Summary and Impact of SCEC Research Computing

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Southern California Earthquake Center (SCEC)

- Mission: solve problems in earthquake system science
  - Understand and model the physics of earthquake processes, from tectonic stress to fault rupture to ground motions
  - Use SoCal as our natural laboratory
- Large collaborative center
  - Multi-disciplinary Planning Committee develops yearly science plan
  - Support fundamental AND applied science
  - Over 1,000 participants
  - 18 core institutions, 44 domestic participating institutions, 13 international
- NSF & USGS funded center

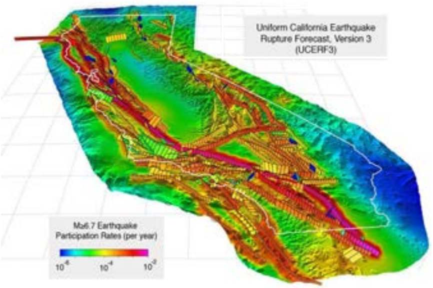
Special Projects: coordinated research activities in targeted research

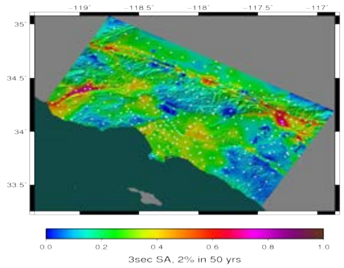
Portfolio consists of all the projects supported by programs *other* than Core NSF and USGS

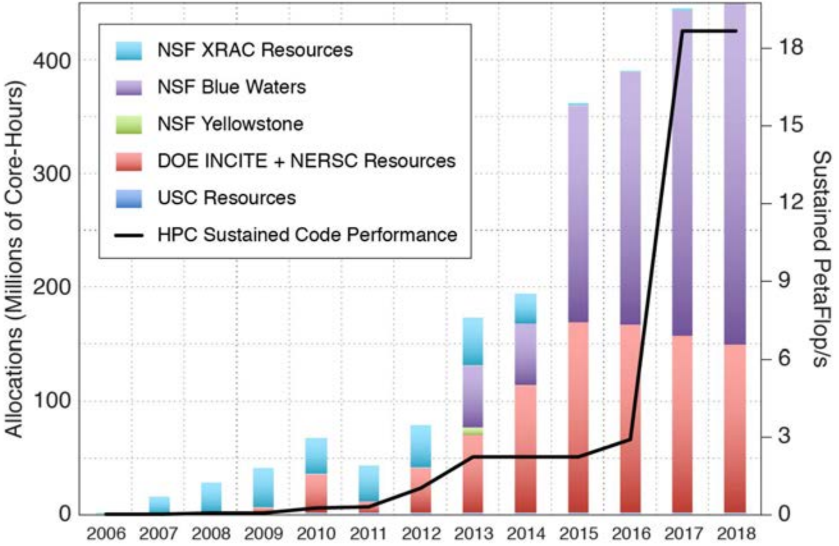
Leverage and support Core Program goals and activities

Provide additional resources

- Funding (NSF SSI/CSSI and Geoinformatics programs,PG&E, W.M. Keck Foundation, others)
- High Performance Computer (HPC) allocations (INCITE, XSEDE, PRAC, ASCR/ALCC, USC HPCC)







SCEC Extreme-Scale Earthquake Computations

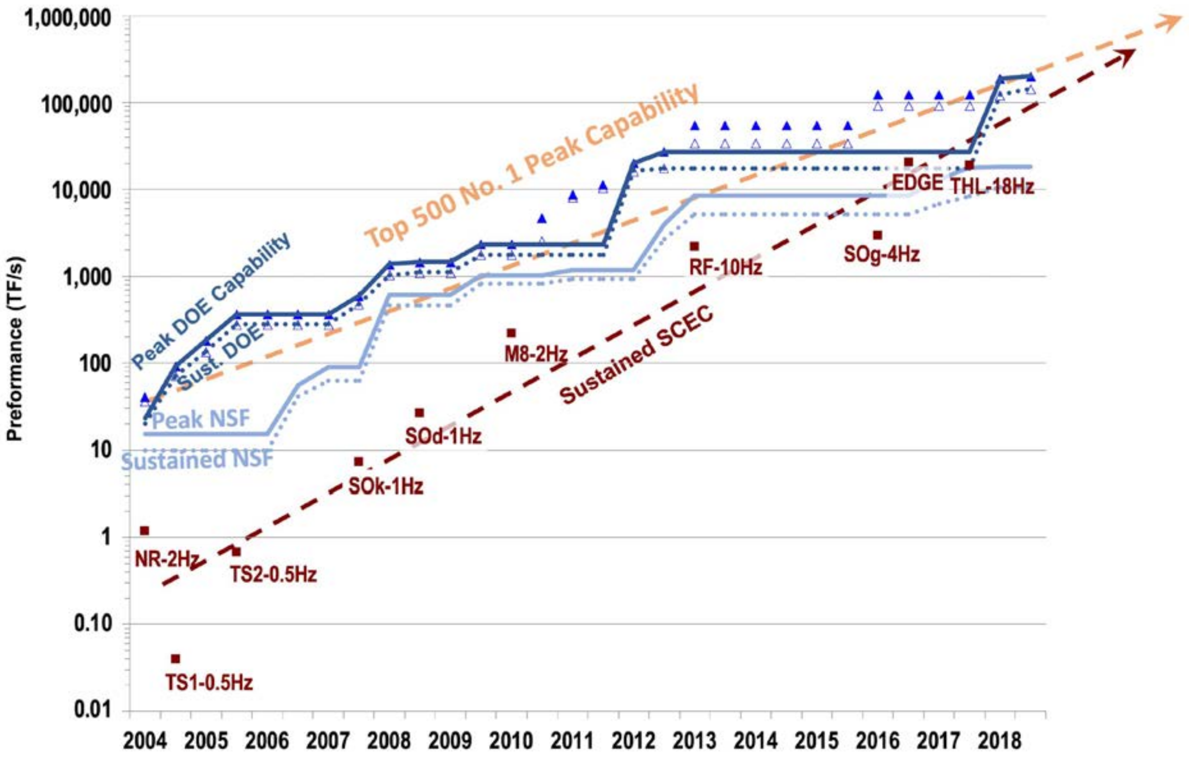


Figure 2. Improvements of SCEC HPC codes over the years, its scale increase has tracked the performance of the largest HPC systems, demonstrating the earthquake modeling needs has remained on the "bleeding edge" of HPC-enabled research. NR – Hercules Northridge (Akcelik et al., 2003); TSk - TeraShake kinematic source (Olsen et al., 2004); TSd - TeraShake dynamic source (Olsen et al., 2008); SOk - ShakeOut kinematic sourc (Olsen et al., 2007); SOd - ShakeOut dynamic source (Olsen et al., 2009); M8 - Wall-to-Wall (Cui et al., 2010); RF – Rough fault (Cui et al., 2013); SOg – ShakeOut with plasticity (Roten et al., 2016); TF - Tangshan fault (Fu et al., 2017); EDGE: Extreme-scale Discontinuous Galerkin Environment (Breuer et al., 2017). Allocated SCEC computing core-hours on national HPC facilities operated by NSF PRAC/XRAC and DOE INCITE reaches 450M in 2018.

