SCEC SIV workshop, Sept. 13, 2009
Source Inversion Validation

- **Introduction to the 2009 SCEC SIV workshop**
- **A few words on past activities**
- **Short notes on 'Methods'**

Morgan Page

Martin Mai

Danijel Schorlemmer

Salam al'eikum from Martin …

… greetings from Thuwal at the Red Sea in Saudi Arabia, where KAUST (King Abdullah University of Science & Technology) has just opened …

Too bad I cannot attend the SCEC meeting and SIV workshop this time, despite my best hopes and efforts to make it happen! But the enormity of the tasks when starting up a new university has overwhelmed everyone!

We all are simply trying to steer the boat into calm waters and begin a coordinated work & family life … which turns out to be a difficult endeavor under the given conditions, in particular when the surrounding life comes to a halt at day-time due to Ramadan …

…. but next time I will be at the SCEC meeting, and hopefully we can host one of the next SIV validation workshops here at KAUST, and the shores of the Red Sea ….

Schedule

PART A : METHODS

08:00 – 08:15	Morgan Page/Martin Mai	Introduction and review of SIV activities
08:15 – 08:45	Ralph Archuleta	Uncertainty assessment in source inversions
08:45 – 09:15	Damiano Monelli	Bayesian inference of kinematic source parameters
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09:45 – 10:15	Coffee break	
10:15 – 10:45	Takahiko Uchide	Detailed Process of Multiscale Source Inversion Analysis
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11:15 – 11:25	Sarah Minson	A Bayesian Approach to Source Inversion
11:25 – 12:00	OPEN DISCUSSION ON METHODS SECTION	
12:00 – 13:30	LUNCH	

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PART B : SIV Implementation

13:30– 13:45	Masha Liukis	The testing centers of the Collaboratory for the Study of Earthquake Predictability
13:45 – 14:15	D. Schorlemmer	Proposal for a Simple SIV Testing Center
14:15 – 15:00	OPEN DISCUSSION ON IMPLEMENTATION OF SIV	
15:00 – 15:30	Coffee break	
15:30 – 17:00	OPEN SESSION: Planning the next steps	

- Expectations for the forward-modeling problems
  - Point-source Green's function
  - Finite-fault with known (and simple) inhomogeneous rupture
- Expectations for inverting for a simple, but inhomogeneous rupture
- Workshop in March 2010:
  - Date, location & duration
  - Source of future funding
  - Commitment to participation of the modeling groups

Past Activities

- **SPICE source inversion blindtest**
  - Initiated March 2005, started August 2005
  - 9 participating groups submitted their result in a variety of formats
  - Special AGU session (Dec 2007) with invited speakers, presentations on the blindtest methods, and a summary of the key finding of the blindtest
    - ➢ **Unexpected large variability of inverted models**

- **SCEC workshop on earthquake source inversion (Sept. 2008)**
  - ~50 participants, 6 invited speakers, and ~3 hrs intense discussions
  - General consensus that **SIV** (**S**ource **I**nversion **V**alidation) has to continue
  - Collection of general ideas on how to setup the problems and how to organize ourselves … but no formal decisions or "constitution of a core group"

