Sacramento Soil Moisture Accounting (SAC-SMA) Model

1. Description of Algorithm

https://vlab.ncep.noaa.gov/documents/207461/1893022/23sacsma.pdf

2. Model Parameters

SAC-SMA uses an xml representation of model parameters where each parameter is captured within a separate xml tag. The tags are closely related to the NWSRFS definition of SAC-SMA defined at

https://vlab.ncep.noaa.gov/documents/207461/1893022/533sacsma.pdf

The table below shows the available parameter tags. For the parameters with type of string, the values are case-insensitive. For example, "YES" and "Yes" are treated by the program as the same value, but "Y" will be treated as error. The sequence of parameters in the table below or in the xml file has no any significance.

Name	Type	Required [Yes/No]	Comment
Basin SAC-SMA Parameters			
SASC_INPUT_OPTION	string	No	○ It can be only "Yes" or "No"; ○ If absent or present with value of "No", do not use the input SASC time series, regardless it is present or not; ○ If present with value of "Yes", use input SASC time series, which is required to be present in input xml file. It is used in regular SACSMA calculation, and in the Frozen Ground calculation.

Name	Type	Required [Yes/No]	Comment
RUNOFF_COMPONENT_INTERVAL	integer	No	○ Default value is 24; ○ Runoff component time series (ROCL) interval. Must be multiple of the input RAIM time series interval ○ Runoff component has 6 time series: impervious runoff (IMP_RO), direct runoff (DIR_RO), surface runoff (SUR_RO), interflow runoff (INT_RO), supplemental baseflow (SUP_RO) and primary baseflow (PRI_RO)
SMZC_INTERVAL	integer	No	○ Default value is 24; ○ Soil moisture storages time series (SMZC) interval. Must be multiple of the input RAIM time series interval ○ SMZC has 5 time series: upper zone tension water deficit (UZTWM-UZTWC, i.e. UZTDEF), upper zone free water contents (UZFWC), lower zone tension water deficit (LZTWM-LZTWC, i.e. LZTDEF), lower zone free supplemental contents (LZFSC) and lower zone free primary contents (LZFPC)
MAPE_INPUT	string	No	○ It can be only "Yes" or "No"; ○ If absent or present with value of "No", input MAPE time series is not used, regardless whether it is present or not. Then etDemand 12 values represent ET-demand 16th of each month, daily values are computed by linear interpolation. ○ If present with value of "Yes", use input MAPE time series, which is required in the input xml file. etDemand 12 values are PE-adjustment factor for the input MAPE time series.

Name	Type	Required [Yes/No]	Comment
ET_DEMAND_CURVE	table	Yes	○ ET-demand or PE-adjustment factor (the table contains 12 values) ○ If PE data used (i.e. MAPE_INPUT is "Yes"), then values are PE-adjustments; if PE data not used, then values represent ET-demand. ○ Both 16th of each month (Jan. through Dec.; units of MM/day); daily values are computed by linear interpolation.
PXADJ	double	Yes	○ Precipitation adjustment factor
PEADJ	double	Yes	○ ET-demand adjustment factor
UZTWM	double	Yes	○ Upper zone tension water capacity; ○ Units of MM
UZFWM	double	Yes	○ Upper zone free water capacity; ○ Units of MM
LZTWM	double	Yes	○ Lower zone tension water capacity; ○ Units of MM
LZFSM	double	Yes	○ Lower zone supplemental free water capacity; ○ Units of MM
LZFPM	double	Yes	○ Lower zone primary free water capacity; ○ Units of MM; ○ LZFSM and LZFPM are input as total values and not just as the visible (channel component) portion.
UZK	double	Yes	○ Fractional daily upper zone free water withdrawal rate
LZSK	double	Yes	○ Fractional daily supplemental withdrawal rate
LZPK	double	Yes	○ Fractional daily primary withdrawal rate
PCTIM	double	Yes	○ Minimum impervious area; ○ Unit of percent/100
ADIMP	double	Yes	○ Additional impervious area; ○ Units of percent/100
RIVA	double	Yes	○ Riparian vegetation area; ○ Units of percent/100
EFC	double	Yes	○ Effective forest cover; ○ Units of percent/100
ZPERC	double	Yes	○ Maximum percolation rate
REXP	double	Yes	○ Exponent for the percolation equation