SCEC Community Model Environment (CME)

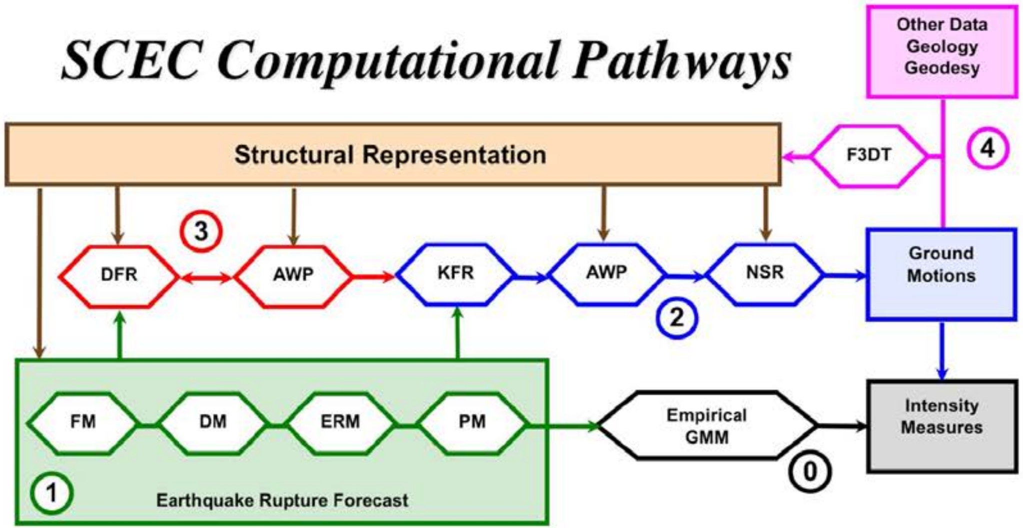
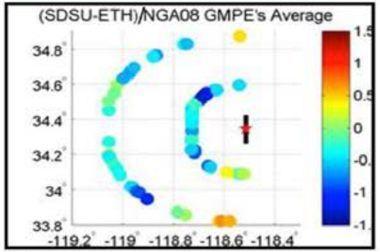
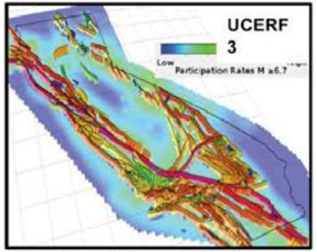


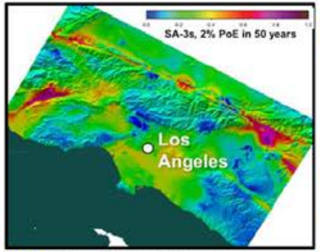
Figure 1. Wiring diagram for the SCEC computational pathways of earthquake system science (left) and large-scale calculations exemplifying each of the pathways (below). (0) SCEC Broadband Platform use for the development of empirical ground-motion models (GMMs), run on USC clusters (1) Uniform California earthquake rupture forecast, UCERF3, run on TACC *Stampede*. (2) CyberShake ground motion prediction model 15.4, currently run on NCSA *Blue Waters* (3) Dynamic rupture model including fractal fault roughness, run on XSEDE *Kraken*. (4) 3D velocity model for Southern California crust, CVM-S4.26, run on ALCF *Mira*. Model components include dynamic and kinematic fault rupture (DFR and KFR), anelastic wave propagation (AWP), nonlinear site response (NSR), and full-3D tomography (F3DT).



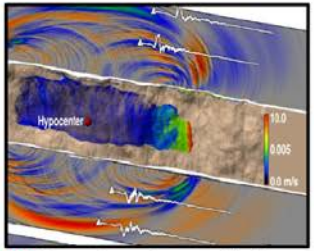
0 SCEC Broadband Platform and Empirical GMM Development



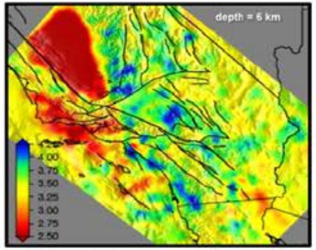
1 Uniform California Earthquake Rupture Forecast (UCERF3)



