Cover Page for Proposal Submitted to the National Aeronautics and Space Administration

NASA Proposal Number

TBD on Submit

NASA PROCEDURE FOR HANDLING PROPOSALS

This proposal shall be used and disclosed for evaluation purposes only, and a copy of this Government notice shall be applied to any reproduction or abstract thereof. Any authorized restrictive notices that the submitter places on this proposal shall also be strictly complied with. Disclosure of this proposal for any reason outside the Government evaluation purposes shall be made only to the extent authorized by the Government.

SECTION I - Proposal Information

Principal Investigator	E-mail Address	Phone Number
Andrea Donnellan	**Andrea.Donnellan@jpl.nasa.gov**	**818-354-4737**

Street Address (1)	Street Address (2)
4800 Oak Grove Dr	**Mail Stop 183-501**

City	State / Province	Postal Code	Country Code
Pasadena	**CA**	**91109-8001**	**US**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

Proposed Start Date	Proposed End Date	Total Budget	Year 1 Budget	Year 2 Budget	Year 3 Budget	Year 4 Budget
02 / 01 / 2012	**01 / 01 / 2016**	**1,994,990.00**	**497,300.00**	**499,880.00**	**499,190.00**	**498,620.00**

SECTION II - Application Information

NASA Program Announcement Number	NASA Program Announcement Title
NNH11ZDA001N-AIST	**Advanced Information Systems Technology**

For Consideration By NASA Organization *(the soliciting organization, or the organization to which an unsolicited proposal is submitted)*
NASA , Headquarters , Science Mission Directorate , Earth Science

Date Submitted	Submission Method	Grants.gov Application Identifier	Applicant Proposal Identifier
	Electronic Submission Only		

Type of Application	Predecessor Award Number	Other Federal Agencies to Which Proposal Has Been Submitted
New		

International Participation	Type of International Participation
No	

SECTION III - Submitting Organization Information

DUNS Number	CAGE Code	Employer Identification Number (EIN or TIN)	Organization Type
095633152	**23835**	**951643307**	**2A**

Organization Name (Standard/Legal Name)	Company Division
Jet Propulsion Laboratory	

Organization DBA Name	Division Number
JET PROPULSION LABORATORY	

Street Address (1)	Street Address (2)
4800 OAK GROVE DR	

City	State / Province	Postal Code	Country Code
PASADENA	**CA**	**91109-8001**	**USA**

SECTION IV - Proposal Point of Contact Information

Name	Email Address	Phone Number
Andrea Donnellan	**Andrea.Donnellan@jpl.nasa.gov**	**818-354-4737**

SECTION V - Certification and Authorization

Certification of Compliance with Applicable Executive Orders and U.S. Code

By submitting the proposal identified in the Cover Sheet/Proposal Summary in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in the two Certifications and one Assurance contained in this NRA (namely, (i) the Assurance of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs, and (ii) Certifications, Disclosures, and Assurances Regarding Lobbying and Debarment and Suspension.

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S. Code, Title 18, Section 1001).

Authorized Organizational Representative (AOR) Name	AOR E-mail Address	Phone Number

AOR Signature *(Must have AOR's original signature. Do not sign "for" AOR.)* **Date**

PI Name : **Andrea Donnellan**		NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**		**TBD on Submit**
Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**		

SECTION VI - Team Members

Team Member Role	Team Member Name	Contact Phone	E-mail Address
PI	**Andrea Donnellan**	**818-354-4737**	**Andrea.Donnellan@jpl.nasa.gov**
Organization/Business Relationship: **Jet Propulsion Laboratory**		Cage Code: **23835**	DUNS#: **095633152**
International Participation: **No**	U.S. Government Agency: **Other**		Total Funds Requested: **1,624,210.00**
Co-I	**Geoffrey Fox**	**812-856-7977**	**gcf@indiana.edu**
Organization/Business Relationship: **Indiana University**		Cage Code: **4E748**	DUNS#: **006046700**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**
Co-I	**Margaret Glasscoe**	**818-393-4834**	**Margaret.T.Glasscoe@jpl.nasa.gov**
Organization/Business Relationship: **Jet Propulsion Laboratory**		Cage Code: **23835**	DUNS#: **095633152**
International Participation: **No**	U.S. Government Agency: **Other**		Total Funds Requested: **98,610.00**
Co-I	**Robert Granat**	**818-393-5353**	**granat@jpl.nasa.gov**
Organization/Business Relationship: **Jet Propulsion Laboratory**		Cage Code: **23835**	DUNS#: **095633152**
International Participation: **No**	U.S. Government Agency: **Other**		Total Funds Requested: **144,020.00**
Co-I	**Lisa Grant Ludwig**	**949-824-2889**	**lgrant@uci.edu**
Organization/Business Relationship: **University Of California, Irvine**		Cage Code: **0VWL0**	DUNS#: **046705849**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**
Co-I	**Dennis McLeod**	**213-740-4504**	**mcleod@usc.edu**
Organization/Business Relationship: **University Of Southern California**		Cage Code: **1B729**	DUNS#: **072933393**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**
Co-I	**Jay Parker**	**818-354-6790**	**Jay.W.Parker@jpl.nasa.gov**
Organization/Business Relationship: **Jet Propulsion Laboratory**		Cage Code: **23835**	DUNS#: **095633152**
International Participation: **No**	U.S. Government Agency: **Other**		Total Funds Requested: **133,000.00**
Co-I	**Marlon Pierce**	**812-856-1212**	**marpierc@indiana.edu**
Organization/Business Relationship: **Indiana University**		Cage Code: **4E748**	DUNS#: **006046700**
International Participation: **No**	U.S. Government Agency:		Total Funds Requested: **0.00**

Team Member Role	Team Member Name	Contact Phone	E-mail Address
Co-I	John Rundle	530-752-6416	jbrundle@ucdavis.edu
Organization/Business Relationship: University Of California, Davis		Cage Code: 1CBG4	DUNS#: 047120084
International Participation: No	U.S. Government Agency:		Total Funds Requested: 0.00
Co-I	Terry Tullis	401-863-3829	Terry_Tullis@brown.edu
Organization/Business Relationship: Brown University		Cage Code: 23242	DUNS#: 001785542
International Participation: No	U.S. Government Agency:		Total Funds Requested: 0.00
Collaborator	Don Atwood	907-474-7380	datwood@asf.alaska.edu
Organization/Business Relationship: University Of Alaska, Fairbanks		Cage Code: 3R2B4	DUNS#: 615245164
International Participation: No	U.S. Government Agency:		Total Funds Requested: 0.00
Collaborator	Jean-Pierre Bardet	213-740-0609	bardet@usc.edu
Organization/Business Relationship: University Of Southern California		Cage Code: 1B729	DUNS#: 072933393
International Participation: No	U.S. Government Agency:		Total Funds Requested: 0.00
Collaborator	Elizabeth Cochran	626-583-7238	ecochran@usgs.gov
Organization/Business Relationship: USGS Menlo Park		Cage Code: 37AW6	DUNS#: 074672841
International Participation: No	U.S. Government Agency: United States Geological Survey (USGS)		Total Funds Requested: 0.00
Collaborator	Charles Meertens	303-381-7465	meertens@unavco.org
Organization/Business Relationship: UNAVCO, Inc.		Cage Code: 4F1V9	DUNS#: 142357032
International Participation: No	U.S. Government Agency:		Total Funds Requested: 0.00

PI Name : **Andrea Donnellan**

Organization Name : **Jet Propulsion Laboratory**

NASA Proposal Number

TBD on Submit

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION VII - Project Summary

We will develop a multi-source, synergistic, data-intensive computing system to support modeling earthquake faults individually and as complex interacting systems. This will involve information technology research and development for data management and data-centric cloud computing. Numerous and growing online data sources from NASA, USGS, NSF, and other resources provide researchers with an exceptional opportunity to integrate varied data sources to support comprehensive efforts in data mining, analysis, simulation, and forecasting. The primary focus of this project is to extend this infrastructure to support fault modeling with a focus toward earthquake forecasting and response, but the developed technology can support a wide array of science and engineering applications.

This project will: 1) Develop bridging services within the QuakeSim service-oriented architecture that will integrate data from multiple sources, including interferogram, GPS position and velocity measurements, and seismicity; 2) Develop a fundamental cloud computing framework to support fault model optimization through the integration of multiple data types; 3) Develop the cyberinfrastructure within the QuakeSim science gateway to handle the computing requirements of the optimization framework; 4) Improve the QuakeTables fault database to handle issues of model contribution, provenance, version tracking, commenting, rating, etc of fault models produced by the optimization framework; and 5) Use the improved fault models in downstream earthquake hazard assessment and forecasts such as by the SCEC simulations group.

Understanding crustal deformation and fault behavior leads to improved forecasting, emergency planning, and disaster response. Accurate fault models supported through complementary information such as geologic observations, crustal deformation from InSAR and GPS, and seismicity. Fault models are subject to both known and unknown uncertainties that propagate through any analysis and downstream applications. Providing better constraints on the models by integrating multiple data collections, delivering these models through flexible, Web-based catalog services, and validating these models with numerous downstream applications will improve our understanding of earthquake processes. Analysis of crustal deformation data often indicates the existence of otherwise unknown faults. This project provides the computing infrastructure to identify, characterize, model and consider the consequences of unknown faults.

Handling large volumes of InSAR data and integrating the data with model applications is necessary for optimizing the utility of NASA's DESDynI-R mission, which will produce tremendous volumes of InSAR data products. All developed capabilities will be made available through QuakeSim's science gateway infrastructure. The project concludes with a deployment of selected project components at appropriate production facilities, including the Alaska Satellite Facility and UNAVCO.

Infusion will be through several collaborations and will support disasters. Through collaboration with the NASA-funded E-DECIDER project to deliver tools to emergency response communities. We will infuse the crustal deformation modeling tools into analysis of flow of fluids in reservoirs to the civil engineering community. We will work closely with the US Geological Survey to develop deformation and aftershock assessment tools that are coupled to the QuakeCatcher early warning network. QuakeSim simulations will feed into the Southern California Earthquake Center Simulations group, which in turn will be used for new versions of the Uniform California Earthquake Rupture Forecast (versions 3 and 4).

This four-year project has a period of performance for this work is from February 2012 through January 2016. Entry level TRL for the project is 2 with an exit TRL of 5. The entry level TRL for the infusion part of the project is 2 and the planned exit TRL is 7.

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION VIII - Other Project Information

Proprietary Information

Is proprietary/privileged information included in this application?

Yes

International Collaboration

Does this project involve activities outside the U.S. or partnership with International Collaborators?

No

Principal Investigator	Co-Investigator	Collaborator	Equipment	Facilities
No	**No**	**No**	**No**	**No**

Explanation :

NASA Civil Servant Project Personnel

Are NASA civil servant personnel participating as team members on this project (include funded and unfunded)?

No

Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year	Fiscal Year
Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs	Number of FTEs

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION VIII - Other Project Information

Environmental Impact

Does this project have an actual or potential impact on the environment?	Has an exemption been authorized or an environmental assessment (EA) or an environmental impact statement (EIS) been performed?
No	**No**

Environmental Impact Explanation:

Exemption/EA/EIS Explanation:

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION VIII - Other Project Information

Historical Site/Object Impact

Does this project have the potential to affect historic, archeological, or traditional cultural sites (such as Native American burial or ceremonial grounds) or historic objects (such as an historic aircraft or spacecraft)?

No

Explanation:

PI Name : **Andrea Donnellan**	**NASA Proposal Number**
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION IX - Program Specific Data

Question 1 : Short Title:

Answer: QuakeSim: Data Intensive Computing

Question 2 : Type of institution:

Answer: NASA Center (including JPL)

Question 3 : Will any funding be provided to a federal government organization including NASA Centers, JPL, other Federal agencies, government laboratories, or Federally Funded Research and Development Centers (FFRDCs)?

Answer: Yes

Question 4 : Is this Federal government organization a different organization from the proposing (PI) organization?

Answer: No

Question 5 : Does this proposal include the use of NASA-provided high end computing?

Answer: Yes

Question 6 : Research Category:

Answer: 10) Development/application of information technology/data and information systems and tools

Question 7 : Team Members Missing From Cover Page:

Answer:

N/A

Question 8 : This proposal contains information and/or data that are subject to U.S. export control laws and regulations including Export Administration Regulations (EAR) and International Traffic in Arms Regulations (ITAR).

Answer: No

Question 9 : I have identified the export-controlled material in this proposal.

Answer: N/A

Question 10 : I acknowledge that the inclusion of such material in this proposal may complicate the government's ability to evaluate the proposal.

Answer: N/A

Question 11 : Are you planning for undergraduate students to be involved in the conduct of the proposed investigation?

Answer: No

Question 12 : If yes, how many different undergraduate students?

Answer: N/A

Question 13 : What is the total number of student-months of involvement for all undergraduate students over the life of the proposed investigation?

Answer: N/A

Question 14 : Provide the names and current year (1,2,3,4) for any undergraduate students that have already been identified.

Answer:

N/A

Question 15 : Are you planning for graduate students to be involved in the conduct of the proposed investigation?

Answer: Yes

Question 16 : If yes, how many different graduate students?

Answer: 3

Question 17 : What is the total number of student-months of involvement for all graduate students over the life of the proposed investigation?

Answer: 12

Question 18 : Provide the names and current year (1,2,3,4, etc.) for any graduate students that have already been identified.

Answer:

Not yet identified

Question 19 : Please select one proposal topic category.

Answer: Advanced Data Processing

Question 20 : The proposal entry Technology Readiness Level is:

Answer: TRL-2

Question 21 : Are you proposing to the Technology Infusion Option?

Answer: Yes

Question 22 : If yes, identify the Earth science application area of your end user organization for the technology infusion option:

Answer: Disasters

Question 23 : The proposed development PRIMARILY supports which of the following ESD Science Focus Areas?

Answer: Earth Surface and Interior

Question 24 : The proposed development additionally supports which of the following ESD Science Focus Areas?

Answers :

Water and Energy Cycles

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Cumulative Budget

Budget Cost Category	Funds Requested ($)				
	Year 1 ($)	Year 2 ($)	Year 3 ($)	Year 4 ($)	Total Project ($)
A. Direct Labor - Key Personnel	141,620.00	145,390.00	144,660.00	144,410.00	576,080.00
B. Direct Labor - Other Personnel	0.00	0.00	0.00	0.00	0.00
Total Number Other Personnel	0	0	0	0	0
Total Direct Labor Costs (A+B)	141,620.00	145,390.00	144,660.00	144,410.00	576,080.00
C. Direct Costs - Equipment	0.00	0.00	0.00	0.00	0.00
D. Direct Costs - Travel	5,000.00	5,000.00	5,000.00	5,000.00	20,000.00
Domestic Travel	5,000.00	5,000.00	5,000.00	5,000.00	20,000.00
Foreign Travel	0.00	0.00	0.00	0.00	0.00
E. Direct Costs - Participant/Trainee Support Costs	0.00	0.00	0.00	0.00	0.00
Tuition/Fees/Health Insurance	0.00	0.00	0.00	0.00	0.00
Stipends	0.00	0.00	0.00	0.00	0.00
Travel	0.00	0.00	0.00	0.00	0.00
Subsistence	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00
Number of Participants/Trainees					0
F. Other Direct Costs	240,370.00	240,230.00	239,860.00	239,560.00	960,020.00
Materials and Supplies	2,000.00	2,000.00	2,000.00	2,000.00	8,000.00
Publication Costs	1,000.00	1,000.00	1,000.00	1,000.00	4,000.00
Consultant Services	0.00	0.00	0.00	0.00	0.00
ADP/Computer Services	0.00	0.00	0.00	0.00	0.00
Subawards/Consortium/Contractual Costs	237,370.00	237,230.00	236,860.00	236,560.00	948,020.00
Equipment or Facility Rental/User Fees	0.00	0.00	0.00	0.00	0.00
Alterations and Renovations	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00
G. Total Direct Costs (A+B+C+D+E+F)	386,990.00	390,620.00	389,520.00	388,970.00	1,556,100.00
H. Indirect Costs	110,310.00	109,260.00	109,670.00	109,650.00	438,890.00
I. Total Direct and Indirect Costs (G+H)	497,300.00	499,880.00	499,190.00	498,620.00	1,994,990.00
J. Fee	0.00	0.00	0.00	0.00	0.00
K. Total Cost (I+J)	497,300.00	499,880.00	499,190.00	498,620.00	1,994,990.00
Total Cumulative Budget					1,994,990.00

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2012	**01 / 01 / 2013**	**Project**	**1**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Donnellan, Andrea	PI	0.00				31,720.00	15,890.00	47,610.00
Granat, Robert	CO-I	0.00				23,490.00	11,760.00	35,250.00
Parker, Jay	CO-I	0.00				22,860.00	11,430.00	34,290.00
Glasscoe, Margaret	CO-I	0.00				16,290.00	8,180.00	24,470.00
							Total Key Personnel Costs	141,620.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	0.00
						Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	141,620.00

PI Name : **Andrea Donnellan**	**NASA Proposal Number**
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2012	**01 / 01 / 2013**	**Project**	**1**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**5,000.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**5,000.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Andrea Donnellan**	**NASA Proposal Number**
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2012	**01 / 01 / 2013**	**Project**	**1**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**2,000.00**
2. Publication Costs	**1,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**237,370.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**240,370.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**386,990.00**

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MPS (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**16,090.00**
ADC (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**47,440.00**
Gen. (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**46,780.00**
Cognizant Federal Agency: None		**Total Indirect Costs**	**110,310.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**497,300.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**497,300.00**

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2013	**01 / 01 / 2014**	**Project**	**2**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Granat, Robert	CO-I	0.00				24,470.00	12,260.00	36,730.00
Glasscoe, Margaret	CO-I	0.00				16,110.00	8,080.00	24,190.00
Parker, Jay	CO-I	0.00				23,270.00	11,630.00	34,900.00
Donnellan, Andrea	PI	0.00				33,020.00	16,550.00	49,570.00
							Total Key Personnel Costs	145,390.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	0.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	145,390.00

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2013	**01 / 01 / 2014**	**Project**	**2**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**5,000.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**5,000.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2013	**01 / 01 / 2014**	**Project**	**2**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**2,000.00**
2. Publication Costs	**1,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**237,230.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**240,230.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**390,620.00**

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MPS (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**16,780.00**
ADC (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**47,440.00**
Gen. (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**45,040.00**
Cognizant Federal Agency: **None**		Total Indirect Costs	**109,260.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**499,880.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**499,880.00**

PI Name : **Andrea Donnellan**	**NASA Proposal Number**
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2014	**01 / 01 / 2015**	**Project**	**3**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Granat, Robert	CO-I	0.00				24,770.00	12,410.00	37,180.00
Glasscoe, Margaret	CO-I	0.00				15,610.00	7,820.00	23,430.00
Parker, Jay	CO-I	0.00				21,620.00	10,850.00	32,470.00
Donnellan, Andrea	PI	0.00				34,360.00	17,220.00	51,580.00
							Total Key Personnel Costs	144,660.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	**Total Number Other Personnel**					**Total Other Personnel Costs**	0.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	144,660.00

PI Name : **Andrea Donnellan**			NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**			**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2014	**01 / 01 / 2015**	**Project**	**3**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**5,000.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**5,000.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2014	**01 / 01 / 2015**	**Project**	**3**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	**2,000.00**
2. Publication Costs	**1,000.00**
3. Consultant Services	**0.00**
4. ADP/Computer Services	**0.00**
5. Subawards/Consortium/Contractual Costs	**236,860.00**
6. Equipment or Facility Rental/User Fees	**0.00**
7. Alterations and Renovations	**0.00**
Total Other Direct Costs	**239,860.00**

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	**389,520.00**

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MPS (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**17,780.00**
ADC (reported as Direct Costs per NASA Prime Contract)	**0.00**	**0.00**	**46,760.00**
Gen. (reported as Direct Costs per NASA Prime Contract	**0.00**	**0.00**	**45,130.00**
Cognizant Federal Agency: None		**Total Indirect Costs**	**109,670.00**

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	**499,190.00**

J. Fee

	Funds Requested ($)
Fee	**0.00**

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	**499,190.00**

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2015	**01 / 01 / 2016**	**Project**	**4**

A. Direct Labor - Key Personnel

Name	Project Role	Base Salary ($)	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
Granat，Robert	CO-I	0.00				22,520.00	11,280.00	33,800.00
Glasscoe，Margaret	CO-I	0.00				17,550.00	8,810.00	26,360.00
Parker，Jay	CO-I	0.00				19,690.00	9,860.00	29,550.00
Donnellan，Andrea	PI	0.00				36,450.00	18,250.00	54,700.00
							Total Key Personnel Costs	144,410.00

B. Direct Labor - Other Personnel

Number of Personnel	Project Role	Cal. Months	Acad. Months	Summ. Months	Requested Salary ($)	Fringe Benefits ($)	Funds Requested ($)
0	Total Number Other Personnel					Total Other Personnel Costs	0.00

Total Direct Labor Costs (Salary, Wages, Fringe Benefits) (A+B)	144,410.00

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2015	**01 / 01 / 2016**	**Project**	**4**

C. Direct Costs - Equipment

Item No.	Equipment Item Description	Funds Requested ($)
	Total Equipment Costs	**0.00**

D. Direct Costs - Travel

	Funds Requested ($)
1. Domestic Travel (Including Canada, Mexico, and U.S. Possessions)	**5,000.00**
2. Foreign Travel	**0.00**
Total Travel Costs	**5,000.00**

E. Direct Costs - Participant/Trainee Support Costs

		Funds Requested ($)
1. Tuition/Fees/Health Insurance		**0.00**
2. Stipends		**0.00**
3. Travel		**0.00**
4. Subsistence		**0.00**
Number of Participants/Trainees:	**Total Participant/Trainee Support Costs**	**0.00**

PI Name : **Andrea Donnellan**	NASA Proposal Number
Organization Name : **Jet Propulsion Laboratory**	**TBD on Submit**

Proposal Title : **QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science**

SECTION X - Budget

Start Date :	End Date :	Budget Type :	Budget Period :
02 / 01 / 2015	**01 / 01 / 2016**	**Project**	**4**

F. Other Direct Costs

	Funds Requested ($)
1. Materials and Supplies	2,000.00
2. Publication Costs	1,000.00
3. Consultant Services	0.00
4. ADP/Computer Services	0.00
5. Subawards/Consortium/Contractual Costs	236,560.00
6. Equipment or Facility Rental/User Fees	0.00
7. Alterations and Renovations	0.00
Total Other Direct Costs	239,560.00

G. Total Direct Costs

	Funds Requested ($)
Total Direct Costs (A+B+C+D+E+F)	388,970.00

H. Indirect Costs

	Indirect Cost Rate (%)	Indirect Cost Base ($)	Funds Requested ($)
MPS (reported as Direct Costs per NASA Prime Contract)	0.00	0.00	18,010.00
ADC (reported as Direct Costs per NASA Prime Contract)	0.00	0.00	46,480.00
Gen. (reported as Direct Costs per NASA Prime Contract)	0.00	0.00	45,160.00
Cognizant Federal Agency: None		**Total Indirect Costs**	109,650.00

I. Direct and Indirect Costs

	Funds Requested ($)
Total Direct and Indirect Costs (G+H)	498,620.00

J. Fee

	Funds Requested ($)
Fee	0.00

K. Total Cost

	Funds Requested ($)
Total Cost with Fee (I+J)	498,620.00

TABLE OF CONTENTS

1. PROJECT DESCRIPTION FOR TECHNOLOGY DEVELOPMENT

We will develop a multi-source, synergistic, data-intensive computing infrastructure for modeling earthquake fault models individually and as part of complex interacting systems. Numerous and growing online data sources from NASA, USGS, NSF, and other resources provide an exceptional opportunity to integrate varied data sources to support comprehensive efforts in data mining, analysis, simulation, and forecasting. The primary focus of this project is fault modeling and its application to earthquake forecasting, but the developed technology can support a wide array of science and engineering applications. We have put together a team of investigators and collaborators to maximize the utility of this system.