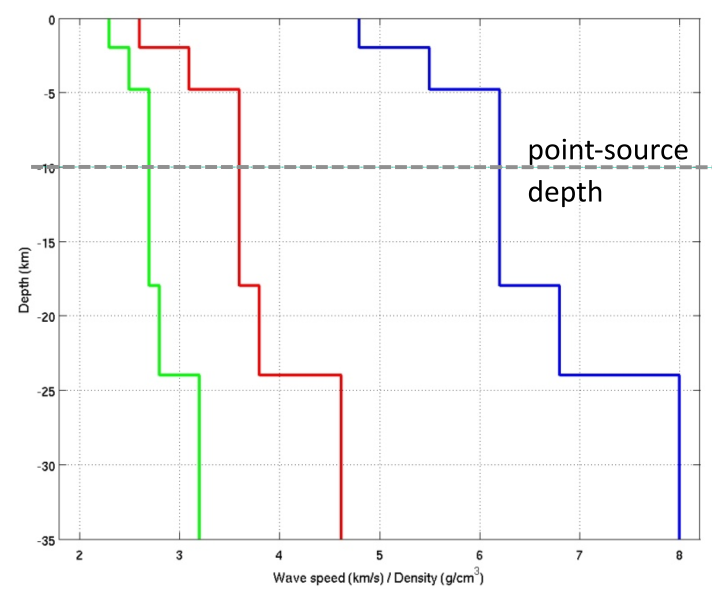
Past Activities, cont'd

- **Proposal to SCEC (Nov '08) for financial support to continue the SIV-project**
  - 2009 workshop funded
  - For long-term (3-5 year) support, we need to secure additional funding sources
- **Dedicated webpage launched (March 2009)** http://siv.usc.edu
  - Online platform to distribute the inversion problems and all relevant meta-data
  - General communication & exchange platform for everyone interested in SIV
  - Planned: tools for uploading /comparing inverse solutions and corresponding data predictions
- **Mini-workshop during SSA 2009 (April 2009)**
  - ~20 participants for general ~2 hrs discussion on future activities
  - Problem 1: Setup of Green's function test and initial forward-modeling exercise

Problem 1a: Green's Function Validation (point source)

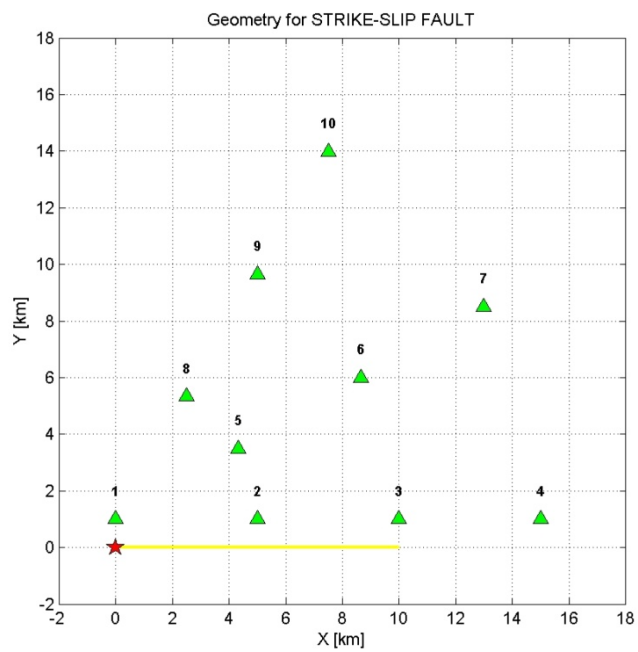
- **During the 2008 SCEC workshop, it was questioned if all groups participating in the blind test calculated the Green's functions correctly**
- **The SIV-project thus starts with a test to verify GF-computations:**
  - "point-source" at 10 km depth, parameterized as a 1 x 1 km^2 slip patch with homogeneous slip and boxcar slip-function of duration $t_r = 0.2$ sec
  - The shear-modulus at the given depth result in: M_w 4.992, $M_0 = 3.4992 \times 10^{16}$

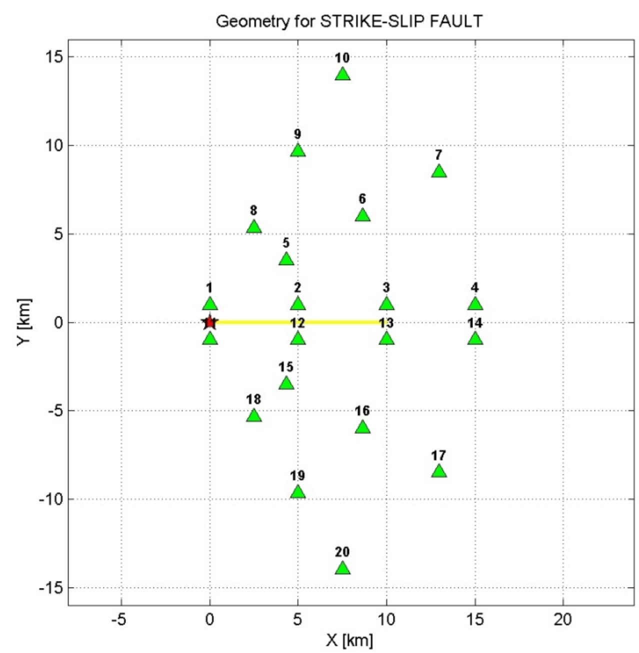
Depth [km]	**V_P** [km/s]	**V_S** [km/s]	**Density** [g/cm^3]
0.0	4.8	2.6	2.3
-2.0	4.8	2.6	2.3
-2.0	5.5	3.1	2.5
-4.8	5.5	3.1	2.5
-4.8	6.2	3.6	2.7
-18.0	6.2	3.6	2.7
-18.0	6.8	3.8	2.8
-24.0	6.8	3.8	2.8
-24.0	8.0	4.62	3.2
-45.0	8.0	4.62	3.2



