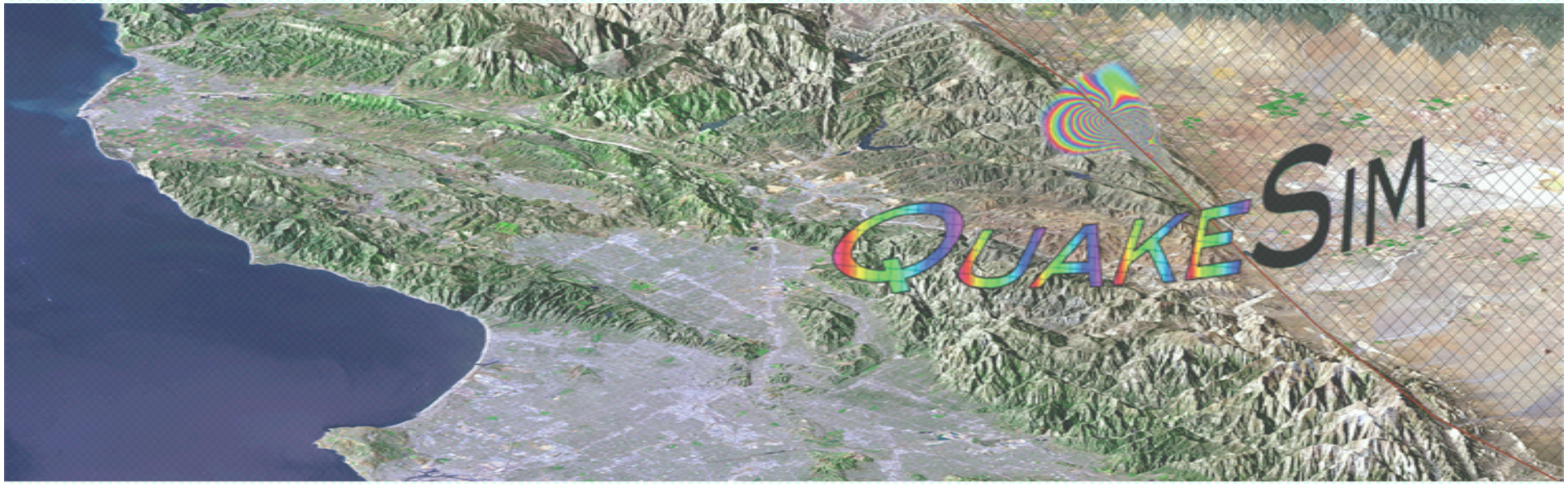
National Aeronautics and Space Administration

Building GeoFEST Models



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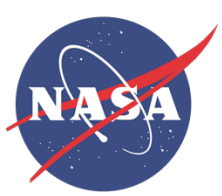
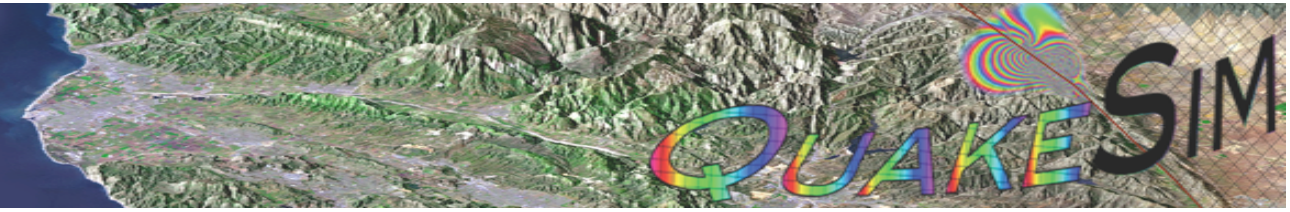
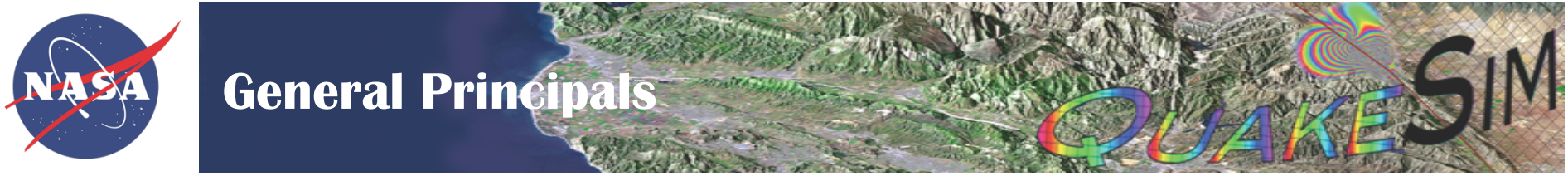


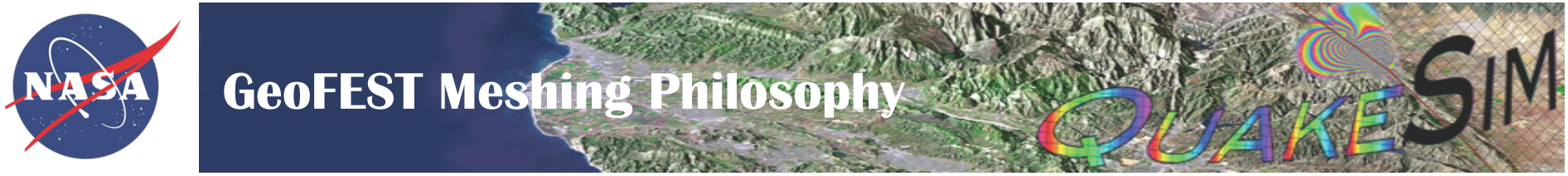
Topics



- General Principals
  - Observations about GeoFEST input file
- Specific Models
  - Sliding wall box: cubevalid01.dat
  - Fault in a layered box: San Francisco
  - Fault cutting through: Simple San Andreas
  - Many rectangular faults, dips: Mojave
- Visualization by subsetting