Name	Type	Required [Yes/No]	Comment
PFREE	double	Yes	○ Percent/100 of percolated water which always goes directly to lower zone free water storages
RSERV	double	Yes	○ Percent/100 of lower zone free water which cannot be transferred to lower zone tension water
SIDE	double	Yes	○ Ratio of non-channel baseflow (deep recharge) to channel (visible) baseflow
Frozen Ground Parameters			
FROZEN_FROUND_CALC_OPTION	string	No	○ It can be only "Yes" or "No"; ○ If absent or present with value of "No", do not use Frozen Ground calculation; ○ If present with value of "Yes", use Frozen Ground calculation.
WE_INPUT_OPTION	string	No	○ It can be only "Yes" or "No"; ○ If absent or present with value of "No", do not use the input SWE time series, regardless it is present or not; ○ If present with value of "Yes", use input SWE time series, which is required to be present in input xml file
FGIX_TS_INTERVAL	integer	No	○ Output time series interval. Default value is RAIM interval; ○ Must be multiple of the input RAIM time series interval
CSOIL	double	Yes	○ Bare ground frost coefficient for a given time interval; ○ Units of $DEGC^{-1}*HR^{-1}$
CSNOW	double	Yes	○ Reduction in CSOIL per MM of snow water equivalent
GCH	double	Yes	○ Daily thaw rate from ground head; ○ Units of DEGC/DAY
RTHAW	double	Yes	○ Thaw coefficient for water entering the soil; ○ Units of DEGC/MM
FRTEMP	double	Yes	○ FI value above which there is no reduction in percolation or interflow withdrawal; ○ Units of DEGC

Name	Type	Required [Yes/No]	Comment
SATR	double	Yes	○ Reduction in percolation and interflow withdrawal per DEGC of FI below FIl under saturated soil conditions; ○ Units of $DEGC^{-1}*HR^{-1}$
FREXP	double	Yes	○ Exponent

3. Model States

Like all the other models, SAC-SMA model states are also defined in a property file format. An example is shown below. The sequence of property names in the state file or in the table below has no any significance. The model state property names are:

Property Name	Description
UZTWC	Upper zone tension water contents; units of MM
UZFWC	Upper zone free water contents; units of MM
LZTWC	Lower zone tension water contents; units of MM
LZFSC	Lower zone free supplemental contents; units of MM
LZFPC	Lower zone free primary contents; units of MM
ADIMC	Tension water contents of the ADIMP area; units of MM. If not known then use UZTWC+LZTWC
FGIX	Initial value of the frost index; units of DEGC. If starting with no frozen ground the value is zero.
UNIT	This entry is optional. The presence of "UNIT=METRIC" in state file is only for visual information, because the state is always in METRIC units, never in ENGLISH units; An exception will be thrown if "UNIT=ENGLISH" is present in the state file.

Sample state file:

UZTWC=60.0
UZFWC=0.5018389
LZTWC=100.0
LZFSC=11.14569
LZFPC=46.98808
ADIMC=159.9019
FGIX= 0.0
UNIT=METRIC

4. Model Time Series

Basic SAC-SMA model has 1 required input time series (RAIM) and 2 optional input time series (SASC and MAPE). The Frozen Ground feature has one additional required input time series (MAT) and one additional optional input time series (SWE).

The units of the input time series are very flexible. If it is length unit, like RAIM time series, it can be any length unit (CM, M etc). If it is temperature unit, like MAT time series, it can be DEGC or DEGF. The program will internally convert the input time series to expected units. The "Units" column in the table below, for the input time series, indicates the internal model units; for the output time series, indicates the output time series units.

INPUT TIME SERIES:

Time Series Type	**Units**	**Time Series Interval(HR)**	**Missing Values Allowed**	**Required [Yes or No]**
Basic SAC-SMA Model				
RAIM	MM	Any	No	Yes
SASC	PCTD	Any 2/	No	No 7/
MAPE	MM	Any 2/	No	No 7/
Frozen Ground Feature				
MAT	DEGC	Any 2/	No	YES
SWE	MM	Any 2/	No	No 7/

OUTPUT TIME SERIES:

Time Series Type	**Units**	**Time Series Interval(HR)**	**Missing Values Allowed**
Basic SAC-SMA Model			
TCI	MM	Any 1/	No
6 runoff components: 1) IMP_RO 5/ 2) DIR_RO 5/ 3) SUR_RO 5/ 4) INT_RO 5/ 5) SUP_RO 5/ 6) PRI_RO 5/	MM	Any 3/	No
LZDEFR 5/ $LZDEFR = 1.0 - \frac{LZTWC + LZFSC + LZFPC}{LZTWM + LZFSM + LZFPM}$	REAL	Any 1/	Yes

