'MARSSIM' LANDSCAPE EVOLUTION MODEL ***release 4.0***

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This is the documentation for a landform evolution model variously termed DELIM and MARSSIM the publications listed below. The model is built upon the landform evolution model first described by Howard (1994). The core model primarily focuses on landform evolution at relatively long temporal scales (relative to the timescale for noticeable landform change) through fluvial and mass wasting processes. The program is designed be computationally efficient such that individual runs can be done on a modern microcomputer in no more than a few tens of hours. The more recent additions to the model have focused on processes relevant to planetary landscapes, including lava flows, groundwater seepage and sapping, impact cratering, surface-normal accretion and ablation, and volatile redistribution by radiation-induced sublimation and recondensation. Individual process formulations vary from completely heuristic to modestly mechanistic. Important limitations for some potential applications are the assumption of a single representative bed material grain size in the fluvial system and no tracking of internal stratigraphy of sedimentary deposits (except for total thickness and surface morphology). Some stratigraphic information can be gleaned by frequent reporting of elevation changes through time on sedimentary deposits.

The package includes 6 directories:

- **accessory_programs**: See **accessory_programs** below
- **documentation**: This file and the GUI interface with its subdirectories
- **execution_directory_files**: the parameter files, example files for a simple simulation, clearerode.sh (linux) and clearerode.(windows) erases any lingering files from previous runs. runname.sh (linux) rinname.bat (windows) renames output files to have a six letter/number prefix (from the command line) and creates a zipped archive. ERODE.STOP.NO, ERODE.STOP, and ERODE.STOP.YES for controlling program execution.
- **parameter_files**: Another copy of the default parameter files
- **real_craters**: A directory containing the files necessary to simulate new craters using martian fresh craters

source_files: The source files for MARSSIM plus example compilation and files for linux using intel fortran. This uses the –fast option which requires static clib libraries. If these are not installed substitute –O3 for -fast. For debugging substitute –g for –fast.

This package also includes a GUI interface to documentation and parameter editing. This interface consists of the python program ***interface.py*** which interfaces with the tkinter and tk modules of the base distribution of Python3. To use the interface you must have interface.py in a directory with the full set of parameter files plus two subdirectories, doc and backup. The doc subdirectory has all the explanatory text files supplying the documentation. The backup directory can initially be empty but will a repository for edited version of the 13 parameter files included with the distribution. To use the program the entire folder **AppJar** must be copied to the **lib** directory of the Python 3 distribution. This is a public domain interface to tkinter. The simplest way to use ***interface.py*** is to open a terminal (linux) or Command Prompt (Windows) in an environment with execution paths to the Python 3 package and change to the directory containing interface.py and its subdirectories. Type *idle* or *idle3* and open the ***interface.py*** program and then run the program. Two main tabs appear. The initially-displayed tab, *DOCUMENTATION*, has buttons which bring up windows containing documentation about various aspects of the MARSSIM package. Just click on the X or the red dot (Mac OS) on the title bar to close any open window. The *EDIT PARAMETERS* tab displays the names of the 13 parameter files and three other buttons. **The *Parameter Editing and Description* button describes the functionality of this part of the interface and should be read before opening individual parameter files**. The *Read parameter files from a directory* button can be used to transfer all the parameter files to the directory including ***interface.py***, and similarly *Write parameter files to a directory* can be used to transfer the edited parameter files to a MARSSIM execution directory. These directories must exist prior to reading or writing. **Because the edited file are stored in the interface directory, be sure to invoke *Write parameter files to a directory* into the program execution directory**. Clicking on any of the parameter files opens an editing and documentation window containing the parameter file in 3 columns. The leftmost column contains the numerical parameters in an editable window. The second column brings up a subwindow with detailed information about the role of the parameter, permissible values, and in some cases hints about the appropriate value range for the parameter. The third column is a short identification of the parameter. If you edit a parameter and want to save its value, be sure to click the *Save* button at the bottom of the window, because saving is not done automatically. The third main tab *RUN MARSSIM* is incomplete and may be eliminated. **Even if the GUI interface is not used for parameter editing, the detailed parameter documentation for each parameter file contains important information for using MARSSIM and about the inner workings of the program.** A table describing the role of individual parameters is also included in the present document, although the GUI version descriptions are considered to be the definitive documentation.

In addition to this document and the GUI interface, the program source code contains numerous comments within the source files. If martian fresh craters are to be used to simulate new crater morphology, see the discussion at the end of this document.

The process formulation is described in the following publications:

1994 Howard, A.D., A detachment-limited model of drainage basin evolution, *Water Resources Research*, Vol. 30, No. 7, p. 2261-2285.

1997 Howard, A. D., Badland morphology and evolution: Interpretation using a simulation model. *Earth Surface Processes and Landforms*, v. 22, 211-227.

1999 Howard, A.D., Simulation of Gully Erosion and Bistable Landforms, book chapter, in *Incised River Channels*, edited by S. Darby and A. Simon, John Wiley & Sons, p. 277-300 & plates.

1999 Howard, A. D., Simulation of lava flow inundation on Martian cratered terrain, Lunar and Planetary Science Conference XXX, Abstract 1112. http://www.lpi.usra.edu/publications/meetingpubs.shtml

2004 Forsberg-Taylor, N.K., Howard, A.D. and Craddock, R.A., Crater degradation in the Martian Highlands: morphometric analysis of the Sinus Sabaeus region and simulation modeling suggest fluvial processes, *Journal of Geophysical Research, Planets.*109, E05002, doi:10.1029/2004JE002242.

2004 Fagherazzi, S., Howard, A. D., and Wiberg, P. L., Modeling fluvial erosion and deposition on continental shelves during sea level cycles. *Journal of Geophysical Research,* v. 109, doi:10.1029/2003JF000091.

2004 Howard, A. D., Simple non-fluvial models of planetary surface modification, with application to Mars, Lunar and Planetary Science Conference XXXV, Abstract 1054. http://www.lpi.usra.edu/publications/meetingpubs.shtml

2007 Howard, A. D., Simulating the development of martian highland landscapes through the interaction of impact cratering, fluvial erosion, and variable hydrologic forcing, *Geomorphology*, v. 91, p. 332-363.

2008 Howard, A. D., and Moore, J. M., Sublimation-driven erosion on Callisto: A landform simulation model test. *Geophysical Research Letters,* v. 35, L03203, doi:10.1029/2007GL032618.

2008 Luo, W., and Howard, A. D., Computer simulation of the role of groundwater seepage in forming Martian valley networks, *Journal of Geophysical Research, Planets,* vol. 113, E05002, doi:10.1029/2007JE002981.

2009 Barnhart, C. J., Howard, A. D., Moore, J. M., Long-term precipitation and late-stage valley network formation: Landform simulations of Parana Basin, Mars, *Journal of Geophysical Research Planets,* vol. 114, E01003, doi:10.1029/2006JE003122.

2011 Matsubara, Y., Howard, A. D., Drummond, S. A., Hydrology of early Mars: Lake basins, *Journal of Geophysical Research,* 116, doi:10.1029/2010JE003739.

2012 Howard, A. D., and Tierney, H.E., Taking the measure of a landscape: Comparing simulated and natural landscapes in the Virginia Coastal Plain, USA., *Geomorphology* 137, p. 27-40.

2012 Howard, A. D., Moore, J. M., Schenk, P. M., White, O. L., and Spencer, J. Sublimation-driven erosion on Hyperion. Topographic analysis and landform simulation model tests. *Icarus,* 220, 268-276.

2016 Howard, A. D., Breton, S. and Moore, J. M, Formation of gravel pavements during fluvial erosion as an explanation for persistence of ancient cratered terrain on Titan and Mars, *Icarus,* 270, 100-113, http://dx.doi.org/10.1016/j.icarus.2015.05.034.

2017 Moore, J. M., Howard, A. D., Umurhan, O.M. and 13 additional authors, Sublimation as a landform-shaping process on Pluto, *Icarus,* 287, 320-333, doi:10.1016/j.icarus.2016.08.025.

2018 Matsubara, Y., Howard, A. D., Irwin, R. P. III, Constraints on the Noachian paleoclimate of the martian highlands from landscape evolution modeling, *Journal of Geophysical Research, Planets,* 123, 2958-2979, doi:10.1029/2018JE005572

In addition, the following document, included with the distribution, summarizes most of the model components and also includes two unpublished sections on dimensionless scaling and two schemes for measuring the relative amounts of surface modification by various processes (fluvial transport, mass wasting, eolian deposition, and impact cratering).

2002 Howard, A.D., Simulation models for landform evolution on early Mars: Cratering, lava emplacement, eolian modification, weathering, mass wasting, mass flow, and fluvial processes. ***[Marsmodel.pdf, included in distribution]***

The program is coded in standard Fortran 90 in free-form format. It has been successfully compiled with a number of compilers, including *Intel Fortran* (Windows and Linux), *PGI Fortran* (linux), and the public-domain *gfortran*. The *Intel Fortran* and the Linux environments are recommended for fastest execution times. The program runs in a command-line environment (Command Prompt window in Windows, Terminal window in Linux). The following programs and files are included with the distribution (subroutines and functions in the various files are indicated in bold):

marssim_program_v4.doc - this document

Source files (files include subroutines that are generally grouped by process or function) **:**

global_variables.f90	Definition of global variables. These are grouped into several modules related to particular process suites. Most matrices are defined as allocatable arrays whose size is determined at runtime by the input files. Only matrices used for the selected processes are actually allocated.
main_program.f90	This is the main program (**program marssim**), which opens output files, initializes the program, conducts the iterations, and closes the program. **setup_fluvial_slope_erosion** initializes several initial variables and matrices. **do_fluvial_and_slope** is called each iteration when fluvial and/or slope erosion is modeled to invoke the processes. It also calls various routines at set intervals to report on process rates and landform states and to write data files. **finalize_fluvial_slope_erosion** closes down the fluvial and slope modeling parts of the program, summarizes the system state, and writes out and closes output files. **report_max** provides debugging information if calls to it are embedded in the source files.
Initial_and_boundary_conditions.f90	**read_input_parameters** performs as suggested, as well as allocating matrices, reading in the initial elevations plus any other necessary input files from *MARSSIM_INITIAL_BOUNDARY_CONDITIONS.PRM*. The subroutine **initialize_variables** initializes a number of variables and small matrices primarily used for fluvial and mass wasting erosion and file output. In addition it sets up lookup tables for rates of mass wasting and rock weathering as functions of local gradient. If a time-varying ocean level is specified, it reads in the requisite file of levels and times. **normal_random_deviate,** **lognormal_random_deviate,** **lognormal_random_deviate1,** **exponential_distribution,** and **rrand** generate random numbers following the indicated probability distributions (**rrand** provides uniformly distributed numbers between zero and one) **boundary_conditions** is called each iteration to control base level as a function of time (for simulations with an eroding lower boundary) and performs any rock deformation.

	determine_erodibility is called if rock resistance varies through 3-D space. It calls **read_erodibility** to read rock resistance from an input file, '***resist.in'*** **determine_erosion_rate** is called if process parameters change abruptly at set time intervals. **make_event** is called at set times if some abrupt change in the system state is desired. For example, changing certain process parameters or leveling part of the landscape by simulated wave erosion (as included in the source file). This routine would typically be tailored to specific landform evolution scenarios. **find_ocean_elevation** determines the relative level of the ocean if it is time-varying. **change_flow_direction** is used if flow across alluvial surfaces or deltas has a memory requiring a probabilistic event to change (e.g., avulsions of birdfoot deltas) **setup_events** is called at the beginning of the program if specified changes are to be introduced during the simulation. The routine make_event effects the changes. **determine_cratering_rate** can change the background cratering rate during the simulation if so programmed. **allocerror** stops the program if allocatable variables are not successfully initialized.
fluvial_slope_erosion.f90	This contains the main subroutines for fluvial and mass wasting erosion. **read_bedrock_channel_parameters** reads parameters governing bedrock channel evolution from the file *BEDROCK_CHANNEL_PARAMETERS.PRM*. **read_alluvial_channel_parameters** reads parameters from *ALLUVIAL_CHANNEL_PARAMETERS.PRM* governing alluvial sediment transport and deposition in streams and bodies of water. **fluvial_detachment** determines the local fluvial bedrock and regolith erosion rates as a function of shear stress and/or abrasion. It calls **local_values** to determine the spatial variability of controlling variables. It also implements the various options for modeling channel bed erosion **do_the erosion** is the master subroutine coupling fluvial erosion, sediment transport and deposition, mass wasting, weathering, and seepage weathering for each iteration, calling a number of the other subroutines. It controls the overall time increment if fluvial and slope erosion is modeled. It also does elevation changes by fluvial and slope processes during each iteration and controls changes in state (whether locations are alluvial

	or bedrock, in normal or accelerated state of erosion, if the erosion is in a surface crust). **write_debug** and **print_around** are called for debugging purposes. **local_values** calculates fluvial process variables at individual matrix locations.
mass_wasting.f90	**read_mass_wasting_parameters** inputs parameters governing mass wasting from the file *MASS_WASTING_PARAMETERS.PRM***.** **do_mass_wasting** is called by **do_the_erosion** to determine the rate of mass wasting on regolith-covered slopes and to route weathered debris on rock slopes to the nearest downslope non-bedrock location. **rapid_creep** is a lookup function for the rate of mass wasting as a function of local gradient. **rock_mass_wasting** is a lookup function for the rate of mass wasting of bedrock slopes as a function of local gradient
sediment_routing.f90	Contains several routines associated with transport and deposition of alluvium in channels, fans, and deltas. **find_downstream_location** is used to determine the next location downstream for routing of sediment. **write_debug_data** does as it says. **sediment_transport_flux** determines the rate of sediment transport as a function of gradient, flow properties, and sediment characteristics. **equilibrium_sediment_gradient** determines the steady-state alluvial gradient corresponding to specified values of bedload flux and local discharge. **sediment_flux_divergence** is called by **do_the_erosion** and determines the rate of change in alluvial surface elevation as a function of the spatial divergence of sediment transport. **route_sediment** is called by **do_the_erosion** and determines changes in alluvial surface elevation by routing sediment at an equilibrium gradient through channels, across fans, or on deltas. The procedures and assumptions are presented in Howard (1994). This subroutine is called multiple times during an iteration for each location where a bedrock channel debouches on to an alluvial surface. **smoothsed** is optionally called each iteration to cosmetically smooth out the sediment surface calculated by **route_sediment.** **check_if_change_flow_direction** is optionally called *within* individual iterations to change the flow directions