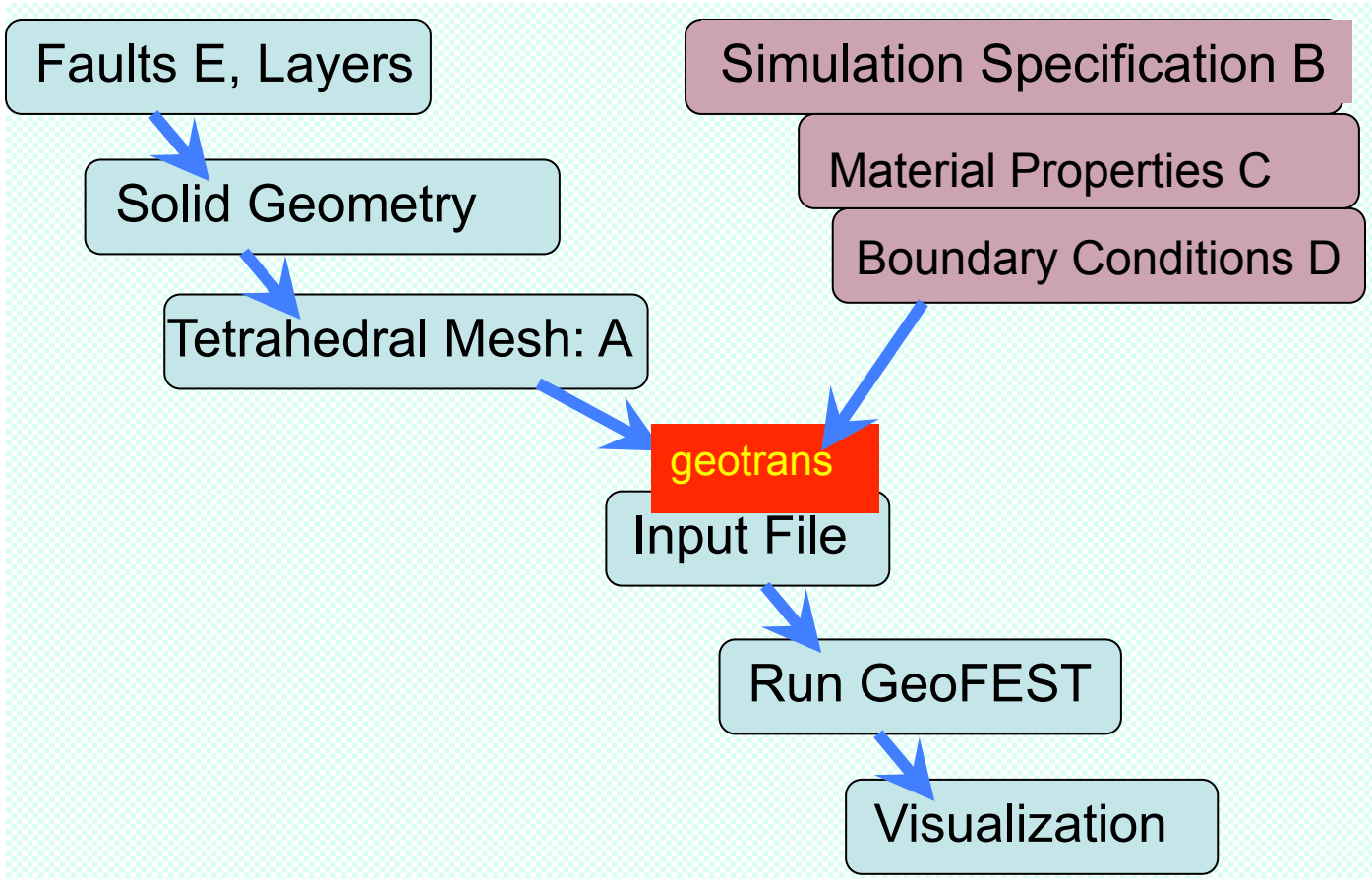


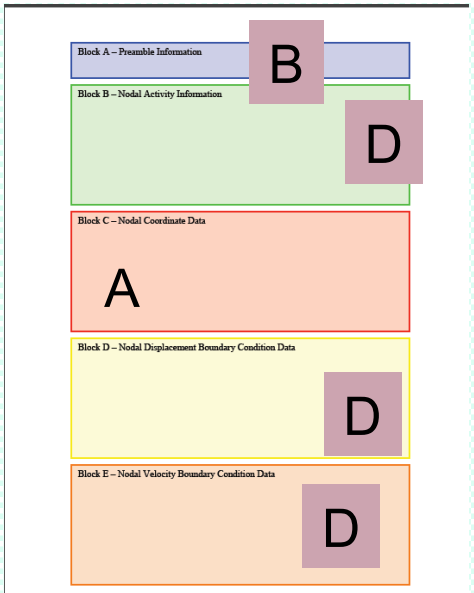
- Three kinds of input:
  - High bulk: nodes, element lists (LaGriT is good at this)
  - Medium bulk: faults (split nodes), boundaries, output subsets
  - Trivial: control directives (Time steps, method flags)
- GeoFEST is particular: all items must be in right place
  - Although white space is always ok.
- Strategy:
  - For high bulk, use specialied tools (eg LaGriT)
  - Medium: mark with LaGriT, translate with mesh-savvy script
  - Trivial: specify in a flexible text format, translate with script.
  - “geotrans”

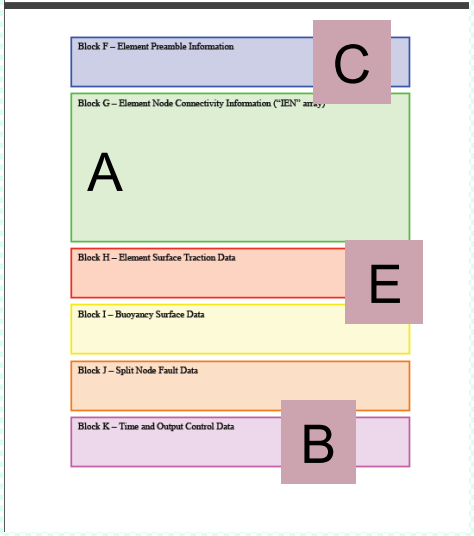


- Initial mesh covers geometric details (not solution)
  - We don't know solution mesh needs perfectly
- Solution accuracy through refinement
- Refined mesh: allow local performance waste
  - Accuracy more important than performance
  - Parallel computers have abundant capacity
- Cannot overmesh everywhere – h^4 cost overwhelms
- Supersize domain to avoid BC errors
  - use coarse mesh far from sources