Time Series Type	Units	Time Series Interval(HR)	Missing Values Allowed
6 states: 1)UZTWC 5/ 2)UZFWC 5/ 3)LZTWC 5/ 4)LZFSC 5/ 5)LZFPC 5/ 6)ADIMC 5/	MM	Any 1/	No
6 states percentage: 1)UZTWC_PERC(UZTWC/UZTWM) 5/ 2)UZFWC_PERC (UZFWC/UZFWM) 5/ 3)LZTWC_PERC (LZTWC/LZTWM) 5/ 4)LZFSC_PERC (LZFSC/LZFSM) 5/ 5)LZFPC_PERC (LZFPC/LZFPM) 5/ 6)ADIMC_PERC(ADIMC/(UZTWM+LZTWM) 5/	PCTD	Any 1/	No
2 ET variables: 1)ETDEMAND 2)ETACTUAL	MM	Any 1/	No
Frozen Ground Feature			
FGIX 6/	DEGC	Any 4/	No

Notes:
1/: Must be same as RAIM interval;
2/: Must be a multiple of RAIM interval.
3/: Must be a multiple of RAIM interval, default is 24 hr.
4/: Must be a multiple of RAIM interval, default is RAIM interval.
5/: These time series are only available when the "SACSNOW" option is set to "TRUE" (full version).
6/: only available when running the Frozen Ground Algorithm and "SACSNOW" option is set to "TRUE" (full version).
7/: All these optional input time series are controlled by individual parameters if they are used (in that case, they are required) or not: "SASC_INPUT_OPTION", "MAPE_INPUT" and "WE_INPUT_OPTION". See the parameter description in Section 2 above for more details. The input SASC time series is used in regular SACSMA calculation, but it could also be used in Frozen Ground calculation.

There are two versions for the model to run – "slim version" or "full version". The version ran is determined by the technique "SACSNOW" (default value is false).When SACSNOW is true, the model runs the "full version" and when it is absent or false, the "slim version" is executed. This technique is used by both SNOW-17 and SAC-SMA model. Slim version is much faster than full version, because it only produces one the primary output time series (TCI). All the rest time series are the secondary output time series and are only generated when running in "full version".

Note: the soil moisture storage output time series (SMZC) contains 3 states time series (UZFWC, LZFSC and LZFPC). If SMZC interval specified by the parameter xml file is different from RAIM interval, the 3 state time series will show up twice in the outputs.xml file, one with SMZC interval and one with RAIM interval.

5. Modifications (Mods)

The SAC-SMA model has six Mods; all the Mods must be within the observation time period, not applied in the future period. All the new state values are checked against the maximal values specified in the parameter xml file. The units are for the model internal units.

- SACCO Mod has seven parameter Ids. SACCO Mod set the specific state to the value entered.
- UZTWCADJ and LZTWCADJ Mods allow forecaster to increment/decrement the tension waters for multiple basins at a time. Both Mods set the specific state as shown below:

  NewState U/LZTWC = OldStates U/LZTWC + (±U/LZTWCADJ Mods)

- UZTWD and LZTWD Mods are helpful to apply widespread deficits to several basins when it has been drier than normal. Both Mods set the specific state as shown below:

  NewState U/LZTWC = U/LZTWM – U/LZTWD Mods

  Where U/LZTWC is state and U/LZTWM is parameter.

- Finally, SACBASEF Mod multiplies the baseflow runoff by the specified value. In addition, SACBASEF Mod cannot be applied at the initial state time.

Parameter Id	Units	Time Step	Description
SACCO Mod			
UZTWC	MM	Any 1/	Changes the upper zone tension water contents. Must be less than or equal to the parameter UZTWM.
UZFWC	MM	Any 1/	Changes the upper zone free water contents. Must be less than or equal to UZFWM.
LZTWC	MM	Any 1/	Changes the lower zone tension water contents. Must be less than or equal to LZTWM.
LZFPC	MM	Any 1/	Changes the lower zone free primary water contents. Must be less than or equal to LZFPM.