Accurate fault models are required for understanding earthquake processes and require the integration of multiple types of data. Analysis of crustal deformation data repeatedly indicates the existence of otherwise unknown faults (e.g. Donnellan et al., 1993). Identifying, characterizing, modeling and considering the consequences of unknown faults, and improving the models of known faults, is necessary for mitigating the damaging affects of earthquake. Understanding crustal deformation and fault behavior leads to improved forecasting, emergency planning, and disaster response. Existing fault catalogs provide the best available geometric fault models, from which more sophisticated models can be built and used in simulation, and from which forecasting methods for interacting fault systems may be derived. Fault models are, however, constructions that must be measured indirectly through techniques such as surface deformation and displacement measurements. These models are supported through complementary information such as GPS time series, InSAR, and seismicity. Fault models are thus subject to both known and unknown uncertainties that propagate through any analysis and downstream applications. We will provide better constraints on the models by integrating multiple data collections, delivering these models through flexible catalog services, and validating these models with numerous downstream applications

Numerous types of data that cover timescales of seconds to millions of years contribute to solid Earth science studies where processes occur on scales of seconds to millions of years. Integrating the heterogeneity of data is challenging. Domain experts study various aspects of these scales using experimental, theoretical, modeling, or statistical tools. Over the last decade in part due to the advent of new computational methods there has been an increasing focus on mining and integrating the heterogeneous data into complex models as necessary for understanding solid Earth process.

Earthquake research activities are hampered by the uncoordinated (but improving) state of current data collections, and the lack of formal modeling tools capable of ingesting multiple data types. To address these issues, we propose the following comprehensive set of activities: 1) Develop bridging services within the QuakeSim service-oriented architecture that will integrate data from multiple sources, including interferogram, GPS position and velocity measurements, and seismicity; 2) Develop a fundamental framework for fault model optimization through the integration of multiple data types; 3) Develop the cyberinfrastructure within the QuakeSim science gateway to handle the computing requirements of the optimization framework; 4) Enhance the QuakeTables fault database to handle issues of model contribution, provenance, version tracking, commenting, rating, etc of fault models produced by the optimization framework; and 5) Use the improved fault model catalogs in QuakeTables in downstream applications, and particularly in simulations by the SCEC simulations group led by

Terry Tullis. QuakeSim team members are part of the simulators group (e.g. Rundle – Virtual California, Parker – GeoFEST).

The focus of this work will be primarily on earthquake forecasting and response, but understanding fluid flow is necessary for separating tectonic from non-tectonic signals. As a result, QuakeSim also will put the tools in place to study surface deformation associated with various types of reservoirs. Such reservoirs can include aquifers, oil or gas reservoirs, carbon sequestration reservoirs, or magma chambers. We include a civil engineering team member (J.-P. Bardet), to exploit QuakeSim tools for civil engineering applications.

1.1. APPLICABILITY TO EARTH SCIENCE MISSIONS

In the past three decades NASA has contributed greatly to the study of earthquakes and solid Earth processes through the development and deployment of spaceborne technologies to measure crustal deformation. Global Positioning System (GPS) stations provide precise position and motion measurements with very high temporal resolution but coarse spatial resolution. Interferometric Synthetic Aperture Radar (InSAR) instruments on airborne (UAVSAR) and spaceborne platforms provide line of site measurements over large areas, although with very limited time resolution. Such methodologies are being widely adopted by the earthquake and crustal deformation communities, but infrastructure to manage, process, and analyze the increasing volumes of data is still a great need. In the past, data were sparse and datasets were small, making it possible for individual investigators to oversee the end-to-end process of data analysis through interpretation. This approach is no longer possible.

This project addresses current needs to integrate and model the ever-growing and increasingly multisource GPS and InSAR data volumes, improving and expanding our catalog of fault models that are in turn used in downstream forecasting, simulation, and emergency planning and response applications. It also lays the foundation for maximizing the utility of future missions such as the DESDynI-R Mission (Deformation Ecosystem and Dynamics of Ice – Radar) recommended in the Earth Science Decadal Survey (Anthes et al., 2007). The Decadal Survey also "recommends supporting the development of cutting-edge models, data-assimilation tools, and high-performance computers, which are critical for the success of the priority missions." "Full exploitation of the missions identified by the Earth science and applications decadal survey requires not only timely and substantive initial analyses but also reanalyses as models and data-assimilation systems advance." Data from the current missions that are relevant to our proposal are widely distributed (Table 1). This work addresses the Earth Observing Systems Missions Applications Workshop, which recommends accelerating the "use of NASA data for applications and societal benefit," developing and maximizing "government, private, and academic partnerships," and "improved infrastructure to "provide access to high level data products." The Solid Earth and Natural Hazards Panel of the NASA SMD Computational Modeling Capabilities Workshop states that the "next great revolution in Earth sciences will involve development of predictive models of complex, interconnected solid Earth processes." Developing predictive models of earthquake processes by incorporating the many temporal and spatial scales is the goal of this work. The workshop report points out that computing done today is highly distributed. The emerging "Cloud Computing" paradigm and an SOA (service-oriented architecture) are expected to become standard practice for much of solid Earth science. The proposal aims to address the distributed nature of solid Earth science data and modeling.

Table 1. Current data, distribution of data and processing centers, and base data volume. GPS volume refer to 30 minute, 5 minute, or 1 second solutions for the 10 year time series.

Data Sources	**Storage Centers**	**Processing**	**Volume**
GPS			
Southern California Integrated GPS Network	Scripps/SOPAC JPL	Scripps/SOPAC JPL USGS Pasadena	Current: 250 stations 10 years daily 50 MB Future: 30 min: 5 GB 5 min: 30 GB 1 sec: 10 TB
Bay Area Regional Deformation Network	USGS UC Berkeley	USGS Menlo Park	100 stations 10 years daily
Plate Boundary Observatory	UNAVCO	Scripps/SOPAC JPL UNAVCO	1000 stations 5 years daily
InSAR			
UAVSAR	JPL Alaska Satellite Facility QuakeSim USC	JPL	Current: 250 InSAR 1–25 GB each 7 GB average 2 TB total
International InSAR	UNAVCO/WinSAR (raw) QuakeSim (processed)	WinSAR Investigators	100 InSAR 250 MB each ~25 GB total

Efficiently analyzing, integrating, and modeling the data requires not only digital storage of all of the data, including the fault specifications, but also automated access of the data through network services as well. Furthermore, as the data sources, volumes and regions of interest grow it will become increasingly necessary for applications, not just humans, to access the data for remote automated processing. The data are distributed and under the cognizance of a wide array of agencies and institutions. Developing standards through formal and informal collaborations and partnerships will be key to maximizing the use of solid Earth science data. We will strive to enable these standards through this project. The potential applications of the data are even more varied and are many-fold times larger than the centers that process or store the data. Numerous processes result in deformation of the Earth's surface, and accessing, mining, and modeling those data are key to understanding those processes. This proposal focuses on earthquake and reservoir processes, but the broader scope of processes also includes volcanoes, landslides, aquifers, CO_2 sequestration, and oil pumping.

Addressing the data storage, processing, mining, and analysis challenges now is imperative to maximizing the utility of the DESDynI-R mission. A tremendous investment will be placed on designing, launching, and operating the mission. Realizing the benefits of that investment will only be possible if the infrastructure is in place for numerous investigators and users can access and interpret the data from that mission.

1.1.1. RELEVANCY SCENARIO

Use Case

Understanding: Identify active regions from GPS and InSAR/UAVSAR data. Invert crustal deformation data for fault motions constrained by paleoseismic fault data. Develop simulations based on fault locations and behavior. Search for GPS time series transient anomalies that indicate previously unknown characteristics of crustal behavior.

Forecasting: Identify active faults from multiple data sources: GPS, UAVSAR, InSAR, paleoseismic fault data, seismicity. Carry out pattern analysis for anomalous features from GPS time series and seismicity data. Simulate interacting faults and carryout statistical analysis of the interactions. Evaluate earthquake probabilities on short to decade scales. Integrate into Uniform California Earthquake Rupture Forecast.

Response: Event occurs. Estimate deformation from models. Estimate locations of future aftershocks. Steer collection of UAVSAR and GPS data. Refine deformation estimates. Define damage zone from event as a polygon. Reformat damage products for ingestion into loss estimation tools. Target acquisition of remote sensing data for emergency response. Refine aftershock assessment. Feed products to emergency responders

Applicable NASA Mission(s) or measurement(s)

GPS, UAVSAR, DESDynI

This project enables current NASA geodetic imaging activities. These include GPS measurement and processing of crustal deformation and production of UAVSAR Repeat Pass Interferometry (RPI) products. At present UAVSAR data users must be familiar with UAVSAR RPI data formats as well as use or develop their own tools and download the data to their local computer. This work will enable users to browse UAVSAR data without downloading or developing tools. Gaining deeper insight into crustal deformation requires understanding the line-of-sight range changes for interferometric products, which requires visualization tools (e.g. plotting sections) and modeling tools. This lays the groundwork for the future DESDynI mission. Without such tools only a handful of users will be equipped to analyze and interpret either UAVSAR or DESDynI data.

Technology Platform

Ground-based system for integrating and analyzing multiple data types from multiple sources. System is distributed and resides in the storage and compute cloud.

Meeting Mission/Measurement Schedules

The entry level TRL is low because of the challenge of accessing and analyzing disparate and heterogeneous datasets that keep growing in volume and complexity. We plan to be at an operational TRL by year four of this project, which precedes the launch of DESDynI. Development now is essential to maximize the use of GPS and UAVSAR data, but also because earthquakes are an ever-present hazard in California and elsewhere. A system to evaluate earthquake hazard and respond to them when they occur will mitigate loss of life and property.

1.2. DESCRIPTION OF PROPOSED TECHNOLOGY

We will maximize the utility of current GPS and InSAR/UAVSAR crustal deformation data while increasing the value of the future DESDynI-R mission by developing advanced data processing techniques to enable multi-source data across models, satellites, airborne platforms, and in-situ sensors. The system will enable rapid data fusion and will include visualization tools for effective communication of the meaning of the data and models. By data fusion, we mean using different data sources and types to better constrain models.

Current analysis of crustal deformation is messy and time consuming. GPS data are now collected in a systematic fashion, but continual improvements in processing methods necessitates reprocessing and hence re-analysis of data – at least for identifying smaller or more subtle signals in the data. Earthquakes occur globally and unpredictably, and as a result data collection and analysis efforts are often in response to an event. Earthquake response is not yet automated or systematic and would be greatly facilitated through the existence of routine automated methods. Faults deform on many temporal and spatial scales and are not uniformly or systematically distributed. The multiple temporal and spatial scales necessitate a consistent subsetting of various datasets both geographically and temporally. Heterogeneous material properties further complicate the models. Simple models can approximate crustal deformation, but more realistic models are complex, and typically broken down into millions of elements and can have hundreds of thousands of time steps. Steering the models with data increases the computational burden, requiring high performance compute power.

Understanding earthquakes requires understanding other signals such as deformation induced by fluid low in aquifers or reservoirs. Because tools must be developed to separate fluid motions from tectonic motions it is ideal to involve the applications community at the outset, so that they can make use of these tools for their own studies. Such studies include water reservoirs, flow in oil and gas reservoirs, carbon sequestration, and proposed injection of sewage into depleted oil reservoirs for methane generation.

1.2.1. DESCRIPTION OF PROPOSED SYSTEM

The proposed system constitutes the back-end for earthquake forecasting and response, crustal deformation modeling, and modeling of fluids within the crust. Each of these applications requires the user to do the following either in an automated manner or with user intervention: 1) Select data in terms of types, time, and space; 2) Subset data to relevant focus of interest; 3) Move data for mining, modeling, or visualization; 4) Analyze data by modeling, inverting, or data mining; 5) Visualize data and results; and 6) Track data and models. For small data sets or regions of interest these steps can be done manually and in fact such investigations provide excellent examples for developing workflow for larger and more complicated cases. Current data volumes and in particular those for DESDynI-R motivate the need for an end-to-end architecture in which data can be systematically analyzed, modeled, and interpreted. Automation requires interfaces between the widely distributed data sets, data products, and applications. Without such a system in place at launch the vast majority of DESDynI-R data will be under or not utilized.

1.2.2. TECHNICAL APPROACH

Our technical approach involves identifying and pulling in data from numerous sources, simplifying or automating data assimilation, mining, and modeling workflow, and providing feeds and interfaces for generalized data users. The scaling of compute power should occur on the back end and be transparent to the user. We are users of the high-end computers at NASA Ames and use the facility primarily for modeling interacting fault system and nucleation. Under this work we will extend the use of the machines to include UAVSAR inversions for fault motion and for time series analysis. The time series analysis software has been ported to the high-end computers. We require an average of 256 processer, but runs range from 8 to 2048 processors. We estimate 40 runs per year which require 100,000 processor hours.

Data Centric Cloud Computing for Solid Earth Research: A growing body of research indicates that Cloud Computing approaches are a good match for many large-scale data-centric scientific computing problems (Bégin, 2008; Jackson et al, 2010; Lu et al, 2010; Ericson et al, 2010; Pireddu et al, 2011; Stein, 2011). Cloud Computing infrastructure in many fields is overtaking the traditional data center. The size of data in many fields (such as the life sciences) is growing so rapidly that frequent data movement is impractical, and so computing must be brought to the data. It is important to prototype these approaches for NASA data collections, particularly the anticipated large collections of InSAR imagery from the DESDynI-R mission. Through QuakeTables we have sample InSAR data sets and a comprehensive set of UAVSAR interferograms for the western United States. These data provide essential information for modeling earthquake processes and particularly for developing accurate fault models. The infrastructure must also be flexible enough to support other data sets and use cases.

Standard definitions for cloud computing are beginning to emerge from the National Institute of Standards and Technology. Large deployments are available from Amazon, Google, Microsoft and other vendors, and open source software for building research and private clouds, with the NASA-led OpenStack project as a prominent example. Two relevant Cloud Computing approaches are Infrastructure as a Service (IaaS) and Software as a Service (SaaS). We must evaluate and prototype a system based on relevant IaaS services. Microsoft Azure's Blob storage service, Amazon's S3, and the Lustre file system-based Whamcloud are examples of unstructured storage, and BigTable, HBase, and the Azure Table Service are examples of structured data storage. We will evaluate these for the storage and access of large collections of individually large data sets. A key observation from our research on cloud systems for science is that data storage and computing must be coupled. We must therefore couple our IaaS prototyping with SaaS prototyping. Specifically, the SaaS models that we will consider are MapReduce and its derivatives. MapReduce-style approaches are particularly useful for data-parallel computing problems such as DESDynI-R image processing and GPS signal analysis.

For these tests, we will use Indiana University's FutureGrid system, an NSF-funded testbed that is designed to foster research on Cloud Computing for science and other advanced topics. We will use FutureGrid to help build and evaluate prototypes, which we will deliver to partner deployment sites funded by NASA ACCESS, particularly UNAVCO (GPS) and ASF (interferograms). Representatives from both of these organizations are collaborators on this proposal. Because cloud research is dominated by industry, we will also build on pre-existing partnerships with Microsoft Research. We will package these tools with a workflow engine and a user portal. We currently intend to use Apache Airavata for workflow. We note that several studies have shown that clouds offer science cost effectiveness computing and important new programming model (see for example Bégin, 2008 and Jackson et al, 2010). Data analysis is particularly attractive on clouds as it does not typically need the tight synchronization of most large-scale parallel simulations. Technically, the software will be delivered with cluster and cloud solutions supporting both intranode (threading) and internode parallelism. We will use

MPI for cluster intranode communication and Iterative MapReduce as the cloud solution. We will use the Twister Iterative MapReduce software (http://www.iterativemapreduce.org/) developed by Fox's group (Ekanayake et al, 2009, 2010; Zhang et al 2010), which is already available for Amazon and Azure and has been tested on several applications with significant research activity to enhance it. Iterative MapReduce also runs well on a cluster, allowing a portable environment that could be attractive but lacks the maturity (performance, support of full range of languages) of the MPI solution.

Data: At present, QuakeSim data are stored on a database server at USC and in a large storage system at IU. This approach is functional, but has significant limitations, which we have observed and propose to address. We have observed that it is essential to have all QuakeSim data in highly sustained (secure, durable) storage. We have also found that it is essential to provide adequately fast transfer for large data objects (such as UAVSAR imagery), for users who are geographically distributed; this includes those stored by QuakeSim, and those referenced by QuakeSim (and stored elsewhere). We need to subset the data so that only essential data are transferred and ideally keep the applications close to the large data sources.

We propose to utilize a new USC internal Cloud-based storage system (virtualized storage), along with IU's FutureGrid testbed infrastructure to address the key issues outlined above. In particular, IU's Bravo cluster (part of FutureGrid), with large memory and large, high-speed local storage, is designed specifically for prototyping data-intensive computing problems on computing clouds. We will use this as a prototype for larger scale cloud center deployments required by DESDynI-R. Further, we propose to work closely with the Alaska Satellite Facility (ASF) DAAC (Distributed Active Archive Centers), so that QuakeSim products can be stored and accessed via the QuakeSim portal as well as via the ASF DAAC interface. To provide for constant availability and the huge increase in data demand after a significant seismic event, we will mirror the QuakeSim data, so that there are at least two active online copies of it available at all times. As the project progresses, we also plan to develop a QuakeSim database copy using commercial cloud storage systems. An accompanying requirement is to support "fast enough" access for users and applications, even during high usage periods. In consequence, all our research and prototyping will be structured so as to be scalable in terms of data size, speed requirements, and number of users.

The content of the QuakeSim federated database is of course dynamic, in the sense that new data are being added with time. We propose to support three methods of data "ingestion": (1) QuakeSim expert scientists arrange to have collections of data added, e.g., UCERF3; (2) data from selected trusted sources can be automatically added to QuakeSim (e.g., for UAVSAR processed data generated by a trusted processing method from a trusted source); and (3) annotations and data products derived from the data in QuakeSim can be placed into the database directly by trusted users. We will provide capabilities to access/retrieve/deliver data from the QuakeSim database to users and applications in four ways: (1) users can use the QuakeSim portal to find and select data of interest; (2) data can be presented to a user via various visualization methods; (3) data can be specified to be delivered to simulation/modeling programs - "fed" as needed; and (4) users can define "alerters", which specify data selection criteria - when new data enters the database satisfying those criteria, the user is notified with an optional "feed" to the user/application of the data or a portion thereof. Details of the key observational data are complicated and it is those details that must be considered. Here we outline some of the details, present state of the art, and issues related to processing.