Steps to creating your simulation

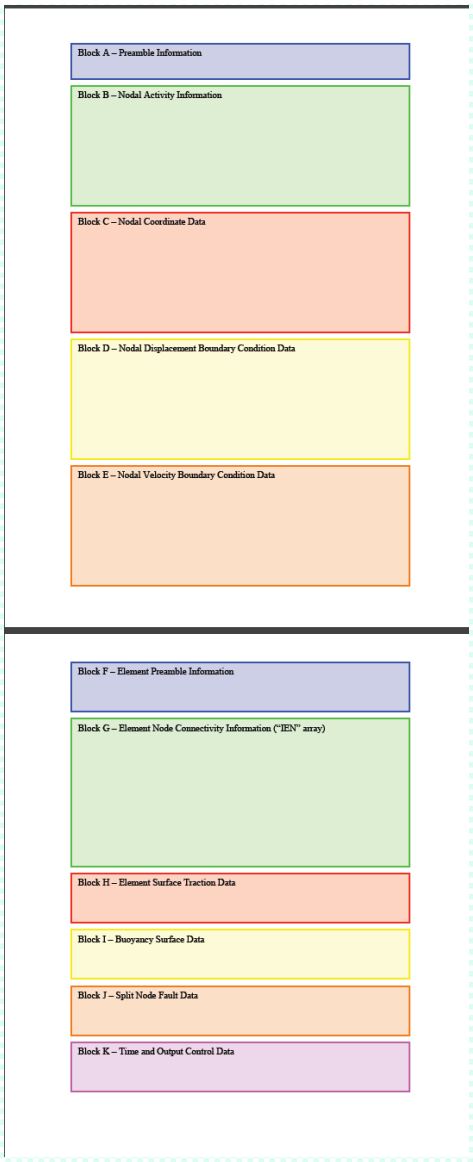






Sliding wall box: cubevalid01.dat

```
cbv01a.out
this is a 3d cube of 3x3 cells of size 0.4 ; bc compress in x;iter solve*
each cell composed of 5 tetrahedra *

64

3 3 0 1 2

1       0       0       0       0
2       0       1       0       0
------------------skip--------------------
63      0       1       0       0
64      0       0       0       0
0 0

1       0        0.00000         0.00000         0.00000
2       0        0.40000         0.00000         0.00000
------------------skip--------------------
63      0        0.80000         1.20000         1.20000
64      0        1.20000         1.20000         1.20000
0 0


4 0 -1.00 0.0 0.0
8 0 -1.00 0.0 0.0
------------------skip--------------------
60 0 -1.00 0.0 0.0
64 0 -1.00 0.0 0.0
0 0


1
135
4 1 0 0 0
1000.0 1000.0  10000.0 1.0   0.0 0.0 0.0


1   0  1     1  2  6  18
2   0  1     6  5  1  21
------------------skip--------------------
134   0  1     63  64  60  48
135   0  1     43  63  60  48
0 0


-1  -1

1   5   5000  0
100.0  1.0  0.2


7
0.0
1.0
5.0
10.0
30.0
60.0
100.0

NO_RESTART

test.dmp
```

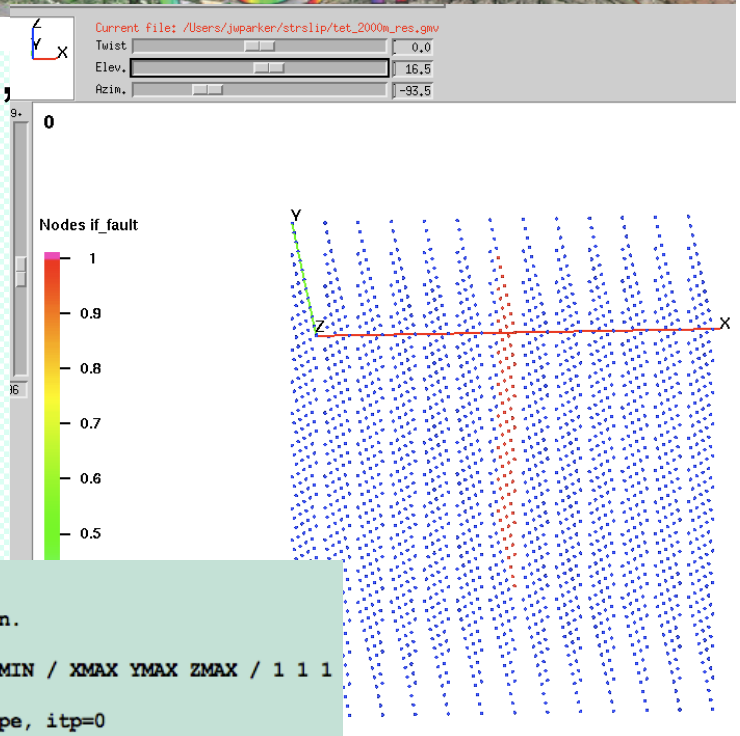


Strslip: Fault in half box

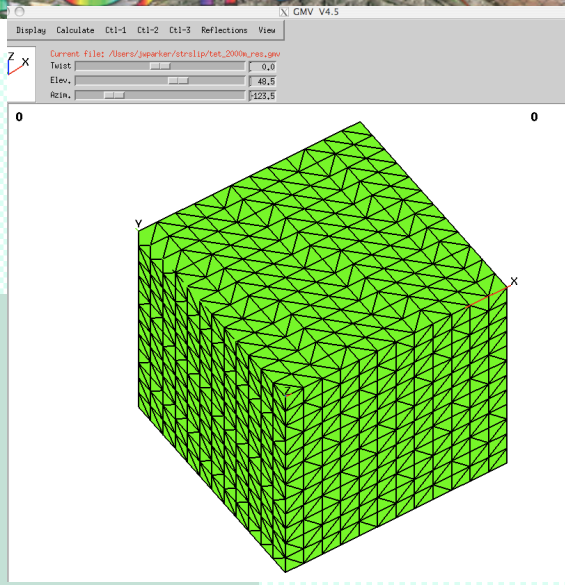
- Simplified strike_slip_benchmark,
  - slip=1 m(const)
  - 2 km spacing.

```
define / XMIN / 0.0
define / XMAX / 24000.
define / YMIN / 0.0
define / YMAX / 24000.
define / ZMIN / -24000.
define / ZMAX / 0.0
*
* Build mesh with 1000m point spacing
*
define / CMO_NAME / cmo1_tet
define / OUTPUT_table /  tet_2000m_res.table
define / OUTPUT_gmv /    tet_2000m_res.gmv
define / OUTPUT_avs /    tet_2000m_res.inp
define / OUTPUT_gft /   tet_2000m_res.gft
define / OUTPUT_zone /   tet_2000m_res
*
define / NX / 13
define / NY / 13
define / NZ / 13
*
infile build_mesh.mlgi
finish
```

```
cmo / create / CMO_NAME / / / tet
*
* Create a rectalinear point distribution.
*
createpts / xyz / NX NY NZ / XMIN YMIN ZMIN / XMAX YMAX ZMAX / 1 1 1
*
* Set node material type, imt=1, node type, itp=0
*
cmo / setatt / CMO_NAME / imt / 1 0 0 / 1
cmo / setatt / CMO_NAME / itp / 1 0 0 / 0
*
* Delaunay connect nodes
*
connect / noadd
cmo / setatt / CMO_NAME / itetclr / 1 0 0 / 1
*
* Set itp values itp=0=interior itp=10=exterior
*
resetpts / itp
*
infile / identify_fault_nodes.mlgi
*
infile / output_files.mlgi
*
cmo / delete / CMO_NAME

finish
```