Parameter Id	Units	Time Step	Description
LZFSC	MM	Any 1/	Changes the lower zone free secondary water contents. Must be less than or equal to LZFSM.
ADIMC	MM	Any 1/	Changes the additional impervious water contents. Must be less than or equal to the sum of UZTWM and LZTWM. It also must be greater than or equal to UZTWC.
FGIX	MM	Any 1/	Changes the Frozen Ground Index value
SACBASEF Mod			
SACBASEF	REAL	Any 2/	Multiplies the lower zone free primary (LZFPC) and secondary water contents (LZFSC). The final LZFPC must be less than or equal to LZFPM; The final LZFSC must be less than or equal to LZFSM.
UZTWCADJ Mod			
UZTWCADJ	MM	Any 2/	Computes the upper zone tension water contents (UZTWC) based on adjusted mod for the date specified. *NewState UZTWC = OldState UZTWC+ (±UZTWCADJ).* If NewState UZTWC is greater than limit UZTWM then set it to UZTWM If NewState UZTWC is less than or equal to zero then set it to zero.
LZTWCADJ Mod			
LZTWCADJ	MM	Any 2/	Computes the lower zone tension water contents (LZTWC) based on adjusted mod for the date specified. *NewState LZTWC = OldState LZTWC+ (±LZTWCADJ)* If NewState LZTWC is greater than limit LZTWM then set it to LZTWM If NewState UZTWC is less than or equal to zero then set it to zero.
UZTWD Mod			

Parameter Id	Units	Time Step	Description
UZTWD	MM	Any 1/	Computes the upper zone tension water contents (UZTWC) based on UZTW deficit mod for the date specified. *UZTWC = UZTWM – UZTWD* If computed UZTWC is less than zero then set to 0.0.
LZTWD Mod			
LZTWD	MM	Any 1/	Computes the upper zone tension water contents (LZTWC) based on LZTW deficit mod for the date specified. *LZTWC = LZTWM – LZTWD* If computed LZTWC is less than zero then set to 0.0

Notes:
1/: a non-equidistant time series: There is no time step interval. The time step events no need to be continuously present from the start date to the end date. Its xml file header contains the following:
<timeStep unit="nonequidistant"/>

2/: an equidistant time series: the time step interval is fixed and all the time steps must be present from the start date to the end date. Its xml file header contains the following (e.g. 6 hour time interval):
<timeStep unit="hour" multiplier="6"/>

6. Notes about configuring Model in FEWS workflow

- Samples configuration for UZTWCADJ/LZTWCADJ and UZTWD/LZTWD Mods in FEWS.

ModuleConfigFiles/xxxx/SACSMA_XXXXX_XXXXX_UpdateStates.xml and SACSMA_XXXXX_XXXXX_Forecast.xml	
Add Mod <timeSeriesSet> to <exportFile>mods_sacsma_**ne.**fi</exportFile> section after <timeSeriesSets> tag for UZTWD and LZTWD	<timeSeriesSet> <moduleInstanceId>ExportMODS</moduleInstanceId> <valueType>scalar</valueType> <parameterId>**UZTWC**</parameterId> <locationId>XXXXX</locationId> <timeSeriesType>external historical</timeSeriesType> <timeStep unit="nonequidistant"/> <relativeViewPeriod unit="hour" end="0"/> <readWriteMode>read only</readWriteMode> <ensembleId>main</ensembleId> </timeSeriesSet>

<table>
<tr><td>- Repeat the <timeSeriesSet> …</timeSeriesSet> block for any other Mods; parameterId and locationId appropriately.</td><td></td></tr>
<tr><td>Add Mod <timeSeriesSet> to

<exportFile>mods_sacsma_eq.fi</exportFile>

section after <timeSeriesSets> tag for UZTWCADJ and LZTWCADJ

- Repeat the <timeSeriesSet> …</timeSeriesSet> block for any other Mods; parameterId and locationId appropriately.</td><td><timeSeriesSet>
<moduleInstanceId>ExportMODS</moduleInstanceId>
<valueType>scalar</valueType>
<parameterId>UZTWCADJ</parameterId>
<locationId>XXXXX</locationId>
<timeSeriesType>external historical</timeSeriesType>
<timeStep multiplier="6" unit="hour"/>
<relativeViewPeriod end="0" endOverrulable="true" unit="hour"/>
<readWriteMode>read only</readWriteMode>
<ensembleId>main</ensembleId>
</timeSeriesSet></td></tr>
<tr><td colspan="2">RegionConfigFiles/Parameters.xml</td></tr>
<tr><td>- Add new Mods parameterId to after <parameterGroup id="SAC-SMA Modifiers_L" name="SAC-SMA States"> tag</td><td><parameter id="UZTWD" name="Upper Zone Tension Water Deficit">
<shortName>UZTWD</shortName>
</parameter>

<parameter id="LZTWD" name="Lower Zone Tension Water Deficit">
<shortName>LZTWD</shortName>
</parameter>

<parameter id="UZTWCADJ" name="UZTWCADJ - Upper Zone Tension Water Content Adjusted">
<shortName>UZTWCADJ</shortName>
</parameter>