2 CyberShake 15.4 seismic hazard model for LA region

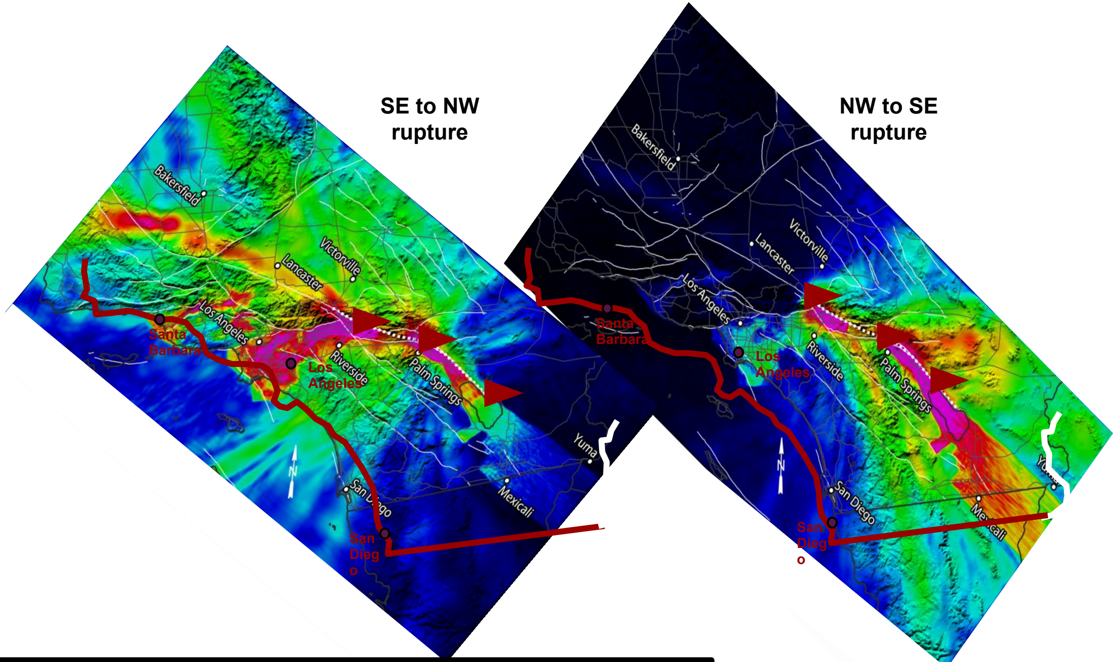


3 Dynamic rupture model of fractal roughness on SAF



4 Full-3D tomographic model CVM-S4.26 of S. California

TeraShake Simulations of M7.7 Earthquake on the San Andreas Fault



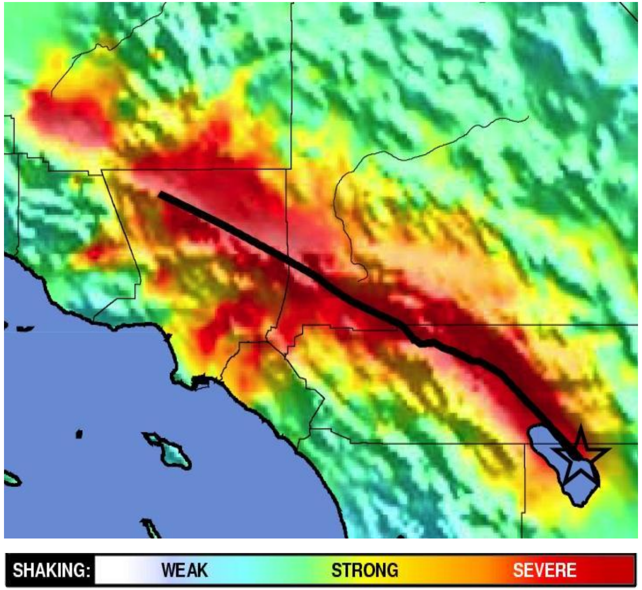
Olsen, K. B., S. Day, J. B. Minster, Y. Cui, A. Chourasia, M. Faerman, R. Moore, P. Maechling & T. H. Jordan (2006)

Simulations indicated strong 3D focusing of ground motions from strike-slip faults in Southern California

- **Quantified the importance of source directivity AND basin excitation effects in earthquake forecasting and PSHA**
- **GMM used in PSHA started to include Basin terms (NGA-West1&2, 2008-2014)**

The ShakeOut Scenario: *One* Possible "Big One"

www.shakeout.org/scenario



Shaking intensity

Scenario

- M7.8 mainshock
- 180 km long rupture
- 100 sec of fault rupture
- Over 2 minutes of shaking in many places
- Simulated broadband ground motions (0-10 Hz)
- Large aftershocks
  M7.2, M7.0, M6.0, M5.7…

Impacts

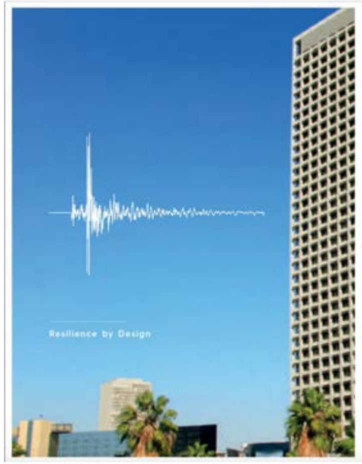
- 10,000-100,000 landslides
- 1,600 fire ignitions
- $213 billion in direct economic losses
  - 300,000 buildings significantly damaged
  - Widespread infrastructure damage
  - 270,000 displaced persons
  - 50,000 injuries
  - 1,800 deaths
- No water for months
- Long recovery time

Outcomes

- Largest emergency response exercise in US history
- Demonstrated that existing disaster plans were inadequate for an event of this scale
  - Motivated reformulation of system preparedness and emergency response
  - Scientific basis for the LA Seismic Task Force report, *Resilience by Design*

Impact on City of LA

RESILIENCE BY DESIGN (DECEMBER 2014)

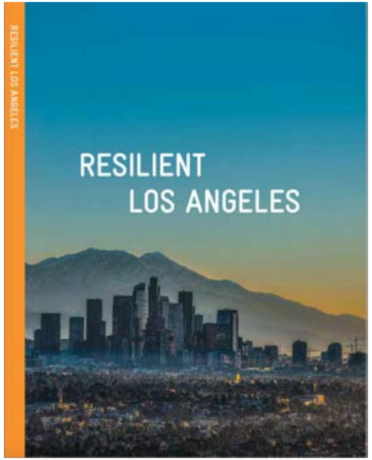


"This Report's approach to evaluating the severity of the risk relies on the ShakeOut Scenario… created by a multidisciplinary team convened by the Multi-Hazards Demonstration Project of the USGS…"

Team included USGS, CGS, FEMA, SCEC, and nearly 200 other partners in government, academia, emergency response, and industry.

… address Los Angeles' greatest earthquake vulnerabilities, including **seismic retrofits for buildings** and steps to **secure our water supply** and **communications infrastructure**. Recommendations of the Mayoral Seismic Safety Task Force and suggests strategic solutions to protect the lives of our residents; improve the capacity of the City to respond to earthquakes; prepare the City to recover quickly from earthquakes; and protect the economy.

RESILIENT LOS ANGELES (MARCH 2018)



…strategy to build the city's resilience through leadership and engagement, **disaster preparedness and recovery, economic security**, climate adaptation, and infrastructure modernization. 15 goals, 96 actions.