GPS: Data products include position time series, velocities, and offsets. Time series data provide information about time scales, processing quality or errors, and transients. Traditional work relies on daily time series: for each receiver station (a pin on the map), a full day produces an estimated offset in east, north, and up, but analysis of the time series at each station provides additional insight into transient processes. The number of GPS stations is under 10,000, which may appear to be a very small data set, but there are a small but increasing number of stations that are being processed for higher sampling rates. Rather than every 24 hours, data are processed for time series with samples every 5 minutes or even every second. There are many issues associated with the GPS data, which includes their availability. Many national networks such as Japan restrict data access. Interference such as from tides, rumbling trucks or fluid motions add noise. Data latency is also large issue. It takes about two weeks for GPS data products to become available making any sort of real-time or near real-time statistical analysis of data for meaningful anomalies impractical. There are good reasons for the delays in producing data products. Predicted or rapid orbits are not as good as precise orbits calculated from many days of data, and as a result the rapid GPS time series are contaminated with noise. However detecting any anomalous signal in GPS data that can be used for hazard evaluation must be done in near real-time. We will work with our partners to provide rapid solutions, but must develop techniques to evaluate the quality of those rapid solutions.

*UAVSAR***:** Repeat pass interferometry products are produced in a strips of high-resolution images that are closely registered with the real world. The strips are generally up to 25x300 km in area and data files for the complex phase interferograms are up to 4.5 Gb in size. There are currently about 120 of these, most spanning a six-month interval with yearly products now being produced. A phase image shows how the landscape has changed in the time interval. As with GPS, QuakeSim is not in the interferogram production business (taking raw radar signals to images). The images are stored in a simple way as raster lines of binary data. We typically want a small region of the image, hence a small part of the file (the neighborhood of a fault, a GPS station, etc). Latencies for this data have often been months - time spent processing the essential data, putting it though a partially manual quality control process, reprocessing the images, etc.

Satellite InSAR: We have a handful of interferograms (landscape change images, recorded as phase). There is a fairly substantial amount we can obtain through our membership in the WinSAR consortium, but WinSAR houses the raw data, not the interferograms. Much of this is old data, which is good for science, but not helpful for emergency responders. Analysis of the data is useful, however for producing a better understanding of faults in a given region.

Faults: QuakeTables takes fault models developed through official channels or from modeling activities and formats them in a database that can be accessed through QuakeSim applications. The QuakeTables fault database continues to grow as modeling regions of interest expand. For example, the May 2011 National Level Exercise drew attention to the Central US and lack of digital fault models. As a result, the Quakesim team is developing a Central US fault dataset for QuakeTables. The faults in the database need to be continuously validated and assessed as models are refined or new official fault specifications are produced.

Seismicity: Pattern analysis of earthquakes requires access to seismic catalogs. Services such as ANSS provide a useful resource for access by QuakeSim applications.

Tools and Applications

Crustal Deformation Modeling: Because the time and spatial scales of tectonic processes are so variable, a key challenge is subsetting data to the relevant time or region of interest. For crustal deformation modeling the most frequent question will probably always be "how did this area deform between Day 1 and Day 2," which can be days apart in the event of an earthquake or months or years apart for studying slow processes. With GPS this is typically done by differencing a few-day average of the time series about both days. To our knowledge, there is no web-based tool that does this, either for a single station or for a collection chosen on a map. We have discussed this issue with Chuck Meertens from UNAVCO and will collaborate to appropriately develop this type of tool for the modeling community.

A UAVSAR user finds the image that spans the time of interest covering the relevant area on the ground. Since the images are not produced systematically they tend to be based on six month or year long repeat intervals. A geophysical process may be intermittent and complications quickly arise. Estimating the "coseismic motion" (essentially within one day) by observing the change in a bracketing 6-month period requires quantifying other processes, like the background tectonic drift. Additionally, a single radar flight line means we don't have a 3D east-north-up deformation map like we do with GPS; instead, we have 'radar line of sight' component of deformation (say, the 40% up, 60% north component). There are cases with additional flight lines covering the time/space of interest, but they are not common.

Problems such as long- vs. short- term processes sampled at 6 months or restriction to one look angle suggest that data fusion is essential. GPS, radar, known faults, and seismicity combined with some sort of model resolve the ambiguities in the data. QuakeSim investigators are active earthquake researchers and as a result current research in crustal deformation, pattern analysis, and forecasting drives development of QuakeSim workflow and tools. Examples of such problems include the 2010 El Mayor-Cucapah earthquake and 2011 Tohoku-Oki earthquake and drive development that others will use in the course of the proposed work. To date, all the data and models cannot be assimilated into a comprehensive optimal estimation such as is done for weather models. Crustal deformation related to earthquakes is done with much trial and error. For example, the data are evaluated for consistency with a simple model, which may be an approximation, but is one that can be computed quickly. Are there spots on the map (and in time) where we can test the consistency of the GPS with the radar measurement? Can we estimate the noise level in each kind of data by examining a part of the image that we think is geophysically quiet? Is analysis best done by extracting a cross-section? What are the changes on surrounding faults? We need visualization tools to see cross-sections of the radar image, at high resolution, but zoomed in around a known fault.

At the computer requirement level, such investigations can be served with a set of tools to support initial exploration (Steps 1-4), followed by large-scale simulations (Step 5): 1) Discovery tools (what GPS cover the time and region of interest? What radar observations?); 2) Verification of discovery: the ability to page through radar images (usually at low resolution) with a time-slider control (and map navigation); interactive GPS time series graph tools; 3) Extraction of small parts, preferably without requiring the downloading of large files. 1-D cross sections and time series must be supplied to the user as simple ASCII lists: CSV or white space delimited files of columns; 4) Math operations, typically at the server. For example the GPS "change from day 1 to day 2;" the ability to subtract (or add) phase images (if UAVSAR supplies images every six months, in time the user will need to know how the region changed over 2 years and so will want to add the changes, coregistered pixel by coregistered pixel). There are opportunities here to do simple operations over many GPS stations or many points along a line of a UAVSAR interferogram; 5) The ability to set up a work flow: For example, take all the images spanning the five main southern California faults, and all GPS stations in that region, find all locations where these stations and images overlap, process the overlap data to estimate noise, find outliers, etc; use GPS to constrain the unknown phase offset for each strip, use GPS to bound vertical motion in each strip subregion, and estimate the average rate of slip on each major fault and also estimate if there are times of abnormal slip.

These goals drive needs for computational power. Initially users may invert small time/space problems such as 1-2 radar strips and the overlapping GPS stations, and with the radar down sampled by as much as 2500:1. These models will have increasing area, resolution, stations, and timespans. Doing so will require spawning dozens of inversion jobs with different initial conditions. For example, 25 initial conditions, 20 radar strips (spread over both time and space), 20,000 interesting data points per strip, and 5000 iterations each requiring evaluation of 100 fault/volcano/aquifer model fault patches, each requiring a forward model of about 500 operations per pixel requires 2.5×10^{15} flops, which is 1 Gflop for 29 days. The goal is to build the distributed data and services that allow exploration of concepts and model fitting to multi-source data using distributed suites of simplex inversion runs. Integrating GIS tools improves analysis of the data and models and increases the utility for engineering or response applications.

Scaling from UAVSAR to DESDynI-R for the largest fits will increase data sizes by a factor of 100. Sampling on time and space scales will be necessary to handle the large volumes of data. DESDynI analysis will be more oriented toward time series of images and imaging from different directions, which could bring the relevant data needed for a problem up by another factor of 10. The number of interested investigators will rise steeply with an easily useable analysis environment; we estimate this increase to be 100 times the current QuakeSim users. Consequently, we will need a robust system that can handle many users, with loads that vary from a background ongoing research level to high usage after any major geophysical event where up to thousands of users may access the system.

Time Series Analysis: Currently, publically available GPS data sets consist of daily, integrated 3-D displacement measurements over several years on a few hundred stations. However, new techniques for fast orbit correction are leading to the production of data sets with time resolutions of as little as five minutes (Simons et al., 2011). Some date centers are also starting to release uncorrected, almost raw data sets with resolutions as little as one second (Ayden et al, 2007). Combined with the ongoing expansion of GPS networks, the net effect will be that GPS data sets will soon be two to five orders of magnitude larger than they are today.

Even at current data rates, there is now a growing awareness in the geophysical research community that traditional (i.e., manual inspection) approaches to investigating GPS time series are insufficient because the volume of data has grown too large. Moreover, because it is now widely recognized that study of the "quiet periods" between earthquakes is vitally important to obtaining a full understanding of the earthquake cycle, increasing focus is now being placed on detecting subtle inter-earthquake transient deformation signals (seismic anomaly and SCEC transient detection exercise references). These challenges can only be met through the use of automated, data-driven analysis methods that help to focus the attention of scientists on interesting or anomalous signals and suggest hypothesis about the underlying physics. In previous work on the QuakeSim project we were able to successfully demonstrate this mode of research employing the RDAHMM hidden Markov model based time series analysis software to detect unusual signals associated with the recent El-Mayor/Cucapa and Tohoku-Oki earthquakes.

Meeting the near future challenge of much higher data rates demands that a premium be placed on automated analysis methods that are efficient and scalable. Some approaches that are used with great success today, such as principal components analysis (PCA) and the network inversion filter (Segall et al., 1997) do not scale well with dramatic increases in the number of stations and observation frequency. We will instead focus on analysis methods that can capitalize on an "embarrassingly parallel" approach in which the initial analysis of individual time series can be performed separately and thereby farmed out to processes in a cluster or cloud, and only after this step is synthesis across stations performed on the high-level results. These methods include hidden Markov modeling (Granat et al, 2007), covariance descriptor analysis (reference), and robust Kalman filtering (Ting et al, 2007). We will make all of these analysis methods available to users through the QuakeSim web portal environment, allowing users to compare and contrast the results of different methods across different data sets.

Interacting Fault Simulations: Calculating earthquake probabilities can be accomplished by the use of numerical simulations such as the code Virtual California (VC) (Rundle, 1988; Rundle et al., 2006; Van Aalsburg et al., 2007; Yikilmaz et al., 2010) or GeoFEST. These models include stress accumulation and release as well as stress interactions including the San Andreas and other adjacent faults. The model is based on a set of mapped faults with estimated slip rates, a prescribed plate tectonic motion, earthquakes on all faults, and elastic interactions (Rundle, 1988; Rundle et al., 2001, 2002, 2004). Earthquake activity data and slip rates on these model faults are obtained from geologic databases. At present, VC includes only strike slip fault models, which are responsible for the great majority of the seismic moment release. However, we are in the process of developing the software needed to include faults of any orientation, dip, or mode of offset, using a finite element code to compute the stress Green's functions. Similar types of simulations have been developed by Ward (1992, 1996), Ward and Goes (1993), Goes and Ward (1994), Robinson (2004), Richards-Dinger and Dieterich (2008).

Loading of each fault segment occurs due to the accumulation of a slip deficit at the prescribed slip rate of the segment ("backslip model"). The vertical rectangular fault segments interact elastically. Earthquake initiation is controlled by friction coefficients along with the space- and time-dependent stresses on fault segments, which are computed by means of boundary element methods. To prescribe the friction coefficients, historical earthquakes are used that have moment magnitudes $m \geq 6.0$ in California during the last 200 years. A consequence of the fault segmentation is that the simulations do not generate earthquakes having magnitudes less than about $m \approx 5.8$. It is possible to construct simulated interferograms associated with major simulated earthquakes, which can be quantitatively compared to actual interferograms.

Earthquake Probabilities: To use simulations to compute earthquake probabilities, a method is in development that includes the following steps (Van Aalsburg et al., 2007): 1) A numerical simulation is carried out resulting in a "long" record of earthquake simulation data (typically 40,000 or more simulation years); 2) The actual past history of earthquakes (paleoseismology) is used to determine which of the 40,000 or more years of simulation data is "most similar" to today (e.g., 2009); 3) Using the top ~150 of these "optimal simulation times", the 30 years of simulation earthquakes following the optimal times are combined to produce a set of space- and time- statistical distributions; 4) These 30-year statistical distributions are used to compute earthquake probabilities during the 30-year interval from 2009 - 2039.

1.2.3. *OPERATIONAL CONCEPT ADDRESSING EARTH SCIENCE NEEDS*

In this end-to-end system users will be able to evaluate data, develop science models, produce improved earthquake forecasts, and respond to disasters in intuitive map-based interfaces. Fault models will be constrained and improved not just by geology, but also by feature identification from InSAR (UAVSAR) and inversions of both GPS and InSAR crustal deformation data (*Donnellan et al, 2002*, *Samsonov et al.*, 2008, *Wei et al,* 2010). Forecasting is improved by development of better interacting fault models and pattern analysis and fusion of both seismicity and crustal deformation data. By increasing the accessibility and utility of GPS, InSAR, and geologic data, this project will address current science challenges such as earthquake forecasting or fluid migration. It will also enable new observations by providing tools to conduct simulation experiments and new information products for use in a wide variety of fields ranging from earthquake research to earthquake response. The proposed work will enable new civil applications such as fluid migration related to aquifers, oil reservoirs, and CO_2 sequestration. Timely and affordable delivery of information to users in the form of high-level products is necessary for earthquake forecasting and emergency response, but it also necessary for exploiting crustal deformation data in new ways to enable new discoveries and uses.

1.2.4. *POSSIBLE CROSS-CUTTING OR COMMERCIAL BENEFITS*

QuakeSim forecasting methodology has already been successfully transferred and expanded on by the Open Hazards Group. In return, QuakeSim displays the Open Hazards forecasts on the QuakeSim web page. We plan to continue this successful technology transfer. There is an increased interest and expectation of using simulations for developing future Uniform California Earthquake Hazard Forecasts. QuakeSim team members are key members of the SCEC simulators group (co-investigator Terry Tullis chairs the group). The forecasts are used to set earthquake insurance rates for California, so there is a very real commercial benefit from the work accomplished under this task. We will also explore, with J-P Bardet the use of models for understanding oil shale and impacts of hydrofracturing. Infusing QuakeSim tools into the civil engineering community will take time, but the tools provide potential commercial benefit.

1.3. COMPARATIVE TECHNOLOGY ASSESSMENT

Development of a data-intensive computing infrastructure will provide a modeling and visualization environment to a broad geophysical community, which will support multiple data types without the need to download large data sets. Today, access to GPS, InSAR, faults models and seismicity are uncoordinated: large amounts of data must move to the investigator's computer, and integration into models is ad hoc. The state of the art for interacting-fault simulations centers on local efforts at the research group level, with comparisons taking place largely at infrequent workshops; the web-service based interface will allow public, independent verification and comparison of simulators and statistical forecast methods, feeding directly into regional hazard models. Current data discovery is ad hoc and likely to miss important elements of data fusion and cross validation: the ontology-based methods we develop will allow immediate discovery of topically or space-time related data. Rather than bringing all data to the user, our system will place substantial processing in cloud computing services close to original or mirrored data archives. By designing around the system from data to investigators, widespread use of enormous data collections such as gathered by DESDynI-R will be enabled, rather than ad hoc use by a small community of experts such as attends InSAR data today. It will be necessary to couple computing capabilities to the data storage using cloud computing approaches for management of very large data sets to be produced by DESDynI-R. Our prototype system will lay the foundation for the next generation of NASA's data management sites, with ASF and UNAVCO representing the current state of the art. The fault modeling connects the observational data sets to downstream simulation and forecasting techniques. To support this, we will enhance the fault cataloging services available in QuakeSim's QuakeTables to ingest, store, and deliver a much wider range of faults (from catalogs, generated automatically, from specific users) with the associated provenance and security tracking. A comparable system does not currently exist to support solid earth research.

1.4. TRL ASSESSMENT

This proposal contains new QuakeSim components with individual TRLs of 2. As shown in the milestones, we will have working prototypes by the end of Year 2 for the new components, bringing the TRL to 4. Our proposal goal is for new project components to be deployed in appropriate production environments (including ASF and UNAVCO) in the project's Year 4, bringing the final TRL for the new components to 5. Our primary success criteria will be deployment into production environments at ASF and UNAVCO.

1.5. RESEARCH MANAGEMENT PLAN

There are seven milestones in this project, and three technology infusion milestones (outlined later). We plan to lay the groundwork and develop working relationships throughout the project for successful infusion.

1) *Data provenance/trust and history tracking:* We will develop and deploy techniques to record the provider of a data product, as well as the date/time/method of entry. For some data, such as UAVSAR RPI data, processing history is retained for downstream interpretation, while aggregated collections like fault models the system will retain source and update history. We will provide for several levels of trust to match the generally level of reliability of the information.

   Success Criteria: Scientists can effectively utilize history and provenance information to improve the quality of modeling and forecasting.

2) *Review and update fault models and data:* include thrust faults and ingest UCERF3 faults: Compare fault models with those being used by other groups and if differences are found, determine if possible which are best, using all available data. Update and notify users when components change. Determine preferred models or use simulation to document trade-offs.

   Success Criteria: The above tasks are completed successfully, namely comparisons with data and other models are made, alterations are made if necessary, and the importance of model uncertainties on results are determined.

3) *Simulations statistical algorithm and interface:* link to backtest algorithms and deploy on QuakeSim portal: Using upgraded models from Virtual California and GeoFEST (including dipping faults) in simulations, we will assess leading statistical methods, including Optimal Simulation Times and Interval Statistics. This will lead to a public web-based interface that will enable independent verification and comparison of simulators and statistical forecast methods.

   Success Criteria: Public portal access to simulated interacting earthquake time series and statistical tools.

4) *Mirrored, secure Cloud storage connected with ASF:* Evaluate and implement best-fit Cloud Architecture: Storage models (BigTable, Azure Table Service, Whamcloud/Lustre, Amazon S3) and programming models (MapReduce, cloud workflows) for large data collections.

   Success Criteria: Reliable cloud-based storage acceptable to ASF and users of InSAR image data. Used in portal-based data processing to show change in deformation cross section for multiple time periods.

5) *Deploy "auto feed" out and from trusted sources:* Provide portal-based methods for QuakeSim managers, approved automatic data providers and trusted users to submit public data into the project database. Deliver data for browsing, anomaly alerts, and incorporation into simulations.

   Success Criteria: Submission of data by members of each of the trust categories, with the features stated above.

6) *High data rate multi source GPS time series analysis:* Extension of current data ingestion and processing to high data rate GPS sources. Quantities derived from these time series will link directly to the simplex inversion tool for estimation of geophysical source processes (such as fault slip or aquifer loading).

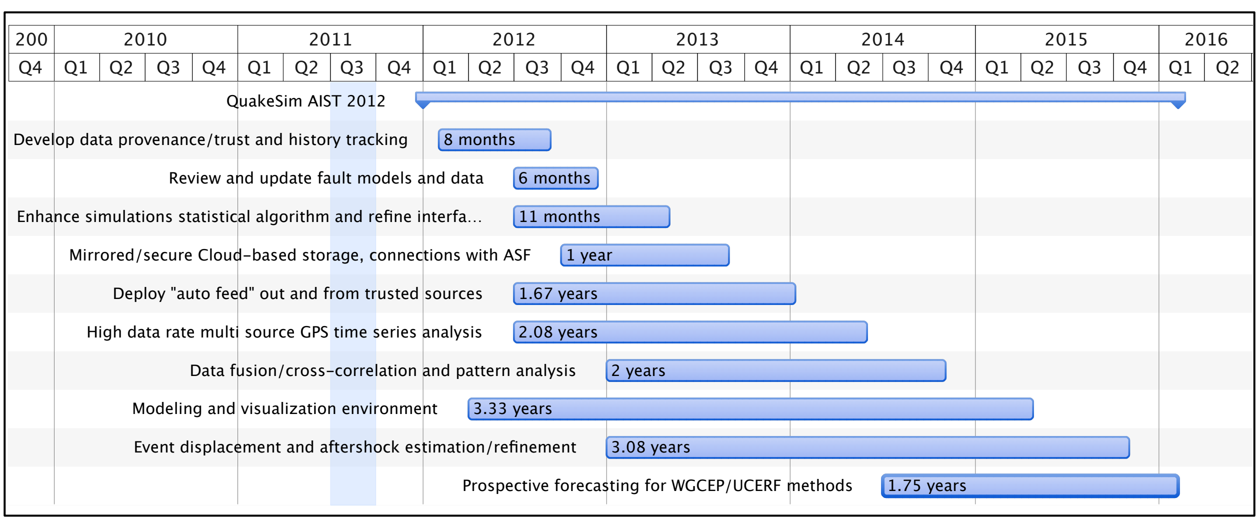
   Success Criteria: Display of pattern-recognition features in high-rate GPS data through the web portal, including single-station analysis and multiple-station highlighting of regional changes resulting in estimation of source processes.

7) *Data fusion/cross-correlation and pattern analysis:* We will implement ontology-based techniques to cross-correlate and connect various related data, whose relationships may be implicit. This will include semantic web techniques as well as pattern-based data mining. Consistency checks will be available by means of mechanical simulations (GeoFEST).

   Success Criteria: Example scientific studies are enhanced, or new studies are enabled by the cross-correlations make explicit in the QuakeSim federated database.

1.5.1. Milestone Schedule Chart

Table 2. Milestone chart showing activities and target end dates or milestones of the activities. Note that this chart includes the infusion activities.



1.6. PERSONNEL

Each team member brings a unique skill to the project and a long record of working together.