	on alluvial surfaces resulting from the **route_sediment** subroutine. **print_sediment_diagnostics** does as indicated.
weathering.f90	This subroutine weathers rocks. **read_weathering_parameters** inputs the parameters governing rock weathering from the file *WEATHERING_PARAMETERS.PRM.* **calculate_divergence** is called by **do_weathering** to determine local slope divergence. It is based on the local and 8 surrounding points. **new_calculate divergence** uses 25, 49, or 81 points to calculate local divergence if called with NN=5,7, or 9. Thus it determines divergence over a broader spatial scale than **calculate_divergence.** **do_weathering** weathers the bedrock surface both for locations with exposed bedrock (*is_rock_surface* true) and for regolith-covered locations. If it is a regolith-covered surface it increases the thickness of the regolith (*regolith* takes a positive value indicating regolith thickness in this case). If it is a bedrock surface *regolith* takes a negative value indicating the rate of bedrock weathering. For bedrock surfaces weathering rates can be determined by slope steepness and local divergence (e.g., exfoliation) as well as solar radiation (on planetary surfaces), groundwater seepage rates, and glacial erosion. If it is a regolith-covered surface the rate of weathering of the bedrock surface can either be a negative exponential function of regolith thickness or a humped function of regolith thickness (chemical weathering). For glacial flow modeling, eolian deposition and erosion, ablation and condensation the material eroded, deposited, or flowing is labeled as regolith. **find_depression** just determines if the location is a local elevation minimum.
gradient_and_flow_directions.f90	***gradient_and_flow_direction*** determines local topographic gradients (*d8_gradient*) and downstream flow directions (*flow_direction*). The latter is negative for local topographic minima and is unity for fixed boundary locations.
flow_routing.f90	This routes runoff across the landscape. There are two implementations, 1) **drainage_basin_area_flow** routing water under either hyperarid conditions (where runoff disappears instantly in depressions) or fully wet conditions (no evaporation or infiltration – *complete_runoff* is true), or 2)

	drainage_basin_lake_flow which accounts for partial runoff from uplands and evaporation from lakes. **read_flow_parameters** reads the file *FLOW_PARAMETERS.PRM* containing parameter values related to flow routing. **discharge_from_cell** determines the flux of water from each simulation cell, which can be a function of local slope divergence, seepage from groundwater, or state of accelerated erosion. Usually it is just proportional to cell area. **is_it_submerged** determines whether individual cells are under water. **drainage_basin_area_flow** does the flow routing, determining drainage areas and flow amounts within the drainage network, as well as routing sediment through the bedrock channel portions of the network (where transport rates are assumed to be very rapid compared to the simulation time step). Lake elevations and outlet locations are determined (if *complete_runoff* is true) and channel width is determined as a function of local discharge. **basin_report** is used for debugging. **drainage_basin_lake_flow** functions like drainage_basin_area_flow except for partially filled lakes and conditional lake overflow depending upon the evaporation rate. **drawline** and **drawsline** are used to connect inflows to lakes to their exit in order to create images of the flow network. **pelagic_deposit** deposits suspended sediment in lakes. It also diffuses the deposited sediment to create a smooth basin floor. **check_flow_path** is a debugging routine
groundwater_flow.f90	This routes groundwater as DuPuit (horizontal unconfined) flow as a function of assigned infiltration rate, aquifer depth, and permeability. Steady flow is assumed. The rate of seepage back to the surface is determined. This seepage can optionally contribute to (or dominate) surface flows and increase rock weathering rates (see Luo and Howard, 2008) **read_groundwater_parameters** inputs parameters from *GROUNDWATER_PARAMETERS.PRM.* **exponential_hydr_cond_grndwtr** calculates the groundwater flow under the assumption that permeability decreases exponentially with depth beneath the surface.

	constant_hydr_cond_grndwtr calculates the groundwater flow assuming a constant thickness, constant permeability aquifer.
impact_cratering.f90	Geometrically simulates impact cratering using random spatio-temporal impacts following a given production function and crater geometry. See Forsberg_Taylor et al. (2004) and Howard (2007). If desired new craters can be modeled after the topography of selected fresh martian craters. **read_cratering_parameters** inputs parameters from *CRATERING_PARAMETERS.PRM*. **do_impact_cratering** is the master routine called for each simulated impact, calling the other routines. **get_crater_size** determines the crater size as a function of the production function. **find_modification_range** determines how far out from the impact site that ejecta deposition must be modeled **find_impact_site** determines where in X-Y space the impact occurs **create_crater** does the heavy shoveling, transporting, and ejecta spreading if craters are geometrically modeled. **add_central_peak** optionally adds a central peak to craters in the gravitational regime. **find_reference_elevation** determines the average ground location into which the crater is excavated. **create_sediment_cover** optionally sets the crater ejecta to be considered sediment rather than rock or regolith. **create_real_crater** if selected, uses a database of martian fresh crater topography to create a new crater at a specified location and crater diameter.
lava_flows.f90	This simulates episodic lava flows from multiple specified vents. There is some documentation in the file. **read_lava_parameters** reads parameters governing lava flows from *LAVA_FLOW_PARAMETERS.PRM*. **do_lava_flows** is the main subroutine. **find_active_lava_sites** determines where on lava flows new lava extension can occur **find_lava_start_place** determines where a new flow starting from a vent goes **find_next_lava_site** determines where the next cell to be occupied by the flow is.
eolian_erosion_deposition.f90	This heuristically models eolian landform mantling. See Forsberg-Taylor et al. (2004). Some of the routines and parameters are shared with **surface_erosion_deposition**

	routines. **read_eolian_parameters** reads parameters from *EOLIAN_PARAMETERS.PRM*. **do_eolian_change** is the main subroutine. **exposure** determines the degree to which a given location is "exposed" or "sheltered" from the wind. **total_exposure** is an alternate method for determining "exposure"
surface_erosion_deposition.f90	This routine includes heuristic modeling of surface-normal erosion or deposition on planetary surfaces. **read_accretion_ablation_parameters** reads values from *ACCRETION_ABLATION_PARAMETERS.PRM*. **do_accretion_ablation** models surface-normal or vertical uniform addition or removal of sediment from a surface. **do_exposure_dependent_creep** models mass wasting where the creep diffusivity depends upon the surface exposure (as in the eolian modeling) as well as gradient **find_top_exposure_index** is another method for determining "exposure" **setup_distance_weighting** sets up a matrix of weights that decrease as a negative exponential from the given location **rad_erode** heuristically models solar-induced sublimation from planetary surfaces by reflected-reemitted IR radiation. See Howard and Moore (2008) and Moore et al., (2017). **deposit_ice** heuristically models ice accretion on surfaces not exposed to reflected solar radiation. **find_rad_change** determines the sublimation rate at a given location.
mass_flow.f90	This models flow and optionally erosion by deep mass flows, either through Bingham flow incorporating a yield stress or through Glen Flow glacial flow. The model is limited to depth-averaged flow. **read_mass_flow_parameters** reads in the parameters from *MASS_FLOW.PRM*, including selecting Bingham versus Glen Law flow. **do_bingham_mass_flow** routes mobile material via Bingham rheology. **do_glen_law_flow** routes mobile material via Glen's Law rheology with a specified stress exponent.
gravel_transport_and_abrasion.f90	This models gravel transport and abrasion through a fluvial network and evolves surface topography using multiple gravel grain sizes. This is a 2D implementation of the Gary Parker model AgDegNormGravMixPW. As

	implemented it does not readily interact with other process components other than flow_routing and gradient_and_flow_directions **read_gravel_transport_parameters** inputs values from *GRAVEL_MIXURE.PRM*. **gravel_mixture_initialize** sets up the gravel simulation. **gravel_mixture_transport** is called to do the transport and abrasion. **find_shields_stresses** calculates the shield number for gravel transport. **find_load** calculates the transport rate for each size range **gg** calculates the function G. **ggwc** calculates the function ggwc **find_omega1** and **find_omega2** calculate the omega variable. **find_new_elevation** calculates evolves the transport flux and determines changes in bed elevation. **write_output_gravel** outputs gravel state variables. **real_write** outputs matrices **write_sediment_flux** episodically outputs sediment flux.
summary_statistics.f90	Calculates a variety of morphometric parameters on simulated landscapes. Designed primarily for fluvially-eroded landscapes with near-steady-state topography. **moments** sums the first four moments of passed values **reset_moments** zeros out the moment vector **calculate_moments** calculates the first four statistical moments (mean, variance, skewness, kurtosis) of values passed in an X-Y array **print_moments** prints out the calculated moments **find_topographic_extrema** identifies the total number of summits, sinks, and saddles on a topographic surface **calculate_topo_divergence** prints the moments of planform and profile curvature, gradient divergence, and ln(area/gradient). **print_morphometry** summarizes various statistical characteristics of a simulated landscape **print_simulation_information** episodically reports on the statistical characteristics of a simulation, including rates of landform modification **print_variable_summaries** calculates correlations and anova relationships between simulation state and rate variables as well as percentile distribution values for a number of state variables **correlate** finds the correlation between two matrices

	print_bedrock_statistics finds correlations between rate processes and topographic properties. **print_rate_statistics** summarize the rates of landform modification **slope_runoff_characteristics** prints information on the spatial distribution of runoff if slope-dependent runoff is selected.
channel_properties.f90	**channel_properties** summarizes representative stream profiles within the simulation domain
stream_network_properties.f90	**summarize_channels** calculates a number of classic measures of channel network geometry. For specifics see the source file. **percentiles** calculates the 16^{th}, 25^{th}, 50^{th}, 75^{th} and 84^{th} percentile values of a vector
determine_stream_network.f90	**find_stream_network** calculates and prints information about stream network geometry, working together with **summarize_channels**
write_debug_information.f90	**print_debugging_data** does as it says, and utilizes a number of associated routines: **print_integer_matrix_data** **print_basin_information** **print_logical_matrix_data** **print_real_matrix_data** **summarize_matrix_data** **summarize_regolith_data** **summarize_logical_matrix**
read_and_write_data_files.f90	As the name suggests, most data input and output is done through these subroutines. Most read or write values of a single matrix. Includes the following, mostly self-explanatory subroutines. Most of the output files are written in asci 'append' format at set intervals during the simulation. Each write outputs the matrix dimensions, mx and my, and then the data by the pseudo code do i=1,mx do j=1,my write data(i,j) enddo enddo **read_erosion_mask** reads a binary file with the same spatial dimensions as the simulation that can be used to restrict erosion and deposition to specific locations within he spatial domain. **read_alluvial_locations** **write_exposure** outputs values of the local "exposure" to eolian erosion and deposition.

	read_bistable_locations **read_bedrock_locations** **read_sediment_base** **read_elevations** **read_regolith_thickness** **read_deformation** **write_debug_info** **write_gradient_info** (just a shell) **write_alluvial_locations** **write_bedrock_locations** **write_lake_info** **write_erosion_depth_index** **write_accelerated_erosion_state** **write_sediment_base** **write_avalanche_flux** **write_regolith_thickness** **write_deformation** **write_rock_resistance** **write_elevation_matrix** **write_data_sample** **write_report** **write_image** **write_shaded_relief_image** in PGM format **write_groundwater_flow** **write_groundwater_elevation** **find_groundwater_flux** **write_mass_flux** **write_routed_discharge** **output_binary_data** (writes in binary format rather than ascii) **write_discharges** **write_submerged_locations** **write_crater_sites** **grad_disch_write** **write_color_shaded_relief_image** (not presently used) **write_lava_info** **write_lava_ages** **write_final_state** Writes asci files of the final states of elevations, regolith thickness, sedbase, sedcover, bedrock **write_net_change_matrices** outputs, at the end of the simulation, the net changes in several state variables, all labeled as 'cumulative'.

Input files:

INELEV.DAT -initial elevations for the simulation It, and most other data files read or written by the program, is read by the following pseudocode:

```
read (indata,*) mx,my !the x and y dimensions of the simulation domain
do i=1,mx
do j=1,my
 read(indata,*) elevation(i,j) !elevation is the surface elevation at location i,j
enddo
enddo
```

1: ***MARSSIM_INITIAL_BOUNDARY_CONDITIONS.PRM*** - the master parameters for the simulations.

Parameters for specific processes are read from the following files. Each of these files must be present in the execution directory.

Additional files may be needed depending upon the processes being simulated..

2: ***BEDROCK_CHANNEL_PARAMETERS.PRM***
3: ***ALLUVIAL_CHANNEL_PARAMETERS.PRM***
4: ***FLOW_PARAMETERS.PRM***
5: ***WEATHERING_PARAMETERS.PRM***
6: ***ACCRETION_ABLATION_PARAMETERS.PRM***
7: ***CRATERING_PARAMETERS.PRM***
8: ***EOLIAN_PARAMETERS.PRM***
9: ***GRAVEL_MIXTURE.RM***
10: ***GROUNDWATER_PARAMETERS.PRM***
11: ***LAVA_FLOW_PARAMETERS.PRM***
12: ***MASS_FLOW.PRM***
13: ***MASS_WASTING.PRM***

ERODE.STOP -This file is read every 10 iterations, reading a single integer. If it is 1 the program stops and writes out files, otherwise if 0 the program continues. To stop the program in mid-simulation without discarding results, copy ***ERODE.STOP.YES*** to ***ERODE.STOP***. But be sure to copy ***ERODE.STOP.NO*** to ***ERODE.STOP*** before the next simulation.

For simple simulations of upland drainage basin evolution, ***INELEV.DAT*** and parameter files are all the files that are needed. Other files will be needed depending upon processes being simulated depending upon the processes being simulated:

RESIST.IN -a 3-D matrix of rock resistance
INREG.DAT -initial conditions for regolith thickness
INRATES.DAT -reads time-varying simulation parameters
INRIVER.PRM -allows specification of rivers entering the domain from outside
EVENTS.PRM - specifies the time of specified programmed "events'

CRATER_EVENTS_PRM – Locations and sized of simulated craters. Additional files are needed if fresh martian craters are used to represent new craters.
REAL_CRATERS.TXT - a database of fresh martian craters. The content of this file depends upon the scale, CELL-SIZE of the simulation.
GRAVEL_VALUES.TXT - parameter values for simulations with multiple gravel grain sizes
LAVA_SOURCES.TXT - Locations of lava sources within simulation domain in i,j pairs
OCEANLEVELS.DAT - times and levels of the ocean if variable ocean elevations are modeled
SURFACE_CRUST.DAT - spatial distribution of initial surface crust thicknesses if modeled
SPATIAL_VARIATION.DAT - the spatial variation in runoff coefficients and/or weathering rates if variable runoff or variable weathering is modeled.
Output files (most are written in subroutines in ***read_and_write_data_files.90*** – see the program routines for formatting and further explanation – most of these consist of several concatenated records of data output at intervals during the simulation in the same general format as ***inelev.dat*** – relatively important output files are indicated in bold italics). Some files will not be created unless the appropriate processes are included in the simulation, and some may be created but not written to.

