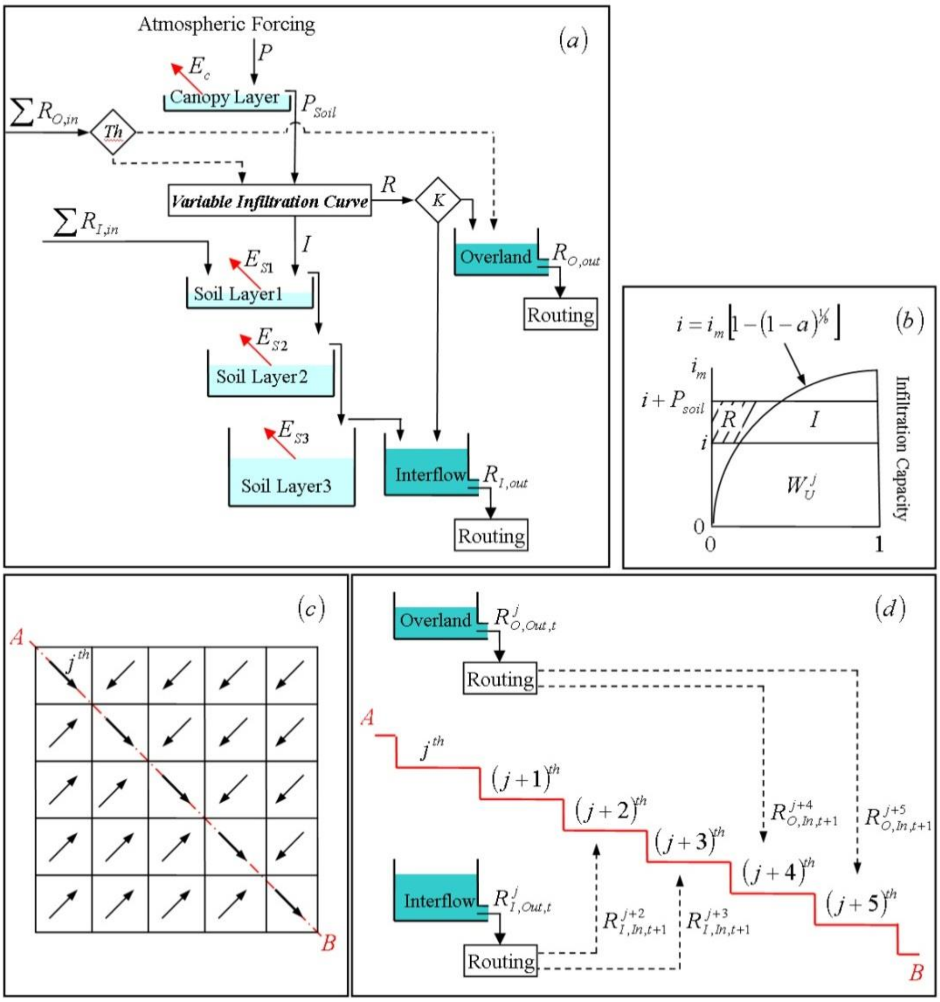
NASA University of Oklahoma (OU) HyDROS Lab (http://hydro.ou.edu)

CREST

Coupled Routing and Excess STorage
User Manual

Version 2.1 (released in Jul. 2015)



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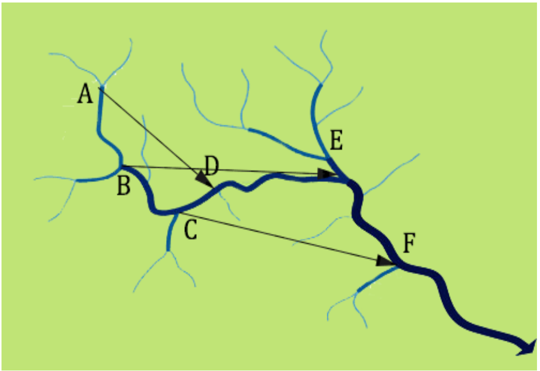

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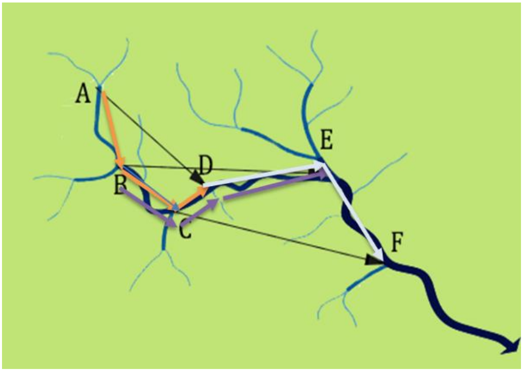

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Cover: **CREST**——Coupled Routing and Excess Storage User Manual Version 2.1

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1 Model Overview

1.1 Overview of CREST

The **C**oupled **R**outing and **E**xcess **ST**orage (CREST) distributed hydrological model is a hybrid modeling strategy developed by the University of Oklahoma (http://hydro.ou.edu) and NASA SERVIR Project Team (www.servir.net). The CREST model was initially developed to provide real-time regional and global hydrological prediction by running at fine spatiotemporal resolution with maintaining economical computational cost (http://eos.ou.edu). CREST simulates the spatiotemporal variation of water and energy fluxes and storages on distributed grid cells of arbitrary user-defined resolution, which enables multi-scale applications (Figure 1-1). The scalability of CREST simulations is accomplished through the sub-grid scale representation of soil moisture storage capacity (using a variable infiltration curve), multi-scale runoff generation processes (using multi-linear reservoirs) and a fully distributed routing scheme (using the fully distributed linear reservoir routing (FDLRR)). The primary water fluxes such as infiltration and routing are physically affected by the geographic variables land surface characteristics (i.e., vegetation, soil type, and etc.). The runoff generation and routing components are coupled, therefore CREST includes more realistic interactions between lower atmospheric boundary layers, terrestrial surface, and subsurface water than other distributed hydrological models. The above features make CREST applicable at global, regional, and catchment scales.

This user manual and the accompanying example basin provide a single basin helps user to install, test and learn how to use the model. The CREST model is forced by gridded potential evapotranspiration (PET) and precipitation datasets that are measured, estimated or forecasted. Users can freely switch between the simulation and calibration running styles and between the continuous and flood events running modes by simply modifying the control file.

