ASPECT Hackathon 2021

Introduction

To further develop the geodynamic modeling code ASPECT and to grow and foster its user community, 25 users and developers of ASPECT worked virtually over two weeks in July 2021.

Below is the timeline and a description of the individual contributions.

Timeline

Day	**Scheduled items** **(in Pacific time; US East: +3h; Central Europe: +9h)**
Thursday, 07/01 (location: Main Zoom room)	9 am: Welcome, Integrated Development Environments, setup VS code 10 am: Setup git and Github 11 am: Installation help for deal.II and ASPECT
Tuesday, 07/06	9 am: Welcome, Introductions, What is a hackathon (Wolfgang), Code of Conduct (Lorraine) 10 am: Introductions 11 am: Form groups / Starter projects
Wednesday, 07/07	10 am: Daily rounds 11 am: Anisotropic viscosity Agi
Thursday, 07/08	10 am: Daily rounds
Friday, 07/09	10 am: Daily rounds
Monday, 07/12	10 am: Daily rounds
Tuesday, 07/13	10 am: Daily rounds 11 am: Debugging in VS code
Wednesday, 07/14	10 am: Daily rounds 11 am: World builder (intro + what is new)
Thursday, 07/15	10 am: Daily rounds
Friday, 07/16	10 am: Daily rounds 11 am: Logistics, Announcements, The Future

Participants and areas of interest

Name, affiliation, email	**Time zone**	**Goals and interests for this hackathon**
Rene Gassmoeller, University of Florida, rene.gassmoeller@mailbox.org	US East Coast	Help others achieve their goals Review pull requests Cleanup duty Particle optimizations
Lorraine Hwang UC Davis ljhwang@ucdavis.edu	PDT UTC+7(?)	1. Logistics 2. Writing 3. ASPECT Networks 4. Planning
Wolfgang Bangerth Colorado State University bangerth@colostate.edu	US Mountain Time	1. Review pull requests 2. Help others 3. Write documentation 4. Output for surface quantities 5. WorldBuilder improvements
Juliane Dannberg University of Florida judannberg@gmail.com		1. Help others 2. Review pull requests 3. Finish PR with teaching resources 4. Material model restructuring 5. Make a cookbook/plugin for reproducing the Christensen & Yuen 1985 models 6. Add code for reading in the dominant phase from a P-T table
Timo Heister heister@clemson.edu	US, Eastern Standard Time	1. Review pull requests 2. Help others 3. Infrastructure work (testing, cmake, etc.) 4. Linear solvers (multigrid, Schur complement)
Menno Fraters UC Davis menno.fraters@tutanota.com	US, Pacific Standard Time	1. Help others 2. Review pull requests 3. Add documentation about how to use the Newton solver 4. Add documentation about how to use the world builder which could double as a subduction cookbook. 5. Add CPO related code 6. Explorer the option of an Euler pole boundary plugin 7. Discuss addition of melt and GMG to Newton solver

John Naliboff New Mexico Tech john.naliboff@nmt.edu	US., Mountain Standard Time	1. Help others achieve their goals 2. Review pull requests 3. Add a section to the manual about lithospheric, rheology and material model structure 4. Finish PR on composite rheology formulation 5. Update continental extension cookbook 6. Work on two-phase flow + plasticity implementation
Anne Glerum	CEST	1. Lithospheric melt model (Bob) 2. Convert initial topography plugins to initial mesh deformation plugins (and in the end remove initial topography functionality) 3. Particles & iterative Advection issues 4. Extract solution on surface mesh (Wolfgang) 5. Finish subduction cookbooks (Menno, Magali) 6. Issues with elasticity, restarting 7. Help and review pull requests
Jacky Austermann Lamont-Doherty Earth Observatory jackya@ldeo.columbia.edu	US, Eastern Standard Time	1. Figure out how to deal with boundary terms in adjoint equations for Stokes flow 2. Move adjoint implementation into plugin 3. Work on adjoint equations for gravity observations 4. Viscoelasticity / GIA: help implementation of sea level equation and water loading for DT 5. Help and review
Arushi Saxena University of Florida saxena.arushi@ufl.edu	US, Central Standard Time	1. Test instantaneous 3D mantle models to best-match the surface observables, and create additional plugins required for it. Also test the World builder performance in these models. 2. Work on the open issues in the ASPECT github repository.
Magali Billen	US, Pacific Standard Time	1. Implement static temperature option so can advect and build up initial elastic stress without slab geometry changing. 2. Add a half-space derived temperature for initial oceanic plate and slab temperature in worldbuilder 3. Get better at Git 4. Help with subduction cookbooks?
Maaike Weerdesteijn UiO Oslo m.f.m.weerdesteijn@geo.uio.no	CEST, but I can be flexible and work late European hours	1. Viscoelasticity / GIA a. Surface loads on a 3D spherical shell b. Sea level equation implementation c. Include load gravitational attraction d. Include time-varying ocean basins

Haoyuan Li hylli@ucdavis.edu	US, Pacific Standard Time	1. Adapt previous implementation of Hefesto look up table(phase diagrams) in an extended Boussinesq approximation 2. Implement peierls rheology from Hansen 19 and compare different versions. 3. An approach to visualize phase diagram & rheology diagram implemented in ASPECT
Erin Heilman erin.heilman@utexas.edu	US CDT	1. Solve temperature/viscosity issues in viscoplastic for 3D spherical (90 degree opening/chunk) 2. Solve viscosity oscillation issues in 2D cylindrical + 2D chunk viscoplastic 3. Work on strain healing implementation in viscoplastic (negative strain values)
Bob Myhill University of Bristol bob.myhill@bristol.ac.uk	BST (GMT+1)	1. Continue viscoelastoplastic models w/ free surface (w/ John) 2. Make a new multicomponent reactive melt model for upper mantle hydrous melting. 3. Help and review pull requests.
Cedric Thieulot c.thieulot@uu.nl	CEST but I can be flexible and work late	1. rheology 2. Adding gravity & geodynamics cookbook(s) 3. Reading in Large data sets
Agi Kiraly agnes.kiraly@geo.uio.no	CEST	1. Add anisotropic viscosity to LPO/CPO development of olivine (Menno)
Valentina Magni valentina.magni@geo.uio.no	CEST	1. Set-up 2D visco(elasto)plastic model of oceanic lithospheric extension 2. Learn how to use particles (vs. compositional fields) 3. Discuss melt migration in lithospheric extensional models 4. Getting more comfortable / familiarize with changing the code and using Git
Sibiao Liu sliu@geomar.de	CEST	1. Modeling of crustal accretion at spreading ridges: prescribed dilation function in VP material model (talk to Timo & Juliane) 2. Add a simplified process of hydrothermal circulation in VP (and VEP) material model 3. Add the data-assimilation function: initial T, composition fields based on seafloor age data from GPlates (talk to Rene)

		4. Learn more about debugging in Eclipse or VS code
Becky Fildes UC Davis rfildes@ucdavis.edu	US Pacific Time	1. Set up 2D visco-elastic-plastic subduction model with initial slab geometry using world builder 2. Improve knowledge and use of github
Elodie Kendall GFZ Potsdam kendall@gfz-potsdam.de	CEST	1. Push my implementation of different plasticity for different phases if developers think this will be useful for others 2. Get ideas for speeding up 2D spherical shell viscoplastic models with early earth T/viscosity 3. Implement a synthetic sediment layer, add option to change yield stress based on sediment load, in addition to the existing dependence on plastic strain rate
Andrew Hollyday, Lamont-Doherty Earth Observatory andrewh@ldeo.columbia.edu	US, Eastern Standard Time	1. Adapt ASPECT output for easier use with Yt Project visualization. 2. Implement present-day dynamic topography water loading amplification in ASPECT. 3. Learn more about how ASPECT works and improve development skills. Definitely seeking mentorship!
Jiaqi Zhang Clemson University jiaqi2@clemson.edu	US, Eastern Standard Time	1. Help with git, c++, and deal.ii questions 2. Interested in working on advection schemes (levelset) 3. Interested in implementing linear solver improvements
Daniel Douglas University of Hawaii daniel92@hawaii.edu	US, Hawaii Stand Time	1. Help with git 2. Create pull request for plate cooling model temperature plugin 3. Get feedback on time dependent heating plugin I wrote/create pull request 4. Create pull request for traction plugin/cookbook
Paul Bremner MSFC paul.m.bremner@nasa.gov	US, Eastern Standard Time	1. Static-lid dynamics 2. Surface processes 3. Gravity 4. Rheology