BASIN.LST -a text file that summarizes the simulation parameters plus a good bit of data on the progress of the simulations and a variety of rate-process information

OUTELEV.DAT -a text file of the surface elevations written at various times during the simulation. This file usually includes several sequential datasets.
ALLUVIAL.DAT -an ascii file of 0's to indicate locations that are bedrock channels, and 1's for alluvial channels
DISCHARGE????.RAW - raw image files of the logarithm of discharges within the drainage network. Normalized so that low discharges are black, highest is white. The dimensions of these images equals that of the elevation matrix.
BEDROCK.DAT -an ascii file of 0's for regolith-covered locations, and 1's for bare bedrock
SUBMERGE????.RAW - raw image files indicating submerged (black) and unsubmerged (white) locations. The dimensions of these images equals that of the elevation matrix.
SUBMERGED.DAT-an ascii file of 1's for underwater locations, otherwise 0's for subaerial
EROSION_DEPTH_INDEX.DAT -if variable rock resistance is used, this is the z-index of the surface in the 3-D rock resistance file
OUTBASE.DAT - the elevation of the bottom of alluvial deposits, or, where they are absent, the land surface elevation.
REGOLITH.DAT -the regolith thickness
DEFORM.DAT -if the rocks are actively deformed, writes the total amount of deformation during the simulation
RESIST.OUT -writes the erosional resistance for rocks at the surface (for variable rock resistance is a slice through resist.in
REPORT.PRN -a record of relief and erosion rate
RECORD.DAT -a record of several variables expressing the progression towards a steady-state landscape
SUMMARY.DAT - some of the data printed out in basin.lst, but in bare-bones format
STATISTICS.PRN – writes a sampling of the simulation state for emergent points at intervals

during the simulation

CHANNEL.DAT -information on stream channels

CRATER.DAT -information about individual simulated impact craters

RELELE???.RAW -files consisting of raw b&w images of surface elevation- scaled so that the lowest elevation is black and the highest is white. The dimensions of these images equals that of the elevation matrix.

TOPO.DAT -a file that gives information on the elevation range corresponding to the images in *relele???.raw*

BSHADE????.PGM -shaded relief images of the surface topography, output in sequential order during the simulation and periodic intervals. Can be put together in Adobe Photoshop to make a movie. If periodic boundary conditions are used these files can paste strips from the opposite side in order to better portray the topography if selected. If neither boundary is periodic the image size is (2*(MX-1), 2*(MY-1), If the image is periodic in, say, the X dimension, then the horizontal image size increases to 2*(MX-1)+2*(MX/2+2) and similarly if the image is periodic in the Y dimension.

ATPRESENT.PGM: - The most recent shaded relief file. Useful for monitoring the progression of the simulation

BISTABLE.DAT – output file of locations that are (1) and are not (0) in the accelerated erosion state.

DEBUG.PRN - A file of debugging data written by **write_debug**

SOURCE.DAT - A file of stream source information written by **stream_network_properties** if it is utilized

QQ.DAT -if groundwater flow is simulated, is the matrix of groundwater discharges

EWATER.DAT -if groundwater flow is simulated, is the water table elevation

ACTIVE.DAT -if groundwater sapping is simulated, is locations that are presently undergoing sapping erosion.

LAVA.DAT -if lava flows are simulated, whether lava has been deposited at that location

LACTIVE.DAT -if lava flows are simulated, is the locations where lava flows are active

LAGE.DAT -if lava flows are simulated, is the age since the last lava was deposited at that location.

EOLIAN.DAT -if eolian deposition is simulated, is the amount of eolian deposition or erosion

BINGHAM_FLUX.DAT – if Bingham mass flow is modeled, gives the flux magnitude

GLEN_FLUX.DAT – If Glen Law flow is selected gives the mass flux.

SEDFLUX.DAT - Spatial distribution of sedement flux during multi-size gravel simulations

DSGS.DAT - Spatial distributions of the 50th percentile grain sizes during multi-size gravel simulations

D90.DAT - Spatial distribution of D90 grain sizes during multi-size gravel simulations

SANDFRACTION.DAT - The amount of transported sediment than gravel during multi-size gravel simulations

SEDTEMP.DAT - detailed information about sediment routing if write_sediment_diagnostics is True.

EXPOSURE.DAT - information about the initial relative exposure of locations for eolian or sublimation modeling

AVALANCHE.DAT - Avalanche flux rates if mass wasting avalanching and erosion is modeled

CHPROP.PRN - Information about channel properties at regular locations if printing morphometric data is selected

CUMULATIVE_...DAT -net changes in state variable matrices during the simulation. Exact name and number of files depends upon which processes are simulated. See the subroutine ***write_net_change_matrices*** for details.

FINAL_...DAT – These are the final values of state variables. Useful to analyze simulation results and to use to continue a simulation. See the subroutine ***write_final_state*** for details.

BINARY_....DAT – if selected these are cumulative binary output files of surface elevation, stream discharges, lake locations, and impact crater events. This was specifically included to permit making movie files of landform evolution. See the subroutine ***output_binary_data*** for details.

Accessory Programs:

extract.F -reads *outelev.dat* and extracts a specific output record to write out in the file *lastelev.dat*

tosurfer.F -like *extract.F,* but outputs an ascii ".grd" file for input into the commercial program **Surfer**.

matrix_2D.F90 -makes a pseudo-random 2-D matrix to be input as initial elevations. See the program for documentation. Output file is named *matrix_2D.out*. A shaded-relief image *m3dshade.raw* is also created.

matrix_3D.F90 –makes a pseudo-random 3-D "cube", primarily for use as rock resistance input. See the program for documentation. Output file is named *matrix_3D.out*, and is a direct-access, unformatted file. For use as rock resistance input, rename this file to *resist.in* . See the program and *boundary_conditions.F90* for how to create and read the file.

rescale.f90 –this takes the output from the matrix_2D program and rescales the matrix to a given elevation range or a given maximum gradient and optionally adds an overall slope to the topography

clearerode.bat -This is an MSDOS batch file that deletes most files left over from previous runs. Since most of the output is appended to any existing files, run this before you start a new run.

runname.bat -This is a MSDOS batch file that renames output files from the program to a single prefix with a variety of suffixes and moves most of them to a ".zip" file. Requires pkzip.exe to be in executable path. The batch file requires a 6 digit alphanumeric code in the command line that uniquely identifies the run, e.g. ***runname abcdef,*** followed for the next run by, say, ***runname abcdeg***. It does not incorporate the image (*.raw and *,pgm) files in the zip file.

pkzip.exe - command-line archiving utility for Windows– needs to be in your search path in order to run ***runname.bat.*** use *zip* in Linux

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MARSSIM PARAMETER FILES

The parameter input files for the MARSSIM Landform Evolution Model

Most parameters and variables for individual runs are in the *marssim.prm* file, which should be edited for individual runs. The left column shows typical values for input parameters and the right column shows the variable names that are read as input (in bold). Many of the input variables are switches to turn on or off particular features. In general 1 indicates yes (.true.) and 0 indicates no (.false.). Logical variables that are set in response to the switches are shown in bold between square brackets. If particular portions of the simulation program are turned off (e.g., in the third input line) then the values for the controlling variables for that process suite are read in but not used. Program units (unless otherwise noted) are in kg, m, s. Erosion rates are expressed in (m/yr) and iterations are expressed in (years/iteration) .

MARSSIM_INITIAL_BOUNDARY_CONDITIONS.PRM	
*************************** BOUNDARY CONDITIONS ********************	
4632819 - ISEED	**ISEED,** A integer random seed
1 – NEW SIMULATION 1 – SWITCH FOR FLUVIAL AND SLOPE MODELING 0 – SWITCH FOR IMPACT CRATER MODELING 0 – SWITCH FOR LAVA FLOW MODELING 0 – SWITCH FOR EOLIAN PROCESSES 0 – SWITCH FOR A GLOBAL OCEAN LEVEL 0 – SWITCH FOR ABLATION/ACCRETION MODELING 0 – SWITCH FOR LAKE EVAPORATION MODELING 0 – SWITCH FOR AVALANCHE ROUTING AND EROSION 0 – SWITCH FOR MASS FLOW MODELING (BINGHAM OR GLENS LAW FLOW)	These select various major model components, in order (0=don’t, 1=do): **INEW_SIMULATION** **[NEW_SIMULATION]** 0 = continuation run; 1=new **IDOEERODE** **[FLUVIAL_AND_SLOPE_MODELING]** 1 = fluvial and slope erosion **IDOCRATER** **[MODEL_IMPACT_CRATERING]** 0 = NO impact cratering **IDOLAVA** **[MODEL_LAVA_FLOWS]** 0 = NO lava inundation **IDOEOLIAN** **[MODEL_EOLIAN_CHANGES]** 0 = NO eolian deposion **IDOOCEAN** **[MODEL_OCEAN_LEVEL]** 0 = DON’T have an ocean

	IDOACCRETION **[MODEL_ACCRETION_AND_ABLATION]** 0 = NO accretion modeling **IDOLAKES** **[MODEL_LAKE_EVAPORATION]** 0 = No modeling runoff and evaporation with lakes **IDOAVALANCHE** **[DO_AVALANCHE]** 0 = No avalanche modeling **IDOMASSFLOW** **[USE_MASS_FLOW]** 1 = Do model mass flow
500 – MX 500 – MY 100 – MZ 40.0 – CELL SIZE 1.0 – VERTICAL SCALING 1.0 – CONVERT TO METERS	**MX** – NUMBER OF COLUMNS IN DEM **MY** – NUMBER OF ROWS IN DEM **MZ** – NUMBER OF VERTICAL CELLS (NOT GENERALLY USED) **INPUT_CELL_SIZE** – THE CELL DIMENSION, IN WHATEVER UNITS **VERTICAL_SCALING_FACTOR** – THE VERTICAL SCALE UNIT, IN WHATEVER UNITS (NEEDS TO BE SAME UNITS AS INPUT_CELL_SIZE) **CONVERT_TO_METERS** – WHAT IS NEEDED TO MULTIPLY INPUT_CELL_SIZE AND VERTICAL_SCALING_FACTOR TO GET TO METERS, WHICH IS THE INTERNAL PROGRAM SCALE
0 – SWITCH FOR TIME-VARYING PARAMETERS 0 – DO EVENTS	**IUSEVARRATEUSE** **[VARIABLE_EROSION_RATE]** – 0 IF MODEL PARAMETERS ARE CONSTANT, 1 IF THEY VARY THROUGH TIME IN A SPECIFIED MANNER (ALMOST ALWAYS ZERO) **DO_EVENTS** – IF >0 THEN SIMULATION INCLUDES EVENTS AT SPECIFIC TIMES AS SPECIFIED IN ***EVENTS.PRM***.
1.0 – DEFAULT CHANNEL TIMESTEP 0.3 – MINIMUM_TIME INCREMENT 0.3 - MAXIMUM TIME INCREMENT	**CHANNEL_TIMESTEP_SCALING** **[DEFAULT_CHANNEL_TIMESTEP]** **MAXIMUM_TIME_INCREMENT**

0 - SWITCH FOR HAVING SEDIMENT FLUX CONTRON TIMESTEP 1.0E+07 – SEDIMENT YIELD TIMESTEP FACTOR	**MINIMUM_TIME_INCREMENT** THESE CONTROL SIMULATION TIME STEPS. EXPERIMENT TO SEE HOW LARGE THESE CAN BE BEFORE INSTABILITY SETS IN (UNITS IN YEARS)
25 - HORIZONTAL (I) LOCATION OF DEBUGGINS WINDOW 50 – VERTICAL (J) LOCATION OF DEBUGGINS WINDOW 4 - NO. OF HORIZONTAL CELLS 15 - CENTER (I,J) AND SIZE (NI,NJ) OF DEBUG WINDOW 0 – DO DEBUGGIN PRINTOUT	**ICENT** **JCENT** **IWIDTH** **JWIDTH** IF THINGS GO WRONG, THE RANGE OF DEM CELLS FOR WHICH DEBUG INFO IS PRINTED **IXDEBUG [DO_DEBUGGING]** – PRINT OUT DEBUGGING INFO (GENERALLY DON'T USE)
0 - 0=no, 1=do morphometric stats	**STATISTDO [DO_MORPHOMETRY]** IF MORPHOMETRIC STATISTICS ARE TO BE CALCULATED SET TO 1.
0 – PRINT REPEAT EDGES FOR PERIODIC BOUNDARIES 0 – USE A FIXED SUN ANGLE 0.47 – SUN ANGLE GRADIENT	**SHADE_BORDER_INDEX.** If 1 then the ***BSHADE????.PGM*** files have a border from the opposite side for periodic boundaries. This allows better visualization of connections across borders. **FIXED_SUNANGLE_INDEX** If 0 then shaded relief images use grazing illumination of steepest slope, if 1 then the illumination angle is set by **SUN_ANGLE_GRADIENT**
0 - HORIZONTAL_LOWER_BOUDNARY IF 1, OTHERWISE 0 0.0 – RATE OF LOWERING OF HORIZONTAL LOWER BOUNDARY 0 – INDEX FOR A HON-ERODING LOWER BOUNDARY 1=YES 1 – INDEX FOR A HORIZONTAL PERIODIC BOUNDARY 1=YES 1 – INDEX FOR A VERTICAL PERIODIC BOUNDARY 1=YES 0 – INDEX FOR FIXED EXTERNAL BOUNDARIES 1=YES	**IHORIZONTAL_LOWER_BOUNDARY** **[HORIZONTAL_LOWER_BOUNDARY]**– USED IF THE SOUTHERN BOUNDARY IS LEVEL (ONLY USED IF NON-PERIODIC LOWER BOUNDARY CONDITIONS) **INON_ERODING_LOWER_BOUNDARY** **[NON_ERODING_LOWER_BOUNDARY]** – USED IN CONJUNCTION WITH A LEVEL LOWER BOUNDARY **USEYPERIODIC** **[IS_Y_PERIODIC]** – ZERO IF NOT VERTICAL PERIODIC BOUNDARIES, ONE OTHERWISE **USEXPERIODIC** **[IS_X_PERIODIC]** – ZERO IF NOT HORIZONTALLY