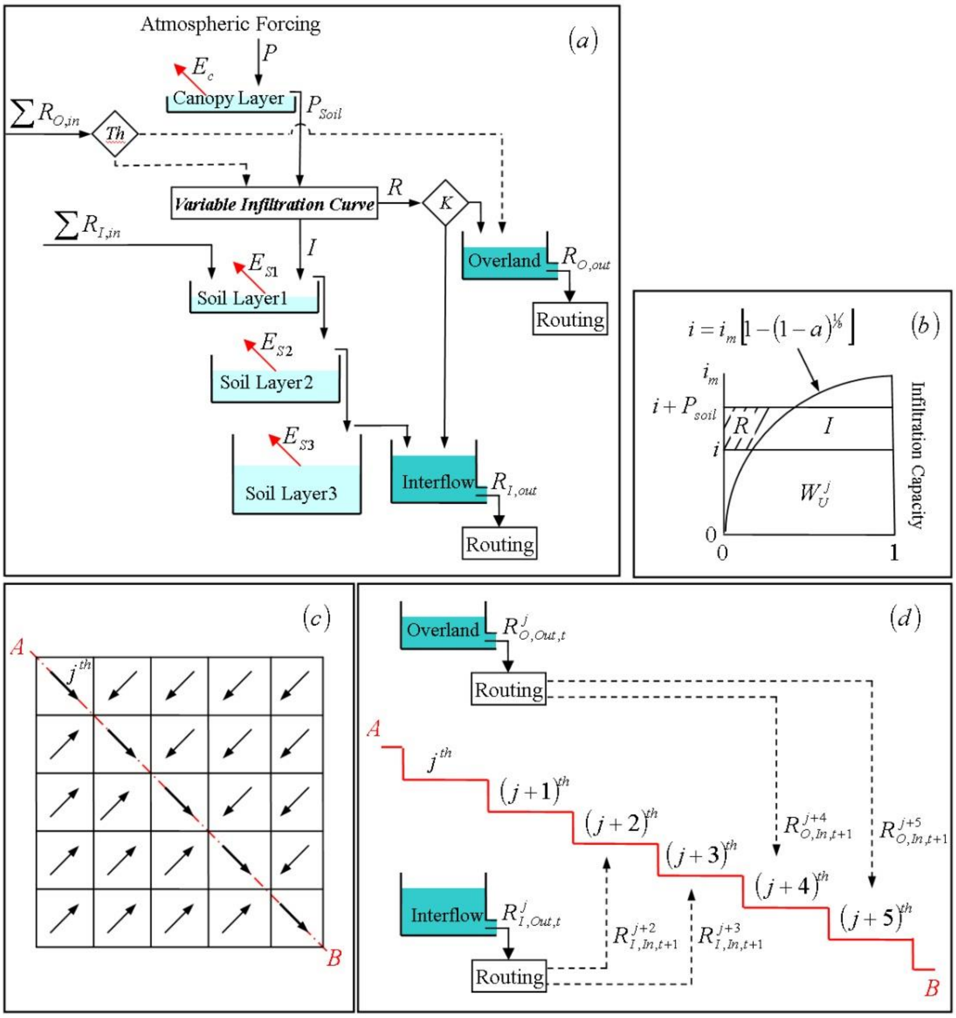


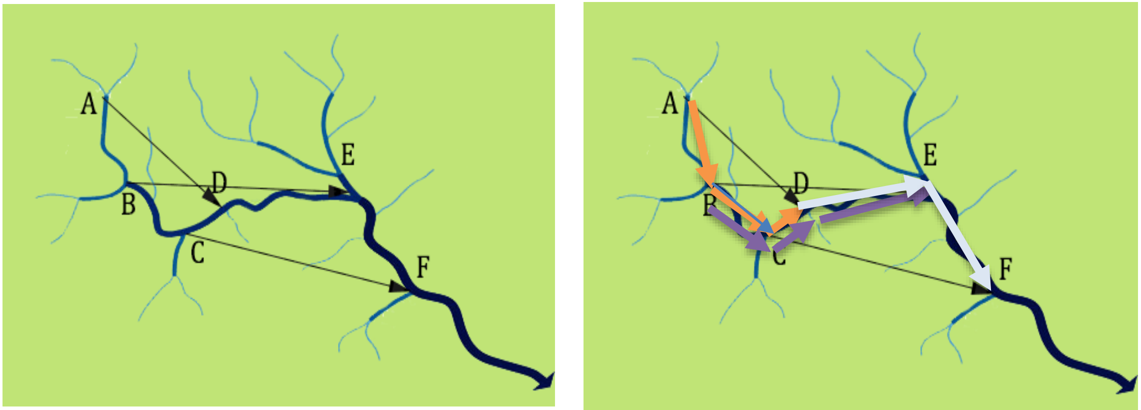
Figure 1-1 Core Components of the CREST model

(a) Vertical profile of a cell including rainfall-runoff generation, evapotranspiration, sub-grid cell routing and feedbacks from routing; (b) variable infiltration curve of a cell; (c) plane view of cells and flow directions; and (d) vertical profile along several cells including sub-grid cell routing, downstream routing, and subsurface runoff redistribution from a cell to its downstream cells.

1.2 What's new in CREST v2.1

The major upgrade is on the routing scheme. The cell-to-cell routing scheme used in previous versions of CREST is a quasi-distributed linear reservoir routing (QDLRR) method which we found problematic to apply to a distributed hydrological model in practice. In CREST v2.1, a fully distributed LRR method (FDLRR) is proposed and used to replace the QDLRR module of CREST. The conception of the QDLRR and the FDLRR is shown in Figure 1-2. Suppose that in one time step, water moves from A to

D, B to E and C to F and take C as the observation cell. In previous versions as shown in Figure 1-2(a), only the water from C to F contributes to the final runoff (discharge) of C while water from A to D and B to F is denied of contribution as if the water jumps over cell C. On the contrary, in CREST v2.1, all these three terms contributes to the runoff of cell C because they either sets off from or passed via cell C.



(a) (b)

Figure 1-2 Routing Conception of v2.0 and v2.1. (a) Linear reservoir routing (LRR) method used in V2.0 and (b) Fully distributed linear reservoir (DLRR) used in v2.1.

Minor upgrade includes: 1) the full vectorization of the computation which boosts the efficiency by nearly one order (no routines loop cell by cell in the new version); 2) acceptance of more advanced geographic data formats 3) automatic decompression, reprojection, resampling and clipping of the forcing data to accommodate data in different formats, coordinate system and resolution; 4) adding a flood event mode and 5) switching on and off a) the feedback mechanism, b) the existence of interflow in channels.

2 Installation

CREST v2.1 is written in Matlab that is OS (operating systems) independent. It is compatible with R2013a and later versions of matlab. However, it integrates the GDAL libraries to implements I/O (input/output) functionality, which is OS dependent. Please install CREST v2.1 using the following steps:

Compile and install the GDAL

For Linux OS, the components and links are provided blow. Please install them in order. Specifically, GDAL needs to be no older than 1.11.0.

1) Geos

via http://trac.osgeo.org/geos/

2) proj.4

via https://trac.osgeo.org/proj/

3) GDAL

via http://trac.osgeo.org/gdal/wiki/DownloadSource

and compile following the same commands below

http://trac.osgeo.org/gdal/wiki/BuildingOnUnix

For Windows OS, compiled x64 binaries are provided with the model, users do not have to compile GDAL themselves unless they need to support some additional image formats.