Mentor/Mentee lists

Name, affiliation, email	**Mentor**	**Mentees**
Rene Gassmoeller, University of Florida, rene.gassmoeller@mailbox.org	------	1. Agi 2. Magali 3. Maaike
Lorraine Hwang UC Davis ljhwang@ucdavis.edu	------	------
Wolfgang Bangerth Colorado State University bangerth@colostate.edu	-------	1. Andrew (yt) 2. Jiaqi 3. Jacky 4. Arushi
Juliane Dannberg University of Florida judannberg@gmail.com	------	1. Haoyuan 2. Sibiao
Timo Heister heister@clemson.edu	------	1. Jiaqi
Menno Fraters UC Davis menno.fraters@tutanota.com	------	1. Agi 2. Becky
John Naliboff New Mexico Tech john.naliboff@nmt.edu	------	1. Erin 2. Valentina 3. Daniel
Anne Glerum	------	1. Elodie
Jacky Austermann Lamont-Doherty Earth Observatory jackya@ldeo.columbia.edu	Wolfgang Rene	1. Maaike 2. Andrew
Arushi Saxena University of Florida	Juliane Wolfgang	------

saxena.arushi@ufl.edu		
Magali Billen	Rene Menno	1. Becky 2. Haoyuan
Maaike Weerdesteijn UiO Oslo m.f.m.weerdesteijn@geo.uio.no	Jacky Rene	------
Haoyuan Li hylli@ucdavis.edu	Juliane Menno Magali	------
Erin Heilman erin.heilman@utexas.edu	John	------
Bob Myhill University of Bristol bob.myhill@bristol.ac.uk	------	Cedric (apparently :D) :)
Cedric Thieulot c.thieulot@uu.nl	Bob	Paul
Agi Kiraly agnes.kiraly@geo.uio.no	Menno Rene	------
Valentina Magni valentina.magni@geo.uio.no	John Anne	------
Sibiao Liu sliu@geomar.de	Juliane Rene	------
Becky Fildes UC Davis rfildes@ucdavis.edu	Menno Magali	------
Elodie Kendall GFZ Potsdam kendall@gfz-potsdam.de	Anne	------

Andrew Hollyday, Lamont-Doherty Earth Observatory andrewh@ldeo.columbia.edu	Jacky Austermann (GIA) John Naliboff (Yt) Timo Heister (Yt) Wolfgang Bangerth (Yt)	------
Jiaqi Zhang Clemson University jiaqi2@clemson.edu	Timo Wolfgang	------
Daniel Douglas University of Hawaii daniel92@hawaii.edu	John	------
Paul Bremner MSFC paul.m.bremner@nasa.gov	Cedric Bob	

Resources

Things to do before the start of the hackathon

- Create an account on https://github.com if you don't have one yet.
- Make sure you have Zoom installed and can use it in a reasonable environment to participate using audio/video in our discussions
- Put your name into the table "Participants and areas of interest" below and fill in your goals and interests for the hackathon
- Join the Slack workspace: https://join.slack.com/t/cig-aspect/shared_invite/zt-gdn947lt-xRu8SpWkzI2rgnfOLCOpYw
- Install the latest developer version of ASPECT (using deal.II version 9.3.0 or the current deal.II development version). **Note:** The deal.II 9.3.1 release is still being finalized. The next section has instructions with commands to type for Mac, Linux, and Windows. General instructions and technical requirements are here: https://geodynamics.org/cig/events/calendar/2021-aspect-hackathon/technical-requirements/

Installing deal.II on Mac

Download and install the Mac OS X “dmg” package from https://dealii.org/download.html .

Installing deal.II on Linux

If you are running Ubuntu, and if you have *root* rights on this machine, then issue the following commands:

```
sudo apt-get install -y software-properties-common
sudo add-apt-repository ppa:ginggs/deal.ii-9.3.0-backports
sudo apt-get update
sudo apt-get install -yq --no-install-recommends libdeal.ii-dev
```

If you are running on any other Linux variant, the following commands will install deal.II and all of its dependencies from scratch by compiling them from source:

```
git clone https://github.com/dealii/candi.git
cd candi
git checkout 9.3-no-complex-trilinos
./candi.sh  --packages="once:astyle once:hdf5 once:p4est once:trilinos dealii" -j 2 -y
.  ~/deal.ii-candi/configuration/enable.sh          # note the dot at the beginning of the line
```

Installing deal.II on Windows

Follow the instructions linked to from here, installing first the Windows Subsystem for Linux (WSL) and then deal.II within it:

https://github.com/dealii/dealii/wiki/Getting-deal.II#windows

Visual Studio Code Tutorial

- VS Code is an Integrated Development Environment (IDE) that simplifies programming
- It is free, powerful, and used by the majority of open-source software developers
- If you are already comfortable with a different IDE stick to it, if you do not use an IDE so far, please install VS code
- It is simpler for us to explain and help you if most of us use the same IDE
- How to get: https://code.visualstudio.com/
- Documentation: https://code.visualstudio.com/docs
- Necessary/Useful extensions for this hackathon:
    - https://marketplace.visualstudio.com/items?itemName=ms-vscode.cpptools
    - https://marketplace.visualstudio.com/items?itemName=eamodio.gitlens
    - https://marketplace.visualstudio.com/items?itemName=davydden.dealii-prm
    - https://marketplace.visualstudio.com/items?itemName=MS-vsliveshare.vslivesharе

Git Tutorial

- Git commands cheat sheet: https://education.github.com/git-cheat-sheet-education.pdf
- Github workflow: https://guides.github.com/introduction/flow/
- Git tutorial: https://swcarpentry.github.io/git-novice/

1. Explain and set up Git:
    a. Git install: https://carpentries.github.io/workshop-template/#git
    b. https://swcarpentry.github.io/git-novice/01-basics/index.html
    c. https://swcarpentry.github.io/git-novice/02-setup/index.html
    d. Config git name: `git config --global user.name "Vlad Dracula"`
    e. Config git email: `git config --global user.email "vlad@tran.sylvan.ia"`
2. Explain Github Workflow:
    a. https://guides.github.com/introduction/flow/
    b. Ensure forked repositories (you should own your_username/aspect on github)
    c. Ensure proper remotes (remote 'upstream' pointing to geodynamics/aspect, remove 'origin' pointing to your_username/aspect)
3. Setup ASPECT in VS Code
4. Walkthrough (these are terminal commands, I will walk you through the IDE instead)
    a. Create Branch
        i. 'git checkout master'
        ii. 'git pull upstream master'
        iii. 'git checkout -b remove_unused_option'
    b. Make changes for ASPECT_USE_PETSC in one of the files (remove the option for ASPECT_USE_PETSC == true):
        i. include/aspect/global.h
        ii. source/global.cc
        iii. source/main.cc (Rene)
        iv. source/mesh_deformation/diffusion.cc
        v. source/mesh_deformation/free_surface.cc
        vi. source/mesh_deformation/interface.cc Maaike
        vii. source/postprocess/matrix_statistics.cc (Andrew)
        viii. source/simulator/assembly.cc
        ix. source/simulator/core.cc /Agi
        x. source/simulator/melt.cc (Becky)
        xi. source/simulator/nullspace.cc (Els)
        xii. source/simulator/solver.cc (Valentina)
        xiii. tests/petsc_use_petsc.cc
    c. Create commit
        i. 'git add FILE'
        ii. 'git commit -m 'Removed a deprecated option'
    d. Push and open PR
        i. 'git push origin remove_petsc_option'

        ii. Open PR on github (CTRL-Click on shown link)
    e. Wait for review
    f. Address review (repeat steps b,c,d)
    g. Success!
    h. Alternative to fix: Look for DEAL_II_VERSION_GTE(9,1,0)
5. Now repeat the steps in 3. on your own. Pick a section of the manual in doc/manual/manual.tex that interests you. Find a sentence or description or formula to improve. Then repeat 3. and make your changes to the file doc/manual/manual.tex.

Report on projects the participants worked on

Remove PETSc support

(Rene Gassmöller, Agi Kiraly, Elodie Kendall, Rebecca Fildes, Valentina Magni, Cedric Thieulot, Andrew Hollyday, Wolfgang Bangerth)

We removed support for PETSc vectors and solvers in ASPECT. PETSc had been supported for several years as an experimental option, but it was not tested and provided no tangible benefit over Trilinos.

Force color for ninja build

(Menno Fraters)

I added a CMake option for ninja builds to produce colored output when showing compiler and other messages.

Thermodynamic lookup equation of state

(Bob Myhill)

ASPECT now has a ThermodynamicTableLookup equation of state plugin. This plugin allows material models to read in one or more Perple_X or HeFESTo table files, interpolate material properties at desired pressures and temperatures, and use the interpolated properties as material model outputs.

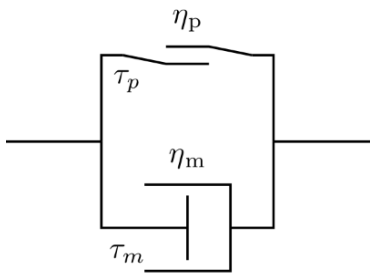
Added the capability to read in the dominant phase

(Juliane Dannberg)

The ThermodynamicTableLookup equation of state plugin can now read in a column that contains a string with the dominant phase from lookup tables. The dominant phase can be accessed in the material model to set parameters like the viscosity.

