GCAM-MCS

Distributed Monte Carlo Simulation framework for GCAM

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GCAM Community Workshop
December 3, 2015

ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

CHALLENGES OF MONTE CARLO SIMULATION WITH GCAM

- 10-15 min run-time precludes MCS on desktop system
- Running MCS on a cluster is technically challenging

Carver @ NERSC.gov: 1202 compute nodes (9,984 processor cores)

CHALLENGES OF MONTE CARLO SIMULATION WITH GCAM (cont.)

Step in performing MCS with GCAM

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2. Specify probability distributions

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3. Use random values to perturb parameters

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2. Specify probability distributions
3. Use random values to perturb parameters
4. Setup separate workspace to run GCAM

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Step in performing MCS with GCAM

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3. Use random values to perturb parameters
4. Setup separate workspace to run GCAM
5. Run baseline and policy case(s)

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3. Use random values to perturb parameters
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5. Run baseline and policy case(s)
6. Extract results from each scenario

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3. Use random values to perturb parameters
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6. Extract results from each scenario
7. Calculate differences (policy – baseline)

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2. Specify probability distributions
3. Use random values to perturb parameters
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7. Calculate differences (policy – baseline)
8. Store results for analysis

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Step in performing MCS with GCAM

1. Identify “parameters” in GCAM
2. Specify probability distributions
3. Use random values to perturb parameters
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6. Extract results from each scenario
7. Calculate differences (policy – baseline)
8. Store results for analysis
9. Analyze and plot results

DISTRIBUTED MONTE-CARLO SIMULATION FRAMEWORK

– Goal –
Enable modelers to run MCS and robustness analysis with models that in practice require cluster computing.

Open-source framework designed for flexibility and extensibility.

and many open-source Python modules

Available at https://bitbucket.org/plevin/

CORE PACKAGE + MODEL-SPECIFIC FEATURES

coremcs

- Database management
- Latin-hypercube sampling
- Generalized parameter file handling
- Creation of model execution "sandboxes"
- Execution of model on Linux cluster
- Extraction of model results
- Storage of scalar / timeseries results in DB
- Uncertainty importance analysis
- Several types of plots

gcammcs

- Handle XML input files
- Set up GCAM workspace
- Run batch queries via ModelInterface
- Handle cleanup of several large files
- Run post-processing script