Compile the matlab GDAL interface

Similar to the GDAL binaries, windows-x64 users can skip this subsection because the compiled *.mexw64 are provided with CREST v2.1. For Linux users, please follow the following orders to compile all *.cpp/*.c files in the MEX folder using the “mex” command in matlab environment as the example below. The order is arbitrary.

```
>> mex '-IYOURGDALPATH \include' '-LYOURGDALPATH\lib' 'cppFILENAME’
```

where YOURGDALPATH is the directory GDAL is installed in your machine. cppFILENAME stands for any c/cpp file in the MEX folder.

On Windows x64 OS

The installation of CREST includes only two steps on Windows OS:

1) Download the **CREST** and **Dependency** files from our website http://hydro.ou.edu/research/crest
2) Decompress the two zipped files and put all subfolders and files in the same folder. Consequently, you should have 4 components in your arbitrary **program folder**

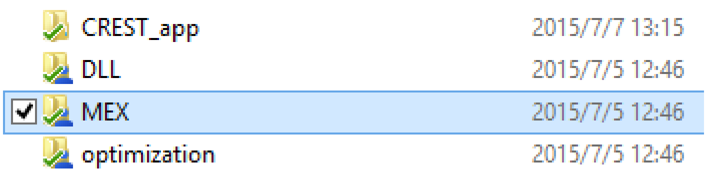


Figure 2-1 All components included in CREST v2.1

On Linux

The executable of Linux 64-bit version is the same as the windows version except that 1) the files in the MEX folder end with ".amd64" and 2) the DLL folder is not required. The reason is that the GDAL library and its dependency must be compiled by the user before installing CREST. It's not able for us to distribute a compatible binary for any version of Linux. Besides an image format of interest, users must install the minimum libraries found below. We provided the links of the source codes but users are free to try other source or newer versions of the same functionality. If a user is not familiar to the installation of these libraries, please contact the server administrators or simply visit gdal.org. CREST developers are not responsible for the instruction on GDAL installation.

3 Framework and User Interface of CREST v2.1

3.1 Model Structure and running commands

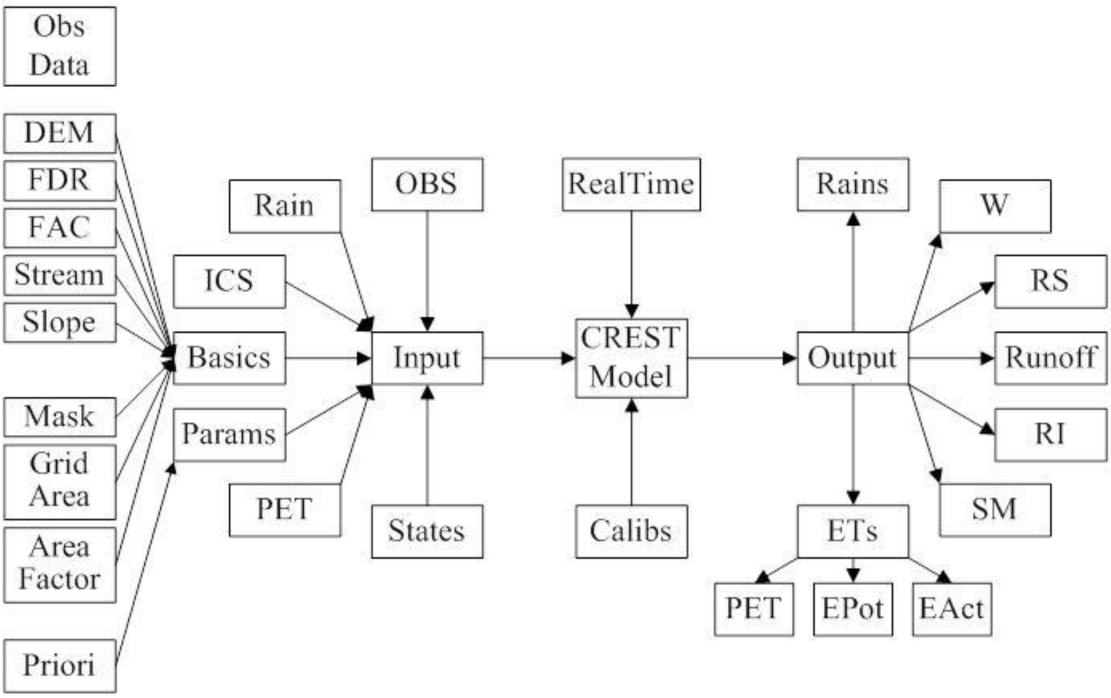


Figure 3-1. Project structure of CREST v2.1

The user interface of CREST v2.1 is remains similar as that of CREST v2.0.

Although the data files needed in CREST can be stored anywhere in principle, it is recommended to store all the data and control files needed by the given basin in a single project folder.

In CREST v2.1, the control file is named "*.Project", which stores the running options and physical locations of all other data files needed by CREST and is usually put in the root of the project folder. Other data files, as shown in Figure 3-1, are distributed in several folders of the project according to their categories. These folders are specified in the control file including “basic”, “rains”, “PETs” “Param”, “obs”,”calib” and “results”.

The control file and these folders will be described in the following subsections. Setting up a basin is to create and fill these folders and the control file.

After a basin is setup, users can run CREST using the following matlab command

>> CREST(globalCtl, opt, nCore);

where

opt=’mean’|’real’ refers to use the presumed mean height difference or the real one at the outlet. The mean height difference is usually used because the clipped geographic data contained in the basic folder usually lacks the information of the next downstream cell of the basin outlet and it can also be a “sink” at the outlet cell.

gdalPath is the path where gdal_csharp.dll is stored. By default, it should be in the subfolder ”.\ gdal_1110_dll” in the decompressed CREST folder.

nCore is the number of allowed parallel workers. It is only effective in the calibration mode and can be ignored in the simulation mode.

3.2 Control File

The control file described in this subsection contains model settings and data directories.

Note: The statements in the control file should be listed in order in a keywords-value manner as following: **Keyword = Value** The statement appearing on the same line should be tab-separated. Comment should begin with a pound sign, #. Keyword is not case sensitive.

Note 1. Keyword and value format

Keywords with * is new in CREST v2.1.

Model Area (obsolete)

CREST v2.1 accepts common geographic data formats that contain information of coordinate systems and projections. Therefore the “Model Area” is removed.

3.2.1 Temporal Settings

The description of keywords and values in the Section of Temporal Settings is given in Table 3-1.

Please note that an EXPLICIT time line system is employed in CREST v2.1 to avoid any confusion of the model time lines. In the system, we define three time conventions in CREST to explicitly represent the time line of the model and forcing, “Begin”, “Center” and “End”. For example, if the time convention is “Begin”, and the start time specified in the control file is 200201010000 (format is yyyymmddHHMM), the time step is 1 hour, then the model runs over its first time step from Jan, 1st ,2002, 00:00 to Jan, 1st ,2002, 01:00. If the time convention is “Center”, the same setting makes the first time step span from Dec, 31st, 2001, 23:30 to Jan 1st , 2002, 00:30. If the time convention is “End”, the model runs from Dec, 31st, 2001, 23:00 to Jan, 1st, 2002, 0:00 at its first time step.