Investigator	Role	Experience	End User?
Andrea Donnellan	Principal Investigator	QuakeSim development; GPS and UAVSAR; modeling	Yes
Jay Parker	Model development	Finite element model development; InSAR and GPS analysis; inversion techniques; data subsetting	Yes
Robert Granat	Time Series Analysis	Expert in transient detection; Hidden Markov Modeling	Yes
Margaret Glasscoe	E-DECIDER PI	End-user infusion; HAZUS infusion	Yes
John Rundle	Simulations and forecasting	Spurred development in simulations and intermediate forecasting	Yes
Geoffrey Fox	Cloud computing	High-performance, grid, and cloud computing expert	
Marlon Pierce	Cloud computing and data access	Developed QuakeSim web services, science gateway, workflow expert	
Dennis McLeod	Database	Leader in federated data; data provenance; data access	
Lisa Grant	Geology and faults	Population and validation of fault database; seismic hazard analysis	Yes
Terry Tullis	Simulations	Chair of SCEC Simulators Group; Chair of NEPEC	Yes

1.7. FACILITIES AND EQUIPMENT

Each of the institutions on the project has a network of computers that will be used. Standard computers are needed and are available for the work at each of the institutions. We are making use of University of Southern California's virtual storage system and are migrating our data there. We have access to the NASA Ames high performance computers, the JPL computer cluster, and the NSF XSEDE. The portal and cloud computing work will be carried out on Indiana University and University of Southern California machines. Indiana University's Community Grids Laboratory maintains a heterogeneous network-computing environment to support the lab's development and research efforts. The review and update of geologic data integration work for this project will be done at UC Irvine at Grant's Environmental Geology and GIS Laboratory. The UCI campus and the School of Social Ecology have licenses for standard office software and GIS database software.

1.8. SPECIAL MATTERS

The amount and sources of crustal deformation and fault data have burgeoned since QuakeSim's inception in 2001 and are expected to continue to do so. The user base has also grown, and methods for assessing earthquake hazards are growing to include simulations in addition to geologic data. During our past projects we have successfully attracted a diverse set of users through training and conference participation. For example, GeoFEST is available through Open Channel Software and has been downloaded over 200 times.

1.9. Quad Chart

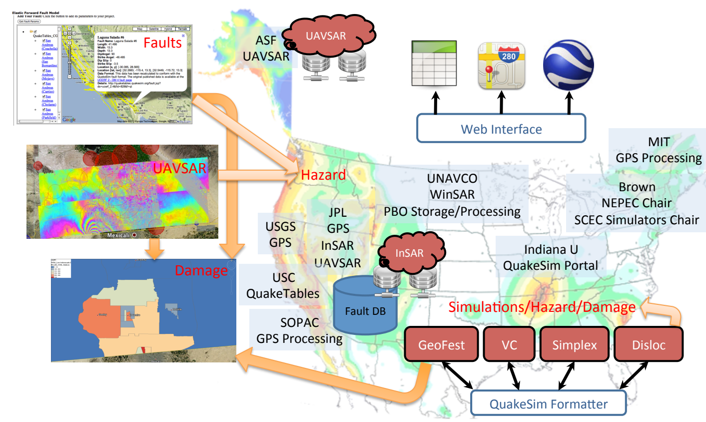
QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science

PI: Andrea Donnellan, JPL

Objectives

- Extend infrastructure to support fault modeling with a focus toward earthquake forecasting and response
- Integrate varied data sources to support comprehensive efforts in data mining, analysis, simulation, and forecasting
- Infuse improved fault models in earthquake hazard assessment and forecasts
- Deliver tools to emergency response and civil engineering community

Operational Concept:



Approach

- Develop bridging services to integrate multi-source data
- Develop cloud computing framework to support fault model optimization through the integration of multiple data types
- Develop cyberinfrastructure to handle the computing requirements of the optimization framework
- Integrate model contribution, provenance, version tracking, commenting, rating, etc. of fault models produced by the optimization framework

Co-Is/Partners:

J. Parker, R. Granat, M. Glasscoe, JPL; J. Rundle, UC Davis; L. Grant, UC Irvine; D. McLeod, USC; G. Fox, M. Pierce, Indiana U; T. Tullis, Brown U

Key Milestones

• Data provenance/trust and history tracking	08/12
• Review and update fault models and data	07/09
• Simulations statistical algorithm and interface	04/10
• Mirrored, secure Cloud storage connected with ASF	07/10
• Deploy "auto feed" out and from trusted sources	09/10
• High data rate multi source GPS time series analysis	04/11
• Data fusion/cross-correlation and pattern analysis	08/11
• Prospective forecasting for WGCEP/UCERF methods	11/11
• Event displacement and aftershock estimation/refinement	11/11
• Modeling and visualization environment	11/11

TRL_{in} = 2

ESTO Earth Science Technology Office

08/11

2. TECHNOLOGY INFUSION OPTION FOR EARTH SCIENCE APPLICATION

Our infusion activities are multifold with a general breakdown between earthquake forecasting, earthquake response, and development of tools for civil applications. The forecasting will feed into the Uniform California Earthquake Rupture Forecast models led by Ned Field at the US Geological Survey (see letter of support) with Terry Tullis acting as the liaison, both as Chair of the Southern California Earthquake (SCEC) Simulators Group and as the National Earthquake Prediction Evaluation Council (NEPEC). Lisa Grant is vice-chair of the SCEC Board of Directors and will also facilitate infusion. Response will focus on development of high-level data products that can be served through E-DECIDER to the end user community (led by Margaret Glasscoe with a product advisory board). For response, we will also focus on rapidly providing displacement maps and estimates of future aftershock in concert with the USGS early warning development efforts led by Elizabeth Cochran. QuakeSim develops tools to separate fluid from tectonic motions and, as such, can be used for understanding fluid motions at depth. Jean-Pierre Bardet who is currently chair of the Civil Engineering Department at the University of Southern California, and soon will be the Dean of Engineering at University of Texas, Arlington will be the liaison for using QuakeSim tools for various reservoir and fluid motion projects. Development of standards and data access is necessary for our infusion activities to be successful and so we partner with the UAVSAR DAAC at the Alaska Satellite Facility (Don Atwood) and UNAVCO (Charles Meertens) for GPS products and services. These are required for both research and infusion tools. We address the Disaster Program within NASA Applied Sciences.

2.1. DESCRIPTION OF PROPOSED INFUSION

We will enable infusion of modern cloud techniques, developed under this project, into the applications of forecasting, response, and civil infrastructure. We will provide a rich data access, usage, delivery, preservation, and tracking functionality for the key datatypes we support. By doing so we will change the fundamental architecture of forecasting and response systems increasing the capability and cost-effectiveness of computing support.

Development of our system will be accomplished in concert with the end-users and with a product development board. Membership of the board will be from local, state, and federal emergency responders and will be guided by Bruce Davis from Department of Homeland Security (see attached letter of support). We will develop and test our integrated system by participating in the SCEC Simulators Group and other SCEC or national earthquake forecasting activities. For response we will participate in state and federal earthquake exercises such as the National Level Exercise (NLE) and the ShakeOut. We will automate our output and will develop routine tasks to be accomplished for all sizes of earthquakes so that when large earthquakes occur the workflow process is already established and functional.

Our civil engineering application highlights the cross-cutting benefit of our system. Tools developed to separate fluid motions from the tectonic motions of interest can be used to model reservoirs in their own right. With an increased emphasis of applications for the DESDynI-R mission water it is important to have tools that address these applications such as ground-water migration and carbon sequestration. QuakeSim tools will also help with loss of life and property by supporting both mitigation and response activities. The Open Hazards Group is a spin-off company of QuakeSim highlighting the commercial benefits of this project.

Table 3. Decision making activities and the end users.

Decision Making Activity	Topic/Issue Served	End-User Organizations	End-User Responsibility
Earthquake Forecasting	Mitigation of loss of life and property from earthquakes	USGS Earthquake insurers DHS Infrastructure Protection	Establishing estimates of earthquake hazards Used for mitigation and setting earthquake rates
Earthquake Response	Damage estimation Aftershock probabilities	USGS FEMA Other emergency responders	Aftershock estimates Damage estimates Prioritization of response and resources
Fluid in reservoirs	Water management Resource management	LADWP Metropolitan Water District County/city DOE for Carbon Sequestration	Water management Impact of oil withdrawal Stability of sequestration

2.1.1. Forecasting: The Working Group on California Earthquake Probabilities

The Uniform California Earthquake Rupture Forecast (UCERF) models for the USGS draw heavily on expertise and data from the geology community. Future versions UCERF will incorporate simulators, which at minimum allow for implementation of elastic-rebound based probabilities. A question to be addressed before simulators can be incorporated into the UCERF models is whether they can reliably model the multi-fault rupture possibilities given uncertainties in the fault endpoints. The UCERF-3 Grand Inversion will use expert opinion for this based on analysis of: 1) higher resolution fault maps; 2) micro-seismicity distribution; 3) statistics from global empirical data; 4) static stress change analysis; and 5) dynamic rupture modeling. Simulation results will be included as an appendix in the next UCERF report (UCERF-3). Continued development of techniques will continue for incorporating simulators into future models. A key to incorporating simulations into hazard models is to analyze, visualize, and compute hazard from simulator results.

A project related to this proposed work is underway under the sponsorship of the Southern California Earthquake Center (SCEC). This SCEC Earthquake Simulators Comparison Project is conducted as a Technical Activity Group (TAG). Terry Tullis is the leader of this TAG. The project involves testing and improving a variety of earthquake simulators, computer codes that are capable of generating long histories of earthquake occurrence on complex fault systems such as those in California. The testing involves comparisons between the results of five different earthquake simulators and between these simulator results and what is known about actual earthquake histories in California from instrumental, historic, and paleoseismic data. The fault geometry and fault slip rates used by these earthquake simulators is that created by the SCEC

Working Group on California Earthquake Probabilities (WGCEP) that has created a series of Uniform California Earthquake Rupture Forecasts (UCERF).

Earthquake insurance rates in California are set through a complex process involving the California Earthquake Authority, a public-private consortium of insurance companies and the state of California; commercial damage-and-loss modeling companies; and the Working Group on California Earthquake Probabilities ([8] WGCEP07). The latter produces the official forecast of 30-year earthquake risk for use in setting the insurance rates. California law mandates that the California Earthquake Authority (CEA) use the best available science in setting earthquake insurance rates. The CEA uses the UCERF reports to set those rates. Up until now earthquake simulators have not been used in producing the UCERF reports, but as a result of recent progress made in the Earthquake Simulators Comparison Project it is likely that they will be used in future UCERF reports. A variety of tools for plotting the results of the earthquake simulators have been created to date as part of the SCEC TAG work, but more are needed. For example, additional tools for visualizing the results of the simulations that are being and/or could be produced by the QuakeSim group would be of value to the earthquake simulation activities. This could include hazard maps depicting the probabilities of earthquakes of various magnitudes in California based on the earthquake simulation results.

The UCERF framework has a sequence of four model types: a fault model that gives the physical geometry of the larger, known faults; a deformation model that gives slip rates and aseismicity factors to each fault section; an earthquake rate model that gives the long-term rate of all earthquakes of magnitude five or greater ($M \geq 5$) throughout the region; and a probability model that gives a probability of occurrence for each earthquake during a specified (future) time interval. Time dependence of probabilities is introduced both by traditional Poisson models, as well as statistical renewal models. The result is a set of Poisson probabilities for the occurrence of earthquakes with $M \geq 6.7$ over the next 30 years, the length of time for an average US fixed-rate home mortgage. A Poisson probability P(t) is determined by computing the 30-year rate of occurrence λ of events having $M \geq 6.7$, i.e., $P(t) = 1 - e^{-\lambda t}$.

There are major differences between the simulation-based probabilities and the statistical probabilities given by the WGCEP07. With simulations such as VC, it is not necessary to prescribe a probability distribution of inter-event times. The major difference between the two methods lies in the way in which inter-event times and probabilities for joint failure of multiple segments are computed. In the simulation approach, these times and probabilities come from the modeling of fault interactions through the inclusion of basic dynamical processes in a topologically realistic model. In the WGCEP07 and earlier statistical approach, times and probabilities are embedded in the choice of an applicable probability distribution function, as well as choices associated with a variety of other statistical weighting factors describing joint probabilities for multi-segment events.

2.2. Earthquake Response: Damage and Aftershock Assessment

Emergency responders need to know where and how large an event is. In the case of earthquakes it is very important to understand aftershock probabilities in order to take special precautions in vulnerable structures. Products must be understood intuitively as responders do not have time to fight a steep learning curve. We will provide the tools to access multiple sources of data in higher level data product formats for easy use by emergency responders in the field and in operations centers.

2.3. CIVIL APPLICATIONS: FLUID FLOW IN RESERVOIRS

Deformation monitoring and modeling based on GPS observations is maturing as an accepted technique (for example Szostak-Chrzanowski, 2005). Time series for several stations surrounding the recently filled Diamond Valley Lake near Hemet, California are part of the Plate Boundary Observatory data included in our system, and also within the target area of regular UAVSAR flights. Station response to fluctuating lake levels constrain models of both dam rigidity and shallow crust mechanical properties.

2.4. TRL ASSESSMENT

Our entry level TRL is 2. By the time this project is complete we anticipate to be at TRL 7. We will have a prototype system in an operational environment. Putting the results of the simulations into an appendix of UCERF-3 is essentially this. If the simulations prove very successful then the actual system will be completed and qualified through test and demonstration in an operational environment through the UCERF-4 (or above) model, bringing the TRL to 8 for forecasting. We anticipate a TRL or 7-8 for the response portion as well. For infusion into civil applications we expect to have a prototype system complete in an operational environment or a TRL of 7.

2.5. INFUSION MANAGEMENT PLAN

We will accomplish the infusion by including infusion team members in QuakeSim activities from the inception of this project. We will develop a product advisory board made up of state, local, and federal users. Our milestones are:

1) *Prospective forecasting for WGCEP/UCERF methods:* define success criteria using reliability and ROC tests: Forecasts based on simulated seismicity are made and are tested within a framework such as that of the Collaboratory for the Study of Earthquake Predictability (CSEP) presently being run by the Southern California Earthquake Center, including true prospective tests and pseudo prospective tests. Attempt to produce time-dependent forecasts based on simulations and on recent earthquake history and test these prospectively within CSEP.

   Success Criteria: Forecasts are entered into CSEP testing. If the forecasts are found to have skill relative to meaningful null hypotheses, the success of this milestone will be taken to be extremely significant, although the time required to determine this for prospective testing may exceed the grant period.

2) *Event displacement and aftershock estimation/refinement:* With low latency, automatically integrate displacement data into the earthquake-local model. When a significant event occurs, estimate deformation, estimate locations of future aftershocks, steer data collection, refine deformation, define damage zone, refine aftershock assessment

   Success Criteria: If no major-event data is available close to the milestone, ingest simulated data (or data saved from a past event) into the system and produce the data products listed above. Opportunistically take advantage of any real events to produce automated data products that update the local hazard picture.

3) *Modeling and visualization environment:* Develop and deploy a finite element modeling component for the web-environment investigation system. We will design and implement web service-appropriate integrated mesh generation, solution iteration with refinement,

solution reporting on user-defined subdomains, and interactive visualization of stress, oriented Coulomb stress, strain energy, and displacement, displayed as map overlays.

Success Criteria: A working example is designed and run through the web environment, such as a Central US New Madrid sequence simulation. Visualization options include display of principal axis coulomb stress and synthetic interferograms.

2.6. Personnel

Additional team members will serve to ensure infusion of QuakeSim capabilities developed under this work. They are all listed as collaborators on this proposal. The main team will carry out the work to complete the infusion. Informal conversations have started with each of these investigators prior to the inception of this proposal, suggesting a need for infusion. We plan to work with these collaborators from the beginning of the project, though the fourth year will hold particular emphasis on ensuring that the infusion is successful.

The main project, during the first three years, will focus on the technical challenges of handing large distributed datasets. The focus in the fourth year with the personnel listed here will be on integrating the components into the end user applications. In the case of UNAVCO and the Alaska Satellite Facility the infusion is bidirectional. QuakeSim will make use of GPS and InSAR data products and the interchange will ensure transfer of relevant QuakeSim technologies out, but will also ensure that QuakeSim services will be able to access the data products from the two facilities.

Collaborator	Role	Experience	End User?
Terry Tullis	Co- Investigator	Chair of SCEC Simulators Group; Chair of NEPEC	Yes
Elizabeth Cochran	QuakeCatcher PI USGS	Early warning, deformation and aftershock probability refinement	Yes
Don Atwood	Alaska Satellite Facility Chief Scientist	Role is to ensure interactions between science users and ASF and will facilitate interchange with the UAVSAR DAAC and QuakeSim applications	Yes
Charles Meertens	UNAVCO	Web services, and GPS data services	Yes
Margaret Glasscoe	E-DECIDER PI	Infusion of QuakeSim output to HAZUS via PESH files	Yes
Jean-Pierre Bardet	Civil Engineering	Expertise in fluid flow in reservoirs and interested in civil infrastructure	Yes

2.7. Facilities and Equipment

There are no changes in facilities or equipment of the infusion part of the work.

2.8. Special Matters

We have added team members to accomplish our infusion goals. We also plan to establish a product advisory board to ensure broad application and use of QuakeSim tools and products.

3. REFERENCES AND CITATIONS

Anthes, R.A., B. Moore III, et al., *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, National Research Council Committee on Earth Science and Applications from Space, National Academies Press, 11820, (2007).

Aydin, G., Qi, Z. Pierce, M.E., Fox, G. C., Bock, Y., "Architecture, performance, and scalability of a real-time global positioning system data grid," *Phys. Earth Planet. In.*, **163**, 347-359, DOI: 10.1016/j.pepi.2007.04.012 (2007).

Bégin, M-E., "An EGEE comparative study: Grids and clouds Evolution or revolution?," in EGEE Document Series. (2008).

Donnellan, Andrea., B. H. Hager, and R. W. King, "Discrepancy between geologic and geodetic deformation rates in the Ventura basin," *Nature,* 366, 333–336, (1993)

Donnellan, A., Parker, J.W. and Peltzer, G., Combined GPS and InSAR models of postseismic deformation from the Northridge earthquake, *Pure Appl. Geophys.*, **159**, 2261-2270 (2002)

Ekanayake, J, Thilina Gunarathne, and Judy Qiu, "Cloud Technologies for Bioinformatics Applications," *IEEE Trans. Parallel and Distr. Sys.* **22**(6): 998-1011. DOI:10.1109/TPDS.2010.178 (2009)

Ekanayake, J., H.Li, B.Zhang, T.Gunarathne, S.Bae, J.Qiu, and G.Fox, "Twister: A Runtime for iterative MapReduce," *Proceedings of the First International Workshop on MapReduce and its Application*, ACM Chicago, Illinois. (2010)

Ericson, K, Shrideep Pallickara, and C. W. Anderson, "Analyzing Electroencephalograms Using Cloud Computing Techniques," *2010 IEEE Second International Conference on Cloud Computing Technology and Science (CloudCom)*, 185-192, DOI: 10.1109/CloudCom.2010.80.

Goes, S. D. B. and Ward, S. N. "Synthetic seismicity for the San Andreas fault," *Ann. Geofisica* **37**, 1495-1513 (1994).

Granat, R., G. Aydin, M. Pierce, Z. Qi, and Y. Bock, Analysis of streaming GPS measurements of surface displacement through a web services environment, *Proc. IEEE Symposium on Computational Intelligence and Data Mining*, 2007.

Jackson, R. Lavanya Ramakrishnan, Karl J. Runge, and Rollin C. Thomas, "Seeking supernovae in the clouds: a performance study," *Proceedings of the 19th ACM International Symposium on High Performance Distributed Computing*. ACM. Chicago, Illinois. 421-429. DOI: 10.1145/1851476.1851538. (2010)

Murray-Moraleda, J. R. and Lohman, R.,"Workshop Targets Development of Geodetic Transient Detection Methods," *EOS Trans.*, **91,** 58-59, DOI: 10.1029/2010EO060008, (2010).

Pireddu, L, Simone Leo, and Gianluigi Zanetti, "MapReducing a Genomic Sequencing Workflow," *MapReduce 2011* (2011).

Robinson, R., Zhou, S., Johnston, S., Vere-Jones, D., "Precursory accelerating seismic moment release (AMR) in a synthetic seismicity catalog: A preliminary study," *Geophys. Res. Lett.* 32 L07309, doi: 10.1029/2005GL022576 (2005)

Rundle, J. B. “A physical model for earthquakes. 2. Application to Southern California,” *J. Geophys. Res.* **93**, 6255-6274 (1988).

Rundle, P. B., Rundle, J. B., Tiampo, K. F., SÁ Martins, J. S., McGinnis, S., and Klein, W. (2001), “Nonlinear network dynamics on earthquake fault systems,” *Phys. Rev. Lett.* 148501 (2001).

Rundle, J. B., Tiampo, K. F., Klein, W., & Sa Martins, J. S. “Self-organization in leaky threshold systems: The influence of near-mean field dynamics and its implications for earthquakes, neurobiology, and forecasting.” *Proc. Nat. Acad. Sci.* **99**, 2514-2521 (2002).

Rundle, J. B., Rundle, P. B., Donnellan, A., and Fox, G. C., “Gutenberg-Richter statistics in topologically realistic system-level earthquake stress-evolution simulations,” *Earth Planets Space* ***56***, 761-771 (2004).

Rundle, JB, PB Rundle, A Donnellan, D Turcotte, R Shcherbakov, P Li, BD Malamud, LB Grant, GC Fox, D McLeod, G Yakovlev, J Parker, W Klein, KF Tiampo, “A simulation-based approach to forecasting the next great San Francisco earthquake,” *Proc. Nat. Acad. Sci.,USA* **102**, 15363-15367 (2005)

Samsonov, S, KF Tiampo and JB Rundle, Application of DInSAR-GPS optimization for derivation of three-dimensional surface motion of the southern California region along the San Andreas fault, *Cmptrs. & Geosci*., **34**, 503-514 (2008)

Segall, P., and M. Matthews, "Time dependent inversion of geodetic data," *J. Geophys. Res*., **102**, 22,391– 22,400, 1997.