Added firmoviscous element to elastic rheology

(Bob Myhill)



The elastic rheology in ASPECT now has a new input parameter called “Elastic damper viscosity”. This parameter corresponds to the viscosity of an isotropic viscous damper which deforms at the same strain rate as the elastic element. The default value of 0 Pa.s corresponds to purely elastic deformation. Values greater than 0 Pa.s cause viscous damping of the elastic element, stabilizing the rheology.

Peierls Cutoff Stress

(Daniel Douglas)

$$\dot{\epsilon} = A\sigma^n \exp\left(-\frac{E_p}{RT}\left(1-\left(\frac{\sigma}{\sigma_p}\right)^p\right)^q\right),$$

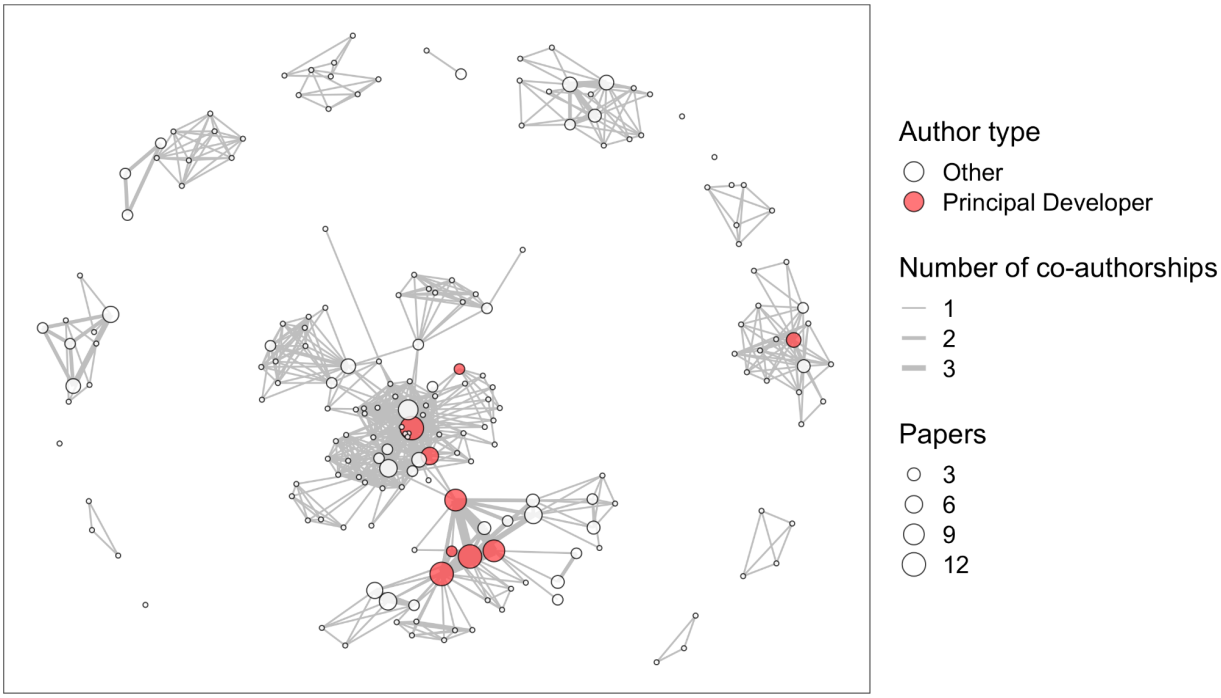
For Peierls creep, some laboratory experiments find that a stress exponent (*n*) of 0 fits data best. However, when setting *n=0* in the above expression, the strain rate no longer goes to 0 when the stress goes to 0 which creates convergence issues. This update allows the user to set a ‘cutoff stress’. For stresses above this cutoff value the code is unchanged. For stresses below the cutoff value, a strain rate is approximated as a quadratic function of stress to ensure that the strain rate does go to 0 as the stress goes to 0.

Co-Author Networks

(Lorraine Hwang)

The following network diagram shows the connection between authors of ASPECT papers:

ASPECT Co-author Relationships



Adding physical units to output files

(Andrew Hollyday, Wolfgang Bangerth)

Some postprocessing tools can make use of information about the physical units of quantities stored in output files. We added initial functionality to visualization postprocessors to collect this information, along with a patch to deal.II that outputs it into VTK and VTU files.

Modernizing the use of C++

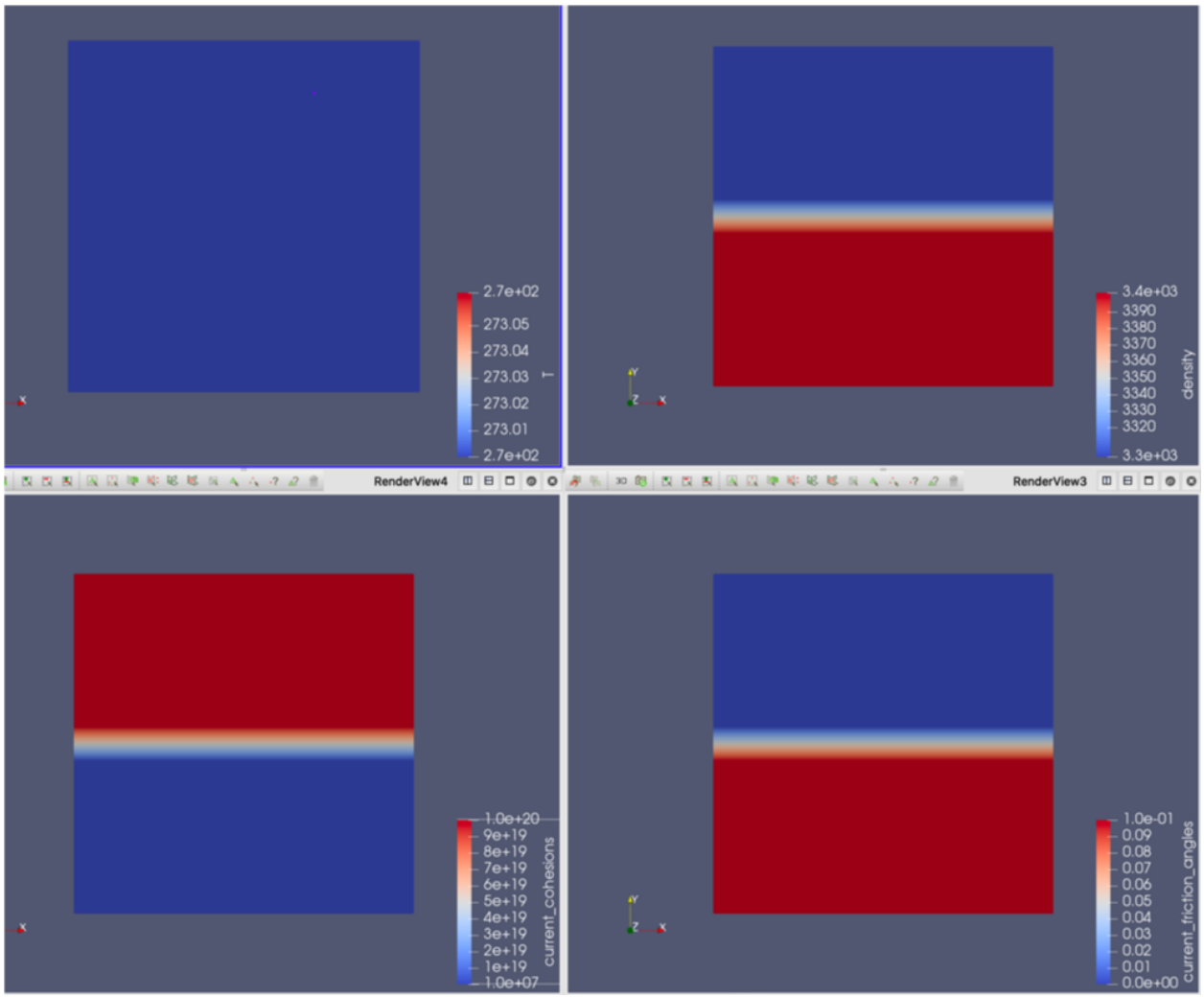
(Wolfgang Bangerth)

ASPECT now builds on deal.II 9.2, which in turns requires the use of a compiler that supports C++11. This allows for several simplifications in our code base that were done through a number of pull requests during the hackathon. Specifically, we now use std::unique_ptr in more places where std::shared_ptr was used before. Globally, we now also avoid the pre-C++11 requirement to use '> >' to close nested template arguments and instead omit the space and write `>>`.
A couple of additional patches were queued for the moment when we will require deal.II 9.3 (which will require C++14), hopefully a couple of weeks after the hackathon ends.
Together, all of these changes touch nearly every file of ASPECT.