The model time step of CREST UNIQUELY follows the “Center” convention and there is no place to set or modify it. As a result, all the model output time series variables will align to the central time lines defined in this section. For instance, for the temporal settings defined in Figure 3-2, the central lines of each time step are: 200201010030, 200201010130, 200201010230, … In addition, the observation runoff data also follow the same “Center” convention time defined in this section.

Users can offset their own model time lines by simply offset the StartDate, WarmupDate and EndDate while integrating their observation data to the same center. In practice, different forcing data files can have different time convention that can be different from the model’s. Users are required to provide the actual time convention of the forcing data files to let CREST find the best matched forcing date time for the model time lines.

```
################################################################################
# CREST Project File
################################################################################
Version         =       2.1.0
################################################################################
# MODEL Temporal Settings
################################################################################
TimeMark        =       h  #y(year);m(month);d(day);h(hour);u(minute);s(second),
TimeFormat      =          yyyymmddHHMM
TimeStep        =       1
StartDate       =       200201010030
NLoad       =       0
WarmupDate      =       200206310030
EndDate         =       201306240030
################################################################################
```

Figure 3-2 A sample of temporal settings section in the control file (regular mode).

```
TimeFormat      =       yyyymmddHHMM
TimeStep        =       1
StartDate       =       200201010030
NLoad       =       8
WarmupDate_1        =       200301240030
EndDate_1       =       200303170030
WarmupDate_2        =       200303170030        # calib1
EndDate_2       =       200304070030
WarmupDate_3        =       200304070030
EndDate_3       =       200304240030
WarmupDate_4        =       200305060030
EndDate_4       =       200306060030
WarmupDate_5        =       200408140030        #calib2
EndDate_5       =       200408300030
WarmupDate_6        =       200606120030        #calib3
EndDate_6       =       200606250030
WarmupDate_7        =       200611050030        #calib4
EndDate_7       =       200612220030
WarmupDate_8        =       201003270030
EndDate_8       =       201004100030
WarmupDate      =       200206310030
EndDate     =       201306240030
```

Figure 3-3 Sample temporal settings in the control file (flood event mode)

Table 3-1 Temporal Settings in the control file

Keyword	Value (type)	Description
TimeMark	d|h|u	The unit of time step. "**d**" (day), "**h**" (hour), "**u**" (minute).
TimeStep	integer	Time interval (step) in TimeMark
TimeFormat*	string	The time format convention used by all temporal variables in this section e.g. "yyyymmddHH"
StartDate	date	The start time of the simulation or calibration. Its format is defined by TimeFormat
NLoad*	integer	The number of flood events. In the regular mode, NLoad=0 and "StartDate", "WarmupDate" and "EndDate" controls the running period. In flood event mode, CREST only simulate/calibrate the period during "NLoad" flood events an while "StartDate", "WarmupDate" and "EndDate" are ineffective
WarmupDate	date	The ending date time of warming up of the simulation. Its format is defined by "TimeFormat"
EndDate	date	The end time of the simulation, its format is defined by "TimeFormat".
WarmupDate_i	integer	The beginning date time to load state variables to run CREST

		in the flood event mode.
EndDate_i	integer	The End date time to load state variables to run CREST in the flood event mode, where 0<i<=NLoad. Its format is defined by "TimeFormat".

3.2.2 Style and Options

Users set the running style and model options in this section in the control file.

```
##############################################################################
#Style and Options
##############################################################################
RunStyle		=	simu # simu, cali_SCEUA
Feedback		=	No	# routing feeds the LSM back
hasRiverInterflow	=	No	#No: all interflow turns to surface flow in the river
UseLAI		=	No	# compute the rainfall interception
##############################################################################
```

Figure 3-4 A sample of the Style and Options Section in the control file

Table 3-2 Style And Options Section in the control file

Keyword	Value	Default	Description
RunStyle	simu|calib_SCEUA	N/A	"simu" stands for the simulation mode while "calib_SCEUA" stands for the automatic calibration mode using the SCE-UA method.
Feekback*	Yes|No	Yes	"Yes" means that the routing process feeds back the rainfall-runoff process
hasRiverInterflow*	Yes|No	No	"No" means that all interflow turns to surface flow in channels
useLAI*	Yes|No	No	"Yes" is reserved for later versions.

3.2.3 Model Directory

In this section in the control file, directory of all input and output data files is specified.

```
BasicFormat      =   .tif #any gdal supported formats
BasicPath        =   "\\TRAJANVS\simulation\US_Basins\Tar\BASIC\"
################################################################################
ParamPath        =   "\\TRAJANVS\simulation\US_Basins\Tar\Param\Parameters_nofeed_noRiverInterflow_02-05.txt"
################################################################################
StatePath        =   "\\TRAJANVS\simulation\US_Basins\Tar\States\"
################################################################################
ICSPath          =   "\\TRAJANVS\simulation\US_Basins\Tar\ICS\"
################################################################################
# external rainfall settings
RainFormat       =   .24h.Z
RainDateFormat      =    yyyymmddHH
RainDateConv        =    End
RainStart     =      2002010112
RainDateInterval        =      0000000100
RainPathExt         =   "\\TRAJANVS\data\mete_data\StageIV_daily\ST4."
RainTsScaling       =   1
# internal rainfall setting
RainPathInt      =       "\\TRAJANVS\simulation\US_Basins\Tar\rains_daily\rain."
################################################################################
PETFormat        =   .bil
PETDateFormat       =   yymmdd
PETDateConv      =      Begin
PETStart      =   020101
PETDateInterval     =   000001
PETPathExt          =    "\\TRAJANVS\data\mete_data\PET_FEWS\et"
PETTsScaling     =   100 # FEWS data has a 100 scaling factor: http://earlywarning.cr.usgs.gov/fews/global/web
# internal PET setting
PETPathInt    =      "\\TRAJANVS\simulation\US_Basins\Tar\PETs_daily\PET."
################## LAI is not utilized in v2.1.0 yet. This part can be ignored in this version
LAIFormat        =   _mosaic.tif
LAIDateFormat       =   yyyy\DOY
LAIStart      =   2006\001
LAIDateInterval     =   0000\008
LAIPathExt          =    "C:\data\LAI\Mosaic\"
LAITsScaling     =   10 # LAI data has a 10 scaling factor and 255 is water body: http://glass-product.bnu.edu
LAIDateConv      =      Center/d/file/wendangziliao/suanfawendang/2014-03-13/GLASS%20LAI%E4%BA%A7%E5%93%81%E7%9
LAIPathInt          =    "C:\data\LAI\Mosaic\"
LAIPathInt          =    "\\TRAJANVS\simulation\US_Basins\Tar\LAI_daily\"
################################################################################
ResultPath       =   "\\TRAJANVS\simulation\US_Basins\Tar\result\"
################################################################################
CalibPath        =   "\\TRAJANVS\simulation\US_Basins\Tar\Calib\"
################################################################################
OBSDateFormat       =    yyyymmdd
OBSPath          =   "\\TRAJANVS\simulation\US_Basins\Tar\OBS\"
```

Figure 3-5 A sample of Model Directory in the control file

As shown in Figure 3-5, CREST separates the input and output data into 9 categories: "Basic", "Param", "States", "ICS", "Rains", "PETs", "Result", "Calib" and "OBS". Each category has a standalone folder denoted by "*Path", for example, the "BasicPath". The name of the folders is user-specified while the keywords are fixed. The statements in this section is written in the keyword/value format defined in Note 1.