Simons, M., Minson, S. E., Sladen, A., Ortega, F., Jiang, J., Owen, S. E., Meng, L. Ampuero, J-P., Wei, S., Chu, R., Helmberger, D. V., Kanamori, H., Hetland, E., Moore, A. W., Webb, F. H., “The 2011 Magnitude 9.0 Tohoku-Oki Earthquake: Mosaicking the Megathrust from Seconds to Centuries,” *Science* **17** 1421-1425. DOI:10.1126/science.1206731 (2011)

Stein, L., “The case for cloud computing in genome informatics,” *Genome Biology*,. **11**(5): 207. http://genomebiology.com/2010/11/5/207(2011).

Szostak-Chrzanowski, Anna, Adam Chrzanowski, Michel Massiera, "Use of deformation monitoring results in solving geomechanical problems--case studies," *Engineering Geology*, **79**, 3-12,DOI: 10.1016/j.enggeo.2004.10.014, (2005).

Ting, J.-A., Theodorou, E., Shaal, S., "A Kalman filter for robust outlier detection," IEEE/RSJ International Conference on Intelligent Robots and Systems, DOI: 10.1109/IROS.2007.4399158 (2007).

Tuzel, Oncel, Fatih Porikli, Peter Meer, "Pedestrian Detection via Classification on Riemannian Manifolds," *IEEE Trans. Pattern Analysis and Machine Intelligence*, 1713-1727, (2008).

Van Aalsburg, J, LB Grant, G Yakovlev, PB Rundle, JB Rundle, DL Turcotte and A Donnellan, “A feasibility study of data assimilation in numerical simulations of earthquake fault systems,” *Phys. Earth. Planet. Int.* , **163**, 149-162 (2007).

Ward, S. N. “An application of synthetic seismicity in earthquake statistics: The middle America trench.” *J. Geophys. Res*. **97**, 6675-6682 (1992).

Ward, S. N., and Goes, S. D. B. "How regularly do earthquakes recur? A synthetic seismicity model for the San Andreas Fault," *Geophys. Res. Lett.* **20** 2131-2134 (1993)

Ward, S. N. "A synthetic seismicity model for southern California: Cycles, probabilities, and hazard," *J. Geophys. Res.* **101**, 22,393-22,418 (1996).

Wei, M, D Sandwell and B Smith-Konter, Optimal combination of InSAR and GPS for measuring interseismic crustal deformation, *Adv. Space Res*., **46**, 236-249 (2010).

4. Biographical Sketches

4.1. Andrea Donnellan

Education

Ph.D., Geophysics, California Institute of Technology (1991)
M.S., Computer Science, University of Southern California (2003)
M.S., Geophysics, California Institute of Technology (1988)
B.S., Geology, Ohio State University, *with honors and distinction in geology* (1986)

Professional Experience

Jet Propulsion Laboratory (1993 – present)
- QuakeSim Principal Investigator (2001–present)
- NASA HQ Program Area Co-Lead for Natural Disasters (2009–2011)
- Lead Scientist, InSAR, (2005–2007); DESDynI pre-project scientist (2007–2008)
- Deputy Manager, Science Division (2002–2006)
- Deputy Manager, Exploration Systems Autonomy Section (2000-2002)
- Principal Researcher, Inf. and Comp. Science, Adv. Technology R&D (2000-2000)
- Supervisor, Data Understanding Systems Group (1999–2001)
- Senior Researcher, Inf. and Comp. Science, Adv. Technology R&D (1999-2000)
- Research Scientist, Satellite Geodesy and Geodynamics Systems Group (1997–1999)
- Memb. of Tech. Staff, Satellite Geodesy and Geodynamics Sys. Group (1993–1997)

Res. Prof., Dept. of Earth Sciences, University of Southern California (1999–present)
Visiting Assoc., Seism. Laboratory, California Institute of Technology, (1995–1996)
Nat. Res. Council Postdoctoral Fellow, NASA Goddard Space Flight Center (1991–1993)
Graduate Research Assistant, California Institute of Technology (1986–1991)
Ohio State University
- Research Assistant, Institute of Polar Studies, Ohio State University (1983–1986)
- Thin Section Laboratory Technician, Ohio State University (1983)

Geochemistry Group, Sohio Research and Development (1985)

Relevant Experience

NASA HQ Program Area Co-Lead for Natural Disasters (2009–2011)
Nat. Acad. of Sci. Spatial Data Enabling USGS Strategic Science in the 21st Cent. comm.
InSAR/DESDynI Study/Pre-Project Scientist (2005–2008)
US Rep. to the Int. Sci. Board of the APEC Coop. on Earthquake Sim.(2000–present)
Global Geodetic Observing System (GGOS) Science Panel Member (2006-present)
Convener NASA Earth Obs. Missions Applications Workshop (Colorado Springs, 2010)
Convener DESDynI Applications Workshop (Sacramento, 2008)

Awards

GeoFESTv.4.8 NASA Space Act Award (2009)
MUSES California Science Center Foundation, Woman of the Year (2006)
NASA Space Act awards for QuakeSim, Simplex, and Disloc (2005)
Women at Work Medal of Excellence (2004)
Team bonus award for QuakeSim Parallel GeoFest development (2004)
NASA Space Act Award for GeoFESTv.4.3 finite element software (2004)
Women in Aerospace Award for Outstanding Achievement (2003)
JPL Lew Allen Award for Excellence (2000)
Southern California Earthquake Center Outreach Award for Education (1998)

Presidential Early Career Award for Scientists and Engineers (1996)
National Research Council Postdoctoral Fellowship (1991–1993)
Outstanding Student Paper Award, Geodesy Section, Fall AGU Meeting (1990)
Amoco Scholarship (1985)
Undergraduate Research Scholarship, Ohio State University (1985–1986)
Ohio State University Field Camp Scholarship (1985)
Outstanding Student Award, Ohio State University Field Camp (1985)
Antarctic Service Medal (1985)
Ohio State University Geology Book Award (1985)

Publications

[1] Van Aalsburg, J, L.B Grant, P.B. Rundle, G. Yakovlev, J.B. Rundle, D.L. Turcotte, **A. Donnellan**, K.F. Tiampo, J. Fernandez-Torres, I. Dobson, Space- and time- dependent probabilities for earthquake fault systems from numerical simulations: Feasibility study and first results, *PAGEOPH*, 167, 967-977, 2010.

[2] Parker, J.W., **A. Donnellan**, Impact of InSAR Sampling Interval on Discrimination of Postseismic Processes, in revision.

[3] Glasscoe, M.T., R.A. Granat, J.B. Rundle, P.B. Rundle, **A. Donnellan**, L.H. Kellogg, Analysis of emergent fault element behavior in Virtual California, *Concurrency and Computation: Practice and Experience*, 9999, 1532-0626, 2009.

[4] Van Aalsburg, J, L.B Grant, P.B. Rundle, G. Yakovlev, J.B. Rundle, D.L. Turcotte, **A. Donnellan**, K.F. Tiampo, J. Fernandez-Torres, I. Dobson, Space- and time- dependent probabilities for earthquake fault systems from numerical simulations: Feasibility study and first results, *PAGEOPH*, in press, 2009.

[5] Plag, H-P, Z. Altamimi, S. Beddatpur, G. Beutler, G. Beyerle, A. Casanave, D. Crossley, **A. Donnellan**, R. Forsburg, R. Gross, J. Hinderer, A. Komjathy, C. Ma, A.J. Mannucci, C. Noll, A. Nothnagel, E.C. Pavlis, M. Pearlman, P. Poli, U. Schreiber, K. Senior, P.L. Woodworth, S. Zerbini, C. Zuffada, The Goals, Achievements, and Tools of Modern Geodesy, chapter in Global Geodetic Observing System, Meeting the Requirements of a Global Society on a Changing Planet in 2020, H-P. Plag, and M. Pearlman, eds., Springer-Verlag, Berlin Heidelburg, 2009.

[6] Parker J., Lyzenga G., Norton C., Zuffada C., Glasscoe M.), Lou J., **Donnellan A.**, Geophysical finite-element simulation tool (GeoFEST): Algorithms and validation for quasistatic regional faulted crust problems, *PAGEOPH*, 165, 497-521, 2008.

[7] Holliday, J.R., C.C. Chen, K.F. Tiampo, J.B Rundle, D.L. Turcotte, **A. Donnellan**, A RELM earthquake forecast based on pattern informatics, *Seismological Res. Lett.* 78, 87–93, 2007.

[8] **Donnellan, A.**, and B. Luyendyk, GPS Evidence for a Coherent Plate and for Postglacial Rebound in Marie Byrd Land, West Antarctica, *Global and Planetary Change*, 42, 305–311, 2004.

[9] **Donnellan, A.**, J. Parker, and G. Peltzer, Combined GPS and InSAR models of postseismic deformation from the Northridge earthquake, *PAGEOPH*, 2261–2270, 2002.

[10] Granat, R., and **A. Donnellan**, Deterministic annealing hidden Markov models for geophysical data exploration, *PAGEOPH*, 2271–2284, 2002.

4.2. JAY W. PARKER

RELEVANT EXPERIENCE

26 years R&D of diverse numerical methods for geophysics simulations. Software engineer and co-I for QuakeSim. Assisted in DESDynI mission science definition analysis. Major coauthor of GeoFEST crustal finite element application, Simplex data inversion code, SEASCRAPE atmospheric inversion of infrared lines; also contributed to GIPSY GPS analysis package and electromagnetic scattering simulators.

Education:

Ph.D., Electrical Engineering (1988) University of Illinois, Urbana.
M.S., Electrical Engineering (1986) University of Illinois, Urbana.
B.S., E. E. with honors (1981) California Institute of Technology.
Professional Experience:
Current Positions:
1989–: Scientific Applications Software Engineer, Geodynamics and
Space Geodesy Group, JPL

Previous Positions:

1996–2009: Senior Scientist (part-time), RSA Systems Inc., Altadena CA

PROFESSIONAL ACTIVITIES:

APEC Cooperation for Earthquake Simulation, Chair of
Data Understanding and Assimilation working group (2001-)
American Geophysical Union

AWARDS: NASA Tech brief Award "Geodetic Strain Analysis Tool"
NASA Board Act Award, 2008 – GeoFEST v4.8 –
NASA Space Act Award, 2004 – Simplex – NASA NTR 41078

Refereed Publications

Baxter, S. C., Kedar, S., Parker, Jay W., Webb, Frank H., Owen, S. E., Sibthorpe, A., Dong, D. (2011), Limitations of strain estimation techniques from discrete deformation observations, Geophy. Res. Lett., 38, L01305, doi:10.1029/2010GL046028

J. Parker, C. Norton and Lyzenga, G. (2010), Parallel GeoFEST for regional faulted deformation. Concurrency and Computation: Practice and Experience, 22: 1604–1625. doi: 10.1002/cpe.1511

J. Parker, G. Lyzenga, C. Norton, C. Zuffada, M. Glasscoe, J. Lou, A. Donnellan,. Geophysical Finite Element Simulation tool (GeoFEST): algorithms and validation for quasistatic regional faulted crust problems, Pure Appl. Geophys. 165, 497-521, 2008.

A. Donnellan, J. Rundle, G. Fox, D. McLeod, L. Grant, T. Tullis, M. Pierce, J. Parker, G. Lyzenga, R. Granat, M. Glasscoe (2006), QuakeSim and the Solid Earth Research Virtual Observatory, *Pure Appl. Geophys, 163*, 2263-2279.

J. Parker , Lyzenga G., , Donnellan A., Judd M, Baker T, Norton C, Tisdal1 E, Li P (2004),Using the GeoFEST faulted region simulation system, *ACES 4th Meeting Proceedings*, Beijing China July 9-14.

4.3. ROBERT A. GRANAT

Jet Propulsion Laboratory, Mail Stop 306-463
4800 Oak Grove Drive, Pasadena, CA 91109
818-393-5353 *Robert.Granat@jpl.nasa.gov*

Education

University of California, Los Angeles, Los Angeles, CA
Ph.D. Electrical Engineering (Signal Processing), June 2004.
University of California, Los Angeles, Los Angeles, CA
M.S. Electrical Engineering (Signal Processing), October 1998.
California Institute of Technology, Pasadena, CA
B.S. Engineering and Applied Science (Computation and Neural Systems), March 1996.

Experience

Jet Propulsion Laboratory, Pasadena, CA
Group Supervisor, Machine Learning and Instrument Autonomy Group (2008-present)
Senior Research Staff (2000-present)
Research Staff (1996-2000)

Selected Relevant Publications

Granat, R. and A. Donnellan, GPS Time Series Analysis of Southern California Associated with the 2010 M7.2 El Mayor/Cucapah Earthquake, *Earthscope National Meeting,* Austin, TX, 2011.

Granat, R., B. Moghaddam, S. Owen, X. Gao, Y. Ma, M. Pierce, and A. Donnellan, Analysis of 30-Minute Resolution GPS Time Series from the Tohoku-Oki Earthquake via Statistical Modeling, *9th ACES Int'l Workshop*, Maui, HI, 2011.

Granat, R., D. Dong, S. Kedar, J. W. Parker, and B. Tang, Detection and Characterization of Transient Deformation in GPS Data, *American Geophysical Union Fall Meeting*, San Francisco, CA, 2009.

Granat, R. A., X. Gao, M. Pierce, The QuakeSim Web Portal Environment for GPS Data Analysis, *Workshop on Sensor Networks for Earth and Space Science Applications*, April, 2009.

Granat, R., M. Pierce, X. Gao, and Y. Bock, Change and Anomaly Detection in Real-Time GPS Data, *American Geophysical Union Fall Meeting*, San Francisco, CA, 2008.

Granat, R., G. Aydin, M. Pierce, Z. Qi, and Y. Bock, Analysis of streaming GPS measurements of surface displacement through a web services environment, *Proc. IEEE Symposium on Computational Intelligence and Data Mining*, 2007.

Granat, R., Support vector machines for short term earthquake forecasting, *Seismological Research Letters*, 78 (2), pp. 244, 2007.

Granat, R., Detecting Regional Events via Statistical Analysis of Geodetic Networks*, Pure and App. Geophys.*, 163 (11-12), pp. 2497-2512, 2006.

Baker, T., R. Granat, and R. W. Clayton, Real-time Earthquake Location Using Kirchhoff Reconstruction, *Bulletin of the Seismological Society of America*, 95(2), pp. 699-707, 2005.

Granat, R. A., A Method Of Hidden Markov Model Optimization For Use With Geophysical Data Sets, *Comp. Sci.*, 2659, pp. 892–901, 2003.

Granat, R. A. and A. Donnellan, A Hidden Markov Model Based Tool For Geophysical Data Exploration, *Pure and App. Geophys.*, 159, 10, pp. 2271–2283, 2001.

4.4. MARGARET T GLASSCOE

Margaret Glasscoe is a Science Researcher in the Solid Earth Group at the Jet Propulsion Laboratory. She is the Principal Investigator of the E-DECIDER (Earthquake Data Enhanced Cyber Infrastructure for Disaster Evaluation and Response) project, a NASA decision support effort to provide rapid remote sensing and modeling results to disaster managers and responders following earthquakes. She has experience working with a number of modeling codes, including viscoelastic finite element models (GeoFEST). Her research includes modeling deformation of the Earth's crust to study postseismic response to large earthquakes, numerical models of the rheological behavior of the crust, and simulations and analysis of interacting fault systems.

Education

M.S., Geology, University of California, Davis (2003)

B.S., Geological Sciences, University of Southern California, *Magna Cum Laude* (1997)

B.A., Print Journalism, University of Southern California, *Magna Cum Laude* (1997)

Professional Experience

Jet Propulsion Laboratory

Science Researcher (Geophysicist), Solid Earth Group, 2004-present

Member of the Technical Staff, Data Understanding Systems Group, 2000-2004

Research Assistant, Satellite Geodesy and Geodynamics Systems Group, 1996-2000

Awards

JPL SPOT Award, 2010, NOVA Award, 1997, 1998

NASA Board Act Award: GeoFEST v. 4.8, 2008

JPL Outstanding Accomplishment Award: InSAR Workshop Report, 2006

JPL Team Bonus Award: QuakeSim Parallel GeoFEST Development Team, 2004

NASA Graduate Student Research Prog. Fellowship, 1999-2000, 2000-2001, 2001-2002

Sigma Xi Grants in aid of Research Award, June 2000

NSF Graduate Research Fellowship Honorable Mention, 1998

Southern California Earthquake Center Community Outreach Award (Education), 1998

Selected Publications

Donnellan, A., Rundle, J., Fox, G., McLeod, D., Grant, L., Tullis, T., Pierce, M., Parker, J., Lyzenga, G., Granat, R., and **Glasscoe, M.**, 2005, QuakeSim and the Solid Earth Research Virtual Observatory, Pure and Applied Geophysics, v. 163, pp. 2263-2279.

Donnellan, A., **Glasscoe, M.**, and Zebker, H., 2005, Community InSAR Workshop calls for robust program and dedicated satellite mission, EOS Trans. AGU, v. 86:8, p. 79.

Glasscoe, M.T., Granat, R.A., Rundle, J.B., Rundle, P.B., Donnellan, A., and Kellogg, L.H., 2009, Analysis of emergent fault element behavior in Virtual California, Concurrency and Computation: Practice and Experience, DOI: 10.1002/cpe.1546.

Glasscoe, M.T., Donnellan, A., Kellogg, L.H., and Lyzenga, G.A., 2004, Evidence of strain partitioning between the Sierra Madre fault and the Los Angeles Basin, southern Cal. from numerical models, Pure and Appl. Geophys. 161, 2343-2357.

Parker, J., Lyzenga, G., Norton, C., Zuffada, C., **Glasscoe, M.**, Lou, J., and Donnellan, A., 2008, Geophysical Finite Element Simulation tool (GeoFEST): algorithms and validation for quasistatic regional faulted crust problems, Pure and Applied Geophysics, v. 165, pp. 497-521.

Turcotte, D.L. and **Glasscoe, M.T.**, 2004, A damage model for the continuum rheology of the upper continental crust, Tectonophysics, 383, 71-80.

4.5. JOHN RUNDLE

Professional Training

Ph.D., Geophysics and Space Physics, UCLA (1976)
M.S., Planetary and Space Science, UCLA (1973)
B.S.E. Engineering Physics, Princeton University (1972), *magma cum laude*

Honors and Awards

Phi Beta Kappa, Princeton University, 1972
Tau Beta Pi, Princeton University, 1972
Sandia National Laboratories: Exceptional Contribution Award for Fundamental Research, 1982 ($2500 Award)
US Geological Survey, Branch of Geologic Risk Assessment, Best Paper 1989 ($500 Award)
Association Lecturer, International Association of Seismology and Physics of the Earth's Interior, Wellington, NZ, 1994.
US Department of Energy Award for Fundamental Contributions in Research, given at US Department of Energy , Basic Energy Sciences, Office of Geosciences Program Review, Berkeley, California, 1996.
Distinguished Visiting Scientist, Jet Propulsion Laboratory, 1996-present
Aki Award for Distinguished Service as Chair (1994-1996) of the Advisory Board of the Southern California Earthquake Center, Given at the Southern California Earthquake Center Annual Meeting, 2001.
4th Edward N. Lorenz Lecturer, American Geophysical Union Meeting, Fall, 2004.
Elected Fellow, American Physical Society, 2005
Selected for inclusion in Who's Who in America, 60th edition, 2005
Elected Fellow, American Geophysical Union, 2008.
External Professor, The Santa Fe Institute, 2008-
Distinguished Professor, University of California, 2009-
Recognized by Thomson Reuters as one of the Top 10 most cited authors in the field of "earthquakes" during 2000 – 2010 (ScienceWatch, 2010)

Appointments

Distinguished Professor, Physics and Geology, University of California, Davis (2009-)
Professor,Physics and Geology, University of California, Davis (2002-2009)
Director, California Institute for Hazard Research of the University of California (2006-)
Professor, Department of Physics, and Fellow, Cooperative Institute for Research in Environmental Sciences, University of Colorado (1996–2002)
Director, Colorado Center for Chaos & Complexity, (1997-2002)
Deputy Director, Cooperative Institute for Research in Environmental Science, (1998-)
Associate Professor, Department of Physics and Geology, and Fellow, Cooperative Institute for Research in Environmental Sciences, U of Colorado (1993-1996)
Physicist, Lawrence Livermore National Laboratories (1990–1993)
Member of Technical Staff, Sandia National Laboratories (1977–1990)
Visiting Scholar, Condensed Matter Theory Group, Department of Physics, Boston University (1988–1989, concurrent with above)
Visiting Associate, Calif. Institute of Technology (1981–1984, concurrent with above)

Publications

Over 230 publications in the peer-reviewed literature (available on request)

4.6. GEOFFREY FOX

Professional Preparation

Cambridge University	Mathematics	B.A. 1961-64
Cambridge University	Theoretical Physics	Ph.D. 1964-67
Cambridge University	Mathematics	M.A. 1968

Appointments

2011- Distinguished Professor, Indiana University

2010- Member of Board Open Grid Forum

2009- Associate Dean School of Informatics and Computing, Indiana University Bloomington

2008- Director of Digital Science Center, Pervasive Technology Institute, Indiana University

2008-2009	Chair Department of Informatics, Indiana University Bloomington
2006-	Senior Research Associate, Center for Computational Science and Advanced Distributed Simulation, University of Houston Downtown
2005-	Visiting Scholar for Cyberinfrastructure Development at the Alliance for Equity in Higher Education
2001-	Professor of Computer Science, Informatics, and Physics; Director, Community Grids Laboratory, Pervasive Technology Labs, Indiana University
2000-01	Professor of Computer Science; Associate Director of School for Computational Science and Information Technology -- Director of Computational Science and Information Laboratory; Chief Technologist of Office of Distributed and Distance Learning, Florida State University
2000-	Distinguished Visiting Scientist, JPL
2000-	Chief Technology Officer, Anabas Inc
1990-2002	Professor of Computer Science; Professor of Physics; Director of Northeast Parallel Architectures Center, Syracuse University
1989-2004	Visiting Professor in Computer Science, Rice University
1979-1990	Professor of Physics, California Inst. of Tech.
1986-88	Associate Provost for Computing, California Inst. of Tech.
1983-85	Dean for Educational Computing, California Inst. of Tech.
1981-83	Executive Officer of Physics, California Inst. of Tech.
1974-79	Associate Professor of Physics, California Inst. of Tech.
1971-74	Assistant Professor of Physics, California Inst. of Tech.
1970-71	Millikan Research Fellow in Theoretical Physics, Caltech

Awards and Honors

Senior Wrangler and Mayhew Prize, Part III Mathematics, Cambridge (1964)

Alfred P. Sloan Foundation Fellowship (1973-75); Fellow of the American Physical Society (1990)

Journal Editor

Concurrency and Computation: Practice and Experience, (1989-); *The Journal of Supercomputing* (1987-); *Future Generation Computer Systems* (2002-); *Computing in Science and Engineering* (2001-)

Career Synopsis: Fox has supervised the PhD of 62 students and published over 600 papers in physics and computer science with an h-index of 51. He currently works in applying computer science to Bioinformatics, Defense (Command and Control), Earthquake and Ice-sheet Science, Particle Physics and Chemical Informatics. He is principal investigator of FutureGrid – a new facility to enable development of new approaches to computing. He is involved in several projects to enhance the capabilities of Minority Serving Institutions. His expertise is in systems and software architecture including parallel and distributed systems.