	PERIODIC, ONE OTHERWISE. IMPORTANT: THE USUAL TWO COMBINATIONS OF THESE PARAMETERS THAT ARE USED ARE: **1 1 0 1 0**(FOR NON-VERTICALLY PERIODIC SIMULATIONS) **0 0 1 1 0** (FOR DOUBLY-PERIODIC BOUNDARY CONDITIONS) **USEFLOWBOUND** **[DO_FLOW_BOUNDARIES]–** USED WHEN ALL BOUNDARIES ARE POTENTIAL FLOW EXITS AND NON-ERODING (FOR EXAMPLE, WHEN SIMULATING EVOLUTION OF A RECTANGULAR REGION EXTRACTED FROM A LARGER DOMAIN). WHEN USED, IT SETS THE VALUES OF THE PREVIOUS FOUR PARAMETERS TO 0 0 0 0 (ALL FALSE)
************************ OUTPUT AND RECALCULATION TIMING ************	
0 - STARTING_ITERATION 0.0 – INITIAL TIME	**STARTING_ITERATION** **PRESENT_TIME** (YEARS) GENERALLY THESE ARE BOTH ZERO FOR NEW SIMULATION RUNS
10000000 - MAXIMUM NUMBER OF ITERATIONS 1.6e+25 - MAXIMUM ELAPSED TIME TIME	**MAXIMUM_ITERATION** - THIS IS THE MAIN VARIABLE DETERMINING THE LENGTH OF THE PROGRAM RUN. SET TO A LARGE NUMBER IF TERMINATION IS TO BE CONTROLLED BY MAXIMUM_SIMULATION_TIME **MAXIMUM_SIMULATION_TIME** – THE MAXIMUM TIME, IN YEARS, THAT THE SIMULATION CAN RUN. USUALLY A LARGE NUMBER IF TERMINATION IS TO BE CONTROLLED BY MAXIMUM_ITERATION
10000 - ELEVATION_PRINT_INTERVAL	**ELEVATION_PRINT_INTERVAL** HOW MANY ITERATIONS BETWEEN WRITING OUT A LOT OF INFO
10000 - OUTPUT_PRINT_INTERVAL	**OUTPUT_PRINT_INTERVAL** HOW OFTEN TO SUMMARIZE SIMULATION PREOGRESS. GENERALLY SHOULD BE THE SAME AS ELEVINTERVAL
1 - RECALCULATE_GRADIENT_INTERVAL 1 – RECALCULATE DISCHARGE INTERVAL	**RECALCULATE_GRADIENT_INTERVAL** HOW OFTEN TO RECALCULATE GRADIENTS AND

	AREAS. LEAVE AT 1 **RECACLULATE_DISCHARGE_INTERVAL** Usually set to 1, but can be increased to shorten simulation time with some loss of fidelity.
20 - WRITE_CHANGE_INTERVAL	**WRITE_CHANGE_INTERVAL** HOW OFTEN TO PRINT OUT INFORMATION ON THE RATE OF CHANGE IN GRADIENTS AND FLOW DIRECTIONS. LEAVE AS IS
5 - KWRITE, MIN. CONV. CHAN. PLOT 1=0;2=.1;3=.2;4=.4,5=.8;6=1.6	**KWRITE -** THIS HAS TO DO WITH THE DEFINITION OF WHERE CHANNELS START IN MORPHOMETRIC PRINTOUTS.
1 - WRITE_ABSOLUTE_ELEVATION, 0=RELATIVE, 1 = ABSOLUTE	**ONEONLY** **[WRITE_ABSOLUTE_ELEVATION]** WHETHER TO WRITE OUT RELATIVE OR ABSOLUTE ELEVATIONS. GENERALLY LEAVE AS IS (ABSOLUTE ELEVATIONS)
10000 IMAGE_OUTPUT_INTERVAL 5 - DIVERGENCE_INTERVAL	**IMAGE_OUTPUT_INTERVAL** – HOW OFTEN TO PRINT OUT SHADED RELIEF IMAGES **DIVERGENCE_INTERVAL** – LEAVE AS IS
1 – SWITCH FOR WRITING BINARY OUTPUT FILES 1=YES, 0-NO	**WRITE_BINARY_IMAGE_FILE**
************************ RANDOM VARIATION OF SIMULATION PARAMETERS ***	
0 1 1.0 2.0 1.0 – RANDOM_CRITICAL_SHEAR, USE_RANDOM_DISCHARGE, CRITICAL_SHEAR_VARIABILITY, DISCHARGE_COEFF_VARIATION, OMEGA_WEIGHT	CONTROLS RANDOM VARIATION OF DISCHARGE AND CRITICAL SHEAR STRESS **RANDTHRESHUSE** **[RANDOM_CRITICAL_SHEAR]** – USE (>0) IF SHEAR RESISTANCE OF SURFACE IS CONSIDERED TO VARY RANDOMLY THROUGH TIME, GENERALLY KEEP AT ZERO **RANDDISCHUSE** **[USE_RANDOM_DISCHARGE]** – USE (>0) IF SUCCESSIVE RUNOFF EVENTS ARE CONSIDERED TO VARY RANDOMLY USING A LOGNORMAL DISTRIBUTION. **CRITICAL_SHEAR_VARIABILITY** – SCALING FOR RANDOM CRITICAL SHEAR **DISCHARGE_COEFF_VARIATION** – STANDARD ERROR

	OF DISCHARGE, ASSUMING LOGNORMAL DISTRIBUTION **OMEGA_WEIGHT** – KIND OF LIKE A HURST PARAMETER GOVERNING INHERITANCE FROM PAST VALUE. KEEP AT UNITY FOR NO INHERITANCE.
************************ ROCK AND SURFACE DEFORMATION ****************	
0 – DO ROCK AND SURFACE DEFORMATION 1=YES, 0=NO 1.0 - PARAMETER GOVERNING RATE OF DEFORMATION	**DEFORMUSE** **DEFORMSCALE** STUB FOR INCLUDING ROCK DEFORMATION – NOT CURRENTLY IMPLEMENTED.
******************** OCEAN PROCESS PARAMETERS ************************	
0 – VARIABLE_OCEAN_ELEVATION	**IOCEANVAR** **[VARIABLE_OCEAN_ELEVATION]** >0 IF THERE IS A TEMPORALLY-VARYING OCEAN LEVEL. IF IT IS VARIABLE, THEN THE TIMES AND RESPECTIVE SEA LEVELS ARE READ IN FROM ***OCEANLEVELS.DAT***
0 – USE EROSION MASK	**Generally set at zero. If set to 1 a binary mask is read in which inhibits erosion and mass wasting at cells with values less than 127.**
************************SPATIAL VARIATION OF WEATHERING AND RUNOFF****	
0 - YSE SPATIAL VARIATION	**SPATIAL_VARIATION_USE** >0 if spatially-varying runoff rate or weathering rate is used. If it is, then the following matrix of relative spatial rates is read in: **SPATIAL_VARIATION.DAT**
FLOW_PARAMETERS.PRM	
************************ FLOW ROUTING AND DRAINAGE AREA *************	
0 - USEWET (0 for dry 1 for wet depressions that overflow) 1 - RESCALE_DISCHARGES	**USEWET** **[COMPLETE_RUNOFF]** – 0 IF ALL DEPRESSIONS ARE INFINITE SINKS OF WATER, 1 IF ALL DEPRESSIONS FILL WITH WATER AND OVERFLOW MOST MARS SIMULATIONS HAVE USED 0 HERE, BUT SOME SIMULATIONS WITH NON-PERIODIC BOUNDARY CONDITIONS USE UNITY (IF USEWET IS SET TO

	UNITY WITH DOUBLY PERIODIC BOUNDARY CONDITIONS AT LEAST ONE INFINITE SINKHOLE NEEDS TO BE SPECIFIED) **IQCONSTANT** **[RESCALE_DISCHARGES]** – IF THIS IS GREATER THAN ZERO THEN EFFECTIVE DISCHARGES ARE RESCALED AS A POWER FUNCTION OF CONTRIBUTING AREA. (E.G. Q= K A**E), WHERE, TYPICALLY (0.5<E<1.0).
0 - USE_RANDOM_FLOWROUTING (0 = determinstic d8, 1 = random d8)	**RANDDIRUSE [USE_RANDOM_FLOWROUTING]** IF GREATER THAN ZERO FLOW DIRECTIONS HAVE A RANDOM COMPONENT. GENERALLY LEAVE AT ZERO
3.0e-05 - DISCHARGE_CONSTANT 0.7 - DISCHARGE_EXPONENT	**DICHARGE_CONSTANT** **DISCHARGE_EXPONENT** CONTROLS HYDROLOGY THROUGHOUT DRAINAGE SYSTEM WHEN IQCONSTANT>0, DISCHARGE=DISCHARGE_CONSTANT*AREA**DISCHARGE_EXPONENT (M**3/S). THE VALUES HERE ARE FOR TYPICAL TERRESTRIAL DRAINAGE NETWORKS FOR MEAN ANNUAL FLOOD
0.0 - AREAFACTOR (0.0 to -1.0 0.000025 RAINDEPTH 1.0 – RAINSD	**AREAFACTOR** **RAINDEPTH** **RAINSD** GENERALLY NOT USED
0 – USE DIVERGENCE DEPENDENT RUNOFF (1-YES, 0-NO) 0.0 DIVERGENCE FOR MEAN RUNOFF 1.0 HIGH DIVERGENCE RUNOFF PARAMETER 0.2 – LOW DIVERGENCE RUNOFF PARAMETER 1.0 – DIVERGENCE SCALE PARAMETER 1 – RANGE IN NUMBER OF CELLS OVER WHICH DIVERGENCE IS CALCULATED	**VARYIELDUSE** **[DIVERGENCE_DEPENDENT_RUNOFF]** **MEAN_CONVERGENCE_RUNOFF** **HIGH_CONVERGENCE_RUNOFF** **LOW_CONVERGENCE_RUNOFF** USED IF RUNOFF DEPTH FUNCTIONALLY DEPENDS ON TOPOGRAPHIC CONVERGENCE.
0 – DO SPATIALLY-VARYING DISCHARGE 0.2 – SCALE FACTOR FOR LOWEST RUNOFF 1.6 – SCALE FACTOR FOR HIGHEST RUNOFF	**DO_SPATIAL_RUNOFF.** If this is selected, then the matrix SPATIAL_VARIATION is used to calculate local runoff rates, scaled by the two parameters **LOW_RUNOFF_SCALE** and **HIGH_RUNOFF_SCALE.** The matrix values might be based on, e.g. elevations, or relative

	slopes. Note that **DO_SPATIAL_VARIATION** must also be true to invoke spatially-varying runoff.
0 – INDEX FOR RUNOFF DIFFER FOR SEDIMENT VERSUS NON-SEDIMENT SURFACE (0= N,1=YES) 1.5 – FACTOR FOR RUNOFF FOR SEDIMENT COVERED AREAS 0 – USE REGOLITH-DEPTH DEPENDENT RUNOFF (0=NO, 1=YES 1.5 – FACTOR FOR RUNOFF FOR BEDROCK AREAS O – USE REGOLITH_DEPTH DEPENDENT RUNOFF 0.2 – FACTOR FOR RUNOFF FOR DEEP REGOLITH 0.1 – RUNOFF DEPTH DECAY RATE FOR REGOLITH	**SEDIMENT_DEPENDENT_RUNOFF_USE.** If true, multiply runoff on sediment-covered regions by **SEDIMENT_RUNOFF_FACTOR.** **REGOLITH_DEPTH_RUNOFF_USE.** If use, runoff for bedrock locations is multiplied by **RUNOFF_SCALE_BEDROCK,** but if regolith covered, runoff is determined by the regolith depth thruout the **RUNOFF_SCALE_DEEP_REGOLITH** and the **RUNOFF_DEPTH_DECAY_RATE**
0 – USE GRADIENT-DEPENDENT RUNOFF 0.1 – SLOPE GRADIENT FOR MEDIAN RUNOFF 2.0 – SLOPE RUNOFF SCALE FACTOR	
1 – NUMBER OF ITERATIONS BETWEEN EVAPORATION RECALCULATION 20 – NUMBER OF ITERATIONS BETWEEN CHANGING EVAPORATION RATE 2.5 – MEAN X-RATIO 0.0 – STANDARD DEVIATION OF X-RATIO	**NCALCEVAP** **NCHANGEEVAP** **X-RATIO_MEAN** **X-RATIO_STANDARD_DEVIATION** USED IF LAKE EVAPORATION IS MODELED, NCALCEVAP IS HOW MANY ITERATIONS BETWEEN RECALCULATING EVAPORATION RATES. NCHANGEEVAP IS HOW MANY ITERATIONS BETWEEN STOCHASTIC CHAGES IN EVAPORATION RATES. EVAPORATION_MEAN IS THE MEAN YEARLY EVAPORATION DEPTH (M). EVAPORATION_STANDARD_DEVIATION IS THE S.D. OF MEAN EVAPORATION DEPTH.
1 – MODEL PELAGIC DEPOSIION IN LAKES 0.5 – FRACTION OF DELIVERED SEDIMENT THAT IS WASHLOAD 0.2 – AMOUNT OF "CREEP-LIKE" DIFFUSIVITY IS USED IN PELAGIC DEPOSITION 25.0 – MINIMUM SIZE OF DEPRESSIONS (IN NUMBER OF CELLS) FOR PELAGIC DEPOSITION	**IMODEL_PELAGIC_DEPOSITION** **[MODEL_PELAGIC_DEPOSITION]** **WASHLOAD_FRACTION** **PELAGICCREEP** IF IMODEL_PELAGIC_DEPOSITION IS GREATER THAN ZERO, DEPOSITION OF SUSPENDED SEDIMENT IN ENCLOSED BASINS IS MODELED. WASHLOAD_FRACTION IS THE FRACTION OF

	SEDIMENT DELIVERED TO BASINS THAT IS DEPOSITED AS PELAGIC SEDIMENT. PELAGICCREEP (A DIFFUSIVITY) DETERMINES HOW MUCH POST-DEPOSIION DIFFUSION OCCURS IN RECENTLY-DEPOSITED PELAGIC SEDIMENT.
0 - HAVE_INFLUENT_RIVERS (0 FOR NO INCOMING RIVERS, 1 FOR INCOMING RIVER(S))	**DOINRIVER [HAVE_INFLUENT_RIVERS]** IF DOINRIVER IS GREATER THAN ZERO, RIVERS ENTER THE SIMULATION DOMAIN WITH SPECIFIED LOCATION, DISCHARGE, AND SEDIMENT LOAD. MOSTLY USED TO SIMULATE COASTAL-CONTINENTAL SHELF ENVIRONMENTS. IF THERE ARE IFLUENT RIVERS THEIR LOCATION, DISCHARGE, AND SEDIMENT LOAD IS READ FROM '*inriver.prm*'. USUALLY ZERO.
BEDROCK_CHANNEL_PARAMETERS.PRM	
*********************** BEDROCK CHANNEL PARAMETERS ***************	
0 - DO_FLUVIAL_DETACHMENT(0,1 DONT,DO 1 - EXPLICIT_CHANNEL_BED_STATE (0= IMPLICIT, 1= EXPLICIT)	**DETACHUSE [DO_FLUVIAL_DETACHMENT]**– LEAVE AT UNITY FOR ALMOST ALL TYPES OF SIMULATIONS EXCEPT WHEN FLUVIAL EROSION, TRANSPORT, AND DEPOSITION ARE NOT BEING MODELED WHEREAS SLOPE PROCESSES ARE. **BEDEXPLICIT [EXPLICIT_CHANNEL_BED_STATE]** – GREATER THAN ZERO FOR EXPLICIT MODELLING OF REGOLITH DEPTH (INCLUDING BARE ROCK) – USED IN HOWARD, 2007. IF ZERO, REGOLITH DEPTH IS IMPLICITLY MODELED AS IN HOWARD, 1994.
0 – IFLUXDEPENT 0=STREAM POWER, 1= SKLAR BED ABRASION, 2= WHIPPLE FLUX-BASED INCISION 1.0 - SKLAR ROCK_TENSILE_STRENGTH (MPa) 1.15E-2 – SKLAR MULTIPLICATIVE CONSTAT 0 – USE SHEAR RATIO IN SKLAR DENOMINATOR 0=NO, 1=YES 1 - SATURATION FACTOR 0=SKLAR PARABOLIC, 1=TUROWSKI EXPONENTIAL	THREE MODELS CAN BE USED FOR BEDROCK CHANNEL EROSION, THE HOWARD MODEL, SKLAR, AND WHIPPLE. **IFLUXDEPEND** **[USE_SKLAR_BED_ABRASION]** **[USE_WHIPPLE_BED_ABRASION]** – 0 FOR HOWARD MODEL 1 FOR SKLAR SALTATION