3.2.3.1 The Basic Section

The basic folder contains the raster files of the same format that stores the geographic information of the basin. The full path of these files is "known" by CREST using the information specified in this section as described in Table 3-3. For e.g., the full path of the DEM file is specified as BasicPath +"dem"+ BasicFormat.

Table 3-3 Basic section in the control file.

Keyword	Value	Description
BasicFormat	The extension of an image file. Default is Geotiff '.tif'	file name extension
BasicPath	A string of a valid directory that ends with a '\'	Physical path of the basic folder

3.2.3.2 Param, State and ICS Sections

The “Param” and “ICS” folders contain text files of model parameters and the initial condition respectively. The key/value format of these files appears the same as in the control file defined in Note 1. The file format in “Param” and “ICS” folders is fixed to ‘.txt’ while the format in the States folder is fixed to “.mat”.

3.2.3.3 Forcing Sections

The forcing Sections are the trickiest. It includes the rainfall, PET and the LAI subsections. The three forcing sections have the same structure with the rainfall section being shown in Figure 3-6 as an example. CREST incorporates two mechanisms to efficiently read the forcing file: reading from external formats and from the internal format. The external format can be in arbitrary image format of a standard coordinate system. The internal format is in matlab’s “.mat” matrix. When the model runs in the simulation mode, it first check the existence of internal files, if they exist, the model uses read the internal files; otherwise, it tries to read the external file on the missing date time and then save it in the internal format for next time use. Reading the external forcing file can be significantly slower than the internal one because it may involve the decompression, resampling, reprojection and clipping. As a result, it is recommended to run the model in the simulation mode for the first time and then to play the model at any styles the user desire.

Table 3-4 lists the variables in the rainfall section as an example. In this example, daily stageIV data is used, the file name without directory is “yyyymmdd12.24h.Z”. It should be noted that different forcing data source has its own label (file name) convention. Since stageIV data follows the “End” time convention, in the previous example, yyyymmdd12 means the rainfall time step starts from yyyy year mm month dd-1 day 12 am. and ends at yyyy year mm month dd day 12am.. Therefore, it centers at yyyy year mm month dd day 0 am. Please refer 3.2.1 to the definition of different time conventions.

Considering the external forcing time step/convention can be different from the model’s, users are required to provide the NEAREST date time of the forcing to the model’s actual start time as ForcingStart (RainStart, PETStart, LAIStart). Please compare the forcing and temporal settings sections in the control file of the example basin for clarity.

```
################################################################################
#_external_rainfall_settings
RainFormat          =     .24h.Z
RainDateFormat          =     yyyymmddHH
RainDateConv            =     End
RainStart           =     2002010112
RainDateInterval            =     0000000100
RainPathExt         =     "G:\mete_data\StageIV_daily\ST4."
RainTsScaling           =     1
#_internal_rainfall_setting
RainPathInt         =     "G:\simulation\US_Basins\Tar\rains_daily\rain."
```

Figure 3-6 A sample of the Forcing Section in the control file.

Table 3-4 Basic section in the control file

Keyword	Example Value	Description
RainFormat	.24h.Z	The extension of the EXTERNAL forcing file. Note that the extension means all content after the date time part The file can be a compressed file. CREST will identify this by its extension (.zip, .rar, .z, .7z) and decompress it using the user specified decompression software if necessary. WinRAR is currently supported in windows platforms.
RainDateFormat	yyyymmddHH	The time format used by RainStart, and RainDateInterval.
RainDateConv	Begin|Center|End	The time convention used by the time label (file name) of rain forcing files
RainStart	2002010112	The first start date time of rain forcing that will be used by the model.
RainDateInterval	0000000100	The rain time interval in RainDateFormat.
RainPathExt	"\\server\StageIV_daily\ST4."	The directory of external rain files
RainTsScaling	1	The scaling factor to convert the original data contained in rain file to mm/TimeMark.
RainPathInt	"\\Server\Tar\rains_daily\rain."	The directory of internal rain files.

3.2.3.4 The Result Section

The result Section specifies the directory of the result folder.

3.2.3.5 The Calibration Section

The calibration Section specifies the directory of the calibration folder and the calibration mode which is either parallel or sequential as in

```
################################################################################
# calibraton information
################################################################################
CalibFormat     =     asc
CalibPath       =     "G:\simulation\US_Basins\Tar\Calib\"
CalibMode       =     Parallel # Sequential
```

Figure 3-7 A sample of the Calibration Section in the control file

3.2.3.6 The Observation Section

The observation section specifies the directory of the “OBS” folder, the observation date format and the no-data value of the runoff records. Please refer to Chapter 3.2.1 for the requirement of observation time lines.

```
################################################################################
OBSDateFormat    =   yyyymmdd
OBSPath          =   "G:\simulation\US_Basins\Tar\OBS\"
OBSNoDataValue   =   -9999
```

Figure 3-8 A sample of the Observation Section in the control file.

OutPix Information (obsolete)

The shape file contains the information of all sites and thus the outpix information is not needed anymore.

3.2.4 Hydrograph and Channel Output

CREST v2.1 retains the hydrograph from multiple sites whose location is provided in the shape file specified in Section 3.2.5. The sub-basin masks for internal sites are automatically generated by CREST and stored in the result folder.

Instead of outputting selected pixel information, CREST v2.1 outputs the selected variables of the entire river network whose location is read from the stream file in the basic folder.

3.2.5 Outlet Information

CREST v2.1 uses a point feature in the ESRI shape file format to represent the location of the outlet rather than texts of the latitude and longitude. Therefore, only the file name of the shape file is specified in the control file. In addition, the shape file MUST contain a projection.

```
################################################################################
#Outlet_Information
################################################################################
HasOutlet        =   yes
OutletName       =   02083500   #02083500_the_filename_of_observation
SitesShpFile     =   Tar_All_sites.shp  # the shapefile name
```

Figure 3-9 A sample of the outlet information in the control file.