Advance seismic safety, prioritizing the most vulnerable buildings, infrastructure, and systems

The Great ShakeOut Earthquake Drills

- Schools, organizations, and families practice earthquake safety and other aspects of their emergency plans
- 2018: **62+ million** people worldwide
- Learn more and register:
  ShakeOut.org

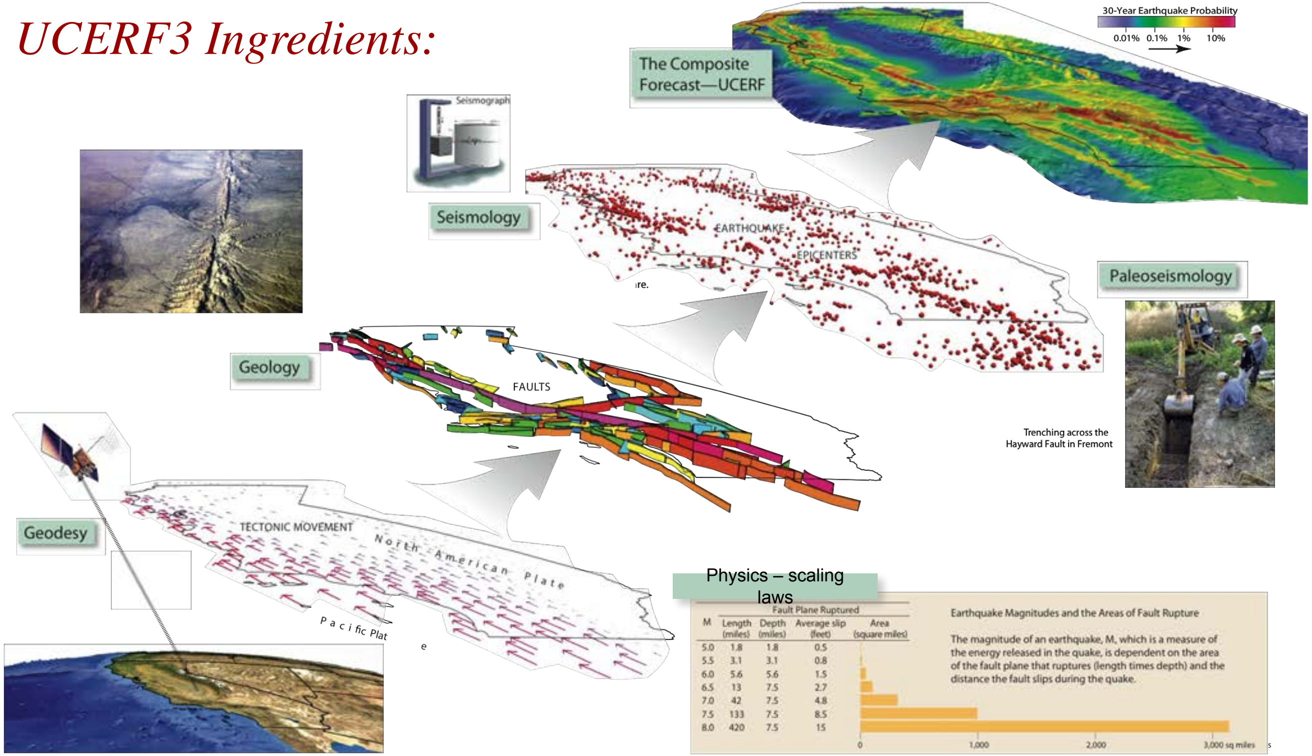
In *most* situations and building types:

ShakeOut websites are now online in English, Spanish, French, Italian, and Japanese.

Uniform California Earthquake Rupture Forecast 3 (UCERF3)

(CEA)

UCERF3 Ingredients:



M	Fault Plane Ruptured Length (miles)	Depth (miles)	Average slip (feet)	Area (square miles)
5.0	1.8	1.8	0.5	
5.5	3.1	3.1	0.8	
6.0	5.6	5.6	1.5	
6.5	13	7.5	2.7	
7.0	42	7.5	4.8	
7.5	133	7.5	8.5	
8.0	420	7.5	15	

"Grand Inversion" to obtain
- Updated MFD that match observations
- Updated slip rates

UCERF3 allows large low probability ruptures not accounted for before

UCERF3 used to refine CA model for National Seismic Hazard Maps used in Building Code

Impacted insurance rates in CA

SCEC-USGS-CGS collaboration

Broadband Platform (BBP)
(PG&E)

BBP is an open-source distribution

Broadband 0.1-20+ Hz (deterministic up to ~ 1Hz)

Simple source and path (1D)

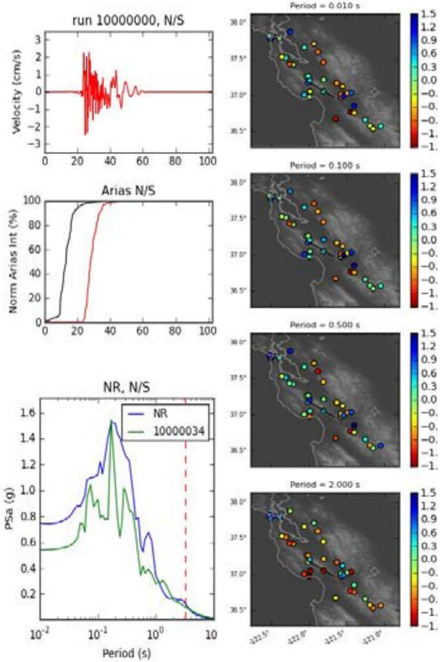
7 alternative simulation codes

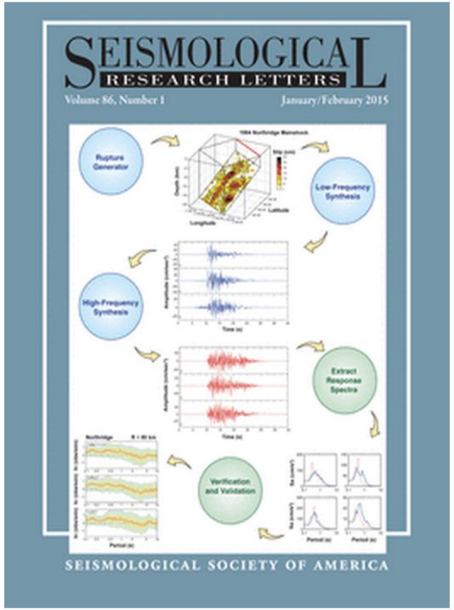
Validated for spectral response

- **19 worldwide events, 2 generations of empirical GMMs**
- **Multiple rounds of validation/improvements**
- **Independent review panel**

Continuation of work in 2019

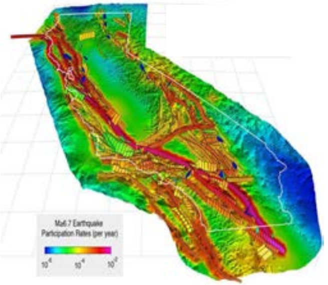
Used for large ground motion characterization projects: NGA-West2, NGA-East, NPP design (SWUS)





SRL Special Focus on BBP Validation – 9 papers - Jan. 2015

CyberShake: PSHA from Physics-Based Simulations



Earthquake Rupture Forecast
(e.g. UCERF)