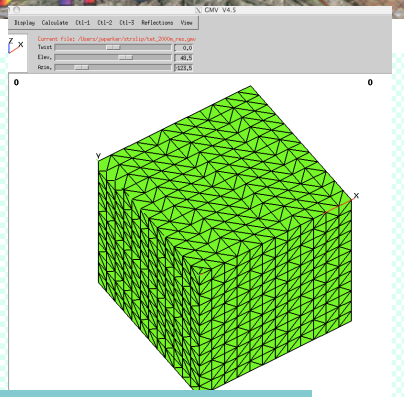
Strslip: more LaGriT




```
==><MY><==#jwparker#310$ cat identify_fault_nodes.mlgi
********************************
*
* Carl W. Gable
* gable@lanl.gov
* LaGriT Control File
* http://lagrit.lanl.gov
* http://meshing.lanl.gov
*
********************************
* Add an integer node attribute vector (if_fault)
* Add an real    node attribute vector (slip)
*
cmo / addatt / CMO_NAME / if_fault / vint    / scalar / nnodes
cmo / addatt / CMO_NAME / slip     / vdouble / scalar / nnodes
*
* Make a pset of the fault nodes.
*
define / ZBOT / -16001.0
pset / p_fault / geom/xyz/ 1 0 0 /11999.9 0. ZBOT/12000.01 16000.01 1.0
*
* Set nodes of attribute if_fault to:
* 0 = not fault node
* 1 = fault node
*
cmo / setatt / CMO_NAME / if_fault / 1 0 0 / 0
cmo / setatt / CMO_NAME / slip / 1 0 0 / 0.0
cmo / setatt / CMO_NAME / if_fault / pset get p_fault / 1
cmo / setatt / CMO_NAME / slip     / pset get p_fault / 1.0
finish
```

```
==><MY><==#jwparker#313$ cat output_files.mlgi
********************************
*
* Carl W. Gable
* gable@lanl.gov
* LaGriT Control File
* http://lagrit.lanl.gov
* http://meshing.lanl.gov
*
********************************
*
* Turn off output of imt, itp, icr, isn, iign
*
cmo / modatt / CMO_NAME / imt / ioflag / l
cmo / modatt / CMO_NAME / itp / ioflag / l
cmo / modatt / CMO_NAME / icr / ioflag / l
cmo / modatt / CMO_NAME / isn / ioflag / l
*
*
dump / zone_outside / OUTPUT_zone / CMO_NAME / keepatt
*
* Output a list of all nodes with fault, top, bottom, left, right, front, back
*
dump / avs2 / OUTPUT_table / CMO_NAME / 0 0 1 0
* ALSO NEED PSET TO BE OUTPUT FOR FAULT - AS IN PAST WORK.

dump / geofest / OUTPUT_gft / CMO_NAME
pset/p_fault/write/p_fault.pset/ascii
*
* Output a GMV file of the mesh.
*
dump / gmv /  OUTPUT_gmv / CMO_NAME / ascii
*
* Output an AVS file of the mesh. The AVS file has attribute output turned
* off because the attribute information is in the file OUTPUT_table.
*
dump / avs2 / OUTPUT_avs / CMO_NAME / 1 1 0 0
*
* Write some diagnostics to the screen.
*
cmo / status / brief
quality
cmo / printatt / CMO_NAME / -all- / minmax
*
finish
```

strslip: Simulation Specification

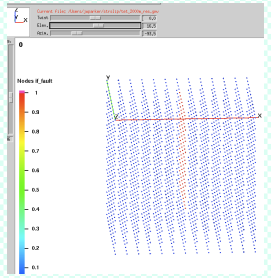


LaGriT produces:
strslip.gft file: node coords, tets ***in GeoFEST format***
tet_2000m_res_outside.zone file
(lists nodes on the box sides)
p_fault.pset files (lists nodes on fault)

Still need moderate bulk parts: GeoFEST split nodes records, boundary condition flags and values.
User can develop their own approach for this, or use geotrans.

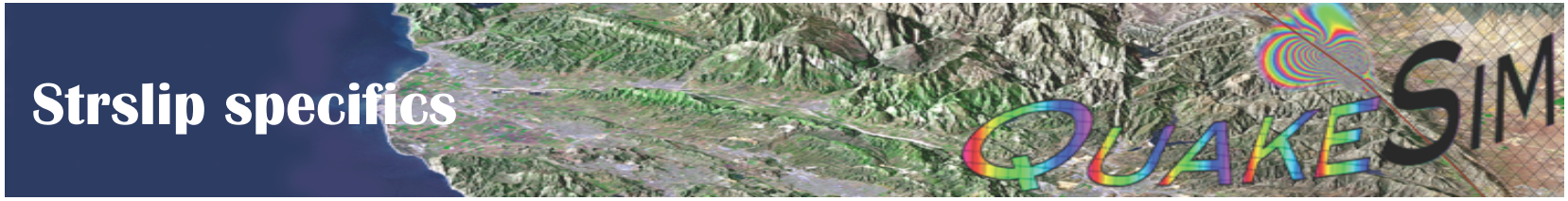
For geotrans, User must create:
<layer>.materials file
<fault>.params file
<run_specifics> file

lamelambda 2.755200e+01
lamemu ` .622400e+01
viscosity 0.000000e+00
exponent 1.000000



==><MY><==#jwparker#319$ cat p_fault.params
number dip(o) strike(o) slip(m) rake(o) length(km) width(km) depth(km) origX origY 1st repeat
1 90.0 0.0 1.0 180.0 16000. 16000. 16000. 12000. 0.0 0.0 5000.

➔>>*geotrans creates GeoFEST input*



- What's in the <run_specifics> file "specs"?
- Keyword-value pairs, order doesn't matter
- Chiefly required items for GeoFEST input (geotrans copies)

```
==><MY><==#jwparker#320$ cat specs
comment1 strikeslip model in symmetric half y>0
comment2 based on strike_slip_benchmark, simplified
output_filename strslip.out
ELASTIC1        1
ELAS_OUT1       1
REFINE  0
REFINE_OUT      0
ELASTIC2        0
ELAS_OUT2       0
VISCO   0
gft_file tet_2000m_res.gft
outside_zone_file tet_2000m_res_outside.zone
nrates 0
top_bc free node 0 0. 0. 0. 1.
east_bc locked node 0 0. 0.0 0. 1.
west_bc locked node 0 0. 0.0 0. 1.
```

Flow control

Ignored

```
north_bc locked node 0 0. 0. 0. 1.
south_bc free node 0 0. 0. 0. 1.
bottom_bc locked node 0 0. 0. 0. 1.
reporting_nodes all
reporting_elements none
number_time_groups 1
backup_steps 5000
end_time 0.
alpha 1.0
time_step 0.1
print_times_type steps
number_print_times 1
print_interval 1.
start_from_file NO_RESTART
checkpoint_file NO_SAVE
```