4.7. MARLON PIERCE

Leader, Science Gateway Group
Pervasive Technology Institute
Indiana University
mpierce@cs.indiana.edu
http://pti.iu.edu/sgg

Professional Preparation

Florida State University	Physics	Ph.D. 1998
Louisiana Tech University	Physics	B.S. 1990

Appointments

2010-Present	Leader of the Science Gateway Group at the Pervasive Technology Institute
2006-2010	Assistant Director, Community Grids Lab, Indiana University
2004-06	Senior Research Associate, Community Grids Lab, Indiana University
2001-04	Senior Postdoctoral Research Associate, Community Grids Lab, Indiana University
1999-2001	Information and Communication/Enabling Technologies On-Site Lead, Aeronautical Systems Center Major Shared Resource Center for the Department of Defense High Performance Computing Modernization Program
1999	Postdoctoral Researcher, Florida State University

Selected Publications

Selected from over 50 relevant, peer-reviewed publications:

Marlon E. Pierce, Xiaoming Gao, Sangmi Lee Pallickara, Zhenhua Guo, Geoffrey Fox: The Quakesim portal and services: new approaches to science gateway development techniques. Concurrency and Computation: Practice and Experience 22(12): 1732-1749 (2010)

Zhenhua Guo, Raminderjeet Singh, Marlon E. Pierce: Building the PolarGrid portal using web 2.0 and OpenSocial. SC-GCE 2009.

Geoffrey Fox, Marlon E. Pierce: Grids challenged by a Web 2.0 and multicore sandwich. Concurrency and Computation: Practice and Experience 21(3): 265-280 (2009)

Marlon E. Pierce, Geoffrey Fox, Jong Y. Choi, Zhenhua Guo, Xiaoming Gao, Yu Ma: Using Web 2.0 for scientific applications and scientific communities. Concurrency and Computation: Practice and Experience 21(5): 583-603 (2009)

Jay Alameda, Marcus Christie, Geoffrey Fox, Joe Futrelle, Dennis Gannon, Mihael Hategan, Gopi Kandaswamy, Gregor von Laszewski, Mehmet A. Nacar, Marlon E. Pierce, Eric Roberts, Charles Severance, Mary Thomas: The Open Grid Computing Environments collaboration: portlets and services for science gateways. Concurrency and Computation: Practice and Experience 19(6): 921-942 (2007)

Mehmet S. Aktas, Geoffrey Fox, Marlon E. Pierce: A Federated Approach to Information Management in Grids. Int. J. Web Service Res. 7(1): 65-98 (2010)

Robert Granat, Galip Aydin, Marlon E. Pierce, Zhigang Qi, Yehuda Bock: Analysis of streaming GPS measurements of surface displacement through a web services environment. CIDM 2007: 750-757

4.8. DENNIS MCLEOD

Professor, Computer Science Department
University of Southern California
Los Angeles, CA 90089-0781
Phone: (213) 740-4504 E-mail: mcleod@usc.edu Web: http://sir-lab.usc.edu

Professional Preparation

Ph.D. in Computer Science, Massachusetts Institute of Technology (MIT), August 1978.
M.S. in Computer Science, MIT, May 1976.
B.S. in Electrical Engineering and Computer Science, MIT, February 1974.

Appointments

Professor of Computer Science (tenured), University of Southern California (USC), September 1991-present.

Co-PI and Deputy Director, Center for Knowledge Integration and Discovery, Department of Homeland Security, 2007-present.

Director, USC Semantic Information Research Laboratory, 2005-present.

Strategic Scientist, and Research Area Director, USC Integrated Media Systems Center (IMSC), National Science Foundation Engineering Research Center, 1996-2005.

Associate Professor of Computer Science (tenured), USC, 1983-1991.

Assistant Professor of Computer Science, USC, 1978-1983.

Research and Teaching Assistant, Massachusetts Institute of Technology (MIT), Laboratory for Computer Science, 1974-1978.

Research Staff, IBM Research Laboratory, San Jose CA,1975 (summer).

Software Systems Manager, Forest Hospital, 1974-1975.

Programmer/Analyst, Behavior Reviews Inc., 1970-1974.

Selected Publications

Donnellan, A., Parker, J., Granat, R., Rundle, J., Fox, G., Pierce, M., McLeod, D., Alghanmi, R., Grant, L., and Brooks, W., "QuakeSim: Efficient Modeling of Sensor Web Data", *Proceedings of 2008 Earth Science Technology Conference*, College Park MD, July 2008.

Donnellan, A., Rundle, J., Fox, G., McLeod, D., Grant, L. Tullis, T., Pierce, M., Parker, J., Lyzenga, G., Granat, R. and Glascoe, M., "QuakeSim and the Solid Earth Research Virtual Observatory", *Pure and Applied Geophysics*, Volume 163, Numbers 11-12, December 2006, Pages 2263-2279.

Atkas, M., Aydin, G., Donnellan, A., Fox, G., Granat, R., Grant, L. Lyzenga, G., McLeod, D., Pallickara, S., Parker, J., Pierce, M., Rundle, J., Sayar, A., and Tullis, T., "iSERVO: Implementing the International Solid Earth Virtual Observatory by Integrating Computational Grid and Geographical Information Web Services", *Pure and Applied Geophysics*, Volume 163, Numbers 11-12, December 2006, Pages 2281-2296.

Grant, L., Donnellan, A., McLeod, D., Pierce, M., Fox, G., Chen, Y., Gould, M., Sung, S., and Rundle, P., "A Web-Service Based Universal Approach to Heterogeneous Fault Databases", *Computing in Science and Engineering - Special Issue on Multi-Physics Modeling*, Volume 7, 2005, Pages 51-57.

Grant, L., Donnellan, A., McLeod, D., Pierce, M., Chen, A., Gould, M., Noriega-Carlos, G., Paul, R., Sung, S., and Ta, M., "QuakeTables: The QuakeSim Fault Database for California", *Proceedings of 2004 SCEC Conference*, Palm Springs, September 2004.

4.9. Lisa Grant Ludwig

Education: Ph.D. Geology and Geophysics, 1993, Caltech; M.S. Geol., 1990, Caltech
M.S. Environmental Engineering Science, 1989, Caltech
B.S. Environmental Earth Science, 1985, Stanford University

Selected Experience and Appointments:

Associate Professor, Program in Public Health, UC Irvine, 2006 – present
Assist. to Assoc. Prof., Environmental Health, Science & Policy, UC Irvine,1998-2011
Assist. Professor, Program Dir. for Environmental Science, Chapman Univ., 1995-98
Assist. Project Scientist, Woodward-Clyde Consultants, Santa Ana, CA 1993 – 1995
Assoc. Dir., California Institute for Hazards Research, Univ. of California, 2006-2011
Graduate Advisor, Program in Public Health, UC Irvine, 2009 –
Member, Nat. Acad. of Sci. U. S. Nat. Comm. for the IUGG, 2003 -2011
Natl. Corresp., Intl. Assoc. for Seism. and Phys. of the Earth's Int. (IASPEI) 2008 - 2011
Member, Board of Directors, Seismological Society of America, 2010 -
Vice Chair, Board of Dir., Southern California Earthquake Center (SCEC), 2007-2011

Selected publications:

Vidale, J., Atkinson, G., Green, R., Hetland, E., Grant Ludwig, L**.**, Mazzoti, S., Nishenko, S. and L. Sykes (2011). Rept. of the Indep. Expert Pan. on New Madrid Seismic Zone Earthquake Haz. to the Nat. Earthquake Pred. Evaluation Council (NEPEC) and Dr. Marcia McNutt, Director of the U.S. Geological Survey, April 16, 2011.

Runnerstrom E. E. and Grant Ludwig, L. (2011). Toward an understanding of the gap between earthquake science and local policy-makers in Orange County, California: *Seismol. Res. Lttrs,* v. 82., no. 2, p

Akciz, S. O., Grant Ludwig, L., Arrowsmith, J R., and Zielke, O., (2010). Century-long average time intervals between ruptures on the San Andreas fault in the Carrizo Plain, *Geology,* 38, no 9, 787-790.

Grant Ludwig, L., Akciz, S. O., Noriega, G. R., Zielke, O., Arrowsmith, J R., (2010) Climate-modulated channel incision and rupture history of the San Andreas Fault in the Carrizo Plain, *Science*, DOI: 10.1126/science.1182837.

Zielke, O., Arrowsmith, J R., Grant Ludwig, L., Akciz, S. O., (2010) Slip in the 1857 and earlier large earthquakes along the Carrizo Plain, San Andreas Fault, *Science*, DOI: 10.1126/science.1182781.

Plesch, A., Shaw, J. H., Bensen, C., Bryant, W. A., Carena, S., Cooke, M., Dolan, J., Fuis, G., Gath, E., Grant, L**.**, Hauksson, E., Jordan, T., Kamerling, M., Legg, M., Lindvall, S., Magistrale, H., Nicholson, C., Niemi, N., Oskin, M., Perry, S., Planasky, G., Rockwell, T., Shearer, P., Sorlien, C., Suss, M. P., Suppe, J., Treiman, J., and R. Yeats (2007). Community fault model (CFM) for Southern California. *Bull. Seism. Soc. Amer*., v. 97, no. 6, 1793-1802. doi:10.1785/0120050211

Donnellan, A., Rundle, J., Fox, G., McLeod, D., **Grant, L.,** Tullis, T., Pierce, M., Parker, J., Lyzenga, G., Granat, R., and Glasscoe, M. QuakeSim and the Solid Earth Research Virtual Observatory. *Pure and Applied Geophysics*, 163, 2263-2279, 2006

Grant, L. B., Gould, M. M., Donnellan, A., McLeod, D., Chen, A. Y., Sung, S., Pierce, M., Fox, G. C., and Rundle, P., A Web-service based universal approach to heterogeneous fault databases, *Comp. in Sci.e and Eng.,* July/Aug. 2005, p. 51- 57.

Grant, L. B. and M. M. Gould. Assimilation of paleoseismic data for earthquake simulation. *Pure and Applied Geophysics*, 161, no. 11/12, 2295-2306, 2004.

4.10. TERRY TULLIS

Professional Preparation:
Carleton College - B.A. Geology 1964
UCLA - M.S. Experimental Geophysics 1967
UCLA - Ph.D. Experimental Geophysics 1971

Appointments:
Brown University, Dept. of Geol. Sci.:
Asst. Prof., 1970- 1976; Assoc. Prof., 1976-1989; Prof., 1989-2005; Emeritus and Research Prof. 2005-present
Geophysicist, Oct-Dec, 1990, U.S. Geological Survey, Office of Earthquakes
Visiting Professor, Sept-Oct, 1990, Harvard University, Dept. of Applied Sciences
Geologist, Jan-June 1977, U.S. Geological Survey, Office of Earthquake Studies
Visiting Fellow, September 1976-January 1977, Australian National University, Research School of Earth Sciences

Publications: Selected publications most relevant to this proposal:
Stuart, W. D. and Tullis, T. E., Fault model for preseismic deformation at Parkfield, California, J. Geophys. Res., 100, 24079-24099, 1995
Tullis, T. E. Rock friction and its implications for earthquake prediction examined via models of Parkfield earthquakes, in Earthquake Prediction: the Scientific Challenge, ed. by Leon Knopoff, Proc. Natl. Acad. Sci. USA, 93, 3803-3810, 1996.
Kato, N. and T. E. Tullis, Numerical simulation of seismic cycles with a composite rate- and state-dependent friction law, Bull. Seis. Soc. Am., 93, 841-853, 2003.
Tullis, T. E., Friction of rock at earthquake slip rates, in Treatise on Geophysics, G. Schubert (ed.), v. 4, Earthquake Seismology, H. Kanamori, (ed.), Chapter 5, p. 131-152, Elsevier Ldt., Oxford, 2007.
Beeler, N. M., and T. E. Tullis, A Barnes Hut scheme for simulating fault slip, Nonlin. Processes Geophys., 18, 133-146, doi:110.5194/npg-5118-5133-2011, 2011.
Tullis, T. E., et al., Preliminary results from SCEC Earthquake Simulator Comparison Project Eos Trans. AGU, Fall Meet. Suppl, 91, NG44A-08, 2010.

Synergistic Activities:
Review Panel for Research Proposals submitted to U.S. Geological Survey Earthquake Hazards Reduction Program: April 21-24, 1982; April 20-23, 1983; April 29-May 2, 1984; May 7-10, 1986; May 5-8, 1987; April 30-May 3, 1988; August 19-20, 1992.
General Secretary, American Geophysical Union, 2002-2006.
Chair, Fault and Rock Mechanics (FARM) Disciplinary Committee, Southern California Earthquake Center (SCEC), 2001-2006; Chair, Earthquake Forecasting and Predictability Focus Group, Southern California Earthquake Center (SCEC), 2006-; Organizer of three FARM workshops held by SCEC, September 2002, 2003, Aug 2004 and five workshops on Earthquake Simulators, Nov. 2007, June 2008, 2009, July 2010, May 2011.
Member, SCEC Planning Committee, 2001-2011 ; Member, SCEC Board of Directors, 2001-2006; Leader, SCEC Technical Activity Group on Earthquake Simulators, 2011-.
Chair, National Earthquake Prediction Evaluation Council; Member, Scientific Earthquake Studies Advisory Committee (reporting to the USGS).

5. Current and Pending Support

5.1. Current Awards

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Andrea Donnellan - JPL				
Andrea Donnellan	3D Simulations of Active Tectonic Processes	Earth Surface and Interior NASA John LaBrecque 202-358-1373 john.labrecque@nasa.gov	11/08 – 3/12 $645,000	2.5
Andrea Donnellan	UAVSAR Imaging of Seismically and Tectonically Active Regions in Northern and Southern California	EarthScope Geodetic Imaging NASA Craig Dobson 202-358-0254 craig.dobson@nasa.gov	10/08 – 3/2012 $740,000	2.5
Andrea Donnellan	QuakeSim: Increasing Accessibility and Utility of Spaceborne and Ground-Based Earthquake Fault Data	Advanced Information Systems Technology NASA Michael Seablom 202-358-0442 michael.s.seablom@nasa.gov	2/09 – 1/2012 $1,500,000	2.5
Jay Parker - JPL				
Andrea Donnellan	QuakeSim: Increasing Accessibility and Utility of Spaceborne and Ground-based Earthquake Fault Data	NASA Advanced Information Systems Technology Steven A. Smith 301-286-7336 Steven.A.Smith@gsfc.nasa.gov	04/09 – 04/12 $1500.0K	2
Gregory Lyzenga	Numerical simulations of crustal deformation and postseismic processes in northern and southern California using GeoFEST finite element tools	NASA Earth Surface and Interior John LaBrecque 202-358-1373 jlabrecque@mail.hq.nasa.gov	10/08 – 9/11 $607.6K	1.2
Andrea Donnellan	Three-Dimensional Simulations of California's Earthquake Fault Systems	NASA Earth Surface and Interior John LaBrecque 202-358-1373 jlabrecque@mail.hq.nasa.gov	11/08 – 3/12 $645.7K	1.8

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Andrea Donnellan	UAVSAR Imaging of Seismically and Tectonically Active Regions in Northern and Southern California	NASA EarthScope Craig Dobson 202-358-0254 Craig.Dobson-1@nasa.gov	09/08-09/11 $1210K	1.2
Robert Granat - JPL				
Andrea Donnellan	QuakeSim: Increasing Accessibility and Utility of Spaceborne and Ground-based Earthquake Fault Data	Advanced Information Systems Technology (AIST) / NASA / Steven A. Smith, 301-286-7336	**01/01/09-12/31/11 / $1780K**	2.5 Person-Months per Year
Margaret Glasscoe - JPL				
Margaret Glasscoe	Earthquake Data Enhanced Cyber-Infrastructure for Decision Evaluation and Response	NASA Applied Sciences Lawrence Freidl 202-358-1599 LFriedl@nasa.gov	9/09-10/2013 $1500.0K	3.6
Gregory Lyzenga	Numerical simulations of crustal deformation and postseismic processes in northern and southern California using GeoFEST finite element tools	NASA Earth Surface and Interior John LaBrecque 202-358-1373 jlabrecque@mail.hq.nasa.gov	10/08 – 9/11 $607.6K	3.6
Andrea Donnellan	Three-Dimensional Simulations of California's Earthquake Fault Systems	NASA Earth Surface and Interior John LaBrecque 202-358-1373 jlabrecque@mail.hq.nasa.gov	05/08 – 09/10 $645.7K	1.2
Marlon Pierce – Indiana University				
Marlon Pierce	SDCI NMI Improvement: Open Grid Computing Environments Software for Science Gateways	Office of Cyberinfrastructure, National Science Foundation, Manish Parashar, mparasha@nsf.gov, (703) 292-4766	7/1/07-8/31/11 $1.7 M (total)	2 months/year

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Andrea Donnellan (PI), Marlon Pierce (Co-PI)	QuakeSim: Increasing Accessibility and Utility of Spaceborn and Ground-Based Earthquake Fault Data	Advanced Information Systems Technology NASA Michael Seablom 202-358-0442 michael.s.seablom@nasa.gov	2/1/09-01/31/12 $65K/year	2 months/year
Marlon Pierce	SDCI NMI Improvement: Open Gateway Computing Environments – Tools for Cyberinfrastructure-Enabled Science and Education	Office of Cyberinfrastructure, National Science Foundation, Manish Parashar, mparasha@nsf.gov, (703) 292-4766	08/01/10 – 07/31/13 $1.5M (total)	2 months/year
James Basney (PI), Marlon Pierce (Co-PI)	SDCI Sec: Distributed Web Security for Science Gateways	Office of Cyberinfrastructure, National Science Foundation, kthompso@nsf.gov, (703) 292-8962	08/01/11 – 07/31/14, $350K (total)	2 months/year
Margaret Glasscoe (PI), Marlon Pierce (CO-PI)	Earthquake Data Enhanced Cyber-Infrastructure for Disaster Evaluation and Response (E-DECIDER)	Applied Sciences DISASTERS NASA Lucien Cox 202-358-2164 elbert.l.cox@nasa.gov	10/01/09 – 09/30/13, $180K (total)	2 months/year
Geoffrey Fox – Indiana University				
Geoffrey Fox	FutureGrid: An Experimental, High-Performance Grid Test-bed	Track IID, NSF OCI, Robert Pennington, (703) 292-7025, rpenning@nsf.gov	10/1/09-9/30/13, $10,100K	4.2
Prasad Gogineni	STC: Center for Remote Sensing of Ice Sheets Science and Technology Center	NSF Science and Technology Centers, Julie M. Palais, (703) 292-8033, jpalais@nsf.gov	6/1/10-5/31/15, $1,219K	0.6
Andrea Donnellan	QuakeSim: Increasing Accessibility and Utility of Spaceborn and Ground-Based Earthquake Fault Data	Advanced Information Systems Technology NASA Michael Seablom 202-358-0442 michael.s.seablom@nasa.gov	2/1/09-01/31/12 $195K	0.5

