they will be given the same rank. Models that did not converge are assigned a rank equal to the total number of models so there may be a gap in values between their rank and the lowest ranked model. Previously if two models had the same value they were assigned equal rank but in that case the highest ranked model would have a rank less than one.
- Corrected an error that occurred in some instances when only some of the estimated parameters were averaged or if they were not listed in the same order as in the parameter estimation.
- Corrected an error that occurred in some instances in model averaging if some of the models in the group to be averaged were not included due to non-convergence or unreasonable parameter values
- Corrected an error in which the final sum of squares weighted residuals was used instead of the lowest sum of squares weighted residuals in cases where the final sum of squares weighted residuals was not the lowest
- Compiled with JUPITER API 1.3.1

MMA Version 1.000 8/10/2007 - Initial release.

DATA REQUIREMENTS

In order to use MMA, the main MMA input file needs to be created and refer to data_exchange files as described in the MMA documentation. Input data are read from files.

SYSTEM REQUIREMENTS

MMA is written primarily in Fortran 90. The code has been used on UNIX-based computers and personal computers running various forms of the Microsoft Windows operating system.

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See

http://water.usgs.gov/software/ordering_documentation.html

for information on ordering printed copies of USGS publications.