Table 3-5 Outlet Information section in the control file

Keyword	Example Value	Description
HasOutlet	Yes|No	Yes: the basin has an outlet. In this version, it is always yes.
OutletName	02083500	The name used to specify the observation file and the

		first field of the site (a point feature) in the shape file.
OutletShpFile	02083500.shp	File name of the shape file that contains the outlet location as a point feature. The first field of the point feature must be the OutletName. The default directory of the shape file is the “obs” folder.

3.2.6 Grid Outputs

Grid Outputs is used to select the 2-D gridded variables to output at EVERY time step. The selected (of Yes value) variables will be output to the result folder and the file name will be suffixed by the date time in model’s temporal format. The default format of the 2-D gridded files is GeoTiff (.tif). Grid outputs is time consuming and not recommended during the calibration.

```
##############################
#Grid Outputs
##############################
GOVar_Rain          =      no
GOVar_PET           =      no
GOVar_EPot          =      no
GOVar_EAct          =      no
GOVar_W             =      no
GOVar_SM            =      no
GOVar_R             =      no
GOVar_ExcS          =      no
GOVar_ExcI          =      no
GOVar_RS            =      no
GOVar_RI            =      no
##############################
```

Figure 3-10 Sample Grid Outputs in the control file

Keyword	Description
GOVar_Rain	The input precipitation in mm/timestep
GOVar_PET	The input PET; in mm/timestep
GOVar_EPOT	**GoVar_PET*KE, calibrated PET used in the model**
GOVar_EAct	The actual evapotranspiration in mm/ timestep
GOVar_W	The depth of water filling the pore space bucket "**WM**"
GOVar_SM	volumetric soil moisture that equals **GOVar_W/WM**
GOVar_R	The simulated discharge of **EACH** grid cell **IN THE RIVER** in m^3/s.
GOVar_ExcS	The depth of surface excess rain in mm
GOVar_ExcI	The depth of infiltrated excess rain in mm
GOVar_RS	The depth of overland flow in mm

GOVar_RI	The depth of interflow flow in mm

3.2.7 State to Save

CREST v2.1 is able to run at a flood event (FE) mode, in which the initial state of each event must be reloaded. These states were saved during a previous simulation. The previous run can be at a different time step while save the states as at an offset time (in its file name) to adjust to the time line in the FE mode. For instance, in Figure 3-11, the first save date time is at 0:00 am., Oct. 8th, 2002. To adjust to a FE mode at hourly scale that centered at XX:30, a minimum 30 min offset is added to make the first saving date time 00:30 am., Oct. 8th 2002.

```
################################################################################
NumOfOutputDates    =    24 #0
SaveDateFormat      =    "yyyymmddHHMM"
DateOffset          =    000000000030
OutputDate_1        =    2002100800
OutputDate_2        =    2002120500
OutputDate_3        =    2003012400
OutputDate_4        =    2003031700
OutputDate_5        =    2003040700
OutputDate_6        =    2003050600
OutputDate_7        =    2003060600
OutputDate_8        =    2003080300
OutputDate_9        =    2003091700
OutputDate_10       =    2003120600
OutputDate_11       =    2004081400
OutputDate_12       =    2004083000
OutputDate_13       =    2006061200
OutputDate_14       =    2006082900
OutputDate_15       =    2006110500
OutputDate_16       =    2009022800
OutputDate_17       =    2009031500
OutputDate_18       =    2009102700
OutputDate_19       =    2009120200
OutputDate_20       =    2010011700
OutputDate_21       =    2010032700
OutputDate_22       =    2010091900
OutputDate_23       =    2011082300
OutputDate_24       =    2013060800
```

Figure 3-11 Sample Output Dates in the control file

Keyword	Example Value	Description
NumOfOutputDates	24	The number of saving states
SaveDateFormat	"yyyymmddHHMM"	The date time format AFTER offset
OutputDate_i	2002100800	A string that contains the saving date time BEFORE offset

3.2.8 Unzip software and OS Information

This section provides the decompression software strings and the information of operational system (OS). The OS is either windows or linux. The string specified by **DecompBeforeSrc** stores the command needed before the compressed file name while the string specified by **DecompBeforeDst** stores the command needed before the uncompressed file. The complete command of decompression of the example in Figure 3-12 would be,

"C:\sys\WinRaR\WinRAR.exe" -ibck x zipfileFullPath unzipfileFullPath

```
##############################################################################
# unzip software and OS information
##############################################################################
DecompBeforeSrc    =    ""C:\sys\WinRaR\WinRAR.exe" -ibck x "
DecompBeforeDst    =    " "
OS                 =    "windows" #linux
```

Figure 3-12 A sample of the Unzip Software and OS Section in the control file

3.3 Folders and Files

CREST v2.1 can read more than 200 the raster file formats supported by GDAL. Users only need to prepare the basic files and other text files. The decompression, reprojection, resample and clipping of the forcing file according to the configuration of the basic file is automatically conduct by CREST. Therefore, Users can save their space and time in preparing forcing files for each basin.

3.3.1 Basic Folder

This folder contains the raster files that represent the geographic information of the basin and a text file that defines the average height difference: a DEM (Digital elevation model) file, an FDR (Flow Direction) file an FAC (Flow Accumulation) file a stream file. All files except the slope file is in a geographic data format with a projection. From CREST v2.1, the model accepts any commonly used raster formats supported by GDAL. Raster files in this folder only contains grid-cell values within the basin area while the grids out of the basin is marked by Null value which is explicitly recorded in the each raster file, as done by the SetNull function of the ArcGIS Map Algebra tool. In addition, the regions in all four raster files MUST have exactly the same size and basin area. Users can use a GIS tool to generate the files in this folder. We also attached a python script that calls ArcGIS routines to prepare all raster files for CREST.

Table 3-6 Contents in the basic folder

Name	File name by default	Format	***Optional***	Description
DEM	dem.*	any	No	The digital elevation model
FDR	fdr.*	any	No	Flow direction (code defined as in ArcGIS, 1-128)
FAC	fac.*	any	No	Flow accumulation (value defined as in HydroSHEDS, i.e., the high ends(minimum value) is 1) in pixel

stream	stream.*	any	No	Value in the river is 1, otherwise is 0
slope	Slope.def	.def (text)	No	Contains the GM value that defines the pre-defined mean height difference. It is used for calculate the slope at the outlet or other places where the slope value is invalid from the DEM map. A second value is the height of the adjacent downstream cell of the outlet. The second value is optional.

Mask, GridArea and AreaFact files are obsolete since CREST v2.1.