Problem 1a: Green’s Function Validation (point source)

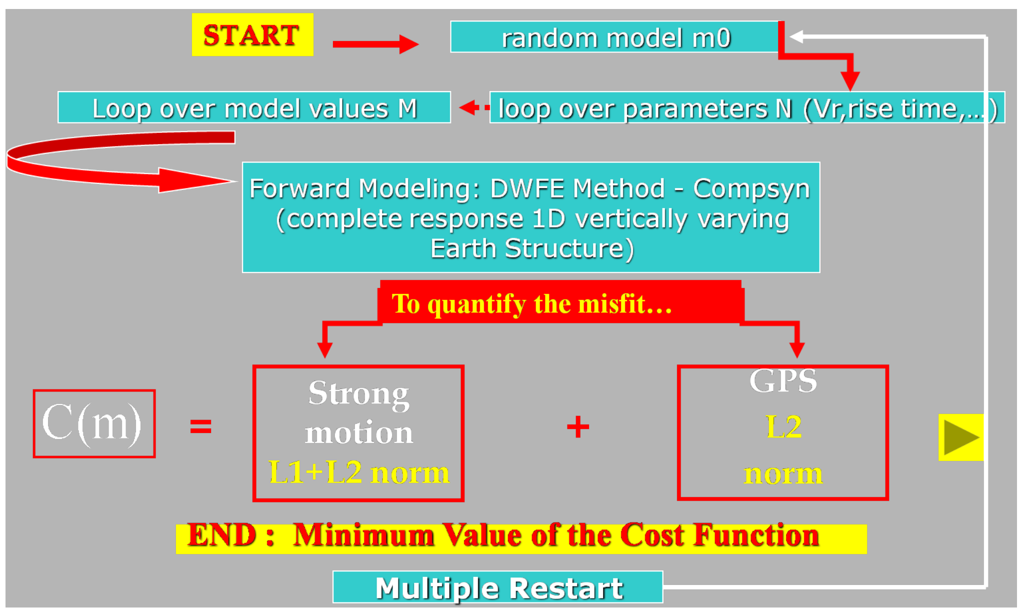
- **Two cases are considered for the Green’s function test**
  - purely left-lateral strike-slip rupture on a vertical fault
  - purely thrust-motion on a 40° dipping fault
  - Stations at Y = 1 km parallel to surface projection of fault plane, and two arrays that are 30° and 60° rotated from the fault-parallel direction





Methods of two participating groups

- **INGV Rome (Cirella, Piatanesi, Cocco):** ***A global search inversion to constrain earthquake kinematic history and to assess model uncertainty***
  - Joint inversion of strong motion and GPS data
  - Finite-fault divided into subfault; in each subfault kinematic parameters are allowed to vary; several analytical slip-velocity source time functions are tested
  - Solving for peak slip velocity, rise time, rupture velocity, rake angle
  - Stage I: building model ensemble (simulated annealing)



Methods of two participating groups

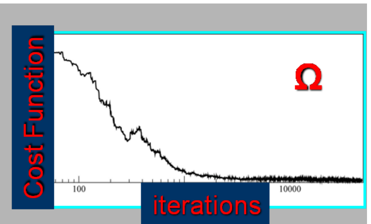
- **INGV Rome (Cirella, Piatanesi, Cocco):** ***A global search inversion to constrain earthquake kinematic history and to assess model uncertainty*** INGV
  - Stage II: appraising the ensemble

"Limiting the analysis to the features present in only the best fitting model is often insufficien because of non-uniqueness in the problem and noise in the data " e.g. Mosegaard & Sambridge, 2002).