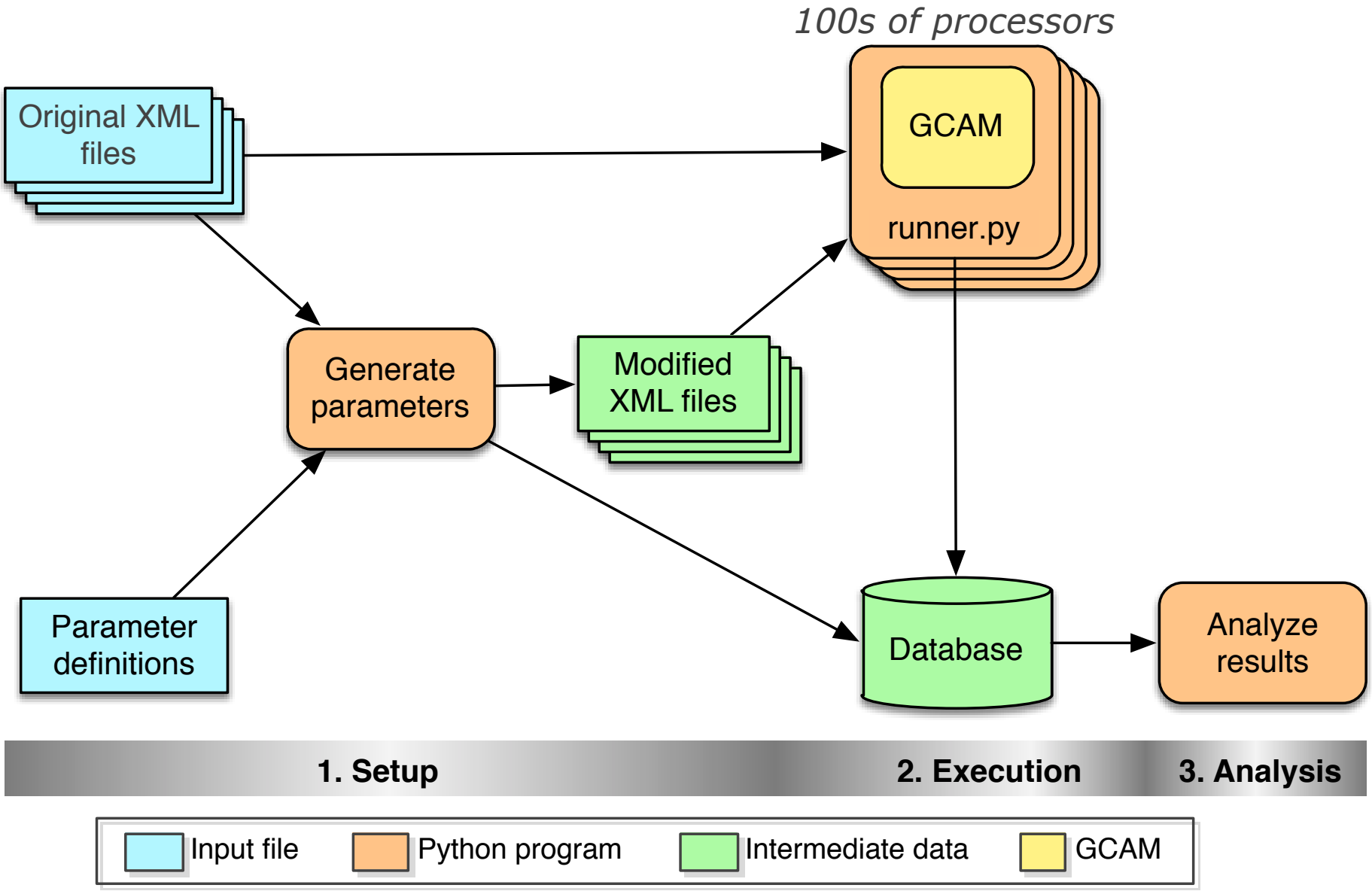
gtapmcs

- Handle "HAR" input & output files
- Handle sets used to iterate over matrices
- Set up GTAP workspace
- Construct proper GTAP command-line
- Extract "accuracy" from GTAP log file

ilucmcs

- Extensions to handle multiple sub-models
- LUC carbon accounting via AEZ-EF
- Calculation of carbon intensity etc.

GCAM MONTE-CARLO SIMULATION FRAMEWORK



MAIN GCAM-MCS COMMANDS

- gcammcs *global-args subcmd subcmd-args*
- gcammcs new *args*
  - Initialize a new user-application run-time structure
- gcammcs gensim *args*
  - Generate a simulation
- gcammcs queue *args*
  - Queue batch runs of GCAM on Linux cluster
- gcammcs analyze *args*
  - Generate statistics and figures from MCS results
- gcammcs config *args*
  - Get, set, and list MCS configuration parameters

Allows user to control:

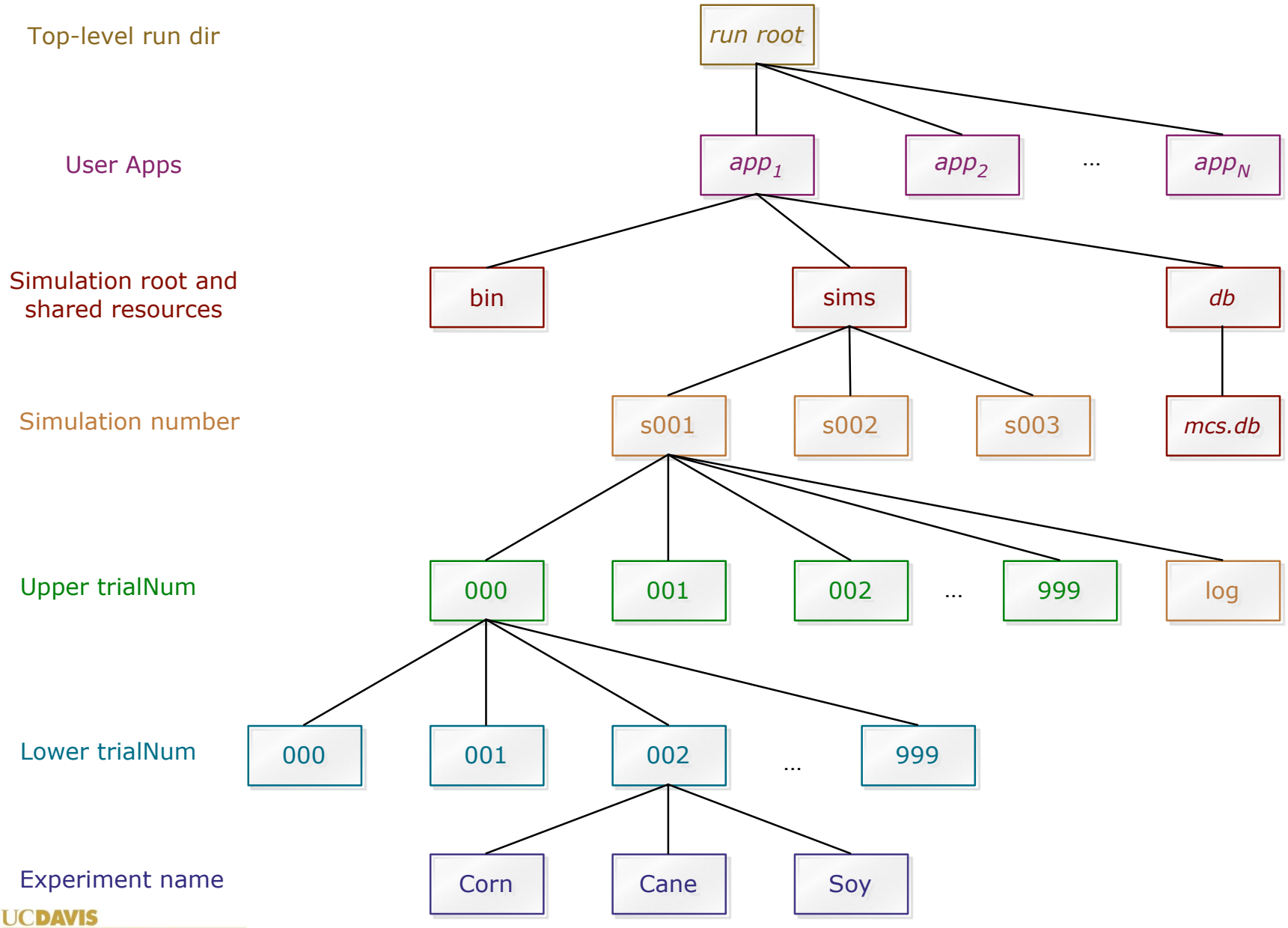
- System configuration (database, Mac/Linux differences)
- Location of key files and directories
- Run-time parameters
- Batch queries to run when GCAM completes
- Post-processing script to run after queries complete
- Plotting defaults
- User-application configuration info

EXTENSIVE CONFIGURATION SYSTEM ALLOWS CUSTOMIZATION

```
[DEFAULT]
Core.LogLevel     = INFO         ; must be one of {DEBUG, INFO, WARNING, ERROR, FATAL}
Core.LogConsole   = True
Core.MinPerTask   = 30

GCAM.RootDir      =%(Home)s/GCAM
GCAM.ModIntDir    = %(GCAM.RootDir)s/current/ModelInterface

GCAM.RunDbDir     = %(Core.RunDir)s/db
GCAM.RunWorkspace = %(Core.RunDir)s/workspace
GCAM.RunCvsDir    = %(GCAM.RunWorkspace)s/cvs
GCAM.RunExeDir    = %(GCAM.RunWorkspace)s/exe
GCAM.RunInputDir  = %(GCAM.RunWorkspace)s/input
GCAM.RunLibsDir   = %(GCAM.RunWorkspace)s/libs
GCAM.RunQueryDir  = %(GCAM.RunWorkspace)s/queries

GCAM.LinuxJarFile = %(GCAM.ModIntDir)s/ModelInterface.jar
#GCAM.MacJarFile  = %(GCAM.ModIntDir)s/ModelInterface.app/Contents/Resources/Java/ModelInterface.jar
GCAM.JarFile      = %(GCAM.LinuxJarFile)

GCAM.QueryPath    = .:%(GCAM.RunQueryDir)s:%(GCAM.RunQueryDir)s/Main_queries.xml

# A file with the names of queries to run, one per line
GCAM.BatchQueryFile =

# Optional regional mapping to use for extracted query definitions
GCAM.RegionMapFile =

# Executable to run when GCAM completes; default is none
#GCAM.PostProcessor = gcammcs diff -s{simId} -t{trialNum} -p{scenario}
GCAM.PostProcessor  =

GCAM.Years = 1990,2005-2100:5    ; years to evaluate
```