- Plus names of LaGriT files to read,
- boundary conditions
- print times parameters

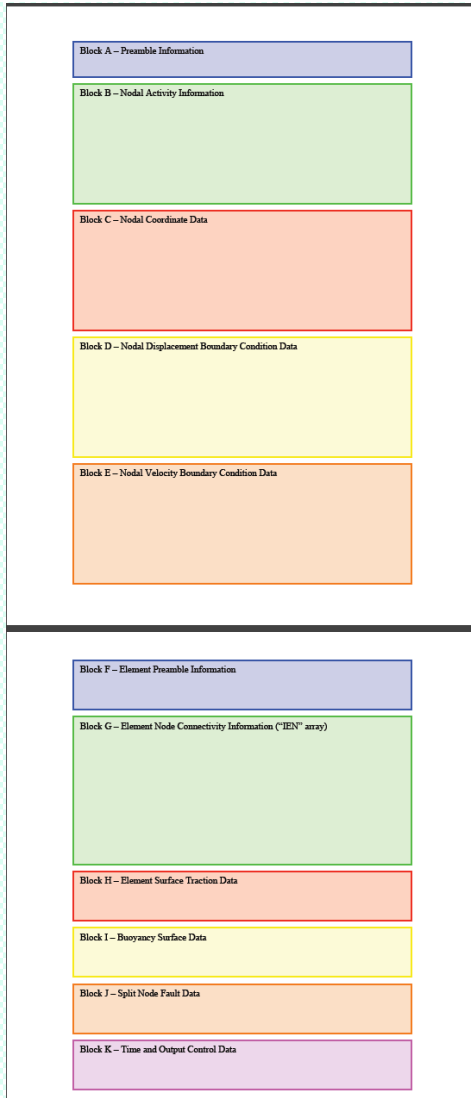
Strslip: file size

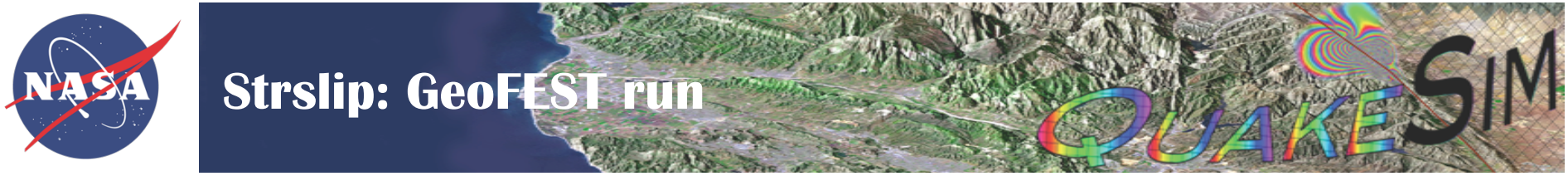
- 5 p_fault.flt
- 2 p_fault.params
- 11 p_fault.pset
- 14786 strslip.dat
- 12477 tet_2000m_res.gft
- 123 tet_2000m_res_outside.zone
- 4 tot.materials
- 23 tot.sld

Strslip:GeoFEST input

- Main product of geotrans:
  - run-ready GeoFEST input

```
strslip.out
strikeslip model in symmetric half y>0 *
based on strike_slip_benchmark, simplified *

ELASTIC1        1
ELAS_OUT1       1
. . .

2197
3       3       0       1       2

1  0    0       0       0
2  0    0       0       0
. . .
0 0

1       0        0.00000         0.00000        -24000.00000
2       0       2000.00000       0.00000        -24000.00000
0 0

0 0

1

10269

4 1 0 0 81
1.622400e+01    2.755200e+01    0.000000e+00    1.000000e+00    0.00  0.00  0.00

1       0       1       170     1       14      2
2       0       1       16      186     17      29
 . . .
0 0

683     1        0.00000        -0.00000        -1.00000        -0.00000        -1.00000        0.00000         1.00000
696     1        0.00000        -0.00000        -1.00000        -0.00000        -1.00000        0.00000         1.00000
-1 0

1   1   5000   1
0.   1.0   0.1
1
0

1       5000.   0.0

NO_RESTART
```





- Produces messages to stdout (send to a log)
- Cghist.txt file: iteration history
  - time=0 converged in 155 iterations
  - starting norm=153484 , ending norm=1.46575e-13
- Strslip.out: node displacements, elt stress

- strikeslip model in symmetric half y>0
- based on strike_slip_benchmark, simplified
- Global coordinates & displacements & delt displacements
- Simulation time = 0.000000 ; step size = 0
- coordinates displacements del_displacements
- node 1 0.000000 0.000000 -24000.000000 0 0 0 0 0 0
- node 171 2000.000000 0.000000 -22000.000000 0.00991398 0.00763253 0.0108999 0.00991398 0.00763253 0.0108999
- node 172 4000.000000 0.000000 -22000.000000 0.016031 0.0177823 0.0216023 0.016031 0.0177823 0.0216023

Visualization by subsets

- *get_block* - extracts a block of displacement data from a geofest output file.
- *get_surf_soln* - extracts surface nodes (z=0) from stdin nodal results
- These will also strip off node numbers; result:
- (coordinates) (accumulated disp) (this step disp)
- x y z dx dy dz ddx ddy ddz
- 38.709090 -14.332980 -15.000000 -1.66327e-12 -0.00774182 -1.27257e-11 -1.66327e-12 -0.00774182 -1.27257e-11

Creating a plot is now easy, for example using gnuplot:
> gnuplot
gnulplot> plot 'Cr2.surf.810.txt' using 1:8 with points

(Or drop file into Kaleidagraph, result at right).