  - Model ensemble inference: *Rather then simply looking at the best model, we extract the most stable features of the rupture process that are consistent with the data and give us an estimate of the variability of each model parameter.*

Output of kinematic inversion:

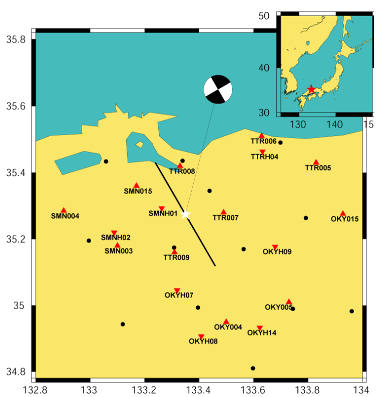
Model Ensemble Ω = Rupture Models **m** & Cost Function **C(m)**

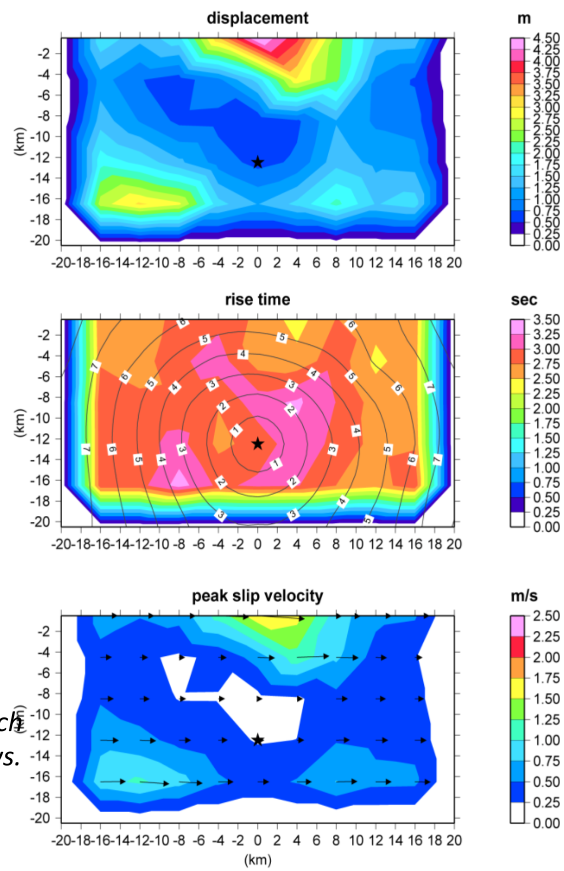


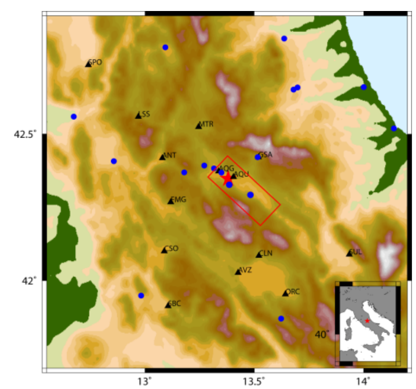
- Best Model: $m = m_{ij|\min(E_{ij})}$
- Average Model: $\langle m \rangle = \dfrac{\sum_{j\in\Omega} m_{ij}/E_{ij}}{\sum_{j\in\Omega} 1/E_j}$
- Standard Deviation: $\langle \sigma_i \rangle^2 = \dfrac{\sum_{j\in\Omega} \left(m_{ij} - \langle m_{ij} \rangle\right)^2 / E_j}{\sum_{j\in\Omega} 1/E_j}$

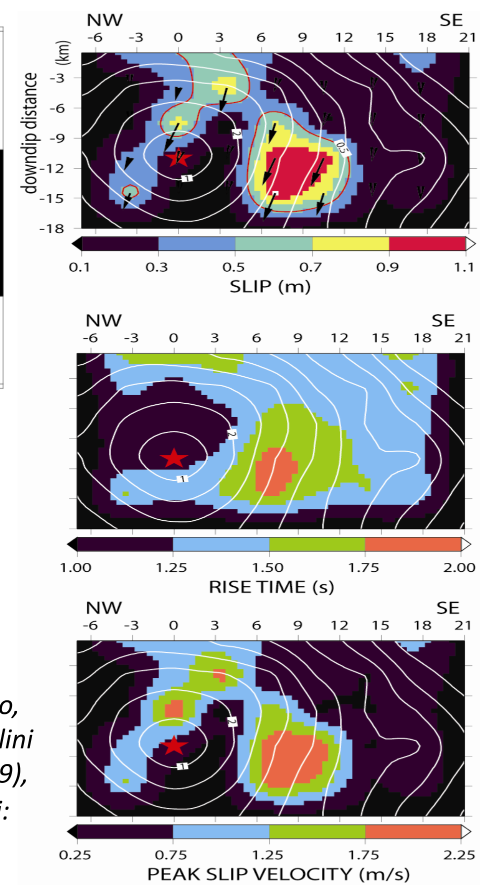
Methods of two participating groups

- **INGV Rome (Cirella, Piatanesi, Cocco):** ***A global search inversion to constrain earthquake kinematic history and to assess model uncertainty*** INGV
  - Applications: ***Tottori earthquake (M$_w$ 6.6)*** ***L'Aquila earthquake (M$_w$ 6.3)***