This is just a small sample of configuration options

GCAM-MCS RUN-TIME FILE STRUCTURE



RELATIONAL DATABASE

- Supports sqlite3 and postgresql
- Stores:
  - Meta-data (simulation, run, scenario, inputs, outputs)
  - Run-time status
  - Input and output values (scalar and timeseries)

simId	expName	status	count(*)
1	base-1	alarmed	14
1	base-1	failed	35
1	base-1	running	1
1	base-1	succeeded	950
1	corn-1	alarmed	19
1	corn-1	failed	26
1	corn-1	succeeded	955
1	stover-1	failed	51
1	stover-1	succeeded	949

Parameters.xml

- Defines parameters and their distributions
  - parameter => elements returned by XPath query
- Original values are added to, multiplied by, or replaced by random values from distribution
- "Hooks" to call Python functions for custom processing per parameter or per XML file

EXAMPLE PARAMETER DEFINITIONS

```
<ParameterList>
  <InputFile name="demand">
    <!-- Price elasticity of food crop demand. Currently zero everywhere, so can't multiply -->
    <Parameter mode="shared" name="food-crop-price-elast">
      <Query>//energy-final-demand[@name="FoodDemand_Crops"]/price-elasticity[@year>=2015]</Query>
      <Distribution apply="direct" name="triangle" min="-0.2" mode="0" max="0"/>
    </Parameter>

    <!-- Price elasticity of meat demand -->
    <Parameter mode="shared" name="meat-price-elast">
      <Query>//energy-final-demand[@name="FoodDemand_Meat"]/price-elasticity[@year>=2015]</Query>
      <Distribution apply="multiply" name="triangle" factor="0.2"/>
    </Parameter>

    <!-- Income elasticity of food crop demand -->
    <Parameter mode="shared" name="food-crop-income-elast">
      <Query>//energy-final-demand[@name="FoodDemand_Crops"]/income-elasticity[@year>=2015]</Query>
      <Distribution apply="add" name="triangle" range="0.2"/>
    </Parameter>
  </InputFile>
</ParameterList>
```

EXAMPLE DISTRIBUTIONS

```
name="Normal" mean="50" stdev="10"
name="Normal" type="delta"  mean="50" stdev="10"
name="Normal" type="factor" mean="50" stdev="10"

name="Uniform" min="10" max="20"
name="Uniform" type="factor" min="10" max="20"
name="Uniform" type="delta" range="2"

name="LogUniform" type="factor" factor="2"

name="LogNormal" mean="50" std="5"
name="LogNormal" low95="3" high95="50"

name="Triangle"  min="20" max="40" mode="35"

name="Binary"

name="Grid" min="5" max="30" count="5"
```