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Margaret Glasscoe	Earthquake Data Enhanced Cyber-Infrastructure for Disaster Evaluation and Response (E-DECIDER)	NASA Applied Sciences Lawrence Freidl 202-358-1599 LFriedl@nasa.gov	10/01/09 – 09/30/13, $180K	0.5
Madhav Marathe	SDCI NMI New: From Desktops to Clouds – A Middleware for Next Generation Network Science	NSF OCI SDCI NMI, Manish Parashar, (703) 292-4766, mparasha@nsf.gov	08/01/2010 – 07/31/2013, $255K	0.5
Craig Stewart	ABI Development: National Center for Genome Analysis Support	NSF Bio ABI, Peter McCartney, (703) 292-8470, pmccartn@nsf.gov	03/01/2011 – 02/28/2014 $1.479K	0.0
Dennis McLeod – Indiana University				
Andrea Donnellan	QuakeSim: Increasing Accessibility and Utility of Spaceborne and Ground-Based Earthquake Fault Data	Advanced Information Systems Technology NASA Michael Seablom 202-358-0442 michael.s.seablom@nasa.gov	2/2009 – 1/2012 $65,000	1.5
John Rundle – University of California, Davis				
Dr. John Rundle	Data Mining and Pattern Informatics Application to NASA Space Geodetic Data	NASA; Agency POC: Dr. John Labrecque; phone: 202-358-1373; e-mail: john.labrecque@nasa.gov	01/14/08 – 01/13/12	0.5
Dr. John Rundle	QuakeSim: Increasing Accessibility and Utility of Spaceborne and Ground-based Earthquake Fault Data	Jet Propulsion Laboratory (JPL); Agency POC: Dr. Andrea Donnellan (JPL); phone: 818-354-4737; e-mail: Andrea.Donnellan@jpl.nasa.gov	04/01/09 – 04/01/12	0.5
Dr. John Rundle	Earthquake Data Enhanced Cyber-Infrastructure for Disaster Evaluation and Response (E-DECIDER)	NASA/Jet Propulsion Laboratory (JPL); Agency POC: Ms. Maggi Glasscoe; phone: 818-393-4834; e-mail: Margaret.T.Glasscoe@jpl.nasa.gov	12/11/09 – 09/30/11	0.25

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Dr. John Rundle	Three-Dimensional Simulations of California's Earthquake Fault System	NASA/Jet Propulsion Laboratory (JPL); Agency POC: Dr. Andrea Donnellan (JPL); phone: 818-354-4737; e-mail: Andrea.Donnellan@jpl.nasa.gov	03/01/09 – 09/30/11	0.25
Dr. John Rundle	A Collaborative Project: Comparison, Verification, and Validation of Earthquake Simulators	Southern California Earthquake Center (USC); Agency POC: Mr. John McRaney; phone: 213/740-5843; e-mail: mcraney@usc.edu	02/01/11 – 01/31/12	0.25
Lisa Grant Ludwig – University of California, Irvine				
Andrea Donnellan (PI), Lisa Grant Ludwig (Co-PI)	QuakeSim: Increasing Accessibility and Utility of Spaceborn and Ground-Based Earthquake Fault Data	Advanced Information Systems Technology NASA Michael Seablom 202-358-0442 michael.s.seablom@nasa.gov	2/1/09-01/31/12 $25K/year	0.25
Lisa Grant Ludwig	Using precariously balanced rocks (PBRs) to constrain activity of UCERF "B" faults and evaluate rupture direction	Southern California Earthquake Center John McRaney 213-740-5842 McRaney@usc.edu	2/10 – 1/12 $30,000	0.5
Lisa Grant Ludwig	Rupture history of the San Andreas fault in the Carrizo Plain prior to 1300 AD	National Earthquake Hazard Reduction Program US Geological Survey John Filson jfilson@usgs.gov	6/10 – 5/12 $52,000	0.9
Lisa Grant Ludwig	Paleoseismology of the Borrego and Pescadores faults in Northern Baja California: Characterizing the Past Rupture History of a Complex Transtensional fault zone	Southern California Earthquake Center John McRaney 213-740-5842 McRaney@usc.edu	2/10 – 1/12 $5,996	0.1

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Lisa Grant Ludwig	New slip rate estimates from Wallace Creek and Phelan Creek paleoseismic sties: Re-sampling, Re-dating and Re-synthesizing	Southern California Earthquake Center John McRaney 213-740-5842 McRaney@usc.edu	2/10 – 1/12 $34,151	0.25
Terry Tullis – Brown University				
Terry E. Tullis	Collaborative Research: Rock Friction, Nanoindentation, and Atomic Force Microscope Experiments Focused on Understanding Earthquake Mechanics	Geophysics NSF Eva Zanzerkia (703) 292-8556 ezanzerk@nsf.gov	9/08 – 8/12 $308,352	0.25
Terry E. Tullis	Collaborative Research: Laboratory Investigations of the Origin of Fault Zone Pulverization	Geophysics NSF Eva Zanzerkia (703) 292-8556 ezanzerk@nsf.gov	9/07 – 8/11 $260,000	0
Terry E. Tullis	Collaborative Research: Fast Multipole Algorithms for Geophysical Stress Modeling and Their Use in Large-scale Simulation of Earthquake Occurrence	Collaborations in Mathematical Geosciences NSF Junping Wang (703) 292-4488 jwang@nsf.gov	8/09 – 7/12 $129,411	1.5
Terry E. Tullis	Laboratory Experiments on Fault Shear Resistance Relevant to Coseismic Earthquake Slip	Southern California Earthquake Center NSF/USGS John McRaney (213) 740-5842 mcraney@usc.edu	2/11 – 1/12 $20,000	0.2

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Terry E. Tullis	Shear localization in faulting experiments and implications for source physics	Southern California Earthquake Center NSF/USGS John McRaney (213) 740-5842 mcraney@usc.edu	2/11 – 1/12 $24,000	0.85
Terry E. Tullis	A Collaborative Project: Comparison and Validation of Earthquake Simulators	Southern California Earthquake Center NSF/USGS John McRaney (213) 740-5842 mcraney@usc.edu	2/11 – 1/12 $20,000	0.81
Terry E. Tullis	Workshop on Earthquake Simulators	Southern California Earthquake Center NSF/USGS John McRaney (213) 740-5842 mcraney@usc.edu	2/11 – 1/12 $10,000	0
Terry E. Tullis	Experiments to Understand Dynamic Friction During Earthquakes	NEHERP USGS Elizabeth Lemersal (703) 648-6716 Lemersal@usgs.gov	9/11 – 7/12 $78,000	0.7
Terry E. Tullis	Earthquake Fault System Dynamics	Frontiers in Earth System Dynamics NSF Robin Reichlin (703) 834-3038 rreichli@nsf.gov	8/11 – 7/16 $250,000	1.8

5.2. Pending Awards

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Andrea Donnellan - JPL				
Jay Parker	Integrated Detection, Modeling, and Simulation for Assessment of Seismic Hazard	NASA Earth Surface and Interior John LaBrecque 202-358-1373 jlabrecque@mail.hq.nasa.gov	10/11 – 9/15 $590.2K	1.7

Name of PI on Award	Award/Project Title	Program Name Sponsoring Agency Point of Contact Telephone and e-mail	Period of Performance Total Budget	Commitment (Person-months per year)
Jay Parker	Application of UAVSAR Imaging to California Earthquake Potential Due to Tectonic Deformation	EarthScope Geodetic Imaging NASA Craig Dobson 202-358-0254 craig.dobson@nasa.gov	5/11 – 4/14 $673,300	2.5
Jay Parker - JPL				
Jay Parker	Integrated Detection, Modeling, and Simulation for Assessment of Seismic Hazard	NASA Earth Surface and Interior John LaBrecque 202-358-1373 jlabrecque@mail.hq.nasa.gov	10/11 – 9/15 $590.2K	1.7
Jay Parker	Application of UAVSAR Imaging to California Earthquake Potential Due to Tectonic Deformation	EarthScope Geodetic Imaging NASA Craig Dobson 202-358-0254 craig.dobson@nasa.gov	5/11 – 4/14 $673,300	2.5
Robert Granat - JPL				
Robert Granat	A Rapid Observation Delivery System for Earthquake Response	ACCESS/NASA/Stephen Berrick/ (202) 358-1757 / access@mail.nasa.gov	1/1/12-12/31/13	1.2 Person-Months per Year
Margaret Glasscoe - JPL				
Jay Parker	Integrated Detection, Modeling, and Simulation for Assessment of Seismic Hazard	NASA Earth Surface and Interior John LaBrecque 202-358-1373 jlabrecque@mail.hq.nasa.gov	10/11 – 9/15 $590.2K	1.7
Marlon Pierce – Indiana University				
Marlon Pierce	SDCI Sec: Distributed Web Security for Science Gateways	University of Illinois at Urbana-Champaign	8/11 – 7/14 $249,876	1.2

Name of PI on Award	**Award/Project Title**	**Program Name Sponsoring Agency Point of Contact Telephone and e-mail**	**Period of Performance Total Budget**	**Commitment (Person-months per year)**
Marlon Pierce	The Open Science Grid – The Next Five Years: Distributed High Throughput Computing for the Nation's Scientists, Researchers, Educators and Students	National Science Foundation	10/11 – 9/16 $4,174,881	0.0
Geoffrey Fox – Indiana University				
XiaoFeng Wang	Privacy-preserved cloud computing for mapping sensitive human genomic sequences	NIH, Pending	8/1/11-7/31/14, $1,110K	0.5
Geoffrey Fox	MyRain: Dynamic Provisioning of Cloud, Grid and HPC Systems	NSF OCI Pending	10/1/11-9/30/14, $1.635K	1.0
Dennis McLeod – Indiana University				
None pending				
John Rundle – University of California, Davis				
Dr. Louise Kellogg	Optimal Models for Earthquake Deformation and Probabilities: Utilizing NASA and Other Data to Understand Earth Surface Change	NASA;	04/01/11 – 03/31/14	2.5
Lisa Grant Ludwig – University of California, Irvine				
Lisa Grant Ludwig	Paleoseismic investigation of an active fault scarp subparallel to the main trace of the San Andreas Fault at the Bidart Fan Site in the Carrizo Plain	National Earthquake Hazard Redudction Program US Geological Survey John Filson jfilson@usgs.gov	5/12 – 12/12 $73,081	.25
Lisa Grant Ludwig	A benchmark study of National Seismic Hazard Maps and seismic safety planning at the local level	National Earthquake Hazard Reduction Program US Geological Survey John Filson jfilson@usgs.gov	1/12 – 12/12 $59,225	1

Name of PI on Award	**Award/Project Title**	**Program Name Sponsoring Agency Point of Contact Telephone and e-mail**	**Period of Performance Total Budget**	**Commitment (Person-months per year)**
Terry Tullis – Brown University				
Terry E. Tullis	Pending: Experiments to Understand Dynamic Friction During Earthquakes	NEHERP USGS Elizabeth Lemersal (703) 648-6716 Lemersal@usgs.gov	5/12 – 4/13 $125,276	2.5

6. Statements of Commitment and Letters of Support

6.1. Elizabeth Cochran, United States Geological Survey

Sunday, August 7, 2011 1:32:05 PM PT

Subject: Letter of Collaboration
Date: Saturday, August 6, 2011 9:18:52 AM PT
From: Elizabeth Cochran (sent by escochran@gmail.com <escochran@gmail.com>)
To: Donnellan, Andrea (3200)

Dear Andrea,

I am looking forward to developing collaborations between QuakeCatcher (http://qcn.stanford.edu/) and QuakeSim. As you know, we are developing early warning capability based on low cost accelerometers and distributed computing that makes use of the Berkeley Open Infrastructure for Network Computing (BOINC). We will be working to provide early earthquake source information to QuakeSim, which can be used to rapidly compute potential displacements from the event. The displacements can be used to estimate damage from the event as well as refine deployment of sensors following the earthquake in order to optimize estimation of aftershock locations and their sizes.

Elizabeth

Elizabeth S Cochran
Research Geophysicist
US Geological Survey
525 S. Wilson Ave
Pasadena, CA 91106
ecochran@usgs.gov
Ph: 626-583-7238
Fax: 626-583-7827

6.2. NED FIELD, UNITED STATES GEOLOGICAL SURVEY

United States Department of the Interior

U.S. GEOLOGICAL SURVEY

Geologic Hazards Science Center
USGS, Denver Federal Center
MS 966, Box 25046
Denver CO 80225
Ph: (626) 644-6435
field@usgs.gov

August 9, 2011

Dear Andrea,

I have been in charge of producing the Uniform California Earthquake Rupture Forecast (UCERF) models being developed by the Working Group on California Earthquake Probabilities (http://www.WGCEP.org). We recently completed UCERF-2, which draws heavily on expertise and data from the geology community. However, this model has severe limitations in terms of leaving out both multi-fault ruptures and spatiotemporal clustering, both of which were dramatically shown to contribute to hazard in the recent New Zealand and Japan earthquakes. Physics-based earthquake simulators constitute our best long-term hope of solving these deficiencies.

Earthquake simulators, including Virtual California, have already influenced the development of our next model (UCERF3) in terms of providing an improved methodology for computing elastic-rebound-based earthquake probabilities. How much more simulators will be able to influence UCERF3 remains to be seen, but at the very lease we will include a comprehensive evaluation of their reliability as an appendix in the forthcoming UCERF3 report.

Beyond that, I am convinced that simulators will play a larger and larger role in the development of earthquake forecasts, and could quite possibly constitute the sole basis of UCERF4 (if adequate progress can be made).

QuakeSim, through the use of Virtual California and other components is an important part of this endeavor, and I very much look forward to collaborating directly with your group to make the most of your valuable resources.

Sincerely,

Edward (Ned) H. Field
Chair of the WGCEP (http://www.WGCEP.org)
U.S. Geological Survey

6.3. Bruce Davis, Department of Homeland Security

Monday, August 8, 2011 12:48:40 PM PT

Subject: Project Support
Date: Monday, August 8, 2011 12:29:01 PM PT
From: Davis, Bruce
To: Donnellan, Andrea (3200)

Dear Andrea,

I have been watching with interest the development of QuakeSim and E-DECIDER and see great opportunity for DHS and emergency responders to benefit from these tools. Federal, State, and Local emergency responders that participated in the Joint DHS-Naval Post Graduate School Project on Earthquakes that was held in January 2011 were very interested in the improvement in preparedness that would result from intermediate rather than long term earthquake forecasts. Products that E-DECIDER is developing complete the interface between the science and response observations and models and make it possible to ingest the PESH (Potential Earth Science Hazard) files into the HAZUS model. This was highlighted in the participation of the projects in the Central US National Level Exercise that took place in May 2011.

My role in DHS is to move advanced technologies to the end user. I would recommend setting up a tiered product advisory board make up of county, state, and federal agencies with response and recovery responsibilities for this project. I will also encourage participation in all state and national earthquake exercises, such as the annual ShakeOut exercises in California and the National Level Exercise. These exercises provide an excellent opportunity to determine the effectiveness of your information and will steer your products to providing maximum utility for end users. I understand that you are already developing a relationship with the USGS in Pasadena to integrate early warning and estimates of crustal deformation. This is very important for assessing damage as well as estimating aftershock probabilities. Furthermore, the your partnership with USGS is important because of their role as the authoritative source for scientific and technical information along with the appropriate state agencies for information on earthquake hazards. Bringing all of these efforts together as a system will greatly improve our ability to prepare for the future as well as understand the severity and extent of damage when an earthquake does occur.

Sincerely yours,

Bruce

Bruce A. Davis, Ph.D.
Senior Program Manager
Science and Technology Directorate
Department of Homeland Security
202 254 5893
Bruce.A.Davis@dhs.gov

6.4. Jean-Pierre Bardet, USC Civil Engineering

USC
VITERBI
SCHOOL OF
ENGINEERING

Andrea Donnellan
Jet Propulsion Laboratory

August 8, 2011

onny Astani
epartment of
ivil and
nvironmental
ngineering

ean-Pierre Bardet
hair and
rofessor

irector,
SC Center on
egacities

Dear Andrea,

I am looking forward to collaborating with you on various crustal deformation applications. As you know, I am moving to become Dean of the School of Engineering at University of Texas, Arlington.

We have several applications that can benefit from QuakeSim tools. We have already collaborated on the water pipe break report for the Los Angeles Department of Water and Power. QuakeSim tools were used to analyze crustal deformation in the vicinity of the pipe breaks. QuakeSim can also be used to model water discharge and recharge of aquifers. I am exploring a new collaboration with the county to evaluate the possibility of pumping sewage into depleted oil reservoirs, which can be used to generate methane gas. Pumping fluids in to or out of reservoirs causes surface deformation and your modeling tools can be used to evaluate the impact of fluid migrations. I can see other applications of QuakeSim tools such as observing and modeling crustal deformation related to carbon sequestration.

We already have a track record of collaborating and I am looking forward to further strengthening our ties.

Best regards,

niversity of
outhern California
os Angeles, CA 90089-
531
el: (213) 740-0609
ax: (213) 744-1426
ardet@usc.edu
ttp://www.usc.edu/cee

6.5. Charles Meertens, UNAVCO

UNAVCO

August, 7, 2011

Dr. Andrea Donnellan
Jet Propulsion Laboratory
M/S 183-335
4800 Oak Grove Drive
Pasadena, CA 91109

6350 Nautilus Drive
Boulder, Colorado
80301-5553
T 303.381.7500
F 303.381.7501
www.unavco.org
support@unavco.org

Re: UNAVCO support for your project titled: QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science

Dear Andrea,

As the provider of GPS and InSAR data for the EarthScope community, we are developing tools and interfaces for better distribution and use of the data. We are very interested in strengthening ties between UNAVCO and QuakeSim. As we've discussed, I plan to increase interchange between our groups so that we both maximize the utility of our tools while at the same time not duplicating efforts. This is an exciting time for solid Earth science as more and more data are becoming available while concurrently computational capabilities are allowing us to better share and interchange data and models. We realize the need for presenting data in various ways (such as velocities over different time periods) and will make sure that we understand your requirements in these areas. We wish you the best of luck with your proposal and hope we have the opportunity to work together on this important effort.

Sincerely yours,

Charles Meertens

Dr. Charles Meertens
UNAVCO Facility Director

cc: F. Boler

6.6. DONALD ATWOOD, ALASKA SATELLITE FACILITY

Alaska Satellite Facility ASF
Geophysical Institute. University of Alaska Fairbanks

08 August 2011

Dr. Andrea Donnellan
Deputy Division Manager
Earth and Space Sciences Division
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive M/S 183-335
Pasadena, CA 91109-8099

Subject: Letter of Support

Dear Dr. Donnellan:

The Alaska Satellite Facility (ASF) is looking forward to working with QuakeSim. As you know, ASF is the assigned Distributed Active Archive Center for the Jet Propulsion Laboratory Uninhabited Aerial Vehicle (UAVSAR) data and ASF wants to make sure that the National Aeronautics and Space Administration's investment in UAVSAR is realized through cultivation of a broad user base. Such a user base will grow through tools that allow for easy and intuitive access to UAVSAR data by users and interfaces, as well as services that allow various applications to directly access the data.

Sincerely,

D Atwood

Donald Atwood, Ph.D.
ASF Chief Scientist

903 Koyukuk Drive, Fairbanks, Alaska 99775-7320 Phone: (907) 474-6166 Fax: (907) 474-6441 http://www.asf.alaska.edu

7. BUDGET JUSTIFICATION

The following narrative describes the basis of estimate and rationale for each proposed component of cost, including direct labor, subcontracts/subawards, consultants, and other direct costs (including travel). Labor costs are based on full cost accounting.

7.1. BUDGET NARRATIVE

7.1.1. PERSONNEL AND WORK EFFORT

Name	Organization	Role	Work Commitment (Fractions of Work Year–1840 hours)			
			Year 1	Year 2	Year 3	Year 4
Andrea Donnellan	JPL	Principal Investigator	.21	.21	.21	.21
Jay Parker	JPL	Co-Investigator	.21	.21	.18	.16
Robert Granat	JPL	Co-Investigator	.18	.18	.17	.15
Margaret Glasscoe	JPL	Co-Investigator	.16	.15	.14	.15
John Rundle	UC Davis	Co-Investigator	.30	.30	.30	.30
Geoffrey Fox	Indiana University	Co-Investigator	.04	.04	.04	.04
Marlon Pierce	Indiana University	Co-Investigator	.02	.02	.02	.02
Lisa Grant	UC Irvine	Co-Investigator	.01	.01	.01	.01
Dennis McLeod	Univ. Southern Cal.	Co-Investigator	.26	.26	.26	.26
Terry Tullis	Brown University	Co-Investigator	.03	.03	.03	.03
Total Work Commitment			1.42	1.41	1.36	1.33

7.1.2. FACILITIES AND EQUIPMENT

Each of the institutions on the project has a network of computers that will be used. Standard computers are needed and are available for the work at each of the institutions. We are making use of University of Southern California's virtual storage system and are migrating our data there. We have access to the NASA Ames high performance computers, the JPL computer cluster, and the NSF XSEDE. The portal and cloud computing work will be carried out on Indiana University and University of Southern California machines. Indiana University's Community Grids Laboratory maintains a heterogeneous network-computing environment to support the lab's development and research efforts. The review and update of geologic data integration work for this project will be done at UC Irvine at Grant's Environmental Geology and GIS Laboratory. The lab currently has three dedicated, networked computers, two workstations, a laptop, color laser printers, large format poster printer, scanner and related computing equipment. The UCI campus and the School of Social Ecology have licenses for standard office software and GIS database software.

7.2. BUDGET DETAILS

This cost proposal was prepared using JPL's Pricing System and the current internally published Cost Estimation Rates and Factors dated January 2011. The derivation of the cost estimate is a grassroots methodology based on the expert judgment from a team of experienced individuals who have performed similar work. They generate the resource estimates for labor, procurements, travel, and other direct costs for each work element of the proposal. The resource estimates are aggregated and priced using JPL's Pricing System. JPL's process ensures that estimates are developed and reviewed by the performing organizations and their management who will be accountable for successfully completing the proposed work scope within their estimated cost.

The first three years will be focused on research, while the last year will be focused on infusion. However, we intend to interact with our infusion partners and as such devote a small fraction of time to infusion during the first three years of the project. We anticipate that some research will need to be done to accomplish our infusion task and hence allow for 5% of the total project for research needs.

Table 4. Percentage of research and infusion during each year of the project.