Piatanesi A., A.Cirella, P. Spudich and M. Cocco (2007), J.Geophys. Res., 112(B7), B07314, doi: 10.1029/2006JB004821.

Cirella A., Piatanesi A., M. Cocco, Tinti E., Scognamiglio L., Michelini A., Lomax A. And E.Boschi (2009), Geophys. Res. Lett., in press doi: 10.1029/2009GL039795.

Methods of two participating groups

- **Bertrand Delouis (University of Nice)**
  - Each subfault is represented by a point source (except if the submesh option, see below)
  - The hypocenter coincides with one of the point sources
  - Several fault segments may be used, with different faulting (strike, dip, central rake)
  - The average slip on each subfault is obtained from the seismic moment of the subfault, itself determined by integrating the local STF in time.
  - Rupture time offsets of the subfaults are bounded according to the minimum and maximum allowed rupture velocities
  - **Submesh option**: A mesh of point sources may be superimposed on each subfault, but with constant slip. A prescribed constant rupture velocity is then used to propagate the rupture on individual subfaults (*Remark: it is generally more convenient to discretize the fault finely enough and use a single point source for each subfault)*

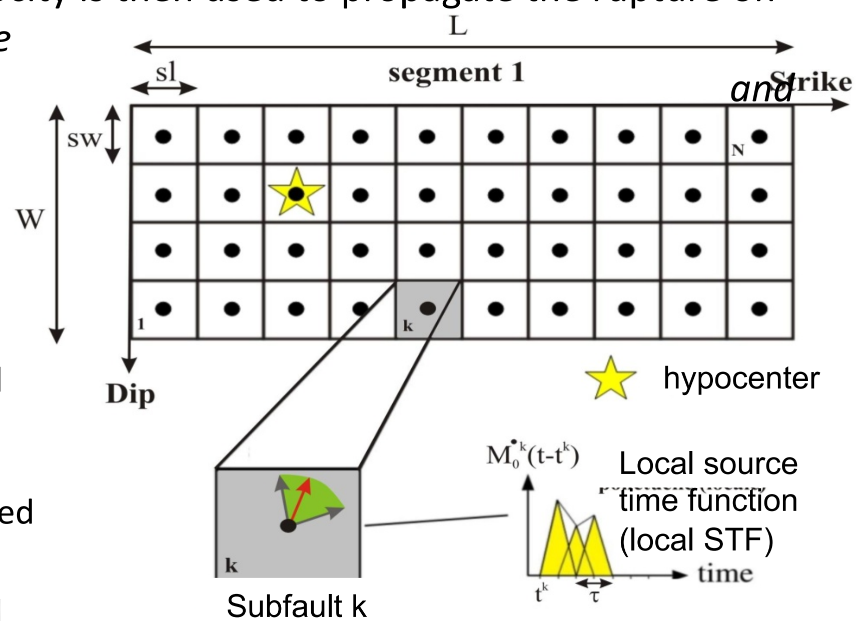


Figure: model in the case of a single segment. The local STF of each subfault (local moment rate function) is represented by a series of Elementary Triangular Functions (ETFs) of length τ mutually overlapping (shifted by $\tau/2$). t^k is the rupture onset time of subfault k.

Methods of two participating groups

- **Bertrand Delouis (University of Nice)**

Parameters to be fixed before inversion:

- **geometry**: strike, dip; fault dimensions (L, W); subfault dimensions (sl, sw)
- **slip function parameterization**: number of Elementary Triangular Functions (ETFs) to represent the local STFs; length of the ETFs (t)
- **Search space**:
  - minimum and maximum allowed rupture velocities in the model
  - central value of rake together with the maximum allowed angular deviation
  - maximum allowed slip related to an individual ETF

Parameters to be inverted for in each subfault:

- **rupture onset time**
- **rake angle**
- **amplitudes of the ETFs**

Methods of two participating groups

- **Bertrand Delouis (University of Nice)**

Inversion method: simulated annealing

- The **cost function** to be minimized is the sum of the weighted RMS misfit functions of the different datasets (seismological, geodetic…), plus a function minimizing the total seismic moment, plus eventually a smoothing function.

