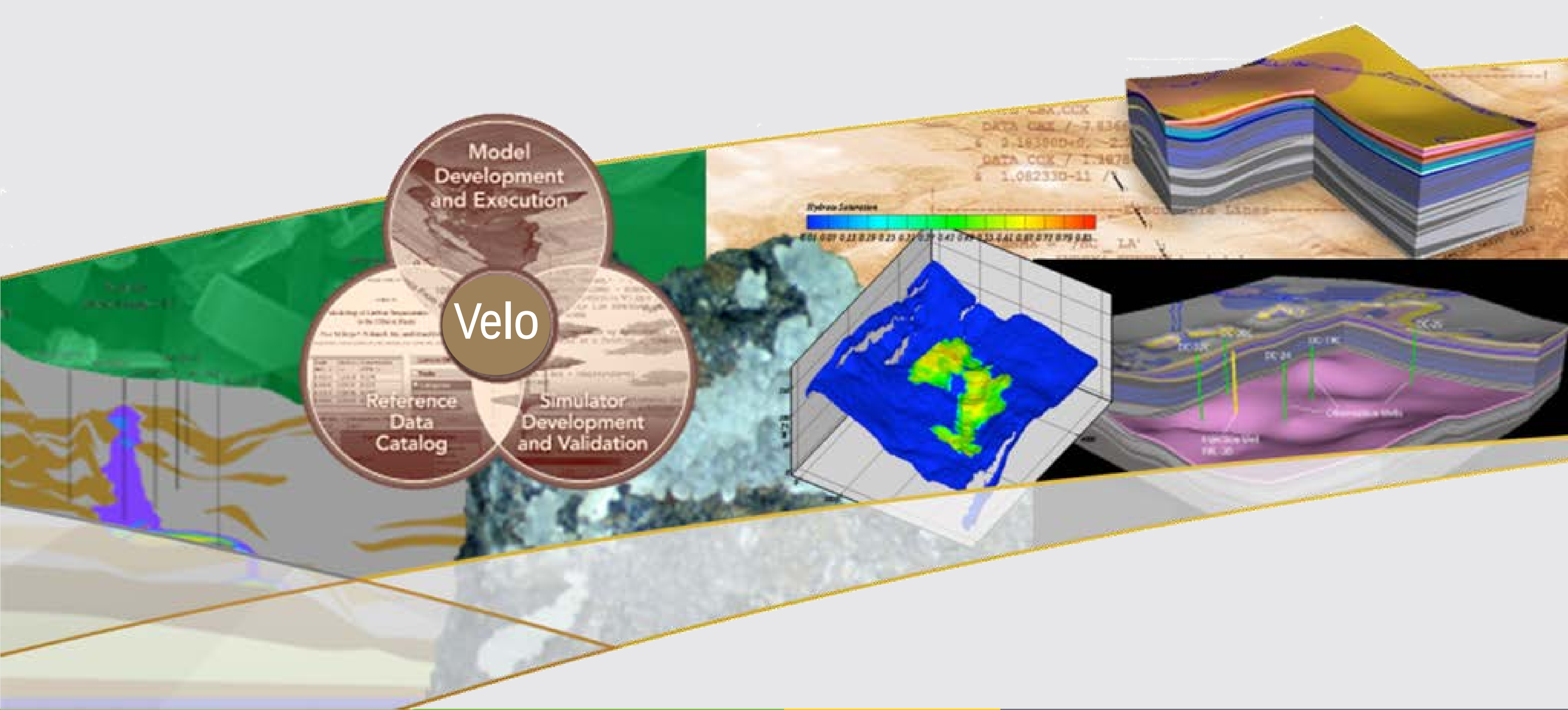

PNNL Support of the DOE GTO Model Comparison Activity

Project Officer: Lauren Boyd

Total Project Funding: $550,000

April 23, 2013

Principal Investigator: Tim Scheibe

Pacific Northwest National Laboratory

Modeling Track

PNNL-SA-94295

Relevance/Impact of Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Project Objective: Identify and quantify strengths and weaknesses of diverse numerical simulation codes for geothermal technology design and evaluation

Challenges and Knowledge Gaps:

- Use of numerical simulation of subsurface processes is increasing because of a strong need for quantitative design and evaluation prior to undertaking major investment, aided by significant recent advances in numerical simulators and computational power
- However, model predictions are inherently uncertain
  - Natural environment is not controlled like the engineered environment
  - Ubiquitous heterogeneity across many orders of magnitude of length scale
  - Limited access to and difficulty of characterizing the subsurface environment
  - **Diverse assumptions, process descriptions and numerical solution techniques are embodied in a wide range of highly complex and computationally intensive simulation codes**
- There has not been a major benchmarking study for geothermal simulators since the Stanford study of 1981

Project Impacts:

Rigorous testing and comparison of several codes on common problems will 1) improve understanding of, and confidence in, code performance, 2) identify areas of need for code improvements, and 3) provide a baseline for evaluating progress when code advancements are made

- Increase reliability of EGS reservoir engineering and management strategies, especially in areas of permeability enhancement and evolution
- **Support GTO Goals for Enhanced Geothermal Systems**
  - Demonstrate 5 MW reservoir creation by 2020
  - Lower LCOE to 6 cents/kWh by 2030

Innovative Aspects:

Use of a web-based wiki platform for collaboration and knowledge management (“Velo”)

- Efficient implementation and strong interaction among participating teams
- Improve documentation of codes, problems, and solution
- Provide a long-term resource to the broader community

Scientific/Technical Approach

- Implement initial custom instance of Velo for demonstration to IPGT and GTO
- Coordinate with IPGT Reservoir Modeling Working Group
- Invite broad participation by GTO-funded modeling groups
- Conduct workshop to refine objectives and define specific test case and challenge problems
- Implement custom tools and information on Velo
- Coordinate simulation process and compilation of results
- Conduct follow-up workshop to review results
- Publish results in peer-reviewed journal article(s)

Accomplishments, Results and Progress

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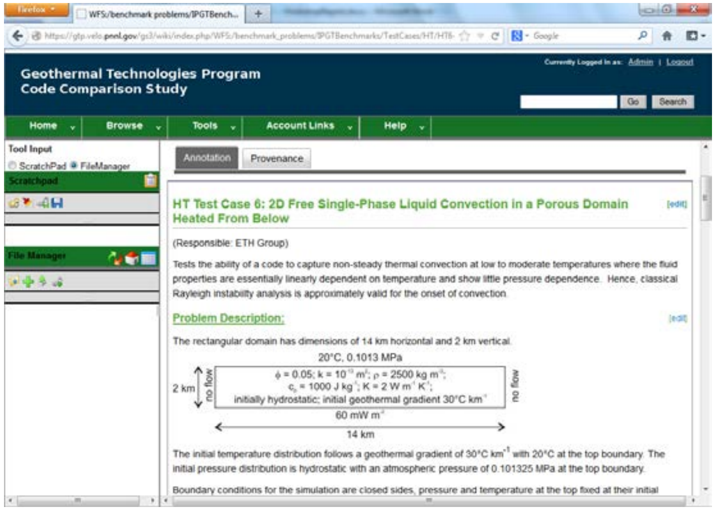
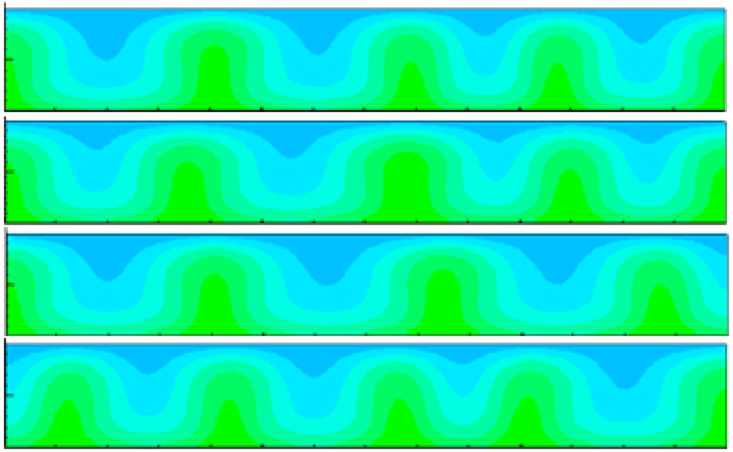
Original Planned Milestone/ Technical Accomplishment	Actual Milestone/Technical Accomplishment	Date Completed
Stand up Velo instance for demonstration at IPGT workshop (9/15/2012).	Velo instance was implemented and demonstrated at the IPGT workshop	9/15/2012 (demo on 9/24/2012)
Conduct a kickoff workshop and identify initial benchmark problems (1/31/2013)	Kickoff workshop with ~40 participants was held and nine test case problems were identified	2/14/2013
Integrate custom elements into the geothermal Velo instance (4/30/2013)	Custom elements include problem descriptions, customized data dictionary, code catalog, discussion forum. Over 20 accounts have been issued.	On schedule