	Research ($K)	Infusion ($K)	Total ($K)	% research
Year 1	475	25	500	95%
Year 2	450	50	500	90%
Year 3	450	50	500	90%
Year 4	25	475	500	5%

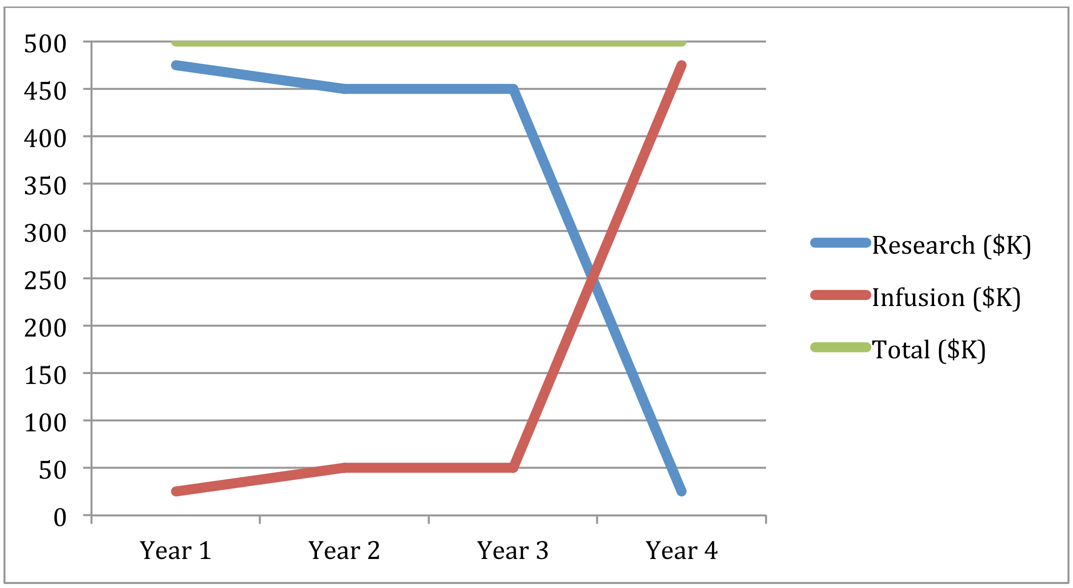


Figure 1. Research and infusion effort over the course of the project. The focus on infusion will be in year 4.

7.2.1. Budget Details

The details of the budget in each of the years closely match each other. We call out differences where they exist.

Direct Labor - JPL

- Andrea Donnellan is the PI of the project and will oversee all aspects of the work. She will devote 21% of her time to this work. Her time is spent managing the project, carrying out software development, and testing and validating QuakeSim tools.
- Robert Granat will devote 18% of his time to the project in the first two years and 17% and 15% of his time to the project in years 3 and 4. His time is spent on developing methods to

detect transients in data as well as identify other subtle features in the data through machine learning techniques.

- Jay Parker will devote 21% of his time to the project in years 1 and 2 and 18% and 16% of his time to the project in years 3 and 4. He acts as deputy PI, filling in to manage the project when necessary. He devotes much of his time to development of simulation and inversion tools, and to accessing, subsetting, and parsing data for model ingestion.
- Margaret Glasscoe is the E-DECIDER PI and a co-investigator on this project. She serves as an important liaison for development of QuakeSim and infusion efforts. She will devote 16%, 15%, 14%, and 15% of her time to the project in years 1-4 respectively.

Other Direct Costs

Equipment (in JPL Procurements: Purchase Orders)

- There are no major equipment purchases necessary.

Travel – each year

- Team members are expected to participate in QuakeSim periodic meetings, many of which are local. Team meetings tend to focus on a specific aspect of QuakeSim and as such the relevant team members may vary. We allow for two meetings per year at $1K each for a cost of $2K/yr. Participants do not incur expenses for local meetings.
- Two team members will attend the Annual Fall American Geophysical Union meeting each year. Each trip is estimated at $750 for a total of $1.5k/yr
- One team member will travel to one of the EarthScope/UNAVCO annual meeting or the Southern California Earthquake Center annual meeting. The estimated cost for this is $1K/yr.

Materials and Supplies (in JPL Procurements: Purchase Orders)

- $2K are budgeted per year for materials and supplies. These supplies include disks, web, office, or graphing software, and other miscellaneous office supplies.

Publication Costs (in JPL Procurements: Purchase Orders)

- We anticipate $1K/yr in publication charges for page charges and color figures as necessary.

Consultant Sevices (in JPL Procurements: Subcontracts)

- There are no consultants required for this task.

Subawards (in JPL Procurements: Subcontracts and Chargebacks)

- Co-I subcontract to Indiana University for Geoffrey Fox and Marlon Pierce of $65K/yr. Details are in section 7.3.1.
- Co-I subcontract to University of California, Davis for $65K/yr for John Rundle and a graduate student. Details are in section 7.3.2.
- Co-I subcontract to University of Southern California for $65K/yr for Dennis McLeod and a graduate student. Details are in section 7.3.3.
- Co-I subcontract to University of California, Irvine for $25K/yr for Lisa Grant Ludwig. Details are in section 7.3.4.
- Co-I subcontract to Brown University to Terry Tullis for $10K/yr. Tullis will be the liaison to the simulators group for infusion as well as the National Earthquake Prediction Evaluation Council (NEPEC). Details are in section 7.3.5.
- Desktop-Network Chargebacks (estimated at $5.40/ user labor hr.): All JPL computers are subject to a monthly service charge that includes hardware, software, and technical support. This service is provided through a subcontractor.

JPL Services (also includes JPL Procurements: Caltech Transfers)

- There are no JPL services required in this work.

Other Direct Costs

Budgets for NASA Co-Investigators and their associated costs are listed as “Other Direct Costs” in NSPIRES, but are by-pass costs (not subject to JPL Indirect Costs). NASA Civil Servant salaries are NOT included in these costs, nor are any NASA civil servants part of this project.

Indirect Costs

See the end of this section for a discussion of these costs. These appear in the NSPIRES budget under Indirect Costs, but per the NASA Prime Contract, are reported as Direct Costs.

	Year 1 ($K)	**Year 2 ($K)**	**Year 3 ($K)**	**Year 4 ($K)**
Multiple Program Support (MPS)	16.1	16.8	17.8	18.0
Allocated Direct Costs (ADC)	47.4	47.4	46.8	46.5
Applied General ADC	46.8	45.0	45.1	45.1
Total Estimated Costs	**497.3**	**499.9**	**499.2**	**488.6**

Timephased Cost Estimate Sheet
Dollars (Does not include Gov't Co-I's Salaries)

	Feb 2012 - Jan 2013		Feb 2013 - Jan 2014		Feb 2014 - Jan 2015		Feb 2015 - Jan 2016		Total Program		
Hours / (FTEs)											
Andrea Donnellan (PI)	376	(0.21 FTE)	377	(0.21 FTE)	377	(0.21 FTE)	384	(0.21 FTE)	1,514	(0.84 FTE)	
Robert Granat (Co-I)	318	(0.18 FTE)	318	(0.18 FTE)	310	(0.17 FTE)	271	(0.15 FTE)	1,216	(0.68 FTE)	
Jay Parker (Co-I)	376	(0.21 FTE)	368	(0.21 FTE)	330	(0.19 FTE)	288	(0.16 FTE)	1,362	(0.77 FTE)	
Maggie Glasscoe (Co-I)	288	(0.16 FTE)	273	(0.15 FTE)	254	(0.14 FTE)	275	(0.15 FTE)	1,090	(0.60 FTE)	
Total Hours:	1,357	(0.76 FTE)	1,336	(0.75 FTE)	1,270	(0.71 FTE)	1,218	(0.67 FTE)	5,181	(2.89 FTE)	*Subtotal*
Amount		$94,360		$96,870		$96,360		$96,210		$383,800	*JPL Direct Labor Cost w/o Fringe*
Fringe		$47,260		$48,520		$48,300		$48,200		$192,280	*Fringe*
Category A		$0		$0		$0		$0		$0	*Cat A Direct Labor Cost*
Total Direct Compensation (includes Employee Benefits)		$141,620		$145,390		$144,660		$144,410		$576,080	*Subtotal*
Travel		$5,000		$5,000		$5,000		$5,000		$20,000	*Direct Travel Cost*
JPL Services		$0		$0		$0		$0		$0	*Direct Services Cost*
Procurements											
Chargebacks		$7,370		$7,230		$6,860		$6,560		$28,020	*Direct Chargebacks cost*
Subcontracts		$230,000		$230,000		$230,000		$230,000		$920,000	*Direct PS cost*
Procurement RSA		$0		$0		$0		$0		$0	*Direct RSA cost*
Purchase Orders		$3,000		$3,000		$3,000		$3,000		$12,000	*Direct PM cost*
Caltech Transfers		$0		$0		$0		$0		$0	*Direct CT cost*
Multi-Program Support		$16,090		$16,780		$17,780		$18,010		$68,660	*Direct MPS cost*
Total Direct Costs		**$403,080**		**$407,400**		**$407,300**		**$406,980**		**$1,624,760**	*Subtotal*
Allocated Direct Charge		$47,440		$47,440		$46,760		$46,480		$188,120	*Total ADC*
General & Admin		$46,780		$45,040		$45,130		$45,160		$182,110	*Total G&A*
Reserves (Burdened)		$0		$0		$0		$0		$0	
Total JPL Costs		**$497,300**		**$499,880**		**$499,190**		**$498,620**		**$1,994,990**	*Subtotal*
Government Co-I's Not in JPL's Costs		**$0**		**$0**		**$0**		**$0**		**$0**	*Bypass*
Total Costs		**$497,300**		**$499,880**		**$499,190**		**$498,620**		**$1,994,990**	*Subtotal*

JPL Cost Accumulation System

Introduction

All costs incurred at the Laboratory, including JPL applied burdens, are billed to the Government as direct charges at the rates in effect at the time the work is accomplished.

Allocated Direct Costs

Allocated Direct Cost (ADC) rates contain cost elements benefiting multiple work efforts, including Project Direct, MPS, and Support and Services activities. Rate applications for cost estimates are specific to the given category as stated below:

1) Engineering and Science (E&S)
2) Procurement: Purchase Order, Subcontract, Research Support Agreement (RSA)
3) General and Administrative (G&A): Basic, RSA
4) Specialized G&A applications: Remote Site

The accounting process fully distributes these costs to the respective project/task(s).

Multiple Program Support

The Multiple Program Support (MPS) rate applies costs for program management and technical infrastructure. Cost estimates and system application tools will apply the composite rate to all project direct hours charged to projects managed by JPL.

Employee Benefits

All costs of employee benefits are collected in a single intermediate cost pool, which is then redistributed to all cost objectives as a percentage of JPL labor costs, including both straight-time and overtime. Functions and activities covered by this rate include paid leave, vacations, and other benefits including retirement plans, group insurance plans, and tuition reimbursements.

For this proposal the estimated costs have been derived in the same manner as stated above. However, presentation of the estimated costs in the required tables has been adapted in the following ways:

1. The costs for Employee Benefits are included in the Direct Labor costs stated in this proposal.
2. Engineering and Science ADC and Procurement ADC along with MPS costs are displayed in the “Other” category in the Other Direct Costs section.
3. G&A is shown in the Facilities and Administrative Costs section.
4. JPL’s forecasted labor rates equal an hourly laboratory-wide average for each job family and are further broken down by career level within the job family. Labor cost estimates apply the family average or family average career level rate to the estimated work hours. An actual individual’s labor is considered discrete and confidential information and is only released on an exception basis and only if a statement of work identifies that specific individual as the only one able to perform a task. The use of family average or family average career level rates in consistent with the JPL CAS disclosure statement and the Cost Estimating Rates and Factors CDRL published in response to a requirement in NASA prime contract NAS7-03001 I-10 (d) (1).

The proposed budget of the NRA proposal also covers labor costs for serving on NASA peer-review panels and advisory committee at the request of NASA discipline scientists or program managers.

7.3. CO-INVESTIGATOR BUDGETS

7.3.1. MARLON PIERCE AND GEOFFREY FOX - INDIANA UNIVERSITY

Period of Performance:			Salary inflation rate=	3.0%	3.0%	3.0%	3.0%
Program Solicitation:			Fringe benefit rate=	42.00%	42.00%	42.00%	42.00%
Institution: Indiana University			Indirect cost rate=	55.0%	56%	56%	56%
Organization ID: 0018093000							
A. Salaries	**Salary**	**%FTE**	**Total**	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Marlon Pierce	$104,873	2.0%	**8,775**	2,097	2,160	2,225	2,292
Jung Wang	$60,000	44.3%	**105,375**	26,580	26,327	26,265	26,203
A. Total Salaries			**114,150**	**28,677**	**28,487**	**28,490**	**28,495**
B. Fringe Benefits							
12-month fringe @ 42%			**47,943**	12,045	11,965	11,966	11,968
B. Total Fringe Benefits			**47,943**	**12,045**	**11,965**	**11,966**	**11,968**
C. Total Labor (A + B)			**162,093**	**40,722**	**40,452**	**40,456**	**40,463**
D. Total Equipment (+$5K)			**0**	**0**	**0**	**0**	**0**
E. Travel							
Domestic			**4,841**	1,213	1,215	1,210	1,203
Foreign			**0**	0	0	0	0
E. Total Travel			**4,841**	**1,213**	**1,215**	**1,210**	**1,203**
F. Participant Support Costs							
1. Stipends			**0**	0	0	0	0
2. Subsistence			**0**	0	0	0	0
3. Travel			**0**	0	0	0	0
F. Total Participant Support Costs			**0**	**0**	**0**	**0**	**0**
G. Other Direct Costs							
1. MATERIALS AND SUPPLIES			**0**	0	0	0	0
2. PUBLICATION COSTS/DOCUMENTATION			**0**	0	0	0	0
3. CONSULTANT SERVICES			**0**	0	0	0	0
4. COMPUTER SERVICES			**0**	0	0	0	0
5. OTHER - workshop meeting room services/support			**0**	0	0	0	0
6. SUBCONTRACTS			**0**	0	0	0	0
G. Total Other Direct Costs			**0**	**0**	**0**	**0**	**0**
H. Total Direct Costs			**166,934**	**41,935**	**41,667**	**41,666**	**41,666**
MODIFIED TOTAL DIRECT COSTS (Total Direct - Equipment)			**166,934**	41,935	41,667	41,666	41,666
(Total Direct - Equipment - Participant Costs)							
I. Indirect Costs 55% YR1, 56% YRs2-4			**93,064**	23,064	23,333	23,333	23,333
J. IU Total Direct and Indirect Costs			**259,998**	**64,999**	**65,000**	**64,999**	**64,999**

7.3.2. JOHN RUNDLE - UNIVERSITY OF CALIFORNIA, DAVIS

	period 1	period 2	period 3	period 3	TOTAL
	7/1/12 - 6/30/13	7/1/13 - 6/30/14	7/1/14 - 6/30/15	7/1/15 - 6/30/16	
1. Salaries					
PI: John Rundle, Professor (.5 summer mos.)	$9,044	$9,315	$9,595	$9,883	$37,836
Graduate Student Researcher (Step 7)					
Academic Year - 50% for 1 quarter	$6,497	$6,692	$6,892	$7,099	$27,180
Summer - 75%	$9,461	$9,745	$10,037	$10,339	$39,582
Total Salaries	$25,002	$25,752	$26,524	$27,320	$104,598
2. Benefits (UCD Composite Rates used)					
PI	$2,731	$2,860	$2,984	$3,370	$11,945
GSR	$207	$214	$220	$227	$868
Total Salaries and Benefits	$27,941	$28,825	$29,729	$30,917	$117,411
3. Travel					
Domestic	$1,500	$1,500	$1,500	$1,500	$6,000
Foreign	$6,500	$6,500	$6,500	$5,750	$25,250
Total Travel	$8,000	$8,000	$8,000	$7,250	$31,250
4. Other Direct Costs					
Materials and Supplies	$2,567	$1,413	$759	$249	$4,988
Publication Costs	$1,000	$1,000	$750	$525	$3,275
Graduate Student Fee Remission (1 student; 1 qtr)	$4,158	$4,573	$4,573	$5,031	$18,335
Total Other Direct Costs	$7,725	$6,986	$6,082	$5,805	$26,598
Total Direct Costs	$43,665	$43,812	$43,811	$43,971	$175,259
Modified Total Direct Costs	*$39,508*	*$39,238*	*$39,238*	*$38,941*	*$156,924*
5. Indirect Costs					
@ 54% modified Total Direct Costs	$21,335	$21,189	$21,189	$21,029	$84,742
Total Amount Requested	**$65,000**	**$65,000**	**$65,000**	**$65,000**	**$260,001**

Senior Personnel: We request two weeks of summer salary for John Rundle (Co-PI) for each year of the proposal including benefits. Rundle will take primary responsibility for supervising the project and maintaining progress and milestones.

Other Personnel: We request funding for a 1.0 graduate student researchers at % for one academic quarter (3 months) and at 75% in the summer. Costs are included for benefits and fee remissions for the graduate student researcher,

Travel: Domestic travel is requested for the PI to travel to the Jet Propulsion Laboratory in Pasadena. This will cover approximately two trips per year with a stay of 2-5 days. International travel is for trips to the AOGS meeting in Singapore, Hong Kong, then Beijing.

Computers and Software. We request funding to purchase 2 dedicated workstations for modeling and simulations, as well as to provide access to the Columbia supercomputer at NASA Ames Research Center in Mountain View, CA.

Publication Costs: Requested to publish results of this research.

Indirect Cost: Indirect cost rate: 54% MTDC. Cognizant federal agency is Department of Health and Human Services (DHHS). Date of agreement: June 27, 2011.

7.3.3. Dennis McLeod University of Southern California

	Rates	02/01/12 to 01/31/13 12 mos	02/01/13 to 01/31/14 12 mos	02/01/14 to 01/31/15 12 mos	02/01/15 to 01/31/16 12 mos	Total 48 mos
SALARIES						
Principal Investigator						
Dennis James Mc Leod						
75% effort, 1.5 summer months	*75.00%*	19,919	20,716		-	40,635
70% effort, 1.5 summer months	*70.00%*			20,108		20,108
67.5% effort 1.5 summer months	*67.50%*				20,166	20,166
TOTAL SALARIES		19,919	20,716	20,108	20,166	80,909
FRINGE BENEFITS						
FY 11 FB & Beyond	***31.60%***	6,294	6,546	6,354	6,372	25,567
WAGES NOT SUBJECT TO FB						
Graduate Research Assistant						
50% effort, 3 summer months	*50.00%*	6,667	6,933	7,211	7,499	28,310
Base Salary 11-12: $40,000/9	*$40,000*					
Total Compensation		32,880	34,195	33,673	34,037	134,786
MATERIALS & SUPPLIES		2,468	1,500	1,597	858	6,422
Software additional supplies						
TRAVEL		3,000	2,500	2,800	3,000	11,300
Project working meetings and conferences						
TUITION REMISSION		2,270	2,360	2,455	2,553	9,637
FY 12-6 units/year/RA @ $1,513/unit						
Total Direct Costs		40,617	40,555	40,524	40,448	162,145
F & A Base (Total Direct Costs less equipment and tuition and only first $25,000 of Subaward)						
F & A Base FY 12		*15,978*				
F & A Base FY 13-14		*22,370*	*38,195*	*15,862*		
F & A Base FY 15				*22,207*	*15,790*	
F & A Base FY 16 - Future					*22,105*	*152,507*
INDIRECT COSTS (F & A)						
FY 12 - F & A	*63.00%*	10,066	-			10,066
FY 13-14 - F & A	*64.00%*	14,317	24,445	10,152	-	48,913
FY 15 - F & A	*64.50%*			14,324	10,184	24,508
FY 16 - Future - F & A	*65.00%*	-			14,368	14,368
Total Indirect Costs		24,383	24,445	24,476	24,553	97,856
TOTAL COST TO AGENCY		**65,000**	**65,000**	**65,000**	**65,000**	**260,000**

Notes:

Differences may occur due to rounding.

An annual 4% increase was given to the 12 month faculty beginning July 1, 2012.
An annual 4% increase was given to the GRA beginning August 16, 2012.
An annual 4% increase was added to the Tuition beginning August 16, 2012.

Per the Federal Rate Agreements from March 2, 2010 and December 30, 2010 the following Fringe Benefit and Indirect Cost Rates apply:

Fringe Benefits		
07/01/11 - 06/30/2012	*31.60%*	Predetermined
07/01/12 - Future	*31.60%*	Provisional
Indirect Costs		
07/01/11 - 06/30/2012	*63.00%*	Predetermined
07/01/12 - 06/30/2014	*64.00%*	Predetermined
07/01/14 - 06/30/2015	*64.50%*	Predetermined
07/01/15 - 06/30/2016	*65.00%*	Predetermined
07/01/16 - Future	*65.00%*	Provisional

7.3.4. *LISA GRANT - UNIVERSITY OF CALIFORNIA, IRVINE*

1. Direct Labor

   Salaries

   Lisa Grant Ludwig $9k

   Student assistant $1.5k

   benefits $2.5k

2.d. software and computing supplies $1k

2.e. conference travel and project meetings $2k

3. Facilities and Administrative costs $9k

TOTAL $25k per year

7.3.5. *TERRY TULLIS - BROWN UNIVERSITY*

1. Direct Labor: $5,700 salary + $473 Fringe benefits = $6,173

3. Overhead (Indirect administrative costs): $3,827

   Total cost $10,000

8. Special notifications and/or Certifications

None