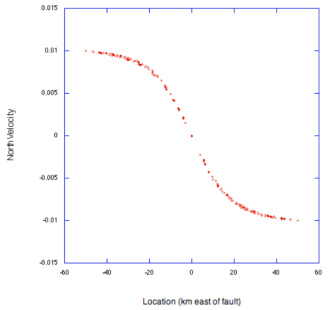
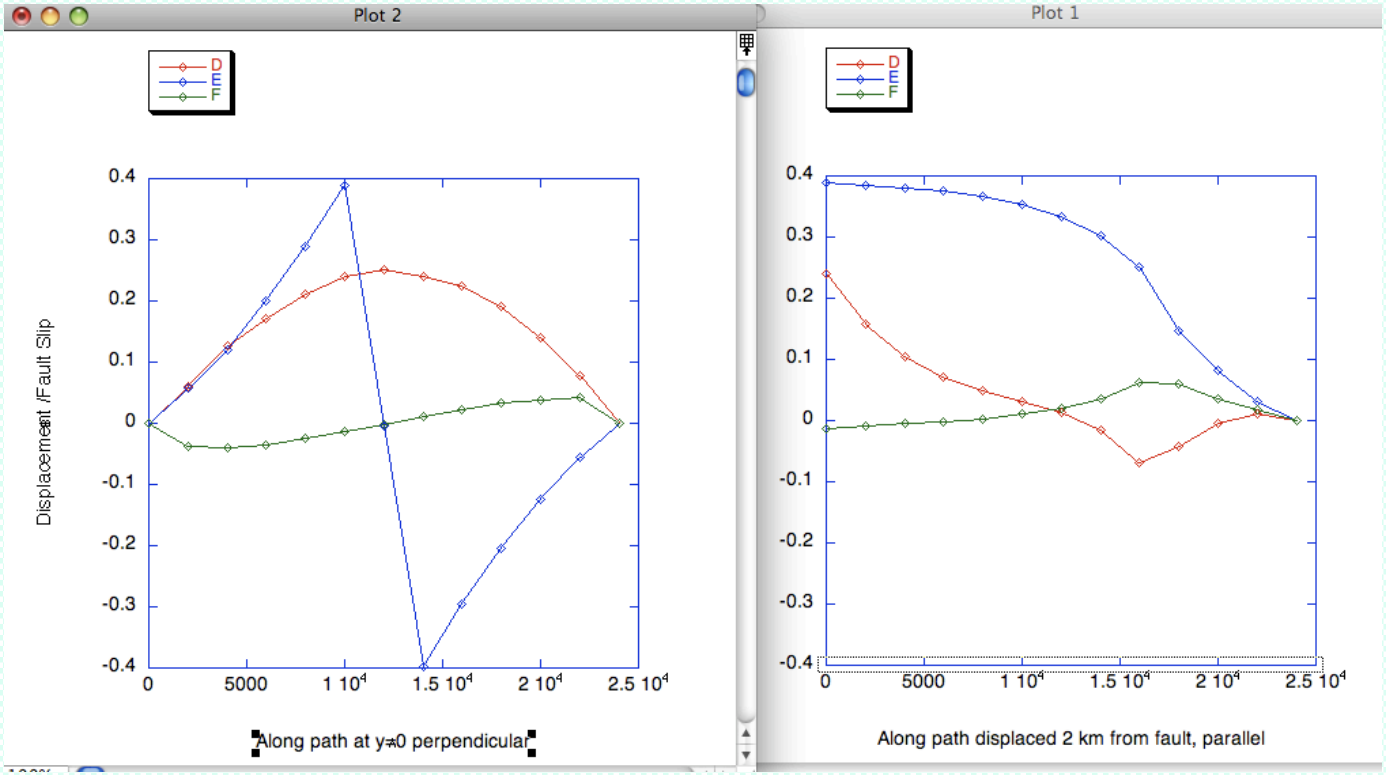


Figure 9. Velocity profile at 810 years, ten years after a seismic event in the crust fault. ***Velocity is in m/yr.***

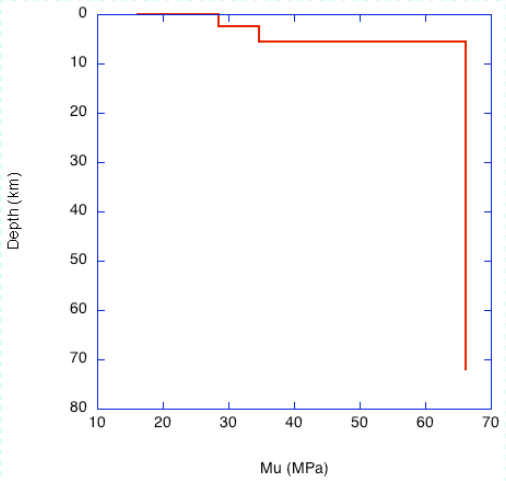
Strslip results plot

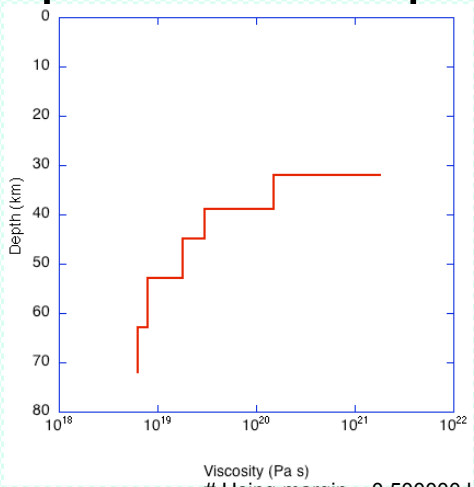
- Tecplot, paraview, . . .
- Quick look: use data reduction scripts
- >get_block –n 0 < *.out |get_surf_soln > surf0.txt

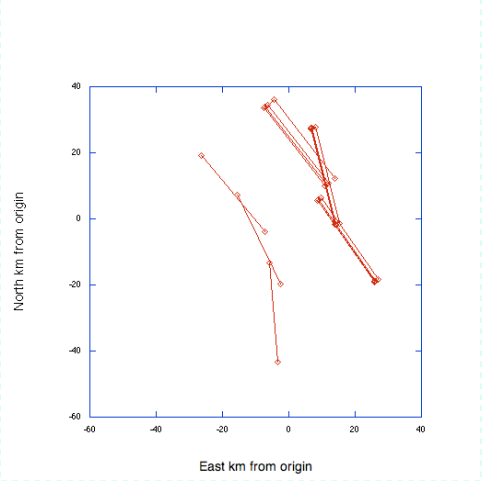


Mojave Model: Extruding Faults, Layers

- There are enough faults (6) and layers (10) that automation helps: more simple files, scripts.