Option for different plasticity for different phases

(Elodie Kendall, Anne Glerum, John Naliboff, Bob Myhill)

We added an option for allowing different plasticity for different phases to help prevent lower mantle plastic yielding and large viscosity contrasts for example.

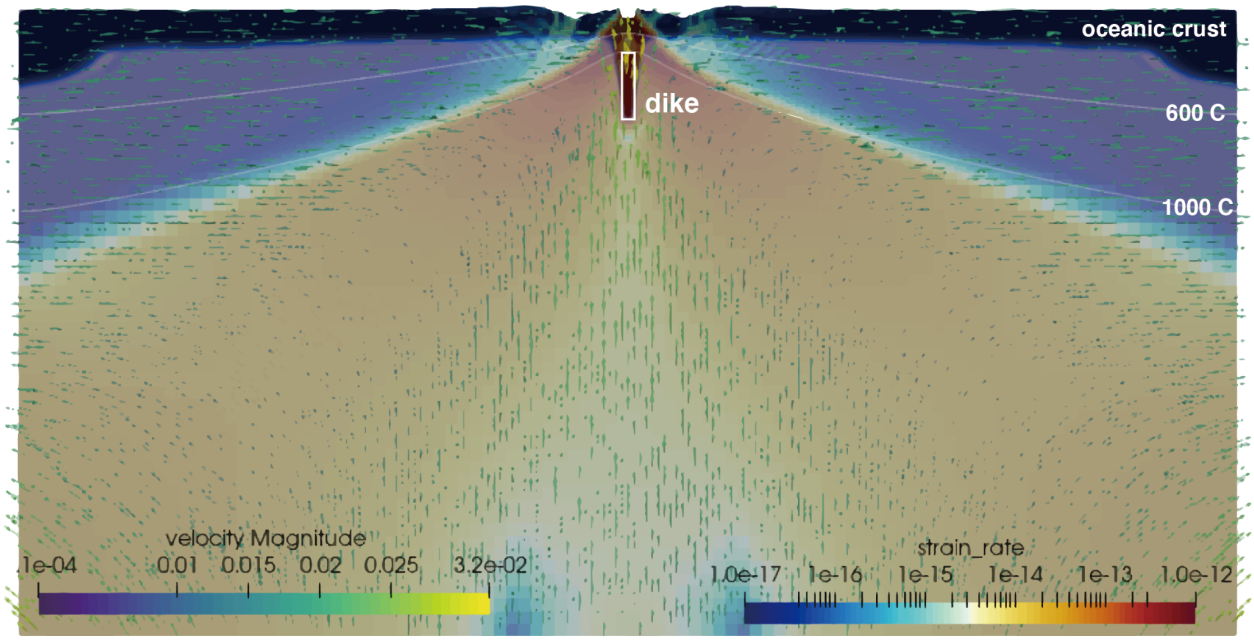


Add a material model of prescribed dilation

(Sibiao Liu, Juliane Dannberg, Timo Heister)

There is now a cookbook that adds a material model of prescribed dilation function. This material model takes any other material model as a base model, and adds additional material model outputs defining a dike injection region of magma via a dilation term applied to the Stokes equations that can be defined as a function depending on position and time in the input file. It also implements the latent heat released during crystallization of the melt lens and heating by

melt injection into the model by adding the latent heat term to the rhs of the energy equation. The method is described in the paper of Theissen et al., EPSL, 2011.



A steady state heat flux termination criterion

(Juliane Dannberg)

Models can now be terminated when the heat flux across a given boundary (or the sum of the heat fluxes across several boundaries) reaches a steady state.

A depth average postprocessor for the rising velocity

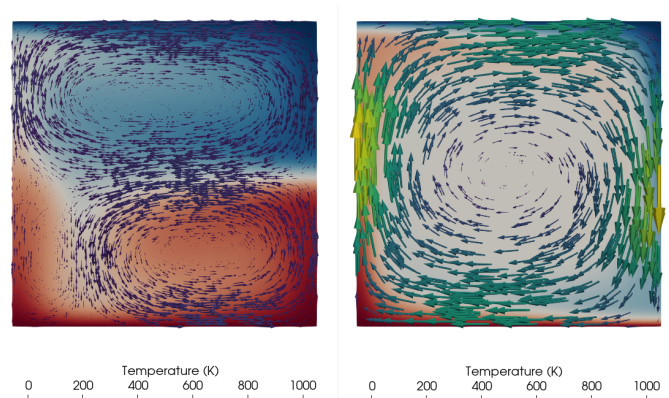
(Juliane Dannberg)

ASPECT now has a postprocessor that computes the average rising velocity over a given depth range. This is in addition to the sinking velocity postprocessor that already existed.

The Christensen & Yuen cookbook

(Juliane Dannberg)

There is now a cookbook that reproduces the setup of Christensen & Yuen, 1985, of convection in a box with a phase transition. Depending on the Clapeyron slope of the transition, convection is either layered (image on

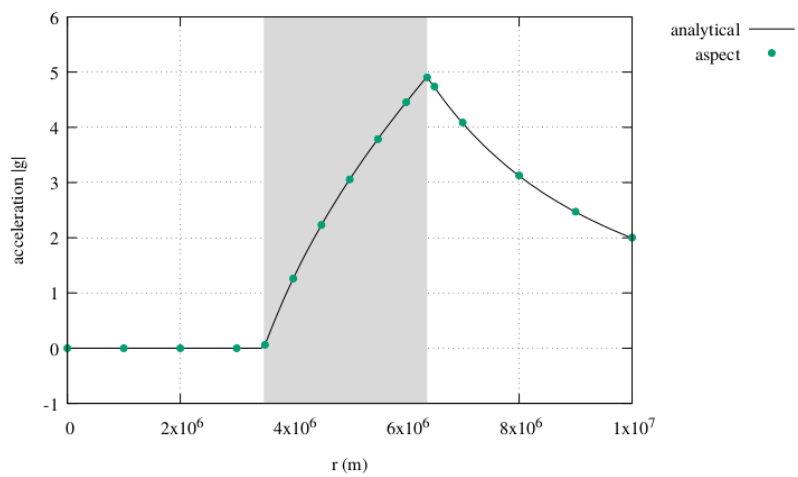


the left), or in the form of one large convection cell (image on the right), or episodic.

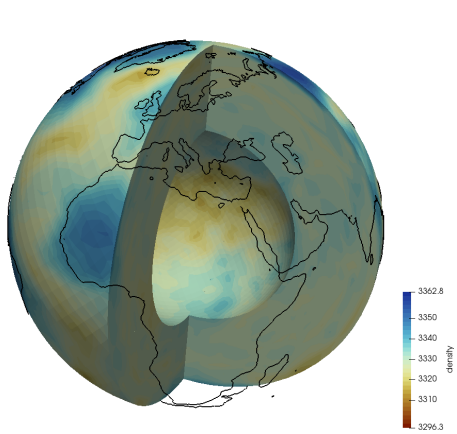
Two new benchmarks + 1 cookbook for the gravity postprocessor

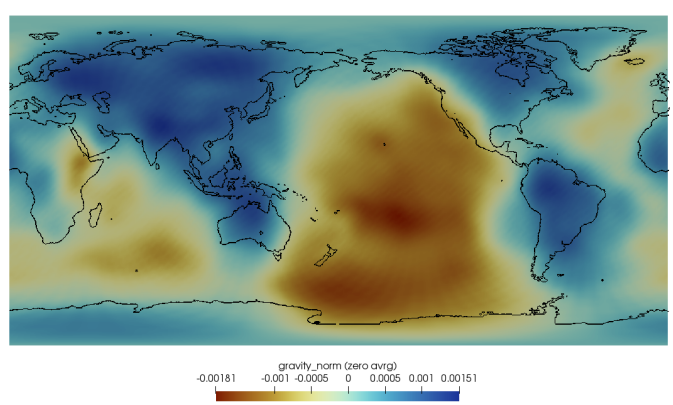
(Cedric Thieulot, Paul Bremner)

Two benchmarks were added for the gravity postprocessor: one for a thin shell, which computes gravity at satellite height; and one for a thick shell, which computes gravity on a line passing through the center of the planet, as shown on the following figure:



A cookbook was also added which uses the S40RTS tomography model to generate a density anomaly distribution in the mantle (left figure). The gravity postprocessor is then used to compute the gravity anomaly at satellite height on a 250km orbit (right figure).