3.3.2 Param Folder

This folder contains a parameter.txt file that records all 15 model parameters that are categorized as physical and conceptual types (see Table 3-7). The model parameters in CREST v2.1.0 remains the same as in CREST v2.0. The parameter.txt file also

Table 3-7 Classification in CREST v2.1

Type	Parameter	Description	Min	Default	Max	Unit
Physical Parameters	RainFact	The multiplier on the precipitation field	0.5	1.0	1.2	
	Ksat	The Soil saturate hydraulic conductivity	0	500	3000	mm/day
	WM	The Mean Water Capacity	80	120	200	mm
	B	The exponent of the variable infiltration curve	0.05	0.25	1.5	
	IM	The impervious area ratio	0	0.05	0.2	
	KE	The factor to convert the PET to local actual	0.1	0.95	1.5	
	coeM	The overland runoff velocity coefficient	1	90	150	
Conceptual Parameters	expM	The overland flow speed exponent	0.1	0.5	2	
	coeR	The multiplier used to convert overland flow The speed to channel flow speed	1	2	3	
	coeS	The multiplier used to convert overland flow The speed to interflow flow speed	0.001	0.3	1	
	KS	The overland reservoir Discharge Parameter	0	0.6	1	
	KI	The interflow Reservoir Discharge Parameter	0	0.25	1	

follows the keyword/value format defined in Note 2. Furthermore, each variable is not only defined by its value, but also defined by its type, i.e., the "varNameType" keyword. The type can only be uniform or distributed. If the type of a parameter is distributed, it's the value should be a file name in the "Param" folder of a raster file that exactly matches size and basin area defined by the files in the basic folder. The limits and the default value of uniform parameters are also listed in Table 3-7.

3.3.3 State Folder

This folder contains the saved model state files named by the date time specified in Section 3.2.7. The state files are in matlab ".mat" format. The State folder is an output folder for regular running mode whereas an input folder for the FE mode. In the FE mode, CREST loads the state variables saved by a previous simulation in the regular mode. However, the date time to load is specified in the "temporal Settings" section in the control file rather than the "State to Save" section.

3.3.4 ICS Folder

This folder has an "initilalCondition.txt" file that contains uniform variables listed in Table 3-8 as the model initial condition. The initial condition file is written in the same format as the parameter file. To let CREST be well distributed, a sufficient warm up period is necessary. This folder is ineffective in the FE mode.

Table 3-8 Classification in CREST v2.1

Keywords	Unit	Description
W0	%	Initial Value of Soil Moisture
SS0	mm	Initial value of Overland Reservoir
SI0	mm	Initial value of Interflow reservoir

3.3.5 OBS Folder

This folder contains the shape file (location) of the outlet and the observed runoff data excel file. For the model calibration or validation. The file name of the observed runoff is "OutletName_Obs.csv" (".csv" is the comma delimited file) where the "OutletName" is specified in the project file and the file name of the shape file is specified in the control file. The OutletName_Obs.csv has two columns WITH head. The first and second columns record the date time and runoff respectively. The date time must follow the model time step. The location shape file specified in Section 3.2.5 contain the position of outlets as point features. Each point feature contains one site. Only the site of the outlet name specified by the **OutletName** keyword is acknowledged as the outlet used to evaluate the model performance and calibrate.

The time zone of CREST is arbitrary but is usually UTC because the date time of most forcing data is measured in UTC. Users should carefully adjust the time zone of their observation data to the model's if their observation data is measured in local time zone. This is especially important for sub-daily running.

3.3.6 Calibs Folder

This folder has a "calibration.txt" file that contains the calibration configuration site name and ratio limits of the model parameters as shown in Figure 3-11 and detailed in Table 3-9.

```
################################################################################
# CREST Calibrations File (Version more than 2.0)
################################################################################
iseed           =       -3
maxn            =       10000
kstop           =       8
pcento          =       0.001
ngs             =       4
################################################################################
NCalibStations  =       1
################################################################################
[Station 1 Begin]
Name_1              =       02083500
RainFact_1          = 0.6   0.8   1.4
Ksat_1              = 1     37    200
WM_1                = 40    120   500
B_1                 = 0.2   1     6
IM_1                = 0.1   1     4
KE_1                = 0.1   1     1.5
coeM_1              = 1     90    150
expM_1              = 0.2   0.5   1.1
coeR_1              = 0.5   1     1.5
coeS_1              = 0.003   1   3.33
KS_1                = 0.001   1   2
KI_1                = 0.001   1   4
[Station 1 End]
```

Figure 3-13 Sample of "Calibrations.txt" file

Table 3-9 content in the Calibrations.txt

keyword	Type	Description
iseed	SCE_UA	The initial random seed
maxn	SCE_UA	The max no. of trials allowed before optimization is terminated
kstop	SCE_UA	The mumber of shuffling loops in which the criterion value must change by the given percentage before optimization is terminated
pcento	SCE_UA	The Percentage by which the criterion value must change in given number of shuffling loops
ngs	SCE_UA	The Number of complexes in the initial population
NCalibStations	Stations	The Number of Calibrated Stations
Name_i	Stations	The name of the **i**th station
Rainfact_i	parameters	The possible range of RainFact
...	parameters	…

The format of for parameters to be calibrated is:

ParameterName_i = Min Value Max

where, **i** is the station No. and Min, Value, Max are the lower limit, initial value and up limit of the parameter to be calibrated. This file is only required in the calibration style. Note that the limits and value of all parameters in the calibration.txt are ratios rather than absolute values. The actual value of a given parameter in the model is the product of its ratio in the "calibration.txt" and its value in "parameters.txt" in a calibration running style. In the simulation style, the calibration folder is ineffective. Currently, CREST only supports single site calibration. Therefore, NCalibStations≡1 and i≡1. Multi-site calibration mode is coming soon.

3.3.7 PETs Folder

This folder only contains the INTERNAL potential evaporation data files named by their date time. Please refer to Chapter 3.2.3.3 on the data time format and directory of this folder. And. In the first time simulation of the basin, if the PETs empty, CREST v2.1 automatically decompresses (if necessary), re-project, resample and clip the external forcing file to the projection, region and resolution defined in your basic (geographic) files. The processed forcing files will be saved in internal ".mat" format in this folder. For later runs, if CREST finds the internal forcing files, it will ignore the external ones and use the internal ones directly. In practice, we encourage you to store your global/regional external forcing files in one fixed location and let model convert between the external and internal files to save your space and preprocessing time. Due to the complex procedure of importing external files, it can be time consuming in simulating a basin for the first time. However, for later simulations or calibrations, the model runs significantly faster.

3.3.8 rains Folder

This folder only contains the internal rainfall files named by their date time. Please refer to Chapter 3.2.3.3 on the data time format and directory of this folder. All rules in Chapter 3.3.7 apply in this folder as well.

3.3.9 Results Folder

This folder contains sub-basin masks hydrographs, output grid-variables and calibration results in multiple formats. The hydrographs are stored in csv files, grid-variables are in .tif fomat and in time series.

4 Run Styles and Modes

In this chapter, we introduce the output differences between running styles and modes. Please refer to 3.2.2 on how to set different running styles and modes in the control file. In CREST v2.1, there are the simulation and calibration running styles, regular and flood event modes.