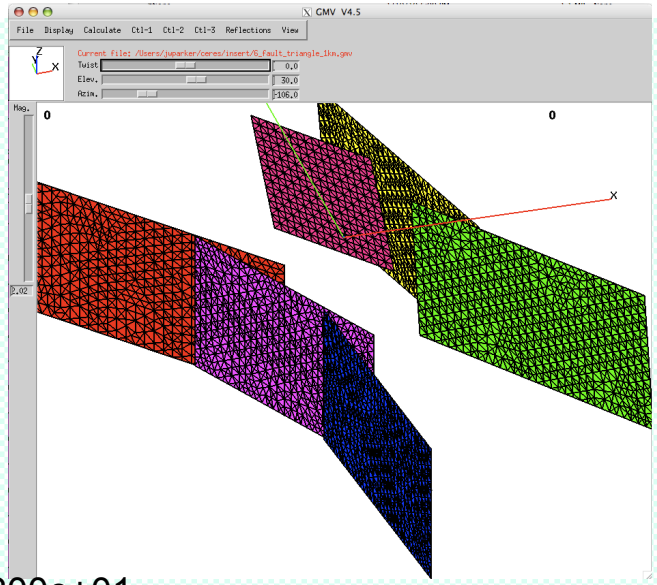





```
# first four from JonesLayers.txt and Jones Helmberger table 2
# remaining (viscosity) from Freed et al 2007 Far Reaching transient
# Motions GRL, Figure 2 darker blue line, extracted by eye and
# listed in email
# Landers/Hector model pieces, layers, materials: notes
# (to self, April 23 2008)
# dtop dbot rho(g/cm^3) mu(MPa) lambda(MPa) visc(Pa s) exp
0. 2.5   2.4000  16.224  27.552 0. 1. cr1
2.5  5.5 2.4000  28.566  15.468 0. 1. cr2
5.5  28 2.6700  34.603  36.766  0. 1. cr3
28 32  3.4200  66.211  78.327  0. 1. cr4
32 39 3.4200  66.211  78.327 1.8e21 1. ma1
39 45 3.4200  66.211  78.327 1.5e20 1. ma2
45 53 3.4200  66.211  78.327 3.0e19 1. ma3
53 63 3.4200  66.211  78.327 1.8e19  1. ma4
63 72   3.4200  66.211  78.327 8.0e18 1. ma5
72 1000 3.4200  66.211  78.327 6.3e18  1. ma6
```

```
# Using margin = 0.500000 km
# from lat2xy.ref.txt, reordered
#converted to bottom (last three lines, above):
#(using kgraph, c6=c0+c2*cos(c5)*cos(c4); c7=c0-c2*sin(c5)*cos(c4))
# Note depth (to bottom) is d_top + w*sin(dip)
# Processing should set rake to 180. as default
#
# Note Homestead has been exteneded (from length 27 to 29) to force
# the trim algorithm to add the requested buffer.
#
#w     d     dip     str     X_bot  y_bot    Length Name First
# f1 HomesteadVly trim by CampRockEmerson gt_s1min: area reduced by 34.856483km^2
# f2 LavicLakeWest trim by LavicLakeMid lt_s2max: area reduced by 95.804040km^2
# f1 LavicLakeMid trim by Bullion lt_s1max: area reduced by 8.919267km^2
15.000000 15.000000 90.000000 355.000000 -3.269800 -43.218000 30.000000 JohnsonVly 0.0
15.000000 15.000000 90.000000 334.000000 -2.507500 -19.592000 26.676234 HomesteadVly 0.0
15.000000 15.000000 90.000000 320.000000 -7.201300 -3.770000 36.000000 CampRockEmerson 0.0
16.200000 16.413000 85.000000 346.000000 15.055805 -0.905082 32.449428 LavicLakeMid 7.0
15.400000 15.136000 75.000000 322.000000 10.200944 17.264248 14.778958 LavicLakeWest 7.0
16.200000 16.407000 85.000000 325.000000 26.964000 -18.225000 30.000000 Bullion 7.0
```

Mojave Model: Simulation Specification



LaGriT produces:
Mojave.gft file: node coords, tets
Mojave.zone_outside.zone file
(lists nodes on the box sides)
<fault>.pset files (lists nodes on fault)

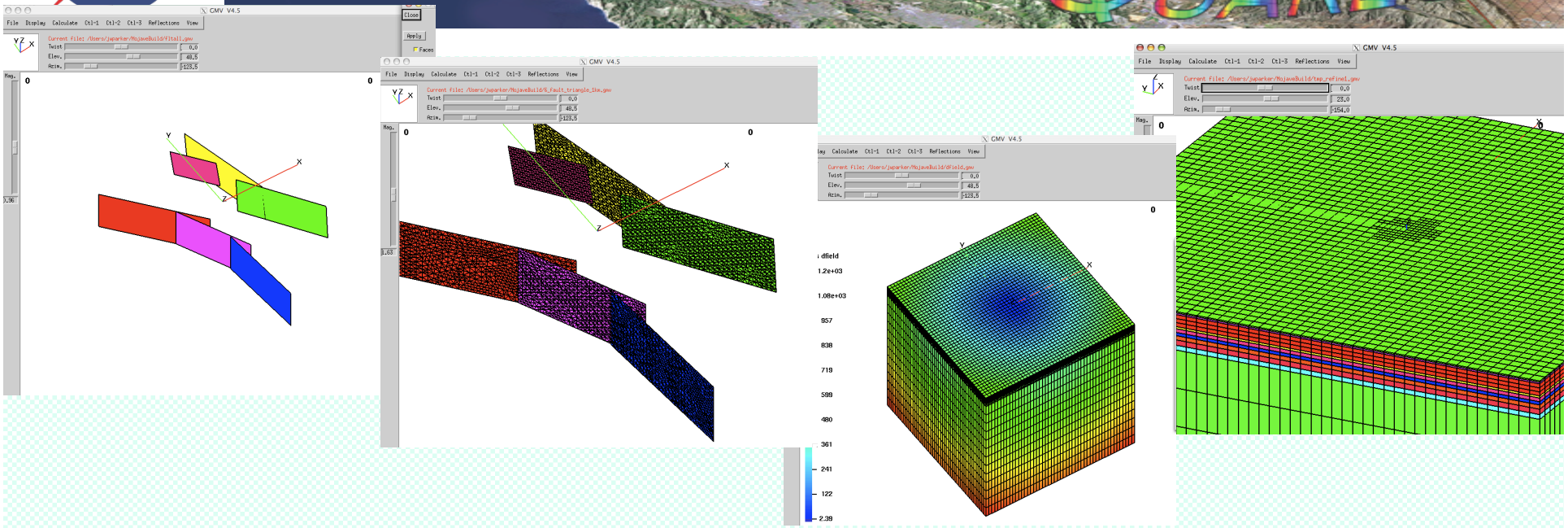
User must create:
<layer>.materials file
<fault>.params file
<run_specifics> file