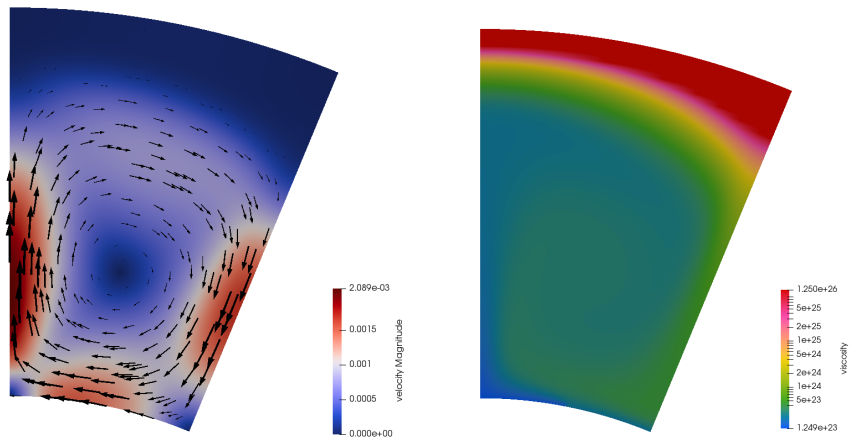




The simple plume cookbook

(Cedric Thieulot, Paul Bremner)

This cookbook is inspired by Kellogg & King (1997) but is not an attempt at reproducing the results of their publication. It takes place in a conical section of an annulus. A patch at the CMB is kept at a high enough temperature so as to generate a convection cell. Models run to steady state and the viscosity is either constant or of diffusion creep type.



Particle performance optimizations

(Rene Gassmoeller, Wolfgang Bangerth, Martin Kronbichler)

We modified ASPECT to use new deal.II functionality to improve the particle performance. Together with changes inside deal.II (version 10.0.pre) this represents a significant speedup for our models that use particles.

Improve ASPECT's build

(Rene Gassmoeller, Timo Heister)

ASPECT can now no longer be accidentally configured in the source directory, which was a long standing problem, because it prevents a clean execution of the test suite from other build directories.

Letting tests depend on each other

(Rene Gassmoeller, Timo Heister)

Tests can now depend on other tests, which is useful for testing the checkpoint/restart functionality (let one test write the checkpoint and the other restart from the generated checkpoint).

Adding geometric multigrid to the Newton solver

(Timo Heister, Menno Fraters, Jiaqi Zhang)

The matrix-free GMG solver learned the necessary features to support the Newton nonlinear solver, potentially making the Newton solver much faster than it was before.

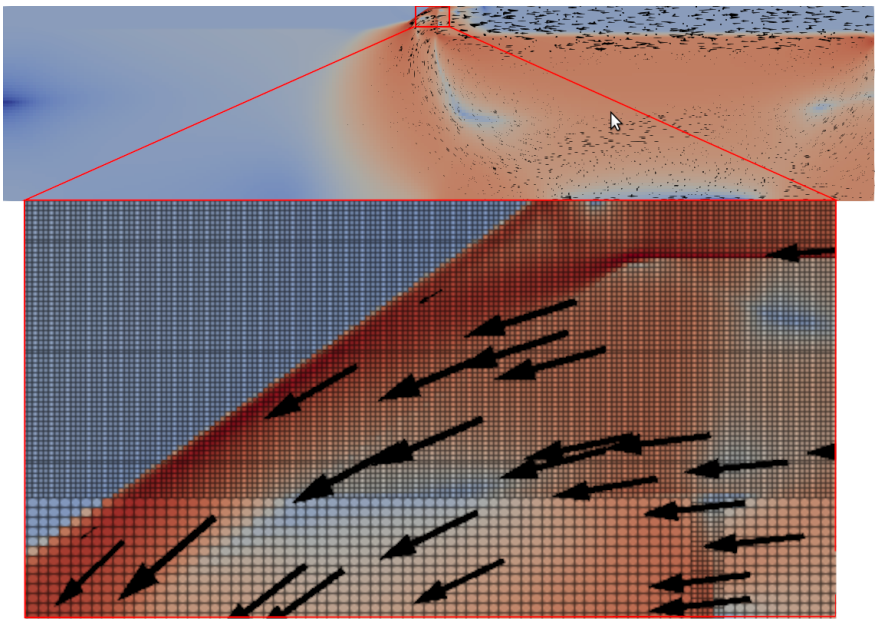
Multigrid support for mesh deformation support

(Timo Heister)
The matrix-free geometric multigrid (GMG) solver now supports mesh deformation. However, for the time being, this still excludes the free surface.

GMG masked velocity boundary conditions

(Timo Heister)

The geometric multigrid solver now supports boundary conditions that are applied to individual velocity components (instead of all components).
With that, we can run a 2d subduction problem with 17m DoFs (4m Stokes DoFs and 7 compositional fields) on a laptop (see image on the right).



Testing with the latest deal.II development version

(Rene Gassmoeller, Timo Heister)

The continuous integration tester now regularly checks that ASPECT compiles with the latest deal.II development version (even if we do not use it to run the tests). This prevents merging changes that do not work with the latest deal.II version, and notifies us immediately if deal.II changes in a way that prevents ASPECT from compiling.

ASPECT on M1 ARM

(Timo Heister)

With various smaller fixes, ASPECT now runs on the new M1 ARM processors from Apple.

Geoid postprocessor with free surface option

(Maaike Weerdesteijn, Rene Gassmoeller, Jacky Austermann)

For a 3D spherical shell the geoid postprocessor now automatically recognizes if the bottom surface and top surface are free surfaces or not. You can choose to include or exclude the bottom and top surface in the geoid calculations. If included and the surface is a free surface, the topography is extracted from the geometry model. If included and the surface is not a free surface, the topography is extracted from the dynamic topography (this postprocessor needs to be used as well). The parameter 'Include the contribution from dynamic topography' is no longer used. Instead, use 'Include surface topography contribution' and 'Include CMB topography contribution'. Existing geoid tests are changed according to this parameter name change, and a new geoid test is added for a top free surface.

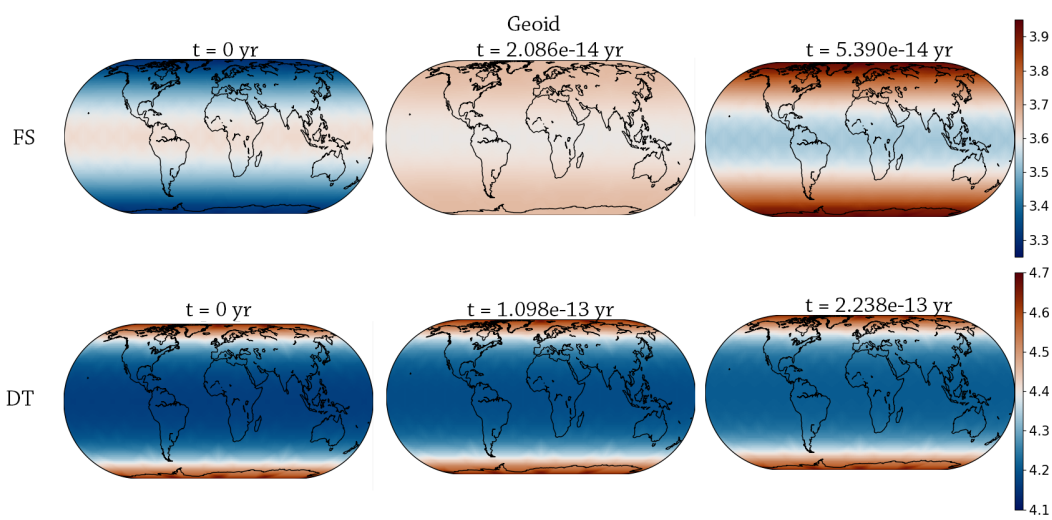


Figure: Geoid displacement [m] for a top free surface and bottom fixed surface case (FS) and for a top and bottom fixed surface case (DT). A large temperature anomaly of degree 2 order 0 is applied at t0. The geoid displacement contributions are from density changes, and top and bottom topography changes. The topography changes are based on the dynamic topography or free surface topography dependent on whether the surface is fixed or a free surface.

Sea level implementation

(Maaike Weerdesteijn, Andrew Hollyday, Jacky Austermann, Rene Gassmoeller)

A new postprocessor that writes the sea level height has been added. The sea level height is the summation of a uniform water thickness layer (equal globally) and non-uniform contribution to the sea level (different for each location). These variables are a function of the surface displacement, geoid displacement, input ice height data, and input topography data used to determine the ocean geometry. Furthermore, a new boundary traction option called GIA_traction calls the function 'compute_total_surface_pressure' in the sea level postprocessor, which computes the new total surface pressure from ice and water loading based on location.

Maximum field depth postprocessor

(Anne Glerum)

I added a new postprocessor that for each compositional field outputs the deepest depth at which the field is present.