4.1 Outputs in the Simulation Style

```
>> CRESI(globalCtl,'mean',gdalPath,4);
2003/01/24:01:30
2003/01/24:02:30
2003/01/24:03:30
2003/01/24:04:30
2003/01/24:05:30
2003/01/24:06:30
2003/01/24:07:30
2003/01/24:08:30
2003/01/24:09:30
2003/01/24:10:30
2003/01/24:11:30
2003/01/24:12:30
2003/01/24:13:30
2003/01/24:14:30
2003/01/24:15:30
2003/01/24:16:30
…
2010/04/09:08:30
2010/04/09:09:30
2010/04/09:10:30
2010/04/09:11:30
2010/04/09:12:30
2010/04/09:13:30
2010/04/09:14:30
2010/04/09:15:30
2010/04/09:16:30
2010/04/09:17:30
2010/04/09:18:30
2010/04/09:19:30
2010/04/09:20:30
2010/04/09:21:30
2010/04/09:22:30
2010/04/09:23:30
2010/04/10:00:30
NSCE=0.77693
Bias=0.56553
CC=0.90774
```

Figure 4-1 Screen output in simulation style.

The hydrographs and other selected model output variables are stored the results folder. The hydrograph is a excel file named by its corresponding outlet as shown in Figure 4-2 . If some gridded outputs are enabled, image files named by the date time are also generated in the result folder.

	Date	rainAct	rain	PET	Eact	W	SM	excS	excI	RS	RI	R	R_Obs
2	2002/01/01:00	0	0	0.012947	0.002589	20.14263	0.199974	0	0	0.630848	0.196405	1.233428	-9999
3	2002/01/01:01	0	0	0.012947	0.002589	20.14004	0.199949	0	0	0.646469	0.189943	1.804652	-9999
4	2002/01/01:02	0	0	0.012947	0.002589	20.13745	0.199923	0	0	0.66126	0.183779	2.421881	-9999
5	2002/01/01:03	0	0	0.012947	0.002588	20.13486	0.199897	0	0	0.67526	0.177898	3.048109	-9999
6	2002/01/01:04	0	0	0.012947	0.002588	20.13228	0.199872	0	0	0.68851	0.172281	3.668472	-9999
7	2002/01/01:05	0	0	0.012947	0.002588	20.12969	0.199846	0	0	0.70105	0.166914	4.281276	-9999
8	2002/01/01:06	0	0	0.012947	0.002587	20.1271	0.19982	0	0	0.712918	0.161783	4.891398	-9999
9	2002/01/01:07	0	0	0.012947	0.002587	20.12451	0.199794	0	0	0.724147	0.156874	5.505929	-9999
10	2002/01/01:08	0	0	0.012947	0.002587	20.12193	0.199769	0	0	0.734769	0.152173	6.131489	-9999
11	2002/01/01:09	0	0	0.012947	0.002586	20.11934	0.199743	0	0	0.744812	0.147669	6.772747	-9999
12	2002/01/01:10	0	0	0.012947	0.002586	20.11676	0.199717	0	0	0.754301	0.143351	7.431767	-9999
13	2002/01/01:11	0	0	0.012947	0.002586	20.11417	0.199692	0	0	0.763261	0.139207	8.107939	-9999
14	2002/01/01:12	0	0	0.012947	0.002585	20.11159	0.199666	0	0	0.771712	0.135228	8.798282	-9999
15	2002/01/01:13	0	0	0.012947	0.002585	20.109	0.19964	0	0	0.779675	0.131405	9.49797	-9999
16	2002/01/01:14	0	0	0.012947	0.002585	20.10642	0.199615	0	0	0.787171	0.127728	10.20096	-9999
17	2002/01/01:15	0	0	0.012947	0.002584	20.10383	0.199589	0	0	0.794218	0.12419	10.90064	-9999

Figure 4-2 snapshot of the hydrograph file.

4.2 Outputs in the Calibration Style

Since CREST v2.0, SCE-UA (Duan et al., 1992) is selected as the kernel algorithm in calibration process. In CREST v2.1, SCE-UA is parallelized using the shared memory multiprocessing (OpenMP) approach.

CREST v2.1 directly uses the screen output of SCE-UA codes in matlab written by Duan et al., 1992. The objective function value is the NSCE of each simulation. CREST v2.1 also outputs the calibration process to a log file in the “Results” folder, named as “log.txt”. The calibration result is output both to the screen and to a file named “SCE_UAyyyymmdd_hh.txt” in the same folder.

4.3 Flood Event (FE) Mode

The only difference between the FE and regular mode is that the FE mode only outputs everything within the period of the flood events specified in the control file. The FE mode can be used in both simulation and calibration style and saves a lot of computational time since it skips the non-flood event periods. Please refer to Chapters 3.2.1 and 3.2.7 about the FE mode.

5 Setting up CREST in other basins

Users can run CREST in their own basins after installation. The CREST model automatically runs over the region defined by geographic images in the basic folder. All files in this folder must be prepared before running the models. Forcing files are also necessary but CREST deals with most of the preprocessing.

Please follow the steps below to setup a basin of a user’s own.

1. Create a project folder that contains all folders described in Chapter 3.2.8.

The name of the project folder is arbitrary.

2. Create a control file by either
    a. Copying the existing project file provided in the example Tar basin folder and modifying the content according to your own basin.

or

    b. Filling the content following the instructions in Chapter 3.2.

    Please note that all sections in the control file are necessary for CREST. Please use the switchers to mute the sections not needed rather than removing those sections
3. Generate the geographic (basic) files required in the basic. Please also refer to Chapter 3.3.1 for the definition and generation of basic files.
4. Create and fill the files needed in the "Param" and "ICS" folders. Please refer to Chapters 3.3.2 and 3.3.4 for the files in these folders.
5. Prepare the observation files needed in the "OBS" folder. Please refer to Chapter 3.2.3.6 and 3.3.5 for these files.
6. Run the model in simulation style using the commands introduced in Chapter 3.1.
7. If a calibration process is needed, please also create and fill the files in the "Calibs" folder and switch the running style in the control file accordingly. Please refer to Chapter 3.3.6 for the calibration file and the parameter difference in the calibration and simulation styles. The parameters used in the simulation style and calibration style are determined by different files. Note that a lot of users failed to calibrate the model by failing to notice this difference.
8. A user must remember to multiply the calibrated "ratios" and magnitude values in the parameter file used in the calibration process provided he needs to simulate the basin using his calibrated model parameters.

6 Contact us

The official version of the OU-NASA CREST model has been developing and maintaining in the Hydrometeorology and Remote Sensing Laboratory, University of Oklahoma (http://hydro.ou.edu) and Atmospheric Radar Research Center (ARRC) located in the National Weather Center (http://nwc.ou.edu). For the information about the current release of the CREST model, the source code of beta versions and technical support, please send e-mail to Prof. Yang Hong (yanghong@ou.edu) and Dr. Xinyi Shen (shen.xinyi@ou.edu).

7 Selected CREST model Related References

7.1 Model References

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7.2 Additional References

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