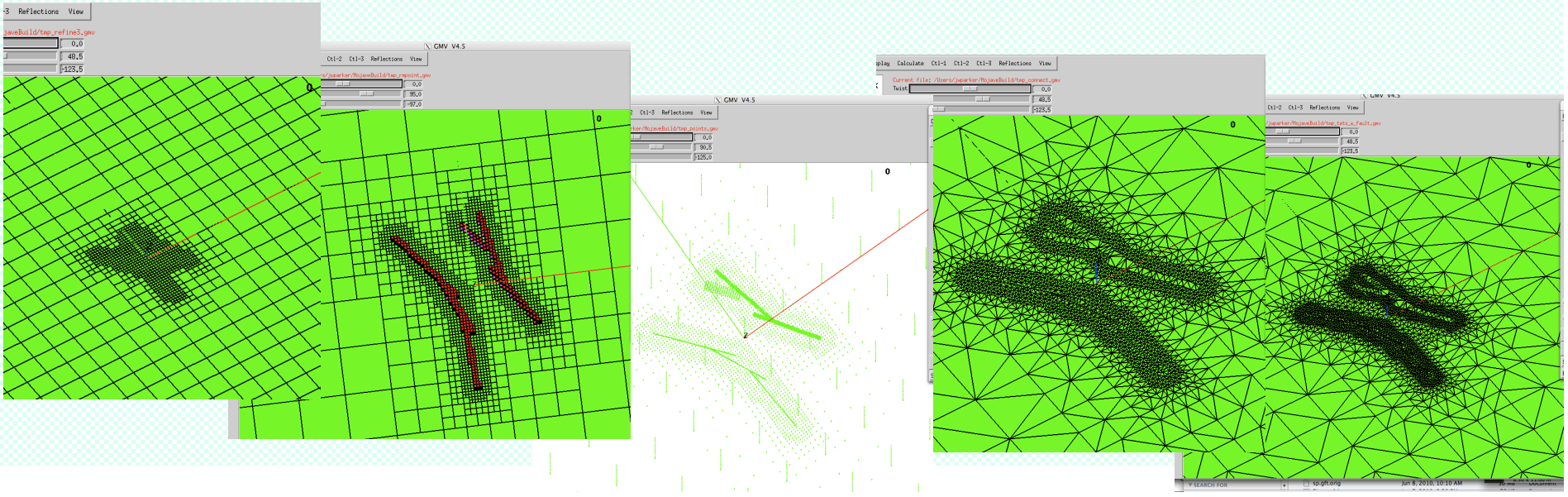
lamelambda 2.755200e+01
lamemu 1.622400e+01
viscosity 0.000000e+00
exponent 1.000000

number dip(o) strike(o) slip(m) rake(o) length(km) width(km) depth(km) origX origY 1st repeat
1.000000 85.000000 325.000000 1.000000 180.000000 30.000000 16.200000 16.407000 26.964000
-18.225000 7.000000 5000.000000

➔>>*geotrans creates GeoFEST input*

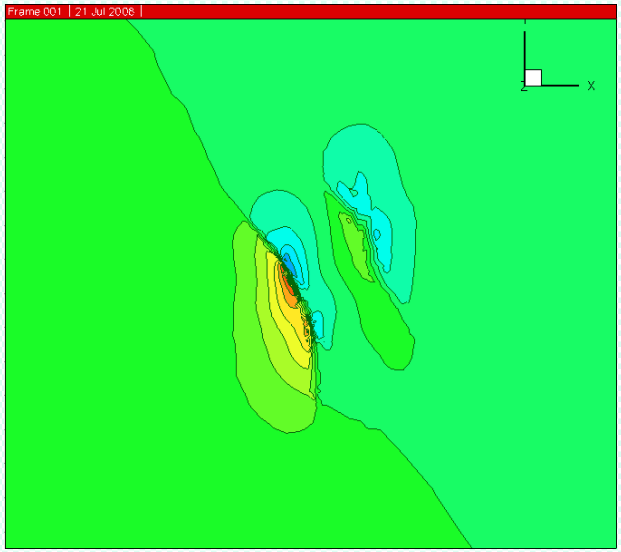
Mojave LaGriT build: gallery

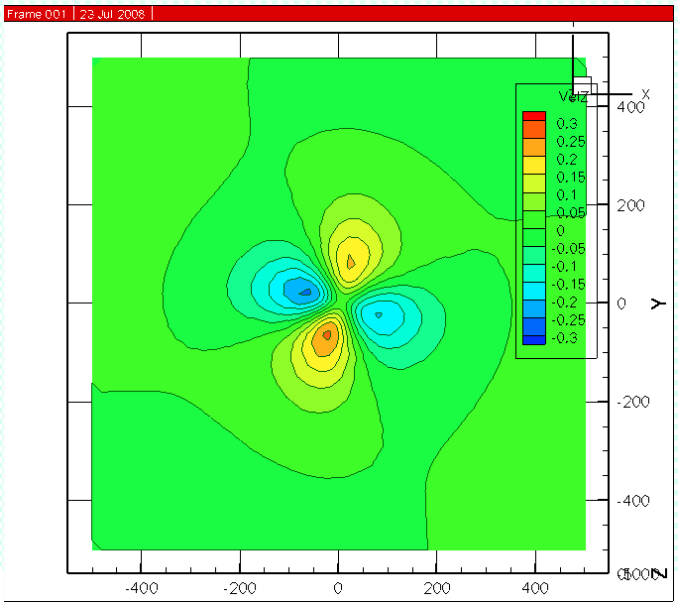




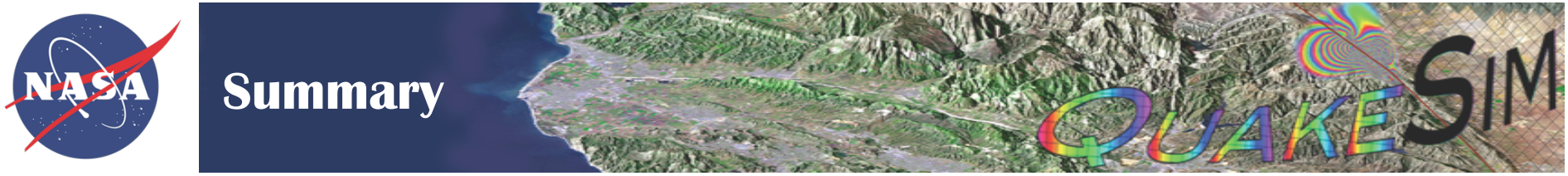
Mojave GeoFEST run

- LaGriT takes many minutes on laptop, produces 1M elements
- Resulting GeoFEST input is too large to run on my laptop;
- Runs on 64 processor system comfortably
- Initial elastic solution with all faults slipping produces str energy.
- This is used to refine mesh to higher density.





* No change required to input file; output file also same (clever code gathers results to one processor, then writes)
* gfmeshparse: Prior to any geofest run,create matching <project>.dat.jpl file. Used by Pyramid library.
•Pyramid keeps track of partitioned mesh, message passing
•Single GeoFEST C-code produces sequential and parallel (makefile does the work).
*Flow control flags defaults differ: parallel defaults to REFINE



- Cubevalid01.dat case used to analyze GeoFEST input format
- Strslip case illustrates LaGriT creation, geotrans translation
- Mojave case illustrates many-layer, many-fault automation