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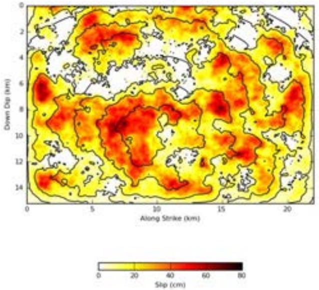

Kinematic source models

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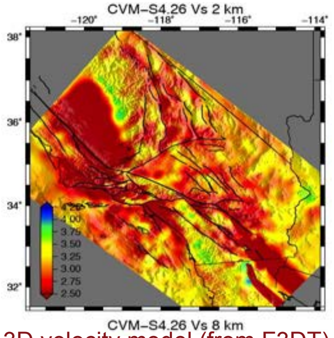

3D velocity model (from F3DT)

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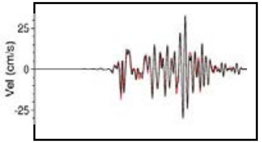
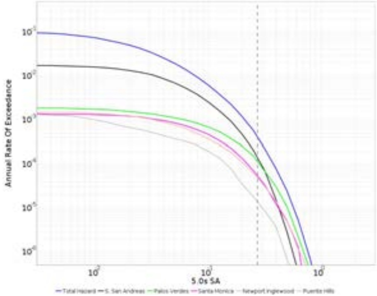
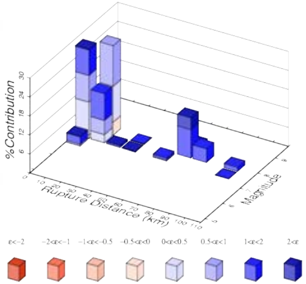


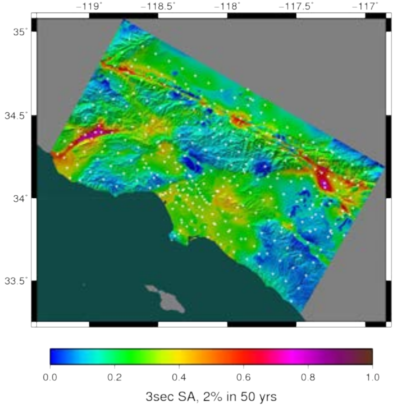
Seismograms
and intensity measures



Hazard Curves and
fault disaggregation

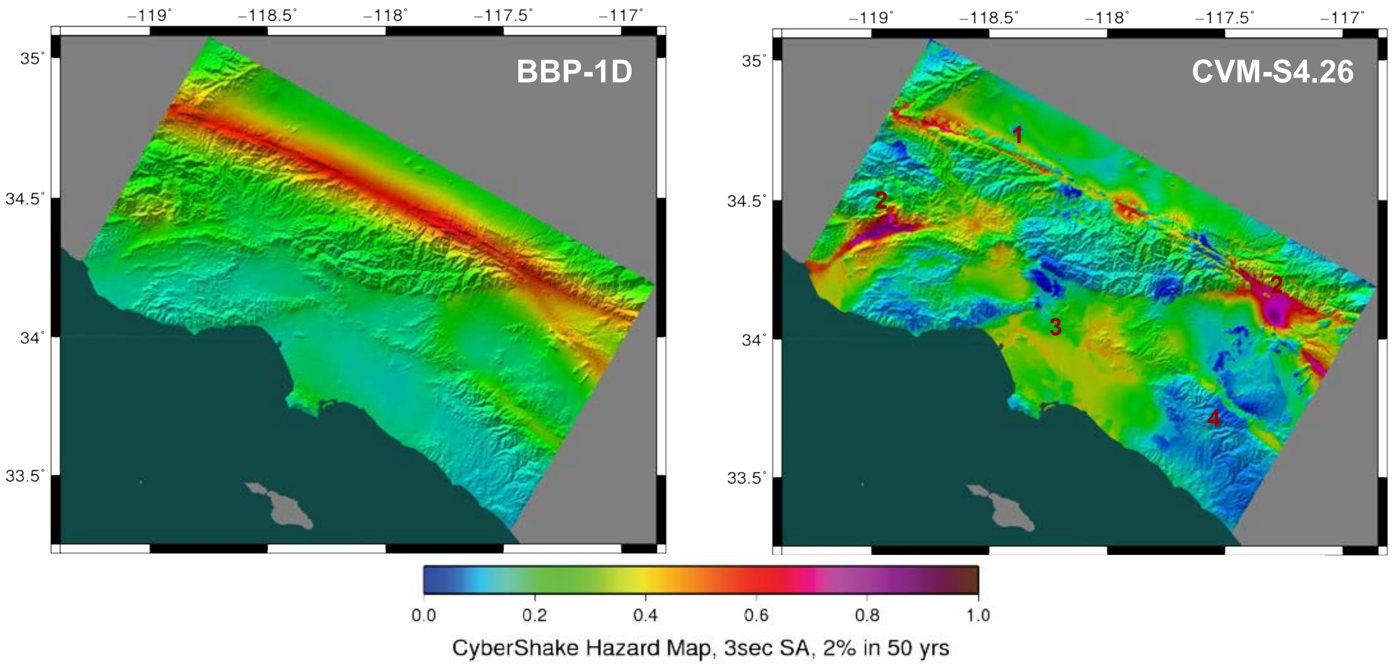


M, R, ε
disaggregation



Hazard maps

Comparison of 1D and 3D CyberShake Models for the LA Region



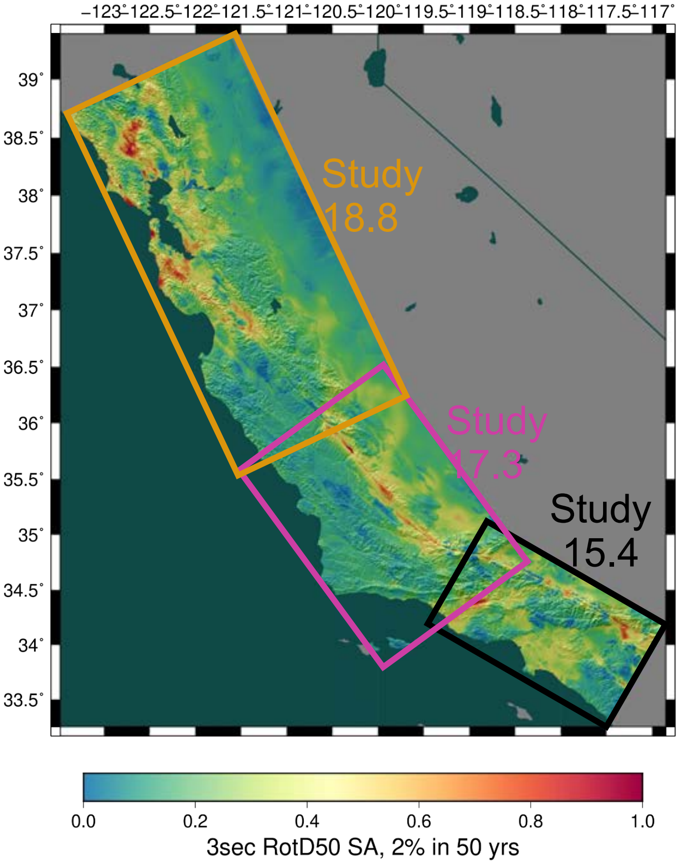
1. lower near-fault intensities due to 3D scattering
2. much higher intensities in near-fault basins
3. higher intensities in the Los Angeles basins
4. lower intensities in hard-rock areas