Viscous dissipation postprocessor

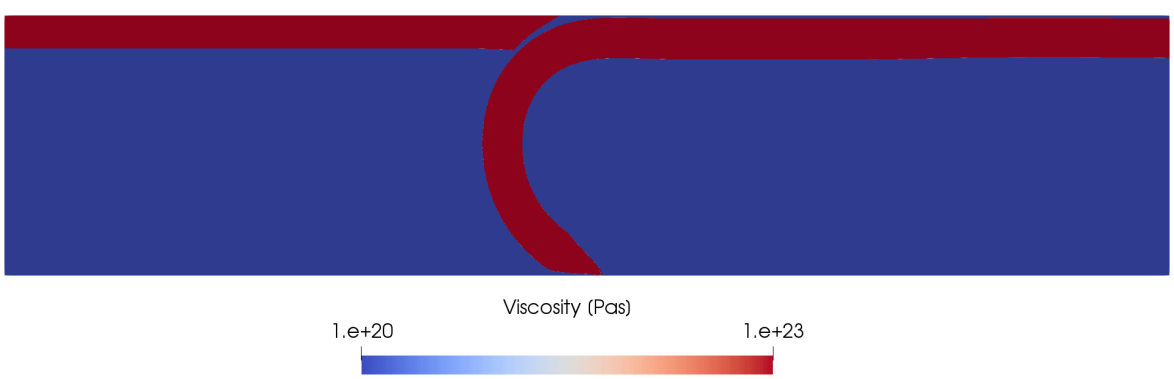
(Anne Glerum)

A new postprocessor that for each compositional field outputs the viscous dissipation as well as for the whole domain has been added.

Subduction cookbook

(Anne Glerum)

This is a new cookbook that discusses a 2D model of kinematically-driven subduction. The figure shows the overriding and subducting plate after 15 My of model time, with the slab curling backwards along the bottom boundary, which mimics the 660 km phase transition.



Iterative Advection schemes with fields that track history and other non-lithological properties

(Anne Glerum)

It is now (almost) possible to use iterative Advection schemes with compositional fields that track for example strain and need the reaction terms to stay constant during the nonlinear iterations within one timestep.

Chunk geometry model that allows for two different boundary conditions on the side boundaries

(Anne Glerum)

There is now a new geometry model that allows the user to specify two different boundary conditions on the side boundaries of the chunk. A use-case is, for example, prescribing plate velocities on the upper part of the side boundaries and traction boundary conditions below on the sublithospheric mantle part of the side boundaries to allow for free in/outflow.

Added log viscosity in the depth average postprocessor

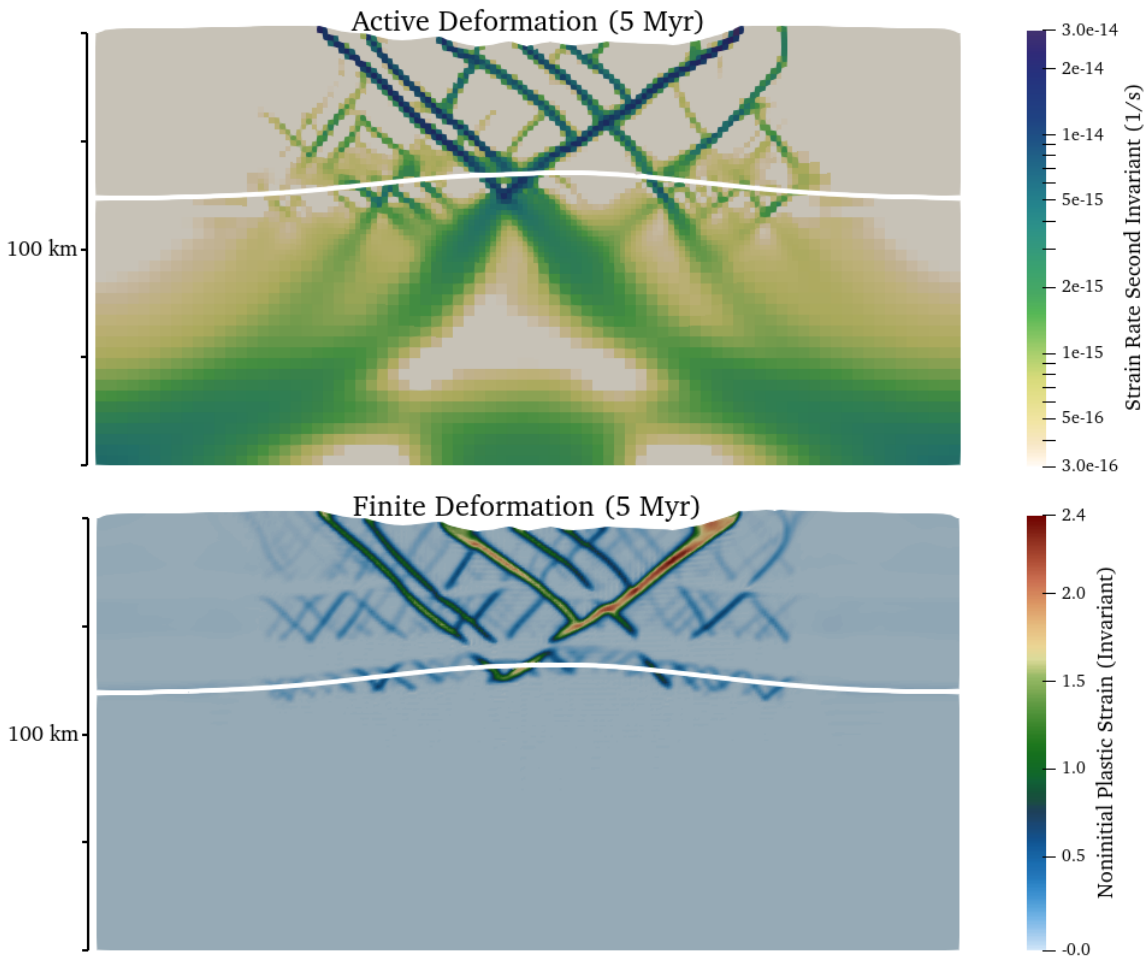
(Arushi Saxena)

The new postprocessor computes the average logarithm of viscosities, instead of using arithmetic averaging for viscosities. For example, the average of two layers with viscosities of 1e20 and 1e22 is 1e21 and not 5.05e21.

Updates to the continental extension cookbook

(John Naliboff, Anne Glerum, Valentini Magni)

The continental extension cookbook has been updated to include a number of new features and improvements. The following images show some of the results:



An option to use the iterative composite rheology in the visco-plastic material model

(John Naliboff, Bob Myhill)

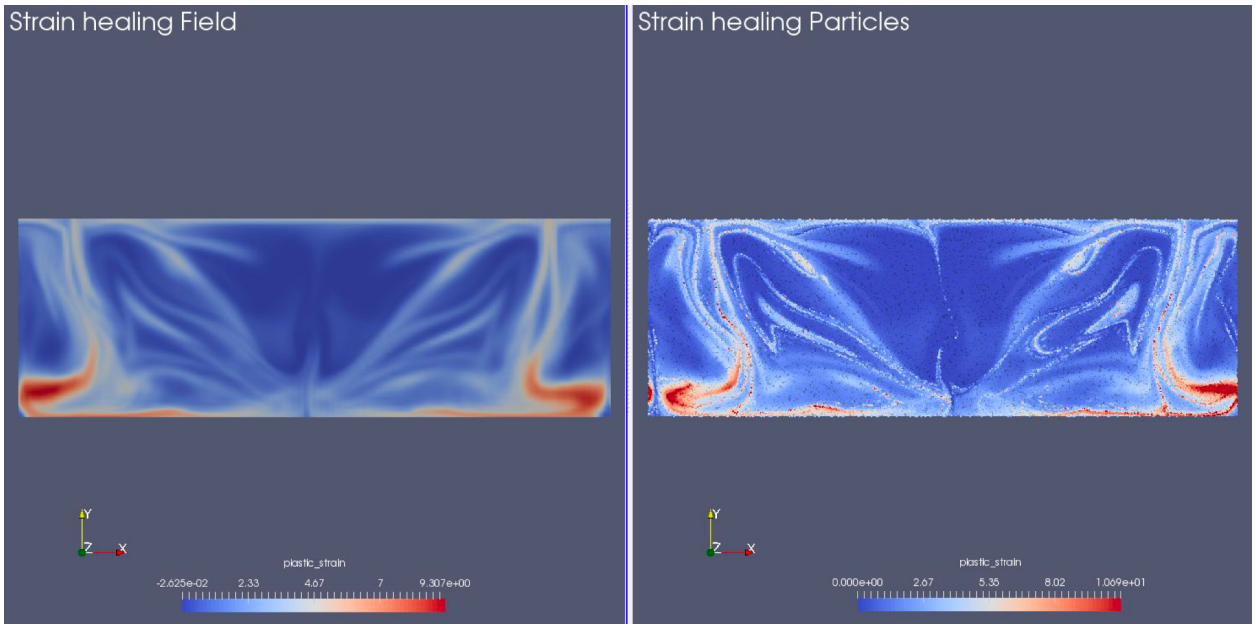
An option has been added to the visco plastic material to use the iterative composite rheology scheme. This is a work in progress, but it has been tested for simple models and now works with strain healing.

