We Tried This In 2015,
And It Didn’t Quite Work Out

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2015 SCEC Project

In 2015, SCEC gave a small grant to Michael Barall and Terry Tullis to convert the SCEC Community Fault Model (CFM) into a form that is accessible for use by earthquake simulators.

This was the idea:

- Faults in the CFM are represented as triangulated surfaces (Tsurfs).
  - Triangles are good for curved surfaces.
- The SCEC simulators TAG had previously developed a standard set of simulator file formats.
  - Several existing earthquake simulators can read their inputs from the standard formats.
- We proposed to convert the CFM Tsurfs into the standard simulator file format.
  - Then several earthquake simulator codes would be able to immediately start running simulations on the CFM.

It turned out we were very naïve about the difficulty of this conversion. We encountered problems that we could not solve satisfactorily during our 2015 grant.

We did produce an input file in standard simulator format, but it isn't satisfactory. Hence, today's workshop to discuss how to proceed.

2015 SCEC Project — The Obstacles

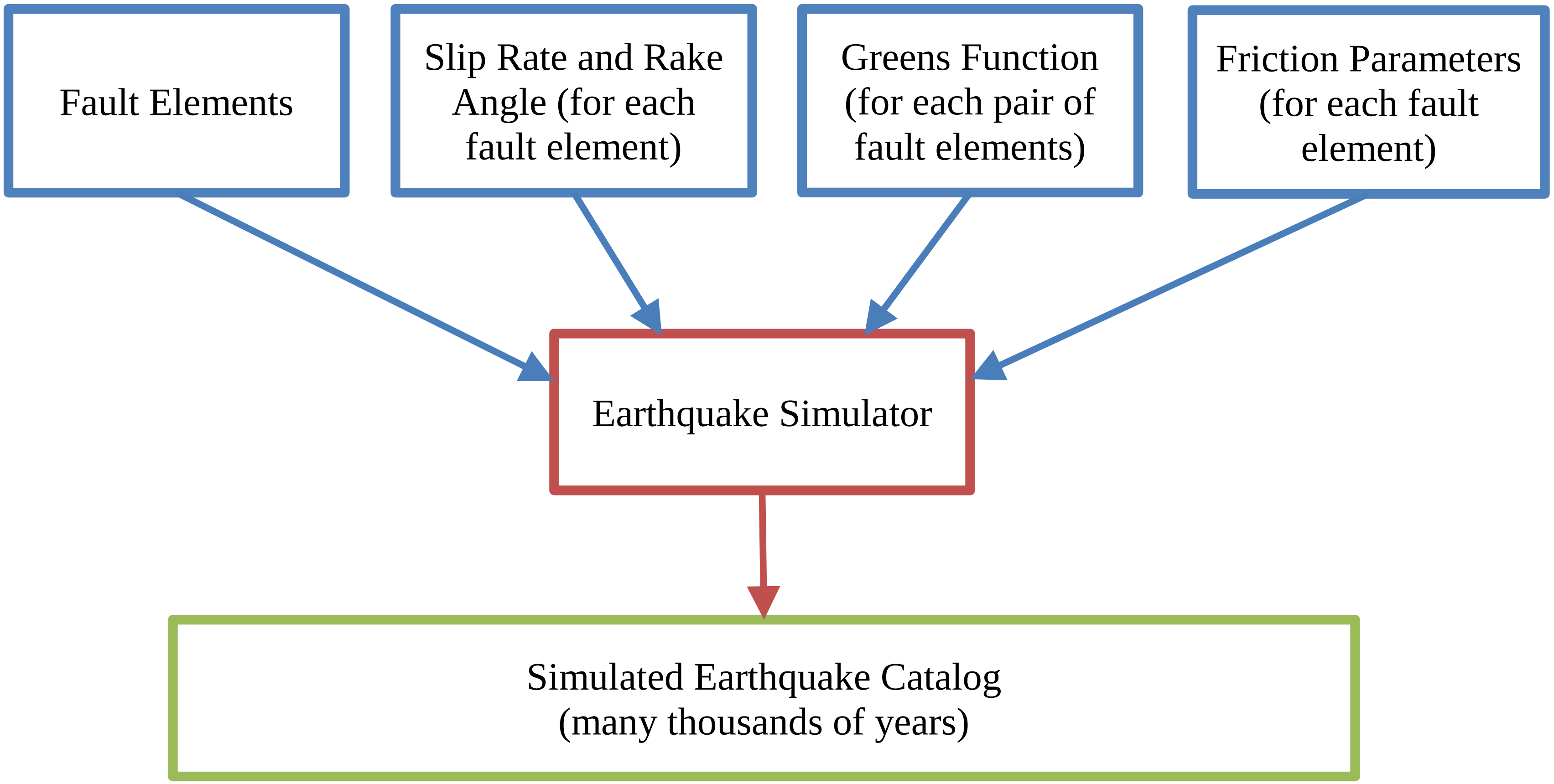
There are three main obstacles to using the CFM with earthquake simulators:

- The CFM does not contain slip rates or rake angles.
    - Simulators need to have slip rates and rake angles.
- The CFM contains surface topography.
    - Simulators require the earth's surface to be flat.
- We need good quality triangles and smooth faults.

In addition to these three main obstacles, we encountered several more minor issues:

- The CFM does not identify which triangle vertices lie on the fault trace.
- Long faults like the San Andreas are represented as several separate faults, and in CFM4 it is not straightforward to put them back together. (Maybe improved in CFM5?)
- Some CFM Tsurf files contain multiple surfaces. Most of these are probably mistakes.
- Some CFM faults have "holes" where there are triangles missing.
- Some CFM faults have very large variation in strike angle over the fault surface, sometimes exceeding 180 degrees. These are probably artefacts or mistakes of some kind.

Earthquake Simulator Inputs and Outputs



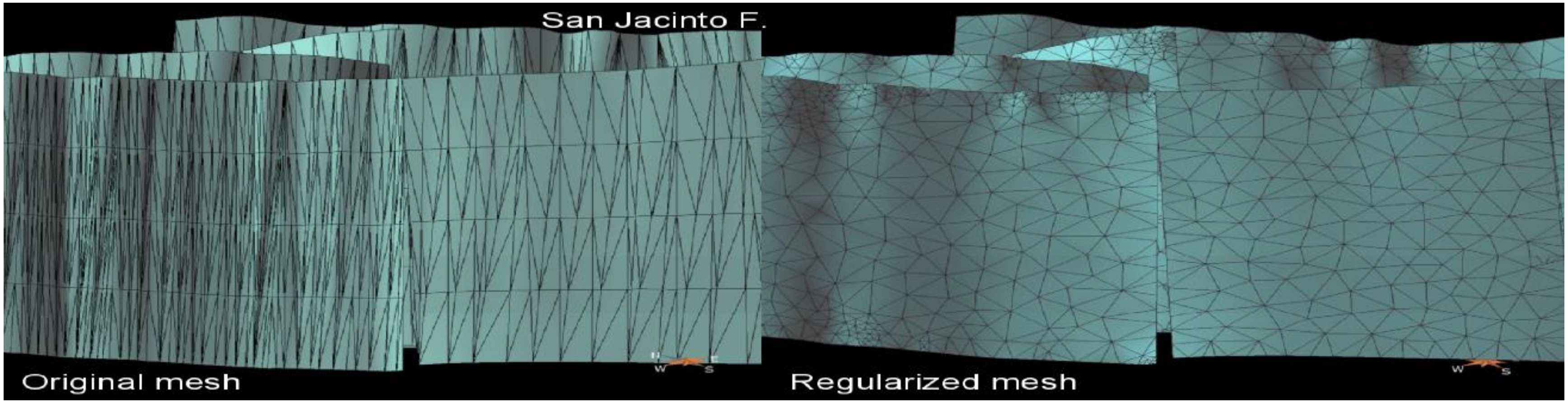
What's in the CFM? (As of 2015)

The CFM gives the geometry of significant faults in Southern California. It consists of two things:

- TSurf files, each of which contains a triangulated fault surface:
  - A list of triangles.
  - The coordinates of each triangle vertex, as northing, easting, and elevation above sea level.
  - Some of the Tsurfs also have azimuth and dip angles for each vertex.
- An Excel spreadsheet with some metadata. For CFM4:
  - Places faults into groups (*e.g.*, "San Andreas Fault System", "Peninsular Ranges").
  - Average strike and dip.
  - QFault ID (for some faults).
  - Quality rating.

CFM4 Re-Meshed

As of 2015, there were two versions: CFM4 and CFM5. We chose to use the older CFM4 because there was a re-meshed version of CFM4 with good quality triangles and smoothed faults.



The original CFM4 mesh has lots of long skinny triangles which are bad for simulators.