Velo Implementation:

- A web-based knowledge and data management framework for numerical simulation and modeling
  - Semantic wiki interface; users can contribute and modify content in collaboration
  - Alfresco data back end; facilitates storage of data and metadata, supports versioning and history
- Previously developed at PNNL, highly customizable to broad set of applications
  - Automated methods for comparing problem solutions
  - Visualization capabilities
  - Automated parsing of relevant documents using a custom data dictionary
  - Interactive development of problem descriptions and online sharing of solutions
  - Online discussion using customized user forum
  - A code catalog containing information on the methods and capabilities of each numerical code
  - Tracking of team progress with a checklist/dashboard tailored to code capabilities





Accomplishments, Results and Progress

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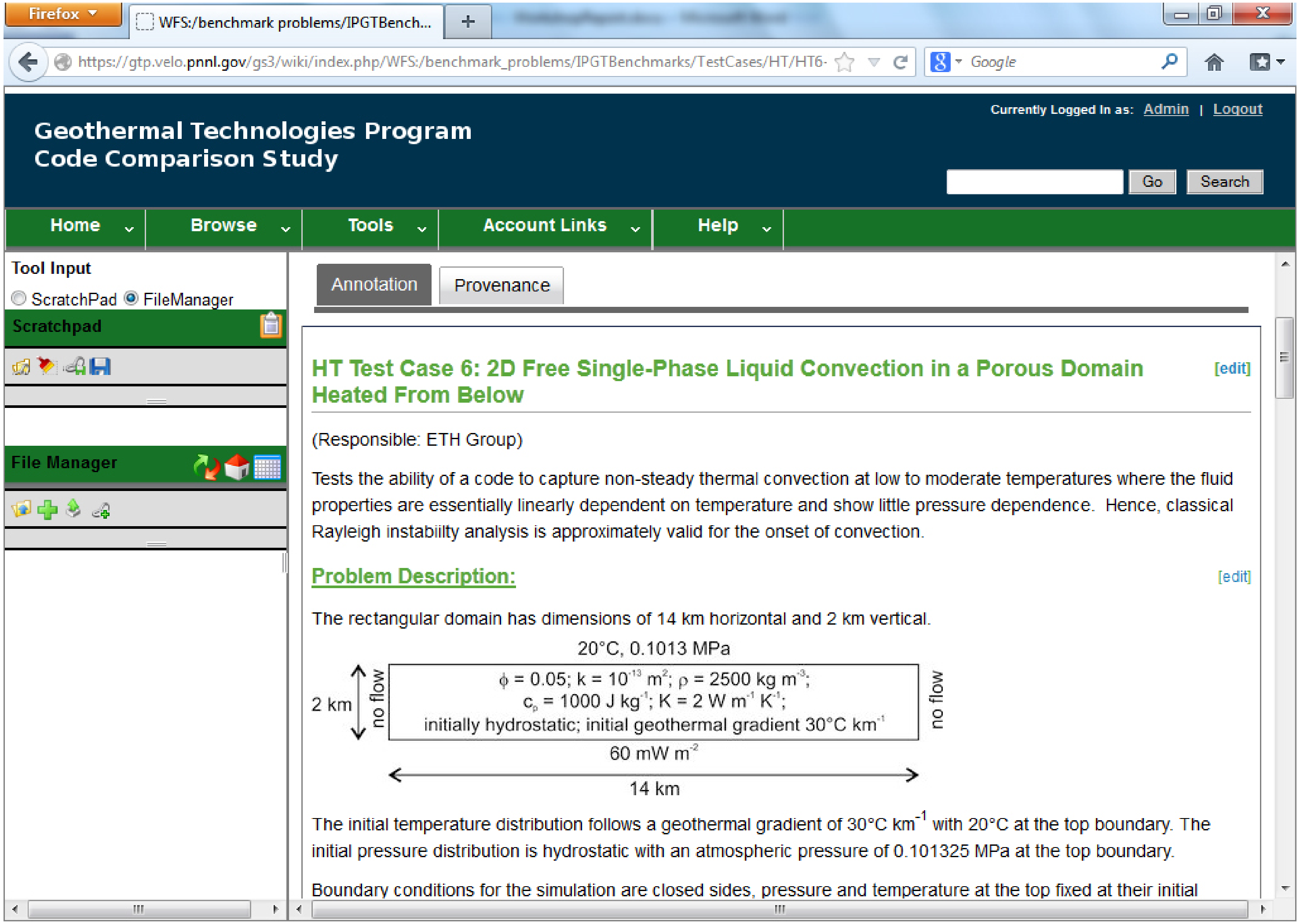
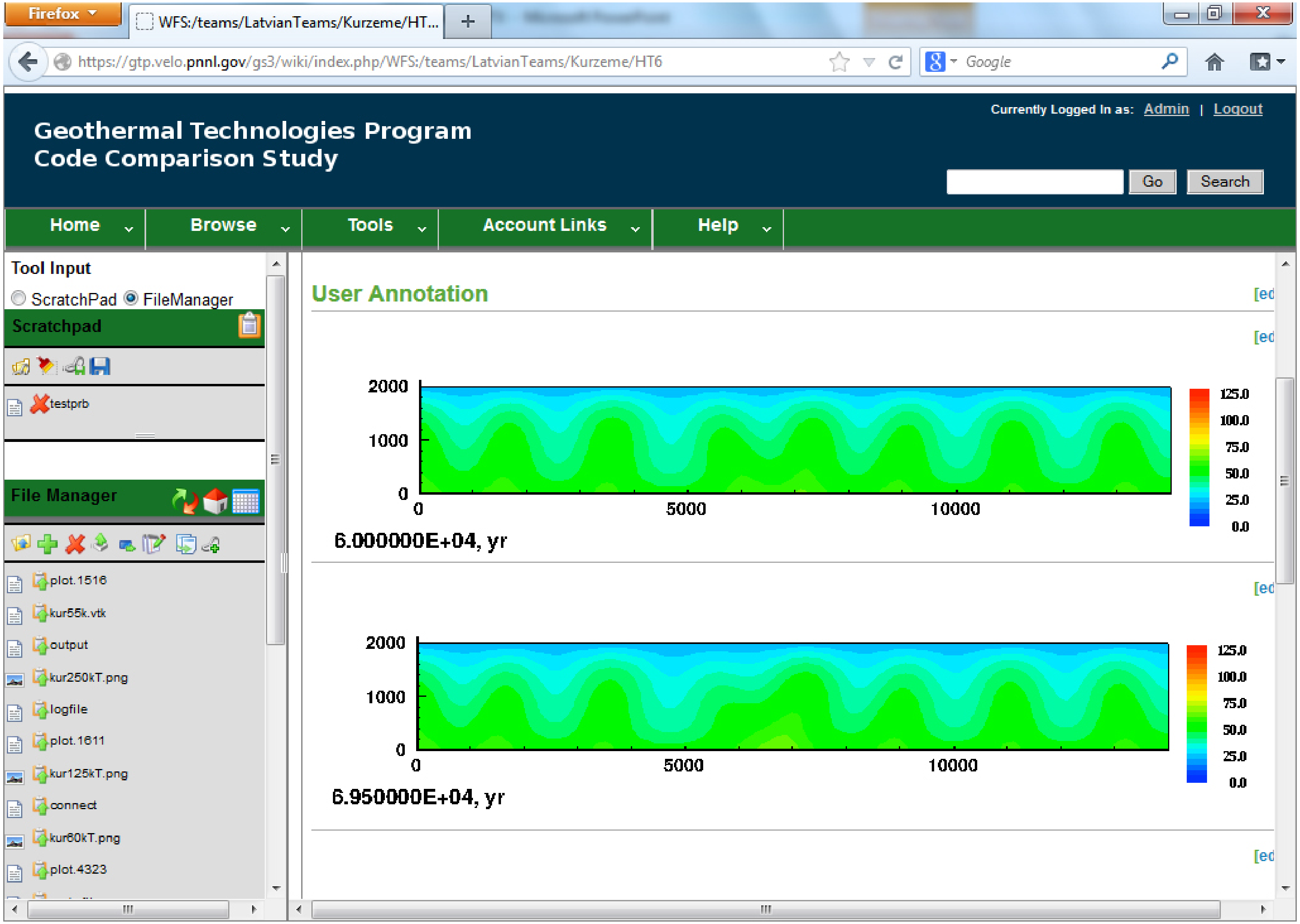