PROCESSING RESULTS

User identifies scalar / timeseries values to save in database

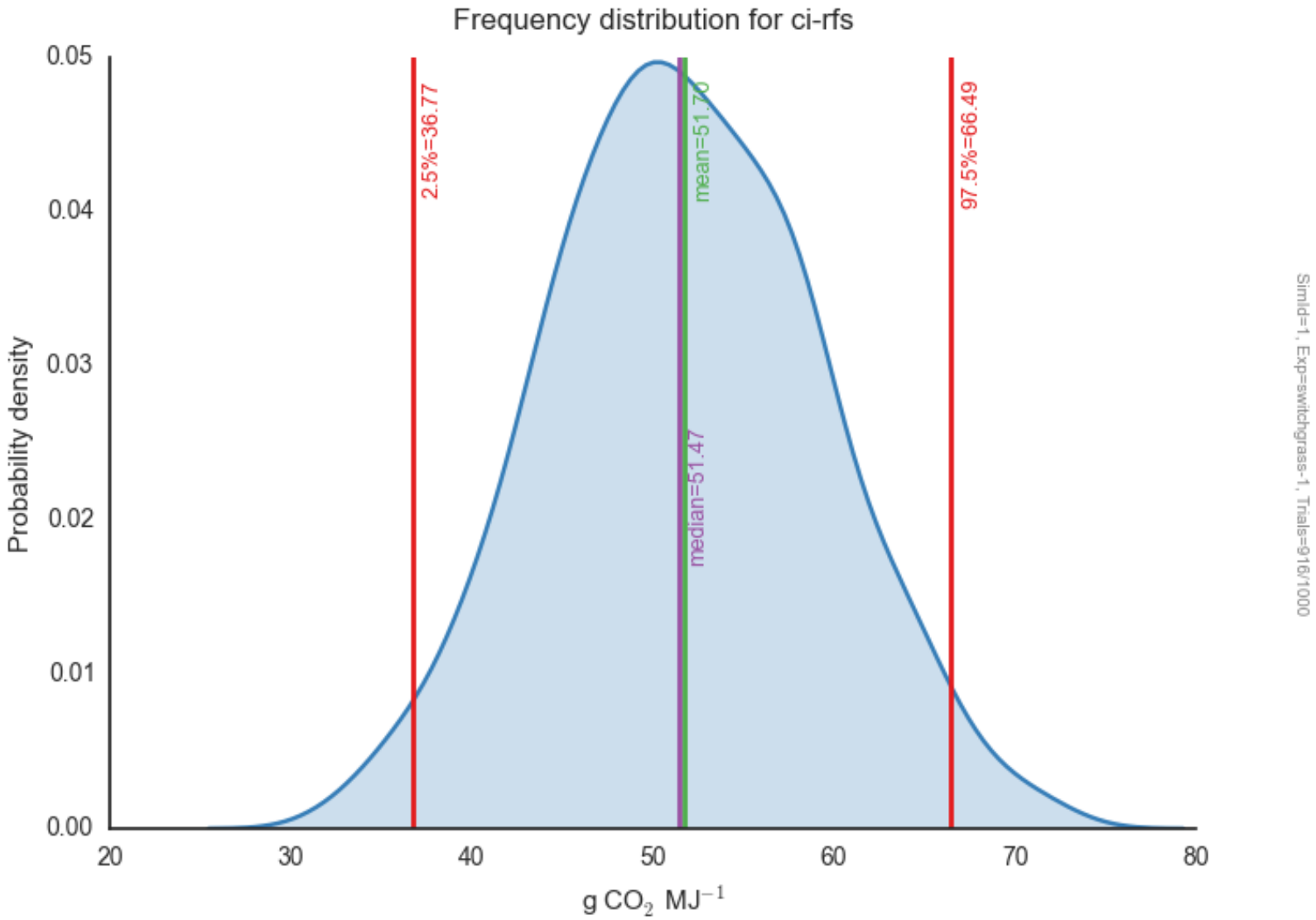
```
<ResultList>
    <Result name="ci-rfs" type="diff"
            desc="Carbon intensity, g CO2e/MJ">
        <File name="carbon_intensity"/>
        <Column name="value"/>
        <Constraint column="method" op="equal" value="ci-rfs"/>
    </Result>

    <Result name="delta-forcing" type="diff"
            desc="Change in RF (W/m^2)">
        <File name="Climate_forcing"/>
    </Result>
</ResultList>
```