	2 FOR WHIPPLE SALTATION **ROCK_TENSILE_STRENGTH** – TENSILE STRENGTH OF BEDROCK IF SALTATION MODEL IS USED **SKLAR_FACTOR :** Multiplicative constant in Sklar bedload incision **SHEAR RATIO:** 0= IGNORE SATURATION EFFECT, 1=USE **SATURATION FACTOR:** IF SATURATION FACTOR IS USED, 0=SKLAR PARABOLIC, 1=TUROWSKI EXPONENTIAL
0.5 - BEDROCK_DISCHARGE_EXPONENT 1.0 - BEDROCK_GRADIENT_EXPONENT	**BEDROCK_DISCHARGE_EXPONENT** – USED FOR STREAM POWER DETACHMENT MODEL **BEDROCK_GRADIENT_EXPONENT** – USED FOR STREAM POWER MODEL, THAT IS RATE OF BEDROCK EROSION IS PROPORTIONAL TO DISCHARGE**BEDROCK_DISCHARGE_EXPONENT * GRADIENT**BEDROCK_GRADIENT_EXPONENT
1.0E-04 - BEDROCK_ERODIBILITY 0.03 – MANNING'S N 3.7 - GRAVITATIONAL CONSTANT 1000.0 – FLUID DENSITY	**BEDROCK_ERODIBILITY** – BEDROCK ERODIBILITY FOR STREAM POWER MODEL – COULD VARY IN NATURAL LANDSCAPES OVER ORDERS OF MAGNITUDE FROM 10**-2 TO 10**-8 **MANNING** – MANNING'S N **GRAVITY** – 3.7 FOR MARS 9.8 FOR EARTH (M/S**2) **FLUID DENSITY**: 1000.0 FOR DILUTE WATER FLOW
0.0 - DETACHMENT_CRITICAL_SHEAR	**DETACHMENT_CRITICAL_SHEAR** USE A NON-ZERO VALUE IF SHEAR STRESS IN STREAM POWER MODEL MUST EXCEED A CRITICAL VALUE. UNITS IN (KG/(M*SEC**2).
10.0 - REGOLITH_ERODIBILITY_FACTOR 10.0 - REGOLITH_CRITICAL_SHEAR_FACTOR	**REGOLITH_ERODIBILITY_FACTOR** – HOW MUCH MORE ERODIBLE IS WEATHERED REGOLITH THAN BEDROCK (MINUMUM VALUE OF UNITY) **REGOLITH_CRITICAL_SHEAR_FACTOR** – BY WHAT RATIO IS THE CRITICAL SHEAR FOR REGOLITH DETACHMENT LESS THAN FOR BEDROCK. GENERALLY SET TO SAME VALUE AS REGOLITH_ERODIBILTY_FACTOR

5.0 – CHANNEL_WIDTH_CONSTANT, 0.5 - CHANNEL_WIDTH_EXPONENT	**CHANNEL_WIDTH_CONSTANT** **CHANNEL_WIDTH_EXPONENT** THESE DETERMINE HOW CHANNEL WIDTH DEPENDS UPON DISCHARGE, GENERALLY AS A FUNCTION OF MEAN_ANNUAL_DISCHARGE. WIDTH=CHANNEL_WIDTH_CONSTANT * DISCHARGE ** CHANNEL_WIDTH_EXPONENT (M)
0 – VARIABLE VEGETATION RESISTANCE 200.0 – UPLAND CHANNEL EROSION RESISTANCE 1.0 – SOWNSTREAM CHANNEL EROSION RESISTANCE 3000.0 – MINIMUM TRANSITION AREA 60000.0 – MAXIMUM TRANSITION AREA	**ITAUAREA –** 0 IF VEGETATION COVER DOES NOT INFLUENCE CHANNEL EROSION, OTHERWISE 1. (SEE HOWARD&TIERNEY (2012) FOR DETAILS **[VARIABLE_VEGETATION_RESISTANCE]** **VEGETATION_UPLAND_RESITANCE** **VEGETATION_CHANNEL_RESISTANCE** **VEGETATION_AREA_MINIMUM** **VEGETATION_AREA_MAXIMUM** THESE PARAMETERS ARE ONLY USED IF VEGETATION INFLUENCE ON EROSION IS BEING MODELED. IF ITAUAREA GREATER THAN ZERO, THEN VEGETATION MODELING IS USED. SHEAR STRESS IN UNITS OF (KG/(M*SEC**2). THE CRITICAL SHEAR FOR REGOLITH DETACHMENT VARIES FROM VEGETATION_UPLAND_RESISTANCE TO VEGETATION_CHANNEL_RESISTANCE AS CONTRIBUTING AREA (M**2) GOES FROM VEGETATION_AREA_MINIMUM TO VEGETATION_AREA_MAXIMUM
*********************** BISTABLE EROSION ***************************	

0 - BISTABLE_FLUVIAL_EROSION (>0=YES) 0 - USE_BISTABLE_BEDROCK (>0=YES) 10.0 - LOW_EROSION_THRESHOLD 15.0 - HIGH_EROSION_THRESHOLD 0.5 – EROSION RATE CHANGE LAG 10.0 – BISTABLE CRITICAL SHEAR 1.0 – BISTABLE RUNOFF FACTOR 5.0 – BISTABLE BEDROCK ERODIBILITY	**HIGHRATEUSE** **[BISTABLE_FLUVIAL_EROSION]** **BEDROCKHIGH** **[USE_BISTABLE_BEDROCK]///EROSION///** **LOW_EROSION_THRESHOLD** **HIGH_EROSION_THRESHOLD** **EROSION_RATE_CHANGE_LAG** **BISTABLE_CRITICAL_SHEAR** **BISTABLE_RUNOFF_FACTOR** **BISTABLE_BEDROCK_ERODIBILITY** USED FOR MODELING OF GULLIES – SEE Howard (1999)
*********************** 3-D SPATIALLY VARYING BEDROCK RESISTANCE ****	
0 – USE VARIABLE WEATHERING AND ERODIBILITY VARIATION (0=NO, 1=YES) 0 – SCALED ROCK ERODIBILITY – 0= ABSOLUTE VALUES OF ERODIBILITY, 1= RANDOM 1.0 - RESISTANCE_VARIABILITY 0.5 - VERTICAL_RESISTANCE_SCALING	**VARIABLE_ROCK_RESISTANCE_USE –** If this is activated, rock resistance to weathering and fluvial erosion is used. **SCALED_ROCK_ERODIBILITY** if this is 0 a 3-D cube of rock resistance values is opened **(*RESIST.IN*)** and is used to determine rock resistance to weathering and fluvial erosion. The resistance file is direct access. If this is 1 rock resistance is random. **RESISTANCE_VARIABILITY** determines the magnitude of rock resistance variability **VERTICAL_RESISTANCE_SCALING** ONLY USED FOR 3-D VARYING ROCK RESISTANCE, SCALE HORIZONTAL TO VERTICAL SCALES (1.0 IF EQUAL). ***3D rock resistance has not been tested in the current model version – use with caution***
0 – CRUST USE (1= SURFACE RESISTANT CRUST, 0 = NONE 0.01 - SURFACE_LAYER_THICKNESS (METERS) 20.0 – SURFACE_LAYER_RESISTANCE	**CRUSTUSE** **[RESISTANT_SURFACE_LAYER]** ONE THING TO EXPERIMENT WITH TO SIMULATE THE EFFECT OF DEVELOPMENT OF A DURICRUST CRUSTUSE – SET TO 1 TO SIMULATE A DURICRUST

	SURFACE_LAYER_THICKNESS – CRUST THICKNESS IN INPUT CELL SIZE UNITS. **SURFACE_LAYER_RESISTANCE** – RELATIVE CRUST SHEAR STRESS FACTOR (>1 FOR A RESISTANT CRUST) SEE BARNHART ET AL. (2009) FOR AN EXAMPLE OF USING A RESISTANT CRUST
ALLUVIAL_CHANNEL_PARAMETERS.PRM	
*********************** ALLUVIAL CHANNEL PARAMETERS ***************	
0 - WRITE_SEDIMENT_DIAGNOSTICS	**ISEDDEBUG** **[WRITE_SEDIMENT_DIAGNOSTICS]** SET TO ONE IF DETAILED SEDIMENT ROUTING INFORMATION IS TO BE PRINTED
1 – DO SEDIMENT TRANSPORT (0=NO, 1=YES) 1 – DO SEDIMENT ROUTING (0=NO, 1=YES) 0 – DO ALLUVIAL SEDIMENT DIFFUSION (0=NO, 1=YES) 0 – USE NO_FLUX_LOWER_BOUNDARY (0=NO, 1=YES)	**ISEDIMENT** **[DO_SEDIMENT_TRANSPORT]** If set to zero alluvial sediment transport is not modeled **ISEDROUTE** **[DO_SEDIMENT_ROUTING]** Sediment routing assumes sediment transport is done with the gradient being adjusted for equilibrium transport with the supplied bedload and discharge. See Howard (1994) for details. **ISEDDIFFUSE** **[DO_SEDIMENT_DIFFUSION]** Finite difference alluvial sediment transport modeling is highly finicky – requires a very small time increment – the use of sediment routing is preferred **IREFLECT** **[NO_FLUX_LOWER_BOUNDARY]** IF ALLUVIAL CHANNELS, DELTAS, AND FANS ARE MODELED SET ISEDIMENT TO ONE. ISEDROUTE IS GREATER THAN UNITY IF SEDIMENT ROUTING DEPOSITION IS USED IREFLECT IS GREATER THAN ONE IF THE LOWER BOUNDARY IS A NO-SEDIMENT-FLUX BOUNDARY (I.E., AGGRADING).

1 - DO_ALLUVIAL_SMOOTHING 0 - DO_ALLUVIAL_REROUTING 0.02 - ALLVIUM_SMOOTHING_FACTOR	**SMOOTHSEDUSE** **[DO_ALLUVIAL_SMOOTHING]** **NEWDIRECTIONUSE** **[DO_ALLUVIAL_REROUTING]** **ALLUVIUM_SMOOTHING_FACTOR** THESE GOVERN SMOOTHING OF ALLUVIAL DEPOSITIONAL SURFACES (FANS AND DELTAS) DURING DEPOSITION. SMOOTHING IS USED IN SMOOTHSEDUSE IS GREATER THAN ZERO. IF NEWDIRECTIONUSE IS GREATER THAN ZERO DIRECTION OF FLOW ACROSS A FAN OR DELTA CAN CHANGE WITHIN A SINGLE ITERATION. ALLUVIUM_SMOOTHING_FACTOR GOVERNS HOW MUCH SMOOTHING OCCURS. IF **USEWET** IS ZERO THEN USE THE FOLLOWING VALUES: 1 1 0.02 IF **USEWET** IS UNITY THEN USE THE FOLLOWING: 1 0 0.02
0 - IREADALLUV (0=NO INITIAL ALLUVIUM, 1= READ IN ALLUVIAL THICKNESS)	**IREADALLUV** GENERALLY ZERO BUT GREATER THAN ZERO IF ALLUVIUM THICKNESS IS READ IN AT BEGINNING OF SIMULATION .
1 – USE_AN_OCEAN (MODEL DELTAS - >0 to use) -50000.0 - OCEAN_ELEVATION, 0.2 - DELTA_FORESET_GRADIENT	**WATERUSE** **[USE_AN_OCEAN]** **OCEAN_ELEVATION** (IN INPUT CELL SIZE UNITS) **DELTA_FORESET_GRADIENT** IF DELTAS ARE MODELED (WHEN **USEWET** IS UNITY) SET WATERUSE TO 1). USUALLY LEAVE AS IS. IF YOU ARE MODELING A GLOBAL OCEAN, YOU CAN SET **OCEAN_ELEVATION** TO YOUR ASSUMED OCEAN LEVEL, OTHERWISE SET IT TO A VERY LOW VALUE. DELTA_FORESET_GRADIENT IS THE FORESET BED GRADIENT.