The re-meshed CFM4 has approximately-equilateral triangles.

Slip Rates & Rake Angles

Slip Rates and Rake Angles — QFault Database (Didn't Work)

It was suggested that we could obtain slip rates and rake angles from the QFault database. This did not work out, because:

- Many faults in the CFM don't have QFault IDs.

- Many of the QFault IDs in the CFM are not valid. (Not recognized by the USGS QFaults web portal.)

- Even when there is a valid QFault ID, the QFault database entry is not helpful because:

    - Slip rates are usually not given as numerical values.
        - They are given as ranges, for example, "between 1 and 5 mm/yr".
        - An earthquake simulator needs a specific numerical value.

    - Rake angles are not given as numerical values.
        - They are given as verbal descriptors, for example, "right lateral".

In the end, the QFault database gave us very little useful information.

Slip Rates and Rake Angles — UCERF3 to the Rescue

The only other plausible source of slip rates and rake angles is UCERF3. In UCERF3, each fault is assigned numerical values for slip rate and rake angle.

The problem is that UCERF3 and CFM4 don't have the same set of faults.

So, we created a "Crosswalk". It's an Excel spreadsheet that matches up CFM4 faults and UCERF3 faults.

B	C	D	E	F	G	H	I	J	K
CFM 4 listing									
fault name	Group		strike (RHL)	dip	USGS ID	average rating		UCERF3 name	UCERF3 alternates, or source, or comment
Basin and Range									
BNRA-BMFZ-MULT-Black_Mountain_fault	1		348	24	113	3		"Death Valley (Black Mtns Frontal)"	
BNRA-NDVZ-MULT-Northern_Death_Valley_fault	1		141	90	141143	3.333333333		"Death Valley (No)"	
BNRA-SDVZ-MULT-Southern_Death_Valley_fault-CFM2	1		322	90	141143	3.5		"Death Valley (So)"	
BNRA-SDVZ-MULT-Southern_Death_Valley_fault-CFM1	2		311	49	141143	4.166666667			
Coast Ranges									
CRFA-BPPM-EAST-Big_Pine_fault	1		272	70	86	3		"Big Pine (Central)"	# Big Pine*
CRFA-BPPM-MULT-East_Big_Pine_fault-CFMA	2		241	80	86	3.833333333			
CRFA-BPPM-LCKV-Lockwood_Valley_fault	1		75	73	86	3.333333333		"Big Pine (East)"	# Big Pine*
CRFA-BPPM-PMTS-Pine_Mountain_fault-CFM1	1		96	44	261	3.5		"Pine Mtn"	
CRFA-BPPM-PMTS-Pine_Mountain_fault-CFM2	2		96	44	261	3			
CRFA-BPPM-WEST-West_Big_Pine_fault	1		94	50	86	3		"Big Pine (West)"	# Big Pine*
CRFA-NAFZ-MULT-Nacimiento_fault	1		132	64	0	3.333333333		"= 0.2 0 270"	# http://geohazards.usgs.gov/cfusion/qfault/show_re
CRFA-SCFZ-MULT-South_Cuyama_fault	1		297	36	252	3.333333333		"South Cuyama"	
CRFA-SJMZ-MRLS-Morales_fault	1		280	5	491	3		"Morales*"	# Morales (East) & Morales (West)

CFM4 / UCERF3 Crosswalk

In constructing the CFM4 / UCERF3 crosswalk, we found:

- In some cases, the correspondence is obvious (faults have identical or very similar names).

- In some cases, CFM4 and UCERF3 use different names for the same fault.
  In some cases, a single fault in one model is two or more faults in the other. Examples:

CFM4	UCERF3
"Lockwood Valley"	"Big Pine (East)"
"Santa Ynez"	"Santa Ynez (East)" and "Santa Ynez (West)"
"San Pedro Basin north" and "San Pedro Basin south"	"San Pedro Basin"

- There are three problem areas where CFM4 and UCERF3 are quite different from each other: the **Elsinore fault zone**, the **San Jacinto fault zone**, and the **San Gorgonio Pass**.

  - In each of the problem areas, UCERF3 has a single through-going fault, while CFM4 has disconnected strands and parallel strands with many different names.

  - In EFZ and SJFZ, we picked out "main strands" in CFM4 and matched them to UCERF3.

  - In the San Gorgonio pass, the differences are so great, and the strands in CMF4 are so complicated, that we couldn't make any matches.