https://gtp.velo.pnnl.gov/

Accomplishments, Results and Progress



Velo Demonstration at the IPGT Working Group Meeting

- International Partnership for Geothermal Technology, Reservoir Modeling Working Group
- September 24, 2012; Tim Scheibe was one of three US delegates
- Presented Velo demo and extended offer for IPGT use in collaboration with the US code comparison effort
- Offer was enthusiastically received, and Tim Scheibe was invited to become a member of the working group

- IPGT workshop led to a preliminary set of problems defined in three groupings: 1) Benchmarks, 2) Test Cases, and 3) Challenge Problems. These were further classified according to the process types incorporated (T=thermodynamics, H=hydrology, M=mechanics, C=chemistry or THMC)
- Problem descriptions were subsequently posted on the Velo site

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Kickoff Workshop (2/14/2013):

- ~40 attendees, one full day. Held at Stanford University. Full report available on Velo or by request.
- Morning: Introduced the project, with focus on IPGT groundwork and Velo demonstration
- Afternoon: Two breakout sessions to discuss and define test problems
  - Two categories: 1) Test Cases and 2) Challenge Problems (Simpler benchmarks will utilize IPGT problems)
  - Nine Test Cases were identified for further development

Kickoff Workshop:

- It was agreed that the benchmark problems were well covered by the IPGT problem set and we could subselect from that as needed
- Focus therefore was placed on Test Cases and Challenge Problems, with specific application to EGS
- Challenge Problems:
  - Primary discussion centered around the question of whether to try to match real field data from a demo site, or to create a better-constrained synthetic problem
  - Current approach is to begin with better-defined Test Cases (next slide) and use experience gained to develop a synthetic Challenge Problem. The CP will be based on a field demo site and utilize actual data from the site to the extent possible, but will provide complete specification where field data are not available through synthetic assignment.
  - Try to maintain as much geological realism as possible while still creating a problem that is well constrained and for which numerical solutions are directly comparable.
  - After completing the synthetic problem, if time and funds allow we will proceed to a purely field-based problem where we attempt to match field observations

Kickoff Workshop:

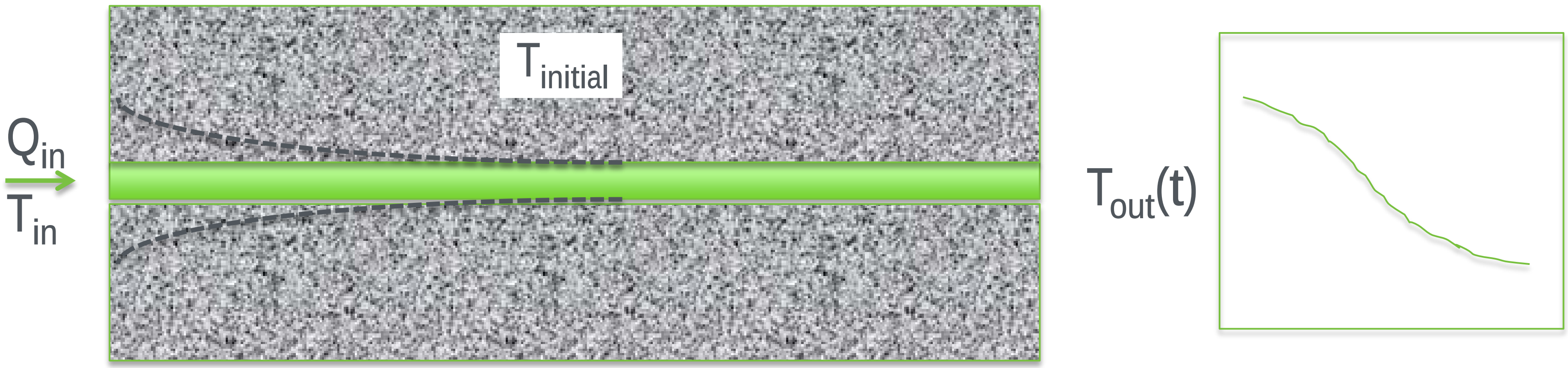
- Test Cases: Nine specific problems identified (with "champions"); more detailed information available in workshop report and on Velo
  1. Poroelastic/thermal transport in a single fracture (THM)
  2. Shear on a single fracture induced by change in effective stress by injection (HM/THM)
  3. Calcite dissolution/precipitation in a fracture/pipe (THC)
  4. Calculation of stress field incipient to fracturing and comparision to lab data (HM)
  5. IPGT Test Case THM #4 applied to a deterministically-specified fracture network (THM)
  6. Inverse modeling of a discrete fracture network simulated as an effective continuum (THM)
  7. Propagation of an open fracture from a well bore (HM/THM)
  8. Surface deformation from a pressurized fracture (HM)
  9. Disc- or lens-shaped existing fracture around a borehole with porous media beyond (THM)

Accomplishments, Results and Progress

Kickoff Workshop:

1. Poroelastic/thermal transport in a single fracture (THM)

- A single pre-existing planar fracture in hot rock with initially uniform aperture
- Cold fluid is injected at a specified rate at one end of the fracture and transported to and extracted at the other end
- The model must account for poroelastic effects due to increased pressure and thermal cooling, which will lead to changes in the fracture aperture (and thus changes in effective permeability and porosity), and must predict the temperature profile over time of the effluent fluid



Future Directions

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Milestone or Go/No-Go	Status & Expected Completion Date
Integrate custom elements into the geothermal Velo instance by April 30, 2013	In process. Although key elements will be in place by the April 30 target, full implementation is pushed out due to funding constraints (full funding not available until April)
Conduct a second workshop to review progress of participating teams and compare initial results by September 30, 2013	Problem definitions being refined and teams being formed; currently over 20 Velo users. On schedule.

FY 14 Plans:

- Finalize code comparison simulations and compilation of results
- Write reports and draft and submit journal manuscripts
- Shepherd journal manuscripts through the review process to final publication
- Develop and implement transition plan for Velo / data sustainability

Mandatory Summary Slide

- Understanding and improving performance of numerical simulators is critical to effective implementation of EGS
- We are undertaking a rigorous comparison study of a suite of codes used for geothermal modeling
- An innovative knowledge and data management platform has been implemented and is being customized (Velo)
- An initial set of Test Case problems has been defined and is being refined by the participating community
- Experience gained from Test Cases will be used to define one or more Challenge Problems
- This work is an integrated effort among PNNL, DOE-GTO, other program PIs, and the international community

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
7/2/2012	9/30/2014	7/17/2012	9/30/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date*	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
$550,000	$0	$145,364	$90,445	$96,000	$454,000

*Reporting Date: Dec. 31, 2012

- Initial FY13 funding installment was received in January
- Remainder of FY13 funding expected to be received in April after which time additional features will be added to Velo.
- Management activities or approaches:
  - Builds and leverages on PNNL prior investment in Velo development.
  - This project involves direct participation by PIs of other modeling projects in the program. Challenge problem(s) will be based on data from field demonstrations.
  - Closely coordinated with international working group (International Partnership for Geothermal Technology – IPGT).