- **Synthetics:** synthetic seismograms are computed using the discrete wavenumber method of Bouchon (1981) at local distances, and using the ray theory approach of Nabelek (1984) at teleseismic distances. Static displacements are computed using the dislocation approach of Savage (1980). Synthetic seismograms may be computed for 1D layered velocity models incorporating Q for P and S waves, while static displacements (to model geodetic data) are computed with a half-space model.

- **Synthetic seismograms** are directly computed for a double couple point source with a triangular source time function. They are pre-computed for two rake values, 0° and 90°, allowing the easy reconstruction of seismograms for any rake value during the inversion.

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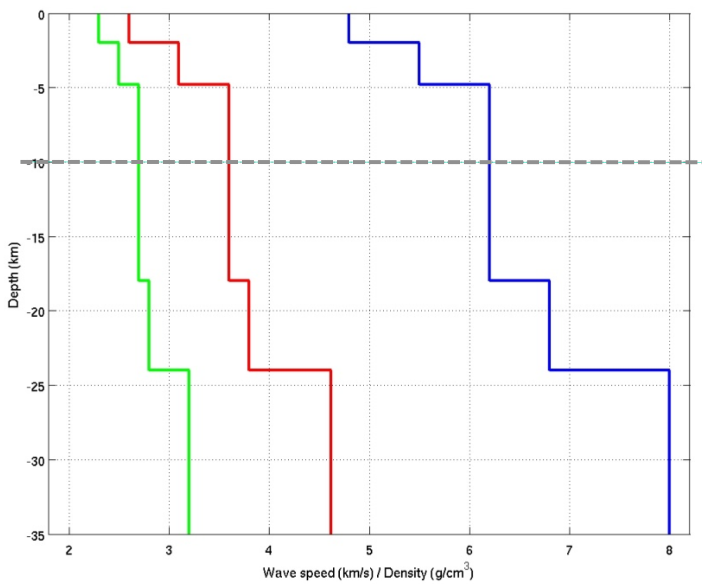
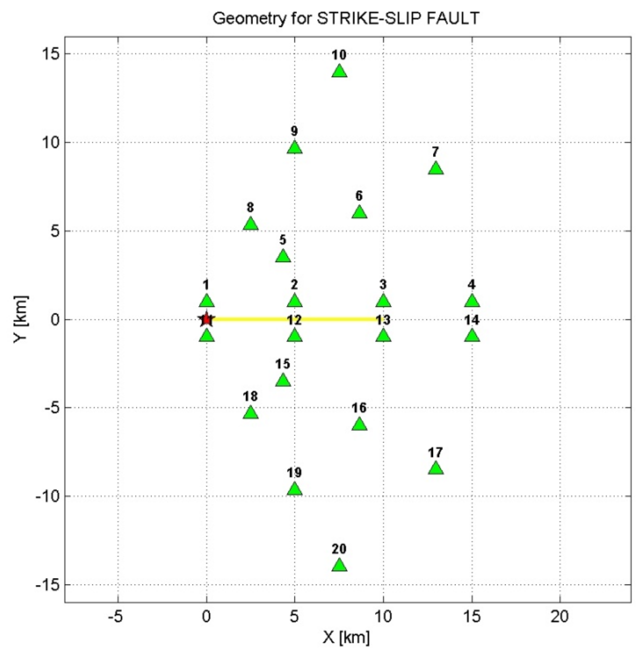
Discussion – Implementation of SIV

- For now (Problems 1 and 2), keep it simple
  - Drop box (write-only FTP site) for submitting models
  - Nothing automated, but handle testing with simple scripts (all models submitted with same format)
- Eventually move to CSEP-like framework ?
  - Ability to run each code automatically (standard input files)
  - Would allow testing with as many source models as we like, as many "experiments" as we like, and test new metrics as they are developed
  - Would require funding for infrastructure development (SCEC intern?)