<parameter id="LZTWCADJ" name="LZTWCADJ - Lower Zone Tension Water Content Adjusted">
<shortName>LZTWCADJ</shortName>
</parameter></td></tr>
<tr><td colspan="2">RegionConfigFiles/ModifierTypes.xml</td></tr>
<tr><td>- Add Mods type for UZTWD and LZTWD after the</td><td><singleValueModifier id="uztwd" name="UZTWD">
<expiryTime unit="day" multiplier="30"/>
<timeSeries></td></tr>
</table>

</singleValueModifier> tag.	<parameterId>**UZTWD**</parameterId> </timeSeries> <softLimits> <maximumValue>25</maximumValue> <minimumValue>0</minimumValue> </softLimits> <hardLimits> <minimumValue>0</minimumValue> </hardLimits> <defaultTime>start run</defaultTime> <offsetDefaultTime unit="day" multiplier="3"/> <defaultValue>0</defaultValue> </singleValueModifier>
- Add Mods type for UZTWCADJ and LZTWCADJ to after the </singleValueModifier> tag.	<singleValueModifier id="**uztwcadj**" name="**UZTWCADJ**"> <expiryTime unit="day" multiplier="30"/> <timeSeries> <parameterId>**UZTWCADJ**</parameterId> </timeSeries> <softLimits> <maximumValue>2</maximumValue> <minimumValue>-2</minimumValue> </softLimits> <defaultTime>start run</defaultTime> <offsetDefaultTime unit="day" multiplier="3"/> <defaultValue>0</defaultValue> </singleValueModifier>

- SAC-SMA allows for three run-time options (known as TECHNIQUES in NWSRFS). When specified they should appear in the run_info.xml file.

  Example of run info using SACSMA run time options:
  <properties>
  …
  <string key="PRINTSMA" value="TRUE"/>
  <string key="SACSNOW" value="TRUE"/>
  <string key="FROST" value="TRUE"/>
  </properties>

  i) PRINTSMA – produces detailed each time step information in the form of a text based table. One example is shown below. The default value is “FALSE”. The similar technique used in SNOW-17 model is “PRINTSNW”.

'10 TIME ZONE=Z

DAY	HR	UZTWC	UZFWC	LZTWC	LZFSC	LZFPC	ADIMC	FGIX	PERC	IMP	DIR	SUR	INT	SUP	PRI	TOT-RO	ET-DMD	ACT-ET	RAIN+MELT
1	6	59.58	0.0	47.0	0.0	16.98	113.88	-34.392	0.0	0.0	0.0	0.0	0.0	0.0	0.02	0.02	0.147	0.145	1.02
1	12	60.0	4.761	47.0	0.0	16.96	117.66	-33.2	0.0	0.0	0.07	0.0	0.0	0.0	0.02	0.09	0.147	0.146	5.33
1	18	60.0	6.461	47.47	0.065	16.99	119.24	-31.675	0.317	0.0	0.04	0.0	0.099	0.0010	0.02	0.16	0.147	0.147	2.54
2	24	60.0	6.981	48.05	0.141	17.03	120.13	-30.9	0.366	0.0	0.024	0.0	0.123	0.0040	0.02	0.172	0.147	0.147	1.52
2	6	60.0	7.229	48.65	0.216	17.08	120.85	-30.458	0.373	0.0	0.021	0.0	0.128	0.0080	0.02	0.177	0.14	0.14	1.27
2	12	60.0	16.454	49.52	0.324	17.15	127.16	-29.6	0.357	0.0	0.211	0.0	0.198	0.013	0.02	0.442	0.14	0.14	10.67
2	18	60.0	23.261	50.99	0.506	17.29	131.85	-28.492	0.338	0.0	0.215	0.0	0.341	0.021	0.02	0.598	0.14	0.14	9.14

ii) SACSNOW – This technique is used by both SNOW-17 and SAC-SMA model. It determines running the model in "slim version" or "full version". See the notes about the output time series above. The default value is "FALSE" (slim version).

iii) FROST – controls whether the Frozen Ground Algorithm should be used. NOTE: This overrides the setting in the parameters xml file. The default value is "TRUE" (if the parameter specifies using Frozen Ground Algorithm, then use it).

Examples:

Module Configuration File
ModuleConfigFiles\SACSMA_CNEO2_CNEO2_Forecast.xml

Module Parameter File
ModuleParFiles\SACSMA_CNEO2_CNEO2_UpdateStates.xml

7. FEWS Adapter Used

The SAC-SMA model uses the OHDFewsadapter to communicate. Information about this adapter can be found at OHDFewsadapter.