0.5 – SEDIMENT_1_EXPONENT 0.3 - SEDIMENT_2_EXPONENT 0.6 -EFFECTIVE_DISCHARGE_RATIO 0.7 – SEDIMENT_GRADIENT_EXPONENT 1.5 - SEDIMENT_TRANSPORT_EXPONENT 40.0 - TRANSPORTFACTOR 0.02 - FLOW_FRACTION	**SEDIMENT_1_EXPONENT** **SEDIMENT_2_EXPONENT** **EFFECTIVE_DISCHARGE_RATIO** THESE PARAMETERS ARE THE SEDIMENT TRANSPORT RELATIONSHIP – SEE MODEL DOCUMENTATION and Howard (1994, 2007) **SEDIMENT_GRADIENT_EXPONENT** **SEDITMENT_TRANSPORT_EXPONENT** **TRANSPORTFACTOR** **FLOW_FRACTION** OF THESE FACTORS ONLY ONE IS GENERALLY CHANGED, AND THAT IS **TRANSPORTFACTOR** **TRANSPORTFACTOR**=40.0 FOR SAND BED **TRANSPORTFACTOR**=8.0 FOR GRAVEL BED **FLOW_FRACTION** SHOULD BE CHANGED TO UNITY IF EROSION BY GROUNDWATER SEEPAGE IS BEING MODELED. SEE MODEL DOCUMENTATION
0.35 – SEDIMENT_POROSITY 2.65 - SEDIMENT_SPECIFIC_GRAVITY 0.0002 - GRAIN_SIZE 0.05 - TRANSPORT_CRITICAL_DIM_SHEAR	**SEDIMENT_POROSITY** **SEDIMENT_SPECIFIC_GRAVITY** **GRAIN_SIZE** **TRANSPORT_CRITICAL_DIM_SHEAR** OF THESE FACTORS ONLY ONE IS GENERALLY CHANGED, AND THAT IS **GRAIN_SIZE.** I HAVE DONE SIMULATIONS FOR SAND (0.0002) AND FOR 2 CM GRAVEL (0.02). SEE MODEL DOCUMENTATION
0 - STICKY_SEDIMENT_ROUTING (0 normal, 1 "sticky") 5.0 - STICKY_ROUTING_CRITICAL_VALUE	**STUCKYUSE** **[STICKY_SEDIMENT_ROUTING]** **STICKY_ROUTING_CRITICAL_VALUE** GENERALLY NOT USED. EXPERIMENT FOR MORE BIRDFOOT-LIKE DELTAS
0.2 - BEDLOAD_FRACTION	**BEDLOAD_FRACTION** THE FRACTION OF ERODED SEDIMENT THAT IS TRANSPORTED AS BEDLOAD. USED FOR CALCULATION OF ALLUVIAL CHANNEL GRADIENTS.
WEATHERING_PARAMETERS.PRM	
************************ REGOLITH WEATHERING PARAMETERS *************	
0.001 – ROCK_WEATHERING_RATE	**ROCK_WEATHERING_RATE** IS THE RATE, IN METERS

0.03 - WEATHER_DECAY_RATE 1.0 – INITIAL_REGOLITH_THICKNESS 1,0 – VOLUME CHANGE COERRICIENT	PER YEAR OF BARE ROCK WEATHERING **WEATHER_DECAY_RATE** – HOW RAPIDLY WEATHERING RATE DECREASES WITH INCREASING REGOLITH THICKNESS – BASED UPON TERRESTRIAL VALUES **INITIAL_REGOLITH_THICKNESS** – INITIAL REGOLITH THICKNESS, IN METERS **VOLUME_CHANGE_COEFFICIENT.** If >1.0 regolith expands in volume relative to rock during weathering, if <0 regolith volume less than rock.
0 – USE TWO-TERM WEATHERING 1.0 – TERM 2 RATE 1.0 – TERM 2 DEPTH RATE DECAY	**WEATHER2USE** **[TWO_TERM_WEATHERING]** **WEATHERING_TERM_2** **WEATHERING_DECAY_2** IF WEATHER2USE IS GREATHER THAN ZERO A “HUMPED” WEATHERING FUNCTION IS MODELED
0 – DO WEATHERING BY SEEPAGE FLUX (>0 FOR SEEPAGE-DEPENDENCE) 0.001 - SEEPAGE_WEATHERING_SCALING 1.0 - SEEPAGE_WEATHERING_EXPONENT	**ISEEPAGEWEATHER** **[SEEPAGE_WEATHERING]** **SEEPAGE_WEATHERING_SCALING** **SEEPAGE_WEATHERING_EXPONENT** IF MODELING SEEPAGE-INDUCED WEATHERING SET FIRST NUMBER TO UNITY ONLY USED IF SEEPAGE FLOW IS MODELED
2.7 – CRITICAL_BEDROCK_GRADIENT 1.0 – WEATHER MULT 0.0 – WEATHER_DIVERGENCE	**CRITICAL_BEDROCK_GRADIENT** **WEATHER_MULT** **WEATHER_DIVERGENCE** CONTROLS WEATHERING OF EXPOSED BEDROCK CRITICAL_BEDROCK_GRADIENT IS THE MAXIMUM BEDROCK SLOPE STEEPNESS. WEATHER_MULT SCALES RATE OF BEDROCK MASS WASTING **WEATHER_DIVERGE_** – IF GREATER THAN ZERO, RATE OF BEDROCK WEATHERING DEPENDS UPON TOPOGRAPHIC DIVERGENCE.
0 - READREGOLITH (>0 read in initial regolith thickness)	**READREGOLITH** KEEP AT ZERO
0 - USE SPATIALLY-VARYING RUNOFF 0.5 - LOWEST WEATHERING RATE RELATIVE TO ROCK_WEATHERING_RATE	**SPATIAL_WEATHERING_USE** IF > 0 THEN WEATHERING RATES VARY SPATIALLY PROPORTIONAL

1.5 - HITHESE WEATHERING RATE RELATIVE TO ROCK_WEATHERING_RATE	TO VALUES IN THE **SPATIAL_VALUES** MATRIX RANGING BETWEEN **LOW_WEATHERING_SCALE** AND **HIGH_WEATHERING_SCALE.** NOTE THAT **SPATIAL_VARIATION_USE** MUST BE >0 TO USE.
MASS_WASTING_PARAMETERS.PRM	
*********************** MASS WASTING PARAMETERS *******************	
1 - DO_MODEL_SLOPES (0 FOR NO SLOPE EROSION MODELLING, OTHERWISE 1 TO MODEL)	**ISLOPEUSE** **[DO_MODEL_SLOPES** This models shallow mass wasting – creep and shallow rapid mass wasting. For deep flows use the MASS_FLOW module
0.02 - SLOPE_DIFFUSIVITY	**SLOPE_DIFFUSIVITY** – determines the relative rate of downslope creep. Generally I have used values between 0.0002 and 0.02 (M**2/YR)
1.0 - ALVCREEPFAC (PROPORTION OF SLOPE CONSTANT IN ALLUVIAL CREEP)	**ALVCREEPFAC** – RELATIVE DIFFUSIVITY OF ALLUVIUM MASS WASTING TO SLOPE MASS WASTING – GENERALLY SET TO UNITY.
1 - CRITICAL_GRADIENT_USE (1 = CRITICAL GRADIENT, 0 = NO CRITICAL GRADIENT) 1 - ROERING_USE (1=USE ROERING FORMULA, 0=USE HOWARD)	**CRITICAL_GRADIENT_USE** **[USE_CRITICAL_SLOPE_GRADIENT]** **ROERING_USE** **[USE_ROERING_MASS_WASTING]** ALLOWS A THRESHOLD MAXIMUM SLOPE GRADIENT IN REGOLITH – IF SET TO ZERO, ONLY LINEAR CREEP
0 – USE DEPTH-DEPENDENT CREEP 0.1 = CREEP RATE HALF DEPTH	**[DEPTH-DEPENDENT-CREEP]It this is selected then the creep rate depends on regolith depth with de depth to where the creep declines by a factor of two being set by CREEP_RATE_HALF_DEPTH**
0.8 - CRITICAL_SLOPE_GRADIENT	**CRITICAL_SLOPE_GRADIENT** MAXIMUM STABLE REGOLITH GRADIENT
3.0 - SLOPE_GRADIENT_EXPONENT	**SLOPE_GRADIENT_EXPONENT** VALUE FOR HOWARD TWO-TERM RELATIONSHIP
0.025 - MAXIMUM_DIFFUSIVITY_INCREASE	**MAXIMUM_DIFFUSIVITY_INCREASE** SETS MAXIMUM INCREASE IN MASS WASTING FLUX AS GRADIENTS APPROACH CRITICAL VALUE
0.05 - SLOPE_FAILURE_DIFFUSIVITY	**SLOPE_FAILURE_DIFFUSIVITY**

	NEAR-FAILURE MASS WASTING CONSTANT IN HOWARD MASS WASTING MODEL
1 - ROUTE REGOLITH OVER BEDROCK	**If this is selected regolith is transported "instantaneously" across bedrock hillslope exposures. This is the default**
1.0 – AVALANCHE_RATE_COEFFICIENT 1.0 – AVALANCHE_SLOPE_EXPONENT 1.0 – AVANANCHE_FLUX_EXPONENT 0.0 – AVALANCHE_CRITICAL_VALUE	**If avalanche erosion modeling is selected in the MARSSIM_INITIAL_BOUNDARY_CONDITIONS.PRM then the rate of bedrock scour is scaled by the AVALANCHE_RATE_COEFFICIENT times the slope gradient times the routed regolith flux raised to their exponent values less any critical erosion value.**
0.0 – MINIMUM_BEDROCK_GRADIENT 0.0 – MINIMUM_ROUTING_GRADIENT	**If MINIMUM_BEDROCK_GRADIENT is greater than 0.0 then slopes gentler than this are considered to be regolith covered** **If MINIMUM_ROUTING_GRADIENT is greater than 0.0 then slopes less than this do not have "instantaneous" regolith routing.**
GROUNDWATER_PARAMETERS.PRM	
*********************** GROUNDWATER FLOW ***************************	
0 - MODEL_GROUNDWATER (>0=YES) 5 - SEEPAGE_ITERATION_INTERVAL 0 - PERMEABILITY_RESCALING 0 - SHOW_GROUNDWATER_CALCULATIONS 1 - EXPONENTIAL_PERMEABILITY_DECAY	**SEEPUSE** **[MODEL_GROUNDWATER]** – IF ZERO NO SEEPAGE MODELING, IF UNITY, SEEPAGE MODELLING. **SEEPAGE_ITERATION_INTERVAL.** ITERATIONS BETWEEN RECALCULATION OF GROUNDWATER FLOW. For description, see Luo and Howard (3008). **IWATERLOWER** **[PERMEABILITY_RESCALING]** IF >0 THEN PERMEABILITY IN EXPONENTIAL VERTICAL DECAY OF PERMEABILITY IS SCALED TO THE PRESENT LAND SURFACE ELEVATION, OTHERWISE TO THE ORIGINAL LAND SURFACE ELEVATION AT THE START OF THE SIMULATION **ISHOWCALC** **[SHOW_GROUNDWATER_CALCULATIONS]** **IEXPFLOW** **[EXPONENTIAL_PERMEABILITY_DECAY]** IF >0, THEN

	PERMEABILITY DECAYS WITH DEPTH BELOW SURFACE, OTHERWISE PERMEABILITY IS CONSTANT THROUGH A FINITE-THICKNESS AQUIFER.
10.0 - YEARLY_RECHARGE 0.0012 FLUID VISCOSITY 1.0 - DARCIES 200.0 - GROUNDWATER_DEPTH_SCALE 1.0 - GROUNDWATER_FLOW_FRACTION 1.0 - INITIAL_GROUNDWATER_DEPTH 1.0 - EPOWER	**YEARLY_RECHARGE** (M/YR) **VISCOSITIY** (OF FLUID – Water on Earth, Methane on Titan) **DARCIES** (PERMEABILITY EXPRESSED IN DARCIES) **GROUNDWATER_DEPTH_SCALE.** FOR EXPONENTIAL PERMEABILITY IS THE DEPTH TO HALF-VALUE OF PERMEABILITY (M). FOR CONSTANT PERMEABILITY IT IS THE AQUIFER THICKNESS. **GROUNDWATER_FLOW_FRACTION** THE AMOUNT OF GROUNDWATER FLOW RELATIVE TO SURFACE FLOW. SET TO UNITY FOR ALL GROUNDWATER FLOW. **INITIAL_GROUNDWATER_DEPTH** INITIAL DEPTH BENEATH THE LAND SURFACE FOR CALCULATION OF STEADY-STATE GROUNDWATER SURFACE **EPOWER** POWER USED IN DEPTH DECAY OF PERMEABILITY. FOR NORMAL EXPONENTAIL DECAY, EPOWER IS UNITY.
4000 - MAXIMUM_GROUNDWATER_ITERATIONS 0.0001 - MAXIMUM_GROUNDWATER_ERROR 1.95 - GROUNDWATER_RELAXATION_COEFFICIENT	**MAXIMUM_GROUNDWATER_ITERATIONS.** MAXIMUM NUMBER OF ITERATIONS PERMITTED IN CALCULATING STEADY-STATE GROUNDWATER TABLE **MAXIMUM_GROUNDWATER_ERROR** MAXIMUM RESIDUAL ERROR IN CALCULATING STEADY-STATE GROUNDWATER TABLE **GROUNDWATER_RELAXATION_COEFFICIENT** S.O.R. COEFFICIENT
0 – USE_GROUNDWATER_FLUX 0=NO 1=YES 0 – SEEPAGE_AVERAGING 0=NO 1=YES	**QQUSE** **[USE_GROUNDWATER_FLUX]**IF EQUALS ZERO, THE GROUNDWATER FLOW TERM USED FOR SEEPAGE CALCULATIONS OF SURFACE FLOWS AND WEATHERING RATE IS THE GROUNDWATER FLUX DIVERGENCE (SEEPAGE RATE TO SURFACE), OTHERWISE IT IS THE GROUNDWATER FLOW RATE PER UNIT AQUIFER WIDTH. **IDIVAVG**

	[SEEPAGE_AVERAGING] IF GREATER THAN ZERO, THE GROUNDWATER FLOW TERM USED IN FURTHER CALCULATIONS IS A NINE-POINT AVERAGE VALUE OF RAW CALCULATED VALUES
EOLIAN_PARAMETERS.PRM	
***********************EOLIAN EROSION/DEPOSITION********************	
1.0 - EOLIAN_EVENT_PROBABILITY	**EOLIAN_EVENT_PROBABILITY** PROBABILITY OF AN EOLIAN DEPOSITION/EROSION EVENT PER UNIT TIME (YEAR OR ITERATION) For description se Forsberg, et al., (2004)
1.0 - EOLIAN_TIME_INCREMENT 0 - USE_TOTAL_EXPOSURE (0 = YES, 1 = ONLY VISIBLE) 1 - DEFAULT_EOLIAN_PROCESS (0=NORMAL TO SURFACE, 1 VERTICAL)	**EOLIAN_TIME_INCREMENT** SCALES THE OVERALL EOLIAN EROSION/DEPOSITION RATE **IUSETOTALEXPOSE** **[USE_TOTAL_EXPOSURE]** IF >0 ALL CELLS WITHING THE CALCULATION WINDOW ARE USED TO COMPUTE THE 'EXPOSURE INDEX', AND IF ZERO ONLY CELLS VISIBLE TO THE LOCAL CELL ARE USED. **IUSENORMAL** **[DEFAULT_EOLIAN_PROCESS]** IF >0 THEN EOLIAN EROSION AND DEPOSITION OCCUR NORMAL TO THE TOPOGRAPHIC SURFACE, OTHERWISE EROSION AND DEPOSITION ARE MODELED AS VERTICAL ADDITIONS OR SUBTRACTIONS.
-0.01 - MINIMUM_EOLIAN_DEPOSIT_RATE 1.0 - MAXIMUM_EOLIAN_DEPOSIT_RATE	**MINIMUM_EOLIAN_DEPOSIT_RATE** CAN BE NEGATIVE (IF EOLIAN EROSION OF EXPOSED LOCATIONS) **MAXIMUM_EOLIAN_DEPOSIT_RATE** GENERALLY UNITY AND SCALED BY EOLIAN_TIME_INCREMENT DETERMINES EOLIAN_CONSTANT_1 AND EOLIAN_CONSTANT_2
3 - ICHOOSE 0 - DO_ONLY_EOLIAN_DEPOSITION	**ICHOOSE** DETERMINES THE MEANING OF THE NEXT TWO PARAMETERS THAT ARE READ: 1: EXPOSE-PARAMETER#1 = EXPOSURE_10_PERCENT EXPOSE-PARAMETER#2 = EXPOSURE_90_PERCENT 2: EXPOSE-PARAMETER#1 = EXPOSURE_50_PERCENT EXPOSE-PARAMETER#2 = EXPOSURE_90_PERCENT 3: EXPOSE-PARAMETER#1= ZERO_PERCENT_EXPOSURE EXPOSE-PARAMETER#2 = EXPOSURE_90_PERCENT