CFM4 / UCERF3 Crosswalk Results

Of the 253 faults in CFM4, we were able to match 173 faults to UCERF3.

We found slip rates and rake angles for 6 additional faults by searching other data sources:

- The USGS QFaults database.
- The Caltech SCEDC (Southern California Earthquake Data Center) database.
- The WGCEP 2007 fault database.
- Google.

So, in the end we assigned slip rates and rake angles to 179 faults, out of a total of 253 faults in CFM4.

Topography

Topography

The CFM includes topography and bathymetry.

- Fault traces follow the topography and bathymetry.

- There is about 4 km of vertical relief in the CFM.

Earthquake simulators require that the earth's surface be flat. What to do?

Topography — Ideas That Were Considered (and Rejected)

Some ideas that were considered:

- Place the flat earth's surface at the highest point in the CFM, and allow faults that should reach the earth's surface to become buried faults.
    - Rejected because some faults would be as far as 4 km below the surface.
- Slice the model horizontally at some sort of average elevation, or possibly at sea level, and just use the part of the model below the slice.
    - Rejected because it would require re-triangulating the model.
- Replace the Z coordinate (elevation) with depth-below-terrain. This would have a flat upper surface in the transformed coordinate system.
    - Rejected because it would transfer surface irregularities (mountains and valleys) to the fault surfaces, so we would have irregular faults instead of the smooth faults we want.

Terrain Flattening

For our 2015 project there was no perfect solution. We adopted the following two-step approach:

- For each fault in CFM4, we constructed a *smoothed* topography which approximates the topography of the fault trace.
    - Compute Fourier transform, keep terms with wavelength > 40 km.
- Then, each Z coordinate in that fault is changed from elevation to depth below the *smoothed* topography.

Results of our terrain flattening algorithm:

- Faults are distorted, but the distortion is very smooth.
- Top of fault is not at the earth's surface, but is generally within ∼200 m of the earth's surface.

Faults and Sections

Fault Reconstruction

UCERF2 had a hierarchical model, with faults and sections.

- The simulator file formats follow the UCERF2 hierarchy.
    - In describing a synthetic earthquake catalog it's very useful to be able to talk about the "San Andreas Fault" (etc.) and not just sections.

UCERF3 formally eliminated the faults and has only sections.

- Sections have names like "San Andreas (Big Bend)" and "San Andreas (Carrizo)".
- You can use the names to put the sections back together and recover the original continuous long faults.

A CFM "fault" is like a UCERF3 "section".

- There isn't a straightforward way to join the CFM4 faults into longer faults. (Better in CFM5?)
- CFM faults don't always connect up to form continuous long faults (endpoints don't match).

We created a heuristic algorithm to reconstruct longer faults by joining together CFM4 faults.

- Our CFM4 / UCERF3 crosswalk is used as a guide.

Results of our 2015 Project

We created a simulator input file containing a large part of CFM4.

Of 253 faults in CFM4:

- 137 faults are included in the simulator input file (as sections).
    - These were joined to form 108 long faults.
- 74 faults are excluded because there is no available data for slip rate and rake angle.
- 31 faults are excluded because there is no Tsurf file in the remeshed CFM4.
- 8 faults are excluded because the strike angle varies by more than 170 degrees.
- 3 faults are excluded because there is a hole in the fault.

Conclusion — CFM Wish List

CFM Wish List — Big Requests

As a numerical modeler, my two biggest wishes are:

1. A version of the CFM with a flat upper surface, good-quality triangles, and smooth faults.

2. Slip rates and rake angles included in the model.

CFM Wish List — Smaller Requests

Other things that would be nice:

1. Mark the vertices that lie on the fault trace (could be done in the Tsurf file).

2. Indicate how the CFM faults join up to form longer faults (where possible), and check to see that the triangulations of adjacent sections connect up continuously (where they should).

3. Fix or remove the invalid QFault IDs.

4. Add references to UCERF3 or other data sources, where appropriate.

5. Check each Tsurf to make sure it contains a single surface with no holes (could be checked by computer).

6. Check faults with very large variation in strike angle to see if they are correct (could be flagged by computer).

7. State the exact mapping transformation that should be used to convert between latitude/longitude and northing/easting. (There used to be a web page for this.)

8. Make the CFM findable online. (There is no link from the Harvard structural geology web page, the links from SCECpedia and Wikipedia don't work, and it is not findable with Google.)

Thank You!