CyberShake Study 18.8 (NorCA)

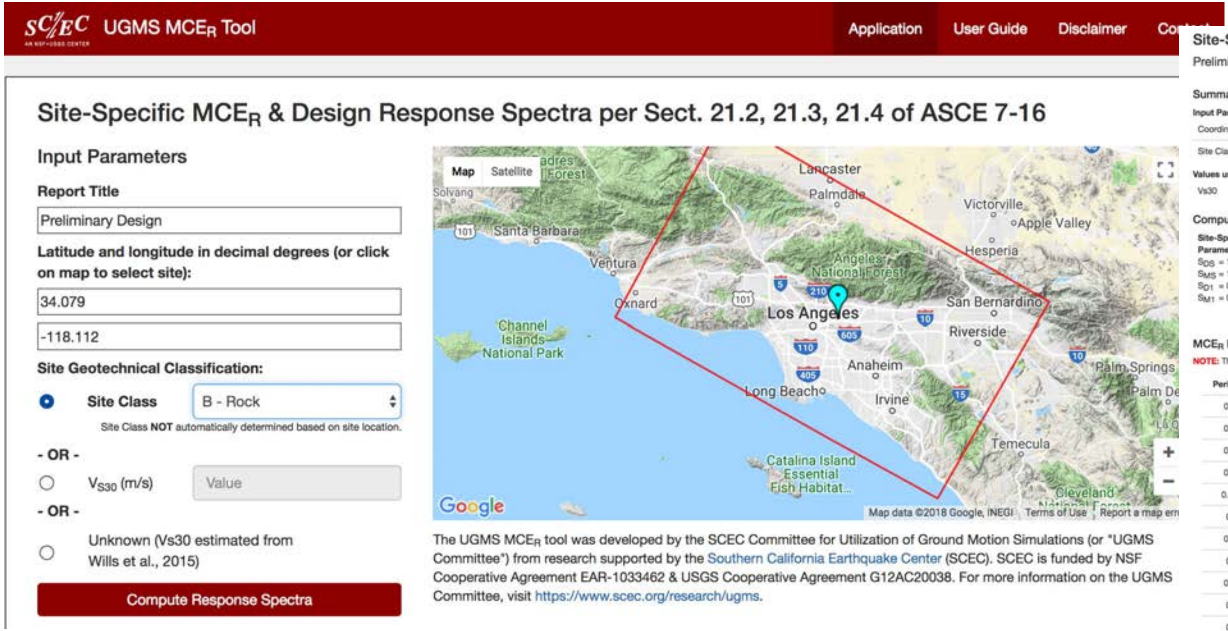
- ~ 500,000 events per site; using reciprocity (assumes linearity)

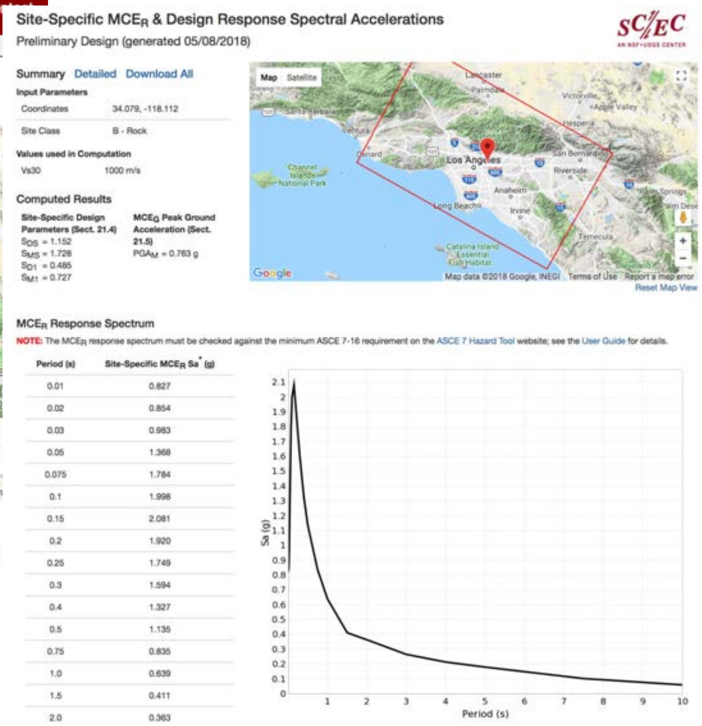
- Study conducted over 128 days
  - NCSA *Blue Waters*, OLCF *Titan*
- Consumed 6.2 million node-hours (120 million core-hours/13,650 core-years)
  - Averaged 2,018 nodes / 38,850 cores
- 1.2 PB of data generated
  - 14.4 TB of final data products
- Synthesized 203 million two-component seismograms
  - 30.4 billion intensity measures

- Require several codes, workflow tools (Pegasus), resource management tools (HTCondor), etc.