	4: EXPOSE-PARAMETER#1 = RATE0 EXPOSE-PARAMETER#2 = EXPOSURE_50_PERCENT THESE ARE USED TO DETERMINE EOLIAN_CONSTANT_3 DEFINING THE SHAPE OF THE EOLIAN EROSION/DEPOSITION CURVE AS RELATED TO THE EXPOSURE INDEX. If DO_ONLY_EOLIAN_DEPOSITION is set to 1 then only locations with modeled deposition are modeled – that is, no eolian erosion is allowed
-0.1 - EXPOSE-PARAMETER#1 0.2 - EXPOSE-PARAMETER#2	**EXPOSE-PARAMETER#1** **EXPOSE-PARAMETER#2**
0.651 - DISTANCE_DECAY_FACTOR 50 - WEIGHTING_CALCULATION_DISTANCE 50 - MAXIMUM CALCULATION DISTANCE 0 – WRITE OUT INITIAL EXPOSURE DATA	**DISTANCE_DECAY_FACTOR** THIS DETERMINES HOW RAPIDLY THE WEIGHTING OF SURROUNDING CELLS IN CALCULATION OF THE 'EXPOSURE INDEX' DECAYS WITH DISTANCE **WEIGHTING_CALCULATION_DISTANCE** THIS SETS THE MAXIMUM DISTANCE (IN NUMBER OF CELLS) THAT ELEVATIONS ARE USED TO CALCULATE THE 'EXPOSURE INDEX'. THESE TWO TERMS ARE ALSO USED IN DOING ACCRETION/ABLATION MODELING MAXIMUM CALCULATION DISTANCE IS FARTHEST DISTANCE THAT WEIGHTING CAN USE WRITE OUT INITIAL EXPOSURE DATA FILE IF >0
LAVA_FLOW_PARAMETERS_PRM	
************************LAVAFLOW***************************************	
3 - NUMBER_OF_LAVA_SOURCES	**NUMBER_OF_LAVA_SOURCES** HOW MANY SOURCES (VENTS, VOLCANOES) ARE PRESENT ON THE SURFACE For description, see Howard (1999)
0.12 - LAVA_EVENT_PROBABILITY	**LAVA_EVENT_PROBABILITY** PROBABLILITY OF A LAVA FLOW EVENT DURING A SINGLE ITERATION
0.01 - MINIMUM_LAVA_FLOW_SLOPE	**MINIMUM_LAVA_FLOW_SLOPE** THIS IS THE MINIMUM GRADIENT FOR LAVA FLOW AT THE FLOW SOURCE
0.01 LAVA_FLOW_THICKNES	**LAVA_FLOW_THICKNESS (M)**ASSUMED THICKNESS OF INDIVIDUAL LAVA FLOW DEPOSITS
0.002 - MINIMUM_FLOW_THICKNESS	**MINIMUM_FLOW_THICKNESS (M)** MINIMUM THICKNESS

	OF A LAVA FLOW THAT CAN FLOW INTO AN ADJOINING CELLS
100 - NEW_SEGMENT_INTERVAL	**NEW_SEGMENT_INTERVAL** THE NUMBER OF ITERATIONS BETWEEN CHANGEOVER BETWEEN DIFFERENT FLOW SOURCES
12500 - SOURCE_CHANGE_INTERVAL	**SOURCE_CHANGE_INTERVAL** THE NUMBER OF ITERATIONS BETWEEN CHANGEOVER BETWEEN DIFFERENT FLOW SOURCES
0.0001 - ERUPTION_STOP_PROBABILITY	**ERUPTION_STOP_PROBABLILITY** THIS IS THE PROBABILITY, PER ITERATION, THT THE EXISTING FLOW WILL SOLIDIFY AND STOP BEING ACTIVE. IF THIS HAPPENS A NEW FLOW STARTS AT THE SOURCE
0.005 - NO_FLOW_PROBABILITY – PROBABILITY OF FLOW CEASING	**NO_FLOW_PROBABILITY** THE OWER LIMIT OF PROBABLITY FOR A CELL TO BE A SOURCE FOR A NEW FLOW SEGMENT. IF THE PROBABLILITY DROPS BELOW THIS VALUE THEN THE CELL IS NO LONGER CONSIDERED TO BE A POSSIBLE FLOW SOURCE
28.0 - LAVA_GRADIENT_WEIGHT	**LAVA_GRADIENT_WEIGHT** A PARAMETER THAT DETERMINES HOW MUCH THE GRADIENT BETWEEN THE EDGE OF A FLOW AND THE NEIGHBORING POINT DETERMINES THE PROBABILTY OF FLOW IN THAT DIRECTION
0.14 - LAVA_DURATION_WEIGHT	**LAVA_DURATION_WEIGHT** THIS DETERMINES HOW RAPIDLY A NEW CELL DIMINISHES IN PROBABILITY THAT IT CAN BE THE SOURCE OF A FLOW INTO A NEIGHBORING CELL
CRATERING_PARAMETERS.PRM	
******************** CRATERING PARAMETERS ****************************	
2.5e-03 - IMPACT_PROBABILITY 0 – IFOLD 0=N0 1=YES 0 - IS_REGOLITH_CRATER CRATERPROB 0=N0 1=YES IFOLD 0=hard, 1=soft 1 – CRATER EDGE ABORT 10000.0 – MINUMUM SIZE OF HARD CRATER 1 – CPRRECT BIAS (0=NO 1=YES) 1 – MAKE CENTRAL PEAK (0=NO 1=YES)	**IMPACT_PROBABILITY** THE PROBABILITY OF AN IMPACT EVENT (PER YEAR). For description see Forsberg-Taylor et al (2004) and Howard (2007) **IFOLD** **[DO_EJECTA_WRAPAROUND]** IF >0 AND IF THE DOMAIN IS BOTH X AND Y PERIODIC, THEN EJECTA DEPOSITION CAN CARRY OVER ONTO THE OPPOSITE

	SIDE CRATER_EDGE_ABORT – If this is set to unity and fixed flow boundaries are selected in MARSSIM_INITIAL_BOUNDARY_CRATERS.PRM then crater impacts whose center would lie outside the simulation domain are not modeled. **ISOFTCRATER** **[IS_REGOLITH_CRATER]** IF >0 THEN CRATER SLOPES AND EJECTA ARE SOFT (REGOLITH) – OTHERWISE CONSIDERED TO BE INITIALLY BEDROCK MINIMUM_HARD_DIAMETER BELOW THIS VALUE ALL CRATER EJECTA IS CONSIDERED "SOFT" **CORRECT BIAS** IF ?O CRATER MORPHOLOGY IS ADJUSTED SO THAT NO NET ELEVATION OCCURS **MAKE CENTRAL PEAK** IF >0 THEN A CENTRAL PEAK IS SIMULATED FOR LARGER CRAERS
12.20 - LARGE_CRATER_DEPTH_SCALE 0.49 - LARGE_CRATER_DEPTH_EXPONENT 0.79 - LARGE_CRATER_RIM_SCALE 0.6 - LARGE_CRATER_RIM_EXPONENT 7000.0 - TRANSITION DIAMETER	**LARGE_CRATER_DEPTH_SCALE** **LARGE_CRATER_DEPTH_EXPONENT** **LARGE_CRATER_RIM_SCALE** **LARGE_CRATER_RIM_EXPONENT** **TRANSITION_DIAMETER** between simple and complex cr BASED UPON SCALING OF FRESH IMPACT CRATERS IN FOR
2.54 - SMALL_CRATER_DEPTH_SCALE 0.67 - SMALL_CRATER_DEPTH_EXPONENT 1.93 - SMALL_CARATER_RIM_SCALE 0.52 - SMALL_CRATER_RIM_EXPONENT	**SMALL_CRATER_DEPTH_SCALE** **SMALL_CRATER_DEPTH_EXPONENT** **SMALL_CRATER_RIM_SCALE** **SMALL_CRATER_RIM_EXPONENT** SEE ABOVE
0.64 - LARGE_CRATER_SHAPE_SCALE 0.13 - LARGE_CRATER_SHAPE_EXPONENT 0.73 - SMALL_CRATER_SHAPE_SCALE 0.113 - SMALL_CRATER_SHAPE_EXPONENT	**LARGE_CRATER_SHAPE_SCALE** **LARGE_CRATER_SHAPE_EXPONENT** **SMALL_CRATER_SHAPE_SCALE** **SMALL_CRATER_SHAPE_EXPONENT** SEE ABOVE
2.0 - CRATER_FREQUENCY_EXPONENT FOR PRODUCTION FUNCTION 0.35 - FREQUENCY_CUTOFF_SCALING	**CRATER_FREQUENCY_EXPONENT** **FREQUENCY_CUTOFF_SCALING** SEE ABOVE
4000.0 - SMALLEST_POSSIBLE_CRATER	**SMALLEST_POSSIBLE_CRATER**

4000.0 - SMALLEST_MODELED_CRATER 50000.0 - LARGEST_MODELED_CRATER	**SMALLEST_MODELED_CRATER** **LARGEST_MODELED_CRATER** THESE CAN VARY DEPENDING UPON THE SCALE OF THE SIMULATION (GENERALLY IN METERS). GENERALLY KEEP **MINDIAM** AT ABOUT 4*(CELL SCALE) AND **MAXDIAM** AT ABOUT 0.5 * CELL SCALE * MX
0.05 - EJECTA_THICKNESS_VARIABILITY 0.0 - NOISED	**EJECTA_THICKNESS_VARIABILITY** **NOISESD** SEE ABOVE
0.9 - INHERITANCE_PARAMETER 0.36 - MAXIMUM_RIM_GRADIENT 1.0 – FRACTION OF EXCAVATED EJECTA IS RETAINED IN EJECA SHEET 9.0 – INHERIT EXPONENT	**INHERITANCE_PARAMETER** **MAXIMUM_RIM_GRADIENT** SEE ABOVE **EJECTA_FRACTION_RETAINED** For large bodies that will typically be 1.0, For small, airless bodies that may be <1.0 **INHERIT_EXPONENT**
5.902 – PEAK_HEIGHT SCALE 0.51 – PEAK HEIGHT EXPONENT 0.177 – PEAK DIAMETER SCALE 1.05 – PEAK DIAMETER EXPONENT	Parameters to model central peaks
1 – USE REAL CRATERS (0=ONLY SIMULATED 1=USE MARTIAN FRESH CRATERS 1.2 – RADIUS_MAX_INHERIT 2.0 – RADIUS_MAX_USE 15000.0 – MINIMUM_REAL_CRATER_DIAMETER 100000.0 - MAXIMUN_REAL_CRATER_DIAMETER 3.0 – COSINE POWER	If selected then a database of martian fresh craters in the diameter range of 15-100 km are used to simulate new fresh impacts. See the discussion of using real crater modeling at the bottom of this file.
ACCRETION_ABLATION_PARAMETERS.PRM	
******************** ACCRETION PARAMETERS *************************	
-0.4 - ACCRETION_RATE	**ACCRETION_RATE** RATE OF NON-FLUVIAL AND NON-EOLIAN SURFACE ACCRETION AND DEGRADATION. See Howard and Moore (2008) and Howard et al. (2012) for explanation.
0 – EXPOSURE_DEPENENT_CREEP 1 - USE_SOLAR_RADIATION 1 – USE TOP EXPOSURE	**EXPOSECREEPUSE** **[EXPOSURE_DEPENDENT_CREEP]** >0 IF THE MASS WASTING CREEP RATE DEPENDS UPON 'EXPOSURE'

0 – USE_INVERSE_EXPOSURE 1 – SMOOTH_EXPOSURE VALUES	**RADIATION_USE** **[USE_SOLAR_EROSION]**IF >0 SUBLIMATION DUE TO REFLECTED RADIATION IS MODELED. **USE_TOP_EXPOSURE** If selected exposure values Are calculated only for cells visible To the target cell. **USE_INVERSE_EXPOSURE** Changes the sign of Calculated exposure values. **SMOOTH_EXPOSURE_VALUES** used 9-point Smoothing of calculated exposure values
0.1 – RADIATION RATE CONSTANT 2.0 – RADIATION SOURCE FACTOR -0.45 – THRESHOLD DEPOSITION CONVEXITY 0.0 - RADIATION_DEPOSITION_RATE 1.0 – FRACTIONAL DEPOSITION VOLUME 0 – USE REGOLITH ABLATION	**RAD_CONST** SCALES RATE OF RADIATION-DEPENDENT SUBLIMATION/DEPOSITION **RAD_DUST_FACTOR** RELATIVE AMOUNTS OF RE-EMITTED THERMAL RADIATION FROM DUST-COVERED SURFACES RELATIVE TO BEDROCK SURFACES **RAD_THRESH_CONVEXITY** CRITICAL VALUE OF EXPOSURE INDEX FOR REDEPOSITION OF SUBLIMATED ICE **RAD_DEPOSIT_RATE** RATE SCALING FOR REDEPOSITION OF SUBLIMATED ICE ON LESS-EXPOSED SURFACES **USE_REGOLITH_ABLATION** If set to 1 regolith covered locations are subject to ablation, if set to 0 only bedrock can be ablated.
MASS_FLOW.PRM	
1 - MASS FLOW TYPE (0=NO FLOW, 1=BINGMAM FLOW, 2-GLEN-LAW FLOW 0.00000001 – FLOW DIFFUSIVITY 35.0 – YIELD PARAMETER FOR BINGHAM FLOW 0.0 – MASS FLOW EROSION RATE 5000.0 – BINGHAM FLOW MAXIMUM THICKNESS 1000.0 – MASS FLOW MATERIAL DENSITY	MASS FLOW TYPE – 0 means deep mass flows are not modeled, 1 uses Bingham flow rheology, and 2 uses Glen's Law rheology. Only "regolith" is susceptible to flow FLOW_DIFFUSIVITY – the multiplicative factor governing flow rates. YIELD_PARAMETER for Bingham Flow. This determines the lower limit of shear stress permitting flow. MASS FLOW EROSION RATE is a multiplicative factor used in calculation of basal/lateral erosion by mass flows

	BINGHAM FLOW MAXIMUM THICKNESS. Regolith below this maximum value is considered to be immobile. Set to a large value if all regolith is mobile MASS FLOW MATERIAL DENSITY – If water ice, this will be ~1000 kg m-3
0.0 - EXPONENT FOR FLUX IN BASAL EROSION 0.0 - EXPONENT FOR FLOW DEPTH IN BASAL EROSION 0.0 – EXPONENT FOR SURFACE SINE IN BASAL EROSION	These are unused in the present version.
0.0 – MASS FLOW CRITICAL VALUE 0.0 – CRITICAL MASS FLOW THICKNESS 100.O – CRITICAL BASAL EROSION FLOW THICKNESS 200.0 MAXIMUM BASAL EROSION DEPTH	**MASS FLOW CRITICAL VALUE** if this is greater Than zero, regolith lying above this depth Will Be immobile. **CRITICAL MASS FLOW THICKNESS**. If the total Regolith thickness is less than this value Then the regolith is not modeled to be Mobile. **MAXIMUM BASAL EROSION DEPTH** = not used, but If implemented in future version will Set a minimum flow depth for basal erosion To occur.
0 – SCHEME FOR DETERMING FLOW DEPTH AT A LOCATION 0 – USE A TIME INCREMENT SCALED TO FLOW DEPTH CHANGE 4.0 – TARGET MAXIMUM ELEVATION CHANGE PER ITERATION	**FLOW DEPTH SCHEME**- See the GUI description or the description in mass_flow.f90. **FLOW DEPTH DEPENTENT TIME INCREMENT**: If this is set to unity, then the simulation timestep is set by **MAXIMUM ELEVATION CHANGE PER ITERATION.**
GRAVEL_MIXTURE.PRM	
0 – DO GRAVEL MODELING 0 – PRINT SIMULATION DETAILS 0 – USE WIDTH-RELATIVE CALCULATIONS 1 = EQUATION SELECTOR (1-Gary Parker, 3- Wilcock)	See Howard et al. (2016) and the references to papers by Parker and Cui et al, as Parker morphodynamics ebook site: http://hydrolab.illinois.edu/people/parkerg/ morphodynamics_e-book.htm
36 – STRAIN CURVE SIZE	

12 – GRAIN ARRAY SIZE	
2.0 ROUGHNESS_FACTOR 1.0 ACTIVE LAYER FACTOR 0.1 – MANNICG COEFFICIENT 1 – UPWIND COEFFIENT 0.5 - AGGRADATION COEFICIENT 0.05 – INTERMITTENCY 1.0E-14 – SEDIMENT CONSTANT 0.0 – MUD FRACTION 0.03 – ABRASION COEFFICIENT 0.0 – DELAY WEIGHT 100 – ITERATIONS PER MASTER SIMULATION ITERATION	See the above papers/ebook and the descriptions in the GUI version of the documentation.