EXAMPLE SCENARIO DEFINITIONS

Scenario files can be generated dynamically from baseline

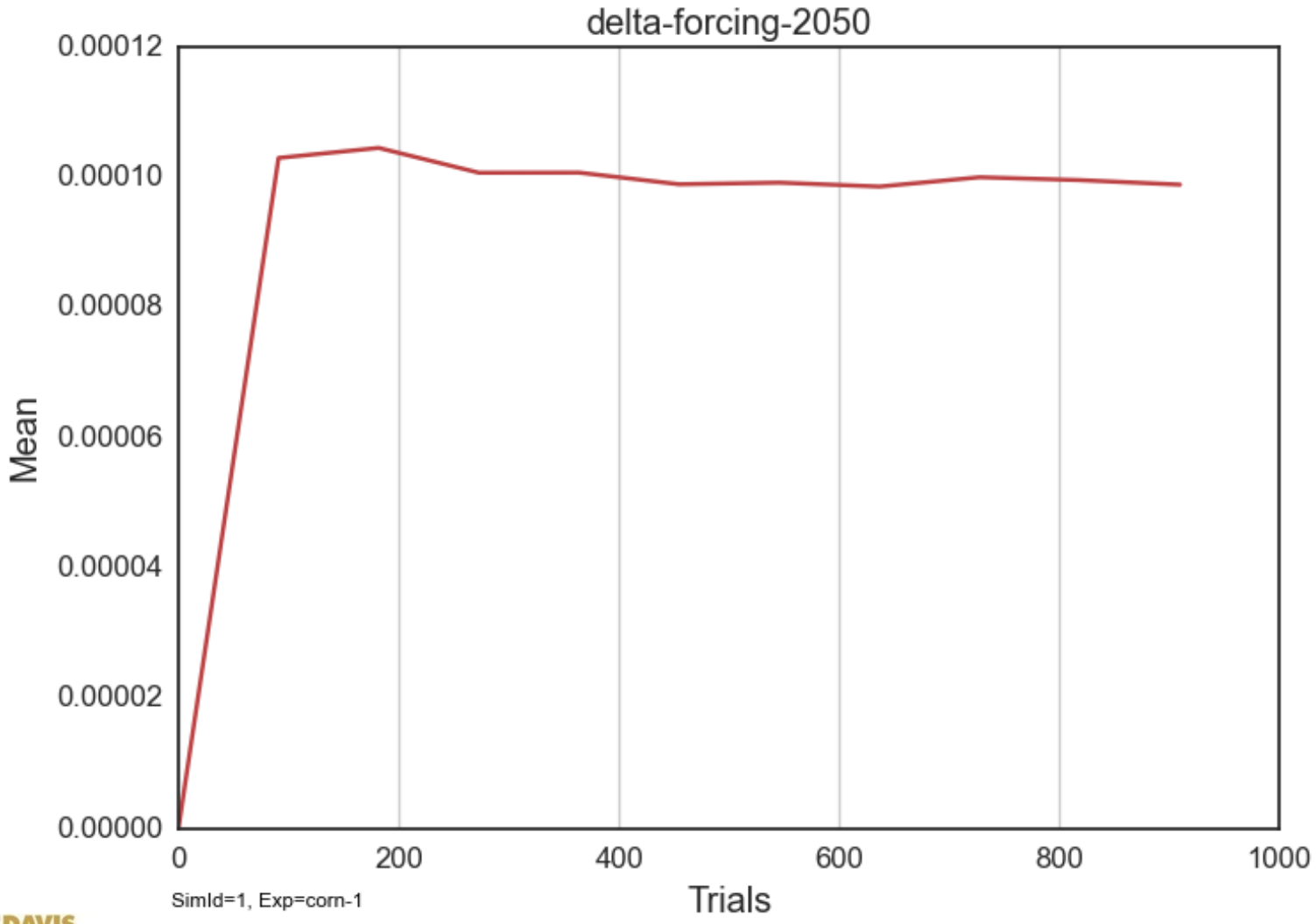
```
<Scenarios>
  <Scenario name="base-1" type="baseline">
    <Description>Paper1 control case</Description>
  </Scenario>

  <Scenario name="corn-1" parent="base-1">
    <Description>Corn ethanol shock</Description>
  </Scenario>

  <Scenario name="switchgrass-1" parent="base-1">
    <Generator>
      genConstraints.py
            --baseline {baseline}
            --policy {policy}
            --xmlOutputDir "{trialDir}/dyn-xml"
    </Generator>
    <Description>Switchgrass ethanol shock</Description>
  </Scenario>
</Scenarios>
```