Update the viscoplastic strain invariant particles to work with strain healing

(Erin Heilman)

I updated the method inside of the viscoplastic strain invariant particle property by reorganizing to follow the method of the elastic stress particle property. The calculations for updating the strain for the particles are now computed only in the material model and the updated reaction terms are given to the particle. This enables strain healing to work on particles now as well, as it

is computed in the material model, and helped solve an issue with large negative values of strain when using strain healing as a compositional field.



A check for non-positive diffusion or dislocation viscosity

(Sibiao Liu, Anne Glerum)

We added an assertion that prints out values of temperature and pressure when nonpositive (i.e., negative or zero) diffusion or dislocation viscosity is detected. This may be helpful to quickly know if a non-positive viscosity is caused by the wrong solution of temperature or pressure.

An option to use the adiabatic pressure for creep viscosity calculation in the visco-plastic material model

(Sibiao Liu, John Naliboff, Juliane Dannberg)

We added an option to determine whether to use the adiabatic pressure instead of the full pressure (default) when calculating creep (diffusion, dislocation, and peierls) viscosity in the visco-plastic material model. This may be helpful in models where the full pressure has an unusually large negative value arising from large negative dynamic pressure, resulting in solver convergence issue and in some cases a viscosity of zero.

Optimization in the WorldBuilder

(Arushi Saxena, Menno Fraters, and Wolfgang Bangerth)

For large and complex models, evaluating initial conditions described through the WorldBuilder could take quite a long time. We added a bounding box for faults and subducting plate models for faster computation of properties (i.e., temperature, composition, and grains) in the world builder. This modification ensures that for each model, the properties are confined in the lateral direction to the bounding box, thereby considerably reducing the time to compute initial conditions. For example, a global mantle convection model takes about 10 times less time to set up the initial temperature and compositions based on a WorldBuilder fault database compared to the previous WorldBuilder version.

Updated gravitational constant

(Paul Bremner)

I updated the gravitational constant to match the recommended value from 2018 CODATA Value. The value changed from 6.67384e-11 to 6.67430e-11 [m^3 kg^-1 s^-2].

New material model (in cookbook) for olivine anisotropic viscosity

(Ágnes Király)

In work in progress, the material model now includes a function that calculates the stress needed on each olivine grain to achieve an input strain rate depending on the orientation of the grain,and the partitioning of the strain rate on the olivine's three slip systems. This function is used to then create a 6x6 symmetric viscosity tensor. From the viscosity tensor we use the stress dependent part to define a scalar viscosity and the tensor part is used to define a stress-strain director 4th rank tensor, which is then used in the assembler.

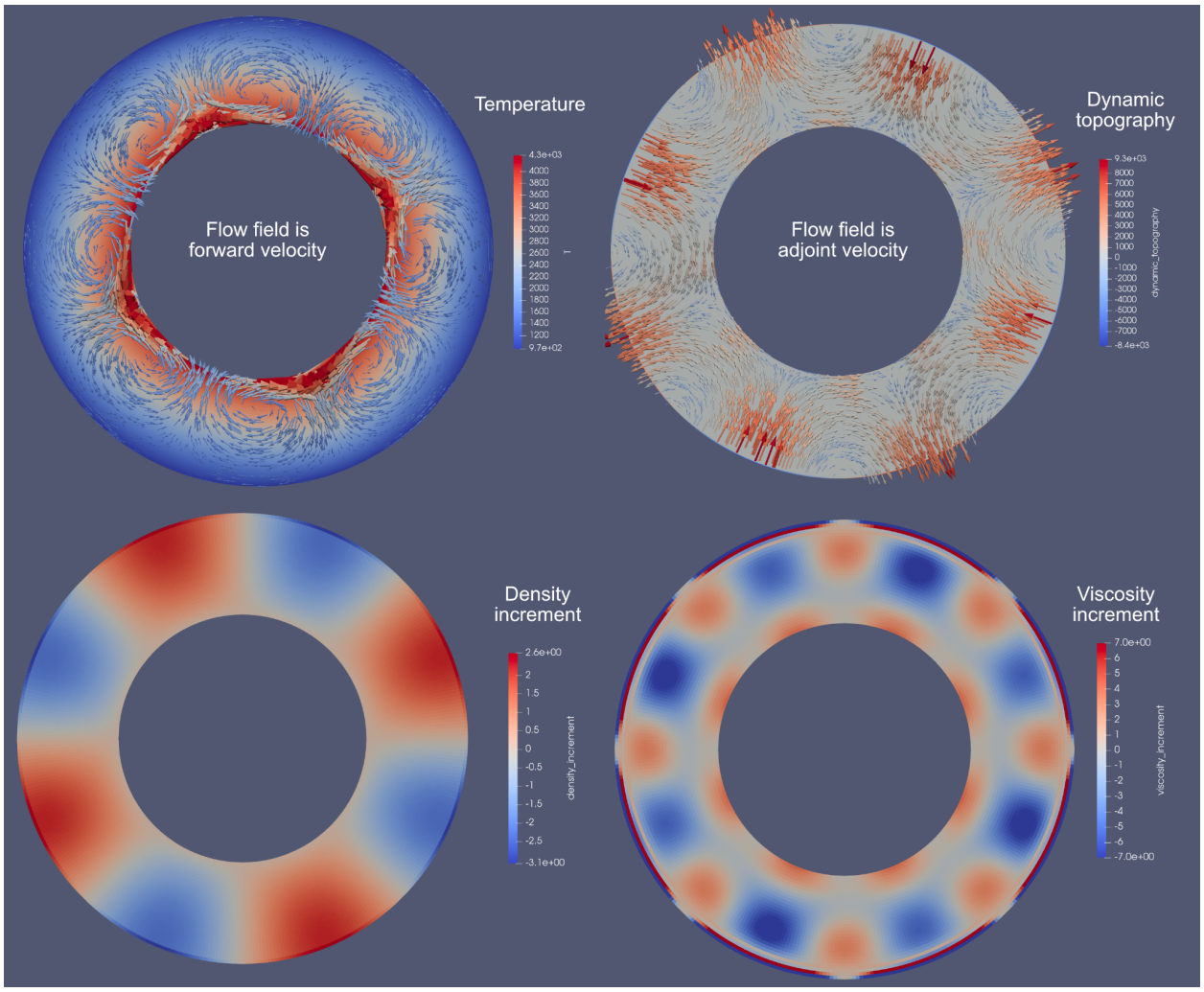
Implementation of adjoint equations

(Jacky Austermann, Wolfgang Bangerth, Rene Gassmöller)

We've continued working on the pull request that implements the adjoint Stokes equations into ASPECT. This work included rearranging code to integrate it most seamlessly with the existing ASPECT structure as well as cleaning up the visualization, fixing several minor bugs, and improving documentation throughout.

The figure below shows the current benchmark calculation, which is a 2D ring with a degree 4 temperature perturbation (the actual benchmark is in a 3D spherical shell). The adjoint

equations take the surface topography as driving force on the right hand side and calculate the resulting flow. High topography leads to upwellings while low topography leads to downwellings (top right panel). Combining the forward and adjoint flow allows us to calculate updates to the density and viscosity field (bottom row). The new material model ‘Additive’ allows updating viscosity and density in an iterative scheme.



Added a “static” temperature field option

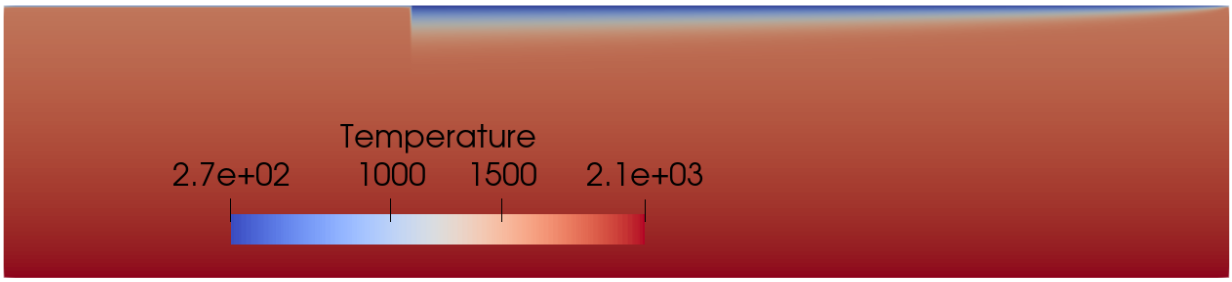
(Rebecca Fildes, Magali Billen)

We added a “static” option that can be used to “solve” the temperature field. It corresponds to the existing “static” field option for compositional fields. The goal was to be able to run instantaneous visco-elastic-plastic subduction models with a prescribed initial slab geometry that do not change when the model runs. This option allows advection to be turned on so that you can still allow elastic stresses to build, but being able to set all other compositional fields and the temperature field to “static” to keep the slab geometry from changing.