Types of boundary conditions

Boundary conditions are set by ***marssim.prm*** with the following parameters read in the given order (in input 1 means they are true, 0 for false):

HORIZONTAL_LOWER_BOUNDARY
NON_ERODING_LOWER_BOUNDARY
USE_Y_PERIODIC
USE_X_PERIODIC
USE_FLOW_BOUNDARIES

Specific sets of these are generally used together. If USE_Y_PERIODIC is true the top and bottom boundaries are periodic – elevations are assumed to be accordant across these boundaries and materials (water or sediment) exiting one boundary enter the opposite side at the same X coordinate. The situation is the same for USE_X_PERIODIC. A simple type of simulation utilizes a horizontal lower boundary with a constant rate of lowering through time (for example, to simulate steady-state landscapes. In this case the boundary condition line would either be:

11000 (if the lateral boundaries are non-periodic)

or

11010 (if the lateral boundaries are X-periodic)

In either of these cases the top boundary is no-flux (generally becoming a drainage divide) and the rate of erosion is set by the parameter BOUNDARY_LOWERING_RATE read from ***marssim.prm***.

Another common type of boundary is where both X and Y edges are periodic. This eliminates artificial lateral drainage divides. This would be used with BOUNDARY_LOWERING_RATE of zero. In this case the input line is:

00110

There is a caveat in using doubly-periodic boundaries. One either must use hyperarid flow conditions (all surface flows disappear in depressions) such that MODEL_LAKE_EVAPORATION is false (0) in line 3 of the marssim.prm file and COMPLETE_RUNOFF is false in line 24. Alternatively, set MODEL_LAKE_EVAPORATION to true and specify a non-zero lake relative lake evaporation rate (EVAPORATION_MEAN) in line 29. Also make sure that the initial input elevations (***inelev.dat***) are doubly periodic.

Another type of boundary condition occurs if a portion of a larger real landscape is being simulated. This would in general only be used if no appreciable flows enter the simulation domain from outside. Because downstream flow controls are important in fluvial networks the most reasonable boundary condition to set is that all the lateral boundaries are non-eroding. Erosion of streams and slopes near the lateral boundaries will not be realistic, but under appropriate conditions the evolution of the interior of the landscape can be simulated for reasonable lengths of times. See, for example, Barnhart et al. (2008). In this case the input boundary condition line would be:

00001

Finally streams with specified discharge and sediment load can be specified to enter a top or lateral boundary by setting HAVE_INFLUENT_RIVERS to true (1) in line 31 of ***marssim.prm***. In that case, the influent river parameters are read from the file ***inriver.prm***. See Fagherazzi et al. (2004).

THE PRESENT DISTRIBUTION DOES NOT YET INCLUDE THE EXAMPLE SIMULATIONS. THE TEXT IS GREYED OUT

Example Simulations. Summary output is included from a number of simulations that illustrate most of the processes and scenarios to which the program has been used in the past. All include the relevant ***marssim.prm*** file, the ***inelev.dat*** file of initial elevations, the final output elevation file, ***outelev.dat*** (sometimes including intermediate results), and one or more shaded relief image files ***bshade???.raw*** showing the initial and final topography. Some include additional output or derived information files, including animated ***.GIF*** files. The simulations are in the zip file ***representative_simulations.zip*** in separate directories. Because of a few recent model changes and bug fixes, the output from simulations using the same parameter and input files may not exactly match the output files, especially when stochastic forcing is used (e.g., impact craters, variable discharges, lava flows…). Each of these packages is summarized below:

TERRESTRIAL APPLICATIONS:

Simple_steady_state: A near-steady-state landscape produced by constant lowering of the lower boundary and laterally-periodic boundaries. In this simulation regolith and bedrock have identical erodibilities. Fluvial sediment transport is not modeled.

Resistant_bedrock: Another near-steady-state simulation but the regolith is 10 times more erodible than bedrock. Fluvial sediment transport is not modeled. For this run morphometric information was created in the ***basin.lst*** and other files in this directory by running the simulation for an additional 100 iterations.

Critical_shear_stress: Another near-steady-state simulation in which bedrock and regolith are equally erodible but a critical shear stress is required for detachment. Fluvial sediment transport is not modeled.

Pediment: In this case erosion of the steady-state landscape of the resistant-bedrock case is continued with a constant elevation lower boundary and sediment transport is modeled. A pediment develops and expands as the slopes and headwater channels continue to erode.

Gully: This is an example of accelerated erosion instigated by a temporary reduction in the critical shear stress for detachment. The initial landscape is the critical_shear_stress endpoint. A gully system develops and expands in low-order tributaries. See Howard (1999). Because the lower portions of the existing slopes were near the maximum critical gradient, slopes adjacent to gullies are not greatly steepened in this example in contrast to the simulations in Howard (1999).

Coastal: This simulation incorporates three additional capabilities of the model. The simulation models evolution of a landscape in coastal plain sediments adjacent to the Potomac River in Virginia. The first is a time-varying sea level which acts as the base level for the system. The timeline of relative land-sea elevation changes is read from ***oceanlevels.dat***, which includes both a detailed sea level curve for the past 3.5 ma (corrected for the Potomac river not fully responding to lowstands) and long-term uplift of the region. See ***oceanlevels.tif***. The second model feature is heuristic modeling of the effect of vegetation in retarding erosion of the soft coastal plain sediment. A critical shear stress decreases in magnitude from high near divides to low in headwater channels. The third model feature are "events" occurring twice within the simulation that instantaneously plane off portions of the landscape near the lower boundary (the modeled Potomac River). This is assumed to correspond to short periods during sea level highstand where wave erosion caused erosional planation. The whole evolution of the landscape is shown in the animated gif, ***coastal.gif***. The target natural landscape (near Colonial Heights) is shown in colonial_image.jpg.

Bedrock: This simulation illustrates a circumstance where bedrock erodibility locally becomes small enough that bedrock becomes exposed. A 3-D file of rock resistance is read in as a direct-access file. The resistance of the rock to both weathering and to fluvial detachment is assumed to vary directly in response to the values of rock resistance (which follow a 3-D pseudo-fractal, lognormal distribution). The direct access file is ***resist.in***. The file ***regolith.dat*** gives the state of regolith thickness during the simulation (positive values are thickness of regolith cover, negative values are, for exposed bedrock, the weathering rate, which is assumed to increase without limit as a limiting slope steepness is approached). ***Resist.out*** gives 2-D timelines of the effective rock resistance at the surface. ***Bedrock.dat*** shows timelines of exposed bedrock (1) and regolith-covered slopes (0). An animated shaded-relief movie of the simulation is provided as ***resistant.gif***. ***BSHADE150_additional.tif*** shows the endpoint of a simulation with a different ***resist.in*** file. The 3-D fractal resistance values are generated by ***matrix_3D.F90***.

An additional application of the model to simulate dissection of continental shelves, imposition of inflowing rivers across model boundaries, and on-shelf delta evolution is illustrated in Fagherazzi et al. (2004) but not included in the package.

PLANETARY SIMULATIONS

Lava: In this simulation lava emerges from a single vent and, through multiple shallow lava flows, inundates the landscape. The model is briefly explained in the Howard (1999) LPSC abstract and internally in the subroutines.

Eolian: In this simulation a cratered surface is differentially blanketed with eolian deposits. This is a heuristic model which assumes the most rapid deposition occurs in depressions and valleys. Hills and summits can optionally be wind-eroded. See Forsberg-Taylor et al. (2004).

Large_crater: This just shows how the program can be used to create a simulated saturation-cratered surface. In this case starting from a flat initial surface. The cell size is 400x400 m. Crater shapes are scaled to Mars.

Small_crater: Like the previous case but the cell size is 100x100 m.

Callisto: This is a simulation of landform evolution on the Jovian satellite Callisto. It is assumed that sublimation (primarily by reradiated solar IR) creates a dusty mantle subject to creep and that some of the ice reprecipitates on convex parts of the landscape (primarily crater rims). See Howard and Moore (2008). In the colored tif images white is exposed, volatile-rich bedrock, purple are dust-mantled parts of the landscape, and yellow is mantled with reprecipitated ices.

Accretion: In this simulation a cratered surface is coated with deposited ice or dust. Accumulation is assumed to occur normal to the surface (uniform accrescence), thus eventually creating rounded, donut-like crater rims. See the Howard (2004) LPSC abstract. Not included is the possibility of complementary simulations of uniform removal (ablation) of a surface.

Non-Linear creep: In the two simulations (convexity-enhanced and convexity-retarded) a cratered surface is subjected to creep in which the diffusivity is a function of local landform convexity as measured by "exposure" as in the eolian modeling.

The remainder of the models illustrates modification of cratered surfaces by fluvial erosion. The first three modify a sloping, cratered surface under various assumptions about the hydrologic and sedimentologic setting. The second three show various degrees of interaction of fluvial erosion with continuing impact cratering. Similar simulations to the preceding are included in Howard (2007). The final two simulations illustrate erosion by groundwater seepage. For similar simulations see Luo and Howard (2008).

arid_slope: A sloping cratered surface is fluvially eroded under hyper-arid hydrologic conditions (all discharge disappears when reaching depressions). Sediment accumulates within craters.

Steady_evaporation: As above, but evaporation within lakes is modeled. The evaporation ratio is a steady 2.5. Note the formation of crater-fringing interior deltas.

variable_evaporation: As above, but evaporation within lakes is modeled. The evaporation rate varies stochastically, so that lake levels, and the associated deltaic deposits occur at various elevations and earlier delta deposits are partially eroded during lower lake levels.

pelagic_sedimentation: Lake evaporation is modeled with a constant value relative to runoff, but 50% of sediment eroded from uplands is assumed to be suspended/wash load deposited in the submerged basin centers. The deposited sediment is diffused to give a smooth deposit.

fluvial_no_cratering: A cratered surface is fluvially modified under hyper-arid hydrologic conditions. Note the doubly-periodic boundary conditions.

fluvial_slow_cratering: Fluvial modification of the initial cratered surface is affected by a slow rate of continuing impact cratering. An intermediate cratering rate is in **fluvial_moderate_cratering**.

fluvial_rapid_cratering: As above but with a higher relative rate of impact cratering diminishes the ability of fluvial erosion to create integrated drainage networks.

Deep_seepage: Fluvial erosion is by seepage produced by groundwater seeps. In order to create seepage erosion, even for sand, a high recharge rate and strongly permeable substrate is required. (similar to some Floridian seepage networks). In this simulation seepage is primarily limited to the interior of craters (at least initially).

Shallow_seepage: As above, but with a combination of higher recharge and lower permeability, so that seeps occur at topographically higher locations and dissection is more widespread.

USING FRESH MARTIAN CRATERS IN SIMULATING NEW CRATERS

If the option is selected to use the topography from real martian craters to represent new impacts(see CR37x) then a database of topography of real martian then a database of topography of real martian fresh craters is used for newly-generated craters, but only if the crater is in the size range 15000 to 100000 meter crater diameter. The use of real craters gives a cosmetically more realistic simulation, but also the craters tend to have wider rim regions than geometrically simulated craters. An important limitation concerns using the MOLA DEMs for the selected CELL_SIZE for the simulation. The distribution includes topographic databases for CELL_SIZE of 1000m, 750m, 500m and 300m. Because of the resolution limits of the MOLA topography, use of this dataset is not useful for CELL_SIZE less than 300m. When a crater diameter for simulation is selected, either randomly or set by scheduled events, The topography for a natural crater closest in size to the crater size being simulated is utilized. The orientation of the real crater DEM (N,S,E.or W) is selected randomly. The natural craters that have been selected have some background topography, so that the natural crater topography exterior to the crater rim is blended with the pre-existing topography of the simulation. Use of real craters requires several data files be available REAL_CRATERS.TXT is the list of the names and diameters of the natural crater database and must be in the execution directory. The first line of this file is the absolute file system path to the directory containing the topographic datasets for the natural craters. There are four real craters text files, REAL_CRATERS-300.TXT, REAL_CRATERS-500.TXT, REAL_CRATERS-750.TXT, and REAL_CRATERS-1000.TXT. The version of the TXT file appropriate to the simulation CELL_SIZE should be copied to REAL_CRATERS.TXT in the execution directory. The parameters used to place fresh craters onto the simulation surface use the following parameters from the CRATERING_PARAMETERS.PRM file:

R_m = RADIUS_MAX_INHERIT
R_u = RADIUS_MAX_USE
β = COSINE_POWER
D = simulated crater diameter
R = simulated crater radius = $D/2$

Between the center of the crater and R_m*R the real crater morphology is used to create the simulated crater after accounting for the mean elevation of the simulated terrain and compensating for any regional tilt of the real crater topography. Between R_m*R and R_u*R the influence of the real crater morphology on modifying the pre-existing surface elevations drops off as:

$$\mathrm{Cos}(\pi*(R- R_m*R)/((R_u*R - R_m*R)*2))^{\beta}$$