Tall building design: CyberShake-based MCE_R tool

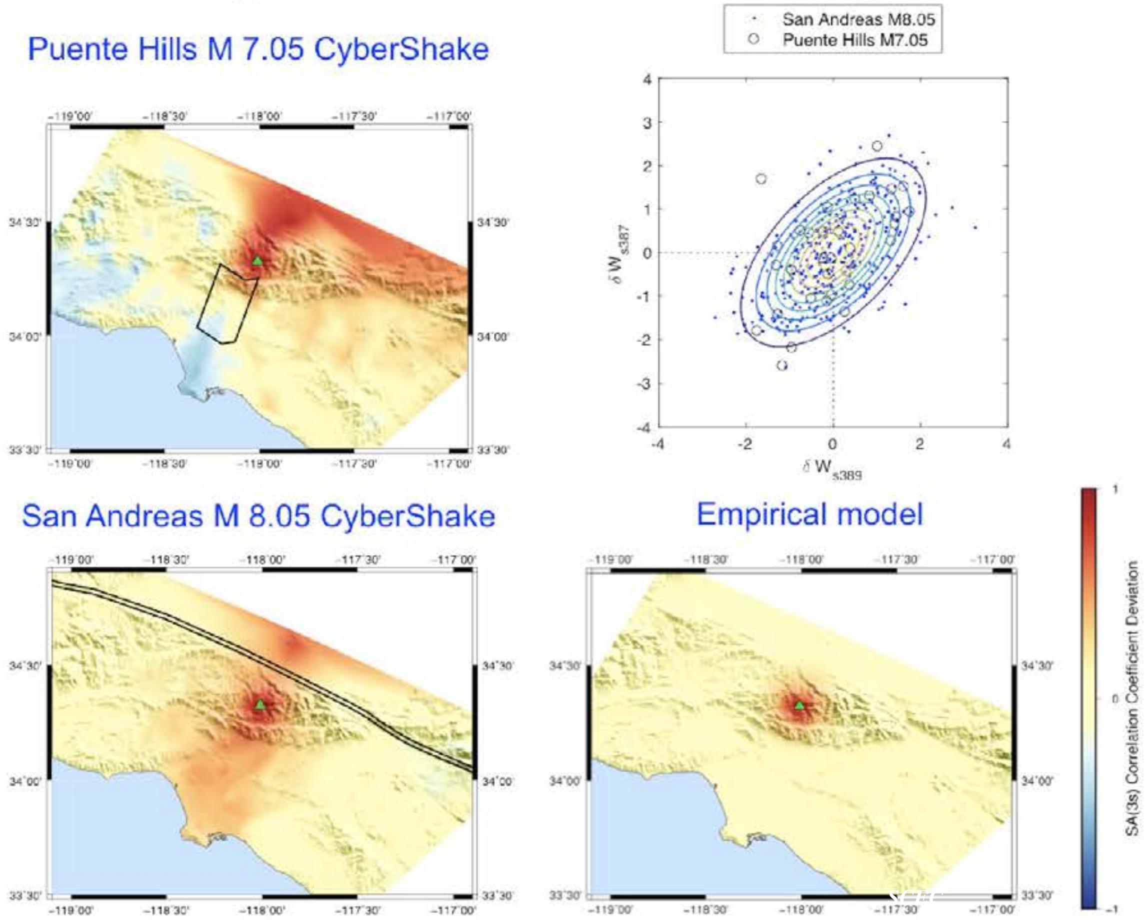




Period (s)	Site-Specific MCE_R Sa* (g)
0.01	0.827
0.02	0.854
0.03	0.983
0.05	1.368
0.075	1.784
0.1	1.998
0.15	2.081
0.2	1.920
0.25	1.749
0.3	1.594
0.4	1.327
0.5	1.135
0.75	0.835
1.0	0.639
1.5	0.411
2.0	0.363

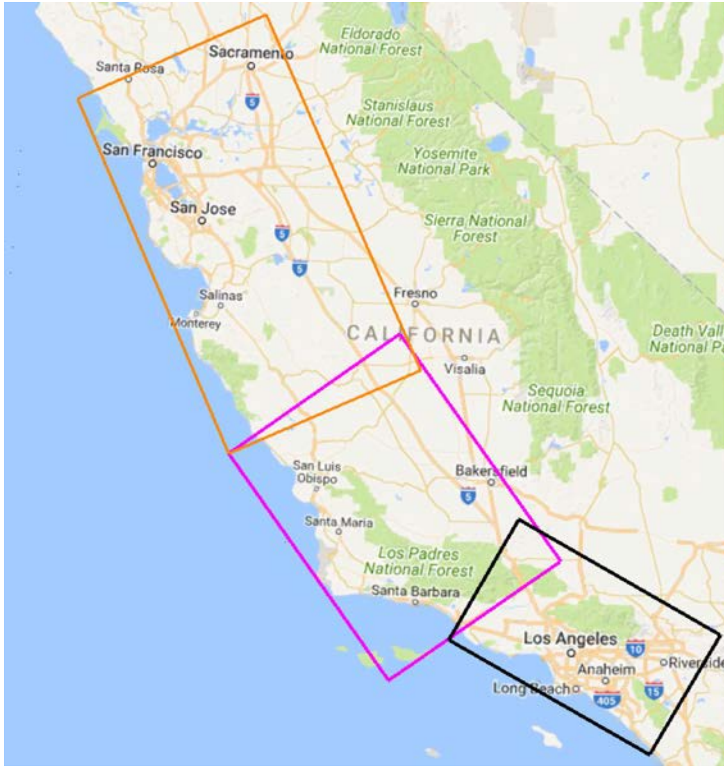
https://data2.scec.org/ugms-mcerGM-tool_v18.4/

Nonstationary ground motion spatial correlations in CyberShake simulations, and implications for regional risk analysis



Validation of CyberShake's source and path heterogeneities. Provides greater insights than sparse recordings can provide. These correlations are important when assessing risk to distributed infrastructure systems (e.g., as indicated in impacts to risk shown in the top right figure). Baker et al. in progress

CyberShake



CyberShake is a transformative step towards physics-based PSHA

- First simulation-based PSHA model
- Leading model in USGS Urban Seismic Hazard Mapping Project; source of new design maps under consideration by building code update
- Used as database for machine-learning of California Earthquake Early Warning system
- For consideration by LA Tall Buildings Structural Design Council
- Results used for understanding spatial variability of ground motions

Software Environment for Integrated Seismic Modeling (SEISM – SEISM2)
(NSF SSI)

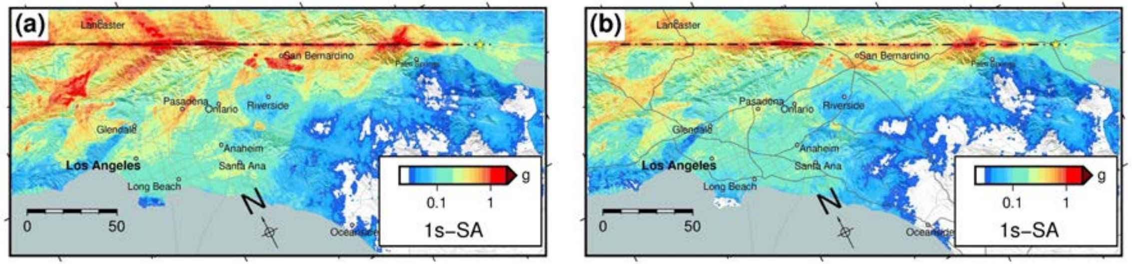
High-F project

Pushing deterministic ground-motion simulations to higher frequencies (~10Hz) while