Discussion of Tests

- **Problem 1a (Point-Source Green's function test)**
- **Problem 1b (Extended Source Green's function test)**
- **Problem 2 (Simple Inversion)**





Discussion on data & data formats

- **Proposed formats: plain ascii files, following exactly specified requirements**
  - Source model files →
  - Seismogram files ↓

```
% -------------------------------------------------------------
% POINT-SOURCE MODEL 1
% used as input for Source Inversion Validation (SIV)
%
% XPOS      ZPOS      ZABS      YPOS      TON       RISE      SS-AMP    DS-AMP
%  km        km        km        km        sec       sec       cm        cm
% -------------------------------------------------------------
  -1.00,     9.00,  9.0000,  0.0000,  0.4714,   0.100,  0.0140,   0.0000
  -0.50,     9.00,  9.0000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
   0.00,     9.00,  9.0000,  0.0000,  0.3333,   0.100,  0.0370,   0.0000
   0.50,     9.00,  9.0000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
   1.00,     9.00,  9.0000,  0.0000,  0.4714,   0.100,  0.0140,   0.0000
  -1.00,     9.50,  9.5000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
  -0.50,     9.50,  9.5000,  0.0000,  0.2357,   0.100,  0.0610,   0.0000
   0.00,     9.50,  9.5000,  0.0000,  0.1667,   0.100,  0.0780,   0.0000
   0.50,     9.50,  9.5000,  0.0000,  0.2357,   0.100,  0.0610,   0.0000
   1.00,     9.50,  9.5000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
  -1.00,    10.00, 10.0000,  0.0000,  0.3333,   0.100,  0.0370,   0.0000
  -0.50,    10.00, 10.0000,  0.0000,  0.1667,   0.100,  0.0780,   0.0000
   0.00,    10.00, 10.0000,  0.0000,  0.0001,   0.100,  0.1000,   0.0000
   0.50,    10.00, 10.0000,  0.0000,  0.1667,   0.100,  0.0780,   0.0000
   1.00,    10.00, 10.0000,  0.0000,  0.3333,   0.100,  0.0370,   0.0000
  -1.00,    10.50, 10.5000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
  -0.50,    10.50, 10.5000,  0.0000,  0.2357,   0.100,  0.0610,   0.0000
   0.00,    10.50, 10.5000,  0.0000,  0.1667,   0.100,  0.0780,   0.0000
   0.50,    10.50, 10.5000,  0.0000,  0.2357,   0.100,  0.0610,   0.0000
   1.00,    10.50, 10.5000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
  -1.00,    11.00, 11.0000,  0.0000,  0.4714,   0.100,  0.0140,   0.0000
  -0.50,    11.00, 11.0000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
   0.00,    11.00, 11.0000,  0.0000,  0.3333,   0.100,  0.0370,   0.0000
   0.50,    11.00, 11.0000,  0.0000,  0.3727,   0.100,  0.0290,   0.0000
   1.00,    11.00, 11.0000,  0.0000,  0.4714,   0.100,  0.0140,   0.0000
```

```
Synthetic Seismograms for model SIVps1
Observer #   8, Station s25
XPOS =  -15.0000, YPOS = 40.0000
NPTS =  4096, DT = 0.0200
Velocity seismograms in cm/sec
    X (EW)       Y(NS) comp     U-D comp
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000     -0.00000     -0.00000
    -0.00000      0.00000      0.00000
     0.00000      0.00000      0.00000
     0.00000      0.00000      0.00000
     0.00000      0.00000      0.00000
```

Will all models be able to have output files in the same format (e.g., even if they use different grid sizes in the inversion?)

Discussion of Timeline

- **Problem 1a (Point-Source Green's function test)**
  - **Currently available at siv.usc.edu**
  - **Due Nov. 15, 2009**
- **Problem 1b (Extended Source Green's function test)**
  - **Available by Nov. 15, 2009**
  - **Due Jan. 31, 2010**
- **Problem 2 (Simple Inversion)**
  - **Available by Nov. 15, 2009**
  - **Due ???**
- **Next Workshop**
  - **~ March 2010**

Next Workshop - Discussion

- Possible Locations
  - KAUST
    - Possible funding for participating modelers
    - ~ March 2010 ?
  - Joint meeting with SSA
    - Portland
    - April 20-23, 2010
  - Joint meeting with EGU
    - Vienna
    - May 2-7, 2010
- Source of Future Funding (SCEC, NSF, NEHRP?)
- Commitment to Participation of the Modeling Groups