A half-space cooling temperature model for oceanic plates in Geodynamic WorldBuilder

(Magali Billen, Menno Fraters)

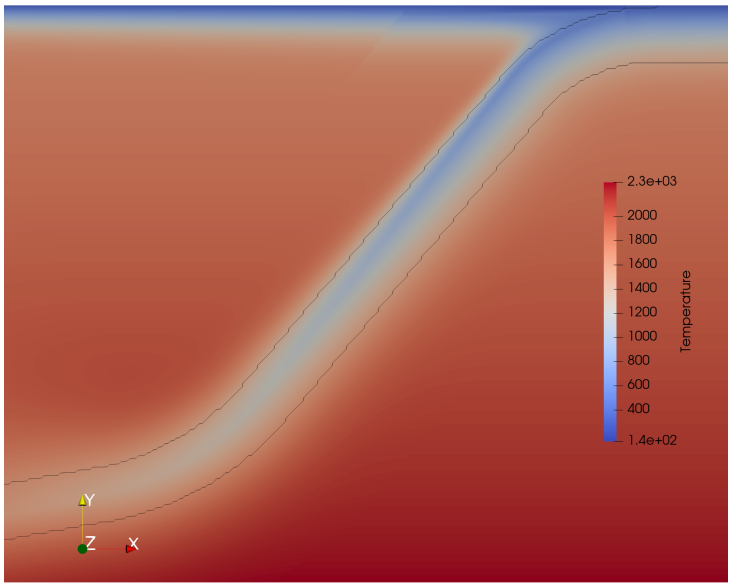
We added an option to the oceanic plate feature to use a half-space (error function) temperature profile. The age of the plate is determined by the user defined plate velocity and distance from the ridge (ridge location is a user input).



A mass-conserving slab temperature model for subducting plates in Geodynamic WorldBuilder

(Magali Billen, Menno Fraters)

We added an option to the subducting plate feature to define a temperature structure that conserves mass as a function of the distance along the slab. The minimum temperature and the offset distance of the minimum temperature from the slab surface are defined by an empirical model calibrated by simple time-dependent subduction models, and are dependent on the subduction velocity. Mass conservation is tracked by first integrating the temperature of the subducting plate at the trench as a function of depth (this is a simple analytical expression assuming a half-space cooling model). Both the mass anomaly and heat content of the slab depend on this integral, so the mass conservation can be enforced by keeping track of either one. The temperature for the bottom of slab (defined as below the location of the minimum temperature), is defined as half space temperature profile, but now with a minimum temperature Tmin and an age tsub + tsink. The heat content of the bottom of the slab is then calculated. Finally the heat content of the top of the plate is defined as the difference between the initial heat content and the heat content of the bottom of the slab. This heat content is then used to define the temperature of the top of the slab using a solution to a 1D infinite half-space (a gaussian). The choice of two different analytic temperature expressions was made to allow for a smooth transition from the subducting plate at the surface and consistent thermal profile for the bottom of the slab, and a smooth growing thermal boundary layer for the top of the slab.


2.3e+03
2000
1800
1600
1400
1200
1000
800
600
400
1.4e+02
Temperature
Y
Z
X

List of hackathon related ASPECT animations

A number of movies and animations were produced at the hackathon. They can be found at the following locations:

2021 winner:
https://www.youtube.com/watch?v=CgUs_SIFMB0

2021 submissions:
OBJ
https://www.youtube.com/watch?v=CgUs_SIFMB0
8 votes

Erin: My entry
https://youtu.be/e4kIU0p9fYs
6 votes

Elodie: My entry
https://www.youtube.com/watch?v=V4SyKykEZZA&ab_channel=elodiekendall
5 votes

Rene: My entry (out of competition since created before the hackathon)
https://youtu.be/1JcbOd_8UOY
4 votes

Anne: My entry (out of competition since created before the hackathon)
https://youtu.be/nSQIbfViOBk
7 votes

2019 winner:
https://www.youtube.com/watch?v=7fmSfNetG3c&feature=youtu.be

2020 submissions:

Cedric: My entries
https://youtu.be/0YeyM5mkUas (not so serious)
https://youtu.be/YIN9Dcq31x0 (not so serious)
https://youtu.be/5SPCU1sFGGc (goes with cookbook I submitted today)

Rene: My entry
https://youtu.be/R92wJfKhJ2I

Juliane: My entry
https://youtu.be/KeHNhWLL7ws

Kiran: My entry
https://youtu.be/LrhCCHNU-B4 (most definitely not working)
https://youtu.be/1IMk1xj77uc (working!)

Anne: My not so serious entry
https://youtu.be/EiHppvAAk98

Timo:
https://youtu.be/Yj4zc8wwhMw

Jonathan P-H: Lower crustal flow in a flexurally/isostatically supported channel.
https://drive.google.com/file/d/1Ih4Uu2LoGeRfowuqilwtmopsrBPoHIZQ/view

Robert:
https://youtu.be/F-90h24DH7U (Impact crater relaxation)

Bob:
https://youtu.be/jqN1_oPg5P0 (Prescribed velocities)

Statistics about ASPECT's growth during the hackathon

The following contains a number of statistics about how much ASPECT has grown during the hackathon:

- Number of source files in ASPECT before/after: 615 -> 625 + 10
- Lines of code in ASPECT before/after: 152,700 -> 155,981 + 3,281
- Number of merged pull requests before/after: 2954 -> 3081 + 127
- Commits in github before/after: 8704 -> 8950 + 246
- Number of tests before/after: 890 -> 914 + 24

For comparison, these were the statistics for last year's (2020) hackathon:

- Number of source files in ASPECT before/after: 572 -> 587 + 15
- Lines of code in ASPECT before/after: 142,784 -> 145,228 + 2,444
- Number of merged pull requests before/after: 2596 -> 2739 + 143
- Commits in github before/after: 7873 -> 8151 + 278
- Number of tests before/after: 805 -> 831 + 23

The comparison of these numbers suggests that the 2021 hackathon was about as productive as the one in the previous year, which had also been an online event. Compared to hackathons we have held over previous years, both this and last year were not bad and the number of new source files, pull requests, commits, and tests are all broadly comparable to previous years.

The difference between the second number in the second table (at the end of the 2020 hackathon) and the first number in each column of the first table above it (at the start of the 2021 hackathon) illustrates the level of development that happened over the course of the year between the hackathons. As in previous years, somewhere around one quarter to one third of the ASPECT development happens during hackathon weeks.

For completeness, the statistics above were generated through the following commands:

- find include/ source/ | egrep '\.(h|cc)$' | wc -l
- cat `find include/ source/ | egrep '\.(h|cc)$'` | wc -l
- git log --format=oneline | grep "Merge pull request" | wc -l
- git log --format=oneline | grep -v "Merge pull request" | wc -l
- ls -l tests/*prm | wc -l

The Playlist Revealed

Title	Artist	Contributor
We Just Disagree	Dave Mason	John
Slinger's Song	Darren Korb	Rene
Old Friends	Darren Korb	Rene
Jurassic Snack Pack	PrototypeRaptor	Maaike
The Chant	Gojira	Cedric
Notte in Bovisa	Calibro 35	Valentina
Transient	Dark Tranquility	Wolfgang
ZZ Top	Rough boy	Wolfgang
Both sides now	Joni Mitchell	Wolfgang
I Still haven't found what I am looking for	U2	Lorraine
Santiano	Santiano	Arushi
The Molecular Shape of you	A capella Science	
Waving Flag	K'Naan	
We Love Hardcore	Scooter	Menno
Stonehenge	Ylvis	
Lone Digger	Caravan Palace	
Sodade	Cesaria Evora	Anne
Regal Sad Remix	Ghetto Kraviz	Elodie
Beggin	Maneskin	Erin
Flower Power	Greta van Fleet	Erin
Van ex a hely ft	Bagossy Brothers	Agnes
Galway Girl	Ed Sheeran	Agnes
Tomorrow Moirning	Jack Johnson	Doug
Dancing Lash Tumbai	Verka Seduchka	Menno
Natural Cause	Emancipator	Andrew
Fault lines	Tom Petty	Jackie
After Hours	We are Scientists	

Emerald Princess	Two hell	steps	from	Sibiao
Angel with a shotgun	Two hell	steps	from	Sibiao