- **Improving computational efficiency**
- **Adding more realistic physics:**
  - **near-fault plasticity**
  - **fault roughness**
  - **small-scale near-surface heterogeneity**
  - **frequency-dependent attenuation, Q(f)**
  - **topography**
  - **near-surface nonlinearity**

Spectral Acceleration at 1s, PSA(1s): Linear

PSA(1s): Nonlinear, Good-Average Rock Quality



Roten et al. 2017

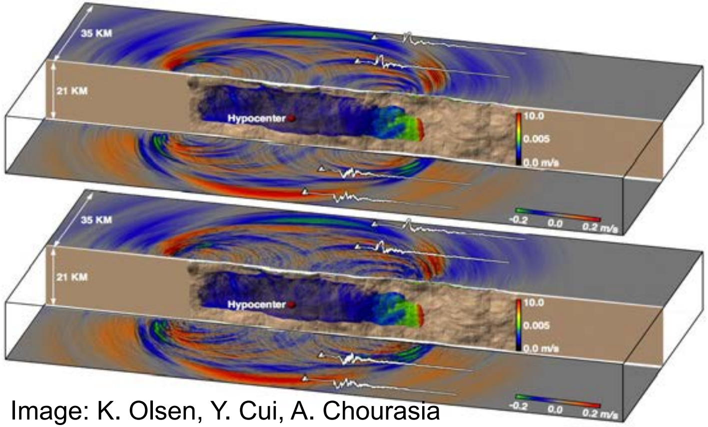
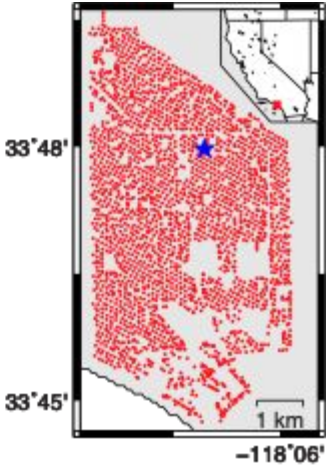


Image: K. Olsen, Y. Cui, A. Chourasia

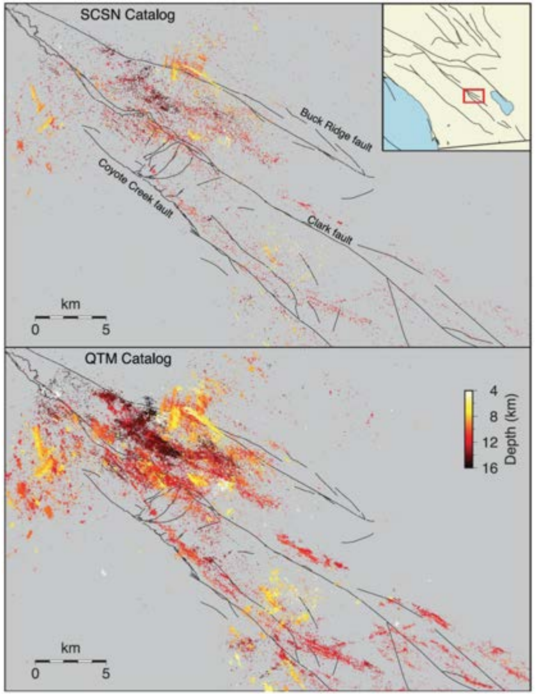
Mining Seismic Wavefields
(NSF Geoinformatics)

Seismology has "big data"



Big Networks (Large-N)
1000s of sensors

Developed new scalable (big data/data mining) algorithms/cyberinfrastructure to extract more information from large seismic data volumes



Ross et al. (2019)

Long Duration (Large-T)
Years of continuous waveforms

Takeaways

- Research computing is critical to scientific progress
- Research computing is necessary to integrate results of research into meaningful products
- Simulation results are already impacting the design of human infrastructure
- Collaboration is essential across disciplines
- Research computing demand keeps increasing; sustainability is an issue

W.M. KECK FOUNDATION

USGS science for a changing world

National Science Foundation

CEA CALIFORNIA EARTHQUAKE AUTHORITY™

U.S. DEPARTMENT OF ENERGY

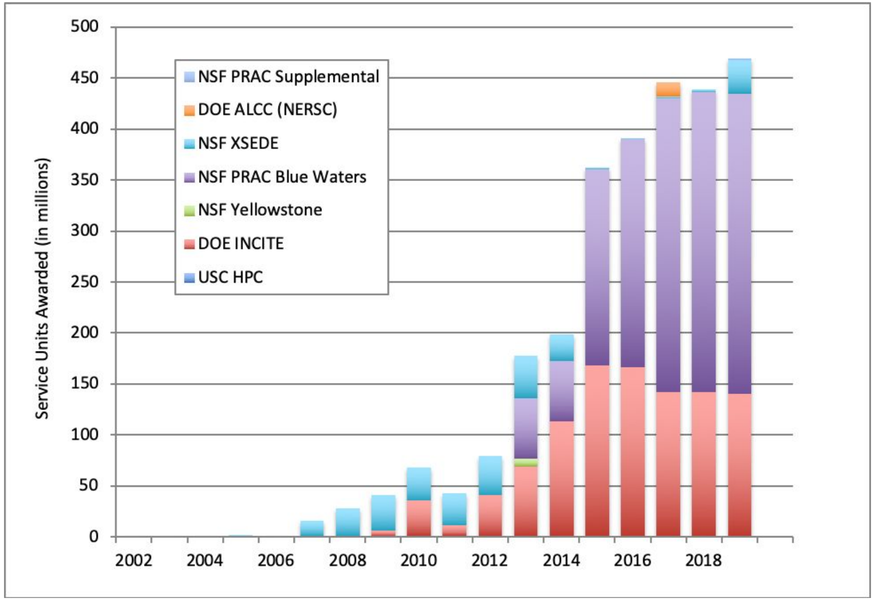
PG&E Pacific Gas and Electric Company®

NCSA

BLUE WATERS SUSTAINED PETASCALE COMPUTING

XSEDE Extreme Science and Engineering Discovery Environment

USC ITS Information Technology Services



Argonne ALCF

OLCF Oak Ridge Leadership Computing Facility

NCCS.GOV National Center for Computational Sciences

U.S. DEPARTMENT OF ENERGY INCITE LEADERSHIP COMPUTING

NICS

PITTSBURGH SUPERCOMPUTING CENTER

intel

pegasus

NWSC NCAR-Wyoming Supercomputing Center

SDSC

Open Science Grid

TACC

IBM

NVIDIA

CRAY