DISTRIBUTION PLOTS

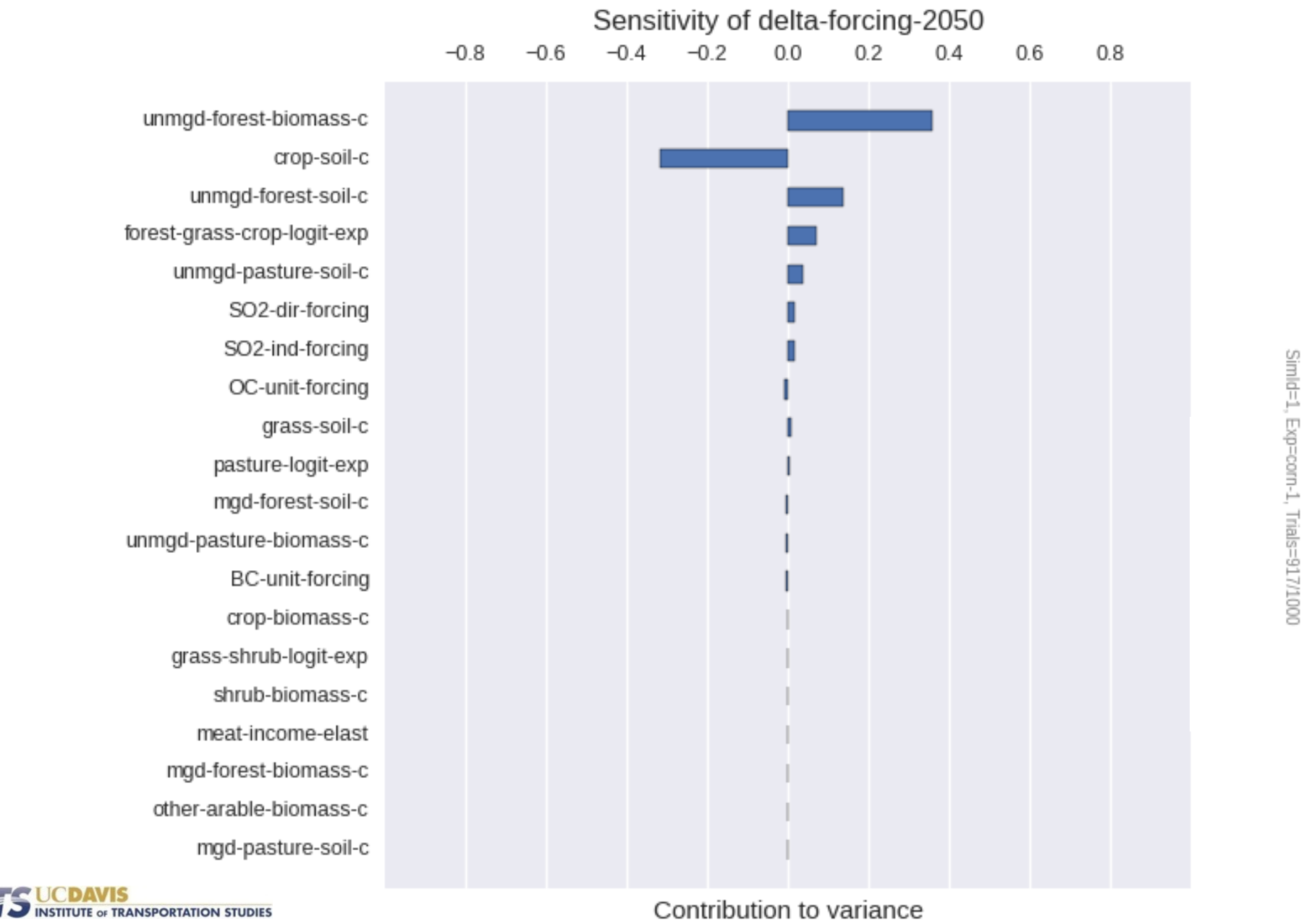


CONVERGENCE PLOTS

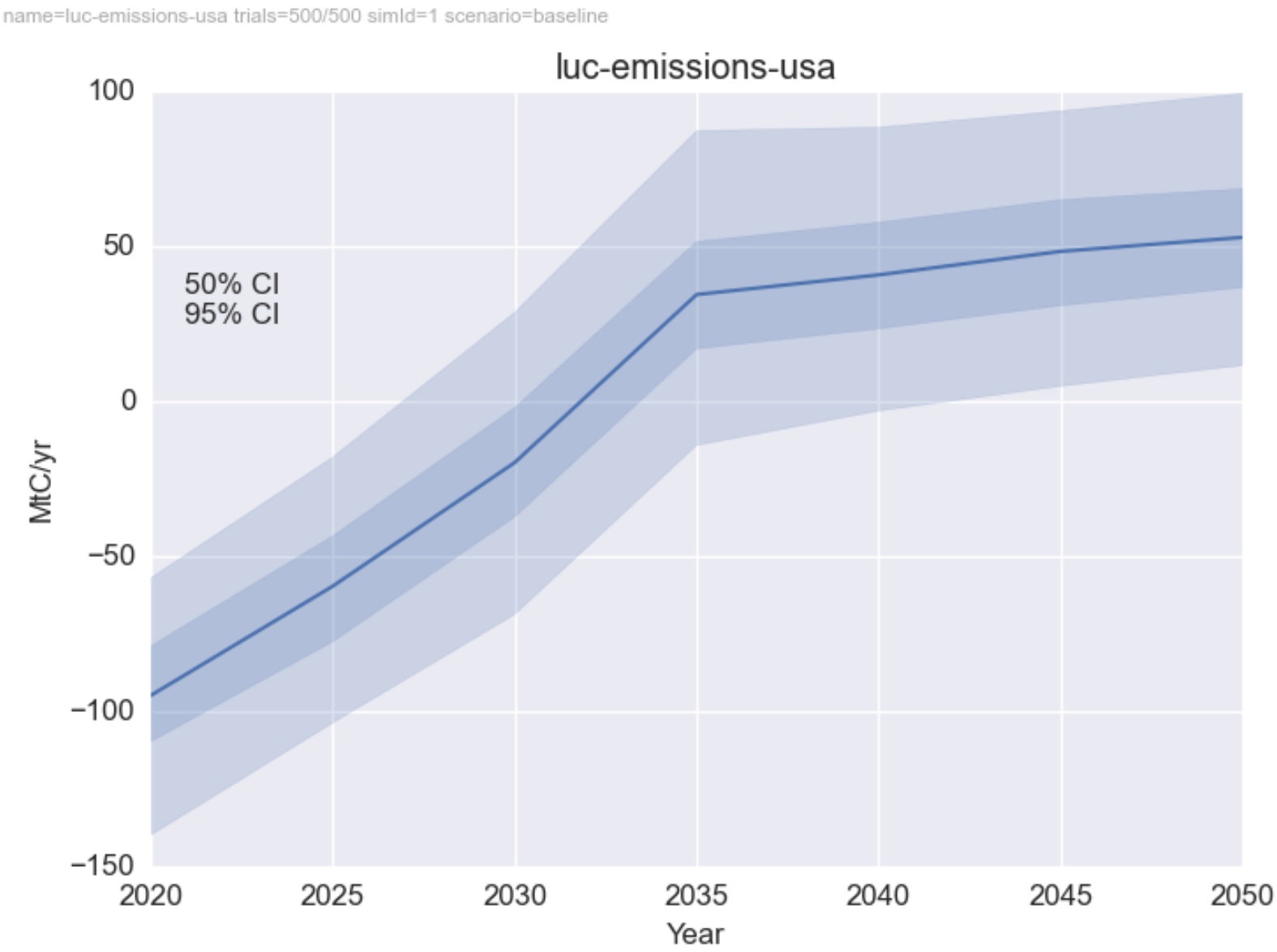
Show convergence of mean, stdev, skewness, 95% CI



UNCERTAINTY IMPORTANCE – CORN ETHANOL ΔRF IN 2050



SAMPLE TIME-SERIES PLOT



Features in common with MCS

- Generate input parameters
- Run on computing cluster
- Collect results into database
- Analyze results

Additional features

- Non-probabilistic methods
- PRIM or similar analysis
- Visualization features

Suite of flexible Python scripts:

- **queueGCAM**: Run GCAM in new workspace, locally or by queueing on Linux cluster
- **batchQuery**: Query GCAM's database to produce a CSV files with on-the-fly region specification & aggregation
- **csvDiff**: Generate a CSV/XLSX file of difference between GCAM query results with optional annual interpolation
- **chartGCAM**: Plots data from GCAM-style CSV files with several plot styles with various aesthetic options

https://bitbucket.org/plevin/gcam-utils